DATA CHANGE NOTICE

SHUTTLE CREW OPERATIONS MANUAL

AMENDMENT: Rev. A, CPN-1	**DATE:** December 15, 2008	**PAGE:** 1 **of** 15

This version of SCOM contains changes reflecting OI-33 updates. All changes are in Appendix E.

APPROVED BY

Michael R. Sterling Book Manager, USA	*Original approval obtained*	Date:	12/15/2008

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Space Program Operations Contract

Shuttle Crew Operations Manual

OI-33

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United Space Alliance

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REVISION LOG

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	CPN-1	OI-33 updates added; OI-32 summary data deleted	12/15/08

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PREFACE

The Shuttle Crew Operations Manual (SCOM) is a unique document containing information about each shuttle system and every phase of a generic space shuttle mission.

The SCOM is a reference document for space shuttle crewmembers. The complexity of the shuttle systems and the unique operational environment, coupled with the numerous malfunction/emergency procedures, necessitated some departures from an aircraft manual approach (e.g. Air Force Dash1 or Navy/Marine Corps NATOPS). Nonetheless, the SCOM is the only single source document, written specifically for shuttle astronauts, with comprehensive data about shuttle systems and operations.

This document contains condensed information from a large number of space shuttle publications, including the Flight Data File (FDF), Crew Training workbooks, Flight Procedure Handbooks (FPH), Flight Rules, Shuttle Operational Data Book, and Shuttle Performance Assessment Data Book. The SCOM is not a replacement for any of these documents. It has been carefully reviewed by Flight Crew Operations Directorate (FCOD) and Mission Operations Directorate (MOD) personnel to ensure accuracy of information. In all cases, should a conflict arise between the SCOM and FDF or Flight Rules, the FDF and Flight Rules will govern. If conflicts arise between the SCOM and workbooks/FPHs, the conflicts should be resolved with the appropriate book manager or system representative.

Information contained in the SCOM is current per the Flight Software Operational Increment (OI) designated on the cover page. If this SCOM is published BEFORE the first launch of the designated OI then the SCOM is current to expected requirements. If this SCOM is published AFTER the first flight of a designated OI, the SCOM will be current per “as-flown” operational feedback from crews and ground operators. CRT displays documented in the text and in Appendix B are the CRT displays documented in the Level C Functional Subsystem Software Requirements Display and Controls Specification, STS 83-0020V, for the designated OI. It should be noted that several CRT displays provided in the body of this document are for illustrative purposes only; certain CRT displays contain data combined in one illustration that do not appear simultaneously in operational use.

Additional information or clarification is presented in three formats: notes, cautions, and warnings. Notes provide amplifying information of a general nature. Cautions provide information and instructions necessary to prevent hardware damage or malfunction. Warnings provide information and instructions necessary to ensure crew safety. The formats in which this material appears are illustrated below.

NOTE

A barberpole APU/HYD READY TO START talkback will not inhibit a start.

CAUTION

After an APU auto shutdown, the APU FUEL TK VLV switch must be taken to CLOSE prior to inhibiting auto shutdown logic. Failure to do so can allow the fuel tank isolation valves to reopen and flow fuel to an APU gas generator bed that is above the temperature limits for safe restart.

WARNING

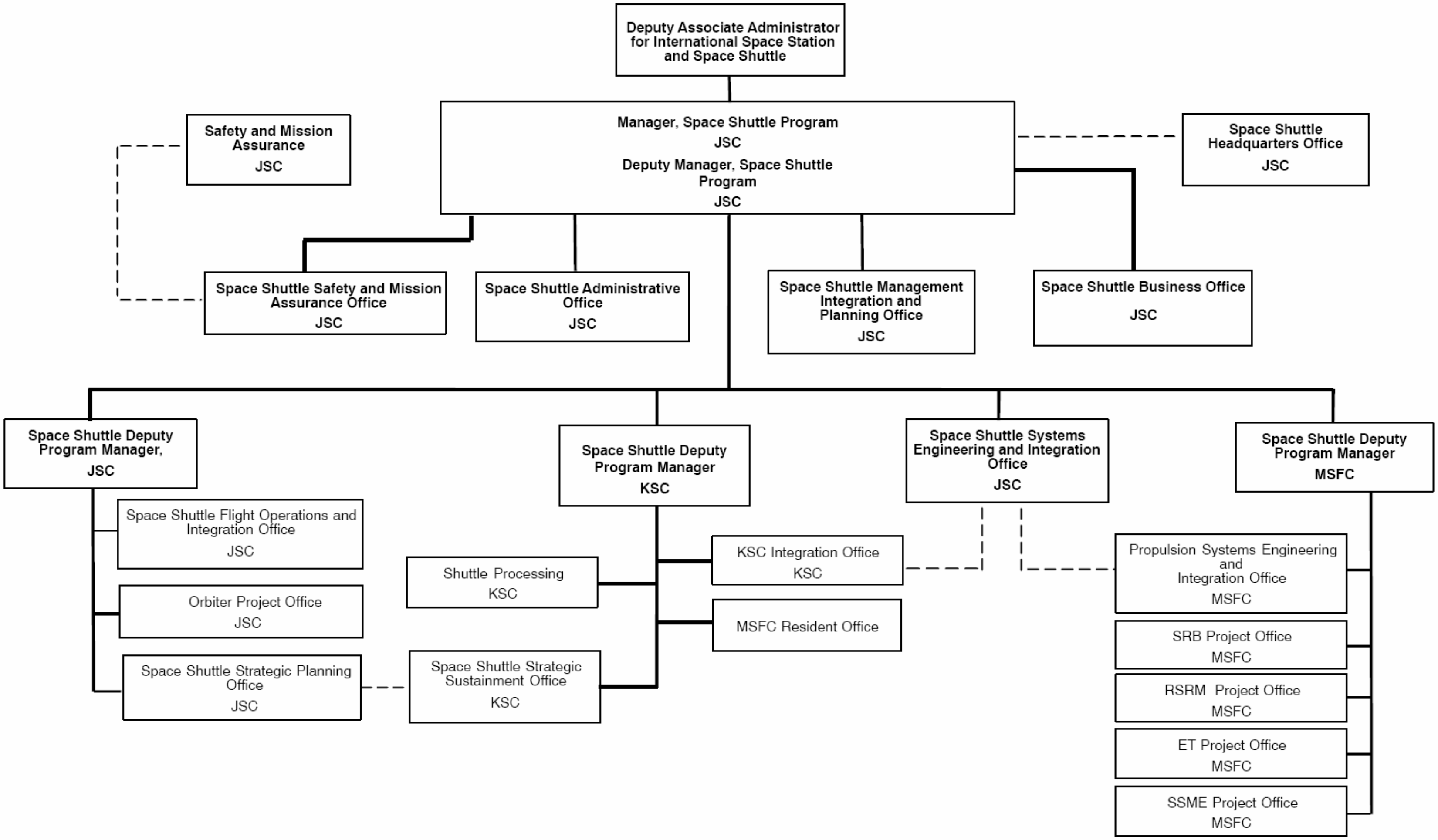
The FUEL CELL REAC switches on panel R1 are in a vertical column with FUEL CELL 1 REAC on top, FUEL CELL 3 REAC in the middle, and FUEL CELL 2 REAC on the bottom. This was done to allow the schematic to be placed on the panel. Because the switches are not in numerical order, it is possible to inadvertently close the wrong fuel cell reactant valve when shutting down a fuel cell.

Configuration Control Plan

The SCOM will be updated per the specifications in the latest Space Flight Operations Contract (SFOC) agreement between the Space Shuttle Program and the United Space Alliance (USA). USA's ongoing MOD and FCOD support in the Shuttle Avionics Software Control Board (SASCB), Program Requirements Control Board (PRCB), Flight Rules Control Board (FRCB), and Crew Procedures Control Board (CPCB) processes will keep the Shuttle Ops community apprised of vehicle impacts to flight operations and associated documentation. The SCOM update effort (including configuration control) will be performed by the SCOM Development Team and led by the SCOM Book Manager. Astronaut Office participation in the SCOM update effort will be coordinated per the SCOM Development Task specified in the Training Operations Handbook.

Program Documentation

There are a multitude of documents delineating the organization and operation of the space shuttle program (SSP). The following charts depict the SSP organization, major program documents (NSTS 07700) and associated processes. Each major process will have a significant collection of associated publications. Several hundred of these documents have been utilized in the development of the SCOM.


Deputy Associate Administrator for International Space Station and Space Shuttle
Manager, Space Shuttle Program JSC
Deputy Manager, Space Shuttle Program JSC
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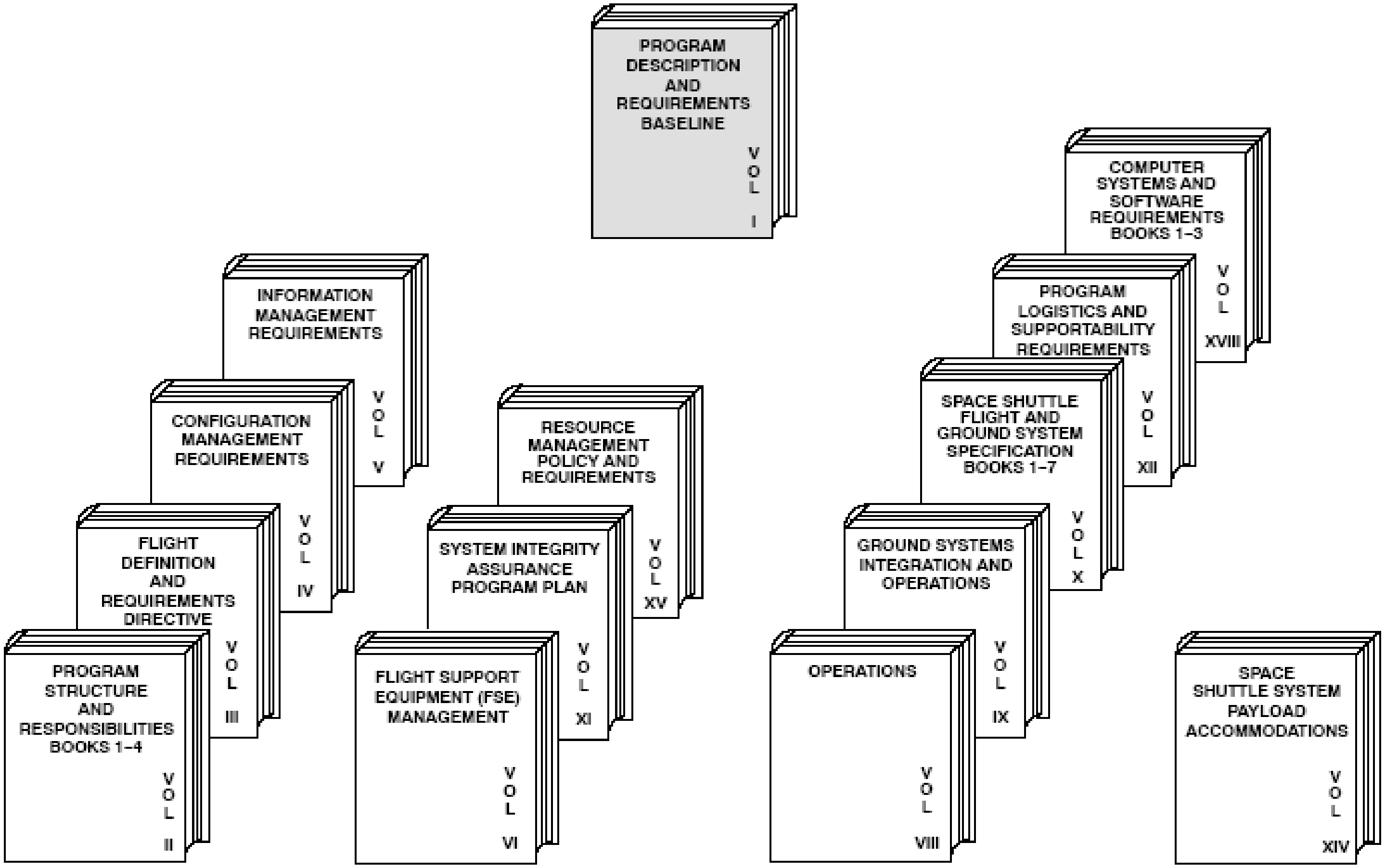
KSC Integration Office KSC
MSFC Resident Office
Propulsion Systems Engineering and Integration Office MSFC
SRB Project Office MSFC
RSRM Project Office MSFC
ET Project Office MSFC
SSME Project Office MSFC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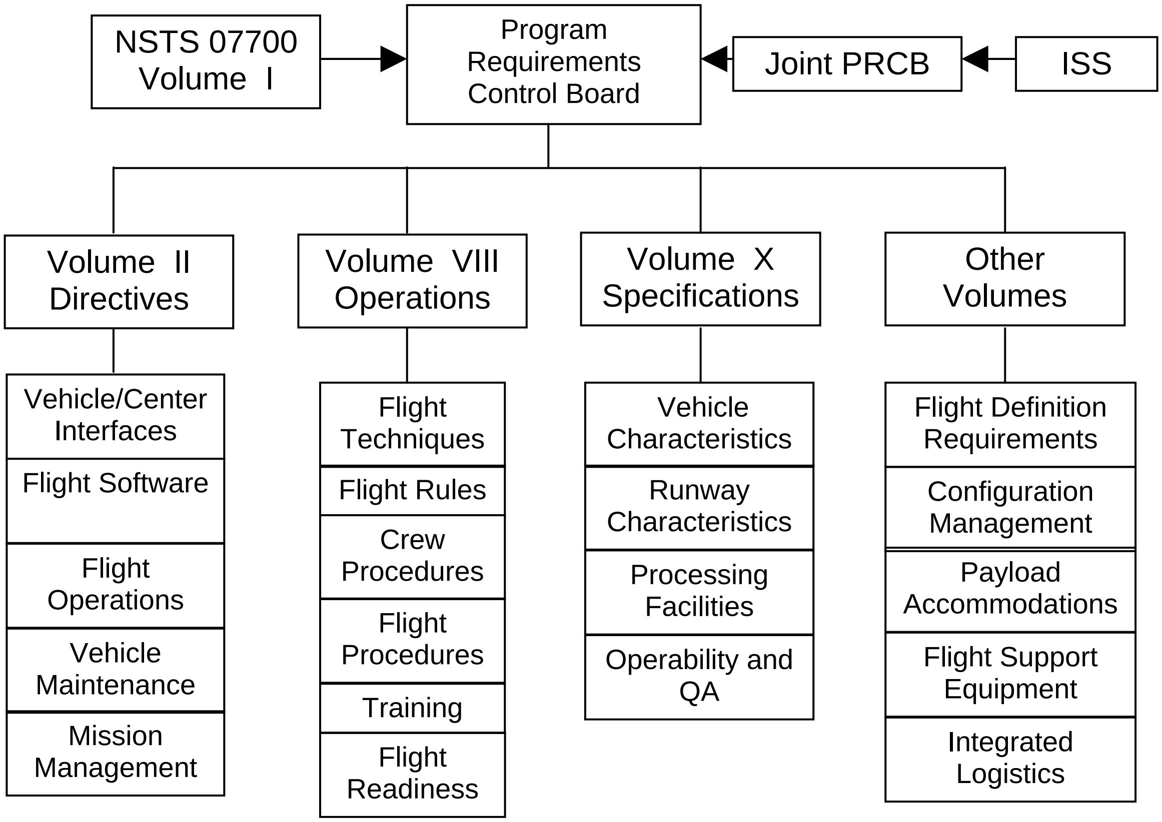
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The section provides general background information about the orbiter, its configuration and coordinate systems, the nominal mission profile, and general procedures followed during a shuttle mission. It also briefly discusses components, such as the external tank and solid rocket, that are not included in the next section on orbiter systems.

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1.1 OVERVIEW

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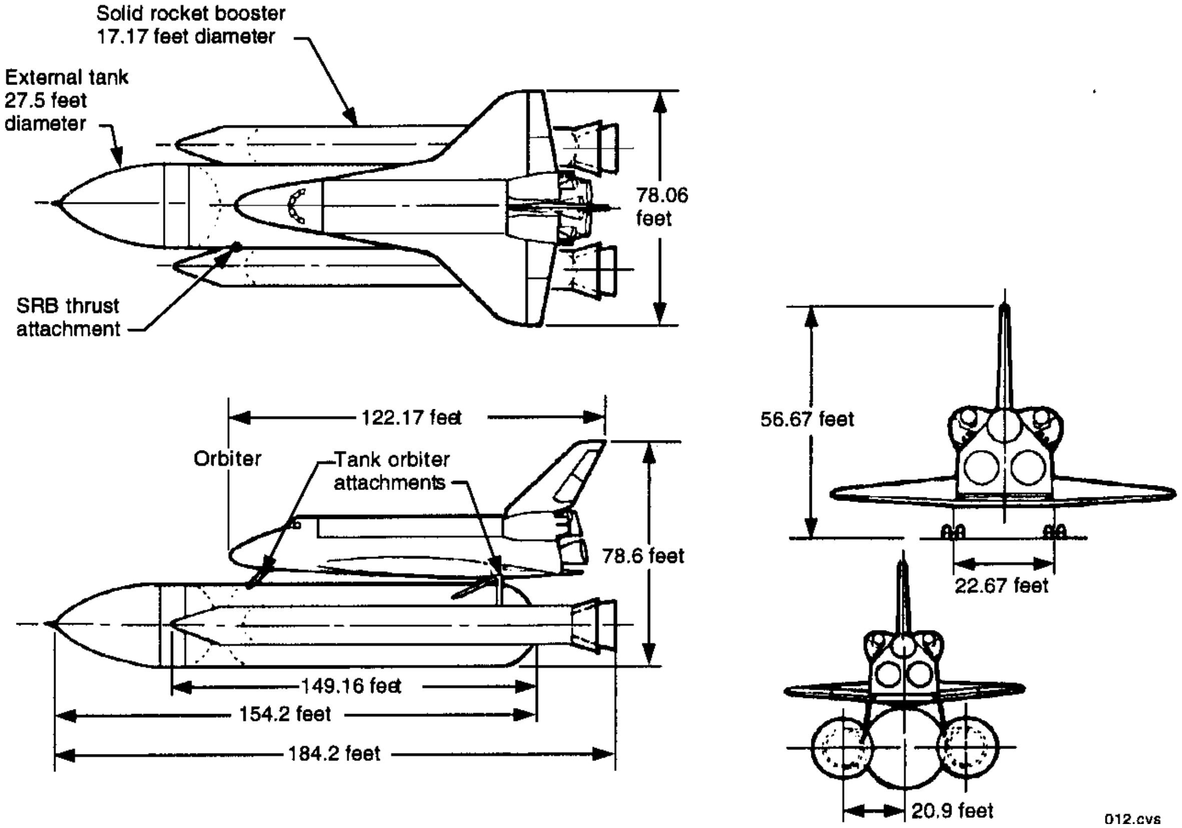
Space Shuttle Requirements

The space shuttle system consists of four primary elements: an orbiter spacecraft, two solid rocket boosters (SRBs), an external tank (ET) to house fuel and oxidizer, and three space shuttle main engines (SSMEs). The shuttle can transport payloads into near Earth orbit 100 to 312 nm above the Earth. Payloads are carried in a bay 15 feet in diameter and 60 feet long. Major system requirements are that the orbiter and the two SRBs be reusable.

The orbiter has carried a flight crew of up to eight persons. The nominal mission is 4 to 16 days in space. The crew compartment has a shirtsleeve environment, and the acceleration load is never greater than 3 g's. In its return to Earth, the orbiter has a crossrange maneuvering capability of about 1,100 nm



Space Shuttle Statistics

Nominal Mission Profile

Launch

In the launch configuration, the orbiter and two SRBs are attached to the ET in a vertical (nose-up) position on the launch pad. Each SRB is attached at its aft skirt to the mobile launcher platform by four bolts.

The three SSMEs, fed liquid hydrogen fuel and liquid oxygen oxidizer from the ET, are ignited first. When it has been verified that the engines are operating at the proper thrust level, a signal is sent to ignite the SRBs. At the proper thrust-to-weight ratio, initiators (small explosives) at eight hold-down bolts on the SRBs are fired to release the space shuttle for lift-off. Elapsed time is a few seconds.

Maximum dynamic pressure is reached early in the ascent, nominally 30 to 60 seconds after lift-off. Approximately 1 minute later (2 minutes into the ascent phase), the two SRBs have consumed their propellant and are jettisoned from the ET. This is triggered by a separation signal from the orbiter.

The boosters briefly continue to ascend, while small thrusters fire to carry them away from the space shuttle. The boosters then turn and descend, and at a predetermined altitude, parachutes are deployed to decelerate them for a safe splashdown in the ocean. Splashdown occurs approximately 141 nm from the launch site. The boosters are recovered and reused.

The orbiter and ET continue to ascend, using the thrust of the three SSMEs. Approximately 8½ minutes after launch, the three engines undergo main engine cutoff (or MECO), and the ET is jettisoned on command from the orbiter.

The forward and aft reaction control system (RCS) jets provide attitude control, translate the orbiter away from the ET at separation, and maneuver the orbiter to burn attitude prior to the orbital maneuvering system (OMS) burn. The ET continues on a ballistic trajectory and enters the atmosphere, where it disintegrates. Its nominal impact is in the Indian Ocean for a 28° inclination launch.

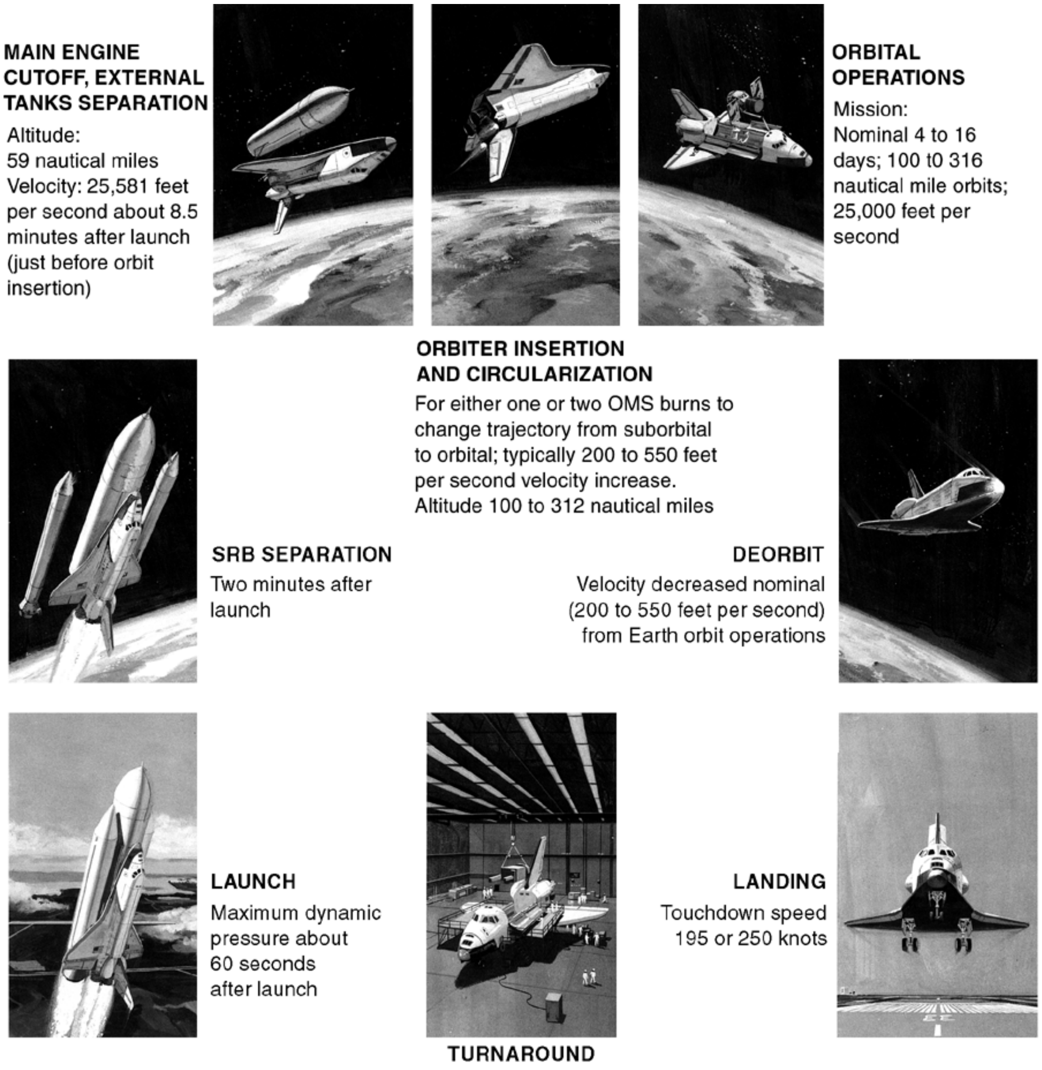
Orbit Insertion and Circularization

The normal ascent profile, referred to as “direct insertion,” places the vehicle in a temporary elliptical orbit at MECO. Orbital altitudes can vary from 100 to 312 nm, depending on mission requirements. The crew then performs an OMS burn, designated as “OMS 2”, to stabilize the orbit. This burn can add anywhere between 200 to 550 fps to the vehicle’s orbital velocity, as necessary.

In cases of severe performance problems during the ascent, the vehicle may find itself well short of the expected MECO velocity, and even sub-orbital. In such cases, the crew performs what is called an “OMS 1” burn, which raises the orbit to a safe altitude. They then peform an OMS 2 burn to stablize that orbit.

Orbit

On orbit, the forward and aft RCS jets provide attitude control of the orbiter, as well as any minor translation maneuvers along a given axis. The OMS engines are used to perform orbital transfers, such as those done to rendezvous with the International Space Station (ISS). While on orbit, the crew fulfills mission objectives, such as ISS assembly and logistics, payload deployment or retrieval, and scientific experiments.



Shuttle Mission Profile

Deorbit

At the completion of orbital operations, the RCS is used to orient the orbiter in a tail-first attitude. The two OMS engines are burned to lower the orbit such that the vehicle enters the atmosphere at a specific altitude and range from the landing site. The deorbit burn usually decreases the vehicle's orbital velocity anywhere from 200 to 550 fps, depending on orbital altitude. When the deorbit burn is complete, the RCS is used to rotate the orbiter's nose forward for entry. The RCS jets are used for attitude control until atmospheric density is sufficient for the pitch, roll, and yaw aerodynamic control surfaces to become effective.

Entry

Entry interface, the point where the vehicle enters the atmosphere, is considered to occur at an altitude of 400,000 feet, approximately 4,200 nm from the landing site, and at a velocity of approximately 25,000 fps. The orbiter is maneuvered to 0° roll and yaw (wings level) and a 40° angle of attack for entry. The flight control system issues the commands to roll, pitch, and yaw RCS jets for rate damping.

The forward RCS jets are not used during entry, as they would adversely affect the vehicle's aerodynamics otherwise. Thus, only the aft RCS jets are initally used to maneuver the vehicle. At a dynamic pressure (qbar) of 10 psf, the orbiter's aerosurfaces become effective for roll control, and the roll function in the aft RCS jets is deactivated. At a qbar of 40 psf, the aerosurfaces become more effective, and the RCS pitch function is deactivated. The orbiter's speed brake is used below Mach 10 to help keep the elevons in the airstream. At Mach 5, the rudder becomes active and is used for trim. Finally, at Mach 1, all RCS jet activity is deactived, leaving only the aerosurfaces to maneuver the vehicle.

Entry guidance must dissipate the tremendous amount of energy the orbiter possesses when it enters the Earth's atmosphere to assure that the orbiter does not either burn up (entry angle too steep) or skip out of the atmosphere (entry angle too shallow). It must also properly position the vehicle to reach the desired touchdown point. Guidance does all this by controlling the atmospheric drag on the orbiter's surface. Higher atmospheric drag levels enable faster energy dissipation with a steeper trajectory.

Controlling atmospheric drag is achieved by varying either the angle of attack or the bank angle. However, varying the angle of attack early during entry creates surface temperatures above the orbiter's design specification. This leaves varying bank angle for energy control. Increasing the bank angle decreases the vertical component of lift, causing a higher sink rate, greater atmospheric drag and thus more energy dissipation. This, too, raises the surface temperature of the orbiter, but not nearly as drastically as would increasing the angle of attack.

If the orbiter is low on energy (i.e. the range to the landing site is much greater than expected, given the current velocity), entry guidance will command lower than nominal drag levels. If the orbiter has too much energy (i.e. the range to the landing site is much less than expected, given the current velocity), entry guidance will command higher-than-nominal drag levels to dissipate the extra energy.

Bank angle is also used to control crossrange. Azimuth error is the angle between the plane containing the orbiter's position vector and the heading alignment cone tangency point and the plane containing the orbiter's position vector and velocity vector. When the azimuth error exceeds a computer-loaded number, the orbiter's bank angle is reversed.

Thus, descent rate and downranging are controlled by bank angle. The steeper the bank angle, the greater the descent rate and the greater the drag. Conversely, the minimum drag attitude is wings level. Crossrange is controlled by bank reversals. The entry thermal control phase is designed to keep the backface and surface temperatures within the design limits. A constant heating rate is established until a velocity below 19,000 fps.

The equilibrium glide phase transitions the orbiter from the rapidly increasing drag levels of the temperature control phase to the constant drag level of the constant drag phase. The equilibrium glide flight is defined as flight in which the flight path angle, which is the angle between the local horizontal and the local velocity vector, remains constant. Equilibrium glide flight provides the maximum downrange capability. It lasts until the drag acceleration reaches 33 fps^2.

The constant drag phase begins at that point. The angle of attack is initially 40°, but it begins to ramp down to approximately 36° by the end of this phase.

In the transition phase, the angle of attack continues to ramp down, reaching approximately 14° at the entry terminal area energy management (TAEM) interface, at an altitude of approximately 83,000 feet, a velocity of 2,500 fps, and a range of 60 nm from the runway. Control is then transferred to TAEM guidance.

During the entry phases described, the orbiter's bank commands keep the orbiter on the drag profile and control crossrange.

TAEM

TAEM (terminal area energy management) steers the orbiter to one of two 18,000-ft radius heading alignment cones (HAC), which are located tangent to and on either side of the runway centerline on the approach end. In TAEM guidance, excess energy is dissipated with an S-turn. This increases the ground track range as the orbiter turns away from the HAC until sufficient energy is dissipated to allow a normal approach and landing guidance phase capture, which begins at 10,000 feet altitude. The orbiter also can be flown near the velocity for maximum lift over drag or wings level for the range stretch case. The spacecraft slows to subsonic velocity at approximately 49,000 feet altitude, about 26 nm from the landing site.

At TAEM acquisition, the orbiter is turned until it is aimed at a point tangent to the HAC and continues until it reaches way point (WP) 1. At WP-1, the TAEM heading alignment phase begins. The HAC is followed until landing runway alignment, ±20°, has been achieved. In the TAEM prefinal phase, the orbiter pitches down to acquire the steep glideslope, increases airspeed, banks to acquire the runway centerline, and continues until on the runway centerline, on the outer glideslope, and on airspeed. The approach and landing guidance phase begins with the completion of the TAEM prefinal phase and ends when the spacecraft comes to a complete stop on the runway.

Landing

The approach and landing trajectory capture phase begins at the approach and landing interface and continues to acquisition of the steep outer glideslope. The approach and landing phase begins at about 10,000 feet altitude at an equivalent airspeed of 300 knots equivalent airspeed (KEAS) and 5.8 or 6.3 nm (for -20° or -18° glideslope, respectively) from touchdown. Approach and landing guidance is initiated at this point to guide the orbiter to the -20° or -18° glideslope aimed at a target 7,500 feet short of the runway. The speed brake is modulated to hold the reference velocity. The descent rate in the later portion of TAEM and approach and landing is greater than 10,000 feet per minute.

At 2,000 feet above ground level (AGL), a preflare maneuver is started to position the spacecraft for a 1.5° inner glideslope in preparation for landing with the speed brake positioned to control touchdown energy. The flight crew deploys the landing gear at 300 feet AGL. The final flare reduces the sink rate of the spacecraft to a target value of 3 fps. Touchdown occurs approximately 2,500 feet past the runway threshold at a speed of 195 KEAS (lightweight orbiters) or 205 KEAS (heavyweight orbiters).

Launch and Landing Sites

The Kennedy Space Center (KSC) in Florida is used for all shuttle launches. Shuttle landings occur at KSC, also, as well as at Edwards Air Force Base in California. Contingency landing sites are also provided in the event the orbiter must return to Earth in an emergency.

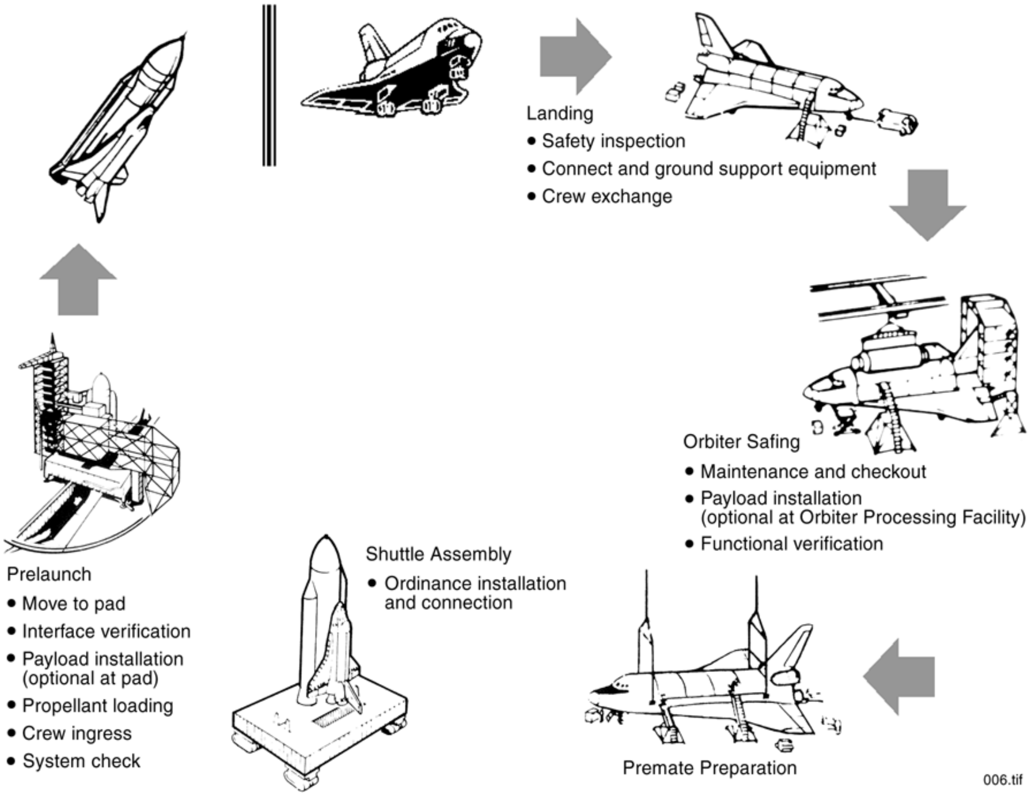
A 035° azimuth launch places the spacecraft in an orbital inclination of 57°, which means the spacecraft in its orbital trajectories around Earth will never exceed an Earth latitude higher or lower than 57° north or south of the equator. A launch path from KSC at an azimuth of 090° (due east from KSC) will place the spacecraft in an orbital inclination of 28.5°.

These two azimuths, 035° and 090°, represent the current launch limits from KSC. Any azimuth angles further north or south would launch a spacecraft over a habitable land mass, adversely affect safety provisions for abort or vehicle separation conditions, or present the undesirable possibility that the SRB or external tank could land on inhabited territory.

The Earth rotates from west to east at a speed of approximately 900 nautical miles (nm) per hour. For due east launches (090° azimuth), the Earth's rotational velocity adds to the velocity increase caused by the SRBs and main engines. Due east launches provide the maximum payload and altitude capability. Launches on azimuths other than due east benefit less and less from Earth's rotation as the launch azimuth approaches north or south. Westerly launches would decrease performance even further.

Orbiter Ground Turnaround

Spacecraft recovery operations at the nominal end-of-mission landing site are supported by approximately 160 space shuttle launch operations team members. Ground team members wearing self-contained atmospheric protective ensemble suits that protect them from toxic chemicals approach the spacecraft as soon as it stops rolling. The ground team members take sensor measurements to ensure the atmosphere in the vicinity of the spacecraft is not hazardous. In the event of propellant leaks, a wind machine truck carrying a large fan is moved into the area to create a turbulent airflow that will break up gas concentrations and reduce the potential for an explosion.



Kennedy Space Center Ground Turnaround Sequence

A ground support equipment (GSE) air-conditioning purge unit is attached to the right-hand orbiter T-0 umbilical so cool air can be directed through the orbiter's aft fuselage, payload bay, forward fuselage, wings, vertical stabilizer, and OMS/RCS pods to dissipate the heat of entry.

A second GSE ground cooling unit is connected to the left-hand orbiter T-0 umbilical spacecraft Freon coolant loops to provide cooling for the flight crew and avionics during the postlanding and system checks. The spacecraft fuel cells remain powered up at this time. The flight crew then exits the spacecraft, and a ground crew powers down the spacecraft. The orbiter and GSE convoy eventually move from the runway to the Orbiter Processing Facility (OPF).

If the spacecraft lands at Edwards Air Force Base, the same procedures and GSE are used after the orbiter has stopped on the runway. The orbiter and GSE convoy move from the runway to the orbiter mate and demate facility. After detailed inspection, the spacecraft is prepared to be ferried atop the Shuttle Carrier Aircraft from Edwards Air Force Base to KSC. For ferrying, a tail cone is installed over the aft section of the orbiter.

In the event of a landing at an alternate site, a crew of about eight will move to the landing site to assist the astronaut crew in preparing the orbiter for loading aboard the Shuttle Carrier

Aircraft for transport back to KSC. For landings outside the U.S., personnel at the contingency landing sites will be provided minimum training on safe handling of the orbiter, with emphasis on crash rescue training, towing the orbiter to a safe area, and prevention of propellant conflagration.

Upon its return to the OPF at KSC, the orbiter is safed (ordnance devices safed), the payload (if any) is removed, and the orbiter payload bay is reconfigured for the next mission. Any required maintenance and inspections are also performed while the orbiter is in the OPF. A payload for the orbiter's next mission may be installed in the orbiter's payload bay in the OPF or when the orbiter is at the launch pad.

While the orbiter is being refurbished, the ET and SRBs (which are also processed at KSC) are stacked and mated on the mobile launch platform in the Vehicle Assembly Building (VAB). Once prepared, the orbiter is towed from the OPF to the VAB mated to the ET/SRB stack. Connections are made, the integrated vehicle is checked, and ordnance is installed.

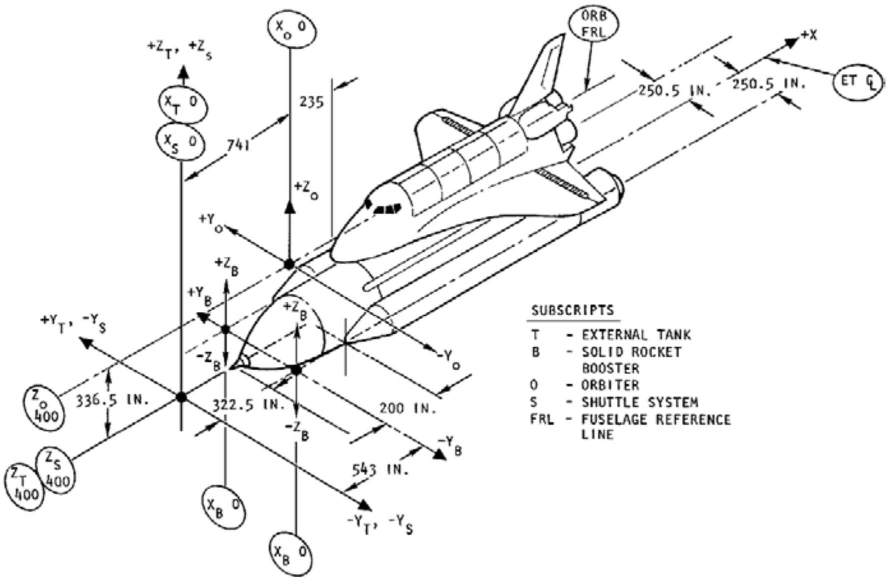
The mobile launch platform moves the entire space shuttle system on a crawler transporter to the launch pad, where connections are made, and servicing and checkout activities begin. If the payload was not installed in the OPF, it is installed at the launch pad followed by prelaunch activities.

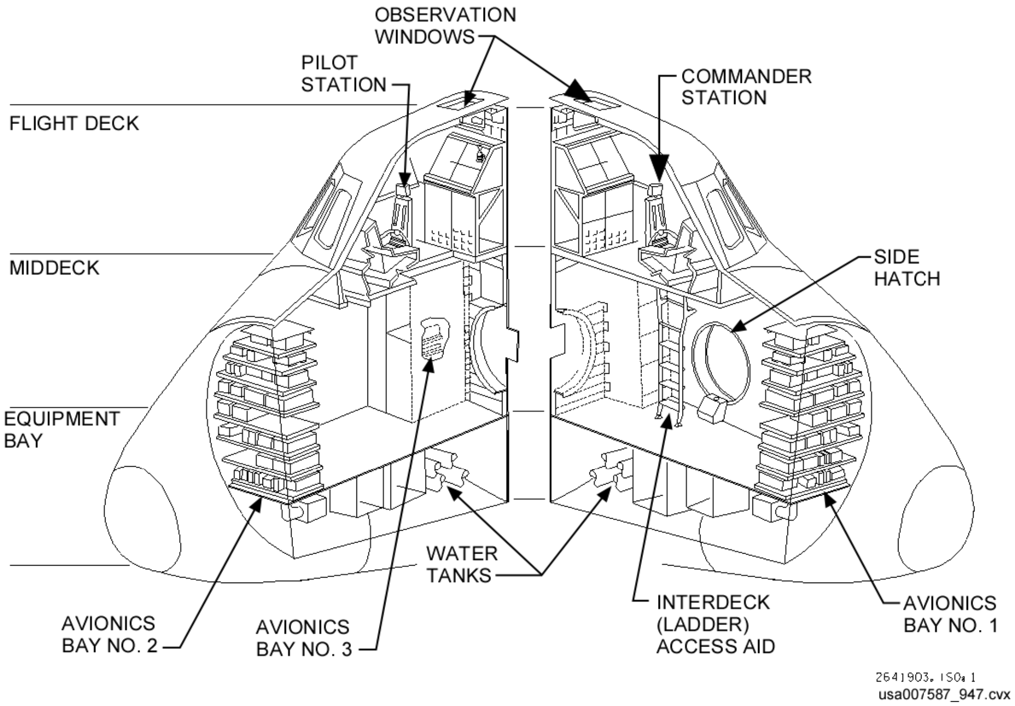
KSC Launch Operations has the responsibility for all mating, prelaunch testing, and launch control ground activities until the space shuttle clears the launch pad tower. Responsibility is then turned over to the Mission Control Center (MCC) at the Johnson Space Center in Texas. MCC's responsibility includes ascent, on-orbit operations, entry, approach, and landing until crew egress, at which time the orbiter is handed over to the postlanding operations at the landing site for turnaround and relaunch.

Space Shuttle Coordinate Reference System

The space shuttle coordinate reference system is a means of locating specific points on the orbiter. The system is measured in inches and decimal places; X_o designates the longitudinal axis, Y_o the lateral axis, and Z_o the vertical axis. The subscript ''o'' indicates orbiter; similar reference systems are used for the ET (T), SRB (B), and overall space shuttle system (S).

In each coordinate system, the X-axis zero point is located forward of the nose tip; i.e., the orbiter nose tip location is 236 inches aft of the zero point (at $X_o = 236$), the ET nose cap tip location is at $X_T = 322.5$, and the SRB nose tip location is at $X_B = 200$. In the orbiter, the horizontal X_o , Y_o reference plane is located at $Z_o = 400$, which is 336.5 inches above the ET horizontal X_T, Y_T reference plane located at $Z_T = 400$. The SRB horizontal X_B, Y_B reference plane





Crew Cabin (Cutaway View)

is located at $Z_B = 0$ and coincident with the ET horizontal plane at $Z_T = 400$. The solid rocket booster vertical X_B, Z_T planes are located at $+Y_S = 250.5$ and $-Y_S = 250.5$. Also, the orbiter, external tank, and shuttle system center X, Z planes coincide.

From the X = 0 point, aft is positive, and forward is negative for all coordinate systems. Looking forward, each shuttle element Y-axis point right of the center plane (starboard) is positive and each Y-axis point left of center (port) is negative. The Z axis of each point within all elements of the shuttle except the SRBs is positive, with Z = 0 located below the element. In the SRBs, each Z-coordinate point below the X_B, Y_B reference plane is negative, and each point above that plane is positive.

The shuttle system and shuttle element coordinate systems are related as follows: the external tank $X_T = 0$ point coincides with $X_S = 0$, the SRB X_B 0 point is located 543 inches aft, and the Y_o, Z_o reference plane is 741 inches aft of $X_S = 0$.

Location Codes

Orbiter location codes enable crewmembers to locate displays and controls, stowage compartments and lockers, access panels, and wall-mounted equipment in the orbiter crew compartments. The crew compartments are the flight deck, middeck, and airlock. A fourth compartment becomes part of the configuration when the Spacehab is flown. Because of compartment functions and geometry, each has a unique location coding format.

Flight Deck Location Codes

A flight deck location code consists of two or three alphanumeric characters. The first character is the first letter of a flight deck surface as addressed while sitting in the commander/pilot seats. The characters are:

L – Left

R – Right

F – Forward

A – Aft

C – Center Console

O – Overhead

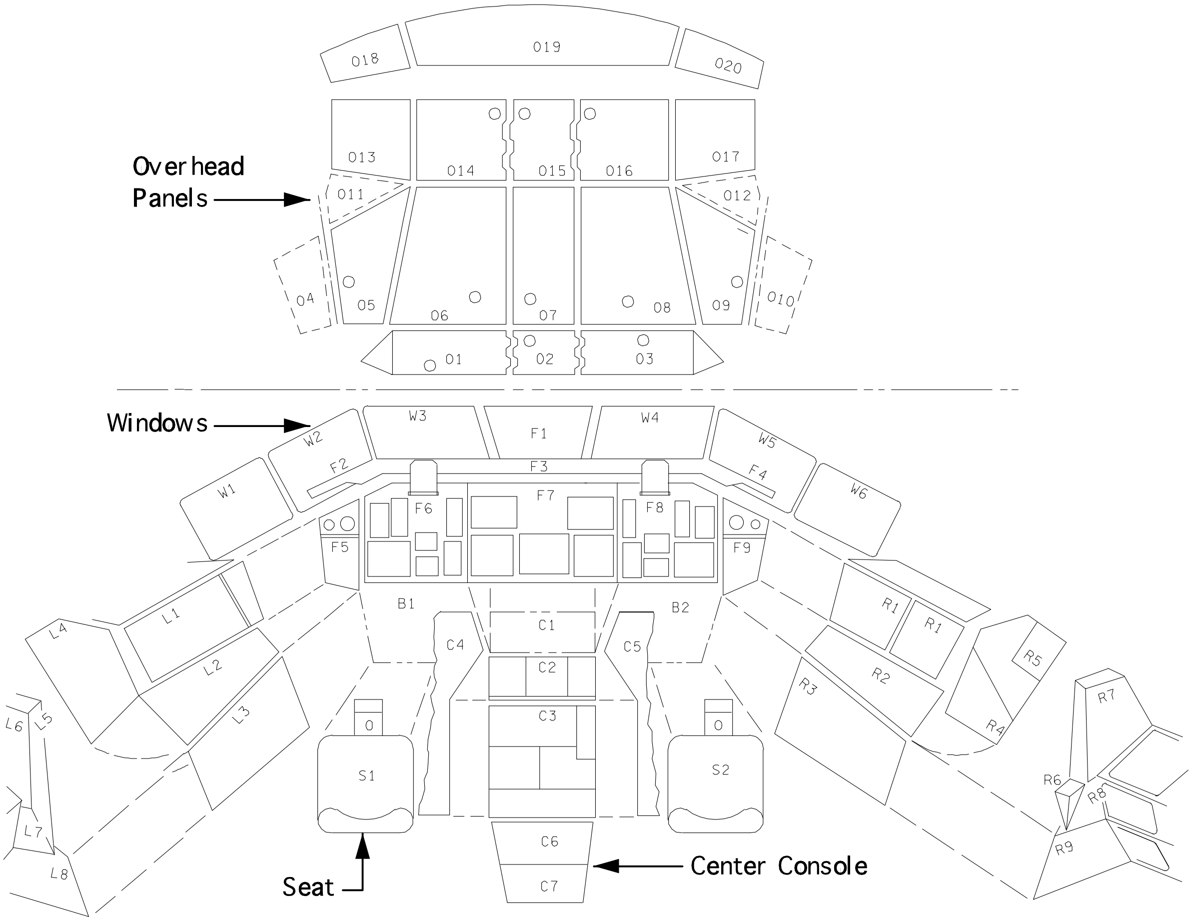
S – Seats

W – Windows

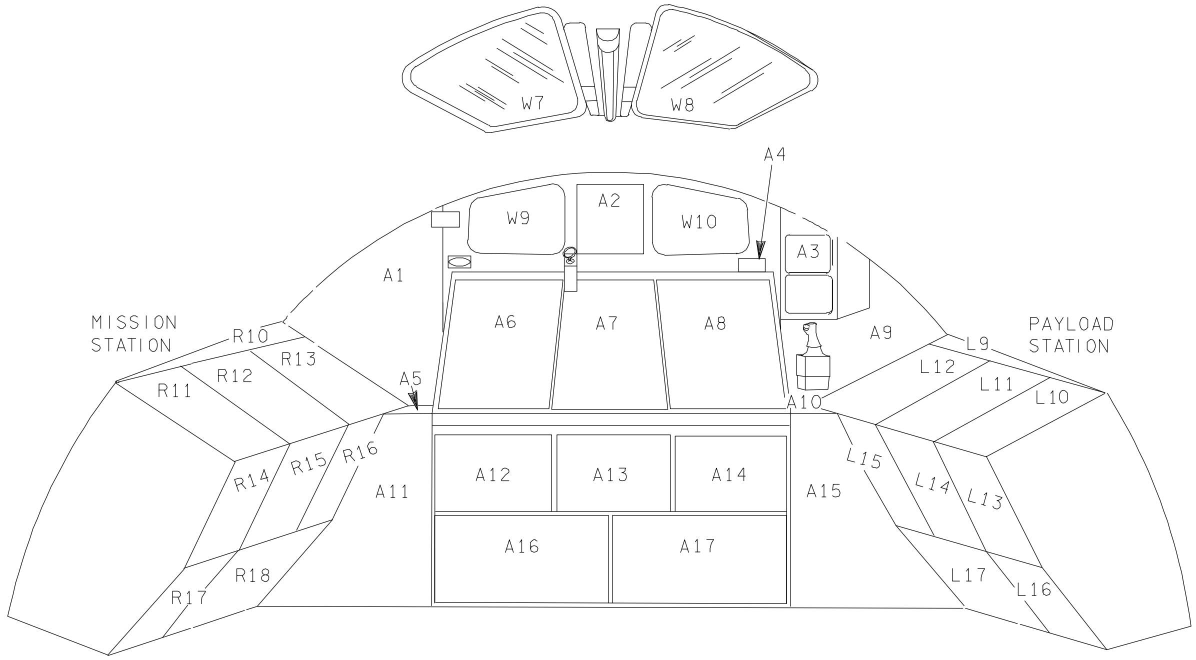
SURFACES	GENERAL NUMBERING PHILOSOPHY
L - Left R - Right C - Center console	• Numbered from the top to bottom, forward to aft
O - Overhead	Numbered from left to right, forward to aft
F - Forward A - Aft	• Numbered left to right, top to bottom • (facing the surface)
W - Windows	• The forward windows are numbered left to right (W1 through W6) facing forward • The overhead windows are numbered left to right (W7 and W8) facing aft • The aft windows are numbered left to right (W9 and W10) facing aft
S - Seats	• The CDR's seat is S1 and the PLT's seat is S2

General Numbering Scheme for Flight Deck Surfaces

The second and third characters are numerics identifying the relative location of components on each flight deck surface. The numbering system philosophy is summarized in the table at left.



Flight Deck Location Codes (1 of 2)



Flight Deck Location Codes (2 of 2)

Middeck Location Codes

The middeck location codes have five characters specifying the following:

First character – M for middeck

Second character – The first letter of a middeck surface; the characters and surfaces are:

L – Left
R – Right
F – Forward
A – Aft
D – Deck
O – Overhead

SURFACES	REFERENCE POSITION
L, R, F, A	Standing on deck facing the surface
D	Standing on deck facing forward (+X) looking down
O	The overhead location grid matches the grid on the deck; i.e., a point on the overhead has the same third, fourth, fifth characters as a point directly below it on the deck

Middeck Location Codes (2 of 2)

The reference position for identifying the surface is standing on the middeck floor (deck) facing forward (+X).

Third/fourth/fifth characters – These characters form a location grid on each middeck surface. The third and fourth characters are numerics indicating the distance from the left side of a surface expressed as a percentage of the total width of the surface (follows the contour of the wall).

The fifth character is an alpha character indicating the distance from the top of a surface expressed alphabetically in increments of 6 inches.

NOTE

The middeck panel numbers are not consistent with the location coding system defined by this document. However, in each case, the location coding, as indicated, is in close proximity to the actual location. Panel numbers were assigned prior to the middeck closeout panel design definition. The starting points for location coding were behind the closeout panels, whereas the starting points used in this document are in front of the closeout panels.

Airlock Location Codes

An airlock code consists of four or five alphanumeric characters, which specify the following:

First character – A for airlock

Second character – The first letter of an airlock surface; the characters and surfaces are:

W – Wall

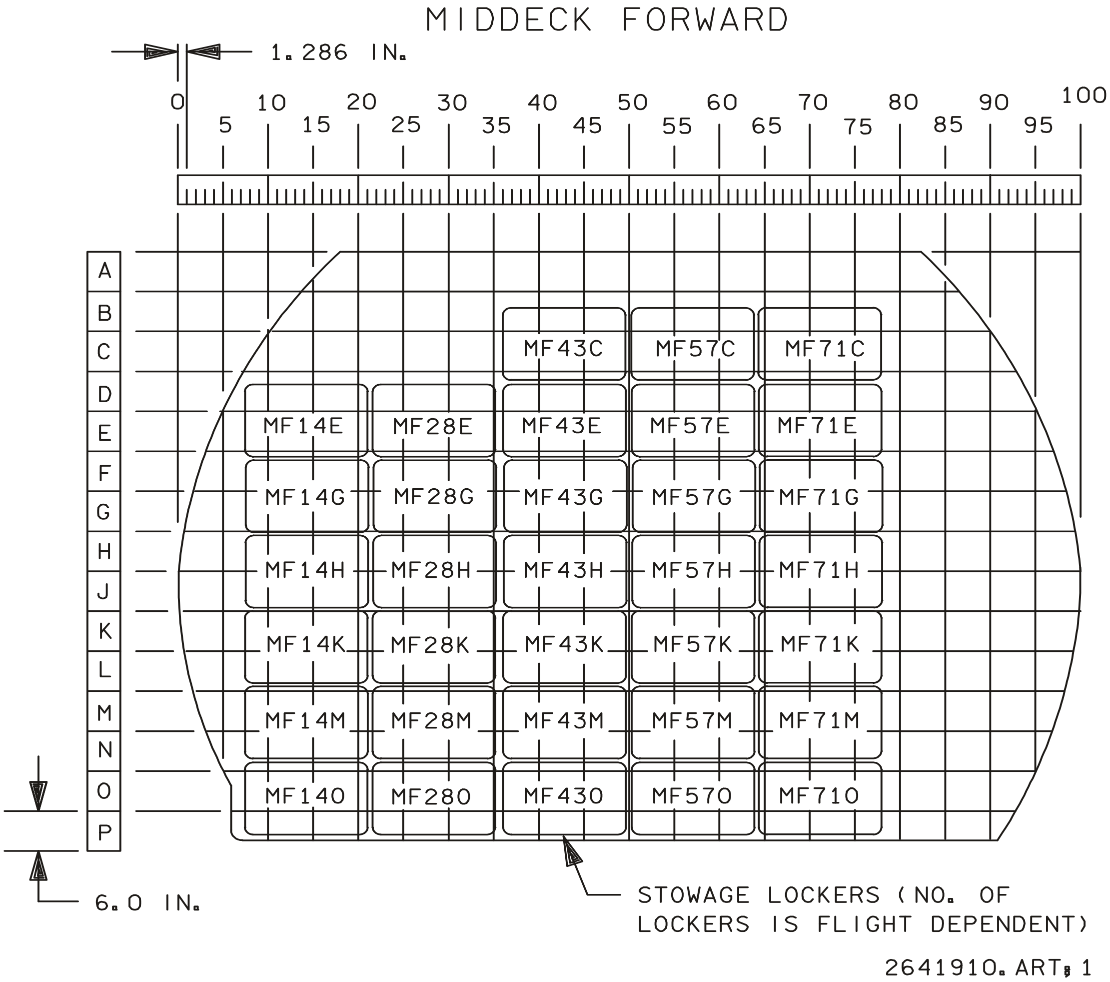
O – Overhead

D – Deck

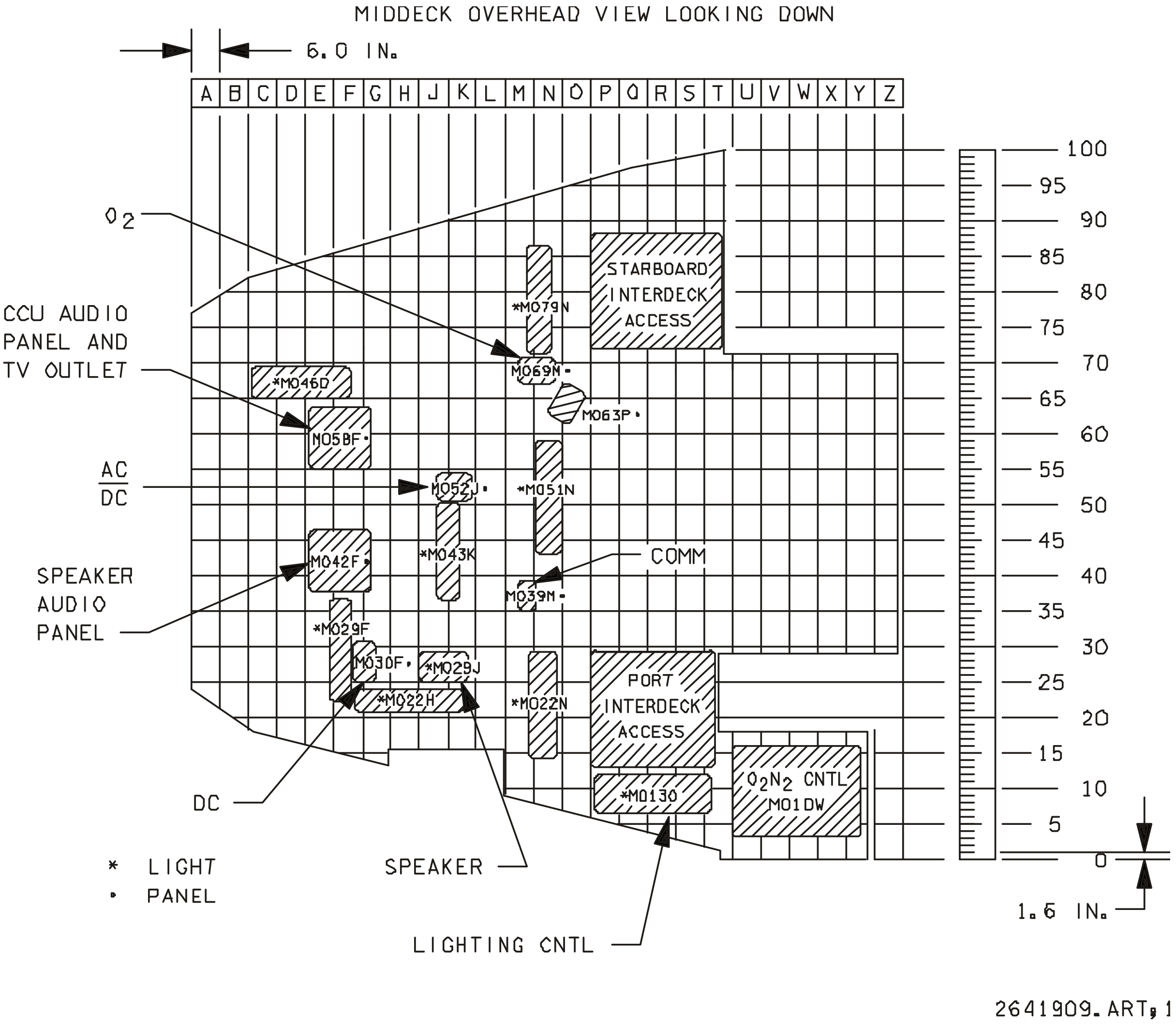
The "wall" is the inner wall of the cylindrical airlock. The "overhead" and "deck" are flat surfaces at each end of the cylinder. The airlock is oriented upside down with respect to the middeck, so that the airlock overhead corresponds to the middeck floor. The wall location codes have five characters, and the overhead/deck codes have four characters.

Third/fourth/fifth characters (wall only) – These characters form a location grid on the airlock wall. The third and fourth characters are numerics indicating the distance (clockwise) from the vertical centerline of the forward hatch (airlock in) expressed as a percentage of the total airlock circumference. The fifth character is an alpha character indicating the distance from the overhead surface expressed alphabetically in increments of 6 inches.

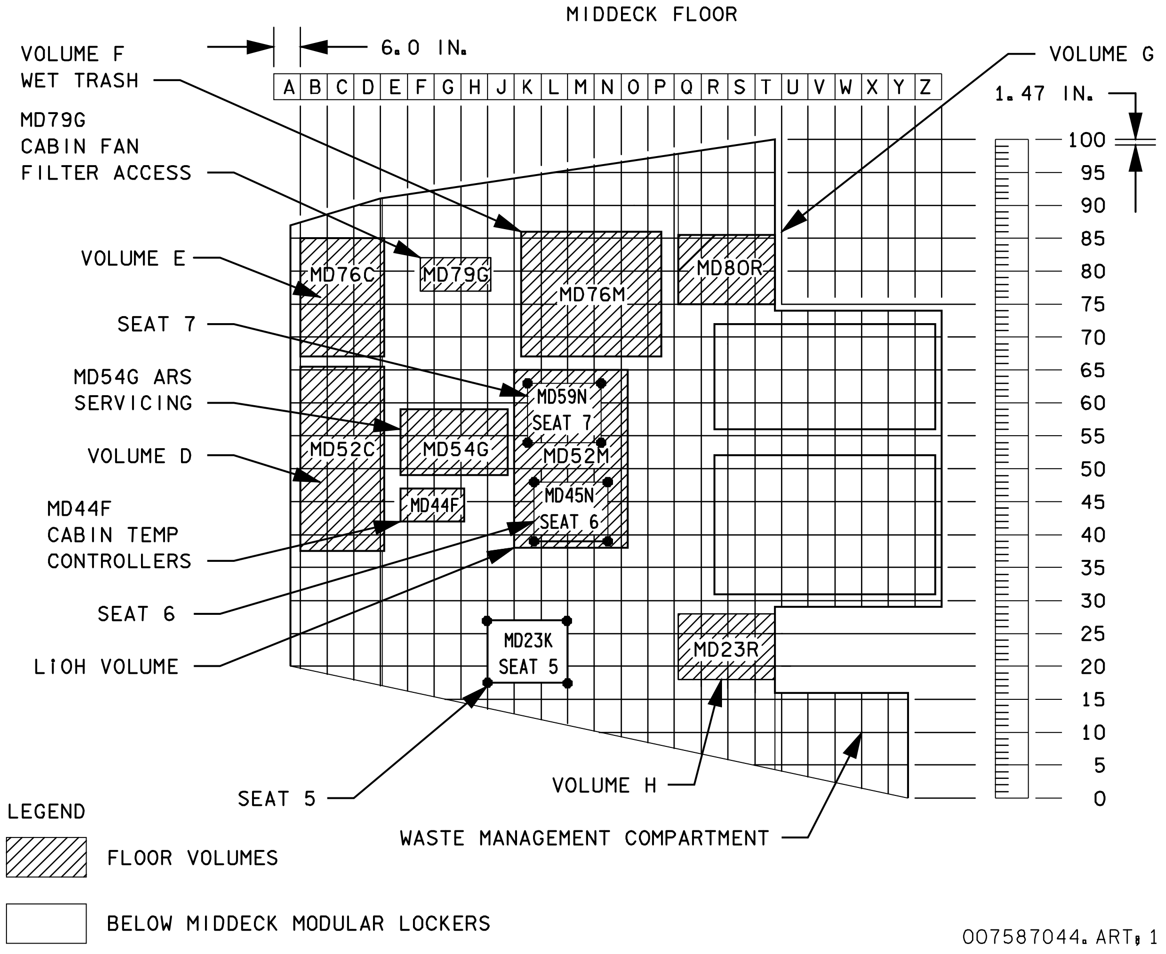
Third/fourth characters (overhead/deck only)– These characters form location grids on the deck and overhead surfaces. Since these surfaces are small, items can be easily located without the aid of the location grids.



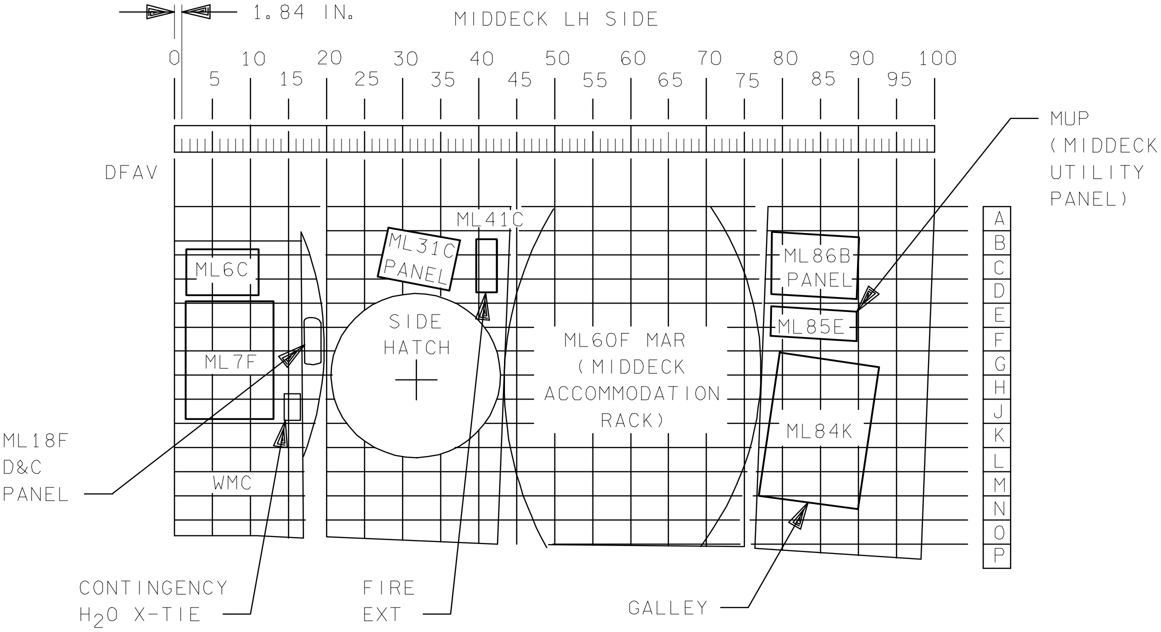
Middeck Location Codes (1 of 7)



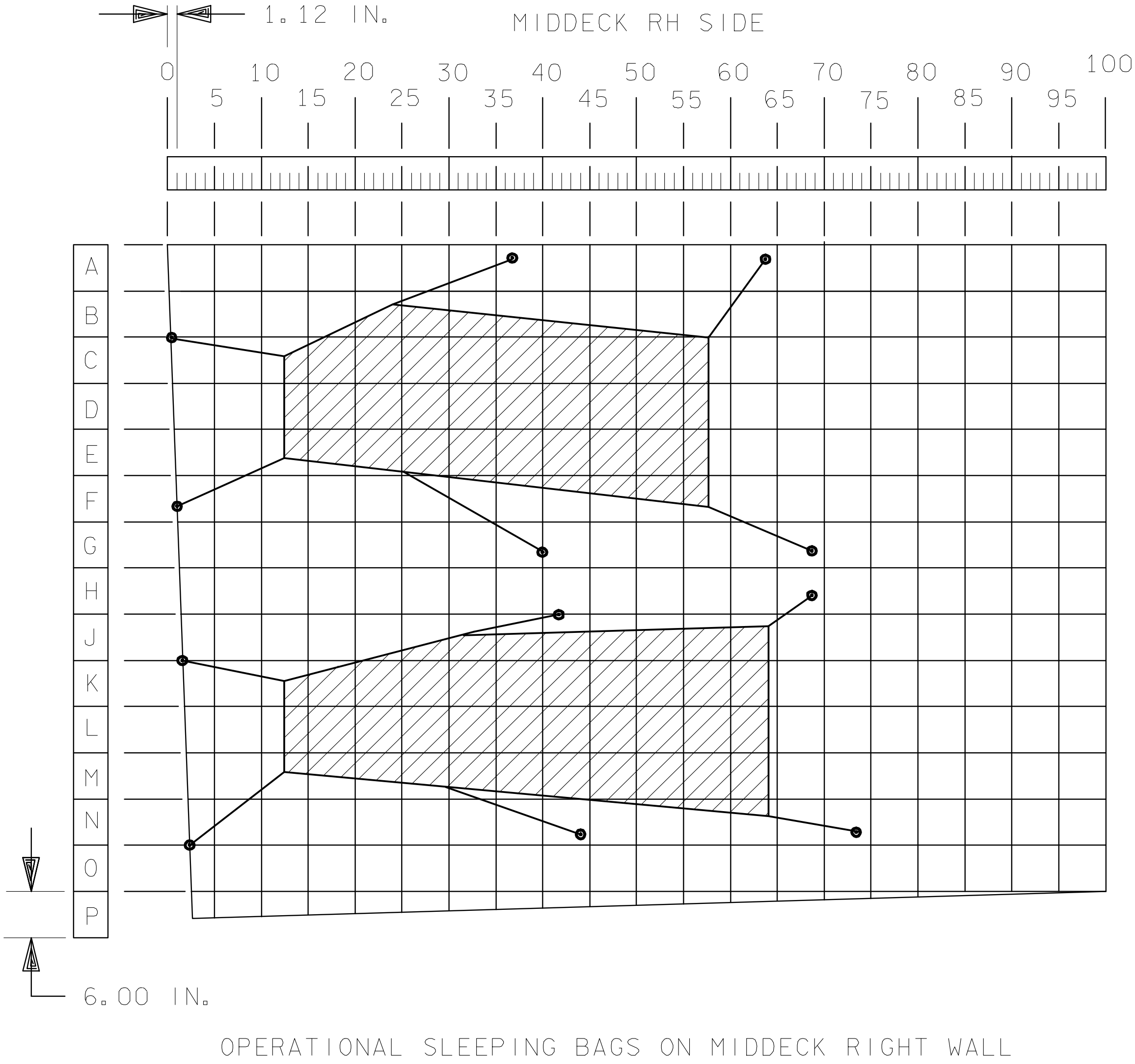
Middeck Location Codes (2 of 7)



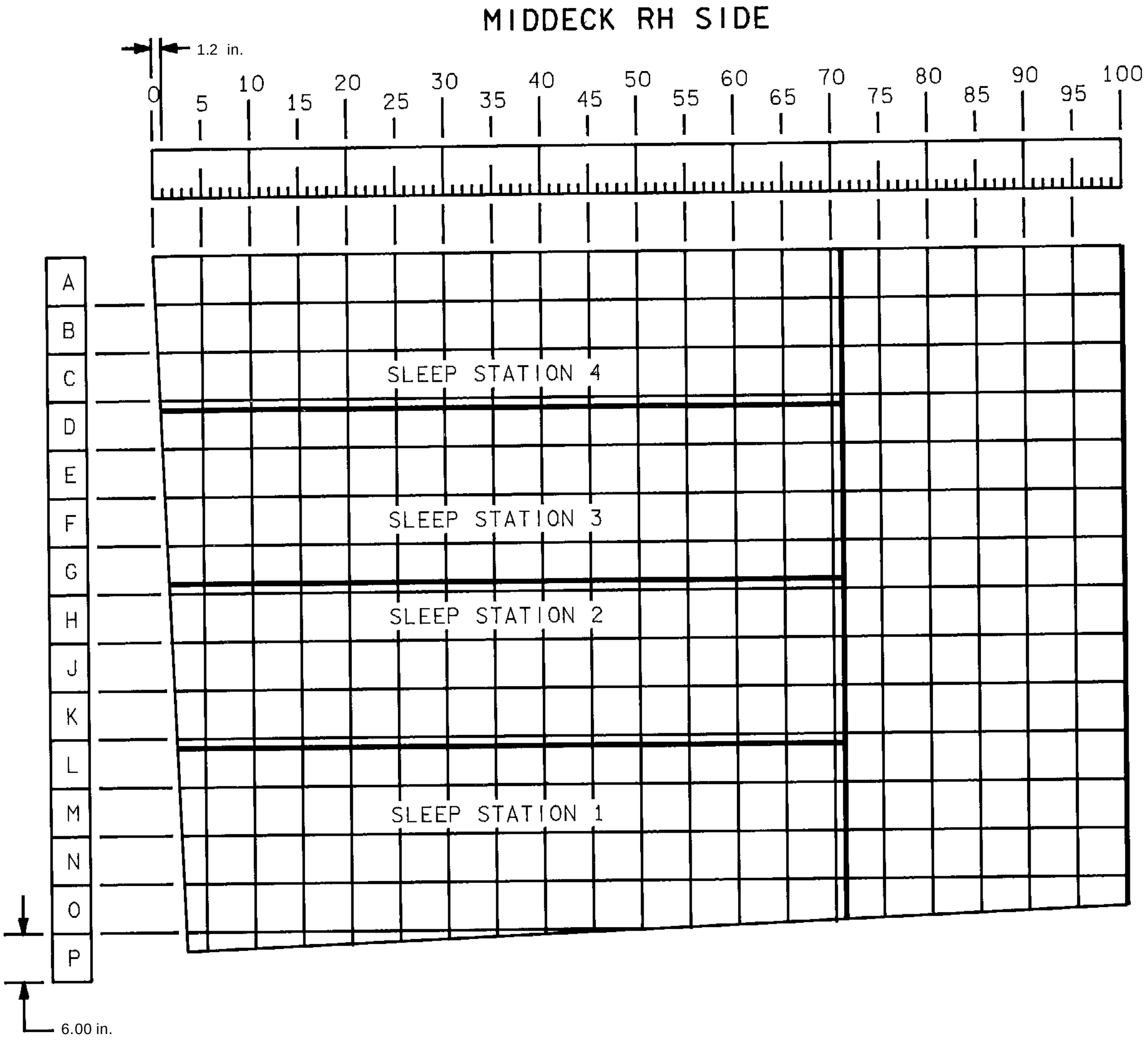
Middeck Location Codes (3 of 7)



Middeck Location Codes (4 of 7)



Middeck Location Codes (5 of 7)



Four±tier sleep station on middeck right wall

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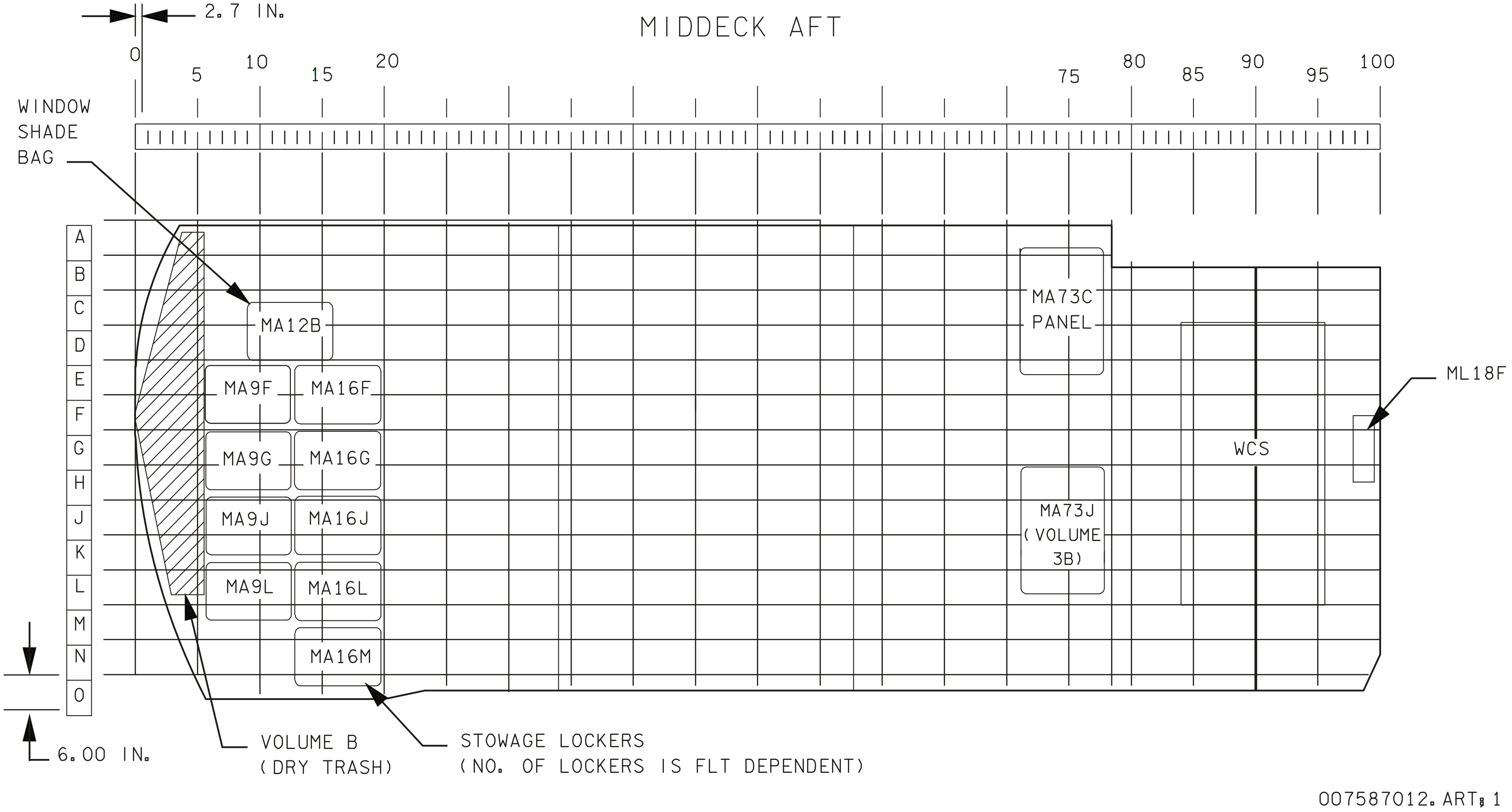
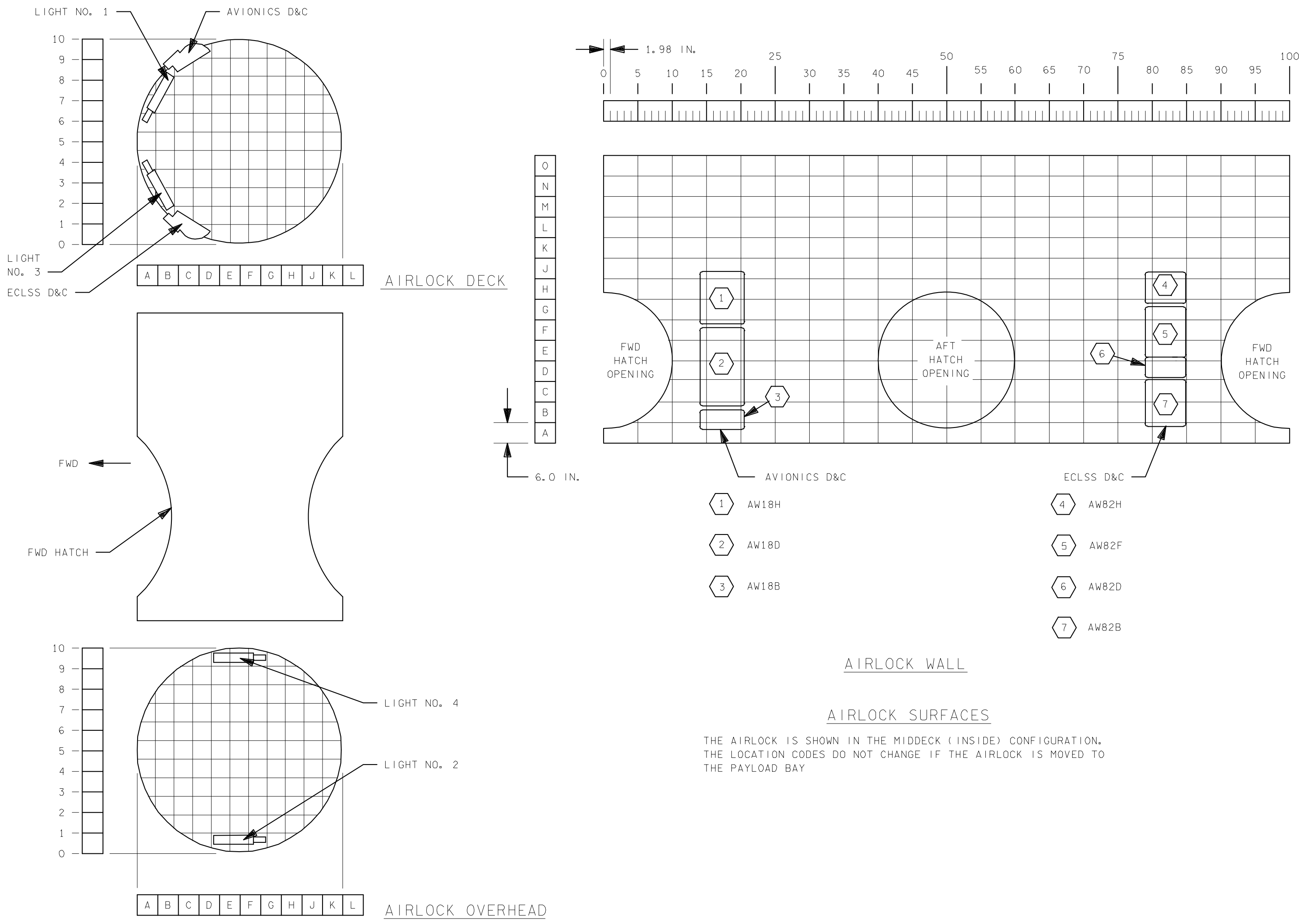
Middeck Location Codes (6 of 7)



Middeck Location Codes (7 of 7)



AIRLOCK DECK

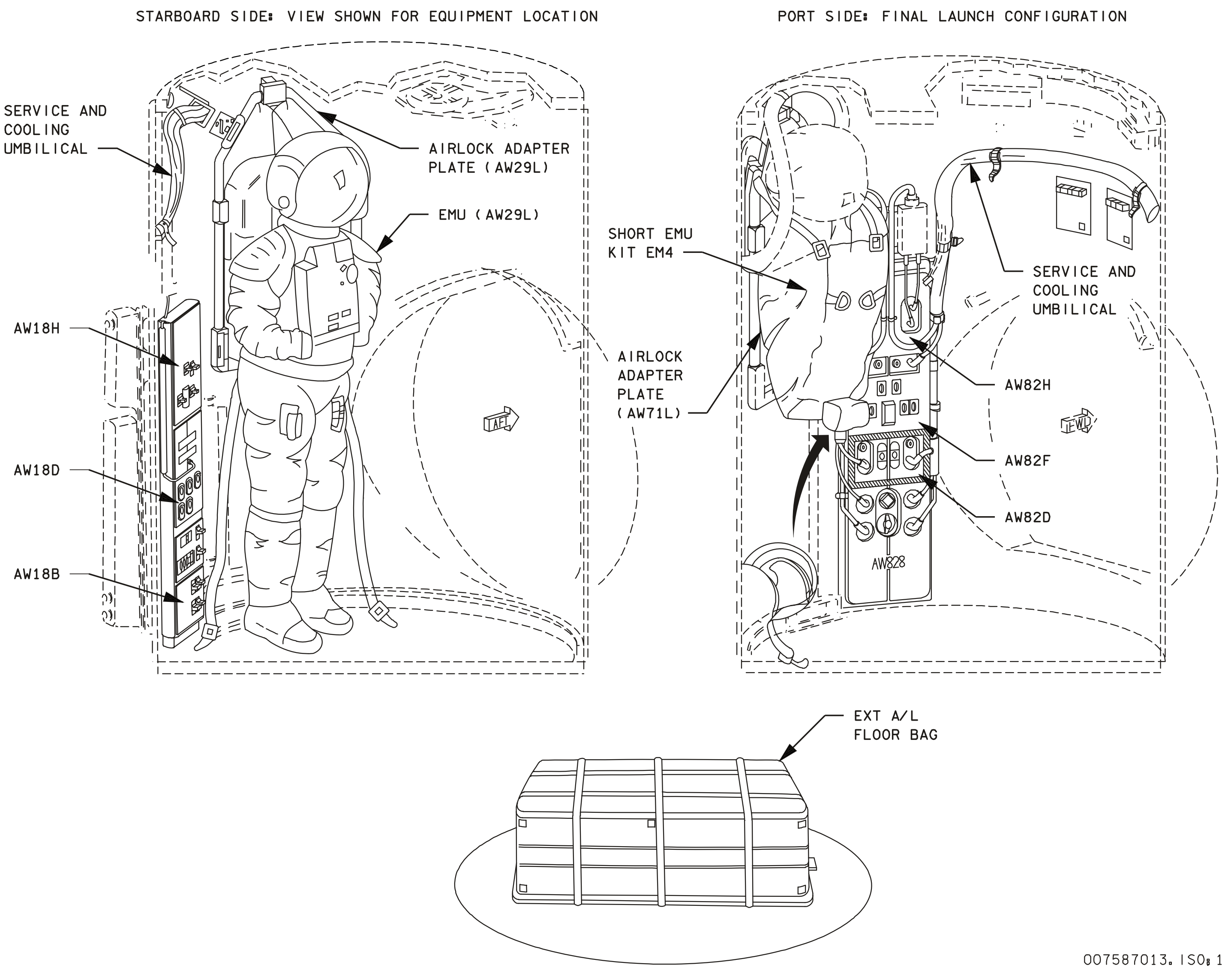
AIRLOCK OVERHEAD

AIRLOCK WALL

AIRLOCK SURFACES

THE AIRLOCK IS SHOWN IN THE MIDDECK (INSIDE) CONFIGURATION.
THE LOCATION CODES DO NOT CHANGE IF THE AIRLOCK IS MOVED TO THE PAYLOAD BAY

Airlock Location Codes



Airlock Equipment and Associated Location Codes

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1.2 ORBITER STRUCTURE

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The orbiter structure is divided into nine major sections: (1) forward fuselage, which consists of upper and lower sections that fit clamlike around a pressurized crew compartment, (2) wings, (3) midfuselage, (4) payload bay doors, (5) aft fuselage, (6) forward RCS, (7) vertical tail, (8) OMS/RCS pods, and (9) body flap. The majority of the sections are constructed of conventional aluminum and protected by reusable surface insulation.

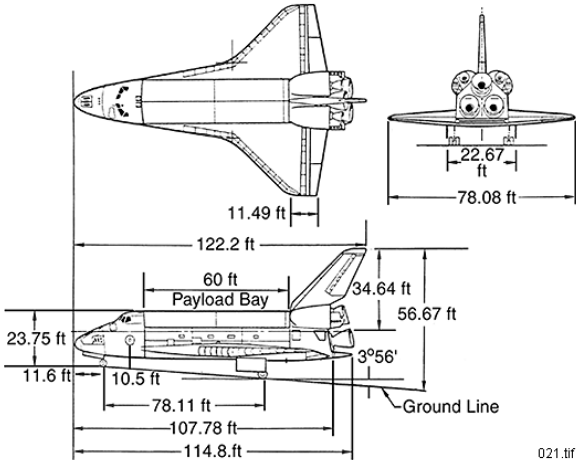
Forward Fuselage

The forward fuselage consists of the upper and lower fuselages. It houses the crew compartment and supports the forward RCS module, nose cap, nose gear wheel well, nose gear, and nose gear doors.

The forward fuselage is constructed of conventional 2024 aluminum alloy skin-stringer panels, frames, and bulkheads. The panels are single curvature, stretch-formed skins with riveted stringers spaced 3 to 5 inches apart. The frames are riveted to the skin-stringer panels. The major frames are spaced 30 to 36 inches apart. The Y_o = 378 upper forward bulkhead is constructed of flat aluminum and formed sections riveted and bolted together; the lower is a machined section. The bulkhead provides the interface fitting for the nose section.

The nose section contains large machined beams and struts. The structure for the nose landing gear wheel well consists of two support beams, two upper closeout webs, drag-link support struts, nose landing gear strut and actuator attachment fittings, and the nose landing gear door fittings. The left and right landing gear doors are attached by hinge fittings in the nose section. The doors are constructed of aluminum alloy honeycomb, and although the doors are the same length, the left door is wider than the right. Each door has an up-latch fitting at the forward and aft ends to lock the door closed when the gear is retracted, and each has a pressure seal in addition to a thermal barrier. Lead ballast in the nose wheel well and on the X_o = 293 bulkhead provides weight and center-of-gravity control. The nose wheel well accommodates 1,350 pounds of ballast, and the X_o = 293 bulkhead accommodates a maximum of 1,971 pounds.

The forward fuselage carries the basic body-bending loads (loads that have a tendency to change the radius of a curvature of the body) and reacts to nose landing gear loads.



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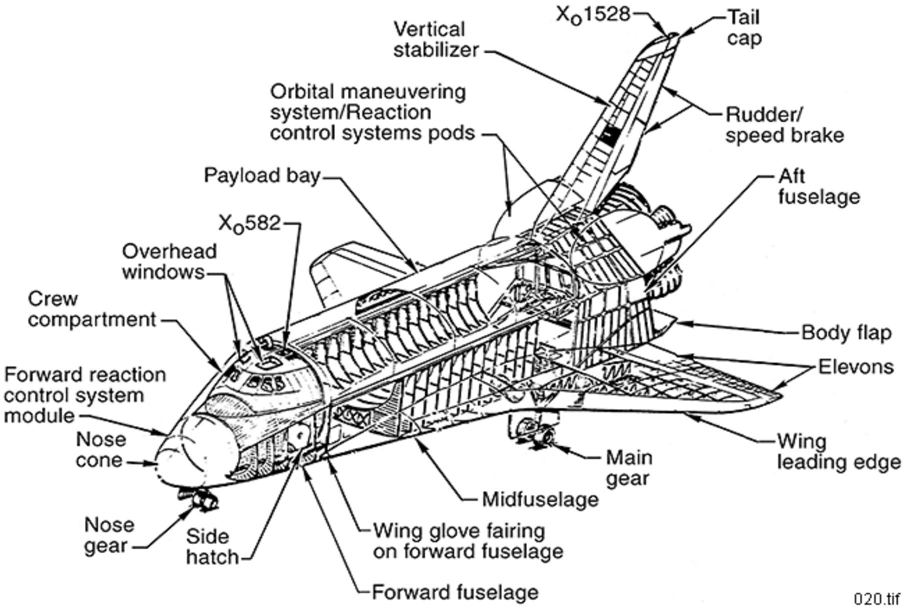
Minimum Ground Clearances	Feet
Body Flap	12.07
Main Gear Door	2.85
Nose Gear Door	2.95
Wing Tip	11.92

Orbiter Dimensions

The forward fuselage is covered with reusable insulation, except for the six windshields, two overhead windows, and side hatch window areas around the forward RCS jets. The nose cap is also a reusable thermal protection system constructed of reinforced carbon-carbon with thermal barriers at the nose cap-structure interface.

The forward fuselage skin has structural provisions for installing antennas, deployable air data probes, and the door eyelet openings for the two star trackers. Two openings are required in the upper forward fuselage for star tracker viewing. Each opening has a door for environ-mental control.

The forward orbiter/ET attach fitting is at the X_o = 378 bulkhead and the skin panel structure aft of the nose gear wheel well. Purge and vent



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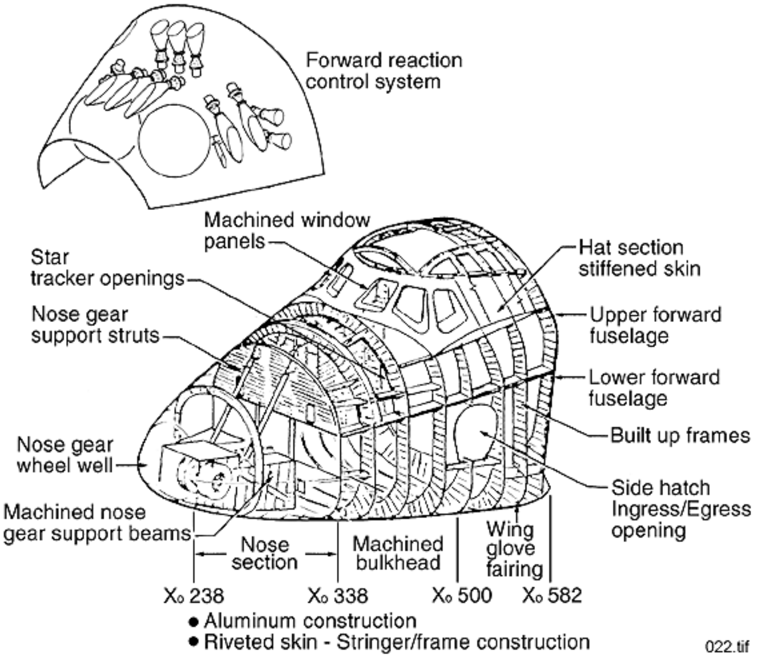
Orbiter



Forward Fuselage Structure

control is provided by flexible boots between the forward fuselage and crew compartment around the windshield windows, overhead observation window, crew hatch window, and star tracker openings. The forward fuselage is isolated from the payload bay by a flexible membrane between the forward fuselage and crew compartment at $X_o = 582$.

The forward RCS module is constructed of conventional 2024 aluminum alloy skin-stringer panels and frames. The panels are composed of single-curvature, stretch-formed skins with riveted stringers. The frames are riveted to the skin-stringer panels. The forward RCS module is secured to the forward fuselage nose section and forward bulkhead of the forward fuselage with 16 fasteners, which permit the installation and removal of the module. The components of the forward RCS are mounted and attached to the module, which has a reusable thermal protection cover, in addition to thermal barriers installed around it and the RCS jet interfaces and the interface-attachment area to the forward fuselage.

Crew Compartment

The three-level crew compartment is constructed of 2219 aluminum alloy plate with integral stiffening stringers and internal framing welded together to create a pressure-tight vessel. The compartment has a side hatch for normal ingress and egress, a hatch into the airlock from the middeck, and a hatch from the airlock into the payload bay for extravehicular activity and payload bay access. The side hatch can be jettisoned.

Redundant pressure window panes are provided in the six forward windshields, the two overhead viewing windows, the two aft viewing windows, and the side hatch windows. Approximately 300 penetrations in the pressure shell are sealed with plates and fittings. A large removable panel in the aft bulkhead provides access to the interior of the crew compartment during initial fabrication and assembly. The compartment supports the ECLSS, avionics, GNC equipment, inertial measurement units, displays and controls, star trackers, and crew accommodations for sleeping, waste management, seats, and an optional galley.

The crew compartment is supported within the forward fuselage at only four attach points to minimize the thermal conductivity between them. The two major attach points are located at the aft end of the crew compartment at the flight deck floor level. The vertical load reaction link is on the centerline of the forward bulkhead. The lateral load reaction is on the lower segment of the aft bulkhead.

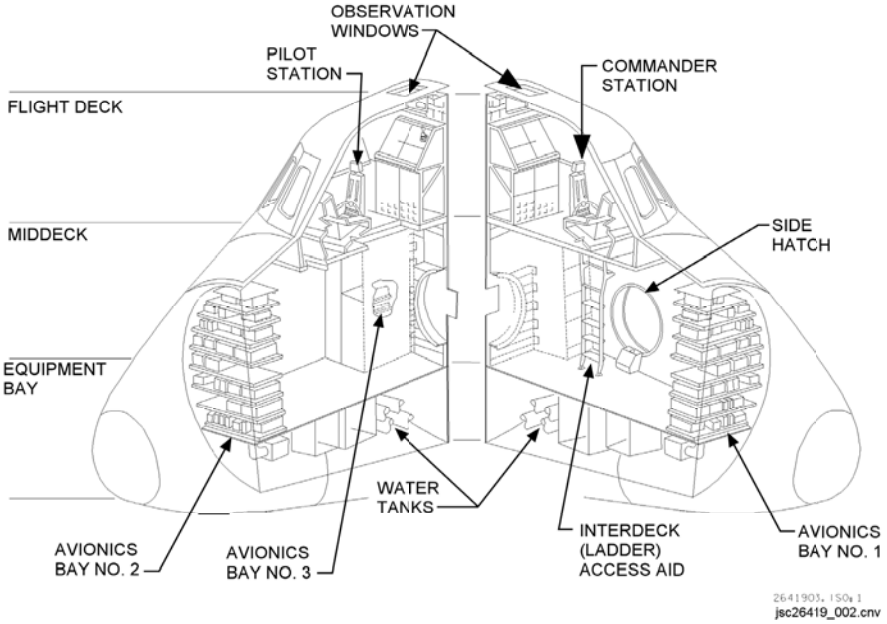
The compartment is configured to accommodate a crew of four on the flight deck and three in the middeck. The crew cabin arrangement consists of a flight deck, middeck, and lower level equipment bay.

The crew compartment is pressurized to 14.7 ± 0.2 psia and is maintained at an 80-percent nitrogen and 20-percent oxygen composition by the ECLSS, which provides a shirt-sleeve environment for the flight crew. The crew compartment is designed for 16 psia.

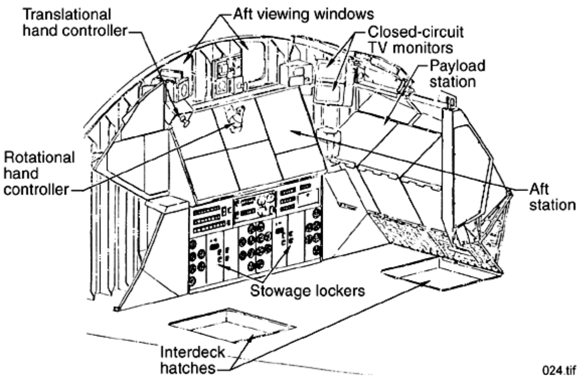
The crew compartment's volume with the airlock in the payload bay is 2,553 cubic feet.

Flight Deck

The flight deck is the uppermost compartment of the cabin. The commander's and pilot's work stations are positioned side by side in the forward portion of the flight deck. These stations have controls and displays for controlling the vehicle throughout all mission phases. Directly behind and to the sides of the commander and pilot centerline are the mission specialist seats.



Crew Compartment and Arrangement



Aft Flight Station

The aft flight deck has two overhead and aft viewing windows for viewing orbital operations. The aft flight deck station also contains displays and controls for executing attitude or translational maneuvers for rendezvous, stationkeeping, docking, payload deployment and retrieval, payload monitoring, remote manipulator system controls and displays, payload bay door operations, and closed-circuit television operations. The aft flight deck is approximately 40 square feet.

The forward flight deck, which includes the center console and seats, is approximately 24 square feet. However, the side console controls and displays add approximately 3.5 more square feet. If the center console is subtracted from the 24 square feet, this would amount to approximately 5.2 square feet.

Middeck

Directly beneath the flight deck is the middeck. Access to the middeck is through two interdeck openings, which measure 26 by 28 inches. Normally, the right interdeck opening is closed, and the left is open. A ladder attached to the left interdeck access allows easy passage in 1-g conditions. The middeck provides crew accommodations and contains three avionics equipment bays. The two forward avionics bays utilize the complete width of the cabin and extend into the middeck 39 inches from the forward bulkhead. The aft bay extends into the middeck 39 inches from the aft bulkhead on either side of the airlock hatch. Attached to the aft bay on the port side of the vehicle is the waste management compartment and closeouts which create a stowage compartment known as volume 3B. Just forward of the waste management system is the side hatch. The completely stripped middeck is approximately 160 square feet; the gross mobility area is approximately 100 square feet.

The side hatch in the middeck is used for normal crew ingress/egress and may be operated from within the crew cabin middeck or externally. It is attached to the crew cabin tunnel by hinges, a torque tube, and support fittings. The hatch opens outwardly 90° down with the orbiter horizontal or 90° sideways with the orbiter vertical. It is 40 inches in diameter and has a 10-inch clear-view window in the center of the hatch. The window consists of three panes of glass. The side hatch has a pressure seal that is compressed by the side hatch latch mechanisms when the hatch is locked closed. A thermal barrier of Inconel wire mesh spring with a ceramic fiber braided sleeve is installed between the reusable surface insulation tiles on the forward fuselage and the side hatch. The total weight of the side hatch is 294 pounds.

Depending on the mission requirements, bunk sleep stations and a galley can be installed in the middeck. In addition, three or four seats of the same type as the mission specialists' seats on the flight deck can be installed in the middeck.

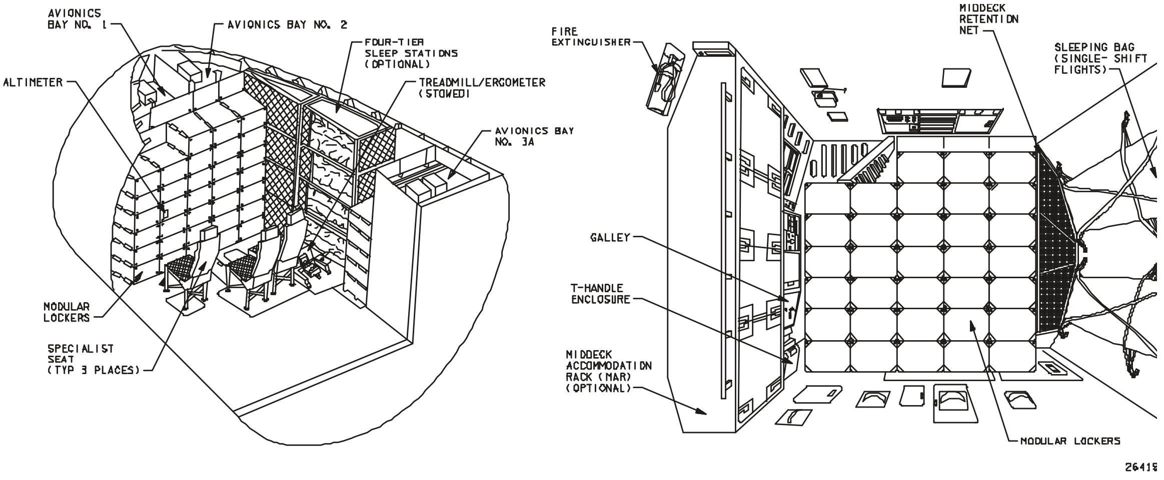
The middeck also provides a stowage volume of 140 cubic feet. Accommodations are included for dining, sleeping, maintenance, exercising, and data management. On the orbiter centerline, just aft of the forward avionics equipment bay, an opening in the ceiling provides access to the inertial measurement units.

The middeck floor contains removable panels that provide access to the ECLSS equipment. The middeck equipment bay below the middeck floor houses the major components of the waste management and air revitalization systems, such as pumps, fans, lithium hydroxide carbon dioxide absorbers, heat exchangers, and ducting. This compartment has space for stowing lithium hydroxide canisters and five separate spaces for crew equipment stowage with a volume of 29.92 cubic feet.

Modular stowage lockers are used to store the flight crew's personal gear, mission-necessary equipment, personal hygiene equipment, and experiments. There are 44 identical boxes that are 11 by 18 by 21 inches.

An airlock located in the payload bay is made of aluminum and covered with thermal blankets. Three hatches are installed. One from the middeck, one to the payload bay and one everhead used while docked. The docking mechanism attached to the top of the airlock is operated by avionics mounted under a false floor in the bottom of the airlock. The airlock is mounted in the payload bay via truss.

Normally, two extravehicular mobility units are stowed in the airlock.



Crew Compartment Middeck

Forward Fuselage and Crew Compartment Windows

The orbiter windows provide visibility for entry, landing, and on-orbit operations. For atmospheric flight, the flight crew needs forward, left, and right viewing areas. On-orbit mission phases require visibility for rendezvous, docking, and payload-handling operations.

The six windows located at the forward flight deck commander and pilot stations provide forward, left, and right viewing. The two overhead windows and two payload-viewing windows at the aft station location on the flight deck provide rendezvous, docking, and payload viewing. There is also a window in the middeck side hatch.

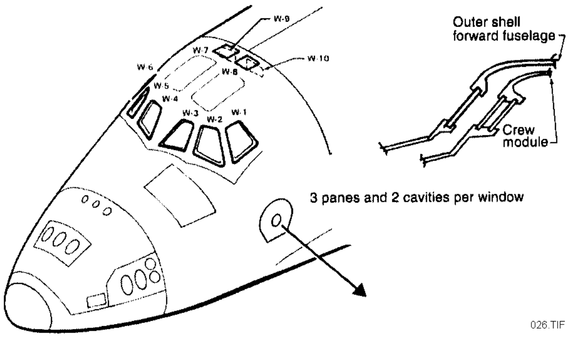
The six platform-shaped forward windows are the thickest pieces of glass ever produced in the optical quality for see-through viewing. Each consists of three individual panes. The innermost pane, which is 0.625 of an inch thick, is constructed of tempered aluminosilicate glass to withstand the crew compartment pressure. Aluminosilicate glass is a low-expansion glass that can be tempered to provide maximum mechanical strength. The exterior of this pane, called a pressure pane, is coated with a red reflector coating to reflect the infrared (heat portion) rays while transmitting the visible spectrum.

The center pane is constructed of low-expansion, fused silica glass because of its high optical quality and excellent thermal shock resistance. This pane is 1.3 inches thick.

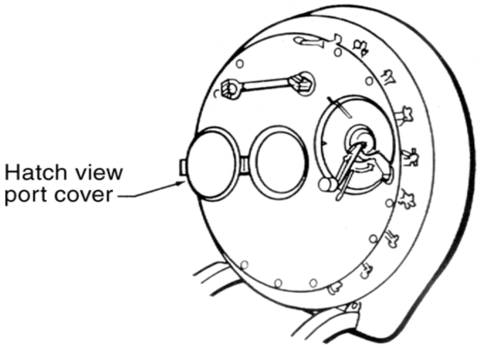
The inner and outer panes are coated with a high-efficiency, anti-reflection coating to improve visible light transmission. These windows withstand a proof pressure of 8,600 psi at 240° F and 0.017 relative humidity.

The outer pane is made of the same material as the center pane and is 0.625 of an inch thick. The exterior is uncoated, but the interior is coated with high-efficiency, anti-reflection coating. The outer surface withstands approximately 800° F.

Each of the six forward windows’ outer panes measures 42 inches diagonally, and the center and inner panes each measure 35 inches diagonally. The outer panes of the six forward windows are mounted and attached to the forward fuselage. The center and inner panes



Flight Deck Windows



Side Hatch (Interior View)

are mounted and attached to the crew compartment. Redundant seals are employed on each window. No sealing/bonding compounds are used.

The two overhead windows at the flight deck aft station are identical in construction to the six forward windows, except for thickness. The inner and center panes are 0.45 of an inch thick, and the outer pane is 0.68 of an inch thick. The outer pane is attached to the forward fuselage, and the center and inner panes are attached to the crew compartment. The two overhead windows' clear view area is 20 by 20 inches. The left-hand overhead window provides the crew members with a secondary emergency egress. The inner and center panes open into the crew cabin, and the outer pane is jettisoned up and over the top of the orbiter. This provides a secondary emergency exit area of 20 by 20 inches.

On the aft flight deck, each of the two windows for viewing the payload bay consists of only two panes of glass, which are identical to the forward windows' inner and center panes. The outer thermal panes are not installed. Each pane is 0.3 of an inch thick. The windows are 14.5 by 11 inches. Both panes are attached to the crew compartment.

The side hatch viewing window consists of three panes of glass identical to the six forward windows. The inner pane is 11.4 inches in diameter and 0.25 of an inch thick. The center pane is 11.4 inches in diameter and 0.5 of an inch thick. The outer pane is 15 inches in diameter and 0.3 of an inch thick.

During orbital operations, the large window areas of transparency expose the flight crew to sun glare; therefore, window shades are provided to preclude or minimize exposure. Shades are provided for all windows on the flight deck. The overhead window shades are stored in the middeck of the orbiter crew compartment. Attachment mechanisms and devices are provided for their installation at each window on the flight deck.

The forward station window shades (W-1 through W-6) are rolled up and stowed at the base of the windows. Solid shades are used on overhead windows (W-7 and W-8).

The aft window shades (W-9 and W-10) are held in place via 0.63-inch-wide strip of Nomex Velcro around the perimeter of the shade. The shade is attached to the window by pressing the Velcro strip to the pile strip around the window opening.

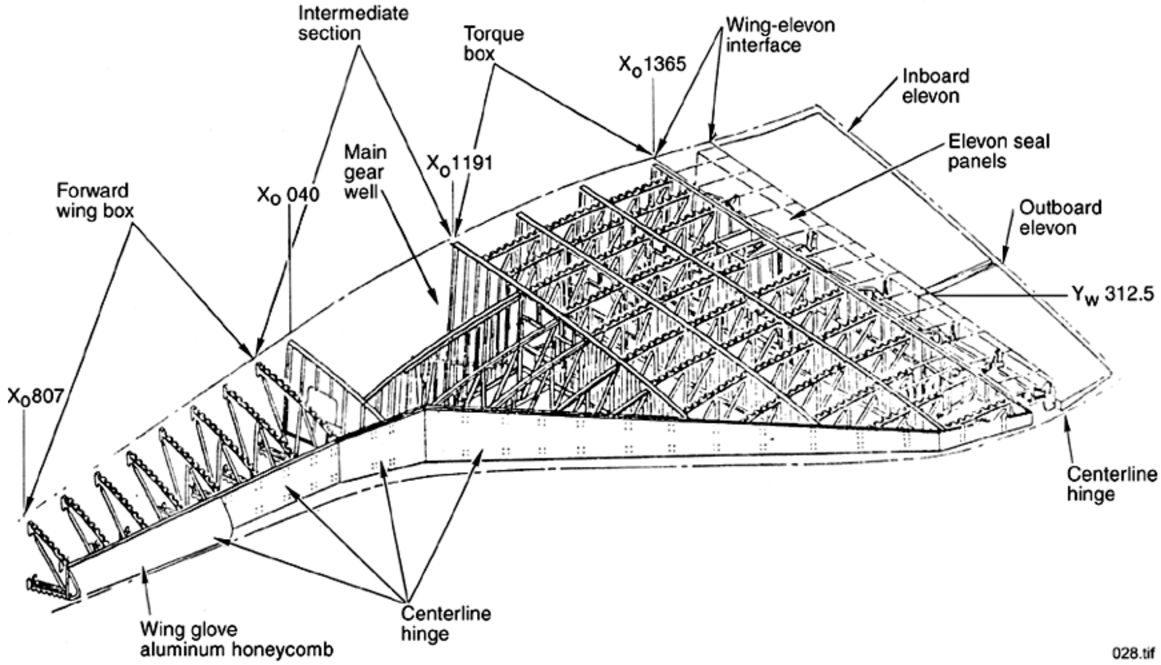
The side hatch window cover is permanently attached to the window frame and is hinged to allow opening and closing.

Wing

The wing is an aerodynamic lifting surface that provides conventional lift and control for the orbiter. The left and right wings consist of the wing glove, the intermediate section (which includes the main landing gear well), the torque box, the forward spar for mounting the reusable reinforced carbon-carbon leading edge structure thermal protection system, the wing/elevon interface, the elevon seal panels, and the elevons.

The wing is constructed of conventional aluminum alloy with a multirib and spar arrangement with skin-stringer-stiffened covers or honeycomb skin covers. Each wing is ≈60 feet long at the fuselage intersection and has a maximum thickness of 5 feet.

The forward wing box is an extension of the basic wing that aerodynamically blends the wing leading edge into the midfuselage wing glove. The forward wing box is a conventional design of aluminum ribs, aluminum tubes, and tubular struts. The upper and lower wing skin panels are stiffened aluminum. The leading



Wing Structure

edge spar is constructed of corrugated aluminum.

The intermediate wing section consists of the conventional aluminum multiribs and aluminum tubes. The upper and lower skin covers are constructed of aluminum honeycomb. A portion of the lower wing surface skin panel includes the main landing gear door. The intermediate section houses the main landing gear compartment and reacts to a portion of the main landing gear loads. A structural rib supports the outboard main landing gear door hinges and the main landing gear trunnion and drag link. The support for the inboard main landing gear trunnion and drag link attachment is provided by the midfuselage. The main landing gear door is conventional aluminum honeycomb.

The four major spars are constructed of corrugated aluminum to minimize thermal loads. The forward spar provides the attachment for the thermal protection system reusable reinforced carbon-carbon leading edge structure. The rear spar provides the attachment interfaces for the elevons, hinged upper seal panels, and associated hydraulic and electrical system components. The upper and lower wing skin panels are stiffened aluminum.

The elevons provide orbiter flight control during atmospheric flight. The two-piece elevons are conventional aluminum multirib and beam construction with aluminum honeycomb skins for compatibility with the acoustic environment and thermal interaction. The elevons are divided into two segments for each wing, and each segment is supported by three hinges. The elevons are attached to the flight control system hydraulic actuators at points along their forward extremities, and all hinge moments are reacted to at these points. Each elevon travels 33° up and 18° down (software limits).

The transition area on the upper surface between the torque box and the movable elevon consists of a series of hinged panels that provide a closeout of the wing-to-elevon cavity. These panels are of Inconel honeycomb sandwich construction outboard of wing station Y_W = 312.5 and of titanium honeycomb sandwich construction inboard of wing station Y_W = 312.5. The upper leading edge of each elevon incorporates titanium rub strips. The rub strips are of titanium honeycomb construction and are not covered with the thermal protection system reusable surface insulation. They provide the sealing surface area for the elevon seal panels.

Except the elevon seal panels, the exposed areas of the wings, main landing gear doors, and elevons are covered with reusable surface insulation thermal protection system materials. Thermal seals are provided on the elevon lower cove area along with thermal spring seals on the upper rub panels. Pressure seals and thermal barriers are provided on the main landing gear doors.

The wing is attached to the fuselage with a tension bolt splice along the upper surface. A shear splice along the lower surface in the area of the fuselage carry-through completes the attachment interface.

B manufacturing the wings for Discovery (OV-103) and Atlantis (OV-104), a weight reduction program resulted in a redesign of certain areas of the wing structure. An assessment of wing air loads was made from actual flight data that indicated greater loads on the wing structure. As a result, to maintain positive margins of safety during ascent, structural modifications were incorporated into certain areas of the wings. The modifications included the addition of doublers and stiffeners.

Midfuselage

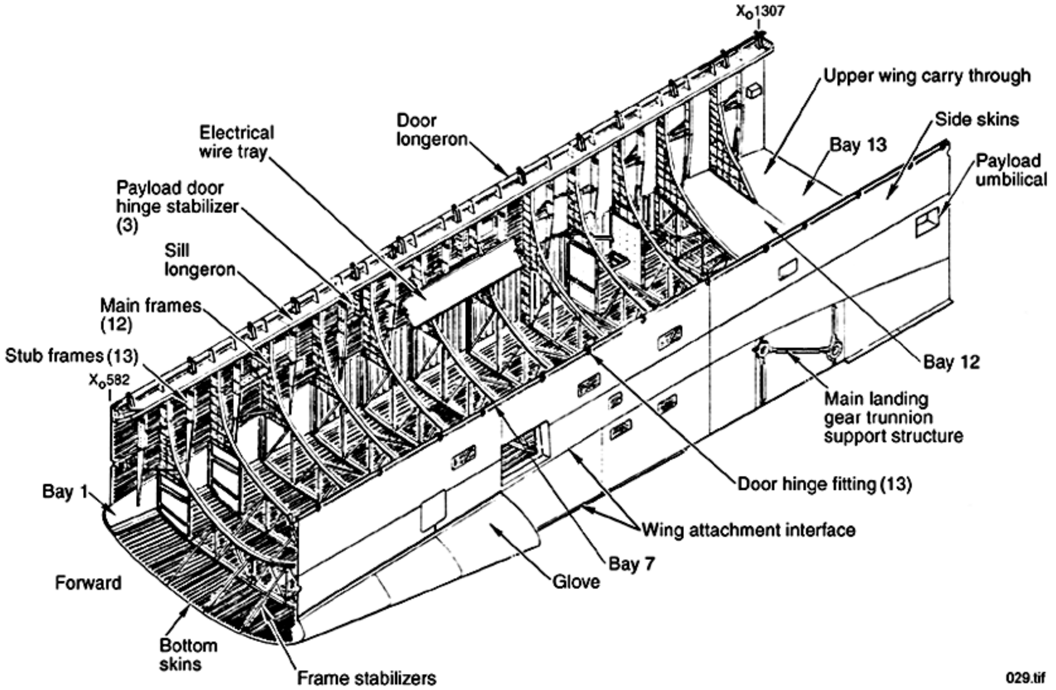
The midfuselage structure interfaces with the forward fuselage, aft fuselage, and wings. It supports the payload bay doors, hinges, tie-down fittings, forward wing glove, and various orbiter system components, and it forms the payload bay area.

The forward and aft ends of the midfuselage are open, with reinforced skin and longerons interfacing with the bulkheads of the forward and aft fuselages. The midfuselage is primarily an aluminum structure 60 feet long, 17 feet wide, and 13 feet high. It weighs approximately 13,502 pounds.

The midfuselage skins are integrally machined by numerical control. The panels above the wing glove and the wings for the forward eight bays have longitudinal T-stringers. The five aft bays have aluminum honeycomb panels. The side skins in the shadow of the wing are also numerically control machined but have vertical stiffeners.

The midfuselage structure is stabilized by 12 mainframe assemblies. The assemblies consist of vertical side elements and horizontal elements. The side elements are machined; the horizontal elements are boron/aluminum tubes with bonded titanium end fittings.

In the upper portion of the midfuselage are the sill and door longerons. The machined sill



Midfuselage Structure

longerons not only make up the primary body-bending elements, but also take the longitudinal loads from payloads in the payload bay. The payload bay door longerons and associated structure are attached to the 13 payload bay door hinges. These hinges provide the vertical reaction from the payload bay doors. Five of the hinges react to the payload bay door shears. The sill longeron also provides the base support for the payload bay manipulator arm (if installed) and its stowage provisions, the Ku-band rendezvous antenna, the antenna base support and its stowage provisions, and the payload bay door actuation system.

The side wall forward of the wing carry-through structure provides the inboard support for the main landing gear. The total lateral landing gear loads are reacted to by the midfuselage structure.

The midfuselage also supports the two electrical wire trays that contain the wiring between the crew compartment and aft fuselage.

Plumbing and wiring in the lower portion of the midfuselage are supported by fiberglass milk stools. The other exposed areas of the midfuselage are covered with the reusable surface insulation thermal protection system.

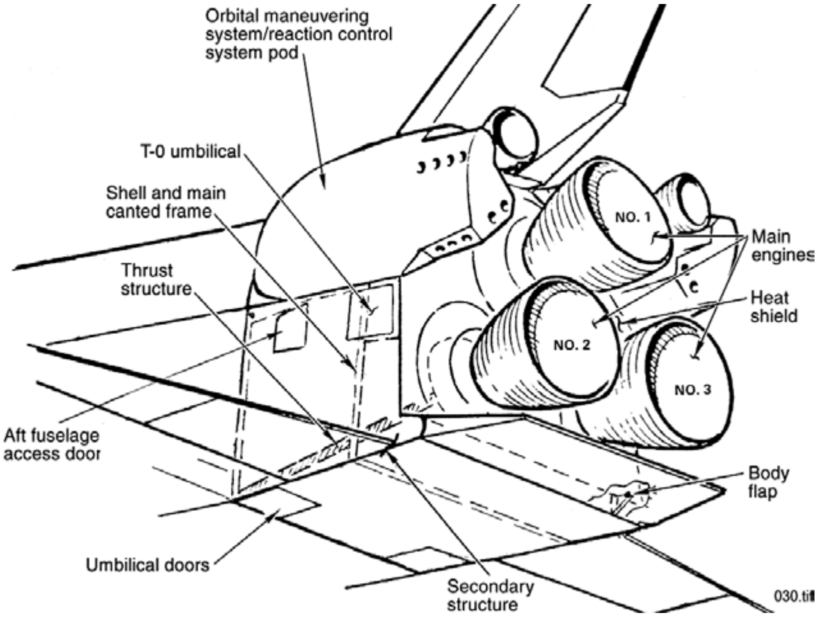
Because of additional detailed analysis of actual flight data concerning descent stress thermal gradient loads, torsional straps were added to the lower midfuselage stringers in bays 1 through 11. The torsional straps tie all stringers together similarly to a box section, which eliminates rotational (torsional) capabilities to provide positive margins of safety.

Also, because of additional detailed analysis of actual flight data during descent, room-temperature vulcanizing silicone rubber material was bonded to the lower midfuselage from bay 4 through 12 to act as a heat sink and distribute temperatures evenly across the bottom of the midfuselage, which reduces thermal gradients and ensures positive margins of safety.

Aft Fuselage

The aft fuselage consists of an outer shell, thrust structure, and internal secondary structure. It is approximately 18-feet-long, 22-feet-wide, and 20-feet-high.

The aft fuselage supports and interfaces with the left-hand and right-hand aft OMS/RCS pods, the wing aft spar, midfuselage, orbiter/external tank rear attachments, main engines, aft heat shield, body flap, vertical tail, and two T-0 launch umbilical panels.



Aft Fuselage Structure

The aft fuselage provides the load path to the midfuselage main longerons, main wing spar continuity across the forward bulkhead of the aft fuselage, structural support for the body flap, and structural housing around all internal systems for protection from operational environments (pressure, thermal, and acoustic) and controlled internal pressures during flight.

The forward bulkhead closes off the aft fuselage from the midfuselage and is composed of machined and beaded sheet metal aluminum segments. The upper portion of the bulkhead attaches to the front spar of the vertical tail.

The internal thrust structure supports the three SSMEs. The upper section of the thrust structure supports the upper SSME, and the lower section supports the two lower SSMEs. The internal thrust structure includes the SSMEs, load reaction truss structures, engine interface fittings, and the actuator support structure. It supports the SSMEs and the SSME low-pressure turbopumps and propellant lines. The two orbiter/external tank aft attach points interface at the longeron fittings.

The internal thrust structure is composed mainly of 28 machined, diffusion-bonded truss members. In diffusion bonding, titanium strips are bonded together under heat, pressure, and time. This fuses the titanium strips into a single hollow, homogeneous mass that is lighter and stronger than a forged part. In looking at the cross section of a diffusion bond, no weld line is visible. It is a homogeneous parent metal, yet composed of pieces joined by diffusion bonding. (In OV-105, the internal thrust structure is a forging.) In selected areas, the titanium construction is reinforced with boron/epoxy tubular struts to minimize weight and add stiffness.

The upper thrust structure of the aft fuselage is of integral-machined aluminum construction with aluminum frames except for the vertical fin support frame, which is titanium. The skin panels are integrally machined aluminum and attach to each side of the vertical fin to react to drag and torsion loading.

The outer shell of the aft fuselage is constructed of integral-machined aluminum. Various penetrations are provided in the shell for access to installed systems. The exposed outer areas of the aft fuselage are covered with reusable thermal protection system.

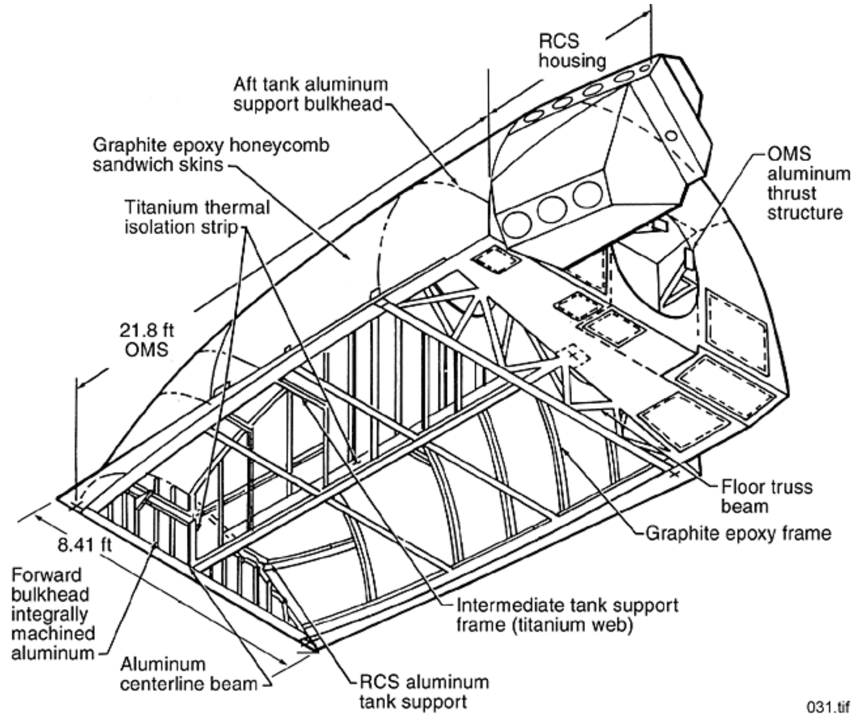
The secondary structure of the aft fuselage is of conventional aluminum construction except that titanium and fiberglass are used for thermal isolation of equipment. The aft fuselage secondary structures consist of brackets, buildup webs, truss members, and machined fittings, as required by system loading and support constraints. Certain system components, such as the avionics shelves, are shock-mounted to the secondary structure. The secondary structure includes support provisions for the auxiliary power units, hydraulics, ammonia boiler, flash evaporator, and electrical wire runs.

The two ET umbilical areas interface with the orbiter's two aft ET attach points and the ET's liquid oxygen and hydrogen feed lines and electrical wire runs. The umbilicals are retracted, and the umbilical areas are closed off after ET separation by an electromechanically operated beryllium door at each umbilical. Thermal barriers are employed at each umbilical door. The exposed area of each closed door is covered with reusable surface insulation.

The aft fuselage heat shield and seal provide a closeout of the orbiter aft base area. The aft heat shield consists of a base heat shield of machined aluminum. Attached to the base heat shield are domes of honeycomb construction that support flexible and sliding seal assemblies. The engine-mounted heat shield is of Inconel honeycomb construction and is removable for access to the main engine power heads. The heat shield is covered with a reusable thermal protection system except for the Inconel segments.

Orbital Maneuvering System/Reaction Control System (OMS/RCS) Pods

The OMS/RCS left- and right-hand pods are attached to the upper aft fuselage left and right sides. Each pod is fabricated primarily of graphite epoxy composite and aluminum. Each pod is 21.8 feet long and 11.37 feet wide at its aft end and 8.41 feet wide at its forward end, with a surface area of approximately 435 square feet. Each pod is divided into two compartments: the OMS and the RCS housings.



Aft Orbital Maneuvering System/Reaction Control System Pod

Each pod houses all the OMS and RCS propulsion components and is attached to the aft fuselage with 11 bolts. The pod skin panels are graphite epoxy honeycomb sandwich. The forward and aft bulkhead aft tank support bulkhead and floor truss beam are machined aluminum 2124. The centerline beam is 2024 aluminum sheet with titanium stiffeners and graphite epoxy frames. The OMS thrust structure is conventional 2124 aluminum construction. The cross braces are aluminum tubing, and the attach fittings at the forward and aft fittings are 2124 aluminum. The intermediate fittings are corrosion-resistant steel. The RCS housing, which attaches to the OMS pod structure, contains the RCS jets and associated propellant feed lines. The RCS housing is constructed of aluminum sheet metal, including flat outer skins. The curved outer skin panels are graphite epoxy honeycomb sandwich. Doors in the skins (24) provide access to the OMS and RCS and attach points.

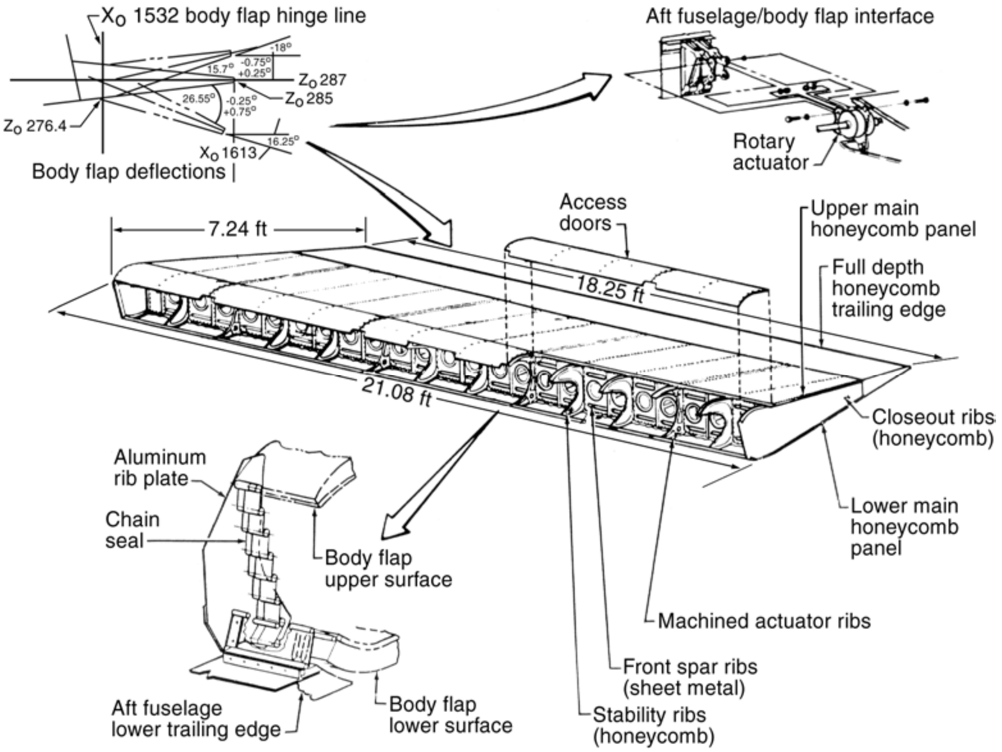
The exposed areas of the OMS/RCS pods are covered with a reusable thermal protection system, and a pressure and thermal seal is installed at the OMS/RCS pod aft fuselage interface. Thermal barriers are installed, and they interface with the RCS jets and reusable thermal protection system. The pods will withstand 162-decibel acoustic noise and a temperature range from minus 170° to plus 135°F.

Body Flap

The body flap thermally shields the three SSMEs during entry and provides the orbiter with pitch control trim during its atmospheric flight after entry.

The body flap is an aluminum structure consisting of ribs, spars, skin panels, and a trailing edge assembly. The main upper and lower forward honeycomb skin panels are joined to the ribs, spars, and honeycomb trailing edge with structural fasteners. The removable upper forward honeycomb skin panels complete the body flap structure.

The upper skin panels aft of the forward spar and the entire lower skin panels are mechanically attached to the ribs. The forward upper skin consists of five removable access panels attached to the ribs with quick-release fasteners. The four integral-machined aluminum actuator ribs provide the aft fuselage interface through self-aligning bearings. Two



Body Flap

bearings are located in each rib for attachment to the four rotary actuators located in the aft fuselage, which are controlled by the flight control system and the hydraulically actuated rotary actuators. The remaining ribs consist of eight stability ribs and two closeout ribs constructed of chemically milled aluminum webs bonded to aluminum honeycomb core. The forward spar web is of chemically milled sheets with flanged holes and stiffened beads. The spar web is riveted to the ribs. The trailing edge includes the rear spar, which is composed of piano-hinge half-cap angles, chemically milled skins, honeycomb aluminum core, closeouts, and plates. The trailing edge attaches to the upper and lower forward panels by the piano-hinge halves and hinge pins. Two moisture drain lines and one hydraulic fluid drain line penetrate the trailing edge honeycomb core for horizontal and vertical drainage.

The body flap is covered with a reusable thermal protection system and an articulating pressure and thermal seal to its forward cover area on the lower surface of the body flap to block heat and air flow from the structures.

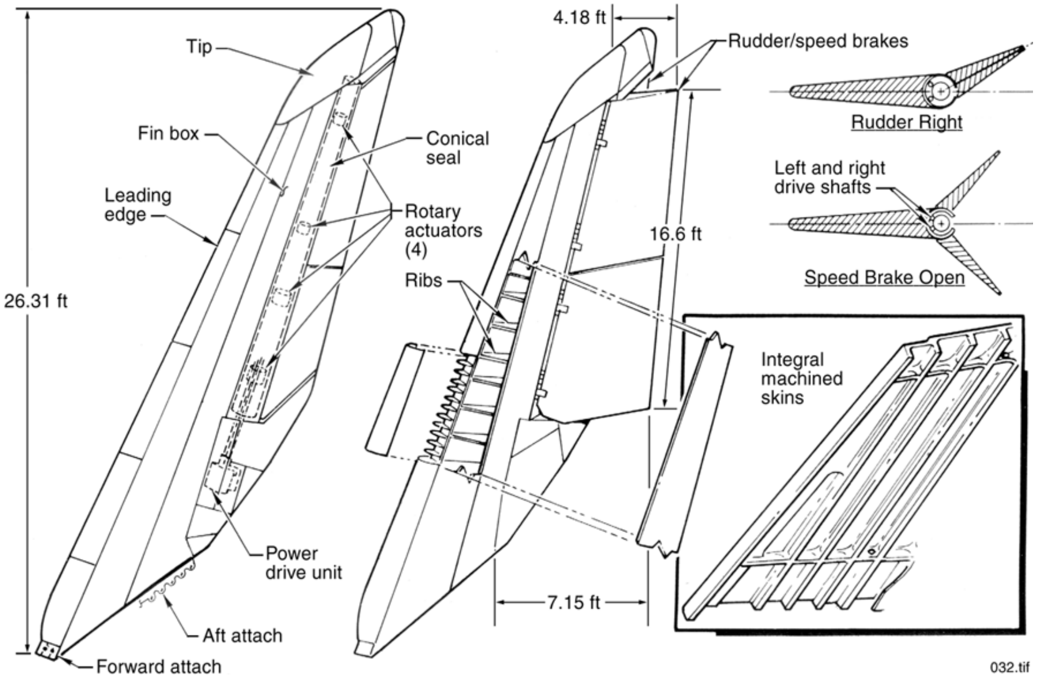
Vertical Tail

The vertical tail consists of a structural fin surface, the rudder/speed brake surface, a tip, and a lower trailing edge. The rudder splits into two halves to serve as a speed brake.

The vertical tail structure fin is made of aluminum. The main torque box is constructed of integral-machined skins and strings, ribs, and two machined spars. The fin is attached by two tension tie bolts at the root of the front spar of the vertical tail to the forward bulkhead of the aft fuselage and by eight shear bolts at the root of the vertical tail rear spar to the upper structural surface of the aft fuselage.

The rudder/speed brake control surface is made of conventional aluminum ribs and spars with aluminum honeycomb skin panels and is attached through rotating hinge parts to the vertical tail fin.

The lower trailing edge area of the fin, which houses the rudder/speed brake power drive unit, is made of aluminum honeycomb skin.



Vertical Tail

The hydraulic power drive unit/mechanical rotary actuation system drives left- and right-hand drive shafts in the same direction for rudder control of plus or minus 27°. For speed brake control, the drive shafts turn in opposite directions for a maximum of 49.3° each. The rotary drive actions are also combined for joint rudder/speed brake control. The hydraulic power drive unit is controlled by the orbiter flight control system.

The vertical tail structure is designed for a 163-decibel acoustic environment with a maximum temperature of 350° F.

All-Inconel honeycomb conical seals house the rotary actuators and provide a pressure and thermal seal that withstands a maximum of 1,200° F.

The split halves of the rudder panels and trailing edge contain a thermal barrier seal.

The vertical tail and rudder/speed brake are covered with a reusable thermal protection system. A thermal barrier is also employed at the interface of the vertical stabilizer and aft fuselage.

Orbiter Passive Thermal Control

A passive thermal control system helps maintain the temperature of the orbiter spacecraft, systems, and components within their temperature limits. This system uses available orbiter heat sources and sinks supplemented by insulation blankets, thermal coatings, and thermal isolation methods. Heaters are provided on components and systems in areas where passive thermal control techniques are not adequate. (The heaters are described under the various systems.)

The insulation blankets are of two basic types: fibrous bulk and multilayer. The bulk blankets are fibrous materials with a density of 2 pounds per cubic foot and a sewn cover of reinforced acrylic film Kapton. The cover material has 13,500 holes per square foot for venting. Acrylic film tape is used for cutouts, patching, and reinforcements. Tufts throughout the blankets minimize billowing during venting.

The multilayer blankets are constructed of alternate layers of perforated acrylic film Kapton reflectors and Dacron net separators. There are 16 reflector layers in all, the two cover halves counting as two layers. Covers, tufting, and acrylic film tape are similar to that used for the bulk blankets.

Thermal Protection System

The thermal protection system (TPS) consists of various materials applied externally to the outer structural skin of the orbiter to maintain the skin within acceptable temperatures, primarily during the entry phase of the mission. The orbiter's outer structural skin is constructed primarily of aluminum and graphite epoxy.

During entry, the TPS materials protect the orbiter outer skin from temperatures above 350° F. In addition, they are reusable for 100 missions with refurbishment and maintenance. These materials perform in temperature ranges from minus 250° F in the cold soak of space to entry temperatures that reach nearly 3,000° F. The TPS also sustains the forces induced by deflections of the orbiter airframe as it responds to the various external environments. Because the TPS is installed on the outside of the orbiter skin, it establishes the aerodynamics over the vehicle in addition to acting as the heat sink.

Orbiter interior temperatures also are controlled by internal insulation, heaters, and purging techniques in the various phases of the mission.

The TPS is a passive system consisting of materials selected for stability at high temperatures and weight efficiency. These materials are as follows:

1. Reinforced carbon-carbon (RCC) is used on the wing leading edges, the nose cap, including an area immediately aft of the nose cap on the lower surface (chine panel), and the immediate area around the forward orbiter/ET structural attachment. RCC protects areas where temperatures exceed 2,300° F during entry.

2. Black high-temperature reusable surface insulation (HRSI) tiles are used in areas on the upper forward fuselage, including around the forward fuselage windows, the entire underside of the vehicle where RCC is not used, portions of the OMS/RCS pods, the leading and trailing edges of the vertical stabilizer, wing glove areas, elevon trailing edges adjacent to the RCC on the upper wing surface, the base heat shield, the interface with wing leading edge RCC, and the upper body flap surface. The HRSI tiles protect areas where temperatures are below 2,300° F. These tiles have a black surface coating necessary for entry emittance.

3. Black tiles called fibrous refractory composite insulation (FRCI) were developed later in the TPS program. FRCI tiles replace some of the HRSI tiles in selected areas of the orbiter.

4. Low-temperature reusable surface insulation (LRSI) white tiles are used in selected areas of the forward, mid-, and aft fuselages, vertical tail, upper wing, and OMS/RCS pods. These tiles protect areas where temperatures are below 1,200° F. These tiles have a white surface coating to provide better thermal characteristics on orbit.

5. After the initial delivery of Columbia, an advanced flexible reusable surface insulation (AFRSI) was developed. This material consists of sewn composite quilted fabric insulation batting between two layers of white fabric that are sewn together to form a quilted blanket. AFRSI was used on Discovery and Atlantis to replace the vast majority of the LRSI tiles. Following its seventh flight, Columbia also was modified to replace most of the LRSI tiles with AFRSI. The AFRSI blankets provide improved producibility and durability, reduced fabrication and installation time and costs, and a weight reduction over that of the LRSI tiles. The AFRSI blankets protect areas where temperatures are below 1,200° F.

6. White blankets made of coated Nomex felt reusable surface insulation

(FRSI) are used on the upper payload bay doors, portions of the midfuselage and aft fuselage sides, portions of the upper wing surface, and a portion of the OMS/RCS pods. The FRSI blankets protect areas where temperatures are below 700° F.

7. Additional materials are used in other special areas. These materials are thermal panes for the windows, metal for the forward RCS fairings and elevon seal panels on the upper wing to elevon interface, a combination of white- and black-pigmented silica cloth for thermal barriers and gap fillers around operable penetrations, such as main and nose landing gear doors, egress and ingress flight crew side hatch, umbilical doors, elevon cove, forward RCS, RCS jets, midfuselage vent doors, payload bay doors, rudder/speed brake, OMS/RCS pods, and gaps between TPS tiles in high differential pressure areas, and room-temperature vulcanizing material for the thick aluminum T-0 umbilicals on the sides of the orbiter aft fuselage.

1.3 EXTERNAL TANK

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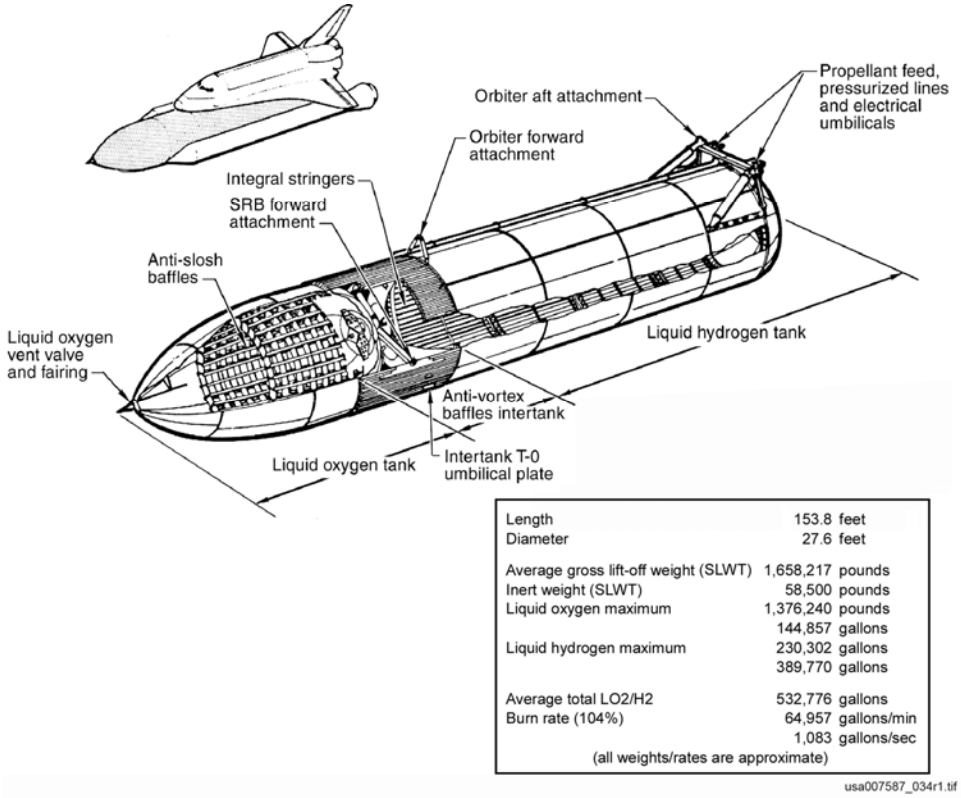
The external tank (ET) contains the liquid hydrogen fuel and liquid oxygen oxidizer and supplies them under pressure to the three SSMEs in the orbiter during ascent. When the SSMEs are shut down, the ET is jettisoned and enters the Earth's atmosphere, where it breaks up and impacts in a remote ocean area. ET impact zones for direct insertion are discussed in Section 1.1.

The largest and heaviest (when loaded) element of the space shuttle, the ET, has three major components: the forward liquid oxygen tank, an unpressurized intertank that contains most of the electrical components, and the aft liquid hydrogen tank.

Since the STS-91 mission, a super lightweight external tank (SLWT) has been used. This tank weighs approximately 58,500 pounds inert. The SLWT is 7500 pounds lighter than the lightweight tank (no longer used) and this reduction provides an increased payload capability over prior configurations.

The ET is attached to the orbiter at one forward attachment point and two aft points. In the aft attachment area, there are also umbilicals that carry fluids, gases, electrical signals, and electrical power between the tank and the orbiter. Electrical signals and controls between the orbiter and the two SRBs also are routed through those umbilicals.



Length	153.8	feet
Diameter	27.6	feet
Average gross lift-off weight (SLWT)	1,658,217	pounds
Inert weight (SLWT)	58,500	pounds
Liquid oxygen maximum	1,376,240	pounds
	144,857	gallons
Liquid hydrogen maximum	230,302	gallons
	389,770	gallons
Average total LO2/H2	532,776	gallons
Burn rate (104%)	64,957	gallons/min
	1,083	gallons/sec

(all weights/rates are approximate)

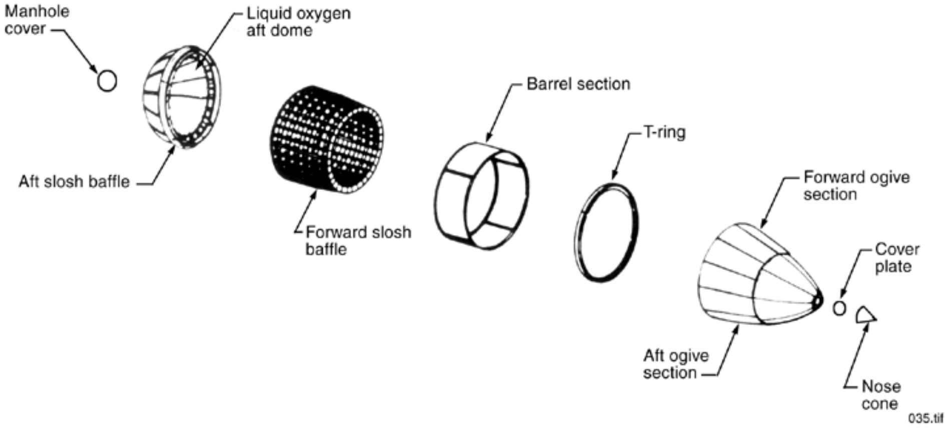
Super Lightweight External Tank

Liquid Oxygen Tank

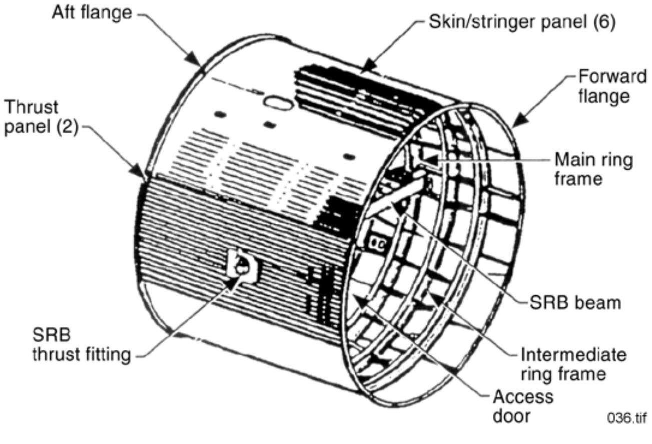
The liquid oxygen tank is an aluminum monocoque structure composed of a fusion-welded assembly of preformed, chem-milled gores, panels, machined fittings, and ring chords. It operates in a pressure range of 20 to 22 psig. The tank contains anti-slosh and anti-vortex provisions to minimize liquid residuals and damp fluid motion. The tank feeds into a 17-inch-diameter feed line that conveys the liquid oxygen through the intertank, then outside the ET to the aft right-hand ET/orbiter disconnect umbilical. The 17-inch-diameter feed line permits liquid oxygen to flow at approximately 2,787 pounds per second with the SSMEs operating at 104 percent or permits a maximum flow of 17,592 gallons per minute. The liquid oxygen tank's double-wedge nose cone reduces drag and heating, contains electrical system components, and serves as a lightning rod. The liquid oxygen tank's volume is 19,563 ft^3. It is 331 inches in diameter, 592 inches long and weighs 12,000 pounds empty.

Intertank

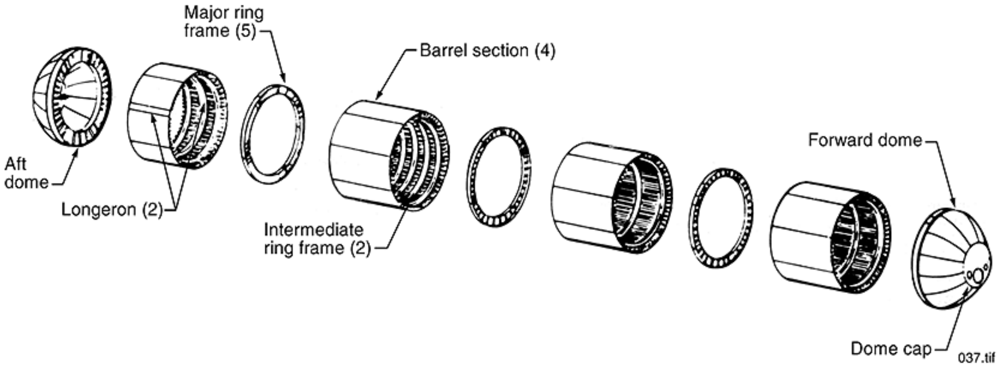
The intertank is a steel/aluminum semimonocoque cylindrical structure with flanges on each end for joining the liquid oxygen and liquid hydrogen tanks. The intertank houses ET instrumentation components and provides an umbilical plate that interfaces with the ground facility arm for purge gas supply, hazardous gas detection, and hydrogen gas boiloff during ground operations. It consists of mechanically joined skin, stringers, and machined panels of aluminum alloy. The intertank is vented during flight. The intertank contains the forward SRB-ET attach thrust beam and fittings that distribute the SRB loads to the liquid oxygen and liquid hydrogen tanks. The intertank is 270 inches long, 331 inches in diameter, and weighs 12,100 pounds.



Liquid Oxygen Tank Structure



Intertank Structure



Liquid Hydrogen Tank Structure

Liquid Hydrogen Tank

The liquid hydrogen tank is an aluminum semimonocoque structure of fusion-welded barrel sections, five major ring frames, and forward and aft ellipsoidal domes. Its operating pressure range is 32 to 34 psia. The tank contains an anti-vortex baffle and siphon outlet to transmit the liquid hydrogen from the tank through a 17-inch line to the left aft umbilical. The liquid hydrogen feed line flow rate is 465 pounds per second with the SSMEs at 104 percent or a maximum flow of 47,365 gallons per minute. At the forward end of the liquid hydrogen tank is the ET/orbiter forward attachment pod strut, and at its aft end are the two ET/orbiter aft attachment ball fittings as well as the aft SRB-ET stabilizing strut attachments. The liquid hydrogen tank is 331 inches in diameter, 1,160 inches long, and has a volume of 53,518 ft^3 and a dry weight of 29,000 pounds.

Thermal Protection System

The ET thermal protection system consists of sprayed-on foam insulation and premolded ablator materials. The system also includes the use of phenolic thermal insulators to preclude air liquefaction. Thermal isolators are required for liquid hydrogen tank attachments to preclude the liquefaction of air-exposed metallic attachments and to reduce heat flow into the liquid hydrogen. The thermal protection system weighs 4,823 pounds.

Hardware and Instrumentation

The external hardware, ET/orbiter attachment fittings, umbilical fittings, electrical, and range safety system weigh 9,100 pounds.

Each propellant tank has a vent and relief valve at its forward end. This dual-function valve can be opened by ground support equipment for the vent function during prelaunch and can open during flight when the ullage pressure of the liquid hydrogen tank reaches 36 psig, or the ullage pressure of the liquid oxygen tank reaches 31 psig.

There are eight propellant-depletion sensors, four each for fuel and oxidizer. The fuel-depletion sensors are located in the bottom of the fuel tank. The oxidizer sensors are mounted in the orbiter liquid oxygen feed line manifold downstream of the feed line disconnect. During SSME burns, the orbiter GPCs constantly compute the instantaneous mass of the vehicle due to the usage of the propellants. Normally, main engine cutoff (MECO) is based on a predetermined velocity; however, once past a flight-specific arming mass, if any two of the fuel or oxidizer sensors sense a dry condition, the engines will be shut down.

The locations of the liquid oxygen sensors allow the maximum amount of oxidizer to be consumed in the engines, while allowing sufficient time to shut down the engines before the oxidizer pumps cavitate (run dry). In addition, 1,100 pounds of liquid hydrogen are loaded over and above that required by the 6:1 oxidizer/fuel engine mixture ratio. The excess hydrogen ensures that the propellant ratio during MECO is fuel-rich. High temperatures during an oxidizer-rich engine shutdown can cause severe erosion of engine components.

Four pressure transducers located at the top of the liquid oxygen and liquid hydrogen tanks monitor the ullage pressures.

Each of the two aft ET umbilical plates mate with a corresponding plate on the orbiter. The plates help maintain alignment among the umbilicals. Physical strength at the umbilical plates is provided by bolting corresponding umbilical plates together. When the orbiter GPCs command external tank separation, the bolts are severed by pyrotechnic devices.

The ET has five propellant umbilical valves that interface with orbiter umbilicals: two for the liquid oxygen tank and three for the liquid hydrogen tank. One of the liquid oxygen tank umbilical valves is for liquid oxygen, the other for gaseous oxygen.

A swing-arm-mounted cap to the fixed service structure covers the oxygen tank vent on top of the ET during the countdown and is retracted about 2 minutes before lift-off. The cap siphons off oxygen vapor that threatens to form ice on the ET, thus protecting the orbiter's TPS during launch.

The liquid hydrogen tank umbilical has two valves for liquid and one for gas. The intermediate-diameter liquid hydrogen umbilical is a recirculation umbilical used only during the liquid hydrogen chill-down sequence during prelaunch.

The ET also has two electrical umbilicals that carry electrical power from the orbiter to the tank and the two SRBs and provide information from the SRBs and ET to the orbiter.

1.4 SOLID ROCKET BOOSTERS

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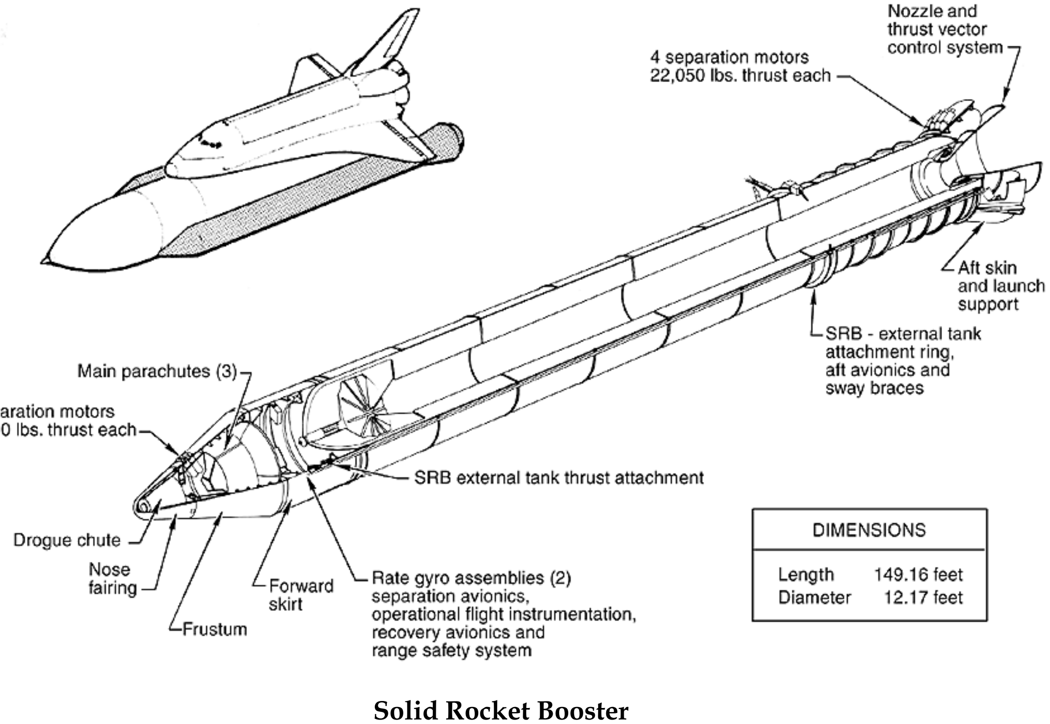
The two solid rocket booster (SRBs) are the largest solid-propellant motors ever flown and the first ever designed for reuse.

Prelaunch, each booster is attached to the mobile launch platform at the aft skirt by four bolts and nuts that are severed by small explosives at liftoff. The ET is then attached to the two SRBs at each SRB's aft frame by two lateral sway braces and a diagonal attachment. The forward end of each SRB is attached to the ET at the SRB's forward skirt. The orbiter is then mated to the ET/SRB stack. In the end, the two SRBs carry the entire weight of the stack and transmit the weight load through their structure to the mobile launch platform.

At liftoff, the SRBs are ignited after the three SSMEs' thrust level is verified. Each booster generates a thrust of approximately 3,300,000 lbs (at sea level), providing 71.4 percent of the thrust at liftoff and during first-stage ascent, lifting the space shuttle off the pad and up to an altitude of about 150,000 ft (or 24 nm). The solid propellant is spent after burning for a little more than two minutes, at which point the SRBs are jettisoned. Parachutes bring the SRBs back down to Earth intact, impacting the ocean approximately 122 nm downrange.

Each SRB measures about 149 ft in length and 12 ft in diameter and weighs approximately 1,300,000 lbs at launch (approximately 1,100,000 lbs of that being propellant).

The propellant mixture in each SRB motor consists of an ammonium perchlorate (oxidizer, 69.6 percent by weight), aluminum (fuel, 16 percent), iron oxide (a catalyst, 0.4 percent), a polymer (a binder that holds the mixture together, 12.04 percent), and an epoxy curing agent (1.96 percent). The propellant is an 11-point star-shaped perforation in the forward motor segment and a double-truncated-cone



Solid Rocket Booster

perforation in each of the aft segments and aft closure. This configuration provides high thrust at ignition and then reduces the thrust by approximately a third some 50 seconds after liftoff. This prevents overstressing the vehicle during maximum dynamic pressure.

The SRBs are used as matched pairs, and each is made up of four solid rocket motor segments. The pairs are matched by loading each of the four motor segments in pairs from the same batches of propellant ingredients to minimize any thrust imbalance. The segmented-casing design assures maximum flexibility in fabrication and ease of transportation and handling. Each segment is shipped to the launch site on a heavy-duty rail car with a specially built cover.

Each nozzle has an expansion ratio of 7.72:1 and has a carbon cloth liner that erodes and chars during firing. Each nozzle is gimbaled for thrust vector control, using a convergent-divergent, movable design in which an aft pivot-point flexible bearing is the gimbal mechanism. To actuate the gimbals, each SRB has its own redundant auxiliary power unit and hydraulic pumps. The all-axis gimbal capability is 8°.

Each SRB has two integrated electronic assemblies (IEA), one in the forward skirt and one in the ET/SRB attach ring. After burnout, the forward IEA initiates the release of the nose cap and frustum. The aft IEA connects with the forward IEA and the orbiter avionics systems for SRB ignition commands and nozzle thrust vector control. Each IEA has a multiplexer/demultiplexer, which sends or receives more than one message, signal, or unit of information on a single communication channel.

Eight booster separation motors (four in the nose frustum and four in the aft skirt) of each SRB burn for 1.02 seconds at SRB separation. Each separation motor is 31.1 inches long and 12.8 inches in diameter.

The recovery crew retrieves the SRBs, frustum/drogue chutes, and main parachutes. The SRB nose caps and nozzle extensions are not recovered. The nozzles are plugged, the solid rocket motors are dewatered, and the SRBs are towed back to the launch site. Once there, each booster is disassembled and washed with fresh and deionized water to limit salt water corrosion. The motor segments, igniter, and nozzle are then shipped back to the manufacturer for refurbishment.

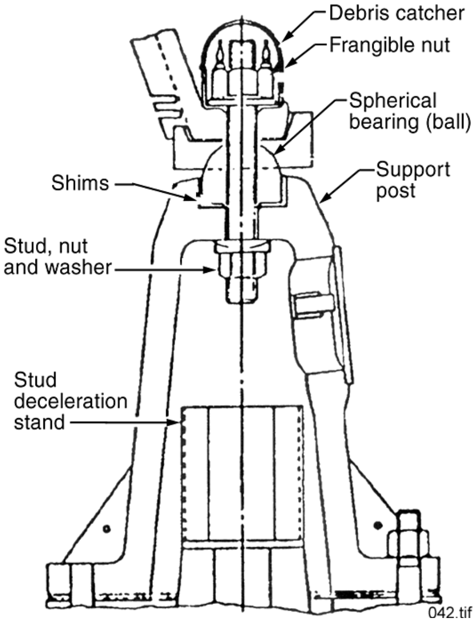
Following the Challenger accident, detailed structural analyses were performed on critical structural elements of the SRB. One such element was the attach ring where the SRBs connect to the ET. Areas of distress were noted in some of the fasteners where the ring attaches to the SRB motor case. This situation was attributed to the high loads encountered during water impact. The attach ring was redesigned to correct the situation and ensure higher strength margins during ascent. Instead of forming a “C” and encircled the motor case 270°, the attach ring now encircles the motor case a complete 360°.

Additionally, special structural tests performed on the aft skirt discovered an anomaly in a critical weld between the hold-down post and skin of the skirt. This led to the addition of reinforcement brackets and fittings in the aft ring of the skirt.

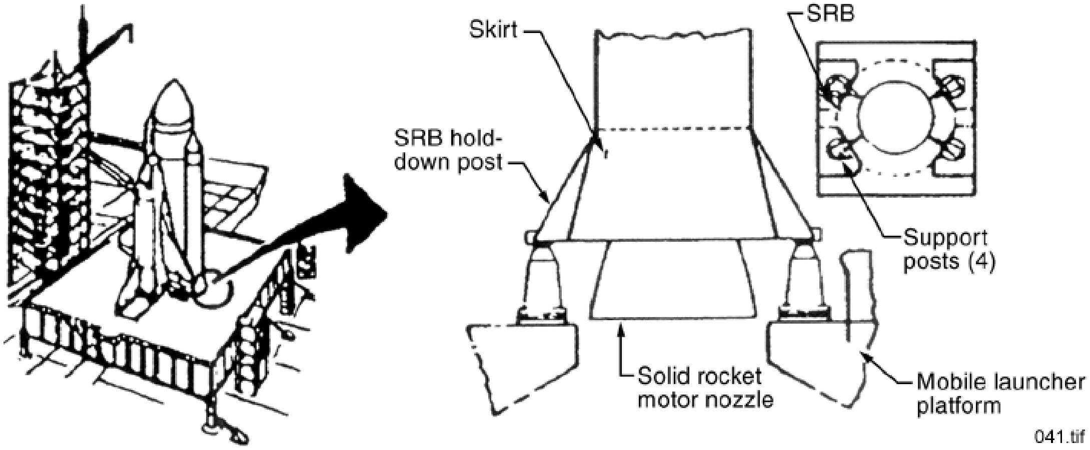
The redesigned attach ring and the addition of the brackets and fittings increased the SRB’s weight by approximately 450 pounds.

Hold-Down Posts

Each SRB has four hold-down posts that fit into corresponding support posts on the mobile launch platform. Hold-down bolts hold the SRB and launcher platform posts together. Each bolt has a nut at each end, but only the top nut is frangible. The top nut contains two NASA Standard Initiator detonators (NSIs), which are ignited at solid rocket motor ignition commands.



SRB Support/Hold-Down Post



SRB Hold-Down Configuration

When the two NSI detonators are ignited at each hold-down, the hold-down bolt travels downward because of a combination of forces; the release of tension in the bolt (pretensioned before launch), NSI detonator gas pressure, and gravity. The bolt is stopped by the stud deceleration stand, which contains sand. The SRB bolt is 28 inches long and is 3.5 inches in diameter. The frangible nut is captured in a blast container.

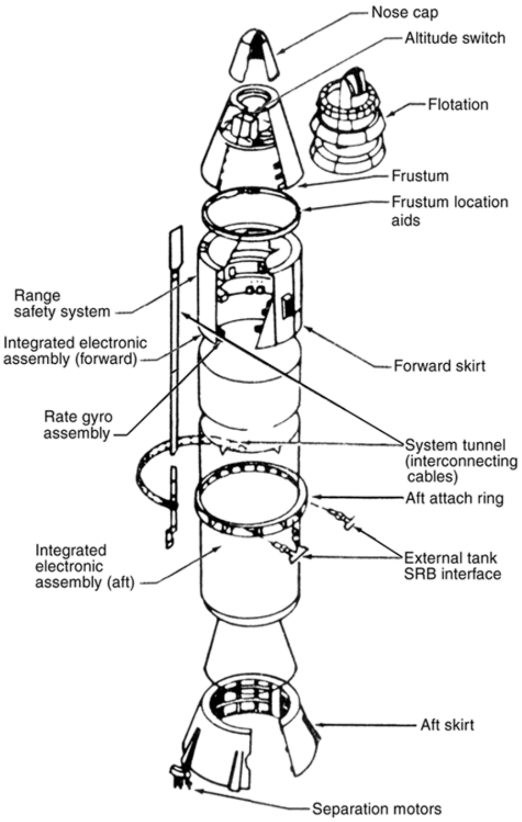
The solid rocket motor ignition commands are issued by the orbiter's computers through the master events controllers to the hold-down pyrotechnic initiator controllers (PICs) on the mobile launch platform. They provide the ignition to the hold- down NSI detonators. The launch processing system monitors the SRB hold-down PICs for low voltage during the last 16 seconds before launch. PIC low voltage will initiate a launch hold.

SRB Ignition

During the final ordnance installation and connection (performed a few days prior to launch) the SRB ignition S&A device's safing pin is removed from the S&A device. This allows the S&A device to be armed remotely during final countdown. Five minutes before launch, the SRB S&A device is rotated to the arm position. The solid rocket motor ignition commands are issued when the three SSMEs are at or above 90-percent rated thrust, no SSME fail and/or SRB ignition PIC low voltage is indicated, and there are no holds from the launch processing system.

The solid rocket motor ignition commands are sent by the orbiter computers through the master events controllers (MECs) to the S&A device's NSI detonators in each SRB. A PIC single-channel capacitor discharge device controls the firing of each pyrotechnic device. Three signals must be present simultaneously for the PIC to generate the pyrotechnic firing output. These signals, arm, fire 1, and fire 2, originate in the GPCs and are transmitted to the MECs. The MECs reformat them to 28-volt dc signals for the PICs. The arm signal charges the PIC capacitor to 40 volts dc (minimum of 20 volts dc).

The fire 1 and 2 commands cause the redundant NSI detonators to fire through a thin barrier seal down a flame tunnel. This ignites a pyrotechnic booster charge, which is retained in the S&A device behind a perforated plate. The booster charge ignites the propellant in the igniter initiator, and combustion products of this propellant ignite the solid rocket motor initiator, which fires down the length of the solid rocket motor igniting the solid rocket motor propellant.



Solid Rocket Booster-Exploded View

The GPC launch sequence also controls certain critical valves in the main propulsion system (MPS) and monitors the engine-ready indications from the SSMEs. The MPS start commands are issued by the GPCs at 6.6 seconds before launch (staggered start—engine 3, engine 2, engine 1—all approximately within 0.25 second), and the sequence monitors the thrust buildup of each engine. All three SSMEs must reach the required 90-percent thrust within 3 seconds; otherwise, an orderly shutdown is commanded, and safing functions are initiated.

Normal thrust buildup to the required 90-percent thrust level will result in the SSMEs being commanded to the liftoff position 3 seconds before liftoff, as well as the fire 1 command being issued to arm the SRBs. Also at 3 seconds before liftoff, the vehicle base bending load modes are allowed to initialize (movement of approximately 25.5 inches measured at the tip of the external tank, with movement towards the external tank).

SRB ignition sequence occurs as follows:

- PIC initiated ignition of S&A pyrotechnic charge
- S&A charge ignites the Initiator propellant
- Initiator propellant ignites rocket motor ignitor
- Ignitor propellant ignites booster motor propellant

At T-0, the two SRBs are ignited, the frangible nuts at each of the eight hold down studs are separated, the onboard master timing unit, event timer, and mission event timers are started, the three SSMEs are at 100 percent and launch is initiated. The ground launch sequence is now terminated.

At 0.23 seconds after liftoff, booster chamber pressure reaches 563.5 psia and liftoff commences. At 0.6 seconds after liftoff, booster chamber pressure reaches maximum limit, nominally 914 psia.

The solid rocket motor thrust profile is tailored to reduce thrust during the maximum dynamic pressure region.

Electrical Power Distribution

Electrical power distribution in each SRB consists of orbiter-supplied main dc bus power to each SRB via SRB buses A, B, and C. Orbiter main dc buses A, B, and C supply main dc bus power to corresponding SRB buses A, B, and C. In addition, orbiter main dc bus C supplies backup power to SRB buses A and B, and orbiter bus B supplies backup power to SRB bus C. This electrical power distribution arrangement allows all SRB buses to remain powered in the event one orbiter main bus fails.

The nominal dc voltage is 28 volts dc, with an upper limit of 32 volts dc and a lower limit of 24 volts dc.

Hydraulic Power Units

There are two self-contained, independent hydraulic power units (HPUs) on each SRB. Each HPU consists of an auxiliary power unit (APU), fuel supply module, hydraulic pump, hydraulic reservoir, and hydraulic fluid manifold assembly. The APUs are fueled by hydrazine and generate mechanical shaft power to a hydraulic pump that produces hydraulic pressure for the SRB hydraulic system. The two separate HPUs and two hydraulic systems are located on the aft end of each SRB between the SRB nozzle and aft skirt. The HPU components are mounted on the aft skirt between the rock and tilt actuators. The two systems operate from 28 seconds before liftoff until SRB separation. The two independent hydraulic systems are connected to the rock and tilt servo actuators.

The APU controller electronics are located in the SRB aft IEA on the aft external tank attach rings.

The APUs and their fuel systems are isolated from each other. Each fuel supply module (tank) contains 22 pounds of hydrazine. The fuel tank is pressurized with gaseous nitrogen at 400 psi, which provides the force to expel (positive expulsion) the fuel from the tank to the fuel distribution line, maintaining a positive fuel supply to the APU throughout its operation.

The fuel isolation valve is opened at APU startup to allow fuel to flow to the APU fuel pump and control valves and then to the gas generator. The gas generator’s catalytic action decomposes the fuel and creates a hot gas. It feeds the hot gas exhaust product to the APU two-stage gas turbine. Fuel flows primarily through the startup bypass line until the APU speed is such that the fuel pump outlet pressure is greater than the bypass line’s. Then all the fuel is supplied to the fuel pump.

The APU turbine assembly provides mechanical power to the APU gearbox. The gearbox drives the APU fuel pump, hydraulic pump, and lube oil pump. The APU lube oil pump lubricates the gearbox. The turbine exhaust of each APU flows over the exterior of the gas generator, cooling it, and is then directed overboard through an exhaust duct.

When the APU speed reaches 100 percent, the APU primary control valve closes, and the APU speed is controlled by the APU controller electronics. If the primary control valve logic fails to the open state, the secondary control valve assumes control of the APU at 113-percent speed.

Each HPU on an SRB is connected to both servo actuators on that SRB. One HPU serves as the primary hydraulic source for the servo actuator, and the other HPU serves as the secondary hydraulics for the servo actuator. Each servo actuator has a switching valve that allows the secondary hydraulics to power the actuator if the primary hydraulic pressure drops below 2,050 psi. A switch contact on the switching valve will close when the valve is in the secondary position. When the valve is closed, a signal is sent to the APU controller that inhibits the 100-percent APU speed control logic and enables the 113-percent APU speed control logic. The 113-percent APU speed enables one APU/HPU to supply sufficient operating hydraulic pressure to both servo actuators of that SRB.

The APU 100-percent speed corresponds to 72,000 rpm and 113-percent to 81,000 rpm.

The APUs/HPUs and hydraulic systems are reusable for 20 missions.

Thrust Vector Control

Each SRB has two hydraulic gimbal servo actuators: one for rock and one for tilt. The servo actuators provide the force and control to gimbal the nozzle for thrust vector control.

The space shuttle ascent thrust vector control (ATVC) portion of the flight control system directs the thrust of the three SSMEs and the two SRB nozzles to control attitude and trajectory during liftoff and ascent. Commands from the guidance system are transmitted to the ATVC drivers, which transmit signals proportional to the commands to each servo actuator of the main engines and SRBs. Four independent flight control system channels and four ATVC channels control six main engine and four SRB ATVC drivers, with each driver controlling one hydraulic port on each main and SRB servo actuator.

Each SRB servo actuator consists of four independent, two-stage servo valves that receive signals from the drivers. Each servo valve controls one power spool in each actuator, which positions an actuator ram and the nozzle to control the direction of thrust.

The four servo valves in each actuator provide a force-summed majority voting arrangement to position the power spool. With four identical commands to the four servo valves, the actuator force-sum action prevents a single erroneous command from affecting power ram motion. If the erroneous command persists for more than a predetermined time, the differential pressure activates causes an isolation valve to remove hydraulic pressure from the defective servo valve. This permits the remaining channels and servo valves to control the actuator ram spool unhindered. Failure monitors are provided for each channel to indicate which channel has been bypassed.

Each actuator ram is equipped with transducers for position feedback to the thrust vector control system. Within each servo actuator ram is a splashdown load relief assembly to cushion the nozzle at water splashdown and prevent damage to the nozzle flexible bearing.

SRB Rate Gyro Assemblies

Each SRB contains two rate gyro assemblies (SRGAs), with each SRGA containing one pitch and one yaw gyro. These provide an output, that is proportional to angular rates about the pitch and yaw axes, to the orbiter computers and guidance, navigation, and control system during first-stage ascent flight in conjunction with the orbiter roll rate gyros until SRB separation. At SRB separation, a switchover is made from the SRGAs to the orbiter RGAs.

The SRGA rates pass through the orbiter flight aft multiplexers/demultiplexers to the orbiter GPCs. The SRGA rates then pass through an interchangeable midvalue selection (IMVS) scheme to provide SRB pitch and yaw rates to the user software. The SRGAs are designed for 20 missions.

SRB Separation

SRB separation is initiated when the head-end chamber pressure of both SRBs is less than or equal to 50 psi. To protect against chamber pressure sensor biases, SRB separation will also occur once a certain time has elapsed from booster ignition.

When the separation sequence is initiated, the ATVC commands the actuators to the null position and puts the SSMEs into a second-stage configuration. This ensures the thrust of each SRB is less than 100,000 pounds. Orbiter yaw attitude is held for 4 seconds, and SRB thrust drops to less than 60,000 pounds.

The SRBs separate from the external tank within 30 milliseconds of the ordnance firing command.

The forward attachment point consists of a ball (SRB) and socket (ET) held together by one bolt. The bolt contains one NSI pressure cartridge at each end. The forward attachment point also carries the range safety system cross-strap wiring connecting each SRB and the ET range safety systems with each other.

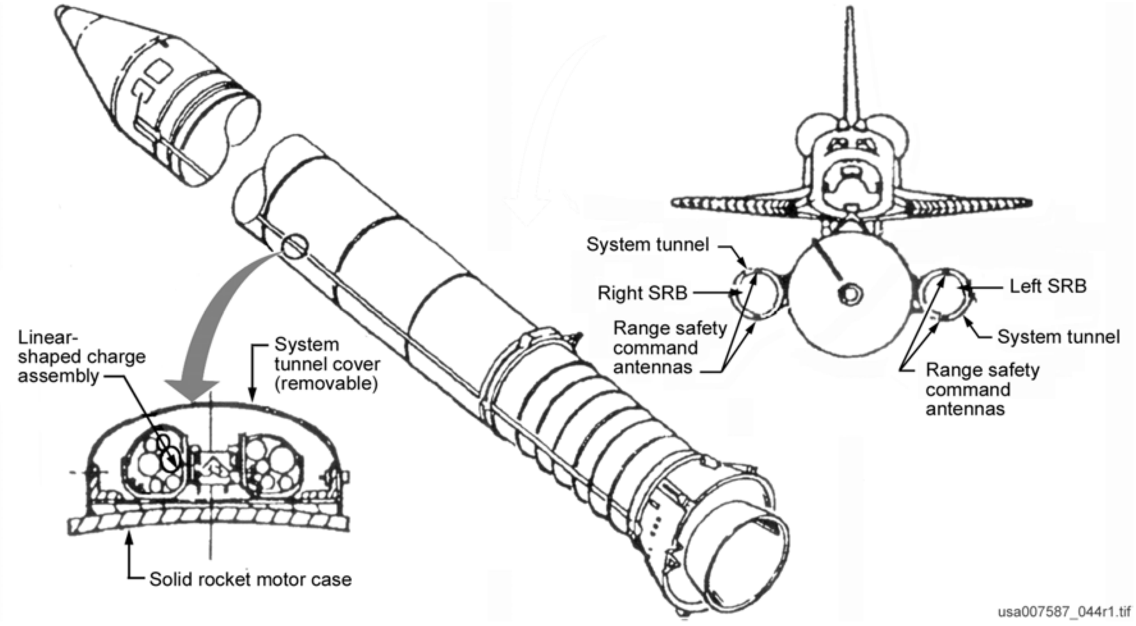
The aft attachment points consist of three separate struts: upper, diagonal and lower. Each strut contains one bolt with one NSI pressure cartridge at each end. The upper strut also carries the umbilical interface between its SRB and the external tank and on to the orbiter.

There are four booster separation motors (BSMs) on each end of each SRB. The BSMs separate the SRBs from the external tank. The solid rocket motors in each cluster of four are ignited by firing redundant confined detonating fuse (CDF) pyrogen initiators from redundant CDF manifolds.

The separation commands issued from the orbiter by the SRB separation sequence initiate the redundant NSI detonator pressure cartridge in each bolt and ignite the BSMs to effect a clean separation.

Range Safety System

The shuttle has two range safety systems (RSSs). One is located in each SRB. Any one or both are capable of receiving two command messages (arm and fire) transmitted from the ground station. The RSS is used only if the shuttle vehicle violates a launch trajectory red line.



SRB Range Safety System

An RSS consists of two antenna couplers, command receivers/decoders, a dual distributor, an S&A device with two NSI detonators, four CDF assemblies, and one linear-shaped charge (LSC).

The antenna couplers provide the proper impedance for radio frequency and ground support equipment commands. The command receivers are tuned to RSS command frequencies and provide the input signal to the distributors when an RSS command is sent. The command decoders use a code plug to prevent any command signal other than the proper command signal from getting into the distributors. The distributors contain the logic to supply valid destruct commands to the RSS pyrotechnics.

The NSI detonators provide the spark to ignite the CDF, which in turn ignites the LSC for shuttle vehicle destruction. The S&A device provides mechanical isolation between the NSI detonators and the CDF before launch and during the SRB separation sequence.

The first message, called arm, allows the onboard logic to enable a destruct and illuminates a light on the flight deck display and control panel at the commander and pilot station. The second message transmitted is the fire command.

The SRB distributors in the SRBs are cross-strapped together. Thus, if one SRB received an arm or destruct signal, the signal would also be sent to the other SRB.

Electrical power from the RSS battery in each SRB is routed to RSS system A. The recovery battery in each SRB is used to power RSS system B as well as the recovery system in the SRB. The SRB RSS is powered down during the separation sequence, and the SRB recovery system is powered up.

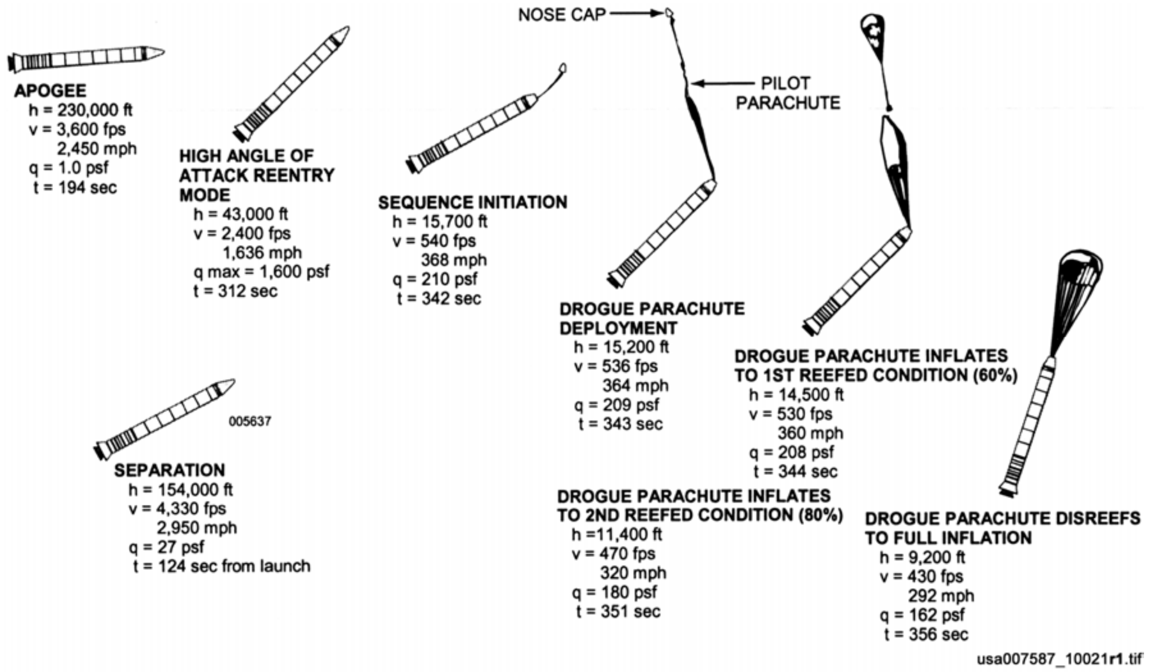
SRB Descent and Recovery

The recovery sequence begins with the operation of the high-altitude baroswitch, which triggers the functioning of the pyrotechnic nose cap thrusters. This ejects the nose cap, which deploys the pilot chute. This occurs at 15,700 feet altitude, 188 seconds after separation. The 11.5-foot-diameter conical ribbon pilot chute provides the force to pull the lanyard activating the zero-second cutter, which cuts the loop securing the drogue retention straps. This allows the pilot chute to pull the drogue pack from the SRB, causing the drogue suspension lines to deploy from their stored position. At full extension of the twelve 95-foot suspension lines, the drogue deployment bag is stripped away from the canopy, and the 54-foot-diameter conical ribbon drogue chute inflates to its initial reefed condition. The drogue disreefs twice after specified time delays, and it reorients/stabilizes the SRB for main parachute deployment. The drogue chute can withstand a load of 270,000 pounds and weighs approximately 1,200 pounds.

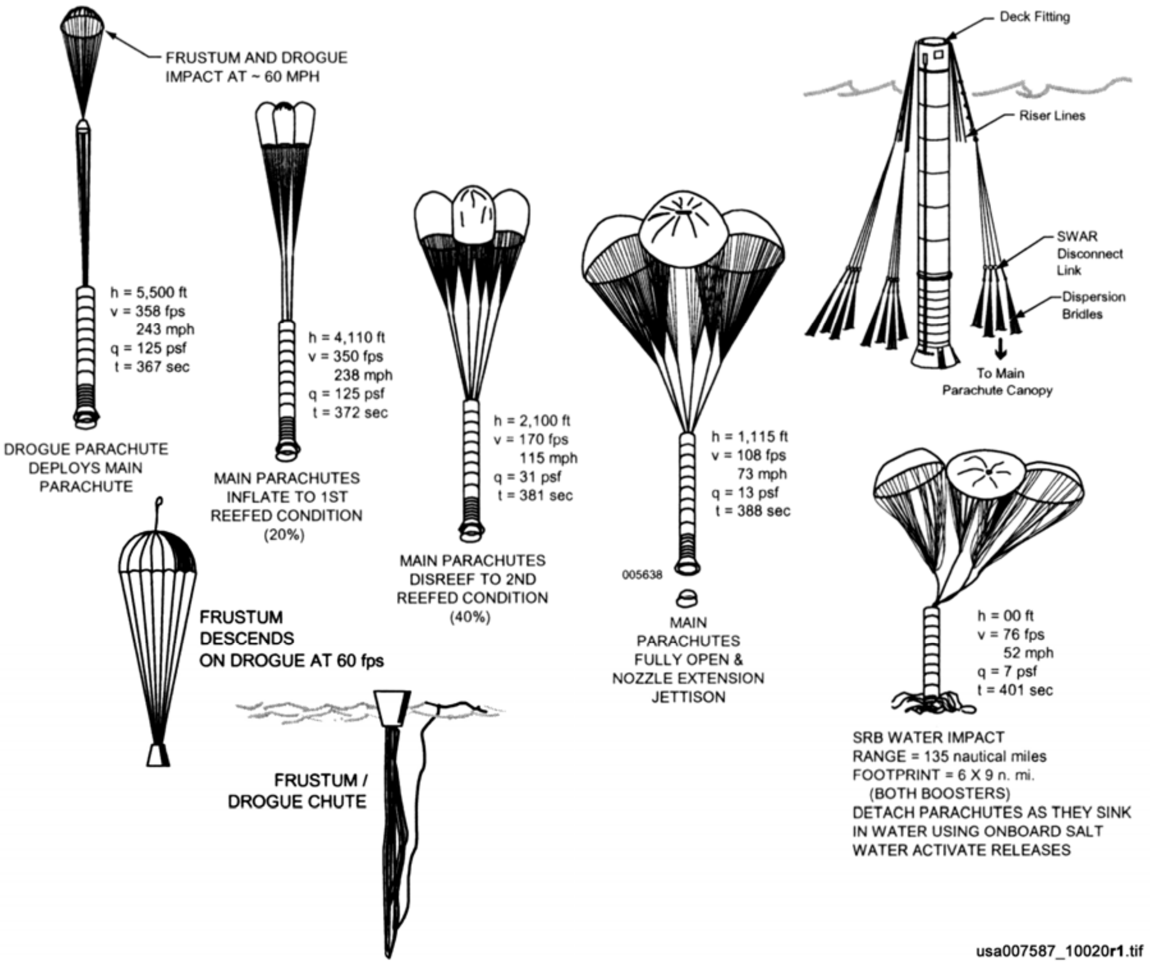
After the drogue chute has stabilized the vehicle in a tail first attitude, the frustum is separated from the forward skirt by a charge triggered via the low-altitude baroswitch at an altitude of 5,500 feet, 243 seconds after separation. It is then pulled away from the SRB by the drogue chute. The main parachute suspension lines are pulled out from deployment bags that remain in the frustum. At full extension of the lines, which are 204 feet long, the three main parachutes are pulled from the deployment bags and inflate to their first reefed condition. The frustum and drogue chute continue on a separate trajectory to splashdown. After specified time delays, the main parachute reefing lines are cut, and the parachutes inflate to their second reefed and full open configurations. The main parachute cluster decelerates the SRB to terminal conditions. Each of the 136-foot-diameter, 20° conical ribbon parachutes can withstand a load of 180,000 pounds and weighs 2,180 pounds. The nozzle extension is severed by pyrotechnic charge at 20 seconds after low baroswitch operation.

Water impact occurs 277 seconds after separation at a velocity of 76 feet per second. The water impact range is approximately 140 miles off the eastern coast of Florida. Because the parachutes provide for a nozzle first impact, air is trapped in the empty (burned out) motor casing, causing the booster to float with the forward end approximately 30 feet out of the water.

The main parachutes are released from the SRB following splashdown using the salt water activated release (SWAR) system. The drogue with frustum and the depleted SRB are buoyant. The main parachutes remain tethered to the SRB until the retrieval ships arrive for recovery operations. Various parameters of SRB operation are monitored and displayed on the orbiter flight deck control and display panel and are transmitted to ground telemetry.



Recovery – Separation Through Drogue Disreef



Recovery – Main Deploy Through Main Disconnect

2. SYSTEMS

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This section discusses in detail each of 25 orbiter systems as listed here in the Table of Contents. The subsections are organized alphabetically, with a detailed internal table of contents provided for each.

Each system subsection begins with descriptive information covering general purpose, function, and location. Relevant elements of each system are then provided in some detail. Where orbiter panels or DPS displays apply, an illustration of such appears as near the reference as possible. In the case of large panels, appropriate fragments are placed in the text, with full panel diagrams provided in Appendix A.

Most system subsections conclude with a summary. Caution and warning summaries and rules of thumb are also provided where appropriate.

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2.1 AUXILIARY POWER UNIT/ HYDRAULICS (APU/HYD)

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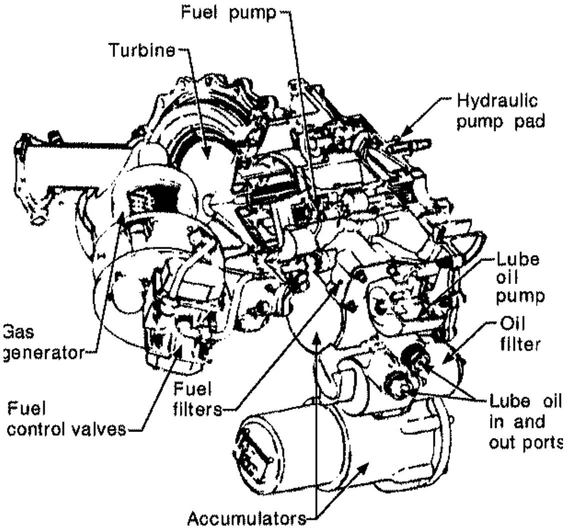


Dimensions: 20 inches wide, 21.80 inches long, 18 inches deep

Auxiliary Power Unit

Description

The orbiter has three independent hydraulic systems. Each consists of a main hydraulic pump, hydraulic reservoir, hydraulic bootstrap accumulator, hydraulic filters, control valves, hydraulic/Freon heat exchanger, electrical circulation pump, and electrical heaters.

Each system provides hydraulic pressure to position hydraulic actuators for:

1. Thrust vector control (*TVC*) of the main engines by gimbaling the three SSMEs
2. Actuation of various control valves on the SSMEs
3. Movement of the orbiter aerosurfaces (elevons, body flap, rudder/speed brake)
4. Retraction of the external tank/orbiter 17-inch liquid oxygen and liquid hydrogen disconnect umbilicals within the orbiter at external tank jettison
5. Main/nose landing gear deployment (system 1)/(system 1 or 2)
6. Main landing gear brakes and anti-skid
7. Nose wheel steering (system 1 with backup from system 2)

Each hydraulic system is capable of operation when exposed to forces or conditions caused by acceleration, deceleration, normal gravity, zero gravity, hard vacuum, and temperatures encountered during on-orbit dormant conditions.

Three identical, but independent, improved auxiliary power units (APUs; also called IAPUs) provide power for the orbiter hydraulic systems. The APU is a hydrazine-fueled, turbine-driven power unit that generates mechanical shaft power to drive a hydraulic pump that produces pressure for the orbiter's hydraulic system. Each unit weighs about 88 pounds and produces 135 horsepower.

Each APU consists of a fuel tank, a fuel feed system, a system controller, an exhaust duct, lube oil cooling system, and fuel/lube oil vents and drains. Redundant electrical heater systems and insulation thermally control the system above 45° F to prevent fuel from freezing and to maintain required lubricating oil viscosity. Insulation is used on components containing hydrazine, lube oil, or water to minimize electrical heater power requirements and to keep high surface temperatures within safe limits on the turbine and exhaust ducts.

The three APUs and fuel systems are located in the aft fuselage. Each APU fuel system supplies storable liquid hydrazine fuel to its respective fuel pump, gas generator valve module, and gas generator, which decomposes the fuel through catalytic action. The resultant hot gas drives a single-stage, dual pass turbine. The turbine exhaust flow returns over the exterior of the gas generator, cooling it, and is then directed overboard through an exhaust duct at the upper portion of the aft fuselage near the vertical stabilizer.

The turbine assembly provides mechanical power through a shaft to drive reduction gears in the gearbox. The gearbox drives a fuel pump, a hydraulic pump, and a lube oil pump. The hydraulic pump supplies pressure to the hydraulic system. The fuel pump increases the fuel pressure at its outlet to sustain pressurized fuel to the gas generator valve module and gas generator. The lube oil system supplies lubricant to the gearbox reduction gears and uses the reduction gears as scavenger pumps to supply lube oil to the inlet of the lube oil pump to increase the pressure of the lube oil system.

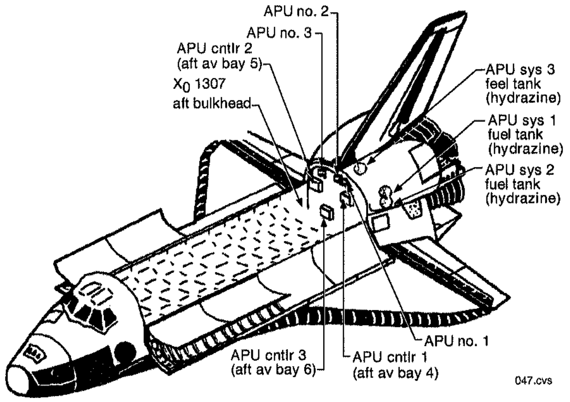
The lube oil of each APU is circulated through a heat exchanger in a corresponding water spray boiler. Three water spray boilers (WSBs), one for each APU, cool the lube oil systems. The hydraulic fluid of each hydraulic pump driven by an APU is also circulated through a hydraulic heat exchanger in the corresponding water spray boiler to cool hydraulic fluid during hydraulic system operation. The three WSBs are also located in the aft fuselage of the orbiter.

Fuel System

The APU fuel system (one for each of the three APUs) includes the fuel tank and fuel isolation valves, the fuel pump, and fuel control valves. The improved APUs use passive heat sinks and heat shields to minimize the effects of heat soakback.

Fuel Tanks

The APU fuel tanks are mounted on supports cantilevered from the sides of the internal portion of the aft fuselage. The fuel is storable liquid anhydrous hydrazine. The hydrazine is stored in a fuel tank with a total capacity of about 350 pounds. The fuel tank, which incorporates a diaphragm at its center, is serviced with fuel on one side and the pressurant (gaseous nitrogen) on the other. The nitrogen is the force acting on the diaphragm (positive expulsion) to expel the fuel from the tank to the fuel distribution lines and maintain a positive fuel supply to the APU throughout its operation. Each typical prelaunch fuel tank load is approximately *332* pounds. The fuel supply supports the nominal power unit operating time of 90 minutes in a mission or any defined abort mode, such as an abort once around, when the APUs run continuously for approximately 110 minutes. Under operating load conditions, an APU consumes approximately 3 to 3.5 pounds of fuel per minute.

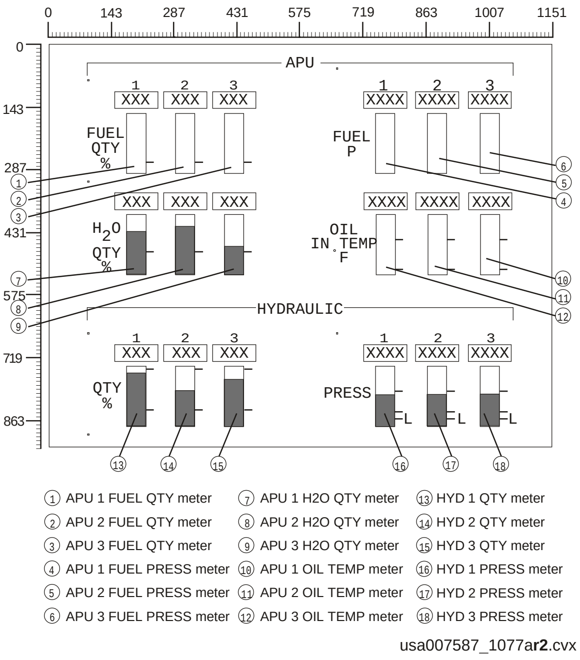


Auxiliary Power Unit Locations

The fuel tanks are 28-inch-diameter spheres. Fuel tanks 1 and 2 are located on the port side of the orbiter's aft fuselage, and tank *3 is* located on the starboard side. Each fuel tank is serviced through its respective fill and drain service connections, located on the corresponding side of the aft fuselage. The gaseous nitrogen servicing connection for each fuel tank is located on the same panel as the fuel servicing connections on the corresponding side of the aft fuselage. The fuel tank is pressurized to 365 psi prelaunch.

Each fuel tank's temperature and gaseous nitrogen pressure are monitored by the APU controller and transmitted to the GPC, where quantity is calculated and transmitted to the APU FUEL/H2O QTY meters on the dedicated MEDS display. The fuel quantity of 100 percent on the meter is equivalent to 350 pounds. Fuel pressure (psia) is shown on the FUEL PRESS meter on the dedicated MEDS display. Fuel quantity in percent is also displayed on the BFS SM SYS SUMM 2 display (FUEL QTY).

The gaseous nitrogen pressure in each fuel tank exerts a force on the tank's diaphragm to expel the hydrazine fuel under pressure to the fuel distribution system. Filters are incorporated into each distribution line to remove any particles. The fuel distribution line branches into two parallel paths downstream of the filter. An isolation valve is installed in each parallel path, providing redundant paths to permit fuel flow to the APU or to isolate the APU from the fuel supply tanks.



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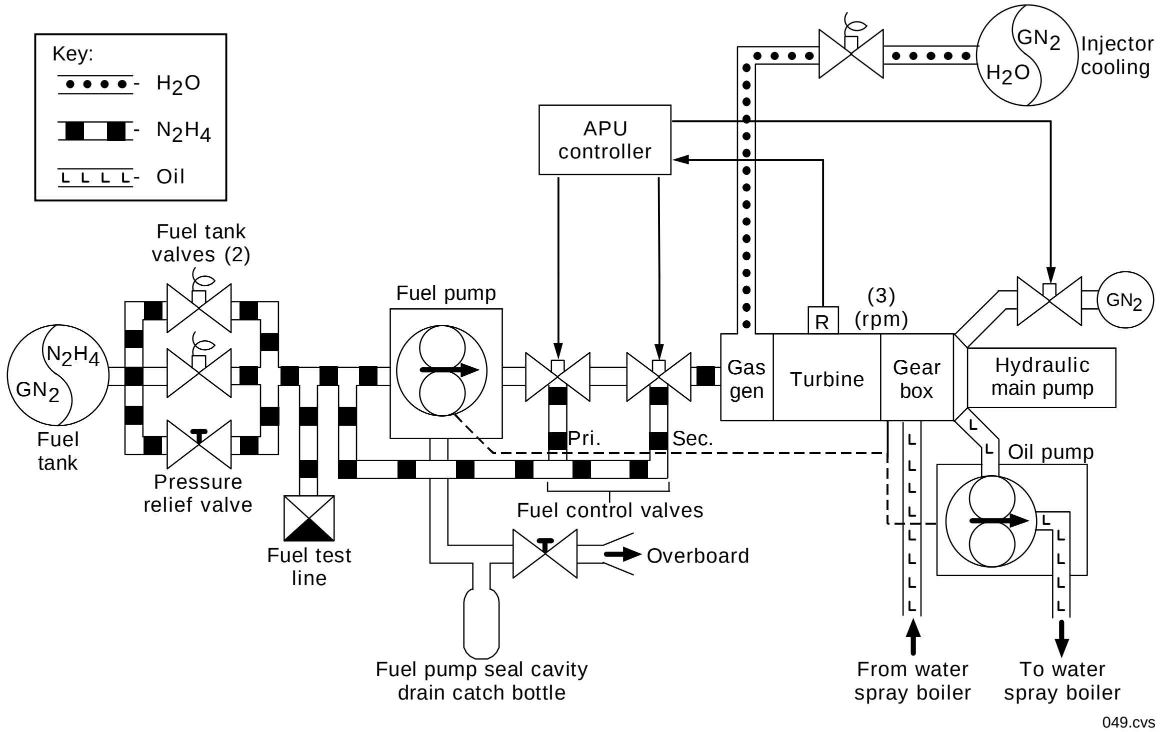
MEDS APU/HYDRAULIC Display



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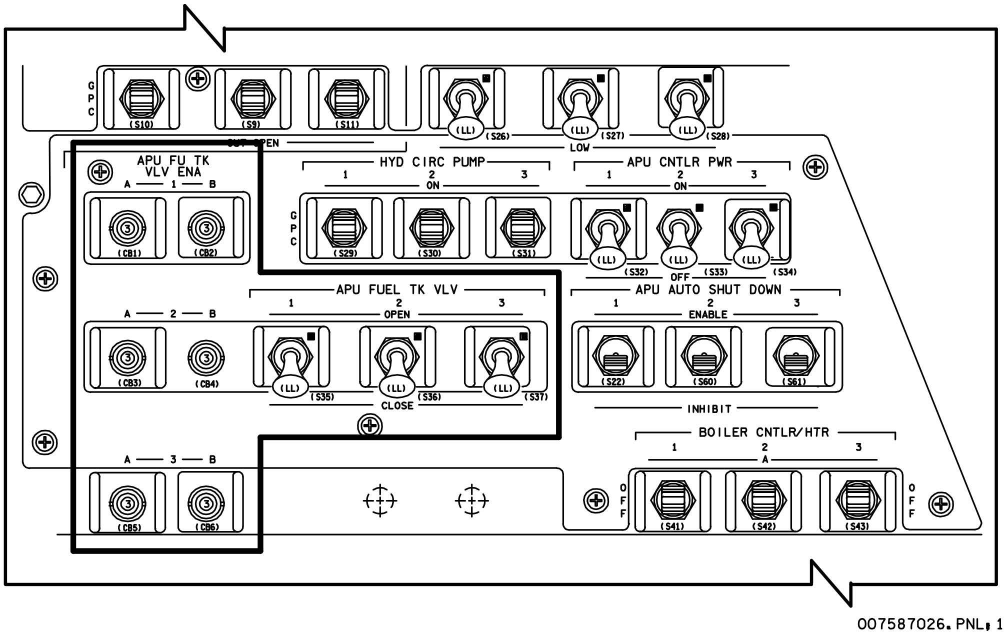
Improved APU Fuel System Schematic



APU FUEL TK VLV Switches and Circuit Breakers on Panel R2

Fuel Tank Isolation Valves

Both isolation valves in each APU fuel distribution system are electrically powered solenoid valves that are controlled by the corresponding *APU FUEL TK VLV 1, 2, 3* switches on panel R2. They are energized open when the corresponding switch is positioned to *OPEN*; both valves are closed when the switch is positioned to *CLOSE*, or if electrical power is lost.

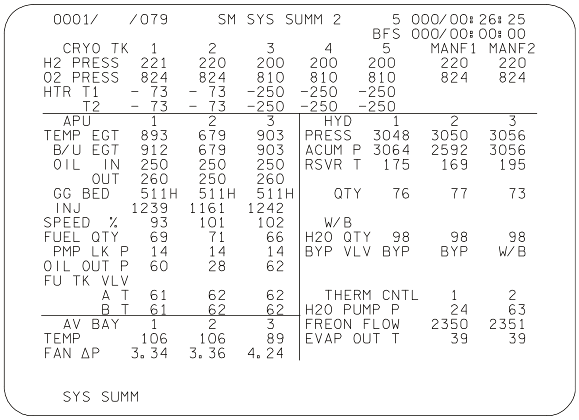
Each valve has a reverse relief function to relieve pressure on fuel trapped in the fuel distribution line downstream of the fuel tank valves when both valves are closed. The valve relieves the downstream pressure when the pressure increases 40 psi to 200 psi above fuel tank pressure due to heat soakback following APU shutdown.

The IAPU fuel tank isolation valves are cooled by fuel flow when the valves are open. Each valve has redundant temperature measurements (two per valve, four per APU). One temperature reading for each valve is displayed on the BFS SM SYS SUMM 2 display and the APU/HYD, DISP 86 display (Ops 201) beside the FU TK VLV AT and BT labels. There are two tank isolation valve circuit breakers per APU (one per valve) located on panel R2. These can be pulled to disconnect electrical power from the solenoid if a valve fails open or shorts. The valve heating profile, when the fuel is stagnant, is gradual and, in the event of a failed open valve or short, permits adequate time for corrective action.

Fuel Pump

Each APU fuel pump is a fixed-displacement, gear-type pump that discharges fuel at approximately 1,400 to 1,500 psi and operates at approximately 3,918 rpm. A fuel filter is located at the fuel pump outlet, and a relief valve relieves at approximately 1,725 psi back to the pump inlet if the filter becomes clogged.

Each fuel pump is driven by the turbine through the reduction gearbox. The fuel pump reduction gear is located in the lube oil system gearbox, and a shaft from the reduction gear drives the fuel pump. Seals are installed on the shaft to contain any fuel or lube oil leakage. If leakage occurs through the seals, it is directed to a drain line that runs to a 500-cubic centimeter catch bottle for each APU. If the catch bottle is overfilled, it will relieve overboard at approximately 45 psia through a burst disk and drain port. After the disk bursts, the pressure relief valve will cycle at approximately 28 psia. On ascent or entry, the flight crew can monitor the catch bottle's line pressure on the BFS SM SYS SUMM 2 display (PMP LK P).



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 0001/   /079      SM SYS SUMM 2      5 000/00:26:25
                                    BFS 000/00:00:00
  CRYO TK   1      2      3      4      5     MANF1 MANF2
H2 PRESS  221    220    200    200    200      220   220
O2 PRESS  824    824    810    810    810      824   824
HTR T1    - 73   - 73   -250   -250   -250
    T2    - 73   - 73   -250   -250   -250
  APU       1      2      3   |  HYD     1      2      3
TEMP EGT  893    679    903   |PRESS   3048   3050   3056
 B/U EGT  912    679    903   |ACUM P  3064   2592   3056
 OIL   IN 250    250    250   |RSVR T   175    169    195
      OUT 260    250    260   |
 GG BED   511H   511H   511H  |   QTY    76     77     73
 INJ     1239   1161   1242   |
SPEED  %   93    101    102   |  W/B
FUEL QTY   69     71     66   |H2O QTY   98     98     98
 PMP LK P  14     14     14   |BYP VLV BYP    BYP    W/B
OIL OUT P  60     28     62   |
FU TK VLV                     |
      A T  61     62     62   |  THERM CNTL      1      2
      B T  61     62     62   |H2O PUMP P       24     63
  AV BAY    1      2      3   |FREON FLOW     2350   2351
TEMP      106    106     89   |EVAP OUT T       39     39
FAN ΔP   3.34   3.36   4.24   |

  SYS SUMM
```

APU Information on BFS SM SYS SUMM 2 Display

Fuel Control Valves

The APU's operating speed is controlled by the primary and secondary fuel control valves, which are installed in series downstream of the fuel pump. These are solenoid-operated pulser-type valves. In the normal APU operating mode, the primary control valve pulses to maintain the APU's speed at about 74,000 rpm (103%), while the secondary control valve attempts to control at 113% rpm. If the APU is taken to high via the *APU SPEED SELECT* switch on panel R2, the primary valve attempts to control at 115% rpm, while the secondary valve begins pulsing, and controls APU speed at about 81,000 rpm (113%). If the secondary valve subsequently fails open, the primary valve will maintain APU speed at about 83,000 rpm (115%). If the secondary valve loses power, it goes to the closed position and shuts down the APU. As noted above, the primary valve goes to full open if it loses power, allowing the secondary valve to take over automatically and control at high speed (113%).

The crew can see APU speed on the BFS SM SYS SUMM 2 display (APU SPEED %) in percent (100 percent = 72,000 rpm). The speed fluctuates due to the nature of the pulse-modulated fuel flow system.

For safety reasons, each APU has an automatic shutdown feature that will shut the APU down if the speed falls below 80 percent (57,600 rpm) or rises above 129 percent (92,880 rpm).

Gas Generator and Turbine

Each gas generator consists of a bed of Shell 405 catalyst in a pressure chamber, mounted inside the APU exhaust chamber. When the hydrazine fuel comes into contact with the catalyst, it undergoes an exothermic reaction, decomposing into a hot gas at approximately 1,700° F. The gas expands rapidly and makes two passes through a single-stage turbine wheel, passes over the outside gas generator chamber, and exits overboard through its own independent exhaust duct, located near the base of the vertical stabilizer. The temperature of the hot gas at the exhaust duct is approximately 1,000° F.

The shaft power from the spinning turbine is sent to the hydraulic main pump associated with the APU via a speed reduction gearbox. It is also used to drive the APU's fuel pump and lubrication oil pump.

The normal speeds of the hydraulic main pump, APU fuel pump, and APU lube oil pump are 3,918 rpm, 3,918 rpm, and 12,215 rpm, respectively. The lube oil system is necessary to lubricate the APU gearbox and the fuel pump.

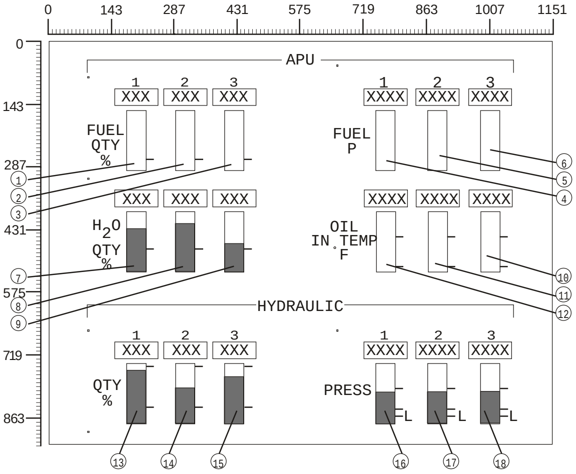
The temperatures of the gas generator bed, the gas generator fuel injector, and the turbine exhaust gas are visible on the BFS SM SYS SUMM 2 DPS display (GG BED, INJ, TEMP EGT). While the APU is running, the gas generator bed temperature transducer goes off-scale high at about *510*° F. On orbit, when the APU is shut down, the gas generator bed temperature transducer is useful to monitor the bed temperature when the bed is kept warm by heaters.

Lubricating Oil

The APU lube oil system is a scavenger-type with a fixed-displacement pump. Each APU turbine, through its gearbox, drives a lube oil pump at 12,215 rpm. The system is pressurized with gaseous nitrogen (GN_2) to provide adequate suction pressure to start the lube oil pump under zero-gravity conditions. Each lube oil system has its own nitrogen gas storage vessel that is pressurized to approximately 140 psia. The pressurization system for each lube oil system has a valve controlled by its corresponding APU controller. The GN_2 pressurization valve for each power unit is energized open by its corresponding controller when the gearbox pressure is below 5.2 psi, ± 1.3 psi, to ensure that gearbox pressure is sufficiently above the requirements for proper scavenging and lube pump operation.

The pump increases the lube oil pressure to approximately 60 psi, directs the lube oil through the corresponding water spray boiler for cooling, and returns the lube oil to the accumulators and gearbox. Two accumulators in each lube oil system allow thermal expansion of the lube oil, accommodate gas initially trapped in the external lube circuit, maintain lube oil pressure at a minimum of approximately 15 psia, and act as a zero-gravity, all-altitude lube reservoir.

The following information is transmitted to the BFS SM SYS SUMM 2 display by the APU controller via the GPC: lube oil pump outlet pressure (OIL OUT P) at approximately 45 psia, outlet temperature at approximately 270° F, and a return temperature from the water spray boiler (OIL IN, OUT) at approximately 250° F for each APU. The lube oil temperature of each APU is also monitored on the APU OIL TEMP meter on the dedicated MEDS display.



① APU 1 FUEL QTY meter
② APU 2 FUEL QTY meter
③ APU 3 FUEL QTY meter
④ APU 1 FUEL PRESS meter
⑤ APU 2 FUEL PRESS meter
⑥ APU 3 FUEL PRESS meter
⑦ APU 1 H2O QTY meter
⑧ APU 2 H2O QTY meter
⑨ APU 3 H2O QTY meter
⑩ APU 1 OIL TEMP meter
⑪ APU 2 OIL TEMP meter
⑫ APU 3 OIL TEMP meter
⑬ HYD 1 QTY meter
⑭ HYD 2 QTY meter
⑮ HYD 3 QTY meter
⑯ HYD 1 PRESS meter
⑰ HYD 2 PRESS meter
⑱ HYD 3 PRESS meter

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MEDS APU/HYDRAULIC Display

Electronic Controller

Each APU has its own digital controller. The controller detects malfunctions, controls turbine speed, gearbox pressurization, and fuel pump/gas generator heaters. Each controller is controlled by its corresponding *APU CNTLR PWR* switch on panel R2. When the switch is positioned to *ON*, 28-volt dc power is sent to that controller and APU. The controllers are redundantly powered via dual internal remote power controllers. When the switch is positioned to *OFF*, electrical power is removed from that controller and APU.

APU Start

An *APU/HYD READY TO START* talkback indicator for each APU is located on panel R2. The talkback signals gray when that APU hydraulic system is ready to start; that is, when the APU gas generator temperature is above 190° F, APU turbine speed is less than 80 percent, WSB controller is ready, a corresponding APU fuel tank isolation valve is open, and corresponding hydraulic main pump is depressurized. When the APU is started, and its turbine speed is greater than 80 percent of normal speed, the corresponding indicator shows barberpole.

NOTE

A barberpole *APU/HYD READY TO START* talkback will not inhibit a start.

APU OPERATE 1, 2, 3 switches are located on panel R2. When the switches are positioned to *START/RUN*, the corresponding APU controller activates the start of that unit and removes electrical power automatically from the unit's gas generator and fuel pump heaters.

To start the APU, fuel expelled from the hydrazine tank flows through the open tank valves and filter to the gas generator valve module, which contains the primary and secondary fuel control valves in series. The primary pulse control valve is normally open, and the secondary pulse control valve is energized open. Fuel flowing through the pump bypass valve is directed to the gas generator, because the fuel pump is not being driven at that moment by the APU turbine.

The fuel in the gas generator decomposes through catalytic reaction, creates hot gas, and directs the hot gas to the single-stage turbine, which begins to rotate. The turbine's mechanical shaft drives the reduction gears, rotating the fuel pump, lube oil pump, and hydraulic pump. The fuel pump increases the fuel pressure at its outlet and provides pressurized fuel to the gas generator valve module and gas generator.

The startup logic delays the APU underspeed logic check for 10.5 seconds after the start command is issued. This allows the APU to reach normal operating speed before the shutdown logic begins checking for a speed lower than 80 percent. The auto shutdown capability of the controller can be disabled by taking the *APU AUTO SHUT DOWN* switch on panel R2 to *INHIBIT*.

The startup logic does not delay the APU overspeed logic. If an overspeed is detected at any time by the controller, the F7 and MASTER ALARM will annunciate. If the *AUTO SHUT DOWN* on panel R2 is *ENABLED*, the controller will automatically close the tank isolation valves and close the secondary control valve.

CAUTION

After an APU auto shutdown, the *APU FUEL TK VLV* switch must be taken to *CLOSE* prior to *having an* auto shutdown. Failure to *close a FUEL TK VLV after an APU Shutdown can result in* the fuel tank isolation valves reopen*ing* and *allowing* flow fuel to an APU gas generator bed that is above the temperature limits for safe restart.

APU Speed Control

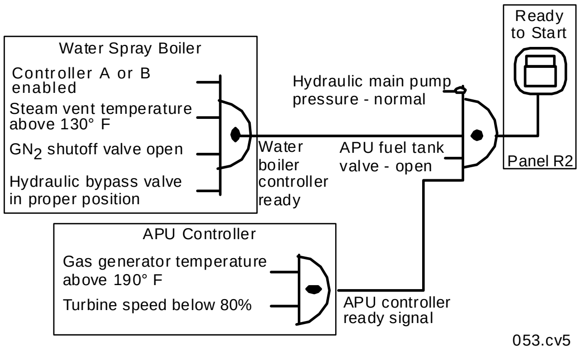
When the APU turbine speed exceeds the control target (103 percent for NORMAL and 113 percent for HIGH) the appropriate control valve closes. The fuel is then diverted through a bypass line back to the fuel pump inlet. When the turbine speed drops below the control target, the appropriate valve opens directing fuel to the gas generator and closing off the bypass line. The primary fuel valve pulses to maintain APU speed. The frequency and duration of the primary fuel control valve pulses are functions of the hydraulic load on the unit.

The secondary fuel control valve normally stays fully open during the operation of the primary. If the primary valve loses power, it goes to the fully open position, and the secondary valve begins pulsing and controlling APU speed. If the secondary valve loses power at any time *it closes and* the APU is shut down. If the auxiliary power unit is taken to a high speed (by the *APU SPEED SELECT* switch on panel R2), the primary valve attempts to control to 115 percent rpm, while the secondary valve controls the unit's speed at 113 percent rpm.

Each APU controller controls the speed of each unit upon the activation of the *APU SPEED SELECT* switch for each APU on panel R2. The *NORM* position controls the speed at 74,160 rpm, 103 percent, plus or minus 8 percent. The *HIGH* position controls the speed at 81,360 rpm, 113 percent, plus or minus 8 percent, with a second backup of 82,800 rpm, 115 percent, plus or minus 8 percent.

APU Auto Shutdown

The *APU AUTO SHUT DOWN* switches on panel R2 enable the automatic shutdown feature in the associated APU controllers. When the switch is positioned to *ENABLE*, each controller monitors its corresponding APU speed. If that APU speed falls below 57,600 rpm (80 percent) or rises above 92,880 rpm (129 percent), the controller automatically shuts down that unit. Each shutdown command closes that unit's secondary fuel valve and the tank isolation valves.

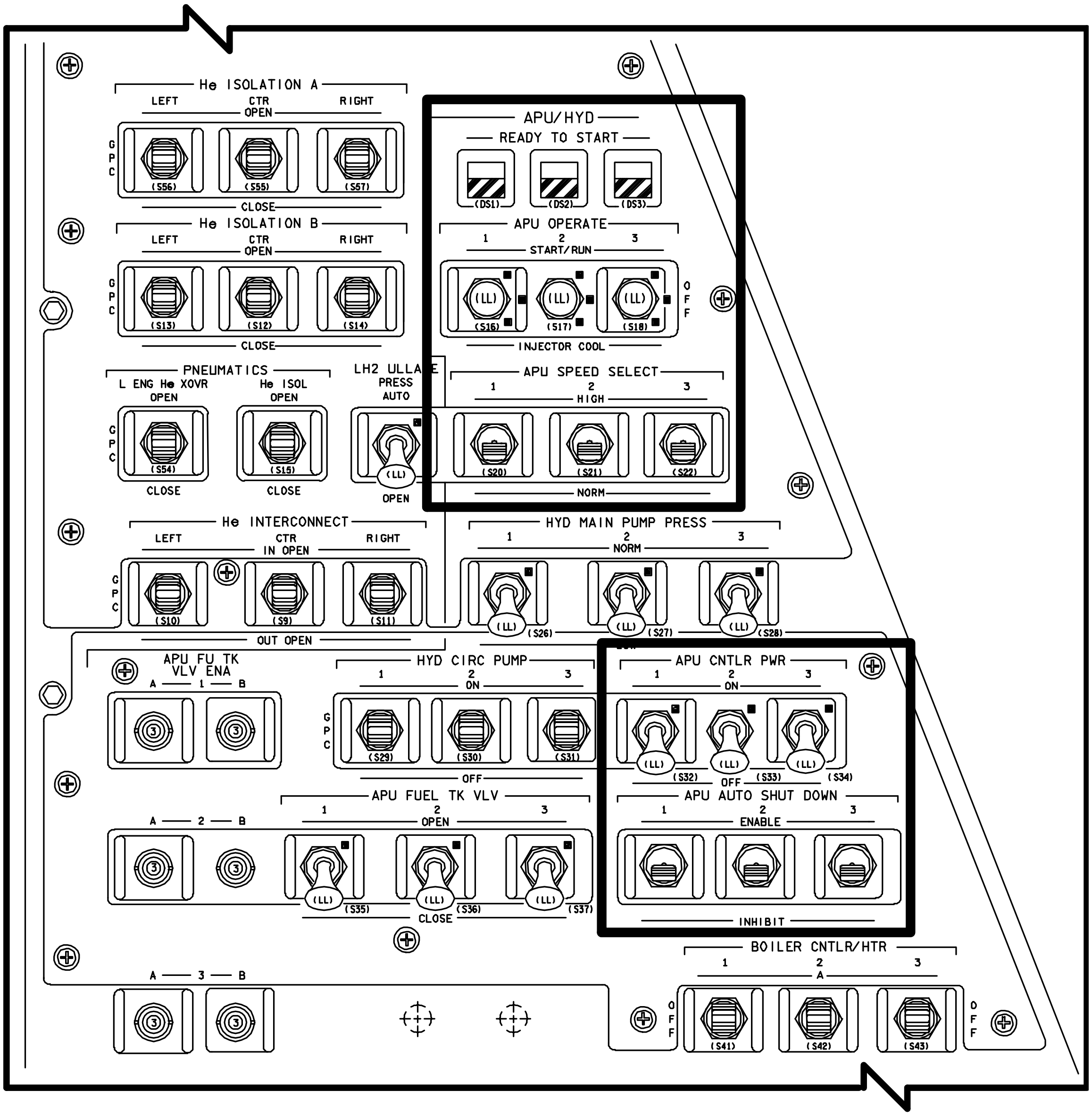


APU Ready-for-Start Talkback Indicator Logic

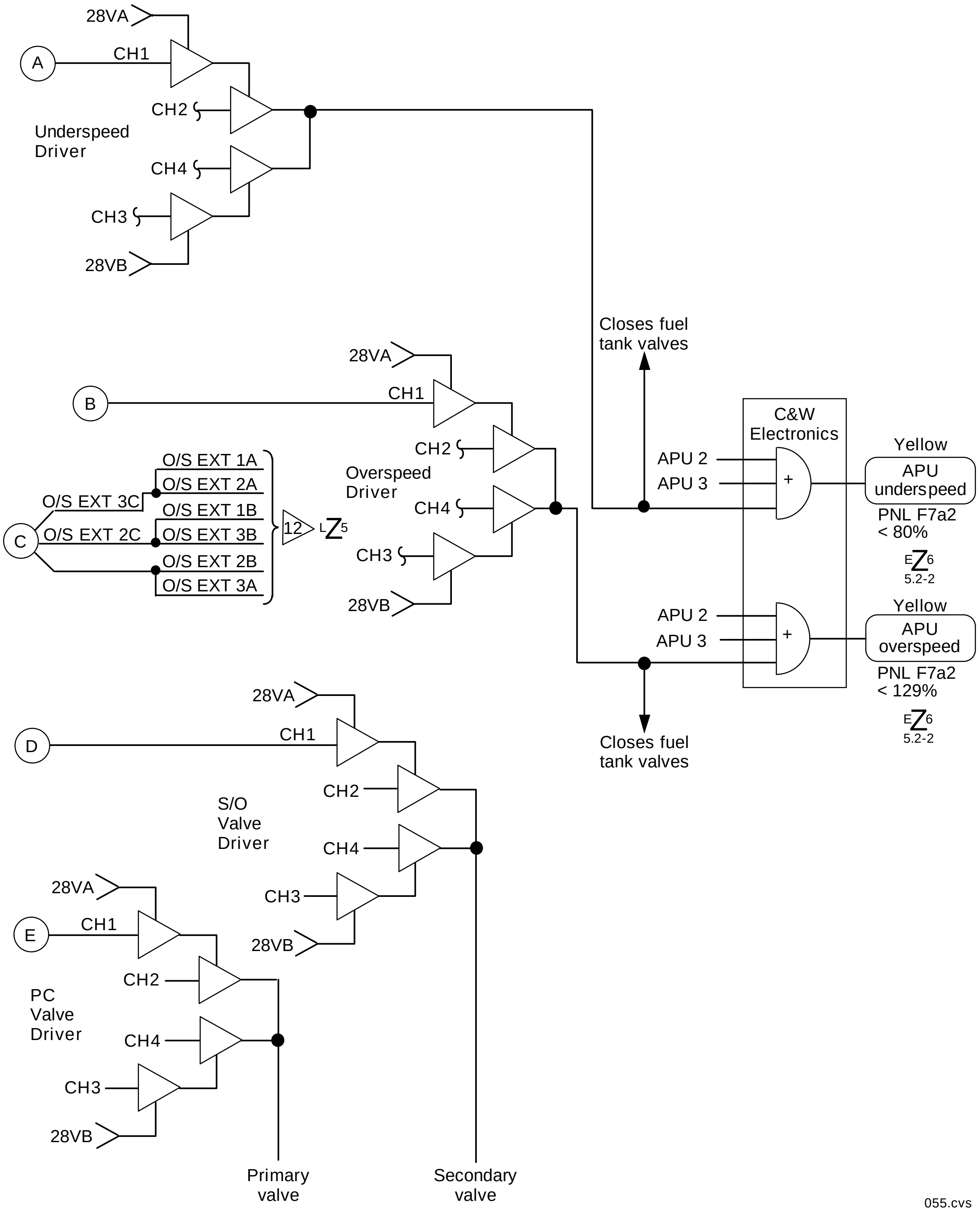
When an *APU AUTO SHUT DOWN* switch is positioned to *INHIBIT*, the automatic shutdown sequence for its APU controller is inhibited. If the turbine speed falls below 80 percent or rises above 129 percent *APU UNDERSPEED* or *APU OVERSPEED* caution and warning lights on panel F7 will be illuminated, and a tone will be generated, even though the *APU AUTO SHUT DOWN* switch is in *INHIBIT*.

CAUTION

An APU should not be restarted after an overspeed shutdown. Uncontained overspeed and turbine wheel breakup could occur if restart is attempted.



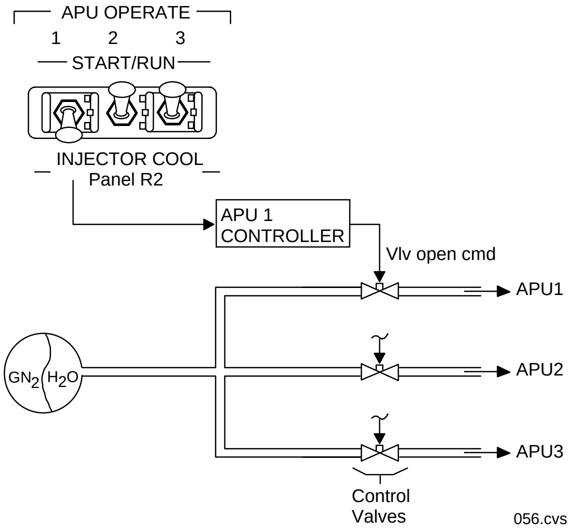
APU/HYD READY TO START Talkbacks, APU OPERATE Switches, APU SPEED SELECT Switches, APU CNTLR PWR Switches, and APU AUTO SHUT DOWN Switches on Panel R2



APU Overspeed/Underspeed Detection

Injector Cooling System

The gas generator injector water cooling system is used only when the normal cool-down period of approximately 180 minutes is not available. The system sprays water to reduce the temperature of the gas generator injector branch passages to less than 400° F in the event that a hot APU must be restarted after it has been recently shut down. The water cooling ensures that the hydrazine will not detonate in the fuel line leading into the injector due to heat soakback from the gas generator. The injector is cooled by circulating water around it. The water from the gas generator injector is exhausted into the aft fuselage.



APU Injector Cooling

A single water tank located in the aft fuselage of the orbiter serves all three APUs. The water tank is 9.4 inches in diameter and loaded with *about* 9 pounds of water *or 21 minutes worth of cooling*. The water tank is pressurized with gaseous nitrogen at a nominal pressure of 120 psi. The pressure acts on a diaphragm to expel the water through three 0.25-inch-diameter lines to three control valves. When the *APU OPERATE* switch on panel R2 for APU 1, 2, or 3 is positioned to *INJECTOR COOL*, the water valve of that unit opens and directs the water into the gas generator *injector to* cool it.

If the injector branch (internal) temperature of an APU is above 400° F from heat soakback, or if the catalytic bed heater temperature is above 430° F, the flight crew must cool the injector for 3.5 minutes before starting the APU. Operational data from hot APUs shows that the GG INJ temperature does not accurately reflect the drop in injector branch temperatures. The crew is safe to attempt a restart if the GG INJ temperature is decreasing and at least 3.5 minutes of continuous injector cooling has been completed. A Class 3 alarm with message "APU 1 (2) Cooldown" will annunciate 225 seconds after APU injector cooling is initiated.

CAUTION

Care must be taken not to delay in the *OFF* position when taking the *APU OPERATE* switch to *START/RUN*. If cooldown is terminated more than 1 second prior to starting the APU, the injector branch temperatures may increase above start limits, and detonation may occur without another cooldown cycle.

The water tank supply is sufficient for about six *total* hot starts. The unit's injector temperature can be monitored on the BFS SM SYS SUMM 2 display (INJ).

Fuel Pump and Gas Generator Valve Module Cooling

The fuel pump and gas generator valve module are cooled by passive cooling. The improved APUs have passive heat sinks and heat shields to absorb conductive and radiant heat. This prevents excessive heat soakback in the gas generator valve and fuel pump assemblies. There are no water tanks or associated plumbing for this module with the APUs. The crew has no requirement to do anything to provide cooling. This passive cooling system, in conjunction with active injector cooling, is used to allow for contingency restarts in the event a deorbit becomes necessary within approximately 180 minutes of APU shutdown.

CAUTION

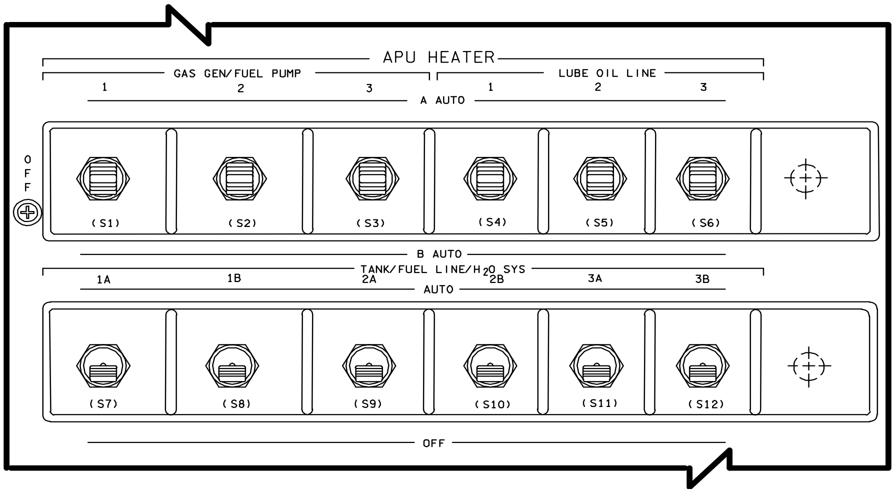
An APU may not be restarted if the temperature of the fuel pump is above 210° F or the temperature of the gas generator valve module is above 200° F, because hydrazine detonation may occur.

APU Heaters

The APU HEATER TANK/FUEL LINE/H2O SYS 1A, lB, 2A, 2B, 3A, 3B switches on panel A12 operate the thermostatically controlled heaters located on the corresponding APU fuel system and water system. The fuel tank, fuel line, and water line heaters for each APU are divided into redundant A and B systems. For example, for APU 1, the TANK/FUEL LINE/ H2O SYS 1A switch powers the A heaters, and the thermostats provide automatic control. Only one set of heaters is used at a time. The 1B switch powers the 1B heaters, and the thermostats provide automatic control. The APU fuel tank and line heater thermostats maintain the temperatures between a nominal 55° F and 65° F. The water system heater thermostats maintain the temperatures between 55° F and 65° F. The OFF position of each switch removes power from the respective heater circuits.

The APU HEATER GAS GEN/FUEL PUMP 1, 2, 3 switches on panel A12 power thermostatically controlled heaters located on the corresponding APU, fuel pump, gas generator valve module, and gas generator bed heater. The thermostats control a series of heaters on the gas generator valve module, fuel pump, and all the fuel lines and the water lines from the fuel pump spray manifold to the gas generator valve module. The heaters are divided into redundant A and B systems for each APU. The A AUTO switch powers the A heater, and the A thermostat automatically controls the corresponding APU fuel pump heater, maintaining fuel pump and gas generator valve module temperatures at about 100° F. The gas generator bed heater is maintained between 360° and 425° F by a comparator in the APU controller that receives its signal from the bed temperature transducer. The gas generator temperature range ensures efficient APU startup through efficient catalytic reaction. The B AUTO switch position provides the same capability for the B heater system. The gas generator and fuel pump heaters are automatically deactivated by the corresponding controller at APU start. The OFF position of each switch removes power from the respective heater circuits. These heater switches also provide redundant power to the gas generator and gearbox pressure signal conditioners for use while the APU controller is off.

The lube oil system lines on each APU also have a heater system. These heaters are controlled by the APU HEATER LUBE OIL LINE 1, 2, 3 switches on panel A12. The lube oil line heaters for each APU are also divided into an A and B system; e.g., for 1, A AUTO, and B AUTO. The A AUTO switch powers the A heater, and the thermostat automatically controls the corresponding lube oil system heater, maintaining the lube oil line in the temperature range of 55° F to 65° F. The B AUTO switch position provides the same capability to the B heater system. The OFF position of each switch removes power from the respective heater circuits.



APU HEATER Controls on Panel A12

Water Spray Boilers

The water spray boiler (WSB) system consists of three identical independent water spray boilers, one for each APU/hydraulic system. The boilers are located in the aft fuselage of the orbiter. Each WSB cools the corresponding APU lube oil system and hydraulic system by spraying water onto their lines; as the water boils off, the lube oil and hydraulic fluid are cooled. The steam that boils off in each water spray boiler exits through its own exhaust duct, located on the starboard side of the vertical stabilizer.

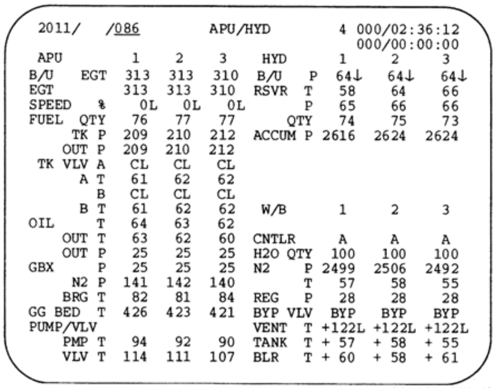
Each WSB is 45 by 31 inches long by 19 inches wide, and including controller and vent nozzle, weighs 181 pounds. They are mounted in the orbiter aft fuselage between X_o 1340 and 1400, at Z_o 488 minus 15, and at Y_o plus 15. Insulation blankets cover each boiler. The boiler's water capacity is 142 pounds.

*The WSBs have had WSB freeze-up problems in the past. WSB freeze-up occurs after the preloaded boiler water has evaporated, and active cooling has not yet begun. During that time, residual water in the core, spray bars, or water feedline is exposed to low pressures and will begin freezing. To alleviate this problem, e*ach WSB stores *a* water *and propylene glycol monomethyl ethel (PGME) mixture* in a bellows-type storage tank. *The tank is* pressurized by gaseous nitrogen, providing positive water expulsion to feed the boiler. *The PGME and water mixture of 47% and 53%, respectively, is the solution to the WSB freeze-up problem. The PGME/water mixture has been flown, preloaded in the boiler since STS-102, and has been flown in the boilers and the WSB tanks since STS-114. Currently, all WSB tanks are loaded with the PGME mixture.*

Hydraulic fluid passes through the boiler three times. APU lube oil passes through the boiler twice. The hydraulic fluid tubes are sprayed with water from three water spray bars, and two water spray bars spray the APU lube oil. Separate water feed valves allow independent control of the hydraulic fluid spray bars and APU lube oil spray bars. Redundant electrical controllers provide completely automatic operation.

The boiler system maintains APU lube oil temperature at approximately 250° F and the hydraulic fluid in the range of 210° to 220° F.

The crew can see the WSB water quantity (H2O QTY), nitrogen tank pressure (N2 P), nitrogen regulator pressure (REG P), and nitrogen tank temperature (N2 T) on the right side of the SM APU/HYD (DISP 86) display on orbit.



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 2011/   /086          APU/HYD         4 000/02:36:12
                                         000/00:00:00
 APU          1    2    3   HYD        1     2     3
B/U   EGT   313  313  310  B/U   P   64↓   64↓   64↓
EGT         313  313  310  RSVR  T    58    64    66
SPEED   %     0L   0L   0L       P    65    66    66
FUEL  QTY    76   77   77      QTY    74    75    73
    TK  P   209  210  212  ACCUM P  2616  2624  2624
   OUT  P   209  210  212
 TK VLV A    CL   CL   CL
      A T    61   62   62
        B    CL   CL   CL
      B T    61   62   62   W/B         1     2     3
OIL     T    64   63   62
   OUT  T    63   62   60  CNTLR       A     A     A
   OUT  P    25   25   25  H2O QTY   100   100   100
GBX     P    25   25   25  N2    P   2499  2506  2492
    N2  P   141  142  140        T    57    58    55
   BRG  T    82   81   84  REG   P    28    28    28
GG BED  T   426  423  421  BYP VLV   BYP   BYP   BYP
PUMP/VLV                   VENT  T +122L +122L +122L
   PMP  T    94   92   90  TANK  T + 57  + 58  + 55
   VLV  T   114  111  107  BLR   T + 60  + 58  + 61
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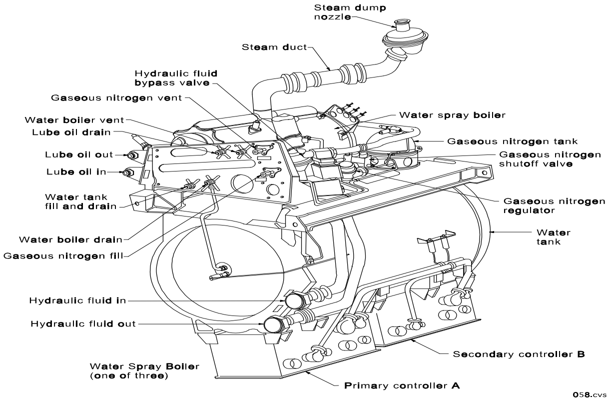
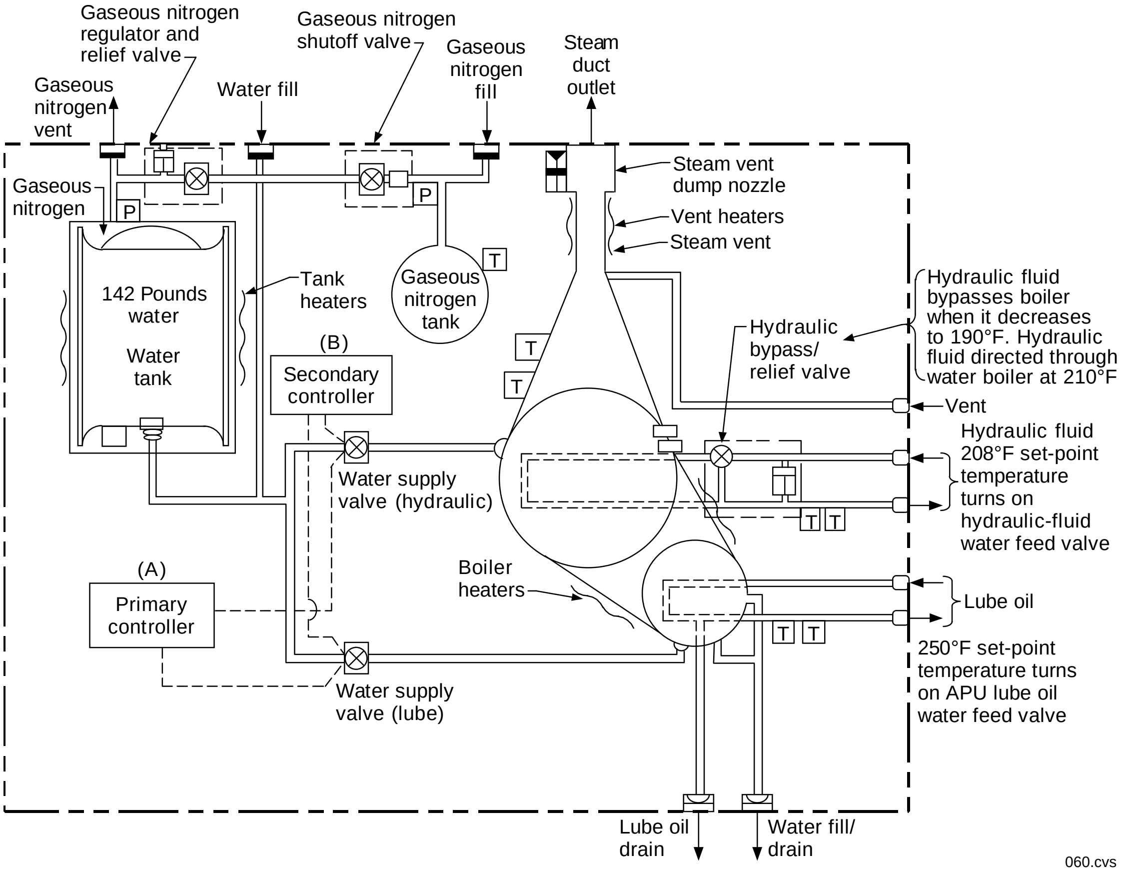
SM APU/HYD Display (DISP 86)



Water Spray Boiler Unit



Water Spray Boiler (One of Three)

Nitrogen Supply System

The gaseous nitrogen pressure for each WSB is contained in a corresponding 6-inch spherical pressure vessel. The pressure vessel contains 0.77 pound of nitrogen at a nominal pressure of 2,400 psi at 70° F. The gaseous nitrogen storage system of each WSB is directed to its corresponding water storage tank. Each storage vessel contains sufficient nitrogen gas to expel all the water from the tank and allow for relief valve venting during ascent.

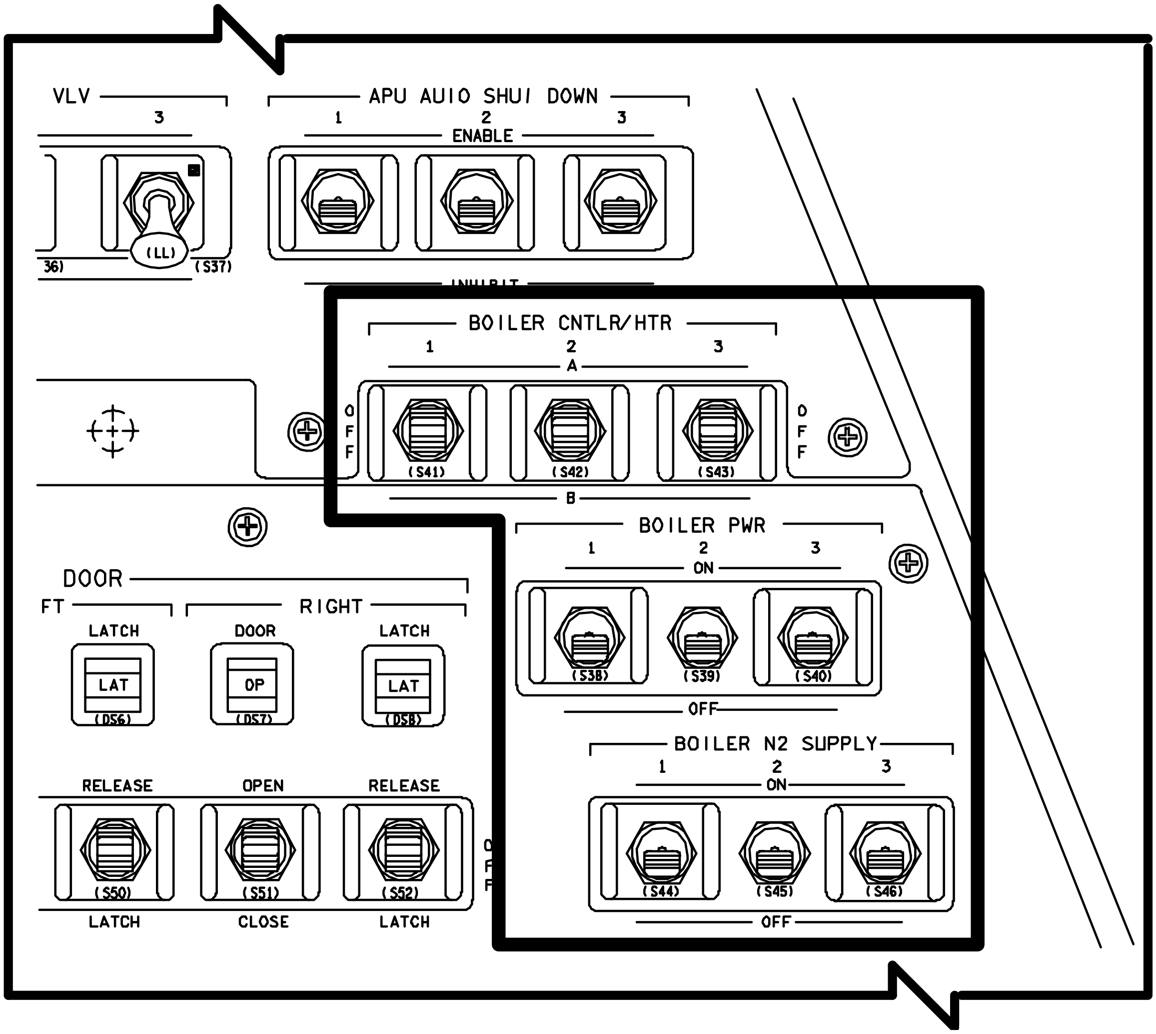
The nitrogen shutoff valve between the pressure valve and water storage tank of each boiler permits the pressure to reach the nitrogen regulator and water tank or isolates the nitrogen supply from the water tank. Each nitrogen valve is controlled by its respective *BOILER N2 SUPPLY 1, 2*, or *3* switch on panel R2. The nitrogen shutoff valve, which is latched open or closed, consists of two independent solenoid coils that permit valve control from either the primary or secondary controller.

A single-stage regulator is installed between the nitrogen pressure shutoff valve and the water storage tank. The gaseous nitrogen regulator for each water spray boiler regulates the high-pressure nitrogen between 24.5 and 26 psig as it flows to the water storage tank.

A relief valve is incorporated inside each nitrogen regulator to prevent the water storage tank pressure from exceeding 33 psig. The gaseous nitrogen relief valve opens between 30 to 33 psig.

Water Supply System

The water supply for each boiler is stored in a positive-displacement aluminum tank containing a welded metal bellows separating the stored water inside the bellows from the nitrogen expulsion gas.



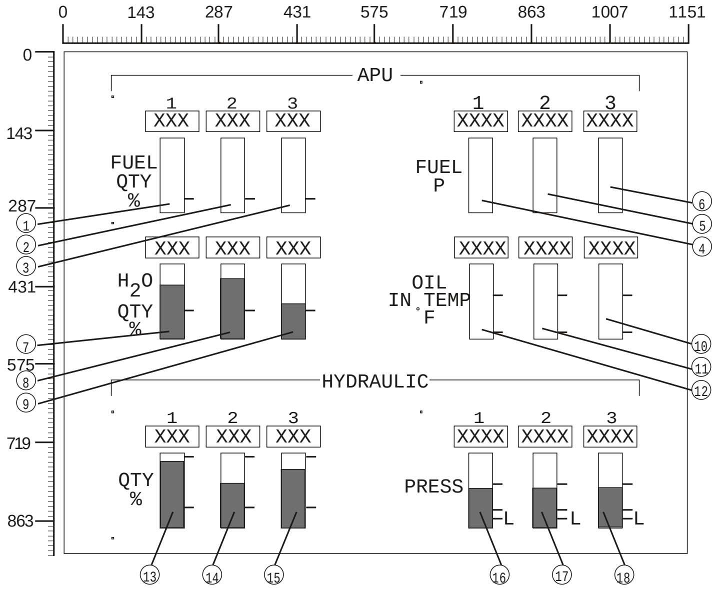
BOILER Switches on Panel R2

Redundant pressure and temperature sensors located downstream from the gaseous nitrogen pressure vessel and on the water tank for each boiler transmit the pressures and temperatures through each controller to the systems management general-purpose computer. The computer computes the water tank quantity from the pressure, volume, and temperature, and transmits the water tank quantity to the dedicated MEDS display for each boiler. Water quantity is available when either the A or B controller is powered.

Downstream of the water storage tank, the feedwater lines to each water boiler split into two parallel lines: one line goes to the hydraulic fluid flow section and one to the lube oil section of the WSB. The H2O spray valves in each feedline are controlled independently by the boiler controller.

Temperature Control

The two boiler controllers are operated by the respective *BOILER CNTLR/HTR 1, 2,* and *3* switches on panel R2. When the applicable switch is positioned to A, the A controller for that boiler is powered; if it is positioned to B, the B controller is powered. The OFF position removes electrical power from both controllers.



① APU 1 FUEL QTY meter
② APU 2 FUEL QTY meter
③ APU 3 FUEL QTY meter
④ APU 1 FUEL PRESS meter
⑤ APU 2 FUEL PRESS meter
⑥ APU 3 FUEL PRESS meter
⑦ APU 1 H2O QTY meter
⑧ APU 2 H2O QTY meter
⑨ APU 3 H2O QTY meter
⑩ APU 1 OIL TEMP meter
⑪ APU 2 OIL TEMP meter
⑫ APU 3 OIL TEMP meter
⑬ HYD 1 QTY meter
⑭ HYD 2 QTY meter
⑮ HYD 3 QTY meter
⑯ HYD 1 PRESS meter
⑰ HYD 2 PRESS meter
⑱ HYD 3 PRESS meter

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MEDS APU/HYDRAULIC Display

The *BOILER PWR 1*, 2, and 3 switches on panel R2 enable (provide the automatic control functions) the specific controller A or B selected for that boiler by the *BOILER CNTLR/HTR 1*, 2, and 3 switches on panel R2. When the applicable controller A or B is enabled for that boiler, a ready signal is transmitted to the corresponding *APU/HYD READY TO START* indicator on panel R2 if the following additional conditions are met: gaseous nitrogen shutoff valve is open, steam vent nozzle temperature is greater than 130° F, and hydraulic fluid bypass valve is in the correct position with regard to the hydraulic fluid temperature.

The core of each WSB is a stainless steel crimped-tube bundle. The hydraulic fluid section is divided into three 17-inch-long passes of smooth tubes (first pass-234 tubes, second pass-224 tubes, and third pass-214 tubes). The lube oil section of the APU comprises two passes with 103 crimped tubes in its first pass and 81 smooth tubes in the second pass. The tubes are 0.0125 of an inch in diameter with a wall thickness of 0.010 of an inch. Crimps located every 0.24 of an inch break up the internal boundary layer and promote enhanced turbulent heat transfer. Although the second pass is primarily a low-pressure drop return section, approximately 15 percent of the unit's lube oil heat transfer occurs there. Three connected spray bars feed the hydraulic fluid section, while two spray bars feed the power unit's lube oil section in each boiler.

When the orbiter is in the vertical position on the launch pad, each boiler is loaded with up to *4.86* pounds of *PGME/*water *mixture*, which is referred to as "pool mode" operation. When each APU/ hydraulic system and WSB are in operation 5 minutes before lift-off, the APU lube oil tube bundle is immersed in the boiler water precharge. As the vehicle ascends during launch, the lube oil system of the APU heats up, eventually the boiler water precharge boils off, and the boiler goes into the spray mode about 13 minutes after launch. The hydraulic fluid usually does not heat up enough during ascent to require spray cooling.

When the APU/hydraulic combination is started for atmospheric entry, the hydraulic fluid and power unit lube oil flow commences, fluid temperatures rise, and spraying is initiated as required. During the lower part of entry, when the boiler temperature reaches 188° F, the water spray boiler returns to the pool mode. The spray bars begin discharging excess water to fill the boiler. When the water reaches the liquid level sensors, the spray is turned off so that the boiler is not overfilled. During entry, because the orbiter's orientation is different from that of launch, the boiler can hold up to 14 pounds of water.

The enabled controller of the operating WSB monitors the hydraulic fluid and lube oil outlet temperature from the APU. The hydraulic fluid outlet temperature controls the hydraulic fluid H2O spray control valve, and the lube oil outlet temperature controls the lube oil water spray control valve. Signals are based on a comparison of the hydraulic system fluid temperature to its 208° F set point and of the lube oil of the power unit to its 250° F set point. When the respective water feed valve opens, instantaneous flows of 10 pounds per minute maximum through the hydraulic section and 5 pounds per minute maximum through the lube oil section enter the water boiler through the corresponding spray bars to begin evaporative cooling of the hydraulic fluid and APU lube oil. The steam is vented out through the overboard steam vent.

The separate water feed valves modulate the water flow to each section of the tube bundle core in each WSB independently in 200-millisecond pulses that vary from one pulse every 10 seconds to one pulse every 0.25 of a second.

Because of the unique hydraulic system fluid flows, control valves are located in the hydraulic system fluid line section of each WSB. Normally, hydraulic system fluid flows at up to 21 gallons per minute; however, the hydraulic system experiences 1- to 2-second flow spikes at up to 63 gallons per minute. If these spikes were to pass through the boiler, pressure drop would increase ninefold and the boiler would limit the flow of the hydraulic system. To prevent this, a relief function is provided by a spring- loaded poppet valve that opens when the hydraulic fluid pressure drop exceeds 49 psi and is capable of flowing 43 gallons per minute at a differential pressure of 50 psi across the boiler. A temperature controller bypass valve allows the hydraulic fluid to bypass the boiler when the fluid temperature decreases to 190° F. At 210° F, the controller commands the bypass valve to direct the fluid through the boiler. When the hydraulic fluid cools to 190° F, the controller again commands the valve to route the fluid around the boiler. Bypass valve (BYP VLV) status is available on the following displays: SM SYS SUMM 2 (PASS AND BFS) and PASS DISP 86 APU/HYD.

Heaters

Each water boiler, water tank, and steam vent is equipped with electrical heaters to prevent freeze-up in orbit. The water tank and boiler electrical heaters are activated by the corresponding *BOILER CNTLR/HTR 1, 2,* and *3* switches on panel R2. The A or B position of each switch selects the A or B heater system and is automatically controlled by the corresponding A or B controller. The steam vent heaters are also activated by the *BOILER CNTLR/HTR 1, 2* and *3* switches but only if the *BOILER PWR 1, 2* or *3* switch on panel R2 is *ON*. The water tank and boiler heaters are cycled on at 50° F and off at 55° F. The steam vent heaters are not operated continuously in orbit; they are activated approximately two hours before APU startup. The steam vent heaters are cycled on at 150° F and cycled off at 175° F.

Main Hydraulic Pump

The main hydraulic pump for each hydraulic system is a variable displacement type. Each operates at approximately 3,900 rpm when driven by the corresponding APU.

Each main hydraulic pump has an electrically operated depressurization valve. The depressurization valve for each pump is controlled by its corresponding HYD MAIN PUMP PRESS 1, 2, or 3 switch on panel R2. When the switch is positioned to LOW, the depressurization valve is energized to reduce the main hydraulic pump discharge pressure from its nominal range of 2,900 to 3,100 psi output to a nominal range of 500 to 1,000 psi to reduce the APU torque requirements during the start of the APU. "APU

Press Low" is one of the inputs required to get a gray READY TO START talkback.

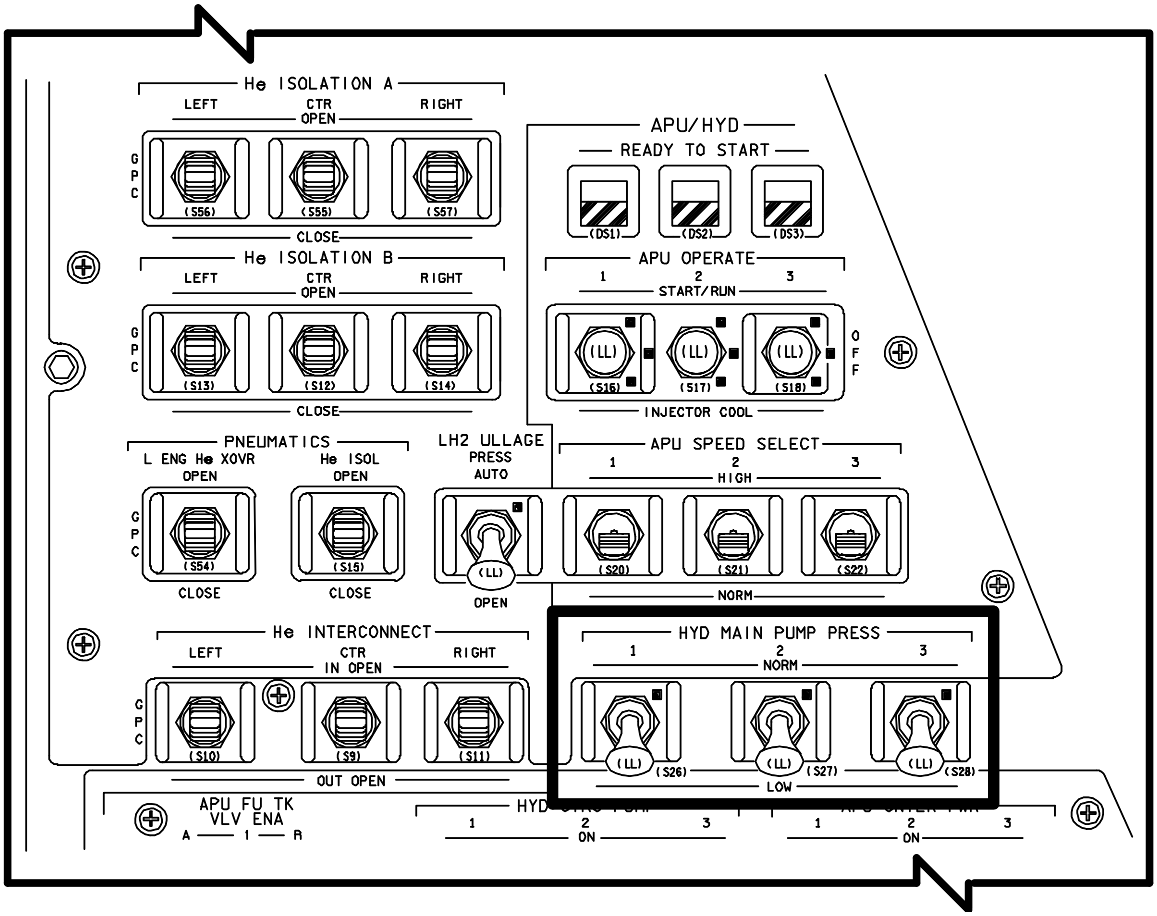
NOTE

> An APU cannot be successfully started with *HYD MAIN PUMP PRESS* positioned to *NORM*.

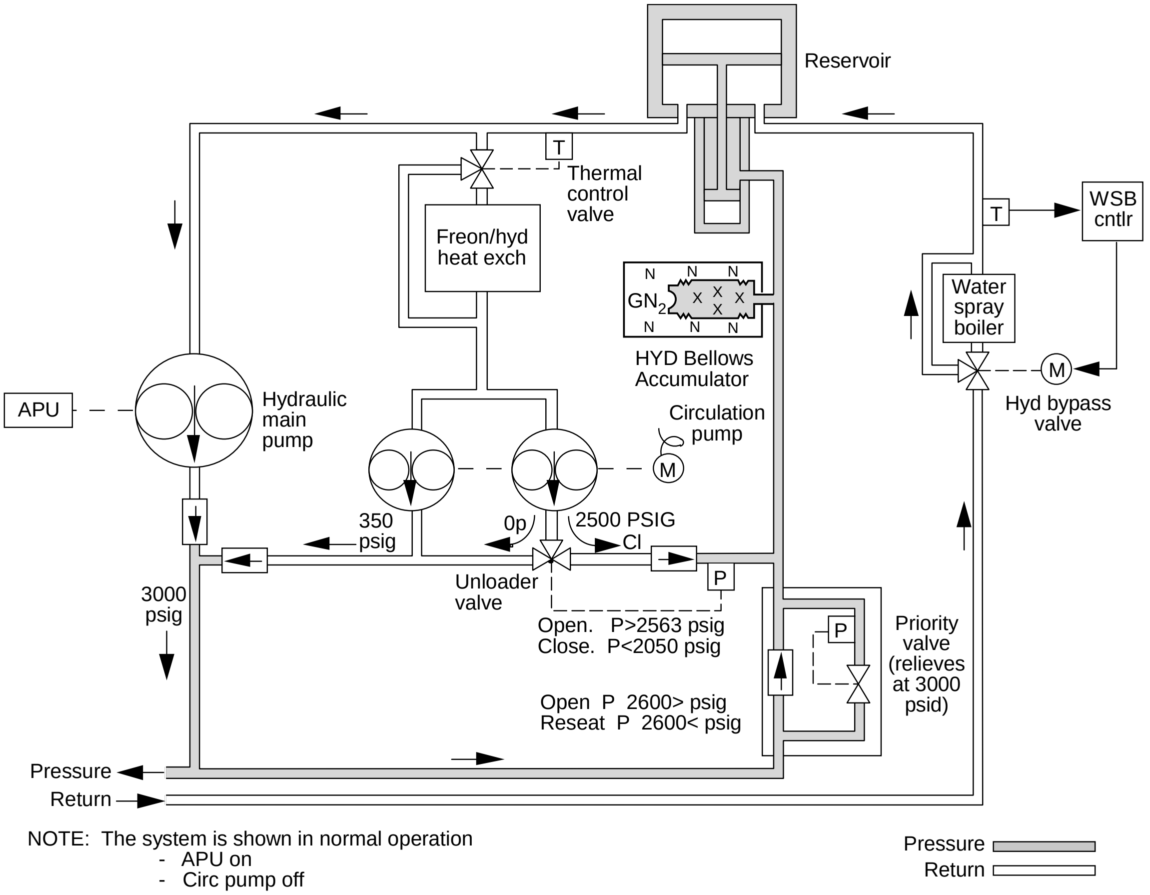
After an APU has been started, the corresponding *HYD MAIN PUMP PRESS* switch is positioned from *LOW* to *NORM*. This de-energizes the respective depressurization valve, allowing that hydraulic pump to increase its outlet pressure from 500 to 1,000 psi to 2,900 to 3,100 psi. Each hydraulic pump is a variable displacement type that provides 0 to 63 gallons per minute at 3,000 psi nominal with the APU at normal speed and up to 69.6 gallons per minute at 3,000 psi nominal with the APU at high speed.

Main pump outlet pressure (HYD PRESS) can be seen by the crew on the BFS SM SYS SUMM 2 or PASS DISP 86 APU/HYD displays. A high-pressure relief valve in the filter module for each hydraulic system also relieves the hydraulic pump supply line pressure into the return line in the event the supply line pressure exceeds 3,850 psid.

A separate pressure sensor (sensor A) in the filter module for each hydraulic system monitors the hydraulic system source pressure and displays the pressure on the HYDRAULIC PRESSURE 1, 2, and 3 meters *on the dedicated MEDS display*. This hydraulic pressure sensor also provides an input to the yellow HYD PRESS caution and warning light on panel F7 if the hydraulic pressure of system 1, 2, or 3 is below 2,400 psi.



HYD MAIN PUMP PRESS 1, 2, 3 Switches on Panel R2



NOTE: The system is shown in normal operation
- APU on
- Circ pump off

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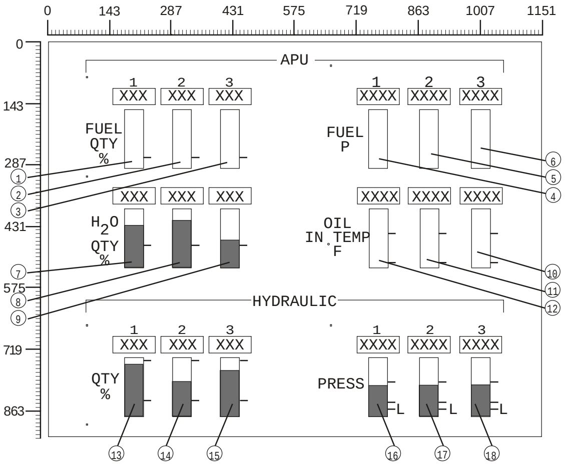
Hydraulic System (Control Section)



① APU 1 FUEL QTY meter
② APU 2 FUEL QTY meter
③ APU 3 FUEL QTY meter
④ APU 1 FUEL PRESS meter
⑤ APU 2 FUEL PRESS meter
⑥ APU 3 FUEL PRESS meter
⑦ APU 1 H2O QTY meter
⑧ APU 2 H2O QTY meter
⑨ APU 3 H2O QTY meter
⑩ APU 1 OIL TEMP meter
⑪ APU 2 OIL TEMP meter
⑫ APU 3 OIL TEMP meter
⑬ HYD 1 QTY meter
⑭ HYD 2 QTY meter
⑮ HYD 3 QTY meter
⑯ HYD 1 PRESS meter
⑰ HYD 2 PRESS meter
⑱ HYD 3 PRESS meter

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HYDRAULIC PRESSURE and QUANTITY Meters on HYD/APU Display

Hydraulic Reservoir

Hydraulic reservoir pressure is maintained using an accumulator bootstrap mechanism. The bootstrap uses a variable area piston assembly to convert high pressure *in* the accumulator to lower pressure in the reservoir (roughly 40:1). This reservoir pressure maintains adequate hydraulic inlet pressure at both the main pump and circulation pump to prevent cavitation during startup and operation. When the main hydraulic pump is in operation, the high-pressure side of the piston and the bootstrap accumulator are pressurized to 3,000 psig from the main pump discharge line. When the main hydraulic pump is shut down, the priority valve closes, and the bootstrap accumulator maintains a pressure of approximately 2,500 psi. The 2,500 psi on the high side results in a main pump inlet (low side) pressure of approximately 62 psia. The minimum inlet pressure to assure a reliable main pump start is 20 psia (which corresponds to a high-pressure side of 800 psi). This prevents the main pump from cavitating (not drawing hydraulic fluid), which could damage the pump.

The quantity in each reservoir is 8 gallons. The hydraulic fluid specification is MIL-H-83282, which is a synthetic hydrocarbon (to reduce fire hazards). The reservoir provides for volumetric expansion and contraction. The quantity of each reservoir is monitored in percent on the HYDRAULIC QUANTITY meters on the dedicated MEDS display. A pressure relief valve in each reservoir protects the reservoir from overpressurization and relieves at 120 psid.

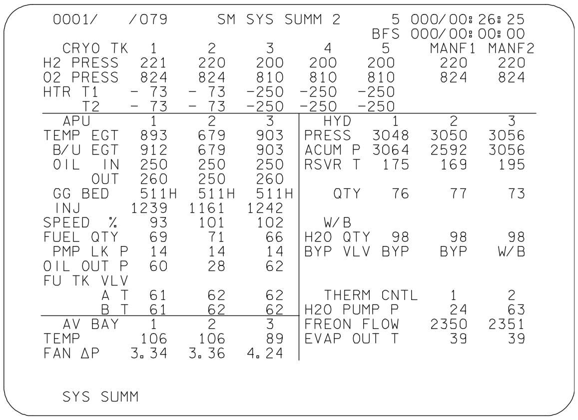
Hydraulic Accumulator

The accumulator is a bellows type, precharged with gaseous nitrogen to 1700 psig at 70° F. The gaseous nitrogen capacity of each accumulator is 115 cubic inches, and the hydraulic volume is 51 cubic inches.

Circulation Pump and Heat Exchanger

The circulation pump is actually two fixed-displacement gear-type pumps in tandem, driven by a single motor. One is a high pressure, low-volume pump (2,500 psig), which is used to maintain accumulator pressure while the hydraulic system is inactive in orbit. The other is a low pressure, high-volume pump (350 psig), which is used to circulate hydraulic fluid through the orbiter hydraulic lines while the hydraulic system is inactive in orbit in order to warm up cold spots. The hydraulic fluid is circulated through a Freon/hydraulic fluid heat exchanger to pick up heat from the orbiter Freon coolant loops. A temperature-controlled bypass valve directs the hydraulic fluid through the heat exchanger if the temperature at the heat exchanger inlet is less than 105° F. The bypass valve bypasses the fluid around the heat exchanger if the temperature is greater than 115° F.

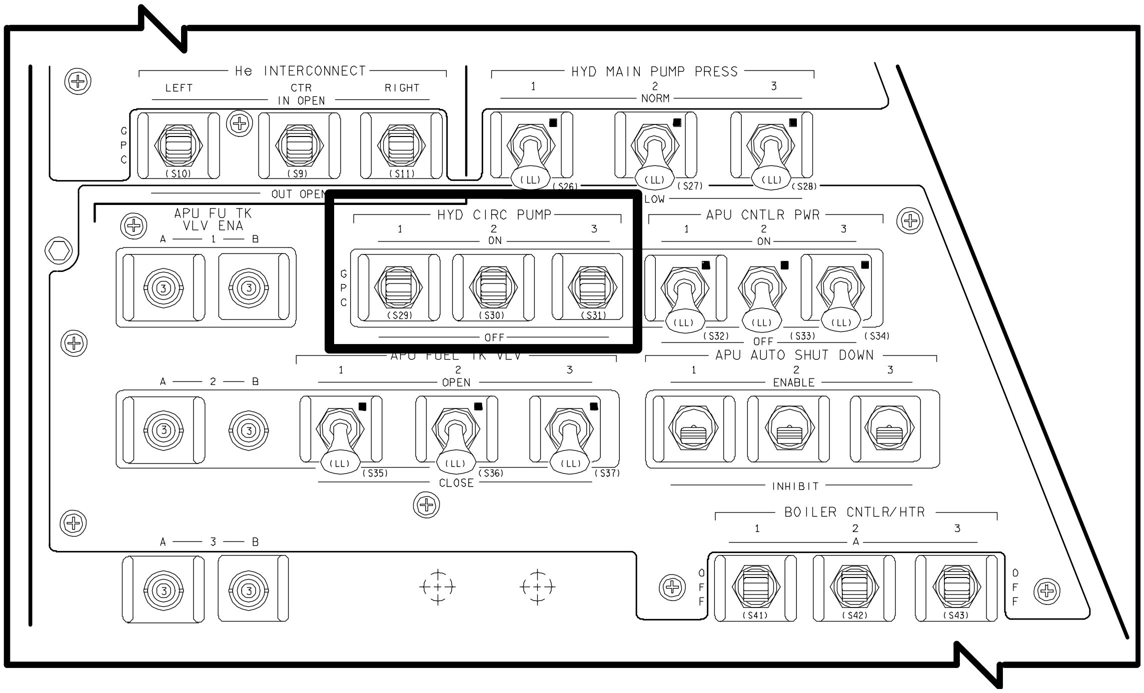
An unloader valve at the circulation pump outlet directs the high pressure output from the circulation pump into the accumulator until the accumulator pressure is greater than 2,563 psia, then redirects the high pressure output to combine with the low pressure output to the hydraulic lines.



```
 0001/   /079     SM SYS SUMM 2     5 000/00:26:25
                                  BFS 000/00:00:00
  CRYO TK  1     2     3     4     5    MANF1 MANF2
H2 PRESS  221   220   200   200   200    220   220
O2 PRESS  824   824   810   810   810    824   824
HTR T1    - 73  - 73  -250  -250  -250
    T2    - 73  - 73  -250  -250  -250
  APU      1     2     3  |  HYD    1     2     3
TEMP EGT  893   679   903 |PRESS  3048  3050  3056
 B/U EGT  912   679   903 |ACUM P 3064  2592  3056
 OIL   IN 250   250   250 |RSVR T  175   169   195
      OUT 260   250   260 |
 GG BED   511H  511H  511H|   QTY   76    77    73
 INJ     1239  1161  1242 |
SPEED  %   93   101   102 |  W/B
FUEL QTY   69    71    66 |H2O QTY  98    98    98
 PMP LK P  14    14    14 |BYP VLV BYP   BYP   W/B
OIL OUT P  60    28    62 |
FU TK VLV                 |
     A T   61    62    62 |  THERM CNTL   1     2
     B T   61    62    62 |H2O PUMP P    24    63
  AV BAY    1     2     3 |FREON FLOW   2350  2351
TEMP      106   106    89 |EVAP OUT T    39    39
FAN ΔP   3.34  3.36  4.24 |

  SYS SUMM
```

**BFS SM SUMM 2 Display
(Hydraulic System Values)**



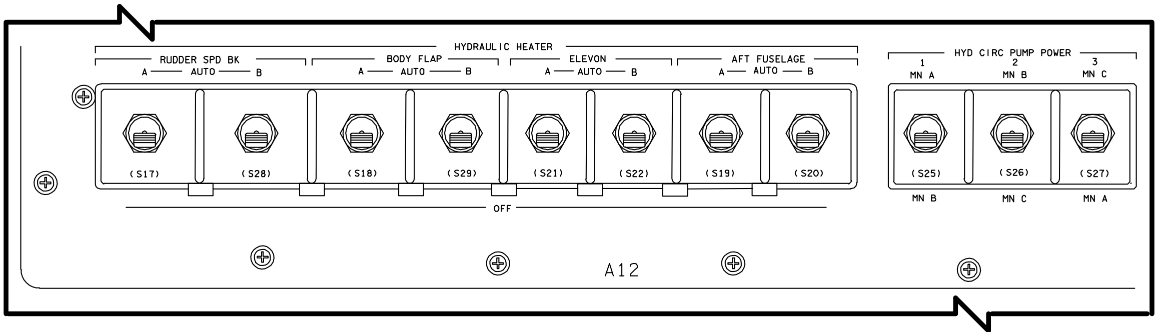
HYD CIRC PUMP Switches on Panel R2

Each circulation pump can be manually turned on or off with the corresponding *HYD CIRC PUMP* switch on panel R2. If the switch is placed in GPC, the pump will be activated and deactivated by the SM *GPC* according to a control software program based on certain hydraulic line temperatures and/or accumulator pressure. This program activates the appropriate circulation pump when any of the control temperatures drop below either 0° F, or -10° F, depending on their locations, and deactivates the circulation pump when all of the control temperatures for that system are greater than 20° F, or after 15 minutes for system 1 and 10 minutes for systems 2 and 3. The activation/deactivation limits for these control temperatures can be changed during the flight by crew or Mission Control.

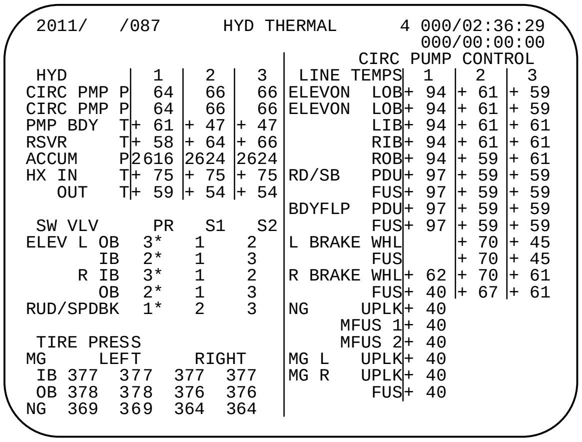
The program also includes a timer to limit the maximum time a circulation pump will run, and a priority system to assure that only one circulation pump is on at a time. *Only one circulation pump is turned on at a time because of the circulation pump's excessive power use.* Each circulation pump uses 2.4 kW of electrical power. This software will also automatically provide for the repressurization of the hydraulic accumulator when the pressure lowers to a value of 1,960 psi. In this contingency, the circulation pump will first receive the highest priority to operate and will be turned ON while other circulation pumps are operating in thermal mode (this means that two pumps can be operating simultaneously). After the pump has been repressurized, the accumulator above 1,960 psi, or a period of 2 minutes (this value can be changed by Mission Control Center uplink) has elapsed, the circulation pump will be commanded to OFF.

The circulation pump is automatically *disconnected* when its corresponding APU Run command is issued by the APU controller. Each circulation pump can be powered by one of two orbiter main electrical buses, selectable by the *HYD CIRC PUMP POWER* switches on panel A12.

The crew can see circulation pump outlet pressure as well as the hydraulic line and component temperatures on the PASS SM HYD THERMAL display, DISP 87.



Hydraulic System Controls on Panel A12



```
 2011/   /087      HYD THERMAL      4 000/02:36:29
                                      000/00:00:00
                                CIRC PUMP CONTROL
 HYD        |  1  |  2  |  3 | LINE TEMPS|  1  |  2  |  3
CIRC PMP P|  64    66    66 |ELEVON  LOB|+ 94 |+ 61 |+ 59
CIRC PMP P|  64    66    66 |ELEVON  LOB|+ 94 |+ 61 |+ 59
PMP BDY  T|+ 61 |+ 47 |+ 47 |        LIB|+ 94 |+ 61 |+ 61
RSVR     T|+ 58 |+ 64 |+ 66 |        RIB|+ 94 |+ 61 |+ 61
ACCUM    P|2616 |2624 |2624 |        ROB|+ 94 |+ 59 |+ 61
HX IN    T|+ 75 |+ 75 |+ 75 |RD/SB   PDU|+ 97 |+ 59 |+ 59
   OUT   T|+ 59 |+ 54 |+ 54 |        FUS|+ 97 |+ 59 |+ 59
                            |BDYFLP  PDU|+ 97 |+ 59 |+ 59
 SW VLV     PR    S1    S2  |        FUS|+ 97 |+ 59 |+ 59
ELEV L OB   3*    1     2   |L BRAKE WHL|     |+ 70 |+ 45
       IB   2*    1     3   |        FUS|     |+ 70 |+ 45
     R IB   3*    1     2   |R BRAKE WHL|+ 62 |+ 70 |+ 61
       OB   2*    1     3   |        FUS|+ 40 |+ 67 |+ 61
RUD/SPDBK   1*    2     3   |NG     UPLK|+ 40
                            |     MFUS 1|+ 40
 TIRE PRESS                 |     MFUS 2|+ 40
MG      LEFT      RIGHT     |MG L   UPLK|+ 40
 IB 377   377   377   377   |MG R   UPLK|+ 40
 OB 378   378   376   376   |        FUS|+ 40
NG  369   369   364   364   |
```

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SM HYD THERMAL Display (DISP 87)

The SM APU/HYD display (DISP 86) shows the hydraulic system pressure, reservoir temperature, reservoir quantity (in percent), and hydraulic accumulator pressure.

Hydraulic Heaters

Areas of the hydraulic lines that cannot be warmed by fluid circulation while the system is inactive on-orbit are warmed by heaters. These heaters are automatically controlled by thermostats to maintain the hydraulic line temperatures in a specified range. Each heated area has redundant heaters (A and B), which are controlled by the HYDRAULIC HEATER switches on panel A12.

Operations

The WSB controllers are powered up at launch minus 8 hours, and the boiler water tanks are pressurized in preparation for APU activation. The controllers activate heaters on the water tank, boiler, and steam vent to assure that the water spray boiler is ready to operate for launch.

APU start is delayed as long as possible to save fuel. At T minus 6 minutes 15 seconds, the pilot begins the prestart sequence. The pilot confirms that the WSB is activated, then activates the APU controllers and depressurizes the main hydraulic pump. Depressurizing the main pump reduces the starting torque on the APU. The pilot then opens the fuel tank valves and looks for three APU ready-to-start indications (gray talkbacks). At T minus 5 minutes, the pilot starts the three units by setting the APU OPERATE switches to START/RUN and checks the hydraulic pressure gauges for an indication of approximately 800 psi. Then the pilot pressurizes the main pump and looks for approximately 3,000 psi on the gauges. All three hydraulic main pump pressures must be greater than 2,800 psi by T minus 4 minutes *5 seconds* or the *ground launch sequencer (GLS) will initiate an auto launch hold.*

The APUs operate during the ascent phase and continue to operate through the first OMS burn. At the conclusion of the main engine purge, dump, and stow sequence, the APUs and WSBs are shut down. The same sequence applies for a delayed OMS-1 burn. If an abort once around is declared, the APUs are left running, but the hydraulic pumps are depressurized to reduce fuel consumption. The units are left running to avoid having to restart hot APUs for deorbit and reentry.

Six hours after lift-off, or as soon as they are required, depending on the environment, the gas generator/fuel pump heaters are activated and are in operation for the remainder of the orbital mission. The fuel and water line heaters are activated immediately after APU/HYD SHUTDN in the post OMS-1 timeframe to prevent the lines from freezing as the APUs cool down.

Two hours after lift-off, during the Post Insertion Checklist, the steam vent heaters of the WSBs are turned on for about 1.5 hours to bake out ice from the steam vents. The hydraulic thermal conditioning is enabled by taking the hydraulic circulation pumps to GPC. Further, the HYD CIRC PUMP POWER switch(es) on panel A12 will be configured to distribute electrical loads when appropriate.

While the vehicle is in orbit, the hydraulic circulation pumps are in the GPC mode--automatically activated when hydraulic line temperatures become too low and automatically deactivated when the lines warm up sufficiently.

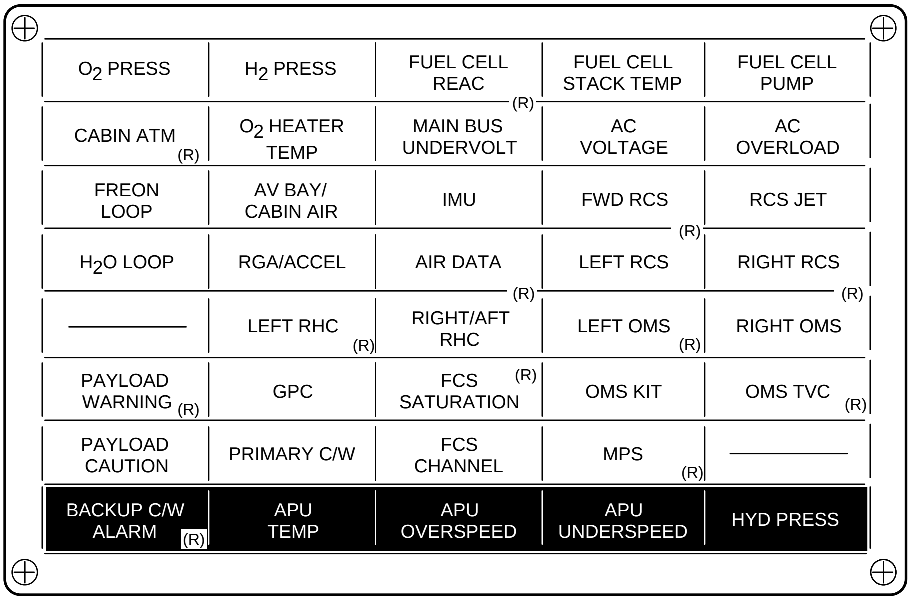
On the day before deorbit, one APU is started to supply hydraulic pressure for flight control system checkout. (Hydraulic pressure is needed to move the orbiter aerosurfaces as part of this checkout.) The associated WSB controller is activated, landing gear and brake isolation valves are confirmed closed, and one APU (selected by the Mission Control Center) is started. The hydraulic main pump is set to normal pressure (approximately 3,000 psi), and aerosurface drive checks are made. After about 5 minutes, the checks are complete, and the APU is shut down. Normally, the unit does not run long enough to require WSB operation.

During deorbit prep (D/O minus 3.5 hours), the APU/HYD systems are configured. The boilers' steam vent heaters are activated to prepare the system for operation during atmospheric entry, and the circulation pumps are turned off. At deorbit minus 2 hours, the brake heaters are activated and the final switch configuration will turn OFF the hydraulic heaters on panel A12. At 45 minutes before deorbit, the WSB water tanks are pressurized, the APU controllers are activated, and the main hydraulic pumps are set to low pressure. The pilot opens the fuel tank valves and looks for three gray APU/HYD READY TO START talkbacks. The pilot then closes the fuel tank valves. This procedure takes place while the crew is in contact with the ground so that flight controllers can observe APU status. Five minutes before the deorbit burn, one APU (selected by Mission Control) is started to ensure that at least one unit will be operating for entry. The hydraulic pump is left in low-pressure operation. The APU operates through the deorbit burn. At 13 minutes before entry interface (400,000-foot altitude), while the orbiter is still in free fall, the other two APUs are started, and all three hydraulic pumps are pressurized to normal. Two main engine hydraulic isolation valves are cycled open and then closed to ensure that the engines are stowed for entry. If required, the aerosurfaces are put through an automatic cycle sequence to make sure warm hydraulic fluid is available in the aerosurface drive units.

After touchdown, a hydraulic load test may be done to test the response of the auxiliary power units and hydraulic pumps under high load (i.e., high flow demand) conditions. This test cycles the orbiter aerosurfaces with one hydraulic system at a time in depressed mode (the remaining two APUs and hydraulic pumps have to drive all the aerosurfaces). This is typically done on the first flight of a new APU. Then the main engine hydraulic isolation valves are opened again, and the engines are set to the transport position. At this point, the hydraulic systems are no longer needed; the APUs and WSBs are shut down.

APU/HYD Caution and Warning Summary

- The yellow *APU TEMP* caution and warning light on panel F7 is illuminated if the APU 1, 2, or 3 lube oil temperature is above 290° F.
- The yellow *APU OVERSPEED* light is illuminated if APU 1, 2, or 3 turbine speed is more than 92,880 rpm (129%). If the *APU AUTO SHUT DOWN* switch on panel R2 is in ENABLE, an automatic shutdown of that APU will occur.
- The yellow *APU UNDERSPEED* light is illuminated if APU 1, 2, or 3 turbine speed is less than 57,600 rpm (80%). If the *APU AUTO SHUT DOWN* switch for that APU is in ENABLE, an automatic shutdown will occur.
- Placing the *APU AUTO SHUT DOWN* switch in INHIBIT only inhibits the automatic shutdown of that APU if its turbine speed is less than 80% or more than 129%. The *APU UNDERSPEED* or *APU OVERSPEED* light will always illuminate, and a tone will be generated.
- The yellow *HYD PRESS* light illuminates when hydraulic system 1, 2, or 3 drops below 2,400 psi for any reason.
- The blue *SM ALERT* illuminates, and the C/W tone is sounded if turbine speed falls below 80% or rises above 129%.
- The red *BACKUP C/W ALARM* illuminates if hydraulic pressure of system 1, 2, or 3 drops below 2,400 psi.



O_2 PRESS	H_2 PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O_2 HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H_2O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS	RIGHT RCS (R)
——————	LEFT RHC (R)	RIGHT/AFT RHC	LEFT OMS (R)	RIGHT OMS
PAYLOAD WARNING (R)	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	——————
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

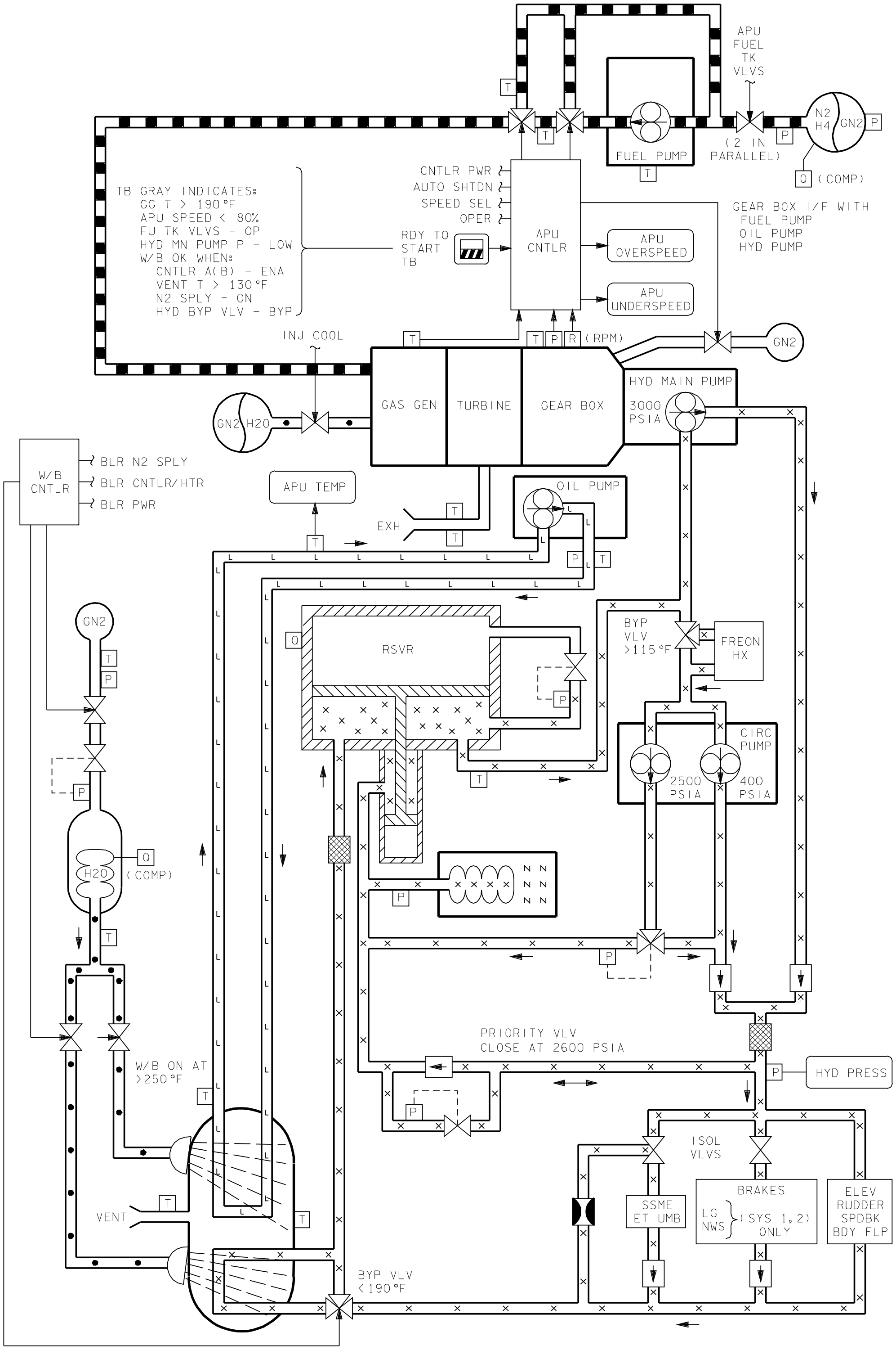
APU/HYD Caution and Warning Lights on Panel F7

APU/HYD Summary Data

- The APU is a hydrazine-fueled, turbine-driven power unit that generates mechanical shaft power to drive a hydraulic pump that produces pressure for the orbiter's hydraulic system.
- The three orbiter hydraulic systems provide pressure to position hydraulic actuators for: gimbaling SSMEs, actuating SSME control valves, moving orbiter aerosurfaces, retracting ET disconnect umbilicals, deploying landing gear, and providing brake power, anti-skid, and nose wheel steering.
- The APUs are located in the aft fuselage of the orbiter.
- Each APU/HYD system has an independent water spray boiler for APU lube oil and hydraulic fluid cooling. Water is used after APU shutdown for injector cooling if a hot restart is required. The APUs share a central supply tank for injector cooling.
- The three APUs are started 5 minutes before lift-off. They continue to operate throughout the launch phase, and are shut down after the main engine propellant dump and stow are completed (post OMS-1). The APUs are restarted for entry: one APU prior to the deorbit burn, and the other two prior to entry interface.
- Each APU fuel tank load is approximately 325 pounds of hydrazine.
- APU/HYD controls are located on panel R2; heater controls are on panel A12.
- Displays containing APU/HYD information include the PASS and BFS SM SYS SUMM 2 display (DISP 79), APU/HYD display (DISP 86), HYD THERMAL (DISP 87), and APU/ENVIRON THERM (DISP 88).
- APU/HYD parameters can be monitored on the APU/HYD MEDS Display if selected.
- APUs can be manually shut down and restarted after completion of a full injector water cooling cycle (3.5 minutes), or after approximately 180 minutes of passive cooling on orbit.

APU/HYD Rules of Thumb

- APU fuel usage rates vary with loading, but average 1% per minute (3 to 3.5 lb/minute). Usage rates are reduced by about half if the hydraulic main pump is taken to low pressure (HYD MAIN PUMP PRESS switch on panel R2 set to LOW), as is done during the abort once around deorbit coast period.
- The APU injector cooling tank shared by all three APUs contains enough water for 21 minutes of continuous flow. This is enough for six complete 3.5-minute hot restart injector cooling cycles.
- If all water spray boiler cooling is lost to the lube oil after an APU reaches full operating temperatures, only 2 to 3 minutes of operating time are available before bearing seizure occurs.



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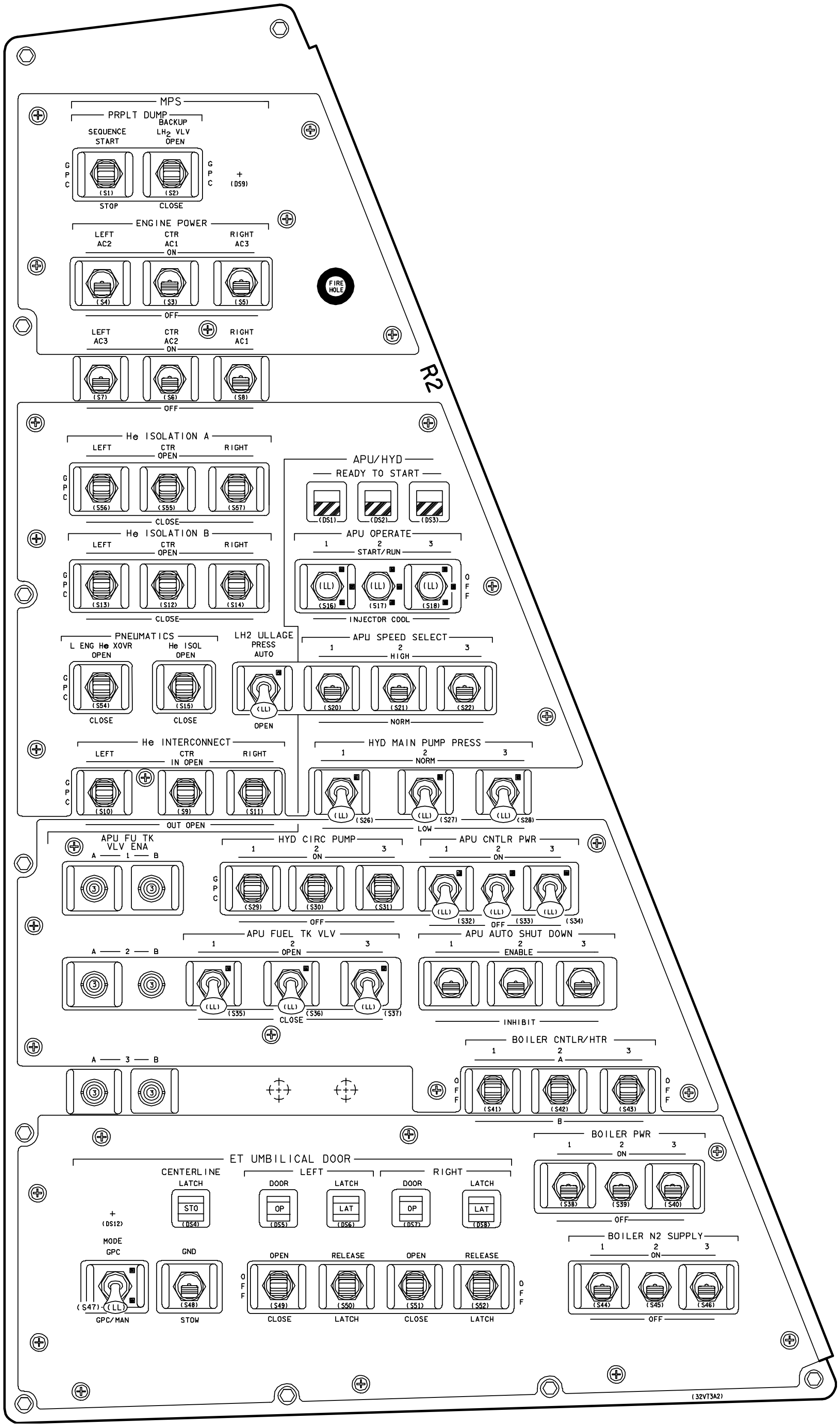
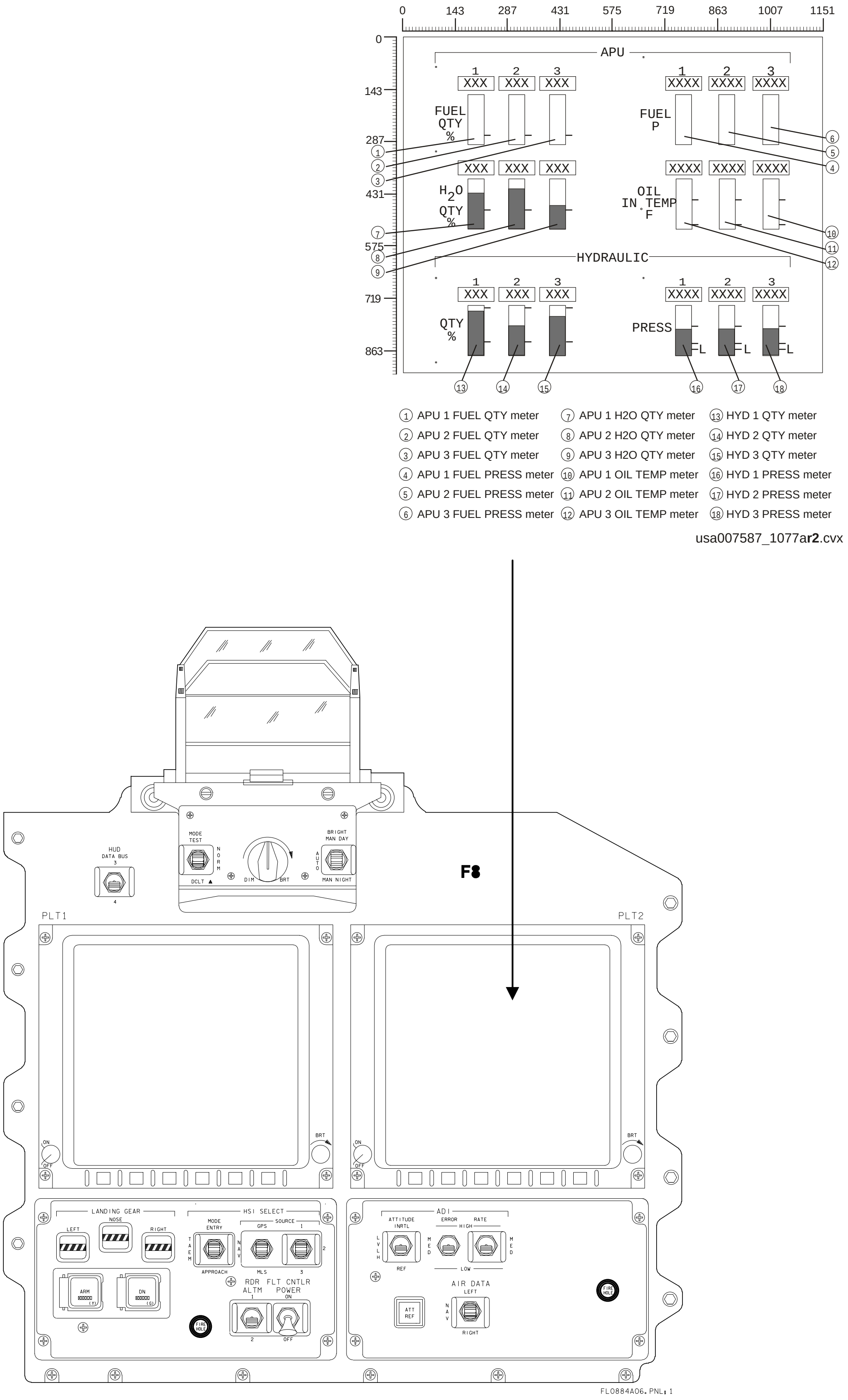
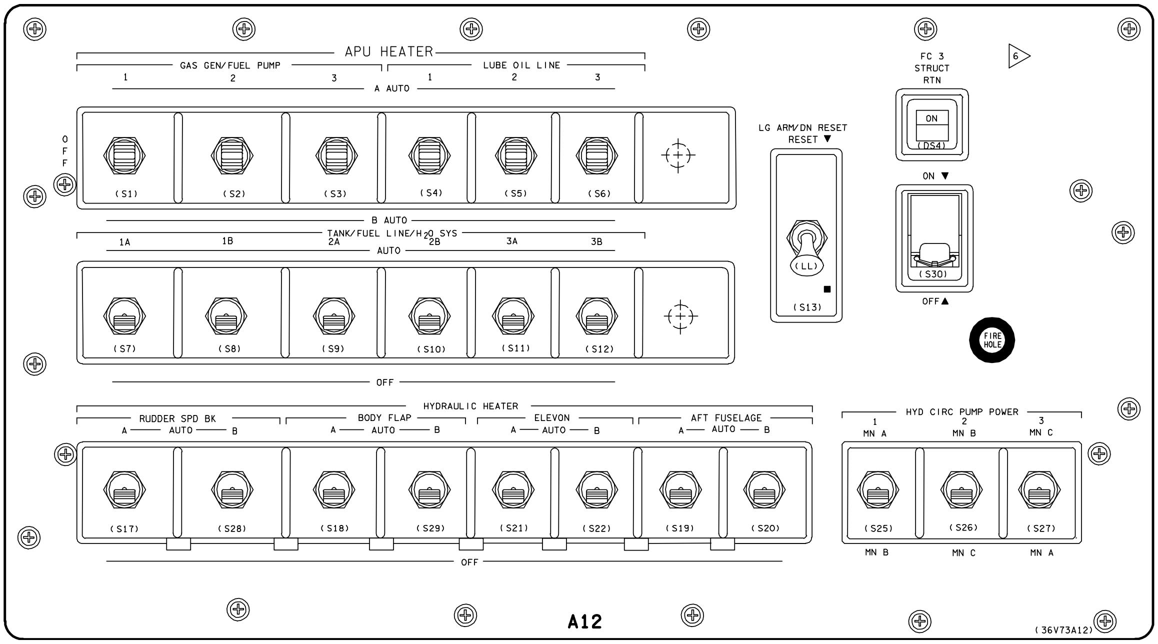
APU/Hydraulic Overview


MPS
PRPLT DUMP
SEQUENCE START
BACKUP LH2 VLV OPEN
GPC
(S1)
(S2)
STOP
CLOSE
GPC
+
(DS9)
ENGINE POWER
LEFT AC2
CTR AC1
RIGHT AC3
ON
(S4)
(S3)
(S5)
OFF
FIRE HOLE
LEFT AC3
CTR AC2
RIGHT AC1
ON
(S7)
(S6)
(S8)
OFF
R2
He ISOLATION A
LEFT
CTR
OPEN
RIGHT
GPC
(S56)
(S55)
(S57)
CLOSE
He ISOLATION B
LEFT
CTR
OPEN
RIGHT
GPC
(S13)
(S12)
(S14)
CLOSE
APU/HYD
READY TO START
(DS1)
(DS2)
(DS3)
APU OPERATE
1
2
3
START/RUN
(LL)
(S16)
(S17)
(S18)
OFF
INJECTOR COOL
PNEUMATICS
L ENG He XOVR OPEN
He ISOL OPEN
GPC
(S54)
(S15)
CLOSE
CLOSE
LH2 ULLAGE PRESS AUTO
(LL)
OPEN
APU SPEED SELECT
1
2
3
HIGH
(S20)
(S21)
(S22)
NORM
He INTERCONNECT
LEFT
CTR
IN OPEN
RIGHT
GPC
(S10)
(S9)
(S11)
OUT OPEN
HYD MAIN PUMP PRESS
1
2
3
NORM
(LL)
(S26)
(S27)
(S28)
LOW
APU FU TK VLV ENA
A
1
B
HYD CIRC PUMP
1
2
3
ON
GPC
(S29)
(S30)
(S31)
OFF
APU CNTLR PWR
1
2
3
ON
(LL)
(S32)
(S33)
(S34)
OFF
APU FUEL TK VLV
1
2
3
OPEN
A
2
B
(LL)
(S35)
(S36)
(S37)
CLOSE
APU AUTO SHUT DOWN
1
2
3
ENABLE
INHIBIT
BOILER CNTLR/HTR
1
2
3
A
A
3
B
OFF
(S41)
(S42)
(S43)
OFF
B
BOILER PWR
1
2
3
ON
(S38)
(S39)
(S40)
OFF
ET UMBILICAL DOOR
CENTERLINE
LATCH
STO
(DS4)
LEFT
DOOR
OP
(DS5)
LATCH
LAT
(DS6)
RIGHT
DOOR
OP
(DS7)
LATCH
LAT
(DS8)
+
(DS12)
MODE
GPC
(S47)
(LL)
GPC/MAN
GND
(S48)
STOW
OPEN
RELEASE
OPEN
RELEASE
OFF
(S49)
(S50)
(S51)
(S52)
OFF
CLOSE
LATCH
CLOSE
LATCH
BOILER N2 SUPPLY
1
2
3
ON
(S44)
(S45)
(S46)
OFF
(32VT3A2)

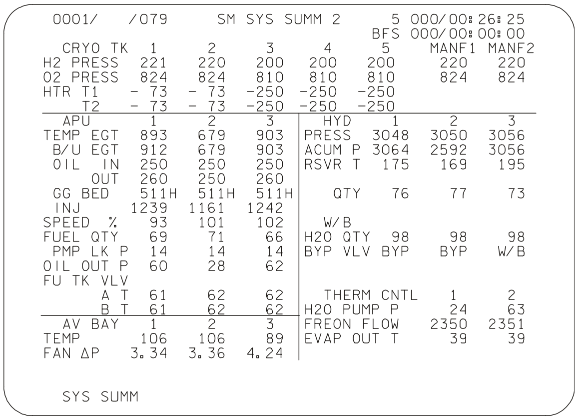
Panel R2


APU
1 2 3
XXX XXX XXX
XXXX XXXX XXXX
FUEL QTY %
FUEL P
H2O QTY %
OIL IN TEMP °F
HYDRAULIC
QTY %
PRESS
L
① APU 1 FUEL QTY meter
② APU 2 FUEL QTY meter
③ APU 3 FUEL QTY meter
④ APU 1 FUEL PRESS meter
⑤ APU 2 FUEL PRESS meter
⑥ APU 3 FUEL PRESS meter
⑦ APU 1 H2O QTY meter
⑧ APU 2 H2O QTY meter
⑨ APU 3 H2O QTY meter
⑩ APU 1 OIL TEMP meter
⑪ APU 2 OIL TEMP meter
⑫ APU 3 OIL TEMP meter
⑬ HYD 1 QTY meter
⑭ HYD 2 QTY meter
⑮ HYD 3 QTY meter
⑯ HYD 1 PRESS meter
⑰ HYD 2 PRESS meter
⑱ HYD 3 PRESS meter
usa007587_1077ar2.cvx
F8
PLT1
PLT2
HUD DATA BUS
MODE TEST
BRIGHT MAN DAY
DCLT
DIM
BRT
MAN NIGHT
LANDING GEAR
LEFT NOSE RIGHT
ARM
DN
HSI SELECT
MODE ENTRY
SOURCE
GPS
MLS
APPROACH
RDR ALTM
FLT CNTLR POWER
ON
OFF
ADI
ATTITUDE INRTL
ERROR
RATE
HIGH
LOW
MED
REF
AIR DATA
LEFT
RIGHT
ATT REF
FL0884A06.PNL;1

Panel F8


APU HEATER
GAS GEN/FUEL PUMP
1
2
3
LUBE OIL LINE
1
2
3
A AUTO
OFF
(S1)
(S2)
(S3)
(S4)
(S5)
(S6)
B AUTO
TANK/FUEL LINE/H2O SYS
1A
1B
2A
2B
3A
3B
AUTO
(S7)
(S8)
(S9)
(S10)
(S11)
(S12)
OFF
LG ARM/DN RESET
RESET ▼
(LL)
(S13)
FC 3
STRUCT
RTN
ON
(DS4)
ON ▼
(S30)
OFF ▲
FIRE HOLE
6
HYDRAULIC HEATER
RUDDER SPD BK
A AUTO B
BODY FLAP
A AUTO B
ELEVON
A AUTO B
AFT FUSELAGE
A AUTO B
(S17)
(S28)
(S18)
(S29)
(S21)
(S22)
(S19)
(S20)
OFF
HYD CIRC PUMP POWER
1
MN A
2
MN B
3
MN C
(S25)
(S26)
(S27)
MN B
MN C
MN A
A12
(36V73A12)

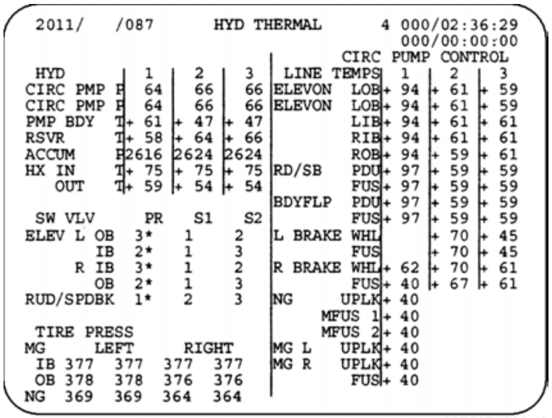
Panel A12



```
 0001/   /079      SM SYS SUMM 2      5 000/00:26:25
                                    BFS 000/00:00:00
  CRYO TK   1      2      3      4      5    MANF1 MANF2
H2 PRESS   221    220    200    200    200    220   220
O2 PRESS   824    824    810    810    810    824   824
HTR T1    - 73   - 73   -250   -250   -250
    T2    - 73   - 73   -250   -250   -250
  APU       1      2      3  |  HYD     1      2      3
TEMP EGT   893    679    903 |PRESS   3048   3050   3056
 B/U EGT   912    679    903 |ACUM P  3064   2592   3056
 OIL  IN   250    250    250 |RSVR T   175    169    195
     OUT   260    250    260 |
 GG BED    511H   511H   511H|   QTY    76     77     73
 INJ      1239   1161   1242 |
SPEED  %    93    101    102 |  W/B
FUEL QTY    69     71     66 |H2O QTY   98     98     98
 PMP LK P   14     14     14 |BYP VLV  BYP    BYP    W/B
OIL OUT P   60     28     62 |
FU TK VLV                    |
      A T   61     62     62 |  THERM CNTL      1      2
      B T   61     62     62 |H2O PUMP P       24     63
  AV BAY    1      2      3  |FREON FLOW     2350   2351
TEMP       106    106     89 |EVAP OUT T       39     39
FAN ΔP    3.34   3.36   4.24 |

  SYS SUMM
```

DISP 79 SM SYS SUMM 2 Display
(PASS and BFS)



```
 2011/   /087      HYD THERMAL      4 000/02:36:29
                                      000/00:00:00
                              |     CIRC PUMP CONTROL
 HYD        |  1  |  2  |  3  | LINE TEMPS|  1  |  2  |  3
CIRC PMP P |  64  |  66 |  66 |ELEVON  LOB|+ 94 |+ 61 |+ 59
CIRC PMP P |  64  |  66 |  66 |ELEVON  LOB|+ 94 |+ 61 |+ 59
PMP BDY  T|+ 61 |+ 47 |+ 47   |        LIB|+ 94 |+ 61 |+ 61
RSVR     T|+ 58 |+ 64 |+ 66   |        RIB|+ 94 |+ 61 |+ 61
ACCUM    P|2616 |2624 |2624   |        ROB|+ 94 |+ 59 |+ 61
HX IN    T|+ 75 |+ 75 |+ 75   |RD/SB   PDU|+ 97 |+ 59 |+ 59
   OUT   T|+ 59 |+ 54 |+ 54   |        FUS|+ 97 |+ 59 |+ 59
                              |BDYFLP  PDU|+ 97 |+ 59 |+ 59
 SW VLV      PR    S1    S2   |        FUS|+ 97 |+ 59 |+ 59
ELEV L OB    3*    1     2    |L BRAKE WHL|     |+ 70 |+ 45
       IB    2*    1     3    |        FUS|     |+ 70 |+ 45
     R IB    3*    1     2    |R BRAKE WHL|+ 62 |+ 70 |+ 61
       OB    2*    1     3    |        FUS|+ 40 |+ 67 |+ 61
RUD/SPDBK    1*    2     3    |NG     UPLK|+ 40
                              |     MFUS 1|+ 40
 TIRE PRESS                   |     MFUS 2|+ 40
MG      LEFT       RIGHT      |MG L   UPLK|+ 40
 IB 377   377   377   377     |MG R   UPLK|+ 40
 OB 378   378   376   376     |        FUS|+ 40
NG  369   369   364   364     |
```

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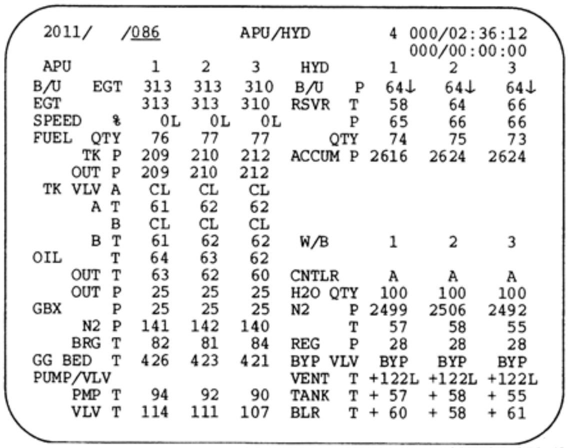
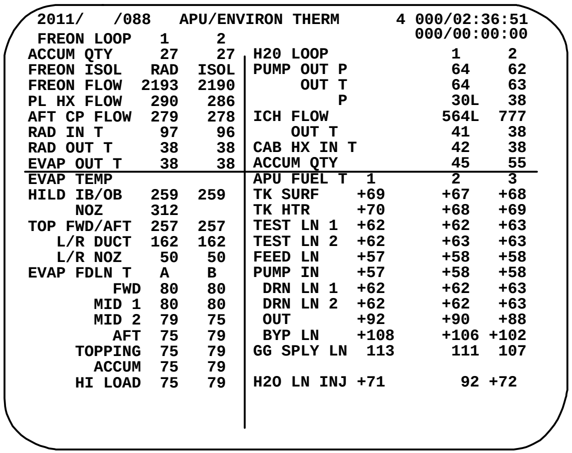
SM HYD THERMAL Display
(PASS DISP 87)



```
 2011/   /086          APU/HYD          4 000/02:36:12
                                          000/00:00:00
 APU          1     2     3    HYD      1      2      3
B/U    EGT   313   313   310   B/U   P  64↓    64↓    64↓
EGT          313   313   310   RSVR  T  58     64     66
SPEED   %     0L    0L    0L         P  65     66     66
FUEL  QTY    76    77    77        QTY  74     75     73
        TK P 209   210   212   ACCUM P 2616   2624   2624
      OUT P  209   210   212
  TK VLV A    CL    CL    CL
         A T  61    62    62
           B  CL    CL    CL
         B T  61    62    62    W/B     1      2      3
OIL        T  64    63    62
      OUT  T  63    62    60   CNTLR    A      A      A
      OUT  P  25    25    25   H2O QTY 100    100    100
GBX        P  25    25    25   N2    P 2499   2506   2492
       N2  P 141   142   140         T  57     58     55
      BRG  T  82    81    84   REG   P  28     28     28
GG BED     T 426   423   421   BYP VLV BYP    BYP    BYP
PUMP/VLV                       VENT  T +122L  +122L  +122L
      PMP  T  94    92    90   TANK  T + 57   + 58   + 55
      VLV  T 114   111   107   BLR   T + 60   + 58   + 61
```

usa007587_059.tif

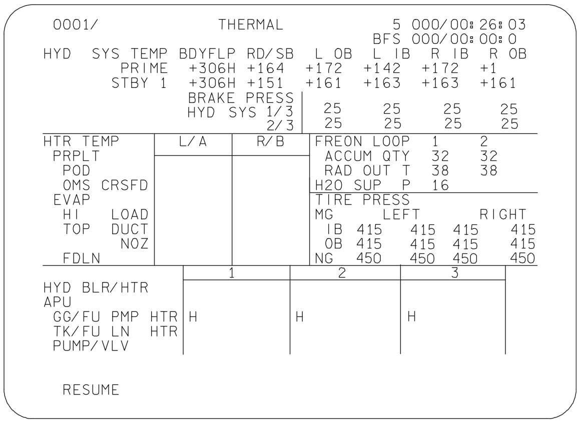
SM APU/HYD Display (PASS DISP 86)



```
 2011/   /088   APU/ENVIRON THERM      4 000/02:36:51
 FREON LOOP   1     2                    000/00:00:00
ACCUM QTY     27    27 |H20 LOOP              1     2
FREON ISOL   RAD  ISOL |PUMP OUT P           64    62
FREON FLOW  2193  2190 |     OUT T           64    63
PL HX FLOW   290   286 |         P           30L   38
AFT CP FLOW  279   278 |ICH FLOW            564L  777
RAD IN T      97    96 |    OUT T            41    38
RAD OUT T     38    38 |CAB HX IN T          42    38
EVAP OUT T    38    38 |ACCUM QTY            45    55
EVAP TEMP              |APU FUEL T  1        2     3
HILD IB/OB   259   259 |TK SURF    +69      +67   +68
     NOZ     312       |TK HTR     +70      +68   +69
TOP FWD/AFT  257   257 |TEST LN 1  +62      +62   +63
   L/R DUCT  162   162 |TEST LN 2  +62      +63   +63
   L/R NOZ    50    50 |FEED LN    +57      +58   +58
EVAP FDLN T   A     B  |PUMP IN    +57      +58   +58
         FWD  80    80 | DRN LN 1  +62      +62   +63
       MID 1  80    80 | DRN LN 2  +62      +62   +63
       MID 2  79    75 | OUT       +92      +90   +88
         AFT  75    79 | BYP LN    +108     +106 +102
     TOPPING  75    79 |GG SPLY LN  113      111  107
       ACCUM  75    79 |
     HI LOAD  75    79 |H2O LN INJ +71        92 +72
                       |
```

sfoc_scom_s2.1_078.cnv

APU/ENVIRON THERM (PASS DISP 88)



```
 0001/            THERMAL          5 000/00:26:03
                                 BFS 000/00:00:0
HYD  SYS TEMP BDYFLP RD/SB  L OB  L IB  R IB  R OB
         PRIME  +306H +164  +172  +142  +172  +1
        STBY 1  +306H +151  +161  +163  +163  +161
                BRAKE PRESS |
                HYD SYS 1/3 |  25    25    25    25
                        2/3 |  25    25    25    25
HTR TEMP     |  L/A  |  R/B  |FREON LOOP  1    2
 PRPLT       |       |       | ACCUM QTY  32   32
  POD        |       |       | RAD OUT T  38   38
  OMS CRSFD  |       |       |H2O SUP  P  16
 EVAP        |       |       |TIRE PRESS
  HI   LOAD  |       |       |MG     LEFT       RIGHT
  TOP  DUCT  |       |       | IB  415   415  415   415
        NOZ  |       |       | OB  415   415  415   415
  FDLN       |       |       |NG   450   450  450   450
               |     1     |      2     |     3     |
HYD BLR/HTR    |           |            |           |
APU            |           |            |           |
 GG/FU PMP HTR |H          |H           |H          |
 TK/FU LN  HTR |           |            |           |
 PUMP/VLV      |           |            |           |

  RESUME
```

BFS SM 0 THERMAL

2.2 CAUTION AND WARNING SYSTEM (C/W)

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Suppression 2.2-5
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C/W Rules of Thumb 2.2-19
F7 Light Summary 2.2-20
Fault Message Table 2.2-23

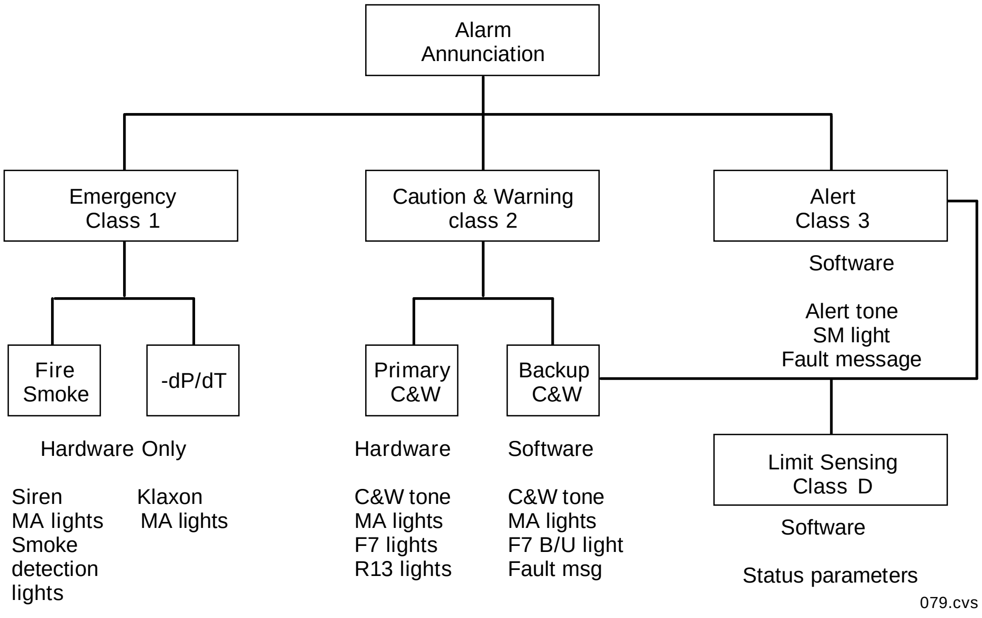
Description

The Caution and Warning System warns the crew of conditions that may create a hazard to orbiter operation and/or crew. Under certain circumstances, the system also alerts the crew to situations that require time-critical (under 5 minutes) procedures to correct them. The system uses data such as temperature, pressure, flow rates, and switch positions to determine whether there is an alarm situation. The system consists of software and electronics that provide the crew with visual and aural cues when a system exceeds predefined operating limits. Visual cues consist of four red MASTER ALARM lights, a 40-light array on panel F7, a 120-light array on panel R13U, GPC annunciated fault messages, and a blue SM *ALERT* light. The aural cue is sent to the communications system for distribution to flight crew headsets or speaker boxes.

The crew interfaces with the C/W system through panel R13U, panel C3, DPS displays, panel F7, panel L1, and the four red MASTER ALARM pushbutton indicators on panels F2, F4, A7, and MO52J.

The C/W system interfaces with the auxiliary power units, data processing system, environmental control and life support system, electrical power system, flight control system, guidance and navigation, hydraulics, main propulsion system, reaction control system, orbital maneuvering system, and payloads.

Inputs enter the software C/W logic circuitry from the onboard computers through multiplexers/demultiplexers (MDMs) to activate alarm tones and the BACKUP C/W ALARM. Some of these are used to turn on the BACKUP C/W ALARM light on panel F7 while crew input resets the MASTER ALARM lights and tones.



Caution and Warning Diagram

Alarms

Four alarm classes constitute the C/W system.

Class 1 - Emergency

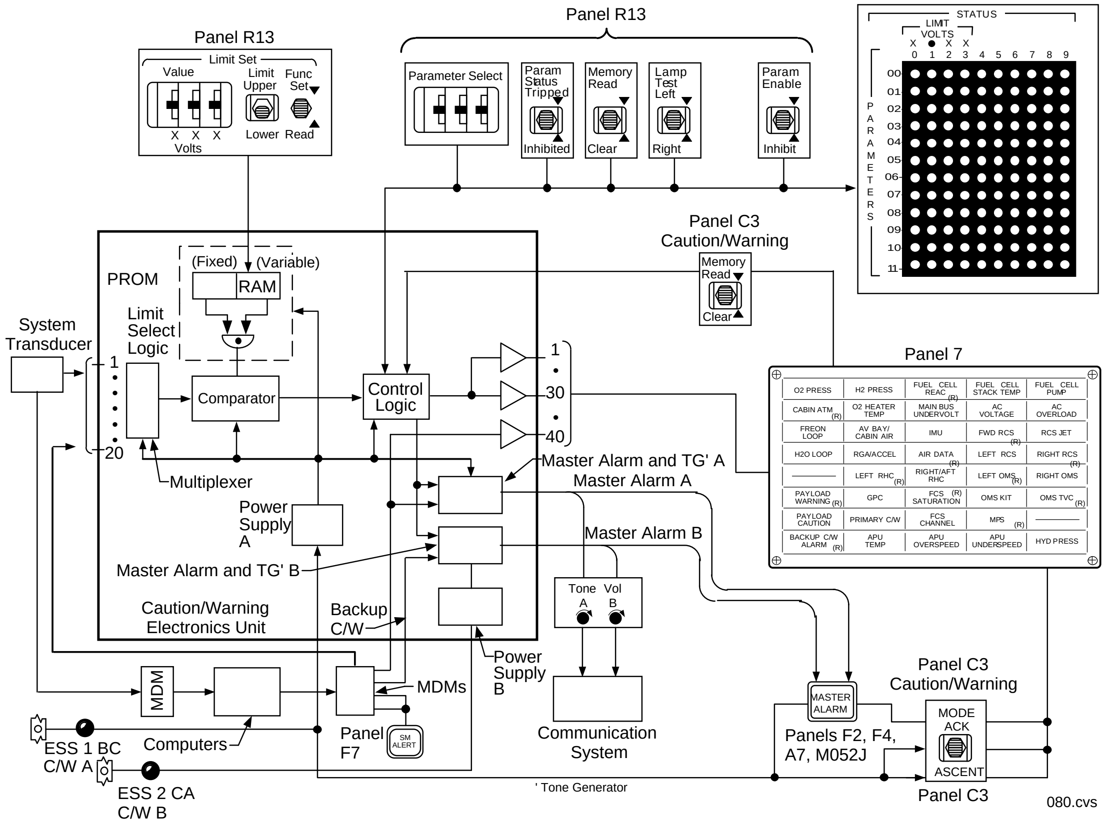
There are two alarms in this class: (1) smoke detection/fire suppression and (2) rapid cabin depressurization. (These systems are discussed in more detail later in this section.) Class 1 is a hardware system only; its input is not processed by any MDMs or software. The system uses hardware, such as hard-wired sensors, to monitor parameters and to issue alarms. Because of the nature of the class 1 alarms, they always receive the highest priority for resolution.

The emergency (class 1) aural alarms consist of a siren (activated by the smoke detection system) and a klaxon (activated by the delta pressure/delta time sensor that recognizes a rapid loss of cabin pressure), and they are annunciated by hardware. The siren tone is similar to emergency sirens on American police cars or other civilian emergency vehicles. The klaxon is a short repeating tone that is unique and readily distinguished from other C/W tones.

The emergency alarm visual cues consist of illumination of the four MASTER ALARM pushbutton indicators on panels F2, F4, A7, and MO52J. The smoke detection system also illuminates SMOKE DETECTION lights on panel L1 and displays information on the SM SYS SUMM 1 display (SMOKE). Similarly, cabin pressure information can be seen on the SM SYS SUMM 1 display (CABIN).

Class 2 - C/W

This class also consists of two subclasses: primary C/W, which is a hardware system, and backup (B/U) C/W, which is a software system.



Caution and Warning System Overview

The primary C/W system has the capacity to monitor 120 inputs, which are received from transducers through either signal conditioners or flight forward MDMs. Baselined limit values are stored in the C/W electronics unit located in avionics bay 3. These values can be changed by the crew through switches on panel R13U. However, if power is lost and subsequently recovered, the limits will return to their original values. The majority of the original stored values are identical to the backup C/W (software) values. Thirty-nine lights on the panel F7 annunciator matrix are dedicated to the primary C/W; the exception is the BACKUP C/W ALARM.

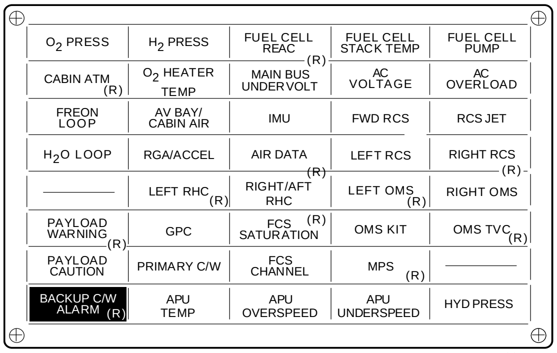
When a primary C/W alarm is issued, the appropriate lamp on the panel F7 annunciator matrix is illuminated, all four MASTER ALARM indicators are illuminated, and the C/W tone sounds. No GPC fault message is generated by the primary C/W.

The C/W system receives power from two sources. This power is supplied to the C/W electronics unit by power supplies that are internal to the electronics unit and are referred to as power supply A and power supply B. Power supply A receives power from the C/W A circuit breaker powered by ESS 1BC on panel 013, and power supply B from C/W B circuit breaker powered by ESS 2CA on panel 013.

A loss of power supply A will cause all panel F7 lights, except BACKUP C/W ALARM, to illuminate. It will also cause a loss of panel R13U status lights and function, smoke annunciation via tone generator A, the CAUTION/WARNING MEMORY READ switch, lower bulbs of the MASTER ALARM light (except for lamp test), primary C/W limit sensing, and tones to the middeck.

A loss of power supply B causes the BACKUP C/W ALARM light to come on in addition to the primary C/W light, a loss of smoke annunciation via tone generator B, upper bulbs of the MASTER ALARM lights (except during a lamp test), and sleep station headset tones.

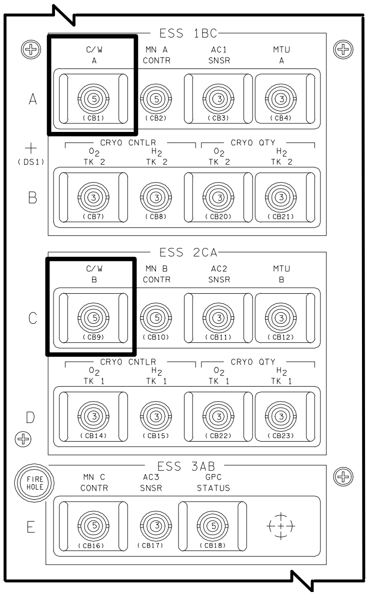
The backup C/W (class 2) system is part of the systems management fault detection and annunciation (FDA), GNC, and backup flight system software programs. Only the C/W alarms that are produced by FDA (software that monitors parameters and initiates alarms) have limits that can be changed and displayed in engineering units accessed through the SM TABLE MAINTENANCE special function display (SPEC 60). The remaining backup C/W alarms that are produced by the guidance and navigation program are accessed through general-purpose computer read/write procedures. A backup C/W out-of-tolerance condition will trigger illumination of the four MASTER ALARM lights, illuminate the red BACKUP C/W ALARM light on panel F7, and display a message on the fault message line and fault summary page.



O_2 PRESS	H_2 PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O_2 HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS	RCS JET
H_2O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS	RIGHT RCS (R)
————	LEFT RHC (R)	RIGHT/AFT RHC	LEFT OMS (R)	RIGHT OMS
PAYLOAD WARNING (R)	GPC	FCS SATURATION (R)	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	————
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

Caution and Warning Annunciator Matrix on Panel F7

The 39 lights shown are dedicated to the primary C/W System. The BACKUP C/W ALARM light is dedicated to the entire backup C/W system. (R) signifies a red warning light.



C/W Circuit Breaker on Panel 013

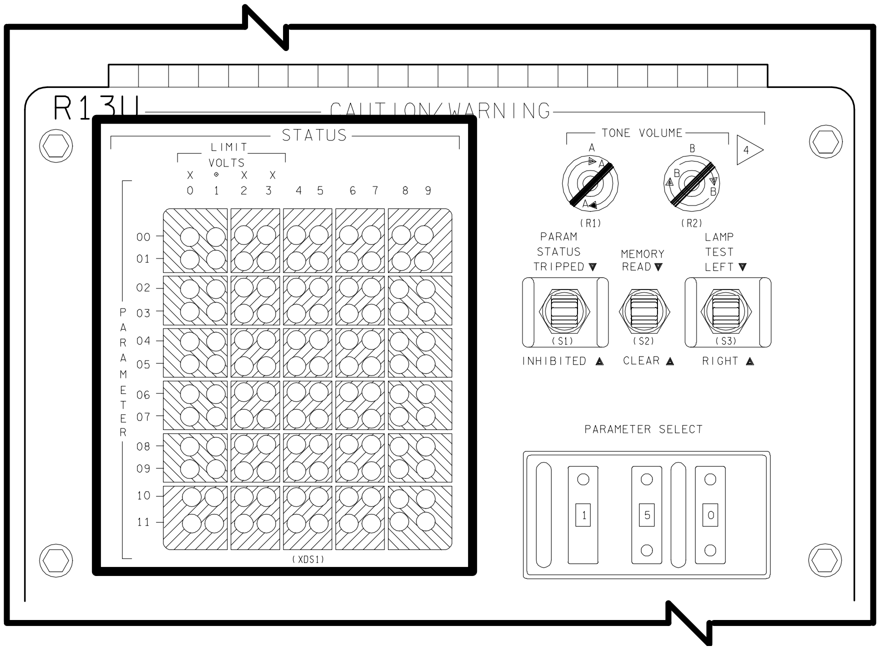
The class 2 (C/W) aural master alarm is activated by the primary (hardware) system, the backup (software) system, or both. The alternating C/W alarm tone is generated when the hardware system detects an out-of-limit condition on any of the 120 parameters it monitors or when the software (backup) system detects a parameter that is out of limits.

Class 2 primary and backup C/W visual cues include a 40-light annunciator matrix on panel F7. This matrix annunciates various system or functional failures. Each light is driven by one or more parameters. With the exception of the BACKUP C/W ALARM light, once a lamp has been illuminated, it will not be extinguished until all parameters driving that light are back within limits or inhibited. THE BACKUP C/W ALARM light is extinguished once a MSG RESET key is pushed.

Panel R13U is the crew's interface with the primary C/W system. It includes a parameter status light matrix that is used to check the status of a parameter and also to check parameter limits. When used to check the status of parameters, the numbers on the left side of the matrix are read first to obtain the first two numbers of the parameter (row), then the number on the top is read to obtain the third number of the parameter. The matrix can display all 120 parameters (numbered from 000 to 119) of the primary C/W system.

C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME
0	CRYO O2 P TK1	25	GPC 3	50	CRYO H2 P TK1	*75		100	L RHC
1	CRYO O2 HTR1 TK1	*26*	RCS LEAK/TK P - F	51	CRYO O2 HTR 2 TK3	76	RCS TK P FU- R	101	FCS SATURATION
2	FC1 REAC O2	27	OMS ENG - L	52	FC3 REAC H2	*77		102	FC2 COOL PUMP
3	DC VOLT MAIN A	*28*	APU 3 EGT	53	AC3 VOLT (ϕA, B, C)	78	APU 2 OVERSPEED	103	IMU
4	CAB PRESS	*29*	MPS HE TK P - R	54	CAB N2 FLOW 1	*79*	MPS MANF P LH2	104	AV BAY 3 TEMP
5	GPC 1	*30*	CRYO O2 P TK 4/5	*55		*80*	CRYO H2 P TK 4/5	105	H2O LOOP 1 PUMP OUT P
6	RCS TK P OX - F	*31*	CRYO O2 HTR 2 TK2	56	RCS LEAK/TK P - L	*81	CRYO O2 HTR1 TK5	106	FREON LOOP 1 FREON FLOW
7	OMS TK P OX - L	*32*	FC2 REAC H2	*57*	OMS ENG - R	82	FC3 STACK T	107	FREON LOOP 1 EVAP OUT T
8	APU 1 EGT	*33*	AC1 VOLT (ϕA, B, C)	*58*	APU 3 OIL T	*83*	AC3 OVLD	108	APU 2 UNDERSPEED
9	MPS HE TK P - C	*34*	CAB PPO2 A	*59*	MS HE REG P - R	*84*	AV BAY 1 TEMP	109	HYD 2 P
10	CRYO O2 P TK2	*35*	GPC 4	*60*	CRYO H2 P TK2	*85		110	R/AFT RHC
11	CRYO O2 HTR 2 TK1	*36*	RCS TK P OX - L	*61*	CRYO O2 HTR 1 TK4	86	RCS LEAK/TK P - R	111	FCS CH BYPASS
12	FC1 REAC H2	*37*	OMS TK P OX - R	*62*	FC1 STACK T	*87		112	FC3 COOL PUMP
13	DC VOLT MAIN B	*38*	APU 1 OIL T	*63*	AC1 OVLD	88	APU 3 OVERSPEED	*113	
14	CAB O2 FLOW 1	*39*	MPS HE REG P - C	*64*	CAB N2 FLOW 2	*89		114	CAB HX OUT T
15	GPC 2	*40	CRYO O2 P TK5	*65		_*90_		*115*	H2O LOOP 2 PUMP OUT P
16	RCS TK P FU - F	41	CRYO O2 HTR 1 TK3	66	RCS TK P OX - R	91	ADTA	*116*	FREON LOOP 2 FREON FLOW
17	OMS TK P FU - L	*42*	FC3 REAC O2	*67*	OMS TVC	*92*	FC1 COOL PUMP	*117*	FREON LOOP 2 EVAP OUT T
18	APU 2 EGT	*43*	AC2 VOLT (ϕA, B, C)	*68*	APU 1 OVERSPEED	*93*	RGA/AA	*118*	APU 3 UNDERSPEED
19	MPS HE TK P - L	*44*	CAB PPO2 B	*69*	MPS MANF PL O2	*94*	AV BAY 2 TEMP	*119*	HYD 3 P
20	CRYO O2 P TK34	45	GPC 5	*70*	CRYO H2 P TK3	*95*	PL WARNING		
21	CRYO O2 HTR 1 TK2	*46*	RCS TK P FU - L	*71*	CRYO O2 HTR 2 TK4	*96*	RCS JET	*	Not used
22	FC2 REAC O2	*47*	OMS TK P FU - R	*72*	FC2 STACK T	*97*	PL CAUTION		
23	DC VOLT MAIN C	*48*	APU 2 OIL T	*73*	AC2 OVLD	*98*	APU 1 UNDERSPEED		
24	CAB O2 FLOW 2	*49*	MPS HE REG P - L	*74*	CAB FAN ΔP	*99*	HYD 1 P		

Hardware Caution and Warning Table



Parameter Status Light Matrix on Panel R13U

Class 3 - Alert

This class is a software system operated by the SM software. It would generally receive lower priority than a class 1 or 2 alarm. Class 3 alert is designed to inform the flight crew of a situation leading up to a class 2 alarm or one that may require a long procedure (over 5 minutes) in order to rectify the problem. When an alert parameter exceeds its limits, the blue SM ALERT light on panel F7 is illuminated, a discrete is sent to the primary C/W system to turn on the alert tone, and the software displays a fault message on the fault message line and fault summary page.

Both guidance, navigation, and control (GNC) and systems management (SM) software sense out-of-limit conditions. These software systems also serve some less critical parameters and annunciate the SM alert tone. This tone is a steady tone of predefined duration generated in the C/W electronics when activated by inputs from the onboard computers.

Class 0 - Limit Sensing

Class 0 is a software system consisting of up and down arrows on the DPS displays next to a parameter. It provides no aural annunciation.

A down arrow displayed next to a parameter would indicate that the low limit for that parameter had been met or violated. In addition, the down arrow is used to indicate a state that does not agree with the nominal state; for example, a fan that is nominally on (e.g., HUM SEP fan) is off.

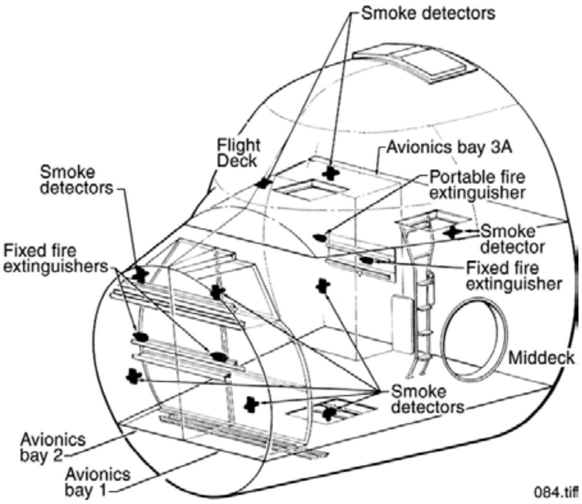
An up arrow displayed next to a parameter would indicate that the upper limit for that parameter has been exceeded.

Smoke Detection and Fire Suppression

This emergency class 1 alarm is hardware driven. The crew is alerted to emergency situations by use of visual and audio alarms.

Smoke detection and fire suppression capabilities are provided in the crew cabin avionics bays and in the crew cabin. *Smoke detectors*, which sense levels of smoke concentrations *and* rate of concentration change, trigger alarms and provide information on smoke concentration levels to the performance-monitoring DPS system and an array of red SMOKE DETECTION lights on panel L1.

The *smoke detector* system is divided into two groups: group A and group B. Group A *smoke detectors* are located in the environmental control and life support system cabin fan plenum outlet beneath the crew cabin middeck floor and in the left return air duct on the crew cabin flight deck, and one element is located in each of the three forward avionics bays (1, 2, and 3A). Group B *smoke detectors* are located in the right return air duct on the crew cabin flight deck and in avionics bays 1, 2, and 3A.

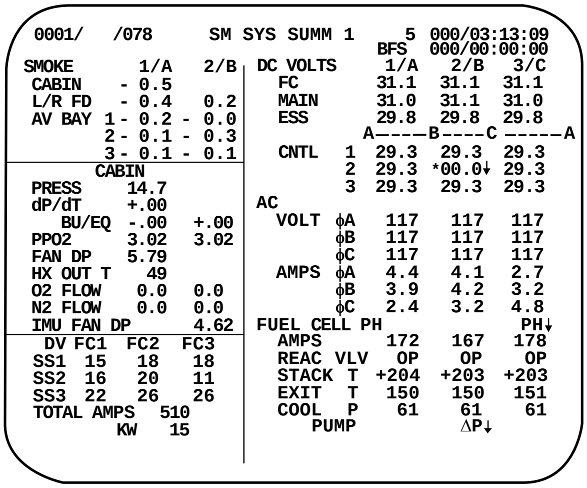


Smoke Detection and Fire Suppression System

If a *smoke detector* senses a smoke particle concentration of 2,000 (±200) micrograms per cubic meter for at least 5 seconds and/or a rate of smoke increase of 22 micrograms per cubic meter per second for eight consecutive counts in 20 seconds, a trip signal illuminates the applicable red SMOKE *DETECTION light* on panel L1, illuminates the four red MASTER ALARM lights on panels F2, F4, A7, and MO52J, and sounds the siren in the crew cabin. The normal reading on the SM SYS SUMM 1 display for the smoke detectors is 0.3 to 0.4 milligram per cubic meter. A reading on the display of 2.0, plus or minus 0.2, corresponds to 2,000 (±200) micrograms per cubic meter.

After an alarm and a reset of the detector, the following conditions may be observed:

- If the alarm returns in 5 seconds, it is due to the concentration exceeding 2,000 ± 200 micrograms per cubic meter for 5 seconds.
- If the alarm returns in 20 seconds, it is due to the concentration increasing at a rate greater than or equal to 22 micrograms per cubic meter per second for eight consecutive counts in 20 seconds.
- If the alarm returns immediately, the detector would be suspect, and a self test should be performed. If available, the concentration readout should be observed on SM SYS SUMM 1.
- If the alarm does not return, perform self test. If available, check concentration on SM SYS SUMM 1.



```
 0001/   /078      SM SYS SUMM 1     5  000/03:13:09
                                   BFS  000/00:00:00
SMOKE        1/A   2/B | DC VOLTS     1/A   2/B   3/C
 CABIN     - 0.5       |   FC         31.1  31.1  31.1
 L/R FD    - 0.4   0.2 |   MAIN       31.0  31.1  31.0
 AV BAY  1 - 0.2 - 0.0 |   ESS        29.8  29.8  29.8
         2 - 0.1 - 0.3 |            A————B————C —————A
         3 - 0.1 - 0.1 |   CNTL   1  29.3  29.3  29.3
        CABIN          |          2  29.3 *00.0↓ 29.3
 PRESS      14.7       |          3  29.3  29.3  29.3
 dP/dT      +.00       | AC
    BU/EQ   -.00  +.00 |  VOLT   ϕA   117   117   117
 PPO2       3.02  3.02 |         ϕB   117   117   117
 FAN DP     5.79       |         ϕC   117   117   117
 HX OUT T     49       |  AMPS   ϕA   4.4   4.1   2.7
 O2 FLOW     0.0   0.0 |         ϕB   3.9   4.2   3.2
 N2 FLOW     0.0   0.0 |         ϕC   2.4   3.2   4.8
 IMU FAN DP       4.62 | FUEL CELL PH             PH↓
  DV FC1  FC2   FC3    |   AMPS       172   167   178
 SS1  15   18    18    |   REAC VLV    OP    OP    OP
 SS2  16   20    11    |   STACK T   +204  +203  +203
 SS3  22   26    26    |   EXIT  T    150   150   151
 TOTAL AMPS   510      |   COOL  P     61    61    61
          KW   15      |      PUMP           ΔP↓
```

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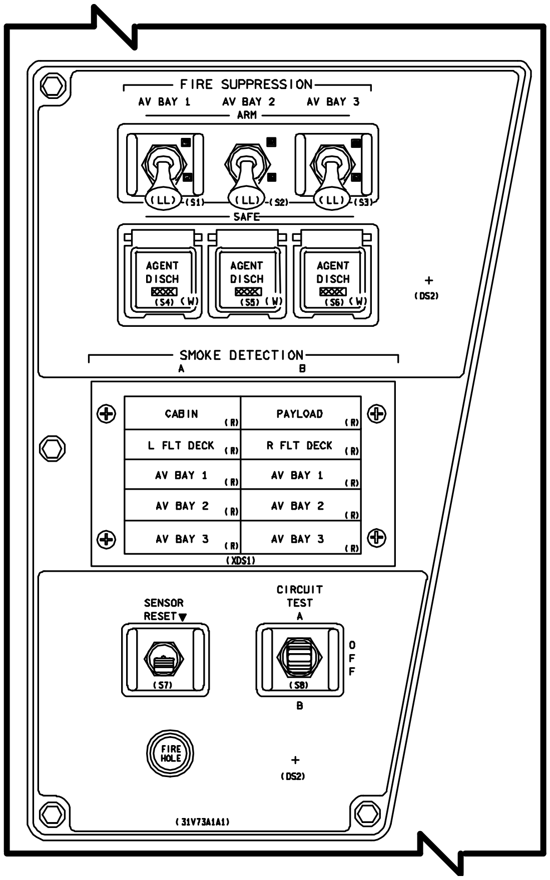
SM SYS SUMM 1 (DISP 78)

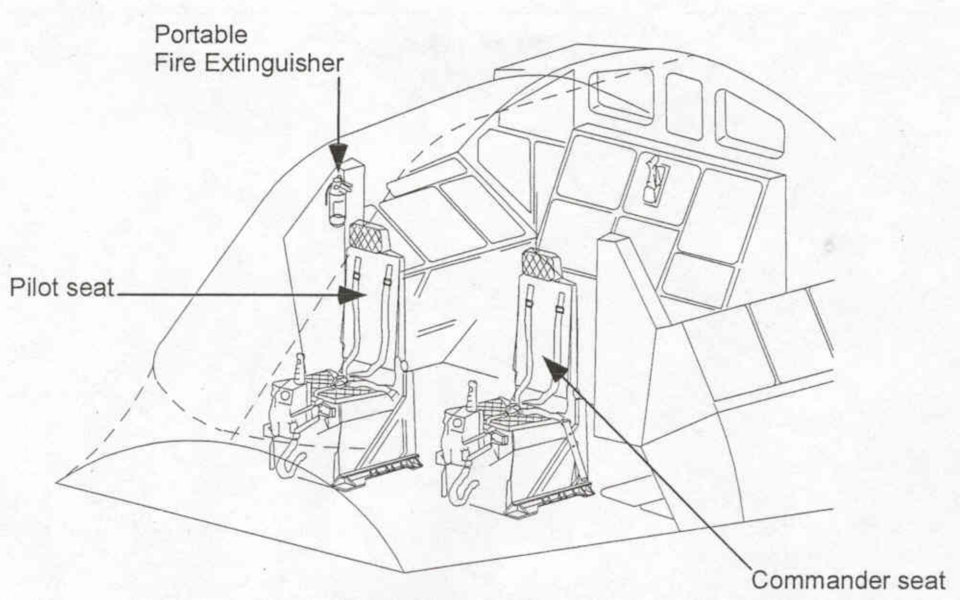
Fire suppression in the crew cabin avionics bays is provided by three Halon extinguisher bottles permanently mounted in avionics bays 1, 2, and 3A. Each bottle contains 3.74 to 3.8 pounds of Halon in a pressure vessel that is 8 inches long and 4.25 inches in diameter. To activate the applicable bottle in an avionics bay, the corresponding *FIRE SUPPRESSION* switch on panel L1 is positioned to *ARM*, and the corresponding *AGENT DISCH* pushbutton indicator on panel L1 is depressed for at least 2 seconds. The *AGENT DISCH* pushbutton indicator activates the corresponding pyro initiator controller, which initiates a pyrotechnic valve on the bottle to discharge the Halon into the avionics bay. The discharge of Halon will produce a noise of approximately 130 decibels in the avionics bay.

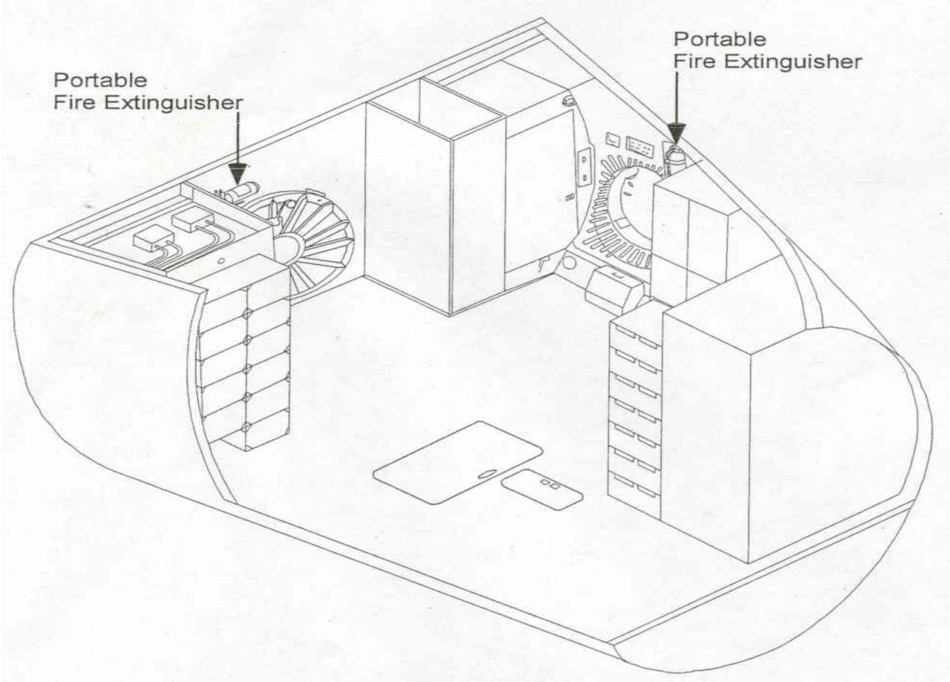


FIRE SUPPRESSION Switches and Pushbuttons and SMOKE DETECTION Lights on Panel L1

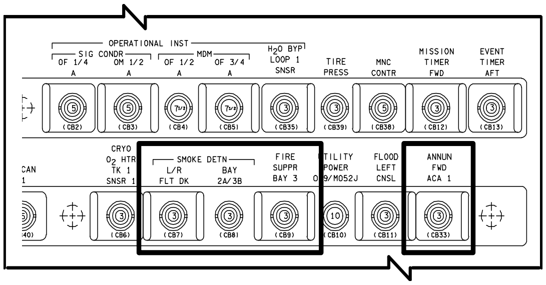
The discharge will give a Halon concentration in the avionics bay of 7.5 to 9.5 percent. A 4 to 5 percent concentration is required to suppress a fire. This concentration will provide protection for approximately 72 hours. When the AV bay fire bottles are discharged, the pushbutton indicators will illuminate when the pressure in the bottle falls below 60 ± 10 psig. This indicates that the bottle is fully discharged.

Red *SMOKE DETECTION* lights on panel L1 are illuminated by the following: the CABIN light is illuminated by a smoke *detector* in the ECLSS cabin fan plenum, the *L FLT DECK* light is illuminated by the crew cabin left flight deck return air duct smoke *detector*, the *R FLT DECK* light is illuminated by the crew cabin right flight deck return air duct smoke *detector*. The *PAYLOAD* light is illuminated by the smoke *detectors* in pressurized payload modules; i.e., Spacehab. Note that although the payload smoke detection light on L1 will illuminate, the smoke concentration data field on Sys Summ 1 will not display data for the payload smoke detector. The SPEC display for the payload will contain that data. The applicable smoke *detector* illuminates the applicable red *AV BAY* light on panel L1, activates the *C/W MASTER ALARM* red light, and sounds the siren in the crew cabin.

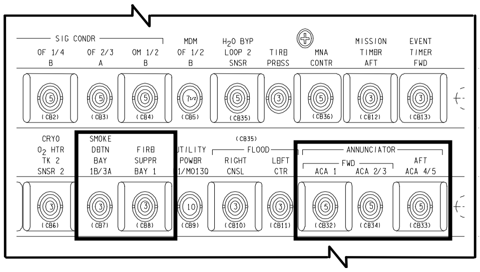




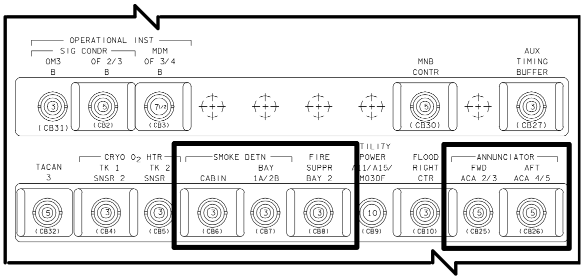
Fire Extinguisher Locations



Fire and Smoke Subsystem Control Circuit Breakers on Panel 014



Fire and Smoke Subsystem Control Circuit Breakers on Panel 015



Fire and Smoke Subsystem Control Circuit Breakers on Panel 016

The circuit breakers that control the fire and smoke subsystem are located on panels 014, 015, and 016. Panel 014 contains the *MN A SMOKE DETN L/R FLT DK* and *BAY 2A/3B*, *FIRE SUPPR BAY 3*, and *ANNUN FWD ACA 1* circuit breakers. Panel 015 contains *MN B SMOKE DETN BAY 1B/3A*, *FIRE SUPPR BAY* 1 and annunciator *FWD ACA 1* and *ACA 2/3* and *AFT ACA 4/5* circuit breakers. Panel 016 contains *MN C SMOKE DETN CABIN* and *BAY 1A/2B*, *FIRE SUPPR BAY 2*, and *ANNUNCIATOR FWD ACA 2/3* and *AFT ACA 4/5*.

Three hand-held fire extinguishers are available in the crew cabin. Two are located in the crew cabin middeck, and one is on the flight deck. Each fire extinguisher nozzle is tapered to fit fire hole ports located in several display and control panels. The holes are of two types: a ½-inch diameter hole covered with a marked label, and an unmarked ½- to ¼-inch diameter tapered hole. These holes give access to the volume immediately behind the individual panel. To suppress a fire behind a panel or within an avionics bay, the extinguisher nozzle should be inserted into the fire hole and the actuating mechanism depressed for 15 seconds. This will ensure a complete discharge. The extinguishing agent is Halon-1301 (monobromotrifluoromethane). Halon-1301 minimizes the major hazards of a *fire*: smoke, heat, oxygen depletion, and formation of *combustion* products such as carbon monoxide. The fire extinguishers are 13 inches long. The portable fire extinguishers can also be used as a backup for extinguishers in the avionics bays. Consideration should be given to the *propulsive* force on the crewmember when discharging the extinguishers on orbit.

Halon 1301

Halon 1301 is used as the extinguishing agent for all fire suppression devices. It is colorless and odorless. Discharge of the agent may create a light mist in the vicinity of the discharge nozzle. Therefore, visibility is not adversely affected. Once the Halon is discharged into an enclosure, it is difficult to detect its presence through normal human senses.

Exposure to Halon in the 5 to 7 percent range produces little, if any, noticeable effect. At levels between 7 and 10 percent, mild central nervous system effects such as dizziness and tingling in the extremities have been reported. Above 10 percent, some subjects report a feeling of impending unconsciousness after a few minutes, although test subjects exposed to up to 14 percent for 5 minutes have not actually lost consciousness. These types of effects were completely reversible upon removal from exposure.

It is considered good practice to avoid all unnecessary exposure to Halon 1301 and to limit exposures to the following times:

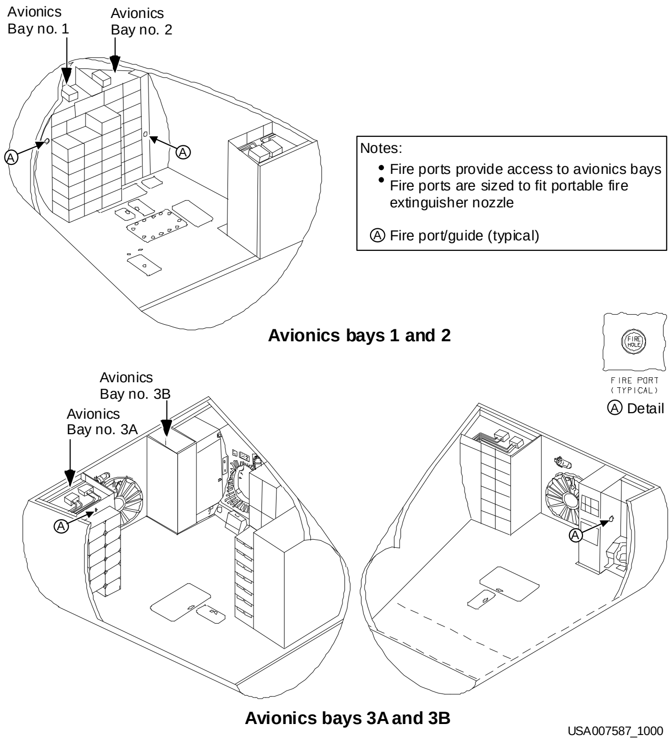
- 7 percent and below: 15 minutes
- 7 to 10 percent: 1 minute
- 10 to 15 percent: 30 seconds
- Above 15 percent: prevent exposure

Anyone suffering from toxic effects of Halon 1301 should immediately move or be moved to fresh air. In treating persons suffering toxic effects, the use of epinephrine (adrenaline) and similar drugs must be avoided. These drugs may produce cardiac arrhythmias, including ventricular fibrillation.

Although Halon 1301 has a low toxicity, its decomposition can be hazardous. These products have a characteristically sharp acrid odor, even in minute concentrations of only a few parts per million. This smell provides a warning system but at the same time creates a noxious, irritating atmosphere.

The accepted theory is that Halon must decompose before it is effective in suppressing fire. The decomposition takes place on exposure to a flame or to a hot surface of approximately 900° F.

Depending on the severity of the fire, length of time Halon is exposed to flame, and concentration of Halon, the decomposition products may be extensive or minimal.



Notes:
- Fire ports provide access to avionics bays
- Fire ports are sized to fit portable fire extinguisher nozzle

Ⓐ Fire port/guide (typical)

Avionics bays 1 and 2

Avionics bays 3A and 3B

Fire Port Locations

The *SMOKE DETECTION CIRCUIT TEST* switch on panel L1 tests the smoke detection system, lights, and alarm circuitry. When the switch is positioned to *A* or *B*, electrical power is applied to the ACA channels controlling the *AGENT DISCH* lights, and the white lights are illuminated. Two tests are completed for both the A and the B circuits to test the complete logic circuitry of the smoke detection system. In one test, after approximately a 20-second delay, the *SMOKE DETECTION* A or B lights are illuminated, and the siren is triggered. In the other test, the *SMOKE DETECTION CIRCUIT TEST* switch is turned off in 5 to 10 seconds, bypassing the 20-second time delay and immediately annunciating a siren and a *SMOKE DETECTION* light (A or B).

Once the alarm system has been triggered, it remains latched until the *SMOKE DETECTION SENSOR* switch on panel L1 is positioned to RESET. When the system is latched, the emergency alarm system will not activate an alarm in case of another fire in the same or any other avionics bay.

Various parameters of the smoke detection system and remote fire extinguishing agent system are provided to telemetry.

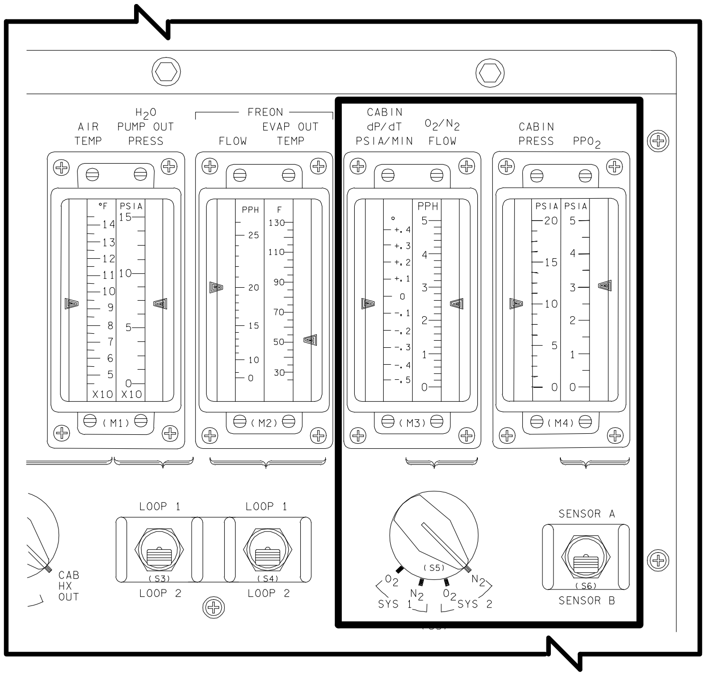
Rapid Cabin Depressurization

The cabin *depressurization* (dP/*dt*) *sensor measures* the rate at which *cabin* pressure is changing in the orbiter (in psi/min). The system alerts the crew to a rapid pressure change with respect to time by annunciation of the four MASTER ALARM pushbutton indicators and sounding of the klaxon (class 1 alarm) *when the measured dP/dt value exceeds -0.08 psi/min. The alarm only annunciates for negative values*. The normal cabin dP/*dt* is zero psi per minute (±0.01) psi for all normal operations.

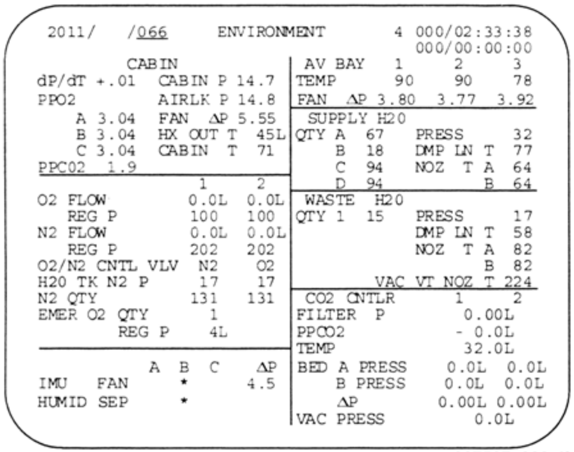
In addition, a class 3 alarm will annunciate for a decrease in pressure greater than or equal to 0.12 psi per minute, based on dP/*dt* or backup dP/*dt*.

Values for dP/*dt* can be monitored on the SM SYS SUMM 1 (dP/*dt*, dP/*dt*-EQ, dP/*dt*-BU), and the dedicated display on panel O1 (dP/*dt*).

The dP/*dt* detector is powered *through* the MN B PPO2 C CABIN DP/DT circuit breaker on panel 015.



Cabin Pressure Meters and Switches on Panel 01



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 2011/   /066      ENVIRONMENT         4 000/02:33:38
                                         000/00:00:00
          CABIN               AV BAY    1      2      3
dP/dT +.01   CABIN P 14.7   TEMP        90     90     78
PPO2         AIRLK P 14.8   FAN  ΔP 3.80   3.77   3.92
    A 3.04   FAN   ΔP 5.55   SUPPLY H2O
    B 3.04   HX OUT T   45L QTY A   67    PRESS       32
    C 3.04   CABIN  T   71      B   18    DMP LN T    77
PPCO2  1.9                      C   94    NOZ   T A   64
                  1      2      D   94              B 64
O2 FLOW          0.0L   0.0L   WASTE  H2O
   REG P         100    100    QTY 1  15    PRESS       17
N2 FLOW          0.0L   0.0L                DMP LN T    58
   REG P         202    202                 NOZ   T A   82
O2/N2 CNTL VLV   N2     O2                            B 82
H2O TK N2 P       17    17              VAC VT NOZ T 224
N2 QTY           131    131    CO2  CNTLR        1      2
EMER O2  QTY       1           FILTER  P        0.00L
           REG P   4L          PPCO2           - 0.0L
                               TEMP             32.0L
             A   B   C    ΔP   BED A PRESS    0.0L   0.0L
IMU   FAN        *        4.5      B PRESS    0.0L   0.0L
HUMID SEP        *                   ΔP      0.00L  0.00L
                               VAC PRESS          0.0L
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ENVIRONMENT Display (DISP 66)

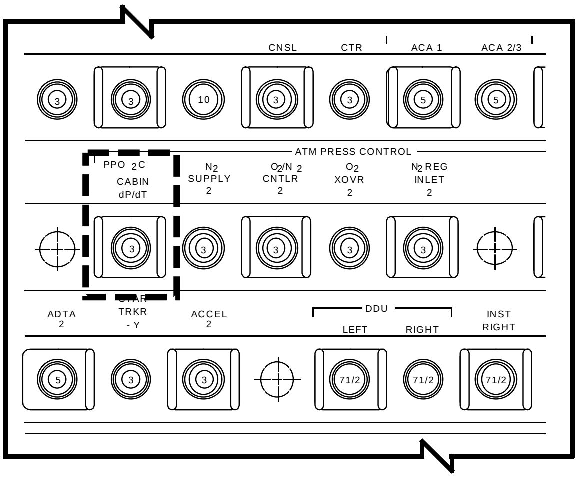
Operations

Primary C/W System

The primary C/W system has three modes of operation: ascent, normal, and acknowledge. These modes are controlled by the *CAUTION/WARNING MODE* switch on panel C3. The switch has three settings: *ASCENT*, *NORM*, and *ACK*. The normal mode is discussed first.

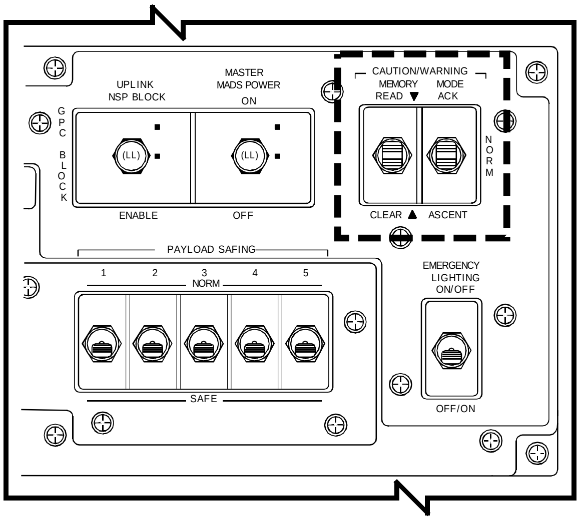
The primary C/W system receives 120 inputs directly from transducers through signal conditioners or from the flight forward multiplexer/demultiplexers, and are fed into a multiplexing system. Of these 120 inputs, 95 come directly from transducers, five are from the general purpose computer (GPC) input/output processors, 18 are provided by the GPC software, through multiplexer/demultiplexer, and two are spares. These inputs can be either analog or bilevel discretes. The analog signals are 0 to 5 V DC; the discretes are either 2.5 or 5 V DC. All of these inputs are designed to provide upper or lower limit detection. If the parameter has exceeded its limits, it will turn on the C/W tone, light the appropriate light on panel F7, illuminate the four red *MASTER ALARM* pushbutton indicators, and store the parameter in memory.

The C/W tone can be silenced and the red *MASTER ALARM* light extinguished by depressing any one of the *MASTER ALARM* pushbutton indicators; however, the C/W light on panel F7 will remain illuminated until the out-of-tolerance condition is corrected or inhibited. Any one of the *MASTER ALARM* pushbutton indicators will reset all tones, including the systems management tone.



MN B PPO₂ C CABIN DP/DT Circuit Breaker on Panel 015

The C/W ascent mode is the same as the normal mode, except that the commander's red *MASTER ALARM* pushbutton indicator will not be illuminated.



CAUTION/WARNING MEMORY and MODE Switches on Panel C3

The C/W acknowledge mode is also the same as the normal mode, except that the 40 annunciator lights on panel F7 will not be illuminated unless one of the red *MASTER ALARM* pushbutton indicators (on panel F2 for the commander or panel F4 for the pilot) is depressed.

Panel R13U

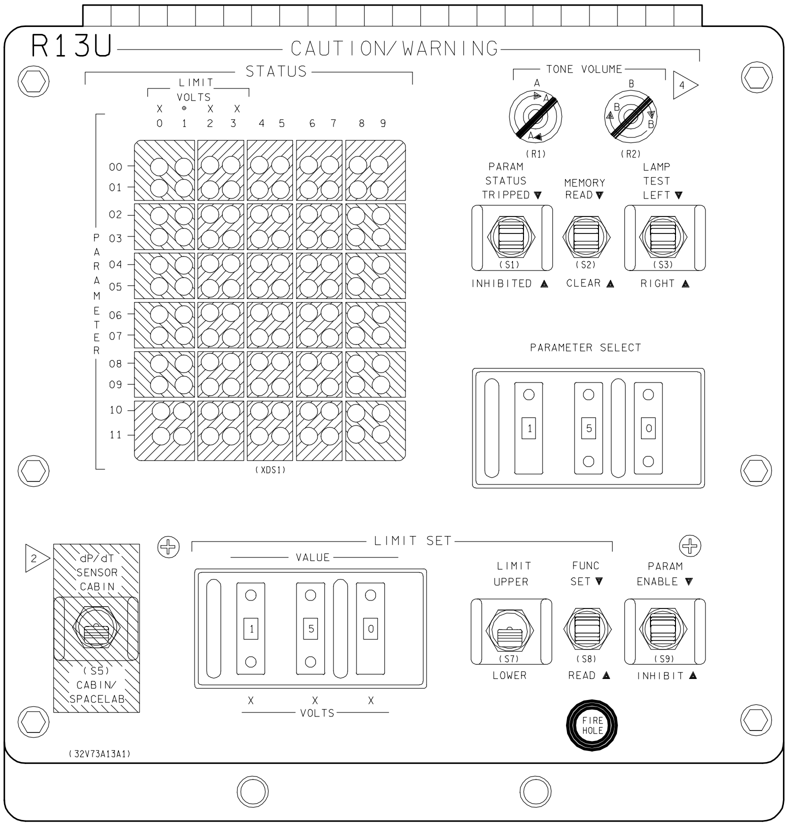
Each of the 120 status C/W red parameter lights on panel R13U receives an input from a specific parameter. A primary C/W parameter matrix cue card identifies the 120 input channels and correlates them to the panel F7 C/W annunciator light matrix. If an out-of-limit condition exists on a specific parameter that is set on panel R13U, it illuminates the corresponding light on panel F7. If the *CAUTION/WARNING PARAM STATUS* switch on panel R13U is held in the *TRIPPED* position when an out-of-limit parameter light on panel F7 is illuminated, the corresponding light on panel R13U will also be illuminated.

Some limits, and the list of parameters monitored, change with flight phase. The crew uses the *PARAM ENABLE/INHIBIT* and *LIMIT* switches on panel R13U to tailor the C/W system for their current configuration.

The three *CAUTION/WARNING PARAMETER SELECT* thumbwheels on panel R13U provide signals to the C/W electronics unit to define a specific parameter. This is required for enabling and inhibiting the selected parameter and also for setting and reading a parameter's current limits.

The *CAUTION/WARNING LIMIT SET* switch grouping on panel R13U is used to change limits or to read a parameter's limits. The three *VALUE* thumbwheels provide the signals to the C/W unit, defining the voltage value setting of a parameter's upper or lower limit, X.XX.

The *UPPER* setting of the *CAUTION/ WARNING LIMIT SET LIMIT* switch on panel R13U provides a signal to the C/W electronics unit, which modes the electronics to set or read the upper limit of a parameter specified by the settings on the *PARAMETER SELECT* thumbwheels for that parameter. The *CAUTION/ WARNING LIMIT SET FUNC* switch is cycled to set or read the upper limit of that parameter. The *LOWER setting* functions in the same manner, except for the lower limit for a parameter.



Panel R13U

The *CAUTION/WARNING LIMIT SET FUNC SET* switch position on panel R13U provides a signal to the C/W electronics unit, which sets the value specified by the *LIMIT SET VALUE* thumbwheels into the parameter as specified by the PARAMETER SELECT thumbwheels and LIMIT SET LIMIT switch. The LIMIT SET FUNC READ switch position on panel R13U provides a signal to the C/W electronics unit, which illuminates the lights under the STATUS LIMIT VOLTS X.XX columns on panel R13U that correspond to the voltage parameter limit specified by the PARAMETER SELECT thumbwheels and the LIMIT SET LIMIT switch. The value read corresponds to the parameter's full-scale range on a scale of zero to 5 volts DC. The LIMIT SET FUNC switch center position disables the set and read functions.

The *ENABLE* position of the *CAUTION/ WARNING PARAM* switch on panel R13U provides a signal to the C/W electronics unit to enable the parameter indicated on the *PARAMETER SELECT* thumbwheels, which allows the parameter to trigger the primary C/W alarm when out of limits. The *INHIBIT* position operates the same as *ENABLE*, except it inhibits the parameter from triggering the primary C/W alarm. The center position of the switch disables the enable and inhibit functions.

The *TRIPPED* position of the *CAUTION/ WARNING PARAM STATUS* switch on panel R13U provides a signal to the C/W electronics unit, which illuminates the C/W status lights that correspond to the parameters that are presently out of limits, including those that are inhibited. The *INHIBITED* position illuminates those C/W lights on panel R13U that have been inhibited. The center position disables the tripped and inhibited functions.

The *CAUTION/WARNING MEMORY READ* switch position on panel R13U provides a signal to the C/W electronics unit, which provides access to a memory buffer that stores inputs from parameters that are currently out of limits or have been out of limits since the memory buffer was last cleared. Moving the *CAUTION/WARNING MEMORY* switch to READ displays the parameters that are currently out of limits or have been out of limits since the buffer was last cleared. The CLEAR position on panel R13U or panel C3 provides a signal to the C/W electronics unit that clears from the memory any parameters that are back within limits, but any parameters that are out of limits during this action remain in memory. The center position of the switch on panel R13U or panel C3 disables the clear and read functions.

The *CAUTION/WARNING TONE VOLUME* A *potentiometer (recessed setscrew)* on panel R13U, when adjusted clockwise, increases the system A siren, klaxon, C/W, and SM tone generator output signals to the audio central control unit. The B *potentiometer* functions the same as the A *potentiometer* for system B tone generators.

The *CAUTION/WARNING LAMP TEST* switch on panel R13U, when positioned to *LEFT*, provides a signal to the C/W electronics unit, which illuminates the left five columns of the C/W status matrix lights on panel R13U. The *RIGHT* position functions the same as the *LEFT*, except for the right five columns of lights. This allows the verification of all 120 lights, making sure that none have burned out.

Software (Backup) Caution and Warning

When the software caution and warning system detects an out of limits condition, it sounds an aural tone or master alarm, lights the *MASTER ALARM* or *SM ALERT* light, and issues a fault message that is displayed flashing on the DPS display fault message line. The master alarm light and tones are reset by depressing a *MASTER ALARM* light pushbutton. The fault message will flash until acknowledged by a depression of the ACK key or until the MSG RESET key is depressed to erase the message. The MSG RESET key will also extinguish the *SM ALERT* light.

The displayed fault message is used to diagnose system failures and frequently is used as the title of the Flight Data File procedure to be worked by the crew in response to the failure. The text of the fault message identifies the system where limits are being exceeded. A list of individual fault messages is presented in the summary at the end of this section.

For some general classes of fault messages, the first part of the text contains the SPEC number to be consulted to determine the specific parameter that is out of limits. The GPCs declaring the fault are enumerated after the message text. In parentheses at the end of the fault message, software will display the number of other fault messages generated while the current message was being displayed. To view these messages and the time at which they were annunciated, the crew must look at the fault summary page, or scroll through them using the *ACK* key.

After reset of the displayed fault message, the message line will be blank until another new message is generated by the software. To avoid missing messages in a multi-failure scenario, crews should occasionally review all messages on the fault summary page and try to reset messages on the fault line as quickly as possible after reviewing them.

Fault messages for some parameters are issued every time the software completes the required number of data counts with the parameter out of limits. This can result in a steady stream of fault messages and *MASTER ALARMS* that may obscure other important fault messages. If this situation is encountered, the crew or Mission Control can inhibit the affected parameter to prevent nuisance messages and alarms in OPS 2 or OPS 4. In OPS 1, 6, or 3, the crew generally has to tolerate the extra alarms/fault messages and pay extra close attention to the fault summary display.

In order to clear messages from the fault summary page, the crew enters a SPEC 99 PRO on the keyboard. If the fault summary (DISP 99) is called up using a SPEC 99 PRO instead of the FAULT SUMM key, the fault summary page will appear, and then immediately clear itself.

Software caution and warning limits for some parameters change depending on the phase of flight. These changes can be entered by the crew via the SPEC 60 TABLE MAINTENANCE display or uplinked from the ground. The ground uplink for limits changes is called a Table Maintenance Block *Update* (TMBU).

SPEC 60, SM Table Maintenance

The primary avionics software system (PASS) includes three types of applications software, called major functions. The first, systems management (SM), is the function that is active on orbit. The second, guidance, navigation, and control (GNC), is active during all flight phases. The third, payload software, provides operations support to payloads. The backup flight system (BFS), normally used only during ascent and entry, also contains both SM and GNC software.

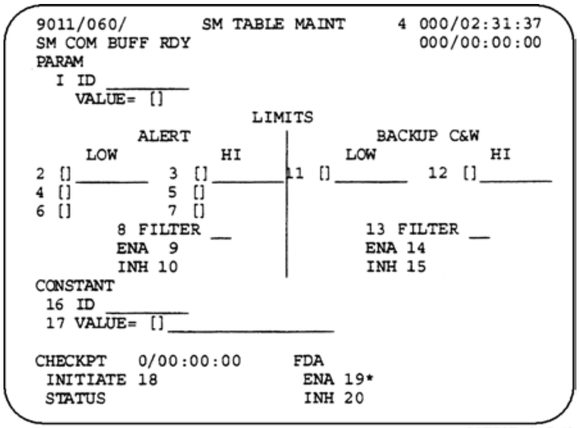
Modules within both SM and GNC software monitor parameters and initiate alarms. To change the characteristics of the PASS GNC, BFS GNC, and BFS SM parameters, the crew would have to perform a GPC memory read/write procedure. (This procedure is described in the DPS HW/SW 21002 Training Manual.)

However, PASS SM parameters can be accessed directly by the crew. Within PASS SM is a module called fault detection and annunciation. This module monitors the backup C/W and alert parameters and initiates alarms.

SPEC 60 SM TABLE MAINT is the crew interface with the PASS SM parameters. Using SPEC 60, the crew can read and change the following for each PASS SM backup C/W or alert parameters: (1) lower and upper limits, (2) noise filter value, and (3) enable/inhibit status. Additionally, the crew can read and change SM program constants, initiate a checkpoint, and enable or inhibit the entire fault detection and annunciation software module.

SPEC 60, which is a PASS SM SPEC, is available during SM OPS 2. When the SM TABLE MAINT display is called up by its SPEC number (SPEC 60 PRO), each field will be blank except CHECKPT time and FDA ENA. When SPEC 60 is called by pressing RESUME, the fields that were previously in use will retain their data. When a legal item entry is made, the new data will be displayed in the appropriate field and will overwrite any previous data.

Any *B*ackup C/W *or Alert* parameter may be accessed by entering its software ID number in item 1 of the SM TABLE MAINT display. The limits, noise filter value, and enable/inhibit status of *Alert* parameters may be changed with items 2 through 10. The same characteristics of *Backup* C/W parameters are available through items 11 through 15. These display parameters are discussed in more detail below.



```
9011/060/         SM TABLE MAINT      4 000/02:31:37
SM COM BUFF RDY                         000/00:00:00
PARAM
  I ID ________
    VALUE= []
                        LIMITS
        ALERT              |         BACKUP C&W
     LOW           HI      |      LOW           HI
2 []________   3 []________|11 []________  12 []________
4 []           5 []        |
6 []           7 []        |
       8 FILTER __         |         13 FILTER __
       ENA  9              |         ENA 14
       INH 10              |         INH 15
CONSTANT
 16 ID ________
 17 VALUE= []__________________

CHECKPT   0/00:00:00       FDA
 INITIATE 18                ENA 19*
 STATUS                     INH 20
```

usa007587_097.tif

SM TABLE MAINT (SPEC 60)

PARAM ID (Item 1) and PARAM Value

The software ID number for the desired fault detection and annunciation (FDA) parameters is entered in item 1. The software IDs are located in the C/W and FDF TABLE of the Flight Data File Reference Data Book.

When a valid ID is entered, the ID number will be displayed in the PARAM ID space, and the current value of the parameter will be displayed in the PARAM VALUE field. The status of the parameter is indicated by the presence or absence of an up or down arrow. The appropriate ALERT or BACKUP C/W data will appear in the LIMITS portion (items 2 through 10 or items 11 through 15 respectively).

If the PARAM ID is not valid, all associated data fields will be blank, and an ILLEGAL ENTRY message will be displayed.

Limits Alert Low and Hi (Items 2 through 7)

These fields contain the upper and lower alert limits of the FDA parameter identified in item 1. The limit values are displayed in engineering units and can be changed by entering the desired data in the appropriate items.

Alert parameters that are preconditioned may have two or three limits sets. All other alert parameters have only one limit set. The SM software selects which set of limits is currently active and places an asterisk next to that set (before item 2, 4, or 6). (There is no item entry that allows the crew to move the asterisk to directly select which set of limits is active. This is done exclusively by software.) If only one set of limits exists for the parameter, this set will be displayed in the first limit set location, and the asterisk will be placed by item 2. If a value is entered in a limit set that does not exist for the selected parameter, an illegal entry message will be displayed.

Limits Backup C/W Low and Hi (Items 11 and 12)

The backup C/W system limits for the FDA parameter identified in item 1 are displayed in these fields. The limit values, which are in engineering units, can be changed by entering the new data in the desired item. Backup C/W parameters have one set of limits.

Limits Alert Filter (Item 8)

The Alert parameter noise filter value can be read or changed through item 8. It is the number of consecutive times the parameter has to be sensed out of limits before an alarm annunciates. The reverse is true for returning back into limits. The range of valid values is 1 through 15.

Limits Backup C/W Filter (Item 13)

The backup C/W filter functions similarly to the Alert filter (item 8).

Limits Alert ENA or INH (Items 9 and 10)

The annunciation of an out-of-limits Alert parameter may be either enabled or inhibited by executing the respective item. The items are mutually exclusive, and an asterisk indicates the current annunciation status by appearing after the more recently selected item.

The class 0 status indicators (up and down arrows) and transducer data symbols (H, L, M, ?) are not affected by this item.

Limits Backup C/W ENA or INH (Items 14 and 15)

These backup C/W items operate similarly to the Alert items 9 and 10.

FDA ENA or INH (Items 19 and 20)

The PASS FDA software can be either inhibited or enabled by executing the respective item. The items are mutually exclusive, and an asterisk denotes the current state. The display is initialized with FDA enabled.

When FDA is inhibited, the following FDA functions are disabled:

- FDA alarm annunciation. This includes backup C/W (class 2), Alert (class 3), and limit sensing up or down arrows (class 0).
- Limit sensing (class 0). The last value of each out-of-limits parameters status indicator is displayed.
- Precondition steering.
- False alarm avoidance noise filters.

Other parameter status indicators (H, L, M, ?) are not affected because they are not generated by the FDA software.

Constants

SM constants may be accessed through items 16 and 17. These constants are primarily involved in SM special processes such as water loop pump cycling, alert preconditioning, and payload deployment.

Constant ID (Item 16)

When a constant ID number is entered in item 16, both the CONSTANT ID and VALUE fields are filled. If the ID was illegal, both data fields are blanked.

The constant IDs and values are not typically carried onboard the orbiter, although various malfunction procedures contain occasional constants. If a constant must be changed, Mission Control will either provide the crew with the data or directly change the constant through a TMB Uplink. (See TMBU description in this section.)

Constant Value (Item 17)

This field contains the current value of the constant identified in item 16. The constant value can be changed by entering the new data in item 17.

TMBU

TMBU is the type of uplink that Mission Control uses to change the following data:

- Parameter limit values
- Parameter noise filter values
- Parameter annunciation enable/inhibit status
- SM constant values

The use of TMBUs decreases the crew's workload because the changes that are uplinked do not have to be entered on SPEC 60.

SPEC 60 operations and TMBUs are interlocked such that TMBU loads are rejected if SPEC 60 is active. If a TMBU is in progress when SPEC 60 is called, the flashing words UPLINK and UL will be displayed on the display, and all item entries will be prohibited by an ILLEGAL ENTRY message.

Uplink

The flashing word UPLINK is displayed in the top center of SPEC 60 to indicate that a TMBU is in progress.

UL

When any two-stage command (including a TMBU) is uplinked, a flashing UL is displayed in the upper right corner of all DPS displays associated with the GPC(s) that are being commanded.

Checkpoints

When a checkpoint is performed, the following information is saved in a *mass* memory unit:

- Parameter limit values
- Parameter noise filter values
- Parameter annunciation enable/inhibit status

- SM constant values
- Checkpoint timetags

The checkpoint capability is valuable because changes made through item entries on SPEC 60 affect only the SM GPC software and not the mass memory unit software. If these changes are not saved in a mass memory unit, and the SM GPC fails, flight software will lose the changes that have been made. The changes would then have to be reentered.

When checkpoint retrieval is enabled, the software loaded into an SM GPC from a mass memory unit will contain the most recent version of changes saved during checkpoint.

Checkpoint Initiate (Item 18), Checkpoint Status, and Time

When item 18 is executed, the STATUS field will go blank. While the checkpoint is being performed, a flashing BSY will be displayed next to SM COMM BUFF at the top left of SPEC 60. This indicates that the SM communications buffer is in use. When the checkpoint is completed, the CHECK PT STATUS field will contain GOOD. If the SM common buffer was not available, CHECK PT STATUS will be FAIL, and item 18 should be executed again.

The mission elapsed time (MET) of the most recent successful checkpoint will be displayed as DD/HH:MM:SS, in the checkpoint time field.

SM COMM BUFF - BSY, or RDY

Either a flashing BSY or a status RDY is displayed after SM COMM BUFF to indicate the status of the SM Common Buffer. BSY (busy) indicates that the SM COMM BUFF is being used; RDY (ready) means the buffer is available. Keypad entries are rejected if BSY is flashing.

CKPT RETRV ENA (SPEC 1, Item 12)

Executing this item will alternately select or deselect CKPT RETRV ENA. An asterisk appears next to item 12 when checkpoint retrieval is enabled.

MMU Assignment
(DPS Utility - SPEC 1, Items 3 and 4)

A checkpoint saves the changes in the mass memory unit assigned to the SM software by item 3 or 4. In order to save the checkpoint in both, two checkpoints must be performed.

C/W Summary Data

- The C/W system consists of four alarm classes: emergency (class 1), C/W (class 2), alert (class 3), and limit sensing (class 0).
- Emergency alarms cover two situations: smoke detection/fire suppression and cabin pressure.
- Smoke detection and fire suppression capabilities are provided in the crew cabin avionics bays, the crew cabin, and the pressurized payload modules.
- Increased smoke particle concentration will illuminate *SMOKE DETECTION* lights on panel L1, illuminate four red *MASTER ALARM* lights on panels F2, F4, A7, and MO52J, and sound the siren in the crew cabin.
- Fire suppression in the crew cabin avionics bay is provided by one permanent Halon extinguisher bottle in avionics bays 1, 2, and 3A. The bottle is operated by switches on panel L1.
- Three portable hand-held extinguishers in the crew cabin are operated by inserting them into fire holes located in several display and control panels.
- A class 1 alarm (four *MASTER ALARM* pushbutton indicators and the sounding of the klaxon) is triggered when there is a rapid change in cabin pressure with respect to time.
- Class 2 alarms include primary (hardware) and backup (software) systems. The crew interfaces with the primary C/W system through the 40-light annunciator matrix on panel F7 and a 120-parameter monitor on panel R13U. The interface with the backup (software) system is via software messages and SPEC 60 TABLE MAINT.
- Some Class 3 alerts warn the crew of a situation leading up to a class 2 alarm or of one that may require a long procedure.
- Class 0, a software system, consists of up and down arrows displayed on the DPS displays next to a parameter.
- The SPEC 60 TABLE MAINT display allows the crew to change limits, noise filter values, and status of backup C/W or alert system parameters.
- Pressing the *MASTER ALARM* light will silence the alarm and reset the light.
- Pressing the ACK key will stop the fault messages from flashing. Subsequent pressing of ACK key will scroll through fault messages.
- Pressing the MSG RESET key will erase fault messages from the DPS displays and extinguish the *SM ALERT* light.

C/W Rules of Thumb

- The *SENSOR RESET* switch on panel L1 should be pressed when smoke concentration goes below 1.8. This prevents masking of alarms.
- When panel R13U is not in use, the *PARAMETER SELECT* thumbwheels should be set to a value greater than 119.
- Crewmembers should reset fault messages as quickly as possible after review to avoid covering other messages.
- The fault summary should be reviewed regularly to avoid missed fault messages.

F7 Light Summary

NOTE

> A Class 2 audible tone and *MASTER ALARM* lights accompany the appropriate C/W light. Most lights are hardware-driven, but many parameters are also software-sensed by the PASS or BFS GPCs. The software provides a GPC fault message and illuminates the *BACKUP C/W ALARM* light. The hardware channels listed below are the same as the channels on the C/W STATUS light matrix on panel R13U. The color of each light is indicated by (R) for red and (Y) for yellow.

O2 PRESS (Y): Indicates an O2 tank 1, 2, 3, or 4 pressure or the O2 kit (Tank 5) pressure out of limits. The hardware channels are 0, 10, 20, 30, and 40 for Tanks 1, 2, 3, 4, and 5, respectively.

H2 PRESS (Y): Indicates either an H2 Tank 1, 2, 3, or 4 pressure or the H2 kit (Tank 5) pressure out of limits. The hardware channels are 50, 60, 70, 80, and 90 for Tanks 1, 2, 3, 4, and 5, respectively.

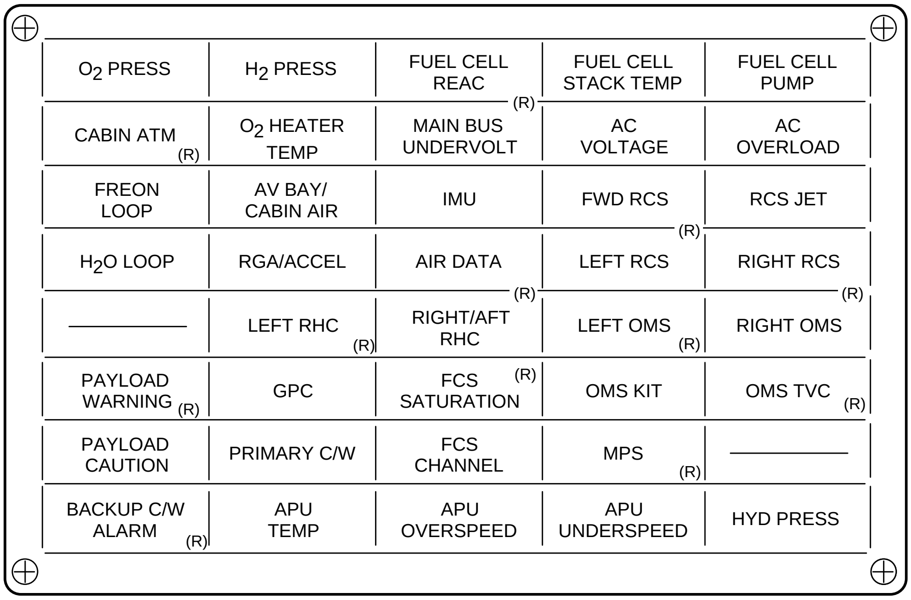
FUEL CELL REAC (R): Indicates an O2 or H2 Fuel Cell 1, 2, or 3 reactant valve is closed. The hardware channels are 2, 12, 22, 32, 42, and 52 for FC 1, 2, and 3 O2 and H2, respectively.

FUEL CELL STACK TEMP (Y): Indicates a Fuel Cell 1, 2, or 3 stack temperature out of limits. The hardware channels are 62, 72, and 82 for FC 1, 2, and 3, respectively.

FUEL CELL PUMP (Y): Indicates a Fuel Cell 1, 2, or 3 pump ΔP out of limits. The hardware channels are 92, 102, and 112 for FC 1, 2, and 3, respectively.

CABIN ATM (R): Indicates either cabin pressure, PPO2, O2 flow rate, or N2 flow rate out of limits. The hardware channels are 4, 14, 24, 34, 44, 54, and 64 for cabin press, O2 SYS 1 and 2 flow rate, PPO2 A and B, and N2 SYS 1 and 2 flow rate, respectively.

O2 HEATER TEMP (Y): Indicates an O2 Tank 1, 2, 3, or 4 heater temp or O2 kit (Tank 5) heater temp out of limits. The hardware channels are 1, 11, 21, 31, 41, 51, 61, 71, and 81 for O2 Tank 1 HTR 1 and 2, Tank 2 HTR 1 and 2, Tank 3 HTR 1 and 2, Tank 4 HTR 1 and 2, and Tank 5, respectively.



O_2 PRESS	H_2 PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O_2 HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H_2O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS	RIGHT RCS (R)
————	LEFT RHC (R)	RIGHT/AFT RHC	LEFT OMS (R)	RIGHT OMS
PAYLOAD WARNING (R)	GPC	FCS SATURATION (R)	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	————
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

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Caution and Warning Light Matrix on Panel F7

F7 Light Summary (continued)

MAIN BUS UNDERVOLT (R): Indicates main bus A, B, or C voltage low. The hardware channels are 3, 13, and 23 for main bus A, B, and C respectively.

AC VOLTAGE (Y): Indicates AC bus 1, 2, or 3 phase A, B, or C out of limits. The hardware channels are 33, 43, and 53 for AC bus 1, 2, and 3 respectively.

AC OVERLOAD (Y): Indicates an inverter 1, 2, or 3 phase A, B, or C output of 225 percent overload for 20 sec or 300 percent for 4 to 6 sec. The hardware channels are 63, 73, and 83 for inverter 1, 2, and 3 respectively.

FREON LOOP (R): Indicates a low Freon loop 1 or 2 flow rate or a temperature out of limits. The hardware channels are 106, 116, 107, and 117 for loop 1 and 2 flow rate, and loop 1 and 2 temp respectively.

AV BAY/CABIN AIR (Y): Indicates out of limits condition on cabin fan ΔP, AV Bay 1, 2, or 3 air out temp, or cabin heat exchanger air temp. The hardware channels are 74, 84, 94, 104, and 114 for cabin fan ΔP, AV Bay 1, 2, or 3 Temp, and CAB HX temp respectively.

IMU (Y): Indicates detection of an inertial measurement unit (IMU) failure or dilemma. The hardware channel is 103 and is a discrete driven from the GNC software.

FWD RCS (R): Indicates detection of an out of limits condition on a forward RCS oxidizer tank ullage pressure, fuel tank ullage pressure, or forward oxidizer or fuel leak. The hardware channels are 6, 16, and 26 for oxidizer tank press, fuel tank press, and leak respectively.

RCS JET (Y): Indicates detection of an RCS jet failed on, failed off, or leaking. The hardware channel is 96 and is a discrete driven from the GNC software.

H2O LOOP (Y): Indicates an out of limits condition on H_2O loop 1 or 2 pump out pressure. The hardware channels are 105 and 115 for loop 1 and 2 respectively.

RGA/ACCEL (Y): Indicates detection of a rate gyro assembly (RGA) 1, 2, 3, or 4 failure, or an accelerometer 1, 2, 3, or 4 failure. The hardware channel is 93 and is a discrete driven from the GNC software.

AIR DATA (R): Indicates detection of an air data transducer assembly (ADTA) dilemma. The hardware channel is 91 and is a discrete driven from the GNC software.

LEFT RCS (R): Indicates detection of a left RCS oxidizer, fuel tank ullage pressure out of limits, or left oxidizer or fuel leak. The hardware channels are 36, 46, and 56 for oxidizer tank press, fuel tank press, and leak respectively.

RIGHT RCS (R): Indicates detection of a right RCS oxidizer, fuel tank ullage pressure out of limits, or right oxidizer or fuel tank leak. The hardware channels are 66, 76, and 86 for oxidizer tank press, fuel tank press, and leak respectively.

SPARE: Available for future warning parameter growth.

LEFT RHC (R): Indicates detection of a left rotational hand controller (RHC) pitch, roll, and yaw disagree. The hardware channel is 100 and is a discrete driven from the GNC software.

RIGHT/AFT RHC (R): Indicates detection of a right or aft RHC pitch, roll, or yaw disagree. The hardware channel is 110 and is a discrete driven from the GNC software.

LEFT OMS (R): Indicates detection of a left OMS pod oxidizer, fuel tank ullage pressure out of limits, or an engine abnormal (OMS engine fail to cutoff, fail to ignite, or early shutdown) condition. The hardware channels are 37, 47, and 57 for the oxidizer, fuel tank press, and engine abnormal respectively. The hardware channels are 7, 17, and 27 for the oxidizer, fuel tank press, and engine abnormal respectively.

RIGHT OMS (R): Indicates detection of a right OMS pod fuel tank ullage pressure out of limits, or an engine abnormal (OMS engine fail to ignite, or early shutdown) condition.

F7 Light Summary (continued)

PAYLOAD WARNING (R): Indicates detection of up to five payload parameter inputs out of limits. The hardware channels are 55, 65, 75, 85, and 95.

GPC (Y): Indicates GPC 1, 2, 3, 4, or 5 has determined itself failed and issued a self-fail discrete. The hardware channels are 5, 15, 25, 35, and 45 for GPC 1, 2, 3, 4, and 5 respectively.

FCS SATURATION (Y): Indicates detection of elevon position or hinge moment saturation. The channel is 101 and is a discrete driven from the GNC software.

OMS KIT (Y): Indicates detection of an OMS kit oxidizer or fuel tank ullage pressure out of limits. The hardware channels are 77 and 87 for oxidizer and fuel respectively.

OMS TVC (R): Indicates detection of an OMS pitch or yaw gimbal failure. The hardware channel is 67. An OMS TVC failure may also result in a LEFT or RIGHT OMS light.

PAYLOAD CAUTION (Y): Indicates detection of a payload parameter input out of limits. The hardware channel is 97 and is not presently implemented.

PRIMARY C/W (Y): Indicates detection of a C/W system self-test failure internal to the C/W EU. The failures include the loss of power supply A or B, loss of A or B timing, or the inability of a C/W self-test parameter to pass limit check. No channel number. The parameter is internal to the C/W unit hardware itself. The light also illuminates each time the ESS 1BC C/W A circuit breaker is closed after being opened and extinguishes when the MASTER ALARM pushbutton indicator is depressed.

FCS CHANNEL (Y): Indicates detection of an elevon, rudder, or speedbrake actuator failure, SRB rock or tilt actuator failure, or MPS engine pitch and yaw actuator failure. The hardware channel is 111 and is a discrete driven from the GNC software.

MPS (R): Indicates detection of an MPS engine He tank press, He regulator out press, LO2 manifold press, or LH2 manifold press out of limits. The hardware channels are 9, 19, 29, 39, 49, 59, 69, and 79 for Engine 1, 2, and 3 He TK, He reg, and LO2 and LH2 pressure respectively.

SPARE (R): Available for future warning parameter growth.

BACKUP C/W ALARM (R): Indicates detection of a C/W alarm via SM, GNC, or BFS software monitoring. In OPS 2 SM parameter limits can be accessed, changed, enabled, and inhibited through SPEC 60 TABLE MAINT display.

APU TEMP (Y): Indicates an APU 1, 2, or 3 exhaust gas temp or lube oil temp out of limits. The hardware channels are 8, 18, 28, 38, 48, and 58 for APU 1, 2, and 3 EGT and lube oil temp respectively.

APU OVERSPEED (Y): Indicates an APU 1, 2, or 3 speed greater than a specified percentage of the designed speed. The hardware channels are 68, 78, and 88 for APU 1, 2, and 3 respectively.

APU UNDERSPEED (Y): Indicates an APU 1, 2, or 3 speed less than a specified percentage of the designed speed. The hardware channels are 98, 108, and 118 for APU 1, 2, and 3 respectively.

HYD PRESS (Y): Indicates a hydraulics system 1, 2, or 3 supply pressure out of limits. The hardware channels are 99, 109, and 119 for APU 1, 2, and 3 respectively.

Fault Message Table

The fault message table located in the FDF Reference Data Book provides a reference to crewmembers on all software-generated messages. The following explains the table and a typical fault message table is shown.

Message	The message column notes the exact message annunciated.
OPS availability	This column is broken into two subcolumns: PASS and BFS. Under each subcolumn is a list of GPC Operational Sequences (OPS) in which a particular message can be received.
Cause	This column lists the possible causes that drive the message.
Comments	This column provides additional clarifying notes. • Clarifies conditions that must be present for a message to be annunciated. For example, an FRCS LEAK message is generated for an OX/FUΔ QTY >9.5 percent, which is indicated by a bilevel discrete. • Identifies conditions with no corresponding long form malfunction procedure (in other words, NO MAL. • Identifies procedures or actions required when it is not clear. For example, the RCS LEAK ISOL PKT C/L procedure should be used for an F RCS He P msg. • Identifies impacts. Examples include "quantity calculation suspended" and "cause termination of auto sequence."

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
F RCS (cont)	RJET	G1,2,3, 6,8		• F RIGHT JET 2(4,5) FAIL ON/OFF/LK	• FAIL OFF DETECTION NOT PERFORMED IN MM101 & 102 FOR PASS
	UJET	G1,2,3, 6,8		• F UP JET 1(2,3) FAIL ON/OFF/LK	
	He P	G2,8	G,1,3,6	• F He (FU OR OX) TK P 2 LOW	• PKT C/L - RCS LEAK ISOL
	LEAK	G,2,3,8	G1,3,6	• PROP/He LEAK	• OX/FU Δ QTY > 9.5%
	PVT	G2,3,8		• LOSS OF P OR T DATA FRO RCS QTY CALC	• NO MAL • QTY CALC SUSPENDED
	TK P	G2,8	G1,3,6	• FWD RCS (FU OR OX) TK ULL PRESS HI/LOW	• QTY CALC SUSPENDED
S69 FC AMPS	1(2,3)	S2,4		• FC AMPS ↑↓	
SM1 FC AMPS 1(2,3)			SM		
S69 FC COOL P	1(2,3)	S2,4		• FC COOL P ↑↓	
SM1 FC COOL P 1(2,3)			SM		
S69 FC DELTA V	1(2,3)	S2,4		• FC SUBSTACK Δv > 150 MV	
SM1 FC DELTA V 1(2,3)			SM		
S69 FC EXIT T	1(2,3)	S2,4		• FC EXIT T ↑↓	
SM1 FC EXIT T 1(2,3)			SM		
S69 FC H2 FLOW	1(2,3)	S2,4		• FC H2 FLOW ↑	
S69 FC H2 PUMP	1(2,3)	S2,4		• FC H2 PUMP STATUS ↑↓	

Typical Fault Message Table

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2.3 CLOSED CIRCUIT TELEVISION (CCTV)

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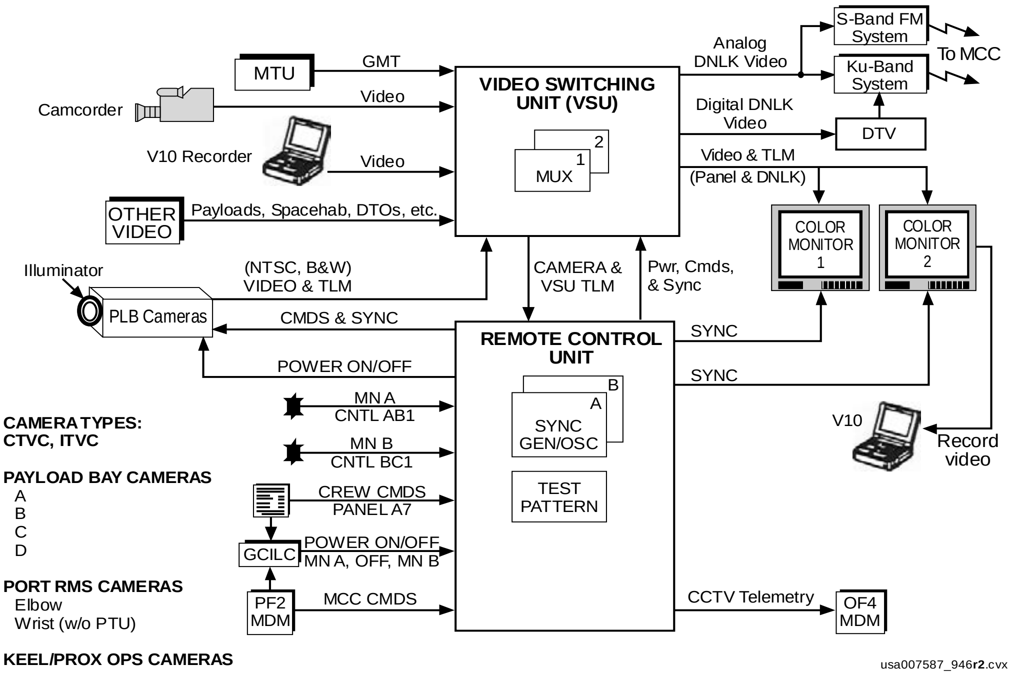
Description

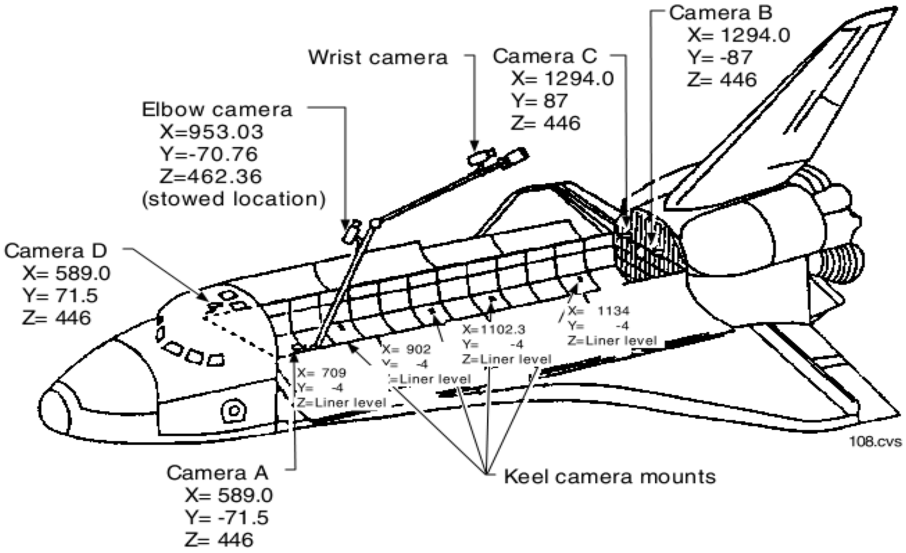
The closed circuit television (CCTV) system is used on orbit to provide support to orbiter and payload activities. This support includes transmitting real-time and recorded video from the orbiter to Mission Control Center through the S-band FM, S-Band PM, or Ku-band communications systems. Ku-band can be either analog or digital. Mission requirements for CCTV and camera configurations are specified in the Flight Requirements Document for each shuttle flight.

The CCTV system consists of video processing equipment, TV cameras, pan/tilt units (PTUs), camcorders, video tape recorders (VTRs), color television monitors (CTVMs), and all the cabling and accessories required to make these components work together. The crew can control almost all CCTV operations. Most CCTV configuration commands can be executed by the Instrumentation and Communications Officer (INCO) at Mission Control Center (MCC). Among the commands MCC cannot uplink are those to configure and operate loose CCTV equipment, such as camcorders and VTRs, wireless video system (WVS), digital television (DTV) system, and the selection of inputs to the color monitors.

Standard CCTV components are powered via circuit breakers located on panel R14. Flight-specific keel cameras (prox ops or berthing) are usually powered from a cabin payload bus. CCTV pushbuttons on panel A7U have lights to illuminate visual feedback on camera and CCTV routing configuration. These lights are powered via the ANNUNCIATOR light switches located on panel A6U.



CCTV System Overview



Payload Bay CCTV Camera Locations

CCTV Cameras

Three types of CCTV cameras are flown in the payload bay. The cameras are designated as color television camera (CTVC), intensified television camera (ITVC), and Videospection. The ITVC and Videospection camera are black-and-white (B&W) cameras. Camera names and locations are shown in the above diagram.

Some missions require additional cameras in the payload bay. These cameras are usually positioned in one or more of four keel camera mounts. Occasionally, these cameras are mounted on payload support structures and are used to assist with berthing operations. A CTVC mounted in the orbiter docking system (ODS) is used for docking missions as a centerline camera. The Videospection camera is used on a flight-specific basis.

All payload bay CCTV cameras have heaters for both the camera and the PTUs. These heaters are independently powered from circuit breakers located on panel R14. The heaters are thermostatically controlled and activate when the temperature reaches -8° C and turn off at 0° C. All CCTV cameras and PTUs in the payload bay are covered with thermal blankets.

Field sequential color (FSC) was selected by the Space Shuttle Program (SSP) as the color video standard rather than the National Television Standards Committee (NTSC) standard because NTSC cameras in the 1970s were much larger and consumed more power than their FSC counterparts. In addition, FSC cameras performed well for the Apollo program in the late 1960s and early 1970s. Today, miniaturization of electronics allows NTSC cameras (both CCTV and camcorders) to occupy a smaller volume and consume less power than in years past. The SSP retired the FSC lens assemblies and use only color or black and white NTSC cameras.

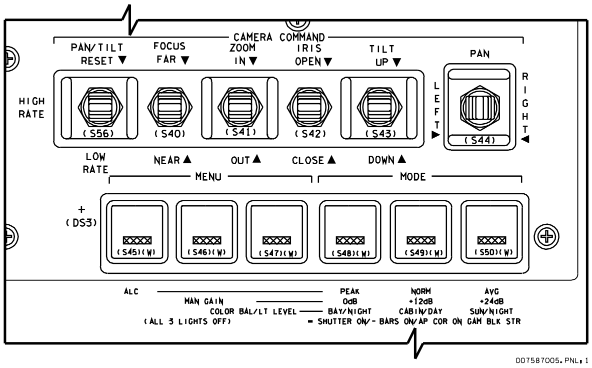
Color Television Camera (CTVC)

The CTVC provides an RS-170A (NTSC) color video signal that does not require additional processing in MCC prior to distribution to the media. NTSC is the color video standard in North America, Japan, and other areas. Great Britain and France are among nations with television standards other than NTSC.

The CTVC overall size is 16.0 inches long, 5.88 inches wide, and 5.94 inches high. The CTVC lens is encased within the CTVC housing. The CTVC has a maximum horizontal field-of-view of 77° and a minimum of about 9°. The CTVC uses three charge-coupled devices (CCDs) to take discrete samples of light passing through a prism after entering the lens. The red, green, and blue (RGB) light separated by the prism is directed to RGB CCDs. The CCDs are strobed by the camera's timing circuits to provide RGB component signals. The RGB signals are processed independently to provide color balancing. Payload bay floodlights, compact portable lights (CPLs) in the cabin, and sunlight are composed of different light spectra.

The nomenclature on the MENU and MODE pushbutton indicators (PBIs) is no longer used. A CTVC decal is used to assist crews in operating the CTVCs. This menu system for configuring the CTVCs provides control of the CTVC operating modes using existing PBIs and uplink commands.

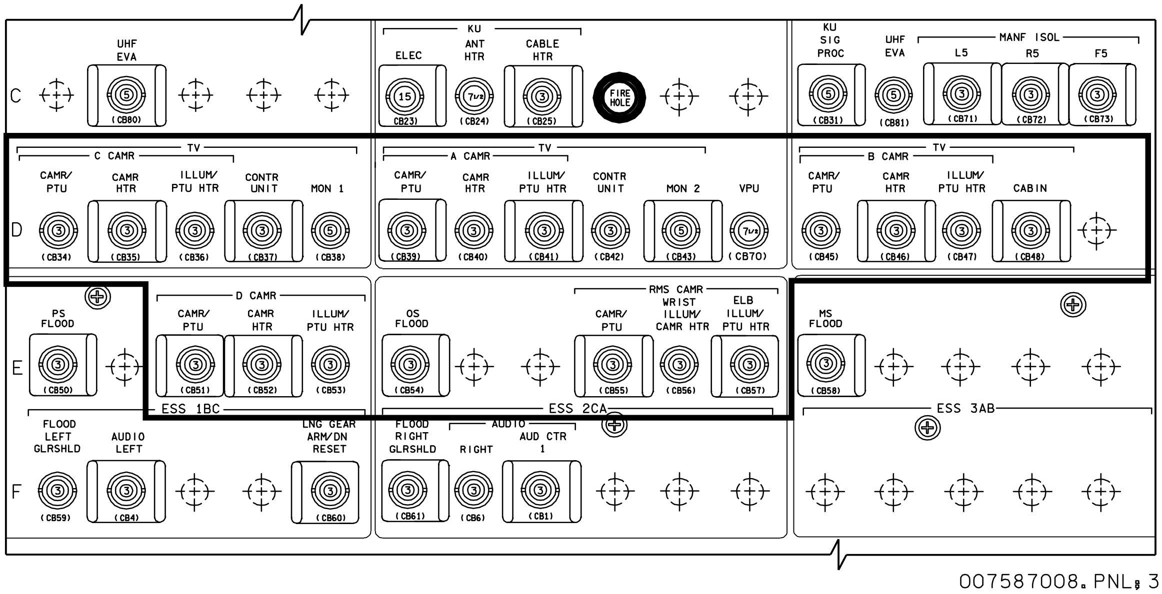
Color Television Camera (CTVC)



CTVC Decal

Intensified Television Camera

The ITVC is essentially a B&W version of the CTVC. The automatic light control (ALC), manual gain, and gamma settings are exactly the same. However, the ITVC has only one CCD (versus the three on CTVC) and is optimized for a low-light environment. Instead of color balance, the ITVC includes day and night operating modes. The night mode provides additional gain, which can be used with any ALC setting as well as manual gain settings. This feature allows a high gain option without sacrificing the ALC protection, particularly around orbital sunrise. A combination of night mode and manual gain 24 dB will make the ITVC sensitive down to 0.03 lux and provide a full-level output at around 0.02 lux.



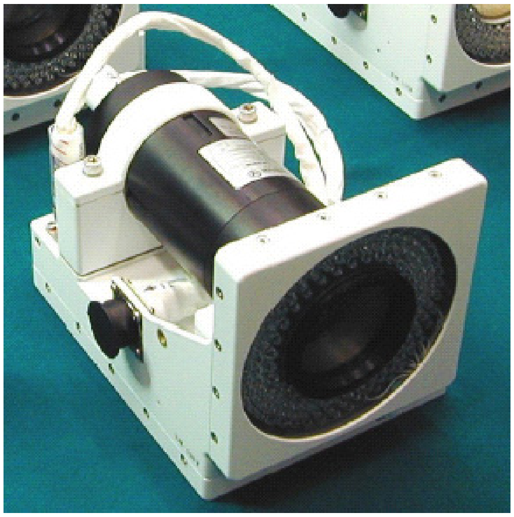
CCTV Circuit Breakers on Panel R14

If the night mode is used with daylight, the video will appear granular (noisy). The daylight mode essentially deactivates the night mode. The ITVCs also include an aperture correction (AP COR) that provides finer detail (improves resolution) if there is enough light. In low light conditions, the scene will look better if AP COR is off. Power-on defaults are similar to the ITVC. Manual mode of 0 dB is displayed on panel A7U and night operation mode and gamma black stretch are active in the background. The ITVC is configured using the CTVC decal.

Intensified Television Camera (ITVC)

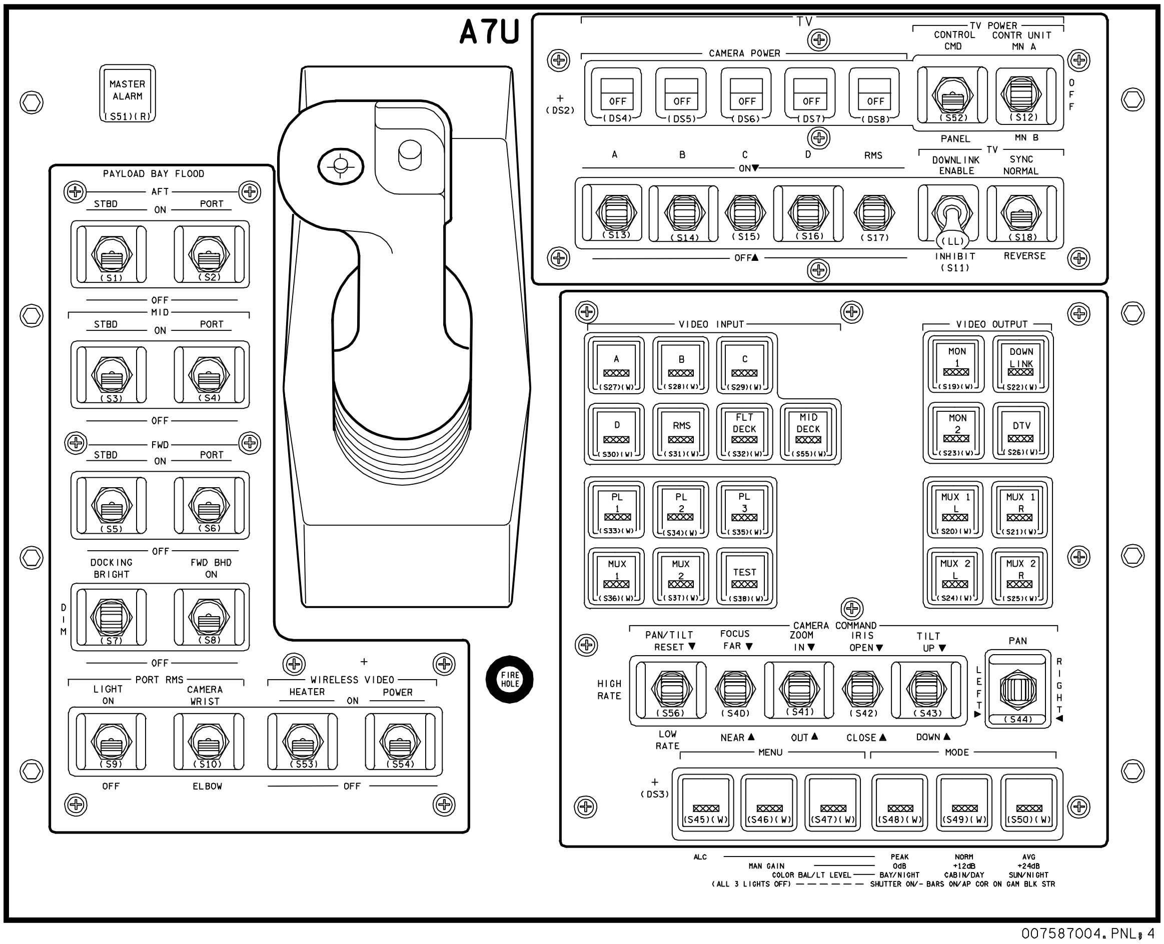
Camera Power

The CTVC and ITVC cameras have three associated circuit breakers (cbs) on R14: CAMR/PTU, CAMR HTR, and ILLUM/PTU HTR. In order to operate a camera, the appropriate CAMR/PTU cb needs to be pushed in. This cb also provides power to the PTU. The CAMR HTR cb provides power to each camera heater circuit that is thermostatically controlled. The PTU HTR enables the PTU heater circuits that are thermostatically controlled and also enables the logic for activating light emitting diode (LED) illuminators when flown.



Videospection Camera

The Videospection camera is a simple fixed focus, fixed field-of-view, B&W camera. It is either on or off, with no available controls to adjust the video it produces. It does automatically open and close its iris to adjust for different light settings. It is powered via a standard switch panel switch. It has been used as a keel/berthing camera for various payloads. It has also been attached to the remote manipulator system (RMS) end effector to provide a side view compared to the end effector camera. Due to this configuration, it has been known as the special purpose end effector (SPEE) camera or the RMS sideview camera (RSC). Like the CTVC and ITVC, it can also accommodate an LED illuminator to aid its low-light viewing situations. However, its illuminator may be a three-way illuminator that has low, medium, and high intensity settings.



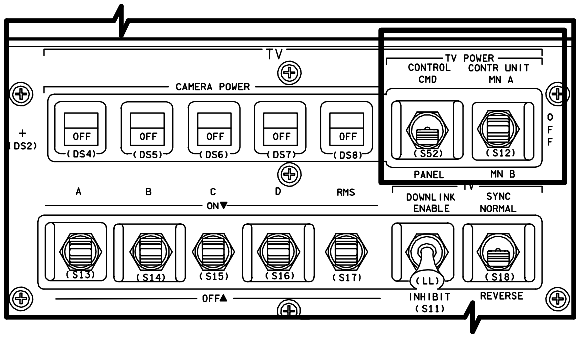
TV Control Panel A7

Video Processing Equipment

The video control unit (VCU) is the central processor/controller for the CCTV system. The VCU consists of two line replaceable units (LRUs): the remote control unit (RCU) and the video switching unit (VSU). Both LRUs are located behind panels R17 and R18 in the aft flight deck. These units are forced air cooled by cabin fans, although neither LRU includes a temperature sensor. An extension of the VSU is the video processing unit (VPU), which allows for more video interfaces than the VSU can provide. It is located in panel R12. The latest addition to the Shuttle video processing equipment is the DTV system, which is located at L10L. Finally, one non-installed piece of equipment is the sequential still video (SSV) system that allows the shuttle to send sequential still video snapshots to MCC during Ku-band loss of signal (LOS) periods.

Remote Control Unit

The RCU receives all CCTV commands from both the crew and MCC. Ground command interface logic (GCIL) control switch located on panel A7U determines whether MCC can send commands to the CCTV system. When the TV POWER CONTROL switch is in the CMD position, MCC can uplink commands to the CCTV system, and the crew will be able to use all panel A7U TV switches except the TV POWER CONTR UNIT MN A / OFF / MN B switch. This TV POWER CONTR UNIT switch enables GCIL drivers to power up the VCU through either DC Main A or B via panel R14, thus this is the one true GCIL switch. The GCIL drivers prevent the crew and MCC from activating or deactivating the VCU simultaneously. When the GCIL TV POWER CONTROL switch is in PANEL, the crew can configure the TV POWER CONTR UNIT switch to provide VCU power or to turn the VCU off. All uplink commands to the CCTV system are inhibited when the GCIL switch is in PANEL.



007587007.PNL;3

TV POWER Controls on Panel A7U

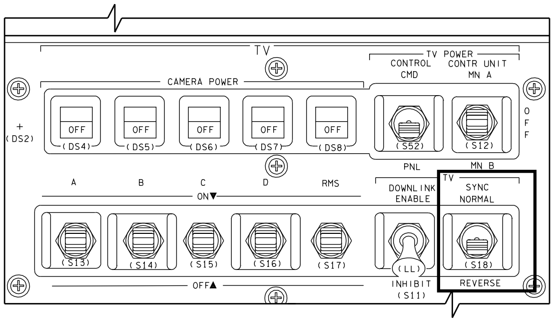
Uplink commands to the RCU must pass through payload 2 mutiltiplexer/demultiplexer (PF2 MDM). The VCU power MN A / OFF / MN B commands to the GCIL drivers use PF1 or PF2 MDM like all other GCIL commands. However, if the GCIL Main C circuit power provided from panel R14 were to fail, the RCU will inhibit all uplink CCTV commands, except for the VCU power-on commands. The crew can send any uplink CCTV command by executing a real-time command (RTC) on SPEC1 of the Systems Management General Purpose Computer (SM GPC). The TV POWER CONTROL switch must be in the CMD position for crews to use this feature. Crews do not carry any CCTV specific RTCs in any Flight Data File (FDF) documents. This capability would only be used if MCC were unable to uplink commands or for functions not available from panel A7U. The RCU includes two independent video sync generators. The sync generators are tied to the power on logic and TV SYNC NORMAL/REVERSE switch on panel A7U.

When the TV SYNC switch is in NORMAL, sync generator A is powered by Main A with sync generator B on Main B. The bus that powers the VCU also applies power to the sync generator tied to that bus. When the TV SYNC switch is in REVERSE, sync generator A is tied to Main B and sync generator B is tied to Main A. This feature is provided to allow the crew to switch sync generators without power cycling the VCU in case of a sync generator failure. MCC can see the status of this switch, but cannot send a command to switch sync generators without switching main bus power sources.

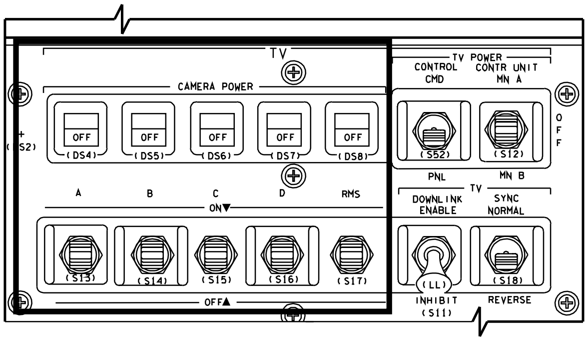
In addition to generating master sync signals, the RCU also generates a full-field test signal, better known as a test pattern. The test pattern is black and white. The test pattern can be selected as a video source from panel A7U or via an uplink command.

The sync signal is distributed to CCTV cameras and the VSU for synchronization purposes. Commands to the cameras are embedded in the sync signal. Each camera has a unique address. This address is sent out with the command in the sync signal. Therefore, only the correctly addressed camera will respond to the command. Uplinked commands are sent on a different sync (horizontal scanning) line than A7U commands. It is possible for the crew and MCC to send conflicting commands to a camera at the same time; coordination between crew and MCC is very important to prevent potential conflicts. Usually, the crew configures cameras and MCC selects cameras for downlink. Prior to launch, each crew should talk with the lead INCO for their flight to work out CCTV responsibilities during crew activity and sleep shifts.

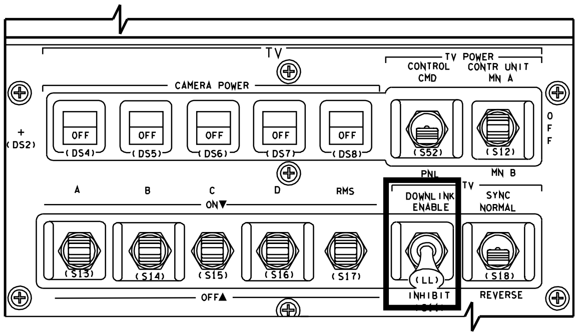
The crew activates payload bay cameras using the TV CAMERA POWER switches located at the top of panel A7U. These switches are momentary in both the ON and OFF positions. The ON/OFF talkbacks are set by the RCU. The talkbacks indicate the status of a 28 V dc discrete signal that enables a remote power controller (RPC) to provide panel R14 circuit breaker power to a payload bay camera and PTU. The talkback status can be misleading because the talkback can indicate ON when the circuit breaker that provides power to the camera is out. Crews should always use these switches to power off the cameras prior to deactivating the VCU to ensure correct camera powerdown.



TV SYNC Switch on Panel A7U



CAMERA POWER Switches and Talkbacks on Panel A7U



TV DOWN LINK switch on Panel A7U

There are two RMS camera switches to note. In addition to the RMS TV CAMERA POWER switch, another RMS camera switch is located below the aft rotational hand controller (RHC) on panel A7U. The RMS CAMERA WRIST/ELBOW select switches toggle between the wrist (end effector) and elbow cameras. Only one RMS camera can be activated at a time. Cycling the switch powers off one camera and powers on the other. MCC cannot select between the wrist and elbow cameras nor can MCC identify the position of the switch using downlinked telemetry.

In addition to TV SYNC NORMAL/REVERSE and RMS CAMERA WRIST/ELBOW switches, MCC is unable to configure the TV DOWNLINK ENABLE/INHIBIT switch function. This lever lock switch inhibits the VSU output to the analog downlink Ku-Band and S-Band FM communications systems. This switch can be used to ensure that no video is downlinked during "sensitive" mission operations. For the majority of mission operations, this switch should be in the ENABLE position. MCC receives telemetry that indicates the position of the TV DOWNLINK switch. For DTV, this enable/ inhibit function is performed by the MUX/ VTR/CC switch on the DTV MUX on panel L10L.

The RCU provides some telemetry to the pulse code modulation master unit (PCMMU) via OF4 MDM. This includes camera overtemp, downlink enable, VCU power source, sync normal/reverse, sync generator active, and "camera select." The camera select is the camera selected for downlink. This may be a different camera from the one the crew or MCC is commanding at the time. The crew and MCC can command different cameras at the same time. The ALC/Gamma status of the downlink camera will be included in the telemetry to the PCMMU.

Video Switching Unit (VSU)

The VSU can accommodate up to 13 video inputs and 7 outputs. However, panel A7U only provides for 10 inputs and 4 outputs. Adding pushbuttons to expand the VSU operational capability has been determined by the SSP as being too expensive for the increase in capability and is planned for the advanced VPU.

The VSU is used to route video from a source to a destination. All commands to the VSU are processed by the RCU before being sent to the VSU. Note that the crew routes video by selecting a destination and then a source, whereas MCC selects a source and then a destination. When the crew selects a destination on panel A7U, that output PBI illuminates. Once an input is selected for that particular output, the input PBI will illuminate as well. If the input is a camera, the crew can select ALC/Gamma PBI settings and/or send PTU/lens commands to that camera and pan/tilt unit.

The VSU is synchronized to the RCU via the sync generators. This allows the VSU to change video sources for a destination at the end of a video field to prevent visible picture distortion when the video switches engage. The synchronization of the CCTV also allows the VSU to read CCTV camera telemetry. The VSU can read camera ID, temperature, and pan/tilt angles. If the VSU detects a camera exceeding 45° Celsius, an overtemp warning is sent to the RCU. The RCU sets a telemetry bit high so that the SM GPC will annunciate a SM Alert and a S76 COMM CAM TEMP message. The temperature limit is set in the VSU and cannot be changed by a table maintenance block update (TMBU). A TMBU can be used to inhibit the SM alert and message.

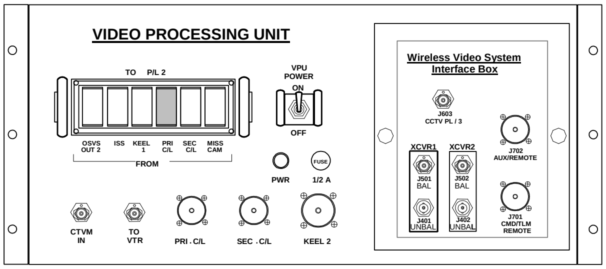
The VSU is also capable of generating multiplex (mux) scenes that appear as a split screen of two CCTV cameras. The VSU takes the center portion of a camera scene and places it on the left or the right side of the mux picture. The VSU determines where to extract the center portion of the video source from the RCU's sync signals. The VSU can only mux synchronous video sources. VTR playback and camcorders cannot be muxed by the VSU.

The VSU receives GMT from the orbiter timing buffer. The GMT is formatted and inserted in the vertical retrace interval by the VSU, using sync timing from the RCU as a reference. This GMT is inserted in all incoming video lines when the VSU is in the sync mode. Since both camcorders and VTRs are asynchronous devices (i.e., not in sync with the RCU), the VSU fails to insert the GMT timetag in the correct location of the asynchronous video. Crews and flight controllers will see this as a thin, flashing, segmented white line that scrolls across the screen of the color monitors and in the downlink video. The VSU interprets the GMT as an elevated camera temperature. This will produce a false SM S76 COMM CAM TEMP message. An asynchronous (async) mode command is available to inhibit GMT timetags and disable the VSU's temperature sensing circuits. The async mode affects camera mode sensing in the VSU. The ALC and Gamma pushbuttons on panel A7U may remain static and not reflect the true configuration of standard orbiter payload bay cameras. This async mode is usually enabled for VTR playback to downlink and for downlinking camcorder video. Otherwise, a white line will be visible in the scene.

The asynchronous mode does not mean that the CCTV System is no longer synced together. CCTV cameras are still slaved to the RCU, as is the VSU. Since almost all payload customers require a GMT timetag in recorded and real-time video, crews and flight controllers must coordinate the use of async mode.

Video Processing Unit

The VPU first flew on STS-92 in October 2000. The VPU provides two video signals from the orbiter CCTV system to the International Space Station (ISS) and provides one video signal from the ISS to the orbiter CCTV system. The VPU also provides the capability to patch one of six video inputs to the CCTV PL2 video input of the VSU. A subcomponent of the VPU is the wireless video system (WVS) interface box (WIB). The WIB provides the in-cabin communication link to the WVS system. WVS is a wireless extravehicular activity (EVA) helmet camera system controlled by a laptop in the crew cabin and can provide a single video signal into the TV system via the PL3 VSU input and a view from each helmet to a Sony V10 for viewing and recording. Each EVA helmet can provide a single view from one of three available lenses. Commands to the helmet are transmitted via one *ultrahigh frequency* (UHF) antenna, while video returns via one of seven S-band antennas in the payload bay. The VPU is located on panel R12 and is powered by a circuit breaker located on MN B R14 Row D.



Video Processing Unit

Digital Television

The DTV system first flew on STS-110 in April 2002. The DTV system provides the shuttle with the capability to downlink a video signal in a digital format. It takes any analog NTSC formatted video signal from the CCTV system, converts it to a digital signal, and records and/or downlinks it to MCC via the Ku-band channel 3 PAYLOAD MAX channel. The system hardware is located in L10L and consists of three main components: the vertical interval processor (VIP), a Sony DSR-25 VTR, and a multiplexer (mux).

The VIP is AC powered from AC2 PAYLOAD 3 Phase. It conditions the video, audio and vertical interval for processing by the DSR-25 VTR.

The Sony DSR-25 VTR takes the signals from the VIP, converts it to digital, and passes it to the mux. It provides up to 3 hours of video recording and is DC powered from the mux.

The mux organizes the data for processing by the Ku-band system. It receives its DC power from the PAYLOAD AUX bus and provides power for the VTR and can directly power a camcorder. MCC only has insight to the status of the DTV mux when the mux is on and a Ku-band link is established. INCO will configure the Ku-band system between a digital downlink (channel 3 PL MAX) and an analog downlink (channel 3 TV).

Digital Television (DTV) Hardware

Sequential Still Video (SSV)

The SSV system provides MCC with the capability to view a video signal from the shuttle without having to rely on Ku-band signal coverage. It utilizes the S-band PM system, which has more coverage than the Ku-band system. Unfortunately, it can only provide a snapshot of the video signal that is refreshed periodically. This refresh rate is dependent upon a sample rate and the available downlink rate through the shuttle S-band data system, but is typically every 10 seconds.

For the SSV to work, the crew must configure a compression encoder box and cables in the crew cabin. The encoder digitizes the video signal to be downlinked to MCC as data instead of video. Once configured, INCO has the only control of the signal being routed to the encoder box from the VSU SPARE 1 video output, which is not available to the crew on panel A7U.

SSV Compression Encoder

CCTV Camera Lens Control

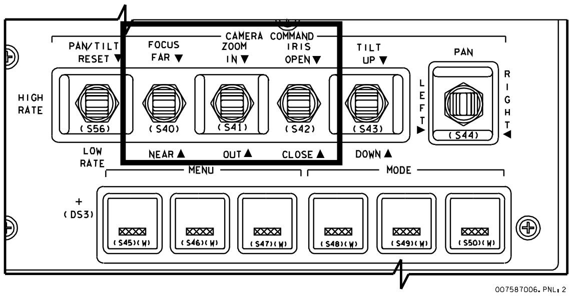
The CTVC and ITVC cameras are normally operated in an ALC mode; the three ALC settings are peak, normal, and average. To select an ALC mode, the crew will use panel A7U MENU and MODE pushbuttons. MCC/INCO can also select ALC settings via uplink commands. The peak ALC setting is most sensitive to incoming light; therefore, the iris will allow less light to enter the lens than with an ALC setting of normal. The average ALC setting will command the iris to open more and increase the voltage gain when compared to the ALC setting of normal.

Each CCTV camera type uses the same switches and command sequences to adjust the field-of-view of the camera. Just above the six MENU/MODE PBIs is a row of switches used to send commands to the cameras and PTUs.

Lens commands are used to adjust the lens and iris settings. The focus, zoom, and iris commands provide the crew and MCC with direct control of lens settings. The CTVC and ITVC insert lens data into the video. The color monitors are able to display the lens data in the upper portion of the monitor's display. This data is also available to INCO in the MCC. In addition to changing the field-of-view, the zoom function can affect the apparent scene brightness when the camera is in an ALC mode. As bright objects increase or decrease in size, the ALC adjusts accordingly to increase or decrease the amount of light entering the lens. The IRIS switch provides manual control of the iris to the user. Use of this switch or an iris open/close command by MCC disables ALC. When using this switch, crews must not leave the payload bay cameras unattended.

NOTE

Direct sunlight can permanently damage these cameras if a camera iris remains open.



Focus, Zoom, and Iris Control

Pan/Tilt Units

The PTUs are used with cameras A, B, C, D, and the RMS elbow. The PTUs are used to change the camera field-of-view by moving a camera about two axes. The PTUs can pan and tilt 170° in either direction, positive or negative, when any CCTV camera is attached.

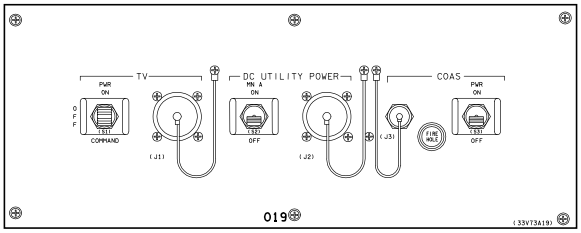
The PAN/TILT RESET/HIGH RATE/LOW RATE switch on panel A7U is used to configure the rate of movement for the PTU of the camera selected. The RESET position is momentary and resets the camera's pan/tilt coordinates to zero. The HIGH RATE position allows the PTU to pan and tilt at a rate of 12° per second. The LOW RATE position allows the PTU to be commanded at a rate of 1.2° per second. The TILT UP/DOWN and PAN LEFT/RIGHT momentary switches are used to initiate and maintain movement about the tilt and pan axis until the switches are released or a hardstop is encountered. Pan and tilt commands can be executed simultaneously. The PTUs may encounter clutch slippage during operation, particularly when configured for high rate. When the clutch slips, there is a temporary suspension in PTU movement. The camera will continue counting during this period because there is no feedback from the PTUs to the camera to suspend counting. This affects the accuracy of camera pointing in support of payload activities.

Pan/Tilt Unit and Camera with Thermal Blankets

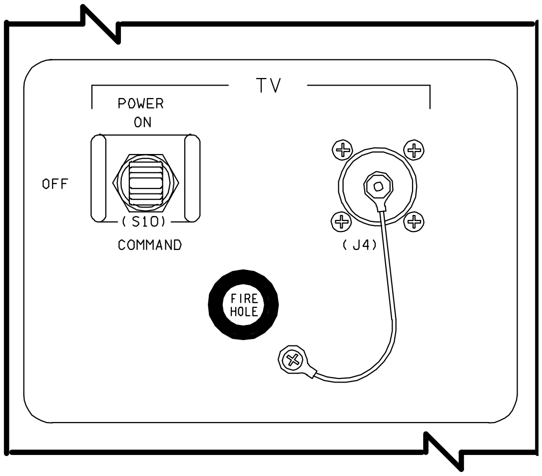
MCC is capable of configuring the pan/tilt rate to be different from what the crew has set. For uplinked commands, the rate defaults to high during CCTV activation. INCOs usually use the low rate for more effective management of CCTV camera movement because of the time delays in the orbiter's communications systems.

Cabin Cameras

Although all CCTV cameras are compatible with the TV outlets located on panels O19 and MO58F, there are no plans to regularly use these cameras in the flight deck or middeck areas. Camcorders have replaced the CCTVs in the orbiter crew compartment. In addition to providing excellent real-time video, the camcorders can also record and play back video without using an external video recorder. The current main cabin camera is the Sony PD100 camcorder. Another cabin camera that is used in the shuttle is called the minicam. Unlike the camcorder, it only produces a video signal.



Cabin Camera Power Connectors/Control on Panel 019



Cabin Camera Power Connectors/ Controls on Panel MO58F

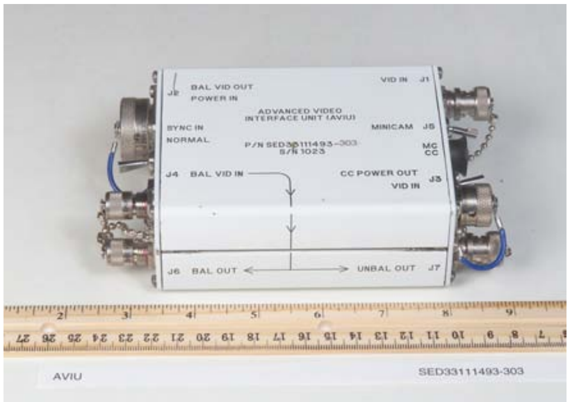
Sony PD100 Camcorder

The Sony PD100 digital camcorder is a commercial off-the-shelf (COTS) device that can be used in one of three ways. It can be used either as a camcorder to record video captured by its integrated lens, a video camera that can send a video signal into the orbiter TV system, or a VTR that can record and playback video with audio if needed. It processes video with three CCDs, one for each color. It has a wide conversion lens that can be attached to the integrated lens to widen its field-of-view. It has an integrated 3.5-inch liquid crystal display (LCD) monitor that can be used to view live camera video or playback VTR video. It uses a 40-minute digital DVCAM format tape for its video recording/playback operations.

The PD100 can operate from either orbiter power via an advanced video interface unit (AVIU), from the DTV MUX, by battery power or by a camcorder power interface (CCPI) unit. The AVIU must be connected to either of the TV ports. The battery is a Canon camcorder battery, which requires an adapter to allow it to be used on the Sony camcorder. The battery lasts from 40 to 60 minutes depending on how the camcorder is used. This same adapter is required to power the camcorder from an AVIU. No adapter is required when powered from the DTV MUX. The CCPI can be connected to either a TV port or from an orbiter DC power port. The CCPI can power up to two camcorders along with one compact portable light (CPL). The CCPI can only supply power, not transform return video. The CCPI and CPL are rarely used.

The PD100 can record, playback or generate live video in either analog or digital formats. Live analog video from the camcorder must go through the AVIU to be converted from unbalanced to balanced video. It is then routed into either of the TV ports. Live digital video from the camcorder can go directly into the DTV MUX with a single cable. Video from a connector on the back of the color monitors can be sent to the camcorder to be recorded. The AVIU is required to convert the balanced output video of the monitor to an unbalanced signal usable by the camcorder. The vertical interval (VI) data that is imbedded in this video cannot be recorded by the camcorder. An audio terminal unit (ATU) recorder cable is required to interface with the orbiter audio system to record and playback analog audio. Although the camcorder can record and playback stereo audio signals, the orbiter audio system is not capable of transmitting or receiving stereo (one audio channel only).

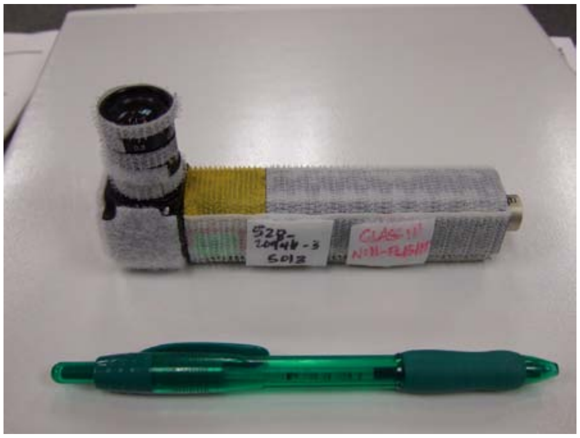
Sony PD100 Camcorder



Advanced Video Interface Unit (AVIU)

Minicam

The minicam is a small Sony XC-999 single-CCD video camera that can route NTSC video into either of the orbiter TV ports. It requires an AVIU for power and video conversion. The four lenses that screw into the camera body are a fish-eye 3.5mm lens, a normal 6mm lens, and two telephoto lenses (12mm and 23mm). Since it is just a camera, it requires an LCD monitor to view the video and some kind of VTR to record the video. The minicam is used for ascent and entry video and is sometimes used during the on-orbit phase of flight as another in-cabin camera in addition to the camcorder. *Minicam video can be configured to be a synchronous video source or an asynchronous video source per AVIU switch configuration.*



Minicam body

Minicam lenses

VTRs

Even though the PD100 camcorder can be used as a VTR, it normally is not used in that manner on orbit. This task is left to one of two VTRs in the crew cabin: a small, portable Sony V10 VTR and the DTV VTR (Sony DSR-25) that is an integrated part of the DTV system. Both are digital recorders that are in the same family as the PD100 camcorder so all of the video recorders work well with each other and share the same tape types/formats.

Sony V10 VTR

The Sony V10 digital VTR is a COTS video recorder/player that can be used in-cabin for various tasks. It is powered just like the Sony PD100 camcorder and can record video through an AVIU just like the camcorder. It has an integrated 5.5-inch LCD monitor that can be used to monitor video being sent to the VTR or for viewing playback video. It uses the same 40-minute DVCAM digital tapes that the camcorder uses. It can also record and play back orbiter audio just like the camcorder. Like the PD100, the V10 can record and/or play back analog or digital video and audio. Also like the PD100, the V10 cannot record VI data that is imbedded in the orbiter analog video. This means that information like payload bay camera settings and GMT time will not be recorded. The only way to record this data is with the DTV VTR.

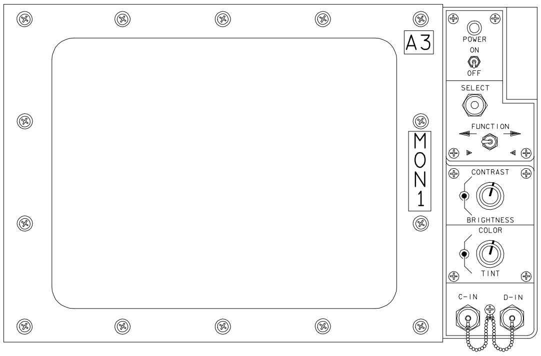
Sony V10 VTR

The DTV VTR is an integrated part of the DTV system. *The DSR-25 replaced the DSR-20 after tape jamming failures were discovered on STS-107 and STS-114 that were specific to the DSR-20. The DSR-25 first flew on STS-115 as the official replacement in September of 2006. It is installed in a bucket at L10L along with the VIP.* It is a digital VTR that performs the analog-to-digital conversion for the DTV system. It provides a built-in, long-duration video recording and playback capability for the crew. It can use either the 40-minute DVCAM digital tapes that the PD100 and V10 use or a 3-hour DVCAM digital tape without any special adapters. Unlike the other units, it can record the VI data that the VIP strips from the orbiter video signal. It records this data on its audio channel 2. Orbiter audio can be recorded on its audio channel 1 via the direct link to the VIP and a cable connected to a crew communications umbilical (CCU). Playback video/audio/VI data from the DSR-25 is designed to be sent to MCC via the digital downlink route. It can be configured to downlink video and audio through the analog downlink route in an alternate configuration. The DSR-25 does have an integrated monitor to view live or playback video. The crew can also route a video monitoring signal to either one of the CCTV monitors (nominal), a V10 VTR, or a battery operated LCD monitor.

Sony DSR-25 VTR

Monitors

The CCTV system uses a variety of monitors to display video. Two color television monitors located on panel A3 are always flown. The color monitors replaced B&W monitors that had been flown since the beginning of the SSP. Portable LCD monitors are flown to display camcorder and VTR video without having to use either CCTV color monitor.



Color Television Monitor (CTVM)

CCTV Color Monitor

The CTVMs are the primary display equipment of the CCTV system. These 10-inch monitors display NTSC and FSC color. Rotary knobs are used to control the contrast, brightness, color, and tint of the video displayed. The color and tint are only effective displaying NTSC video; they are not effective with FSC video.

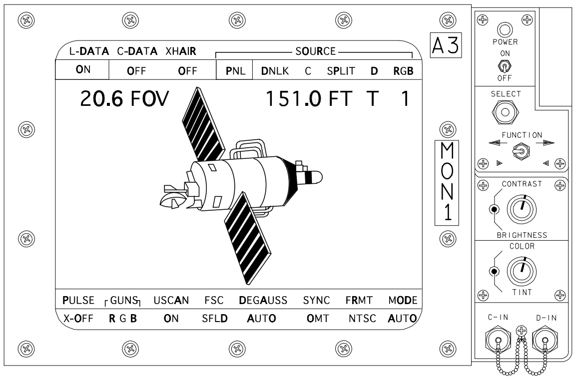
Each monitor uses a graphical menu for configuration control. The menu can be displayed by activating either the FUNCTION or SELECT controls. The menu will be displayed for 12 seconds after the last command (FUNCTION or SELECT) is executed. The FUNCTION switch is used to move through different menu headings. The SELECT pushbutton allows the user to toggle between different options within each menu heading.

The menu can be used to enable viewing of CTVC/ITVC lens data, CCTV camera data, and crosshairs. Data and crosshairs that appear green are characters generated within the color monitor and can be activated by selecting GRN for camera data and crosshairs by turning on lens data. White characters are generated within the VSU and can be displayed by selecting WHT for camera data and crosshairs. Lens data will display zoom, focus, and iris settings of the CTVC and ITVC cameras. These fields are static when a video source other than a CTVC or ITVC is displayed. Lens data, when activated, will appear at the top of the screen. The camera data will display camera ID, pan and tilt angles, and temperature, although the white data displays temperature of the camera only when the VSU detects a camera with an elevated temperature. Camera data is displayed in the lower portion of the screen.

Each color monitor can select from one of five independent video sources. PNL will display any video routed to the monitor using panel A7U. The DNLNK will allow the user to view any video selected for downlink. The C and D selections will view video from equipment connected to the C IN or D IN connectors on the front of the monitor. RGB will allow the user to view video that directly drives the red, green, and blue electron guns of the monitor (such as NTSC component). The RGB connector is located on the rear panel of the monitor. SPLT is another source available and provides a split screen image of C and D inputs.

There are two ground checkout menu functions on the lower left portion of the menu (PULSE-X ON/OFF and GUNS R G B). USCAN ON/OFF enables or disables the underscanning feature. When ON, the underscan allows viewing of edge-to-edge video (horizontal and vertical) with no loss of image data; i.e., you see what the camera sees. When USCAN is OFF, about 5 percent of each horizontal and vertical edge is lost. In addition, the top line of the upper menu and the bottom line of the lower menu cannot be seen when USCAN is OFF. The FSC function selects between 6FLD (6 field) and 3FLD (3 field). This feature determines how often FSC color is updated to the screen. 6FLD is the default and preferred setting, except for viewing FSC video of objects in rapid motion. This function only applies to cameras with wide-angle lens assembly (WLA) or color lens assembly (CLA) lenses. The DEGAUSS function dissipates magnetic fields that build up around the monitor as the orbiter moves at high speed through the Earth's magnetic field, but only when DEGAUSS is in the default AUTO position. AUTO engages the degaussing circuitry every 90 seconds. OFF disables this feature.

The SYNC function of the monitor displays the source of sync used to display video and graphics (menu and green data). When no video is detected by the monitor, the field under SYNC will indicate EXT for external source. This means that the sync line from the RCU to the monitor is providing the sync pulses necessary to display the menu and data. This field can be useful for quick troubleshooting for loss of video (camera power fail vs. iris stuck closed).



CCTV color monitor with menu and L-Data

Video format can be selected manually or automatically. The CTVMs default to AUTO MODE in which the monitor determines the video format from data embedded in the CCTV camera video. CTVCs will use the NTSC format, and ITVCs will use B&W decoding. Camcorders do not provide this data; hence the monitors will process the camcorder video using the default NTSC converter. The crew can override the AUTO selected format by taking MODE to MAN and then toggling the FRMT to select NTSC, FSC, or B&W. If a mux scene is routed to a monitor, the monitor will select FSC because of the nature of the video processing by the VSU in creating the mux scene. In order to display NTSC color from a CTVC in a mux scene, the user must manually override the format and select NTSC.

The CTVMs have a connector labeled J3 on the rear of the monitor. This connector provides a balanced video signal of whatever video is routed to the monitor output pushbutton on panel A7U. A VTR or a camcorder can record this video. Any VSU (white) data requested by the monitor will be recorded by the camcorder. Monitor (green) data will not be recorded.

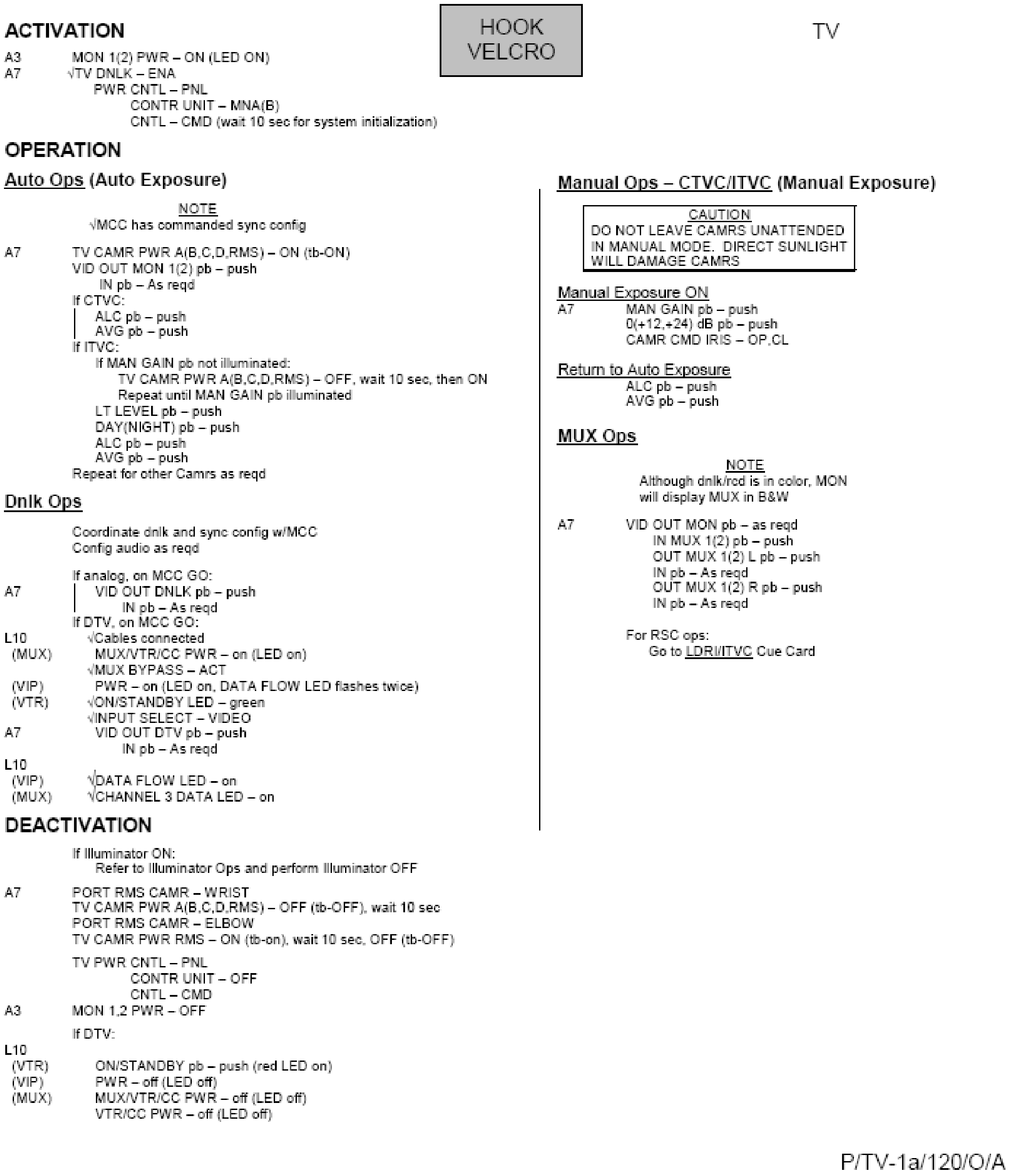
LCD Monitor

The LCD monitor is a battery operated monitor that can be used with any analog video device to display video. Typical uses are with a camera such as the minicam or with the DTV VTR for playback or live video such as entry video. It takes six AA batteries that are placed in a separable battery compartment with all of the batteries arranged in the same orientation. It will only appear to work when video is actually flowing into the device and it will drain batteries at a relatively rapid rate. Therefore, it is not used very often.

LCD Monitor

TV Cue Card

The TV cue card includes activation procedures for the CCTV system and payload bay cameras. This cue card also includes steps that can command the cameras to different operating modes. The steps indicated are good guidelines for setting up cameras in a safe (ALC active) configuration. However, crews should not hesitate to command cameras out of their normal operating modes. Since lighting conditions on orbit are quite dynamic, ALC modes, manual gain modes, and gamma settings may require changes. Crews should take the initiative and adjust the cameras to provide the best possible video of the object(s) in view. CCTV camera operation is more of an art than a science when it comes to getting acceptable looking video. However, please note the caution block, as the CCTV cameras are susceptible to damage by direct sunlight while in a manual mode.



HOOK
VELCRO

TV

ACTIVATION

A3 MON 1(2) PWR – ON (LED ON)
A7 √TV DNLK – ENA
PWR CNTL – PNL
CONTR UNIT – MNA(B)
CNTL – CMD (wait 10 sec for system initialization)

OPERATION

Auto Ops (Auto Exposure)

NOTE
√MCC has commanded sync config

A7 TV CAMR PWR A(B,C,D,RMS) – ON (tb-ON)
VID OUT MON 1(2) pb – push
IN pb – As reqd
If CTVC:
ALC pb – push
AVG pb – push
If ITVC:
If MAN GAIN pb not illuminated:
TV CAMR PWR A(B,C,D,RMS) – OFF, wait 10 sec, then ON
Repeat until MAN GAIN pb illuminated
LT LEVEL pb – push
DAY(NIGHT) pb – push
ALC pb – push
AVG pb – push
Repeat for other Camrs as reqd

Dnlk Ops

Coordinate dnlk and sync config w/MCC
Config audio as reqd

If analog, on MCC GO:
A7 VID OUT DNLK pb – push
IN pb – As reqd
If DTV, on MCC GO:
L10 √Cables connected
(MUX) MUX/VTR/CC PWR – on (LED on)
√MUX BYPASS – ACT
(VIP) PWR – on (LED on, DATA FLOW LED flashes twice)
(VTR) √ON/STANDBY LED – green
√INPUT SELECT – VIDEO
A7 VID OUT DTV pb – push
IN pb – As reqd
L10
(VIP) √DATA FLOW LED – on
(MUX) √CHANNEL 3 DATA LED – on

DEACTIVATION

If Illuminator ON:
Refer to Illuminator Ops and perform Illuminator OFF

A7 PORT RMS CAMR – WRIST
TV CAMR PWR A(B,C,D,RMS) – OFF (tb-OFF), wait 10 sec
PORT RMS CAMR – ELBOW
TV CAMR PWR RMS – ON (tb-on), wait 10 sec, OFF (tb-OFF)

TV PWR CNTL – PNL
CONTR UNIT – OFF
CNTL – CMD
A3 MON 1,2 PWR – OFF

If DTV:
L10
(VTR) ON/STANDBY pb – push (red LED on)
(VIP) PWR – off (LED off)
(MUX) MUX/VTR/CC PWR – off (LED off)
VTR/CC PWR – off (LED off)

Manual Ops – CTVC/ITVC (Manual Exposure)

CAUTION
DO NOT LEAVE CAMRS UNATTENDED IN MANUAL MODE. DIRECT SUNLIGHT WILL DAMAGE CAMRS

Manual Exposure ON
A7 MAN GAIN pb – push
0(+12,+24) dB pb – push
CAMR CMD IRIS – OP,CL

Return to Auto Exposure
ALC pb – push
AVG pb – push

MUX Ops

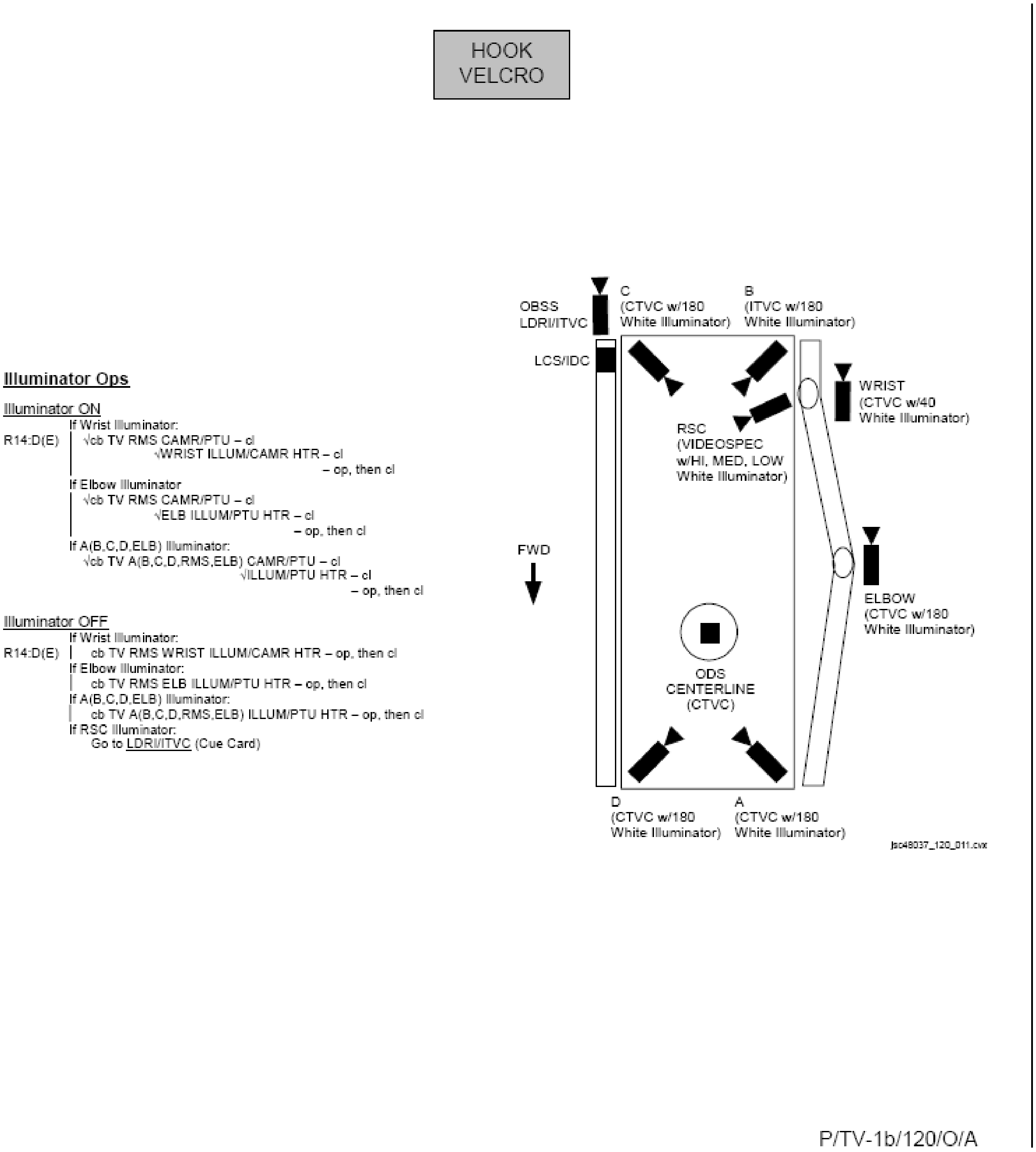
NOTE
Although dnlk/rcd is in color, MON will display MUX in B&W

A7 VID OUT MON pb – as reqd
IN MUX 1(2) pb – push
OUT MUX 1(2) L pb – push
IN pb – As reqd
OUT MUX 1(2) R pb – push
IN pb – As reqd

For RSC ops:
Go to LDRI/ITVC Cue Card

P/TV-1a/120/O/A

TV Cue Card From Photo/TV Checklist (Front)



HOOK
VELCRO

Illuminator Ops

Illuminator ON

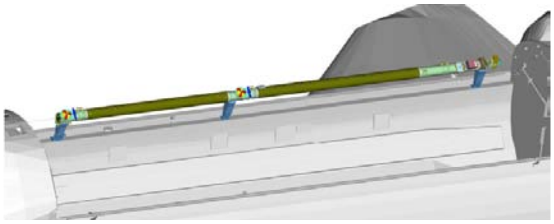
```
          If Wrist Illuminator:
R14:D(E)  |  √cb TV RMS CAMR/PTU – cl
          |                √WRIST ILLUM/CAMR HTR – cl
          |                                      – op, then cl
          If Elbow Illuminator
          |  √cb TV RMS CAMR/PTU – cl
          |                √ELB ILLUM/PTU HTR – cl
          |                                  – op, then cl
          If A(B,C,D,ELB) Illuminator:
             √cb TV A(B,C,D,RMS,ELB) CAMR/PTU – cl
                                     √ILLUM/PTU HTR – cl
                                                    – op, then cl
```

Illuminator OFF

```
          If Wrist Illuminator:
R14:D(E)  |   cb TV RMS WRIST ILLUM/CAMR HTR – op, then cl
          If Elbow Illuminator:
          |   cb TV RMS ELB ILLUM/PTU HTR – op, then cl
          If A(B,C,D,ELB) Illuminator:
          |   cb TV A(B,C,D,RMS,ELB) ILLUM/PTU HTR – op, then cl
          If RSC Illuminator:
              Go to LDRI/ITVC (Cue Card)
```

P/TV-1b/120/O/A

TV Cue Card From Photo/TV Checklist (Back)



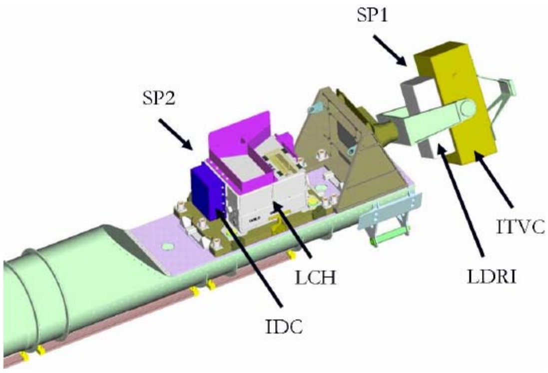
OBSS on Starboard Sill

Orbiter Boom Sensor System (OBSS)

The OBSS first flew on STS-114 in July 2005. The OBSS consists of a 50-foot boom stowed on the starboard sill with two sensor packages on the aft end of the boom. The main goal of the OBSS is to provide on-orbit inspection video and data of the orbiter thermal protection system (TPS) to determine if the orbiter can safely return to Earth or if it needs repair before coming home. The OBSS is grappled by the shuttle remote manipulator system (SRMS) and moved around by the crew to position the sensor packages to take the inspection video and data for further MCC processing. The orbiter Ku-band system provides the downlink to MCC of the sensor packages video and data. The OBSS has two different sensor packages, each with pros and cons. By having two different sensor packages there is not a single or common failure point to take out both sensor assemblies. Also by having two different sensor packages, it provides MCC with more tools to complete inspection objectives.

ITVC/Laser Dynamic Range Imager (LDRI)

The first sensor package (SP1) is the ITVC/LDRI system. The big picture of the system is that the ITVC provides 2-dimensional (2-D) NTSC black and white images of the TPS surfaces and the LDRI provides 3-D information of the orbiter TPS surfaces. Both the LDRI video and the boom ITVC video are considered synchronous sources to the CCTV system. The ITVC/LDRI video is sent to the VPU MISS CAM port, labeled LDRI/ITVC with a crew preference decal, and is viewable by selecting the PL2 input. The orbiter DTV system is used to downlink the video and data. The video and data can be sent to MCC via the orbiter analog TV path in case of a DTV failure, but DTV is preferred because the video image is not degraded like the transmission of the analog video. The ITVC is mounted on a pan/tilt unit with the LDRI mounted on the bottom of the ITVC, so both the LDRI and ITVC are using the same pan/tilt unit. LDRI video and ITVC video cannot be viewed simultaneously. The laser is infrared (IR) at 805 n. mi. and not visible to the human eye. The LDRI camera is sensitive to IR and produces NTSC black and white video. The LDRI camera is similar to the ITVC video in that they are both NTSC black and white 2-D video with similar resolution when there is no laser modulation. When there is laser modulation, the LDRI video appears to flicker and when the data is processed at MCC, it provides length, width, and depth of the scanned area. The crew can manually put the LDRI in six different modes of operation per the panel A7 PBIs. The LDRI/ITVC Cue Card in the Photo/TV Checklist has the steps for activation, general LDRI control, and deactivation. The PDRS C/L directs the crew when to go to different LDRI modes and when to start and stop recording.



Aft End of OBSS

Laser Camera System (LCS)

The second sensor package (SP2) is the LCS. The LCS consists of the laser camera head (LCH), a crew cabin payload general support computer (PGSC) called the laser camera controller (LCC), a black and white integrated sensor inspection system digital camera (IDC), and a lab at JSC for ground processing. The LCS operates at around 1500 n. mi. and produces detailed 3-D images of the scanned area. The LCS output is a binary data file stored on the LCC PGSC and downlinked to MCC via the normal orbiter communication adapter (OCA) methods through the orbiter Ku-band system. The LCS does not have a pan/tilt unit and must rely on the position of the boom. Activation, operation, and deactivation of the system are found on the LCS Cue Card in the P/TV C/L. The IDC is used for a secondary view to obtain still images of the damaged area after the primary scan is complete.

OBSS Modes of Operation

The crew or MCC can command the LDRI into six different modes of operation. Mode 1 has the LDRI in a standby mode and is the default mode upon activation. Mode 2 cycles the LDRI laser on and off to act as an illuminator for the ITVC. The human eye cannot see the laser, but the electronics in the ITVC are sensitive enough to pick up the IR and it make the scene look brighter. In both modes 1 and 2, only ITVC video can be seen. The LDRI camera video can only be seen in modes 3 through 6. Mode 3 is a 2-D mode with the LDRI camera on, gamma black stretch off, and the laser cycling on and off but no modulation or phase shift, which means no 3-D data and the scene is not flickering as it does in modes 5 and 6. Mode 4 is the same as mode 3 but with gamma black stretch on, so the darker regions of the scene are brighter. Mode 5 is a 3-D mode with the LDRI camera on, gamma black stretch off, and the laser cycling on and off with modulation and phase shift to provide 3-D data. The LDRI scene appears to flicker in this mode. Mode 6 is the same as mode 5 but with gamma black stretch on, so the darker regions of the scene are brighter.

The LDRI was designed to recognize commands when a certain sequence of buttons *is* pushed. For the crew to command to the LDRI, the procedures in the LDRI/ITVC Cue Card in the Photo/TV Checklist have them push the MUX1L output PBI, then the MIDDECK PBI, and then one of the six MENU or MODE PBIs. Going from left to right on the MENU and MODE PBIs are the six LDRI modes. The left most MENU PBI is LDRI mode 1 and LDRI mode 6 is the right most MODE PBI. When the crew is commanding the LDRI, there is no feedback on the MENU or MODE PBIs to let them know what mode they are in, meaning the MENU or MODE PBIs will not light up when a LDRI mode is commanded. The LDRI mode telemetry is in the LDRI video, which is coming through the CCTV system via the PL2 input. The crew will only see what LDRI mode they are in on the MENU or MODE PBIs when they push the output PBI that is assigned to PL2 input and LDRI video is being routed (which are modes 3 through 6). In modes 1 and 2 the MENU and MODE PBIs would show the ITVC settings such as ALC AVG. When the crew has the MUX1L and the MIDDECK PBIs pushed, the only commands to the LDRI are the six different modes and the iris open or close commands via the IRIS switch, which provides gain control for the LDRI in mode 3 through 6 to make the scene look brighter or darker. When viewing the LDRI video on the monitor and L-Data is on, the monitor shows T stop values between 70 and 280. Default is 280, which is the darkest and 70 is the brightest. If the gain is changed from the default while in modes 3 through 6, the gain will remain unchanged when switching to other modes, except when going back to mode 1, where it will default back to 280. There are times when the crew will be commanding the boom ITVC in the blind when the LDRI is in modes 3 through 6 and the video output PBI is pushed that is assigned to the PL2 input PBI. In this scenario, the crew is viewing LDRI video but any MENU or MODE PBIs pushed or IRIS switch changes are going to the ITVC in the blind because the crew cannot see the changes since they are viewing the LDRI video. If pan or tilt adjustments are made, the crew would see the pan and tilt numbers change on the monitor with even though LDRI video is displayed because the LDRI is attached to the bottom of the ITVC and the pan and tilt data is in the LDRI video as well. To prevent the ITVC from being commanded to an unwanted mode and possibly incurring damage, it is recommended pan and tilt adjustments be made when in the ITVC viewing mode. The LDRI/ITVC pan range is +9.8° to -170°. The tilt range is +175° to -125°.

There are three different modes of operation for the LCS: quickview, detailed scan, and line scan. The quickview is used so the crew can visually verify in 10 to 30 seconds the scene has the correct field of view by seeing a low resolution scanned image. The detailed scan produces a high resolution 3-D image. The ground processes the data to produce the 3-D models. The scan is in a rectangular pattern and is used for stop and stare operations. The line scan is used when the RMS is providing continuous motion and it is scanning in one direction. This mode produces 3-D images but can also be used to supplement 2-D images.

CCTV System Summary

- The CCTV system is used on orbit to support payload and orbiter activities by using real-time and recorded video.
- The CCTV system is composed of CCTV cameras, pan/tilt units, color monitors, camcorders, video tape recorders, video processing equipment, and accessories.
- All CCTV functions can be controlled by the crew. Most CCTV functions can be configured by MCC via uplink commands. Both crew and MCC can command all CCTV camera functions.
- CCTV equipment is powered from circuit breakers located on panel R14.
- Crews use panel A7U to control the CCTV system.
- The video control unit is the heart of the CCTV system and is the central processor. The VCU is composed of the remote control unit and the video switching unit.
- The CTVC provides NTSC color video. In addition to CCTV camera data, CTVCs also provide lens data.
- The ITVC generates black and white video. This CCTV camera is designed to operate in a low-light environment.
- Two 10-inch color monitors display video onboard. The monitors are located on panel A3 and provide connectors for VTRs to use for recording. The monitors are configured via a display menu system.

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2.4 COMMUNICATIONS

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Description

The orbiter communication system transfers the following types of information:

- Telemetry information to the ground about orbiter operating conditions and configurations, systems, and payloads
- Commands from the ground to the orbiter systems to perform a function or configuration change
- Documentation from the ground that is printed out through an orbiter communications adapter and laptop networked printer
- Voice communications among the flight crew members and between the flight crew and ground, ISS, and EMU

This information is transferred through hardline and radio frequency (RF) links. Hardline refers to wires that connect communicating devices, and RF refers to radio signals. RF communication takes place directly with the ground sites or through a tracking and data relay satellite (TDRS).

Direct communication for NASA missions takes place through space flight tracking and data network (STDN) ground stations. For military missions, Air Force Satellite Control Facility (AFSCF) remote tracking station sites, also known as space-ground link system (SGLS) ground stations, are used. Direct signals from the ground to the orbiter are referred to as uplinks (UL), and signals from the orbiter to the ground are called downlinks (DL).

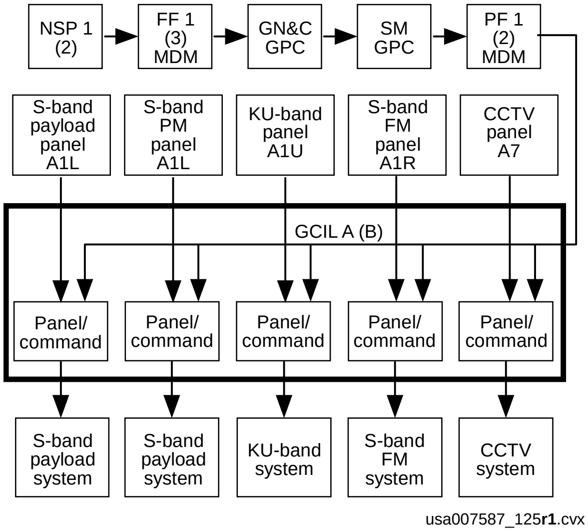
TDRS communication takes place through the White Sands Ground Terminal (WSGT) and Second TDRS Ground Terminal (STGT). These indirect signals from the TDRS to the orbiter are referred to as forward links (FL), and the signal from the orbiter to the TDRS is called the return link (RL). Communication with a detached payload from the orbiter is also referred to as forward link, and return link is the signal from the payload to the orbiter.

The orbiter communication system is divided into several smaller systems: S-band phase modulation (PM), S-band frequency modulation (FM), Ku-band, ultrahigh frequency (UHF) simplex, space-to-space orbiter radio (SSOR), payload communications, audio, and closed-circuit television (CCTV). (CCTV is discussed separately in Section 2.3.)

The S-band FM, S-band PM, Ku-band, and UHF simplex systems are used to transfer information between the orbiter and the ground. The SSOR is used to transfer information between the orbiter and ISS/EMU. The payload communication system is used to transfer information between the orbiter and its payloads through either hardline or RF links. The audio system provides analog voice between the orbiter comm station and MCC/POCC on the ground. The CCTV system is used to visually monitor and record activities.

The ground command interface logic (GCIL), also referred to as the ground command interface logic controller (GCILC), controls selected functions of the S-band PM, S-band FM, Ku-band, payload communication, and CCTV systems. Each of these communications systems has an associated *CONTROL* switch with the positions *PANEL* and *COMMAND*. When the switch is set to *PANEL*, the system can be accessed by the crew using panel switches. When the switch is set to *COMMAND*, control is by ground command via GCIL. The locations and operations of these switches are provided in the individual communications systems discussions that follow.

All commands are sent to the orbiter from the ground through S-band system uplink or Ku-band system forward link and are routed to the onboard GPC through the network signal processor (NSP) and associated flight forward (FF) multiplexor/demultiplexor (MDM). The commands to reconfigure the GCIL controlled communication systems are routed from the GPC through the payload forward (PF) MDMs to GCIL.



Ground Command Interface Logic

NOTE

Because of the large number of distinct elements of the Communications system, a separate Operations subsection is not included. That information is provided within the separate element discussions.

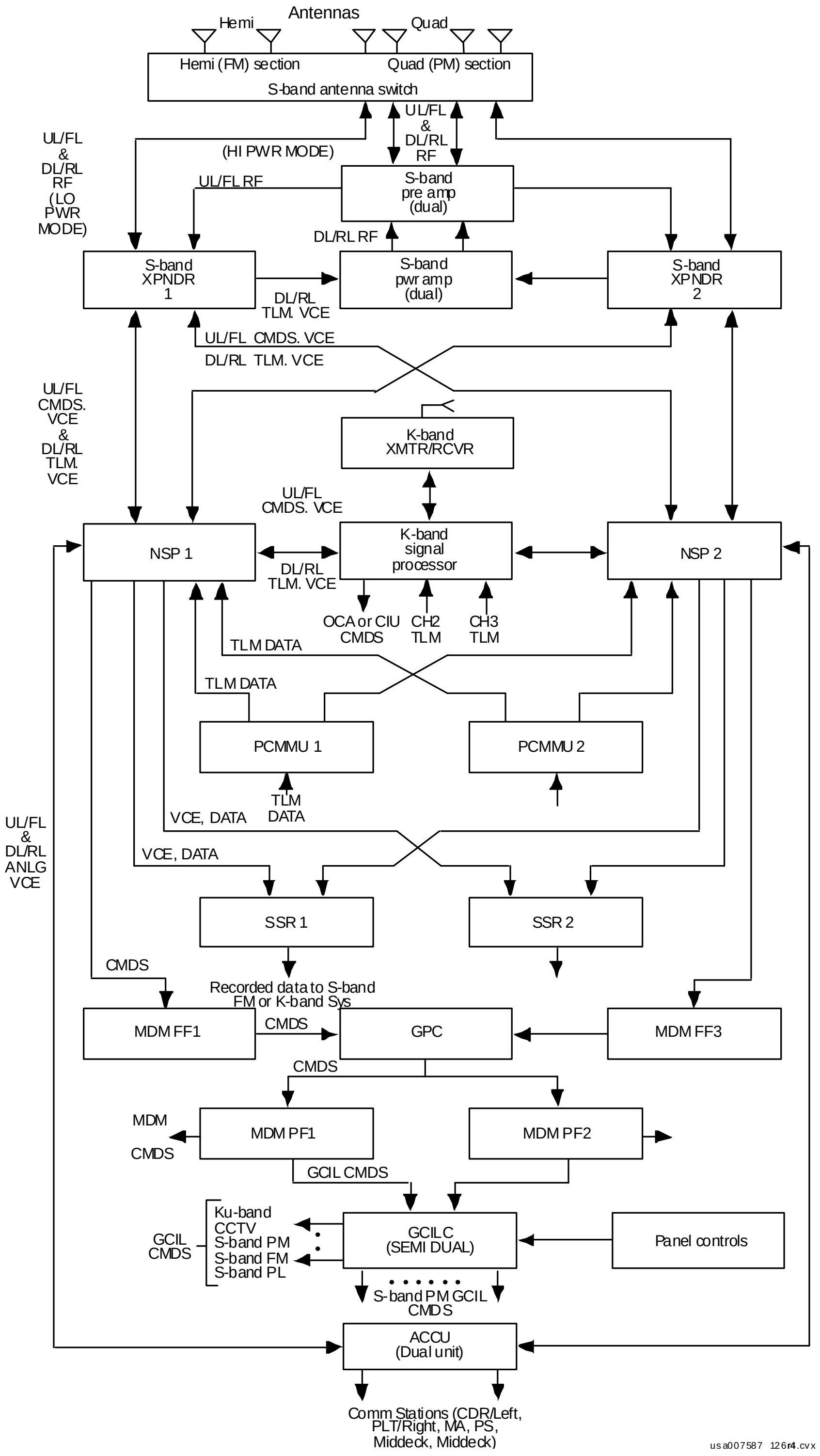
S-Band Phase Modulation

The S-band PM system provides two-way communication between the orbiter and the ground, either directly or through a relay satellite. It provides communication channels for five functions:

- Command channel: used to send commands from ground to orbiter.
- Voice channel(s): used for two-way voice communications between ground and orbiter.
- Telemetry channel: carries real-time orbiter and payload operational telemetry data to ground.
- Turnaround tone ranging channel: used to determine slant range from a known point to the orbiter. Tones are transmitted from the ground to the orbiter where they are "turned around" and transmitted back to ground from the orbiter on a coherent RF carrier. Slant range can be computed from net total two-way phase delay of the major tone for the "round trip."
- Two-way Doppler tracking: used to aid in tracking the orbiter. An RF carrier, of precisely known frequency, is transmitted to the orbiter.

A characteristic of RF signals in the S-band range is that "line-of-sight" must exist between transmitting and receiving antennas to permit communications. With the availability of the Tracking Data Relay Satellite System (TDRSS) network, communications coverage can be about 80 percent, excluding a communications gap called the zone of exclusion (ZOE). In the ZOE, the orbiter will not be in the line-of-sight with either satellite. Geographically, the ZOE is over the Indian Ocean region. During critical phases, such as orbit docking or OMS-2/deorbit burns, the ZOE can be covered by scheduling a TDRS Z satellite, thus providing nearly 100 percent communication coverage with MCC for these orbits. For some missions, vehicle attitude constraints imposed by payload experiment or station requirements may cause loss of comm because line-of-sight is obstructed, causing a loss of signal (LOS) or “ratty comm” conditions; i.e., when TDRS is oriented off the nose or off the tail of the orbiter.

For orbit operations, the TDRSS network provides most of the comm relay between the orbiter and MCC. The TDRSS network has nine satellites supported by the WSGT and STGT facilities. Typically, the satellites used for operational support are located approximately 130° apart in geosynchronous orbit. The satellites are commonly referred to as “east” and “west,” “A” and “B,” or, more correctly, by their logitudinal locations, such as –47 and –171.



S-Band PM System Interfaces and Data Flow

S-Band Forward Link

The S-band forward link operates through the STDN or TDRS. It is phase modulated on a center carrier frequency of either 2,106.4 MHz (secondary) or 2,041.9 MHz (primary). The two frequencies would prevent interference when another satellite or payload is in operation at the same time and place. One user selects the high frequency, and the other selects the low frequency.

The forward link originates from Mission Control through the NASA STDN ground stations for ascent and entry, or through the WSGT/STGT via the TDRS system for orbit operations. The high data rate is 72 kilobits per second (kbps), consisting of two air-to-ground (A/G) voice channels at 32 kbps each and one command channel at 8 kbps, two-way Doppler, and two-way tone ranging. The low data rate of 32 kbps (currently not nominally used) consists of one A/G voice channel at 24 kbps and one command channel of 8 kbps, two-way Doppler, and two-way ranging. The two-way ranging does not operate through the TDRS.

S-Band Return Link

The S-band return link operates through the STDN or TDRS. It is phase modulated on a center carrier frequency of 2,287.5 MHz (secondary) or 2,217.5 MHz (primary). The two frequencies prevent interference if two users are operating at the same time and place.

The S-band PM return link can originate from one of two redundant S-band PM transponders aboard the orbiter. The link transmits the data through the NASA STDN ground stations for ascent or entry, or through the TDRS via the WSGT/STGT to Mission Control for orbit operations.

The high data rate of 192 kbps consists of two A/G voice channels at 32 kbps each and one telemetry link of 128 kbps, two-way Doppler, and two-way ranging. The two-way Doppler and two-way ranging are operative only when in view of the NASA STDN ground stations at ascent or entry. The two-way ranging does not operate with the TDRS.

The S-band return link low data rate of 96 kbps (currently not nominally used) consists of one A/G voice channel at 32 kbps and one telemetry link at 64 kbps, two-way Doppler, and two-way ranging. As noted, the two-way Doppler and two-way ranging are used in the same manner as in the high-data-rate mode.

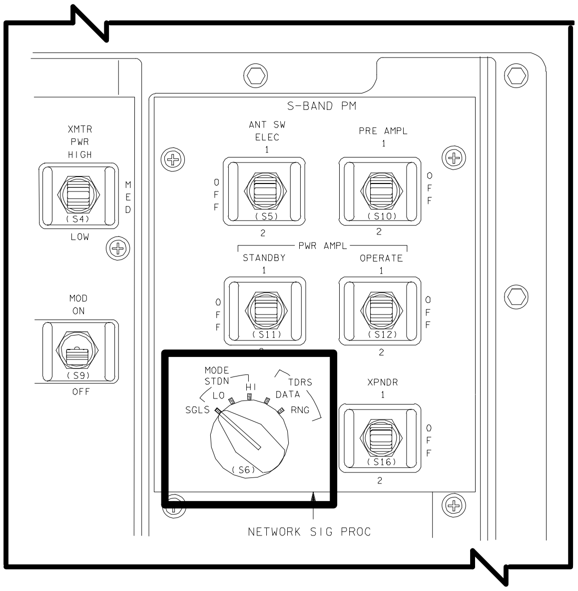
Department of Defense Links

The Department of Defense (DoD) S-band forward link is phase modulated on a center carrier frequency of either 1,831.8 MHz (secondary) or 1,775.5 MHz (primary) from the Air Force Satellite Control Facility (AFSCF) through its own ground stations (SGLS ground stations).

The DoD S-band return link is phase modulated on a center carrier frequency of 2,287.5 MHz (secondary) or 2,217.5 MHz (primary) through the SGLS mode to the AFSCF ground stations, and also does not operate through the TDRS. The two S-band return link frequencies also would prevent interference if two users were in operation at the same time.

S-Band PM Power Modes

S-band PM power modes may be selected by the crew using the S-BAND PM MODE rotary switch on panel A1L. (Usually this is configured by uplink command from MCC.) Selectable modes are SGLS, STDN LO and HI, and TDRS DATA and RNG (TDRS RNG is not used). In high power modes (TDRS and STDN HI), incoming (received) signals from a quad-selected antenna are directed through a preamplifier before reaching the transponder. Outgoing (transmit) signals are routed through a power amplifier and the preamplifier assembly diplexer after leaving the transponder en route to an antenna. In low power modes (STDN LO and SGLS), incoming signals flow from the antenna directly to the transponder, and outgoing signals go directly from the transponder to the selected antenna without amplification.

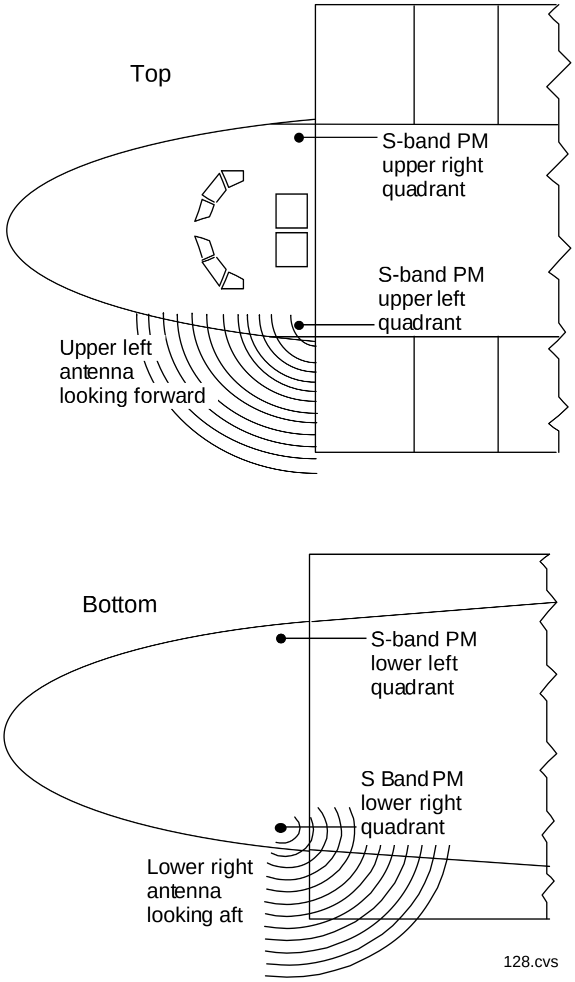


S-BAND PM MODE Rotary Switch on Panel A1L

S-Band PM Antennas

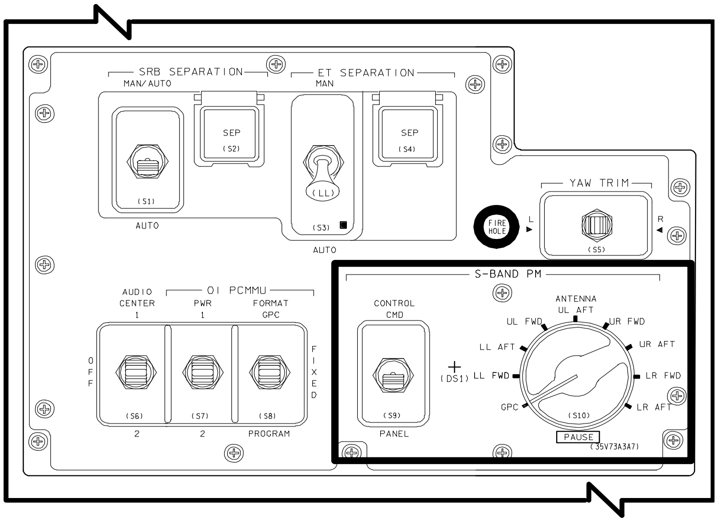
Four quadrant S-band PM antennas covered with a reusable thermal protection system are located approximately 90° apart on the forward fuselage outer skin of the orbiter. On the flight deck viewed through the forward windows, the quadrant antennas are to the upper right, lower right, lower left, and upper left. These antennas are the radiating elements for transmitting the S-band PM return link and for receiving the S-band PM forward link. Each quad antenna is a dual-beam unit that can "look" forward or aft for both transmission and reception without any physical movement, effectively creating eight antennas for the S-band PM system: LL F (lower left forward), LL A (lower left aft), UL F (upper left forward), UL A (upper left aft), UR F (upper right forward), UR A (upper right aft), LR F (lower right forward), and LR A (lower right aft).

These antennas are selected by the antenna switch electronics via GPC control, uplink command, or manual crew selection using the S-BAND PM ANTENNA rotary switch on panel C3. When the switch is set to the GPC position, antenna selection is nominally automatic by the PASS SM or BFS GPC, but can be commanded by real-time command from MCC. The antenna switching commands are sent to the switch assembly through the PF MDMs. Antenna selection is based on the computed line of sight to the NASA STDN ground station, the AFSCF ground station, or the TDRS in view, depending on the orbiter communication mode. The current antenna selection and operating antenna switch electronics is shown on the OPS 201 ANTENNA display. Also on the display are related items such as the S-band ground station in view, TDRS in line of sight, and whether GPC antenna selection is enabled or inhibited.



S-Band PM Antenna Locations

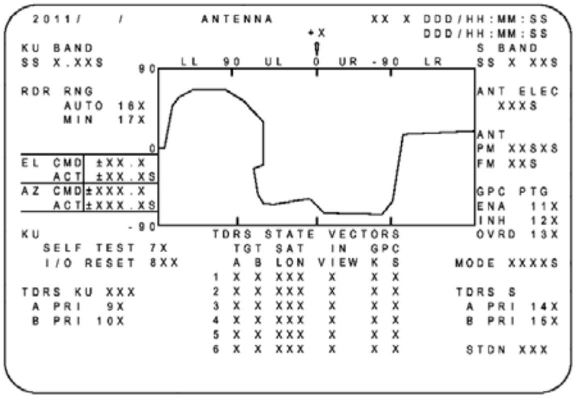
GPC control can be inhibited to permit ground to command an antenna other than the one currently selected by the GPC. The ground sends a command load to inhibit GPC control and a real-time command (RTC) to select the desired antenna. GPC control is restored by sending a load to enable the GPC mode. The crew can perform the same functions by



S-BAND PM System Switches on Panel C3

selecting the ANTENNA display, executing Item 12 (GPC INH), and then selecting the desired antenna by RTC via keyboard. Using GPC OVRD (Item 13), the crew can force the S-band antenna management software to the TDRS mode. An asterisk will be displayed by Item 13 while GPC override is in effect. To restore GPC control, Item 11 (GPC ENA) is executed.

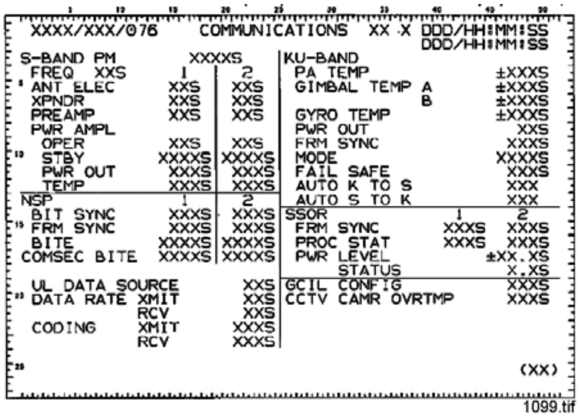
Other S-band PM fields on the ANTENNA display allow prime selection of a TDRS A or B, Items 14 and 15, respectively. Designation of a TDRS A or B is done by Items 1 through 6.These items select the chosen TDRS as prime; if this TDRS is not in view, it selects the other TDRS. If both are in view, the prime is selected. No change is made to TDRS antenna selection if neither is in view. Similar logic holds true for Ku-band system, Items 9 and 10.



```
2011/    /          ANTENNA              XX  X  DDD/HH:MM:SS
                                 +X             DDD/HH:MM:SS
KU BAND                                              S BAND
SS X.XXS        90   LL   90   UL   0   UR  -90   LR   SS X XXS

RDR RNG                                              ANT ELEC
    AUTO  16X                                          XXXS
    MIN   17X
                                                     ANT
                 0                                   PM  XXSXS
EL  CMD   ±XX.X                                      FM  XXS
    ACT   ±XX.XS
AZ  CMD  ±XXX.X                                      GPC PTG
    ACT  ±XXX.XS                                     ENA    11X
                                                     INH    12X
KU             -90   TDRS STATE VECTORS              OVRD   13X
  SELF TEST  7X        TGT  SAT    IN    GPC
  I/O RESET  8XX       A  B  LON  VIEW  K  S        MODE XXXXS
                     1 X  X  XXX   X    X  X
TDRS KU XXX          2 X  X  XXX   X    X  X        TDRS S
 A PRI   9X          3 X  X  XXX   X    X  X         A PRI  14X
 B PRI  10X          4 X  X  XXX   X    X  X         B PRI  15X
                     5 X  X  XXX   X    X  X
                     6 X  X  XXX   X    X  X         STDN XXX
```

OPS 201 ANTENNA Display



```
XXXX/XXX/076    COMMUNICATIONS  XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
S-BAND PM        XXXXS    |KU-BAND
 FREQ  XXS        1  |  2 | PA TEMP              ±XXXS
 ANT ELEC        XXS | XXS| GIMBAL TEMP A        ±XXXS
 XPNDR           XXS | XXS|             B        ±XXXS
 PREAMP          XXS | XXS| GYRO TEMP            ±XXXS
 PWR AMPL            |    | PWR OUT                XXS
  OPER           XXS | XXS| FRM SYNC              XXXS
  STBY         XXXXS |XXXXS| MODE                XXXXS
  PWR OUT       XXXS | XXXS| FAIL SAFE            XXXS
  TEMP          XXXS | XXXS| AUTO K TO S           XXX
NSP               1  |  2 | AUTO S TO K           XXX
 BIT SYNC       XXXS | XXXS|SSOR           1       2
 FRM SYNC       XXXS | XXXS| FRM SYNC    XXXS    XXXS
 BITE          XXXXS |XXXXS| PROC STAT   XXXS    XXXS
COMSEC BITE    XXXXS |XXXXS| PWR LEVEL          ±XX.XS
                          |     STATUS            X.XS
 UL DATA SOURCE       XXS |GCIL CONFIG            XXXS
 DATA RATE XMIT       XXS |CCTV CAMR OVRTMP       XXXS
           RCV        XXS |
 CODING    XMIT      XXXS |
           RCV       XXXS |

                                                  (XX)
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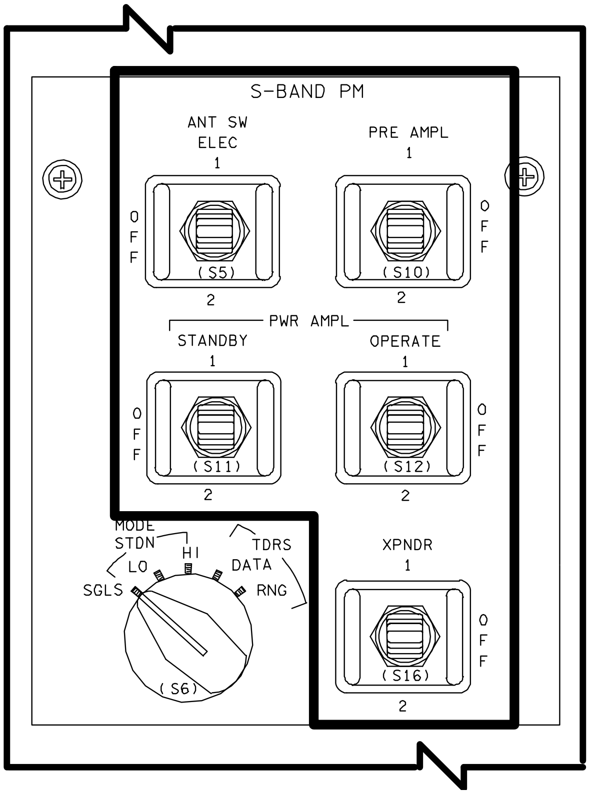
1099.tif

COMMUNICATIONS Display

Preamplifiers

The dual S-band preamplifier is used in the TDRS and STDN HI modes for amplification. In TDRS mode, the preamplifier is required full-time for the forward link radio frequency because of the much greater distance and, consequently, lower strength signal from the TDRS to the orbiter geosynchronous orbit (minimum of about 22,300 miles) than from the STDN to the orbiter (typically, slant ranges are in the low hundreds of miles). The preamplifier is not used in the SGLS or STDN LO modes. One of the two redundant units is used at a time, and the output of either unit can be cross-strapped to feed either transponder. The preamplifier provides an RF gain of about 25 decibels.



S-BAND PM ANT SW ELEC, PRE AMPL, PWR AMPL, and XPNDR Switches on Panel A1L

The PRE AMPL control switches are on panel A1L; this function is generally under ground command control. If the S-BAND PM CONTROL switch on panel C3 is set to PANEL, preamp 1 or 2 is selected, depending on the position of the S-BAND PM PRE AMPL switch on panel A1L. The COMMUNICATIONS display (SPEC 76) under SM OPS 201 shows preamp status and frequency configuration (PREAMP and FREQ).

Power Amplifiers

The S-band power amplifiers provide amplification of transponder RF output for STDN HI and TDRS operational modes. The nominal power gain is about 17 decibels. There are two redundant power amplifiers; one is used at a time, and the input of either can be cross-strapped with the output of either transponder. The output of the power amplifiers can also be routed through either frequency diplexer in the preamp assembly.

The power amplifiers use a traveling wave tube, which has a filament that must be warmed up before high voltage is applied to the tube. A 140-second timer provides the delay when the OPERATE mode is selected from a cold start. With the system in STANDBY, the filament is kept heated, ready for "instant on" operation.

The PWR AMPL STANDBY and OPERATE switches are on panel A1L; these functions are generally under ground control. If the S-BAND PM CONTROL switch on panel C3 is set to PANEL, the switches on panel A1L establish power amplifier configuration.

NOTE

> Both the PWR AMPL STANDBY and OPERATE switches should be in the same position to avoid a reset of the 140-second timer when the backup system is selected.

The COMMUNICATIONS display, SPEC 76, also shows power amplifier status (PWR AMPL: OPER, STBY, PWR OUT, and TEMP).

Transponders

The S-band PM transponders function as multipurpose, multimode transmitter/ receivers. The transponder can simultaneously transmit and receive, transmit only, or receive only. There are two redundant transponders; only one transponder operates at one time. The selected transponder transfers the forward link commands and voice to the network signal processor and receives the return link telemetry and voice from the network signal processor.

The transponders may be cross-strapped. Transponder 1 or 2 may be used with network signal processor 1 or 2. The radio frequency sections of either transponder can be used with either preamplifier and power amplifier 1 or 2.

The selected transponders provide a coherent turnaround of the PM forward link and PM return two-way Doppler and two-way tone ranging signals. These two-way signals operate when the orbiter is in view of a NASA STDN ground stations at ascent, entry, or when it is in view of SGLS mode ground stations. The two-way Doppler operates through the TDRS, but the two-way ranging does not.

Two-way Doppler is used by ground stations to track the orbiter. The S-band PM forward and return links are directly proportional to the forward link frequency (two-way Doppler). The S-band transponder provides a coherent turnaround of the forward link carrier frequency necessary for the two-way Doppler data. By measuring the forward link and using return link frequencies expected from the orbiter, the ground tracking station can measure the double Doppler shift that takes place and can calculate the radial velocity (range rate) of the orbiter with respect to the ground station. Because these links are PM, the S-band carrier center frequency is not affected by the modulating wave. It would be impossible to obtain valid Doppler data of the S-band carrier center frequency if it were affected by the modulating technique.

The S-band transponder also provides a subcarrier for two-way tone ranging. The transponder is used to determine slant range from a known point to the orbiter and operates only when in view of a NASA STDN ground stations during ascent, entry, or in view of SGLS mode ground stations. This capability does not operate through the TDRS. The ground station forward-links ranging tones at 1.7 MHz and computes vehicle slant range from the time delay in receiving the return link 1.7-MHz tones to determine the orbiter's range. The orbiter's azimuth is determined from the ground station antenna angles.

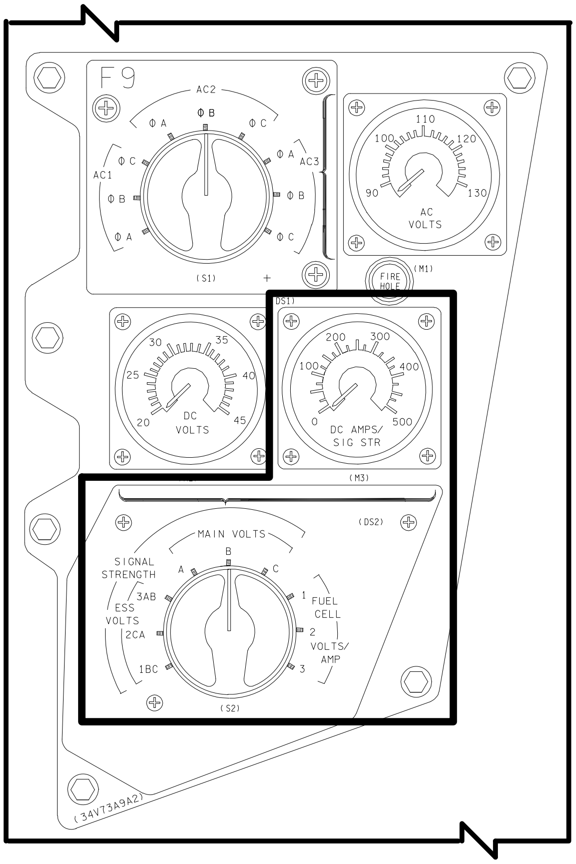
The S-BAND PM XPNDR switch is located on panel A1L; this function is generally handled by ground command via the GCIL. If the S-BAND PM CONTROL switch on panel C3 is set to PANEL, the XPNDR selection is made from panel A1L.

The orbit COMMUNICATIONS display, SPEC 76, gives transponder status (XPNDR and MODE). The OPS 201 ANTENNA display also shows the mode for the active transponder.

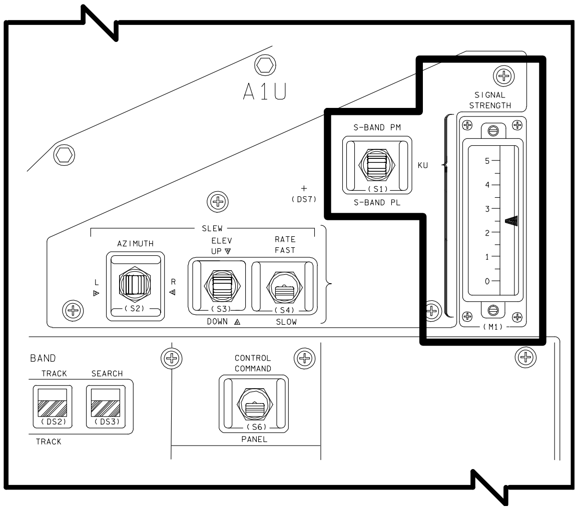
Received S-band PM RF signal strength is shown on the DC AMPS/SIG STR meter on panel F9 when the rotary switch below the meter is set to one of six SIGNAL STRENGTH positions, and on the SIGNAL STRENGTH indicator on panel A1U when the switch to the left of the indicator is set to S-BAND PM. Signal strength is also shown on the OPS 201 ANTENNA DISPLAY (SIG STR). During ascent and entry, this display is not available.

NOTE

The panel AIU signal strength indication comes directly from the operating S-Band PM Transponder. Signal strength indications on the F9 meter are processed first by DSC OF3 before being displayed. The OPS 201 ANTENNA display signal strength comes from OI MDM OF3 *data.*



DCAMPS/SIG STR Meter and Rotary Switch on Panel F9



SIGNAL STRENGTH Indicator and Switch on Panel A1U

Network Signal Processors

One of two redundant onboard network signal processors (NSPs) receive commands (forward link) and transmit telemetry data (return link) to the selected S-band transponder. The active processor receives one or two analog voice channels from the onboard audio central control unit (ACCU), depending on whether one (in the low-data-rate mode) or both (in the high-data-rate mode) of the A/G channels are being used. Nominally, the HDR mode is used. Both voice channels are downlinked only if the NSP is high data rate on both forward and return links. It converts them to digital voice signals, time-division-multiplexes them with the telemetry from the pulse code modulation master unit, and sends the composite signal to the S-band PM transponder for transmission on the return link. On the forward S-band PM link, the NSP does just the reverse. It receives the composite signal from the S-band transponder and outputs it as either one or two analog voice signals to the audio central control unit. The composite forward link also has ground commands that the NSP decodes and sends through the FF MDMs (NSP 1 to FF 1 or NSP 2 to FF 3) to the onboard computers, which route the commands to the intended onboard systems. The NSP data routing/ processing modes are controlled by command or the NETWORK SIG PROC switches on panel A1L. The NSP also routes return link (telemetry and voice) and receive forward link (commands and voice) via the Ku-band system.

Communications Security

Communications security (COMSEC) equipment provides the capability for encryption/ decryption of operational data aboard the orbiter. The COMSEC equipment works with the NSPs to provide selectable transmit, receive, and record combinations under NSP mode control.

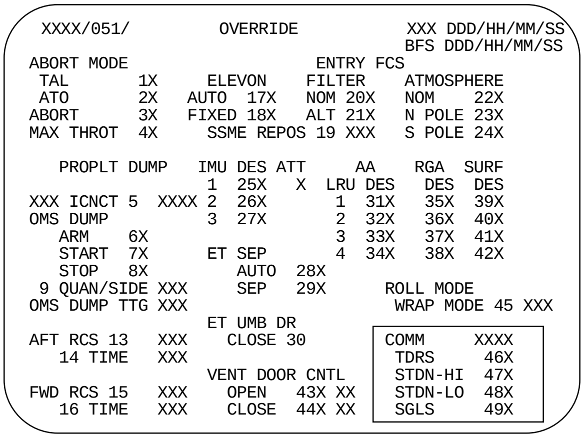
The NSP routes data of the indicated type through the COMSEC encryptor or decryptor as appropriate and gets the data back from the COMSEC line-replaceable unit encrypted or decrypted; if "BYP," the indicated data are handled directly by the NSP, and the COMSEC is bypassed.

The three ENCRYPTION switches on panel A1L provide power and routing control for encrypted data through the NSP. Our current operational mode is to use the COMSEC in the SELECT/RCV mode - only the uplink (voice and commands) is encrypted.

NSP *ENCRYPTION* Switch *MODES*		Link function
ALL (DOD)		Recorded Data Encrypted* Transmitted Data Encrypted Received Data Encrypted
SELECT (NASA)	*T/R*	Recorded Data Clear (unencrypted) ** Transmitted Data Encrypted Received Data Encrypted
	RCV	Recorded Data Clear (unencrypted) ** Transmitted Data Clear (unencrypted) Received Data Encrypted
	BYPASS	Recorded Data Clear (unencrypted) ** Transmitted Data Clear (unencrypted) Received Data Clear (unencrypted)

* Data rate determined by NSP downlink DTA RATE switch.
** HDR only.

The crew can perform S-band PM communications system reconfiguration (TDRS, STDN HI, STDN LO, or SGLS) by a single item entry on BFS GNC OVERRIDE display (SPEC 51). The COMM status will show LOCK (if NSP is locked) and NOLK (if NSP is not locked), based on the status from the pulse code modulation master unit (PCMMU). LOCK will depend on the active NSP FRAME SYNC lock. For Items 46-49, an asterisk "*" will show when telemetry conditions for TDRS, STDN HI, STDN LO, or SGLS, respectively, are met. No more than one asterisk will be displayed at one time. If data are not available from the PCMMU, all asterisks will be blanked.



```
 XXXX/051/         OVERRIDE           XXX DDD/HH/MM/SS
                                      BFS DDD/HH/MM/SS
ABORT MODE                   ENTRY FCS
 TAL       1X     ELEVON    FILTER    ATMOSPHERE
 ATO       2X   AUTO  17X   NOM 20X   NOM    22X
ABORT      3X   FIXED 18X   ALT 21X   N POLE 23X
MAX THROT  4X     SSME REPOS 19 XXX   S POLE 24X

   PROPLT DUMP   IMU DES ATT     AA    RGA  SURF
                  1  25X   X  LRU DES   DES  DES
XXX ICNCT 5  XXXX 2  26X       1  31X   35X  39X
OMS DUMP          3  27X       2  32X   36X  40X
   ARM    6X                   3  33X   37X  41X
   START  7X      ET SEP       4  34X   38X  42X
   STOP   8X         AUTO  28X
 9 QUAN/SIDE XXX     SEP   29X      ROLL MODE
OMS DUMP TTG XXX                     WRAP MODE 45 XXX
                  ET UMB DR
AFT RCS 13   XXX    CLOSE 30        COMM     XXXX
   14 TIME   XXX                     TDRS     46X
                  VENT DOOR CNTL     STDN-HI  47X
FWD RCS 15   XXX    OPEN   43X XX    STDN-LO  48X
   16 TIME   XXX    CLOSE  44X XX    SGLS     49X
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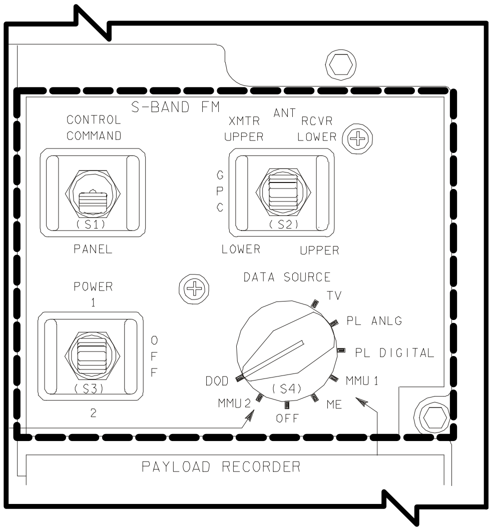
OVERRIDE Display

S-Band Frequency Modulation

The S-band FM system cannot receive information; it is used to downlink data from up to seven different sources, one at a time, directly to the ground when there is a line of sight between the orbiter and STDN or Air Force ground stations. The S-band FM return link can originate from one of two redundant S-band FM transmitters aboard the orbiter. Both transmitters are tuned to 2,250 MHz. The S-band FM return link can be transmitted simultaneously with the S-band PM return link to a STDN ground station or to an Air Force ground station. The S-band FM return link does not operate through the TDRS system.

Crew controls for the S-band FM system are on panel A1R. Status and configuration control of the S-band FM system electronic elements can be selected either by panel switches or GCIL, depending on whether the CONTROL switch is set to COMMAND or PANEL. Set to PANEL, the switches allow rotary switch selection of the DATA SOURCE, and FM Power 1, Off, or 2.



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S-BAND FM Switches on Panel A1R

The FM signal processor is commanded to select one of seven sources for output to the S-band FM transmitter, which transmits it to the S-band FM return link through the STDN ground station or the DOD AFSCF ground station. The S-band FM return link transfers one of the following:

- Real-time SSME data from the engine interface units during launch at 60 kbps each (ME)
- Real-time video (TV)
- Solid State Recorder (part of the Mass Memory Units) dumps of high- or low-data-rate telemetry at 1,024 kbps (MMU 1 or MMU 2)
- Payload analog at 300 hertz or 4 MHz (PL ANLG)
- Payload digital data at 200 bps or 5 Mbps (PL DIGITAL)
- DOD data at 16 kbps or 256 kbps in real time or 128 kbps or 1,024 kbps of playback (DOD)

Only one of the two FM signal processors is used at a time. FM signal processor 1 interfaces with FM transmitter 1, and FM signal processor 2 interfaces with FM transmitter 2. The transmitters and processors cannot be cross-strapped.

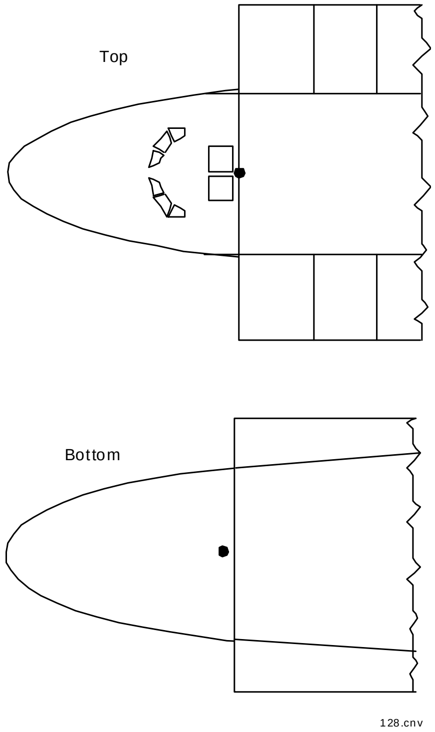
S-band FM is currently used primarily for transmitting ME data during ascent and MMU1/2 data recorder dumps during orbit operations.

S-Band FM Antennas

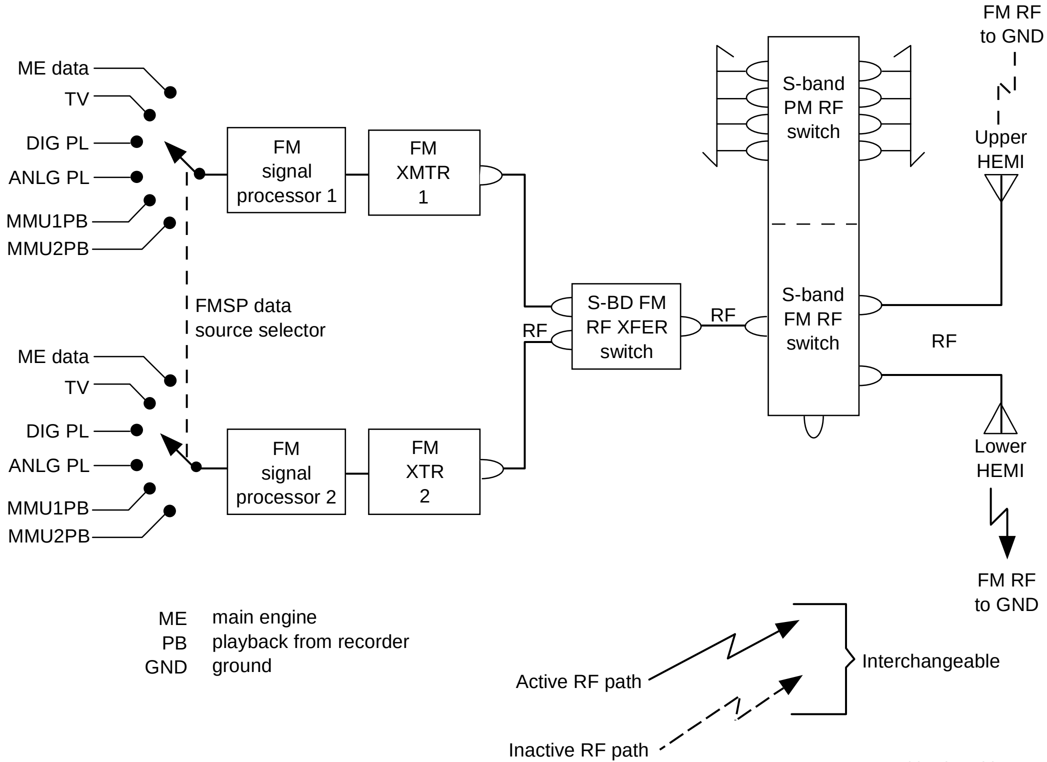
Two hemispherical S-band FM antennas covered with a reusable thermal protection system are located on the forward fuselage outer skin of the orbiter approximately 180° apart. On the flight deck, the hemispherical antennas are above the head (upper) and below the feet (lower) and radiate the S-band FM return link.

The S-band antenna switch assembly provides the signal switching among the two S-band FM transmitters and either of the two hemispherical antennas. The proper antenna is selected automatically by onboard or real-time command from the ground, computer control, or manual flight crew selection using the S-BAND FM XMTR UPPER, RCVR LOWER switch on panel A1R. In the GPC mode, the onboard SM computer selects the proper hemispherical antenna to be used whenever an S-band FM transmitter is active. The antenna selection is based on the computed line of sight to the NASA STDN ground or the AFSCF ground stations.

The basic difference between the quadrant and hemispherical antennas is that the hemispherical antennas have a larger beamwidth, whereas the quadrant antennas have a higher antenna gain. The hemispherical antennas are so named because there are two of them, one on the top of the orbiter and one on the bottom.



S-Band FM Antenna Locations



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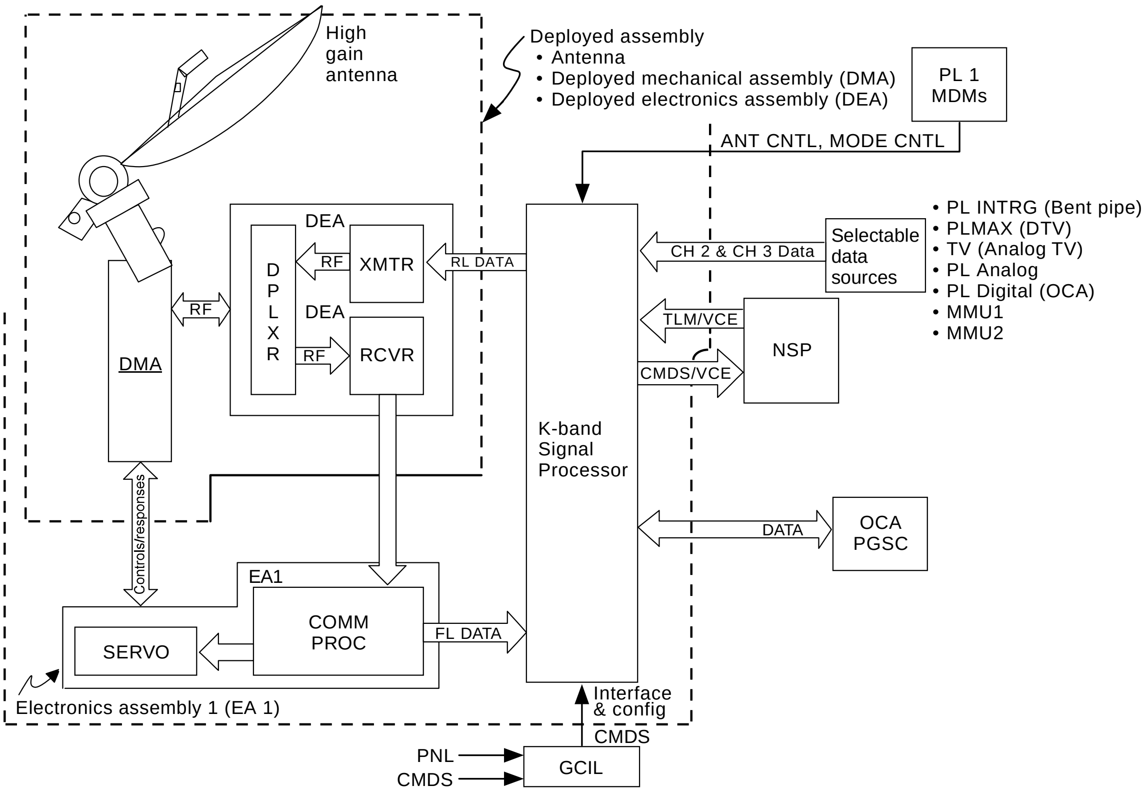
S-Band FM System Block Diagram



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Ku-Band Communications System

Ku-Band System

The Ku-band system operates between 15,250 MHz and 17,250 MHz. The Ku-band carrier frequencies are 13,755 GHz from the TDRS to the orbiter and 15,003 GHz from the orbiter to the TDRS. The Ku-band antenna is located in the payload bay. After the payload bay doors are opened, the Ku-band antenna is deployed. Once the antenna is deployed, the system can be used to transmit information to and receive information from the ground through the TDRS. The Ku-band antenna can also be used as a radar system for target tracking objects in space, but it cannot be used simultaneously for Ku-band communications and radar operations.

When the Ku-band antenna is deployed and activated in the communications mode, the NSP directs the return link data stream to both the Ku-band signal processor and the S-band PM transponder. The return link data stream is transmitted through both the Ku-band and S-band PM antennas to the TDRS in view, via the TDRS systems, to Mission Control.

The NSP accepts the forward link from the Ku-band signal processor and the S-band PM transponder; however, the NSP processes only one of these signals. The source of the forward link selected for processing depends on whether S-band or Ku-band has been selected through GCIL by the ground or by the NSP UPLINK DATA switch on panel A1L. It is possible to transmit the downlink through the Ku-band and receive the forward link through the S-band, and vice versa.

The SM software can automatically switch NSP uplink configuration to support either Ku-band or S-band PM. The SM COMMUNICATIONS display (SPEC 76) shows an AUTO K TO S and AUTO S TO K status; the status fields will show Enable (ENA) or Inhibit (INH), based on uplink command configuration for these functions. If both are enabled and the correct conditions are met in the Ku-band system (good forward link), the AUTO S TO K commands through the GCIL to configure the NSP for TDRS Ku. If the Ku-band forward link is subsequently lost, or failures in the Ku-band uplink occur when using Ku-band forward link, the AUTO K TO S function switches the NSP back to a TDRS S-band PM uplink configuration. The “Fail Safe” function, shown on SPEC 76, is no longer used.

The Ku-band system can handle more data than the S-band systems. In either of two uplink communications modes, it transmits three channels of data, one of which is the same interleaved voice and telemetry processed by the S-band PM system. The possible sources of information sent on the other two channels are selectable by two KU SIG PROC rotary switches on panel A1U, one for HIGH DATA RATE and one for LOW DATA RATE (or by ground commands).

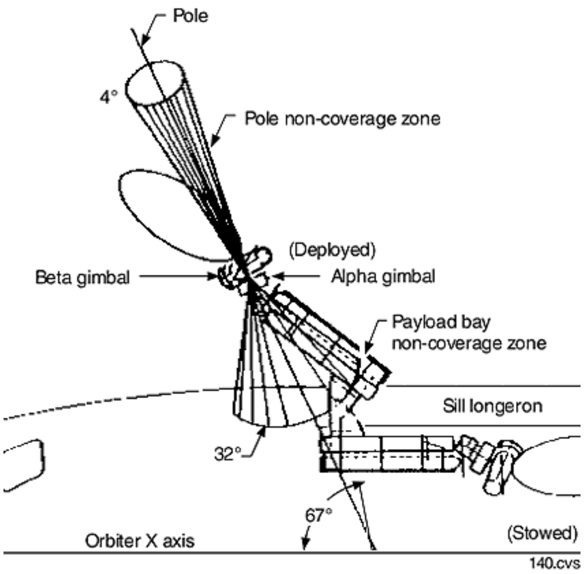
Mode 1 return link consists of three channels. Channel 1 consists of 192 kbps of operational data (128 kbps of GPC downlist, OI and payload telemetry plus two 32 kbps A/G voice links). Channel 2 consists of a 2 Mbps low data rate source selectable by the crew or by MCC. The source for channel 2 can be one of the following:

- Payload interrogator
- Attached payload digital (OCA)
- MMU 1 or MMU 2 SSR

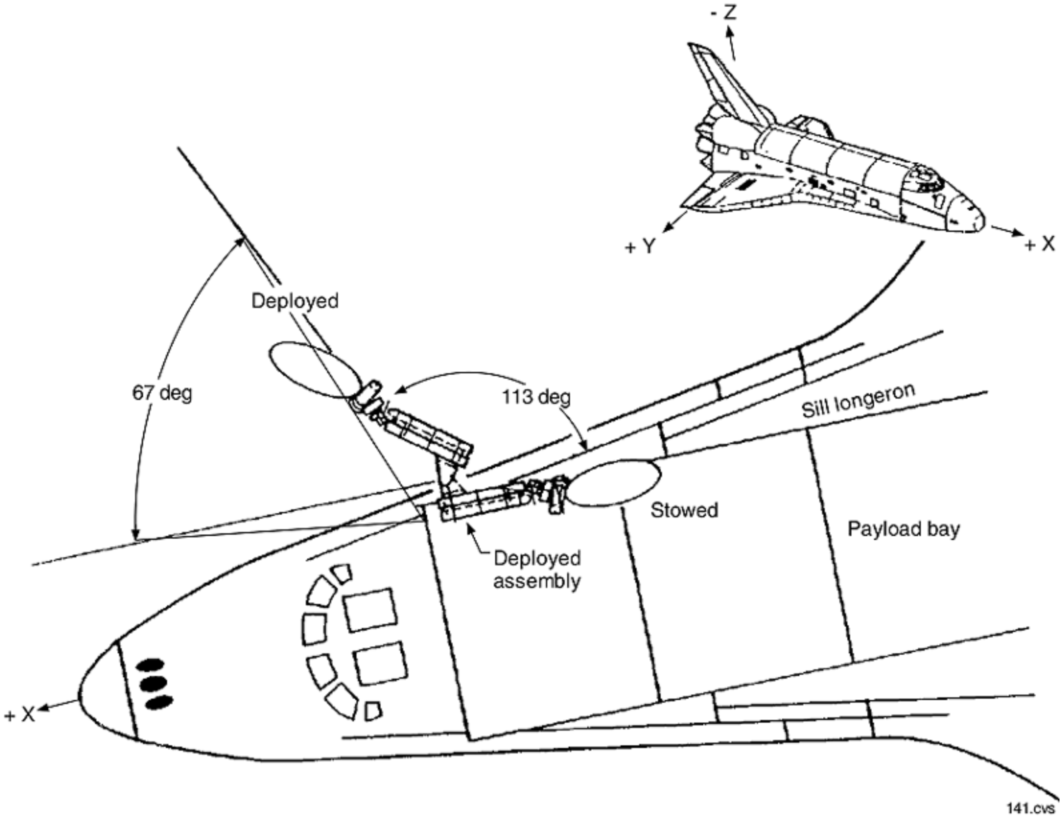
Channel 3 consists of 50Mbps high data rate PL MAX data (attached payload digital data, currently DTV real-time or playback video).

Mode 2 return link also consists of three channels, but differs from Mode 1 by the data source selectable for Channel 3. In Mode 2, Channel 3 consists of a 4 Mbps high data rate source selectable by the crew or by MCC. The source for Mode 2 Channel 3 can be one of the following:

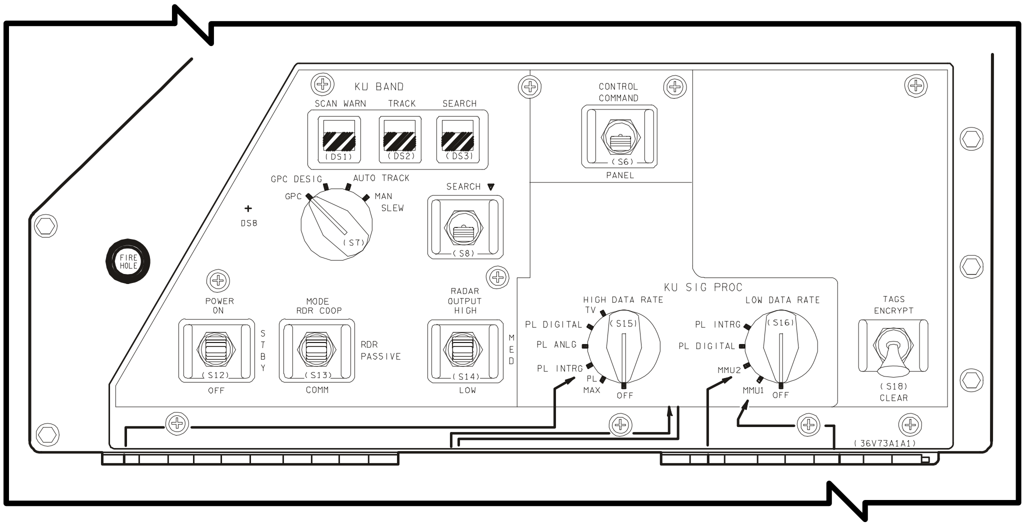
- Payload interrogator
- Attached payload analog
- Attached payload digital (OCA)
- Real-time CCTV video downlink



Ku-Band Antenna Non-Coverage Zones



Ku-Band Deployed Assembly Location



KU-BAND Controls on Panel A1L

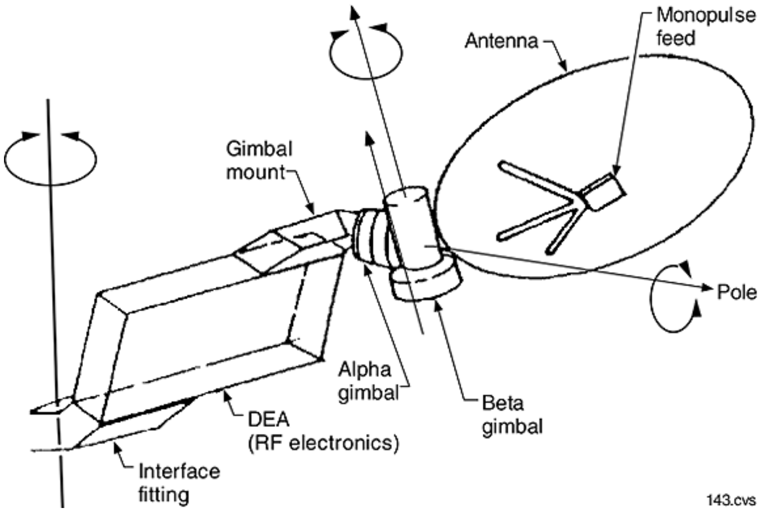
The three channels of data are sent to the Ku-band signal processor to be interleaved with the return link. This signal then goes to the deployed electronics assembly, which contains the transmitter, to be transmitted to the TDRS through the Ku-band antenna.

The Ku-band system forward link Mode 1 consists of 72-kbps data (two A/G voice streams at 32 kbps each and 8 kbps of command), 128-kbps for orbiter communications adapter (OCA) uplink, and 16-kbps synchronization. Mode 2 consists of only the 72-kbps operational data (two A/G voice streams at 32 kbps each and 8 kbps of command).

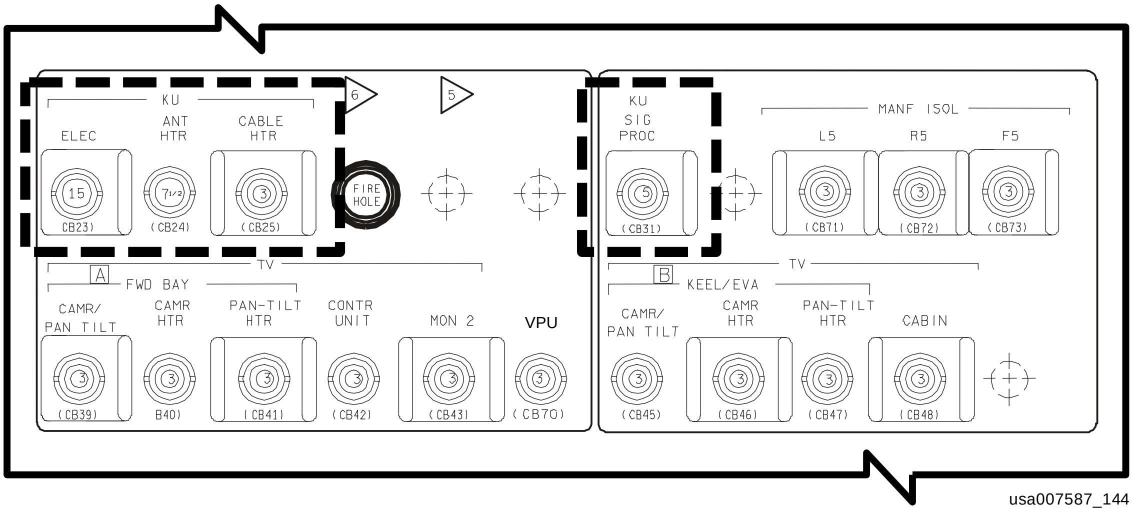
Three Ku-band modes of operation can be selected by the MODE switch on panel A1U. In the COMM mode, incoming signals go through an internal electronics assembly (EA1) to the Ku-band signal processor, which processes and routes Ku-band communications data. Voice and commands are sent to the network signal processor. A separate output from the Ku-band signal processor can be directed to the OCA for PGSC computer file uplinks. In the RDR COOP and RDR PASSIVE modes, incoming signals are routed from the deployed electronics assembly to EA2, the radar signal processor. The signal is processed to provide target angle, angle rate, range, and range rate information. This status information is then routed to EA1 to be used for target tracking.

Ku-Band Deployed Assembly

The Ku-band deployed assembly provides the interface with the TDRS when there is a line of sight between the orbiter and TDRS. The assembly is mounted on the starboard sill longeron in the payload bay. The deployed assembly consists of a two-axis, gimbal-mounted, high-gain antenna, an integral gyro assembly, and a radio frequency electronics box. The gimbal motors position the Ku-band antenna, and rate sensors determine how fast the antenna is moving. The Ku-band deployed antenna assembly is 7 feet long and 1 foot wide when stowed in the payload bay. The graphite epoxy parabolic antenna dish is 3 feet in diameter. The deployed antenna assembly weighs 180 pounds. The weight of the entire system is 304 pounds.



Ku-Band Deployed Assembly



KU-Band Circuit Breakers on Panel R14

The antenna dish is edge-mounted on a two-axis gimbal. The alpha gimbal provides a 360-degree roll movement around the pole or axis of the gimbal. The beta gimbal provides a 162-degree pitch movement around its axis. The alpha gimbal has a stop at the lower part of its movement to prevent wraparound of the beta gimbal control cable. Since the beta gimbal has only a 162-degree movement, there is a 4-degree diameter non-coverage zone outboard around the pole and a 32-degree diameter non-coverage zone toward the payload bay.

The antenna can be steered in several selectable modes under manual control by the flight crew using panel A1U or automatically by the SM software. The KU BAND CONTROL switch on panel A1U selects COMMAND (control by GCIL or keyboard commands) or PANEL (crew control by panel switches and selectors). With the switch in PANEL, the antenna steering mode can be selected using the rotary switch on the left side of the panel. The switch positions are GPC (GPC pointing and auto track), GPC DESIG (GPC pointing only), AUTO TRACK (manual pointing and auto track), and MAN SLEW (manual pointing only).

At times, the Ku-band system, in view of a TDRS, is interrupted because the orbiter blocks the Ku-band antenna's view to the TDRS or because orbiter attitude requirements or payloads’ or ISS’ radiation sensitivities prohibit its use.

When the Ku transmitter is enabled and capable of outputting, but the MCC through ground commands has inhibited the RF carrier for flight-specific reasons, the control of this RF carrier radiation is called Ku antenna "masking." These masking modes are used to provide protection from Ku radiation for payloads, EVAs, and ISS. The types of masking, commandable from the ground, include: 1) inhibiting the Ku transmitter when a specified beta gimbal angle is exceeded (beta MASK) or when both a specified beta gimbal angle and the orbiter hardware obscuration zone are exceeded (beta + MASK), 2) inhibiting the Ku-band transmitter in a specified EVA protection zone, defined by certain elevation and azimuth angles of the antenna relative to the orbiter's X, Y, and Z axes. Ku software also modes the Ku system to standby mode, if the antenna remains near the beta stops for a certain period of time, to prevent excessive antenna gimballing.

None of these masking modes is readily evident to the crew unless they monitor RF out power on SM SPEC 76. Only the orbiter hardware obscuration zone is shown on the SM ANTENNA display (see ANTENNA display on page 2.4-6).

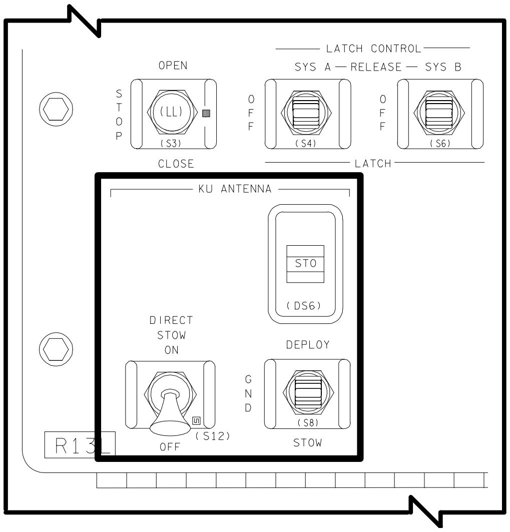
Ku-Band Antenna Deployment and Stowage

When the shuttle reaches orbit, before the Ku-band antenna is deployed, the KU ANT HTR circuit breaker on panel R14 is closed to energize thermostatically controlled heaters for the deployed electronics assembly, gimbals, and antenna assembly. During Ku-band activation, the KU ELEC and KU SIG PROC circuit breakers on panel R14 are closed. (There is also a CABLE HTR circuit breaker on panel R14. The Ku-band system was originally designed to have a cable heater, but it was never installed. Therefore, this circuit breaker is always open.) These circuit breakers provide electrical power to the Ku-band electronic elements, electronics assemblies 1 and 2, the signal processor assembly, and Ku-band portions of panels A1U and A2. Actual deployment involves the KU ANTENNA controls and associated talkbacks on panel R13L. The antenna is locked in the stowed position to clear the adjacent payload bay doors and radiators when they are closed or moving.

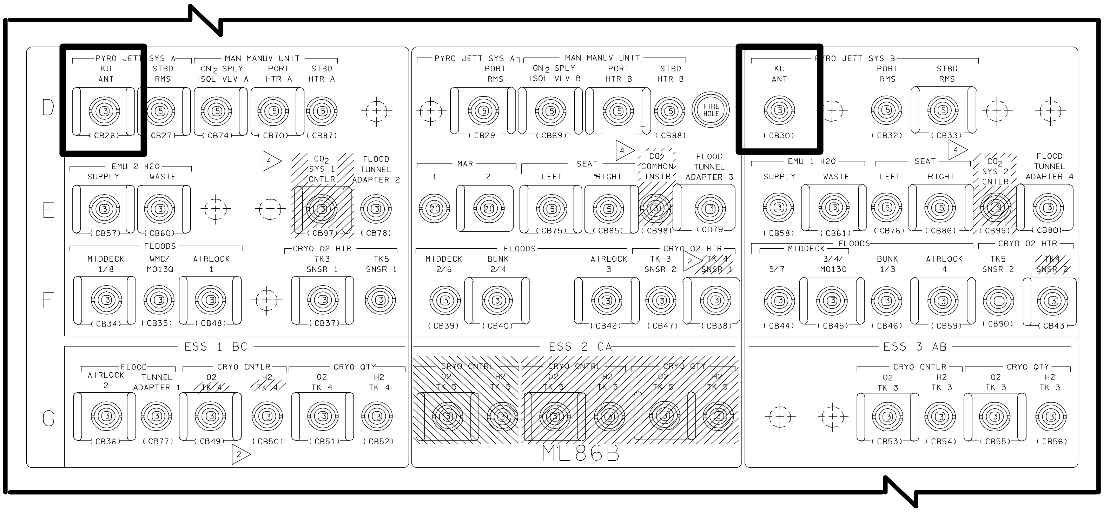
It normally takes 23 seconds to deploy or stow the assembly. In the deployed position, the assembly forms a 67-degree angle with the orbiter X axis. Activating the Ku electronics and taking the KU BAND POWER switch on panel A1U to ON frees the antenna gimbals by removing the gimbal locking pins. The beginning of stow operations contains approximately 30 seconds of gimbal lock sequencing before assembly stow begins.

The Ku-band antenna must be stowed before the payload bay doors are closed in preparation for entry. This is done by setting the KU ANTENNA three-position switch on panel R13L to the STOW position. If the assembly does not respond to normal stow operations, the KU ANTENNA DIRECT STOW switch on panel R13L is used. Setting this switch to ON bypasses the normal stow control sequences and causes the assembly to be driven inside the payload bay. The KU ANTENNA DIRECT STOW switch procedure is only used if locking the alpha and beta antenna gimbals is successful in their stow position, because entry with antenna gimbals unlocked may cause unacceptable damage. DIRECT STOW merely positions the entire deployed assembly inside the payload bay and does not affect gimbal locking.

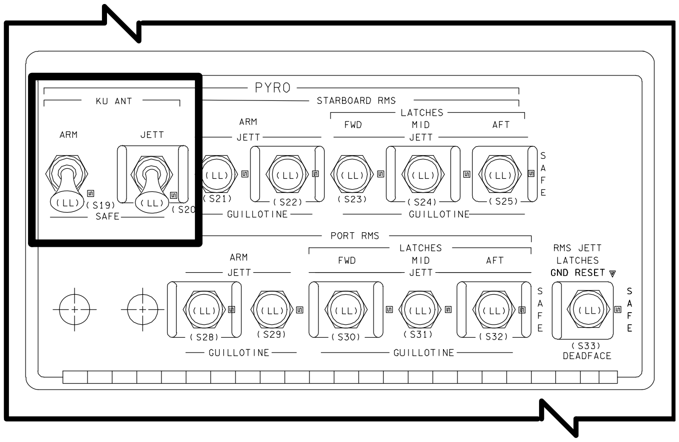
If neither the normal stow nor the DIRECT STOW can position the assembly inside the payload bay, the assembly can be jettisoned. To jettison the deployed assembly, the crew closes the MN A and MN C PYRO JETT SYS A and SYS B KU ANT circuit breakers on panel ML86B to provide redundant jettison power. The crew then activates the PYRO KU ANT ARM and JETT switches on panel A14, which causes a guillotine to cut the cables to the deployed assembly and releases a clamp holding it to the pivot assembly. The separation point is between the assembly and deployment mechanism about 20 inches above the sill longeron. No ejective force is imparted; the assembly is merely cut loose, and the orbiter maneuvers away from it. The jettison operation takes about 4 seconds.



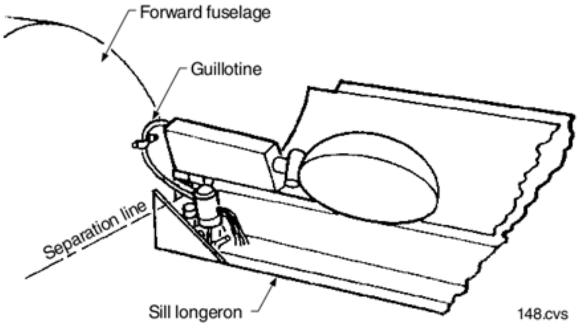
KU ANTENNA Switches and Talkback on Panel R13L



PYRO JETT KU Circuit Breakers on Panel ML86B



KU ANT Switches on Panel A14



Ku-Band Antenna Jettison Separation

Ku-Band Rendezvous Radar

The orbiter Ku-band system includes a rendezvous radar that skin-tracks satellites or payloads in orbit. For large payloads that must be carried into orbit one section at a time, the orbiter will rendezvous with the payload segment currently in orbit to add on the next section. The gimballing of the Ku-band antenna permits it to conduct a radar search for space hardware. The Ku-band system is first given the general location of the hardware by the orbiter computer; then the antenna makes a spiral scan of the area to pinpoint the target (in GPC mode).

Radar may also be used to search for space hardware using a wide spiral scan of up to 60°. Objects may be detected by reflecting the radar beam off the surface of the target (RDR PASSIVE MODE) or by using the radar to trigger a transponder beacon on the target (RDR COOP MODE). These modes are selectable using the KU BAND MODE switch on panel A1U. To date, only RDR PASSIVE MODE has been used.

During a rendezvous operation, the radar system is used as a sensor that provides target angle, angle rate, and range rate information for updating the rendezvous navigation data in the GNC computer. The operation is similar to using the crew optical alignment sight or star trackers, except that the radar provides range data in addition to angle data. Angle tracking maintains appropriate antenna pointing to keep the target within the antenna beam. Range tracking is accomplished by electronically measuring the time between a transmitted pulse and a return pulse from the target. The return pulse may be reflected from a passive (skin-tracked) target or cooperative target transmitter that is triggered by the radar-initiated pulse. The latter provides a longer range capability.

Angle tracking can be accomplished in two ways: computer or manual designations or automatic (auto) servo. During manual or computer-designated tracking, the antenna beam angle is positioned by services external to the Ku-band system. Computer tracking (used in GPC and GPC DESIG modes) provides designated angle data based on combined target and orbiter state vector information. Manual tracking (used in MAN SLEW and AUTO TRACK modes) applies manually initiated rates to the antenna control system from switches at the orbiter aft flight deck station (A1U).

Automatic angle tracking applies error rates to the antenna control system from a receiving station that measures the target position relative to the antenna beam center. This closed-loop servosystem, internal to the Ku-band system, ignores external computer or manual designations. It is the only angle tracking mode that provides angle data for updating navigation data.

Range tracking is always automatic, although computer-designated ranges are applied to the Ku-band system until automatic tracking is achieved. In the automatic tracking mode, the Ku-band system provides actual antenna angle, angle rate, range, and range rate data through an MDM for rendezvous and proximity operations. Data routed to the indicators on panel A2 represent hard-wired azimuth, elevation, range, and range rate information, which is not processed by the GPCs.

Before any radar mode is used, the orbiter is normally maneuvered to an attitude with the minus Z axis pointing at the target location. In all modes, therefore, the radar antenna is normally maneuvered around the minus Z axis.

The Ku-band system provides for antenna steering modes, each with a different combination of capabilities for acquiring and tracking a target: GPC, GPC DESIG, AUTO TRACK, and MAN SLEW. All are mutually exclusive and crew selectable using the rotary switch on panel A1U.

The GPC mode is fully automatic in all phases of target acquisition. Two DPS display commands are required before this mode can be initiated (GNC SPEC 33, REL NAV DISP). One command enables target position data to be routed from the GNC to the SM antenna management program through the intercomputer data bus (GNC SPEC 33, REL NAV DISP, item 1). The antenna management program converts the target position to antenna pointing angles and estimated orbiter-to-target range data. Another command enables the antenna management program to send designated antenna pointing and range data to the Ku-band system through the payload 1 data bus and the payload forward 1 MDM (GNC SPEC 33, item 2).

When the GPC mode is selected, the antenna points to the commanded angles and adjusts the ranging system to the specified range. If a receive signal is detected, the automatic closed-loop system tracks the target in angles and range and provides data for the SM and GNC computers and panel displays. If the target is not detected, the antenna is automatically commanded to search around the designated point. The antenna is inertially stabilized during the search operation.

The *GPC DESIG* mode provides the same designated pointing as the GPC mode without angle search or angle-tracking capabilities. No closed-loop angle tracking is provided. The designated angles are updated every 2 seconds. Range search and tracking are automatic. The antenna may be either inertially or body stabilized.

The *AUTO TRACK* mode begins with manual antenna control, including a manually initiated search and inertial stabilization during the target acquisition phase. Once the target is detected, automatic angle and range tracking is initiated and manual control is inhibited until auto tracking is broken.

The *MAN SLEW* mode allows manual control of antenna movement with maximum automatic range search. Once the target is detected, an automatic range track is initiated, but angles are still under manual control. No angle search is available in this mode.

The *SEARCH* mode, selected by a switch on panel A1U, involves a programmed antenna movement that causes the radar beam to describe a spiral pattern starting at the designated angles. The beam angle spirals out to a maximum of 30° from the designated angle. In the GPC steering mode, the variation of the maximum angle of search from the designated point is inversely proportional to designated range. The smallest search spirals outward to a maximum of 6.2° from the designated point for ranges from 145 to 300 nautical miles (n. mi). At minimum ranges (0 to 8 n. mi.), the spiral search is the maximum 30° from the designated point. If the antenna drive system detects but overshoots the target during a spiral search, a miniscan program is automatically initiated near the point of detection. The miniscan searches to a maximum of 9° from the starting point in 1 minute. In the auto track steering mode, only the manually initiated main 30-degree scan is available.

In addition to angle search, the Ku-band system provides a range search. The process includes electronically varying the timing within the range system until it coincides with the time interval between the transmitted and received radar pulses. Once the intervals coincide, radar tracking is established, and the range data output represents the range between the target and the orbiter. The crew can read the range and range rate values as panel and DPS display parameters.

The crew is provided with two controls associated with range. Transmitter power output is automatically varied in proportion to range when a target is being tracked to keep the return signal relatively constant, regardless of range. If, however, the track is lost, and the range system begins to search, the transmitter may transmit maximum power during the search. The crew can limit the maximum transmitter power by using an aft station panel control. The other control is a DPS command that limits the range search in GPC steering mode to 2,400 feet.

The Ku-band system has body and inertial antenna stabilization modes. When the body is stabilized, the antenna beam remains in a fixed relationship to the orbiter X, Y, and Z axes during orbiter attitude changes. When the system is inertially stabilized, the antenna beam remains aligned to a point in inertial space, regardless of the orbiter attitude changes. Both of these modes are effective only when the radar angle-tracking system is not tracking a target. In the target angle-tracking mode, the system aligns the antenna beam to the target, and antenna movement is independent of orbiter attitude changes.

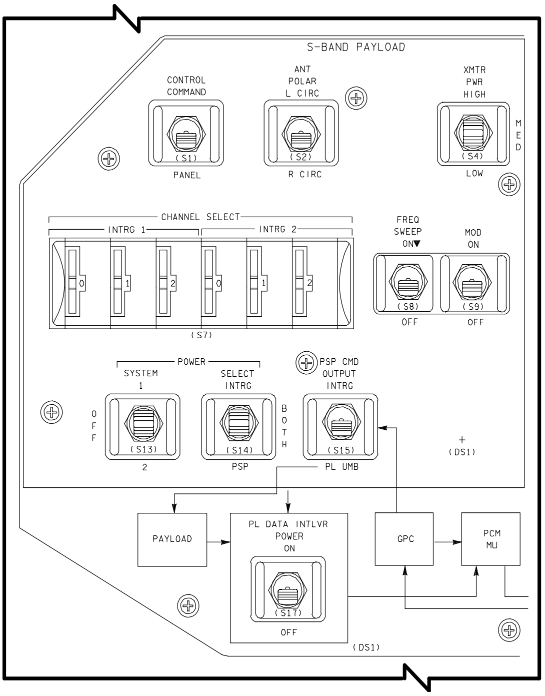
Each antenna steering mode, except the designate mode, has a specific stabilization mode. The designate mode selects either body or inertial stabilization on the basis of a real-time GPC command (not available to the crew). Since the designate mode provides range tracking only, inertial stabilization is effective during target tracking.

The SM COMMUNICATIONS display, SPEC 76, provides the status of Ku-band temperatures (PA, GMBL, GYRO), power out (in watts), frame sync, and mode (COMM or RDR), to flight crews.

Payload Communication System

The payload communication system is used to transfer information between the orbiter and its payload(s). It supports hardline and radio frequency communications with a variety of payloads. The system is used to activate, check out, and deactivate attached and detached payloads.

Communication with an attached payload takes place through the payload patch panel at the crew compartment flight deck aft station, which is connected to payloads in the payload bay. All command and telemetry signals that meet the payload communication system specifications can be processed onboard. Incompatible signals can be sent to the ground through Ku-band or directly to payload ground stations. This method of transmission, referred to as bent-pipe telemetry, means that no onboard signal processing occurs before the telemetry is sent to the Ku-band system. Payload telemetry can be directly transmitted to the ground through the S-band FM or Ku-band systems via the payload interrogator, payload analog, or payload digital source selects or it can be combined with other payload data in the payload data interleaver (PDI). The PDI provides payload telemetry to the pulse code modulation master unit (PCMMU), where the data can be accessed for display on various payload-related controls and displays. Then it is routed to the active NSP to be combined with voice and sent to MCC and POCCs, local to Johnson Space Center or around the world.

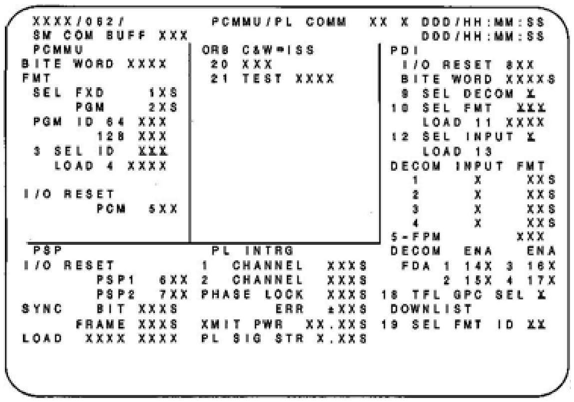


S-BAND PAYLOAD Switches on Panel A1L

The S-band payload antenna is located on the top of the outer skin of the orbiter's forward fuselage, just aft of the S-band FM upper hemispherical antenna. The payload antenna is covered with reusable thermal protection system. This antenna is used as the radiating element for S-band payload transmission and reception to and from the orbiter to detached payloads, *such as the Hubble Space Telescope (HST).*

Communication problems involving antenna position relative to payload position are not evident while the payload is within a half mile of the orbiter, along the minus Z axis. However, to maintain good communication with the orbiter from distances of several miles, the payload must be within an 80-degree beamwidth (with reference to the minus Z axis) of the orbiter's payload interrogator antenna. The boundary of the 80-degree beamwidth is the 3-decibel point (or half-power point), which must be considered during communication with deployed payloads. This constraint is normally satisfied by the payload deployment and retrieval process.

The basic elements in the payload communication system are the payload interrogator (PI), payload signal processor (PSP), payload data interleaver (PDI), and PCMMU. These elements are in the forward avionics bays. Commands to the payload communication system are routed through the GCILC from the payload MDMs 1 and 2, although these MDMs are also used for orbiter commanding. Status and control of payload communication systems can also be accessed by the PCMMU/PL COMM display (SPEC 62). *For ISS missions, an orbiter interface unit (OIU) 1 or 2 is used to provide translation functions between the payload communication system and 1553 ISS devices.*



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 XXXX/062/             PCMMU/PL COMM   XX X DDD/HH:MM:SS
 SM COM BUFF XXX                            DDD/HH:MM:SS
 PCMMU            ORB C&W=ISS           PDI
BITE WORD XXXX     20 XXX                I/O RESET 8XX
FMT                21 TEST XXXX          BITE WORD XXXXS
 SEL FXD    1XS                           9 SEL DECOM X
     PGM    2XS                         10 SEL FMT  XXX
 PGM ID 64 XXX                              LOAD 11 XXXX
       128 XXX                          12 SEL INPUT X
 3 SEL ID  XXX                              LOAD 13
   LOAD 4 XXXX                          DECOM INPUT FMT
                                           1     X     XXS
I/O RESET                                  2     X     XXS
       PCM   5XX                           3     X     XXS
                                           4     X     XXS
                                        5-FPM         XXX
 PSP                  PL INTRG          DECOM  ENA    ENA
I/O RESET            1  CHANNEL    XXXS   FDA 1 14X 3 16X
       PSP1   6XX   2  CHANNEL    XXXS       2 15X 4 17X
       PSP2   7XX   PHASE LOCK    XXXS  18 TFL GPC SEL X
SYNC   BIT XXXS            ERR   ±XXS  DOWNLIST
     FRAME XXXS   XMIT PWR   XX.XXS   19 SEL FMT ID XX
LOAD  XXXX XXXX   PL SIG STR X.XXS
```

PCMMU/PL COMM Display (SPEC 62) - OI-32

Payload Interrogator

Detached payloads communicate with the orbiter on an RF signal through the payload antenna by the payload interrogator. The payload interrogator is a transmitter/receiver/transponder unit that provides full duplex RF communications between the orbiter and a detached payload. It transmits commands to and receives telemetry from NASA payloads through the payload antenna. Payload interrogator controls are located on panel A1L.

The main carrier frequency of the detached payload telemetry is demodulated by the *PI. The telemetry is routed directly to the Ku-band system for transmission to the ground (bent-pipe telemetry) when a payload signal is not compatible with the PSP. For PSP compatible payloads, the PSP demodulates the telemetry from the subcarrier and sends it to the PDI to be interleaved with other payload data.*

Hardline payload commands are routed through the *PSP* and then output through the payload patch panel directly to an attached payload. Detached RF commands are routed through the *PSP* and then through the payload interrogator for transmission to the payload through the payload antenna.

The payload interrogator receiver automatically sweeps to acquire and track an unmodulated or modulated RF signal. Payload interrogator telemetry is available through an operational instrumentation MDM to verify signal strength and frequency lock. If payload frequencies are near the orbiter S-band PM frequencies, care must be taken to prevent interference.

When the payload outputs a data rate that is not compatible with the PSP, *the signal must be routed directly via Ku-band or S-band FM system, or the payload customer, such as HST team, must provide an interface device from the patch panel to the PDI.*

Payload Signal Processor

The payload signal processor is the RF and hardline command interface between the ground or flight crew and the payload. It is also a detached payload telemetry interface to the payload data interleaver. The *PSP* is controlled by the switches on panel A1L. The *PSP* output is commanded or selected by the PSP CMD OUTPUT switch.

The PI and PSP are commanded through GCILC/MCC or selected by the crew (AIL) using the *associated control switches*.

In past HST servicing mission (SM) flights, a "PSP-Bypass" configuration was used to allow bypassing the PSP for HST return link telemetry via a jumper cable from the PI to the PDI. Post-STS-61, a communications improvement team (GSFC and JSC) convened to come up with better methods of downlinking low-rate HST telemetry. The result was the HST PGSC assembly (HPGSCA). The main purpose of the HPGSCA was to receive the HST 32-Kbps data from the PI, "clean up" the bits and amplify them, and send the data stream to the PDI.

The HPGSCA was flown on STS-82, -103, and -109. During these missions, there were some issues with the HPGSCA. If the laptop "hung up," it required crew time to reboot the system. With this in mind, the HST team at Goddard (GSFC) decided to design a replacement for the HPGSCA with easier crew operation and better functionality. The replacement unit is the bit sync assembly (BSA). The BSA uses the heritage Aydin PC355 ISA cards and minimizes the setup, teardown, and configuration time required; it should be used on the final HST servicing mission.

Orbiter Interface Unit

The OIU is an asynchronous LRU that serves two separate functions. The OIU checks and expedites commands to the ISS or devices using ISS-compatible protocol. It also processes telemetry (data) from these devices to route to the PDI in PDI-compatible serial data streams. Both the commands and telemetry path between the OIU and ISS device use the Military Standard 1553 B (MS 1553B) protocol. Specifically, the OIU is the translator, or interface LRU, between the orbiter PSP, the PDI, and the ISS command and data handling (C&DH) system MS 1553B communication buses. The OIU also provides a MS 1553B interface to the SSOR, adding an RF command and telemetry path to the ISS while in the proximity operations phase of flight (end of rendezvous timeline). The OIU is manifested like a shuttle payload whenever an ISS mission or payload requiring the MS 1553B protocol is flown.

Payload Data Interleaver

The payload patch panel interfaces attached payloads to the PDI. The PSP acts as the interface for detached payloads. Attached payloads are wired to specific input channels of the PDI via the payload patch panel during prelaunch activities. When the PDI is reconfigured by the flight crew, programming procedures include assigning inputs in the PDI to one of four decommutators.

The PDI allows the payload communication system to interface with the rest of the orbiter communication system and computers. It receives up to six different inputs from attached or detached payloads and one ground support equipment input. For missions using the payload signal processor, a maximum of five attached payloads can be accommodated on inputs 1 through 5. Input 6 is reserved for detached payload telemetry using the RF link through the payload signal processor *and payload interrogator.* The PDI has four decommutators that can process up to four payload data streams. The PDI ships the payload telemetry to the PCMMU, where it can be accessed by the SM GPC for display, and combined with orbiter telemetry for transmission to the ground. The *PL DATA INTLVR POWER* switch is on panel A1L.

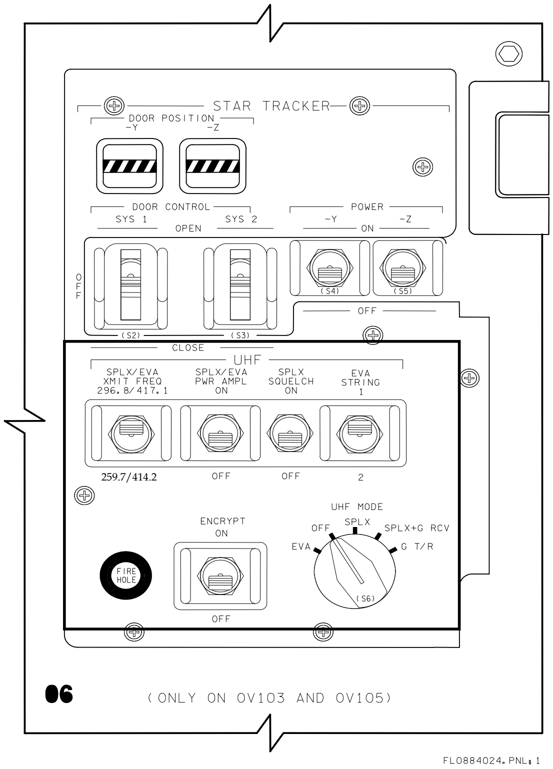
Ultrahigh Frequency System

The ultrahigh frequency system actually consists of two separate systems with different capabilities. They are the UHF simplex (SPLX) system and the UHF SSOR system. A five-position UHF MODE rotary switch on panel O6 activates power to these systems. The OFF selection disables *both* systems. The simplex (SPLX) selection activates the 259.7 MHz (296.8 MHz as backup) transceiver. The SPLX + G RCV selection activates the guard 243.0 MHz emergency receiver together with the SPLX transmitter/receiver. The G T/R selection activates the guard 243.0 MHz transceiver for emergency voice communications through any available ground station and disables the SPLX transceiver. Selection of any of these three modes automatically connects the UHF air traffic controller (ATC) transceiver to the orbiter audio central control unit (ACCU) air-to-air (A/A) voice loop.

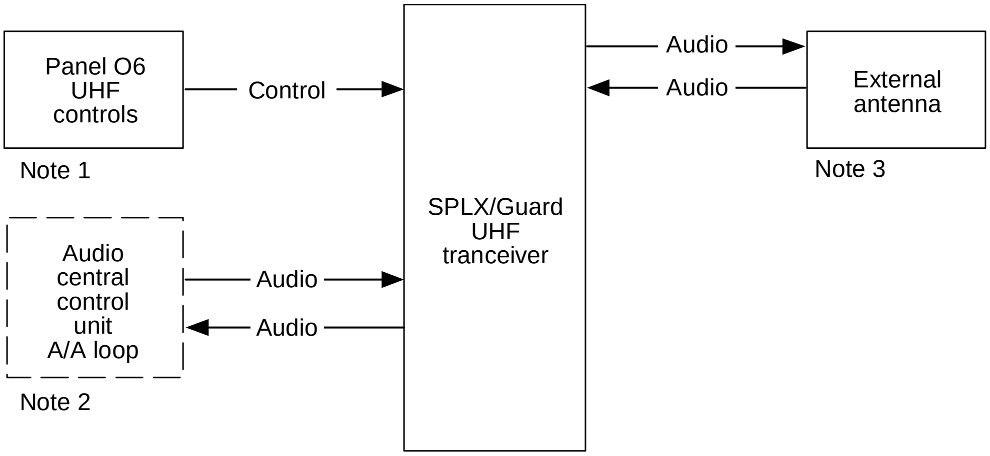
The UHF simplex, or ATC, system is used as a backup for the S-band PM during ascent and entry phases of flight for communications with MCC through the STDN ground stations. Simplex mode means that the orbiter flight crew can transmit or receive, but cannot do both simultaneously. The UHF system may also be used for air traffic control and two-way voice with chase aircraft during landing operations.

In the SPLX or GUARD mode, the UHF transceiver takes the voice signal from the audio central control unit "A/A" loop and routes it through the external UHF antenna on the bottom of the orbiter forward fuselage for transmission to the ground station. The incoming UHF signal goes through the external antenna to the UHF transceiver, which demodulates it and routes it as an audio signal to the audio central control unit "A/A" loop for distribution in the orbiter.

Part of the UHF configuration is controlled through three two-position toggle switches on panel O6 labeled XMIT FREQ, SPLX PWR AMPL, and SQUELCH. The XMIT FREQ switch selects one of the two UHF frequencies, 259.7MHz primary or 296.8 MHz secondary, for external transmission. The SPLX PWR AMPL switch enables or inhibits the UHF power amplifier circuit. When the switch is positioned to ON, the UHF system transmits 10 watts of power through the antenna. When the switch is positioned to OFF, the power transmission is reduced to 0.25 watts by bypassing the power amplifier circuit. SPLX SQUELCH is used in the SPLX mode only. The ON selection activates a squelch circuit to reduce background radio noise. This function may be selected to OFF if the voice communication is weak. This switch is normally selected to ON.



UHF System Controls on Panel O6



Note 1 — Selects UHF mode, XMT FREQ, power, and squelch
Note 2 — Connected to the A/A only
Note 3 — External antenna is for communication with locations external to orbiter

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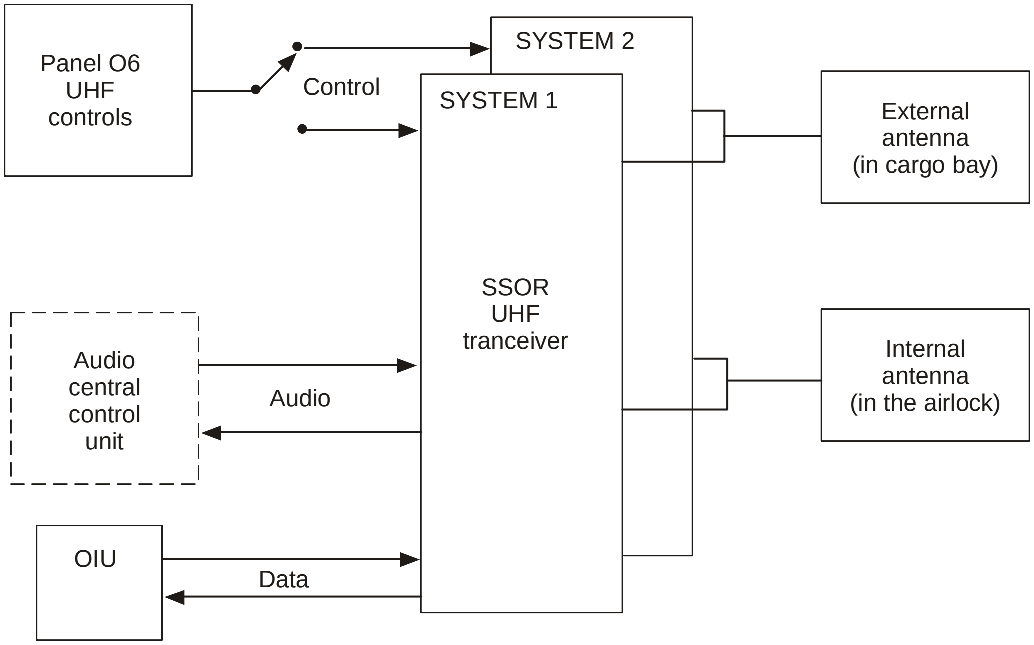
SPLX/GUARD UHF Subsystem Functional Block Diagram



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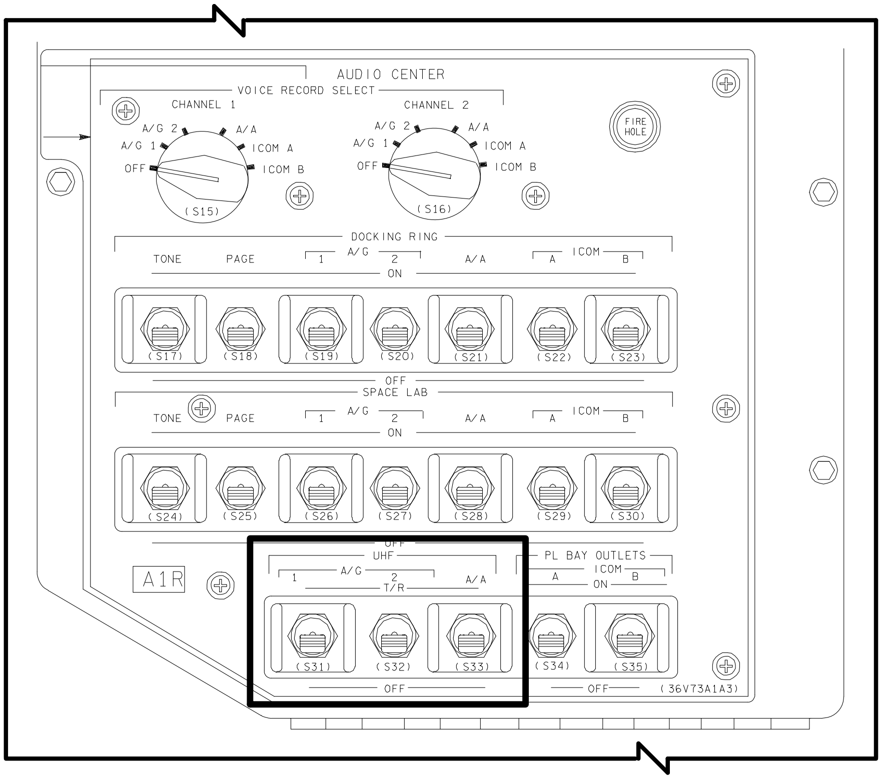
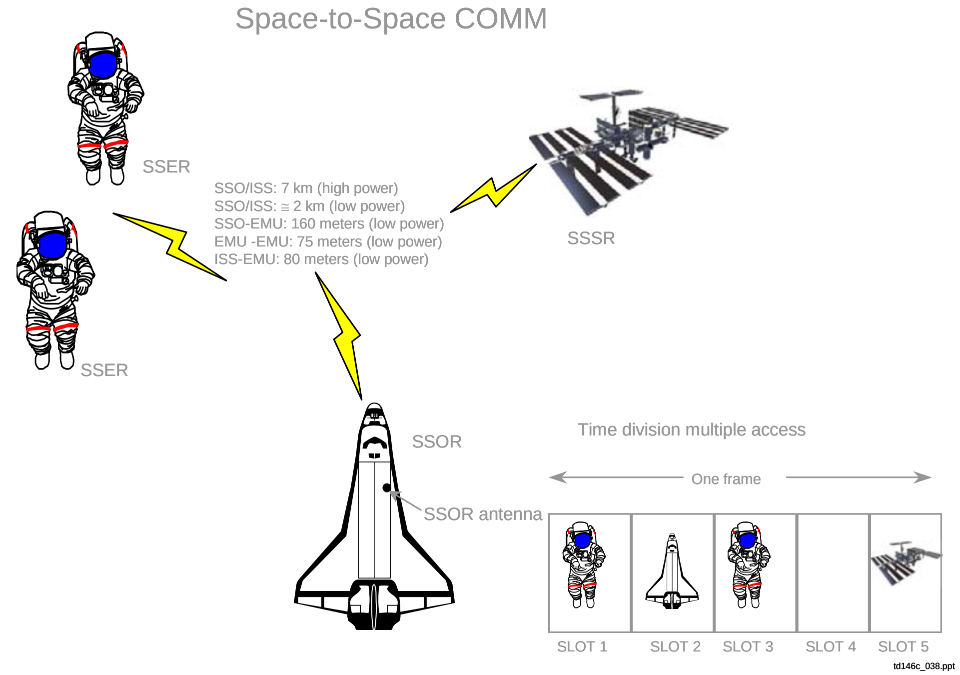
EVA/SSOR UHF Subsystem Functional Block Diagram



UHF *SSOR* Controls on Panel A1R



Time Division Multiplexing

The UHF MODE EVA selection activates the UHF SSOR *or UHF EVA system and* disables the SPLX UHF systems. In the EVA mode, a separate UHF system is used for communicating voice and data between the orbiter, the ISS, and EVA crewmembers. The orbiter system is called the SSOR and is part of the space-to-space communications system (SSCS). The SSCS is a time division multiplexed network that provides slots for five users, including the SSOR, space-to-space station radio (SSSR), and up to three space-to-space EVA radios (SSER).

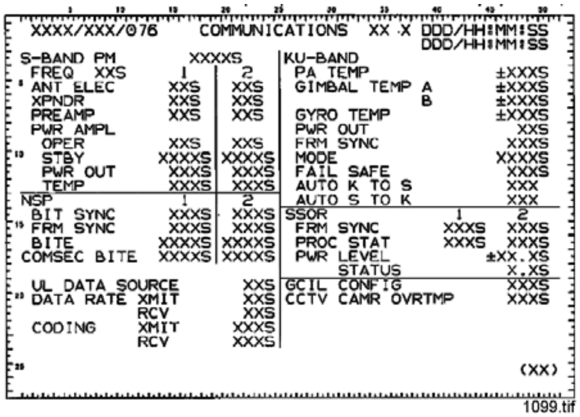
The SSCS operates at 417.1 or 414.2 MHz, depending on the selection of the SPLX/EVA XMIT FREQ switch. All of the panel O6 UHF switches, except SQUELCH, apply to the SSOR system. The main antenna for SSOR is mounted on the starboard side of the airlock truss. The SSOR is also connected to an antenna inside the orbiter airlock for EVA checkout prior to egress.

The SSOR is connected to the orbiter audio system through the A1R AUDIO CENTER panel UHF switches. EVA conversations are routed to Mission Control via the S-band PM or Ku-band system on A/G 1 or A/G 2, depending on the configuration of the UHF switches on panel A1R. A/G 1, A/G 2, and/or A/A may be used; however, A/G 1 normally is selected. EVA biomedical/suit data is routed through the OI system once it is removed from the UHF/SSOR carrier.

The SSOR system has a prime and backup set of radios, selectable by 1 or 2 on the EVA STRING switch. String 1 is designated as prime. Transmitter power out is determined by selecting the SPLX/EVA PWR AMP switch. Low or high power is 19.1 dBm (~80 mW) to 31.6 dBm (~1.44 W), respectively. High power is never used - it exceeds FCC limits.

The SSOR may be operated with encryption. If so, the ENCRYPT will be selected to ON.

The SSOR status is visible to the crew on two orbiter DPS displays, SM COMMUNICATIONS SPEC 76 and SM OIU SPEC 212. Prime (PRI) and backup (B/U) status are indicated. Frame sync (FRM SYNC) – YES indicates that all active SSCS users are established in the network and communication should be good. FRM SYNC – BAD indicates no communication in the network. Processor status (PROC STAT) – OK indicates which system is on. BAD indicates the system is off.



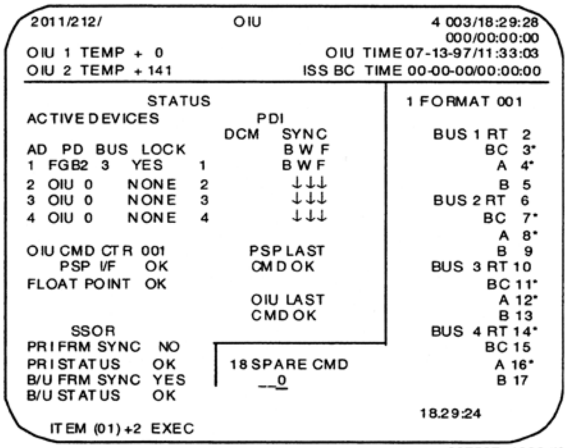
```
XXXX/XXX/076    COMMUNICATIONS  XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
S-BAND PM         XXXXS    KU-BAND
 FREQ  XXS       1     2    PA TEMP                ±XXXS
 ANT ELEC       XXS   XXS   GIMBAL TEMP A          ±XXXS
 XPNDR          XXS   XXS               B          ±XXXS
 PREAMP         XXS   XXS   GYRO TEMP              ±XXXS
 PWR AMPL                   PWR OUT                  XXS
  OPER          XXS   XXS   FRM SYNC                XXXS
  STBY        XXXXS XXXXS   MODE                   XXXXS
  PWR OUT      XXXS  XXXS   FAIL SAFE               XXXS
  TEMP         XXXS  XXXS   AUTO K TO S              XXX
NSP              1     2    AUTO S TO K              XXX
 BIT SYNC      XXXS  XXXS  SSOR             1        2
 FRM SYNC      XXXS  XXXS   FRM SYNC      XXXS    XXXS
 BITE         XXXXS XXXXS   PROC STAT     XXXS    XXXS
COMSEC BITE   XXXXS XXXXS   PWR LEVEL            ±XX.XS
                                STATUS             X.XS
 UL DATA SOURCE        XXS GCIL CONFIG              XXXS
 DATA RATE XMIT        XXS CCTV CAMR OVRTMP         XXXS
           RCV         XXS
 CODING    XMIT       XXXS
           RCV        XXXS

                                                   (XX)
```

1099.tif

COMMUNICATIONS Display (SPEC 76)

The power level (PWR LEVEL) indication can be between 19.1 dBm and 31.6 dBm, depending on the SPLX/EVA PWR AMP switch selection. This parameter defaults +15.0 L when both systems are powered off (OFF or SPLX modes). The STATUS parameter indicates the system current, from 0 to 70 amps. Typically, 35 amps is indicated for the active system and 0.0 L is indicated if deactivated.



```
2011/212/                  OIU              4 003/18:29:28
                                              000/00:00:00
OIU 1 TEMP + 0              OIU TIME 07-13-97/11:33:03
OIU 2 TEMP + 141          ISS BC  TIME 00-00-00/00:00:00
              STATUS                     1 FORMAT 001
ACTIVE DEVICES            PDI
                     DCM    SYNC            BUS 1 RT  2
AD  PD   BUS  LOCK          B W F                BC  3*
1   FGB2  3   YES    1      B W F                 A  4*
2   OIU   0   NONE   2      ↓↓↓                   B  5
3   OIU   0   NONE   3      ↓↓↓             BUS 2 RT  6
4   OIU   0   NONE   4      ↓↓↓                  BC  7*
                                                  A  8*
OIU CMD CTR 001           PSP LAST                B  9
    PSP I/F    OK         CMD OK            BUS 3 RT 10
FLOAT POINT    OK                                BC 11*
                          OIU LAST                A 12*
                          CMD OK                  B 13
     SSOR                                   BUS 4 RT 14*
PRI FRM SYNC   NO                                BC 15
PRI STATUS     OK      18 SPARE CMD               A 16*
B/U FRM SYNC   YES        __0                     B 17
B/U STATUS     OK
                                         18.29:24
  ITEM (01) +2  EXEC
```

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OIU Display (SPEC 212)

Audio Distribution System

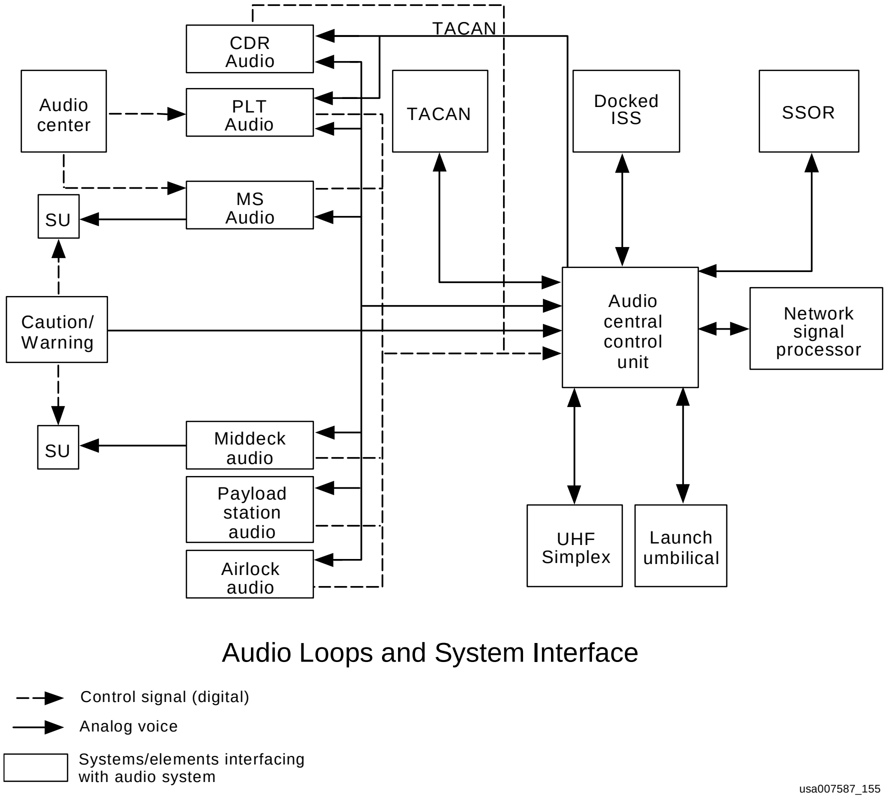
The audio distribution system (ADS) routes audio signals throughout the orbiter. It provides the means by which crew members communicate with each other and with external locations, such as Mission Control, through the S-band PM, Ku-band, UHF and SSOR systems. It also interfaces with the caution and warning system for reception of C/W (tone) signals and with the three tactical air navigation (TACAN) sets for monitoring the TACAN audio identification codes.

The major elements of the ADS include:

1. Audio central control unit (ACCU), *which* acts as a central switchboard to gather and route audio signals throughout the orbiter. *It is an* internally redundant *LRU.*
2. Audio terminal unit (ATU) at crew *communication* stations that permits crewmembers to select audio talk/listen *lines* and to control external/internal communication keying modes and listen volume levels.
3. Speaker unit (SU) consisting of one *speaker* mounted on the flight deck aft A2 panel, the second mounted on middeck ceiling panel MO29J. Both *SUs* are connected to and subject to an associated ATU configuration.
4. Audio center panel, *which is the control* center for extending audio buses to docked ISS (the "Spacelab" switches) and SSOR (the "UHF" switches) and for selecting up to two voice signals for recording on the solid state recorders in the MMUs.
5. Loose communications equipment *consisting of* miscellaneous small, stowable items such as the headset interface unit (HIU), headset/helmet cables, very light weight headset (VLHS), multi-headset adapter (MHA), battery powered speaker mic unit (BPSMU), and handheld mic (HHM).
6. Crew communications umbilical (CCU) jack, *which is an* individual panel-mounted jack at crew *communication* stations where mating headset plugs give the crew access to audio buses. *E*ach CCU location *ha*s an associated ON/OFF switch to control power to the headset interface unit (HIU) microphone.

The eight loops in the audio system are:

1. A*ir-to-Ground 1 (A/G 1)*
2. A*ir-to-Ground 2 (A/G 2)*
3. Air-to-Air *(A/A or UHF SPLX)*
4. Intercom A *(ICOM A)*
5. Intercom B *(ICOM B)*
6. Paging *(PAGE)*
7. C/W
8. TACAN



Audio Loops and System Interface

External communications are accomplished by routing A/G 1*, A/G* 2, and A/A. A/G 1 *&* 2 are used to communicate with the ground through the S-band PM and Ku-band systems and with the EV crewmember through SSOR during EVA operations. A/A is used to communicate with MCC via the UHF *or* ATC system when over ground sites that support UHF. I*COM* A and B are used to communicate from *communication* station to *communication* station within the orbiter and to ISS *via hardline connections in the orbiter docking system (ODS).* The page loop allows one crewmember to send voice transmissions to all active stations. The C/W loop sounds different tones for different malfunctions or emergencies. The TACAN loop, accessible only at the commander's and pilot's stations, is used to identify TACAN ground stations for navigation.

Audio Central Control Unit

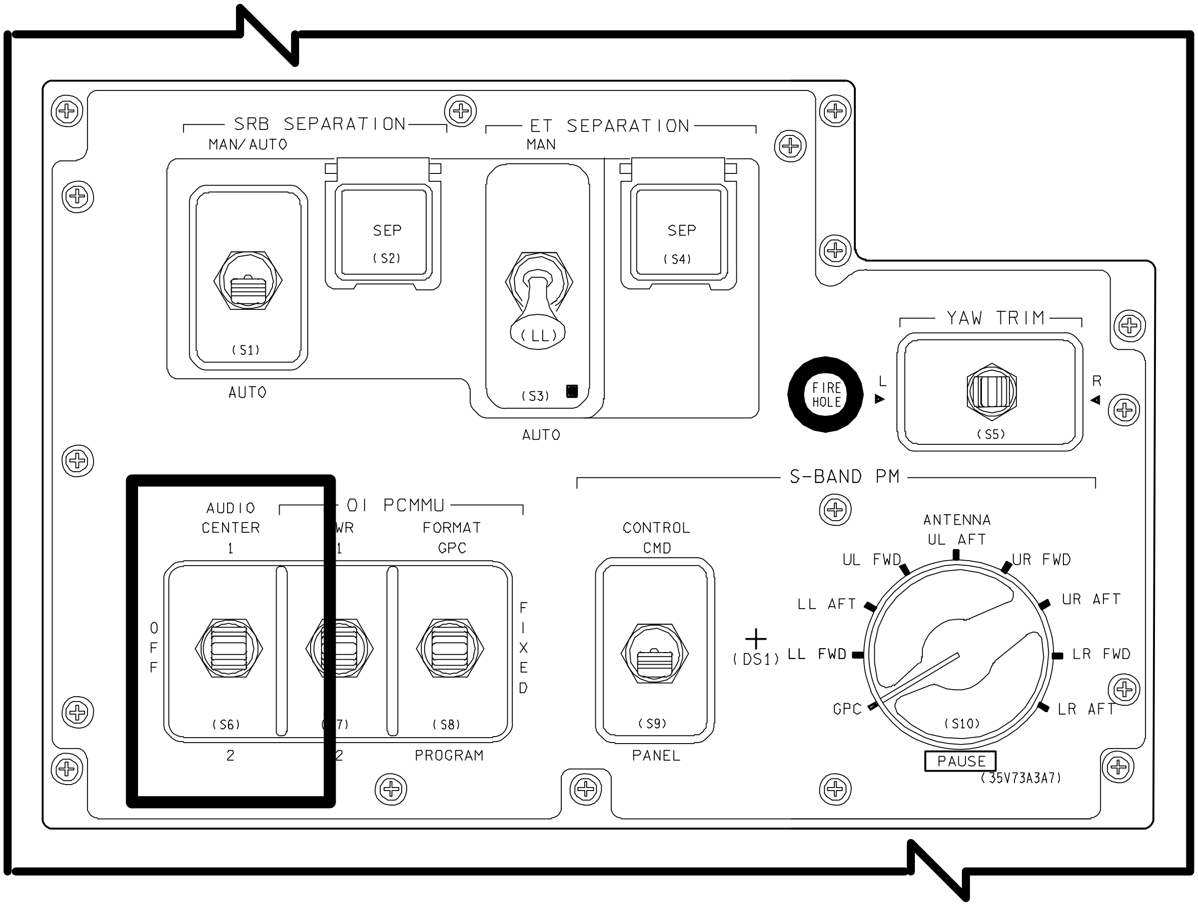
The ACCU, the heart of the audio system, is located in the crew compartment middeck forward avionics bay. (There are two redundant ACCUs *within the same hardware*, but only one is used at any given time.) The unit identifies, switches, and distributes analog audio signals among the various audio distribution system components. Both digital and audio signals are received and processed by the ACCU. The digital signals are used to control the internal configuration of the ACCU per the switch positions on the ATUs and other devices. The audio signals are keyed and routed in response to this internal configuration.

The *AUDIO CENTER* selection switch is on panel C3. Setting the switch to 1 applies primary power to the control center unit from the *ESS 2CA AUD CTR 1* circuit breaker on panel R14. Selecting 2 applies power to the secondary unit electronics from *MN C AUD CTR 2* circuit breaker on panel R14. OFF removes all power from the ACCU.

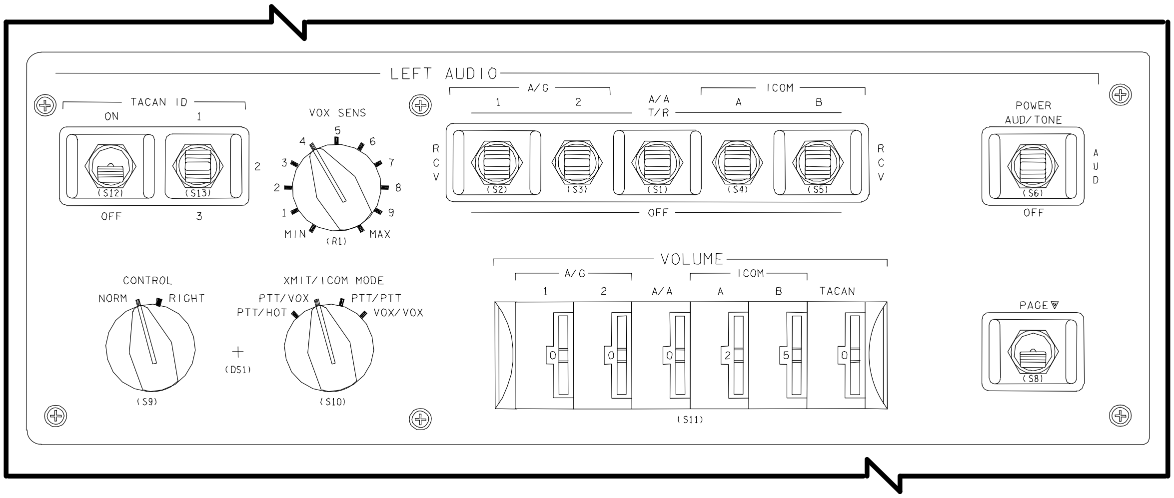
NOTE

> With the AUDIO CENTER selection switch OFF, all normal audio functions will be inoperative. However, the commander and pilot can communicate via headset if one of their ATU CONTROL switches is set to the alternate position. This is also true for any two stations that share ATUs through an audio control switch position (i.e., mission specialist and payload specialist, airlock CCU 1 and middeck ATU, and airlock CCU 2 and payload specialist).

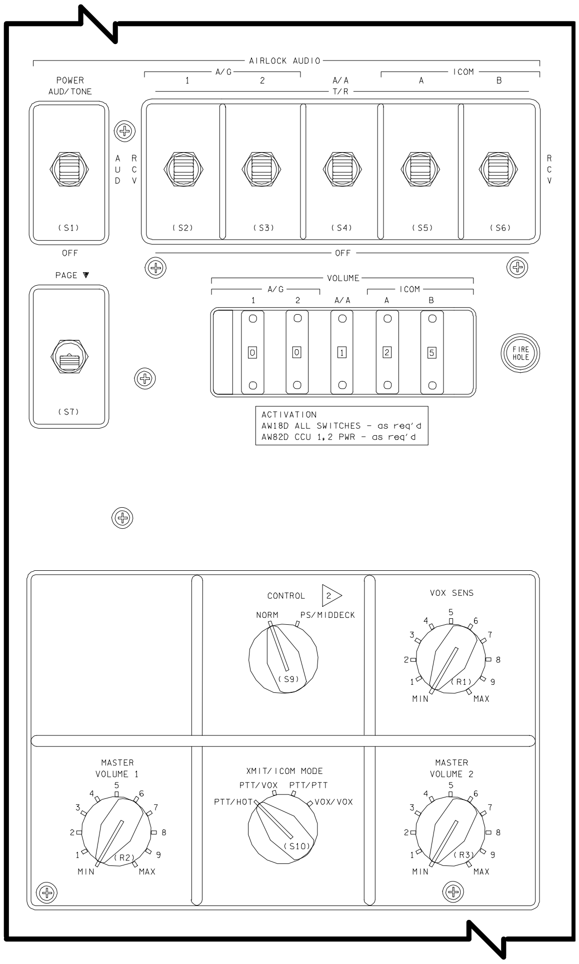
The ACCU circuitry activates signals from the launch umbilical connection intercom A and B channels. Any crew station ATU can then be configured to transmit and receive intercom signals from Launch Control Center (LCC) through the umbilical. (Only intercom signals are processed through the umbilical.)



AUDIO CENTER Selection Switch on Panel C3



Commander's Audio Terminal Unit of Panel 05



Audio Terminal Unit on Panel AW18D

Audio Terminal Units

Six audio terminal units (ATUs) are used in the crew compartment to select and control the volume of each audio loop . ATU panels are located at the following crew stations:

- Panel O5 (LEFT AUDIO)
- Panel O9 (RIGHT AUDIO)
- Panel R10 (MISSION STATION AUDIO)
- Panel L9 (PAYLOAD STATION AUDIO)
- Panel M042F (MID DECK SPEAKER AUDIO)
- Panel AW18D (AIRLOCK AUDIO)

These panels control signals routed through audio hardware connected to the associated crew communications umbilical (CCU). The MS ATU controls the loops routed to the Flight Deck speaker; the MD ATU controls the loops routed to the Mid Deck speaker.

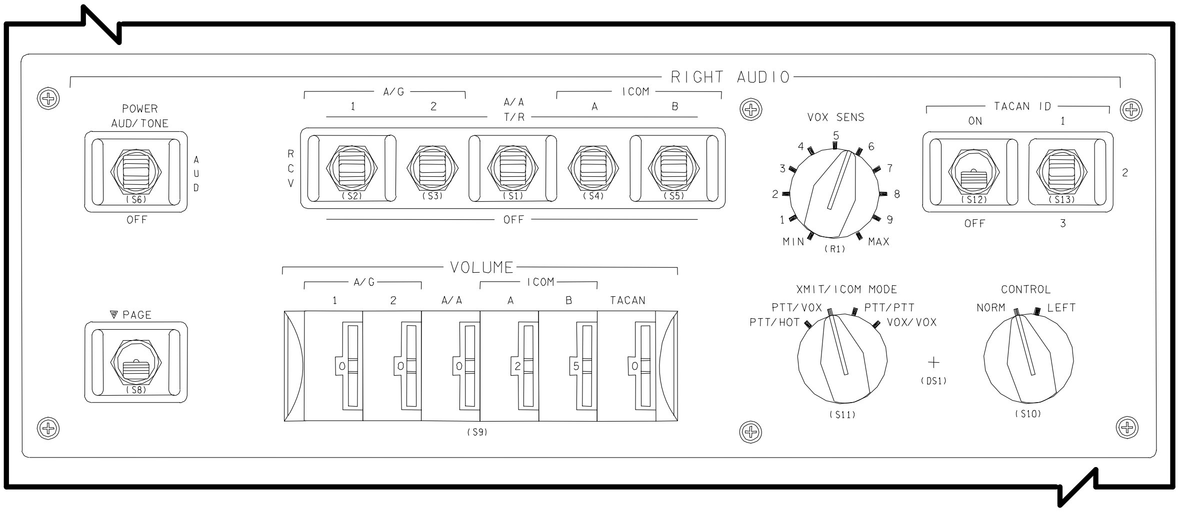
Each ATU has a three-position power switch to control all signals to or from the ATU. The switch positions are AUD/TONE, AUD, and OFF. In the AUD/TONE position, all available functions of the ATU are armed, and transmission and receptions may be made through the ATU, depending on the position of other switches on the ATU. C/W tone signals are sent to the ACCU to allow C/W audio to reach the ATU, the CCU, and the speaker unit. The AUD position has the same functions as AUD/TONE except that C/W signals are blocked from the ATU. The OFF position shuts off power to the ATU power supply, for the ATU amplifiers.

NOTE

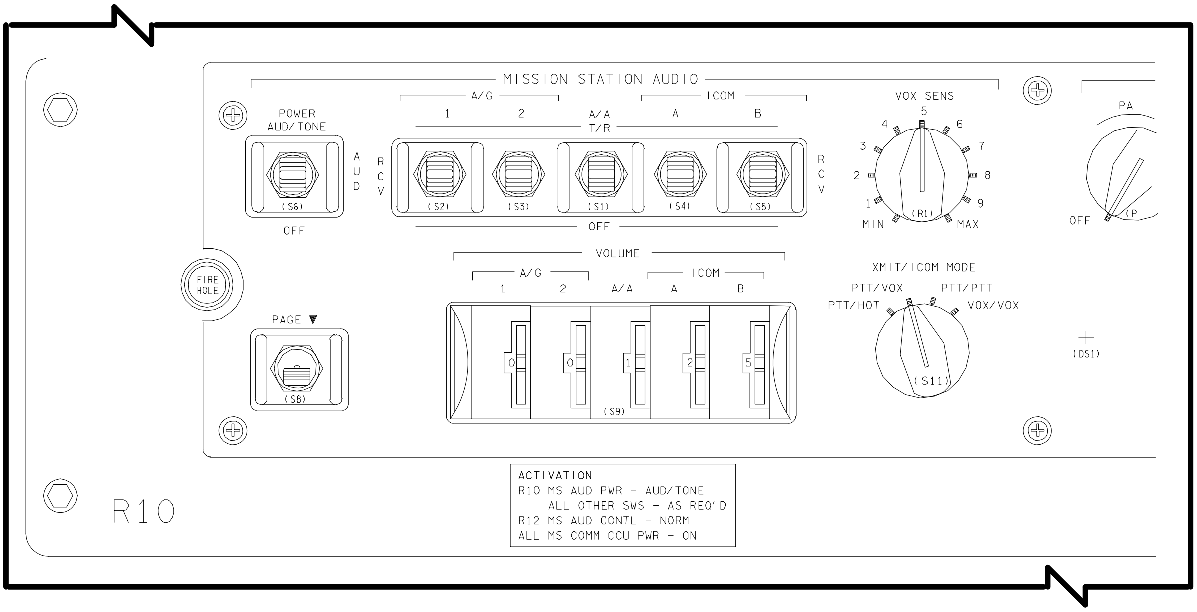
> Klaxon (cabin air pressure) and siren (fire) C/W signals go directly to a speaker unit, even with the speaker power off.

Each ATU has a two-position, PAGE switch that must be held in the PAGE position to activate the circuit. When activated, the circuit enables the ATU to transmit to all other ATUs, the SSOR, and the docked ISS. Any number of stations may use the page circuit simultaneously regardless of the position of the other channel control switches.

On all ATUs, the two air-to-ground channels, the air-to-air channel, and intercom channels A and B have individual three-position control switches for selecting access to particular channels for transmission or reception. The switch positions are T/R, RCV, and OFF. The T/R position permits transmission or reception over the selected channel. The RCV position deactivates transmission capability on the selected channel and permits only reception of signals. The OFF position deactivates transmission and reception on the selected channel.

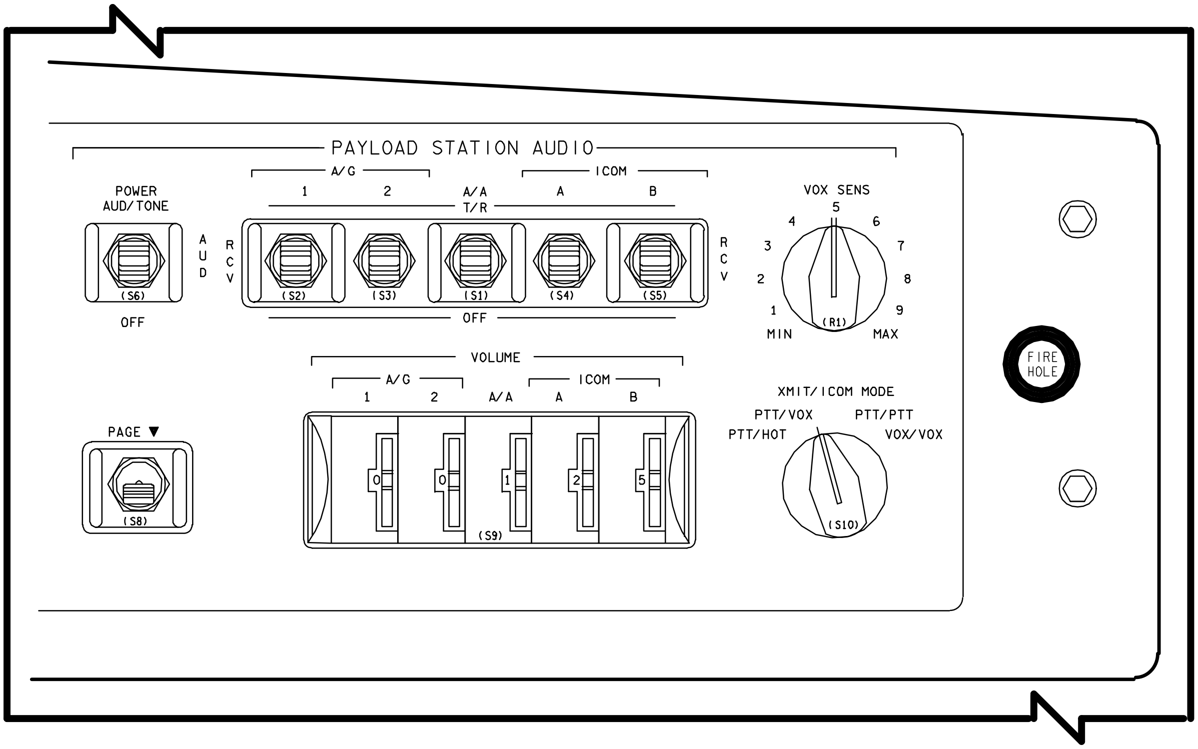


Pilot’s Audio Terminal Unit on Panel O9

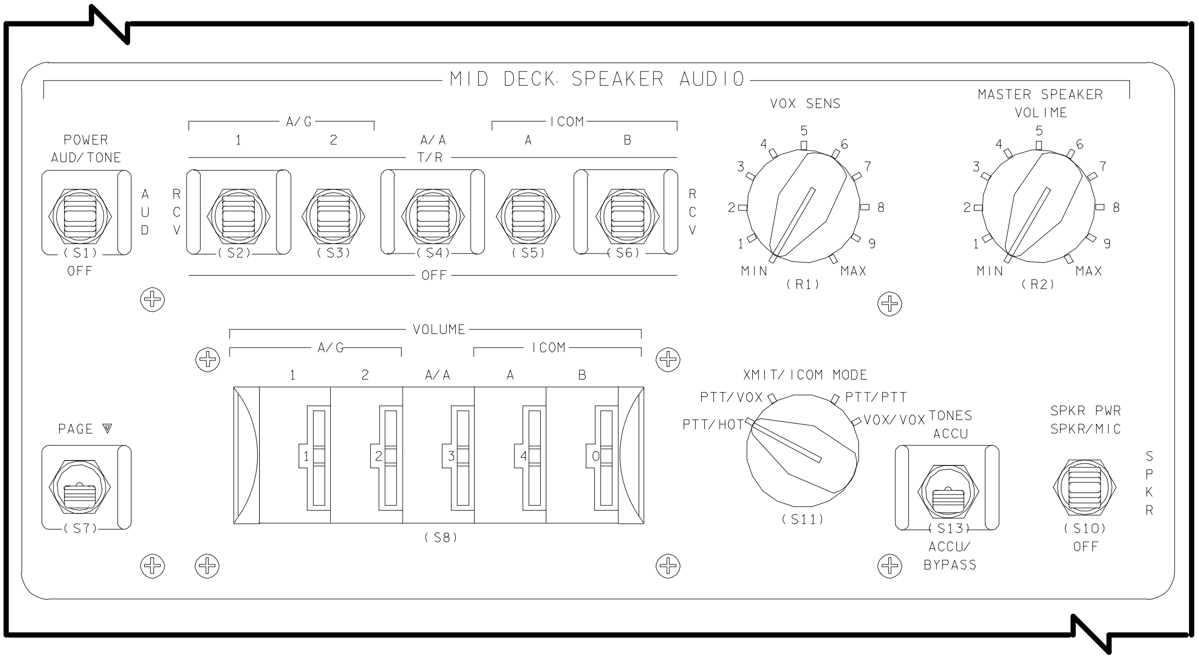


ACTIVATION
R10 MS AUD PWR - AUD/TONE
ALL OTHER SWS - AS REQ'D
R12 MS AUD CONTL - NORM
ALL MS COMM CCU PWR - ON

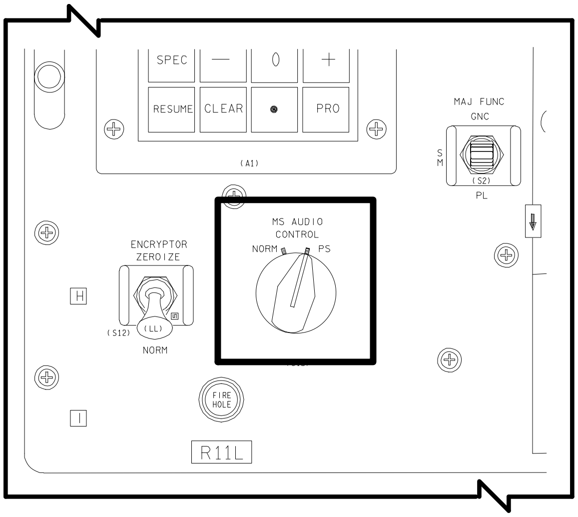
Audio Terminal Unit on Panel R10



Audio Terminal Unit on Panel L9



Audio Terminal Unit on Panel MO42F



MS AUDIO CONTROL Switch on Panel R11L

Each channel control switch has a thumbwheel VOLUME control to adjust signal intensity on the related channel. The thumbwheels cover a range of approximately 27 decibels in 3-decibel increments.

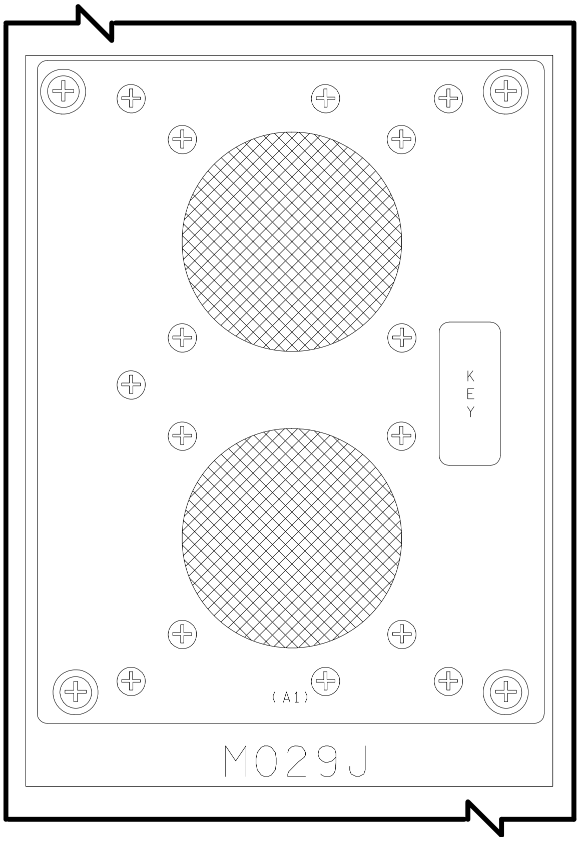
The *XMIT/ICOM MODE* rotary switch controls four combinations of external and intercom transmissions. In the *PTT/HOT* mode, transmission through A/G 1, A/G 2, and A/A requires manual keying of the audio hardware XMIT push-*to-talk* (PTT) button; *ICOM* A and B will be hot mike. In the *PTT/VOX* mode, A/G 1, A/G 2, and A/A require PTT of the XMIT button, while *ICOM* A and B are voice keyed. In the *PTT/PTT* mode, all voice channels are push button keyed. In the *VOX/VOX* mode, all voice channels are voice *activated.*

The *VOX SENS* rotary potentiometer on the ATUs regulates the volume of the signal required for voice keying. The *MAX* setting requires a lower decibel level to key the circuit than the *MIN* setting.

Volume control of all incoming signals to speakers is adjusted by the *MASTER SPEAKER VOLUME* controls on panels A13 and MO42F. The airlock ATUs have unique *MASTER VOLUME* 1 and 2 potentiometers on panel AW18D, which control volume to the CCU1 and CCU2 outlets in the airlock.

Four ATUs (on panels O5, O9, AW18D, and R10) allow a crewmember at a malfunctioning ATU to switch to an alternate ATU. The left may be switched to the right (commander's to pilot's ATU), or right ATU control may be switched to the left (pilot's to commander's ATU). The commander's and pilot's *CONTROL* knobs are located on panels O5 and O9. Mission specialist ATU may be switched to the payload specialist's ATU using the MS *AUDIO CONTROL* switch on panel R11L. Airlock ATU control may be switched to the middeck and payload specialist's ATUs using the *CONTROL* rotary switch on panel AW18D.

When the *CONTROL* switch is in the *NORM* position, control of the ATU is from the panel to which the knob belongs. The other position of the knob indicates the ATU to which control can be transferred. The *CONTROL* knob changes all ATU functions to the alternative ATU except the master volume control. This redundancy protection is used in the event of a failure or malfunction of any of the four audio terminal units that have a *CONTROL* knob.



Speaker Unit on Panels A2 and M02J

Speaker Units

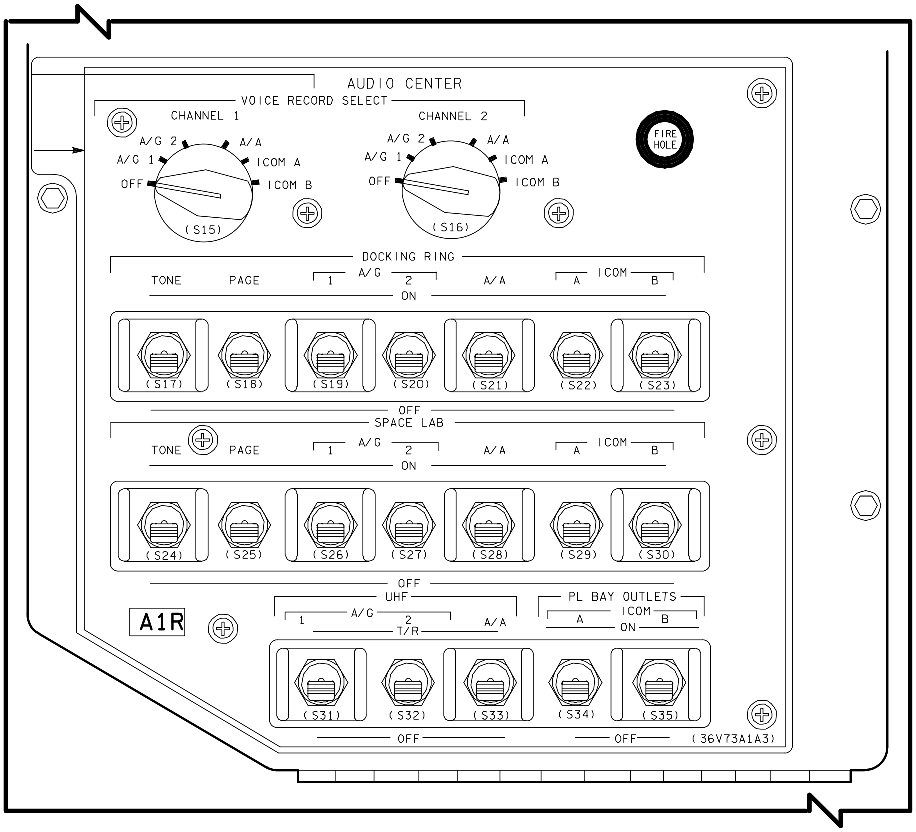
Speaker units are located on panels A2 and MO29J. They are controlled by *the MS* ATU on panel R10 and *the MD ATU on panel* MO42F. The speaker unit has a three-position *SPKR PWR* switch. Only the OFF and SPKR positions are used. In the OFF position, no signals go through the *associated* ATU. In the SPKR position, audio selected on the associated ATU, including C/W tones, are enabled. The SPKR/MIC position is functionally identical to the SPKR position. The top speaker is used for audio and the bottom is dedicated to the klaxon/siren.

The KEY light *on the speaker* illuminates when a microphone on the associated ATU is keyed (PTT, VOX, etc.). The KEY light indicates that the speaker is muted.

Audio Center Panel

The *AUDIO CENTER* controls on panel A1R have four functions: voice interface capability with SSOR (UHF switches) and docked ISS (Spacelab switches), the payload bay comm outlets (not used), and loop selection for recording. All switches on the panel send digital impulses to the ACCU, enabling the selected functions to communicate with the docked ISS, SSOR, and recorders.

Two rotary knobs labeled *VOICE RECORD SELECT* control various audio signals to be sent to the recorders via the NSP. *A/G 1, A/G 2, A/A,* and *ICOM A* or *B* audio can be sent to either recorder. Any two signals may be recorded at the same time, one on channel 1 and the other on channel 2. Either channel may be turned off.



AUDIO CENTER Controls on Panel A1R

Loose Communications Equipment

Launch and Entry Helmets

During launch and entry, each flight crewmember wears a launch and entry helmet to lessen the severe noise levels encountered at launch and to allow intelligible air-to-ground communications. A communications carrier assembly *(CCA)* headset containing microphones and earphones fits over the crewmember's head. *Also, there is* a connector and cable interface with *the HIU, which is* connected through communications cables to *the* respective *crew communication umbilical and associated ATU.* The microphones can be positioned to suit the individual crewmember. For emergency egress, a pull-away connection is used between the communications carrier assembly and headset interface unit, in addition to the standard communications carrier assembly/headset interface unit twist-on connector.

The helmets have redundant noise-canceling microphones and electrically isolated earphones. When air is inhaled, the demand breathing regulator shuts off the microphones to avoid transmitting breathing sounds.

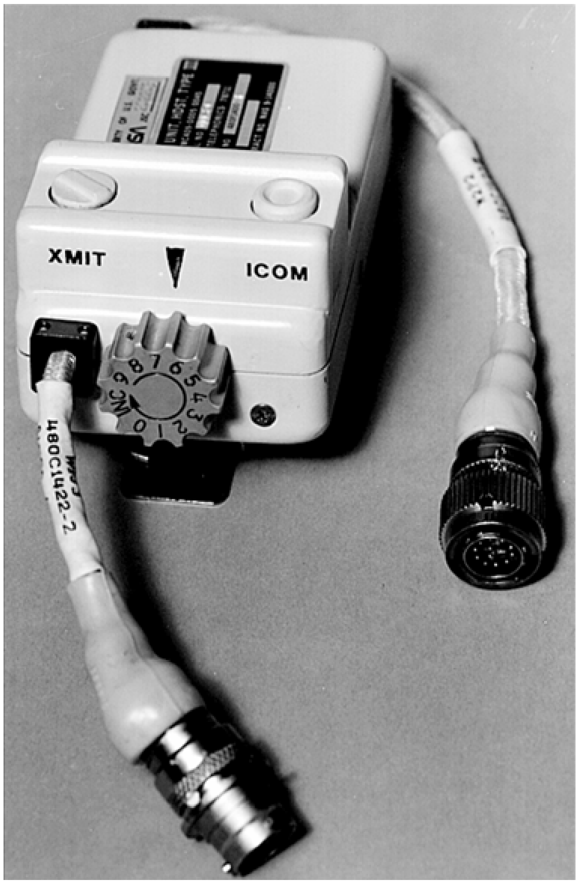
NOTE

An improper face seal will cause enough oxygen flow to cut off microphones.

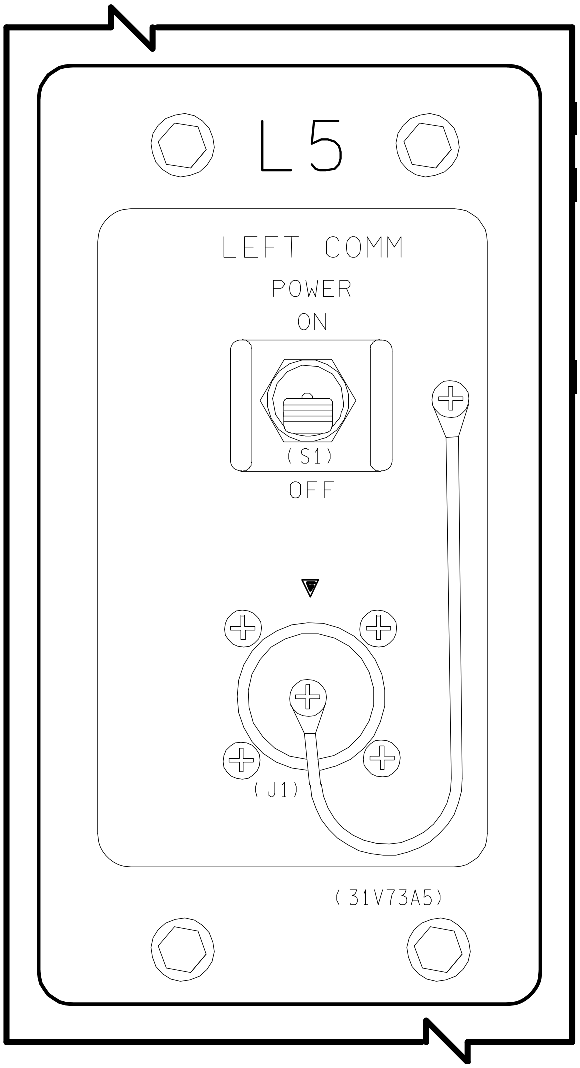
Headset Interface Unit

The headset interface unit has separate push-to-talk (PTT) buttons for transmit and intercom modes and a volume control that determines the level of sound heard through the earphone (microphone sound level is determined by automatic gain control circuitry within the audio terminal unit). Push-to-talk means that a pushbutton must be depressed to allow a crewmember to talk through the system. The *transmit (*XMIT*)* pushbutton allows access to intercom *(ICOM)* and external circuits, while the ICOM pushbutton is for intercom only. The volume control knob acts in series with the loop volume controls on the associated audio terminal unit (ATU). In addition, the commander and pilot have PTT switches on their rotational hand controllers for XMIT keying.

The headset interface unit provides volume control and PTT capabilities to the communications carrier assembly used for EVA and to the communications carrier assembly. The headset interface unit has a clip that attaches to the crew's flight suits.



Headset Interface Unit



Crewman Communications Umbilical on Panel L5

Cables

The communication cables vary in configuration, depending on seat location. Each seat has two 4-foot communication cables or a 14-foot length, as required. One 4-foot cable is flown as a spare. The cables connect to crewman communications umbilical (CCU) outlets at various locations in the crew compartment. Each CCU has a specific audio terminal unit that controls communication loop configurations. The CCU associated with the ATU on panel O5 is located on panel L5 (*LEFT COMM*); for O9 on R6 (*RIGHT COMM*); for R10 on A11 (MS COMM), for L9 on A15 (*PS COMM*), and for MO42F on MO39M (*MID DECK COMM*); two others for the airlock ATU are located on panel AW82D (*CCU* 1 and *CCU* 2).

Each CCU outlet has a power switch that controls the associated microphone power. *If the* CCU power *is* off, *it results in a* listen-only mode, independent of audio terminal unit configuration.

Multiple Headset Adapter

A multiple headset adapter *(MHA)* may be plugged into the CCU outlets. *It contains* three *additional* CCU outlets *to allow up to* three crewmembers to share one CCU outlet. When any one person connected to an *MHA* keys (in PTT mode) or activates the voice-operated transmitter, *all* three microphones will be keyed, and individuals sharing the *MHA* will hear each other talking on the side tone.

Wireless Communications Units

Wireless communications units are rarely used by current crews. On orbit, the crew may use wireless communication units in place of communication cables. A wireless unit consists of one wall unit (audio interface unit) and two leg units (crew remote units) worn by crewmembers during orbital operations. The wall unit connects to a CCU outlet and remains attached to the crew compartment wall. Each wall unit transmits on a unique pair of UHF frequencies. Leg units may be configured to work with any wall unit. A leg unit may be converted into a wireless handheld microphone by attaching a noise-cancelling mic at the headset connector. Each wall unit is identified by a letter enclosed in a box. Each unit is stowed with its cabling attached. The wall unit has a 23-inch cable to interface with the CCU outlet, and the leg unit has a 22-inch cable attached to a lightweight headset.

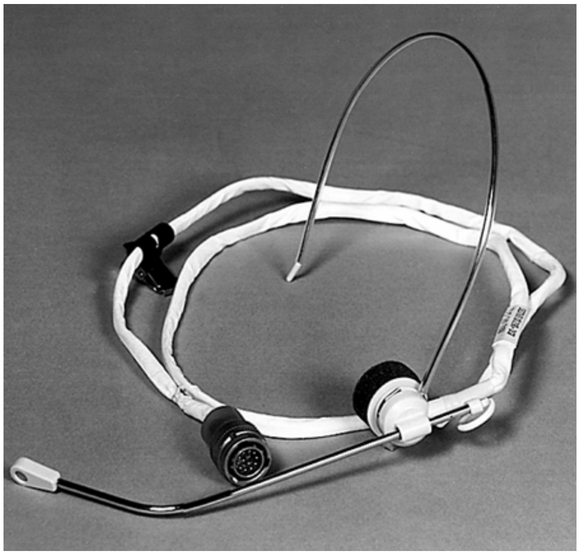
NOTE

If the two leg units are set to use the same frequency, one of the units' transmit signals will be muted.

When the wireless unit is unstowed, part of the assembly necessary is to insert and tighten the flexible antenna in the bottom of each wall and leg unit. The wall unit receives power from the CCU outlet. All other switches are set as required; typically, the individual communication loops are used. The leg unit is attached to the crewmember's leg with a wraparound elastic strap. The rotary ON/OFF/VOLUME knob (unlabeled) is turned clockwise past the ON/OFF detent, and the volume is set as desired. Each leg unit is powered by a replaceable lithium battery pack. A weak battery is identified by a continuous beeping sound when the leg unit is powered on. A single battery pack provides about 35 hours of service. Sliding a new battery pack into the unit causes both the electrical connector and mechanical connector to latch.

Very Lightweight Headset

The very lightweight headset *(VLHS)* is the interface between the leg unit and crewmember. A single-strand wire headband holds the earphone against the ear and supports a thin boom holding a noise-cancelling microphone near the mouth. A cable and connector are attached to the crewmember's leg unit. The lightweight headset cable and connector also can interface with the headset interface unit.



Very Lightweight Headset

Handheld Microphone

The handheld microphone is a noise-canceling microphone that connects directly to any CCU outlet. The microphone is used primarily with the SUs located at panels A2 and MO29J. To avoid feedback when using the speakers, one ATU and its corresponding CCU outlet on the aft flight deck and one ATU and associated CCU on the middeck are equipped with a speaker muting capability. *M*uting is controlled through ATUs at panels R10 and MO42F.

Two PTT pushbuttons are provided for XMIT and ICOM audio modes. When used to record audio on the videotape recorder, either can be used. The pushbuttons should face the operator to ensure that the noise-canceling feature of the microphone remains functional. The handheld microphone is equipped with a 7-foot cable that can connect at any CCU or to other cables. The microphone/SU configuration is used for on-orbit communication configurations.

Instrumentation

Orbiter operational instrumentation (OI) collects, processes, and routes information from transducers and sensors throughout the orbiter and its payloads. More than 3,000 data parameters are monitored.

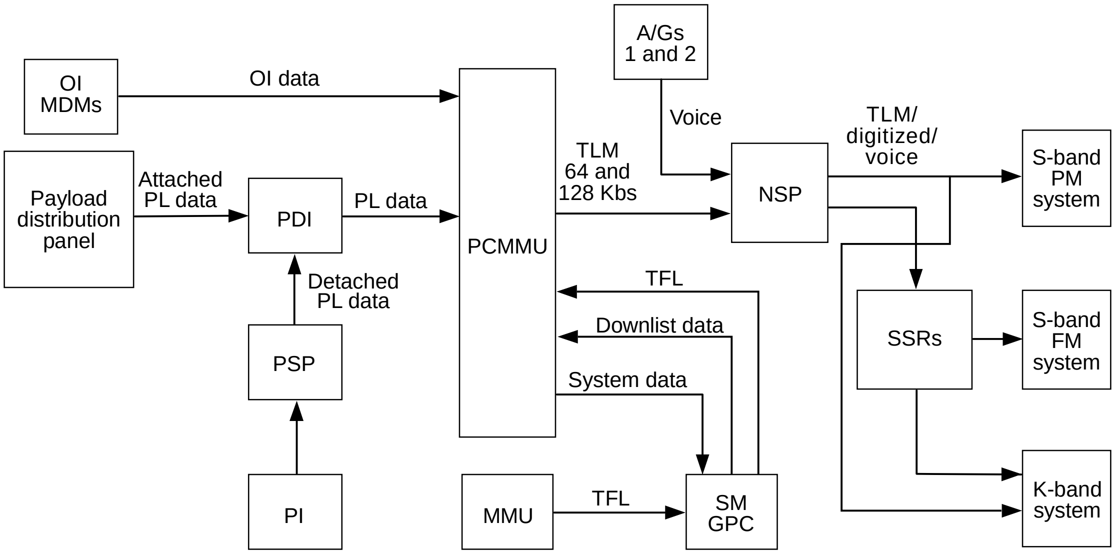
The instrumentation system consists of transducers, 14 dedicated signal conditioners *(DSCs),* 7 MDMs, 2 PCMMUs, 2 recorders, master timing equipment, and onboard checkout equipment.

The OI system senses, acquires, conditions, digitizes, formats, and distributes data for display, telemetry, recording, and checkout. It provides for pulse code modulation recording, voice recording, and master timing for onboard systems. Instrumentation equipment, except sensors and selected dedicated signal conditioners, is located in the forward and aft avionics bays. Sensors and DSCs are located throughout the orbiter in areas selected on the basis of accessibility, minimum harness requirements, and functional requirements. Abbreviations used to designate the locations of equipment are as follows: OA refers to operational aft, OF to operational forward, OL to operational left, OR to operational right, and OM to operational mid.

Dedicated Signal Conditioners

Dedicated signal conditioners acquire and convert various sensor data from thousands of orbiter sensors into a 0-5 V dc pulse acceptable to MDMs. Sensors requiring DSCs include frequency, temperature, rate, voltage, current, and analog parameters.

There are 14 orbiter DSCs, 4 in forward avionic locations (OFs), 3 in the aft avionic bays (OAs), 3 under the payload bay (MID) (OMs), and 4 in the right and left tail sections (ORs and OLs).



A/G	Air-to-Ground
CIU	Communication Interface Unit
GPC	General Purpose Computer
MDM	Multiplexer/Demultiplexer
MMU	Mass Memory Unit
NSP	Network Signal Processor
OI	Operational Instrumentation
SSR	Solid State Recorders
PCMMU	Pulse Code Modulation Master Unit
PDI	Payload Data Interleaver
PI	Payload Interrogator
PL	Payload
PSP	Payload Signal Processor
SM	Systems Management
TFL	Telemetry Format Load
TLM	Telemetry

usa007587_171**r3**.cvx

Operational Instrumentation System Overview

Multiplexer/Demultiplexers (MDMs)

MDMs can operate in two ways. As multiplexers, they take data from several sources, convert the data to serial digital signals (a digitized representation of the applied voltage), and interleave the data into a single data stream. As demultiplexers, the MDMs take interleaved serial digital information, separate and convert it to analog, discrete, or serial digital, and send each separate signal to its appropriate destination.

The OI MDMs act only as multiplexers. Upon request from the pulse code modulation master unit (PCMMU), the MDMs send these interleaved streams to the PCMMU through the OI data buses. When the MDM is addressed by the PCMMU, the MDM selects, digitizes, and sends the requested data to the PCMMU in serial digital form. The PCMMU/OI MDM interface is based on demand and response; that is, the OI MDMs do not send data to the PCMMU until the PCMMU makes the request. There are seven OI MDMs, four OFs, and three OAs for forward and aft multiplexing of DSC and direct data signals.

Pulse Code Modulation Master Unit (PCMMU)

The PCMMU receives data from the OI MDMs, downlist data from the GPCs under control of flight software, and payload telemetry from the Payload Data Interleaver (PDI). It then interleaves the data, formats data according to programmed instructions stored within the PCMMU (the telemetry format load, or TFL), and sends the interleaved data to the network signal processor to be combined with the air-to-ground voice data from the audio central control unit for transmission through the S-band PM downlink and Ku-band system return link, channel one. Telemetry from the PCMMU is also sent through the network signal processor to the solid state recorders (SSRs) for storage and subsequent downlink on the S-band FM or Ku-band system. OI and payload data collected by the PCMMU are available to the

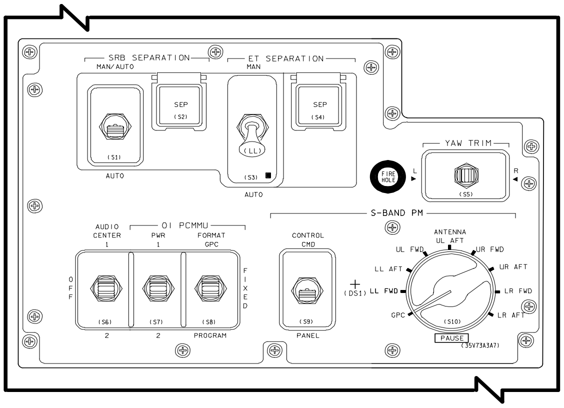
GPCs for display and monitoring purposes upon request. All data received by the PCMMU are stored in memory and periodically updated.

The PCMMU has two formatter memories: programmable read only (PROM) and random access (RAM). The read-only memory is hard coded; the RAM is reprogrammed several times during flight. The PCMMU uses the formatters to load data from the computers and OI MDMs into PCM telemetry data streams for downlinking.

NOTE

> When the PCMMU is powered off (as when switching to the alternate unit), the TFL changes to the fixed format loaded in the PROM.

One of the two redundant PCMMUs and network signal processors operates at a time. The one used is controlled by the crew through the flight deck display and control panel. The primary port of each MDM operates with PCMMU 1 and the secondary port operates with PCMMU 2.



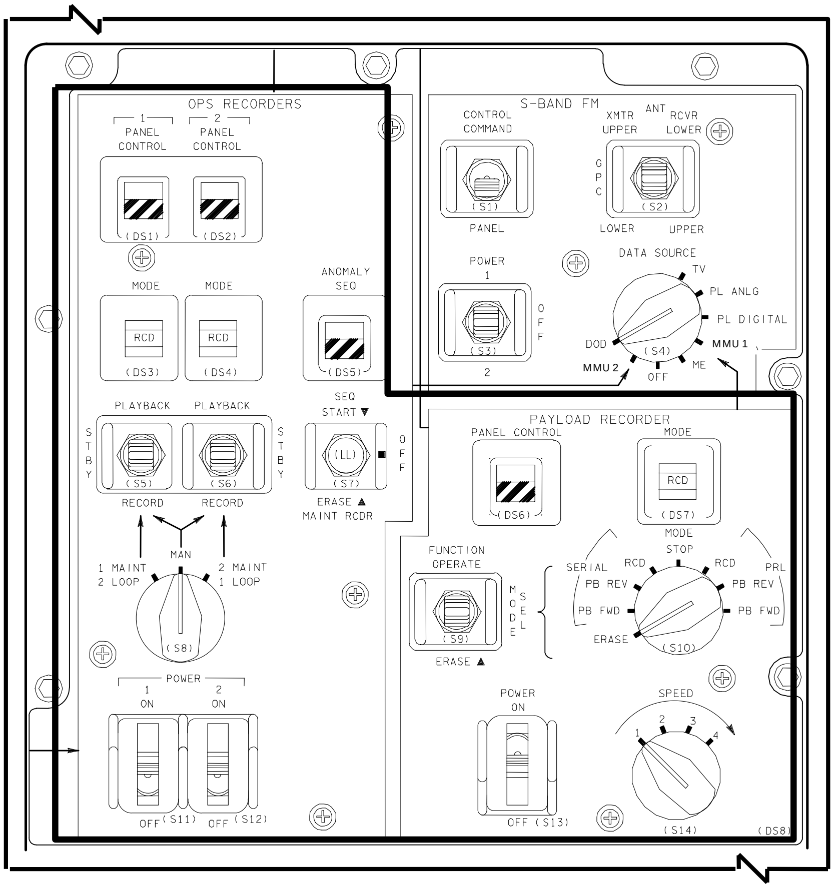
OI PCMMU Controls on Panel C3

The PCMMUs receive a synchronization clock signal from the master timing unit. If this signal is not present, the PCMMU provides its own timing and continues to send synchronization signals to the payload data interleaver and network signal processor.

The OI PCMMU controls are located on panel C3.

Master Timing Unit

The master timing unit is a stable crystal-controlled timing source. It provides synchronization for instrumentation, payloads, and other systems. The master timing unit is described in more detail in Section 2.6.



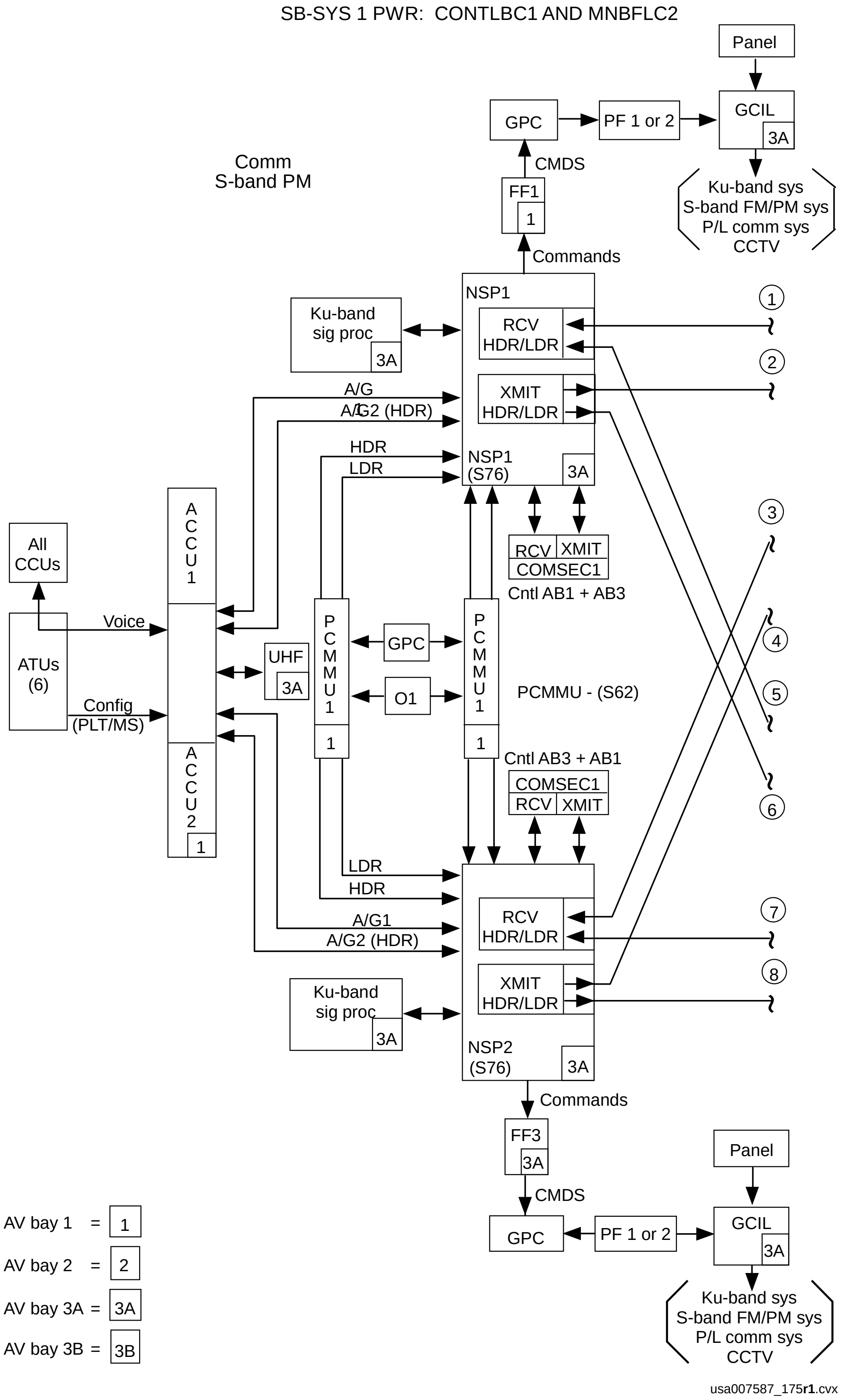
Obsolete Recorder Controls on Panel A1R

Solid State Recorders

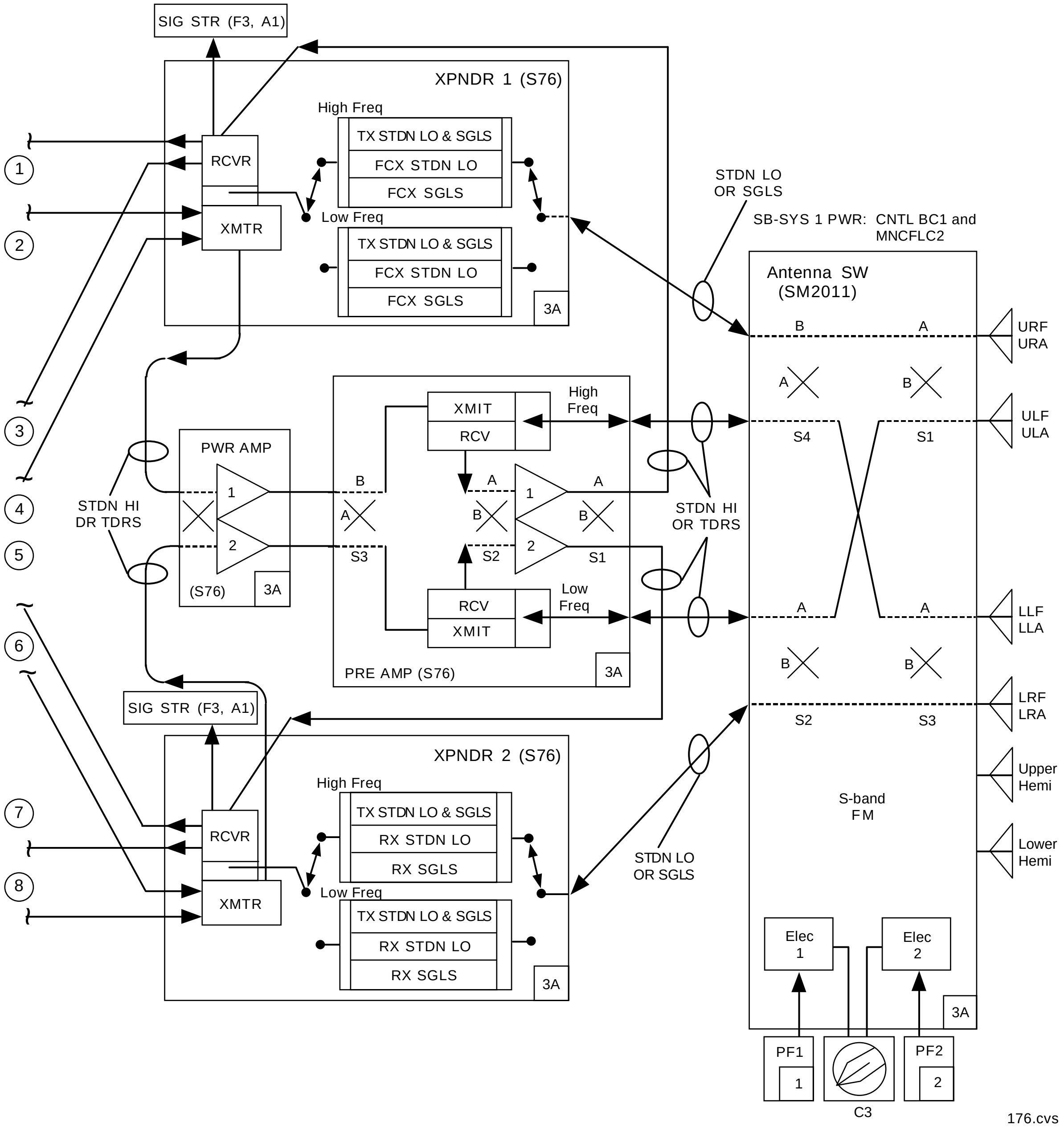
Two solid state recorders (SSRs) are used for serial recording and dumping of digital voice and pulse code modulation (PCM) data from the OI systems. These recorders are embedded in the mass memory units (MMUs); therefore, the recorders are labeled "MMU1" and "MMU2" on panel A1 for dumps through Ku-band or S-band FM. The recorders are controlled entirely by ground command, with no crew controls available.

Communications System Summary

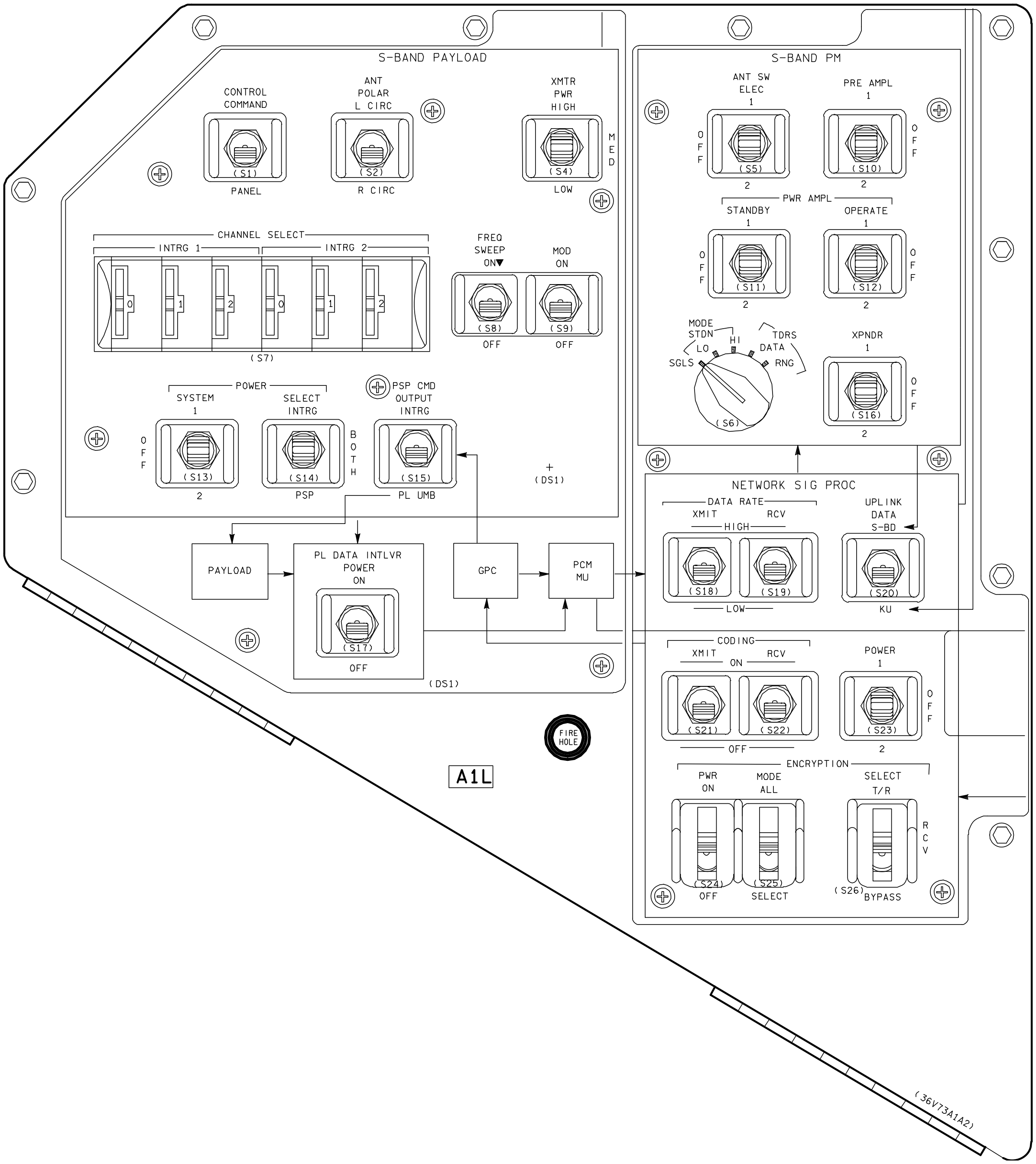
- The orbiter communications system transfers information between the orbiter and the ground, either through hardline or radio frequency links.
- The system is divided into several smaller systems: S-band phase modulation (PM), S-band frequency modulation (FM), Ku-band, UHF, payload communications, audio, and CCTV.
- The S-band PM system provides two-way communication between the orbiter and the ground, through either an STDN/SGLS ground station or a TDRS. It provides channels for five functions: command, voice, telemetry, turnaround tone ranging, and two-way Doppler tracking.
- Four quadrant S-band antennas provide a selection of eight directions.
- The S-band FM system cannot receive information. It is used to downlink data directly to the ground from seven different sources: SSME interface units, the video switching unit, the solid state recorders, payload analog, or payload digital.
- There are two hemispherical S-band FM antennas.
- The Ku-band system provides for on-orbit communication between the orbiter and the ground. It can also be used as a radar system for tracking objects in space.
- The Ku-band antenna is deployed when the payload bay doors are opened, and stowed when they are closed. The antenna is steerable.
- TV data can be downlinked over Ku-band and S-band FM only.
- The payload communication system is used to transfer information between the orbiter and its payloads.
- The UHF simplex system is used as a backup for the S-band PM and Ku-band voice communications. SSOR is used as the primary communications link with EVA astronauts.
- The audio distribution system gathers audio signals from multiple sources and routes them throughout the orbiter. It is used as the means by which crewmembers communicate with each other and with ISS during rendezvous and undocking.
- The major elements of the audio distribution system are: the ACCU, ATU, speaker units, CCU, and loose communications equipment. The audio center panel allows the crew to connect the audio distribution system to SSOR, docked ISS, and SSRs.
- Orbiter operational instrumentation (OI) collects, routes, and processes information from transducers and sensors throughout the orbiter and its payloads.
- The OI system consists of transducers, 14 DSCs, 7 MDMs, 2 pulse code modulation master units, encoding equipment, 2 solid state recorders, master timing unit, and onboard checking equipment.
- Major communications equipment and control panels are A1R, A1U, A1L, R13L, O5, O6, O9, R10, L9, and R12. Others are found on panels A13, A14, A15, L5, F9, C3, R11L, R15, MO29J, MO42F, and AW18D.
- Specific communications system DPS displays are OPS 201 ANTENNA, COMMUNICATIONS (SPEC 76), and PC MMU/PL COMM (SPEC 62).



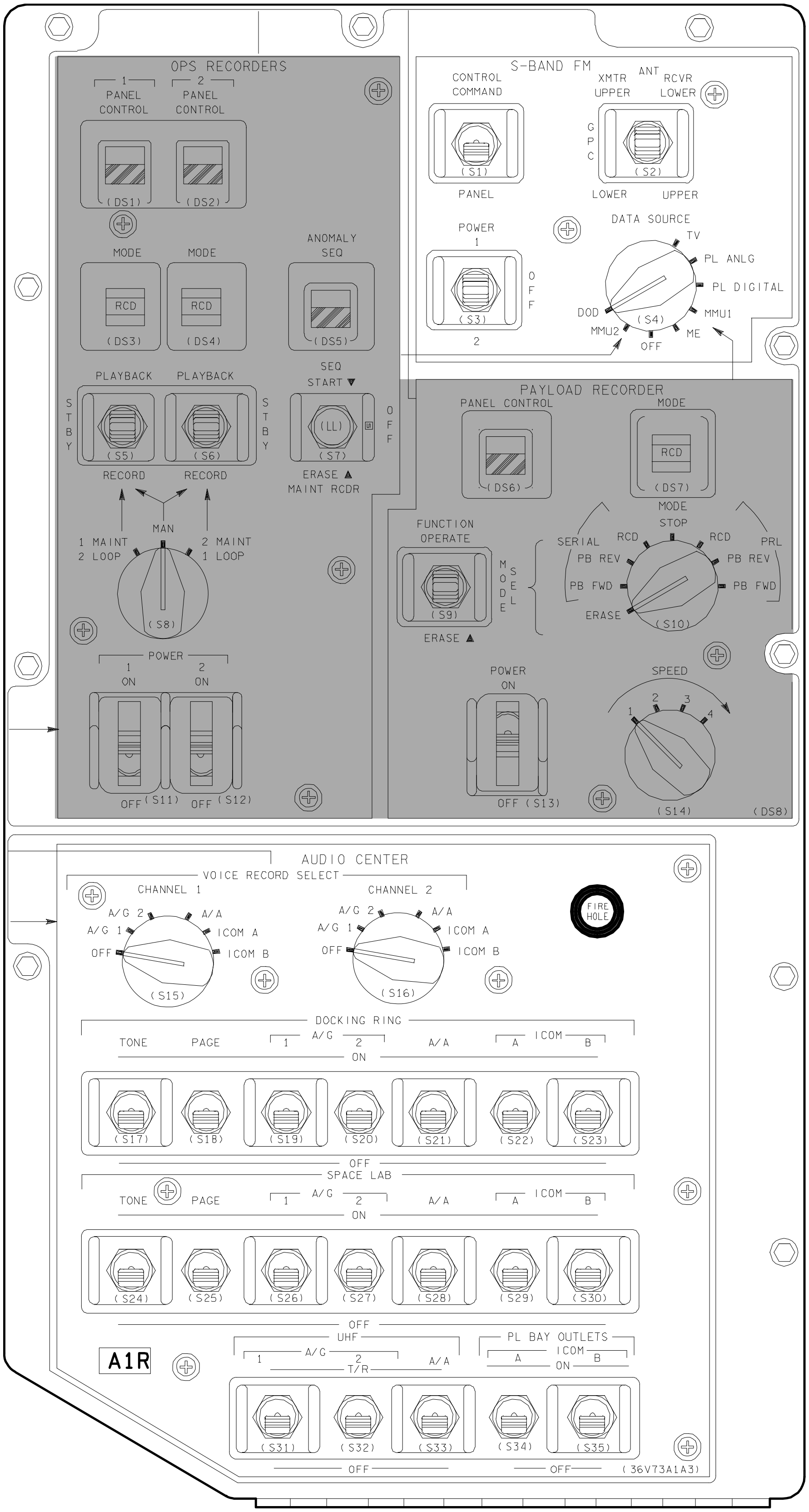
S-Band System 1 Power



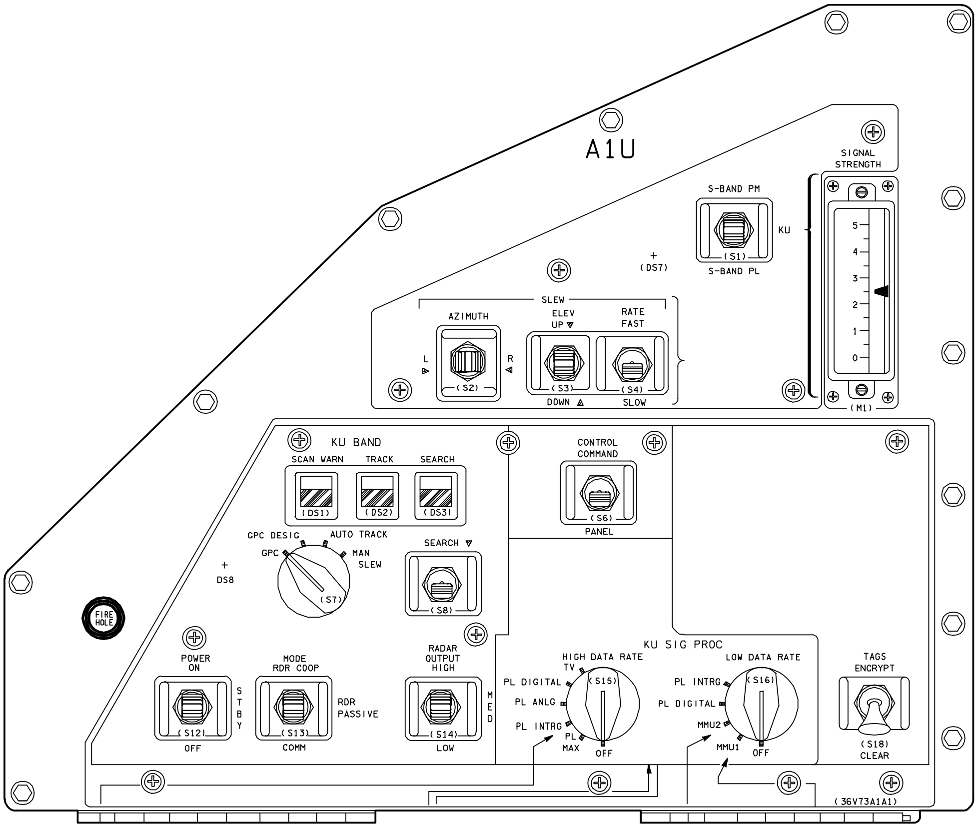
S-Band System 2 Power


S-BAND PAYLOAD
CONTROL
COMMAND
(S1)
PANEL
ANT
POLAR
L CIRC
(S2)
R CIRC
XMTR
PWR
HIGH
(S4)
MED
LOW
CHANNEL SELECT
INTRG 1
INTRG 2
0
1
2
0
1
2
(S7)
FREQ
SWEEP
ON▼
(S8)
OFF
MOD
ON
(S9)
OFF
POWER
SYSTEM
1
OFF
(S13)
2
SELECT
INTRG
(S14)
BOTH
PSP
PSP CMD
OUTPUT
INTRG
(S15)
PL UMB
+
(DS1)
PAYLOAD
PL DATA INTLVR
POWER
ON
(S17)
OFF
(DS1)
GPC
PCM
MU
FIRE
HOLE
A1L
S-BAND PM
ANT SW
ELEC
1
OFF
(S5)
2
PRE AMPL
1
OFF
(S10)
2
PWR AMPL
STANDBY
1
OFF
(S11)
2
OPERATE
1
OFF
(S12)
2
MODE
STDN
LO
HI
SGLS
TDRS
DATA
RNG
(S6)
XPNDR
1
OFF
(S16)
2
NETWORK SIG PROC
DATA RATE
XMIT
RCV
HIGH
(S18)
(S19)
LOW
UPLINK
DATA
S-BD
(S20)
KU
CODING
XMIT
RCV
ON
(S21)
(S22)
OFF
POWER
1
OFF
(S23)
2
ENCRYPTION
PWR
ON
(S24)
OFF
MODE
ALL
(S25)
SELECT
SELECT
T/R
RCV
(S26)
BYPASS
(36V73A1A2)

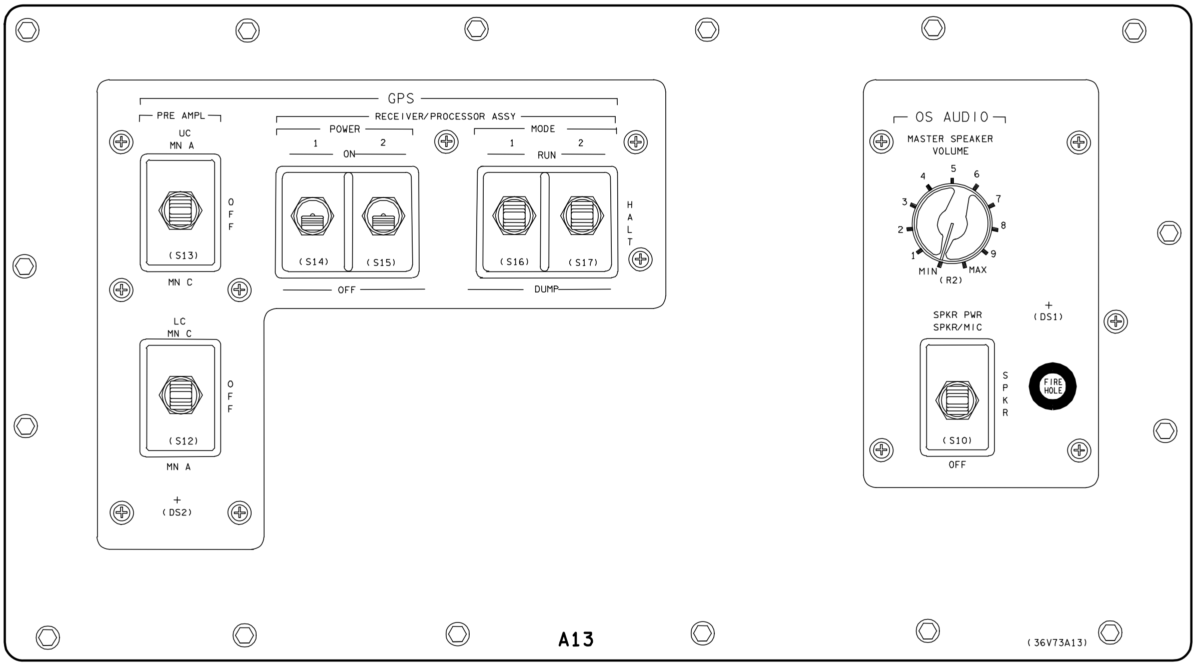
Panel A1L


OPS RECORDERS
1
2
PANEL CONTROL
PANEL CONTROL
(DS1)
(DS2)
MODE
MODE
RCD
RCD
(DS3)
(DS4)
ANOMALY SEQ
(DS5)
PLAYBACK
PLAYBACK
STBY
STBY
(S5)
(S6)
RECORD
RECORD
SEQ START ▼
(LL)
(S7)
OFF
ERASE ▲
MAINT RCDR
MAN
1 MAINT 2 LOOP
2 MAINT 1 LOOP
(S8)
POWER
1 ON
2 ON
OFF (S11)
OFF (S12)
S-BAND FM
CONTROL COMMAND
(S1)
PANEL
ANT
XMTR UPPER
RCVR LOWER
GPC
(S2)
LOWER
UPPER
POWER 1
(S3)
OFF
2
DATA SOURCE
TV
PL ANLG
PL DIGITAL
MMU1
ME
OFF
MMU2
DOD
(S4)
PAYLOAD RECORDER
PANEL CONTROL
(DS6)
MODE
RCD
(DS7)
FUNCTION OPERATE
(S9)
ERASE ▲
MODE SEL
MODE
STOP
SERIAL
RCD
PB REV
PB FWD
ERASE
RCD
PRL
PB REV
PB FWD
(S10)
POWER ON
OFF (S13)
SPEED
1
2
3
4
(S14)
(DS8)
AUDIO CENTER
VOICE RECORD SELECT
CHANNEL 1
A/G 2
A/A
A/G 1
ICOM A
OFF
ICOM B
(S15)
CHANNEL 2
A/G 2
A/A
A/G 1
ICOM A
OFF
ICOM B
(S16)
FIRE HOLE
DOCKING RING
TONE
PAGE
A/G
1
2
ON
A/A
ICOM
A
B
(S17)
(S18)
(S19)
(S20)
(S21)
(S22)
(S23)
OFF
SPACE LAB
TONE
PAGE
A/G
1
2
ON
A/A
ICOM
A
B
(S24)
(S25)
(S26)
(S27)
(S28)
(S29)
(S30)
OFF
A1R
UHF
A/G
1
2
T/R
A/A
PL BAY OUTLETS
ICOM
A
ON
B
(S31)
(S32)
(S33)
(S34)
(S35)
OFF
OFF
(36V73A1A3)
usa007587_1104

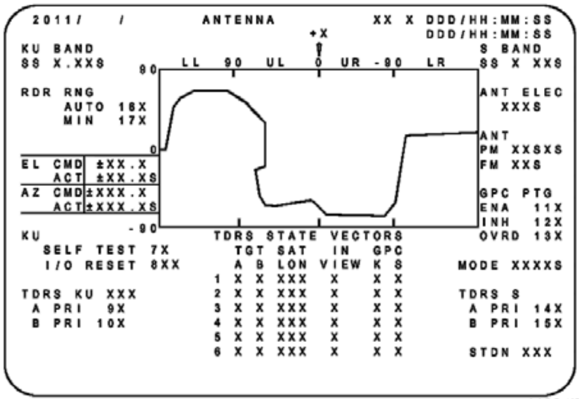
Panel A1R



Panel A1U



Panel A13

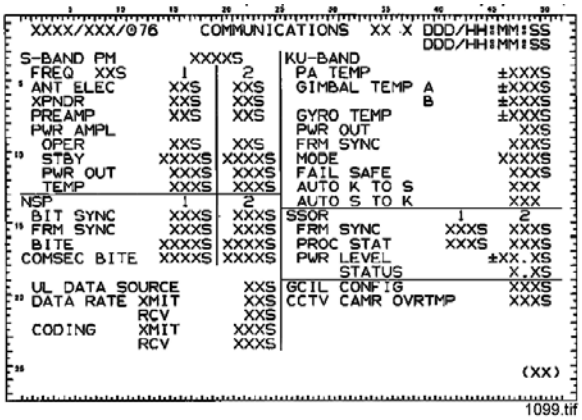


```
2011/    /            ANTENNA              XX X DDD/HH:MM:SS
                               +X               DDD/HH:MM:SS
KU BAND                                               S BAND
SS X.XXS      90  LL   90   UL   0   UR  -90   LR   SS X XXS

RDR RNG                                             ANT ELEC
     AUTO 16X                                         XXXS
     MIN  17X
                                                    ANT
               0                                    PM XXSXS
EL  CMD  ±XX.X                                      FM XXS
    ACT  ±XX.XS
AZ  CMD ±XXX.X                                      GPC PTG
    ACT ±XXX.XS                                     ENA   11X
                                                    INH   12X
KU           -90    TDRS STATE VECTORS              OVRD  13X
   SELF TEST 7X        TGT SAT   IN   GPC
   I/O RESET 8XX       A B LON  VIEW  K S          MODE XXXXS
                     1 X X XXX   X    X X
TDRS KU XXX          2 X X XXX   X    X X          TDRS S
 A PRI   9X          3 X X XXX   X    X X           A PRI 14X
 B PRI  10X          4 X X XXX   X    X X           B PRI 15X
                     5 X X XXX   X    X X
                     6 X X XXX   X    X X            STDN XXX
```

1100.tif

OPS 201 ANTENNA Display

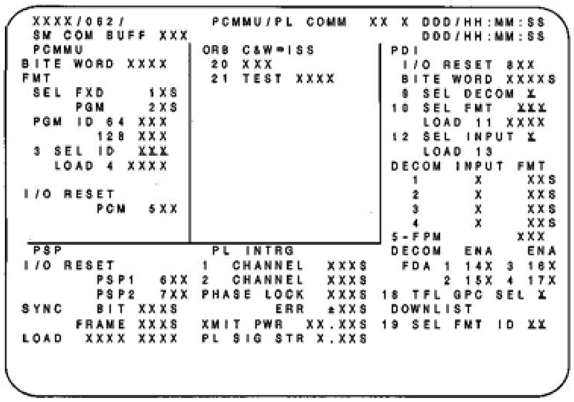


```
 XXXX/XXX/076     COMMUNICATIONS   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
S-BAND PM        XXXXS       |KU-BAND
 FREQ  XXS         1   |  2  | PA TEMP              ±XXXS
 ANT ELEC        XXS   | XXS | GIMBAL TEMP A        ±XXXS
 XPNDR           XXS   | XXS |             B        ±XXXS
 PREAMP          XXS   | XXS | GYRO TEMP            ±XXXS
 PWR AMPL              |     | PWR OUT                XXS
  OPER           XXS   | XXS | FRM SYNC              XXXS
  STBY         XXXXS |XXXXS  | MODE                 XXXXS
  PWR OUT       XXXS | XXXS  | FAIL SAFE             XXXS
  TEMP          XXXS | XXXS  | AUTO K TO S            XXX
NSP               1  |  2    | AUTO S TO K            XXX
 BIT SYNC       XXXS | XXXS  |SSOR            1        2
 FRM SYNC       XXXS | XXXS  | FRM SYNC     XXXS     XXXS
 BITE          XXXXS |XXXXS  | PROC STAT    XXXS     XXXS
COMSEC BITE    XXXXS |XXXXS  | PWR LEVEL           ±XX.XS
                             |     STATUS             X.XS
 UL DATA SOURCE          XXS |GCIL CONFIG            XXXS
 DATA RATE XMIT          XXS |CCTV CAMR OVRTMP       XXXS
           RCV           XXS |
 CODING    XMIT         XXXS |
           RCV          XXXS |

                                                     (XX)
```

1099.tif

COMMUNICATIONS (SPEC 76) Display



```
 XXXX/062/             PCMMU/PL COMM   XX X DDD/HH:MM:SS
 SM COM BUFF XXX                            DDD/HH:MM:SS
 PCMMU             | ORB C&W=ISS          | PDI
BITE WORD XXXX     |  20 XXX              |  I/O RESET 8XX
FMT                |  21 TEST XXXX        |  BITE WORD XXXXS
 SEL FXD     1XS   |                      |  9 SEL DECOM X
     PGM     2XS   |                      | 10 SEL FMT  XXX
 PGM ID 64 XXX     |                      |    LOAD 11 XXXX
       128 XXX     |                      | 12 SEL INPUT X
 3 SEL ID  XXX     |                      |    LOAD 13
   LOAD 4 XXXX     |                      | DECOM INPUT FMT
                   |                      |   1     X     XXS
I/O RESET          |                      |   2     X     XXS
      PCM   5XX    |                      |   3     X     XXS
                   |                      |   4     X     XXS
                   |                      | 5-FPM        XXX
 PSP                 PL INTRG               DECOM  ENA   ENA
I/O RESET            1  CHANNEL   XXXS       FDA 1 14X 3 16X
      PSP1   6XX     2  CHANNEL   XXXS           2 15X 4 17X
      PSP2   7XX     PHASE LOCK   XXXS      18 TFL GPC SEL X
SYNC  BIT XXXS                ERR ±XXS      DOWNLIST
    FRAME XXXS       XMIT PWR  XX.XXS       19 SEL FMT ID XX
LOAD  XXXX XXXX      PL SIG STR X.XXS
```

PCMMU/PL COMM Display (SPEC 62), OI-32

Communications System Rules of Thumb

- When the TDRS has an elevation of greater than +70° or less than -60° relative to the orbiter (as shown on OPS 201), there is a risk of degraded communications as the orbiter nose or tail blocks line of sight between the orbiter antenna and the TDRS.
- Power amplifiers are specified to have a minimum power output of 100 watts. Flight experience has shown that a good downlink can be sustained with a power out of 65 watts. Power amplifiers require 140 seconds to warm up if not in a standby.

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2.5 CREW SYSTEMS

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Sleeping Provisions.............................. 2.5-1
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Air Sampling System 2.5-15

Description

Several types of equipment and systems that the crew uses are not covered in other sections of this manual, since they are not necessarily part of any of the larger systems. These items and systems, which focus on crew efficiency and comfort, are discussed in this section. Where appropriate, operations are described within each separate subject area.

Crew Clothing/Worn Equipment

The crew clothing/worn equipment consists of items that provide for the personal needs of all crewmembers. Prior to each flight, crewmembers select clothing and worn equipment from a list of required and optional flight equipment.

Crew clothing used during on-orbit activities includes such items as trousers, jackets, shirts, sleep shorts, soft slippers, and underwear.

Optional worn/carry-on equipment includes scissors, sunglasses, HP48 calculators, gray tape, flashlight, Swiss army knife, pens and pencils, and chronographs.

Personal Hygiene Provisions

Personal hygiene and grooming provisions are furnished for both male and female flight crewmembers. Ambient warm water for washing comes from a personal hygiene hose (PHH) attached to the galley auxiliary port. Other personal hygiene provisions are stowed in middeck lockers and/or a middeck or airlock stowage bag at launch and are removed for use on orbit.

A personal hygiene kit is furnished for each crewmember for brushing teeth, hair care, shaving, nail care, etc. Additional grooming and hygiene items are available for female crewmembers in the female preference bags.

Two washcloths and one towel per crewmember per day are provided. In addition, wet wipes, tissues, and ʻʻwet washes are provided for personal hygiene. The ʻʻwet wipes are located in Volume G (spares), a middeck locker, and in the galley. Wet washes and tissues are stowed in the waste management compartment (WMC) and in a middeck locker. Rubber grommets in the waste management compartment allow crewmembers to restrain their towels and washcloths.

If the WMS becomes nonfunctional, contingency equipment is located in Volume G. This equipment consists of ʻʻwet washes, urine collection devices, diapers, and Apollo fecal bags.

Sleeping Provisions

During a one-shift operation mission, all crewmembers sleep simultaneously. At least one crewmember wears a communication headset to ensure reception of ground calls and orbiter caution and warning alarms.

A 24-hour period is normally divided into an 8-hour sleep period and a 16-hour wake period for each crewmember. Three hours are allocated for pre/post sleep activities in which crewmembers perform housekeeping, orbiter cleaning, sleep and wake preparation, personal hygiene, and food preparation and eating activities.

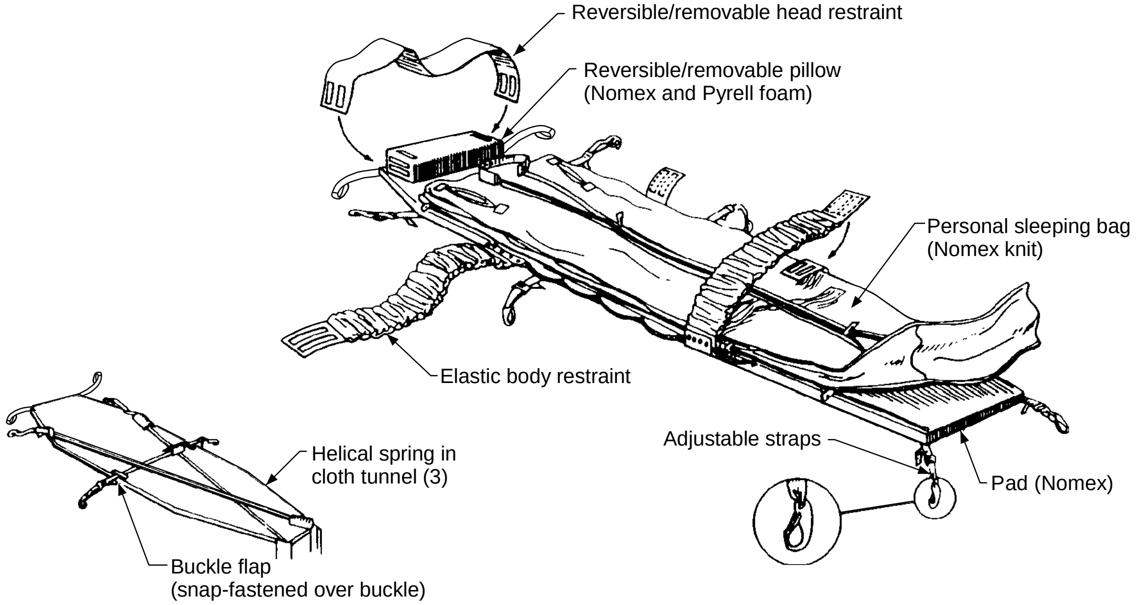
Sleeping provisions for crewmembers consist of sleeping bags and liners, or rigid sleep stations with one sleeping bag and two liners per bunk. Sleeping bags are installed on the starboard middeck wall and relocated for use on orbit. Some sleeping bags can remain on the starboard wall, and some can be attached via pip pins to the middeck lockers. Others can be relocated to the airlock, or flight deck (crew preference). A sleeping bag is furnished for each crewmember and contains a support pad with adjustable restraining straps and a reversible/removable pillow and head restraint.

Eight adjustable straps permit the sleeping bag to be adjusted to its proper configuration. Three helical springs above the adjustable straps on one side of the bag relieve loads exerted by the crewmember on the crew compartment structure. Eight pip pins allow the bag to be attached to the middeck locker face in either a horizontal or vertical configuration. Two elastic adjustable straps restrain the upper and lower parts of the body in the bag. Velcro strips on the ends of both sides of the head restraint attach it to the pillow. A double zipper arrangement permits the sleeping bag to be opened and closed from the bottom to the top of the bag. One zipper on each side of the sleeping bag allows the bag to be attached to a support pad for better rigidity.

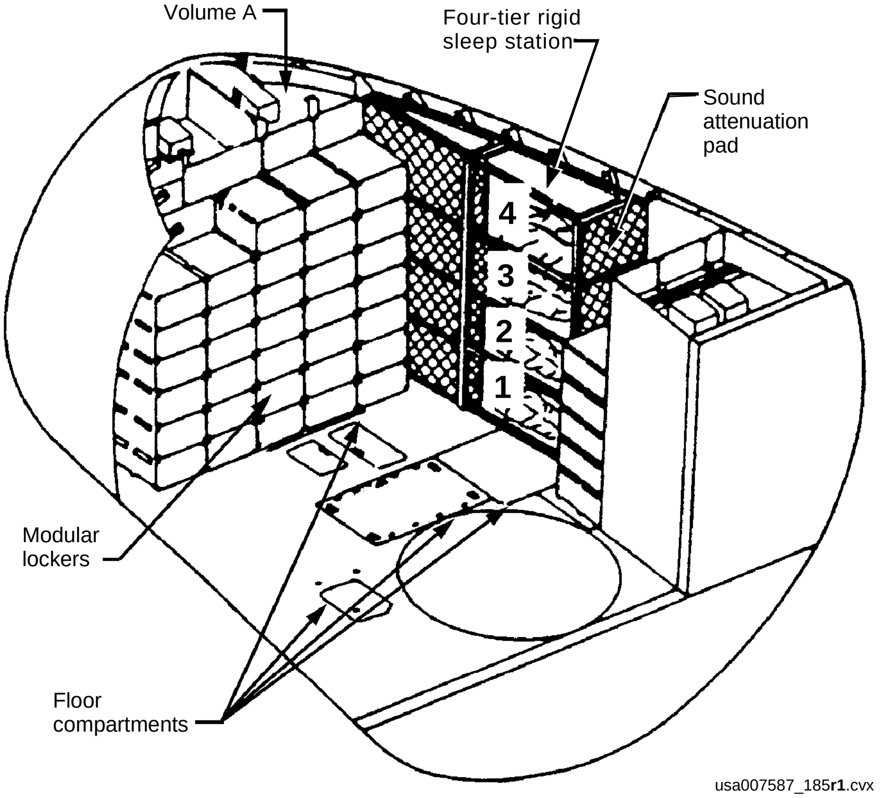
A sleep kit is provided for each crewmember and is stowed in the crewmember's clothing locker during launch and entry. Each kit contains eye covers and ear plugs for use as required during the sleep period.

For 24-hour operations missions, the four-tier, rigid sleep station is flown. If manifested, it is installed on the starboard side of the middeck.

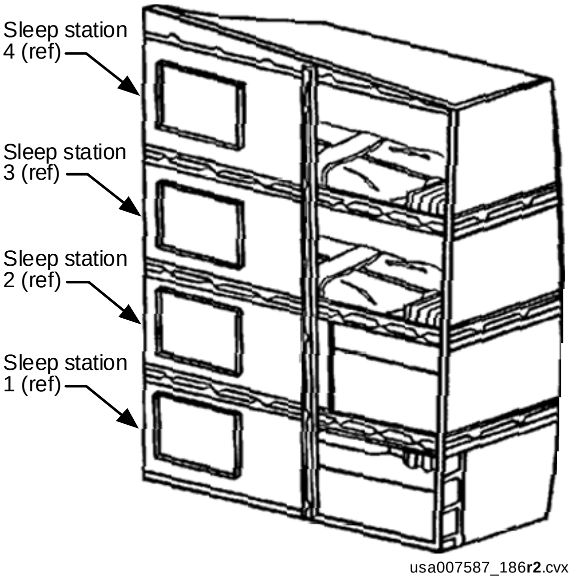
The four-tier rigid sleep stations contain a sleeping bag/liner, personal stowage provisions, a light, and a ventilation inlet and outlet in each of the tiers. The Nomex knit sleeping bag is installed on the ground in each tier and held in place by eight spring clips. The light in each tier is a single fluorescent fixture with a brightness control knob and an off position. The air ventilation inlet duct is an air diffuser similar to an automobile ventilation duct. It is adjusted by moving the vane control knob. The air ventilation outlet duct is located in the fixed panel at each tier and is opened or closed by moving the vane control knob. The air inlet is located at the crewmember's head. The outlet is at the feet. All crewmembers' heads are toward the airlock and their feet toward the avionics bay.



Operational Sleeping Bag



Four-Tier Horizontal Sleep Station



Four-Tier Rigid Sleep Station

Exercise Equipment

The purpose of exercise during flight is to help prevent cardiovascular deconditioning and to minimize bone or muscle loss in the crewmembers. Currently the cycle ergometer (CE) is the primary equipment used to achieve this end.

The CE attaches to the middeck floor studs. The mounting frame is reconfigured on orbit to attach to standard seat floor studs on the flight deck or middeck. The CE uses a standard flywheel and braking band system to generate the required resistive force. Cycling resistance can be controlled electronically by a control panel or by a manual adjustment similar to those found on exercise cycles used at home or in gymnasiums. An accessories bag, which is strapped to the top of the ergometer for launch and entry, contains the attachable hardware as well as crew clothing and shoes necessary for nominal operations.

Housekeeping Equipment

In addition to time scheduled for sleep periods and meals, each crewmember has housekeeping tasks that require from 5 to 15 minutes of time at intervals throughout the day. These include cleaning of the waste management compartment, the dining area and equipment, floors and walls (as required), and the cabin air filters; trash collection and disposal; and changeout of the crew compartment carbon dioxide (lithium hydroxide) absorber canisters. (Changeout of the canisters is discussed in Section 2.9.)

The materials and equipment available for cleaning operations are biocidal cleanser, disposable gloves, general-purpose wipes, and a vacuum cleaner. The vacuum is stowed in a middeck locker or the middeck accommodations rack (MAR), and the remaining hardware is stowed primarily in the waste management compartment. Additional wipes are located with extra hygiene consumables stowed in the middeck, and an additional pair of gloves is located in each personal hygiene kit.

The biocidal cleanser is a lotion-type detergent formulation in a container approximately 2 inches in diameter and 6 inches long with a built-in dispenser. The cleanser is squirted on the surface to be cleaned and wiped off with dry, general-purpose wipes. It is used primarily for periodic cleansing of the waste collection system urinal and seat. It can be used to clean the dining area and equipment and to clean walls and floors. Disposable plastic gloves are worn while using the biocidal cleanser.

A vacuum cleaner is provided for general housekeeping and cleaning of the crew compartment air filters and Spacehab filters (on Spacehab missions). It has a normal hose, extension hose, and several attachments. The crew will fly either an ac or dc powered version depending on orbiter power constraints for the mission. The dc vacuum cleaner has the additional capability of containing wet spills. A muffler to reduce noise is part of the vacuum cleaner assembly.

Trash management operations include routine stowage of wet and dry trash, such as expended wipes, tissues, and food containers. (Wet trash includes all items that could offgas.) The equipment available for trash management includes three trash bags, trash bag liners, wet trash volumes, and the waste collection system (WCS) coffee canister.

Three trash bags for dry trash are located in the crew compartment: one on the inside of the WMC door, one on the port side of the “ditch” area, and one on the port side of the flight deck. Each bag contains one installed disposable trash bag liner and seven spare liners (located outside the installed liner but inside the trash bag). When the liner becomes full, it is removed and stowed in a jettison stowage bag and a new liner is installed.

The WMC wet trash compartment has a volume of 1.85 cubic feet and is vented overboard for odor control. Trash from the WMC is inserted into the circular opening of the auxiliary wet trash compartment and is contained by an elbow bag. Tissues, as well as used WCS coffee canister bags, are disposed of in this wet trash compartment. The coffee canister, which is about the same size and shape as an off-the-shelf can of coffee, is installed near the WMC during post insertion. Trash bags are inserted in the canister and are filled with wipes used for fecal collection. After each WCS use, a used trash bag is disposed of in the WMC wet trash, and a new one is retrieved from the stowage volume on the WMC wall and installed in the canister.

An 8-cubic-foot wet trash stowage compartment is available under the middeck floor (Volume F). This compartment is vented overboard (3 lb/day) for odor control. Any item that can create an odor is considered to be wet trash and is disposed of there.

Restraints and Mobility Aids

Restraints and mobility aids are provided in the orbiter to enable the flight crew to perform all tasks safely and efficiently during ingress (1-g, orbiter vertical), egress (1-g, orbiter horizontal), and orbital flight (orbiter orientation arbitrary).

Mobility aids are located in the crew compartment for movement of the flight crewmembers during ingress, egress, and orbital flight. These devices consist of permanent and soft handholds, a platform and emergency egress net (also referred to as the trampoline) in the middeck, and an interdeck access ladder.

Restraints consist of foot loop restraints, seat restraints, retention nets, Velcro, tape, snaps, cable restraints, clips, bungees, and tethers.

Foot loop restraints are cloth loops attached to the crew compartment decks by adhesive to provide stability in zero g. Before launch, the foot loop restraints are installed by the crew compartment configuration drawings (CCCD) by Flight Crew Equipment (FCE) personnel on the floor areas of the aft flight deck work stations, middeck, and near the waste management system and galley. Spares are stowed in the modular lockers. To install a foot restraint, the protective backing on the underside of the restraint is removed, and the restraint is placed in its desired location. The foot loop restraints are easily used by placing a foot in the loop.

Seat restraints are similar to foot loop restraints. They can be installed prelaunch, and spares are manifested in the same location as the foot restraints. One adhesive patch is placed on one side of the seat, and the other patch is placed on the opposite side. A restraint strap is placed over the seat back and attached to each patch via clips.

A mesh middeck retention net, attached to the forward middeck lockers and the starboard wall (no sleep station), is used to restrain the inflight stowage bags, as well as other hardware. The airlock stowage net, also made of mesh net, can restrain this equipment in the airlock if the sleep station is manifested, or if the crew determines they wish to stow this hardware in the airlock.

Velcro, tape, snaps, cable restraints, clips, bungees, and tethers are all manifested in the IFM locker and can be utilized for a variety of purposes.

Stowage Containers

Inflight Stowage Bags

Ten inflight stowage bags are manifested, one per crewmember plus spares. These mesh bags are used to stow suits, boots, and harnesses on orbit.

Flight Deck Stowage Bags

The flight deck stowage bags provide restraint for flight deck items when those items are not immediately returned to locker stowage compartments. These bags are manifested in the Flight Data File (FDF) locker and are installed on orbit on the back of the CDR and PLT seats (one per seat).

Jettison Stowage Bags

The jettison stowage bags are used for restraining dry trash or early return items, such as FDF, film, and cassettes. (See Section 2.25 for further details on all stowage bags.)

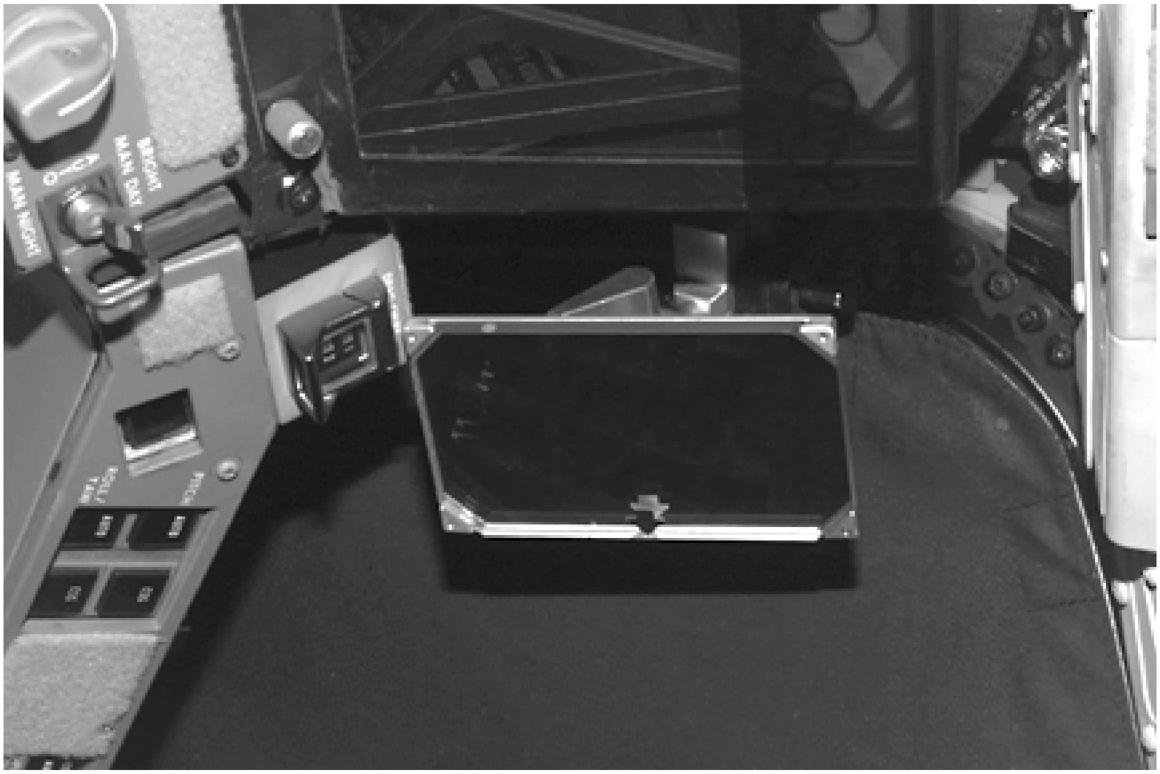
Reach and Visibility Aids

Reach and visibility aids are hardware items that assist the flight crew in monitoring and manipulating displays and controls throughout various phases of flight. These aids consist of CDR/PLT adjustable mirrors, CDR/PLT two axis (Z and X) seat adjustment, wicket tabs, and an auxiliary reach mechanism.

The adjustable mirrors are installed at launch on handholds located between windows 2 and 3 for the CDR and windows 4 and 5 for the PLT. During ascent and entry, the CDR and PLT use the adjustable mirrors to facilitate seeing controls that are in the obscured areas of their vision envelope. On orbit, mirrors can be removed and stowed, if desired.

To install the adjustable mirror, place the split clamp halves around the handhold, fit the handwheel stem into both clamp halves, and tighten the handwheel clockwise. To adjust the mirror, loosen the mirror-lock knob (counterclockwise), move the mirror to the desired orientation, and tighten the mirror-lock knob.

The CDR/PLT seats provide the CDR and PLT with the capability to move their seats along the orbiter Z- (vertical) and X- (longitudinal) axes to facilitate the reach and visibility of controls during the ascent and entry phase of flight. Seat movement for each axis is provided by a single ac motor. The total travel distances for the Z- and X-axes are 10 and 5 inches, respectively. Seat adjustment controls are located on the left side of the seat pan. The controls consist of a three-position toggle switch for power bus selection and one spring-loaded, three-position toggle switch each for control of horizontal and vertical seat movement.



Adjustable Mirror

Seat Power and Controls

To operate the CDR/PLT seat, the crewmember must first assign ac power to his or her seat motors by moving the *POWER BUSS SEL* switch to *AC2* (up) or *AC3* (down). To move the seat along the horizontal axis, crewmembers must actuate the *HORIZ CONTR* toggle switch FWD to move the seat forward and *AFT* to move the seat aft. Similarly, to move the seat along the vertical axis, the crewmember must actuate the *VERT CONTR* toggle switch *UP* to move the seat upward and *DN* to move the seat downward.

If the seat motors fail to work, and seat adjustment is needed, manual adjustment capability is provided. However, manual seat adjustment can take place only on orbit and is accomplished with a special seat adjustment tool provided in the in-flight maintenance tool kit. Manual horizontal and vertical seat adjustment control locations are under the seat pan cushion and on the aft side of the fixed seat structure.

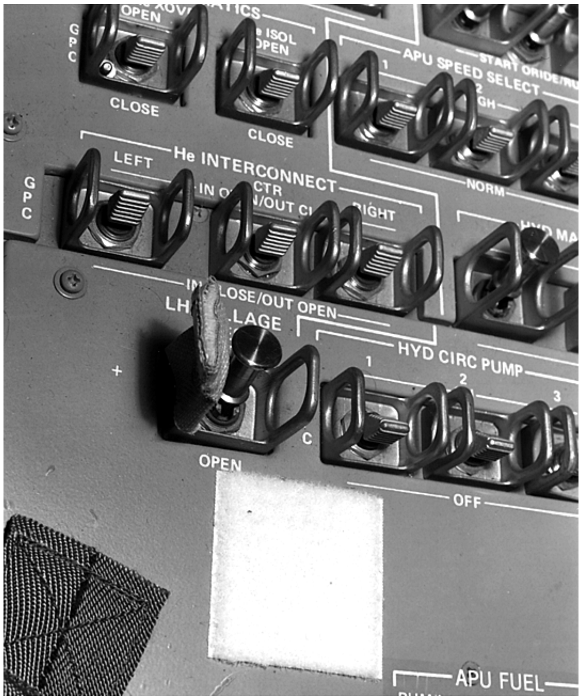
The seat adjustment tool is a ratchet-driven, 3/16-inch Allen wrench inserted into the vertical or horizontal manual adjustment to move the seat along the Z- or X-axis.

Wicket tabs are devices that help the crewmember activate controls when his or her vision is degraded. The tabs provide the crewmember with tactile cues to the location of controls to be activated as well as a memory aid to their function, sequence of activation, and other pertinent information. Wicket tabs are found on controls that are difficult to see on panels O8, C3, and R2 during the ascent and entry flight phases.

The auxiliary reach mechanism, sometimes known as the "swizzle stick," is a short adjustable bar with multipurpose end effectors that are used to actuate controls that are out of the reach of seated crewmembers. The reach aid is used to push in and pull out circuit breakers, move toggle switches, and turn rotary knobs. It is stowed on the inboard side of the PLT seat. It may be used during any phase of flight, but is not recommended for use during ascent because of the attenuation and switch-cueing difficulties resulting from acceleration forces.

Operation of the reach aid consists of extending it and actuating controls with the end effector.

To extend the reach aid, the crewmember depresses the spring-loaded extension tab and pulls the end effector out to the desired length.



Wicket Tabs on Panel R2

Wicket Tabs on Panel C3

The reach and visibility envelope of each crewmember is limited by the ACES. Tactile cues are restricted by the ACES glove. Visibility is reduced because of the helmet and neck ring, and reach is restricted by the bulk of the ACES and the parachute and harness. Crewmembers should practice techniques that enable them to adjust their reach and visibility envelope. The helmet can be swiveled on the neck ring. The neck ring tie down may be adjusted to help open up downward field of view. Mirrors, the auxiliary reach mechanism (swizzle stick), and other crewmembers can aid in locating and actuating controls. Seat headrest pads and helmet pads may be used to adjust the position of the head in the seat and in the helmet. The CDR and PLT seats may be adjusted as necessary.

Photographic Equipment

One still camera system is used on orbit to document crew activities, meet payload requirements, and record Earth observations. Additional cameras can be stowed as required. Nikon D2Xs digital still single lens reflex (SLR) cameras are flown for still photography. The Nikon D2Xs electronic still camera stores digital still images on removable compact flash cards. Digital images can be downlinked for printing and distribution. Additional camera systems may be flown for specific experiments or as part of an ongoing NASA evaluation of new cameras and technology.

Two Nikon D2Xs autofocus SLR cameras are nominally manifested for each mission. The Nikon D2Xs uses a 12-megapixel CMOS sensor that produces 10-MB compressed image files in a Nikon-proprietary .NEF raw format and can expose at ISOs from 100 to 3200. The D2X provides automatic state-of-the-art metering for ambient light and flash exposure and is capable of exposures as brief as 1/8000 of a second. The camera incorporates a "full information" LCD viewfinder display. Interchangeable autofocus lenses of various focal lengths ranging from 10.5mm up to 800mm are available. The camera permits continuous exposures at rates of up to 3 or 5 frames per second. It operates on an 11.1 V dc rechargeable li-ION battery. The Nikon flash (SB-800) operates on four AA batteries. The cameras are used primarily for in-cabin crew activities and experiments. They may also be used to document payload deployments and Earth observations.

The Nikon D2Xs can also be used for EVA missions. A special camera thermal cover and a custom eyepiece that assist the EVA crew with camera *operations are also manifested. The Nikon D2Xs EVA camera can also use a flash (SB800) in a pressurized aluminum housing. While any of the manifested camera bodies are capable of being used for EVA, only a few lenses have been qualified for the harsh EVA environment. A 400mm telephoto lens is flown for handheld photography of the shuttle external tank post-jettison. In addition to the handheld imagery, a Kodak DCS760 digital still camera is used for recording images of the EXTERNAL TANK (ET) from the right umbilical well right after ET separation. The camera automatically takes approximately 30 mapping images of the ET while the shuttle performs an 11-second +X burn. For night launches, two Nikon SB800 flashes are installed in the left umbilical well and are synchronized with the DCS760. In this configuration, the flash only fires every other shot; therefore, only 15 images are usable. Within 24 hours of launch, the crew will downlink the images from this camera with the use of a laptop computer, a converter box, and cables via a connector on panel A13.*

Most of the photography conducted in the orbiter is with handheld equipment. With the exception of flash photography, many of the images and scenes the crew captures can be improved by using the multiuse brackets, clamps, and baseplate adapters. Twenty-two mounts throughout the flight deck, middeck, and airlock permit the crew to mount cameras and accessories. The baseplate adapters (crew installed) provide quick mounts in windows 9 and 10. The multiuse clamp is used on various structures to provide an attachment base for a multiuse arm. The multiuse arm is a modified commercial device that attaches to a camera and a wall mount or clamp. The arm permits universal pointing of the camera until the center "elbow" knob is tightened. When the knob is secure, the camera is held rigidly at the selected orientation (zero g). Multiuse equipment is also used to mount the camcorder and photo floodlight.

Sighting Aids

Sighting aids include all items used to aid the flight crew within and outside the crew compartment. The sighting aids include the crew optical alignment sight (COAS), binoculars, adjustable mirrors, and spotlights. (The COAS is discussed in detail in Section 2.13.) Five models of binoculars are available for on-orbit use. Binocular models include the Zeiss 8X20, Fuji 10X40 gyro stabilized day/night, Fuji 14X40 gyro stabilized, Fuji 16X70, and the Zeiss 20X60 mechanically stabilized. The 8X20 and 20X60 models are routinely flown on each mission.

The spotlight is a high-intensity, handheld flashlight powered by a battery pack, consisting of five 1.2-volt, one-half D-size nickel-cadmium batteries. The spotlight produces a 20,000-candlepower output with a continuous running time of 1.5 hours. The lamp is a 6-volt tungsten filament that cannot be replaced in flight.

The high-intensity search light (HISL) is used in conjunction with the rangefinders during visual acquisition of satellites. It provides crewmembers with the capability to detect and maintain visual contact with a payload for effective rendezvous and stationkeeping at 700 to 1000 feet when on the dark side. The light is portable and has a stainless steel camera mounting rail on the handle that interfaces to the multiuse mounting brackets on the orbiter. The light is aimed out the aft, or overhead, windows of the flight deck.

Window Shades and Filters

Window shades and filters are provided for installation on the orbiter windows to minimize crewmember exposure to sunglare during ascent, entry, and orbital flight phases.

The window shades are stowed in a compartmented bag attached to a mounting pallet on the starboard side of the aft middeck.

To install the W1 through W6 window shades, the crewmember unrolls the shade (white surface outboard) over the window and mates the Velcro with the Velcro on the window frame. Removal of the shades is accomplished by just the reverse. Demate the Velcro, and roll the shade up as compactly as possible (blue surface visible). Insert into window shade holders and close the holders by mating Velcro together.

Aft window shades are installed simply by placing the correct shade in the appropriate window (reflective side outboard) and securing it to the mating Velcro on the window ledges.

To remove a window shade from the window shade stowage container, the crewmember must unfasten the securing straps and pull the Velcro-restrained closure panel away from the desired stowage pouch.

Interdeck light shades are provided to minimize light leakage between the flight deck and middeck during in-cabin photography. The light shade is attached with Velcro to the flight deck floor around the interdeck access. Adjustable louvers are provided to regulate the amount of light between the flight deck and the middeck.

The side hatch viewport is the only optical-quality window on OV 103, 104, and 105. Unlike the 10 windows on the flight deck, the side hatch viewport does not provide protection from solar ultraviolet (UV) rays, which can cause serious injury in as little as 10 seconds. Therefore, a removable UV filter must be placed on the side hatch viewport for on-orbit operations. The filter is held against the viewport by Velcro and is normally installed post insertion and removed during deorbit preparations.

Shuttle Orbiter Medical System

The shuttle orbiter medical system (SOMS) is required to provide medical care in-flight for minor illnesses and injuries. It also provides support for stabilizing severely injured or ill crewmembers until they are returned to Earth.

The SOMS consists primarily of the medical kits that are organized into subpacks, which *group similar* items *together that are* used for specific procedures; e.g., Airway Subpacks. Each subpack contains pockets, sleeves, and elastic restraints that hold individual medications and medical *supplies*. The SOMS contains additional items, such as a sharps container, restraints, and a resuscitator.

Most SOMS items are stowed together in a middeck locker. If the subpacks are required on orbit, they are unstowed and installed where needed using Velcro. The most frequently used subpack is the Drug Subpack because it contains commonly used medications.

The Airway Subpack contains emergency airway management equipment to maintain an open airway. Yellow labels with red lettering identify the items in this subpack as emergency items. Articles in the subpack include an oral airway, laryngoscope, and a CO_2 detector.

The Drug Subpack contains oral, topical, and injectable medications. Oral medications are contained in Ziploc bags that are heat-sealed so that only a few pills may be dispersed *at a time* in microgravity. *Commonly used medications are stowed on the spine of the subpack, giving easy access to them without having to unstow the entire subpack. There is also a medical data log and allergies list on the outside of the subpack.*

The Eye, Ear, Nose, and Throat (EENT) Subpack contains general diagnostic and therapeutic items used to treat EENT problems. The EENT Subpack includes items such as dental medications and instruments, eye drops, nasal spray, and various medications and ointments.

The Intravenous Administration *(IV ADMIN)* Subpack contains the equipment used to start an IV line to deliver medications and/or fluids to an ill or injured crewmember. Skin preparation items, IV extension sets and butterfly needles, a blood pressure cuff, and one 500 ml bag of saline are some of the items stowed in the IV A*DMIN* Subpack.

The saline supply bag contains four 500-ml bags of saline. There are also two 250-ml bags inside the medical middeck locker. There are a total of 3100 ml of saline flown on the shuttle.

The Trauma Subpack contains items necessary to treat in-flight medical emergencies. This subpack contains *equipment necessary for laceration closure and urinary catheterization, such as* bandaging materials, gauze pads, sutures, and urinary catheters.

A sharps container is provided for disposal of injectables and needles. The needle end of the sharp is inserted into the appropriate foam slot.

The patient/rescuer restraint system is emergency hardware that is used if a crewmember becomes ill. The restraints are stored in the medical middeck locker.

The patient restraints secure the patient in the mid-calf area and the chest area. The restraints can be easily tightened to fit the patient. The rescuer restraint wraps around the rescuer's waist and has two extensions from the waist belt with pip pins on the ends to fasten into the locker latches. This allows the rescuer and patient to remain stationary.

The SOMS also includes a resuscitator. The resuscitator consists of a mask with a retaining cap, a manually activated/demand regulated oxygen supply valve, a 6-foot hose, and a quick disconnect fitting.

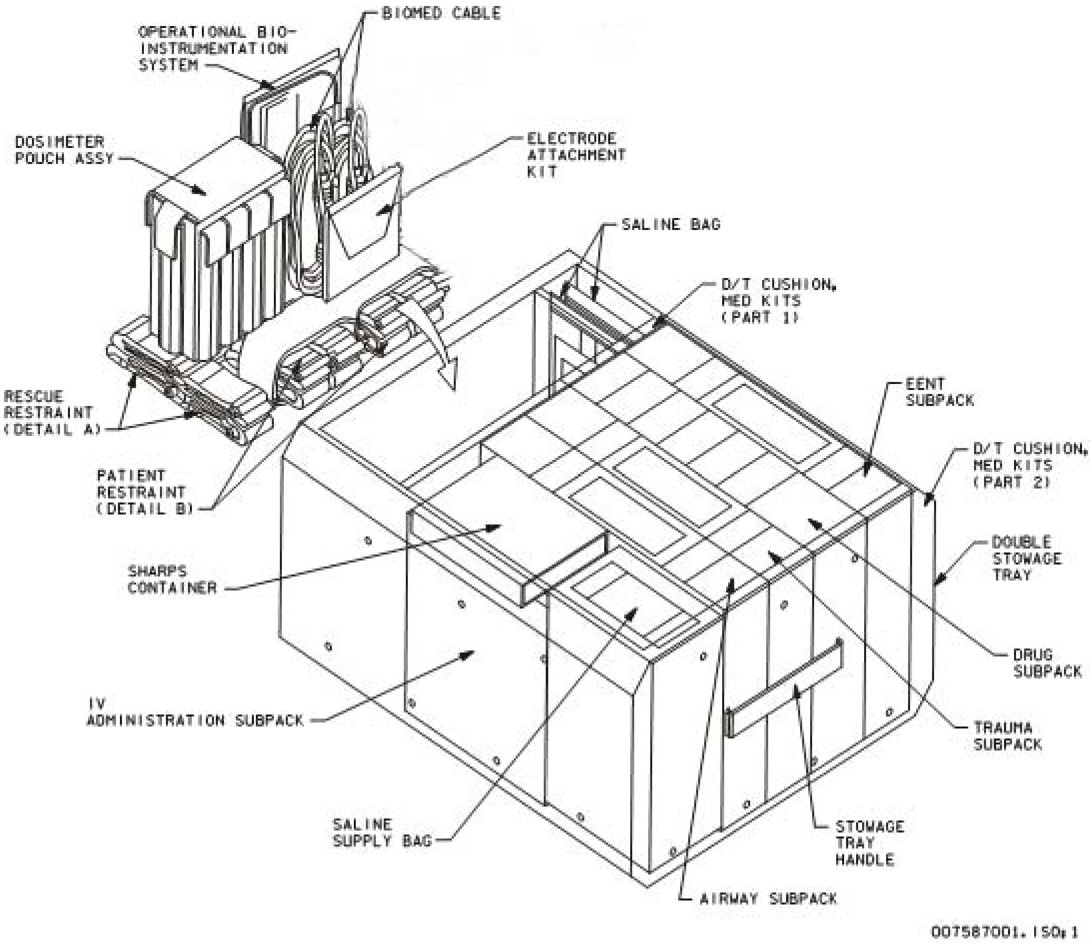
The resuscitator can supply 100 percent supplemental oxygen in two ways: manual delivery by pressing the AMBU bag for unconscious patients, and on-demand flow for conscious patients.

The resuscitator, upon unstowage, can be connected to the orbiter oxygen supply on the middeck connections on panels MO32M and MO69M and the flight deck connection on panel C6. The resuscitator assembly is stored in a middeck locker adjacent to the medical middeck locker.

The Contaminant Cleanup Kit (CCK) is a multipurpose cleanup kit. Its purpose is to protect crewmembers from contamination by toxic and nontoxic particulates within the cabin environment. The CCK houses the shuttle emergency eyewash (SEE), which connects to the clean water supply in the shuttle galley to flush a crewmember's eyes in case of a chemical burn or *smoke irritation of* the eye.

The Medical Accessory Kit (MAK) is a supplemental kit that is manifested on a mission-specific basis. The MAK provides additional stowage capability for crew-specific and/or mission-specific medications; for example, ice packs and ace bandages. Two are flown on each flight.

The onboard Medical Checklist specifies the location of medications/equipment in the subpacks by using the name of the subpack, followed by the pocket number. For example, the laryngoscope is designated in the checklist as being stowed in Airway Subpack – 5.



Medical **Locker Equipment and Locations**

The diagnostic equipment onboard and information from the flight crew allows diagnosis and treatment of injuries and illnesses through consultation with flight surgeons in Mission Control.

Operational Bioinstrumentation System

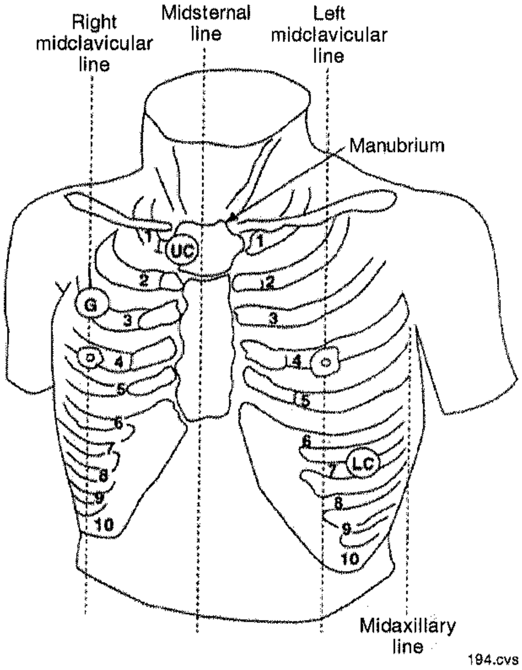
The operational bioinstrumentation system (OBS) provides an amplified electrocardiograph (ECG) analog signal from any crewmember aboard the orbiter to the avionics system, where the signal is converted to digital *data* and transmitted to the ground in real time or stored on tape for dump at a later time. On-orbit use is limited to contingency situations (only at the request of the flight surgeon) *and is for IV use only*.

The Electrode Attachment Kit (EAK) contains components to aid in the application of electrodes. The EAK includes wet wipes, stomaseals, overtapes, electrode paste, and a cue card to illustrate electrode placement.

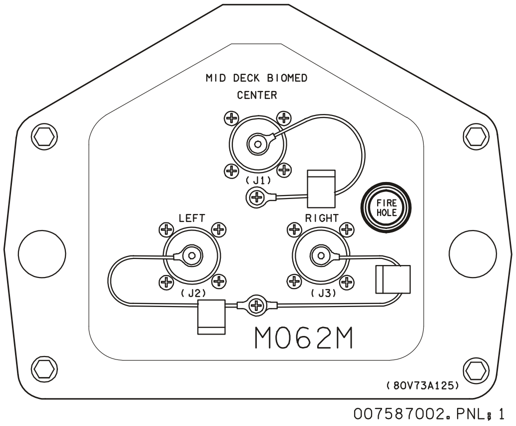
The OBS electrodes are attached to the skin with electrode paste to establish electrical contact. The electrode is composed of a plastic housing containing a non-polarizable pressed pellet. The housing is attached to the skin with double-sided adhesive tape, and the pellet contacts the skin. There are three electrodes on the harness, marked LC (lower chest), UC (upper chest), and G (ground). *The three electrodes are connected to a signal conditioner that converts the ECG signal to digital data to be transferred to the ground.*

The signal conditioner provides a zero- to 5-volt output and has an *ON/OFF* switch within the input plug, which is actuated when the IVA cable is plugged in. The unit has batteries that are not replaced in flight.

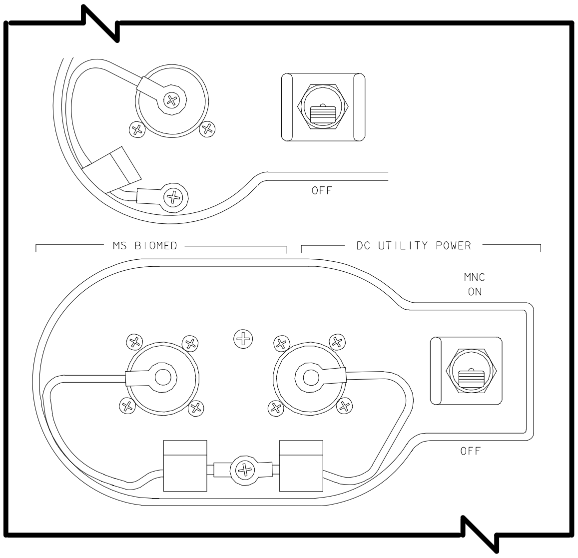
The IVA cable connects to the signal conditioner. *The other end of the IVA cable connects to the biomed cable, which then connects to one of the biomed input* connectors located on panel M062M, A15, or A11. Rotary control switches on panel R10 provide circuits from the biomed outlets to the orbiter's network signal processor for downlink or recording. The two rotary switches on panel R10 are *BIOMED CHANNEL 1* and *CHANNEL 2*.



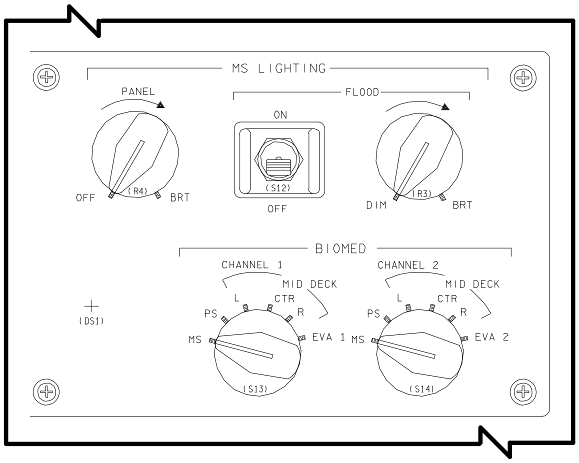
Electrode Attachment Areas: Ground (G), Upper Chest (UC), and Lower Chest (LC)



Panel M062M



MS BIOMED Input Connector on Panel A11



BIOMED Rotary Switches on Panel R10

Radiation Equipment

The harmful biological effects of radiation must be minimized through mission planning based on calculated predictions and by monitoring dosage exposures. Preflight requirements include a projection of mission radiation dosage, an assessment of the probability of solar flares during the mission, and a radiation exposure history of flight crewmembers. In-flight requirements *mandate* that each crewmember carry a passive dosimeter throughout the duration of the flight. In the event of a solar flare or other radiation contingency, the crew would be requested to retrieve and read out one or more of the active dosimeters.

The space shuttle radiation instrumentation system consists of both active and passive dosimeter devices. Active and passive radiation dosimetry devices include crew passive dosimeters (CPDs), passive radiation dosimeters (PRDs), a tissue equivalent proportional counter (TEPC), and a passive dosimeter kit (PDK). High-rate dosimeters (HRDs) are located inside the PDK.

The flight crew's passive dosimeters use thermoluminescent dosimeter chips (TLDs); they must be worn by each U.S. crewmember throughout their flight, including EVAs. The dosimeters measure the radiation dose to which a crewmember is exposed during the course of a mission and will be analyzed on the ground.

Passive radiation dosimeters are placed in the crew compartment before launch by ground support personnel and removed after landing for laboratory analysis. The remaining dosimeters are stowed in the PDK located in a middeck locker.

The TEPC is an active spectrometer that records the dose, dose rate, and the linear energy transfer (LET) spectrum as a function of time. The TEPC is required for most shuttle flights and nominally is stowed and deployed in the aft, starboard middeck area. Normal operations require minimal crew interaction.

The unit is powered up, first at the power outlet, then at the switchbox located inside the TEPC assembly. This task normally is conducted on FD1. The unit is powered down on the last flight day.

Periodically, the crew may be required to read the TEPC displays during certain radiation conditions, such as a solar proton event.

The high rate dosimeter (HRD) is a COTS portable radiation detector used for detecting high-rate Neutron/Gamma radiation doses and Gamma radiation doses. The HRD uses a PMOS-FET for prompt photons and a PIN diode for prompt neutrons. The HRD may respond in a passive manner. Without any power applied to the instrument, the prompt neutrons will "damage" the PIN diode. When the HRD is turned ON, it will read the "damage" as a Dose. The HRD will remain stored in PDK in a locker unless the crew is instructed by the ground to read the instrument. The crew may be requested to do this in the event of a contingency situation.

The HRD shall measure and display radiation doses from 0-600 rad. The rad is a unit based on the amount of energy absorbed and is defined as any type of radiation that is deposited in the absorbing media. Radiation absorbed by humans is expressed in roentgen equivalent in man, or rems. The rem is determined by multiplying rads times a qualifying factor, which is a variable that depends on wavelength, source, etc. For low-inclination orbits (35° and lower), the qualifying factor is approximately equal to one; therefore, the rem is approximately equal to the rad. In space transportation system flights, the doses received have ranged from 0.05 to 0.07 rem, which is well below flight crew exposure limits.

Air Sampling System

There are two modes of air sampling onboard. The grab sample container (GSC) is an air sampling system that provides a method for obtaining cabin atmosphere samples to allow postflight analysis of the gas environment within the crew module. The GSC is stowed in a modular locker for ascent, unstowed for sampling, and restowed for entry.

The GSC is an evacuated steel cylinder that is fitted with a valve operated by the valve knob. A screw cap, which covers the air inlet to prevent dust from contaminating the air sample, is tethered to the valve.

Two GSCs nominally are manifested for each flight. One is to be used during a contingency situation, such as fire or smoke in the cabin, and the other is used nominally during deorbit prep.

Grab Sample Container

The compound specific analyzer – combustion products (CSA-CP) is used for real-time analysis of *three* constituents *(*carbon monoxide (CO), hydrogen cyanide (HCN), *and* hydrogen chloride (HCl)*)*. Nominally, the CSA-CP is unstowed on FD1 as an easy activity. The sensors are evaluated and can be zeroed on-orbit if out of spec. *The CSA-CP* is then stowed *temporarily at a crew selected location*. *The crew should call MCC with the location.*

CSA-CP Pump

CSA-CP Monitor

2.6 DATA PROCESSING SYSTEM (DPS)

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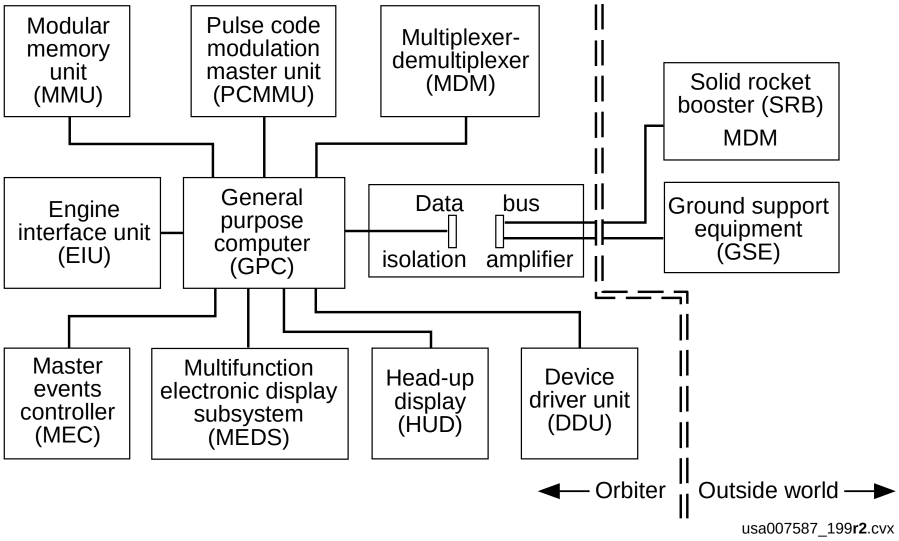
Description

The DPS, consisting of various hardware components and self-contained software, provides the entire shuttle with computerized monitoring and control. DPS functions are:

- Support the guidance, navigation, and control of the vehicle, including calculations of trajectories, SSME burn data, and vehicle attitude control data.
- Monitor and control vehicle subsystems, such as the electrical power system and the environmental control and life support system.
- Process vehicle data for the flight crew and for transmission to the ground, and allow ground control of some vehicle systems via transmitted commands.
- Check data transmission errors and crew control input errors; support annun-ciation of vehicle system failures and out-of-tolerance system conditions.
- Support payloads with flight crew/ software interface for activation, deployment, deactivation, and retrieval.
- Process rendezvous, tracking, and data transmissions between payloads and the ground.

The DPS hardware consists of five general-purpose computers (GPCs), two modular memory units (MMUs) for large-volume bulk storage, and a network of serial digital data buses to accommodate the data traffic between the GPCs and vehicle systems. The DPS also includes 20 orbiter and 4 SRB multiplexers/ demultiplexers (MDMs) to convert and format data from the various vehicle systems, 3 SSME interface units to command the SSMEs, a multifunction electronic display system (MEDS)

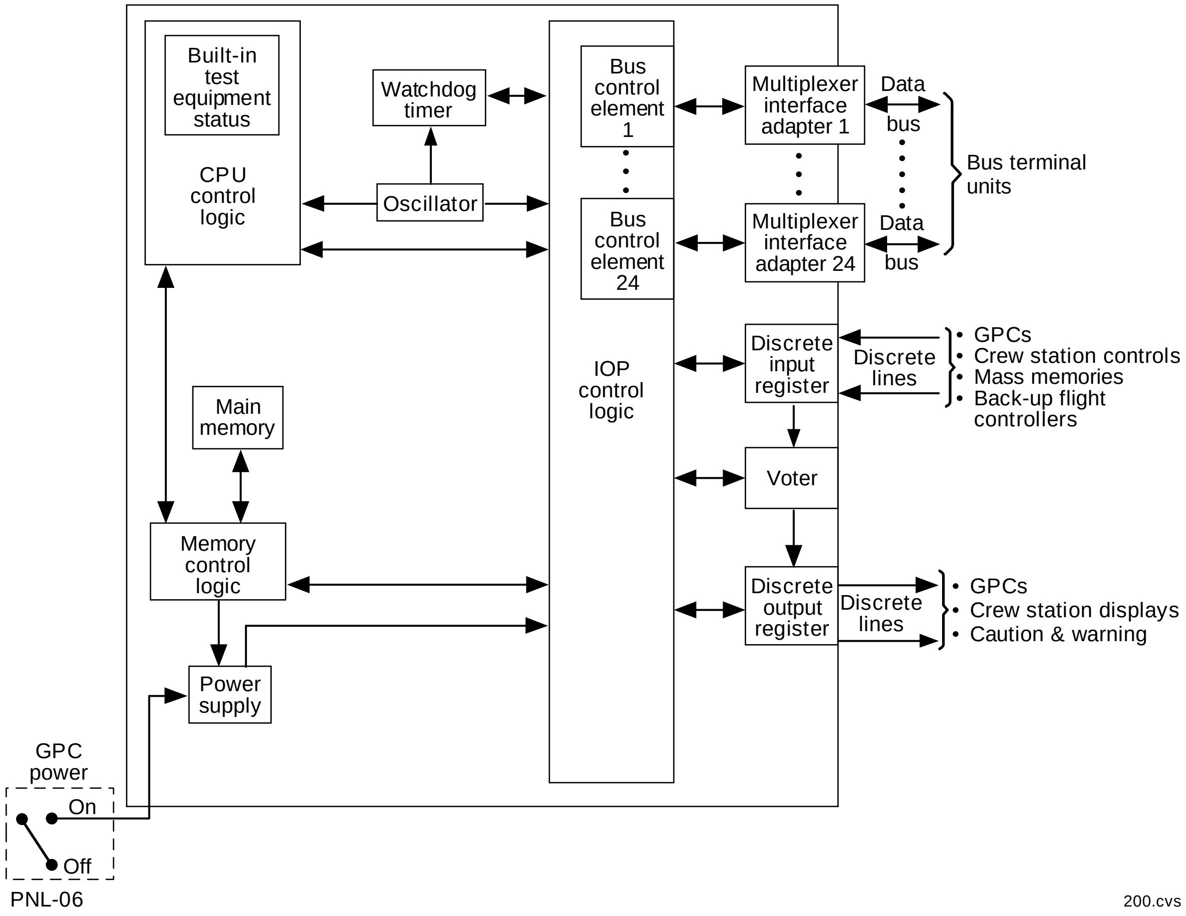


Data Processing System Interfacing Hardware used by the flight crew to monitor and control the vehicle and payload systems, 2 data bus isolation amplifiers to interface with the ground support equipment/launch processing system and the SRBs, 2 master events controllers, and a master timing unit.

DPS software accommodates almost every aspect of space shuttle operations, including orbiter checkout, prelaunch and final countdown for launch, turnaround activities, control and monitoring during launch, ascent, on-orbit activities, entry, and landing, and aborts or other contingency mission phases. A multicomputer mode is used for the critical phases of the mission, such as launch, ascent, orbit, entry, landing, and aborts.

General Purpose Computers (GPCs)

The orbiter has five identical IBM AP-101S GPCs. The GPCs receive and transmit data to and from interfacing hardware via the data bus network. GPCs also contain the software that provides the main on-board data processing capability. Up to four of the systems may run identical software. The fifth system runs different software, programmed by a different company, designed to take control of the vehicle if an error in the primary software or other multiple failures cause a loss of vehicle control. The software utilized by the four primary GPCs is referred to as PASS (primary avionics software system); the fifth GPC is referred to as BFS (backup flight system).



General Purpose Computer Functional Block Diagram

GPCs 1 and 4 are located in forward middeck avionics bay 1, GPCs 2 and 5 are located in forward middeck avionics bay 2, and GPC 3 is located in aft middeck avionics bay 3. The GPCs receive forced-air cooling from an avionics bay fan. (There are two fans in each avionics bay, but only one is powered at a time.)

> **CAUTION**
>
> If both fans in an avionics bay fail, the computers will overheat within 25 minutes (at 14.7 psi cabin pressure) or 17 minutes (at 10.2 psi) after which their operation cannot be relied upon. An operating GPC may or may not survive for up to an additional 30 minutes beyond the certifiable thermal limits.

Each GPC consists of a central processing unit (CPU) and an input/output processor (IOP) stored in one avionics box. The boxes are 19.55 inches long, 7.62 inches high, and 10.2 inches wide; they weigh approximately 60 pounds. The main memory of each GPC is volatile (the software is not retained if power is interrupted), but a battery pack preserves software contents when the GPC is powered off. The memory capacity of the GPCs is 256 k full-words, but only the lower 128 k full-words are normally used for software processing.

The CPU controls access to GPC main memory for data storage and software execution and executes instructions to control vehicle systems and manipulate data.

The IOP formats and transmits commands to the vehicle systems, receives and validates response data transmissions from the vehicle systems, and maintains the status of interfaces with the CPU and the other GPCs.

The 24 data buses are connected to each IOP by bus control elements (BCEs) that receive, convert, and validate serial data in response to requests for available data to be transmitted or received from vehicle hardware.

For timing, each GPC contains an oscillator that sends signals to internal components to regulate operations. The GPC also uses the oscillator to maintain an internal clock to keep track of Greenwich mean time (GMT) and mission elapsed time (MET) as a backup to the timing signal from the master timing unit (MTU).

Each GPC contains a watchdog timer. The watchdog timer is an incrementing clock register in the GPC that is reset about once every second by a signal from the CPU. If the register ever overflows, then a problem exists and is annunciated by a self-fail indication from that GPC. The PASS set does not utilize this hardware feature since it operates in synchronization with each of its GPCs to ensure proper functioning. Since the BFS operates essentially standalone relative to the PASS set synchronization, the BFS mechanization does utilize the watchdog timer function to serve as a check on its operation.

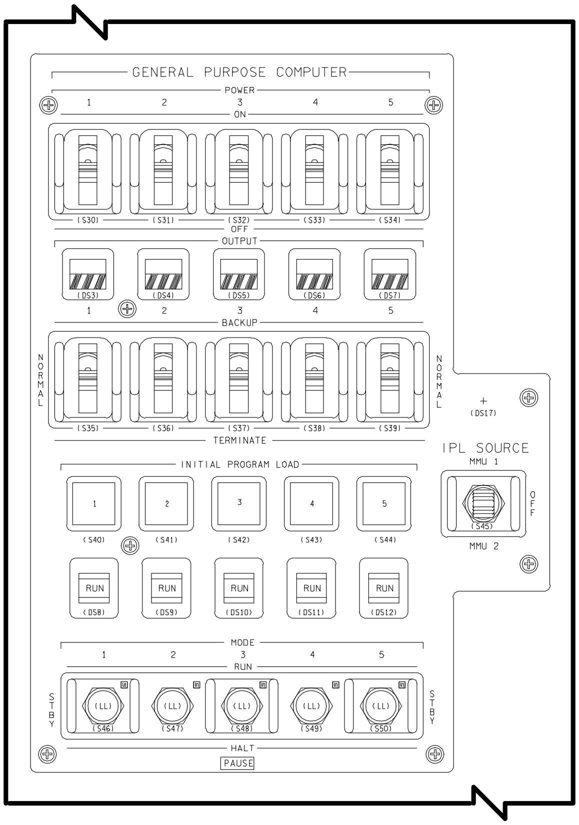
The PASS GPCs use a hardware "voter" to monitor discrete inputs from the other GPCs. Should a GPC receive a fail vote from two or more of the other GPCs, it will cause the GPC to annunciate a self-fail indication that also causes the GPC to inhibit any fail votes of its own against the other GPCs.

GPC Controls

The *GENERAL PURPOSE COMPUTER* hardware controls are located on panel O6. Each of the five GPCs reads the position of its corresponding *OUTPUT* and *MODE* switches and *INITIAL PROGRAM LOAD* pushbuttons from discrete input lines that go directly to the GPC. Each GPC has *OUTPUT* and *MODE* talkback indicators on panel O6 that are driven by GPC output discretes.

Each GPC has a *GENERAL PURPOSE COMPUTER POWER* switch on panel O6. Positioning a switch to ON enables power from three essential buses, ESS 1BC, 2CA, and 3AB. The essential bus power controls remote power controller (RPCs), which permit main bus DC power from the three main buses (MN A, MN B, and MN C) to power the GPC. There are three RPCs for each GPC; thus, any GPC will function normally, even if two main or essential buses are lost. Each computer uses 560 watts of power.

Each *GENERAL PURPOSE COMPUTER OUTPUT* switch on panel O6 is a guarded switch with *BACKUP*, *NORMAL*, and *TERMINATE* positions. The switch provides a hardware override to the GPC that precludes that GPC from outputting on the flight-critical buses. The switches for the PASS GNC GPCs are positioned to *NORMAL*, which permits them to output. The backup flight system switch (GPC 5) is positioned to *BACKUP*, which precludes it from outputting until it is engaged. The switch for a GPC designated on-orbit to be a systems management (SM) computer is positioned to *TERMINATE*, since the GPC is not to command anything on the flight-critical buses.



GENERAL PURPOSE COMPUTER
Hardware Controls

The talkback indicator above each *OUTPUT* switch on panel O6 indicates gray if that GPC output is enabled and barberpole if it is not.

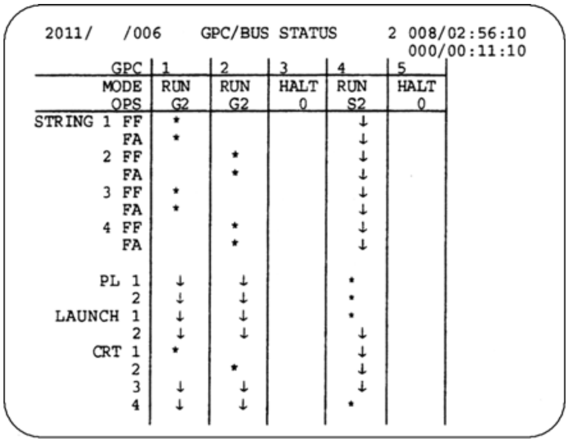
Each GPC receives *RUN*, *STBY*, or *HALT* discrete inputs from its *MODE* switch on panel O6, which determines whether that GPC can process software. The *MODE* switch is lever-locked in the RUN position. The *HALT* position initiates a hardware-controlled state in which no software can be executed. A GPC that fails to synchronize with others is either powered *OFF* or moded to *HALT* as soon as possible to prevent the failed computer from outputting erroneous commands. The talkback indicator above the *MODE* switch for that GPC indicates barberpole when that computer is in *HALT*.

In *STBY*, a GPC is also in a state in which no PASS software can be executed, but it is in a software-controlled state. The *STBY* mode allows an orderly startup or shutdown of processing. It is necessary, as a matter of procedure, for a PASS GPC that is shifting from *RUN* to *HALT* or vice versa to be temporarily (more than 3 seconds) in the *STBY* mode before going to the next state. The *STBY* mode allows for an orderly software cleanup and allows a GPC to be correctly initialized (when reactivated) without an initial program load. If a GPC is moded to *RUN* or *HALT* without pausing in STBY, it may not perform its functions correctly. There is no *STBY* indication on the talkback indicator above the *MODE* switch.

The *RUN* position permits a GPC to support its normal processing of all active software and assigned vehicle operations. Whenever a computer is moded from *STBY* to *RUN*, it initializes itself to a state in which only system software is processed (called OPS 0). If a GPC is in another operational sequence (OPS) before being moded out of *RUN*, that software still resides in main memory; however, it will not begin processing until that OPS is restarted by flight crew keyboard entry. The *MODE* talkback indicator always reads *RUN* when that GPC switch is in *RUN*, and no failures exist.

Placing the backup flight system GPC in *STBY* does not stop BFS software processing or preclude BFS engagement; it only prevents the BFS from commanding the payload buses used by BFS systems management software.

The PASS GPC/BUS STATUS display (DISP 6) indicates the current mode of each PASS GPC in the common set. The display does not differentiate between *STBY* and *HALT*; only *RUN* or *HALT* is displayed (GPC MODE).



```
  2011/   /006    GPC/BUS STATUS     2 008/02:56:10
                                       000/00:11:10
            GPC | 1    | 2    | 3    | 4    | 5
           MODE | RUN  | RUN  | HALT | RUN  | HALT
            OPS |  G2  |  G2  |  0   |  S2  |  0
STRING 1 FF     |  *   |      |      |   ↓  |
         FA     |  *   |      |      |   ↓  |
       2 FF     |      |  *   |      |   ↓  |
         FA     |      |  *   |      |   ↓  |
       3 FF     |  *   |      |      |   ↓  |
         FA     |  *   |      |      |   ↓  |
       4 FF     |      |  *   |      |   ↓  |
         FA     |      |  *   |      |   ↓  |
                |      |      |      |      |
        PL 1    |  ↓   |  ↓   |      |  *   |
           2    |  ↓   |  ↓   |      |  *   |
    LAUNCH 1    |  ↓   |  ↓   |      |  *   |
           2    |  ↓   |  ↓   |      |   ↓  |
       CRT 1    |  *   |      |      |   ↓  |
           2    |      |  *   |      |   ↓  |
           3    |  ↓   |  ↓   |      |   ↓  |
           4    |  ↓   |  ↓   |      |  *   |
```

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GPC/BUS STATUS Display (DISP 6)

The *INITIAL PROGRAM LOAD* pushbutton for a GPC on panel O6 activates the initial program load command discrete input when depressed. When the input is received, that GPC initiates an initial program load (IPL) from the MMU specified by the *IPL SOURCE* switch on panel O6. The talkback indicator above the *MODE* switch for that GPC briefly indicates *IPL* then changes back to barberpole.

During non-critical periods in orbit, only one or two GPCs are used for GNC tasks, and another is used for systems management and payload operations.

A GPC on orbit can also be "freeze-dried"; that is, it can be loaded with the software for a particular memory configuration and then moded to *HALT*. Before an OPS transition to the loaded memory configuration, the freeze-dried GPC can be moded back to *RUN* and the appropriate OPS requested.

NOTE

> Because all BFS software is loaded into the BFS GPC at the same time, the BFS GPC is sometimes referred to as being freeze-dried on orbit when it is placed in *HALT*. The BFS GPC can be moded to *RUN* prior to entry and will begin processing entry software following the OPS 3 request without having to access a modular memory unit. The term freeze-dry or freeze-dried is most often used with respect to the PASS GPCs.

GPC Modes of Operation

GPC modes of operation are redundant set, common set, and simplex. Redundant set operations refer to the mode in which two or more GPCs are concurrently receiving the same inputs, executing the same GNC software, and producing the same outputs. This mode uses a maximum amount of intercomputer communications, and the GPCs must maintain a high level of synchronization (called redundant set synchronization).

During redundant set operations, each GPC outputs only certain portions of its total software output to its interfacing hardware. Therefore, although each GPC "thinks" it is performing all its operations, only the GPC responsible for supporting a specific group of hardware will be able to actually transmit its data and commands. The redundant set GPCs compare all calculations to ensure that individual outputs are the same.

Common set operations occur when two or more GPCs communicate with one another while they are performing their individual tasks. They do not have to be performing the same major function (although they can be), but they do maintain common set synchronization. Any GPC operating as a member of the redundant set is also a member of the common set.

A simplex GPC is in *RUN*, but not a member of the redundant set. Systems management and payload major functions are always processed in a simplex GPC.

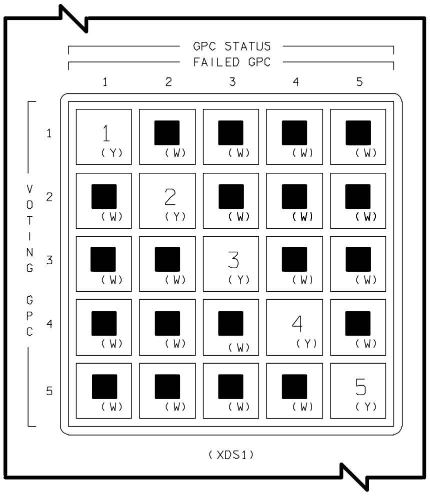
GPCs running together in the same GNC OPS are part of a redundant set performing identical tasks from the same inputs and producing identical outputs. Therefore, any data bus assigned to a commanding GNC GPC (except the instrumentation buses because each GPC has only one dedicated bus connected to it) is heard by all members of the redundant set. These transmissions include all keyboard inputs and mass memory transactions, as well as flight-critical data. If one or more GPCs in the redundant set fail, the remaining computers can continue operating in GNC. Each GPC performs about 1.2 million operations per second during critical phases.

Each computer in a redundant set operates in synchronized steps and cross-checks results of processing hundreds of times per second. Synchronization refers to the software scheme used to ensure simultaneous intercomputer communications of necessary GPC status information among the PASS computers. If a GPC operating in a redundant set fails to meet any redundant synchronization point, the remaining computers will immediately vote it out of the redundant set. If a GPC has a problem with one of its multiplexer interface adapter receivers during two successive reads of response data, or does not receive data while other members of the redundant set do receive data, the GPC with the problem will fail-to-sync.

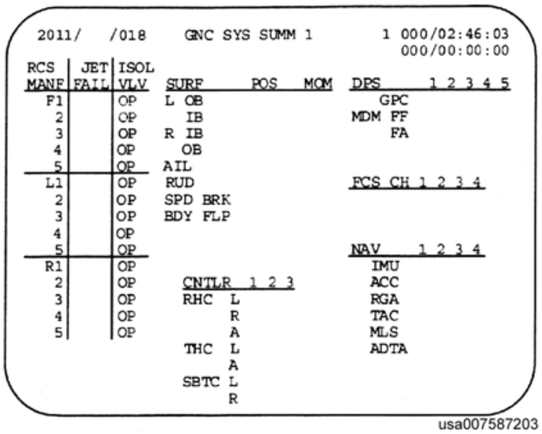
GPC Failure Indications

GPC failure votes are annunciated in a number of ways. Each GPC has discrete output lines for fail votes against each of the other GPCs that go to the other GPCs and the GPC status matrix. A GPC FAIL detection will cause a class 2 GPC fault message with illumination of the *MASTER ALARM*. Error indications will be displayed on DISP 18 GNC SYS SUMM 1 and DISP 6 GPC/BUS STATUS displays.

The GPC *STATUS* matrix (sometimes referred to as the GPC fail CAM) on panel O1 is a 5-by-5 matrix of lights. Each light corresponds to a GPC's fail vote against another GPC or itself. For example, if GPC 2 sends out a failure vote against GPC 3, the second white light in the third column is illuminated. The off-diagonal votes are votes against other GPCs. The yellow diagonal lights from upper left to lower right are self-failure votes. Whenever a GPC receives two or more failure votes from other GPCs, it illuminates its own yellow light and resets any failure votes that it made against other GPCs (any white lights in its row are extinguished). Any time a yellow matrix light is illuminated, the GPC caution and warning light on panel F7 is illuminated, in addition to MASTER ALARM illumination, and a GPC fault message is displayed on the DPS displays.



GPC STATUS Matrix on Panel 01 (W=white; Y=yellow)



```
2011/   /018    GNC SYS SUMM 1          1 000/02:46:03
                                          000/00:00:00
RCS |JET|ISOL
MANF|FAIL|VLV  SURF      POS  MOM   DPS       1 2 3 4 5
  F1|    |OP   L OB                    GPC
   2|    |OP     IB                 MDM FF
   3|    |OP   R IB                     FA
   4|    |OP     OB
   5|    |OP   AIL
  L1|    |OP   RUD                  FCS CH 1 2 3 4
   2|    |OP   SPD BRK
   3|    |OP   BDY FLP
   4|    |OP
   5|    |OP                        NAV      1 2 3 4
  R1|    |OP                          IMU
   2|    |OP     CNTLR  1 2 3         ACC
   3|    |OP     RHC   L              RGA
   4|    |OP           R              TAC
   5|    |OP           A              MLS
                 THC   L              ADTA
                       A
                 SBTC  L
                       R
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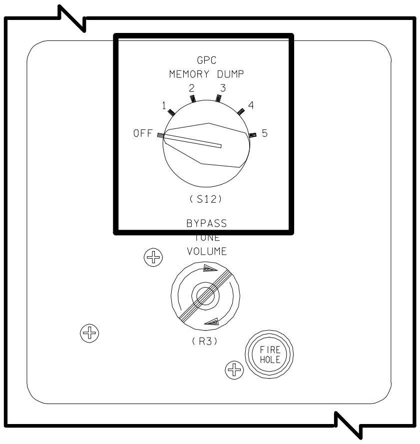
DPS Parameters on GNC SYS SUMM 11 Display (DISP 18)



GPC MEMORY DUMP Switch on Panel M042F

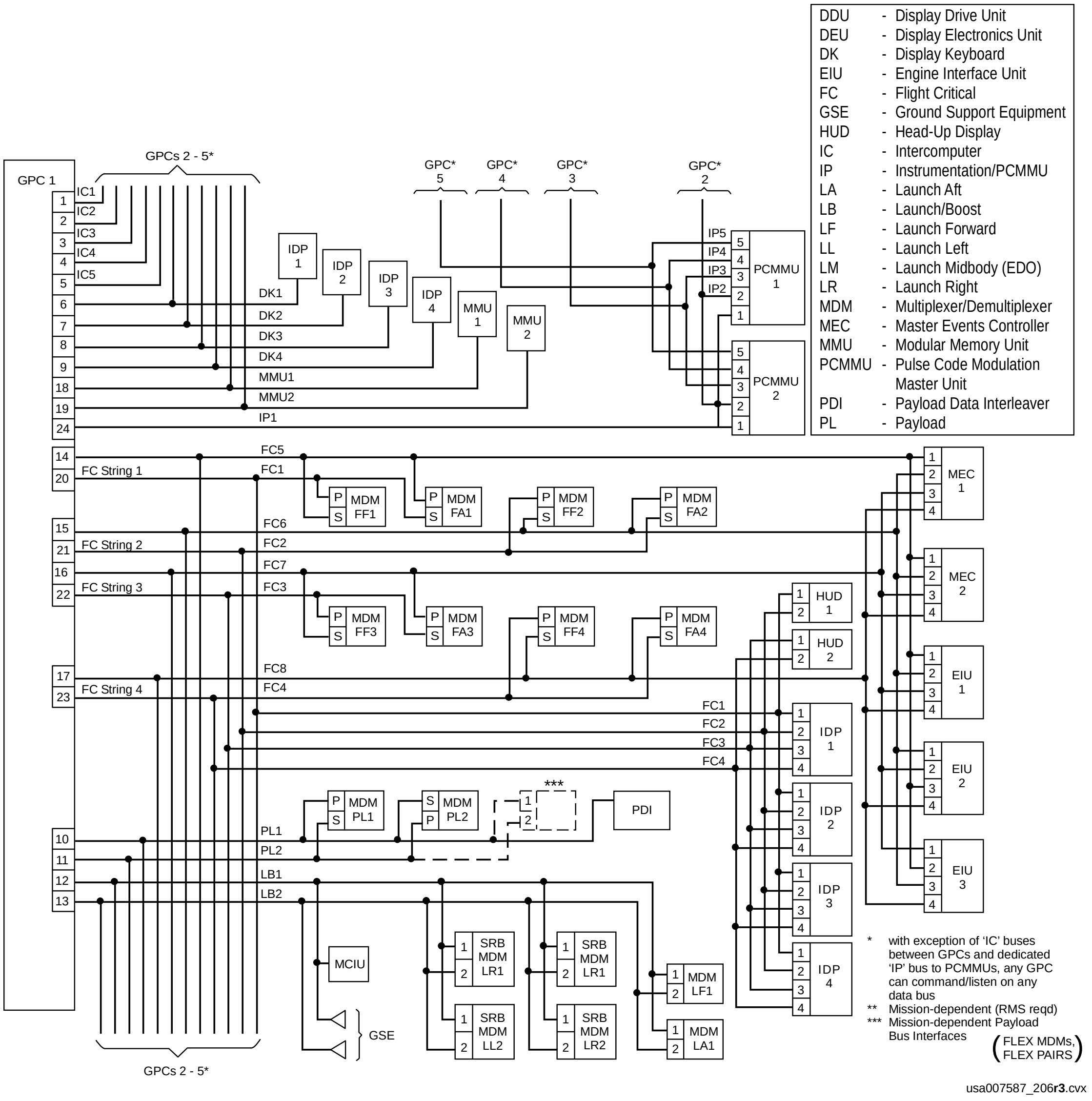
A failed GPC's memory contents can be dumped by powering ON, switching the computer to *TERMINATE* and *HALT*, and then selecting the number of the failed GPC on the GPC *MEMORY* DUMP rotary switch on panel M042F. The GPC is then moded to *STBY* to start the dump. After 2 to 8 minutes, the dump is stopped by moding the GPC to *HALT* and the output to *NORM*. This process is referred to as a hardware-initiated, standalone memory (HISAM) GPC memory dump.

Data Bus Network

The data bus network supports the transfer of serial digital commands and data between the GPCs and vehicle systems. The network has seven groups that perform specific functions:

1. Flight-critical (FC) data buses that tie the GPCs to the FC MDMs, integrated display processors (IDPs), head-up displays (HUDs), engine interface units (EIUs), and master events controllers (MECs).

2. Payload data buses that tie the GPCs to the payload MDMs and the payload data interleaver (PDI), and possibly mission-dependent flex MDMs or sequence control assemblies.



* with exception of 'IC' buses between GPCs and dedicated 'IP' bus to PCMMUs, any GPC can command/listen on any data bus
** Mission-dependent (RMS reqd)
*** Mission-dependent Payload Bus Interfaces (FLEX MDMs, FLEX PAIRS)

Data Bus Network

3. Launch data buses that tie the GPCs to ground support equipment, launch forward, launch aft, launch mid, and SRB MDMs, and the manipulator controller interface unit (MCIU) used by the remote manipulator system.
4. Mass memory data buses for GPC/MMU transactions.
5. Display/keyboard (DK) data buses for GPC/IDP transactions.
6. Instrumentation/PCMMU (IP) data buses.
7. Intercomputer communication (ICC) data buses.

Although all data buses in each group except the instrumentation/PCMMU buses are connected to all five GPCs, only one GPC at a time transmits commands over each bus. However, several GPCs may receive data from the same bus simultaneously.

Each data bus, with the exception of the intercomputer communication data buses, is bidirectional; that is, data can flow in either direction. The intercomputer communication data bus traffic flows in only one direction (a PASS software constraint, not a hardware restriction).

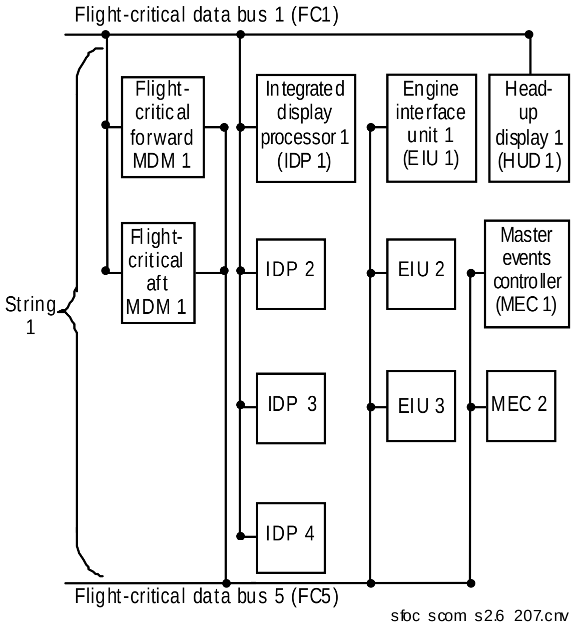
Flight-Critical Data Buses

There are eight FC data buses directed into groups of two, referred to as an FC string. Each FC string can be commanded by a different GPC. Multiple units of each type of GNC hardware are wired to a different MDM and flight-critical bus. FC1, 2, 3, and 4 connect the GPCs with the four flight-critical forward (FF) MDMs, the four flight-critical aft (FA) MDMs, the four integrated display processors, and the two head-up displays. The other four, FC5, 6, 7, and 8, connect the GPCs to the same four FF MDMs, the same four FA MDMs, the two master events controllers, and the three main engine interface units.

A string is composed of two FC data buses: one from the first group (FC1, 2, 3, or 4) and one from the second group (FC5, 6, 7, or 8). Vehicle hardware is segmented into these groups to facilitate GPC command of these components for redundancy, to allow for nominal mission operations in the event of a loss of one string caused by a GPC or MDM failure, and to allow for safe return to Earth in the event of the loss of a second string.

String 1 consists of FC data buses 1 and 5, MDMs FF1 and FA1 and their hard-wired hardware, controls, and displays, the three engine interface units, the two master events controllers, the four integrated display processors, and head-up display 1. This distribution of hardware is fixed and cannot be changed. The other three strings are defined in a similar manner.

During ascent and entry, when there are four PASS GNC GPCs in the redundant set, each is assigned a different string to maximize redundancy. All flight-critical hardware units are redundant, and the redundant units are on different strings. The string concept provides failure protection during dynamic phases by allowing exclusive command of a specific group of vehicle hardware by one GPC, which can be transferred to another GPC in case of failure. All or part of one string can be lost, and all avionics functions will still be retained through the other strings.



Components of String 1

With four PASS GNC GPCs in a redundant set, each GPC is responsible for issuing commands over the string assigned to it; that is, it is the commander of that string. The other GNC GPCs will monitor or listen on this string. When the string's commanding GPC sends a request for data to the hardware on the string, all the other GNC GPCs will hear and receive the same data coming back on the string. This transaction (one commanding GPC and multiple listening GPCs) is occurring in parallel with the other three strings. Therefore, all GNC GPCs will get a copy of all of the data from all four strings. Once all the data are received from the string, the GPCs then agree (or disagree) that the data are consistent.

Payload Data Buses

Two payload data buses interface the five GPCs with the two payload MDMs (also called payload forward MDMs), which interface with orbiter systems and payloads. A PDI is connected to payload data bus 1. Additionally, on some flights, one or two flex MDMs and/or sequence control assemblies connect the payload data buses to communicate with other payload equipment.

Each payload MDM is connected to two payload data buses. Safety-critical payload status parameters may be hard-wired; then these parameters and others can be recorded as part of the vehicle's system management, which is transmitted and received over two payload buses. To accommodate the various forms of payload data, the PDI integrates payload data for transmission to ground telemetry. PDI configuration commands and status monitoring are accomplished via payload data bus 1.

Launch Data Buses

Two launch data buses are used primarily for ground checkout and launch phase activities. They connect the five GPCs with the ground support equipment/launch processing system, the launch forward (LF1), launch mid (LM1), and launch aft (LA1) MDMs aboard the orbiter, and the two left and right SRB MDMs (LL1, LL2, LR1, and LR2). Launch data bus 1 is used on orbit for interface with the remote manipulator system controller by the SM GPC.

Mass Memory Data Buses

Each of two MMUs interfaces with its data bus via a multiplexer interface adapter, which functions just like the ones in the GPCs. Each data bus is connected to all five GPCs. Each MMU is connected to only one mass memory data bus.

In addition, each MMU has a separate discrete line called the "ready discrete" that goes to each of the GPCs. If the discrete is on, it tells the GPC the modular memory unit is ready for a transaction. When the discrete is off, the MMU is either busy with another transaction or is powered off.

Note that all MMU operations and transmissions to the GPCs are on an on-demand basis only. There is no insight into the state of the MMU (other than the ready discrete) unless a specific transaction is requested.

Display/Keyboard Data Buses

The four display/keyboard (DK) data buses, one for each IDP, are connected to each of the five GPCs. The computer in command of a particular display/ keyboard data bus is a function of the current *MAJOR FUNC* switch setting of the associated IDP, current memory configuration, GPC/CRT keyboard entries, and the position of the backup flight control (BFC) CRT switches. (These topics are discussed in more detail under "Operations.")

Instrumentation/Pulse-Code Modulation Master Unit (PCMMU) Buses

The five instrumentation/PCMMU data buses are unique in that each GPC has its own individual data bus to two PCMMUs. All the other data buses interface with every GPC.

Flight controllers monitor the status of the vehicle's onboard systems through data transmissions from the vehicle to the ground. These transmissions, called downlink, include GPC-collected data, payload data, instrumentation data, and onboard voice. The GPC-collected data, called downlist, includes a set of parameters chosen before flight for each mission phase.

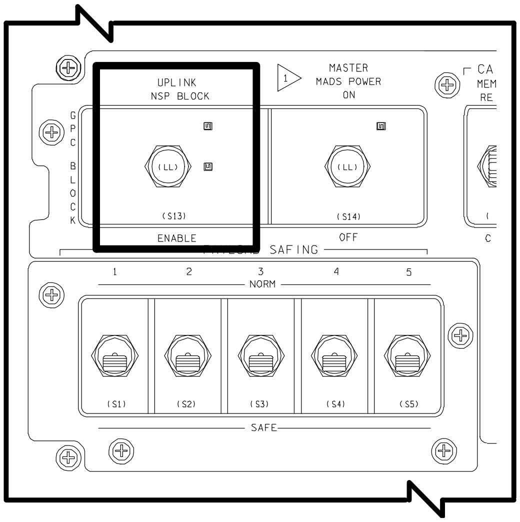
The system software in each GPC assimilates the specified GNC, systems management, payload, or DPS data according to the premission-defined format for inclusion in the downlist. Each GPC is physically capable of transmitting its downlist to the current active PCMMU over its dedicated instrumentation/PCMMU data bus. Only one PCMMU is powered at a time. It interleaves the downlist data from the different GPCs with the instrumentation and payload data according to the telemetry format load programmed in the PCMMU. The resulting composite data set, called the operational downlink, is transmitted to one of two network signal processors (NSPs). Only one NSP is powered at a time. In the NSP, the operational downlink is combined with onboard recorded voice for transmission to the ground. The S-band and Ku-band communications systems transmit the data either to the space flight tracking and data network remote site ground stations or through the Tracking and Data Relay Satellite (TDRS) system to Mission Control.

Uplink is how ground commands originating in Mission Control are formatted, generated, and transmitted to the orbiter for validation, processing, and eventual execution by onboard software. This capability allows ground systems to control data processing, change modes in orbiter hardware, and store or change software in GPC memory and mass memory.

From MCC consoles, flight controllers issue commands and request uplink. The command requests are formatted into a command load for transmission to the orbiter either by the STDN sites or by the TDRS system. The S-band or Ku-band transponder receivers aboard the orbiter send the commands to the active NSP. The NSP validates the commands and, when they are requested by the GPCs through a flight-critical MDM, sends them on to the GPC. The GPCs also validate the commands before executing them. Those GPCs listening directly to the flight-critical data buses then forward uplink commands for those GPCs not listening to the FC buses over the intercomputer communication data buses.

The PCMMU also contains a programmable read-only memory for accessing subsystem data, a random-access memory in which to store data, and a memory in which GPC data are stored for incorporation into the downlink.

To prevent the uplink of spurious commands from somewhere other than Mission Control, the flight crew can control when the GPCs accept uplink commands, and when uplink is blocked. The *GPC BLOCK* position of the *UPLINK* switch on panel C3 inhibits uplink commands during ascent and entry when the orbiter is not over a ground station or in TDRS coverage.



UPLINK Switch on Panel C3

Intercomputer Communication Data Buses

There are five intercomputer communication (ICC) data buses. The following information is exchanged over these buses for proper DPS operation: input/output errors, fault messages, GPC status matrix data, IDP major function switch settings, GPC/CRT keyboard entries, resident GPC memory configuration, memory configuration table, operational sequences, master timing unit time, internal GPC time, system-level display information, uplink data, and state vectors.

All GPCs processing PASS software exchange status information over the ICC data buses. During launch, ascent, and entry, GPCs 1, 2, 3, and 4 are usually assigned to perform GNC tasks, operating as a redundant set, with GPC 5 as the backup flight system. Each of the PASS GPCs acts as a commander of a given ICC data bus and initiates all data bus transactions on that data bus.

The four PASS GPCs are loaded with the same software. Interconnecting the four ICC buses to the four PASS GPCs allows each GPC access to the status of data received or transmitted by the other GPCs so that identical results among the four PASS GPCs can be verified. Each ICC bus is assigned to one of the four PASS GPCs in the command mode, and the remaining GPCs operate in the listen mode for the bus. Each GPC can receive data from the other three GPCs, pass data to the others, and perform any other tasks required to operate the redundant set.

Multiplexers/Demultiplexers (MDMs)

The MDMs convert and format (demultiplex) serial digital GPC commands into separate parallel discrete, digital, and analog commands for various vehicle hardware systems. The MDMs also convert and format (multiplex) the discrete, digital, and analog data from vehicle systems into serial digital data for transmission to the GPCs. Each MDM has two redundant multiplexer interface adapters (MIAs), each connected to a separate data bus. The MDM's other functional interface is its connection to the appropriate vehicle system hardware by hard-wired lines.

There are 20 MDMs aboard the orbiter; 13 are part of the DPS, connected directly to the GPCs and named and numbered according to their location in the vehicle and hardware interface. The remaining seven MDMs are part of the vehicle instrumentation system and send vehicle instrumentation data to the PCMMUs. (They are termed operational instrumentation (OI) MDMs.)

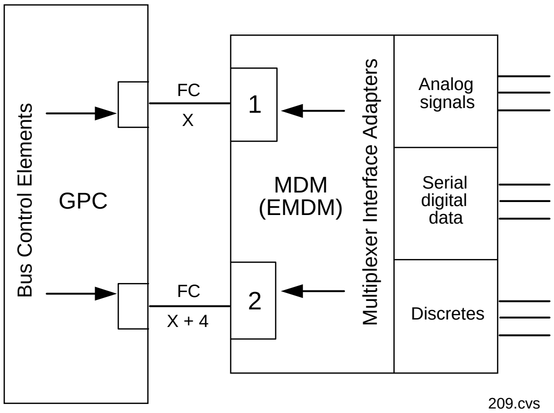
The DPS MDMs consist of flight-critical forward (FF) MDMs 1 through 4, flight-critical aft (FA) MDMs 1 through 4, payload (PL) MDMs 1 and 2, and GSE/LPS launch forward (LF1), launch mid (LM1), and launch aft (LA1). One or two flex MDMs (FMDMs) may also be connected to the PL data buses, depending on the payload needs for a particular flight.

Of the seven operational instrumentation MDMs, four are located forward (OF1, OF2, OF3, and OF4), and three are located aft (OA1, OA2, and OA3).

Also recall, there are four SRB MDMs; i.e., SRB launch left (LL) MDMs 1 and 2 and launch right (LR) MDMs 1 and 2.

The system software in the redundant set GPC activates a GNC executive program and issues commands to authorized buses and MDMs to request a set of input data. Each MDM receives the command from the GPC assigned to command it, acquires the requested data from the GNC hardware wired to it, and sends the data to the GPCs.

Each FC data bus is connected to a flight forward and flight aft MDM. Each MDM has two MIAs, or ports, and each port has a channel through which the GPCs can communicate with an MDM; however, the GPCs can interface on the FC data buses with only one MIA port at a time. Port moding is the software method used to control the MIA port that is active in an MDM. Initially, these MDMs operate with port 1; if a failure occurs in port 1, the flight crew can select port 2. Since port moding involves a pair of buses, both MDMs must be port moded at the same time. The control of all other units connected to the affected data buses is unaffected by port moding. Port moding is a software-only process and does not involve any hardware changes.



GPC/MDM Interfaces

Payload data bus 1 is connected to the primary MIA port of payload MDM 1, and payload data bus 2 is connected to the primary port of payload MDM 2. Payload data bus 1 is connected to the secondary MIA port of payload

MDM 2, and payload data bus 2 is connected to the secondary port of payload MDM 1. Which bus is used to communicate with each MDM is controlled by port moding.

The two launch data buses are also connected to dual launch MDM multiplexer interface adapter ports. The flight crew cannot switch these ports; however, if an input/output error is detected on LF1 or LA1 during prelaunch, an automatic switchover occurs.

The hardware controls for the MDMs are the *MDM PL1*, *PL2*, *PL3*, *FLT CRIT AFT*, and *FLT CRIT FWD* power switches on panel O6. These *ON/OFF* switches provide or remove power for the four aft and four forward flight-critical MDMs and PL1 and PL2 MDMs. The *PL3* switch is unwired and is not used. There are no flight crew controls for the SRB MDMs.

Each MDM is redundantly powered by two main buses. The power switches control bus power for activation of a remote power controller (RPC) for each main power bus to an MDM. The main buses power separate power supplies in the MDM. Loss of either the main bus or MDM power supply does not cause a loss of function because each power supply powers both channels in the MDM. Turning off power to an MDM resets all the discrete and analog command interfaces to subsystems.

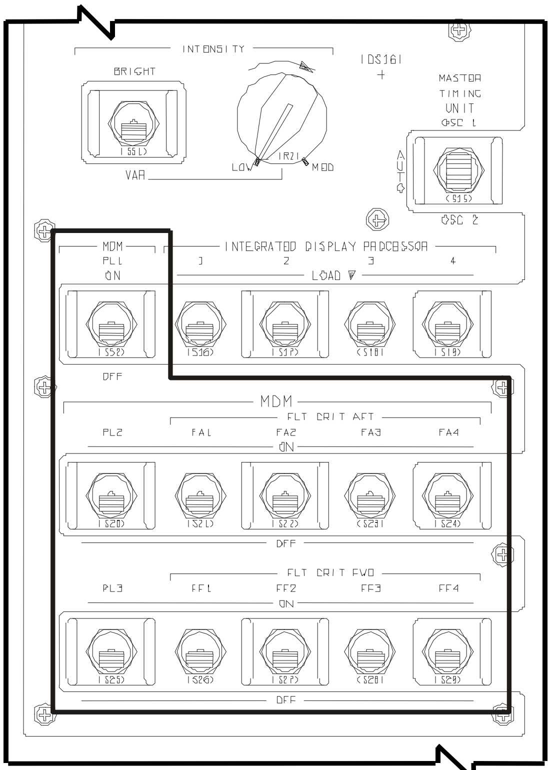
The SRB MDMs receive power through SRB buses A and B; they are tied to the orbiter main buses and are controlled by the master events controller circuitry. The launch forward, mid, and aft MDMs receive their power through the preflight test buses.

The FF, PL, LF, and LM MDMs are located in the forward avionics bays and are cooled by water coolant loop cold plates. LA and FA MDMs are in the aft avionics bays and are cooled by Freon coolant loop cold plates. MDMs LL1, LL2, LR1, and LR2 are located in the SRBs and are cooled by passive cold plates.

Module (or card) configuration in an MDM was dictated by the hardware components to be accessed by that type of MDM. A flight-critical forward and aft MDM are not interchangeable. However, flight-critical MDMs of the same type may be interchanged with another and the payload MDMs may be interchanged.

Each MDM is 13 by 11 by 7 inches and weighs about 38.5 pounds. MDMs use less than 80 watts of power.

Enhanced MDMs (EMDMs) were installed in OV-105. EMDMs will be installed in the other vehicles only as MDMs require replacement (currently both types are on Atlantis). The presence of EMDMs is transparent to the crew except in the case of an MDM OUTPUT message. With MDMs, the message means there is a problem with an MDM or a GPC. An MDM OUTPUT message with EMDMs means it is most likely a GPC problem. Crews flying with a combination of MDMs and EMDMs will receive assistance from flight controllers in interpreting an MDM OUTPUT message.



MDM Power Switches on Panel 06

Modular Memory Units

There are two modular memory units (MMUs) aboard the orbiter. A modular memory unit consists of a solid state recorder (SSR) and a solid state mass memory (SSMM) storage device for GPC software and orbiter systems data. For more information on the SSR, see section 2.4. For simplicity, MMU in this section will refer to the SSMM functions to the DPS.

Computing functions for all mission phases require approximately 600,000 half-words of computer memory. The orbiter GPCs are loaded with different memory configurations from the MMUs. In this way, software can be stored in MMUs and loaded into the GPCs when actually needed.

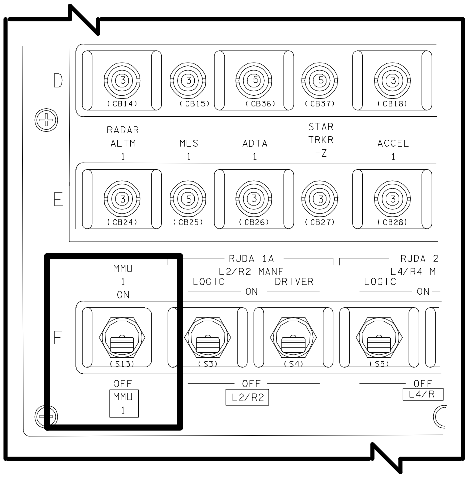
To fit the required software into the available GPC memory space, programs are subdivided into eight memory configurations corresponding to functions executed during specific flight and checkout phases. Thus, in addition to the central memory in the GPCs themselves, 128 Mbit of information can be stored in each of the two MMUs. Critical programs and data are loaded in both MMUs and protected from erasure.

The principal function of the MMU, besides storing the basic flight software, is to store background formats and code for certain displays and the checkpoints that are written periodically to save selected data in case the systems management GPC fails.

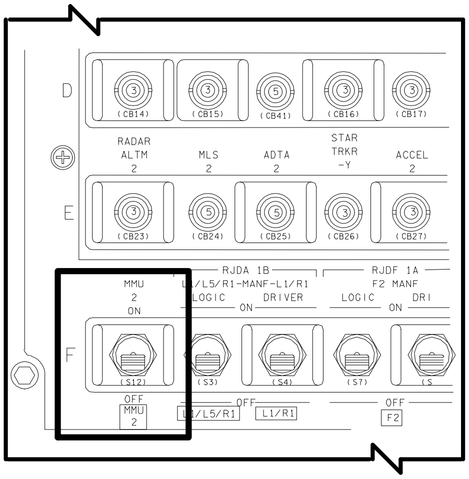
Each MMU interfaces with its mass memory data bus through MIAs that function like the ones in the GPCs. Each mass memory data bus is connected to all five computers; however, each MMU is connected to only one mass memory data bus. All MMU operations are on an on-demand basis only.

The power switches are located on panel O14 for MMU 1 and panel O15 for MMU 2. The *MMU 1* switch on panel O14 positioned to ON allows control bus power to activate an RPC, which allows MNA power to MMU 1. The *MMU 2* switch on panel O15 positioned to ON operates in a similar manner with MNB power. An modular memory unit uses 83 watts of power, with the SSMM consuming 9 of those watts.

MMU 1 is located in crew compartment middeck avionics bay 1 and MMU 2 is in avionics bay 2. Each unit is cooled by water coolant loop cold plates. Each MMU is 7.7 inches high, 12 inches wide, 20 inches long and weighs 40 pounds.



MMU 1 Power Switch on Panel 014



MMU 2 Power Switch on Panel 015

Multifunction Electronic Display System (MEDS)

MEDS allows onboard monitoring of orbiter systems, computer software processing, and manual control for flight crew data and software manipulation.

MEDS has four types of hardware: four IDPs, 11 multifunction display units (MDUs), 4 analog-to-digital converters (ADCs), and 3 keyboard units, which together communicate with the GPCs over the DK data buses.

The system provides almost immediate response to flight crew inquiries through displays, graphs, trajectory plots, and predictions about flight progress. The crew controls vehicle system operation with keyboards in conjunction with the IDPs. The flight crew can alter the system configuration, change data or instructions in GPC main memory, change memory configurations corresponding to different mission phases, respond to error messages and alarms, request special programs to perform specific tasks, run through operational sequences for each mission phase, and request specific displays.

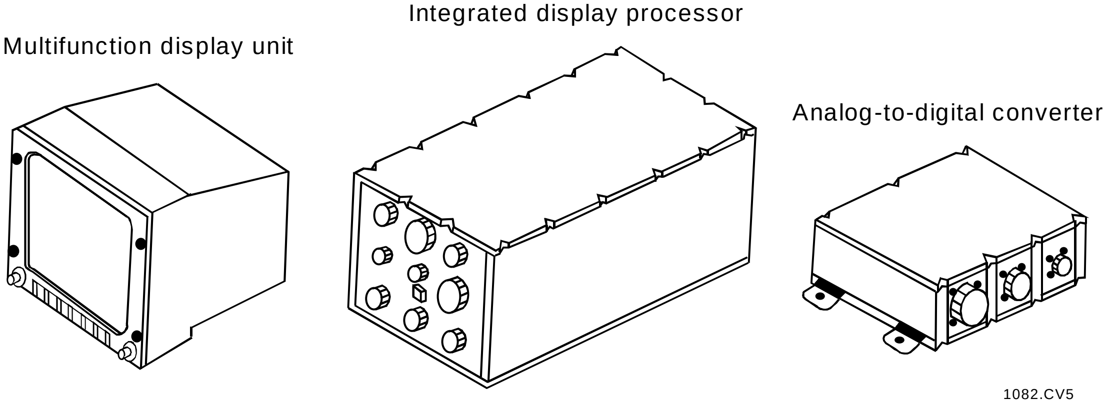
Integrated Display Processor (IDP)

The IDP is the interface between MEDS and the GPCs. It formats data from the GPCs and ADCs for display on the MDUs. Also, it accepts operator inputs from switches, edgekeys, and keyboards. In addition to all of these functions, the IDP monitors its own status and the status of other MEDS LRUs. It has both hardware built-in test equipment (BITE) and software self-tests.

On the GPC side, each IDP is connected to flight-critical data buses 1 through 4 and one DK bus, in addition to the panel switches and the keyboards. In general, it can display flight instrument and subsystem data on more than one crew station (left, right, aft). On the MEDS side, each IDP controls a 1553B data bus that allows the IDP to interface with the MDUs and a pair of ADCs.

IDPs require 28 V dc that is supplied by a main bus (IDP1 – main A/FPC1, IDP2 – main B/FPC2, and IDP3 and 4 – main C/FPC3). The IDP power switches are located on panels C2 and R11. These switches also power their respective CRT MDUs. Cooling is provided through forced-air ducting.

The IDPs are in the forward cockpit beneath panels to the left of the commander and to the right of the pilot. An IFM capability is available to swap a forward IDP with the aft IDP.



MEDS Hardware Units

Multifunction Display Unit (MDU)

The MDU is a full color, flat panel, 6.7-inch-square, active matrix liquid crystal display. Its primary function is to drive the variety of MEDS color displays that are readable in the sunlight.

Similar to the IDP, the MDU has built-in tests to provide various test coverage for the processor, functions, and hardware.

Six edgekeys are located below the display on the bezel of the MDU. A brightness control knob and an ON/OFF switch are also on the bezel on either side of the edgekeys. The edgekeys are used to navigate the MEDS menu system and to perform MEDS-specific activities, not to interact with the rest of the DPS system (i.e., clearing DPS fault messages, item entries).

There are 11 MDUs: CDR 1 and 2 on panel F6; CRT 1, 2, and 3; MFD 1 and 2 on panel F7; PLT 1 and 2 on panel F8; CRT 4 on panel R12; and AFD 1 in the aft station.

In general, each MDU has two ports (primary and secondary) that are connected to two IDPs via a 1553B data bus. Only one IDP commands an MDU at a given time, but both IDPs monitor the status of the MDU. The exception is the CRT MDUs, which use only their primary port. Their secondary port is not connected to any data bus. Thus, they are connected only to a single IDP and indirectly to only one DK data bus. Operationally, the CRT MDUs are dedicated to the DPS display. This configuration maintains a one-to-one relationship between a DK bus, an IDP, and its CRT MDU. While in the autonomous mode, the MDU continues to run and monitors its two ports for an operating IDP.

The MDUs are controlled by the power knob on the display bezel and a circuit breaker on panel R14. However, the CRT MDUs do not have a circuit breaker; they are powered by their respective IDP power switches. Main A powers MFD 2 and PLT 1. Main B powers CDR 2 and MFD 1. Main C powers CDR 1, PLT 2, and AFD 1. The brightness control knob, located to the right of the edgekeys, controls the illumination of the menus and display.

MDUs are cooled via forced-air cooling ducts.

The MDUs on the forward portion of the flight deck have a left and right group that correspond to the flight instrument display switches found on panel F6 (CDR side) and F8 (PLT side). The left side (CDR crew station) consists of CDR 1, CDR 2, MFD 1, CRT 1, and CRT 3. The right side (PLT crew station) consists of CRT 2, PLT 1, PLT 2, and MFD 2. The aft crew station consists of AFD 1 and CRT 4. CRT 4 is slightly tilted to improve readability.

An MDU IFM capability is available.

Analog-to-Digital Converter (ADC)

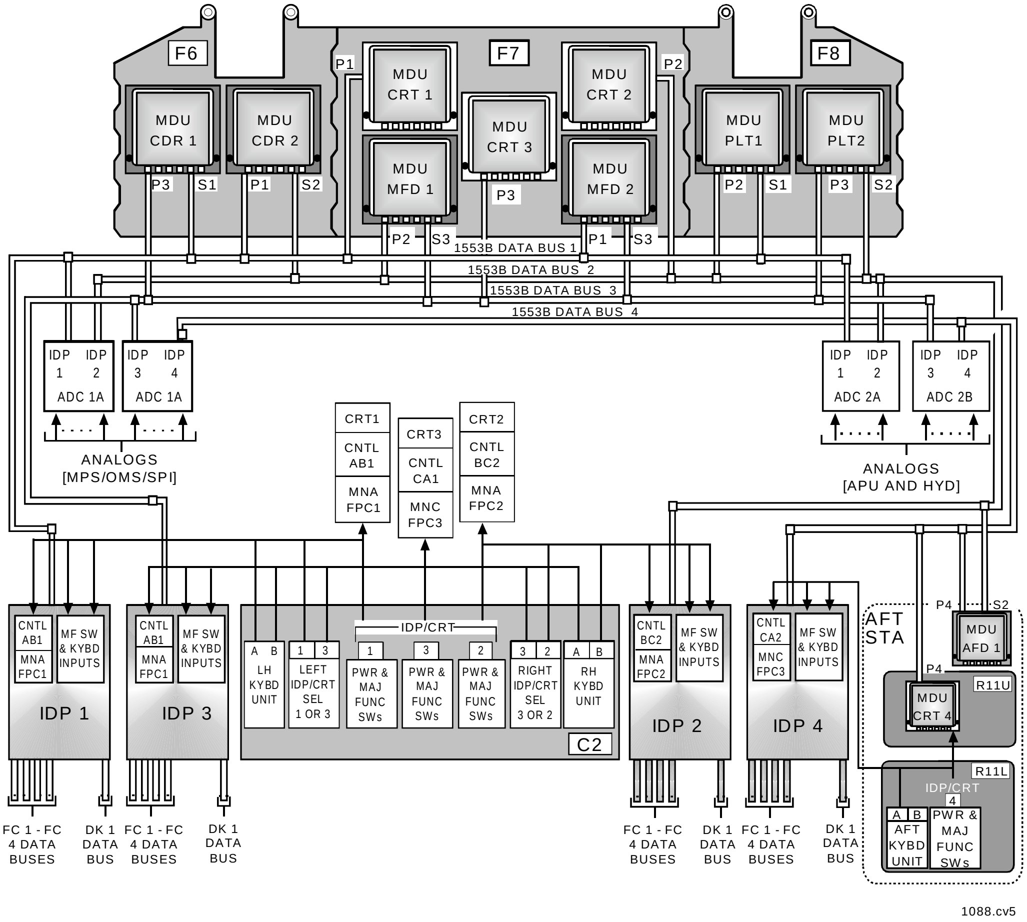
The ADCs convert analog MPS, HYD, APU, OMS, and SPI subsystem data into 12-bit digital data to be used by the IDP to generate the displays on the MDUs. MEDS includes four ADC units (1A, 1B, 2A, 2B). ADCs 1A and 1B convert the analog signals from the MPS, OMS, and SPI meters. ADCs 2A and 2B convert the signals from the APU and HYD meters. Each ADC maintains communication with two IDPs simultaneously (the “As” with IDP 1 and 2 and the “Bs” with IDP 3 and 4). The ADC software performs a continuous self-test.

ADC 1A and 2A are powered by main A via a single circuit breaker on panel R15, while 1B and 2B are powered by main B via a single circuit breaker on panel R15.

Keyboards

Three identical keyboards are located on the flight deck: one each on the left and right sides of the flight deck console (panel C2) and one on the flight deck at the side aft flight station (panel R11L). Each keyboard consists of 32 momentary double-contact pushbutton keys. Each key uses its double contacts to permit communication on separate signal paths to two IDPs. Only one set of contacts on the aft station keys is actually used, because this keyboard is wired to communicate with only the aft IDP.

There are 10 numeral keys, 6 letter keys (used for hexadecimal input), 2 algebraic keys, a decimal key, and 13 special function keys. Using these keys, the crew can ask the GPC more than 1000 questions about the mission and condition of the vehicle.



MEDS Data Bus Network

IFMs are available to swap out keyboards and replace individual keys as failures occur.

Each of the four IDPs responds to computer commands, transmits data, executes its own software to process keyboard inputs, and sends signals to drive displays on the MDUs. The IDPs store display data, generate the displays, update and refresh on-screen data, check keyboard entry errors, and echo keyboard entries to the DPS display shown on the MDU.

MEDS Data Bus Network

Each IDP has its own dedicated 1553B data bus that connects it to MDUs and two ADCs.

Master Timing Unit

The GPC complex requires a stable, accurate time source because its software uses Greenwich mean time (GMT) to schedule processing. Each GPC uses the master timing unit (MTU) to update its internal clock. The MTU provides precise frequency outputs for various timing and synchronization purposes to the GPC complex and many other orbiter subsystems. Its three time accumulators provide GMT and mission elapsed time (MET), which can be updated by external control. The accumulator's timing is in days, hours, minutes, seconds, and milliseconds up to 1 year.

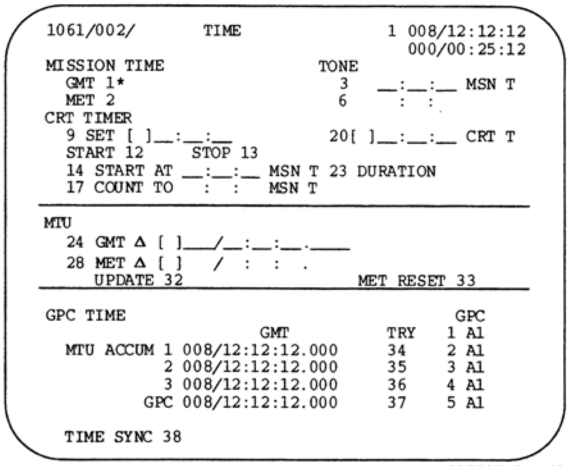
The MTU is a stable, crystal-controlled frequency source that uses two oscillators for redundancy. The signals from one of the two oscillators are passed through signal shapers and frequency drivers to the three GMT/MET accumulators.

The MTU outputs serial digital time data (GMT/MET) on demand to the GPCs through the accumulators. The GPCs use this information for reference time and indirectly for time-tagging GNC and systems management processing. The MTU also provides continuous digital timing outputs to drive the four digital timers in the crew compartment: two mission timers and two event timers. In addition, the MTU provides signals to the PCMMUs, COMSECs, payload signal processor, and FM signal processor, as well as various payloads.

The GPCs start by using MTU accumulator 1 as their time source. Once each second, each GPC checks the accumulator time against its own internal time. If the time is within tolerance (less than one millisecond), the GPC updates its internal clock to the time of the accumulator, which is more accurate, and continues. However, if the time is out of tolerance, the GPC will try the other accumulators and then the lowest numbered GPC until it finds a successful comparison.

The PASS GPCs do not use the MET that they receive from the MTU, because they compute MET on the basis of current GMT and lift-off time.

The TIME display (SPEC 2) provides the capability to observe the current MTU and GPC clock status, synchronize or update the MTU and GPC clocks, and set CRT timers and alert tone duration and timers.



```
1061/002/        TIME                  1 008/12:12:12
                                         000/00:25:12
MISSION TIME                  TONE
  GMT 1*                        3    __:__:__ MSN T
  MET 2                         6      :  :
CRT TIMER
  9 SET [ ]__:__:__            20[ ]__:__:__ CRT T
  START 12     STOP 13
  14 START AT __:__:__ MSN T 23 DURATION
  17 COUNT TO   :  :   MSN T
-----------------------------------------------------
MTU
  24 GMT Δ [ ]___/__:__:__.____
  28 MET Δ [ ]   /  :  :  .
     UPDATE 32                    MET RESET 33
-----------------------------------------------------
GPC TIME                                   GPC
                     GMT           TRY    1 A1
  MTU ACCUM 1 008/12:12:12.000      34    2 A1
            2 008/12:12:12.000      35    3 A1
            3 008/12:12:12.000      36    4 A1
          GPC 008/12:12:12.000      37    5 A1

  TIME SYNC 38
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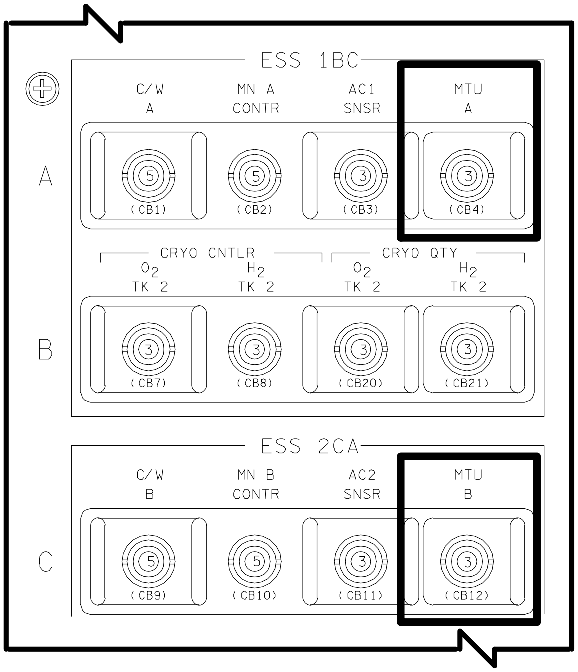
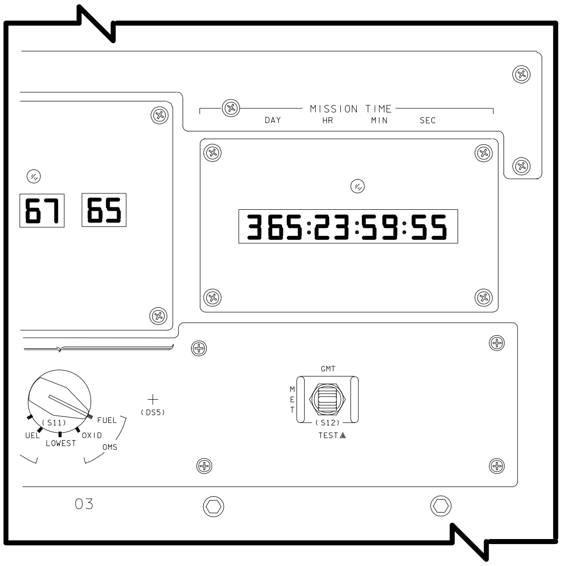
TIME Display (SPEC 2)

The MTU is redundantly powered by the ESS 1BC MTU A and ESS 2CA MTU B circuit breakers on panel O13. The MASTER TIMING UNIT switch on panel O6 controls the MTU. When the switch is in AUTO, and a time signal from one oscillator is out of tolerance, the MTU automatically switches to the other oscillator. For nominal operations, the MTU is using oscillator 2 with the switch in AUTO. The OSC 1 or OSC 2 position of the switch manually selects oscillator 1 or 2, respectively.

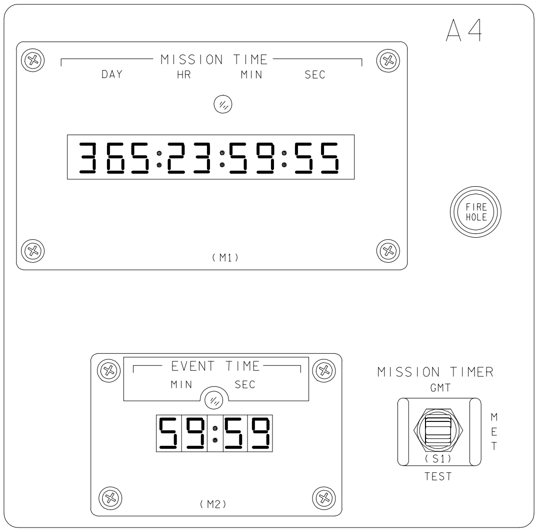
The MTU is located in crew compartment middeck avionics bay 3B and is cooled by a water coolant loop cold plate. The hardware displays associated with the master timing unit are the mission and event timers. MISSION TIME displays are located on panels O3 and A4. They can display either GMT or MET in response to the GMT or MET positions of the switch below the displays. The forward EVENT TIME display is on panel F7, and it is controlled by the EVENT TIME switches on panel C2. The aft EVENT TIME display is on panel A4, and its EVENT TIME control switches are on panel A6U.



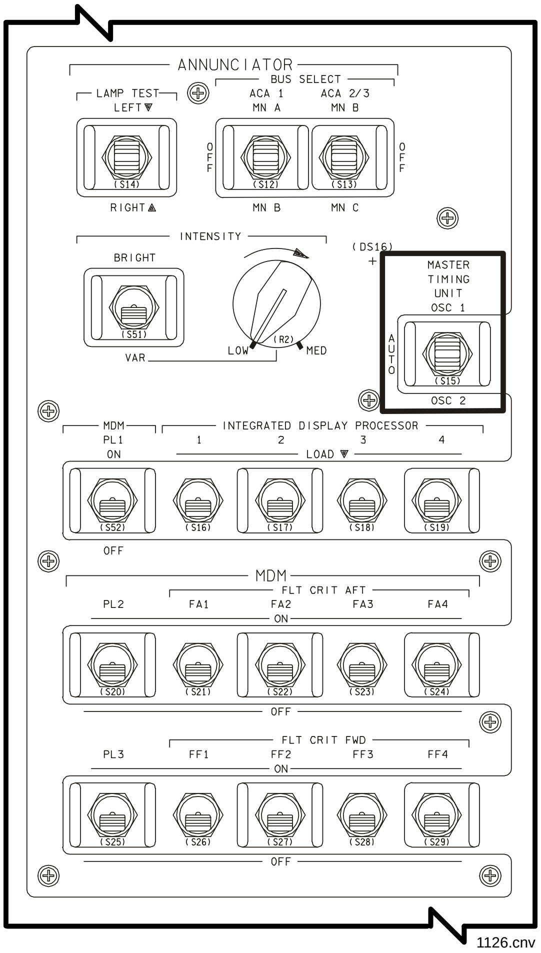
ESS 1BC MTU A and ESS 2CA MTU B Circuit Breakers on Panel O13



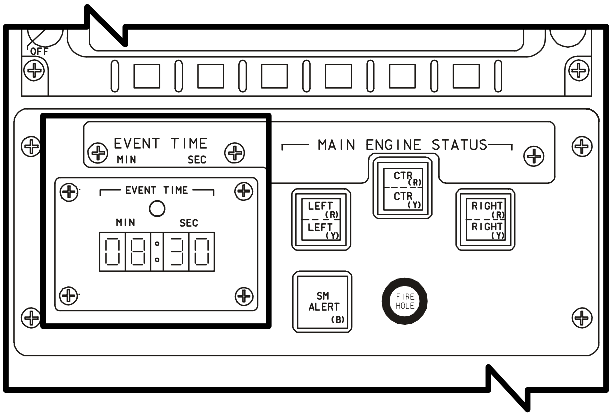
MISSION TIME Display and Switch
on Panel O3



MISSION TIME and EVENT TIME Displays
and MISSION TIMER Switch on Panel A4



MASTER TIMING UNIT Switch
on Panel O6



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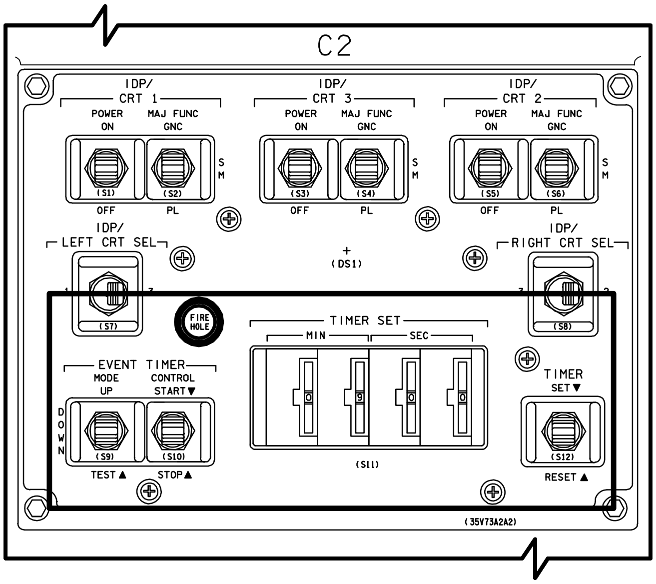
EVENT TIME Display on Panel F7



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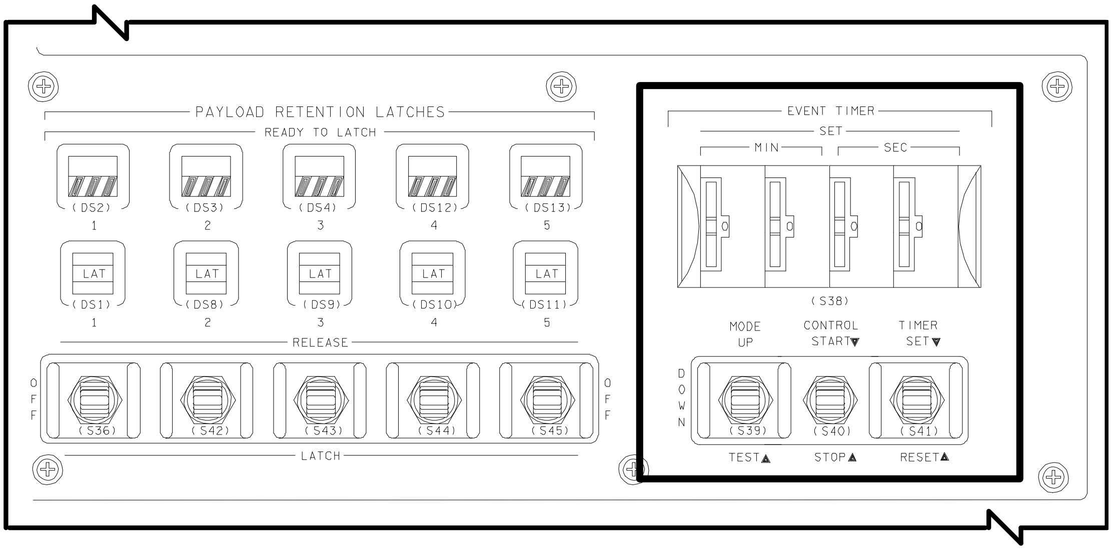
EVENT TIMER Switches and TIMER SET Thumbwheels on Panel C2



EVENT TIMER Switches on Thumbwheels on Panel A6U

Software

Primary Avionics Software System (PASS)

The PASS (also referred to as primary flight software) is the principal software used to operate the vehicle during a mission. It contains all the programming needed to fly the vehicle through all phases of the mission and manage all vehicle and payload systems.

Because the ascent and entry phases of flight are so critical, four of the five GPCs are loaded with the same PASS software and perform all GNC functions simultaneously and redundantly. As a safety measure, the fifth GPC contains a different set of software, programmed by a company different from the PASS developer, designed to take control of the vehicle if a generic error in the PASS software or other multiple errors should cause a loss of vehicle control. This software is called the backup flight system (BFS). In the less dynamic phases of on-orbit operations, the BFS is not required. The information provided below describes how the PASS software relates to the DPS and the crew. Much of the material is common between PASS and BFS; therefore, only BFS differences are discussed immediately after the PASS discussion.

DPS software is divided into two major groups, system software and applications software. The two groups are combined to form a memory configuration for a specific mission phase. The programs are written in HAL/S (high-order assembly language/shuttle) specifically developed for real-time space flight applications.

System software is the GPC operating system software that controls the interfaces among the computers and the rest of the DPS. It is loaded into the computer when it is first initialized. It always resides in the GPC main memory and is common to all memory configurations. The system software controls GPC input and output, loads new memory configurations, keeps time, monitors discretes into the GPCs, and performs many other DPS operational functions.

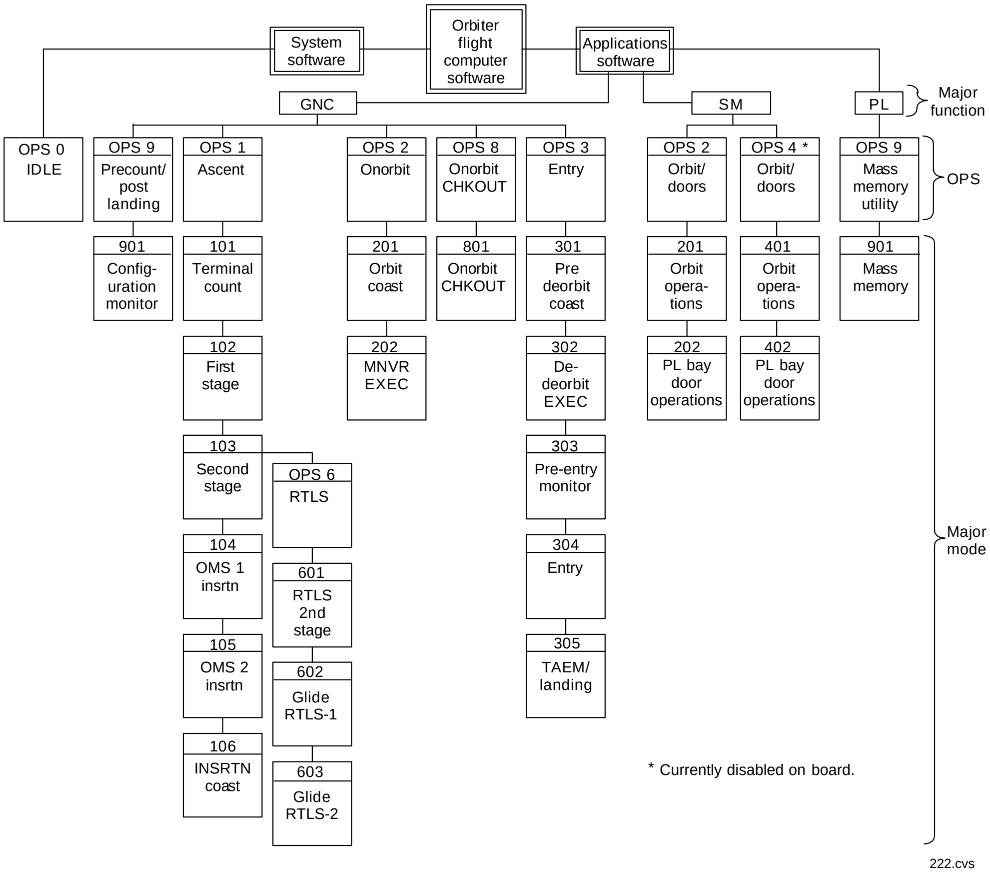
The system software consists of three sets of programs. The *flight computer operating system (FCOS)* (the executive) controls the processors, monitors key system parameters, allocates computer resources, provides for orderly program interrupts for higher priority activities, and updates computer memory. The *user interface programs* provide instructions for processing flight crew commands or requests. The *system control program* initializes each GPC and arranges for multi-GPC operation during flight-critical phases.

One of the system software functions is to manage the GPC input and output operations, which includes assigning computers as commanders and listeners on the data buses and exercising the logic involved in sending commands to these data buses at specified rates and upon request from the applications software.

The applications software performs the functions required to fly and operate the vehicle. To conserve main memory, the applications software is divided into three major functions:

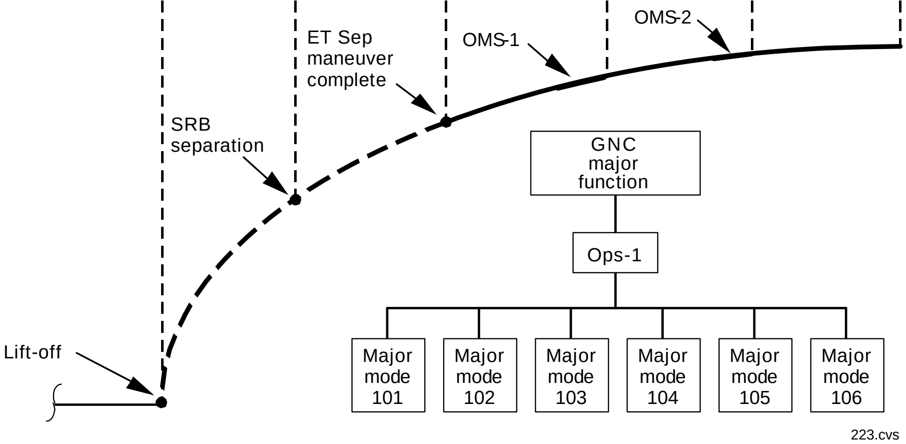
- ***Guidance, navigation, and control (GNC)***: specific software required for launch, ascent to orbit, maneuvering in orbit, entry, and landing. This is the only major function where redundant set synchronization can occur.
- ***Systems management (SM):*** tasks that monitor various orbiter systems, such as life support, thermal control, communications, and payload operations. SM is a simplex major function; only one GPC at a time can actively process an SM memory configuration.
- ***Payload (PL)***: this major function currently contains mass memory utility software. The PL major function is usually *unsupported* in flight, which means that none of the GPCs are loaded with PL software. It is only used in vehicle preparation at KSC, and is also a simplex major function. Note that software to support payload operations is included as part of the SM GPC memory configuration.

Major functions are divided into mission phase oriented blocks called operational sequences (OPS). Each OPS of a major function is associated with a particular memory configuration that must be loaded separately into a GPC from the MMUs. Therefore, all the software residing in a GPC at any given time consists of system software and an OPS major function; i.e., one memory configuration. Except for memory configuration 1, each memory configuration contains one OPS. Memory configuration 1 is loaded for GNC at launch and contains both OPS 1 (ascent) and OPS 6 (RTLS), since there would be no time to load in new software for a return to launch site (RTLS) abort.



Orbiter Flight Computer Software

Mission phase	Launch - 20 min to lift-off	Launch to solid rocket booster sep	SRB sep to external tank sep maneuver complete	ET sep to completion of OMS-1 burn	Completion of OMS-1 burn to completion of OMS-2 burn	Completion of OMS-2 burn to selection of GNC Ops-2
Major mode (for Ops-1)	101	102	103	104	105	106



Major Modes

During the transition from one OPS to another, called an OPS transition, the flight crew requests a new set of applications software to be loaded in from the MMU. Every OPS transition is initiated by the flight crew. When an OPS transition is requested, the redundant OPS overlay contains all major modes of that sequence.

Major modes are further subdivisions of an OPS, which relate to specific portions of a mission phase. As part of one memory configuration, all major modes of a particular OPS are resident in GPC main memory at the same time. The transition from one major mode to another can be automatic (e.g., in GNC OPS 1 from precount MM 101 to first stage MM 102 at lift-off) or manual (e.g., in SM OPS 2 from on-orbit MM 201 to payload bay door MM 202 and back).

Each major mode has an associated DPS display, called a major mode display or base page, that provides the flight crew with information about the current portion of the mission phase and allows crew interaction. There are three levels of DPS displays. Certain portions of each OPS display can be manipulated by flight crew keyboard input (or ground link) to view and modify system parameters and enter data. The specialist function (SPEC) of the OPS software is a block of displays associated with one or more operational sequences and enabled by the flight crew to monitor and modify system parameters through keyboard entries. The display function (DISP) of the OPS software is a group of displays associated with one or more OPS. These displays are for parameter monitoring only (no modification capability) and are called from the keyboard. Display hierarchy and usage are described in detail later in this section.

Backup Flight System

Even though the four PASS GPCs control all GNC functions during the critical phases of the mission, there is always a possibility that a generic software failure could cause loss of vehicle control. Therefore, the fifth GPC is loaded with the BFS software. To take over control of the vehicle, the BFS monitors the PASS GPCs to keep track of the current state of the vehicle. If required, the BFS can take over control of the vehicle upon the press of a button. The BFS also performs the SM functions during ascent and entry because the PASS GPCs are all operating in GNC. BFS software is always loaded into GPC 5 before flight, but any of the five GPCs could be made the BFS GPC if necessary.

Because the BFS is intended to be used only in a contingency, its programming is much simpler than that of the PASS. Only the software necessary to complete ascent or entry safely, maintain vehicle control in orbit, and perform SM functions during ascent and entry is included.

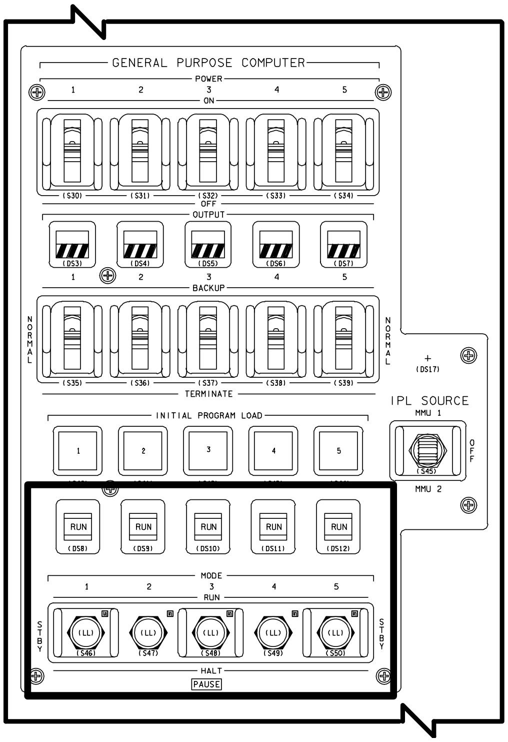
Thus, all the software used by the BFS can fit into one GPC and never needs to access mass memory. For added protection, the BFS software is loaded into the MMUs in case of a BFS GPC failure and the need to IPL a new BFS GPC.

The BFS, like PASS, consists of system software and applications software. System software in the BFS performs basically the same functions as it does in PASS. These functions include time management, PASS/BFS interface, MEDS interface, input and output, uplink and downlink, and engage and disengage control. The system software is always operating when the BFS GPC is not in *HALT*.

Applications software in the BFS has two different major functions, GNC and systems management, but all its applications software resides in main memory at one time, and the BFS can process software in both major functions simultaneously. The GNC functions of the BFS, designed as a backup capability, support the ascent phase beginning at MM 101 and the deorbit/entry phase beginning at MM 301. In addition, the various ascent abort modes are supported by the BFS. The BFS provides only limited support for on-orbit operations via MM 106 or MM 301. Because the BFS is designed to monitor everything the PASS does during ascent and entry, it has the same major modes as the PASS in OPS 1, 3, and 6.

The BFS SM contains software to support the ascent and entry phases of the mission. Whenever the BFS GPC is in the *RUN* or *STBY* mode, it runs continuously; however, the BFS does not control the payload buses in *STBY*. The SM major function in the BFS is not associated with any operational sequence and is always available whenever the BFS is active.

Even though the five GPCs and their switches are identical, the *GENERAL PURPOSE COMPUTER MODE* switch on panel O6 works differently for a GPC loaded with BFS. Since *HALT* is a hardware-controlled state, no software is executed. The *STBY* mode in the BFS GPC is totally different from its corollary in the PASS GPCs. When the BFS GPC is in *STBY*, all normal software is executed as if the BFS were in *RUN*; the only difference is that BFS command of the payload data buses is inhibited in *STBY*. The BFS is normally put in *RUN* for ascent and entry, and in *STBY* whenever a *PASS* systems management GPC is operating. If the BFS is engaged while the *MODE* switch is in *STBY* or *RUN*, the BFS takes control of the flight-critical and payload data buses. The *MODE* talkback indicator on panel O6 indicates RUN if the BFS GPC is in *RUN* or *STBY* and displays barberpole if the BFS is in *HALT* or has failed.



GENERAL PURPOSE COMPUTER MODE Switches and Talkbacks on Panel O6

Pre-engage, the BFS is synchronized with the PASS set using flight-critical I/O so that it can track the PASS and keep up with its flow of commands and data. Synchronization and tracking take place during OPS 1, 3, and 6. During this time, the BFS listens over the flight-critical data buses to the requests for data by PASS and to the data coming back. The BFS depends on the PASS GPCs for acquisition of all its GNC data and must be synchronized with the PASS GPCs so that it will know when to receive GNC data over the FC buses. When the BFS is in sync and listening to at least two strings, it is said to be tracking PASS. As long as the BFS is in this mode, it maintains the current state vector and all other information necessary to fly the vehicle in case the flight crew needs to engage it. When the BFS GPC is tracking the PASS GPCs, it cannot command over the FC buses but may listen to FC inputs through the listen mode. The BFS uses the MTU (like PASS) and keeps track of GMT over the flight-critical buses for synchronization. The BFS also monitors some inputs to PASS IDPs and updates its own GNC parameters accordingly.

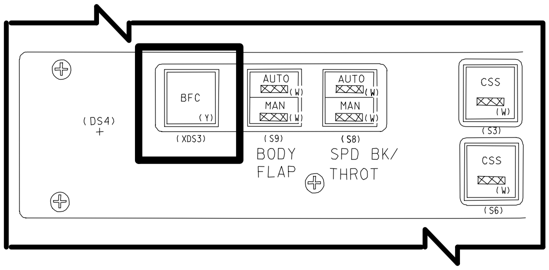
The BFS GPC controls its own instrumentation/ PCMMU data bus. The BFS GPC requirements strictly forbid use of the ICC data bus to monitor or to transmit status or data to the other GPCs. The mass memory data buses are not used except during initial program load, which uses the same IPL SOURCE switch on panel O6 as used for PASS IPL.

The BFC lights on panels F2 and F4 remain unlighted as long as PASS is in control, and the BFS is tracking. The lights flash if the BFS loses track of the PASS and goes standalone. The flight crew must then decide whether to engage the BFS or try to initiate BFS tracking again by an I/O RESET on the keyboard. When BFS is engaged and in control of the flight-critical buses, the BFC lights are illuminated and stay on until the BFS is disengaged.

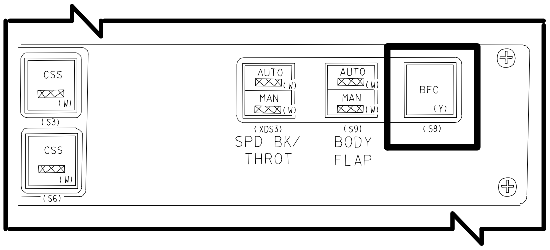
Since the BFS does not operate in a redundant set, its fail votes from and against other GPCs are not enabled; thus, the *GPC STATUS* light matrix on panel O1 for the BFS GPC does not function as it does in PASS. The BFS can illuminate its own light on the *GPC STATUS* matrix if the watchdog timer in the BFS GPC times out when the BFS GPC does not complete its cyclic processing.

To engage the BFS, which is considered a last resort to save the vehicle, the crew presses a *BFS ENGAGE* momentary pushbutton located on the commander's and pilot's rotational hand controllers (RHCs). As long as the RHC is powered, and the appropriate *OUTPUT* switch on panel O6 is in *BACKUP*, depressing the *ENGAGE* pushbutton on either RHC engages the BFS and causes PASS to relinquish control. There are three contacts in each *ENGAGE* pushbutton, and all three contacts must be made to engage the BFS. The signals from the RHC are sent to the backup flight controller, which handles the engagement logic.

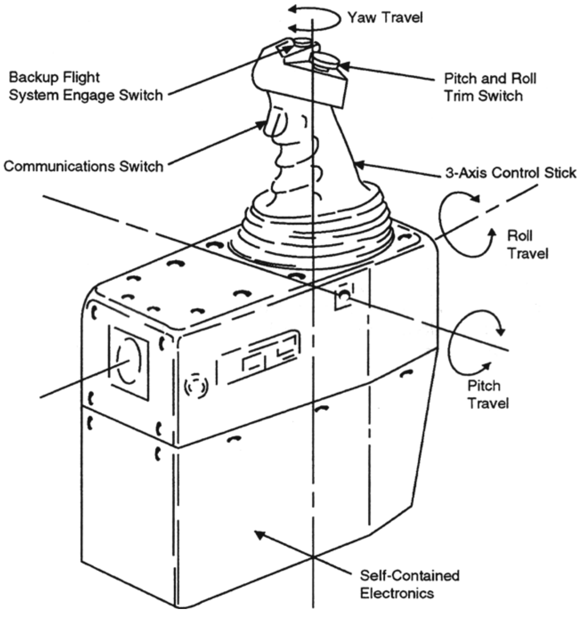
When the BFS is engaged, the BFC lights on panels F2 and F4 are steadily illuminated, the BFS's *OUTPUT* talkback indicator on panel O6 turns gray, all PASS GPC *OUTPUT* and *MODE* talkback indicators on panel O6 display barber-pole, the BFS controls the IDPs selected by the *BFC CRT SELECT* switch on panel C3, big Xs and poll fails appear on the remaining PASS-controlled IDPs, and all four *GPC STATUS* matrix diagonal indicators for PASS GPCs are illuminated on panel O1.



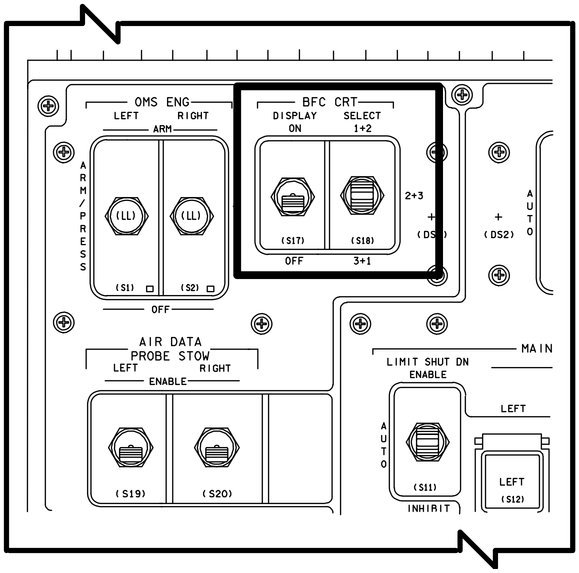
BFC Light on Panel F2



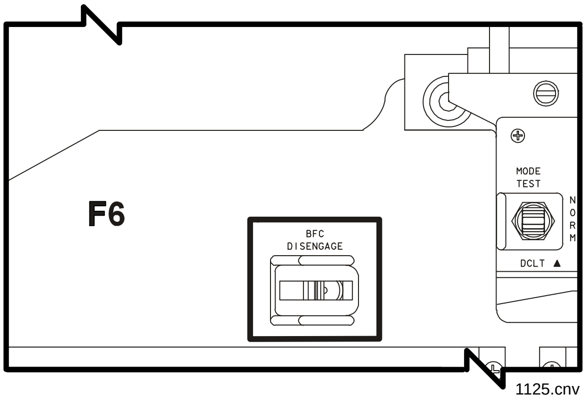
BFC Light on Panel F4



Rotational Hand Controller



BFC CRT DISPLAY and SELECT Switches on Panel C3



BFC DISENGAGE Switch on Panel F6

When the BFS is not engaged, and the *BFC CRT DISPLAY* switch on panel C3 is positioned to ON, the BFS commands the first IDP indicated by the *BFC CRT SELECT* switch. The *BFC CRT SELECT* switch positions on panel C3 are *1 + 2*, *2 + 3*, and *3 + 1*. When the BFS is engaged, it assumes control of the second IDP as well.

If the BFS is engaged during ascent, the PASS GPCs can be recovered on orbit to continue a normal mission. This procedure takes about 2 hours, since the PASS inertial measurement unit reference must be reestablished. The BFS is disengaged after all PASS GPCs have been hardware-dumped and reloaded with PASS software. Positioning the *BFC DISENGAGE* switch on panel F6 to the *RIGHT* position disengages the BFS. The switch sends a signal to the BFCs that resets the engage discretes to the GPCs. The BFS then releases control of the flight-critical buses as well as the payload buses if it is in *STBY*, and the PASS GPCs assume command.

After disengagement, the PASS and BFS GPCs return to their normal pre-engaged states. Indications of the PASS engagement and BFS disengagement are as follows: BFC lights on panels F2 and F4 are out, BFS's *OUTPUT* talkback on panel O6 displays barberpole, all PASS *OUTPUT* talkback indicators on panel O6 are gray, and BFS releases control of one of the IDPs.

If the BFS is engaged, there is no manual thrust vector control or manual throttling capability during first- and second-stage ascent. If the BFS is engaged during entry, the speed brake can be positioned using the speed brake/throttle controller, and the body flap can be positioned manually. Control stick steering (CSS) by either the commander or pilot is required during entry.

Pre-engage, the BFS supplies attitude errors on the Trajectory display, whereas PASS supplies attitude errors to the attitude director indicators; however, when the BFS is engaged, the errors on the Trajectory display are blanked, and attitude errors are supplied to the attitude director indicators.

MEDS

IDP Software

The IDP software manages the edgekey menu system, generates the graphical displays, and emulates the display electronics unit (DEU) for the DPS displays. It also processes data from the flight-critical, display/keyboard, and 1553 data buses, in addition to the switches and the keyboards.

The IDP only receives data on the flight-critical buses. It is able to process data simultaneously on two different flight-critical buses for flight instrument displays on different MDUs. The IDP communicates on the display/keyboard buses on a two-way command/response basis. The IDP receives data over the DK bus for updating the DPS displays. The IDP sends crew inputs and MEDS health status information to the GPC when polled by it.

The IDP also processes the following panel switches: IDP load switch, IDP/CRT select switches (left and right), and the major function switches. The IDP validates keystrokes made on the keyboard for syntax. If at least one of the MDUs controlled by the IDP is displaying the DPS display, the keystrokes will be validated, echoed, and included in the poll response of the IDP to the GPC.

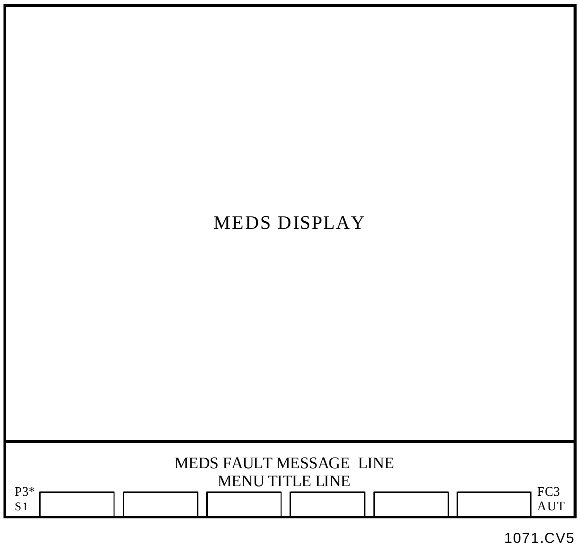
MDU Software

The MDU function (MDUF) software is responsible for drawing the displays on the MDU and providing built-in test capability (BITE).

MEDS Generic Screen Format

Each MDU screen follows a generic screen format. The top portion of the screen is denoted as the MEDS display format. The lower portion contains the MEDS internal configuration information. A horizontal cyan line separates the two portions. The upper portion is blank or displays the selected MEDS display. At the bottom, the legends for the edgekeys are displayed in the six boxes that are aligned with their respective edgekeys. The color of the boxes and the labels normally are cyan, unless they correspond to the current MEDS display, in which case they are white. A blank edgekey legend means no option is available for that edgekey. If the edgekey is pressed, the IDP ignores it. The menu title is displayed above the edgekey boxes and legend. The MEDS fault message line is the line above the menu title. Any MEDS-generated messages are displayed in white on this line. Any GPC generated messages are displayed on the DPS display in orange (above the cyan horizontal line).

MEDS configuration information is displayed to the left and the right of the menu bars. The information to the left indicates which MDU port is selected and which IDP is connected to each MDU port. "P" indicates primary port and "S" indicates the secondary port. The numbers next to the P and S indicate the IDP that is connected to that port of the MDU. An asterisk indicates which port (and thus which IDP) is selected to command the MDU. The information displayed to the right of the menu bars indicates the port select configuration and flight-critical data bus selected for that MDU. The flight-critical data bus selected is the number displayed next to "FC." The port reconfiguration mode is displayed below the flight critical data bus information. "AUT" is displayed when automatic port reconfiguration capability has been selected and "MAN" is displayed when manual reconfiguration capability has been selected. Each MDU retains its current configuration through a power cycle (except for the menu, which reverts to the menu associated with the display on the MDU).



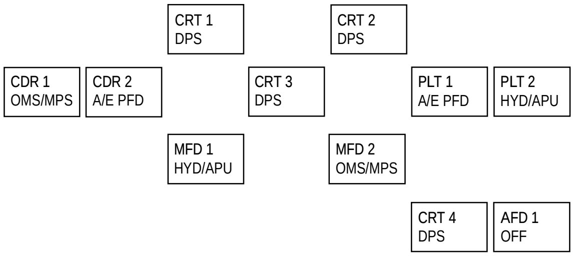
MEDS Generic Screen Format

MEDS Displays

The user may view all flight instrument and subsystem status information via the various MEDS displays.

Flight Instrument Displays

The flight instrument displays give the crew insight into the current attitude, position, and velocity of the vehicle. During ascent and entry, the crew can view the Ascent/Entry Primary Flight Display (A/E PFD). This display consists of several indicators and gauges giving insight into the attitude, altitude, position, velocity, and angle of attack. For orbit, only attitude information is used; therefore, another display is available that consists solely of that data, called the Orbit PFD. The PFDs work as described in Section 2.7, Dedicated Display Systems.



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Typical Ascent MEDS Layout

DPS Display

The MEDS DPS display shows the DPS displays to the crew. The IDP emulates the old "CRT" system using data it obtains over the DK bus. The DPS display allows the crew to interact with the GPCs by entering commands via the keyboards to monitor a variety of systems data.

The GPC fill portion of the DPS display is covered in detail later in this section.

In the MEDS-driven portion, a green outlined box with a number inside of it has been added just below the scratch pad line and centered horizontally. The number represents the IDP that is commanding the MDU.

Subsystem Status Displays

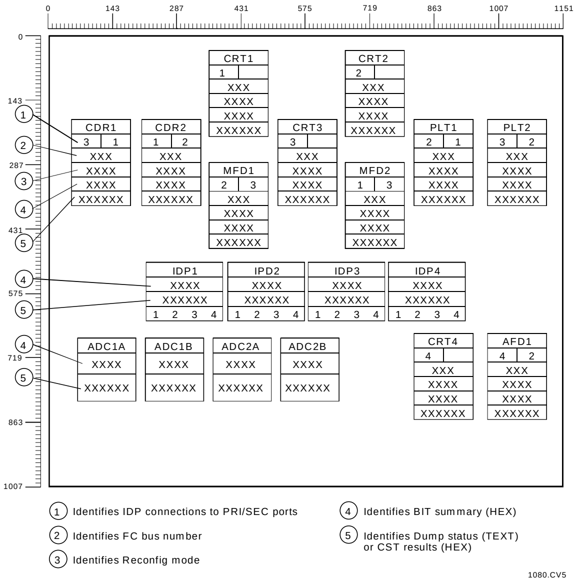
The MEDS Subsystem Status displays are used to monitor the performance of several systems in graphical format.

The displays available include an Orbital Maneuvering System and Main Propulsion System (OMS/MPS) display, a Hydraulic and Auxiliary Power Unit (HYD/APU) display, and a Surface Position Indicator (SPI) display.

For discussion on each of these displays, see the appropriate section of the SCOM.

MEDS Maintenance Display

The MEDS maintenance display provides an overview of the current configuration of the MEDS system as viewed by the commanding IDP of the MDU. The MEDS maintenance display shows all the MEDS LRUs as a box. The forward MDUs are arranged on the display the same way as they are arranged in the forward flight deck. Displayed below them are the four IDPs. The ADCs and the aft MDUs are displayed graphically below the IDPs. Each of the LRUs commanded by the current IDP has a blue background for its box. Each LRU box provides information about its configuration, status, and/or comprehensive self-test (CST) results.



MEDS Maintenance Display

The MDU boxes provide information on the port configuration, flight-critical bus selection, and status of the MDU. The first row in the box indicates the name of the LRU. The second row denotes the IDPs that are connected to the primary and secondary ports. The third row displays the flight-critical bus selected, if that MDU is displaying a flight instrument display; otherwise, it is blank. The fourth row indicates if the MDU is in the AUTO or MANUAL reconfiguration mode. This reconfiguration mode is also displayed on the MDUs with which the IDP is communicating but not commanding (no blue background). The fifth row indicates the operational BITE summary in hex. If one or more bits in the BITE summary are off nominal, the entire BITE summary shows red. The sixth row indicates the dump status (text) or CST results (hex). If one or more bits in a CST result are off nominal, the entire CST result is displayed in red. If a CST has not been performed, the CST results display NO-CST in white. The last row of the box contains the version number of the software loaded in the MDU; e.g., V 0400.

The IDP boxes provide information on the flight-critical bus selection and status of the IDP. The first row in the box indicates the name of the LRU. The second row denotes the operational BIT summary in hex. If one or more bits in the BIT summary are off nominal, the entire BIT summary is red. The third row indicates the dump status (text) or CST results (hex). If one or more bits in a CST result are off nominal, the entire CST result is displayed in red. If a CST has not been performed, the CST results display NO-CST in white. The fourth row indicates which flight-critical data buses currently are being supported. The buses are displayed in reverse video. The last row contains the version number of the software loaded in the IDP; e.g., V 0300.

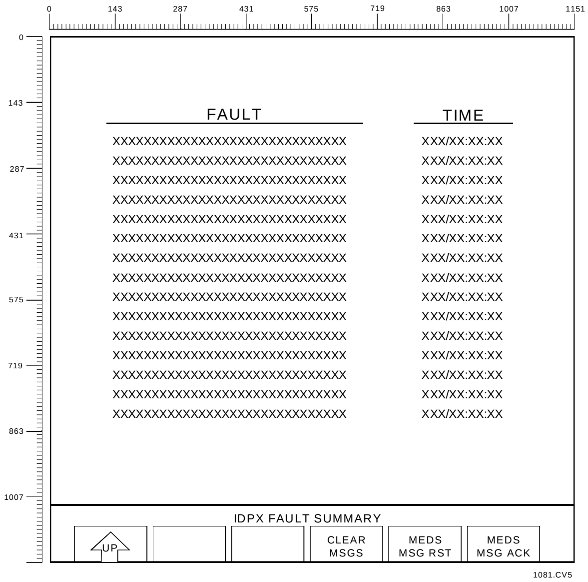
The ADC boxes provide information on the status of the ADC. The first row in the box indicates the name of the LRU. The second row denotes the operational BITE summary in hex. If one or more bits in the BITE summary are off nominal, the entire BITE summary is red. The last row indicates the dump status (text) or CST results (hex). If one or more bits in a CST result are off nominal, the entire CST result is displayed in red.

MEDS Fault Summary Display

The MEDS fault summary display is the MEDS equivalent of the GPC fault summary (SPEC 99). The display lists the past 15 MEDS fault messages and the time of annunciation by the current IDP.

Edgekey Menu System

The user accesses the edgekey menu system to control the MEDS system. The MEDS edgekey operations are organized by function and are displayed in the proper hierarchy. In general, edgekeys call up an additional menu, select a MEDS configuration, select a particular MEDS display, and initialize internal tests of the MDUs, ADCs, and IDPs. Except for the top menu (the main menu), the first edgekey (on the left) is the up arrow, which allows the user to go up to the next level. The main menu allows the user to select the flight instrument menu, subsystem status menu, the DPS display, and the MEDS maintenance display and its menu.



MEDS Fault Summary Display

Throughout the various menus, the user can select MEDS MSG ACK or MEDS MSG RESET. These edgekey operations are single-stroke keys. The MEDS MSG ACK works the same as the keyboard ACK key. The first time that it is pressed, the MEDS fault messages goes static. Subsequent pressings of the edgekey scroll through the remaining MEDS fault messages. The MEDS MSG RESET clears the MEDS fault message line just like the MSG RESET key works for the DPS displays.

The flight instrument menu allows the user to select either ascent/entry or orbit displays, a flight critical data bus, or clear the MEDS fault message line. The A/E PFD displays the COMP ADI/HSI display. The orbit selection displays the ADI only. The data bus select menu maintains the current flight instrument MEDS display, but allows the user to choose flight-critical 1 through 4.

The subsystem status menu allows the user to access the MEDS displays to view the OMS, MPS, HYD, APU, and SPI information that was available previously on the analog meters. The user may swap between these various subsystem displays with just a single press of the appropriate edgekey. This menu allows the user to port select on the MDU in case the current commanding IDP has a problem with an ADC. This submenu also allows the user to select MEDS MSG ACK.

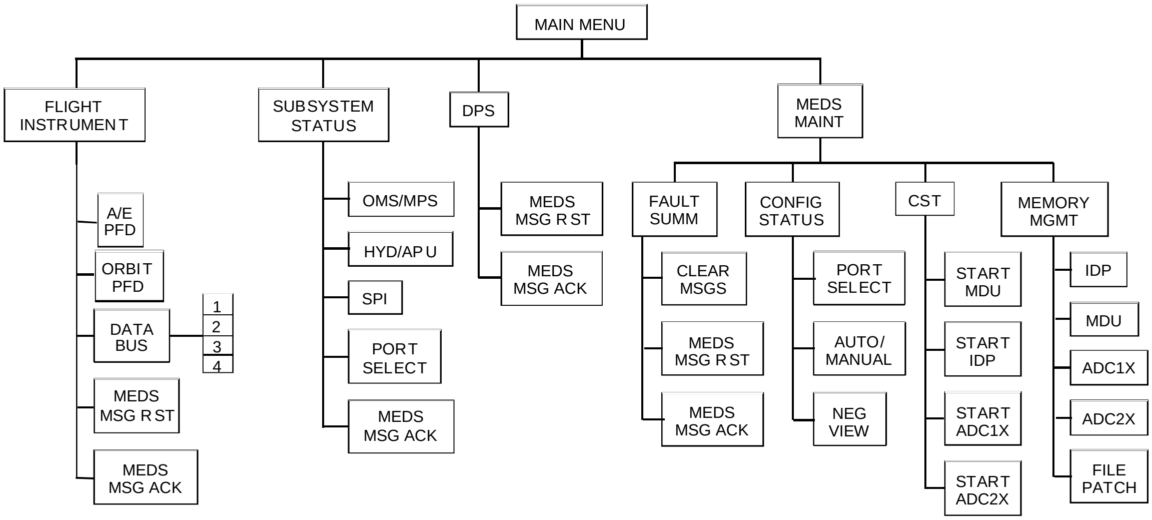
After selecting the DPS menu, the DPS display shows automatically. The edgekey options are the MEDS MSG ACK and MSG RESET.

After selecting the MEDS maintenance menu, the MEDS maintenance display is displayed automatically. From this menu, the user can select any of the following submenus: fault summary, configuration status, CST, or memory management.

After selecting the fault summary option, the MEDS fault summary display is shown. With this submenu, the user can clear the MEDS fault messages, similar to a SPEC 99 PRO but for MEDS. The options to MEDS MSG RESET and ACK are also included on this menu.

The configuration status submenu allows the viewer to port select to the alternate IDP, change its reconfiguration mode to either AUTO or MAN, or change the viewing mode. The viewing mode can be changed only for the Hosiden MDUs (all flight MDUs are Hosiden). The negative viewing mode enhances the readability of the aft MDUs. When negative viewing is selected, “NEG VIEW” is displayed above the flight-critical bus selection and reconfiguration mode on the MEDS status area of the MDU.

The CST submenu lets the user activate the CST for the current MDU, the commanding IDP, and the associated ADC1X and ADC2X for the commanding IDP. The CST is a test of the hardware and the functional use of the MEDS LRU. It has both interactive and noninteractive parts for the IDP and MDU. The ADC CST is not interactive. During the IDP CST, other MDUs being commanded by this IDP will blank and display the message IDP CST INITIATED. The results of the CST are displayed on the MEDS maintenance display.



MEDS Edgekey Menu Hierarchy

The memory management menu has several options. The edgekey menu tree does not display the submenus for each of the possible selections. In general, the memory management menu allows the user to dump the EEPROM and/or RAM for the ADC, MDU, and IDP to the MSU, load IDP or MDU programs from the MSU, load an IDP program load from EEPROM, and patch files on the MSU. Currently, no crew procedure references these memory management functions.

MEDS Fault Messages

Each IDP has various messages that it can annunciate. Each MEDS error can be broken down into seven categories (A through G, with A being the most severe). The IDP generates a MEDS fault message for the categories that warrant crew notification. The other categories cause the IDP to notify the ground, archive the method other than a MEDS fault message.

MEDS fault messages for an IDP are displayed on all commanded MDUs that are showing the DPS display. If none of an IDP's commanded MDUs has a DPS display, the IDP will select the MDU with the highest ranking that is available for the MEDS fault messages.

Operations

The crew interfaces with the five GPCs via the four IDPs and their MDUs. This section first discusses crew operations using PASS, and then discusses crew operations using the BFS.

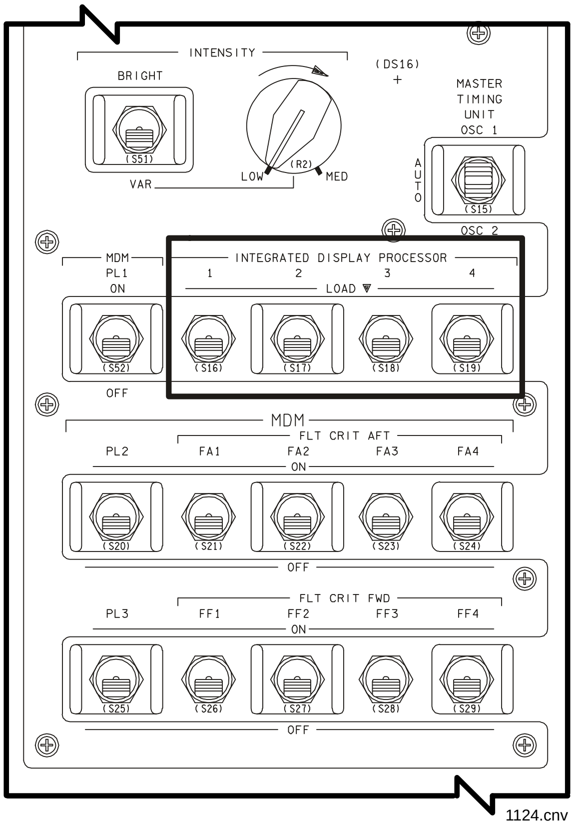
IDP Load Switch

The IDP load switch, located on panel O6, is used to load the critical format information for the DPS displays. The critical formats form a skeleton that the IDP uses and fills with GPC-provided data. When the IDP load switch is toggled and a GPC is running an ops mode that supports the load (SM OPS 2 or 4, PL OPS 9, or post-IPL OPS 0), the IDP receives the GPC information and stores only the critical format information in the EEPROM (other information is sent that was used by the old CRT system).

Nominally, the only time the IDP needs to be loaded with critical formats is after an OI flight software change in the GPCs. If a GPC does not recognize the IDP load request (i.e., it is a GNC computer), an IDP power cycle recovers full capability of the IDP with no loss of its critical formats.

IDP Switches

Switches on panel C2 designate which keyboard controls each forward IDP. When the LEFT IDP/CRT SEL switch is positioned to 1, the left keyboard controls IDP 1; if the switch is positioned to 3, the left keyboard controls IDP 3. When the *RIGHT CRT SEL* switch on panel C2 is set to 2, the right keyboard controls IDP 2; if set to 3, it controls IDP 3. Thus, flight crew inputs are made on the keyboards, and data are output from the GPCs on the DPS displays.



INTEGRATED DISPLAY PROCESSOR
Switches on Panel O6

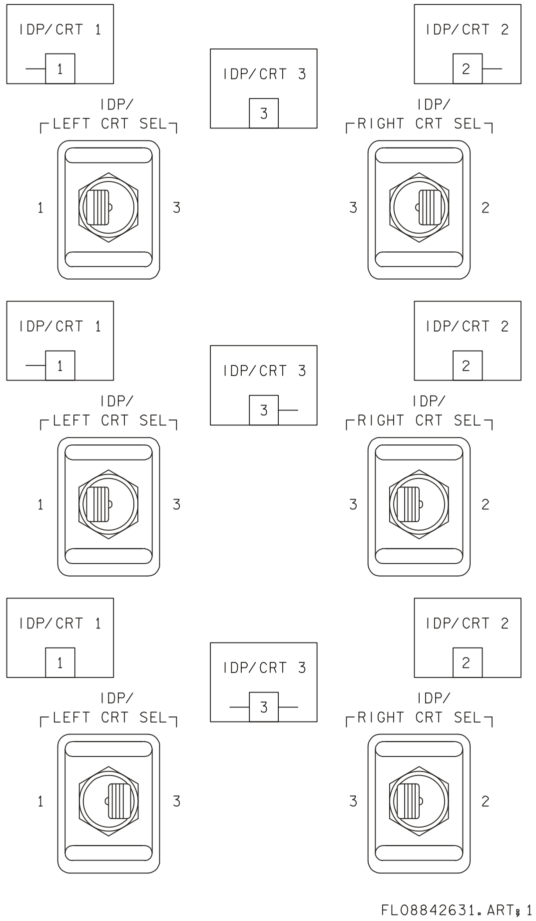
NOTE

> If the *LEFT IDP/CRT SEL* and *RIGHT IDP/CRT SEL* switches are both positioned to 3, keystrokes from both keyboards are interleaved.

The aft station panel R11L keyboard is connected directly to the aft panel R11L IDP; there is no select switch.

These switch positions also drive the MEDS colored keyboard bars. If the LEFT IDP/CRP SEL switch is selected to IDP 3 (in other words, the commander's keyboard is talking to IDP 3), a red horizontal bar will be displayed to the left of the box for IDP 3's DPS display. If the switch is moved to IDP 1, the red bar will disappear from IDP 3's DPS display and move to the left of the box on IDP 1's DPS display. The pilot's keyboard bar is yellow and is displayed to the right of the box. Red and yellow were chosen, because the crew already associates the CDR with red and the PLT with yellow for FDF, food, etc. Because the DPS displays can be called up on any MDU, this information is helpful in knowing which IDP a keyboard is talking to and which IDP's DPS display is being displayed. IDP 4's DPS display does not have any keyboard bars displayed, because only the aft keyboard can talk to it.

Each IDP has an associated *MAJ FUNC* switch. The *IDP/CRT 1, 3, 2, MAJ FUNC* switches on panel C2 tell the GPCs which of the different functional software groups is being processed by the keyboard units and what information is presented on the IDP's DPS display. The *IDP/CRT 4 MAJ FUNC* switch on panel R11L functions in the same manner. This three-position toggle switch allows the crew access to the *GNC*, *SM*, or *PL* software on a desired IDP. The GPC loaded with the desired major function applications software will then drive this IDP's DPS display. Each major function accesses an independent set of display data and functional software.



Possible IDP/Keyboard Assignments in the Forward Flight Station

MDU Configuration

Overview

Nominally, MDUs are configured to their primary ports and are in automatic port reconfiguration mode. CRT MDUs show the DPS (CRT) display. In general, the CDR and PLT MDUs display the flight instruments, while the MFD MDUs display the subsystem displays. This configuration is similar to the old non-MEDS display configuration.

Selecting Alternate MDU Ports

Automatic port reconfiguration capability allows the MDU to swap automatically to the other port if the MDU loses communication with the currently selected IDP. Manual port reconfiguration capability does not do a port select automatically. The user has to manually reconfigure the MDU onto its alternate port. Operationally, MDUs will always be in auto reconfiguration mode. If an MDU is in manual mode and loses communication with the selected IDP, or if an MDU is in automatic reconfiguration mode and loses communication with the IDPs on both ports, the MDU is in autonomous mode. The MDU blanks the MEDS display and displays the following message: MDU IS AUTONOMOUS. The menu changes to allow the user to reconfigure to automatic port selection, manual primary port, or manual secondary port.

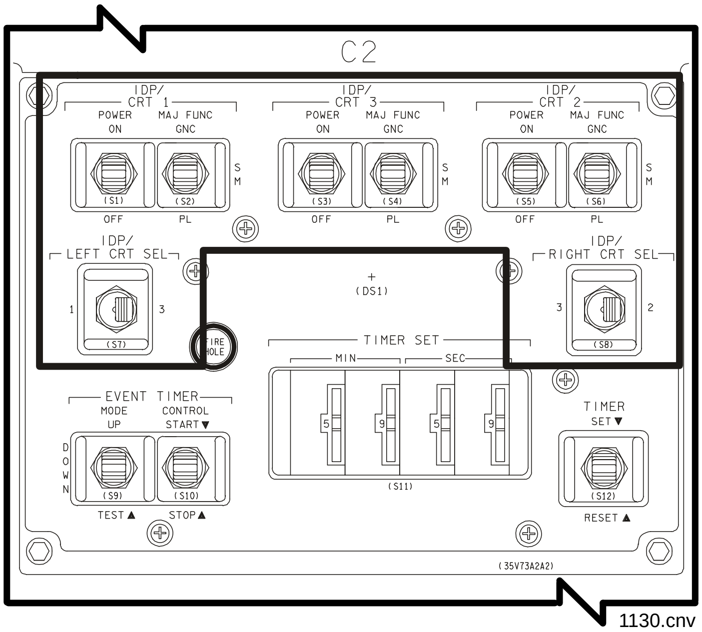
The user can select alternate ports by navigating through the MEDS edgekey menus to either the subsystem menu or the MEDS maintenance menu. The port select option was included in the subsystem menu in case of failure of an ADC. If an ADC that the current IDP commander is using fails, it cannot display all of the subsystem status information. For the MFD MDUs, CDR 1, and PLT 2, the IDPs on the alternate port were wired so that they will access the other set of ADCs. A port reconfiguration allows recovery of all subsystem status information. (Note that nominally, the MFD MDUs display subsystem status displays.)

Recovering from a Disabled Edgekey

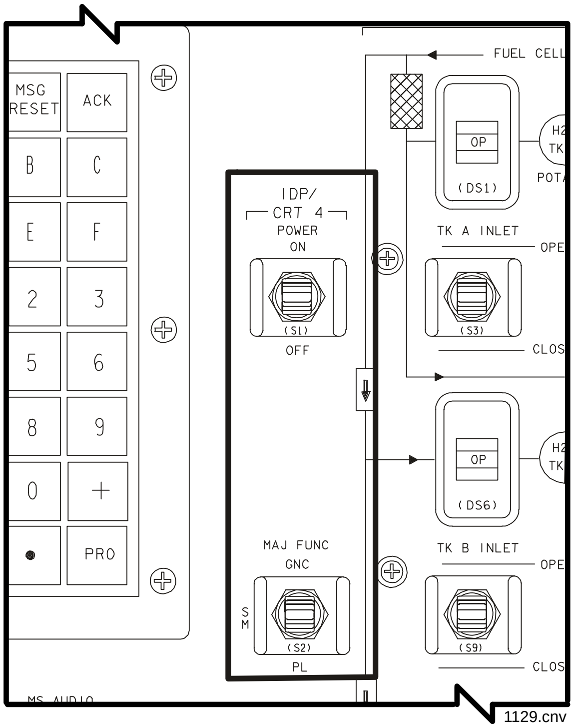
When an edgekey has been disabled, a red "X" appears on the edgekey legend box. An edgekey is disabled when it is pressed continuously for 3 seconds or longer or when MEDS detects that it failed closed. To recover from an accidental edgekey disable, it is necessary to power cycle the MDU via its power knob on the display unit.

Selecting Negative Viewing

The configuration status submenu allows the viewer to change the viewing mode. The viewing mode can be changed only for the Hosiden MDUs. The negative viewing mode enhances the readability of the aft MDUs. When negative viewing is selected, "NEG VIEW" is displayed above the flight-critical bus selection and reconfiguration mode on the MEDS status area of the MDU.



IDP/CRT Switches on Panel C2



IDP/CRT 4 POWER and MAJ FUNC Switches on Panel R11L

Display Hierarchy

DPS display organization consists of three levels of crew software displays within any given major function. The display types parallel the different types of modules used in the GPC software. The established display hierarchy within applications software is operational sequences (OPS), specialist functions (SPEC), and display (DISP) functions.

The OPS is the highest level of crew software control within a major function. Each memory configuration contains one or more OPS. Each OPS allows the crew to accomplish an associated mission phase task. Several operational sequences are defined, each covering some portion of the mission. For example, OPS 1 contains ascent software, OPS 2 contains on-orbit software, and OPS 3 contains entry software.

Each operational sequence is further divided into major modes. Each major mode has an associated display that allows direct crew interface with the software. These are OPS pages, and are also referred to as major mode pages.

Specialist functions (SPECs) are second in the hierarchy. A SPEC allows crew execution of other activities in conjunction with a particular OPS. SPEC displays, like major mode displays, allow direct crew interface with the software. Each SPEC has an associated display that overlays the major mode display when called. When a SPEC is called, its display rolls in on top of the major mode display, which is still active underneath. The SPEC provides access to an associated portion of the software located in the GPC. Some SPECs are contained in systems software, whereas others are resident in the applications load. A SPEC can be associated with a major function or an OPS, but the systems software SPECs can be obtained in most OPS and major functions. (The list of SPECs and their availability is found in the DPS Dictionary.)

Display functions (DISPs) are the lowest level of software. Each DISP has an associated display that presents the status of a predefined set of parameters. Unlike major mode displays or SPECs, a DISP cannot initiate a change in software processing because DISP displays do not permit direct crew interface with the software. They provide information only.

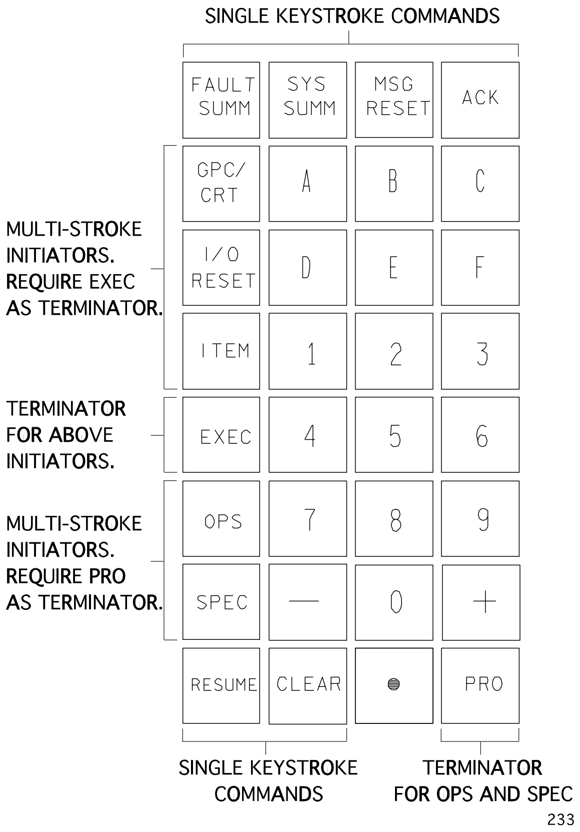
When called, a DISP overlays the major mode display and the SPEC, if one is active. Both the SPEC and the major mode display are overlaid, and access to them can be easily regained. The method of terminating the processing of SPECs and DISPs is discussed later.

The Keyboard

Each keyboard is composed of a 4 x 8 matrix of 32 pushbutton keys. This matrix consists of:

- Sixteen alphanumeric keys: 0 through 9 and A through F, for a hexadecimal numbering system.
- Two sign keys (+ and -) serving the dual roles of sign indicators and delimiters. A delimiter is used to separate discrete keyboard entries from their associated data.
- One decimal point key for use in entering data with decimal notation.

- Thirteen special function keys: some of these keys are single stroke commands, and some are keys that start or finish a multi-stroke command sequence. A key that starts a command sequence is a command initiator and requires a command terminator key to be depressed to tell the IDP the keyboard entry is complete.



Multifunction Electronic Display System Keyboard Unit on Panels C2 and R11L

Each of these keys is discussed below.

ACK acknowledges receipt of a fault message on the fault message line by causing the message to become static and by extinguishing the SM ALERT light and software-controlled tones. If multiple messages are indicated on the DPS display, each subsequent press of the ACK key will bring up the next oldest unacknowledged message and clear out the last acknowledged one.

MSG RESET operates as a single keystroke command that clears both the currently annunciated fault message and the buffer message indicator (if any) from the fault message line. The fault message line is the second to the last line on the DPS display. Depressing this key will also extinguish all software-driven caution and warning annunciators, software-controlled tones, and the SM ALERT light. An ILLEGAL ENTRY message can only be cleared with the MSG RESET key.

SYS SUMM is used to invoke the SYS SUMM display. The particular display called is determined by the selected major function and active OPS.

FAULT SUMM is used to invoke the FAULT display. It operates as a single keystroke command. The FAULT display can be accessed in every major function and OPS.

GPC/CRT initiates a multistroke keyboard entry, allowing the selection of a particular GPC to drive an IDP.

I/O RESET attempts to restore a GPC's input/output configuration to its original status prior to any error detection. It is a command initiator and requires a terminator keystroke.

ITEM is used as a multi-keystroke command initiator for changing the value of defined parameters or implementing configuration changes on a given display (OPS or SPEC).

EXEC acts as a multi-keystroke terminator to command the execution of the action specified on the scratch pad line. It is the terminator for the initiators above it (GPC/CRT, I/O RESET, and ITEM keys). EXEC may also be a single keystroke command to enable an OMS burn.

OPS serves as a multi-keystroke initiator to load a desired OPS load from mass memory into one or more GPCs. It is also used to transition from major mode to major mode within an OPS.

SPEC acts as a multi-keystroke initiator to select a defined SPEC or DISP display within a given OPS. In addition, this key provides the capability to freeze a DPS display. A single depression of the SPEC key freezes the display so it may be statically viewed. The display will remain frozen until another key (other than ACK, MSG RESET, or another SPEC) is entered.

PRO (Proceed) serves as a terminator to the OPS and SPEC keys. The completed command sequence initiates the selection of a desired OPS, SPEC, or DISP display.

RESUME is used to terminate a displayed SPEC or DISP. The highest level SPEC or DISP is cleared and the underlying display is brought to the forefront upon depression of this key.

CLEAR clears the last echoed keystroke from the bottom line (scratch pad line) of the DPS display. For each depression, one additional keystroke is removed, proceeding from right to left. After a command sequence is completed, a single depression of the CLEAR key will erase the static command from the scratch pad line.

Display Selection Procedures

The crew can select a variety of DPS displays in numerous ways. Some of the different ways to select an OPS display and its available SPEC and DISP displays are as follows:

- Selection of the major function is done by placing the MAJ FUNC switch (on panel C2) associated with the IDP in use in the GNC, SM, or PL position.
- An OPS is loaded from the MMU via a three-step keyboard entry. A new OPS is called from mass memory by its first major mode. The OPS is loaded into the GPC that is currently driving the IDP on which the keyboard entry is performed. Once the OPS is loaded, access is provided to major modes in that OPS. Major mode displays are advanced by the same keyboard command. The steps for selecting an OPS display are as follows:

    1. *Depress the OPS key.*
    2. *Key in the three numbers of the desired OPS.* The first digit defines the OPS and the next two digits specify the major mode.
    3. *Depress the PRO key.* Once the OPS is loaded into one or more GPCs, that software can be accessed at any time through any IDP in the proper major function.

Selection of a major mode does not involve a mass memory access. Advancing major modes is done by the same keyboard command as loading an OPS. The first digit will be the same as the OPS number, but the last two digits specify the major mode. For example, to go to GNC MM 202, enter OPS 2 0 2 PRO.

Within each OPS, certain SPEC and DISP displays are available. The steps for selecting a SPEC or a DISP are as follows:

1. *Depress the SPEC key.* The SPEC key is used in calling both SPEC and DISP displays.
2. *Key in the SPEC or DISP number omitting all leading zeros.* SPEC and DISP numbers have three digits. They are differentiated by their numbering scheme. The display is a DISP only if the first digit is a 9, or if the last digit is a 6 through 9. To illustrate the method for keying in SPEC and DISP numbers, DISP number 106 would be keyed in as "106"; SPEC number 034 would be keyed "34"; DISP number 066 would be keyed "66"; and SPEC number 001 would be keyed "1."
3. *Depress the PRO key.*

OPS and Major Mode Transitions

Transitions from major mode to major mode or to another OPS are accomplished by either automatic transitions or proper command entry.

- Automatic transitions: Some major mode transitions occur automatically, usually as a function of some mission event. Examples of automatic transitions are between major modes 101 and 102 (SRB ignition) and between major modes 102 and 103 (SRB separation). Selection of an RTLS abort also results in an automatic OPS transition.
- Command entry: Proper command entry (OPS XXX PRO) is almost always used to transition from one OPS to another. In most cases, it is also a legal transition operation for proceeding from one major mode to the next (e.g.; 301 to 302).

Display Sequencing, Overlaying, and Retention

Certain rules have been established for proceeding from one display to another. These can be categorized into treatment of proper display sequencing, the overlaying of current displays by new displays, and the display retention hierarchy.

SPEC and DISP Displays

The hierarchy of overlaying SPECs and DISPs makes sense if one remembers that a SPEC allows crew interaction and control of specialized operations, whereas a DISP provides display information only. Both SPECs and DISPs overlay the current major mode display when called.

A SPEC need not be previously selected in order to call a DISP. If a DISP is active, and another SPEC or DISP is called, the current DISP is terminated. The terminated DISP can only be viewed again by entering its calling command once more.

If a SPEC is selected, and a DISP is called to overlay it, the SPEC is retained underneath the DISP. If another SPEC is then selected, the underlying SPEC as well as the DISP over it is terminated. The terminated SPEC can only be viewed again if it is recalled.

The RESUME key is used as a single keystroke entry to terminate the SPEC or DISP currently being displayed and to restore the underlying display. If the display being terminated is a DISP, control will be restored to the underlying SPEC, or to the OPS display if no SPEC has been selected. If a SPEC display is terminated, IDP control is restored to the major mode display. It is advisable to press RESUME after completing viewing any SPEC or DISP to avoid confusion and to eliminate locking out certain ground command functions that are inhibited when certain SPECs are active or underlying a DISP; i.e., SM60 and SM62. The RESUME key cannot be used to transition from one major mode display to another or to page backwards through major mode displays.

Display Retention Hierarchy

- Major mode transitions: Both SPECs and DISPs are retained during a major mode transition. If a SPEC or DISP is overlaying the major mode display, the new major mode display can't be seen until the overlaying displays are terminated with the RESUME key.

- Major function change: OPS and SPEC displays are retained within their major function when major function positions are switched. When the crew returns to the first major function, the SPEC last viewed will appear on the screen. Depression of the RESUME key will restore the underlying OPS. If no SPEC had been selected, return to a major function would restore the last major mode display. DISP displays are not retained at major function switch transitions.

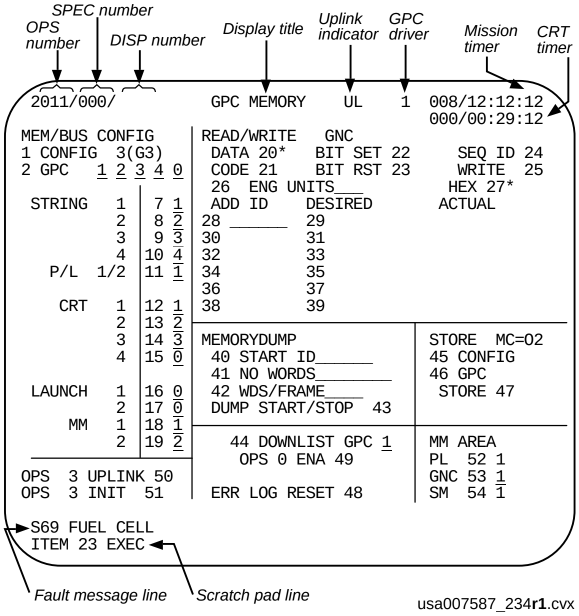
- OPS transition: SPECs, DISPs, and major mode displays are not retained through an OPS transition, since this involves loading an entirely new module of applications software in the GPC. The SPECs may be called again if they are available in the new OPS.

Standard Display Characteristics

Standard Display Features

Two discrete brightness intensities for displayed characters are designated "bright" and "overbright." The bulk of all material is displayed
in the "bright" intensity. Special messages and special characters, such as parameter status indicators, are displayed in "overbright," which appears in a yellow font, to direct the crew's attention during their display scan.

Certain words and messages are designed to flash on and off. Fault messages will flash, indicating a message that needs to be acknowledged. Command initiators are designed to flash until the command is completed, and an incorrect keyboard entry will result in a flashing "ERR" to the right of the erroneous entry.



```
 2011/000/           GPC MEMORY    UL    1  008/12:12:12
                                            000/00:29:12
MEM/BUS CONFIG     | READ/WRITE   GNC
1 CONFIG  3(G3)    |  DATA 20*   BIT SET 22     SEQ ID 24
2 GPC   1 2 3 4 0  |  CODE 21    BIT RST 23     WRITE  25
                   |  26  ENG UNITS___         HEX 27*
 STRING    1  | 7 1|  ADD ID    DESIRED        ACTUAL
           2  | 8 2| 28 ______  29
           3  | 9 3| 30         31
           4  |10 4| 32         33
   P/L  1/2   |11 1| 34         35
              |    | 36         37
    CRT    1  |12 1| 38         39
           2  |13 2|-----------------------------------------
           3  |14 3| MEMORYDUMP              | STORE  MC=O2
           4  |15 0|  40 START ID______      | 45 CONFIG
              |    |  41 NO WORDS________    | 46 GPC
 LAUNCH    1  |16 0|  42 WDS/FRAME____       |  STORE 47
           2  |17 0|  DUMP START/STOP  43    |
     MM    1  |18 1|-----------------------------------------
           2  |19 2|    44 DOWNLIST GPC 1    | MM AREA
 ------------------|     OPS 0 ENA 49        | PL   52 1
OPS  3 UPLINK 50   |                         | GNC 53 1
OPS  3 INIT   51   |  ERR LOG RESET 48       | SM  54 1

 S69 FUEL CELL
 ITEM 23 EXEC
```

Formatting Conventions Common to All Displays

Formatting Similarities

OPS number: The four-digit field in the upper left corner of the first line designates the number of the OPS display being processed. The first digit represents the OPS; the next two digits indicate the major mode. The last digit is always a "1," and it is not used when making keyboard entries.

SPEC number: Directly to the right of the OPS number is a three-digit field. This field displays the number of the SPEC overlaying the OPS. This field is blank if no SPEC is selected.

DISP number: The last field in the upper left corner represents the DISP number. It is a three-digit field. This field is blank if no DISP is currently being displayed.

Display title: Centered on the top line of the display is the title of the display. Portions of some titles are dynamic and will specify the mission phase.

Uplink indicator: Directly to the right of the display title is a two-space field. When an uplink to the GPC is in progress, a flashing "UL" will be displayed. Otherwise this field is blank.

GPC driver: To the right of the uplink indicator is a one-digit field. A number in this field indicates the particular GPC (1, 2, 3, 4, or 5) that is commanding the IDP.

GMT/MET clock: This field displays time in days, hours, minutes, and seconds (DDD/HH: MM:SS). The field is updated every second. The time displayed may be either GMT or MET selectable via a keyboard entry to the SPEC 2 TIME display.

CRT timer: Directly below the GMT/MET clock is a CRT timer field also displayed in days, hours, minutes, and seconds (DDD/HH:MM: SS). This field is also updated every second, and can be set via a keyboard entry to the TIME SPEC display.

Fault message line: The second line from the bottom is reserved for fault messages. Illegal keyboard entry messages and systems fault messages are displayed on this line. In the case of system faults, a number in parentheses to the far right on this line indicates the number of fault messages that have not been viewed and acknowledged (further discussion of fault messages is covered in a later section).

Scratch pad line: The bottom line of the display echoes keyboard entries made by the crew. Command initiators (OPS, SPEC, ITEM, GPC/CRT, and I/O RESET) will flash on the scratch pad line until the command is terminated. The keystrokes remain on the scratch pad line in a static mode until (a) a new command is initiated, (b) the CLEAR key is depressed, or (c) the MAJOR FUNC switch position is changed. Keyboard syntax errors detected by the IDP will result in a flashing "ERR" on the scratch pad line following the keyboard entry.

Specially Defined Symbols

These symbols include an asterisk and a set of parameter status indicators. Parameter status indicators are displayed in "overbright" intensity for quick recognition. These special symbols are defined as follows:

M: This symbol indicates missing data. It is displayed directly to the right of the affected parameter. The parameter value may be blanked, or the last value received by the GPC may be displayed. If data are missing for a parameter that has no numerical value associated with it, then an M is used to indicate the parameter status.

H: This symbol indicates that a parameter is off-scale high. This indicates a transducer limit has been reached, and the scale is registering its highest possible value. The actual parameter being measured may, in fact, be higher than the recorded data, but the instrument in use does not have the capacity to measure the value. Off-scale high indicators do not appear on the display until several (normally two) consecutive readings have verified this finding. This symbol is displayed to the right of the data affected.

L: This symbol indicates off-scale low parameters. This means that the parameter value displayed is the lowest possible reading due to transducer limitations. The actual value of the parameter may exceed the displayed value, but the range of the hardware is not defined to evaluate this reading. As with the "H," the off-scale low indicator is not displayed until a set number of consecutive readings have verified this status.

Up arrow: This symbol, displayed to the right of the affected parameter, indicates a parameter driven out-of-limits high. The value displayed is a true reading but has equaled or exceeded the operational high limit established by the software. The fault detection and annunciation (FDA) software keeps track of the low and high limits for each parameter and annunciates any violation of these limits to the crew by displaying the appropriate "up arrow" or "down arrow" next to the parameter on the appropriate display.

In the case where the transducer limit is the same as the operational limit, the "H" symbol overrides the "up arrow" symbol. Several (normally two) consecutive readings verify this status before the "up arrow" symbol is displayed.

Down arrow: This symbol indicates that a parameter value is equal to or less than the operational low limit. The value displayed is outside the software limits placed upon the parameter. When the software limit established is the same as the transducer limit, the "L" symbol takes precedence over the "down arrow" symbol. A set number of consecutive readings verifies this indication before the "down arrow" is displayed.

In addition, the down arrow is used to indicate a discrete state that does not agree with the nominal state. For example, a high pressure gas supply valve state reading "closed" when its position is normally "open" would drive the "down arrow" symbol.

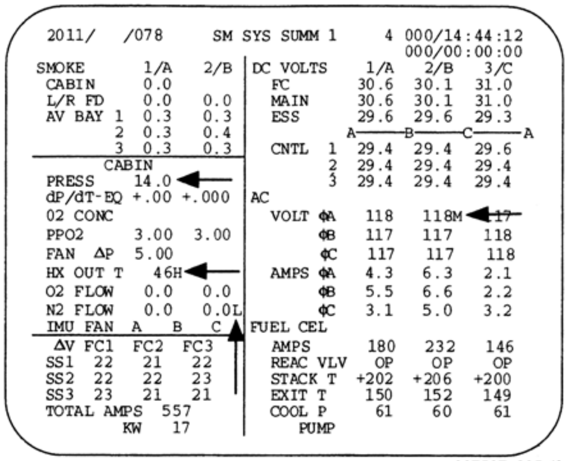
The down arrow is also used to indicate that a hardware unit has been declared failed by a GPC.

?: This symbol indicates a redundancy management dilemma. That is, if two hardware units measuring the same parameter disagree, and the software cannot isolate which of the two is failed, a "?" will be displayed in both places.

*****: This symbol indicates an active state or the selected item of mutually exclusive items.

Item Operations

Within a given display, certain operations can be performed by the crew. Those items that may be altered are identified by an item number. The item number is a maximum of two digits and is placed in such a way that it is readily identifiable with the parameter or status configuration with which it is associated. When item numbering is obvious, item numbers may be implied and will not appear on the display. Item numbering is sequentially ordered for each display. There are never more than 99 items per display. The two basic types of manipulations that the crew can perform are item configuration change and item data entry.



```
2011/   /078      SM SYS SUMM 1       4 000/14:44:12
                                        000/00:00:00
SMOKE       1/A    2/B | DC VOLTS     1/A    2/B    3/C
 CABIN      0.0        |   FC         30.6   30.1   31.0
 L/R FD     0.0    0.0 |   MAIN       30.6   30.1   31.0
 AV BAY 1   0.3    0.3 |   ESS        29.6   29.6   29.3
        2   0.3    0.4 |            A------B------C------A
        3   0.3    0.3 |   CNTL   1  29.4   29.4   29.6
      CABIN            |          2  29.4   29.4   29.4
 PRESS     14.0        |          3  29.4   29.4   29.4
 dP/dT-EQ  +.00  +.000 | AC
 02 CONC               |   VOLT ΦA    118    118M   117
 PPO2       3.00  3.00 |        ΦB    117    117    118
 FAN  ΔP    5.00       |        ΦC    117    117    118
 HX OUT T     46H      |   AMPS ΦA    4.3    6.3    2.1
 02 FLOW    0.0    0.0 |        ΦB    5.5    6.6    2.2
 N2 FLOW    0.0    0.0L|        ΦC    3.1    5.0    3.2
 IMU FAN  A     B     C| FUEL CEL
  ΔV FC1   FC2   FC3   |   AMPS       180    232    146
 SS1  22    21    22   |   REAC VLV   OP     OP     OP
 SS2  22    22    23   |   STACK T   +202   +206   +200
 SS3  23    21    21   |   EXIT T     150    152    149
 TOTAL AMPS   557      |   COOL P     61     60     61
          KW   17      |        PUMP
```

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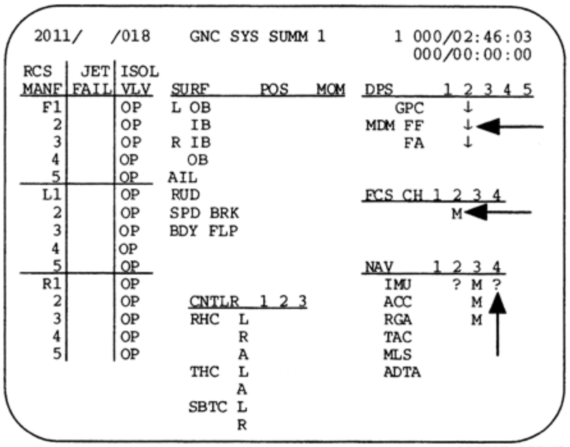

```
2011/   /018     GNC SYS SUMM 1            1 000/02:46:03
                                             000/00:00:00
RCS | JET|ISOL
MANF|FAIL|VLV   SURF        POS   MOM    DPS        1 2 3 4 5
  F1|    |OP    L OB                        GPC      ↓
   2|    |OP      IB                     MDM FF      ↓
   3|    |OP    R IB                         FA      ↓
   4|    |OP      OB
   5|    |OP    AIL
  L1|    |OP    RUD                      FCS CH 1 2 3 4
   2|    |OP    SPD BRK                            M
   3|    |OP    BDY FLP
   4|    |OP
   5|    |OP                             NAV      1 2 3 4
  R1|    |OP                               IMU      ? M ?
   2|    |OP      CNTLR  1 2 3             ACC        M
   3|    |OP      RHC   L                  RGA        M
   4|    |OP            R                  TAC
   5|    |OP            A                  MLS
                  THC   L                  ADTA
                        A
                  SBTC  L
                        R
```

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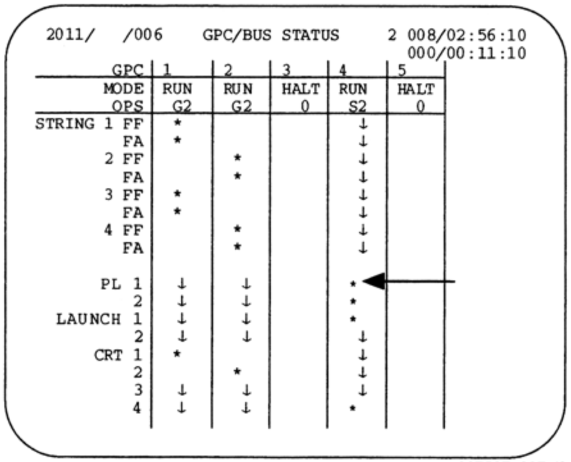

```
2011/   /006     GPC/BUS STATUS         2 008/02:56:10
                                          000/00:11:10
          GPC | 1    | 2    | 3    | 4    | 5    |
         MODE | RUN  | RUN  | HALT | RUN  | HALT |
          OPS |  G2  |  G2  |   0  |  S2  |   0  |
STRING 1 FF   |  *   |      |      |   ↓  |      |
         FA   |  *   |      |      |   ↓  |      |
       2 FF   |      |  *   |      |   ↓  |      |
         FA   |      |  *   |      |   ↓  |      |
       3 FF   |  *   |      |      |   ↓  |      |
         FA   |  *   |      |      |   ↓  |      |
       4 FF   |      |  *   |      |   ↓  |      |
         FA   |      |  *   |      |   ↓  |      |
              |      |      |      |      |      |
       PL 1   |  ↓   |  ↓   |      |  *   |      |
          2   |  ↓   |  ↓   |      |  *   |      |
   LAUNCH 1   |  ↓   |  ↓   |      |  *   |      |
          2   |  ↓   |  ↓   |      |   ↓  |      |
      CRT 1   |  *   |      |      |   ↓  |      |
          2   |      |  *   |      |   ↓  |      |
          3   |  ↓   |  ↓   |      |   ↓  |      |
          4   |  ↓   |  ↓   |      |  *   |      |
```

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Specially Defined Symbols on DPS Displays

Item Configuration Change

This operation allows the crew to choose any of a number of options or to initiate a specific action as defined by the particular display format. Typical purposes of this operation include selecting or deselecting an item, initiating and executing an action, and altering software configurations. The procedure used in performing an item configuration change within a selected display is as follows:

1. *Depress the ITEM key.*
2. *Key in the item number.*
3. *Depress the EXEC key.*

Item Data Entry

This operation lets the crew load data into the software. Typical purposes include initializing parameters, changing software limits, and specifying memory locations. The procedure to perform an item data entry is as follows:

1. *Depress the ITEM key.*
2. *Key in the item number.* Item numbers are ordered sequentially (1, 2, 3, . . .) on each display. They are located next to the parameter to which they are assigned. Some item numbers must be inferred by their surrounding item numbers.
3. *Key in a delimiter* ("+" or "-"). A delimiter serves to separate item number codes from their corresponding data. The delimiter whose sign corresponds to the sign of the data should be used, but if no sign is associated with the data, it doesn't matter which delimiter is used. A "[ ]" after the data field indicates that the entry is sign-dependent.
4. *Key in the data.* Data size specifications depend on the format established for that particular data load. Usually, the data size will be indicated with an underline for each digit. As a general rule, leading zeros need not be entered. Remember that the sign of the delimiter is the sign of the data.
5. *Depress the EXEC key.*

Multiple Data Entries

Multiple item configuration changes cannot be done; but multiple item data entries can. Multiple data entries can be made with separate command strings. This is time-consuming, so the software allows more than one data entry to be made with one command sequence. The procedure is the same as above, except step 4 (after data are keyed in). Add step 4a to make more than one item data entry at once.

4a. Key in a delimiter. Consecutive data entries may be loaded by using a delimiter to separate each parameter. Item entries are incremented sequentially so the item number need not be entered for each parameter following the one already entered. Just hit another delimiter, and the next item number will appear, ready to receive its associated data. To skip an item number, hit a delimiter twice. This way, any amount of item numbers may be skipped until the desired item number is reached.

Both the "+" and the "-" keys can be interchangable as delimiters. However, if skipping item numbers, it is a good idea to use the delimiter corresponding to the sign of the next data entry if there is any sign associated with it. Using the sign key corresponding to the next data entry ensures that the GPC receives the proper data entry.

A sample multiple item data keyboard entry is:

ITEM 7 + 2 + 1 + + 2 + - - 2 EXEC

In this example, Items 7, 8, 10, and 13 have no sign associated with them so the sign of the delimiters does not matter. There is room for four item entries here, but the actual number allowed on the scratch pad line is a function of the size of the data.

This entry appears on the scratch pad line of the corresponding IDP as:

ITEM (07) + 2 (08) + 1 (10) + 2 (13) - 2 EXEC.

All item operations will be one of these two basic manipulations. However, data size and form will differ for each display.

Remember, only OPS and SPEC displays allow item operations. A DISP display does not.

Special Operations and Displays

GPC/CRT Assignment

GPC assignment to a certain IDP is determined via a predefined table of assignments. The table is stored in all the common set GPCs' systems software; the crew can manipulate it. There is a table for each memory configuration (MC) that is valid when that MC is active (loaded in one or more GPCs), and the particular major function is selected. The table can be changed via the GPC MEMORY display (SPEC 0). The current GPC driver for an IDP is controlled by the *MAJ FUNC* switch. That is, the position of the *MAJ FUNC* switch (*GNC*, *SM*, or *PL*) determines the GPC with which the IDP communicates. In some cases, a redundant set of GPCs is formed for GNC, and the GNC IDPs are normally split among them. This is done with the predefined table. The table is looked at by the GPCs when they are loaded with the applications software, and that is when the assignments take effect.

Another way to change the current GPC assignment logic is with the GPC/CRT key. (The old cockpit configuration consisted of a set of CRTs. The key is still labeled GPC/CRT, although its function is to assign a GPC to command an IDP). The GPC/CRT key allows the crew to reassign an IDP to a different GPC commander. The steps for selecting a GPC to command a given IDP are as follows:

1. *Depress the GPC/CRT key*.
2. *Key in the desired GPC number* (1, 2, 3, 4, or 5).
3. *Key in the desired IDP number* (1, 2, 3, or 4). No delimiter is needed between the GPC and the *IDP* numbers.
4. *Depress the EXEC key*.

An assignment is not executed if the assigned GPC does not have the applications software in memory to support the IDP in its current major function. If the GPC specified by a keyboard entry is not a valid assignment, the reassignment does not occur, and the GPC driver retains the IDP. Thus, if an IDP is in GNC, and an attempt is made to assign a GPC that is not in the redundant set to drive it, a redundant set (or valid) GPC will drive the IDP instead of the invalid GPC. If GPC 4 is the SM machine (nominal configuration), it is the only valid GPC to drive an IDP whose *MAJ FUNC* switch is in *SM*.

The payloads major function is usually *unsupported*, which means that none of the GPCs have payload applications software loaded. Any GPC can be assigned to drive an IDP in an unsupported major function. The GPC that was driving the IDP in the previous major function retains the IDP when it is placed in *PL*.

If the keyboard entry specifies a valid GPC, it overrides any assignment made by the software. The keyboard entry assignment remains in effect whenever the *MAJ FUNC* switch is in a position supported by that GPC. A new assignment can be made via the keyboard.

The GPC/CRT key can also be used to isolate an IDP from communication with all GPCs. This is done by using "0" for the number of the GPC. The PASS set can drive only three of the four IDPs at one time, so at least one IDP is always isolated from PASS.

The IDP drives a big X over its DPS display to remind the crew that the IDP is not receiving data. The IDP also annunciates a POLL FAIL message to inform the crew that the GPC is no longer successfully polling the IDP (not attempting to communicate with the IDP).

Memory Configurations

After a GPC has been IPL'd, the only software resident is the systems software, and the GPC is in OPS 0 when moded to *RUN*. Any applications software is loaded in from the MMU during an OPS transition. There are two levels of applications software: the major function base (MFB) and the OPS overlay. The MFB is the software common to all OPS in a particular major function. For GNC, the MFB contains flight-critical software and data that are retained from one mission phase to another; e.g., the current state vector and inertial measurement unit processing. When a GPC transitions from one OPS to another in the same major function (e.g., from GNC OPS 1 [ascent] to OPS 2 [orbit]), the MFB remains in main memory, and only the OPS overlay is loaded from the MMU and written over the old OPS. Of course, when the major function changes (e.g., when GPC 4 is transitioned from GNC OPS 1 to SM OPS 2), a new MFB is loaded from the MMU along with the OPS overlay.

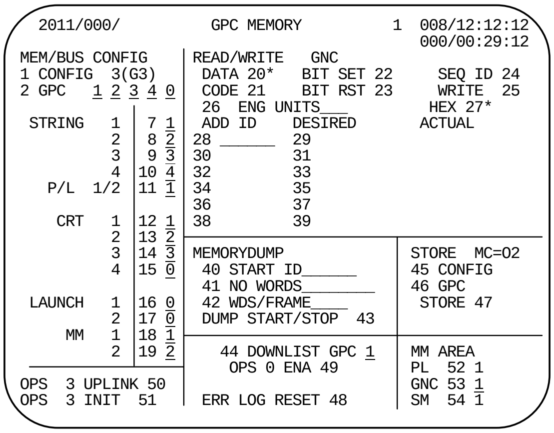
The controls for performing an OPS transition (i.e., loading a new memory configuration into the GPC from the MMU) are on the GPC MEMORY display (SPEC 0), which is also the OPS 0 OPS display. Item 1 determines the memory configuration (CONFIG) to be loaded. Currently, there are eight different memory CONFIGs, besides memory CONFIG 0, which is post-IPL OPS 0(no applications software loaded).

MCC	ABBREV	
1	(G1)	GNC OPS 1 and 6 combined (ascent and aborts)
2	(G2)	GNC OPS 2 (on orbit)
3	(G3)	GNC OPS 3 (entry)
4	(S2)	SM OPS 2 (on orbit)
5	(S4)	SM OPS 4 (on orbit [not used])
6	(P9)	PL OPS 9 (preflight)
No MC 7		
8	(G8)	GNC OPS 8 (on orbit checkout)
9	(G9)	GNC OPS 9 (preflight/postflight)

Memory Configurations

Nominal Bus Assignment Table

Associated with each memory configuration is a nominal bus assignment table (NBAT). It is displayed via items 7-19 on SPEC 0 whenever a memory configuration is entered, and it tells which GPCs are in the target set and which GPCs are to be in command of each data bus. The nominal assignments are already loaded in GPC main memory preflight. However, these bus assignments may be changed any time, including when an OPS transition is performed. A typical NBAT is shown on SPEC 0 GPC MEMORY for GNC OPS 3.



```
 2011/000/              GPC MEMORY         1  008/12:12:12
                                              000/00:29:12
MEM/BUS CONFIG         READ/WRITE   GNC
1 CONFIG  3(G3)         DATA 20*   BIT SET 22     SEQ ID 24
2 GPC   1 2 3 4 0       CODE 21    BIT RST 23     WRITE  25
                        26  ENG UNITS___         HEX 27*
 STRING    1    7 1     ADD ID     DESIRED       ACTUAL
           2    8 2    28 ______   29
           3    9 3    30          31
           4   10 4    32          33
   P/L  1/2    11 1    34          35
                       36          37
    CRT    1   12 1    38          39
           2   13 2
           3   14 3    MEMORYDUMP                 STORE  MC=O2
           4   15 0     40 START ID______         45 CONFIG
                        41 NO WORDS_________      46 GPC
 LAUNCH    1   16 0     42 WDS/FRAME____           STORE 47
           2   17 0     DUMP START/STOP  43
     MM    1   18 1
           2   19 2       44 DOWNLIST GPC 1       MM AREA
                           OPS 0 ENA 49           PL  52 1
OPS  3 UPLINK 50                                  GNC 53 1
OPS  3 INIT  51         ERR LOG RESET 48          SM  54 1
```

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Sample NBAT Data on GPC MEMORY Display (SPEC 0)

- Items 2-6 determine which GPCs will be in the OPS. They are referred to as the "target" GPCs. In this case, GPCs 1-4 are in a redundant set. If a GPC is not to be in that OPS, a 0 is entered in that GPC's item number, which is one more than the GPC number. (Item 2 is for GPC 1, etc.)

- The commanders of the flight-critical data buses or strings are entered in items 7-10. (String 1 is FF1 and FA1, etc.) In this case, each GPC is set to command its same-numbered string.

- The two PL buses are assigned together. For OPS 1 and 3 they are assigned to GPC 1 via item 11 in case the BFS fails. When the BFS is in RUN (as it is for entry), it commands the PL data buses.

- The “CRT” portion of the NBAT refers to which GPCs are assigned to command the IDPs over the DK bus (the word CRT remains from the previous CRT cockpit). IDPs 1, 2, 3 are assigned to GPCs 1, 2, 3 respectively, via items 12-14. Since the PASS can only control three IDPs at a time, no GPC is assigned to IDP 4 during entry. Note that IDP assignments are for a particular major function only.

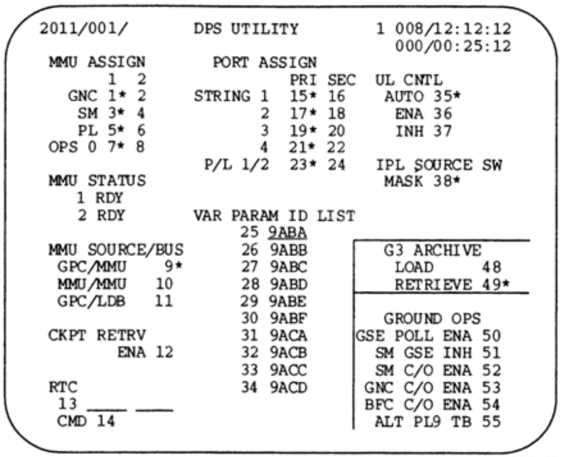
- The launch data buses are assigned via items 16 and 17. Since they have no function during entry, they are deassigned.

- Items 18 and 19 show that GPC 1 will command mass memory bus 1 for the OPS 3 transition, and GPC 2 will command mass memory bus 2, either if the transaction fails on mass memory bus 1 or if MMU 2 is prime selected on SPEC 1 DPS UTILITY.

MMU Assignment

Because there are two identical MMUs, there must be a method to tell the GPCs which one to use for a particular transaction. This is done on DPS UTILITY SPEC 1 display via items 1 through 8. Only one MMU (and its data bus) is assigned to each major function. A post-IPL OPS 0 GPC also has an MMU assigned to it for requesting freeze-dry software for a memory store. This display is initialized with all assigned to MMU 1, and execution of any of the item numbers causes the appropriate MMU to be assigned. Note that each of the pairs of item numbers is mutually exclusive.

When a GPC needs to access mass memory, this table tells it which MMU to use. For example, the SM GPC may need to call a roll-in SPEC or take a checkpoint (discussed later). In the case of OPS transitions, if the MMU selected is busy or fails twice, then the other is automatically tried. For a GNC OPS transition where a redundant set is involved, one GPC is assigned to each mass memory bus via items 18 and 19 on SPEC 0 GPC MEMORY. The indicated GPC will command the mass memory bus selected by item 1 or 2 on SPEC 1 DPS UTILITY, then the other GPC will command the next mass memory bus if the first transaction fails. Of course, all GPCs in the redundant set will be listening over both buses and receive the overlay.



```
2011/001/        DPS UTILITY         1 008/12:12:12
                                       000/00:25:12
 MMU ASSIGN        PORT ASSIGN
       1  2                  PRI SEC   UL CNTL
   GNC 1* 2      STRING 1    15* 16     AUTO 35*
    SM 3* 4             2    17* 18      ENA 36
    PL 5* 6             3    19* 20      INH 37
 OPS 0 7* 8             4    21* 22
                  P/L 1/2    23* 24    IPL SOURCE SW
 MMU STATUS                             MASK 38*
    1 RDY
    2 RDY        VAR PARAM ID LIST
                      25 9ABA
 MMU SOURCE/BUS       26 9ABB        G3 ARCHIVE
  GPC/MMU     9*      27 9ABC          LOAD      48
  MMU/MMU    10       28 9ABD          RETRIEVE 49*
  GPC/LDB    11       29 9ABE
                      30 9ABF          GROUND OPS
 CKPT RETRV           31 9ACA       GSE POLL ENA 50
       ENA 12         32 9ACB         SM GSE INH 51
                      33 9ACC         SM C/O ENA 52
 RTC                  34 9ACD        GNC C/O ENA 53
  13 ____ ____                       BFC C/O ENA 54
  CMD 14                              ALT PL9 TB 55
```

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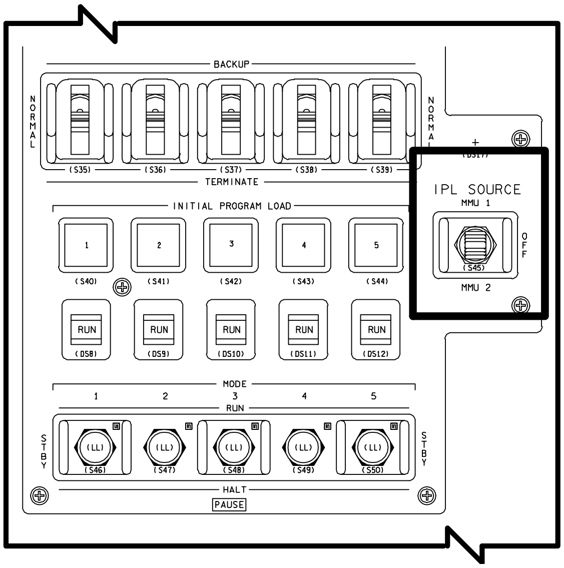
DPS UTILITY Display (SPEC 1)

Software Memory Source Selection

During an initial program load (IPL), an MMU is selected as the software source via the IPL SOURCE switch on panel O6. This switch is a three-position toggle switch that will be either in the MMU 1 or MMU 2 position during the IPL sequence. At all other times, this switch will nominally be in the OFF position.

The controls for selecting the memory source for an OPS transition and the bus over which it is loaded into the GPCs are on SPEC 1 DPS

UTILITY (items 9 through 11). The display is initialized with item 9 selected, which is almost always used. As part of the GPC status exchanged at common set sync, each GPC exchanges its current resident memory configuration. When a request is made for a memory configuration, the software determines whether or not another GPC already has the requested OPS or a current major function base. If another GPC already has any of the requested software, the lowest numbered such GPC will be used as a source for the other GPCs. Such a GPC-to-GPC overlay of software will be done over the mass memory data buses. An overlay that is not available from a GPC will be loaded from an MMU. Note that the major function base may come from another GPC and the OPS overlay from mass memory. For transitions to OPS 3, the G3 archive (stored in the upper 128 k of main memory prelaunch) is simply copied to lower memory and executed.



IPL SOURCE Switch on Panel 06

If there is a problem with both of the mass memory data buses, then item 11 may be selected if there is a GPC source for both overlays. In this case, the GPC-to-GPC overlay is done over the launch data buses.

Memory reconfiguration may be forced from an MMU, regardless of other GPC sources, by selection of item 10 on the DPS UTILITY display. In this case, whether both are required or not, both the major function base and the OPS overlay will be loaded from mass memory. This would only be used if the software in a current GPC was suspect for some reason.

If there is no usable GPC source and the selected MMU is off or being used for another memory transaction, the class 3 fault message OFF/ BUSY MMU 1 (2) is initiated. The current status of each MMU is shown on the DPS UTILITY display as either RDY (ready to respond) or BSY (off or currently responding to a GPC command).

Resetting I/O Configurations

When a GPC detects an error or is missing data from a piece of equipment, a fault message will be displayed on the appropriate DPS displays, the *SM ALERT* light and tone will be activated, and further attempts by the GPC to communicate with the equipment will be terminated. Two common causes of detected errors or missing data are the powering down of equipment or an error in a data transmission. In these two cases, if the equipment is to be powered up, or if the error has been corrected, it is desirable to restore the GPC's data input to the nominal configuration. Restoring input is done through the I/O RESET key in the affected major function. If an I/O RESET is performed only on a GNC GPC, the entire redundant set of GNC GPCs will be restored to nominal I/O configuration. If it is performed on the SM GPC, only the SM GPC's I/O configuration will be restored to nominal. To reset I/O configurations, the procedure is to:

- Select desired *MAJ FUNC.*
- Depress the I/O RESET key.
- Depress the EXEC key.

If the powered down equipment has been powered on, or if a problem with a piece of equipment has been fixed, an I/O RESET resumes communication, and does not cause another fault message annunciation. If the GPC still has a problem with any piece of assigned equipment, a fault message reannunciates after an I/O RESET. This termination of attempts by the GPC to communicate with its assigned equipment is called a commfault (i.e., the input element has been bypassed by the GPC) and the resultant loss of input data to applications software is also referred to as a commfault.

Systems Summary Displays

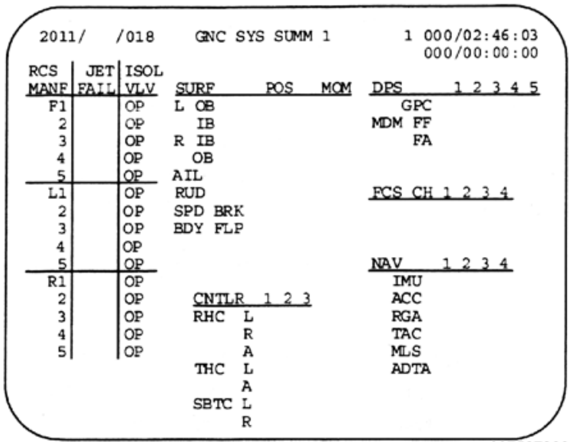
Systems summary displays provide general systems status information that can be accessed quickly to aid immediate diagnosis of a problem. They are designed to support the caution and warning (C/W) matrix located on panel F7. When a C/W alarm occurs, the crew can call a systems summary display that has general information from several systems to pinpoint the problem to a specific system, then continue troubleshooting the problem on system-specific SPECs, DISPs, and hardware panels. The systems summary displays are DISPs and provide information only.

The systems summary displays are major function-specific and are called with the SYS SUMM key. If an IDP's *MAJ FUNC* switch is in *GNC*, and the SYS SUMM key is pressed, GNC SYS SUMM 1 will appear on that IDP. GNC SYS SUMM 1 is DISP 18 so it may also be called with a SPEC 18 PRO, but it is faster to use the SYS SUMM key.

There are four PASS systems summary displays: GNC SYS SUMM 1, GNC SYS SUMM 2, SM SYS SUMM 1, and SM SYS SUMM 2.

The SYS SUMM key is a toggle function in each major function. In SM on-orbit, hitting SM SYS SUMM will cause SM SYS SUMM (DISP 78) to appear on the IDP. If SYS SUMM is depressed again, SM SYS SUMM 2 (DISP 79) will appear, and if SYS SUMM is depressed once more, SM SYS SUMM 1 reappears.

The same toggle function exists in GNC between GNC SYS SUMM 1 (DISP 18) and GNC SYS SUMM 2 (DISP 19).



```
 2011/   /018    GNC SYS SUMM 1         1 000/02:46:03
                                          000/00:00:00
RCS | JET|ISOL
MANF|FAIL|VLV  SURF       POS   MOM   DPS      1 2 3 4 5
  F1|    |OP   L OB                      GPC
   2|    |OP     IB                   MDM FF
   3|    |OP   R IB                       FA
   4|    |OP     OB
   5|    |OP   AIL
  L1|    |OP   RUD                    FCS CH 1 2 3 4
   2|    |OP   SPD BRK
   3|    |OP   BDY FLP
   4|    |OP
   5|    |OP                          NAV     1 2 3 4
  R1|    |OP                            IMU
   2|    |OP     CNTLR  1 2 3           ACC
   3|    |OP     RHC  L                 RGA
   4|    |OP          R                 TAC
   5|    |OP          A                 MLS
                 THC  L                 ADTA
                      A
                 SBTC L
                      R
```

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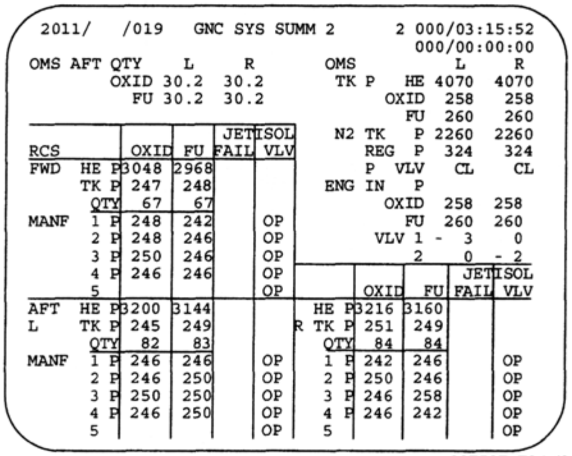
PASS GNC SYS SUMM 2, available in GNC OPS 1, 6, 2, 8 and 3



```
 2011/   /019   GNC SYS SUMM 2       2 000/03:15:52
                                       000/00:00:00
OMS AFT QTY     L      R        OMS          L     R
        OXID 30.2   30.2         TK P    HE 4070  4070
          FU 30.2   30.2               OXID  258   258
                                         FU  260   260
                          JET|ISOL  N2 TK     P 2260  2260
RCS         | OXID| FU |FAIL| VLV      REG   P  324   324
FWD   HE P|3048|2968|    |          P  VLV    CL    CL
      TK P| 247| 248|    |      ENG IN   P
       QTY|  67|  67|    |                OXID  258   258
MANF  1 P | 248| 242|    | OP               FU  260   260
      2 P | 248| 246|    | OP            VLV 1 -  3     0
      3 P | 250| 246|    | OP                2    0   - 2
      4 P | 246| 246|    | OP                            JET|ISOL
      5   |    |    |    | OP         | OXID|  FU|FAIL| VLV
AFT   HE P|3200|3144|    |      HE P|3216|3160|    |
L     TK P| 245| 249|    |    R TK P| 251| 249|    |
       QTY|  82|  83|    |       QTY|  84|  84|    |
MANF  1 P | 246| 246|    | OP   1 P | 242| 246|    | OP
      2 P | 246| 250|    | OP   2 P | 250| 246|    | OP
      3 P | 250| 250|    | OP   3 P | 246| 258|    | OP
      4 P | 246| 250|    | OP   4 P | 246| 242|    | OP
      5   |    |    |    | OP   5   |    |    |    | OP
```

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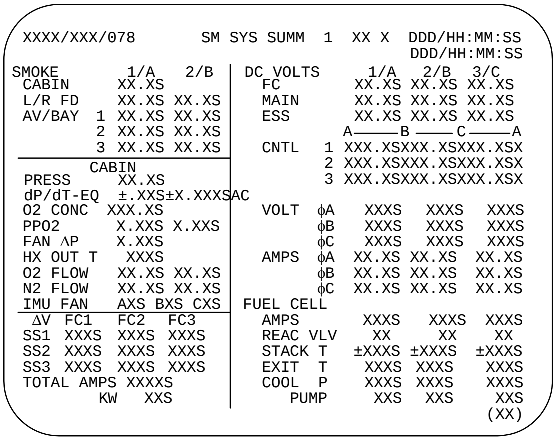
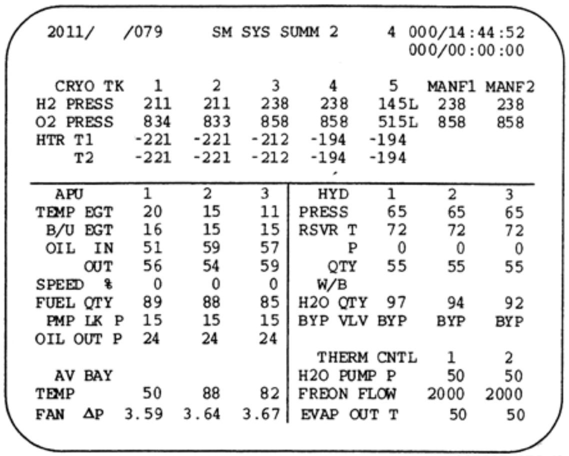
GNC SYS SUMM 2, available in GNC OPS 2 and 8



```
XXXX/XXX/078       SM SYS SUMM  1  XX X  DDD/HH:MM:SS
                                         DDD/HH:MM:SS
SMOKE        1/A    2/B  | DC VOLTS      1/A   2/B   3/C
 CABIN       XX.XS       |   FC          XX.XS XX.XS XX.XS
 L/R FD      XX.XS XX.XS |   MAIN        XX.XS XX.XS XX.XS
 AV/BAY   1  XX.XS XX.XS |   ESS         XX.XS XX.XS XX.XS
          2  XX.XS XX.XS |              A-----B-----C-----A
          3  XX.XS XX.XS |   CNTL   1 XXX.XSXXX.XSXXX.XSX
        CABIN            |          2 XXX.XSXXX.XSXXX.XSX
 PRESS       XX.XS       |          3 XXX.XSXXX.XSXXX.XSX
 dP/dT-EQ   ±.XXS±X.XXXSAC
 O2 CONC   XXX.XS        |   VOLT   φA   XXXS   XXXS   XXXS
 PPO2        X.XXS X.XXS |          φB   XXXS   XXXS   XXXS
 FAN ΔP      X.XXS       |          φC   XXXS   XXXS   XXXS
 HX OUT T     XXXS       |   AMPS   φA  XX.XS XX.XS  XX.XS
 O2 FLOW     XX.XS XX.XS |          φB  XX.XS XX.XS  XX.XS
 N2 FLOW     XX.XS XX.XS |          φC  XX.XS XX.XS  XX.XS
 IMU FAN     AXS BXS CXS | FUEL CELL
  ΔV  FC1    FC2   FC3   |   AMPS         XXXS   XXXS  XXXS
 SS1  XXXS   XXXS  XXXS  |   REAC VLV     XX     XX     XX
 SS2  XXXS   XXXS  XXXS  |   STACK T   ±XXXS ±XXXS  ±XXXS
 SS3  XXXS   XXXS  XXXS  |   EXIT  T     XXXS  XXXS    XXXS
 TOTAL AMPS XXXXS        |   COOL  P     XXXS  XXXS    XXXS
          KW   XXS       |      PUMP      XXS   XXS     XXS
                                                       (XX)
```

085.cnv

PASS SM SYS SUMM 1, available in SM OPS 2



```
  2011/   /079      SM SYS SUMM 2      4 000/14:44:52
                                         000/00:00:00

  CRYO TK    1     2     3     4     5    MANF1 MANF2
 H2 PRESS   211   211   238   238   145L  238   238
 O2 PRESS   834   833   858   858   515L  858   858
 HTR T1    -221  -221  -212  -194  -194
     T2    -221  -221  -212  -194  -194
 --------------------------------------------------------
  APU        1     2     3 |  HYD     1      2      3
 TEMP EGT   20    15    11 | PRESS    65     65     65
  B/U EGT   16    15    15 | RSVR T   72     72     72
  OIL  IN   51    59    57 |      P    0      0      0
      OUT   56    54    59 |    QTY   55     55     55
 SPEED  %    0     0     0 |   W/B
 FUEL QTY   89    88    85 | H2O QTY  97     94     92
  PMP LK P  15    15    15 | BYP VLV BYP    BYP    BYP
 OIL OUT P  24    24    24 |
                           |   THERM CNTL    1      2
  AV BAY                   | H2O PUMP P     50     50
 TEMP       50    88    82 | FREON FLOW   2000   2000
 FAN  ΔP  3.59  3.64  3.67 | EVAP OUT T     50     50
```

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PASS SM SYS SUMM 2, available in SM OPS 2

Fault Detection and Annunciation

Five classes of alarms have been established. Class 1, Emergency, has no interface with software. Class 2, Caution and Warning (C/W), is the second highest alarm class. It is divided into primary (hardware-driven) and backup (software-driven) systems. An alarm of the software-driven class will result in the annunciation of the *BACKUP C/W ALARM* light on the C/W matrix on panel F7, the *MASTER ALARM* lights, and an associated tone. In addition, a fault message will be displayed upon the fault message line of the DPS display. Class 3, Alert, triggers the *SM ALERT* light and corresponding tone. A fault message is displayed on the fault message line. Class 5, Operator Errors, is the lowest priority alarm and is caused only by a crew entry error. It results in an ILLEGAL ENTRY fault message being displayed. Class 0, Limit Sense, provides a status indicator (down arrow, up arrow) to the right of the affected parameter on an appropriate IDP. No fault message, tone, or light is triggered.

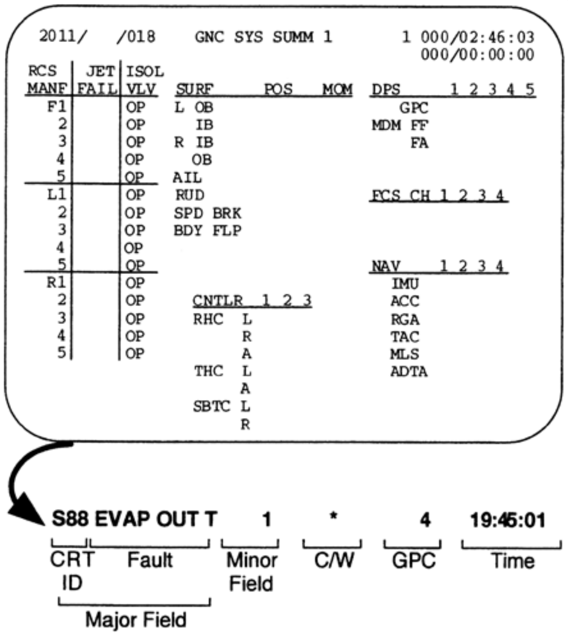
The output of a fault message to the fault message line results in several indications requiring crew interface. Although generally the crew keyboard responses are similar, the effects of these responses differ for each class alarm.

The crew response to a class 2 backup fault message is:

1. *Depress the MASTER ALARM pushbutton indicator*. This will extinguish the *MASTER ALARM* light and caution and warning tone.
2. *Depress the ACK key* (on the keyboard). The fault message will cease flashing. If the crewmember can examine the message while it flashes, this step is unnecessary. Depress the *ACK* key again to look at the next message in a stack if required.
3. *Depress the MSG RESET key*. Depression of this key removes the fault message from the fault message line. In addition, the *BACKUP C/W* light is extinguished. (Hardware-driven lights remain on until the problem is corrected.)

The crew response to a class 3 fault message is:

1. *Depress the ACK key*. This will cause the fault message to become static. Depressing the ACK key will also extinguish the *SM ALERT* light and tone. (The tone duration is set to a crew-selected length and may have stopped before the ACK key is pressed.) Depress the ACK key again to look at the next message in a stack if required.
2. *Depress the MSG RESET key*. This will remove the fault message from the fault message line. If the ACK key had not been depressed, the MSG RESET key would extinguish the SM *ALERT* light and tone.



```
2011/   /018    GNC SYS SUMM 1        1 000/02:46:03
                                        000/00:00:00
RCS | JET|ISOL
MANF|FAIL|VLV   SURF      POS   MOM  DPS      1 2 3 4 5
  F1|    |OP    L OB                    GPC
   2|    |OP      IB                 MDM FF
   3|    |OP    R IB                       FA
   4|    |OP      OB
   5|    |OP    AIL
  L1|    |OP    RUD                  FCS CH 1 2 3 4
   2|    |OP    SPD BRK
   3|    |OP    BDY FLP
   4|    |OP
   5|    |OP                         NAV     1 2 3 4
  R1|    |OP                           IMU
   2|    |OP     CNTLR  1 2 3          ACC
   3|    |OP     RHC  L                RGA
   4|    |OP          R                TAC
   5|    |OP          A                MLS
                 THC  L                ADTA
                      A
                 SBTC L
                      R

S88 EVAP OUT T     1     *     4    19:45:01
```

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Sample CRT Fault Message

A class 5 fault message displays a flashing "ILLEGAL ENTRY" on the fault message line. The crew response is simply to depress the *MSG RESET* key. This clears the fault message from the fault message line. The *ACK* key will not clear an "ILLEGAL ENTRY." It will cause messages stacked under the "ILLEGAL ENTRY" display to be acknowledged and cleared.

Some illegal keyboard entries are detected by the IDP before being sent to the GPCs. When this occurs, a flashing "ERR" appears immediately to the right of the erroneous entry on the scratch pad line. The crew response is simply to depress the CLEAR key. Upon depression of the CLEAR key, the "ERR" and the last keystroke will disappear. Subsequent depressions of the CLEAR key will remove single keystrokes, proceeding from right to left. This feature enables the crew to CLEAR back to the portion of the command that was incorrect, correct it, and proceed. This type of error is not identified by class, since it is not GPC-detected and is known simply as an IDP-detected error.

Fault Messages

Fault messages associated with alarm classes 2, 3, and 5 follow a standard format of five fields.

The major field is a 14-character field. The first three characters identify the display on which more information about the annunciated failure can be found. An S or a G, followed by a two digit number, indicates the major function (G for GNC and S for SM) and the number of the SPEC or DISP. If no display is associated with the fault, this field is blank. In the example below, "S88" is the CRT ID and means that information on the fault can be found on SPEC 88 in SM.

The remaining characters identify the problem or subsystem group associated with the fault. In the example, "EVAP OUT T" is the FAULT portion of the major field and indicates a fault in the flash evaporator subsystem.

The minor field is a four-character field that further identifies the fault. It will specify the subdivision, direction, location, parameter, or specific unit of the subsystem or problem identified in the major field. In the example fault message, "1" is the minor field message and means that the temperature sensor 1 is the area in which the fault was detected.

The C/W field is used only with caution and warning class 2 backup messages. An asterisk appears in this column across from the corresponding fault to denote that the condition is a class 2 backup alarm.

The GPC field identifies the GPC that detected this fault. This characteristic aids the crewmember in locating or identifying internal GPC or I/O errors.

The far right field is the TIME field. This field indicates the time at which the fault occurred. The time is MET and is displayed in hours, minutes, and seconds (HH:MM:SS).

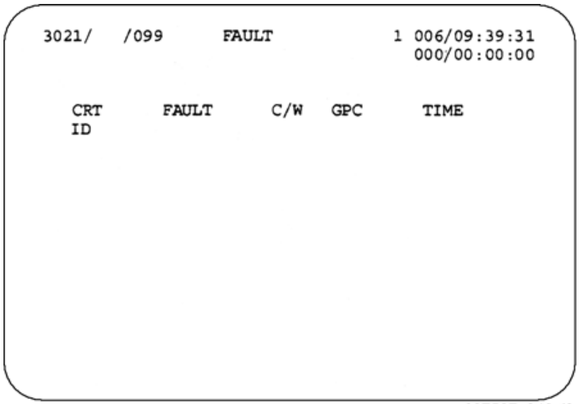
A complete listing of all possible fault messages can be found in the Flight Data File Reference Data Book and in Section 2.2.

A class 5 alarm is annunciated by an "ILLEGAL ENTRY" in the major field, and all other fault message fields are blank. When a class 5 message is received, it is displayed instantaneously on the fault message line of the IDP's DPS display where the error occurred, rather than on all IDPs like class 2 and 3 errors.

To get rid of the class 5 message, a MSG RESET must be done to the IDP where the error occurred. Class 2 backup and class 3 messages are extinguished by a MSG RESET on any IDP.

The Fault Summary Display

A historical summary of class 2 backup and class 3 fault messages is provided via the FAULT display (DISP 99). Class 5 errors are not displayed as they are caused by illegal crew entries to a single IDP. The FAULT display is a DISP available in all OPS. It is selected for viewing by depression of the FAULT SUMM key.



```
3021/   /099      FAULT             1 006/09:39:31
                                      000/00:00:00

  CRT     FAULT     C/W   GPC      TIME
  ID
```

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FAULT Display (DISP 99)

The PASS fault summary display consists of up to 15 fault message lines. They appear in reverse chronological order. The oldest message appears on the bottom line. When a new fault message is generated, it appears on the top line. The other messages are pushed down, and the 15th message (the oldest) disappears.

The only difference between the fault messages on the FAULT display and the fault message on the fault message line is the TIME field. On the FAULT display, the time field includes days as well as hours, minutes, and seconds (DDD/HH: MM:SS).

Sometimes, a subsystem failure or malfunction results in the output of several fault messages, some of which may be identical. The fault detection and annunciation logic can prevent the annunciation of identical fault messages. When a fault message is generated, its major and minor fields are compared to those of the top message of the display. If the fields are the same, and if the new fault message has occurred within a 4.8 second window, the new message is inhibited.

The last message displayed on the fault message line of any DPS display is not necessarily the most recent fault message. Unless the fault message line was cleared with a MSG RESET, the crewmember will not see new messages that came in after the flashing or frozen message. In that case, the crewmembers can see if a new message has been annunciated by looking at a two-character field, which is called the buffer message indicator and is located in the last field on the far right of the fault message line.

The buffer message indicator serves to indicate the number of messages in the fault buffer on the FAULT display since the last MSG RESET. This number includes class 2 backup and class 3 messages only. Class 5 messages and the currently displayed messages are not included in this counter. The number is enclosed by parentheses. If no fault messages are in the stack, this field is blank. To view any of these messages, the crewmember may depress the ACK key to display subsequent messages or look at the FAULT display. A MSG RESET clears both the fault message line and the buffer message indicator.

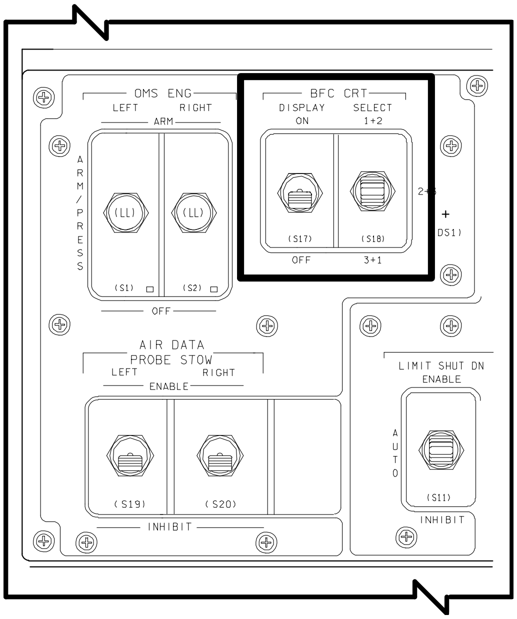
In addition to using the FAULT SUMM key, the FAULT display may also be selected by the keyboard entry "SPEC 99 PRO." However, this command will clear all fault messages from the FAULT display and the fault message lines. This capability is useful if and when the fault messages displayed are no longer significant (i.e., they are old, or they have been dealt with).

Crew Software Interface with the BFS

The crew software interface with the BFS is designed to be as much like PASS as possible, but there are some differences. This section covers the differences between the PASS's and BFS's crew and IDP interfaces. If something is not mentioned in this section, it can be assumed to operate the same as the PASS interface.

BFC CRT Switches

Panel C3 contains two switches relevant to BFS operations. The *BFC CRT DISPLAY* switch is a two-position *ON/OFF* switch. In the *ON* position, the IDP(s) specified by the *BFC CRT SELECT* switch is driven by the BFS computer. (The *BFC CRT SELECT* switch controls IDP assignment to the BFS computer.) The switch is read by the GPC only when the *BFC CRT DISPLAY* switch is in the *ON* position. The *BFC CRT SELECT* switch has three positions. In each position, the first digit is the IDP commanded by the BFS pre-engage. Post-engaged, the BFS also commands a second IDP indicated by the second number. For example, when the *BFC CRT SELECT* switch is in the *1 + 2* position, IDP 1 is connected to the BFS GPC *prior* to engaging the BFS. After the BFS is engaged, this switch position allows the BFS computer to command both IDP 1 and IDP 2. During ascent and entry, one forward IDP will normally be assigned to the BFS via the *BFC CRT SELECT* switch. The nominal position of the switch is the 3+1 position. However, this switch position may be changed at any time, pre-engage or post-engage. If the BFS is engaged with the *BFC CRT DISPLAY* switch *OFF*, the BFS will automatically assume command of IDPs 1 and 2. IDP 4 is typically assigned to the BFS as well via a GPC/CRT assignment (mission specific). No set of *BFC CRT* switches exists for the IDP 4.



BFC CRT DISPLAY and SELECT Switches on Panel C3

BFS Functions of the MAJ FUNC Switch

The *MAJ FUNC* switches on panels C2 and R11L are also functional for the BFS. However, the display data and functional software accessed by the three-position switch are slightly different. The BFS functions of the MAJ FUNC switch are defined as follows:

- *GNC*: Flight critical software including limited guidance, navigation, and control software is contained in this major function. The BFS GNC major function contains only that software necessary for safe orbital insertion and return, including ascent abort logic.
- *SM*: This major function contains limited nonredundant systems management and payload software. There is no room in the BFS for the redundancy management found in PASS. When the *MAJ FUNC* switch is set in the SM position, the THERMAL display is invoked. This display is unique to the BFS.
- PL: This major function is not functional for the BFS. Should the *MAJ FUNC* switch be set in this position, no display change would occur. If the *BFC CRT DISPLAY* switch is turned on, allowing the BFS to drive an IDP already in the PL major function, the DPS display will be blank except for time and GPC driver fields because the BFS has no software to support this major function.

BFS ENGAGE Pushbutton

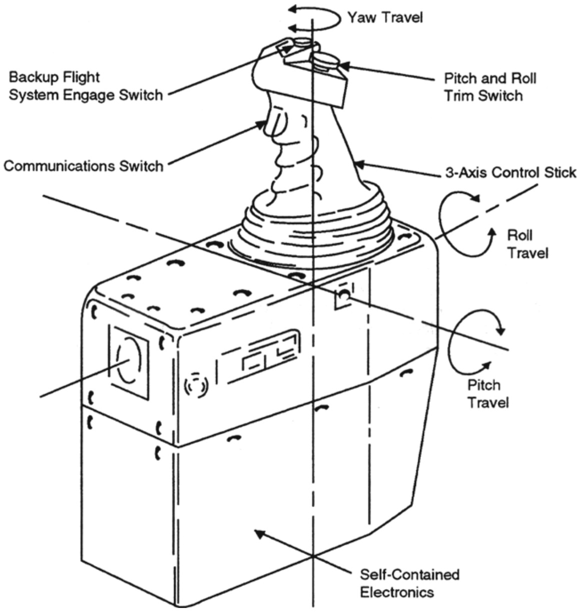
The BFS ENGAGE pushbutton is located on the commander's and pilot's rotational hand controllers (RHCs). During the dynamic flight phases (ascent and entry), the commander and pilot usually rest a hand on or near the RHC. In this way, BFS engagement can occur as quickly as possible. If the crew delays engagement during these flight phases, they could lose control of the vehicle, or the BFS' navigation calculations could degrade very quickly so that control would be essentially lost after engagement.

Some force (8 lb) is required to depress this pushbutton to prevent inadvertent engages. While on-orbit, the pushbutton is essentially disabled by reconfiguring the BFS OUTPUT switch. The BFS cannot track PASS while it is in OPS 2 and is moded to HALT on-orbit. If the BFS needs to be engaged on-orbit, the BFS must be "awakened", and the only software that will be of any use is entry and systems management software.

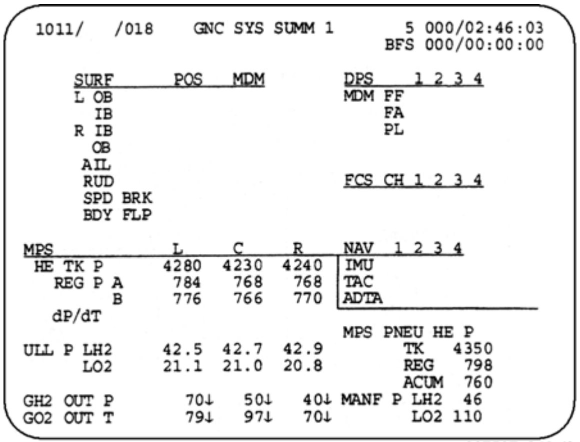
Keyboard and Display Differences for the BFS

The keyboard operates exactly the same way for the BFS as for the PASS. A few additional capabilities need to be mentioned.

- The GPC/CRT key: In addition to the *BFC CRT DISPLAY* switch, this key provides the capability to assign an IDP to (or isolate an IDP from) the BFS GPC. Both methods can be used interchangeably, but as long as the *BFC CRT DISPLAY* switch is working, it is the fastest method of allowing the BFS to drive an IDP or to change BFS IDPs. The *BFC CRT DISPLAY* switch allows PASS to automatically begin driving the IDP again when the BFS is turned off. When the BFS is assigned an IDP with the GPC/CRT key, it is the same as deassigning that screen from PASS with a GPC/CRT 0X EXEC. PASS must be reassigned to resume commanding of that IDP.
- The BFS INDICATOR: When the BFS is commanding an IDP, the BFS indicator will appear on that IDP's DPS display. On the second line of every BFS display a three-character space field has been reserved for the message "BFS." This field is located directly below the GPC indicator. The BFS indicator is displayed in the overbright intensity and is intended to prevent possible confusion of a PASS display with a BFS display. Often the BFS display will be identical or very close to the corresponding PASS display.



Rotational Hand Controller



```
1011/   /018    GNC SYS SUMM 1         5 000/02:46:03
                                     BFS 000/00:00:00

     SURF       POS   MDM          DPS     1 2 3 4
     L OB                          MDM FF
       IB                              FA
     R IB                              PL
       OB
      AIL
      RUD                          FCS CH 1 2 3 4
      SPD BRK
      BDY FLP

MPS              L     C     R     NAV  1 2 3 4
 HE TK P        4280  4230  4240  |IMU
    REG P A      784   768   768  |TAC
          B      776   766   770  |ADTA
   dP/dT                          ------------------
                                   MPS PNEU HE P
ULL P LH2       42.5  42.7  42.9        TK    4350
      LO2       21.1  21.0  20.8        REG    798
                                        ACUM   760
GH2  OUT P        70↓   50↓   40↓ MANF P LH2    46
GO2  OUT T        79↓   97↓   70↓          LO2 110
```

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BFS Indicator on DPS Display

BFS Display Sequencing

The BFS is designed to operate in the same manner as the PASS where possible. BFS requirements, however, demanded a distinction be made between BFS pre-engage and BFS post-engage major mode transitions and associated display sequencing.

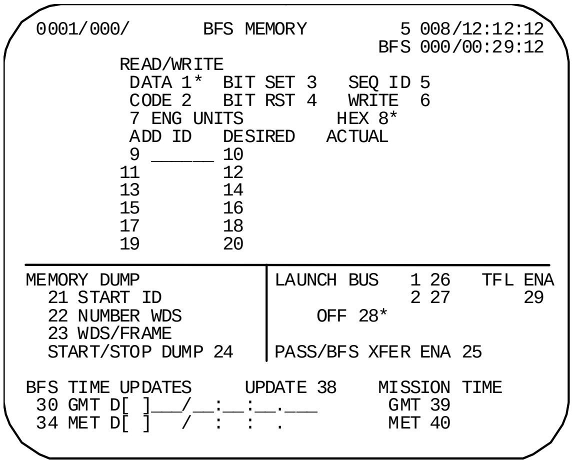
BFS pre-engage major mode display sequencing is either automatic, or it may be performed in the same manner as that of the PASS. Before the BFS is engaged, the BFS is listening to keyboard inputs made to the PASS controlled IDPs across the display/keyboard (DK) buses and updating its software accordingly. This is called DK listening and the BFS can hear PASS item entries, PASS major mode transitions, and PASS GPC/CRT assignments. On the other hand, the PASS doesn't know that the BFS exists, so it never DK listens to the BFS. Therefore, BFS major mode transitions are performed automatically as a function of the major mode transitions performed on a PASS keyboard. If the BFS does not follow the PASS major mode transitions, then the BFS must receive a manual OPS XXX PRO.

BFS post-engage major mode display sequencing is the same as that of the PASS. After the BFS is engaged, the BFS GPC is on its own. It no longer listens to the PASS GPCs. Therefore, major mode display sequencing has been designed to be the same as that of the PASS.

Three operational sequences are defined for BFS GNC; one operational sequence is defined for the BFS SM. Transactions to and from these OPS displays differ considerably from the PASS. BFS keyboard and DPS display peculiarities are outlined as follows:

- BFS GNC OPS 0 - BFS MEMORY display: This display is forced to the DPS display when BFS is not processing either GNC OPS 1 or 3. Nominally, this occurs prior to ascent and again prior to entry. This display corresponds to the PASS GPC MEMORY display and performs the same functions for the BFS. It also performs some of the same functions as PASS SPEC 2, the TIME SPEC, in that time updates can be performed along with selection of GMT or MET to be displayed. GPC MEMORY is the default display for PASS OPS 0, and the BFS MEMORY display is the default display for BFS GNC OPS 0.

- BFS GNC OPS 1 and 6 - Ascent: This OPS must be manually selected via a keyboard assigned to the BFS prelaunch. BFS GNC OPS 1 is available for use during the ascent portion of the mission. The OPS 6 transition is automatic upon abort selection with the ABORT rotary switch and pushbutton, or an OPS 601 PRO may be used.



```
0001/000/       BFS MEMORY        5 008/12:12:12
                                BFS 000/00:29:12
        READ/WRITE
         DATA 1*  BIT SET 3   SEQ ID 5
         CODE 2   BIT RST 4   WRITE  6
         7 ENG UNITS         HEX 8*
         ADD ID   DESIRED   ACTUAL
         9 ______ 10
        11        12
        13        14
        15        16
        17        18
        19        20
MEMORY DUMP            | LAUNCH BUS   1 26   TFL ENA
  21 START ID          |              2 27       29
  22 NUMBER WDS        |     OFF 28*
  23 WDS/FRAME         |
  START/STOP DUMP 24   | PASS/BFS XFER ENA 25

BFS TIME UPDATES     UPDATE 38    MISSION TIME
 30 GMT D[ ]___/__:__:__.___        GMT 39
 34 MET D[ ]   /  :  :  .           MET 40
```

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BFS MEMORY Display

- BFS GNC OPS 3 - Entry: This OPS must be manually selected from BFS GNC OPS 0 or BFS GNC OPS 1. BFS GNC OPS 3 is available for use during the entry portion of the mission. It is a legal transition to go from the BFS GNC OPS 1 to BFS GNC OPS 3 (for aborts), but nominally, the transition will be from BFS GNC OPS 0. In both cases, the manual keyboard entry "OPS 301 PRO" is required.

The major mode displays for BFS OPS 1, 3, and 6 are similar, if not identical, to their PASS counterparts. A complete listing of PASS and BFS displays can be found in the DPS Dictionary.

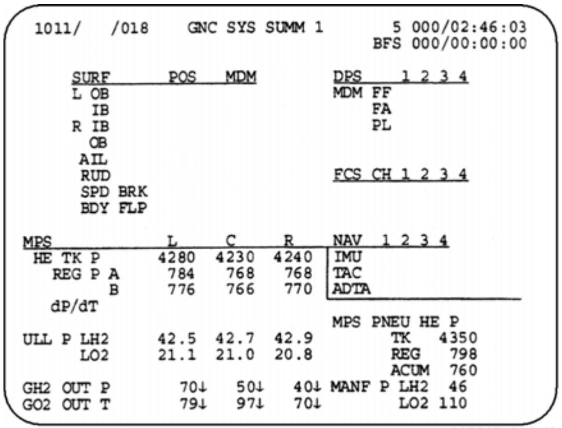
BFS Special Operations and Displays

In the pre-engaged mode, the BFS GPC performs BCE and MDM bypasses when PASS data are bypassed, or it sets its own bypasses. The I/O RESET command when made via the BFS keyboard restores those I/O configurations set by the BFS GPC. That is, a BFS "I/O RESET EXEC" restores the bypasses set by the BFS GPC. In addition, the I/O RESET operation attempts to synchronize the BFS with the PASS GPC listen commands so the BFS can track PASS.

Post-engage, the only bypasses set are those detected by the BFS GPC. The "I/O RESET EXEC" command functions to restore those bypasses.

The BFS systems summary displays operate the same way the PASS displays work. The BFS display numbers are the same as their PASS counterparts and some of the displays themselves are identical. However, three of the BFS SYS SUMM displays are unique to the BFS.

- GNC SYS SUMM. The GNC SYS SUMM consists of two DISPs. GNC SYS SUMM 1 is display format and content unique to BFS. It is called via the SYS SUMM key or by the command "SPEC 18 PRO." GNC SYS SUMM 2 is identical to the GNC SYS SUMM 2 display available in the PASS OPS 2 and 8. It is called by the command "SPEC 19 PRO" or by depressing the SYS SUMM key twice.



```
1011/    /018     GNC SYS SUMM 1          5 000/02:46:03
                                        BFS 000/00:00:00

      SURF         POS    MDM           DPS      1 2 3 4
      L OB                              MDM FF
          IB                                FA
      R IB                                  PL
         OB
       AIL
       RUD                              FCS CH 1 2 3 4
       SPD BRK
       BDY FLP

MPS                L      C      R      NAV  1 2 3 4
 HE TK P         4280   4230   4240   | IMU
   REG P A        784    768    768   | TAC
         B        776    766    770   | ADTA
  dP/dT
                                        MPS PNEU HE P
ULL P LH2        42.5   42.7   42.9            TK   4350
      LO2        21.1   21.0   20.8            REG   798
                                               ACUM  760
GH2  OUT P         70↓    50↓    40↓  MANF P LH2    46
GO2  OUT T         79↓    97↓    70↓         LO2   110
```

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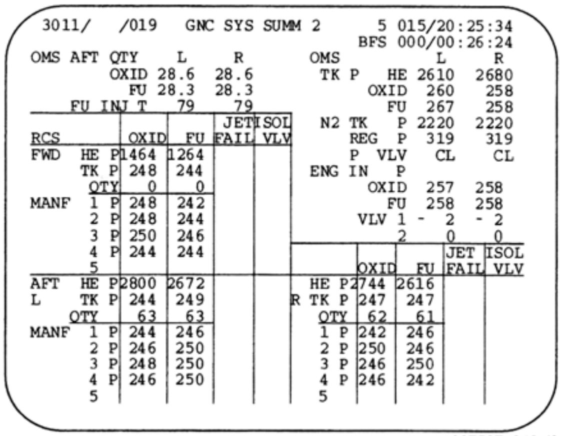
BFS GNC SYS SUMM 1, available in GNC OPS 1, 6, and 3 (Unique to BFS)



```
 3011/    /019    GNC SYS SUMM 2          5 015/20:25:34
                                        BFS 000/00:26:24
OMS AFT QTY     L      R          OMS              L      R
        OXID 28.6   28.6           TK P     HE  2610   2680
          FU 28.3   28.3                  OXID   260    258
    FU INJ T   79     79                    FU   267    258
                         |JET |ISOL    N2 TK     P  2220   2220
RCS         | OXID|  FU  |FAIL| VLV       REG    P   319    319
FWD   HE  P|1464 |1264   |    |           P  VLV     CL     CL
      TK  P| 248 | 244   |    |      ENG IN    P
        QTY|   0 |   0   |    |             OXID   257    258
MANF   1  P| 248 | 242   |    |               FU   258    258
       2  P| 248 | 244   |    |            VLV 1 -   2    - 2
       3  P| 250 | 246   |    |                2     0      0
       4  P| 244 | 244   |    |                           |JET |ISOL
       5   |     |       |    |              | OXID|  FU  |FAIL| VLV
AFT   HE  P|2800 |2672   |    |      HE  P|2744 |2616  |    |
L     TK  P| 244 | 249   |    |    R TK  P|247  | 247  |    |
     QTY   |  63 |  63   |    |      QTY  |  62 |  61  |    |
MANF   1  P| 244 | 246   |    |      1  P |242  | 246  |    |
       2  P| 246 | 250   |    |      2  P |250  | 246  |    |
       3  P| 248 | 250   |    |      3  P |246  | 250  |    |
       4  P| 246 | 250   |    |      4  P |246  | 242  |    |
       5   |     |       |    |      5    |     |      |    |
```

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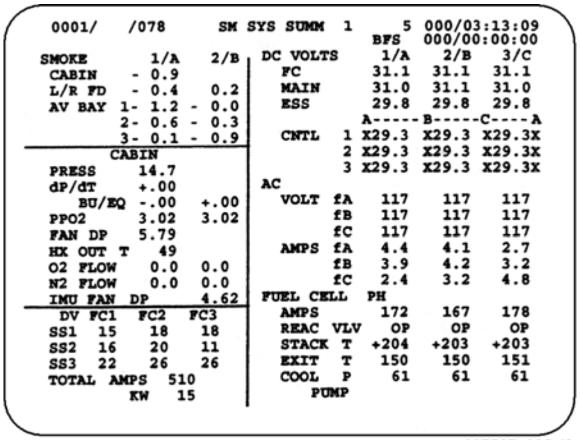
BFS GNC SYS SUMM 2, available in GNC OPS 1, 6, and 3 (Identical to PASS GNC SYS SUMM 2 except shaded lines)

- SM SYS SUMM. There are two SM SYS SUMM displays. SM SYS SUMM 1 is identical to the PASS SM SYS SUMM 1, while BFS SM SYS SUMM 2 is a unique display. They are called in the same manner as the PASS SM SYS SUMM displays.

- THERMAL. This is a systems summary DISP available as the SM OPS 0 display in BFS. It is forced to the screen anytime the MAJ FUNC switch is placed in the SM position (unless an SM SPEC is called up over it). This display is unique to the BFS. It cannot be obtained with a SPEC key, and it never requires a keyboard entry.



```
 0001/    /078      SM SYS SUMM  1      5 000/03:13:09
                                      BFS  000/00:00:00
SMOKE        1/A    2/B | DC VOLTS     1/A    2/B    3/C
 CABIN     - 0.9        |  FC          31.1   31.1   31.1
 L/R FD    - 0.4    0.2 |  MAIN        31.0   31.1   31.0
 AV BAY 1- 1.2  -  0.0  |  ESS         29.8   29.8   29.8
        2- 0.6  -  0.3  |            A-----B-----C----A
        3- 0.1  -  0.9  |  CNTL    1 X29.3  X29.3  X29.3X
         CABIN          |          2 X29.3  X29.3  X29.3X
 PRESS     14.7         |          3 X29.3  X29.3  X29.3X
 dP/dT     +.00         | AC
    BU/EQ  -.00    +.00 |  VOLT  fA   117    117    117
 PPO2      3.02    3.02 |        fB   117    117    117
 FAN DP    5.79         |        fC   117    117    117
 HX OUT T    49         |  AMPS  fA   4.4    4.1    2.7
 O2 FLOW    0.0    0.0  |        fB   3.9    4.2    3.2
 N2 FLOW    0.0    0.0  |        fC   2.4    3.2    4.8
 IMU FAN  DP       4.62 | FUEL CELL  PH
  DV FC1   FC2   FC3    |  AMPS       172    167    178
 SS1  15    18    18    |  REAC VLV    OP     OP     OP
 SS2  16    20    11    |  STACK  T  +204   +203   +203
 SS3  22    26    26    |  EXIT   T   150    150    151
 TOTAL AMPS  510        |  COOL   P    61     61     61
         KW   15        |     PUMP
```

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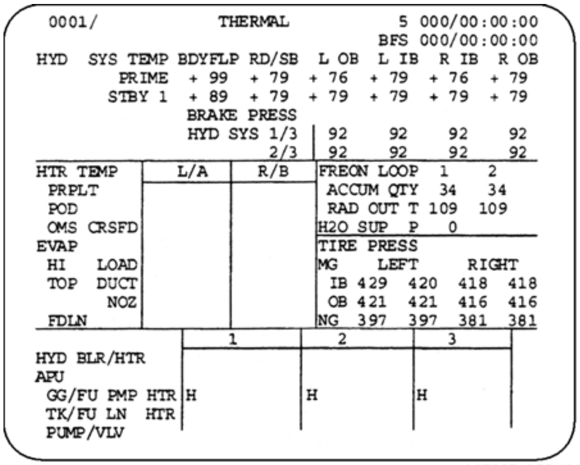
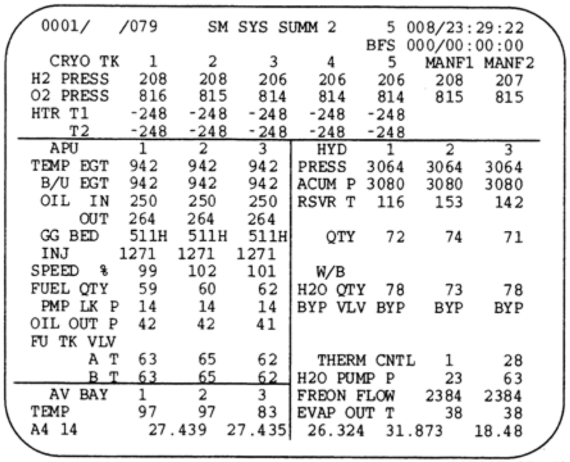
BFS SM SYS SUMM 1, available in SM OPS 0 (Unique to BFS)



```
 0001/              THERMAL               5 000/00:00:00
                                        BFS 000/00:00:00
HYD  SYS TEMP BDYFLP RD/SB  L OB  L IB  R IB  R OB
         PRIME  + 99  + 79  + 76  + 79  + 76  + 79
        STBY 1  + 89  + 79  + 79  + 79  + 79  + 79
                BRAKE PRESS
                HYD SYS 1/3 | 92    92    92    92
                        2/3 | 92    92    92    92
HTR TEMP    |   L/A   |  R/B  |FREON LOOP  1    2
 PRPLT      |         |       | ACCUM QTY  34   34
 POD        |         |       | RAD OUT T 109  109
 OMS CRSFD  |         |       |H2O SUP  P   0
EVAP        |         |       |TIRE PRESS
 HI   LOAD  |         |       |MG    LEFT      RIGHT
 TOP  DUCT  |         |       | IB 429  420  418  418
       NOZ  |         |       | OB 421  421  416  416
 FDLN       |         |       |NG  397  397  381  381
                |     1      |    2     |    3    |
HYD BLR/HTR     |            |          |         |
APU             |            |          |         |
 GG/FU PMP HTR  |H           |H         |H        |
 TK/FU LN  HTR  |            |          |         |
 PUMP/VLV
```

usa007587_255.tif

BFS THERMAL, available in SM OPS 0 (unique to BFS)



```
 0001/   /079      SM SYS SUMM 2      5 008/23:29:22
                                    BFS 000/00:00:00
  CRYO TK    1     2     3     4     5   MANF1 MANF2
H2 PRESS    208   208   206   206   206   208   207
O2 PRESS    816   815   814   814   814   815   815
HTR T1     -248  -248  -248  -248  -248
    T2     -248  -248  -248  -248  -248
  APU       1     2     3  | HYD     1     2     3
TEMP EGT   942   942   942 |PRESS  3064  3064  3064
 B/U EGT   942   942   942 |ACUM P 3080  3080  3080
 OIL  IN   250   250   250 |RSVR T  116   153   142
     OUT   264   264   264 |
 GG BED    511H  511H  511H|  QTY    72    74    71
 INJ      1271  1271  1271 |
SPEED  %    99   102   101 | W/B
FUEL QTY    59    60    62 |H2O QTY  78    73    78
 PMP LK P   14    14    14 |BYP VLV BYP   BYP   BYP
OIL OUT P   42    42    41 |
FU TK VLV                  |
       A T  63    65    62 | THERM CNTL    1    28
       B T  63    65    62 |H2O PUMP P    23    63
  AV BAY    1     2     3  |FREON FLOW  2384  2384
TEMP        97    97    83 |EVAP OUT T    38    38
A4 14          27.439 27.435| 26.324 31.873   18.48
```

usa007587_051.tif

BFS SM SYS SUMM 2, available in SM OPS 0 (unique to BFS)

BFS Fault Messages

Several crew interface characteristics of fault annunciation in the BFS differ from those in the PASS.

- The BFS FAULT display. The BFS FAULT display functions in the same manner as the PASS. The BFS FAULT display is composed of 20 fault lines as compared to 15 in the PASS. The C/W field displays an asterisk when the message annunciated is a class 2 backup alarm. The BFS FAULT display provides a history of only class 2 backup and class 3 messages annunciated by the BFS GPC itself.

- BFS Unique CRT IDs. In BFS SM, all messages referring to SM SYS SUMM 1 or SM SYS SUMM 2 are indicated by the CRT IDs SM1 and SM2. Fault messages referring to the THERMAL display are indicated by the CRT ID SM0.

DPS Summary Data

- The DPS combines various hardware components and self-contained software to provide computerized monitoring and control.

- DPS hardware includes 5 GPCs, 2 modular memory units, a data bus network, 20 MDMs, 4 IDPs, 11 MDUs, and other specialized equipment.

- Each of the five GPCs consists of a CPU and an IOP stored in one avionics box. During ascent/entry, four of the GPCs are loaded with identical PASS software; the fifth is loaded with different software, the BFS.

- The data bus network transfers data between the GPCs and vehicle systems. There are seven types of data buses: flight-critical, payload, launch, mass memory, display/keyboard, instrumentation/PCMMU, and intercomputer communication.

- The 13 DPS MDMs convert data to appropriate formats for transfer between the GPCs and vehicle systems.

- Two modular memory units provide bulk storage for software and data.

- Four IDPs, 11 MDUs, and associated keyboards provide the means for flight crew interaction with the GPCs.

- The two types of DPS software, system software and applications software, combine to form a memory configuration for a specific mission phase.

- The system software is operating software that always resides in GPC main memory.

- The applications software performs the functions required to fly and operate the vehicle. It is divided into three major functions: guidance, navigation, and control (GNC); systems management (SM); and payload (PL).

- Major functions are divided into mission phase oriented blocks called operational sequences (OPS).

- OPS are further divided into blocks called major modes (MM), which relate to specific portions of a mission phase.

- There are three levels of DPS displays: major mode or OPS, specialist (SPEC), and display (DISP).

- The four PASS GPCs control all GNC functions during ascent/entry mission phases; the fifth GPC is loaded with backup flight system (BFS) software to take over in case of PASS GPC failure.

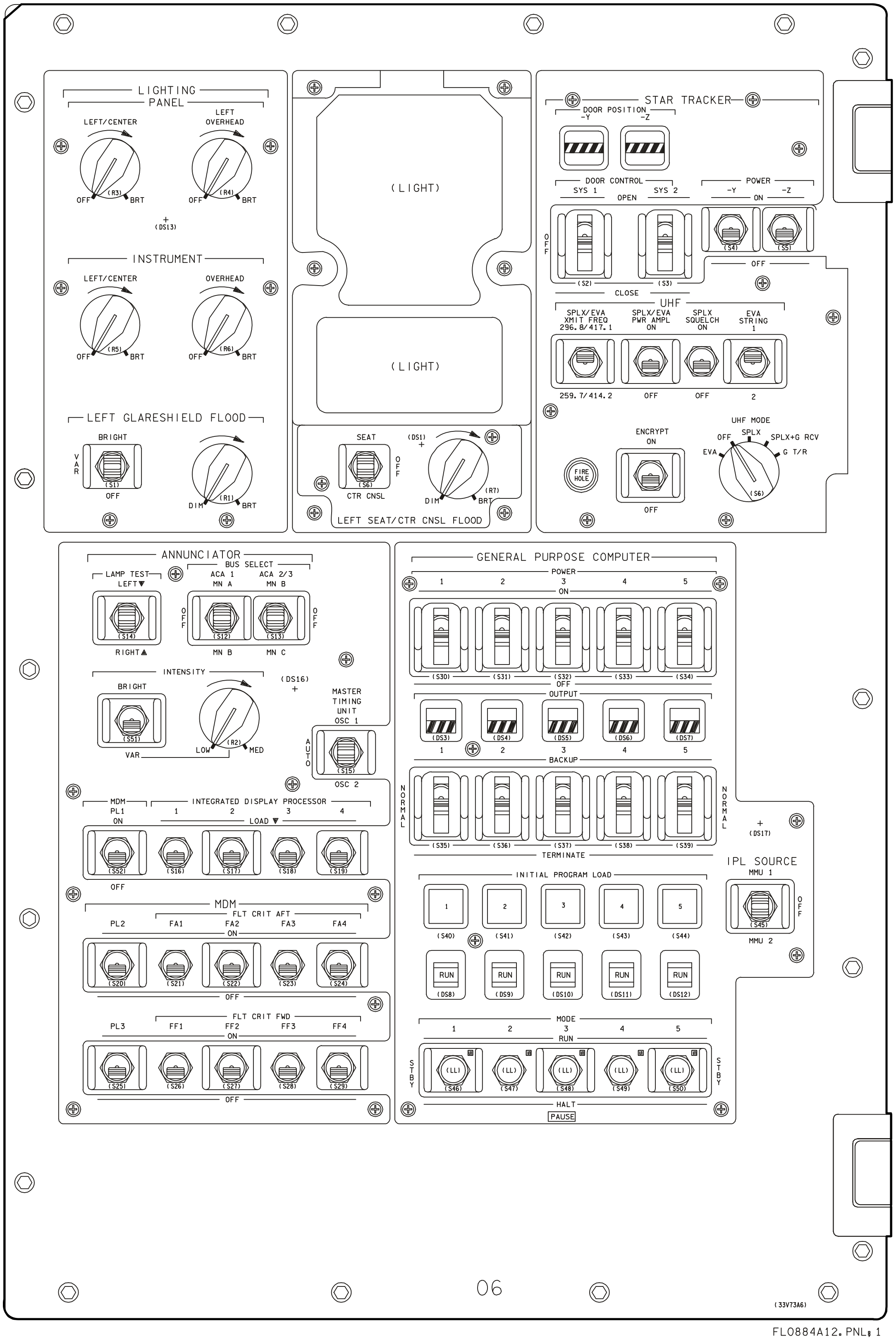
- The BFS contains a limited amount of software; there are some operational differences between BFS and PASS.

- The BFS is engaged by pushbutton on the rotational hand controller.

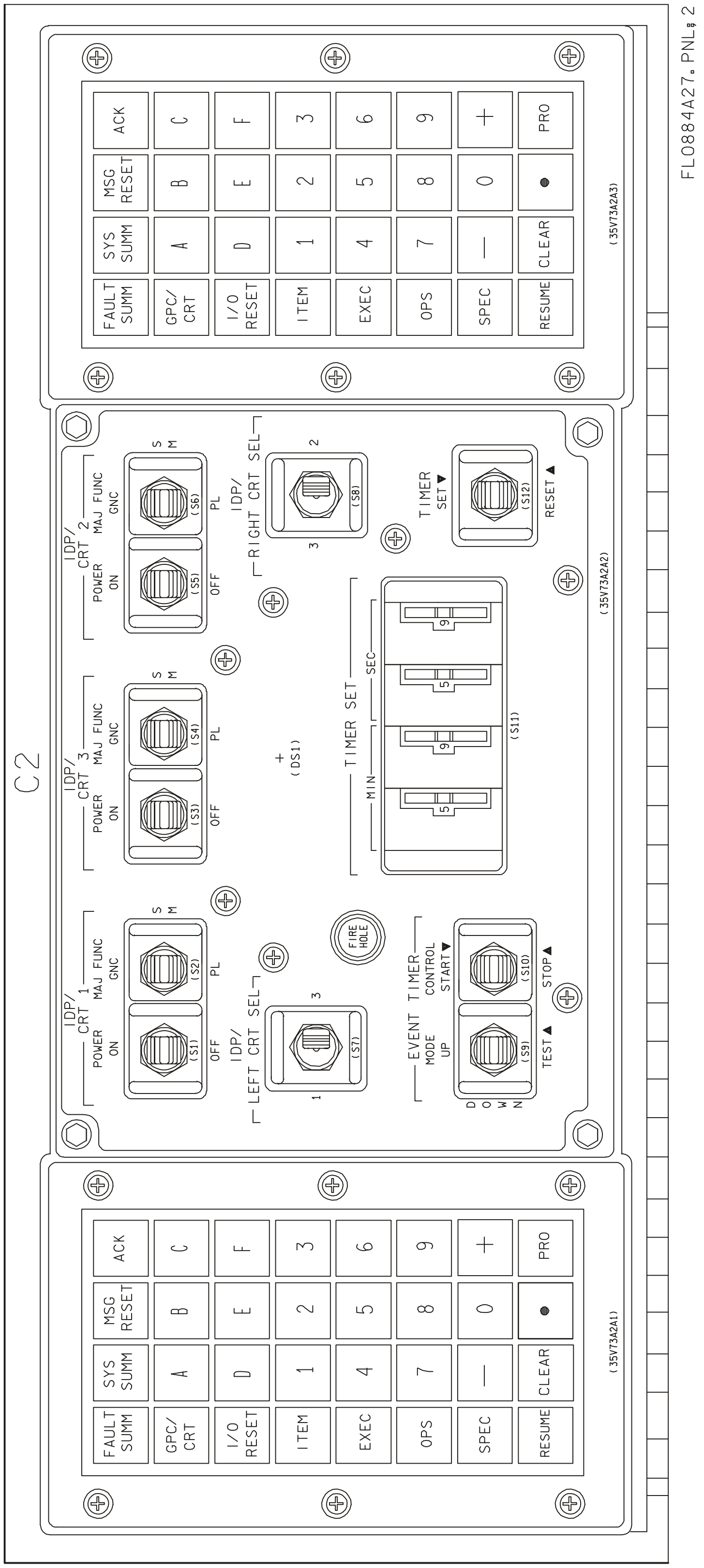
- A GPC FAIL detection will display a class 2 GPC FAULT message with illumination of the MASTER ALARM. The GPC STATUS matrix (sometimes referred to as the computer annunciation matrix (CAM)) on panel O1 lights to indicate failure votes; any time a yellow matrix light is illuminated, the GPC caution and warning light on panel F7 also lights.

- Most DPS control switches are located on panels O6 and C2. Others may be found on panels C3, R11L, F2, F4, F6, and F7.

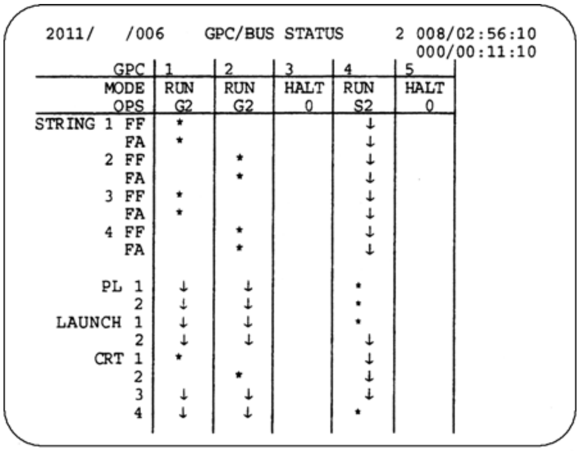
- DPS displays relevant to the DPS are: GPC/BUS STATUS (SPEC 6), GPC MEMORY (SPEC 0), DPS UTILITY (SPEC 1), and TIME (SPEC 2).


LIGHTING PANEL
LEFT/CENTER
LEFT OVERHEAD
OFF (R3) BRT
OFF (R4) BRT
(DS13)
INSTRUMENT
LEFT/CENTER
OVERHEAD
OFF (R5) BRT
OFF (R6) BRT
LEFT GLARESHIELD FLOOD
BRIGHT
VAR
(S1)
OFF
DIM (R1) BRT
(LIGHT)
(LIGHT)
SEAT
(DS1)
(S6)
OFF
CTR CNSL
DIM (R7) BRT
LEFT SEAT/CTR CNSL FLOOD
STAR TRACKER
DOOR POSITION
-Y
-Z
DOOR CONTROL
SYS 1
SYS 2
OPEN
POWER
-Y
-Z
ON
OFF
(S2)
(S3)
(S4)
(S5)
OFF
CLOSE
UHF
SPLX/EVA XMIT FREQ 296.8/417.1
SPLX/EVA PWR AMPL ON
SPLX SQUELCH ON
EVA STRING 1
259.7/414.2
OFF
OFF
2
UHF MODE
ENCRYPT ON
OFF
OFF
SPLX
SPLX+G RCV
EVA
G T/R
(S6)
FIRE HOLE
ANNUNCIATOR
LAMP TEST
LEFT▼
BUS SELECT
ACA 1 MN A
ACA 2/3 MN B
OFF
OFF
(S14)
(S12)
(S13)
RIGHT▲
MN B
MN C
INTENSITY
(DS16)
BRIGHT
(S51)
VAR
LOW (R2) MED
MASTER TIMING UNIT OSC 1
AUTO
(S15)
OSC 2
MDM PL1 ON
INTEGRATED DISPLAY PROCESSOR
1 2 3 4
LOAD ▼
(S52) (S16) (S17) (S18) (S19)
OFF
MDM
FLT CRIT AFT
PL2 FA1 FA2 FA3 FA4
ON
(S20) (S21) (S22) (S23) (S24)
OFF
FLT CRIT FWD
PL3 FF1 FF2 FF3 FF4
ON
(S25) (S26) (S27) (S28) (S29)
OFF
GENERAL PURPOSE COMPUTER
POWER
1 2 3 4 5
ON
(S30) (S31) (S32) (S33) (S34)
OFF
OUTPUT
(DS3) (DS4) (DS5) (DS6) (DS7)
1 2 3 4 5
BACKUP
NORMAL
NORMAL
(S35) (S36) (S37) (S38) (S39)
TERMINATE
(DS17)
INITIAL PROGRAM LOAD
1 2 3 4 5
(S40) (S41) (S42) (S43) (S44)
IPL SOURCE
MMU 1
OFF
(S45)
MMU 2
RUN RUN RUN RUN RUN
(DS8) (DS9) (DS10) (DS11) (DS12)
MODE
1 2 3 4 5
RUN
STBY
(LL) (LL) (LL) (LL) (LL)
(S46) (S47) (S48) (S49) (S50)
STBY
HALT
PAUSE
O6
(33V73A6)
FL0884A12.PNL;1

Panel O6


C2
FL0884A27.PNL;2
ACK
MSG RESET
SYS SUMM
FAULT SUMM
GPC/CRT
I/O RESET
ITEM
EXEC
OPS
SPEC
RESUME
CLEAR
PRO
A
B
C
D
E
F
0
1
2
3
4
5
6
7
8
9
+
—
•
(35V73A2A3)
(35V73A2A1)
(35V73A2A2)
IDP/CRT 1
IDP/CRT 2
IDP/CRT 3
POWER
ON
OFF
MAJ FUNC
GNC
PL
S
M
(S1)
(S2)
(S3)
(S4)
(S5)
(S6)
IDP/LEFT CRT SEL
IDP/RIGHT CRT SEL
(S7)
(S8)
1
2
3
+ (DS1)
FIRE HOLE
TIMER SET
MIN
SEC
(S11)
TIMER
SET ▼
RESET ▲
(S12)
EVENT TIMER
MODE
UP
DOWN
TEST ▲
(S9)
CONTROL
START ▼
STOP ▲
(S10)

Panel C2



```
 2011/   /006    GPC/BUS STATUS     2 008/02:56:10
                                      000/00:11:10
          GPC | 1    | 2    | 3    | 4    | 5
         MODE | RUN  | RUN  | HALT | RUN  | HALT
          OPS |  G2  |  G2  |  0   |  S2  |  0
STRING 1 FF   |  *   |      |      |   ↓  |
         FA   |  *   |      |      |   ↓  |
       2 FF   |      |  *   |      |   ↓  |
         FA   |      |  *   |      |   ↓  |
       3 FF   |  *   |      |      |   ↓  |
         FA   |  *   |      |      |   ↓  |
       4 FF   |      |  *   |      |   ↓  |
         FA   |      |  *   |      |   ↓  |
              |      |      |      |      |
       PL 1   |  ↓   |  ↓   |      |  *   |
          2   |  ↓   |  ↓   |      |  *   |
   LAUNCH 1   |  ↓   |  ↓   |      |  *   |
          2   |  ↓   |  ↓   |      |   ↓  |
      CRT 1   |  *   |      |      |   ↓  |
          2   |      |  *   |      |   ↓  |
          3   |  ↓   |  ↓   |      |   ↓  |
          4   |  ↓   |  ↓   |      |  *   |
```

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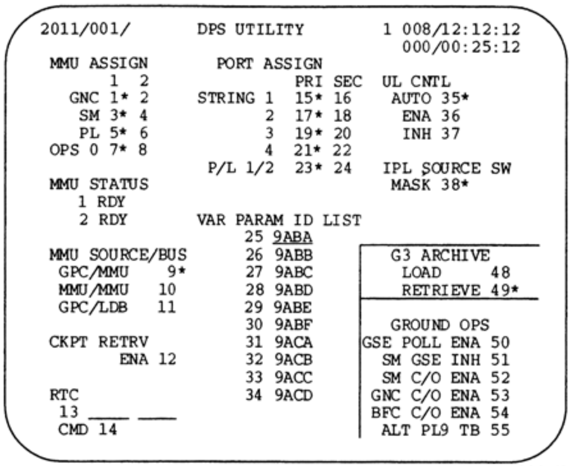
GPC/BUS STATUS (SPEC 6)



```
2011/001/        DPS UTILITY          1 008/12:12:12
                                        000/00:25:12
 MMU ASSIGN        PORT ASSIGN
       1  2                PRI SEC  UL CNTL
   GNC 1* 2      STRING 1  15* 16    AUTO 35*
    SM 3* 4             2  17* 18     ENA 36
    PL 5* 6             3  19* 20     INH 37
 OPS 0 7* 8             4  21* 22
                  P/L 1/2  23* 24   IPL SOURCE SW
 MMU STATUS                          MASK 38*
    1 RDY
    2 RDY        VAR PARAM ID LIST
                       25 9ABA
 MMU SOURCE/BUS        26 9ABB     | G3 ARCHIVE
  GPC/MMU     9*       27 9ABC     |   LOAD      48
  MMU/MMU    10        28 9ABD     |   RETRIEVE 49*
  GPC/LDB    11        29 9ABE     |
                       30 9ABF     |  GROUND OPS
 CKPT RETRV            31 9ACA     |GSE POLL ENA 50
        ENA 12         32 9ACB     |  SM GSE INH 51
                       33 9ACC     |  SM C/O ENA 52
 RTC                   34 9ACD     | GNC C/O ENA 53
  13 ____ ____                     | BFC C/O ENA 54
  CMD 14                           |  ALT PL9 TB 55
```

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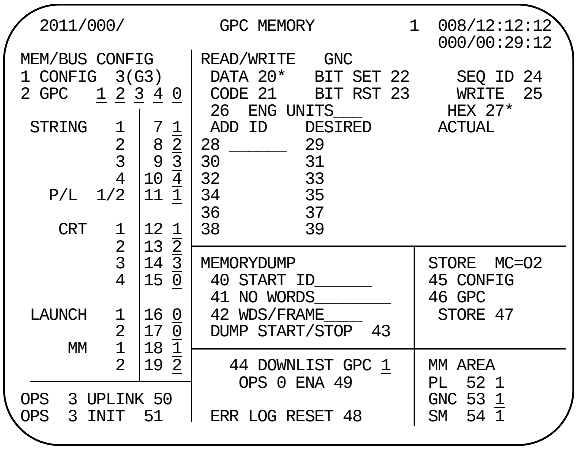
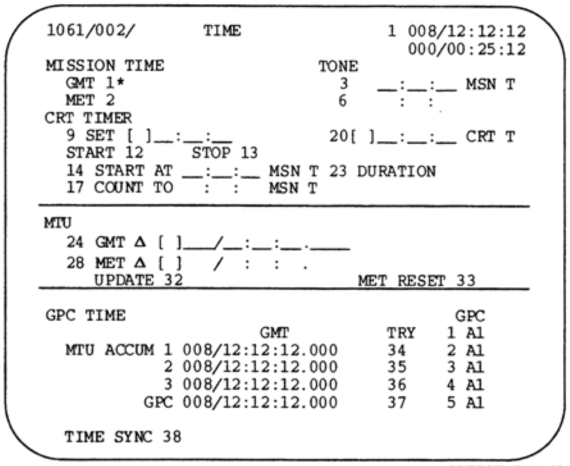
DPS UTILITY (SPEC 1)



```
  2011/000/         GPC MEMORY         1  008/12:12:12
                                          000/00:29:12
MEM/BUS CONFIG     | READ/WRITE   GNC
1 CONFIG  3(G3)    |  DATA 20*   BIT SET 22      SEQ ID 24
2 GPC   1 2 3 4 0  |  CODE 21    BIT RST 23      WRITE  25
                   |  26  ENG UNITS___          HEX 27*
 STRING   1 |  7 1 |  ADD ID     DESIRED        ACTUAL
          2 |  8 2 | 28 ______   29
          3 |  9 3 | 30          31
          4 | 10 4 | 32          33
   P/L  1/2 | 11 1 | 34          35
            |      | 36          37
    CRT   1 | 12 1 | 38          39
          2 | 13 2 |-----------------------------------------
          3 | 14 3 | MEMORYDUMP               | STORE  MC=O2
          4 | 15 0 |  40 START ID______       | 45 CONFIG
            |      |  41 NO WORDS________     | 46 GPC
 LAUNCH   1 | 16 0 |  42 WDS/FRAME____        |  STORE 47
          2 | 17 0 |  DUMP START/STOP  43     |
     MM   1 | 18 1 |-----------------------------------------
          2 | 19 2 |    44 DOWNLIST GPC 1     | MM AREA
 ------------------|     OPS 0 ENA 49         | PL  52 1
OPS  3 UPLINK 50   |                          | GNC 53 1
OPS  3 INIT  51    |  ERR LOG RESET 48        | SM  54 1
```

usa007587_238r1.cvx

GPC MEMORY (SPEC 0)



```
1061/002/      TIME                    1 008/12:12:12
                                         000/00:25:12
MISSION TIME                 TONE
  GMT 1*                       3     __:__:__ MSN T
  MET 2                        6       :  :
CRT TIMER
  9 SET [ ]__:__:__           20[ ]__:__:__ CRT T
  START 12     STOP 13
  14 START AT __:__:__ MSN T 23 DURATION
  17 COUNT TO   :  :   MSN T
------------------------------------------------------
MTU
  24 GMT Δ [ ]___/__:__:__.____
  28 MET Δ [ ]   /  :  :  .
     UPDATE 32                      MET RESET 33
------------------------------------------------------
GPC TIME                                      GPC
                     GMT               TRY    1 A1
  MTU ACCUM 1 008/12:12:12.000         34     2 A1
            2 008/12:12:12.000         35     3 A1
            3 008/12:12:12.000         36     4 A1
          GPC 008/12:12:12.000         37     5 A1

  TIME SYNC 38
```

usa007587_214.tif

TIME (SPEC 2)

DPS Rules of Thumb

- Always HALT fail to sync GPCs and reassign their IDPs to good GPCs to avoid inadvertent entries (NBATs/restrings, burn targets, etc.).
- Before OPS transitions and restrings, always verify the appropriate NBAT is what you want it to be; never assume that it is correct! Also check the proper major function and GPC switch configuration.
- Make sure you have the correct memory configuration called up before you start making NBAT changes.
- During OPS transitions, keep "hands off" everything, including all switches and keyboard entries.
- Clear the Fault Message line as soon as you have seen the message or use the ACK key to display subsequent messages.
- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both MODE and OUTPUT talkbacks are barberpole). If not, take the offending GPC to HALT (or if this does not work, power it OFF) immediately to avoid I/O problems on the flight critical strings.
- It is a very good idea to resume SPECs and DISPs when not using them or before moving the major function switch.
- It is important to be able to identify GPC failures. The information you provide will affect Mission Control analysis and its ability to plan for subsequent failures (both DPS and non-DPS).
- Always hard assign IDPs (both PASS and BFS) via PASS IDPs (BFS will DK listen). If you assign BFS to drive an IDP via a BFS keyboard, and a PASS GPC is currently driving the display, dual DK Bus commanders will result, which can cause PASS redundant set breakups.
- Always distribute your IDPs among different GPCs. On orbit, always be sure to minimize SM usage on all IDPs at the same time; if you lose SM, you also lose PASS IDP interface. The same is true if in single GPC GNC OPS, such as in a Group B powerdown.
- When using the GPC MODE switch, always take your hand off between positions. On past missions, there have been problems with the switch being in essentially two positions at the same time. This problem can occur on other orbiter switches too. It is a good idea to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.
- The IDP/CRT SEL switch should always be checked before making a keyboard entry, and data should always be checked on the scratch pad line before it is entered.
- When moding PASS GPCs into the common set (i.e., STBY to RUN), always pause 10 seconds before and after switch throws to avoid a possible fail-to-sync and to ensure proper common set initialization.

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2.7 DEDICATED DISPLAY SYSTEMS

CONTENTS

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Description

Dedicated displays provide the flight crew with information required to fly the vehicle manually or to monitor automatic flight control system performance. The data on the dedicated displays may be generated by the navigation or flight control system software or more directly by the navigation sensors. The dedicated displays are located in front of the commander's and pilot's seats and on the aft flight deck panel by the aft-facing windows.

The dedicated displays are:

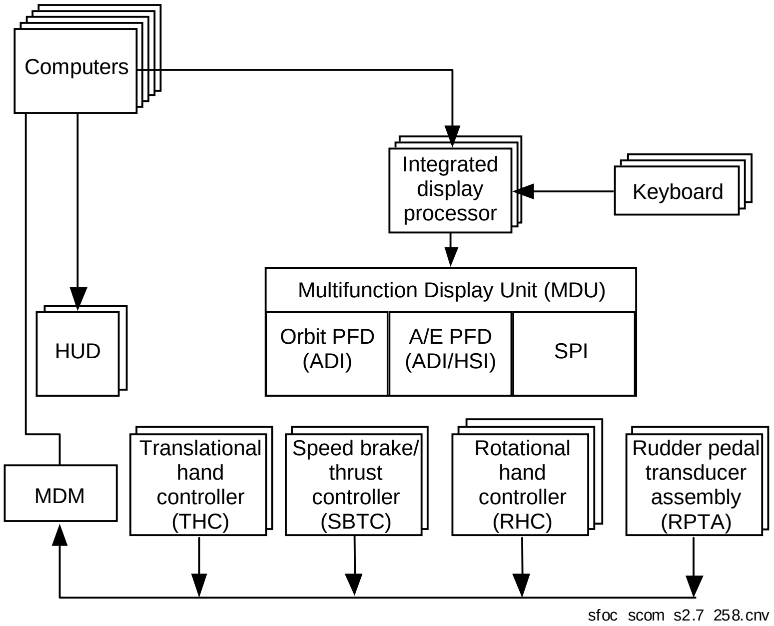
- Primary flight display (PFD) on the MEDS flight instrument display, which displays the attitude director indicator (ADI), horizontal situation indicator (HSI), and Flight Instrument Tapes as appropriate to the flight phase

- Surface position indicator (SPI) on the MEDS SPI display

- Reaction control system activity lights on panel F6

- Head-up display (HUD) on the glare-shield in front of the commander's and pilot's seats

Not all the dedicated displays are available in every operational sequence or major mode. Their availability is related to the requirements of each flight phase.



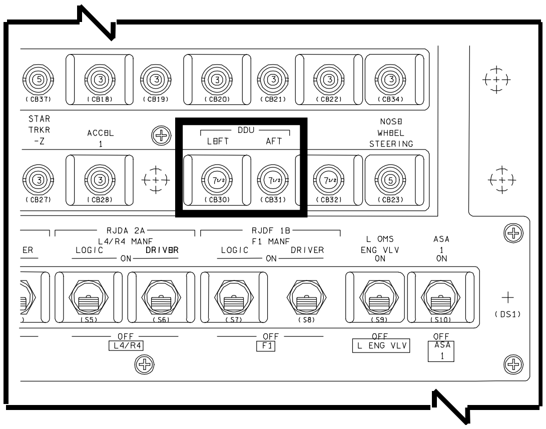
Dedicated Display and Control System

Device Driver Unit

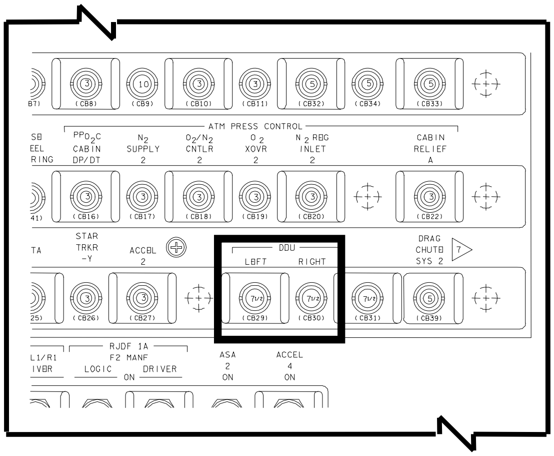
The device driver unit (DDU) is an electronic mechanism that provides dc and ac power for the rotational and translational hand controllers (RHC and THC), the speedbrake/thrust controller (SBTC), and rudder pedal transducer assemblies (RPTA).

The orbiter contains three device driver units: one for the commander's station, one for the pilot's station, and one for the aft station.

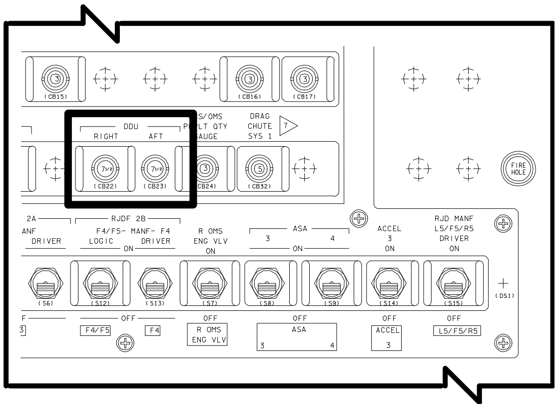
The commander's DDU is powered from the *MN A DDU LEFT* circuit breaker on panel O14 and the *MN B DDU LEFT* circuit breaker on panel O15. The pilot's DDU is powered from the *MN B DDU RIGHT* circuit breaker on panel O15 and the *MN C DDU RIGHT* circuit breaker on panel O16. The aft flight station DDU is powered from the *MN A DDU AFT* circuit breaker on panel O14 and the *MN C DDU AFT* circuit breaker on panel O16.



MN A DDU Circuit Breakers on Panel 014



MN B DDU Circuit Breakers on Panel 015



MN C DDU Circuit Breakers on Panel 016

Selecting a Flight-Critical Data Bus

In MEDS, the Integrated Display Processors (IDPs) handle all the flight-critical (FC) bus data used to drive the flight instrument displays on their commanded Multifunction Display Units (MDUs). The data bus select menu allows the user to select the FC bus (1 - 4) that will be used for the flight instrument displays for that MDU. MEDS software follows two rules when a data bus is selected for an MDU.

- Each IDP can support up to two different FC data bus selections.
- Each IDP supports only one FC bus selection for each crew station (CDR, PLT, and aft).

If the FC data bus selected for an MDU violates one of these rules, other MDUs that are displaying flight instrument displays and that are being driven by this same IDP will also change their FC data bus selection.

To select a different FC data bus, the user can select the DATA BUS option via the edgekeys. The MDU retains the current MEDS display, but a new submenu appears and allows the user to select FC1, 2, 3, or 4 via the edgekey.

NOTE

> Although all displays indicate a FC bus, it is only meaningful on the flight instrument displays. Additionally, because the FC data buses are assigned to specific orbiter GPCs, the selection of a FC bus to drive a flight instrument display also provides a means of assessing the status of individual computers that are assigned to FC1, 2, 3, or 4. See Section 2.6 for detailed data bus information.

Primary Flight Display

The primary flight display (PFD), also referred to as the flight instruments, contains data needed for the crew to fly the vehicle and maintain control. The PFD displays a combination of the attitude director indicator (ADI), horizontal situation indicator (HSI), various tapes and meters showing vehicle parameters, such as angle of attack (α), Mach/velocity (M/V), equivalent airspeed (KEAS), altitude (H), altitude rate (H dot), altitude acceleration (H double dot) and a g-meter. The PFD may also have status indicators that display the current major mode, abort mode, ADI attitude setting, speedbrake, throttle, and DAP status.

The PFD elements will change to show data specific each phase of flight, called phase-tailoring. During some portions of flight, when certain data is not needed, it will be removed from the display. That area will either be left blank or replaced with data more pertainent to that phase of flight. In this section, the PFD elements are presented generically, intended to give an overall understanding. For more detailed discussion of the PFD during the various phases of flight or abort modes, see that particular section.

Example of Ascent/Entry Primary Flight Display in MM103

Attitude Director Indicator (ADI)

The ADI gives the crew attitude information as well as attitude rates and errors, which can be read from the position of the pointers and needles. The ADI can be viewed on the Ascent/Entry PFD (A/E PFD), which is a composite of various flight instruments depending upon flight phase, or on the Orbit PFD.

The commander's and pilot's ADIs (supported by IDPs 1, 2, and 3) are supported throughout the mission; the aft ADI (supported by IDP 4) is active only during orbital operations.

The orbiter's attitude is displayed to the flight crew by a software simulated enclosed ball (sometimes called the eight ball) that is gimbaled to represent three degrees of freedom. The ball, covered with numbers indicating angle measurements (an implied 0 is added as the last digit of each), moves in response to software-generated commands to depict the current orbiter attitude in terms of pitch, yaw, and roll.

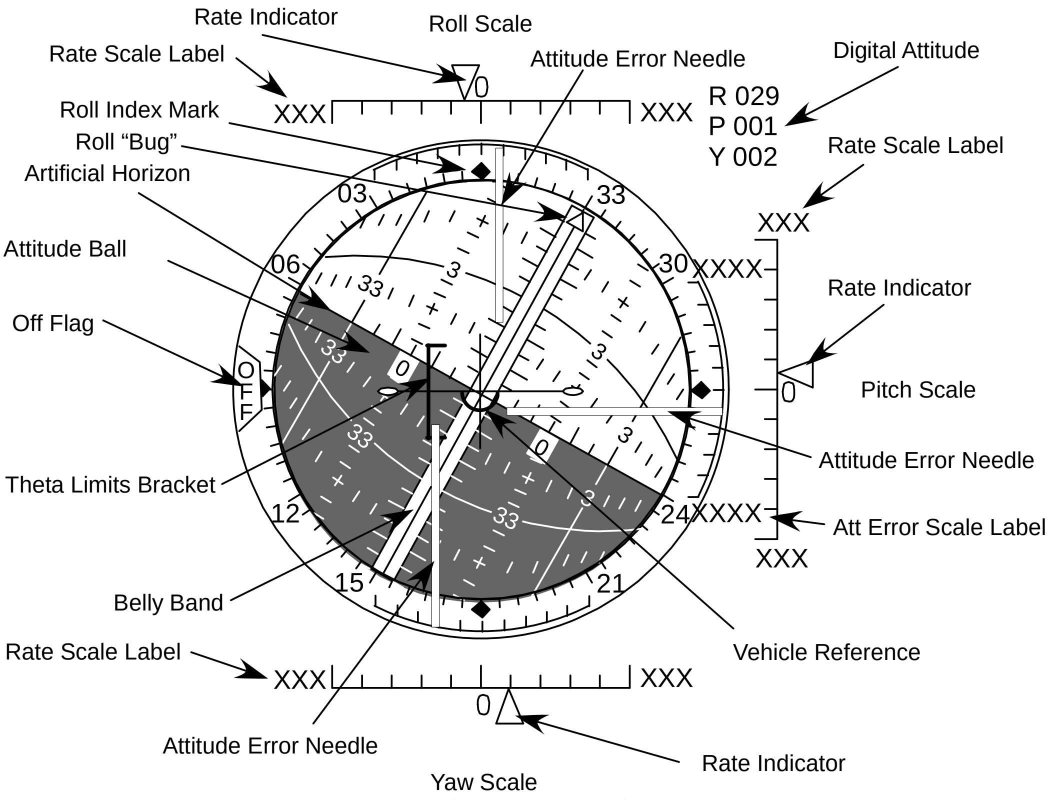
The wide band dividing the ball represents 0° yaw and is referred to as the belly-band. There is also an artifical horizon representing pitch of 0°, where positive pitch angles (0° to 180°) are drawn on the white half of the ball and negative pitch angles (180° to 360°) are drawn on the darker half of the ball.

In addition to the graphical attitude representation of the ADI ball there is a digital readout to the ADI's upper-right showing the current roll, pitch, and yaw attitude in degrees.

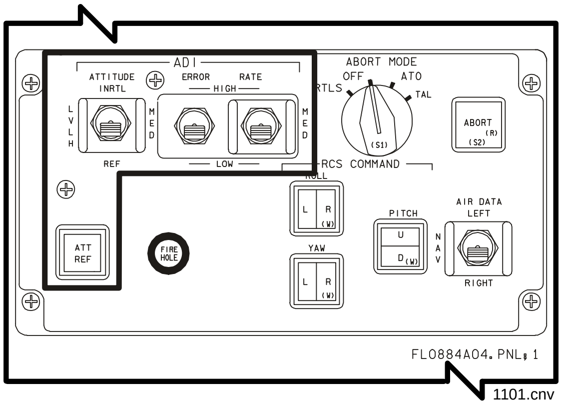
Each ADI has a set of switches by which the crew can select the mode or scale of the readout. The commander's switches are located on panel F6, the pilot's on panel F8, and the aft switches on panel A6U.

The *ADI ATTITUDE* switches determine the unit's frame of reference: *INRTL* (inertial), *LVLH* (local vertical/local horizontal), and *REF* (reference). The *INRTL* position allows the flight crew to view the orbiter's attitude with respect to the inertial reference frame. The *LVLH* position shows the orbiter's attitude from an orbiter-centered rotating reference frame with respect to Earth. The *REF* position is primarily used to see the orbiter's attitude with respect to an inertial reference frame defined when the flight crew last depressed the *ATT REF* pushbutton above/below the *ADI ATTITUDE* switch. The *REF* position is useful when the crew flies back to a previous attitude or monitors an OMS burn for attitude excursions. On ascent pre-MECO and on entry, with the ADI in *LVLH*, yaw is not displayed and the ADI is pinned to the belly-band in yaw.

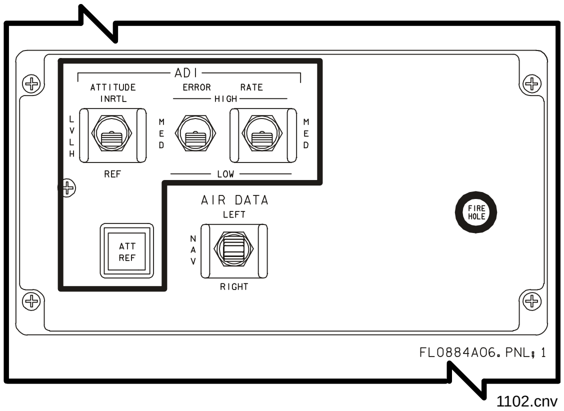
The *ADI ATTITUDE* switches on panels F6 and F8 are active during ascent, orbital, and transition flight phases. However, they have no effect during entry (MM304, 305, 602, and 603), when the ADI attitude is always shown as LVLH. Also, when the backup flight system (BFS) is engaged, only the commander's switches on panel F6 are monitored for configuring both commander and pilot ADIs. The switch on panel A6U, like the aft ADI, is operational only in orbit.



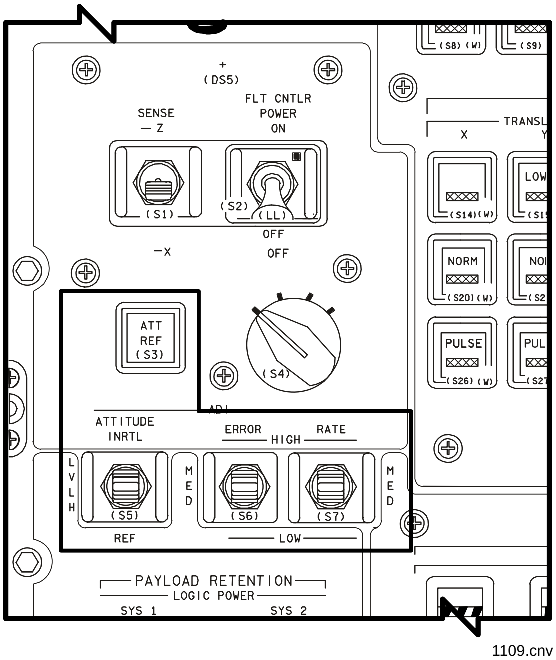
Attitude Director Indicator



Commander's ADI Switches and ATT REF Pushbutton on Panel F6



Pilot's ADI Switches and ATT REF Pushbutton on Panel F8



Aft ADI Switches and ATT REF Pushbutton on Panel A6U

Each ADI has a set of three rate pointers that provide a continuous readout of vehicle body rotational rates. Roll, pitch, and yaw rates are displayed on the top, right, and bottom pointers, respectively. The center mark on the scale next to the pointers represents zero rates. The graduated marks on either side of center indicate positive or negative rates. The *ADI RATE* switch for each indicator unit determines the magnitude of full-scale deflection. *HIGH is the coarsest setting and LOW is the finest setting. Scaling for each switch position is listed in table A*, *ADI Rate Switch vs. Full Range Deflection.* On the A/E PFD, the rate pointer scales will be labeled according to the selected scale. The rate scales are not labeled on the Orbit PFD. These pointers are "fly to" in the sense that the RHC must be moved in the same direction as the pointer to null a rate.

ADI rate readings are independent of the selected attitude reference. During ascent, the selected rates come directly from the solid rocket booster or orbiter rate gyro assembly (RGA) sensors to the ADI processor for display via the rate pointers. During entry, only the RGA selected pitch rate is directly diplayed as the ADI rate. The selected roll and yaw rates are first sent to flight control software, where they are processed and output to the ADI as stability roll and yaw rates. (This transformation is necessary because, in aerodynamic flight, control is achieved about stability axes, which in the cases of roll and yaw differ from body axes.)

In all major modes except TAEM (MM 305 and 603), the rate pointers strictly display vehicle rate information. During TAEM when the *ADI RATE* switch is in *MED*, the ADI rate pointers instead display information on HAC intercept, glideslope error, and crosstrack error, which can be used to help fly the proper HAC profile. During TAEM when the *ADI RATE* switch is in *HIGH* or *LOW*, rates will be displayed on a ± 5° per second scale (see table A). The rate scale labels in TAEM will reflect these changes accordingly.

In addition to the rate pointers, there are three magenta-colored needles on each ADI that display vehicle attitude errors. These error needles extend in front of the ADI ball, with roll, pitch, and yaw arranged in the same manner as the rate pointers. Similar to the rate pointers, each error needle has an arc-shaped background scale (also magenta) with graduated marks that allow the flight crew to read the magnitude of the attitude error. The errors are displayed with respect to the body axis coordinate system and, thus, are independent of the selected reference frame of the ADI.

The ADI error needles are driven by flight control outputs that show the difference between the required and current vehicle attitude. These needles are also "fly to," meaning that the flight crew must maneuver in the direction of the needle to null the error. For example, if the pitch error needle is deflected down, the flight crew must manually pitch down to null the pitch attitude error.

The amount of needle deflection, indicating the degree of attitude error, depends upon the position of the *ADI ERROR* switch for each ADI and the flight phase. For ascent, orbit, and transition phases, in the *HIGH* position, full-scale deflection of the error needles represent 10°, *MED* represents 5°, and *LOW* represents 1°. For entry, the needles signify different errors in different phases (see table B). On the A/E PFD the error scale is also labeled (in magenta) according to *ADI ERROR* switch position.

On entry during TAEM (MM 305 and 603), a Theta Limits bracket (in green) may be driven overlaying the ADI ball. This is a pitch flying reference (maximum/minimum pitch attitude) when air data transducer assembly (ADTA) data is not available to Guidance and Control (G&C) below Mach 2. This is described in more detail in the TAEM section, 7.4.

The *SENSE* switch on panel A6U allows the flight crew to use the aft ADI, RHC, and THC in a minus X or minus Z control axis sense. These two options of the aft ADI and hand controllers correspond to the visual data out of the aft viewing (negative X) or overhead viewing (negative Z) windows.

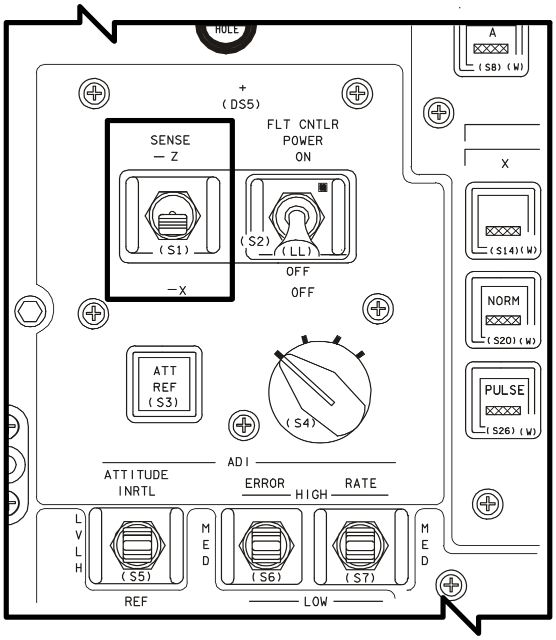
Each ADI has a single flag labeled *OFF* on the left side of the display that is used to indicate whether valid GPC data is driving the ADI software. Presence of the *OFF* flag can be used to determine if a FC bus problem exists at the GPC driving the IDP that is hosting the ADI, and is used to help troubleshoot in DPS malfunction procedures.. There are no flags for the rate and error needles; but these indicators are blanked when they are invalid.

MISSION PHASE		ROLL	PITCH	YAW
Ascent	(101-106, 601)			
Transition/entry	(301-304, 602)	(deg/s)	(deg/s)	(deg/s)
High		10	10	10
Medium		5	5	5
Low		1	1	1
On-orbit	*(201, 202, 801)*	*(deg/s)*	*(deg/s)*	*(deg/s)*
High		*5*	*5*	*5*
Medium		*1*	*1*	*1*
Low		*0.2*	*0.2*	*0.2*
TAEM to HAC intercept	(305, 603)			
High		5 deg/s	5 deg/s	5 deg/s
Medium		Time to HAC intercept (10 sec)	Altitude error (±5000 feet)	Blank
Low		5 deg/s	5 deg/s	5 deg/s
HAC intercept to prefinal	(305, 603)			
High		5 deg/s	5 deg/s	5 deg/s
Medium		Blank	Altitude error (±5000 feet)	HAC X-range error (±5000 feet)
Low		5 deg/s	5 deg/s	5 deg/s
Prefinal to 7000 ft	(305, 603)			
High		5 deg/s	5 deg/s	5 deg/s
Medium		Blank	Altitude error (±1000 feet)	HAC X-range error (±1000 feet)
Low		5 deg/s	5 deg/s	5 deg/s
7000 ft to landing	(305, 603)	(deg/s)	(deg/s)	(deg/s)
High		5	5	5
Medium		5	5	5
Low		5	5	5

(A)
ADI Rate Switch vs. Full Range Deflection

MISSION PHASE		ROLL	PITCH	YAW
Ascent/	(101-106, 601)			
On orbit	(201, 202, 801)			
Transition	(301, 303)	(Deg)	(Deg)	(Deg)
High		10	10	10
Medium		5	5	5
Low		1	1	1
ENTRY (MM 304, 602*)		(Deg)	(Deg)	(*Deg*)
High		25	5	2.5
Medium		25	2	2.5
Low		10	1	2.5
* α recovery & α transition phases				
TAEM (MM 305**, 602*, 603**)		(Deg)	(g's)	(*Deg*)
High		25	1.25	2.5
Medium		25	1.25	2.5
Low		10	0.5	2.5
* Nz Hold phase				
** WOWLON = 0				
WOWLON = 1				
Rollout (MM 305, 603)		(Deg)	(Deg/s)	(Deg)
High		20	10	2.5
Medium		5	5	2.5
Low		1	1	2.5

(B)
ADI Error Switch vs. Full Range Deflection



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SENSE Switch on Panel A6U

Horizontal Situation Indicator (HSI)

The HSI displays a pictorial view of the vehicle's position relative to various navigation points and shows a visual perspective of certain guidance, navigation, and control parameters; e.g., direction, distance, and course/glidepath deviation. The flight crew uses this information primarily to control or monitor vehicle heading/yaw performance. The HSI is only available on the A/E PFD during ascent (MM 102, 103, 104), return to launch site (MM 601, 602) and entry/landing (MM 603, 304, 305) phases.

The HSI provides an independent software source to compare with ascent and entry guidance, a means of assessing the health of individual navigation aids during entry, and information needed by the flight crew to fly manual ascent, return to launch site, and entry.

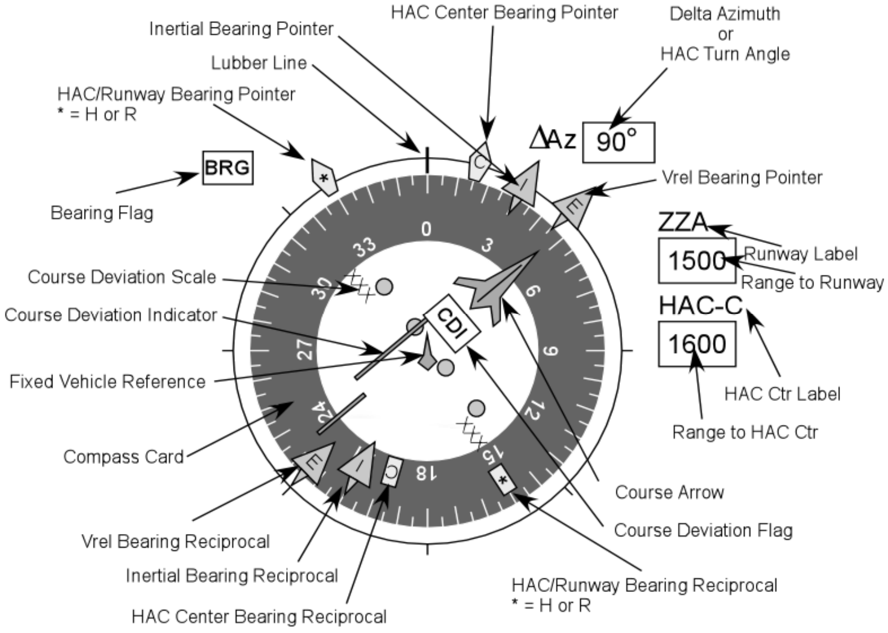
HSI Ascent Displays

During nominal ascent (MM 102 and 103, first and second stage), the HSI provides information about the target insertion orbit. The compass card displays heading with respect to target insertion plane. The mission-defined target insertion plane is defined to be 0° on the compass card and the magenta-colored course arrow points directly to 0. The compass card headings on ascent are also displayed with respect to vehicle orientation. While the orbiter is rolled heads-down, the compass card headings increase in a counterclockwise direction, and while heads-up the compass card is flipped so headings increase in a clockwise direction. The heading of the body plus X axis (the nose of the orbiter) with respect to the target insertion plane is read at the lubber line.

The Earth-relative velocity (Vrel) or "E" bearing pointer provides the heading of the Vrel vector with respect to the target insertion orbit plane. The angular difference between the Vrel and the orbiter nose, Beta, is displayed in a digital readout box to the upper-left of the HSI. Both the "E" pointer and the *Beta* box are pertinent while on the solid rocket boosters (SRBs) and through SRB separation. They will be removed (blank) after a mission-elapsed time (MET) of 2 minutes and 30 seconds, or at an altitude of 200,000 feet.

The inertial velocity (Vi), or "I" bearing pointer, provides the heading of the Vi vector relative to the target insertion plane (course arrow). This is also displayed digitally to the right of the HSI in the delta-inclination (*Δ Inc*) box.

The course deviation indicator (CDI) deflection indicates the lateral offset or crosstrack (in n. mi.) between the current orbital plane and the targeted orbital plane. The scale for the course



Horizontal Situation Indicator

deviation updates throughout ascent from 50 to 10 to 1 n. mi. as the crosstrack decreases. is also displayed digitally to the right of the HSI in the crosstrack (*X-Trk*) box.

HSI Abort Displays

The HSI for ascent aborts is very similar to nominal ascent, with some notable exceptions.

With an abort to orbit (ATO), the desired target inclination may be redefined to equal the current inclination, thus the course arrow would no longer point directly to 0° on the compass card. With the ATO abort, a digital box displaying target inclination (*Tgt Inc*) will appear to the right of the HSI, to help indicate if the target inclination was redefined.

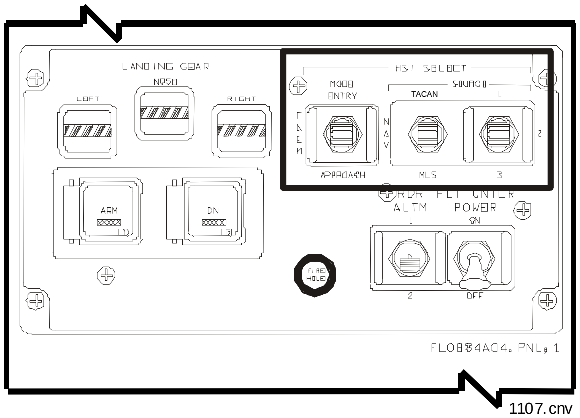
With a transoceanic abort landing (TAL), the HSI will also display a Runway or "R" bearing pointer, which depicts the heading of the TAL landing site with respect to the orbiter nose (lubber line). Also in the TAL ascent phase, the targeted inclination is no longer applicable. Thus the *Δ Inc* box and the CDI are removed and the Crosstrack (*X-Trk*) box is redefined to show the lateral offset in nautical miles (n. mi.) of the Vi vector with respect to the Runway bearing pointer. Also, the magenta course arrow no longer points to the targeted inclination, but instead points to the tangency of a predetermined crosstrack circle defined about the TAL site. A delta crosstrack (*Δ X-Trk*) box is then shown to the right of the HSI to display the lateral offset in nautical miles of the Vi vector with respect to the crosstrack circle tangency (course arrow). If Vi is already pointing inside the crosstrack circle (between the course arrow and the runway pointer), then the delta crosstrack is defined to be 0 n. mi.

With a return to launch site (RTLS) abort, the HSI will also display a Runway or "R" bearing pointer, which depicts the heading of the launch site (KSC) with respect to the orbiter nose (lubber line). Targeted inclination and crosstrack are no longer applicable, thus the course arrow, the CDI, and the digital boxes for *Δ Inc* and *X-Trk* are removed. Inertial velocity is also no longer applicable, but Earth-relative velocity becomes important, so with the RTLS abort, the "I" bearing pointer is removed and the "E" bearing pointer and its associated Beta read-out return. Also with the RTLS abort, the HSI compass card is redefined to represent actual magnetic heading with north, east, south, west (N, E, S, W) directions depicted.

Ascent abort displays for the A/E PFD are shown and described in more detail in their respective ascent abort sections, 6.3 through 6.5.

HSI Entry Display Modes

During entry flight phases (MM304, 305, 602, 603), the HSI software's mode and source configuration may be controlled by cockpit switches. The commander's HSI switches are on panel F6, and the pilot's are on panel F8. The *HSI SELECT MODE* switch selects the mode: *ENTRY, TAEM*, or *APPROACH*. These HSI area navigation software modes are slightly different from the guidance phases with virtually identical names (Entry, TAEM, and Approach and Landing). The *ENTRY* position enables HSI mode auto-switching from Entry to TAEM to Approach. Or the TAEM and Approach modes can be entered directly by respectively taking the *HSI SELECT MODE* switch to *TAEM* and *APPROACH*.



HSI SELECT Switches on Panel F6 and Panel F8

The *HSI SELECT SOURCE* switch selects *TACAN*, navigation (*NAV*), or microwave landing system (*MLS*); the *1, 2, 3* switch selects one of the three TACAN or MLS units. When the *HSI SELECT SOURCE* switch is positioned to *NAV*, the HSI is supplied with data from the navigation processor, and the *1, 2, 3* switch is ignored. This makes the HSI display dependent on the same sources as the navigation software

(IMU, selected air data, selected navigational aids), but it is independent of guidance targeting parameters.

When the *HSI SELECT SOURCE* switch is in *TACAN* or *MLS*, the HSI area navigation software is supplied with data derived from the unit specified by the *1, 2, 3* switch. The *TACAN* and *MLS* positions should only be used when TACAN or MLS data are available. TACAN data is used during entry to update the navigation state, and is usually acquired about 300 nm. from the landing site. MLS has a range of 20 nm. and would be normally be selected after the orbiter is on the HAC.

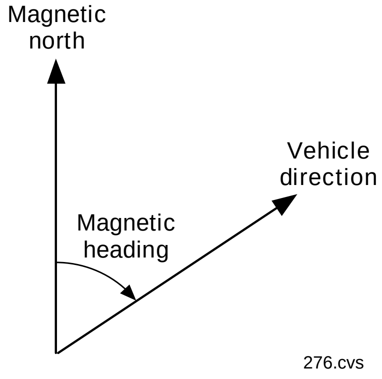
HSI Entry Display Parameters

Depending on phase of entry, each HSI displays magnetic heading (compass card), selected course, runway magnetic heading, course deviation, glideslope deviation, runway and HAC tangency/center bearing, runway and HAC center range, as well as bearing and course deviation indicator (CDI) flags to indicate validity.

Each HSI consists of a compass card measuring 0° to 360°. Fixed at the center of the card is an aircraft symbol about which the compass card rotates.

The magnetic heading (the angle between magnetic north and vehicle direction measured clockwise from magnetic north) is displayed by the compass card and read under the lubber line located at the top of the indicator dial. (A lubber line is a fixed line on a compass aligned to the longitudinal axis of the craft.) The compass card is positioned at N (north) when the heading input is zero degrees. As the heading point is increased, the compass card rotates counterclockwise beneath the fixed lubber line if flying in a heads-up attitude.

In the Entry mode (MM 304 and 602), the compass card heading indicates the magnetic heading of the vehicle's relative velocity vector (Vrel). When the HSI is in the TAEM and Approach modes during MM 305 and 603, the compass card indicates magnetic heading of the body X axis.

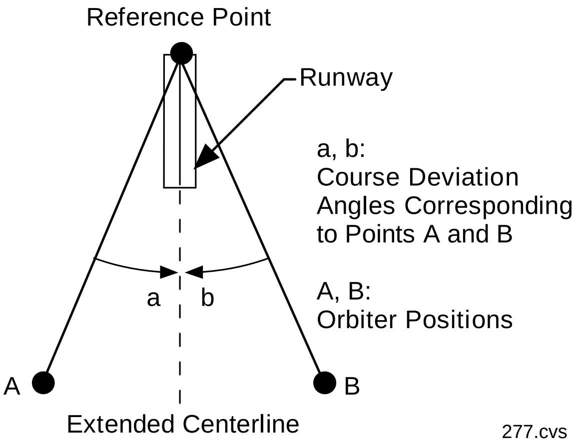


HSI Heading Geometry

The magenta-colored course arrow is used in glided flight (MM 304 & 305 or 602 & 603) to indicate the selected runway heading with respect to true north. As the compass card rotates, the course arrow will rotate with the card. This provides a continuous reference to the selected runway.

On entry, the HSI course deviation indicator (CDI) shows course deviation as an angular measurement of vehicle displacement from the extended runway centerline. The CDI represents course deviation by the deflection of the deviation bar from the course pointer line. When the HSI is in the Entry mode (MM 304 and 602), the CDI is inactive and pegged at zero and the scale is not labeled. When the HSI is in the TAEM mode, full-scale deflection on the CDI is ±10° as reflected by the scale label. When the HSI is in the Approach mode, full-scale deflection is decreased to ±2.5°. The CDI is a "fly to" indicator for flying the vehicle to the extended runway centerline. When the course deviation is zero, the deviation bar is aligned with the end of the course pointer. With the pointer in the top half of the compass card, an increase in course deviation to the left (right) causes the bar to deflect to the right (left). Software processing also ensures that the CDI remains "fly to", even when the orbiter is heading away from the runway.

In course deviation geometry, if the orbiter is to the left of the runway, it must fly right (or if the orbiter is to the right of the runway, it must fly left) to reach the extended runway centerline. The corresponding course deviation bar would deflect to the right (or to the left) accordingly. The sense of the CDI deflection is a function of vehicle position rather than vehicle heading.



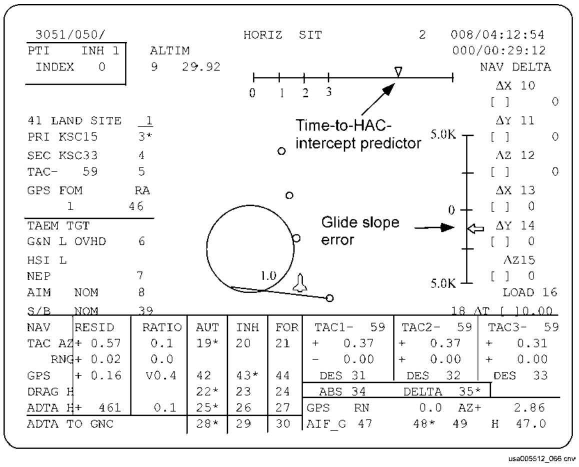
Course Deviation Geometry

HSI mode	Bearing [ ] indicates bearing pointer label	Range [ ] indicates range label	Course deviation (CDI)	Glide slope deviation (GSI)	Compass card (heading)
Entry	[H] Spherical bearing to NEP HAC intercept	[*selected rwy*] Spherical surface range to runway touchdown point via NEP	Pegged at zero (no CDI flag)	Blanked	Magnetic heading of vehicle velocity vector (flight path)
TAEM	[H] Bearing to NEP HAC intercept [C] Bearing to HAC center	[*selected rwy*] Range to fly to runway touchdown point, via the HAC, for selected EP (NEP or MEP) [HAC-C] Horizontal distance to the HAC center	Deviation from runway centerline (full scale ±10°)	Error from guidance TAEM reference altitude (full scale ±5000 ft, ±2500 ft)	Magnetic heading of X body axis
Approach	[R] Bearing to runway touchdown point	[*selected rwy*] Horizontal distance to runway touch-down point	Deviation from runway centerline (full scale ±2.5°)	Error from guidance A/L reference altitude (full scale ±1000 ft). Not computed below 1500 ft (GS flag displayed)	Magnetic heading of X body axis

HSI Function Matrix

With the HSI in the TAEM and Approach modes (MM 305 and 603), glideslope deviation, the distance of the vehicle above or below the desired glideslope, is indicated by the deflection of the glide slope indicator (GSI) pointer displayed to the right of the HSI. The GSI display is blank when the HSI is in the Entry mode. The pointer is a "fly to" indicator, so an increase in glideslope deviation above (below) the desired slope deflects the pointer downward (upward).

The "desired glideslope" is actually only a conceptual term in HSI processing. At any instance, the HSI GSI deviation is really the difference between the current orbiter altitude and a reference altitude computed by Area Nav. This reference altitude may be slightly different than the reference altitude computed by guidance. Also included in the reference altitude equation are factors for a “heavy orbiter” and for high winds.



```
 3051/050/                      HORIZ  SIT           2   008/04:12:54
PTI      INH 1    ALTIM                                  000/00:29:12
 INDEX     0      9   29.92                                NAV DELTA
                                0  1  2  3                  ΔX 10
                                                           [ ]       0
41 LAND SITE  1                                             ΔY 11
PRI KSC15     3*                                   5.0K    [ ]       0
SEC KSC33     4                                             ΔZ 12
TAC-    59    5                                            [ ]       0
GPS FOM       RA                                            ΔX 13
      1      46                                    0       [ ]  0
TAEM TGT                                                    ΔY 14
G&N L OVHD    6                                            [ ]  0
HSI L                                                        ΔZ15
NEP           7                  1.0                       [ ]  0
AIM   NOM     8                                    5.0K      LOAD 16
S/B   NOM     39                                       18 ΔT [ ]10.00
NAV      RESID   RATIO  AUT   INH   FOR  TAC1-   59  TAC2-   59  TAC3-   59
TAC AZ + 0.57     0.1   19*   20    21   +   0.37    +   0.37    +   0.31
   RNG + 0.02     0.0                    -   0.00    +   0.00    +   0.00
GPS    + 0.16    V0.4   42    43*   44    DES 31      DES  32     DES  33
DRAG H                  22*   23    24    ABS 34      DELTA  35*
ADTA H +  461     0.1   25*   26    27   GPS   RN       0.0  AZ+     2.86
ADTA TO GNC             28*   29    30   AIF_G 47      48*  49   H  47.0
```

HORIZ SIT Display (SPEC 50)

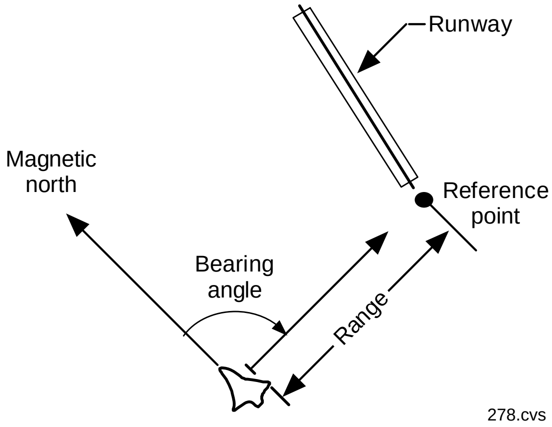
The HORIZ SIT display (SPEC 50) allows the flight crew to configure the software for nominal winds or high head winds. The item 7 entry toggles to select the nominal entry point (NEP) or minimum entry point (MEP), which determines the distance from the runway threshold to the intersection of the glideslope with the runway centerline or aim point. The item 8 entry toggles from the nominal (NOM) aim point to the close-in (CLSE) or high-wind aim point, which pushes the intercept point closer to the runway threshold. The distance selected is factored into the computation of HSI reference altitude from which the glideslope deviation is derived.

The GSI in TAEM indicates deviations from the guidance reference altitude ±5,000 feet. The GSI during approach and landing indicates guidance reference altitude ±1,000 feet.

The HSI GSI computation is not processed below 1,500 feet during the Approach mode; so the glideslope indicator flag (GS) is displayed.

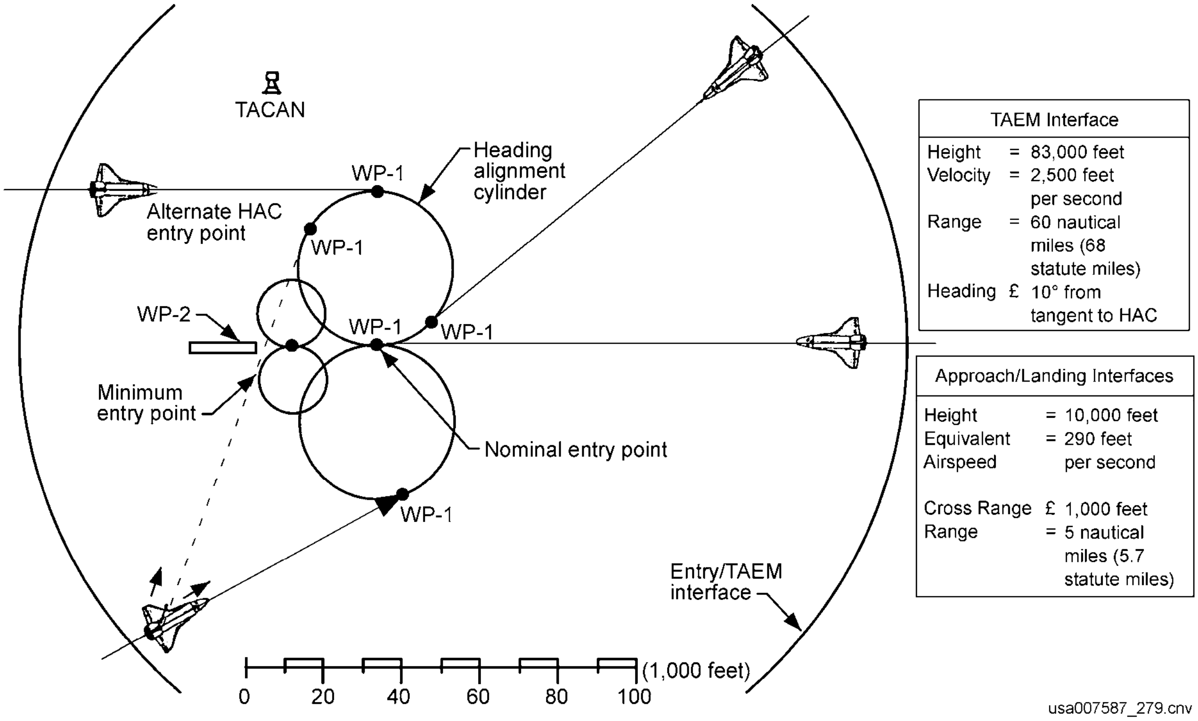
In glided flight, the HSI also displays bearing pointers relative to the compass card. The HAC bearing pointer, labeled “H”, indicates spherical bearing to HAC tangency point (Way Point 1) when in the Entry and TAEM modes (MM 304, 305 and 602, 603). The HAC Center bearing pointer, labeled “C”, indicates bearing to the HAC center when in the TAEM mode (MM 305 and 603). When the HSI is in the Approach mode, the “H” bearing pointer is redefined to indicate the bearing to the touchdown point at the primary runway (way point 2).

When the bearing inputs are zero, the pointers are at the top lubber line, regardless of compass card position. The bearing pointer commands are developed by subtracting the vehicle heading from the calculated bearing values. When the bearing inputs are increased, the pointers rotate clockwise about the compass card. The pointer does not reverse when it passes through 360° in either direction. In other words, each bearing pointer has a reciprocal “tail” of the pointer 180^{o} out.



Horizontal Situation Indicator Bearing and Range Geometry

The HSI also displays range values immediately to the right of the compass card. With TAL, RTLS, or East Coast Abort Landing (ECAL) and entry phases, the selected runway is displayed immediately above a box with a digital readout of range to the runway in nautical miles (nm). On entry this range includes the curvilinear geometry for a path to the HAC tangency, around the HAC and to the runway threshold. In the TAEM mode, a range box for HAC center (*HAC-C*) will also appear, showing the straight-line range from the vehcile to the center of the HAC in nautical miles.



TAEM Interface

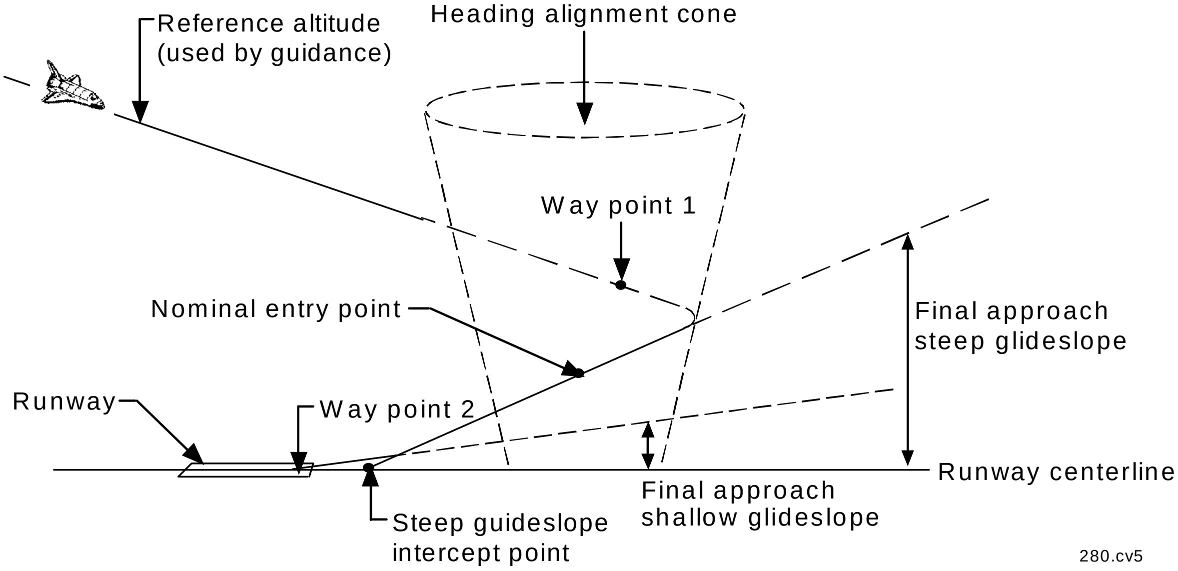
Height = 83,000 feet
Velocity = 2,500 feet per second
Range = 60 nautical miles (68 statute miles)
Heading £ 10° from tangent to HAC

Approach/Landing Interfaces

Height = 10,000 feet
Equivalent Airspeed = 290 feet per second

Cross Range £ 1,000 feet
Range = 5 nautical miles (5.7 statute miles)

HSI Flight Path Geometry-Top View



HSI Flight Path Geometry-Side View

The HSI has three *OFF* flags -- *BRG* (bearing), *GS* (glideslope), and *CDI* -- identifying invalid data. *BRG* indicates invalid course and/or bearing data. *GS* indicates invalid glideslope deviation. *CDI* indicates invalid course deviation data.

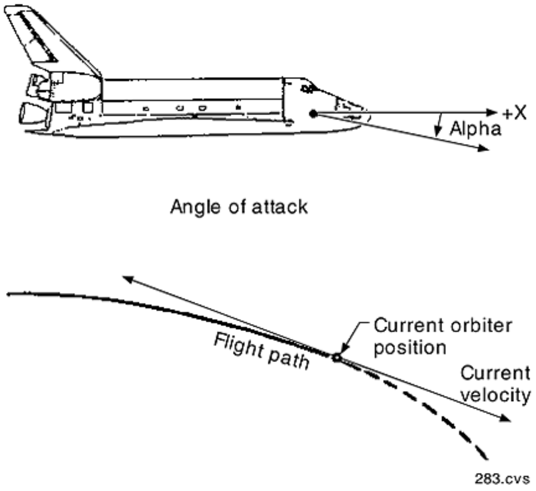
Also during entry and the acquisition phase of TAEM, the current ΔAz (delta azimuth) is displayed to the upper-right of the HSI. ΔAz is the angular difference between the heading to the HAC tangency point and the heading of the relative velocity vector (entry) or the vehicle heading (TAEM). When the guidance enters the HAC phase during TAEM, the ΔAz field is *blanked*.

Flight Instrument Tapes

The flight instrument tapes consist of several meters and/or digital displays indicating angle of attack (α), vehicle Mach or velocity (*M/V*), knots equivalent airspeed (*KEAS*), altitude (*H*), altitude rate (*H dot*), altitude acceleration (*H double dot*), and a g-meter (*Accel/Nz*). For each of the tapes, with the exception of altitude acceleration, the value is read by a digital window centered on the moving tape. The flight instrument tapes are only available on the ascent/entry primary flight display (A/E PFD).

Some documentation refer to the tapes as the alpha/Mach indicator (AMI) and the altitude/vertical velocity indicator (AVVI), refering to the old cockpit configuration when the tapes were displayed in a separate format. The AMI consisted of the angle of attack, velocity and airspeed tapes. The AVVI consisted of the altitude, altitude rate, and altitude acceleration tapes.

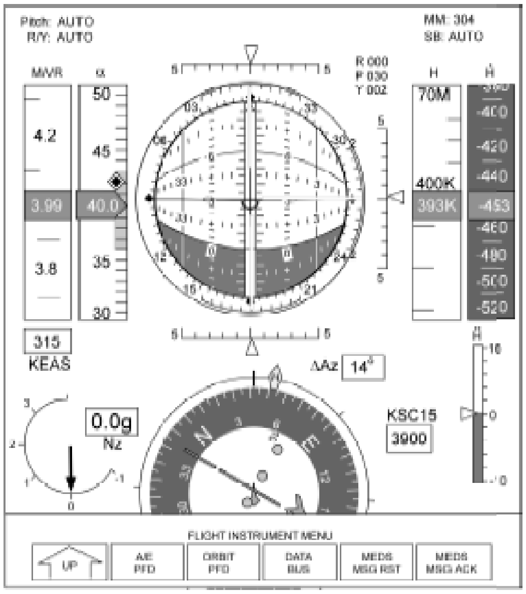
The α tape displays vehicle angle of attack, defined as the angle between the vehicle plus X axis and the wind-relative velocity vector (negative wind vector). Alpha is shown in a scrolling window with a fixed pointer indicating the current angle of attack in 1° increments. The digital decimal value is provided as part of the pointer using white numbers on a black background. Positive alpha values are black numbers on a white background, and negative values are white numbers on a black background. The α tape ranges from -180° to +180°. Below Mach 3.0, a magenta diamond indicates the optimum alpha for maximum lift-over-drag (max L/D). On entry (MM 304, 305, 602, and 603), except for contingency aborts, a green bar on the α tape depicts the range of allowable maximum/minimum alphas.



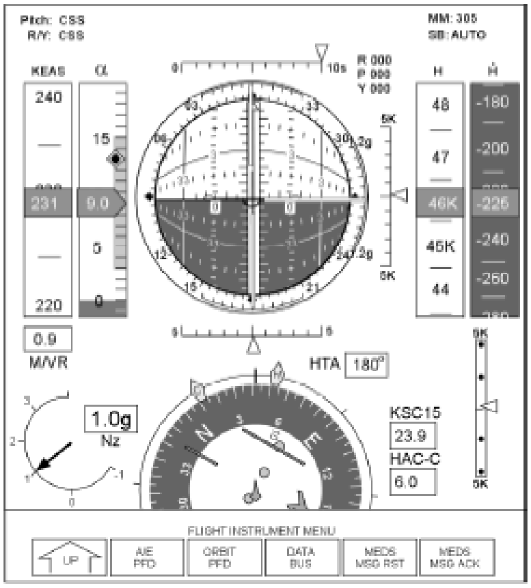
Angle of Attack

On ascent and on entry above Mach 0.9, the *M/V* tape displays Mach number, relative velocity (Vrel), or inertial velocity (Vi). Mach number is the ratio of vehicle airspeed to the speed of sound in the same medium. The Vrel is in feet per second in relation to the Earth. Vi is in feet per second and does not consider the rotational speed of the surface. The actual parameter displayed is always Mach number; the tape is simply rescaled above Mach 4 to read Vrel (MM 102, 304, 305, 602 and 603 with the tape labeled *M/VR*) or Vi (MM 103 and 601 with the tape labeled *M/VI*). The scale ranges from 0 to 27.0K feet per second, with a scale change at Mach 4 (4.0M). Located below the tape is a digital readout box displaying knots equivalent airspeed (*KEAS*).

Below Mach 0.9 on entry, the *M/VR* tape swaps with the *KEAS* digital box. The *KEAS* tape range is zero to 500 knots, and scaling is 1 inch per 10 knots. The digital readout box will then read Mach number.



Entry PFD above Mach 0.9



Entry PFD below Mach 0.9

The *g-meter* is a circular meter in the lower-left corner of the A/E PFD which displays vehicle acceleration from -1g up to 4g on ascent during powered flight (MM 102, 103, and 601) and entry (MM 304, 305, 602 and 603). The value is displayed via a green arrow on the meter and a digital readout box. In powered flight, the meter reflects the IMU-derived vehicle acceleration and is labeled "*Accel*". During glided flight, the meter displays the selected accelerometer assembly (AA) normal acceleration (NZ) value and is labeled "*NZ*". A magenta Target NZ line is provided during MM 602 showing the Target NZ value calculated on RTLS and contingency aborts in glided flight.

The *H* (altitude) tape displays the altitude of the vehicle above the runway (nav-derived or barometric altitude). The scale range is –1,100 feet to +165 n.mi., with scale changes at -100, 0, 200, 2000, 30K, 100K and 400K feet. The scale is in feet from –1,100 to 400K and in n.mi. from +65 nm to +165 n.mi.

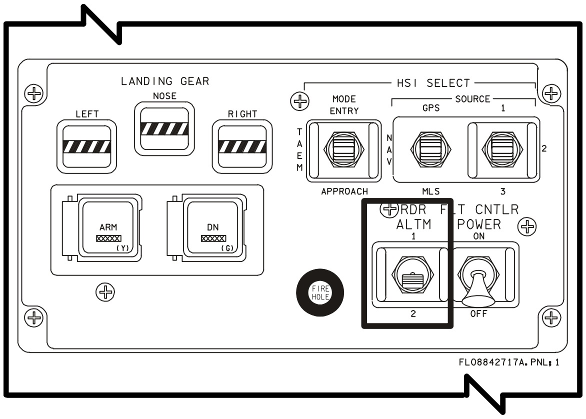
The altitude tape has black number and markings on a white background for altitudes above 2,000 feet. The tape background color is yellow for altitudes below 2,000 feet.

When the radar altimeter (RA) sensor selected by the commander (pilot) is locked on, an "R" appears to the right of the altitude digital, and the digital is driven by the RA data on the commander's (pilot's) PFD. A floating yellow triangle also appears to the right of the tape at the value of the RA altitude. If no RA is locked on, a "K," indicating thousands of feet, or an "M," indicating nautical miles will appear to the right of the altitude tape digital indicating the units.

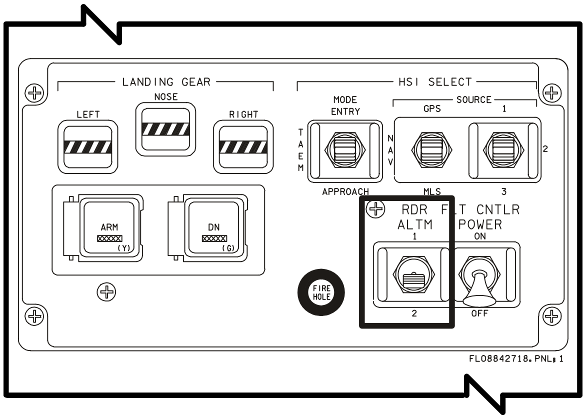
The $\dot{H}$ tape displays vehicle altitude rate. The scale range is –2,940 to +2,940 feet per second with scale changes at –740 feet per second and +740 feet per second. The negative and positive regions are color-reversed: negative numbers are white on a gray background and positive numbers are black on white.

The $\ddot{H}$ tape is dislayed in the lower-right corner of the PFD on entry during MM 304 and 602 and indicates altitude acceleration of the vehicle. A triangular pointer moves along the fixed scale. The scale range is –10 to +10 ft/sec^2, where the negative side is grey and the positive side is white. Software limits acceleration values to ±12.75 ft/sec^2.

The *RDR ALT* indicator is controlled by the *RADAR ALTM* switch on panel F6 for the commander and panel F8 for the pilot. *RADAR ALTM* positioned to *1* selects radar altimeter 1; *2* selects radar altimeter 2.



Commander's RADAR ALTM Switch on Panel F6

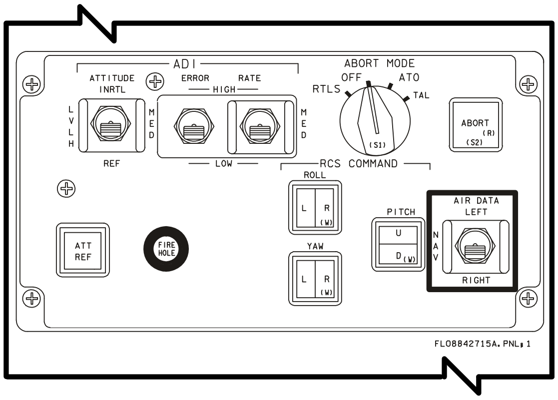


Pilot's RADAR ALTM Switch on Panel F8

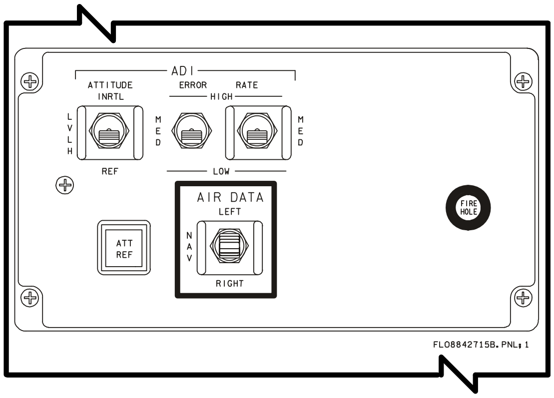
With the *AIR DATA* source switch in the *NAV* position, the *H*, $\dot{H}$, $\ddot{H}$ tapes are navigation-derived. The *AIR DATA* switch is positioned to *LEFT* or *RIGHT* to select the left or right air data probe after air data probe deployment at Mach 5. With the switch in LEFT or RIGHT, the *H*, $\dot{H}$, tapes receive information from the selected air data probe, but the $\ddot{H}$ tape still receives navigation data.

The *AIR DATA* switch on panel F6 for the commander and panel F8 for the pilot also determines the source of data for the *α*, *M/V*, and *KEAS* tapes and/or digital readouts When in the *NAV* position, the same parameters (alpha, Mach and airspeed) that are sent to guidance, flight control, navigation, and other software users are displayed.

With the switch in *LEFT* or *RIGHT* the left or right air data probe assembly data is processed and displayed. The probes are not deployed until below Mach 5, however, the data will not be accurate until the velocity is less than Mach 3.5, due to calibration of the probes.



Commander's AIR DATA Switch on Panel F6



Pilot's AIR DATA Switch on Panel F8

PFD Status Indicators

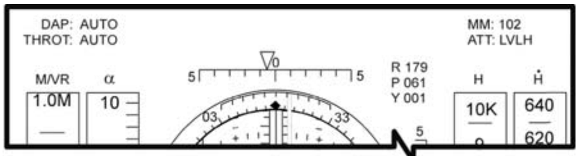
Unlike the Orbit PFD, the A/E PFD has four status fields, two each in the upper left and right corners, which display the major mode, abort mode, DAP, ADI attitude switch position, and SBTC status. These status indicators will change, depending upon the phase of flight, to show appropriate data.

The top right status indicator field always displays the major mode. If an abort has been declared, an indicator will be displayed immediately to right of the major mode (R for RTLS, T for TAL, CA for contingency aborts, AOA, or ATO).

During powered flight (MM 102, 103 and 601), the left side fields display the DAP mode (*AUTO* or *CSS*) and the throttle mode (*AUTO* or

MAN). If either CSS or MAN are selected, a yellow box will outline the field to indicate an off-nominal configuration. Post-MECO (MM 104-106), the DAP mode indicates either AUTO or INRTL, while the throttle field will blank.

Also the bottom right status displays the ADI attitude switch, either *Inrtl*, *LVLH*, or. *Ref* during ascent and post-MECO.

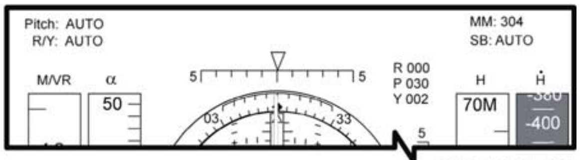


usa007587_10024r1.tif

Example of PFD Status Indicators in MM 102

During entry transition (MM301-303), the status fields display the same functions as post-MECO.

During entry (MM304, 305, 602, and 603), the left side fields display both the DAP pitch and roll/yaw modes (*AUTO* or *CSS*). The bottom right field displays the speedbrake mode (*AUTO* or *MAN*). If either MAN speedbrake is selected, or if CSS is selected above Mach 1.0, a yellow rectangle is drawn around the indicator.



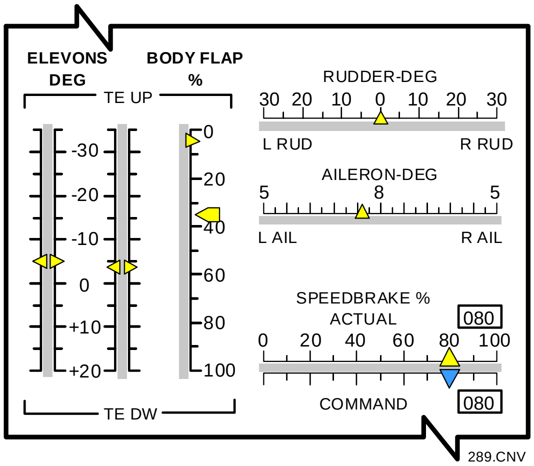
usa007587_10023r1.tif

Example of PFD Status Indicators in MM304

Surface Position Indicator (SPI)

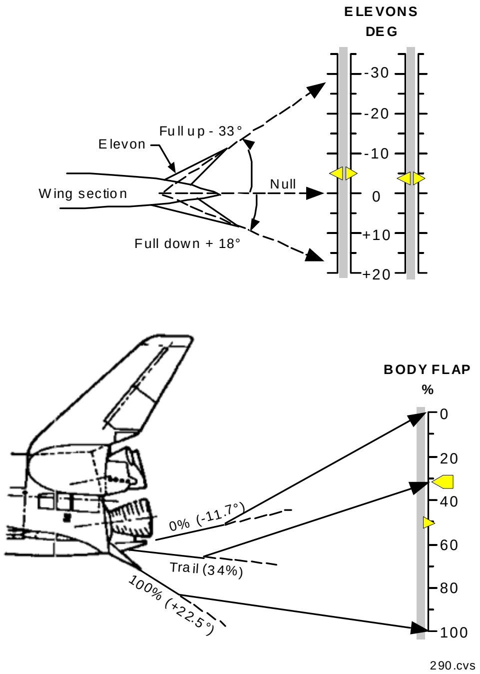
The SPI is a MEDS display that is active during entry (MM 304, 305, 602 and 603) and displays the actual positions of the elevons, body flap, rudder, aileron, and speedbrake, as well as the commanded speedbrake position.

The IDPs get data from analog-to-digital converters (ADCs) 1A and 1B for display on the SPI (see Section 2.6 for more information on IDPs and ADCs). For ADC failures or invalid data cases, the SPI bars will be outlined in red and the triangles will disappear.



Surface Position Indicator

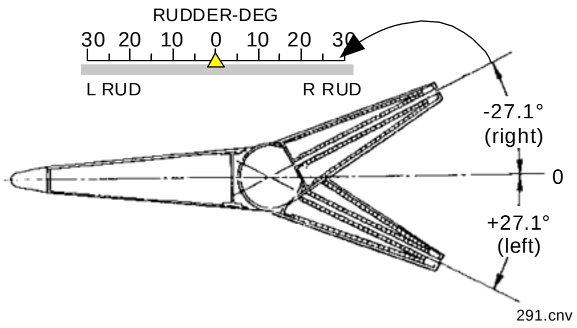
The four elevon position indicators show the elevon positions in the order of appearance as viewed from behind the vehicle (left outboard, left inboard, right inboard, right outboard). The scales all range from +20° to -35°, which are near the software limits for the elevon commands. The pointers are driven by four separate signals and can read different values, but normally the left pair is identical and the right pair is identical. Positive elevon is below the null line (elevon deflected down) and negative is above (elevon deflected up).



SPI Elevon Travel

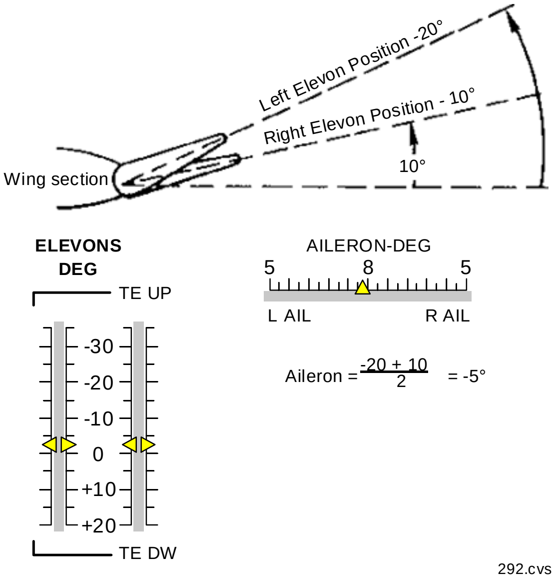
The body flap scale reads body flap positions from zero to 100 percent of software-allowed travel. Zero percent corresponds to full up (-11.7°) and 100 percent corresponds to full down (+22.5°). The small pointer at 34 percent is fixed and shows the trail position.

Rudder position is displayed as if viewed from the rear of the vehicle. Deflection to the left of center represents left rudder. The scale is +30° (left) to –30° (right), but software limits the rudder command to ±27.1°.



SPI Rudder Travel

The aileron display measures the effective aileron function of the elevons in combination. Aileron position equals the difference between the average of the left and right elevon divided by two. Deflection of the pointer to the right of center indicates a roll-right configuration (left elevons down, right elevons up) and vice versa. The scale is –5° to +5°, with –5° at the left side. The aileron command can exceed ±5° (max. ±10°), in which case the meter saturates at ±5°.

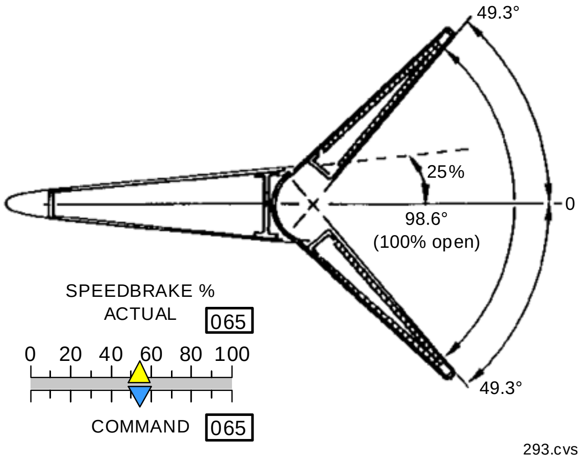


$$\text{Aileron} = \frac{-20 + 10}{2} = -5°$$

SPI Aileron Travel

The speed brake position indicator indicates the actual position on the upper scale and commanded position on the lower scale. The position ranges from zero to 100 percent; zero percent is fully closed, and 100 percent is fully open, which corresponds to 98 percent with respect to the hinge lines.

The speed brake command is scaled identically to position and has the same travel limits. It always represents the speed brake auto guidance command.



SPI Top View of Open Speed Brake

Flight Control System Pushbutton Indicators

The flight control system's pushbutton indicators transmit flight crew moding requests to the digital autopilot (DAP) in the flight control software and reflect selection by illuminating the effective DAP state. These indicators are located on panel F2 for the commander and panel F4 for the pilot.

The pushbutton indicators are used to command and reflect the status of the pitch and roll/yaw control modes. The *PITCH* and *ROLL/YAW* indicator pushbuttons transmit moding requests to the DAP as well as light up to indicate the effective state of the pitch and roll/yaw DAP channels.

AUTO indicates that control of that axis (pitch or roll/yaw) is automatic, and no crew inputs are required. *CSS* is control stick steering; crew inputs are required, but are smoothed by the DAP (stability augmentation, turn coordination).

The *SPD BK/THROT* (speed brake/throttle) pushbutton indicator is a single pushbutton with two separate lights, *AUTO* and *MAN*, to indicate that the DAP speed brake channel is in the automatic or manual mode. When depressed, the pushbutton only transmits the *AUTO* request. The *MAN* indicator will only light up for which ever position, commander or pilot has taken manual control with the speedbrake/thrust controller (SBTC). Only one position at a time, commander or pilot, can have *MAN* selected.

The *BODY FLAP* pushbutton indicator is also one pushbutton with separate *AUTO* and *MAN* lights, indicating the state of the body flap channel.

Reaction Control System Command Lights

The *RCS COMMAND* lights on panel F6 are active post-MECO during MM 104-106, OPS 2, 8, 3, and MM 602-603. Their primary function is to indicate reaction control system (RCS) jet commands by axis and direction during transitional and orbit phases. Their secondary function on entry is to indicate when more than two yaw jets are commanded and when the elevon drive rate is saturated.

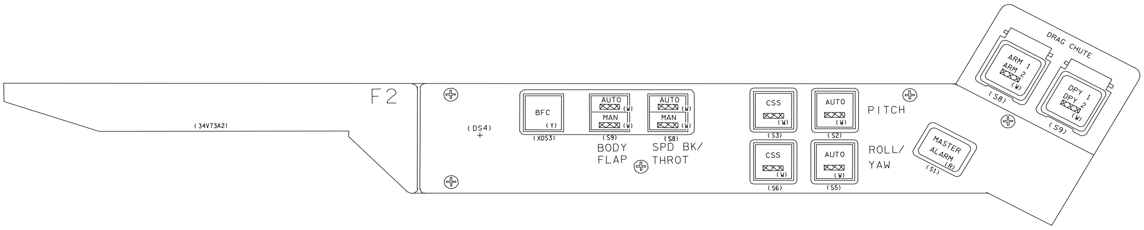
On entry, MM304, until the roll jets are no longer commanded (dynamic pressure exceeds 10 pounds per square foot), the *ROLL L* and *R* lights indicate that left or right roll jet commands have been issued by the DAP. The minimum light-on duration is extended so that the light can be seen even during minimum-impulse firings. On entry (MM304 and 602), when dynamic pressure is greater than or equal to 10 pounds per square foot, the *ROLL* lights are quiescent until 50 pounds per square foot, after which time both lights (*L* and *R*) are illuminated whenever more than two yaw jets are commanded on.

On entry, OPS 3 and 6, the *PITCH U* and *D* lights indicate up and down pitch jet commands until dynamic pressure equals 40 pounds per square foot, after which the pitch jets are no longer used. When dynamic pressure is 50 pounds per square foot or more, the *PITCH* lights, like the *ROLL* lights, assume a new function. Both light (*U* and *D)* whenever the elevon surface drive rate exceeds 20° per second (14° per second if only one hydraulic system is working).

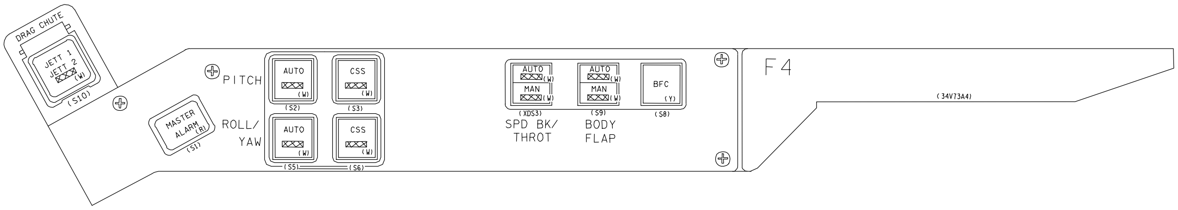
On entry, the *YAW L* and *R* lights function as yaw jet command indicators throughout entry until the yaw jets are disabled at Mach 1. The yaw lights have no other functions.

Entry Flight Control System Mode Pushbutton Indicator Light Logic

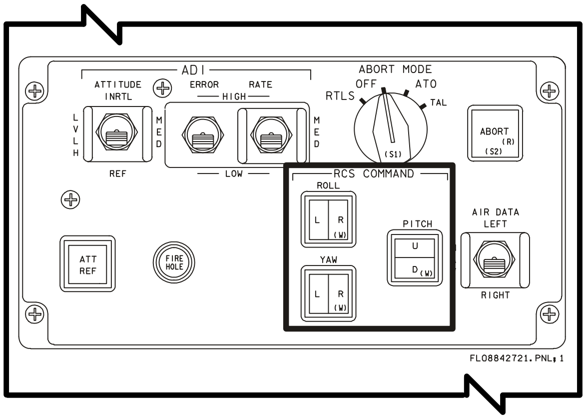
LIGHTS	LEFT/RIGHT LIGHT LOGIC		CAUSES
PITCH AUTO	Both on or both off	Auto, CSS mutually exclusive	*PITCH AUTO* pushbutton indicator depressed
PITCH CSS	both on or both off		*PITCH CSS* pushbutton indicator depressed or RHC out of detent in pitch
ROLL/YAW AUTO	Both on or both off	Auto, CSS mutually exclusive	*ROLL/YAW AUTO* pushbutton indicator depressed
ROLL/YAW CSS	both on or both off		*ROLL/YAW CSS* pushbutton indicator depressed or RHC out of detent in roll or yaw
SPD BK/THROT			
AUTO	Both on or both off	Auto, man. mutually exclusive	Neither SBTC takeover pushbutton depressed or *AUTO* pushbutton depressed
MAN	One on, one off		Either SBTC takeover pushbutton depressed
BODY FLAP			
AUTO	Both on or both off	Auto, man. mutually exclusive	*AUTO* pushbutton indicator depressed
MAN	Both on or both off		*MAN* pushbutton depressed



Commander's Flight Control System Pushbutton Light Indicators on Panel F2



Pilot's Flight Control System Pushbutton Light Indicators on panel F4



RCS COMMAND Lights on Panel F6

Head-Up Display (HUD)

The HUD is an optical miniprocessor that cues the commander and/or pilot during the final phase of entry and particularly in the final approach to the runway. With minimal movement of their eyes from the forward windows (head up) to the dedicated display instruments (head down), the commander and pilot can read data from head-up displays located in the front of them on their respective glareshields. The HUD presents the same data that is presented on several other instruments, including the PFD and the SPI.

The HUD allows out-of-the-window viewing by superimposing flight commands and information on a transparent combiner in the window's field of view. Since the orbiter avionics systems are digital, and minimal impact on the orbiter was paramount, the head-up display drive electronics were designed to receive data from the orbiter data buses. The HUD electronics utilize, to the maximum extent possible, the same data that drive the existing electromechanical display devices. The orbiter display device uses a CRT to create the image, which is then projected through a series of lenses onto a combining glass.

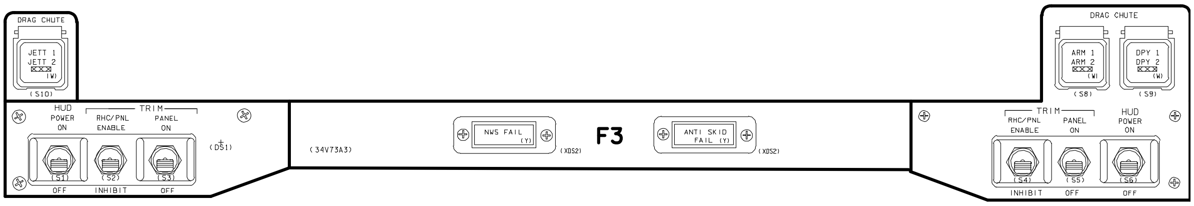
Each HUD is a single-string system, but it is connected to two data buses for redundancy. It is an electronic/optical device with two sets of combiner glasses located above the glareshield in the direct line of sight of the commander and the pilot. Essential flight information for vehicle guidance and control during approach and landing is projected on the combiner glasses and focused at infinity.

The images, generated by a small CRT and passed through a series of lenses, are displayed to the flight crew on the combiners as lighted symbology. The transmissiveness of the combiner allows the crew to look through it and see actual targets like the runway.

For instance, if the crew is 9,000 feet on the final approach course in a solid overcast, the base of which is at 8,000 feet, the lighted outline of the runway would be displayed on the combiner. However, when the orbiter exits the overcast at 8,000 feet, the lighted outline of the runway would be superimposed on the real runway. As the orbiter proceeds down the steep glideslope, the velocity vector is superimposed over the glideslope aim point. At preflare altitude, flare triangles move up to command the pullout. The pilot maintains the velocity vector symbol between the triangles. After a short period of stabilized flight on the shallow glideslope, the guidance diamond commands a pitch-up until the nose is about 8° above the horizon, which is essentially the touchdown attitude. After touchdown, during the rollout phase, the crew maintains the approximate touchdown attitude, +6° theta (nose above the horizon), until 185 knots equivalent airspeed and then commands a derotation maneuver.

The HUD has proved to be a valuable landing aid and is considered the primary pilot display during this critical flight phase.

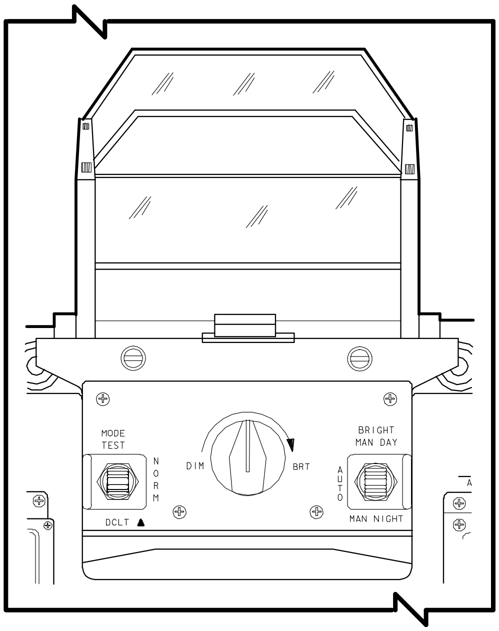
A *HUD POWER ON/OFF* switch located on the left side of panel F3 provides and terminates electrical power to the commander's head-up display on panel F6. A second switch is located on the right side of panel F3 for the pilot's head-up display on panel F8.



Panel F3

WARNING

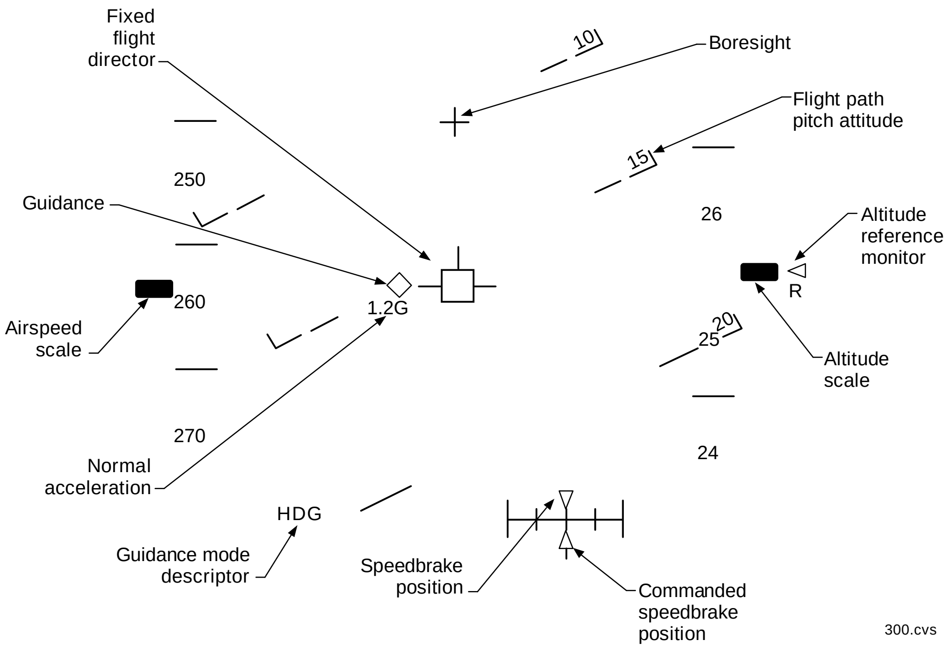
A generic hardware problem has been identified in several HUD units. At 13 KFT, the flight director symbol is uncaged to become a velocity vector (-ȯ-). Cycling HUD POWER after this transition may result in erroneous symbol positioning. Flying these false cues would result in landing short of the runway, at a very high sink rate. (Ref: JSC Memo DF6-90-053)



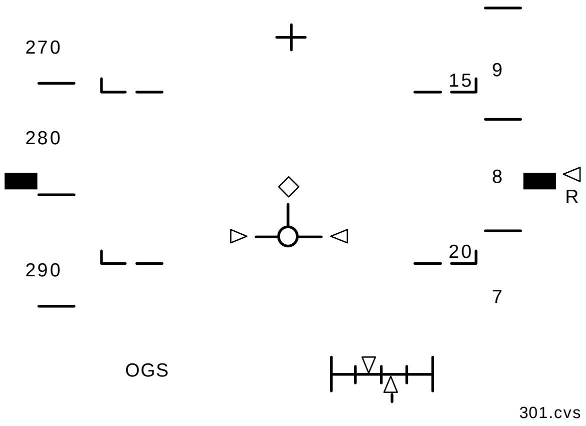
Head-Up Display and Controls on Panel F6 (Identical on Panel F8)

A three-position *MODE* switch is located below the HUD. In the *NORM* position, automatic sequencing of formats and symbology is provided. The *TEST* position forces up a test display for 5 seconds. Selection of the momentary *DCLT* (declutter) position initiates a symbol blanking routine. Successive selections of *DCLT* will serially remove display elements in the following order. The first activation removes the runway symbology. The second activation removes the airspeed and altitude tapes (replacing them with digital values) and the horizon/pitch attitude scales, but leaves the horizon line when within FOV. The third declutter level removes all symbology except for the boresight. A fourth declutter attempt will return the HUD to its original form with all symbols displayed.

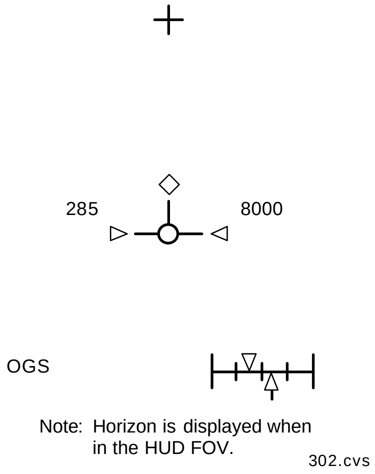
Data displayed on the HUD comes from the GPCs across flight critical (FC) databus 1 or 2 for the CDR's HUD and FC databus 3 or 4 for the PLT's HUD. A HUD databus switch on panel F6 (CDR) or F8 (PLT) controls the data source.



Approach and Land Display (TAEM Heading Phase); No Declutter

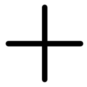


Approach and Land Display (Declutter Level 1)



Note: Horizon is displayed when in the HUD FOV.

Approach and Land Display (Declutter Level 2)



Approach and Land Display (Declutter Level 3)

Dedicated Display Systems Summary Data

- Dedicated displays are located on the flight instrument and subsystem status displays driven on the 11 multifunction display units (MDU) in a MEDS cockpit.

- Dedicated displays include: the primary flight displays (PFDs), SPI, RCS activity lights, and HUDs.

- Circuit breakers for device driver units are located on panels O14, O15, and O16.

- The attitude director indicator (ADI) displays orbiter attitude by a simulated ball gimbaled to represent three degrees of freedom.

- The PFD will alter appearance based upon phase of flight and abort mode.

- The horizontal situation indicator (HSI) visually displays certain guidance, navigation, and control parameters such as directions, distances, and course/glide path deviation.

- The Ascent/Entry PFD (A/E PFD) displays flight instruments, which include angle of attack, vehicle velocity, knots equivalent airspeed, acceleration, altitude, radar altitude. vertical velocity, and vertical acceleration on a flight phase-tailored basis for ascent, aborts, and entry.

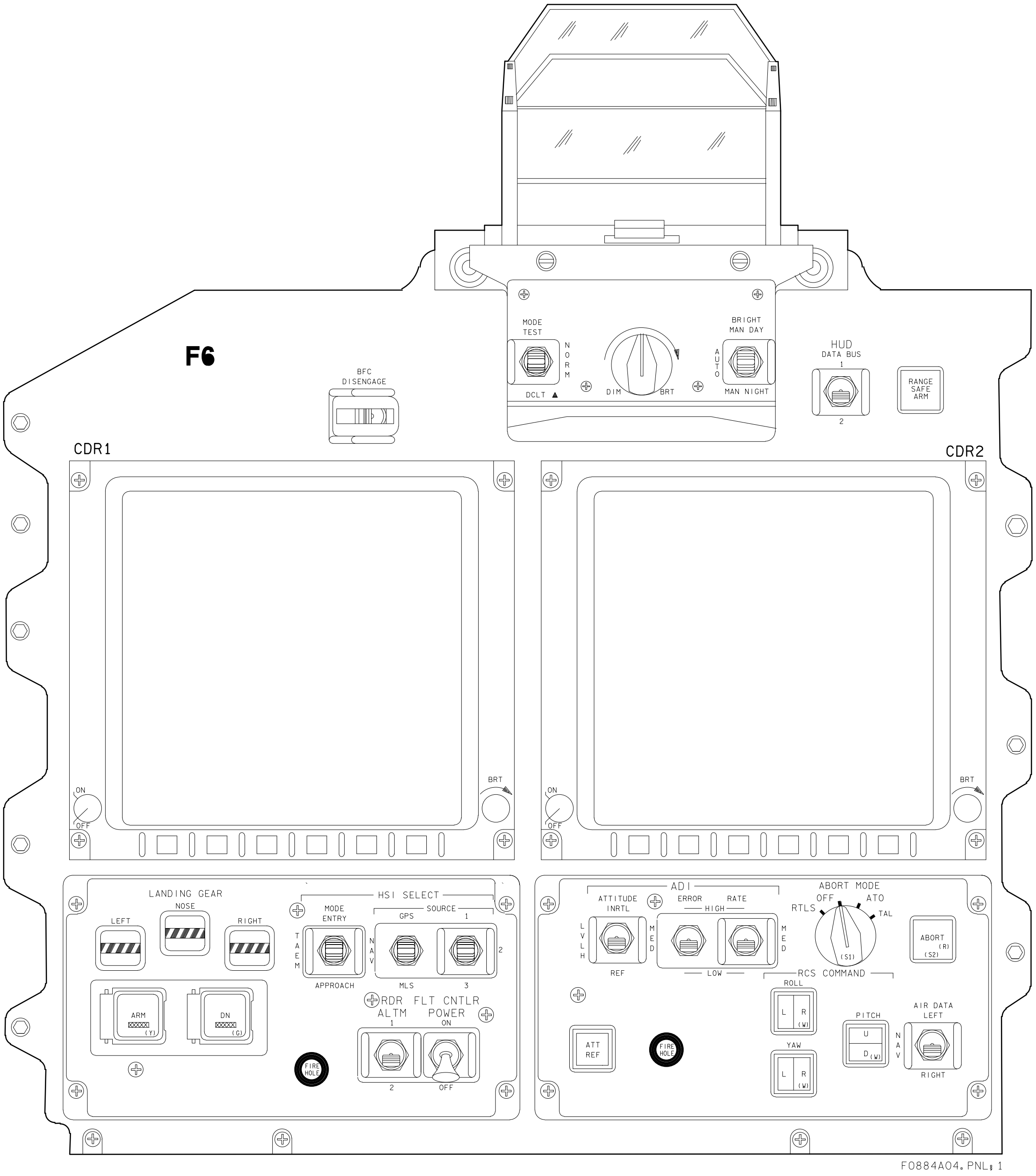
- The A/E PFD has a status indicator field across the top for major mode, abort, and DAP status.

- The orbit PFD is simply an ADI with no status indicators across the top.

- The SPI displays actual positions of the elevons, body flap, rudder, aileron, and speedbrake. Speedbrake commanded position is also displayed.

- The HUD cues the commander and/or pilot during final phases of entry by superimposing flight commands and information on a transparent combiner in the window's field of view. Power switches are located on panel F3.

- On orbit, when in the Flight Control System (FCS) checkout mode (MM 801), all displays can be driven by test software to allow the crew to verify correct operation prior to entry.


F6
BFC
DISENGAGE
MODE
TEST
NORM
DCLT ▲
DIM
BRT
BRIGHT
MAN DAY
AUTO
MAN NIGHT
HUD
DATA BUS
1
2
RANGE
SAFE
ARM
CDR1
CDR2
ON
OFF
BRT
ON
OFF
BRT
LANDING GEAR
LEFT
NOSE
RIGHT
ARM
(Y)
DN
(G)
FIRE
HOLE
HSI SELECT
MODE
ENTRY
TAEM
APPROACH
SOURCE
GPS
NAV
MLS
1
2
3
RDR FLT CNTLR
ALTM
1
2
POWER
ON
OFF
ADI
ATTITUDE
INRTL
LVLH
REF
ERROR
RATE
HIGH
MED
LOW
MED
ABORT MODE
OFF
RTLS
ATO
TAL
(S1)
ABORT
(R)
(S2)
RCS COMMAND
ROLL
L
R
(W)
YAW
L
R
(W)
PITCH
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D
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AIR DATA
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RIGHT
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FIRE
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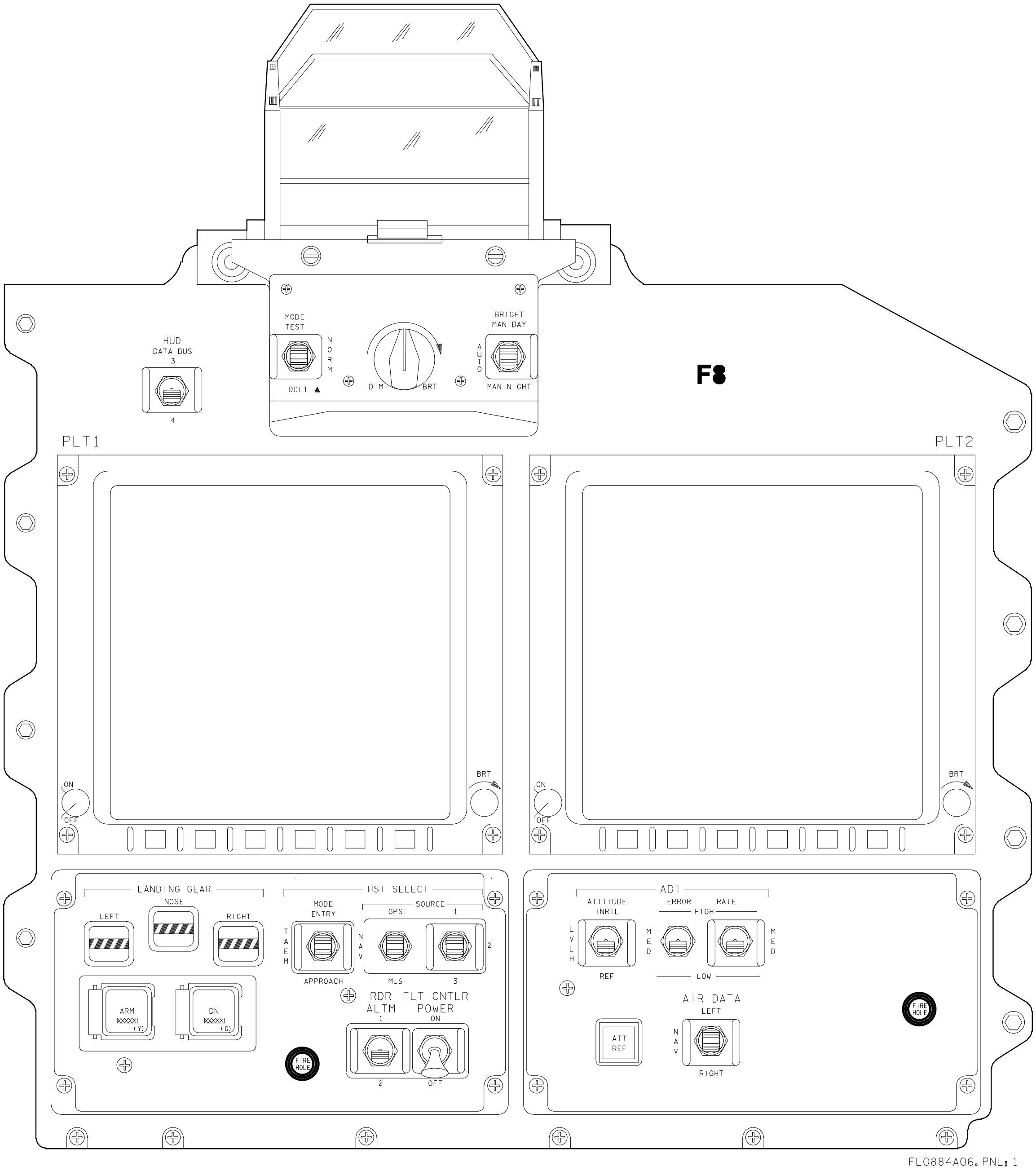
F0884A04.PNL;1

Panel F6


HUD
DATA BUS
3
4
MODE
TEST
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PLT1
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LEFT
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MLS
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1
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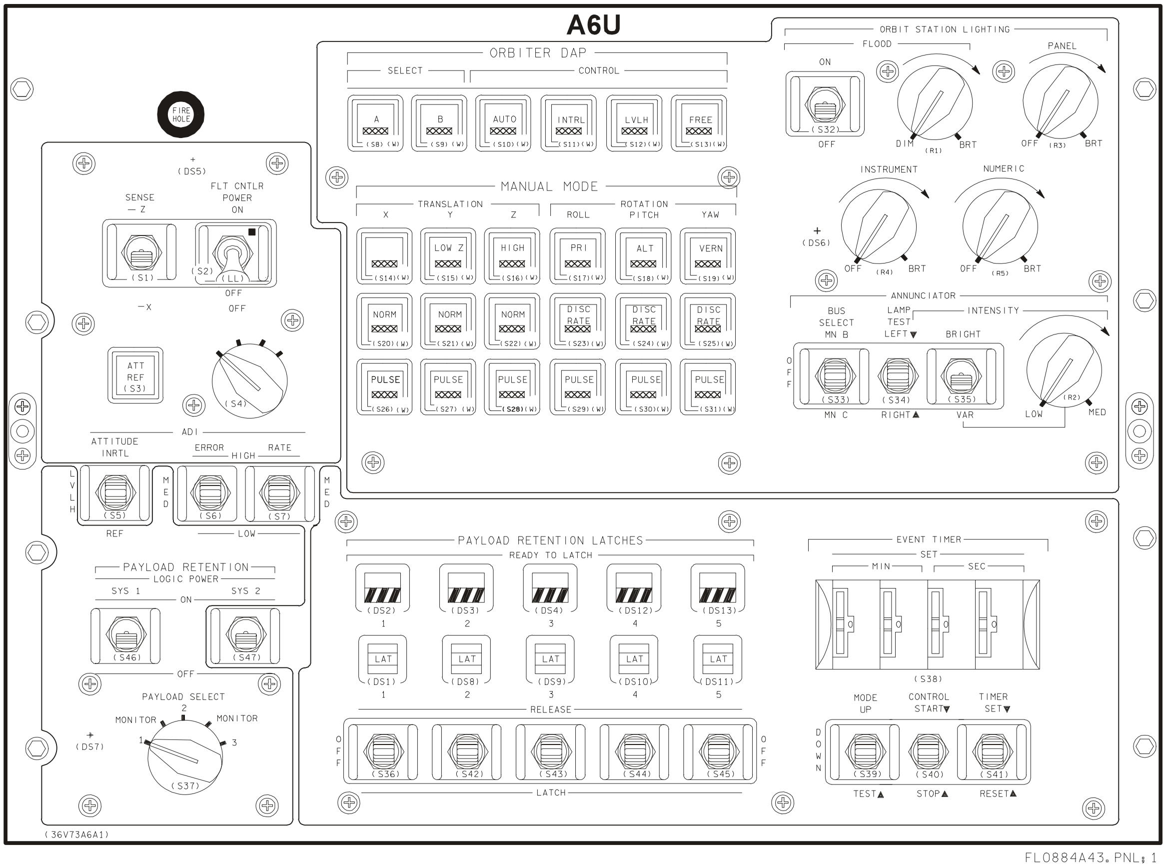
Panel F8


A6U
FIRE HOLE
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SELECT
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A
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(S8) (W)
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(S11) (W)
(S12) (W)
(S13) (W)
MANUAL MODE
TRANSLATION
ROTATION
X
Y
Z
ROLL
PITCH
YAW
LOW Z
HIGH
PRI
ALT
VERN
NORM
DISC RATE
PULSE
(S14) – (S31)
ORBIT STATION LIGHTING
FLOOD
PANEL
ON
OFF
(S32)
DIM
BRT
(R1)
(R3)
INSTRUMENT
NUMERIC
(R4)
(R5)
(DS6)
ANNUNCIATOR
BUS SELECT
MN B
MN C
LAMP TEST
LEFT▼
RIGHT▲
INTENSITY
BRIGHT
VAR
LOW
MED
(R2)
(S33)
(S34)
(S35)
(DS5)
SENSE
−Z
−X
FLT CNTLR POWER
(S1)
(S2)
(LL)
ATT REF
(S3)
(S4)
ADI
ATTITUDE
INRTL
LVLH
REF
ERROR
RATE
HIGH
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LOW
(S5)
(S6)
(S7)
PAYLOAD RETENTION
LOGIC POWER
SYS 1
SYS 2
(S46)
(S47)
PAYLOAD SELECT
MONITOR
1
2
3
(DS7)
(S37)
PAYLOAD RETENTION LATCHES
READY TO LATCH
(DS2)
(DS3)
(DS4)
(DS12)
(DS13)
LAT
(DS1)
(DS8)
(DS9)
(DS10)
(DS11)
4
5
RELEASE
LATCH
(S36)
(S42)
(S43)
(S44)
(S45)
EVENT TIMER
SET
MIN
SEC
(S38)
MODE
UP
DOWN
CONTROL
START▼
STOP▲
TIMER
SET▼
RESET▲
TEST▲
(S39)
(S40)
(S41)
(36V73A6A1)
FL0884A43.PNL;1

Panel A6U

2.8 ELECTRICAL POWER SYSTEM (EPS)

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Description

The electrical power system (EPS) consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter vehicle, and fulfill all the orbiter external tank, solid rocket booster, and payload power requirements, when not connected to ground support equipment. The EPS operates during all phases *of flight*. For nominal operations, very little flight crew interaction is required by the EPS.

The EPS is functionally divided into three subsystems: power reactants storage and distribution (PRSD), three fuel cell *(FC)* power plants, and electrical power distribution and control (EPDC).

Through a chemical reaction, the three FCs generate all 28-volt direct-current electrical power for the vehicle from launch minus 50 seconds through landing rollout. Prior to that, electrical power is provided by ground power supplies and the onboard FCs.

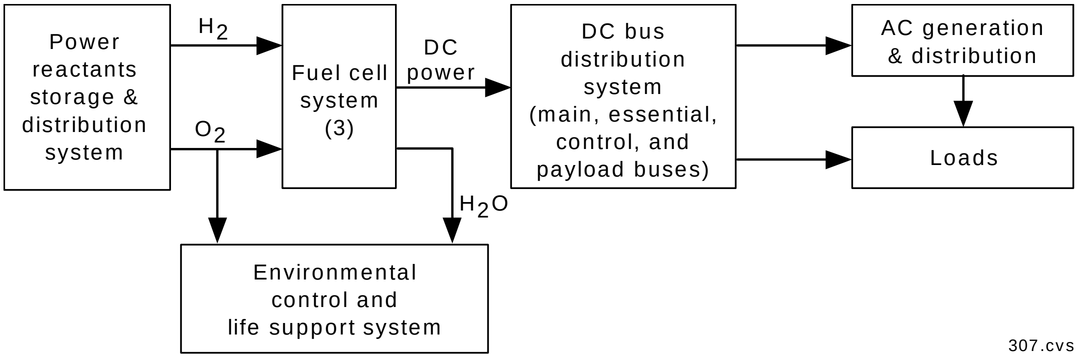
Power is controlled and distributed by assemblies located in the forward, mid, and aft sections of the orbiter. Each assembly is a housing for electrical components such as remote switching devices, buses, resistors, diodes, and fuses. Each assembly usually contains a power bus or buses and remote switching devices for distributing bus power to subsystems located in its area.

Power Reactants Storage and Distribution System

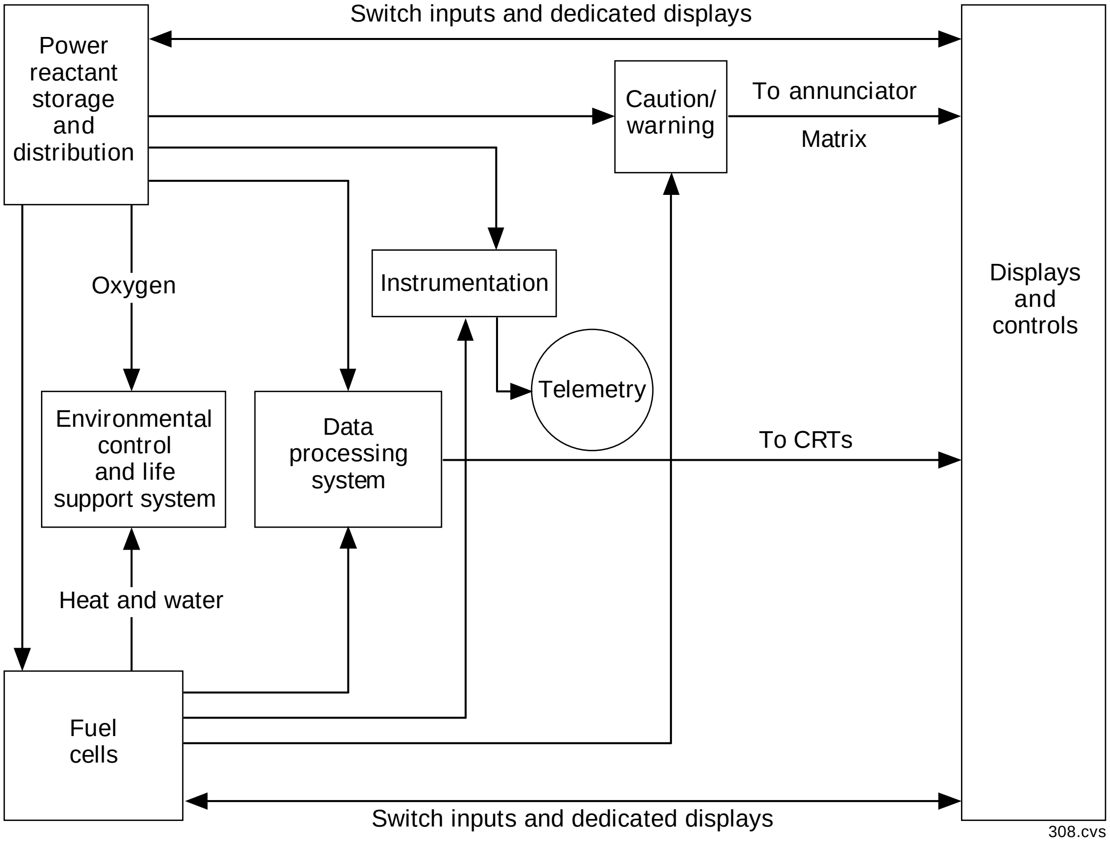
The *PRSD* system stores the reactants (cryogenic hydrogen and oxygen) and supplies them to the three FCs that generate all the electrical power for the vehicle during all mission phases. In addition, the subsystem supplies cryogenic oxygen to the environmental control and life support system (ECLSS) for crew cabin pressurization. The hydrogen and oxygen are stored in tanks at cryogenic temperatures (-285°F for liquid oxygen and -420° F for liquid hydrogen) and supercritical pressures (above 731 psia for oxygen and above 188 psia for hydrogen).

The PRSD system components are located in the orbiter midbody underneath the payload bay liner. The system stores the cryogenic hydrogen and oxygen in double-walled, thermally insulated spherical tanks with a vacuum annulus between the inner pressure vessel and outer tank shell. Each tank has heaters to add energy to the reactants during depletion to control pressure. Each tank has sensors *that* measure *temperature, pressure, and* quantity.

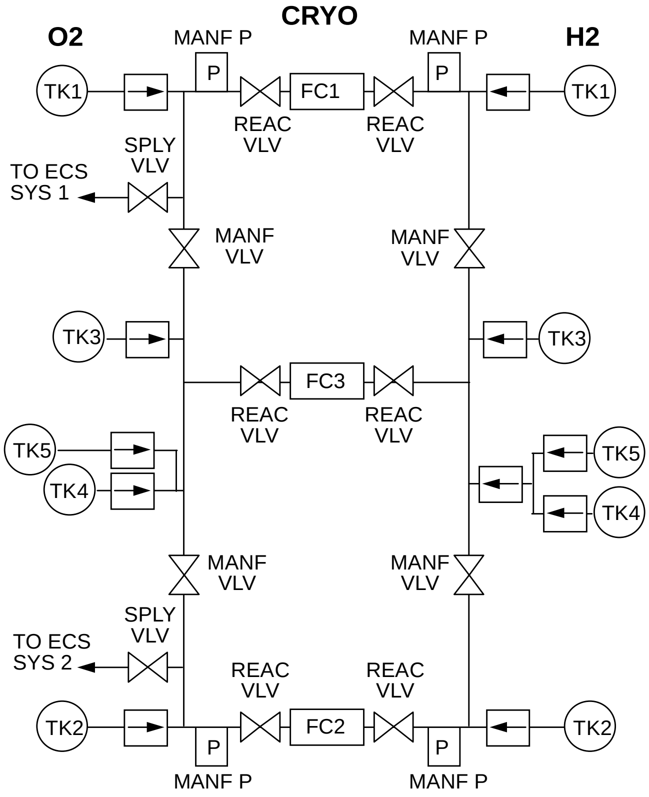
The tanks are grouped in sets of one hydrogen and one oxygen tank. The number of tank sets installed depends on the specific mission requirement and vehicle. Up to five tank sets can be installed in the midfuselage under the payload bay liner.



The Electrical Power System



Electrical Power System Interfaces



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The *PRSD* System

Cryogenic Storage Tanks

All oxygen tanks are identical and consist of inner pressure vessels of Inconel 718 and outer shells of aluminum 2219. The inner vessel is 33.435 inches in diameter and the outer shell is 36.8 inches in diameter. Each tank has a volume of 11.2 cubic feet and stores up to 781 pounds of oxygen. The dry weight of each tank is 215 pounds. Maximum fill time is 45 minutes.

All hydrogen tanks are *also* identical. Both the inner pressure vessel and the outer shell are constructed of aluminum 2219. The inner vessel's diameter is 41.51 inches and the outer shell's is 45.5 inches. The volume of each tank is 21.39 cubic feet, and each stores up to 92 pounds of hydrogen. Each tank weighs 227 pounds dry. Maximum fill time is 45 minutes.

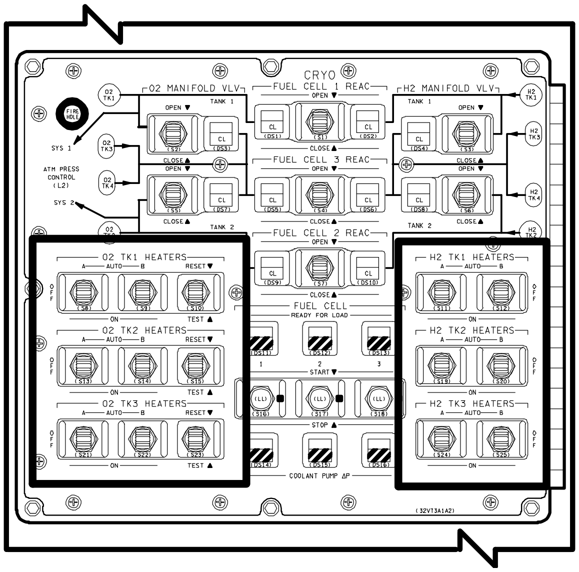
The inner pressure vessels are kept supercold by minimizing conductive, convective, and radiant heat transfer. Twelve low-conductive supports suspend the inner vessel within the outer shell. Radiant heat transfer is reduced by a shield between the inner vessel and outer shell (hydrogen tanks only), and convective heat transfer is minimized by maintaining a vacuum between the vessel and shell. During ground operations, a vacuum ion pump maintains the required vacuum level and is also used as a vacuum gauge to determine the vacuum's integrity. The pump consists of an electrical power supply and an anode, which absorbs free ions between the tank walls.

Cryogenic Tank Heaters

Each hydrogen tank has one heater probe with two elements; each oxygen tank has two heater probes with two elements per probe. As the reactants are depleted, the heaters add heat energy to maintain a constant pressure in the tanks.

The heaters operate in automatic and manual modes. In the automatic mode, the heater is controlled by a tank heater controller. Each heater controller receives a signal from a tank pressure sensor. If pressure in a tank is less than or equal to a specific pressure, the controller turns the heater on. When the pressure in the tanks goes above the upper limit, the respective controller turns the heater off. The O2 TK1, 2, 3, and H2 TK1, 2, 3 heater switches are located on panel R1; switches for the O2 and H2 TK4 heaters are on panel A11. The heater switches for tank set 5 are on panel A15.

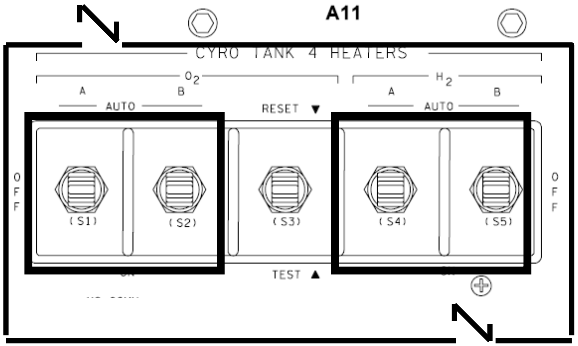
Heater controller psia		
Pressure limits (psia)	Low	High
H_2 tank 1, 2	200-206	220-226
H_2 tank 3-5	217-223	237-243
O_2 tank 1,2	803-819	838-854
O_2 tank 3-5	832-848	866-882



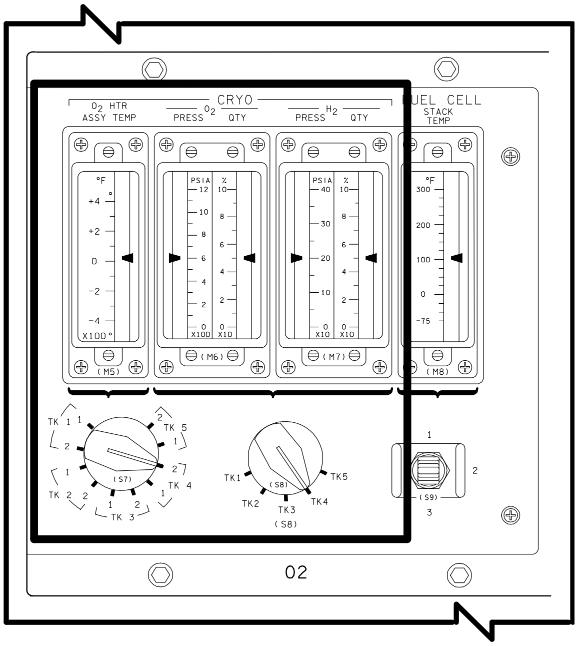
O2 and H2 TK HEATERS Switches on Panel R1

Dual-mode heater operation is available for pairs of oxygen and hydrogen tanks. If the heaters of both tanks 1 and 2, or tanks 3 and 4, are put in the automatic mode, the tank heater logic is interconnected. In this case, the heater controllers of both tanks must sense a low pressure before the heaters will turn on. Once they are on, a high pressure signal from either tank will turn off the heaters in both tanks.

In the manual mode, the flight crew controls the heaters by using the *ON OFF* positions for each heaters switch on panel R1, A11, or A15. Pressure in each tank is shown as O2 TK P and H2 TK P on the DISP 68 CRYO *SYSTEM display*. Pressure is also displayed on the CRYO O_2 and H_2 PRESS meters on panel O2. The specific tank (1, 2, 3, 4, *or 5*) is selected by the rotary switch below the meters.

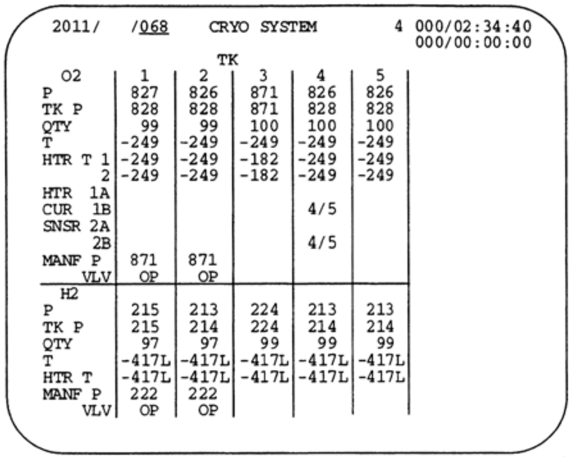


CRYO TANK 4 HEATER Switches on Panel A11



Cryogenic System Meters and Switches on Panel O2

Each tank set has a hydrogen/oxygen control box that contains the electrical logic for the hydrogen and oxygen heaters and controllers. The control box is located on cold plates in the midbody under the payload bay envelope.



```
 2011/    /068      CRYO  SYSTEM          4 000/02:34:40
                                            000/00:00:00
                          TK
  O2      |  1  |  2  |  3  |  4  |  5  |
P         | 827 | 826 | 871 | 826 | 826 |
TK P      | 828 | 828 | 871 | 828 | 828 |
QTY       |  99 |  99 | 100 | 100 | 100 |
T         |-249 |-249 |-249 |-249 |-249 |
HTR T 1   |-249 |-249 |-182 |-249 |-249 |
      2   |-249 |-249 |-182 |-249 |-249 |
HTR  1A   |     |     |     |     |     |
CUR  1B   |     |     |     | 4/5 |     |
SNSR 2A   |     |     |     |     |     |
     2B   |     |     |     | 4/5 |     |
MANF P    | 871 | 871 |     |     |     |
     VLV  |  OP |  OP |     |     |     |
----------------------------------------
  H2      |     |     |     |     |     |
P         | 215 | 213 | 224 | 213 | 213 |
TK P      | 215 | 214 | 224 | 214 | 214 |
QTY       |  97 |  97 |  99 |  99 |  99 |
T         |-417L|-417L|-417L|-417L|-417L|
HTR T     |-417L|-417L|-417L|-417L|-417L|
MANF P    | 222 | 222 |     |     |     |
     VLV  |  OP |  OP |     |     |     |
```

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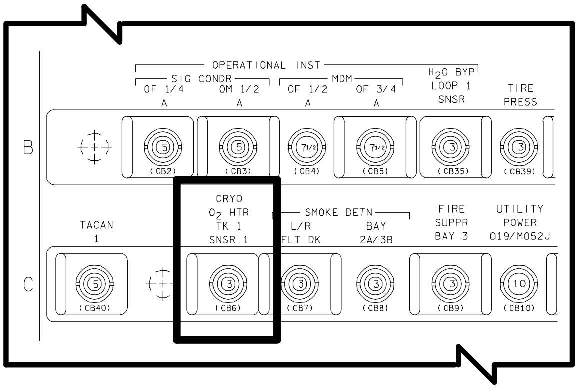
DISP 68 CRYO SYSTEM Display (on orbit)

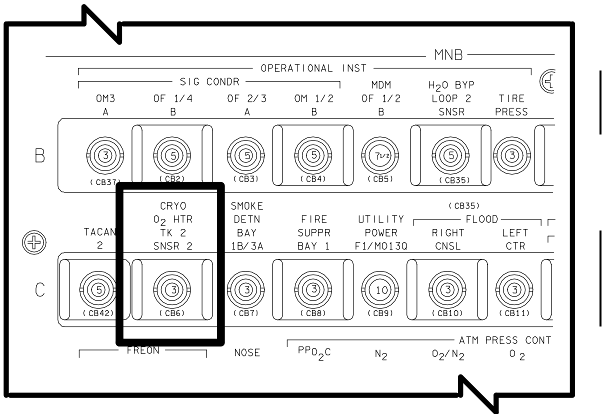
The CRYO O_2 HTR ASSY TEMP meter on panel O2, in conjunction with the rotary switch below it, selects one of the two heaters in each tank and permits the temperature of the heater element to be displayed. The range of the display is from -425° F to +475° F. The temperature sensor in each heater also is hard-wired directly to the caution and warning system, which drives the yellow *O_2 HEATER TEMP* light on panel F7. This light is illuminated if the temperature is at or above 344° F. A signal also is sent to the GPCs where software checks the limit; if the temperature is at or above 349° F, the *BACKUP C/W ALARM* light on panel F7 is illuminated. This signal also is displayed on SM SPEC 68 CRYO SYSTEM and transmitted to the ground.

Two current level detectors are built into the circuit of each oxygen tank heater to interrupt power in case of electrical shorts. The second detector is redundant. Each *heater assembly has a corresponding set of detectors,* A and B, which monitor the heater A current and the heater B current, respectively. The detectors are powered by circuit breakers on panels O14, O15, O16, and ML86B. The detectors monitor the current *going* in*to* and out of a heater. If the current difference is 0.9 amps or greater for 5 milliseconds, a trip signal is sent to the heater logic to remove power from the heaters, regardless of the heater switch position. If one element of a heater causes a "trip-out," power to both elements is removed. The *O_2 TK 1, 2, 3 HEATERS RESET/ TEST* switches on panel R1 and the *O_2 RESET/ TEST* switches on panels A11 and A15 can be used to reapply power to that heater by positioning them to *RESET*. The *TEST* position will cause a 1.5-amp delta current to flow through all four detectors of a specified oxygen tank, causing them to trip out. During on-orbit operations, the flight crew will be alerted to a current level detector trip-out by an *SM ALERT*, S68 CRY0 02 message.

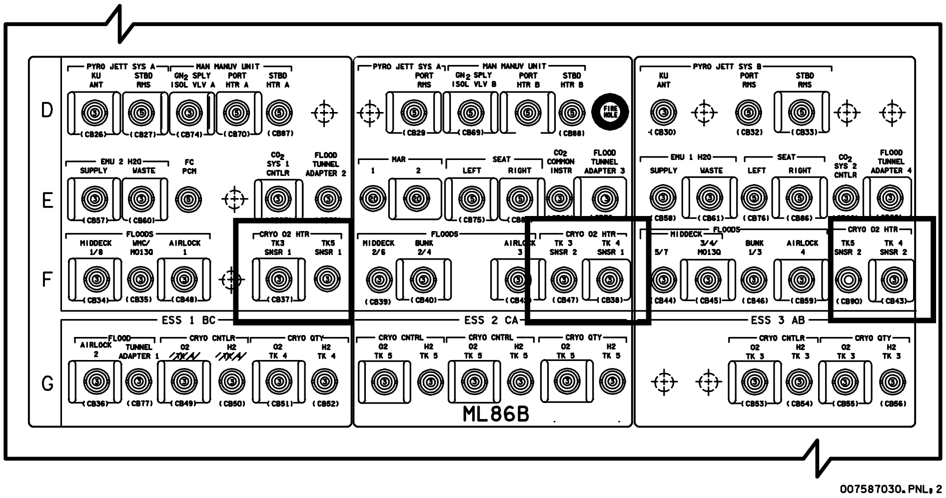


Cryogenic System Heater Sensor Circuit Breaker on Panel O14

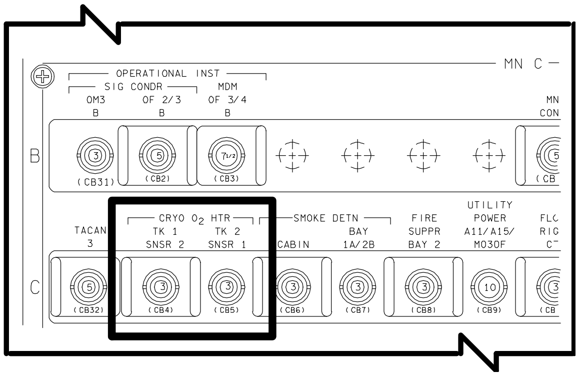
Each oxygen and hydrogen tank has a quantity sensor powered by a circuit breaker. These are identified on panel O13 as *CRYO QTY O_2* (or *H_2*) *TK 1* and *TK 2* and on panel ML86B as *CRYO QTY O_2* (or *H_2*) *TK 3, TK 4,* and *TK 5*. Data from the quantity sensors are sent to panel O2, where the rotary switch below the meters is used to select the tank for display on the CRYO O_2 (or H_2) QTY meters. The range of the meters is zero to 100 percent. The data are also displayed on SM SPEC 68.



Cryogenic System Heater Sensor Circuit Breaker on Panel O15

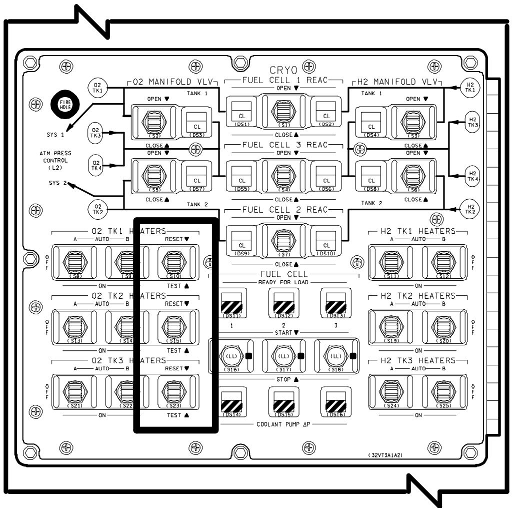


Cryogenic System Heater Sensor Circuit Breaker on Panel ML86B



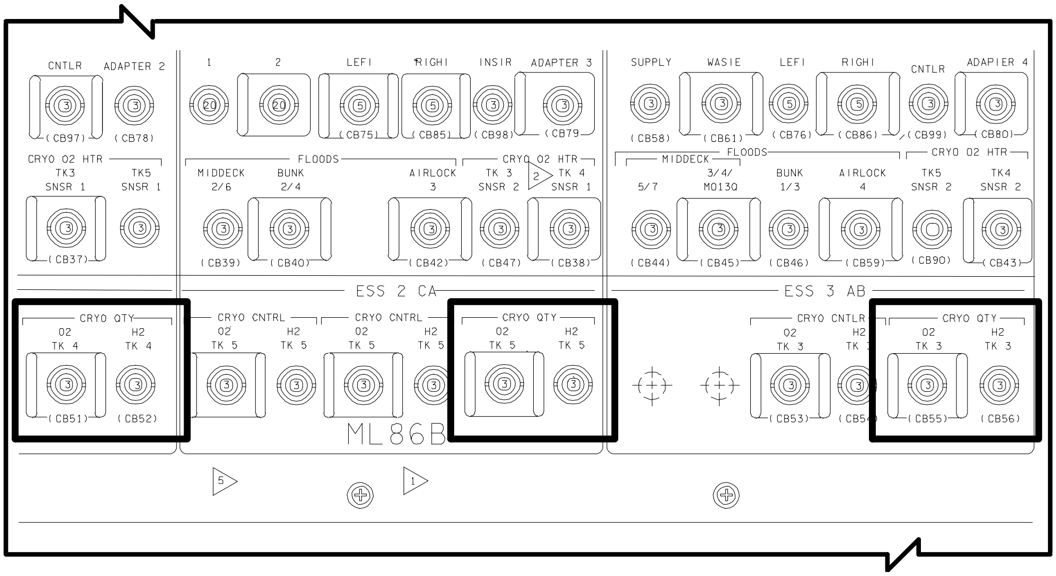
Cryogenic System Heater Sensor Circuit Breaker on Panel O16

There are two pressure sensors for each oxygen and hydrogen tank. One sensor transmits its data to the tank heater controllers, the caution and warning matrix on panel F7, and is displayed as "P" on SM SPEC 68. The yellow *O_2 PRESS* light is illuminated if oxygen tank pressure is below 540 psia or above 985 psia. The yellow *H_2 PRESS* light illuminates if hydrogen tank pressure is below 153 psia or above 293.8 psia. Data from the other sensor is displayed as TK P on SM SPEC 68 and the PRESS meters on panel O2. The *SM ALERT* and *BACKUP C/W ALARM* lights on panel F7 are also driven by the data. The range of the O_2 meter is 0 to 1,200 psia. The H_2 meter's range is 0 to 400 psia. The range of "P" displayed on the PASS and BFS SM SYS SUMM 1 and SM SPEC 68 and SM SPEC 168 is 515 to 1,215 psia for oxygen and 145 to 305 psia for hydrogen.

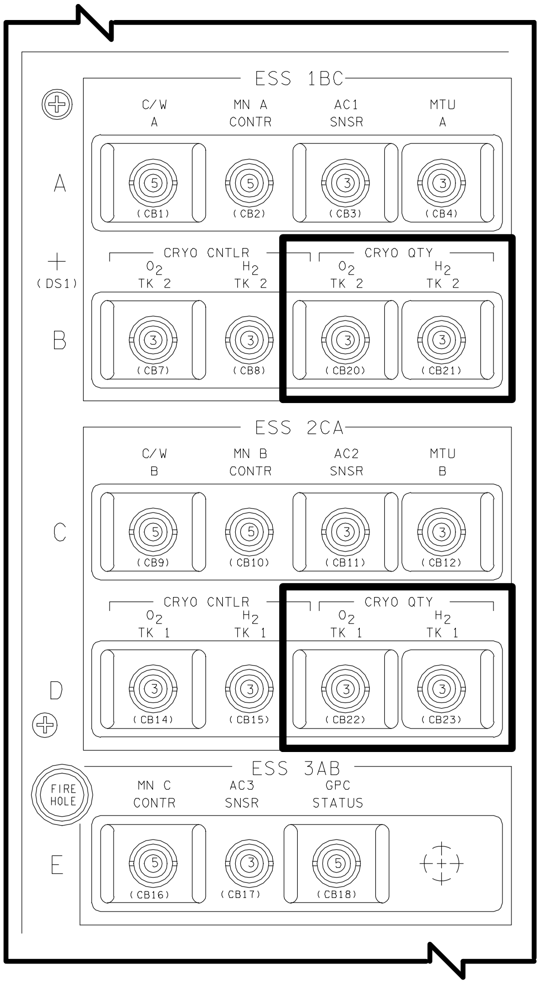


O2 TK 1, TK 2 HEATERS RESET/TEST Switches on Panel R1

The data from oxygen and hydrogen fluid temperature sensors is displayed on SM SPEC 68 and transmitted to the ground.



Cryogenic Tank Quantity Sensor Circuit Breakers on Panel ML86B



Cryogenic Tank Quantity Sensor Circuit Breakers on Panel O13

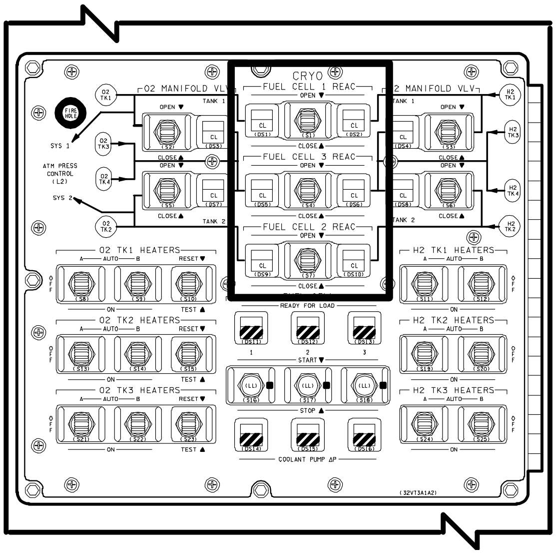
Reactant Distribution

The cryogenic reactants flow from the tanks through a relief valve/filter package module and a valve module. They then flow to the FCs through a common manifold. Hydrogen is supplied to the manifold from the tank at a pressure of 200 to 243 psia and oxygen is supplied at 803 to 883 psia. The pressure of the reactants will be essentially the same at the FC interface as it is in the tanks, since only a small decrease in pressure occurs in the distribution system.

Each tank has a relief valve/filter package module that contains the tank relief valve and a 12-micron filter. The filter removes contaminants that could affect the performance of components within the PRSD and the FCs. The valve relieves excessive pressure overboard that builds up in the tank. The oxygen tank relief valve relieves at 1,005 psia and the hydrogen tank relief valve relieves at 302 psia. Tanks one and two also have a manifold relief valve that relieves pressure in the manifold lines. The manifold relief valves are a built-in safety device in the event a manifold valve and FC reactant valve are closed because of a malfunction. The reactants trapped in the manifold lines would be warmed up by the internal heat of the orbiter and overpressurize. The manifold relief valve will open at 290 psi for hydrogen and 975 psi for oxygen to relieve pressure and allow the trapped reactants to flow back to their tanks.

The reactants flow from the relief valve/filter packages through four reactant valve modules: two hydrogen (hydrogen valve modules 1 and 2) and two oxygen (oxygen valve modules 1 and 2). The valve modules contain a check valve for each cryogenic tank line to prevent the reactants from flowing from one tank to another in the event of a leak. This prevents a total loss of reactants. The oxygen valve modules also contain the environmental control and life support system atmosphere pressure control system 1 and 2 oxygen supply valves. Each module also contains a manifold valve and FC reactant valves.

Each FC has two reactant valves—one for hydrogen and one for oxygen. The valves are controlled by the *FUEL CELL 1, 3, 2 REAC* switches on panel R1. When the switch is positioned to *OPEN*, the hydrogen and oxygen reactant valves for that FC are opened and reactants are allowed to flow from the manifold into the FC. When the switch is positioned to *CLOSE*, the hydrogen and oxygen reactant valves for that FC are closed, isolating the reactants from the FC and rendering that FC inoperative. Each *FUEL CELL REAC* switch on panel R1 also has two talkback indicators, one on each side of the switch. The corresponding talkback indicates *OP* when the valve is *OPEN* and *CL* when the valve is closed. There is redundant capability to close the *REAC VALVES* via the *FUEL CELL REAC VLV* circuit breakers and switches on panel C3.



FUEL CELL 1, 3, 2 REAC Switches and Talkbacks on Panel R1

WARNING

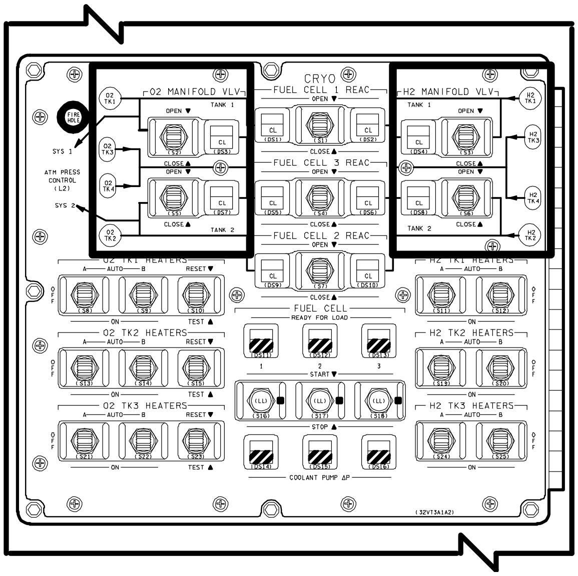
The *FUEL CELL REAC* switches on panel R1 are in a vertical column with *FUEL CELL 1 REAC* on top, *FUEL CELL 3 REAC* in the middle, and *FUEL CELL 2 REAC* on the bottom. This was done to allow the schematic to be placed on the panel. Because the switches are not in numerical order, it is possible to inadvertently close the wrong FC reactant valve when shutting down a FC.

It is critical to have reactants available to the FCs. When any FC reactant valve is closed, the red *FUEL CELL REAC* light on panel F7 is illuminated and a caution/warning tone is sounded. The computers sense the closed valve, which causes the *BACKUP C/W ALARM* light on panel F7 to be illuminated, an *SM ALERT* to occur, and a closed indication to be displayed on SM SPEC 69 and SM SYS SUMM 1. This alerts the flight crew that the FC will be inoperative within approximately 20 to 30 seconds for a hydrogen valve closure and 90 seconds for an oxygen valve closure. The time varies with power loading.

The *O_2* and *H_2 MANIFOLD VLV* switches on panel R1 control the respective hydrogen and oxygen manifold valves. When the two hydrogen and two oxygen manifold valves are in the

CLOSE position, FC 1 receives reactants from cryogenic tank set 1, FC 2 receives reactants from cryogenic tank set 2, and FC 3 receives reactants from cryogenic tank sets 3 and above. ECLSS atmosphere pressure control system 1 receives oxygen from oxygen tank 1, and system 2 receives oxygen from oxygen tank 2. When the switches are positioned to *CLOSE*, the talkback indicator associated with each switch indicates *CL*.

With both H_2 and O_2 *MANIFOLD VLV 1* switches positioned to *OPEN* and the *MANIFOLD VLV 2* switches positioned to *CLOSE*, cryogenic tanks 1, 3 and above supply hydrogen to FCs 1 and 3, and oxygen cryogenic tanks 1, 3 and above supply oxygen to FCs 1 and 3, as well as to ECLSS atmosphere pressure control system 1. The talkback indicator associated with each MANF VLV 1, 2 switch indicates *OP, CL*, respectively. O_2 and H_2 TK 2 continue to supply FC 2.



O2 and H2 MANIFOLD VLV Switches and Talkbacks on Panel R1

CAUTION

There are no relief valves for O_2 and H_2 manifold 3's with manifold valves 1 and 2 closed. This configuration should be avoided except for leak isolation and troubleshooting.

When the H_2 and O_2 MANIFOLD VLV 2 switches are positioned to OPEN, and the MANIFOLD VLV 1 switches are positioned to CLOSE, hydrogen cryogenic tanks 2 and 3 and above supply hydrogen to FCs 2, 3, and oxygen cryogenic tanks 2 and 3 and above supply oxygen to FCs 2 and 3, as well as to ECLSS atmosphere pressure control system 2. The talkback indicator associated with each MANF VLV 1, 2 switch indicates OP, CL, respectively. H_2 and O_2 tank 1 continue to supply FC 1.

With the H_2 and O_2 *MANIFOLD VLV 1* and *2* switches positioned to *OPEN*, all hydrogen cryogenic tanks are available to supply hydrogen to all three FCs, and all oxygen cryogenic tanks are available to supply oxygen to all three FCs, as well as to ECLSS atmosphere pressure control systems 1 and 2. Because tank sets 1 and 2 are regulated at a slightly lower pressure, tank sets 3 and above will feed before tank set 1 and 2. Reactants will be supplied to the FCs by the tank(s) with the highest pressure.

Manifold pressure data from two pressure sensors located in the respective hydrogen and oxygen valve modules is displayed on SM SPEC 68 CRYO SYSTEM. This information is also sent to the systems management computer where its lower limit is checked. If the respective hydrogen and oxygen manifold pressures are below 150 psia and 200 psia respectively, an *SM ALERT* will occur.

Fuel Cell System

The three FCs are located under the payload bay liner in the forward portion of the orbiter's midfuselage. Each FC is 14 inches high, 15 inches wide, 40 inches long, and weighs 255 pounds. Each FC is reusable and restartable. The three FCs are individually coupled to the PRSD subsystem, the active thermal control system (ATCS), the supply water storage subsystem, and the electrical power distribution and control (EPDC) subsystem. The FCs generate heat and water as by-products of electrical power generation. The excess heat is directed to the FC heat exchanger, where it is rejected to the Freon coolant loops. The water is directed to the supply water storage subsystem for the environmental control and life support system.

ACCESSORIES	POWER
Reactant flow monitor	96 cells
Heat rejection	Converts H2 & O2 into:
Water rejection	
Thermal control	Power
Cell performance monitor	Potable water
Electrical control unit	Heat

Fuel Cell Block Diagram

The nominal voltage and current range of each FC is 32.5 volts DC at 2 kW (61.5 amps), decreasing to 27.5 volts DC at 12 kW (436 amps). Each is capable of supplying up to 10 kW maximum continuous power in nominal situations, 12 kW continuously in off-nominal situations (with one or more FCs failed), and up to 16 kW for 10 minutes. The average on-orbit power consumption of the orbiter is approximately 14 kW, leaving additional capability available for payloads. Each FC is serviced between flights and reused until it has accumulated 2,000 hours of on-line service.

The orbiter's three FCs operate as independent electrical power sources, each supplying its own isolated, simultaneously operating DC bus. Each FC consists of a power section and an accessory section. The power section, where hydrogen and oxygen are transformed into electrical power, water, and heat, consists of 96 cells contained in three substacks. Manifolds run the length of these substacks and distribute hydrogen, oxygen, and coolant to the cells. The cells contain an oxygen electrode (cathode), and a hydrogen electrode (anode) that are separated by a porous matrix saturated with potassium hydroxide electrolyte.

The accessory section monitors the reactant flow, removes waste heat and water from the chemical reaction, and controls the temperature of the stack. The accessory section consists of the hydrogen and oxygen flow system, the coolant loop, and the electrical control unit.

The FC generates power through an electrochemical reaction of hydrogen and oxygen. At the hydrogen electrode (anode), hydrogen is oxidized according to the following reaction:

$$2H_2 + 4OH^- \longrightarrow 4H_2O + 4e^-$$

forming water and releasing electrons. At the oxygen electrode (cathode), oxygen is reduced in the presence of water. It forms hydroxyl ions according to the following relationship:

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

The net reaction consumes one oxygen molecule and two hydrogen molecules in the production of two water molecules, with electricity and heat formed as by-products of the reaction.

The FC coolant system circulates a liquid fluorinated hydrocarbon and transfers the waste heat from the cell stack through the FC heat exchanger to the Freon coolant loop system in the midfuselage. Internal control of the circulating fluid maintains the cell stack at a load-dependent operating temperature of approximately 200° F.

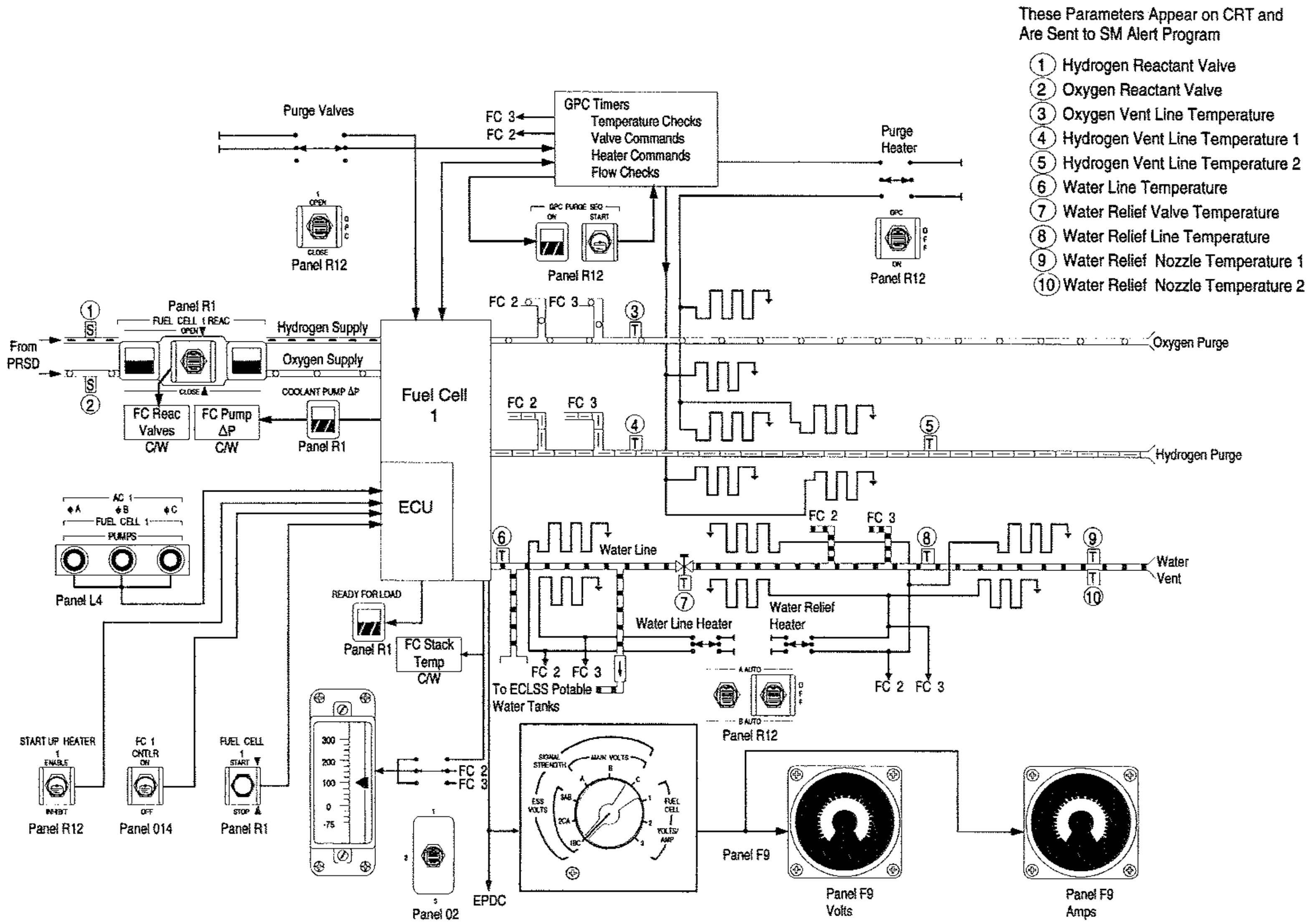
When the reactants enter the FCs, they flow through a preheater (where they are warmed from a cryogenic temperature to 40° F or greater), a 6-micron filter, and a two-stage, integrated dual gas regulator module. The first stage of the regulator reduces the pressure of the hydrogen and oxygen to 100 to 120 psia. The second stage reduces the oxygen pressure to a range of 60 to 65 psia and maintains the hydrogen pressure at 4.5 to 6 psia differential below the oxygen pressure. The regulated oxygen lines are connected to the accumulator, which maintains an equalized pressure between the oxygen and the FC coolant. If oxygen and hydrogen pressure decrease, the coolant's pressure is also decreased to prevent a large differential pressure inside the stack that could deform the cell stack structural elements.

Upon leaving the dual gas regulator module, the incoming hydrogen mixes with the hydrogen-water vapor exhaust from the FC stack. This saturated gas mixture is routed through a condenser, where the temperature of the mixture is reduced, condensing a portion of the water vapor to form liquid water droplets. The liquid water is then separated from the hydrogen-water mixture by the hydrogen pump /water separator. A centrifugal water separator extracts the liquid water and pressure-feeds it to potable tanks in the lower deck of the pressurized crew cabin. Water from the potable water storage tanks can be used for crew consumption and for cooling the Freon loops by feeding the flash evaporator system.

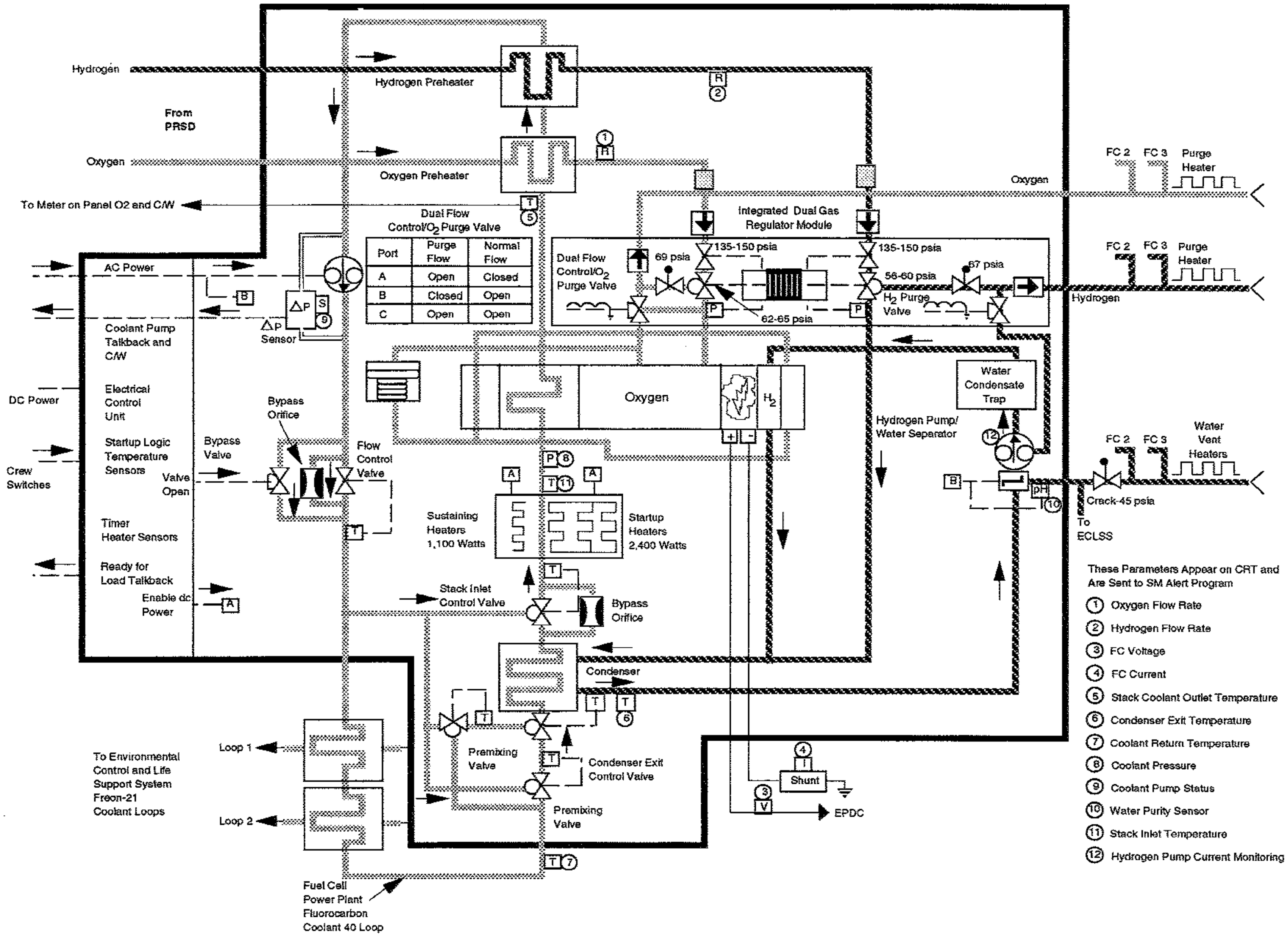
The hydrogen pump uses three-phase AC power to circulate the hydrogen gas back to the FC stack, where some of the hydrogen is consumed in the reaction. The remainder flows through the FC stack, removing the product water vapor formed at the hydrogen electrode. The hydrogen-water vapor mixture then combines with the regulated hydrogen from the dual gas generator module and the loop begins again. The performance at the pump is monitored via the H_2 pump status voltage display on SM SPEC 69.

The oxygen from the dual gas regulator module flows directly through two ports into a closed-end manifold in the FC stack, achieving optimum oxygen distribution in the cells. All oxygen that flows into the stack is consumed, except during purge operations.

Reactant consumption is directly related to the electrical current produced: if there are no internal or external loads on the FC, no reactants will be used. Because of this direct proportion, leaks may be detected by comparing reactant consumption with current produced. An appreciable amount of excess reactants used indicates a probable leak.



Fuel Cell 1 Typical Display and Controls



Dual Flow Control/O_2 Purge Valve

Port	Purge Flow	Normal Flow
A	Open	Closed
B	Closed	Open
C	Open	Open

These Parameters Appear on CRT and Are Sent to SM Alert Program

① Oxygen Flow Rate
② Hydrogen Flow Rate
③ FC Voltage
④ FC Current
⑤ Stack Coolant Outlet Temperature
⑥ Condenser Exit Temperature
⑦ Coolant Return Temperature
⑧ Coolant Pressure
⑨ Coolant Pump Status
⑩ Water Purity Sensor
⑪ Stack Inlet Temperature
⑫ Hydrogen Pump Current Monitoring

Fuel Cell - Typical

Water Removal

Water and electricity are the products of the oxidation/reduction reaction of oxygen and hydrogen that takes place in the *FC*s. The water must be removed or the cells will become saturated with water, decreasing reaction efficiency. With an operating load of about 7 kW, it takes only 110 amp-hr or approximately 20 minutes to flood the *FC* with produced water, thus effectively halting power generation. Hydrogen is pumped through the stack and the portion that is not consumed in the reaction acts as a carrier gas, picking up and removing water vapor on the way. After being condensed, the liquid water is separated from the hydrogen by the hydrogen pump/water separator and discharged from the *FC* to be stored in the ECLSS potable water storage tanks.

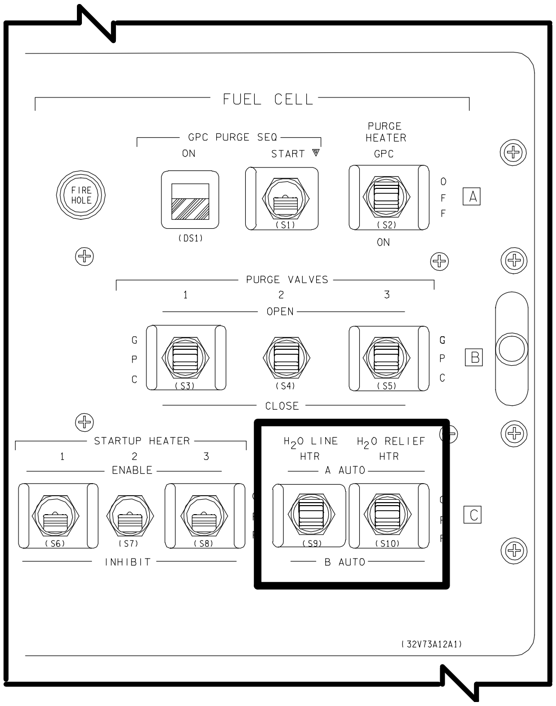
Product water is routed to tank A; when tank A is full, it is routed to tank B, then tanks C and D. An alternate water delivery path is also available to deliver water to the ECLSS tanks if the primary path is lost. If the water tanks are full, or there is line blockage, the water relief valves open at 45 psia to allow the water to vent overboard through the water relief line and nozzle. Check valves prevent water tanks from discharging through an open relief valve.

For redundancy, two thermostatically activated heaters are wrapped around the discharge and relief lines to prevent blockage caused by the formation of ice in the lines. Two switches on panel R11U, *H_2O LINE HTR* and *H_2O RELIEF HTR*, provide the flight crew with the capability to select either *A AUTO* or *B AUTO* for the *FC* water discharge line heaters and the water relief line and vent heaters respectively.

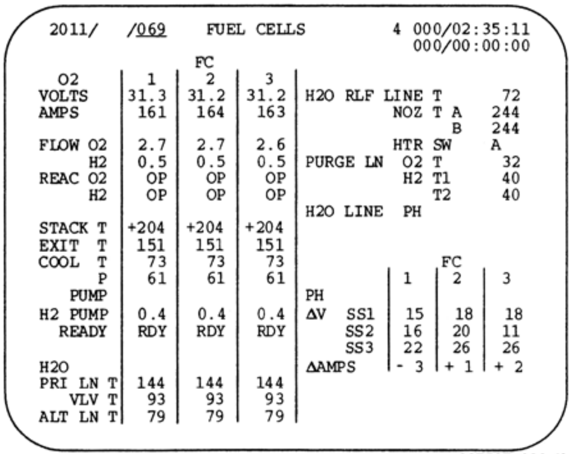
Thermostatically controlled heaters will maintain the water line temperature above 53° F when required. The normal temperature of product water is approximately 140° to 150° F. Thermostatically controlled heaters also maintain the water relief valve's temperature when in use between 70° to 100° F.

FC 1, 2, or 3 *DC* voltage and current can be monitored on the DC VOLTS and DC AMPS/SIG STR meters on panel F9, using the rotary switch below the meters to select a specific *FC*, and on SM SPEC 69. Temperature sensors located on the *FC* water discharge line, relief valve, relief line, and vent nozzle are displayed on SM SPEC 69 FUEL *CELLS.*

If the potassium hydroxide electrolyte in any *FC* migrates into the product water, a pH sensor located downstream of the hydrogen pump/water separator will sense the presence of the electrolyte and alert the crew via an *SM ALERT* and display on SM SPEC 69. A common pH sensor is located downstream of the interface between each *FC*'s primary water path, prior to entering the ECLSS supply H_2O tanks.



H_2O LINE and H_2O RELIEF HTR Switches On Panel R11U



```
 2011/   /069    FUEL CELLS          4 000/02:35:11
                                       000/00:00:00
                        FC
  O2     |  1  |  2   |  3   |
VOLTS    | 31.3| 31.2 | 31.2 | H2O RLF LINE T       72
AMPS     |  161|  164 |  163 |             NOZ T A   244
                                                 B   244
FLOW O2  |  2.7|  2.7 |  2.6 |             HTR SW    A
     H2  |  0.5|  0.5 |  0.5 | PURGE LN  O2 T       32
REAC O2  |   OP|   OP |   OP |           H2 T1      40
     H2  |   OP|   OP |   OP |              T2      40
                               H2O LINE  PH
STACK T  | +204| +204 | +204 |
EXIT  T  |  151|  151 |  151 |
COOL  T  |   73|   73 |   73 |                FC
      P  |   61|   61 |   61 |           |  1 |  2  |  3
   PUMP                        PH
H2 PUMP  |  0.4|  0.4 |  0.4 | ΔV   SS1  |  15|  18 |  18
  READY  |  RDY|  RDY |  RDY |      SS2  |  16|  20 |  11
                                    SS3  |  22|  26 |  26
H2O                            ΔAMPS     | - 3| + 1 | + 2
PRI LN T |  144|  144 |  144 |
   VLV T |   93|   93 |   93 |
ALT LN T |   79|   79 |   79 |
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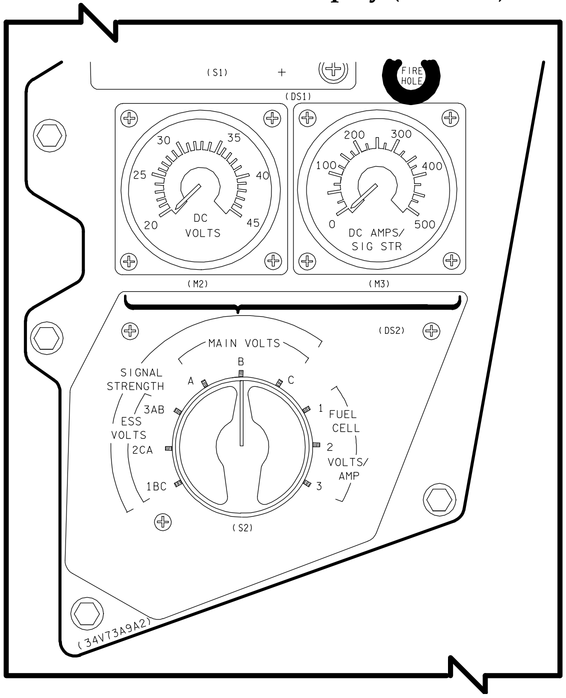
FUEL CELLS DPS Display (DISP 69)

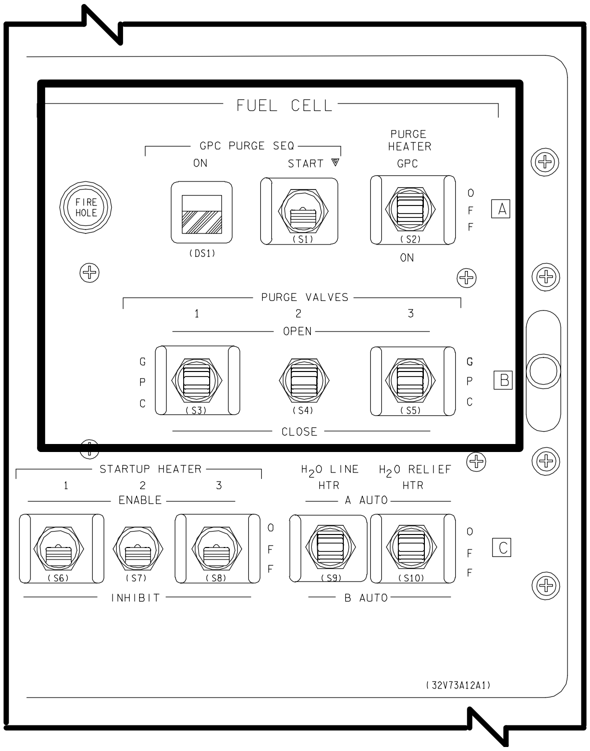


DC VOLTS and DC AMPS Meters and Rotary Switch on Panel F9

Fuel Cell Purge

During normal FC operation, the reactants are present in a closed-loop system and either consumed in the production of electricity or recirculated through the stack. Any inert gases or other contaminants will accumulate in and around the porous electrodes in the cells and reduce the reaction efficiency and electrical load support capability. Purging is performed periodically to cleanse the cells. The purge sequence can be controlled manually by the crew, automatically by flight software, or via commands sent by Mission Control. When a purge is initiated by opening the purge valves, the oxygen and hydrogen systems become open-loop systems; increased flows allow the reactants to circulate through the stack, pick up the contaminants, and blow them overboard through the purge lines and vents. Electrical power is produced throughout the purge sequence. No more than 10 kilowatts (350 amps) should be required from a FC being purged because of the increased reactant flow and preheater limitations.

FC purges can be activated automatically or manually via switches on panel R11U. At the initiation of either an auto or manual purge, the purge line heaters are turned on to heat the purge lines and ensure that the reactants do not freeze in the lines. The hydrogen reactant is the more likely to freeze because it is saturated with water vapor. Depending on orbit trajectory and vehicle orientation, the heaters may require 27 minutes to heat the lines to the required temperatures. Because of limitations on the hydrogen and oxygen preheaters in the FCs, the crew checks the FC current to ensure each FC has a load of less than 350 amps. As the current output of the FC increases, the reactant flow rates increase and the preheaters raise the temperature of the reactants to a minimum of 40° F to prevent the seals in the dual gas regulator from freezing before purging. At loads greater than 350 amps, additional flow during a purge would exceed the maximum flow the preheaters are capable of warming. The crew also checks that the FC is not shut down, that time to deorbit is more than 3 hours, and, for an automatic purge, that an SM OPS transition is not scheduled within the next hour. An SM OPS transition will halt the automatic purge sequence.



FUEL CELL Purge Switches on Panel R11U

The purge lines from all three FCs are manifolded together downstream of their purge valves and associated check valves. The line leading to the purge outlet is sized to permit unrestricted flow from only one FC at a time.

NOTE

> If more than one FC is purged simultaneously, back pressure may build in the purge line. Due to the sizing of the hydrogen and oxygen purge lines, the back pressure in the H_2 line can cause the hydrogen pressure to rise above the oxygen pressure. Although the dual gas regulator is designed to prevent this from happening, it is not advisable to expose all three FCs to this condition at the same time. If there is a generic problem with the dual gas regulator, it could cause all three FCs to fail simultaneously.

For an automatic purge, the FUEL CELL PURGE heater switch is positioned to GPC and the *FUEL CELL PURGE VALVES 1, 2,* and *3* switches on panel R11U are positioned to *GPC*. The *FUEL CELL GPC PURGE SEQ* switch is then positioned to *START* and must be held until 3 seconds after the talkback indicator beside the switch indicates gray. The automatic purge sequence will not begin if the indicator indicates barberpole. First, the GPC turns the purge line heaters on and monitors the temperature of the lines. The one oxygen line temperature sensor must register at least 69° F and the two hydrogen line temperature sensors 79° F and 40° F, respectively, before the purge valves will open. When the proper temperatures have been reached, the GPC will open the hydrogen and oxygen purge valves for FC 1 for 2 minutes, close them, and then repeat the process for FCs 2 and 3. If a FUEL CELL PURGE VALVE switch is not in the GPC position, the software purge sequence will skip that FC and continue to the next FC in the sequence. If the temperatures are not up to the minimum limit after 27 minutes, the GPC will issue an *SM ALERT,* display the data on SM SPEC 69, and stop the auto sequence. Thirty minutes after the FC 3 purge valves have been closed (to ensure that the purge lines have been totally evacuated of water vapor by the heaters), the GPC will turn off the purge line heaters. This provides sufficient time and heat to bake out any remaining water vapor. If the heaters are turned off before 30 minutes have elapsed, water vapor left in the lines may freeze. The GPC purge sequence start can also be initiated using the SPEC 60 SM TABLE MAINT display. The sequence is normally performed by Mission Control uplink on orbit.

The flight crew, using the switches on panel R11U, would also initiate a manual FC purge. In the manual mode, the three FCs must be purged separately. The *FUEL CELL PURGE HEATER* switch is positioned to *ON* for the same purpose as in the automatic mode, and the flight crew verifies that the temperatures of the oxygen line and two hydrogen lines are at the same minimum temperatures as in the automatic mode before the purge sequence is initiated. The *FUEL CELL PURGE VALVE 1* switch is then positioned to *OPEN* for 2 minutes and the flight crew observes that the oxygen and hydrogen flow rates increase on SM SPEC 69. The switch is then positioned to *CLOSE*, and a decrease in the oxygen and hydrogen flow rates is observed on SM SPEC 69, confirming the purge valves are closed. FC 2 is purged in the same manner using the *FUEL CELL PURGE VALVES 2* switch. Then FC 3 is purged in the same manner using the *FUEL CELL PURGE VALVES 3* switch. After the

30-minute line bakeout period, the *FUEL CELL PURGE HEATER* switch is positioned to *OFF*. Manual purges use different heaters than automatic purges. At least one manual purge is scheduled per flight.

Fuel Cell Cooling/Temperature Control

To cool the *FC* stack during its operations, distribute heat during *FC* start-up, and warm the cryogenic reactants entering the stack, the *FC* circulates fluorinated hydrocarbon throughout the *FC*. The *FC* coolant loop and its interface with the ECLSS Freon coolant loops are identical in *FC*s 1, 2, and 3.

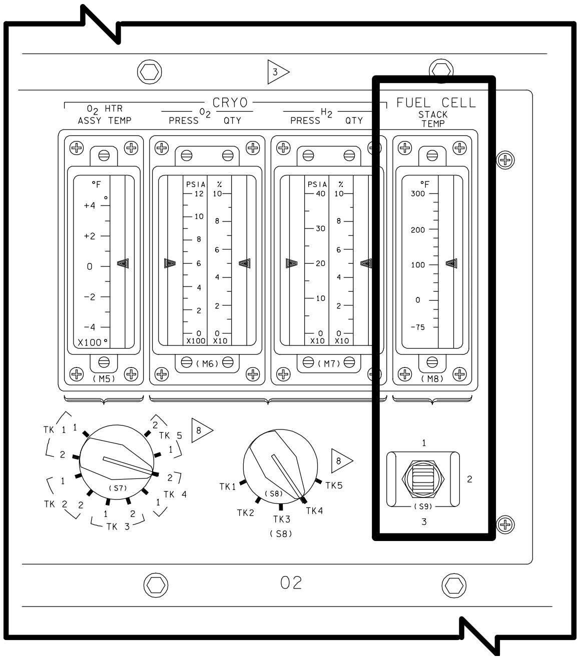
The temperature of the coolant returning from the Freon coolant loops is sensed before it enters the *FC*. This is displayed as COOL T on SM SPEC 69. It then enters the *FC* and passes through a 75-micron filter. After the filter, two temperature-controlled mixing valves allow some of the hot coolant to mix with the cool returning coolant to prevent the condenser exit control valve from oscillating. The control valve adjusts the flow of the coolant through the condenser to maintain the hydrogen-water vapor exiting the condenser at a temperature between 148° and 153° F.

The stack inlet control valve maintains the temperature of the coolant entering the stack between 177° and 187° F. The accumulator interfaces with the oxygen cryogenic reactant to maintain an equalized pressure between the oxygen and the coolant (the oxygen and hydrogen pressures are controlled at the dual gas regulator) to preclude a high pressure differential in the stack. The pressure in the coolant loop is sensed before the coolant enters the stack and is displayed as COOL P on SM SPEC 69.

The coolant is circulated through the *FC* stack to absorb the waste heat from the hydrogen/oxygen reaction occurring in the individual cells. After the coolant leaves the stack, its temperature is sensed and the data is displayed on the FUEL CELL STACK TEMP meter through the three-position switch located below the meter on panel O2 and on the SM SPEC 69 display as STACK T. The yellow *FUEL CELL STACK TEMP*, the red *BACKUP C/W ALARM* light, and the *SM ALERT* light on panel F7 will be illuminated if *FC* and stack temperatures exceed upper or lower limits. The hot coolant from the stack flows through the oxygen and hydrogen preheaters where it warms the cryogenic reactants before they enter the stack.

The coolant pump utilizes three-phase *AC* power to circulate the coolant through the loop. The differential pressure sensor senses a pressure differential across the pump to determine the status of the pump. The *FUEL CELL PUMP* light on panel F7 will be illuminated if *FC* 1, 2, or 3 coolant pump delta pressure is lost and a fault message will be sent to the DPS display. If the coolant pump for *FC* 1, 2, or 3 is off, the *BACKUP C/W ALARM* light will be illuminated and a fault message and a $\Delta P\downarrow$ will be displayed.

The temperature-actuated flow control valve downstream from the pump adjusts the coolant flow to maintain the *FC* coolant exit temperature between 190° and 210° F. The stack inlet control valve and flow control valve have bypass orifices to allow coolant flow through the coolant pump and to maintain some coolant flow through the condenser for water condensation, even when the valves are fully closed due to the requirements of thermal conditioning. The hot coolant that is not used at the mixing valves exits the *FC*s to the *FC* heat exchanger where it transfers its excess heat to be dissipated through the ECLSS Freon coolant loops in the midfuselage.

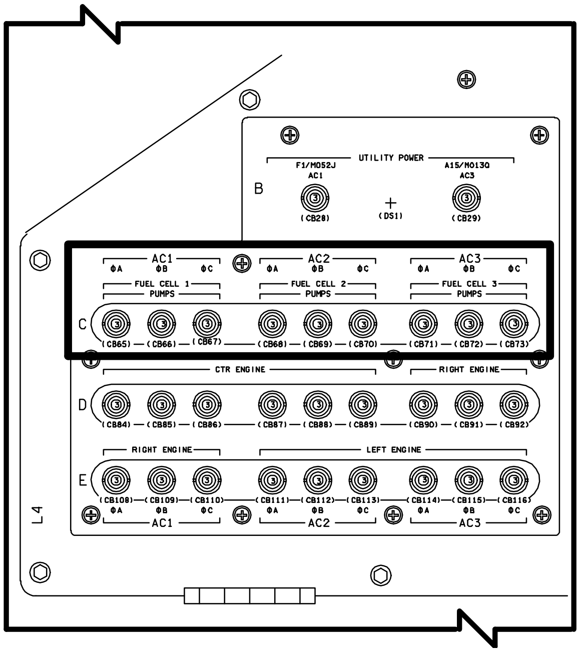


FUEL CELL STACK TEMP Meter and FUEL CELL 1, 2, 3 Switch on Panel O2

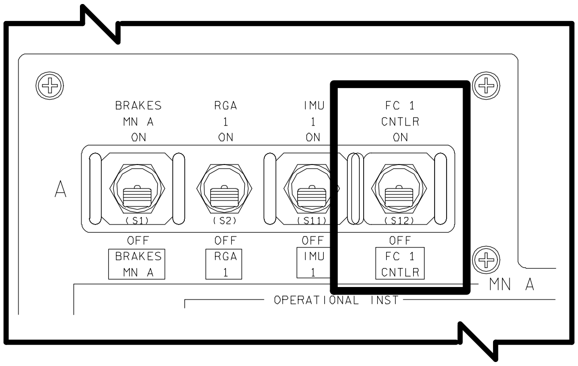
Electrical Control Unit

The electrical control unit located in each FC power plant contains the startup logic, heater thermostats, 30-second timer, and interfaces with the controls and displays for FC startup, operation, and shutdown. The unit controls the supply of AC power to the coolant pump, hydrogen pump/water separator and the pH sensor. It also controls the DC power supplied to the flow control bypass valve (open only during startup) and the internal startup and sustaining heaters. It also controls the status of the *FUEL CELL 1, 2, 3 READY FOR LOAD* and *COOLANT PUMP ΔP* talkback indicators on panel R1.

The nine FC circuit breakers that connect three-phase AC power to the three FCs are located on panel L4. Each FC electrical control unit (ECU) receives its power from an essential bus through the *FC CNTLR* switch on panels O14, O15, and O16.



FUEL CELL Circuit Breakers on Panel L4



FC1 CNTRL Switch on Panel O14

(Note: FC2 on O15 and FC3 on O16 are the same.)

Cell Performance Monitor

As FC life increased with the introduction of the third substack, the likelihood of individual cell failures caused by "wearout" or age increased. Consequently, the *design of the* cell performance monitor (CPM) was *intended* to detect individual cell performance problems or imminent failures such as cell crossover.

Crossover is defined as an uncontrolled mixing of the reactants that results in the generation of excessive product heat. The combination of hydrogen and oxygen requires little heat to explode. During normal FC operation, hydrogen and oxygen are diffusely mixed to produce electricity. The matrix, a fibrous asbestos blotter device within each cell, holds the KOH electrolyte and limits the H_2/O_2 mixing. Crossover occurs when the matrix fails to do its job. A manufacturing flaw in the matrix or an impurity in the matrix fibers may cause a pin hole to develop after hours and hours of exposure to the caustic KOH in the presence of the waste heat within the cell.

As the direct combination of the reactant molecules occurs at the pin hole, increased waste heat may cause the pin hole to burn and enlarge, allowing more reactants to combine. If this reaction continues, it might propagate uncontrollably and possibly cause a violent explosion. Crossover may proceed rapidly or gradually. Before the introduction of the cell performance monitor (CPM) prior to STS-9, the electrical performance indicators of a crossover-distressed cell were not detectable, since the lost electrical performance of the substack with the degraded cell was picked up by the healthy substacks.

The CPM compares each half substack voltage and calculates a delta volts measurement. By comparing both halves of a substack, the CPM can detect cell changes. Since all the cells in a substack are producing the same current, both halves of the substack should be at approximately identical voltages. Ideally $\Delta V = 0$, but small fluctuations are common. A significant voltage loss in any one cell will produce a change in the ΔV with 300 mV being a critical performance loss. ΔV can be either positive or negative, so the CPM converts the positive/negative ΔV between the upper and lower substack halves to an absolute value and then outputs that value (0 to 500 mV). To provide margin and accommodate the absolute value, the C/W limit is set at 150 mV. The output is then converted to a 0 to 5 V *DC* signal for telemetry and crew display systems by a "times 10" amplifier. Calibration curves rescale this to electronic units (EU) (0 to 50 mV).

Every 7.5 minutes the CPM performs a self-test to ensure data accuracy and to prevent *FC* shutdown due to faulty data. During the self-test period:

- The voltage measurement of the substack halves ceases.
- A test signal of 50 mV is input to the voltage measurement logic.
- The output of the "times 10" amplifier is examined for 425 to 575 mV.
- If the test fails, the output voltage is driven to 5 volts until the next self-test is performed 7 ± 1 minute later. A test voltage of 50 mV is introduced and the sequence repeats itself.
- If the self-test is passed, the unit resumes substack half voltage measurements.

Fuel Cell Monitoring System

The fuel cell monitoring system (FCMS) is a data collection system that provides insight into the single cell voltages in the orbiter *FC* powerplants.

The FCMS is a PGSC program that records voltage in each individual cell as well as in all three *FC*s and saves these readings into an ASCII data file. This file is then downlinked to MCC for evaluation.

FCMS has two recording modes, full rate and interval. Full rate records a sample every second until the maximum file size is reached. In interval, FCMS records samples at crew-specified intervals for a certain amount of time, also specified by the crew. In this mode, if the amount of data exceeds maximum file size, the crew receives a message that the program will stop recording when the maximum size is reached. File size is limited to 1.*44* Mb to ensure that it will fit onto a single *floppy* disk*, although flash drives are currently used on board*.

One data sample consists of a GMT time tag for *FC* 1 – the cell 1 reading followed by 288 voltage readings; i.e., 96 cells/*FC* powerplant times 3 *FC* powerplants.

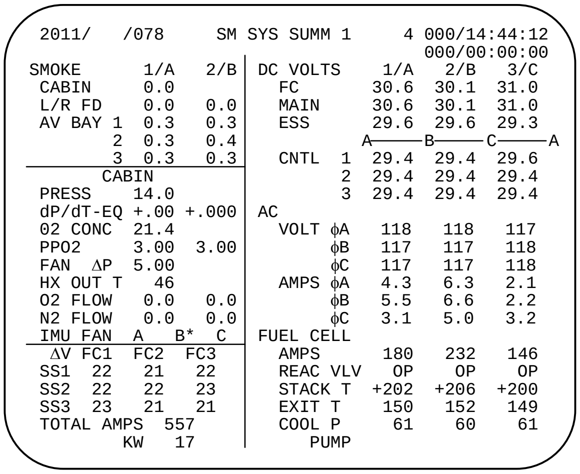
FCMS uses the PCMMU 2 port on the flight deck (panel O5) and a special FCMS cable to collect data for the PGSC program. FCMS data also can be recorded prelaunch directly through the T-0 umbilicals.

Baseline recordings normally are recorded at the beginning of each mission for comparison in the event of a subsequent failure.

Fuel Cell Start

The *FUEL CELL START/STOP* switches on panel R1 are used to initiate the start sequence or stop the FC operation. When a switch is held in its momentary *START* position, the ECU connects the three-phase AC power to the coolant pump and hydrogen pump/water separator (allowing the coolant and the hydrogen-water vapor to circulate through these loops) and connects the DC power to the internal startup and sustaining heaters and the flow control bypass valve. The switch must be held in the *START* position until the *COOLANT PUMP ΔP* talkback (tb) shows gray (approximately 3 to 4 seconds), which indicates that the coolant pump is functioning properly by creating a differential pressure across the pump. When the *COOLANT PUMP ΔP* tb indicates barberpole, the coolant pump is not running.

The *READY FOR LOAD* tb for each FC shows gray after the 30-second timer times out or when the stack-out temperature is above 187° F, whichever occurs last. Stack-out temperature can be monitored on the SM SYS SUMM 1 (STACK T) and SM SPEC 69 FUEL CELLS displays (STACK T). It can also be monitored on the FUEL CELL STACK OUT TEMP meter on panel O2, using the switch beneath the meter to select the FC. When the READY FOR LOAD tb shows gray, the FC is up to the proper operating temperature and is ready for loads to be attached to it. It should not take longer than 25 minutes for the FC to warm up and become fully operational; the actual time depends on the FC's initial temperature. The READY FOR LOAD indicator remains gray until the FUEL CELL START/STOP switch for each FC is set to STOP, the FC CNTLR switch on the overhead panel is set to OFF, or the essential bus power is lost to the ECU.



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 2011/   /078     SM SYS SUMM 1     4 000/14:44:12
                                      000/00:00:00
SMOKE       1/A   2/B | DC VOLTS    1/A   2/B   3/C
 CABIN      0.0       |   FC       30.6  30.1  31.0
 L/R FD     0.0   0.0 |   MAIN     30.6  30.1  31.0
 AV BAY 1   0.3   0.3 |   ESS      29.6  29.6  29.3
        2   0.3   0.4 |           A-----B-----C-----A
        3   0.3   0.3 |   CNTL  1  29.4  29.4  29.6
-----------------------            
       CABIN          |         2  29.4  29.4  29.4
 PRESS     14.0       |         3  29.4  29.4  29.4
 dP/dT-EQ +.00 +.000  | AC
 02 CONC   21.4       |   VOLT φA   118   118   117
 PPO2      3.00  3.00 |        φB   117   117   118
 FAN  ΔP   5.00       |        φC   117   117   118
 HX OUT T    46       |   AMPS φA   4.3   6.3   2.1
 O2 FLOW    0.0   0.0 |        φB   5.5   6.6   2.2
 N2 FLOW    0.0   0.0 |        φC   3.1   5.0   3.2
 IMU FAN   A    B*  C | FUEL CELL
-----------------------
  ΔV FC1   FC2   FC3  |   AMPS      180   232   146
 SS1  22    21    22  |   REAC VLV   OP    OP    OP
 SS2  22    22    23  |   STACK T  +202  +206  +200
 SS3  23    21    21  |   EXIT T    150   152   149
 TOTAL AMPS  557      |   COOL P     61    60    61
         KW   17      |      PUMP
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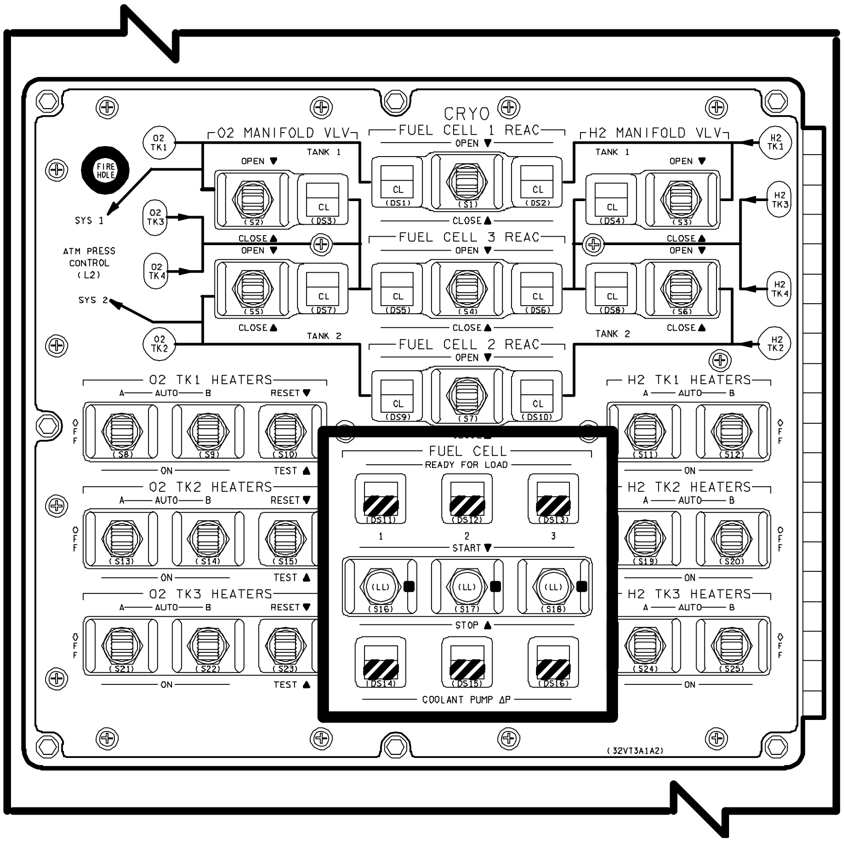
SM SYS SUMM 1 (SPEC 78)

Electrical Power Distribution and Control

The electrical power distribution and control (EPDC) subsystem controls and distributes AC and DC electrical power to the orbiter subsystems, the solid rocket boosters, the external tank, and payloads. The 28 volts DC generated by each of the three FCs is distributed to a main DC bus. The three main DC buses (MN A, MN B, and MN C) are the prime sources of power for the vehicle's DC loads. Each DC main bus supplies power to three solid-state (static), single-phase inverters, which in-turn powers their respective AC bus. These three inverters are phase sequenced with each other to provide three-phase alternating-current (ac). Thus a total of nine inverters convert DC power to 117 volt (rms), 400-hertz AC power for distribution to three AC buses (AC 1, AC 2, and AC 3) for the vehicle's AC loads.



FUEL CELL START/STOP Switches and READY FOR LOAD and COOLANT PUMP P Talkback Indicators on Panel R1

Bus System

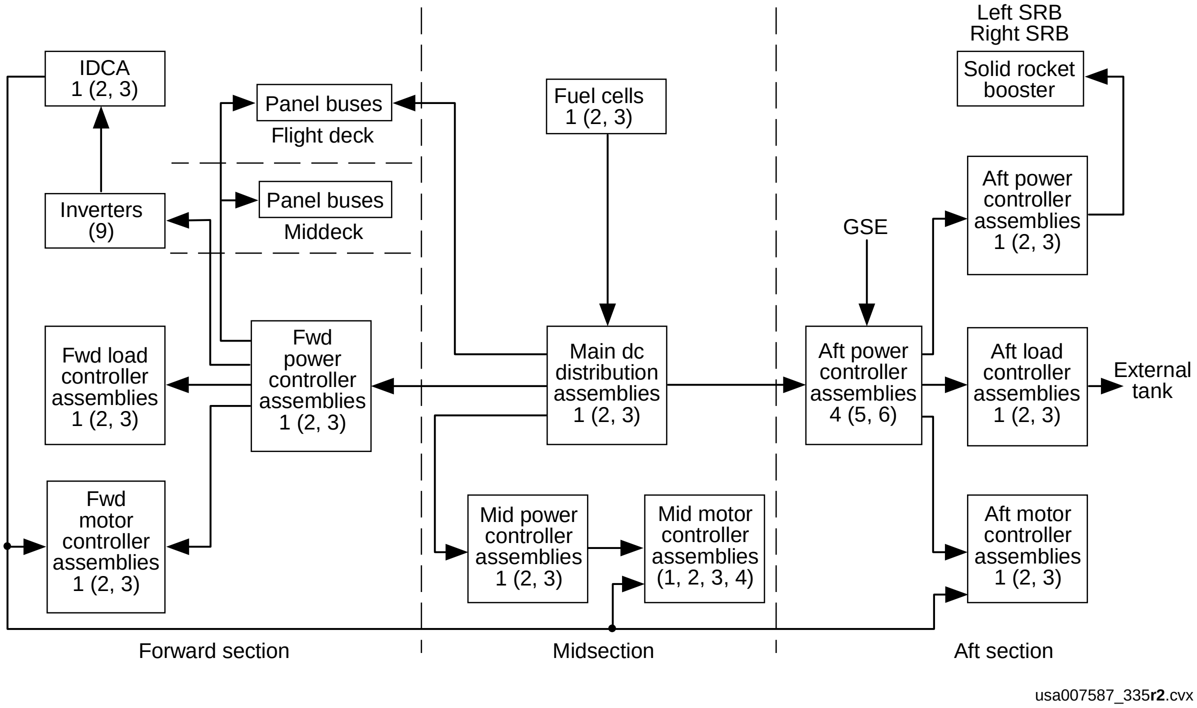
The three main DC buses are main A (MN A), main B (MN B), and main C (MN C). Three AC buses, AC 1, AC 2, and AC 3, supply AC power to the AC loads. Three essential buses, ESS 1BC, ESS 2CA, and ESS 3AB, supply DC power to selected flight crew controls and electrical loads that are deemed essential. Nine control buses - CNTL AB 1, 2, 3; CNTL BC 1, 2, 3; and CNTL CA 1, 2, 3 - are used to supply control power to flight crew controls. Two preflight buses, PREFLT 1 and PREFLT 2, are used only during ground operations.

Depending on the criticality of orbiter electrical equipment, some electrical loads may receive redundant power from two or three main buses. If an electrical load receives power from two or three sources, it is for redundancy only and not for total power consumption.

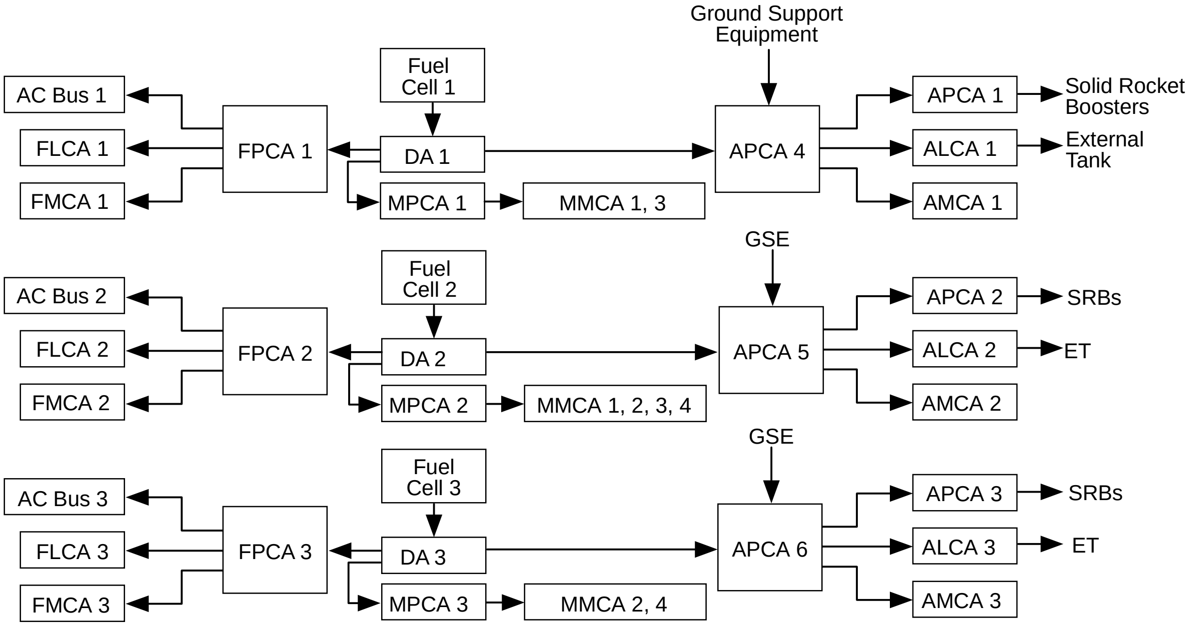
DC Power

Main Buses

The main buses distribute DC electrical power from the FCs to locations throughout the orbiter. Distribution assemblies handle the routing of main bus power.



Electrical Power Distribution Block Diagram



DA - Distribution Assembly
FLCA - Forward Load Controller Assembly
FMCA - Forward Motor Controller Assembly
FPCA - Forward Power Controller Assembly
MPCA - Mid Power Controller Assembly
MMCA - Mid Motor Controller Assembly
APCA - Aft Power Controller Assembly
ALCA - Aft Load Controller Assembly
AMCA - Aft Motor Controller Assembly

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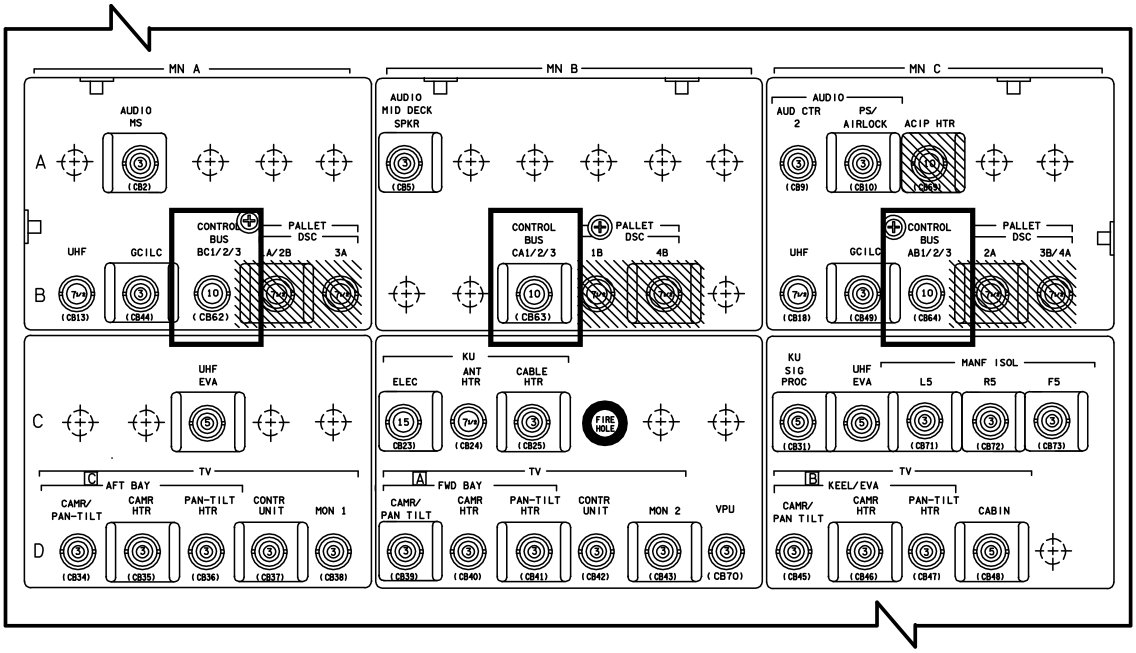
Direct Current Power Distribution Diagram



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CONTROL BUS Circuit Breakers on Panel R14

Essential Buses

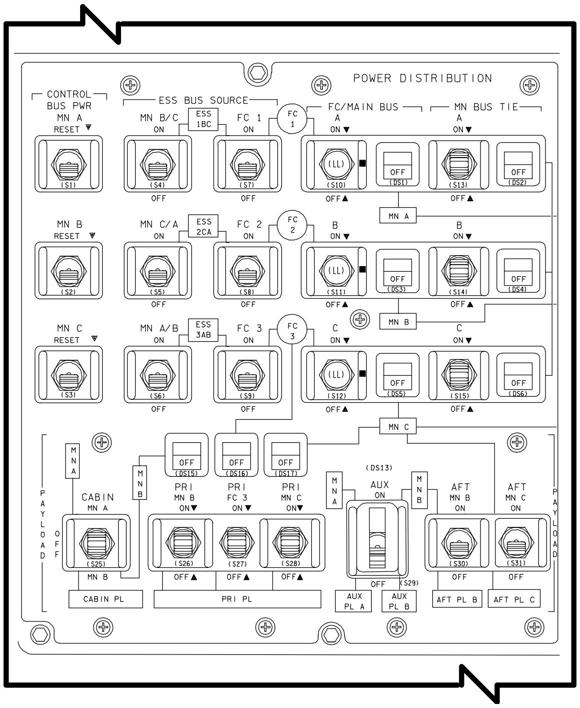
Essential buses supply power to switches that are necessary to restore power to a failed main DC or AC bus and to essential electrical loads and switches. In some cases, essential buses are used to power switching discretes to multiplexers/demultiplexers. Examples of the selected flight crew switches and loads are the EPS switches, GPC switches, TACAN, radar altimeter and microwave scan beam landing system power switches, the caution and warning system, emergency lighting, audio control panel, and master timing unit.

Three essential buses, ESS 1BC, ESS 2CA, and ESS 3AB receive power from three redundant sources. For example, ESS 1BC receives DC power from FC 1 through the ESS BUS SOURCE FC 1 switch on panel R1 via a fuse when the switch is positioned to ON, and from main DC buses B and C through remote power controllers (RPCs) when the ESS BUS SOURCE MN B/C switch on panel R1 is positioned to ON. Electrical power is then distributed from the essential bus in distribution assembly 1 through fuses to the corresponding controller assemblies and to the flight and middeck panels.

Control Buses

Nine control buses supply control power to the display and control panel switches on the flight deck and in the middeck area. A control bus does not supply operational power to any system loads. Each control bus receives power from each main DC bus for redundancy. The main buses identified in the control bus name are connected through RPCs and diodes. For example, CNTL BC1 is powered by MN B and MN C through RPCs. The "unnamed bus", which in this example is MN A, provides power to the control bus through a circuit breaker and a fuse. The number in each control bus name does not refer to a power source for the bus; it is merely a numeric designator for the bus.

The control buses are enabled by the CONTROL BUS PWR MN A, MN B, and MN C switches on panel R1 and the MN A CONTROL BUS BC1/2/3, the MN B CONTROL BUS CA1/2/3 and the MN C CONTROL BUS AB1/2/3 circuit breakers on panel R14.



Bus Control Switches and Talkbacks on Panel R1

The RPCs are powered continuously unless one of the *CONTROL BUS PWR MN A, MN B, MN C* momentary switches on panel R1 is positioned to the RESET position, which turns the corresponding RPCs power off and resets the RPC if it has been tripped off. An *SM ALERT* light is illuminated if the control bus voltage is less than 24.5 volts DC and a fault message is sent to the DPS display. The Mission Control Center can monitor the status of each RPC.

Payload Buses

Payload buses are provided to supply DC electrical power to the payloads. FC 3 may be connected to the primary payload bus by positioning the *PRI FC3* momentary switch on panel R1 to the *ON* position. The talkback indicator above the switch will indicate *ON* when FC 3 is connected to the PRI PL bus. The PRI PL bus is the prime bus for supplying power to the payloads. FC 3 may be disconnected from the payload bus by positioning the *PRI FC3* switch to the *OFF* position. The talkback indicator above the switch will indicate *OFF.*

A second source of electrical power for the PRI PL bus may be supplied from the MN B bus by positioning the *PRI MN B* momentary switch on panel R1 to the *ON* position. The talkback indicator above this switch will indicate *ON*. The MN B bus may be removed from the PRI PL bus by positioning the switch momentarily to OFF. The talkback indicator will indicate *OFF*. A third possible source of electrical power for the PRI PL bus may be supplied from the MN C bus through the *PRI MN C* switch on panel R1, positioned momentarily to the ON position. The talkback indicator will indicate *ON*. The MN C bus may be removed from the PRI PL bus by positioning the switch momentarily to *OFF*. The talkback indicator will indicate *OFF*.

NOTE

> Main buses B and C can be tied via the PRI PL bus. This is referred to as a "backdoor bus tie."

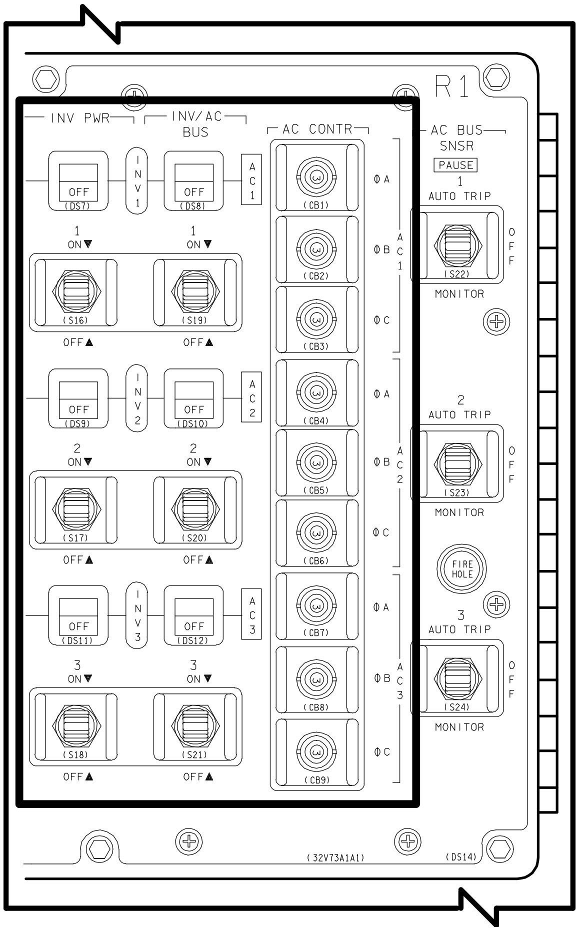
Two additional payload buses are located in the aft section of the payload bay at the aft bulkhead station. The aft payload B bus may be powered up by positioning the *AFT MN B* switch on panel R1 to *ON*. The aft payload C bus may be powered up by positioning the *AFT MN C* switch on panel R1 to *ON*. The *OFF* position of each switch removes power from the corresponding aft payload bus.

The *AUX* switch on panel R1 permits main bus A and main bus B power to be supplied to the AUX PL A and AUX PL B buses when the switch is positioned to *ON*. The auxiliary payload buses can provide power for emergency equipment or controls associated with payloads. The *OFF* position removes power from the AUX PL A and PL B buses. The two auxiliary payload buses may be dioded together to form one bus for redundancy.

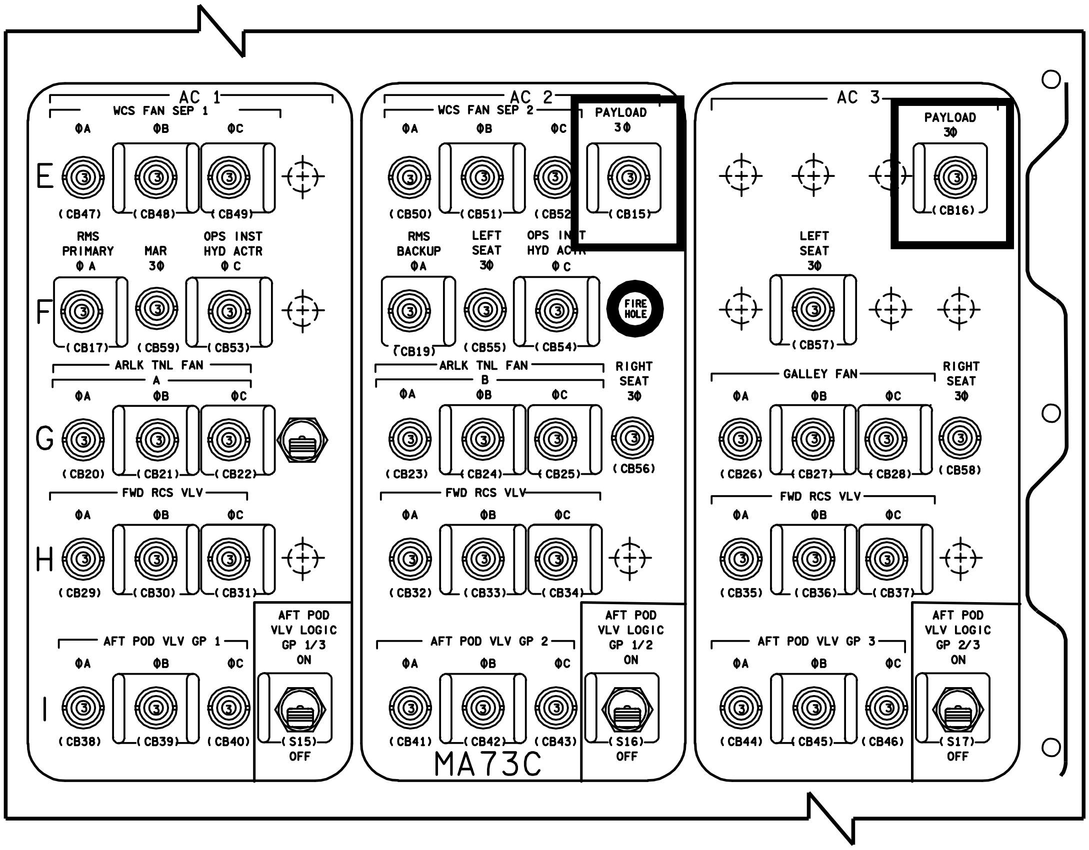
The *CABIN* switch on panel R1 provides MN A or MN B power to patch panels located behind the payload specialist and mission specialist stations on the aft flight deck. These patch panels supply power to the payload-related equipment located on panels at these stations. Two three-phase circuit breakers, *AC 2 PAYLOAD 3ϕ and AC 3 PAYLOAD 3ϕ* on panel MA73C, provide AC power to the payload patch panels.

AC Power Generation

AC power is generated and made available to system loads by the EPDC subsystem using three independent AC buses, AC 1, AC 2, and AC 3. The AC power system includes the AC inverters for DC conversion to AC and inverter distribution and control assemblies containing the AC buses and the AC bus sensors. The AC power is distributed from the inverter distribution and controller assemblies to the flight and middeck display and control panels and from the motor controller assemblies to the three-phase motor loads.



INV PWR and INV/AC BUS Switches and Talkbacks, and AC CONTR Circuit Breakers on Panel R1



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AC2 Cabin PAYLOAD 3∅ and AC3 Cabin PAYLOAD 3∅ Circuit Breakers on Panel MA73C

Each AC bus consists of three separate phases connected in a three-phase array. Static inverters, one for each phase, are located in the forward avionics bays. Each inverter has an output voltage of 117 volts (rms) at 400 hertz.

Input power to the inverters is controlled by the INV PWR 1, 2, 3 switches on panel R1. INV PWR 1 routes power to AC 1 from MN A, INV PWR 2 to AC 2 from MN B, and INV PWR 3 to AC 3 from MN C. All three inverters of AC 1 receive MN A bus power when the INV PWR 1 switch is positioned to ON, and all three must be in operation before the talkbacks above the switches indicate ON. The indicators will show OFF when main bus power is not connected to the inverters. The INV/AC BUS 1, 2, 3 switches on panel R1 are used to apply each inverter's output to its respective AC bus. An indicator above each switch shows its status, and all three inverters must be connected to their respective AC buses before the indicators show ON. The talkback indicators will show OFF when any of the phases are not connected to their respective AC bus.

The INV PWR and INV/AC BUS switches and talkbacks must have control power from the AC CONTR circuit breakers on panel R1 in order to operate. Once AC power has been established, these circuit breakers are opened to prevent any inadvertent disconnection, whether by switch failure or accidental movement of the INV PWR or INV/AC BUS switches.

Electrical Power Distribution and Control Assemblies

Electrical power is controlled and distributed by assemblies. Each assembly (main distribution assembly, power controller assembly, load controller assembly, and motor controller assembly) is in an electrical equipment container.

Distribution Assemblies

The DC power generated by each of the FCs is supplied to a corresponding distribution assembly (DA). FC 1 powers DA 1, FC 2 powers DA 2, and FC 3 powers DA 3. Each distribution assembly contains fuses, relays, and remotely controlled motor-driven switches called power contactors. The DAs control and distribute DC power to a corresponding mid power controller assembly, forward power controller assembly, and aft power controller assembly.

The FC/MAIN BUS A switch on panel R1 positioned to ON connects FC 1 to the MN A DA 1 and controllers and disconnects FC 1 from the MN A DA 1 and controllers when positioned to OFF. The talkback indicator next to the FC/MAIN BUS A switch will indicate ON when FC 1 is connected to main bus A distribution assembly and controllers, and OFF when FC 1 is disconnected from main bus A distribution assembly and controllers. The FC/MAIN BUS B and C switches and talkback indicators on panel R1 function in the same manner. The No. 1 distribution assembly and all No. 1 controllers go with FC 1 and MN A bus, all No. 2 controllers and DA 2 go with FC 2 and MN B, and all No. 3 controllers and DA 3 go with FC 3 and MN C.

Power Controllers

Power contactors are also located in the aft power controller assemblies to control and distribute ground-supplied 28-volt DC power to the orbiter through the T-0 umbilical before the FCs take over the supply of orbiter DC power.

Each of the forward, mid, and aft power controller assemblies supplies and distributes DC power to a corresponding motor controller assembly and DC power to the orbiter is supplied through the T-0 umbilical before the FCs take over the supply of orbiter DC power.

Each of the forward, mid, and aft power controller assemblies supplies and distributes DC power to a corresponding motor controller assembly and DC power to activate the corresponding AC power system.

Aft power controller assemblies 4, 5, and 6 were added to accommodate additional electrical loads in the aft section. Assemblies 4, 5, and 6 are powered by FC 1/MN A, FC 2/MN B, and FC 3/MN C, respectively.

Remote Power Controllers

Each power controller assembly contains RPCs and relays. The RPCs are solid-state switching devices; they have the capability to limit the output current to a maximum of 150 percent of rated value for 2 to 3 seconds. Within 3 seconds, the RPC will trip, removing the output current. To restore power to the load, the RPC must be reset. This is accomplished by cycling a control switch. If multiple control inputs are required before a RPC is turned on, hybrid drivers are usually used as a logic switch, which then drives the control input of the RPC.

Load Controllers

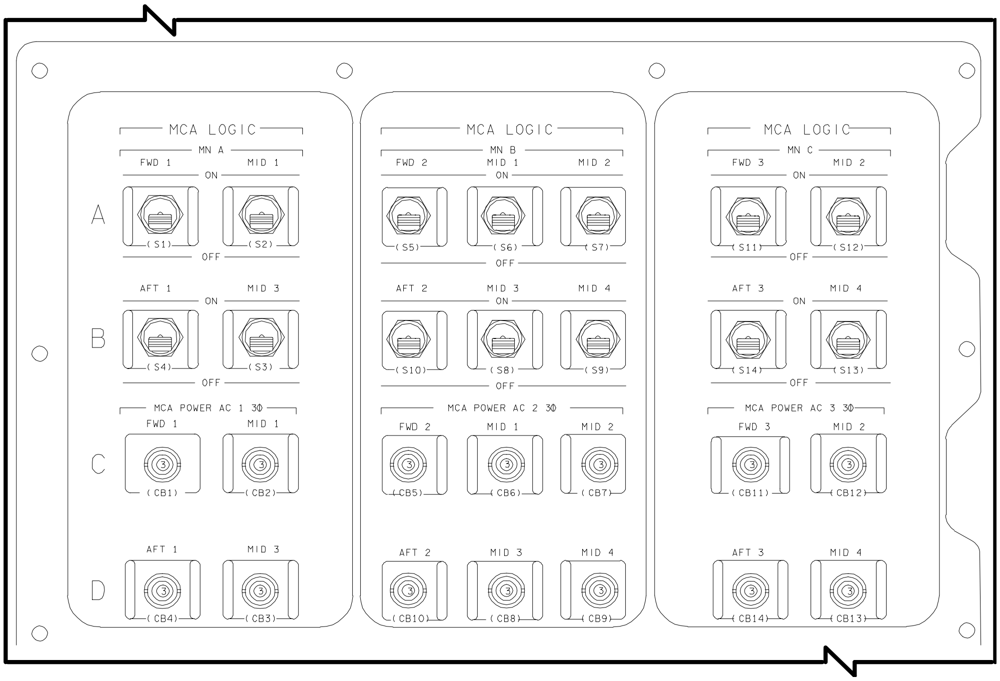
Each load controller assembly contains hybrid drivers, which are solid-state switching devices (no mechanical parts) used as logic switches and for low-power electrical loads. When the drivers are used as a logic switch, several control inputs are required to turn on a load. The hybrid drivers are current protected by internal fuses. Hybrid relays requiring multiple control inputs are used to switch three-phase AC power to motors.

Relays are also used for loads in power controller assemblies and motor controller assemblies.

In the midbody, there are no load controller assemblies; therefore, the mid power controller assemblies contain remote power controllers, relays, and hybrid drivers.

Motor Controllers

There are 10 motor controller assemblies used on the orbiter: three are in the forward area, four are in the midbody area, and three are in the aft area. Panel MA73C contains the controls for the motor controller assemblies. Their only function is to supply AC power to noncontinuous AC loads for AC motors used for vent doors, air data probe, star tracker doors, payload bay doors, payload bay latches, ET doors and latches, RMS deploy motors and latches, and reaction control system/orbital maneuvering system motor-actuated valves. Each motor controller assembly contains main DC buses, AC buses, and hybrid relays that are remotely controlled for the application or removal of AC power to AC motors. The main DC bus is used only to supply control or logic power to the hybrid relays so the AC power can be switched on or off. The hybrid relays permit major electrical power distribution buses to be located close to the major electrical loads, which minimizes use of heavy electrical feeders to and from the pressurized crew compartment display and control panels. This reduces the amount of spacecraft wiring and weight, and permits more flexible electrical load management. If a main bus is lost, the hybrid relays using that main bus will not operate. In some cases, the hybrid relays will use logic power from a switch instead of the motor controller assembly bus.



Motor Controller Assembly Controls on Panel MA37C

The three forward motor controller assemblies (FMC 1, FMC 2, and FMC 3) correspond to MN A/AC 1, MN B/AC 2, and MN C/AC 3, respectively. Each FMC contains DC power from a main bus, an AC bus, and an RCS AC bus. The main bus supplies control or logic power to the relays associated with both the AC bus and RCS AC bus. The AC bus supplies power to the forward left and right vent doors, the star tracker Y and Z doors, and the air data left and right doors. The RCS AC bus supplies power to the forward RCS manifold and tank isolation valves.

The aft motor controller assemblies (AMC 1, AMC 2, and AMC 3) correspond to MN A/AC 1, MN B/AC 2, and MN C/AC 3 respectively. Each aft motor controller assembly receives power from a main bus and its corresponding AC bus and a main RCS/OMS bus and its corresponding RCS/OMS AC bus. Both main buses are used for control or logic power for the hybrid relays. The AC bus is used by the aft RCS/OMS manifold and tank isolation and crossfeed valves, the aft left and right vent doors, and the ET umbilical doors.

The mid motor controller assemblies (MMC 1, MMC 2, MMC 3, and MMC 4) contain two main DC buses and two corresponding AC buses. MMC 1 contains main bus A and B and their corresponding buses, AC 1 and AC 2. MMC 2 contains MN B and C and AC 2 and AC 3 buses. MMC 3 contains the same buses as MMC 1, and MMC 4 contains the same buses as MMC 2. Loads for the main buses/ac buses are vent doors, payload bay doors and latches, radiator panel deployment actuator and latches, RMS deploy motors and latches, and payload retention latches.

Component Cooling

The electrical components in the midbody are mounted on cold plates and cooled by the Freon coolant loops. The power controller assemblies, load controller assemblies, motor controller assemblies, and inverters located in forward avionics bays 1, 2, and 3 are mounted on cold plates and cooled by the water coolant loops. The inverter distribution assemblies in forward avionics bays 1, 2, and 3 are air-cooled. The load controller assemblies, power controller assemblies, and motor controller assemblies located in the aft avionics bays are mounted on cold plates and cooled by the Freon coolant loops.

Bus Tie

In the event of an electrical failure, or to load share between FCs, any main bus can be connected to another main bus through the use of the *MN BUS TIE* switches on panel R1 and power contactors in the distribution assemblies. For example, main bus A can be connected to main bus B by positioning both the *MN BUS TIE A* and the *MN BUS TIE B* switch to *ON*. The talkback indicators next to the switches will indicate *ON* when main bus A is connected to main bus B. Other indications of an effective bus tie are matching voltages for the two buses. To disconnect main bus A from main bus B, the *MN BUS TIE A* and *B* switches must be positioned to *OFF*; the talkback indicators next to the switches will then indicate *OFF*.

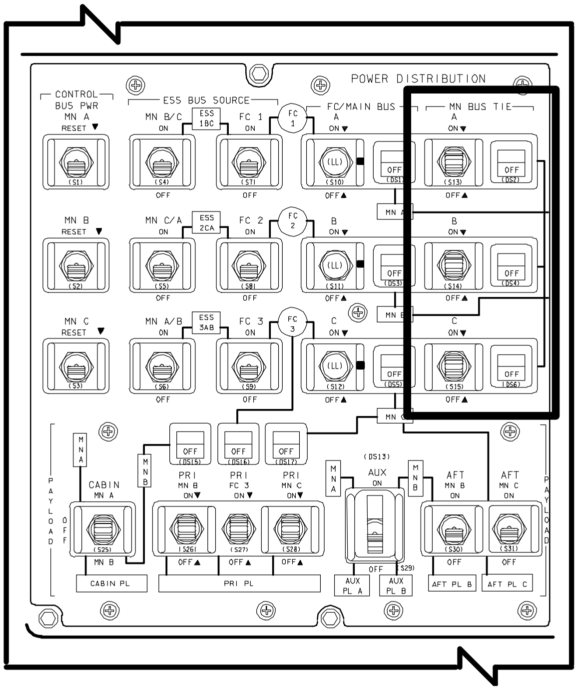
NOTE

> It is also possible to tie the main buses B and C together via the PRI switches. This is done by connecting each main bus to the primary payload bus. This is called a "backdoor" bus tie

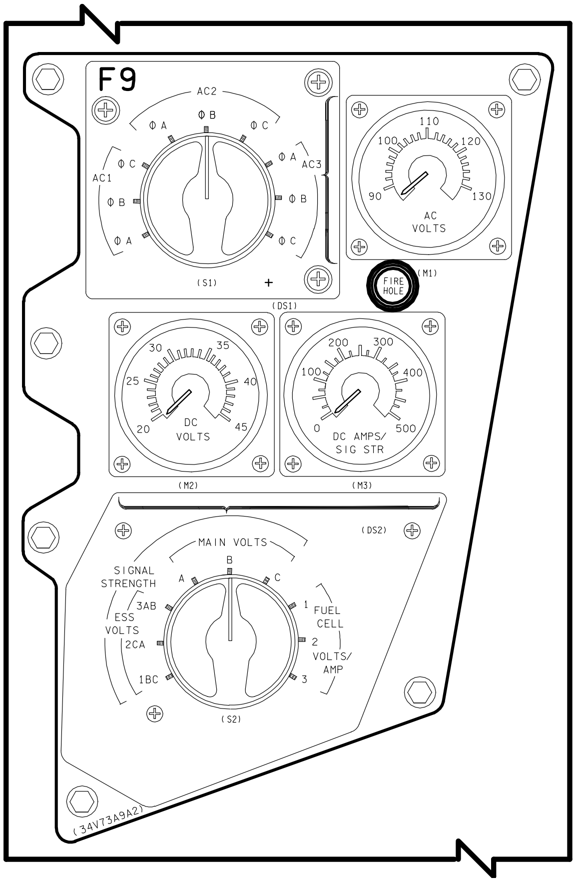
Instrumentation and System Monitoring

Main bus A, B, or C voltages can be displayed on the DC VOLTS meter on panel F9 by selecting *MAIN VOLTS* A, B, or C on the rotary switch beneath the meter. The *MAIN BUS UNDERVOLT* red caution and warning light on panel F7 will be illuminated if main bus A, B, or C voltage is 26.4 volts dc, informing the crew that the minimum equipment operating voltage limit of 24 volts DC is being approached. A *BACKUP C/W ALARM* light will also be illuminated at 26.4 volts dc. An *SM ALERT* light will be illuminated at 27 volts DC or less, alerting the flight crew to the possibility of a future low-voltage problem. A fault message also is transmitted to the DPS display.

The nominal FC voltage is 27.5 to 32.5 volts dc, and the nominal main bus voltage range is 27 to 32 volts dc, which corresponds to 12- and 2-kilowatt loads respectively. If buses are tied, they will indicate the same voltage.



MN BUS TIE Switches on Panel R1

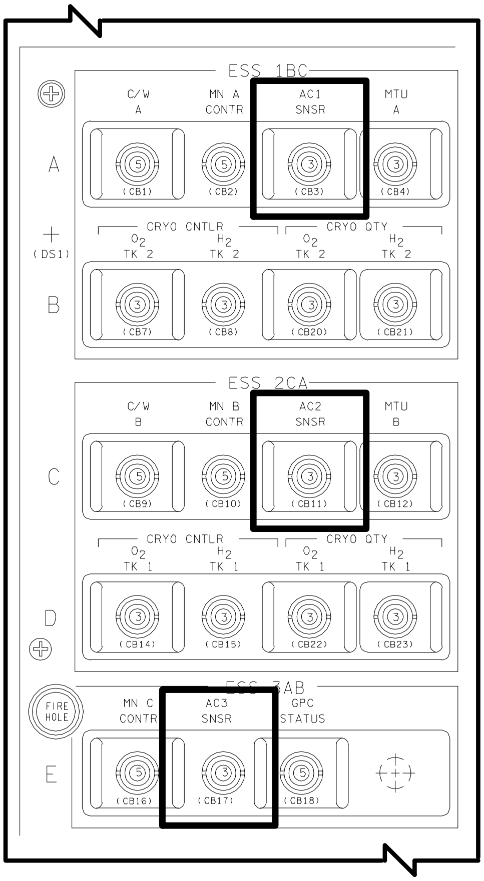


EPS Meters and Switches on Panel F9

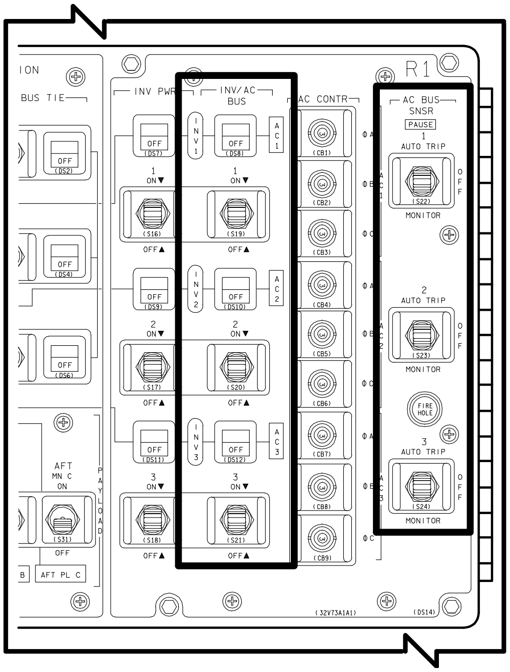
The ESS bus voltage can be monitored on the DC VOLTS meter on panel F9 by selecting *ESS VOLTS 1BC, 2CA, 3AB* on the rotary switch below the meter. An *SM ALERT* light will be illuminated to inform the flight crew if the essential bus voltage is less than 25 volts dc. A fault message also is shown on the DPS display.

Each AC bus has a sensor, switch, and circuit breaker for flight crew control. The *AC 1, 2,* and *3 SNSR* circuit breakers located on panel O13 apply essential bus power to their *respective AC BUS SNSR 1, 2, 3* switch on panel R1 and operational power to the respective *INV/AC BUS* switch and indicator. The *AC BUS SENSR 1, 2, 3* switch selects the mode of operation of the AC bus sensor: *AUTO TRIP, MONITOR*, or *OFF*. The AC bus sensor monitors each AC phase bus for over- or undervoltage, and each phase inverter for an overload signal. The overvoltage limits are bus voltages greater than 123 to 127 volts AC for 50 to 90 milliseconds. The undervoltage limits are bus voltages less than 102 to 108 volts AC for 6.5 to 8.5 milliseconds. An overload occurs when any AC phase current is greater than 14.5 amps for 10 to 20 seconds, or is greater than 17.3 to 21.1 amps for 4 to 6 seconds.

When the respective *AC BUS SNSR* switch is in the *AUTO TRIP* position, and an overload or overvoltage condition occurs, the AC bus sensor will illuminate the respective yellow *AC OVERLOAD* or *AC VOLTAGE* caution and warning light on panel F7 and trip off (disconnect) the inverter from its respective phase bus for the bus/inverter causing the problem. There is only one *AC VOLTAGE* and one *AC OVERLOAD* caution and warning light; as a result, all nine inverters/ac phase buses can illuminate the lights. The DPS display or the AC VOLTS meter and rotary switch beside it on panel F9 would be used to determine which inverter or phase bus caused the light to illuminate. The phase causing the problem would approach 0 amps after the bus sensor disconnects the inverter from the bus. Because of the various three-phase motors throughout the vehicle, there will be an induced voltage on the disconnected phase if only one phase has loss of power.



AC 1, 2, 3 SNSR Circuit Breakers on Panel O13



AC BUS SNSR Switches and INV/AC BUT Switches and Talkback Indicators on Panel R1

Before power can be restored to the tripped bus, the trip signal to the *INV/AC BUS* switch must be removed by positioning the *AC BUS SNSR* switch to OFF, which extinguishes the caution and warning light and resets the bus sensor logic. The signal then goes back to the *AUTO TRIP* position. The *INV/AC BUS* switch is then positioned to ON, restoring power to the failed bus.

If there is an undervoltage, the yellow *AC VOLTAGE* caution and warning light on panel F7 will be illuminated, but the inverter will not be disconnected from its phase bus.

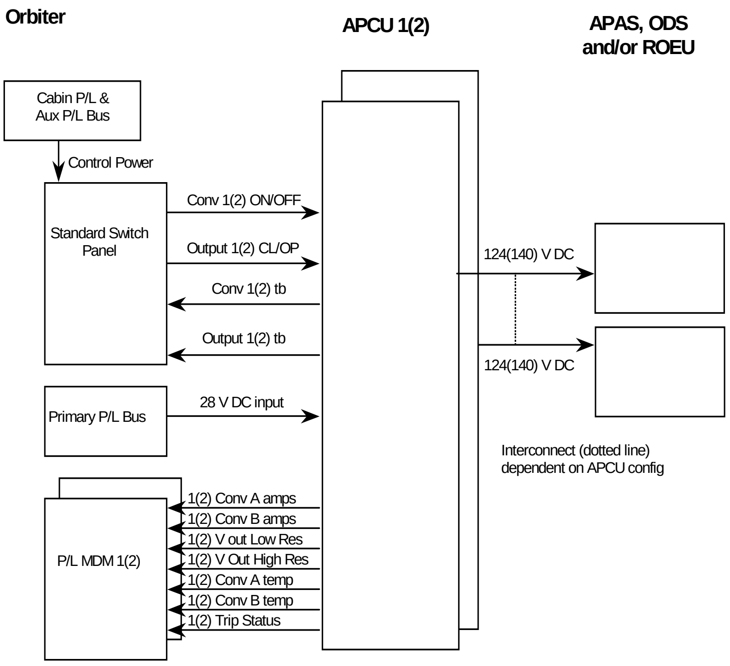
When the *AC BUS SENSR 1, 2, 3* switches are in the *MONITOR* position, the AC bus sensor will monitor for an overload, overvoltage, and undervoltage and illuminate the applicable caution and warning light; but it will not trip off the phase bus/inverter causing the problem.

NOTE

> *AC BUS SNSR* switches are placed in *MONITOR* for ascent to prevent an AC bus problem from causing an AUTO-TRIP, which could result in the loss of SSME controllers on ascent.

When the *AC BUS SNSR* switches are *OFF*, the AC bus sensors are non-operational, and all hardware caution and warning and trip-out capabilities are inhibited. The *BACKUP C/W ALARM* light will be illuminated for overload or over- and undervoltage conditions. A fault message also is sent to the DPS display.

APCU and SSPTS

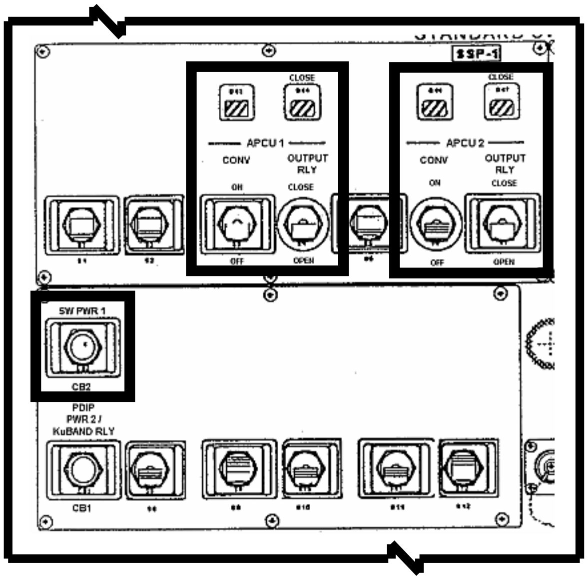


Assembly Power Converter Unit

OV-104 carries hardware to allow the orbiter to power certain payloads at a higher voltage than the orbiter's normal electrical system configuration. The payloads, typically ISS-related, operate at 120 volts DC, whereas the orbiter operates at 28 volts DC. The assembly power converter unit (APCU) is a step-up converter controlled via switches on the orbiter flight deck (Panel L12, also known as Standard Switch Panel 1) that consists of two units of two converters each. Data is visible to the crew on SM SPEC 200 APCU STATUS.

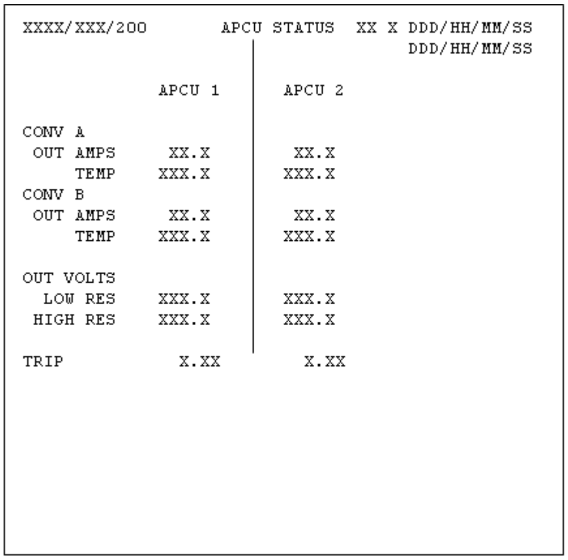
Each APCU contains two converters, both powered on or off by the APCU CONV switch on SSP1. Each APCU also has an OUTPUT RELAY switch, which opens or closes the relay that allows power to be transferred downstream. Both switches have grey/barberpole talkbacks. OPEN means the relay is open and there is no power downstream to the payload, while CLOSE sets the relay to allow power transfer (thus the switch in the up direction is CLOSE and in the down direction is OPEN). The CABIN PL 1 payload bus provides control power to the APCU 1 switches through the SW PWR 1 circuit breaker, while the AUX PL B payload bus provides control power directly to the APCU 2 switches. The talkbacks are driven by voltage, so the CONV talkbacks would be expected to turn gray when the converters are powered on, while the OUTPUT RLY talkbacks would be expected to turn gray once the relay is closed. The power that gets transformed to 120 volts DC comes from the PRI PL bus.

The APCUs have an interconnected mode such that power from one unit may be used to power a payload downstream of the other unit. This configuration is set on the ground and cannot be changed during flight.



APCU Switches and Talkback Indicators on Standard Switch Panel 1 (L12)

On SM SPEC 200, the amps and temperature can be seen for each of the converters. The voltage is shown as high- and low-resolution, but both readings come off a single voltage sensor. The trip status will be one of 16 discretes ranging from -4.84 to +4.88, each of which indicates a particular failure mode of input or output overvoltage, undervoltage, overcurrent, or a combination of any of them. To find out the exact failure mode, a lookup table in the Malfunction book must be consulted, but regardless of the failure mode, by tripping off, the APCU has been safed.

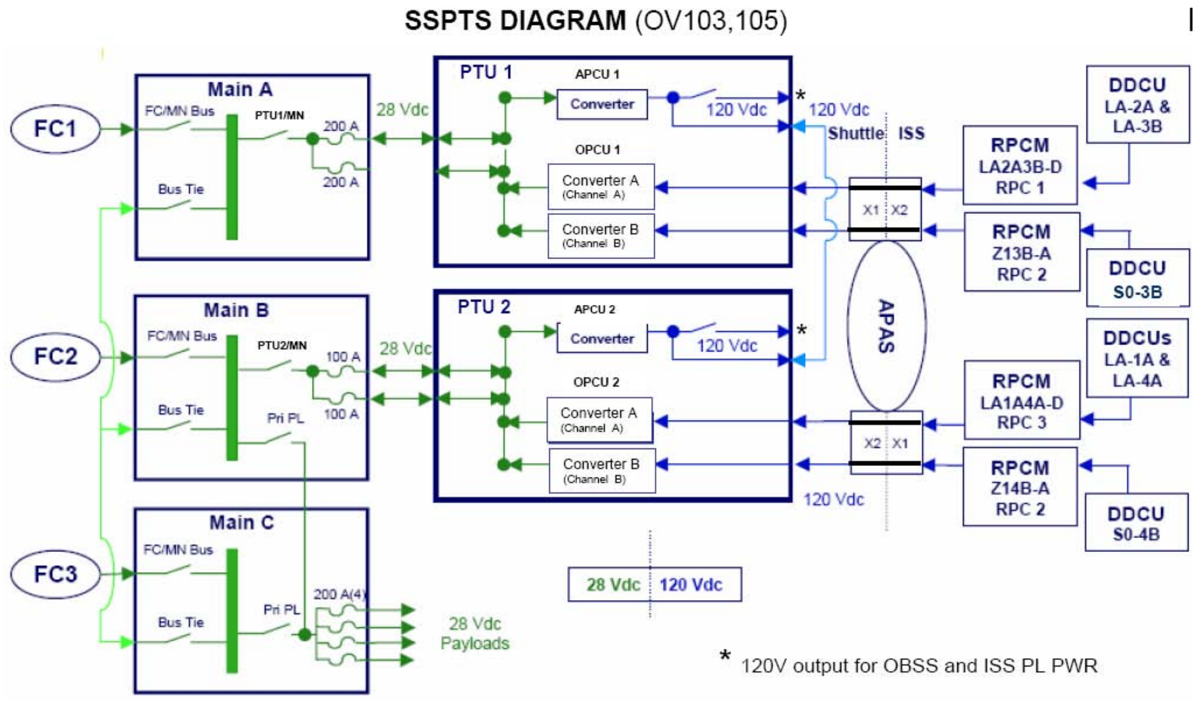


```
XXXX/XXX/200       APCU STATUS  XX X DDD/HH/MM/SS
                                     DDD/HH/MM/SS

             APCU 1      | APCU 2
                         |
CONV A                   |
 OUT AMPS     XX.X       |  XX.X
     TEMP    XXX.X       | XXX.X
CONV B                   |
 OUT AMPS     XX.X       |  XX.X
     TEMP    XXX.X       | XXX.X
                         |
OUT VOLTS                |
  LOW RES    XXX.X       | XXX.X
 HIGH RES    XXX.X       | XXX.X
                         |
TRIP           X.XX        X.XX
```

SM SPEC 200 APCU STATUS

Typically, both APCU 1 and APCU 2 power redundant heaters on ISS hardware carried in the payload bay are in non-interconnected mode. They are powered by 120 volts DC because that is how the ISS power system operates. APCU 2 also powers the heaters and sensor packages at the end of the orbiter boom sensor system (OBSS). The higher voltage in this case is designed to reduce line loss in transferring power the length of the remote manipulator system (RMS) and OBSS boom itself.



Station/Shuttle Power Transfer System (SSPTS)

OV-103 and OV-105 previously carried the standalone version of the APCU described above, but have been upgraded to the newer Station/Shuttle Power Transfer System (SSPTS). Operated via switches on panel A15 that were formerly used by the EDO Cryo Pallet System (which is no longer used), SSPTS consists of two power transfer units (PTUs), each of which has a single APCU voltage step-up converter similar to the ones discussed above, and two voltage step-down orbiter power converter unit (OPCU) converters. The OPCU allows 120 volt DC power from the ISS solar arrays to be transferred to the shuttle's main buses A and B at 28 volts. The OPCU portion of SSPTS offloads some electrical load from the orbiter's FCs onto the ISS solar arrays; the reduction in load on the FCs reduces the cryo usage, which is then used for mission extension days. The APCU portion of SSPTS is usable at any point in the mission, while the OPCU portion is only usable after docking to the ISS. Data is visible to the crew on SM SPEC 179 POWER TRANSFER.

Before any power can be converted either by an APCU or OPCU, the PTUs must be connected to the shuttle's main buses. PTU 1 is associated with main A, and PTU 2 is associated with main B. To connect the PTU to the main bus, the CNTL PWR circuit breakers on A15 row B must be pushed in first. These breakers power the PTU/MAIN BUS switches and talkbacks. Upon successful connection between a PTU and main bus, the associated talkback will turn from OFF to ON. At this point, an APCU may be activated to convert orbiter DC power for payload requirements, and, after docking, the OPCU can be activated to convert ISS DC power for shuttle main bus requirements.

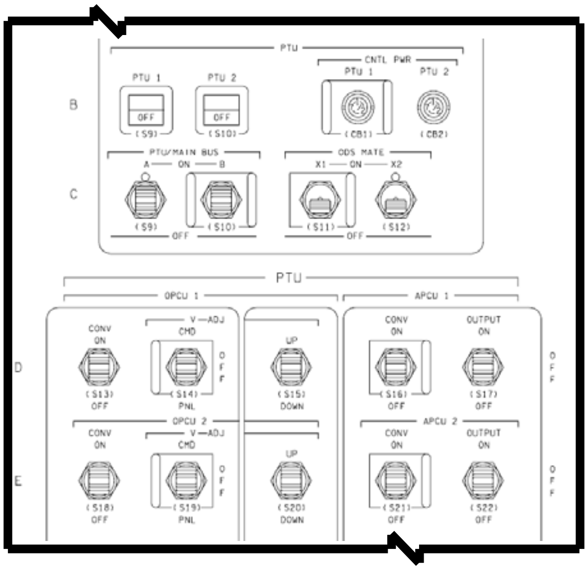
The SSPTS APCU works similarly to the standalone (or "legacy" APCU), except that the SSPTS APCU has a single converter per PTU while the legacy APCU has two converters per unit. The new converter is about twice as efficient as the old ones, so only one is needed. The SSPTS APCU is controlled by a pair of switches, CONV for the converter and OUTPUT for the output relay, but neither has talkbacks. The APCU 1 and 2 switches are on panel A15 rows D and E, respectively. The SSPTS APCU outputs also have the capability of being interconnected, depending on payload requirements; this is changeable only on the ground.

Because the OPCUs take input power from the ISS, they can only be activated after docking. Each of the four OPCU converters receives its power from a remote power control module (RPCM) on the ISS, and any combination and number of these RPCMs may be activated. When an RPCM is activated, power goes through the X1/X2 connectors in the docking system to the OPCU. For troubleshooting, the crew has two ODS MATE switches on A15 (row C) that test the X1/X2 connectors for continuity.

Once the RPCM is activated on the ISS, the OPCU volts and temperature sensors on the shuttle are powered and the data changes from off-scale low to a valid reading. The crew can use this as a method of verifying that the ISS RPCMs have been activated.

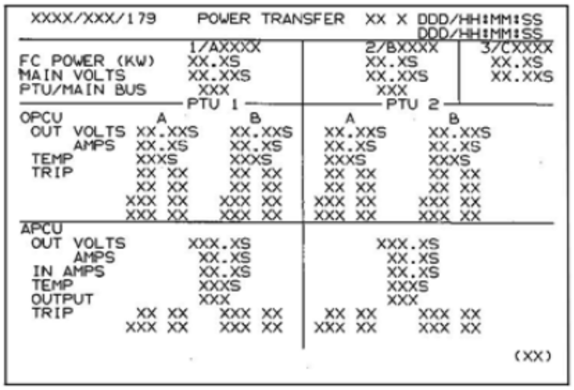
To convert ISS power, the SSPTS OPCU converters are activated via switches on panel A15. Initially, the OPCU output voltage is 31.12 volts DC, generally slightly lower than the main bus voltage, but by increasing the output voltage above the level of the main buses, the OPCUs will draw loads away from the mains. This voltage adjust is accomplished either by the crew or Mission Control. If the V-ADJ voltage adjust switch is in PNL, the crew can manually adjust the voltage up or down in increments of 0.04 volts per switch movement, and if the switch is in CMD, Mission Control will send real-time commands (RTCs) to adjust the voltage. The OPCUs are hardware limited to output 31.80 volts, and maximizing OPCU output volts minimizes FC loads. However, depending on the loads, the OPCUs may go into input-current-limiting mode; when it reaches its maximum output power, it automatically drops the output voltage and allows the FC to pick up additional loads.

Since the OPCUs only take power from main buses A and B, main C tends to pick up some of the dioded loads and carry more of the load. To even out the loads among the three main buses, Mission Control may opt to perform a bus tie to main C to evenly distribute the dioded loads.



SSPTS Switches and Talkback Indicators on Panel A15

At the top of SPEC 179 are fields for fuel cell power (displayed here individually, while on SYS SUM 1 the total power is displayed), main bus volts, and the status of the PTU/main bus connection (ON or OFF). Although only two FC/main buses are used in SSPTS, the third is shown here for completeness. A field next to the main bus letter will read "– TIE" when that bus is tied, using the same telemetry signal that drives the bus tie talkback on panel R1.



```
 XXXX/XXX/179      POWER TRANSFER   XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS
                  1/AXXXX           2/BXXXX    3/CXXXX
FC POWER (KW)     XX.XS             XX.XS       XX.XS
MAIN VOLTS        XX.XXS            XX.XXS      XX.XXS
PTU/MAIN BUS       XXX               XXX
                  PTU 1             PTU 2
OPCU            A        B          A         B
 OUT VOLTS   XX.XXS   XX.XXS     XX.XXS     XX.XXS
     AMPS    XX.XS    XX.XS      XX.XS      XX.XS
 TEMP        XXXS     XXXS       XXXS       XXXS
 TRIP        XX  XX   XX  XX     XX  XX     XX  XX
             XX  XX   XX  XX     XX  XX     XX  XX
            XXX  XX  XXX  XX    XXX  XX    XXX  XX
            XXX  XX  XXX  XX    XXX  XX    XXX  XX
APCU
 OUT VOLTS        XXX.XS              XXX.XS
     AMPS          XX.XS               XX.XS
 IN AMPS           XX.XS               XX.XS
 TEMP              XXXS                XXXS
 OUTPUT            XXX                 XXX
 TRIP        XX  XX  XXX  XX     XX  XX    XXX  XX
            XXX  XX  XXX  XX    XXX  XX    XXX  XX
                                                  (XX)
```

SM SPEC 179 POWER TRANSFER

OPCU data on SPEC 179 is divided by PTU and then by converter. Each of the four converters has output volts, output amps, temperature, and various trip statuses. As mentioned previously, output volts and temperature will be off-scale low until the ISS RPCMs provide input "housekeeping" power. The trip status fields are blank until the converter has tripped, and *show in text format the reason for the trip (e.g., IN OC for input overcurrent and OUT OV for output overvolt).*

APCU data on SPEC 179 is similar to that seen on the legacy display. The crew can see APCU output volts, input and output amps, temperature, output relay status (ON or OFF), and trip status. The output status replaces the need for a talkback on the panel, and the trip status as a numeric discrete has been replaced by text on the display (such as IN UV for input undervolt, OUT OC for output overcurrent, etc.). The trip status on the display is blank unless invoked.

The SSPTS APCUs are used for the same purposes as their standalone predecessor; they power heaters on ISS hardware carried in the payload bay, while APCU 2 also powers the heaters and sensor packages at the end of the OBSS.

Operations

Prelaunch

During prelaunch operations, the onboard *FC* reactants (oxygen and hydrogen) are supplied by ground support equipment to assure a full load of onboard reactants before lift-off. At T minus 2 minutes 35 seconds, the ground support equipment filling operation is terminated. The ground support equipment supplies hydrogen and oxygen to the PRSD manifold at pressures greater than the tank heater control range pressures (approximately 280 psia for hydrogen and 960 psia for oxygen). This helps to prevent cryo tank heater cycling during powered flight. The ground support equipment supply valves close automatically to transfer to onboard reactants.

The *FC*s will be on when the crew boards the vehicle. Until T minus 50 seconds, power to the orbiter is load shared between the *FC*s and ground support equipment, even though the *FC*s are on and capable of supplying power. Main bus power is supplied through the T-0 umbilicals, MN A through the left-side umbilical and MN B and C through the right-side umbilical to aft power controllers (APCs) 4, 5, and 6. From APCs 4, 5, and 6, the ground support equipment power is directed to the distribution assembly where the power is distributed throughout the vehicle. The power for the PREFLT 1 and PREFLT 2 test buses is also supplied through the T-0 umbilical. These test buses are scattered throughout the orbiter and are used to support launch processing system control of critical orbiter loads, although they also power up the essential buses in the APCs when on ground support equipment. As in the main bus distribution, essential bus power from the APCs is directed to the distribution assemblies and then distributed throughout the vehicle. At T minus 50 seconds, the ground turns off the ground support equipment power to the main buses, and the *FC*s automatically pick up the remaining vehicle electrical loads.

Indication of the switchover can be noted on the DPS display and the DC AMPS meter. The *FC* current will increase to approximately 220 amps; the oxygen and hydrogen flow will increase to approximately 4.6 and 0.6 pound per hour respectively; and the *FC* stack temperature will increase slightly. At T minus zero, the T-0 umbilical is disconnected with the preflight test bus wires live.

Prelaunch and On-Orbit Tank Heater Management

Before lift-off, the *O2 TK1 HEATERS A, O2 TK2 HEATERS A, H2 TK1 HEATERS A*, and *H2 TK 2 HEATERS A* switches on panel R1 are set on *AUTO*. As part of the Post OMS 1 Burn procedures, all the switches on O2 and H2 tanks 1 & 2 are positioned to AUTO, while the other tank heaters remain *OFF*. On orbit, the cryo tank heaters are managed to provide for tank quantity balancing. Tanks 3, 4, and 5 will supply reactants to the *FC*s instead of tanks 1 and 2 when all the tank heaters are set to AUTO. This is because the heater controllers in tanks 3, 4, and 5 control to a higher pressure than tanks 1 and 2. For entry, tanks 1 and 2 supply the reactants to the *FC*s.

Fuel Cell Operating Modes

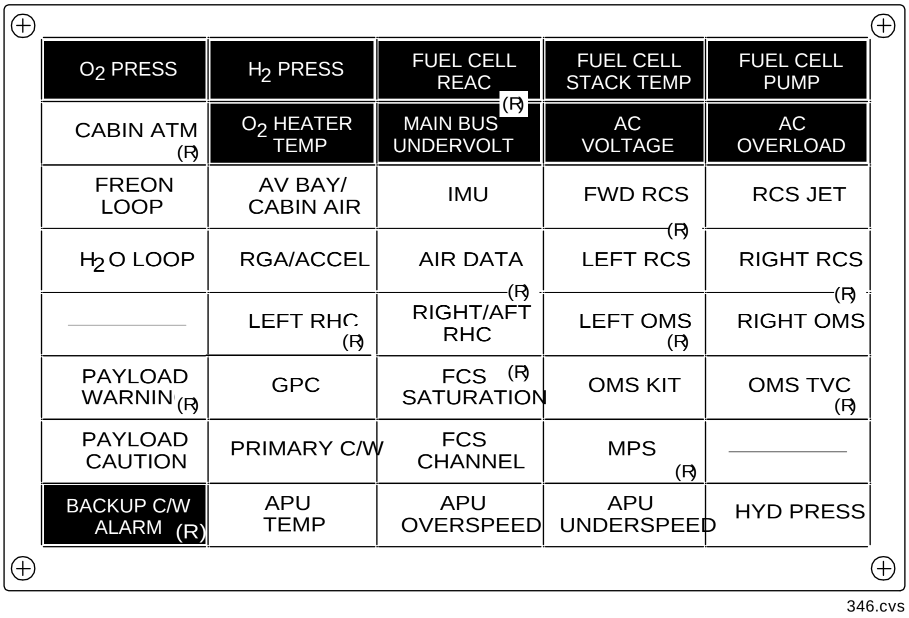
FC standby consists of removing the electrical loads from a *FC* but continuing operation of the *FC* pumps, controls, instrumentation, and valves, while electrical power is supplied by the remaining *FC*s. A small amount of reactants is used to generate power for the *FC* internal heaters. If the temperature in the *FC* compartment beneath the payload bay is lower than 40° F, the *FC* should be left in STANDBY instead of being shut down to prevent it from freezing.

FC shutdown, after standby, consists of stopping the coolant pump and hydrogen pump/water separator by positioning that *FUEL CELL START/STOP* switch on panel R1 to the *STOP* position.

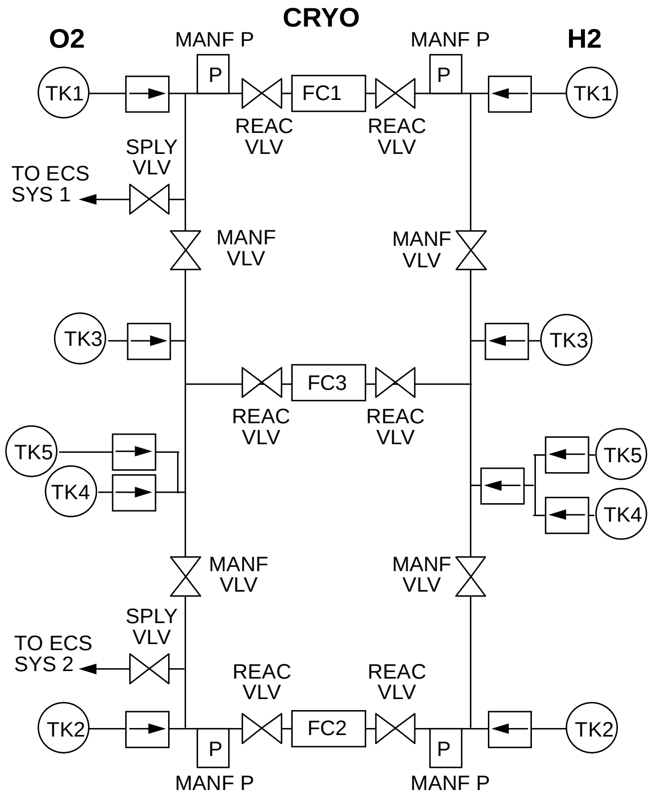
FC safing consists of closing the FC reactant valves and consuming the reactants inside the FC by either leaving the FC connected to its main bus or by keeping the pump package operating with the internal heaters.

EPS Caution and Warning Summary

- The *SM ALERT* will illuminate if a cryo heater current level sensor detects a short on a heater circuit.
- The yellow *O_2 PRESS* and the red BACKUP C/W ALARM lights illuminate if oxygen tank pressure is below 540 psia or above 985 psia.
- The yellow *H_2 PRESS* and the red *BACKUP C/W ALARM* lights illuminate if hydrogen tank pressure is below 153 psia or above 293.8 psia.
- When any FC reactant valve is closed, the red *FUEL CELL REAC* light is illuminated, a tone is sounded and the *BACKUP C/W ALARM* is illuminated.
- The yellow *FUEL CELL STACK TEMP* light will illuminate if FC and stack temperatures are below 170.7° F or above 241.9° F. The red *BACKUP C/W ALARM* and blue *SM ALERT* will also light for similar limits.
- The yellow *FUEL CELL PUMP* light will illuminate if FC 1, 2, or 3 coolant pump delta pressure is lost. If the coolant pump for FC 1, 2, or 3 is off, the *BACKUP C/W ALARM* will be illuminated.
- The yellow *O_2 HEATER TEMP* light on panel F7 illuminates if the temperature sensor senses the oxygen tank temperature is at or above 344° F. Software checks the limit; if it is above 349°F, the *BACKUP C/W ALARM* light illuminates as well.
- The red *MAIN BUS UNDERVOLT* light and the *BACKUP C/W ALARM* illuminate if main bus A, B, or C voltage *is 26.4* volts dc.
- The yellow *AC VOLTAGE* light illuminates for an overvoltage or undervoltage condition in the AC bus. The red *BACKUP C/W ALARM* will also illuminate.
- The yellow *AC OVERLOAD* light illuminates for an overload condition in the AC bus.



EPS Caution and Warning Lights on Panel F7

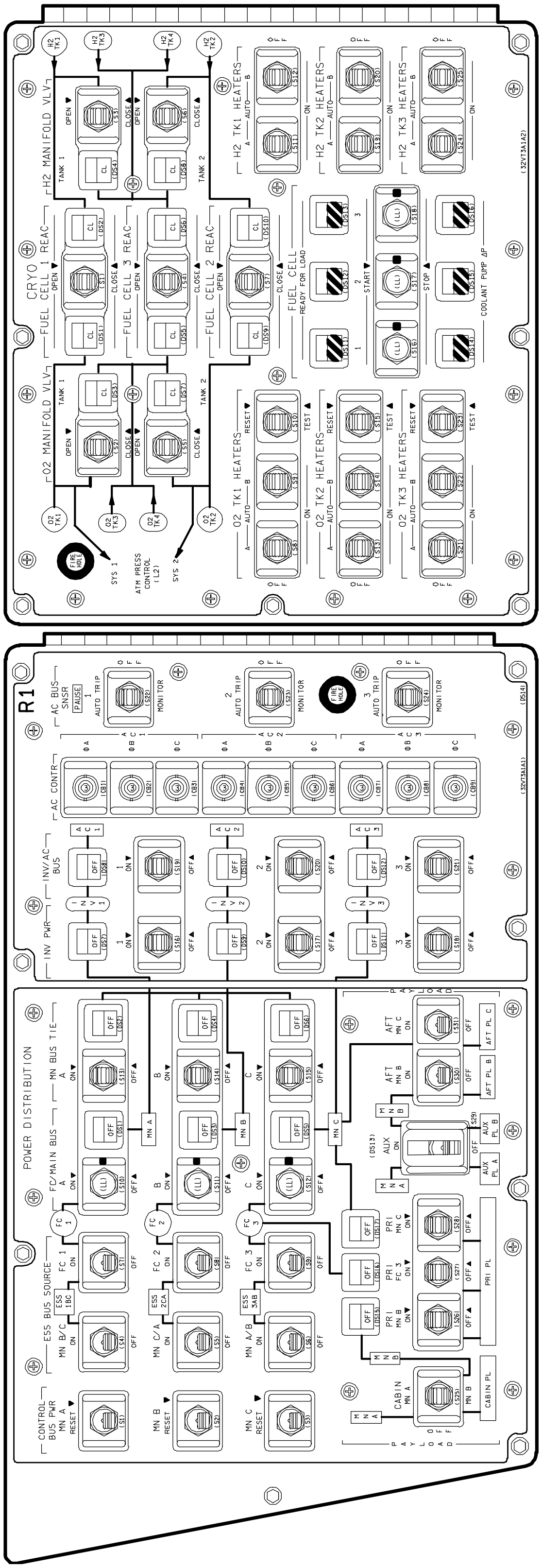


usa007587_309**r3**.cvx

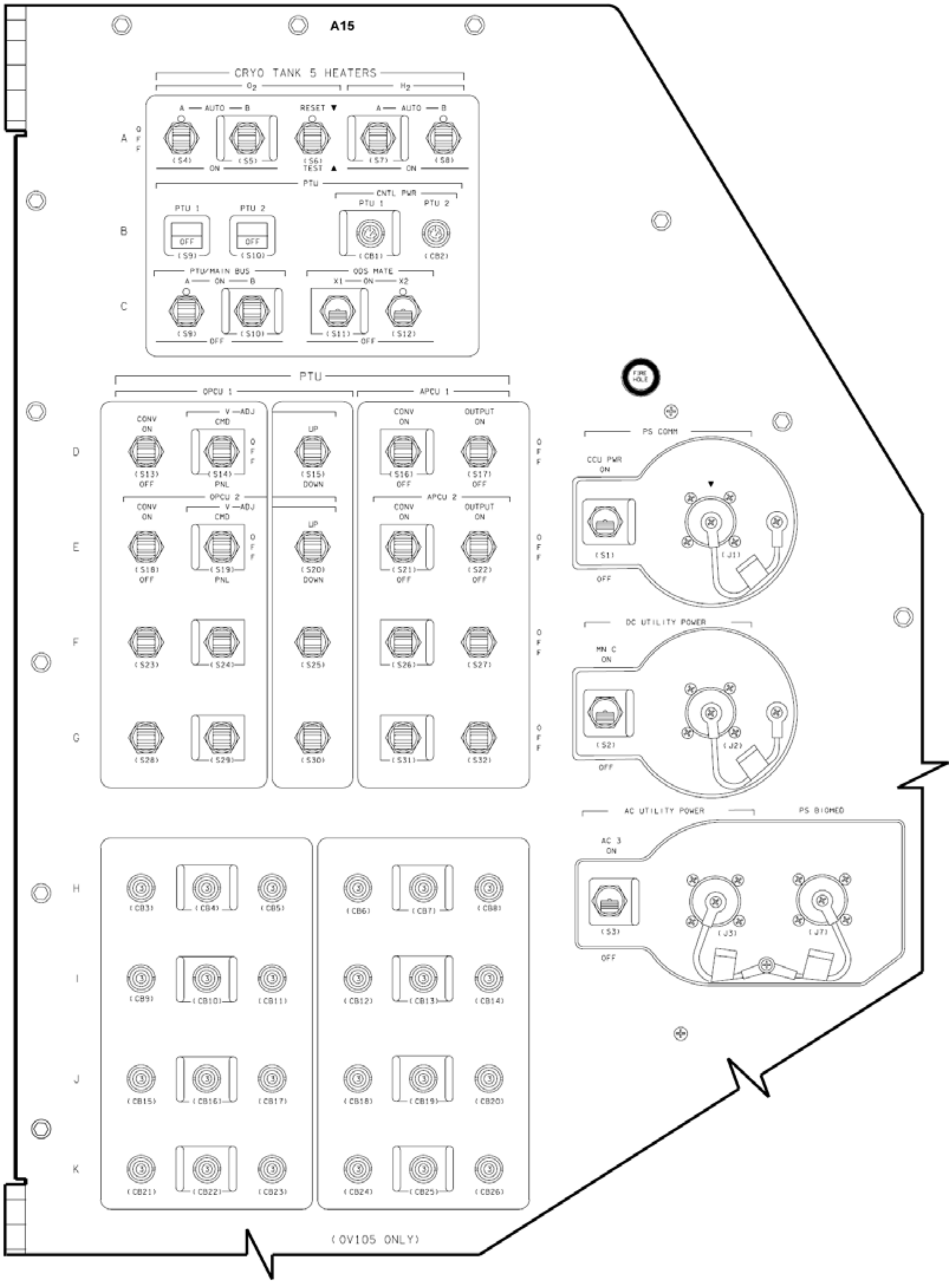
	O2/ H2 HTR LOSS									
BUS LOSS	PAIRED				PAIRED					
	TK1		TK2		TK3		TK 4		TK5	
	A	B	A	B	A	B	A	B	A	B
MNA DA1	A/M				A/M				A/M	
MNB DA2			AUTO	A/M	AUTO	A/M	AUTO	A/M		
MNC DA3	AUTO	A/M	A/M				A/M		AUTO	A/M
CNTL AB1		MAN			MAN					
AB2		A/M			A/M					
CNTL BC1			MAN				MAN			MAN
BC 2			A/M				A/M			
BC 3				MAN						A/M
CNTL CA1	MAN					MAN			MAN	
CA 2	A/M					A/M			A/M	
CA 3				A/M				A/M		
ESS 1BC	AUT0*	AUTO*	AUTO	AUTO	AUTO*	AUTO*	AUTO	AUTO		
2CA	AUTO	AUTO	AUTO*	AUTO*					AUTO	AUTO
3AB					AUTO	AUTO	AUTO*	AUTO*		

* AUTO operation regained if both A and B HTR SW of other paired tank(s) are not in auto. A/M = Auto and Manual loss.

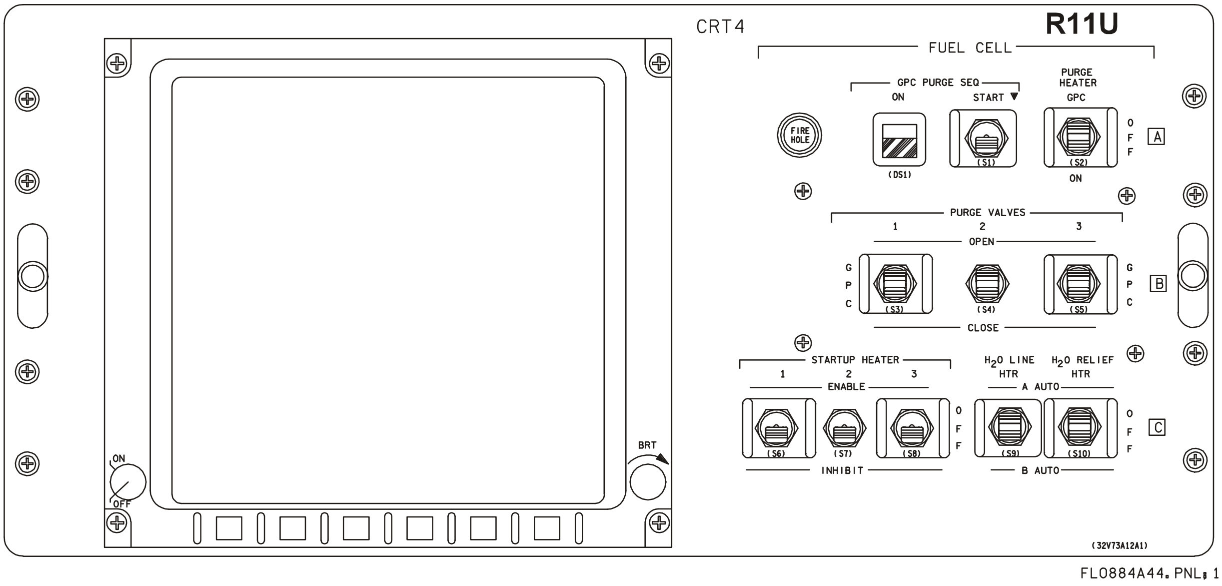
Cryogenic System


CRYO
H2 MANIFOLD VLV
TANK 1
TANK 2
FUEL CELL 1 REAC
FUEL CELL 3 REAC
FUEL CELL 2 REAC
O2 MANIFOLD VLV
H2 TK1 HEATERS
H2 TK2 HEATERS
H2 TK3 HEATERS
FUEL CELL READY FOR LOAD
START
STOP
COOLANT PUMP ΔP
O2 TK1 HEATERS
O2 TK2 HEATERS
O2 TK3 HEATERS
ATM PRESS CONTROL (L2)
SYS 1
SYS 2
R1
AC BUS SNSR
AUTO TRIP
MONITOR
AC CONTR
INV/AC BUS
INV PWR
POWER DISTRIBUTION
MN BUS TIE
FC/MAIN BUS
ESS BUS SOURCE
CONTROL BUS PWR
PAYLOAD
AFT PL C
AFT PL B
AUX PL B
AUX PL A
PRI PL
CABIN PL

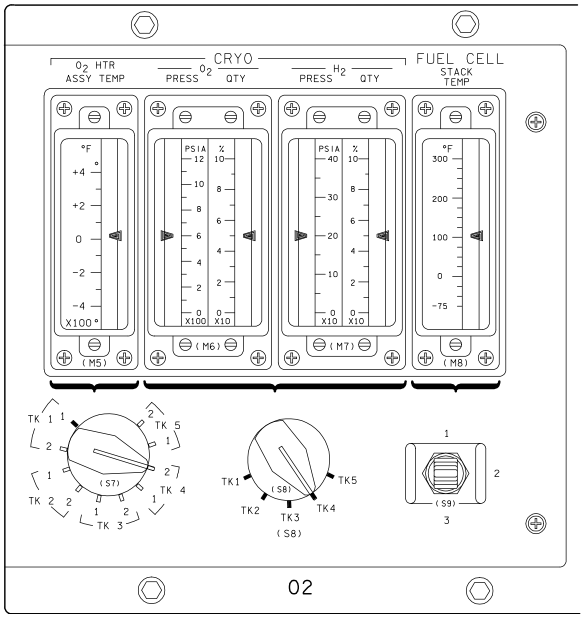
Panel R1


A15
CRYO TANK 5 HEATERS
O2
H2
A — AUTO — B
RESET
A — AUTO — B
A
OFF
(S4)
(S5)
(S6)
TEST
(S7)
(S8)
ON
ON
PTU
CNTL PWR
PTU 1
PTU 2
PTU 1
PTU 2
B
OFF
OFF
(S9)
(S10)
(CB1)
(CB2)
PTU/MAIN BUS
A — ON — B
ODS MATE
X1 — ON — X2
C
(S9)
(S10)
OFF
(S11)
(S12)
OFF
PTU
OPCU 1
APCU 1
CONV ON
V — ADJ
CMD
UP
CONV ON
OUTPUT ON
D
(S13)
OFF
(S14)
PNL
(S15)
DOWN
(S16)
OFF
(S17)
OFF
OPCU 2
APCU 2
CONV ON
V — ADJ
CMD
UP
CONV ON
OUTPUT ON
E
(S18)
OFF
(S19)
PNL
(S20)
DOWN
(S21)
OFF
(S22)
OFF
F
(S23)
(S24)
(S25)
(S26)
(S27)
G
(S28)
(S29)
(S30)
(S31)
(S32)
OFF
FIRE HOLE
PS COMM
CCU PWR
ON
(S1)
OFF
(J1)
DC UTILITY POWER
MN C
ON
(S2)
OFF
(J2)
AC UTILITY POWER
PS BIOMED
AC 3
ON
(S3)
OFF
(J3)
(J7)
H
(CB3)
(CB4)
(CB5)
(CB6)
(CB7)
(CB8)
I
(CB9)
(CB10)
(CB11)
(CB12)
(CB13)
(CB14)
J
(CB15)
(CB16)
(CB17)
(CB18)
(CB19)
(CB20)
K
(CB21)
(CB22)
(CB23)
(CB24)
(CB25)
(CB26)
(OV105 ONLY)

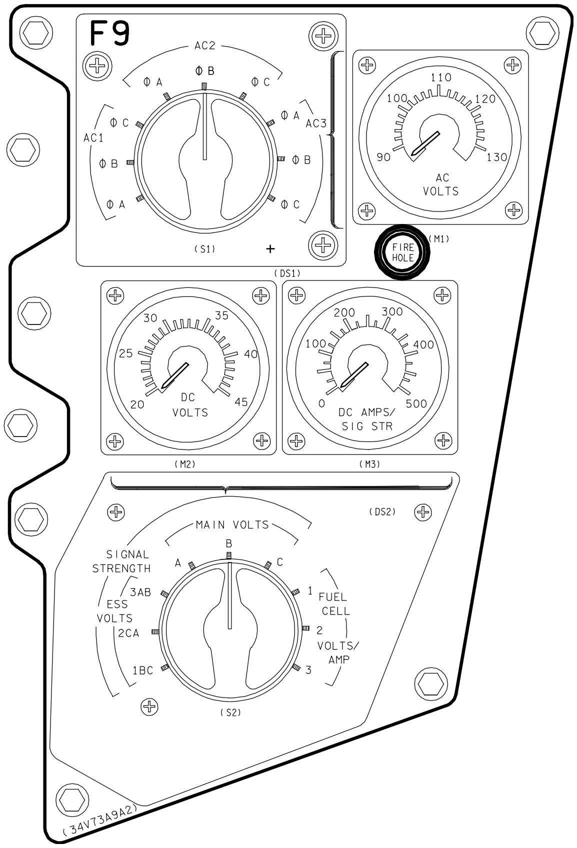
Panel A15



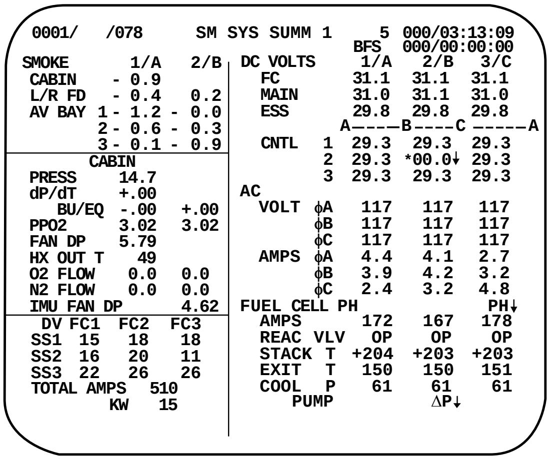
Panel R11U



Panel O2



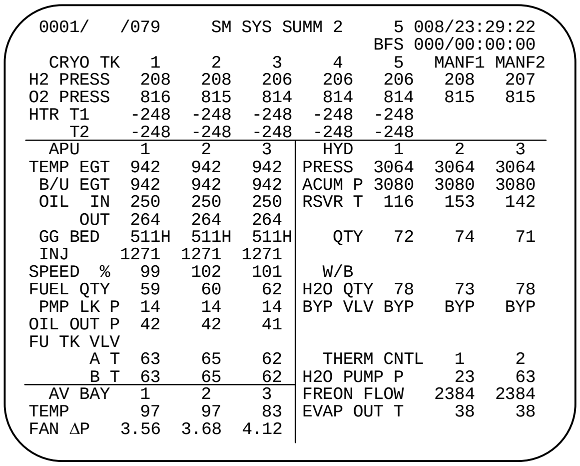
Panel F9



```
 0001/   /078      SM SYS SUMM 1     5  000/03:13:09
                                    BFS  000/00:00:00
SMOKE        1/A   2/B | DC VOLTS     1/A    2/B    3/C
 CABIN     - 0.9       |   FC         31.1   31.1   31.1
 L/R FD    - 0.4   0.2 |   MAIN       31.0   31.1   31.0
 AV BAY  1 - 1.2 - 0.0 |   ESS        29.8   29.8   29.8
         2 - 0.6 - 0.3 |            A----B----C -----A
         3 - 0.1 - 0.9 |   CNTL   1  29.3   29.3   29.3
-----------------------|          2  29.3  *00.0↓  29.3
          CABIN        |          3  29.3   29.3   29.3
 PRESS      14.7       | AC
 dP/dT      +.00       |   VOLT  ϕA   117    117    117
    BU/EQ   -.00  +.00 |         ϕB   117    117    117
 PPO2       3.02  3.02 |         ϕC   117    117    117
 FAN DP     5.79       |   AMPS  ϕA   4.4    4.1    2.7
 HX OUT T     49       |         ϕB   3.9    4.2    3.2
 O2 FLOW     0.0   0.0 |         ϕC   2.4    3.2    4.8
 N2 FLOW     0.0   0.0 | FUEL CELL PH               PH↓
 IMU FAN DP       4.62 |   AMPS       172    167    178
-----------------------|   REAC VLV    OP     OP     OP
  DV FC1   FC2   FC3   |   STACK  T  +204   +203   +203
 SS1  15    18    18   |   EXIT   T   150    150    151
 SS2  16    20    11   |   COOL   P    61     61     61
 SS3  22    26    26   |     PUMP             ΔP↓
 TOTAL AMPS   510      |
           KW   15     |
```

usa007587_085**r4**.cvx

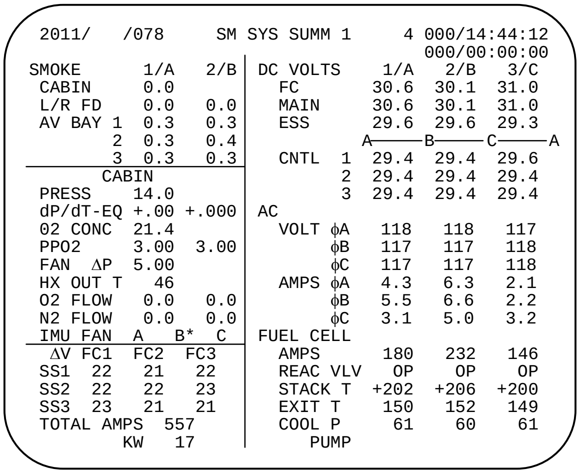
BFS SM SYS SUMM 1



```
 0001/   /079      SM SYS SUMM 2     5 008/23:29:22
                                    BFS 000/00:00:00
  CRYO TK    1     2     3     4     5   MANF1 MANF2
H2 PRESS   208   208   206   206   206   208   207
O2 PRESS   816   815   814   814   814   815   815
HTR T1    -248  -248  -248  -248  -248
    T2    -248  -248  -248  -248  -248
---------------------------------------------------
  APU       1     2     3   |  HYD     1     2     3
TEMP EGT  942   942   942   |PRESS  3064  3064  3064
 B/U EGT  942   942   942   |ACUM P 3080  3080  3080
 OIL  IN  250   250   250   |RSVR T  116   153   142
     OUT  264   264   264   |
 GG BED   511H  511H  511H  |   QTY   72    74    71
 INJ     1271  1271  1271   |
SPEED  %   99   102   101   |  W/B
FUEL QTY   59    60    62   |H2O QTY  78    73    78
 PMP LK P  14    14    14   |BYP VLV BYP   BYP   BYP
OIL OUT P  42    42    41   |
FU TK VLV                   |
      A T  63    65    62   |  THERM CNTL   1     2
      B T  63    65    62   |H2O PUMP P    23    63
----------------------------|FREON FLOW  2384  2384
  AV BAY    1     2     3   |EVAP OUT T    38    38
TEMP       97    97    83   |
FAN ΔP   3.56  3.68  4.12   |
```

usa007587_051**r1**.cvx

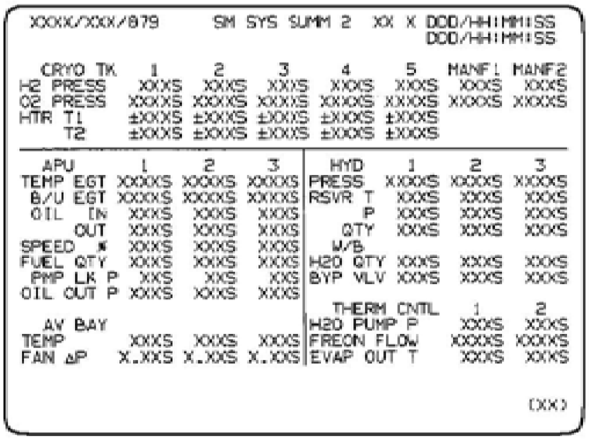
BFS SM SYS SUMM 2



```
 2011/   /078      SM SYS SUMM 1      4 000/14:44:12
                                        000/00:00:00
SMOKE        1/A   2/B | DC VOLTS     1/A   2/B   3/C
 CABIN       0.0       |   FC        30.6  30.1  31.0
 L/R FD      0.0   0.0 |   MAIN      30.6  30.1  31.0
 AV BAY 1    0.3   0.3 |   ESS       29.6  29.6  29.3
        2    0.3   0.4 |            A-----B-----C-----A
        3    0.3   0.3 |   CNTL  1   29.4  29.4  29.6
-----------------------|         2   29.4  29.4  29.4
       CABIN           |         3   29.4  29.4  29.4
 PRESS      14.0       | AC
 dP/dT-EQ  +.00 +.000  |   VOLT ϕA   118   118   117
 02 CONC    21.4       |        ϕB   117   117   118
 PPO2       3.00  3.00 |        ϕC   117   117   118
 FAN  ΔP    5.00       |   AMPS ϕA   4.3   6.3   2.1
 HX OUT T    46        |        ϕB   5.5   6.6   2.2
 O2 FLOW     0.0   0.0 |        ϕC   3.1   5.0   3.2
 N2 FLOW     0.0   0.0 | FUEL CELL
 IMU FAN    A   B*  C  |   AMPS       180   232   146
-----------------------|   REAC VLV    OP    OP    OP
  ΔV FC1   FC2   FC3   |   STACK T   +202  +206  +200
 SS1  22    21    22   |   EXIT T     150   152   149
 SS2  22    22    23   |   COOL P      61    60    61
 SS3  23    21    21   |     PUMP
 TOTAL AMPS  557       |
         KW   17       |
```

usa007587_243**r2**.cvx

PASS SM SYS SUMM 1

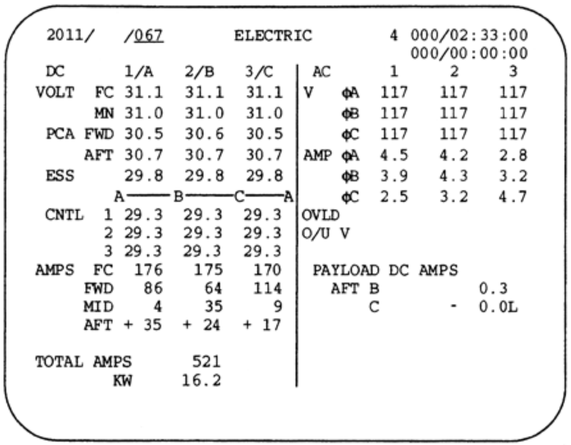


```
XXXX/XXX/079       SM SYS SUMM 2  XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS

  CRYO TK     1      2      3      4      5    MANF1  MANF2
H2 PRESS    XXXS   XXXS   XXXS   XXXS   XXXS   XXXS   XXXS
O2 PRESS   XXXXS  XXXXS  XXXXS  XXXXS  XXXXS  XXXXS  XXXXS
HTR T1     ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS
     T2    ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS
-----------------------------------------------------------
  APU        1      2      3  |  HYD     1      2      3
TEMP EGT XXXXS  XXXXS  XXXXS  |PRESS   XXXXS  XXXXS  XXXXS
 B/U EGT XXXXS  XXXXS  XXXXS  |RSVR T   XXXS   XXXS   XXXS
 OIL  IN  XXXS   XXXS   XXXS  |       P XXXS   XXXS   XXXS
     OUT  XXXS   XXXS   XXXS  |     QTY XXXS   XXXS   XXXS
SPEED  %  XXXS   XXXS   XXXS  |   W/B
FUEL QTY  XXXS   XXXS   XXXS  |H2O QTY  XXXS   XXXS   XXXS
 PMP LK P  XXS    XXS    XXS  |BYP VLV  XXXS   XXXS   XXXS
OIL OUT P XXXS   XXXS   XXXS  |
                              |  THERM CNTL      1      2
  AV BAY                      |H2O PUMP P      XXXS   XXXS
TEMP      XXXS   XXXS   XXXS  |FREON FLOW     XXXXS  XXXXS
FAN ΔP   X.XXS  X.XXS  X.XXS  |EVAP OUT T      XXXS   XXXS

                                                      (XX)
```

PASS SM SYS SUMM 2



```
 2011/   /067          ELECTRIC          4 000/02:33:00
                                           000/00:00:00
 DC       1/A    2/B    3/C  | AC      1      2      3
VOLT   FC 31.1   31.1   31.1 |V   φA  117    117    117
       MN 31.0   31.0   31.0 |    φB  117    117    117
 PCA  FWD 30.5   30.6   30.5 |    φC  117    117    117
      AFT 30.7   30.7   30.7 |AMP φA  4.5    4.2    2.8
 ESS      29.8   29.8   29.8 |    φB  3.9    4.3    3.2
        A------B------C------A|   φC  2.5    3.2    4.7
 CNTL   1 29.3   29.3   29.3 |OVLD
        2 29.3   29.3   29.3 |O/U V
        3 29.3   29.3   29.3 |
AMPS   FC  176    175    170 | PAYLOAD DC AMPS
      FWD   86     64    114 |   AFT B           0.3
      MID    4     35      9 |       C       -   0.0L
      AFT + 35   + 24   + 17 |
                             |
TOTAL AMPS        521        |
        KW       16.2        |
```

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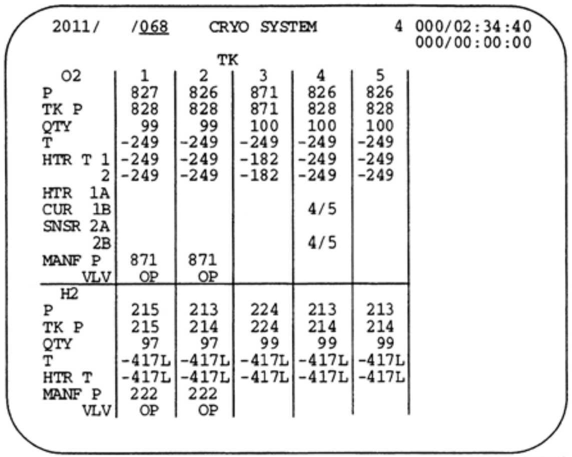
SM SPEC 67 (ELECTRIC)



```
 2011/   /068     CRYO  SYSTEM          4 000/02:34:40
                                          000/00:00:00
                            TK
  O2     |   1  |   2  |   3  |   4  |   5  |
P        |  827 |  826 |  871 |  826 |  826 |
TK P     |  828 |  828 |  871 |  828 |  828 |
QTY      |   99 |   99 |  100 |  100 |  100 |
T        | -249 | -249 | -249 | -249 | -249 |
HTR T 1  | -249 | -249 | -182 | -249 | -249 |
      2  | -249 | -249 | -182 | -249 | -249 |
HTR   1A |      |      |      |      |      |
CUR   1B |      |      |      |  4/5 |      |
SNSR  2A |      |      |      |      |      |
      2B |      |      |      |  4/5 |      |
MANF P   |  871 |  871 |      |      |      |
     VLV |   OP |   OP |      |      |      |
---------+------+------+------+------+------+
  H2     |      |      |      |      |      |
P        |  215 |  213 |  224 |  213 |  213 |
TK P     |  215 |  214 |  224 |  214 |  214 |
QTY      |   97 |   97 |   99 |   99 |   99 |
T        |-417L |-417L |-417L |-417L |-417L |
HTR T    |-417L |-417L |-417L |-417L |-417L |
MANF P   |  222 |  222 |      |      |      |
     VLV |   OP |   OP |      |      |      |
```

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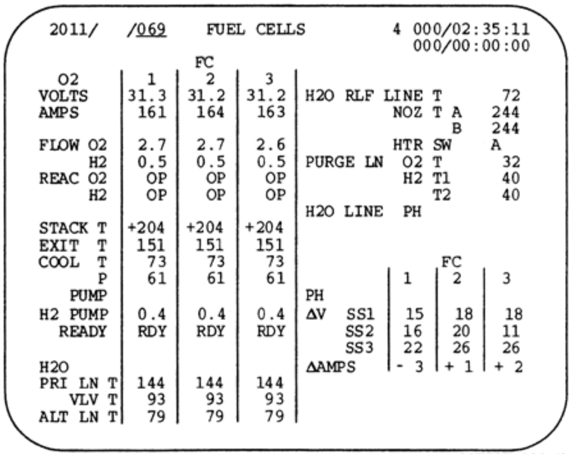
SM SPEC 68 (CRYO SYSTEM)



```
 2011/   /069     FUEL  CELLS          4 000/02:35:11
                                         000/00:00:00
                   FC
  O2     |  1  |  2  |  3  |
VOLTS    |31.3 |31.2 |31.2 | H2O RLF LINE T       72
AMPS     | 161 | 164 | 163 |          NOZ T A    244
         |     |     |     |                B    244
FLOW O2  | 2.7 | 2.7 | 2.6 |          HTR SW    A
     H2  | 0.5 | 0.5 | 0.5 | PURGE LN  O2 T       32
REAC O2  |  OP |  OP |  OP |           H2 T1      40
     H2  |  OP |  OP |  OP |              T2      40
         |     |     |     | H2O LINE  PH
STACK T  |+204 |+204 |+204 |
EXIT  T  | 151 | 151 | 151 |
COOL  T  |  73 |  73 |  73 |                 FC
      P  |  61 |  61 |  61 |          |  1  |  2  |  3
   PUMP  |     |     |     | PH       |     |     |
H2 PUMP  | 0.4 | 0.4 | 0.4 | ΔV   SS1 |  15 |  18 |  18
  READY  | RDY | RDY | RDY |      SS2 |  16 |  20 |  11
         |     |     |     |      SS3 |  22 |  26 |  26
H2O      |     |     |     | ΔAMPS    | - 3 | + 1 | + 2
PRI LN T | 144 | 144 | 144 |
   VLV T |  93 |  93 |  93 |
ALT LN T |  79 |  79 |  79 |
```

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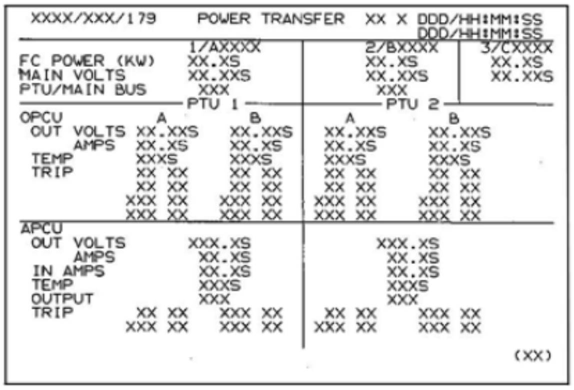
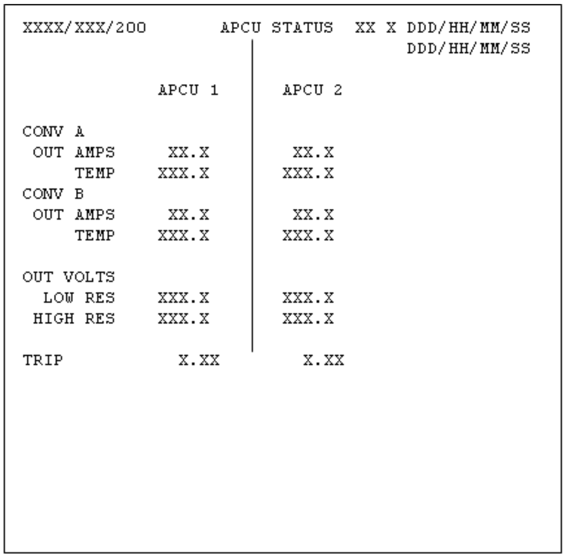
SM SPEC 69 (FUEL CELLS)



```
 XXXX/XXX/179     POWER TRANSFER   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
                    1/AXXXX      |       2/BXXXX   | 3/CXXXX
FC POWER (KW)       XX.XS        |       XX.XS     |  XX.XS
MAIN VOLTS          XX.XXS       |       XX.XXS    |  XX.XXS
PTU/MAIN BUS         XXX         |        XXX      |
-------------------- PTU 1 --------------------- PTU 2 ---------
OPCU            A            B   |     A            B
 OUT  VOLTS  XX.XXS       XX.XXS |  XX.XXS       XX.XXS
      AMPS   XX.XS        XX.XS  |  XX.XS        XX.XS
 TEMP        XXXS         XXXS   |  XXXS         XXXS
 TRIP         XX XX        XX XX |   XX XX        XX XX
              XX XX        XX XX |   XX XX        XX XX
             XXX XX       XXX XX |  XXX XX       XXX XX
             XXX XX       XXX XX |  XXX XX       XXX XX
-----------------------------------------------------------------
APCU                             |
 OUT  VOLTS         XXX.XS       |        XXX.XS
      AMPS           XX.XS       |         XX.XS
 IN   AMPS           XX.XS       |         XX.XS
 TEMP                XXXS        |         XXXS
 OUTPUT              XXX         |         XXX
 TRIP         XX XX       XXX XX |   XX XX       XXX XX
             XXX XX       XXX XX |  XXX XX       XXX XX
                                 |
                                                       (XX)
```

SM SPEC 179 POWER TRANSFER



```
XXXX/XXX/200        APCU STATUS   XX X DDD/HH/MM/SS
                            |                DDD/HH/MM/SS
                            |
                 APCU 1     |    APCU 2
                            |
CONV A                      |
 OUT AMPS          XX.X     |     XX.X
     TEMP         XXX.X     |    XXX.X
CONV B                      |
 OUT AMPS          XX.X     |     XX.X
     TEMP         XXX.X     |    XXX.X
                            |
OUT VOLTS                   |
  LOW RES         XXX.X     |    XXX.X
 HIGH RES         XXX.X     |    XXX.X
                            |
TRIP                X.XX         X.XX
```

SM SPEC 200 APCU STATUS

EPS Summary Data

- The EPS operates during all flight phases and consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter.
- The *FC* picks up full power load support after ground equipment is turned off at T minus 50 seconds, supporting power requirements for the solid rocket booster, orbiter, and payloads.
- EPS subsystems are: power reactants storage and distribution, *FC*s, and electrical power distribution and control.
- The Power Reactants Storage *and* Distribution system stores cryogenic hydrogen and oxygen and supplies them to the *FC*s. It also supplies oxygen to the ECLSS. The components are located in the orbiter midbody underneath the payload bay.
- The *FC* system (three *FC*s) transforms hydrogen and oxygen to electricity by a chemical reaction. The system supplies potable water to the ECLSS and consists of power and accessory sections.
- The electrical power distribution and control system distributes electrical power throughout the orbiter. It has five types of assemblies: power control, load control, motor control, main *DC* distribution, and *AC* distribution and control.
- The EPS requires very little flight crew interaction during nominal operations.
- The majority of the EPS controls are on panels R1 and R11U. Power sources and circuit breakers are distributed on panels O13, O14, O15, O16, ML86B, R14, *A15,* and MA73C. Heaters are controlled from panel R1, A11, and A15.
- Meters for monitoring EPS parameters are located on panels F9 and O2
- DPS displays containing EPS data are BFS SM SYS SUMM 1 and 2, *PASS SM SYS SUMM 1 and 2,* SM SPEC 67 (ELECTRIC), SM SPEC 68 (CRYO SYSTEM), SM SPEC 69 (FUEL CELLS), *SM SPEC 179 (POWER TRANSFER), and SM SPEC 200 (APCU STATUS).*

EPS Rules of Thumb

- Never close a circuit breaker or reset an RPC found out of configuration without MCC coordination.
- Loss of cooling to a *FC* requires crew action within 9 minutes to prevent a catastrophic loss of crew/vehicle due to possible *FC* fire and explosion.
- *FC* run limit prior to shutdown for loss of cooling is 9 minutes at a 7 kW nominal load. Run time is inversely proportional to *FC* load.
- Any interruption of continuous *AC* power during ascent *will* result in the loss of main engine controller redundancy. Reconfiguration of *AC* powered equipment prior to MECO should be avoided.
- Never connect or reconnect power to a known shorted or failed component; this includes switch throws, circuit protection device resets, or bus ties.
- Three oxygen and hydrogen tanks are good for up to 8 days on orbit; five oxygen and hydrogen tanks are good for up to 12 days on orbit; eight oxygen and hydrogen tanks are good for up to 18 days on orbit. Exact duration varies with crew complement and power load.
- A *FC* hydrogen pump uses 0.3 amps/AC phase; a coolant pump uses 0.5 amps/AC phase.

2.9 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS)

CONTENTS

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Atmospheric Revitalization System 2.9-13
Active Thermal Control System 2.9-24
Supply and Waste Water Systems 2.9-37
Operations 2.9-47
ECLSS Caution and Warning Summary . 2.9-50
ECLSS Summary Data 2.9-51
ECLSS Rules of Thumb 2.9-63

Description

The ECLSS maintains the orbiter's thermal stability and provides a pressurized, habitable environment for the crew and onboard avionics. The ECLSS also manages the storage and disposal of water and crew waste.

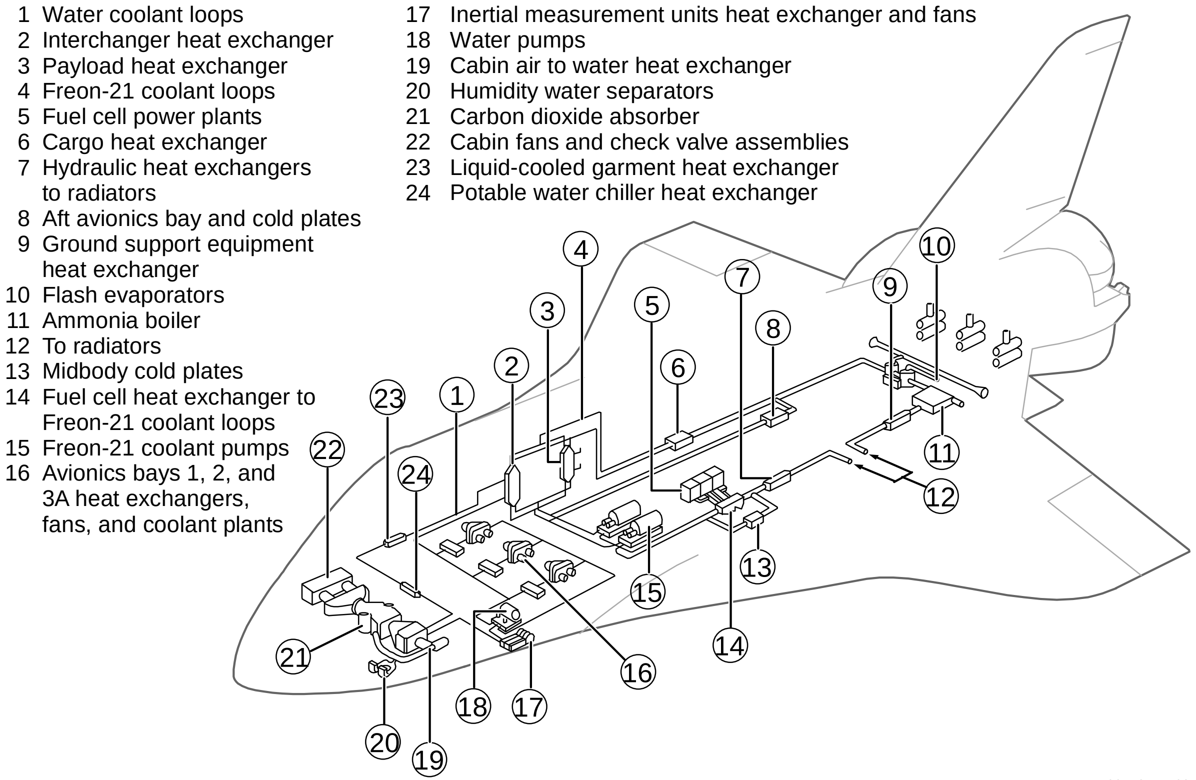
ECLSS is functionally divided into four systems:

1. **Pressure control system (PCS)** maintains the crew compartment at 14.7 psia with a breathable mixture of oxygen and nitrogen. Nitrogen is also used to pressurize the supply and waste water tanks.

2. **Atmospheric revitalization system, (ARS)** uses air circulation and water coolant loops to remove heat, control humidity, and clean and purify cabin air.

3. **Active thermal control system (ATCS)** consists of two Freon loops that collect waste heat from orbiter systems and transfer the heat overboard.

4. **Supply and waste water system** stores water produced by the fuel cells for drinking, personal hygiene, orbiter cooling*, and eventual transfer to the International Space Station (ISS)*. The waste water system stores crew liquid waste and waste water from the humidity separator. The system also has the capability to dump supply and waste water overboard.



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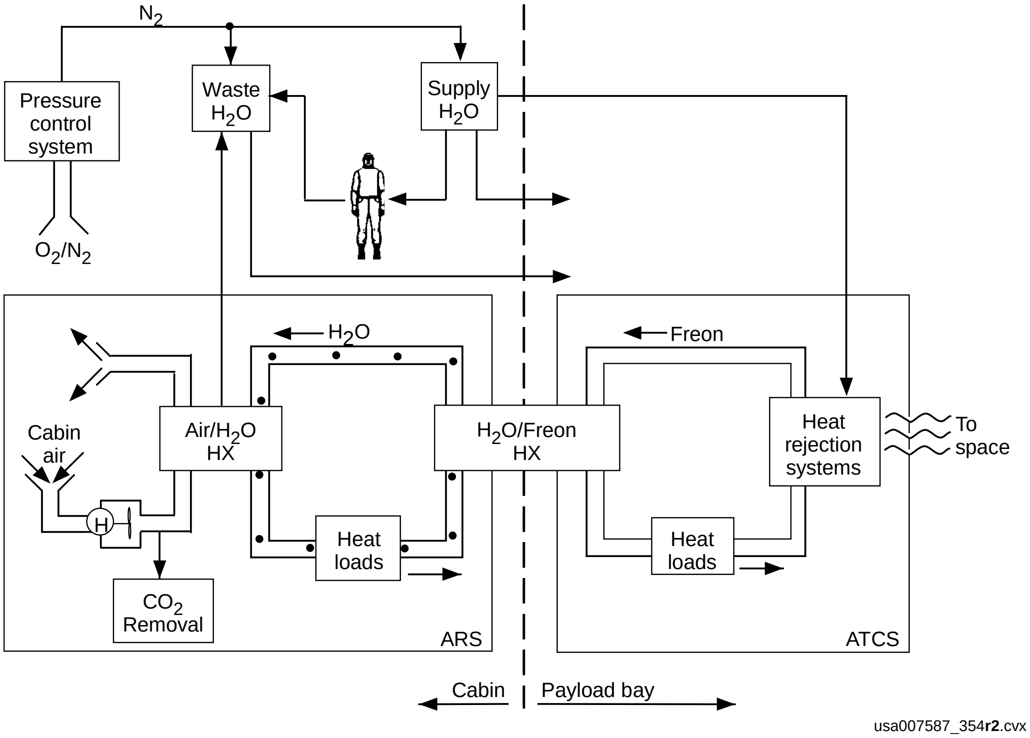
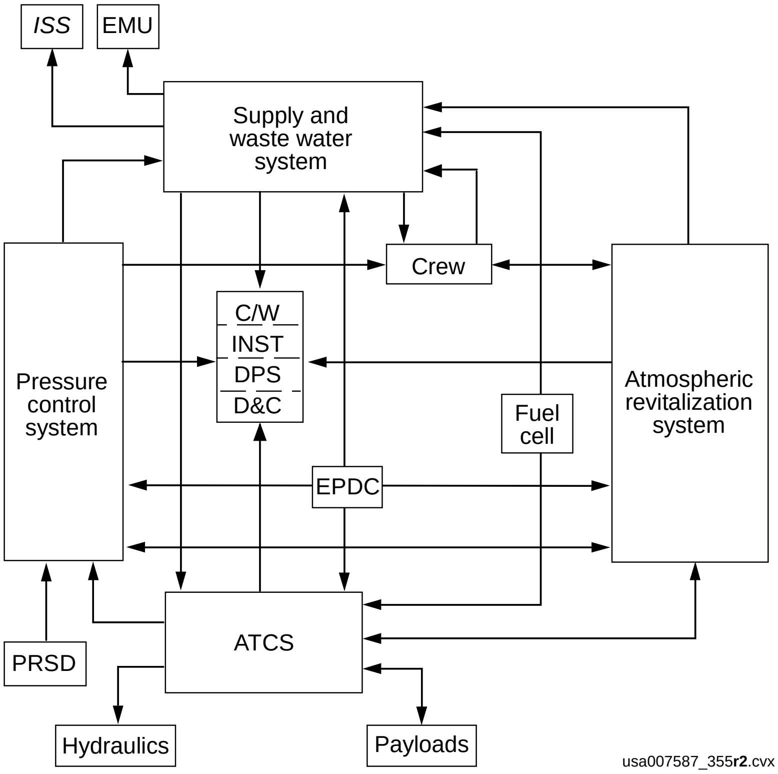
ECLSS



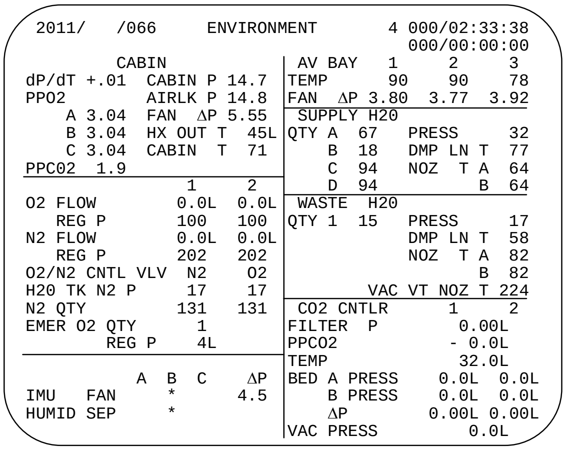
Environmental Control and Life Support System Overview



Environmental Control and Life Support System Interfaces

The crew compartment provides a life-sustaining environment for the flight crew. The cabin volume is 2,475 cubic feet. For extravehicular activity (EVA), an external airlock is depressurized and repressurized. Under normal circumstances, the cabin may be depressed to 10.2 psia to ease prebreathe requirements prior to an EVA. The airlock is outside the middeck in the payload bay and brings the combined cabin volume to approximately 2,*703* cubic feet. The external airlock volume varies and is based on mission-specific configuration. The external airlock is covered in detail in the Orbiter Docking System (ODS) section of this document.

Most ECLSS parameters can be monitored during ascent and entry on BFS DISP 78 (SM SYS SUMM 1) and BFS DISP 79 (SM SYS SUMM 2) displays. On orbit ECLSS parameters are also available on SM DISP 66 (ENVIRONMENT) and SM DISP 88 (APU/ENVIRON THERM) displays.



```
 2011/   /066     ENVIRONMENT       4 000/02:33:38
                                      000/00:00:00
         CABIN                 | AV BAY   1     2     3
dP/dT +.01  CABIN P 14.7       |TEMP      90    90    78
PPO2        AIRLK P 14.8       |FAN  ΔP 3.80  3.77  3.92
    A 3.04  FAN  ΔP 5.55       | SUPPLY H20
    B 3.04  HX OUT T  45L      |QTY A  67   PRESS     32
    C 3.04  CABIN  T  71       |    B  18   DMP LN T  77
PPC02  1.9                     |    C  94   NOZ  T A  64
                   1     2     |    D  94          B  64
O2 FLOW          0.0L  0.0L    | WASTE  H20
   REG P         100   100     |QTY 1  15   PRESS     17
N2 FLOW          0.0L  0.0L    |            DMP LN T  58
   REG P         202   202     |            NOZ  T A  82
O2/N2 CNTL VLV   N2    O2      |                   B  82
H20 TK N2 P      17    17      |        VAC VT NOZ T 224
N2 QTY           131   131     | CO2 CNTLR      1     2
EMER O2 QTY       1            |FILTER  P        0.00L
        REG P     4L           |PPCO2           - 0.0L
                               |TEMP             32.0L
           A  B  C     ΔP      |BED A PRESS    0.0L  0.0L
IMU   FAN     *        4.5     |    B PRESS    0.0L  0.0L
HUMID SEP     *                |    ΔP       0.00L 0.00L
                               |VAC PRESS        0.0L
```

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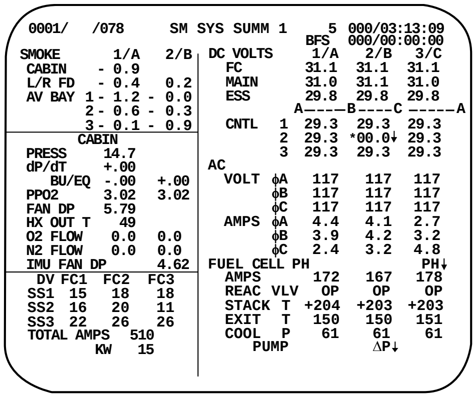
ENVIRONMENTAL Display (DISP 66)



```
0001/   /078     SM SYS SUMM 1     5 000/03:13:09
                                 BFS 000/00:00:00
SMOKE       1/A   2/B | DC VOLTS    1/A   2/B   3/C
 CABIN    - 0.9       |   FC        31.1  31.1  31.1
 L/R FD   - 0.4   0.2 |   MAIN      31.0  31.1  31.0
 AV BAY 1 - 1.2 - 0.0 |   ESS       29.8  29.8  29.8
        2 - 0.6 - 0.3 |           A----B----C -----A
        3 - 0.1 - 0.9 |   CNTL   1  29.3  29.3  29.3
        CABIN         |          2  29.3 *00.0↓ 29.3
 PRESS     14.7       |          3  29.3  29.3  29.3
 dP/dT     +.00       | AC
    BU/EQ  -.00  +.00 |  VOLT  ϕA   117   117   117
 PPO2      3.02  3.02 |        ϕB   117   117   117
 FAN DP    5.79       |        ϕC   117   117   117
 HX OUT T   49        |  AMPS  ϕA   4.4   4.1   2.7
 O2 FLOW    0.0   0.0 |        ϕB   3.9   4.2   3.2
 N2 FLOW    0.0   0.0 |        ϕC   2.4   3.2   4.8
 IMU FAN DP      4.62 | FUEL CELL PH            PH↓
  DV FC1  FC2  FC3    |  AMPS       172   167   178
 SS1  15   18   18    |  REAC VLV    OP    OP    OP
 SS2  16   20   11    |  STACK T  +204  +203  +203
 SS3  22   26   26    |  EXIT  T   150   150   151
 TOTAL AMPS   510     |  COOL  P    61    61    61
          KW   15     |     PUMP         ΔP↓
```

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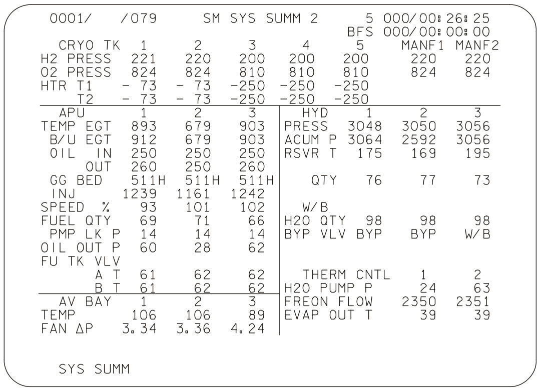
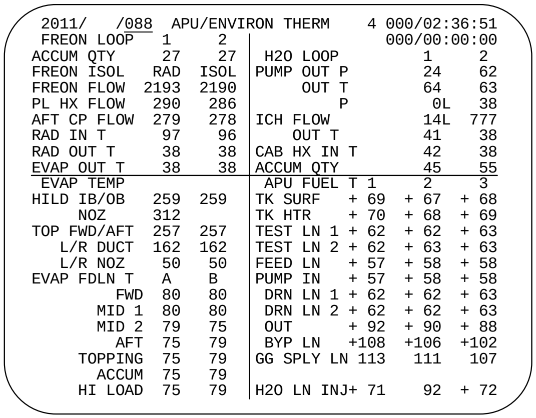
ECLSS Parameters on the BFS SM SYS SUMM 1 Display (DISP 78)



```
 0001/   /079     SM SYS SUMM 2      5 000/00:26:25
                                   BFS 000/00:00:00
  CRYO TK   1     2     3     4     5     MANF1 MANF2
H2 PRESS   221   220   200   200   200     220   220
O2 PRESS   824   824   810   810   810     824   824
HTR T1    - 73  - 73  -250  -250  -250
    T2    - 73  - 73  -250  -250  -250
  APU       1     2     3   | HYD     1     2     3
TEMP EGT   893   679   903  |PRESS  3048  3050  3056
 B/U EGT   912   679   903  |ACUM P 3064  2592  3056
 OIL  IN   250   250   250  |RSVR T  175   169   195
     OUT   260   250   260  |
 GG BED    511H  511H  511H |   QTY   76    77    73
 INJ      1239  1161  1242  |
SPEED  %    93   101   102  |  W/B
FUEL QTY    69    71    66  |H20 QTY  98    98    98
 PMP LK P   14    14    14  |BYP VLV BYP   BYP   W/B
OIL OUT P   60    28    62  |
FU TK VLV                   |
      A T   61    62    62  |  THERM CNTL   1     2
      B T   61    62    62  |H20 PUMP P    24    63
  AV BAY    1     2     3   |FREON FLOW   2350  2351
TEMP       106   106    89  |EVAP OUT T    39    39
FAN ΔP    3.34  3.36  4.24  |


  SYS SUMM
```

ECLSS Parameters on the BFS SM SYS SUMM 2 Display (DISP 79)



```
 2011/   /088  APU/ENVIRON THERM    4 000/02:36:51
 FREON LOOP   1     2    |               000/00:00:00
ACCUM QTY     27    27   | H2O LOOP          1     2
FREON ISOL   RAD   ISOL  |PUMP OUT P         24    62
FREON FLOW  2193  2190   |     OUT T         64    63
PL HX FLOW   290   286   |         P          0L   38
AFT CP FLOW  279   278   |ICH FLOW           14L  777
RAD IN T      97    96   |    OUT T          41    38
RAD OUT T     38    38   |CAB HX IN T        42    38
EVAP OUT T    38    38   |ACCUM QTY          45    55
 EVAP TEMP               | APU FUEL T 1      2     3
HILD IB/OB   259   259   |TK SURF    + 69  + 67  + 68
     NOZ     312         |TK HTR     + 70  + 68  + 69
TOP FWD/AFT  257   257   |TEST LN 1 + 62  + 62  + 63
   L/R DUCT  162   162   |TEST LN 2 + 62  + 63  + 63
   L/R NOZ    50    50   |FEED LN    + 57  + 58  + 58
EVAP FDLN T   A     B    |PUMP IN    + 57  + 58  + 58
         FWD  80    80   | DRN LN 1 + 62  + 62  + 63
       MID 1  80    80   | DRN LN 2 + 62  + 62  + 63
       MID 2  79    75   | OUT       + 92  + 90  + 88
         AFT  75    79   | BYP LN    +108  +106  +102
     TOPPING  75    79   |GG SPLY LN 113   111   107
       ACCUM  75    79   |
     HI LOAD  75    79   |H2O LN INJ+ 71    92  + 72
```

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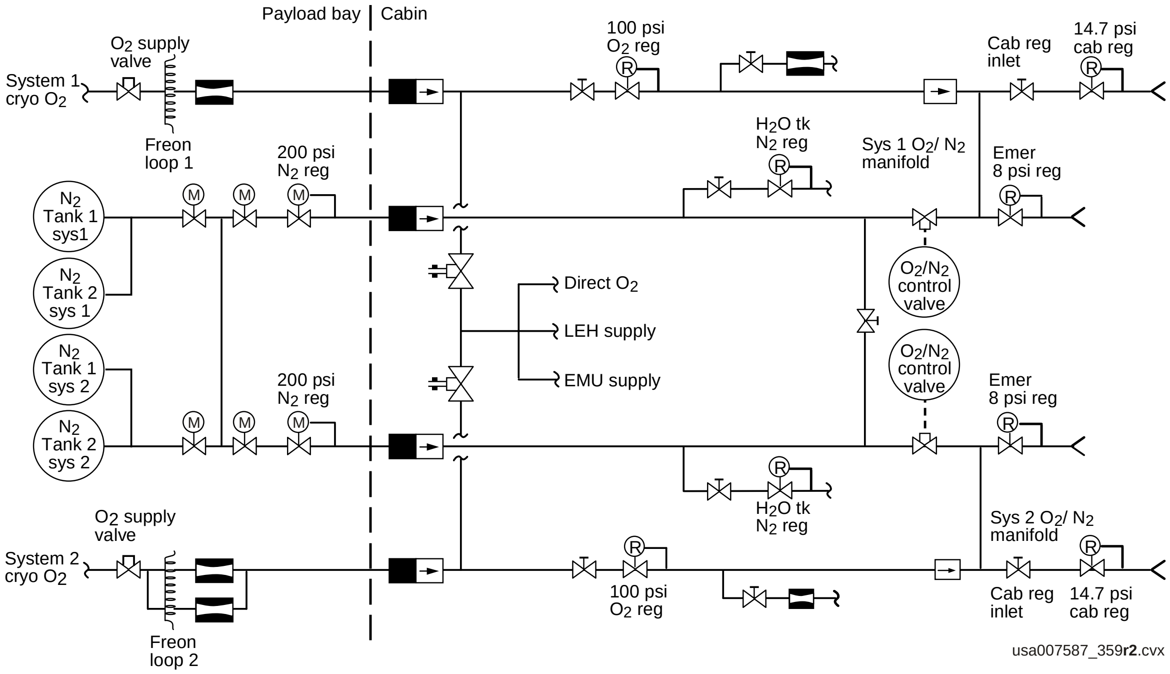
APU/ENVIRON THERM Display (DISP 88)



Pressure Control System

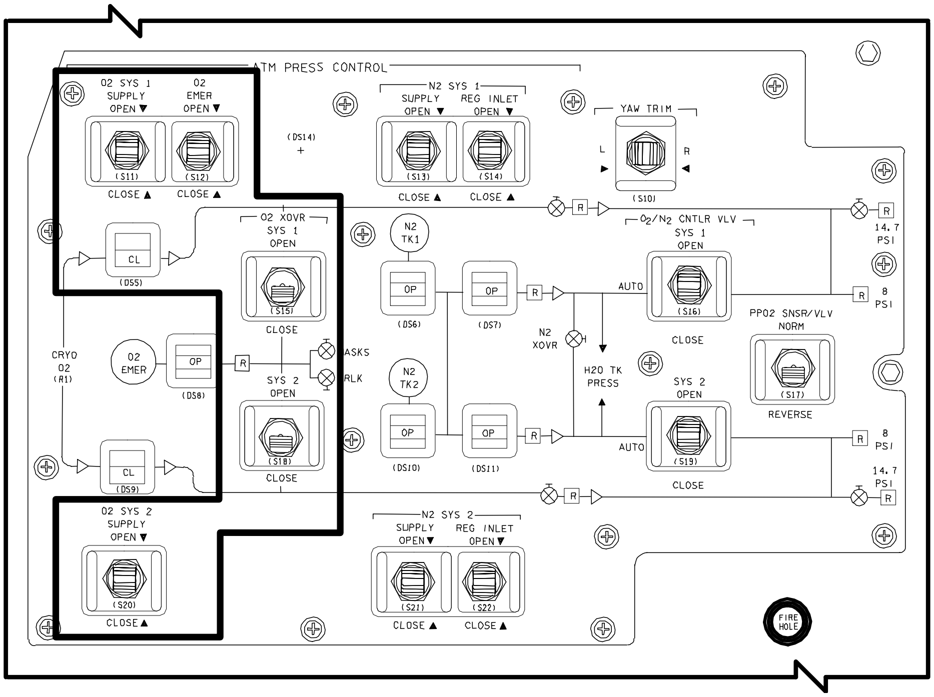
Pressure Control System

The pressure control system normally pressurizes the crew cabin to 14.7 ± 0.2 psia. It maintains the cabin at an average 80-percent nitrogen (130 pounds) and 20-percent oxygen (40 pounds) mixture that closely resembles the atmosphere at sea level on Earth. The system also provides the cabin atmosphere necessary to cool cabin-air-cooled equipment. Oxygen partial pressure is maintained automatically between 2.95 and 3.45 psi, with sufficient nitrogen pressure of 11.5 psia added to achieve the cabin total pressure of 14.7 ± 0.2 psia. Positive and negative pressure relief valves protect the structural integrity of the cabin from over- and underpressurization, respectively. The pressure control system nitrogen is used to pressurize the supply and waste water tanks. The system also provides breathing oxygen directly to the launch and entry suit helmets and to emergency breathing masks.

Cabin pressure is maintained by either of two pressure control systems (designated PCS 1 and PCS 2). Each PCS consists of a liquid oxygen storage system and a gaseous nitrogen storage system. The PCS oxygen is supplied from the electrical power system's (EPS) cryogenic oxygen in the midfuselage of the orbiter. The cryogenic supercritical oxygen storage system is controlled by electrical heaters within the tanks and supplies oxygen to the ECLSS pressure control system at a pressure of 803 to 883 psia in a gaseous state. The nitrogen storage tanks are serviced to a nominal pressure of 2,964 psia at 80° F. Normal on-orbit operations use one oxygen and one nitrogen supply system.

Cabin pressure is controlled by the nitrogen/oxygen control and supply panels, *an associated* PPO_2 sensor, and the pressure relief valves. The nitrogen/oxygen control panel regulates PCS 1 and PCS 2 oxygen and nitrogen. Typically, PCS 1 is activated for the first half of the mission and PCS 2 is activated for the second half. System 1 and system 2 nitrogen/oxygen supply panels are located in the middeck (panel MO10W) and the forward flight deck (panel L2). Both O_2 and N_2 supply systems 1 and 2 have a crossover capability, which allows the respective systems to be tied together.

The oxygen supply system provides the makeup cabin oxygen for flight crew consumption and makeup for normal cabin leakage. The nitrogen system provides nitrogen for pressurizing the cabin and the *supply* and waste water tanks. Each crew member uses an average of 1.76 pounds of oxygen per day. *About 6* pounds of nitrogen and *14* pounds of oxygen are used per day for normal loss of crew



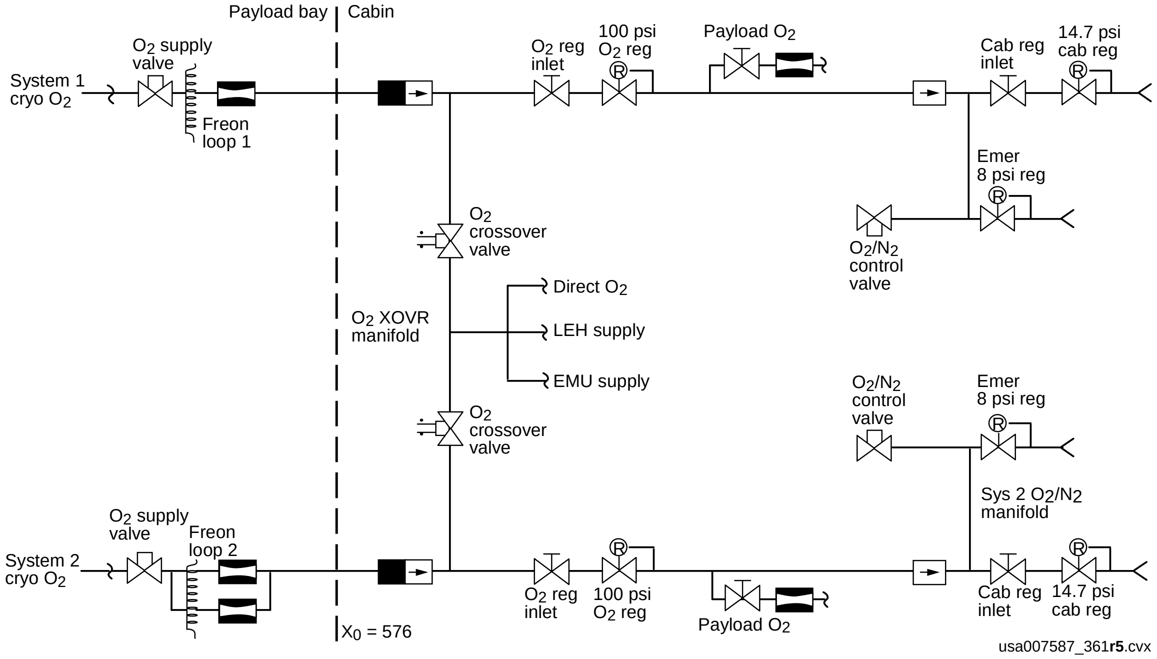
ATM PRESS CONTROL O2 SYS SUPPLY and XOVR Switches and Talkbacks on Panel L2

cabin gas to space and metabolic usage *for a typical seven-member crew*. The *supply* and waste water tanks are pressurized to 17 psig to expel water from the tanks for use by the crew*, for* dumping overboard*, or for supplying water at the appropriate pressure for use by the flash evaporator system (FES)*.

Oxygen System

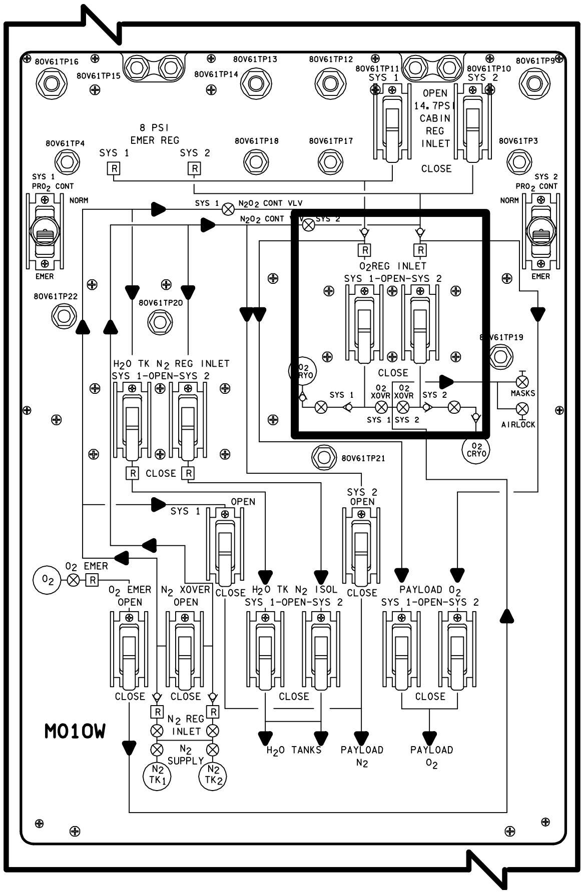
Oxygen from the power reactant storage and distribution system (cryogenic oxygen supply system) is routed to the pressure control oxygen system 1 and system 2 supply valves. These valves are controlled by the *ATM PRESS CONTROL O2 SYS 1 SUPPLY* and *O2 SYS 2 SUPPLY* switches on panel L2. When one of the switches is momentarily positioned to *OPEN*, the corresponding valve opens to permit oxygen to flow through an oxygen restrictor at a maximum flow of approximately 25 pounds per hour for either system 1 or 2. The oxygen restrictor also functions as a heat exchanger with the Freon coolant loop, warming the oxygen supplied to the oxygen regulator of that system before it flows into the cabin. Freon loop 1 warms system 1 oxygen, and loop 2 warms system 2. A talkback indicates *OP* when the O_2 supply valve is open. When the switch is momentarily positioned to *CLOSE*, the valve is closed, isolating that oxygen supply system. The talkback indicates *CL*.

Next, the oxygen piping penetrates the bulkhead and enters the crew compartment. A check valve downstream of the O2 flow restrictor prevents oxygen from flowing from one supply source to the other when the crossover valves are open. Downstream of the oxygen check valve, oxygen systems 1 and 2 are connected by a crossover valve that permits system 1 and system 2 to be interconnected. The crossover valves are controlled by the *ATM PRESS CONTROL O2 XOVR SYS 1* and *SYS 2* switches on panel L2. When one of the switches is positioned to *OPEN*, the associated oxygen supply system is directed to the launch and entry helmet O_2 supply 1 and 2 manual valves, airlock oxygen 1 and 2 extravehicular mobility unit, and direct O_2. If both switches are positioned to *OPEN*, oxygen supply systems 1 and 2 are interconnected. When a switch is positioned to *CLOSE*, that oxygen supply system is isolated from the crossover feature. The crossover valves are normally open.

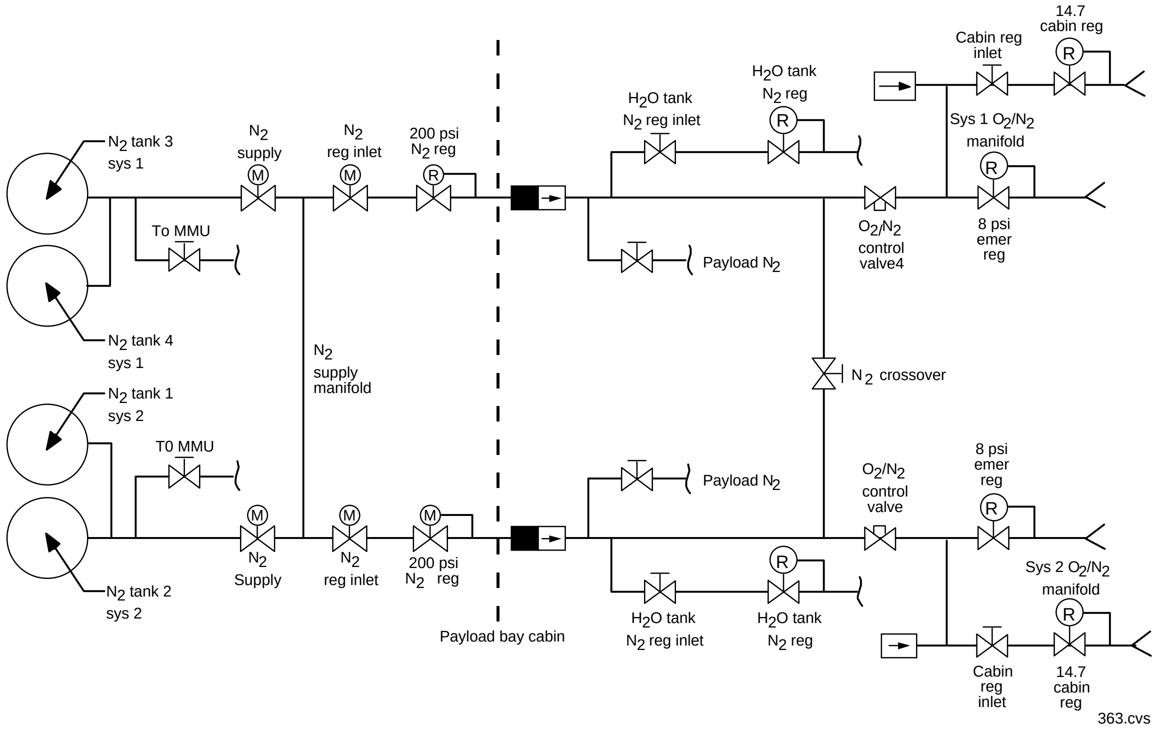


Oxygen System

Downstream of the oxygen crossover line is an oxygen regulator inlet manual valve. When the valve is manually positioned to *OPEN* by the *O_2 REG INLET* switch on panel MO10W, oxygen is directed to a regulator that reduces the oxygen supply pressure to 100 ± 10 psig. Each regulator valve has a manual toggle *OPEN*/*CLOSE* valve, a regulator, and a relief valve. The relief valve relieves pressure at 245 psig and reseats at 215 psig. The relief pressure is vented into the crew cabin. The regulated O_2 then passes through another check valve that prevents downstream nitrogen from entering the oxygen system. The oxygen enters a manifold that is shared by the nitrogen system. This manifold is connected to its 14.7 psi cabin regulator inlet manual valve and the 8 psi regulator. Between the oxygen regulator and the oxygen check valve, the oxygen is fed to the payload oxygen manual valve for use by the payload, if needed. This valve, as well as the 14.7 cabin pressure manual valve, is located on panel MO10W. Makeup O_2 for metabolic usage is provided by a bleed orifice inserted on orbit into LEH O2 8 quick disconnect on panel MO69M. *The bleed orifice is sized to supply 0.24 pounds-mass per hour (lbm/hr) of O_2 for four- to five-member crews and 0.36 lbm/hr for six- to seven-member crews.*



O_2 REG INLET Switches on Panel MO10W



Nitrogen System for Nominal Mission

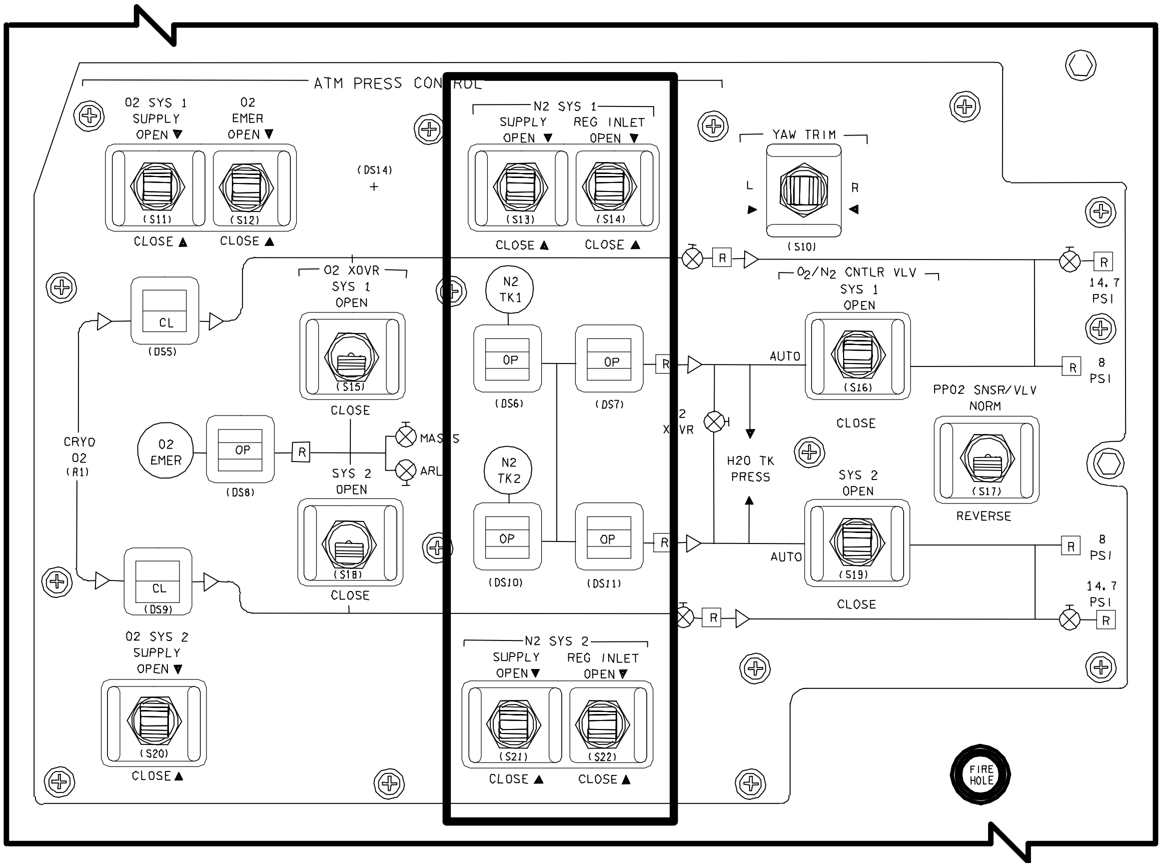
Nitrogen System

Gaseous nitrogen is supplied from two nitrogen systems, consisting of either two or three nitrogen tanks (depending on orbiter) per system that are mounted in the payload bay. System 1 is mounted on the port side and system 2 is on the starboard side. *OV-103 and OV-105* each have a standard six-tank configuration*, while OV-104 is currently equipped with five nitrogen tanks (two in System 1 and three in System 2). On each of the vehicles, additional* tanks may be flown as mission kits.

Note: The N2 tank configuration and number of tanks flown may vary by flight, based on mission requirements.

The nitrogen supply tanks are constructed of filament-wound Kevlar fiber with a titanium liner. Each nitrogen tank is serviced to a nominal pressure of 2,964 psia at 80° F, with a volume of 8,181 cubic inches. The nitrogen tanks in each system are manifolded together.

The PCS 1 and PCS 2 nitrogen supply systems are controlled by the atmosphere pressure control nitrogen supply valves in each system. Each valve is controlled by its corresponding *ATM PRESS CONTROL N2 SYS 1* and *SYS 2 SUPPLY* switch on panel L2. When a switch is momentarily positioned to *OPEN*, nitrogen flows to both atmosphere pressure control system regulator inlet valves, since both sets of tanks are manifolded together downstream of the supply valve. A talkback near the switch indicates barberpole when the motor-operated valve is in transit, and *OP* when the supply valve is open. When the switch is positioned to *CLOSE*, that nitrogen supply system is isolated from the nitrogen system regulator inlet valve, and the talkback indicator shows *CL*.



ATM PRESS CONTROL N2 SYS SUPPLY and REG INLET Switches and Talkbacks on Panel L2

The nitrogen regulator inlet valve in each nitrogen system is controlled by its respective *ATM PRESS CONTROL N_2 SYS REG INLET* switch on panel L2. When the switch is positioned to *OPEN*, that system's nitrogen at source pressure is directed to the system's nitrogen regulator. A talkback indicator below the *SYS 1* switch and above the *SYS 2* switch indicates barberpole when the motor-operated valve is in transit, and *OP* when the valve is open. When the switch is positioned to *CLOSE*, the supplied nitrogen is isolated from the system's nitrogen regulator, and the talkback indicator indicates *CL*.

The nitrogen regulators in supply systems 1 and 2 reduce the pressure to 200 ± 15 psig. Each nitrogen regulator is a two-stage regulator with a relief valve. The relief valve relieves pressure at 295 psig into the vacuum vent line and reseats at 245 psig.

The pressure regulated nitrogen of each system *then enters the crew cabin and encounters a check valve to prevent backflow from one nitrogen source supply to the other if the nitrogen crossover is open. This check valve also prevents flow from the pressure control system out of the crew cabin in the event of an upstream plumbing leak. Past the check valve, each system's regulated nitrogen* is directed to the nitrogen manual crossover valve, the manual water tank regulator inlet valve, the payload manual nitrogen supply valve, and the oxygen and nitrogen controller valve in each system. *Each system can supply nitrogen at a rate of at least 125 lbm/hr.* The manual valves are controlled from panel MO10W, and the controller valve is controlled from the panel L2 *O2/N2 CNTLR VLV* switch.

The nitrogen crossover manual valve connects both regulated nitrogen systems when the valve is open and isolates the nitrogen supply systems from each other when closed. Normally, the valve is always closed.

Oxygen/Nitrogen Manifold

The O_2/N_2 control valve controls the flow of either N_2 or O_2 into the O_2/N_2 manifold, depending on the partial pressure of oxygen in the cabin. Whatever gas (O_2/N_2) is in the O_2/N_2 manifold will flow into the cabin when the cabin pressure drops below 14.7 psia, and the 14.7 regulator *inlet* valve is open. This flow will continue as long as the cabin pressure is less than 14.7. An 8 psia emergency regulator provides flow to maintain a cabin pressure of 8 psia in the event of a large cabin leak. There is no regulator inlet valve to isolate the 8 psia emergency regulator; therefore, it is always configured to provide flow.

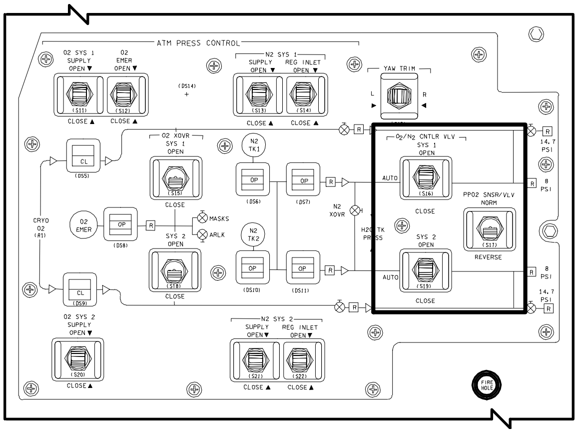
The 14.7 psi cabin regulator regulates the cabin pressure to 14.7 ± 0.2 psia and is capable of a maximum flow of 75 to 125 lb/hr. The 8 psi emergency regulator regulates to 8 ± 0.2 psia and is also capable of a maximum flow of 75 to 125 lb/hr. Both the 14.7 and 8 psi regulators flow into the cabin through a port in panel MO10W located above the waste management system compartment. Regulators consist of two stages: a low-flow regulator (0 to 0.75 lb/hr) for small demand when the cabin pressure is near 14.7 psia and a high flow regulator (0.75 to at least 75 lb/hr) for high demand when cabin pressure is significantly below 14.7 psia.

NOTE

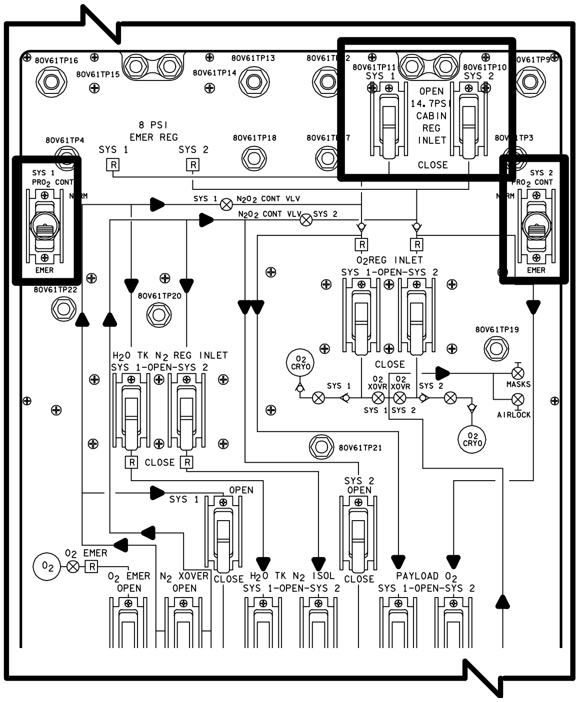
> Crewmembers should be aware that the regulators make a noticeable sound when they flow oxygen or nitrogen into the cabin. It is most noticeable in the vicinity of the waste management system compartment. Additionally, use of the waste control system (WCS) during high N_2 flow is not advisable due to the possibility of hypoxia.

PPO_2 Control

The partial pressure of oxygen (PPO_2) in the crew cabin *can be* controlled automatically during orbit by one of two O_2/N_2 controllers. Two PPO_2 sensors (A and B) located under the mission specialist station provide inputs to the PPO_2 control systems 1 and 2 controller and switches, respectively. *When the O_2/N_2 CNTLR VLV switch on panel L2 is positioned to AUTO in a given pressure control system, the actual position of the valve (OPEN, to flow nitrogen or CLOSE, to inhibit nitrogen flow and allow oxygen to flow into the O_2/N_2 manifold) is governed by the associated O_2/N_2 controller. If the PPO2 SNSR/VLV switch on panel L2 is in the NORM position, O_2/N_2 Controller 1 controls the position of the O_2/N_2 CNTLR VLV in pressure control system 1 and O_2/N_2 Controller 2 controls the position of the O_2/N_2 CNTLR VLV in pressure control system 2. These associations are reversed if the PPO2 SNSR/VLV switch is in the REVERSE position.*



PPO2 SNSR/VLV and O_2/N_2 CNTRL VLV Switches on Panel L2



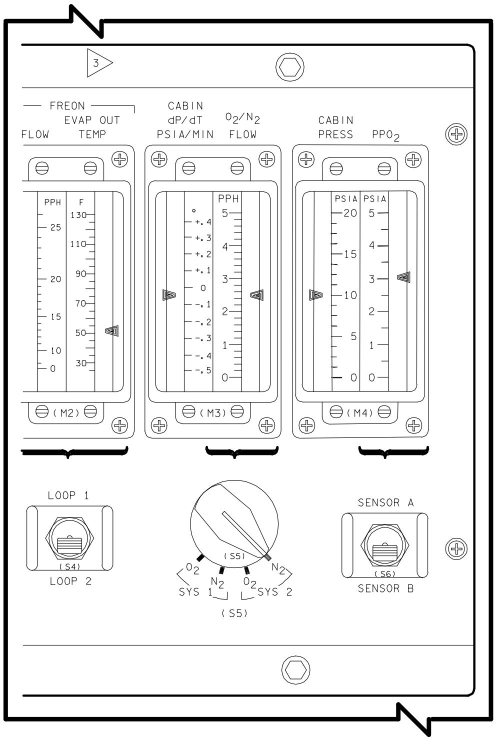
PPO_2 CONT and CABIN REG INLET Switches on Panel MO10W

When the PPO_2 sensor *and O_2/N_2 controller associated with the O_2/N_2 control valve that is in the AUTO position detects low oxygen levels in the crew cabin, the* O_2/N_2 control valve is automatically closed. When the 200-psi nitrogen in the *O_2/N_2* manifold drops below 100 psi, the corresponding oxygen system flows oxygen through its check valve into the manifold and through the 14.7 psi cabin regulator into the crew cabin. When the PPO_2 sensor *and O_2/N_2 controller* determine that the oxygen in the crew cabin is *at the upper end of its allowed control range*, the corresponding O_2/N_2 control valve is automatically opened. The 200-psi nitrogen enters the O_2/N_2 manifold and *forces* the corresponding oxygen system's check valve *closed* and flows through the 14.7 psi regulator into the crew cabin whenever the cabin pressure drops below 14.7 psia ± 0.2. The *OPEN* and *CLOSE* positions of the *O_2/N_2 CNTLR VLV SYS 1* and *SYS 2* switches on panel L2 permit the flight crew to manually control the O_2/N_2 valve in each system and manually switch between O_2 and N_2 systems.

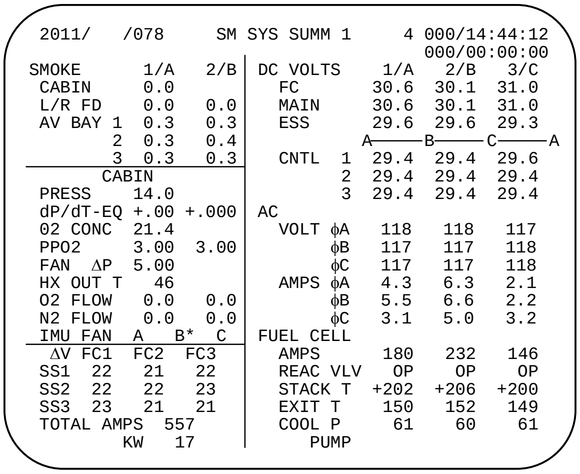
The SYS 1 and SYS 2 PPO_2 CNTLR switches were designed to control the PPO_2 level (via the O_2/N_2 CNTLR) of the cabin between the normal range (2.95-3.45 at 14.7 psi) *and* the emergency range (1.95-2.45 at 8 psi). The control range can be determined by positioning the switch in NORM or EMER. The EMER position is procedurally never used.

The *flow rates of* oxygen systems 1 and 2 and nitrogen systems 1 and 2 can be monitored via the O_2/N_2 FLOW meter on panel O1 *and on the SM SYS SUMM 1 (DISP 78, both BFS and PASS) and SM ENVIRONMENT (DISP 66, PASS only) displays*. The flow of the selected system is displayed on the meter *and CRT displays* in pounds per hour. *The currently used flow sensors go off-scale low (OSL) at 0 lbm/hr flow and off-scale high (OSH) at 5 lbm/hr, and high flow alarms annunciate at 4.9 lbm/hr. To replace a set of failed sensors, new flow sensors are being incorporated into OV-104 that are capable of measuring flow up to 25 lbm/hr. However, these sensors are nonlinear, so they will report a maximum flow rate onboard of 12.4 lbm/hr. Calibration for these sensors has been specified to also annunciate a high flow alarm at 4.9 lbm/hr (actual and displayed), just like the currently used flow sensors.* PPO_2 sensors A and B monitor the oxygen partial pressure and the signal to the *SENSOR* switch on panel O1. When the switch is positioned to *SENSOR A*, oxygen partial pressure from sensor A is monitored on the PPO_2 meter on panel O1 in psia. If the switch is set on *SENSOR B*, oxygen partial pressure from sensor B is monitored. The cabin pressure sensor output is routed directly to the CABIN PRESS meter on panel O1 and is displayed in psia. These parameters can also be viewed on DPS displays SM SYS SUMM 1 (PPO2) and DISP 66, ENVIRONMENT (PPO2 A, B, C).

If the change in pressure versus change in time (dP/dT) decreases at a rate of 0.08 psi per minute or more, a klaxon will sound in the crew cabin, and the *MASTER ALARM* pushbutton light indicators will be illuminated. Normal cabin dP/dT is zero psi per minute ±0.01 psi.



Meters and Switches on Panel O1 (Transducers also supply information for SM SYS SUMM 1, DISP 66, and C/W.)



```
 2011/   /078     SM SYS SUMM 1     4 000/14:44:12
                                      000/00:00:00
SMOKE       1/A   2/B | DC VOLTS    1/A   2/B   3/C
 CABIN      0.0       |   FC       30.6  30.1  31.0
 L/R FD     0.0   0.0 |   MAIN     30.6  30.1  31.0
 AV BAY 1   0.3   0.3 |   ESS      29.6  29.6  29.3
        2   0.3   0.4 |            A-----B-----C-----A
        3   0.3   0.3 |   CNTL  1  29.4  29.4  29.6
      CABIN           |         2  29.4  29.4  29.4
 PRESS    14.0        |         3  29.4  29.4  29.4
 dP/dT-EQ +.00 +.000  | AC
 02 CONC  21.4        |   VOLT ϕA   118   118   117
 PPO2     3.00  3.00  |        ϕB   117   117   118
 FAN  ΔP  5.00        |        ϕC   117   117   118
 HX OUT T   46        |   AMPS ϕA   4.3   6.3   2.1
 O2 FLOW    0.0   0.0 |        ϕB   5.5   6.6   2.2
 N2 FLOW    0.0   0.0 |        ϕC   3.1   5.0   3.2
 IMU FAN  A    B*   C | FUEL CELL
  ΔV FC1   FC2   FC3  |   AMPS      180   232   146
 SS1  22    21    22  |   REAC VLV   OP    OP    OP
 SS2  22    22    23  |   STACK T  +202  +206  +200
 SS3  23    21    21  |   EXIT T    150   152   149
 TOTAL AMPS   557     |   COOL P     61    60    61
          KW   17     |      PUMP
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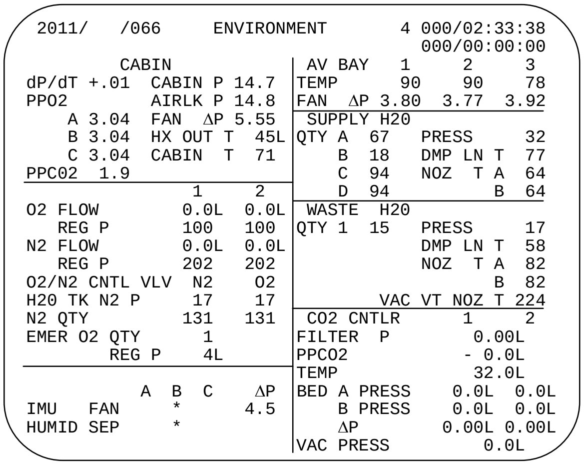
The SM SYS SUMM 1 display is an SM display (DISP78) available in SM OPS 2



```
 2011/   /066     ENVIRONMENT       4 000/02:33:38
                                      000/00:00:00
         CABIN               | AV BAY   1     2     3
dP/dT +.01  CABIN P 14.7     |TEMP      90    90    78
PPO2        AIRLK P 14.8     |FAN  ΔP 3.80  3.77  3.92
    A 3.04  FAN   ΔP 5.55    | SUPPLY H20
    B 3.04  HX OUT T  45L    |QTY A  67   PRESS      32
    C 3.04  CABIN  T  71     |    B  18   DMP LN T   77
PPC02  1.9                   |    C  94   NOZ  T A   64
                  1     2    |    D  94          B   64
O2 FLOW          0.0L  0.0L  | WASTE  H20
   REG P         100   100   |QTY 1  15   PRESS      17
N2 FLOW          0.0L  0.0L  |            DMP LN T   58
   REG P         202   202   |            NOZ  T A   82
O2/N2 CNTL VLV    N2    O2   |                   B   82
H20 TK N2 P       17    17   |        VAC VT NOZ T 224
N2 QTY           131   131   | CO2 CNTLR      1     2
EMER O2 QTY        1         |FILTER  P        0.00L
         REG P     4L        |PPCO2           - 0.0L
                             |TEMP             32.0L
               A  B  C    ΔP |BED A PRESS    0.0L  0.0L
IMU   FAN         *      4.5 |    B PRESS    0.0L  0.0L
HUMID SEP         *          |    ΔP        0.00L 0.00L
                             |VAC PRESS          0.0L
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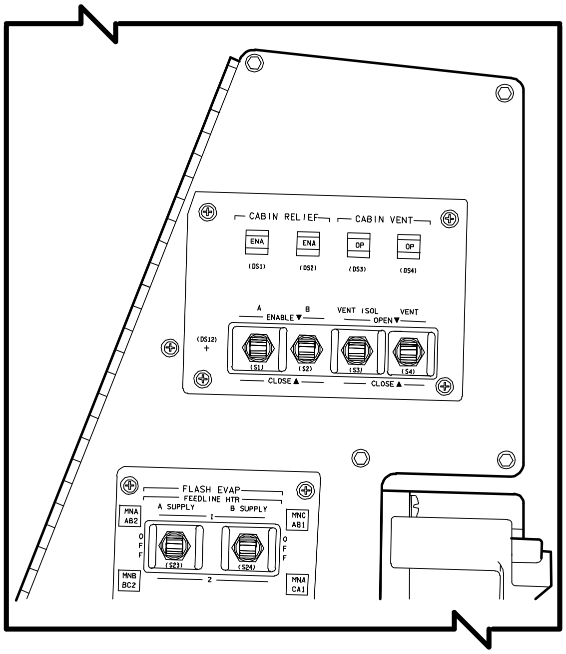
The ENVIRONMENT display is an SM display (DISP 66) available in SM OPS 2



CABIN RELIEF and CABIN VENT Switches and Talkbacks on Panel L2

Cabin Relief Valves

Two positive pressure relief valves are in parallel to provide overpressurization protection of the crew module cabin above 15.5 psid. The valves will crack at 15.5 psid, reach full flow by 16.0 psid, and reseat again below 15.5 psid. Each cabin relief valve is controlled by its corresponding *CABIN RELIEF* switch on panel L2. When the switch is positioned to *ENABLE*, the motor-operated valve opens, exposing cabin pressure to a corresponding positive pressure relief valve. The relief valve maximum flow capability is 150 pounds per hour at 16.0 psid. A talkback indicator above the switch indicates barberpole when the motor-operated valve is in transit, and *ENA* when the motor-operated valve is open. When the switch is positioned to *CLOSE*, the corresponding motor-operated valve isolates cabin pressure from the relief valve and the talkback indicator indicates *CL*.

Vent Isolation and Vent Valves

The cabin vent isolation valve and cabin vent valve are in series to vent the crew cabin to ambient pressure while the orbiter is on the ground. Approximately 1 hour 30 minutes before lift-off, the cabin is pressurized to approximately 16.7 psi for leak checks. Cabin pressure is then monitored for 35 minutes to verify that no pressure decay occurs. During this time, the cabin vent and cabin vent isolation valves are alternately opened and closed to verify that each holds pressure.

The cabin vent isolation valve is controlled by the *VENT ISOL* switch on panel L2, and the cabin vent valve is controlled by the *VENT* switch. Each switch is positioned to *OPEN* to control its respective motor-operated valve. When both valves are open, the cabin pressure is vented into the mid-fuselage. The maximum flow capability through the valves at 2.0 psid is 1080 pounds per hour.

A talkback indicator above each switch indicates the position of the respective valve: *CL when the valve is closed,* barberpole when the valve is in transit, and *OP* when it is open.

> **WARNING**
>
> Because of the high flow capability of the cabin vent isolation valves, these valves should never be opened after lift-off.

Negative Pressure Relief Valves

If the crew cabin pressure is lower than the pressure outside the cabin *(e.g., during the final stages of entry following a cabin leak)*, two negative pressure relief valves in parallel will open at 0.2 psid, permitting flow of ambient pressure into the cabin. Caps over each valve provide a positive pressure seal and will pop off when the valve opens. No crew controls are necessary.

Water Tank Regulator Inlet Valve

The H_2O TK N_2 REG INLET valve in each nitrogen system permits nitrogen to flow to its regulator and H_2O TK N_2 ISOL SYS 1, 2 valve. The REG inlet and isolation manual valves are on panel MO10W. The regulator in each nitrogen system reduces the 200-psi supply pressure to 15.5 to 17.0 psig. Each regulator is a two-stage regulator with the second stage relieving pressure into the crew cabin at a differential pressure of 18.5 ± 1.5 psig.

Airlock Depressurization and Equalization Valves

The airlock pressure is maintained equal with cabin pressure via the airlock equalization valves located on the cabin/airlock hatch. During normal operations the airlock hatch is open. The airlock depressurization valve is used to depressurize the cabin to 10.2 psia and to depressurize the airlock for EVA.

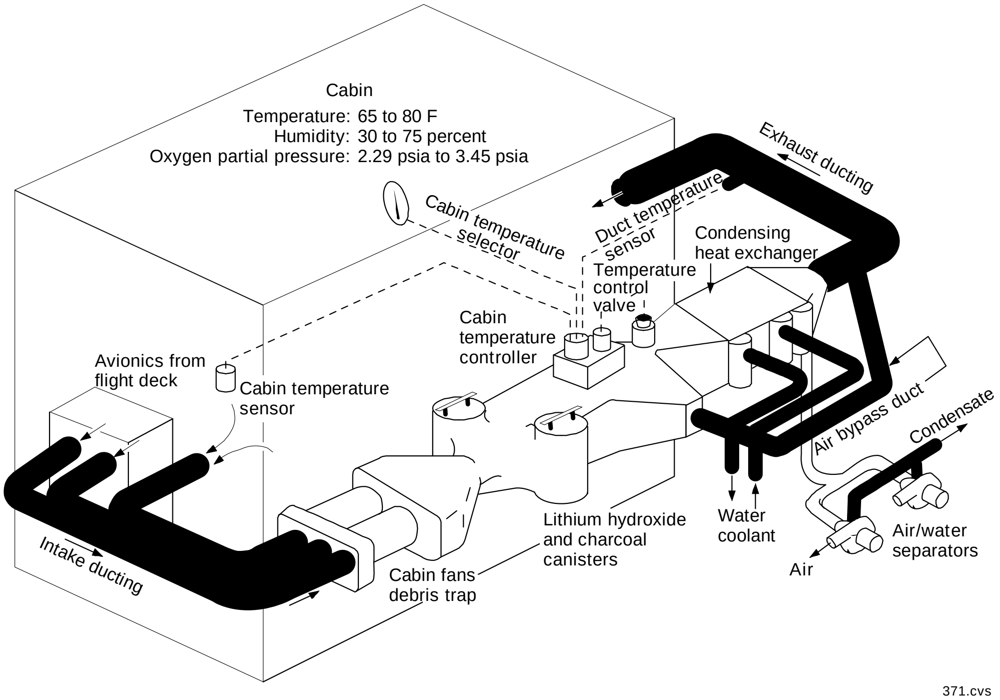
Atmospheric Revitalization System

The atmospheric revitalization system (ARS) circulates air and water throughout the cabin to control ambient heat, relative humidity, carbon dioxide, and carbon monoxide levels. The ARS also provides cooling for cabin avionics.

Cabin air is circulated around the cabin to remove heat and humidity. The heated air is then ducted (via cabin fans) to the cabin heat exchanger, where the heat is removed by the water coolant loops. The water coolant loop system collects heat from the cabin heat exchanger, the inertial measurement unit (IMU) heat exchanger, the cold-plated electronic units in the avionics bays, and the avionics bay heat exchangers. The water coolant loop transfers the heat collected to the Freon/water heat exchanger of the active thermal control system. The active thermal control system then expels the heat overboard.

Cabin Air Flow

Except for ducting, all air loop components are located under the middeck floor. The air circulated through the flight crew cabin also picks up odor, carbon dioxide, debris, and additional heat from electronic units in the crew cabin. Based on the crew cabin volume of 2,300 cubic feet and 330 cubic feet of air per minute, one volume crew cabin air change occurs in approximately 7 minutes, and approximately 8.5 air changes occur in 1 hour.



Cabin Air

The heated cabin air is drawn through the cabin loop and through a 300-micron filter by one of two cabin fans. Each cabin fan (A and B) is controlled by its respective *CABIN FAN* switch on panel L1. Normally, only one fan is used.

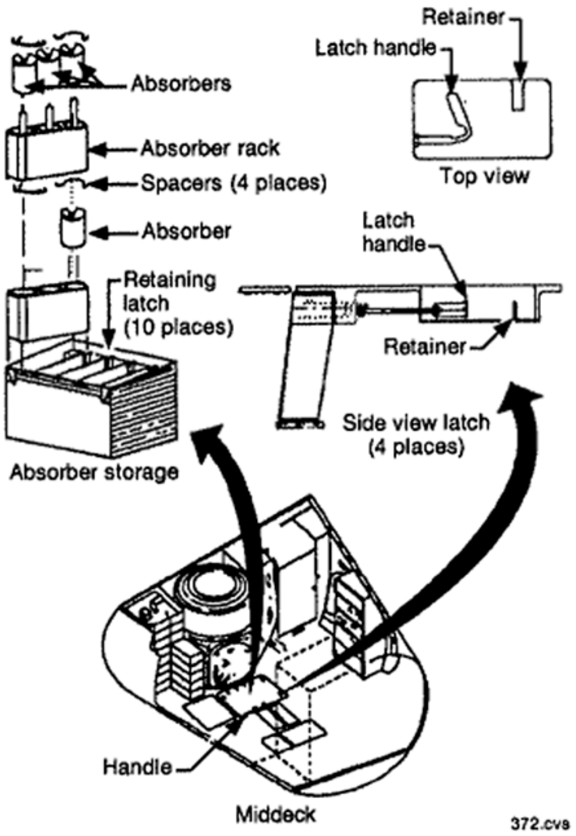
Each fan is powered by a three-phase, 115-volt *AC* motor. These 495-watt motors produce a nominal flow rate of 1,400 lb/hr through the cabin air ducting. A check valve located at the outlet of each fan prevents air from backflowing through the non-operating fan. This flapper-type check valve will open if there is a 2-inch H_2O (.0723 psi) differential pressure across the valve. A cabin fan will not start on two phases of ac. However, if the cabin fan is already operating when a phase of *AC* is lost, the fan will continue to run on two phases of ac. A cabin fan can be started on 2-1/2 phases of ac, with the extra half phase provided by the induced voltage generated by other rotating equipment (that is, fans and pumps) running on that *AC* bus. If a phase of *AC* is lost with a short, then the induced voltage will not be usable, and starting the cabin fan will not be possible.

Lithium Hydroxide Canisters

The cabin air leaves the cabin fan at a rate of about 1,400 lb/hr. An orifice in the duct directs approximately 120 lb/hr to each of two lithium hydroxide *(LiOH)* canisters, where carbon dioxide is removed, and activated charcoal removes odors and trace contaminants. The canisters are changed periodically on a predetermined schedule, generally one or two times a day, through an access door *in the middeck floor*. (For larger crews, the canisters are changed more frequently.) Each canister is rated at 48 man-hours. Up to 30 spare canisters are stored under the middeck floor in a locker between the cabin heat exchanger and water tanks. *The LiOH canisters are the primary means of carbon dioxide (CO_2) control onboard the orbiter.*

CAUTION

During lithium hydroxide canister changeout, the cabin fan(s) should be turned off. Dust from the canisters kicked up by a cabin fan has caused eye and nose irritation. Lithium hydroxide dust may also be a contributing factor to humidity separator failures.



Carbon Dioxide Absorbers

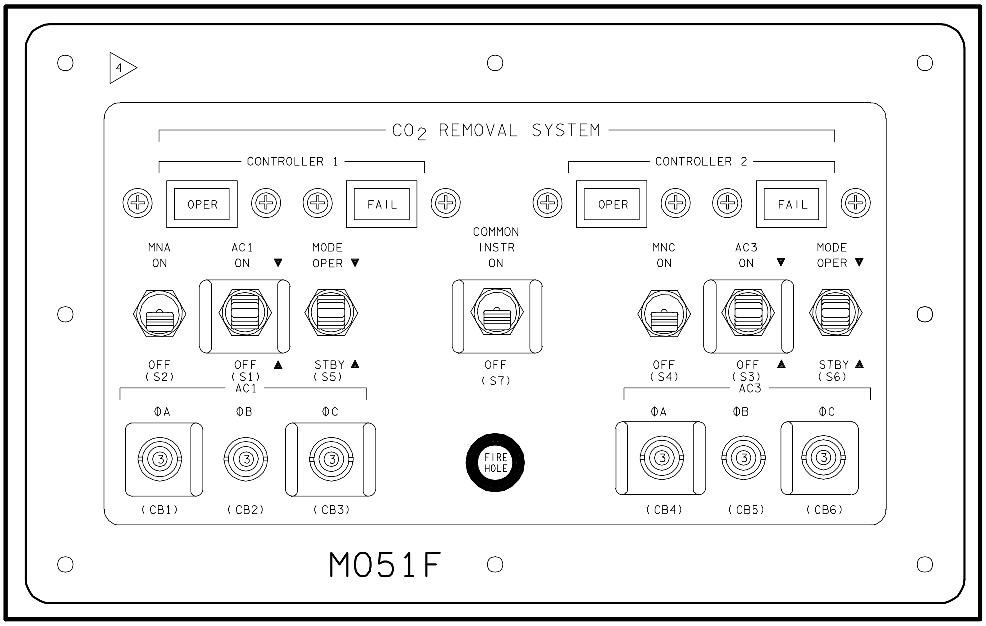
Regenerable Carbon Dioxide Removal System

OV-105 has the hardware capability to perform RCRS operations designed for use on long-duration standalone missions. However, the hardware is not needed while docked to the ISS, and the RCRS is not planned to be used in the future. This is presented as historical information.

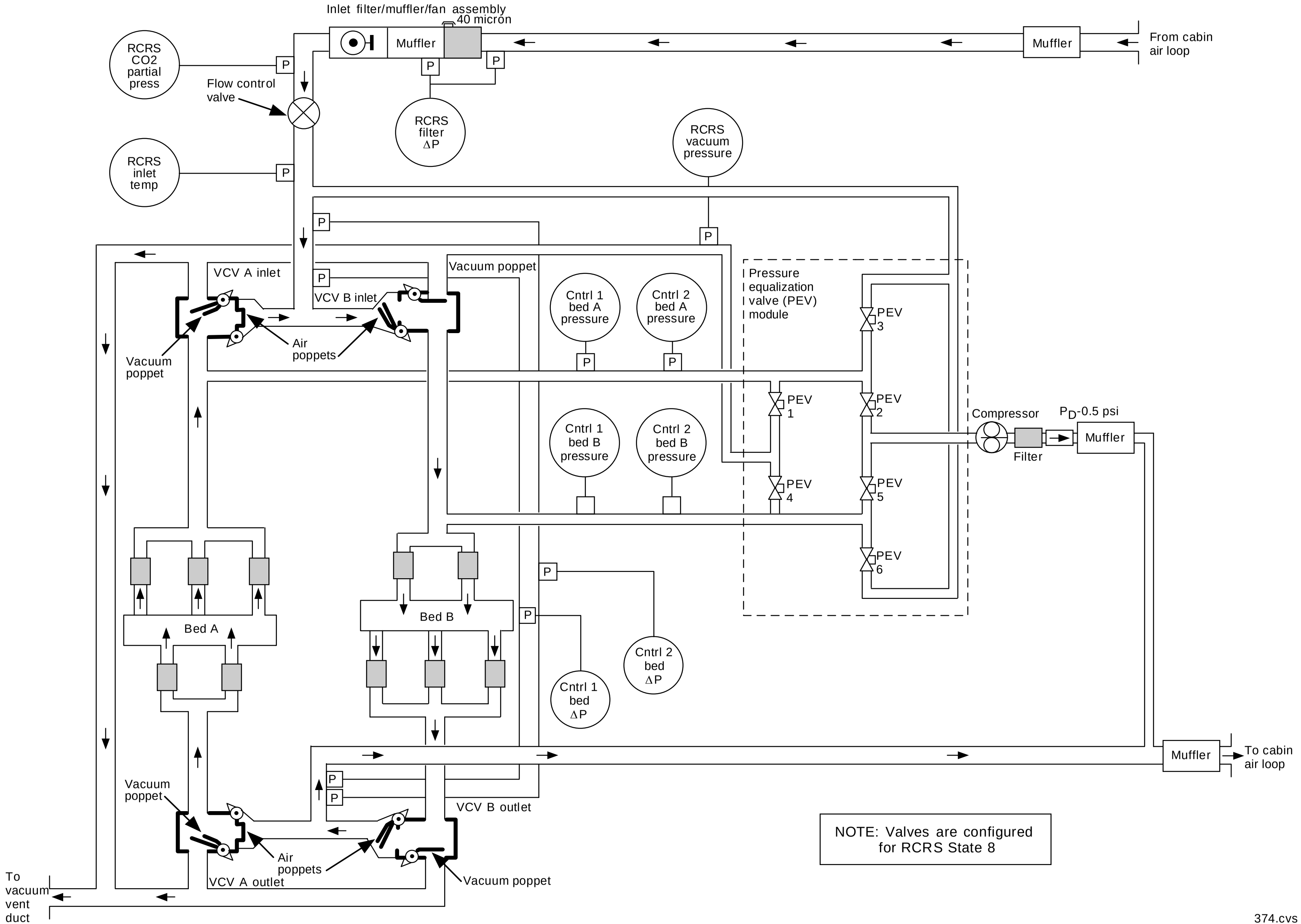
The ability to use the RCRS in the EDO orbiters solved a major weight and volume stowage problem encountered when attempting to conduct 10 to 16 day duration missions for a crew of up to seven astronauts. Carbon dioxide removal is accomplished by passing cabin air through one of two identical solid amine resin beds. The resin consists of a polyethylenimine (PEI) sorbent coating on a porous polymeric substrate. Upon exposure to carbon dioxide laden cabin air, the resin combines with water vapor in the air to form a hydrated amine which reacts with carbon dioxide to form a weak bicarbonate bond. Water is required for the process since dry amine cannot react with the carbon dioxide directly. While one bed adsorbs carbon dioxide, the other bed regenerates with thermal treatment and vacuum venting. This latter requirement prevents the use of the RCRS during ascent or entry. The adsorption/regeneration process runs continuously with the beds automatically alternating processes every 13 minutes. A full cycle is made up of two 13 minute cycles. An RCRS configured vehicle uses a single LiOH canister for launch and another for entry. An activated charcoal canister in the other CO_2 absorber slot removes odors. It is changed out mid mission on 10+ day flights.

When flown, the RCRS is located in volume D under the middeck floor. In addition to the two chemical beds, the major components of the RCRS include a set of vacuum cycle and pressure equalization valves, an RCRS fan, an airflow control valve, an ullage-save compressor, and two redundant controllers (1 and 2). The airflow control valve is set prelaunch for either a crew size of "4" or "5 to 7" crewmembers. These two positions select airflow through the RCRS of 72 or 110 lb/hr respectively. The control switches for the RCRS are located on panel MO51F. Both AC and DC power for the 1 and 2 controllers are operated from this panel. Each controller has a three position momentary switch for selection of *OPER* or *STBY*. This panel also has status lights for each controller that illuminate *OPER* or *FAIL* as appropriate. Crew insight into RCRS operation is found on SPEC 66 ENVIRONMENT in OPS 2.

The scrubbed air is then forced through the cabin heat exchanger.



CO_2 Removal System Panel MO51F



Regenerable Carbon Dioxide Removal System (RCRS)

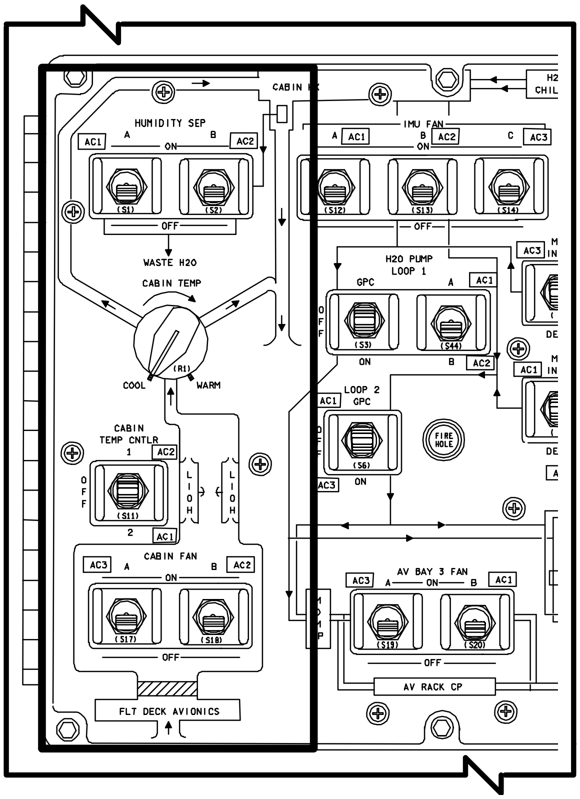
Cabin Air Temperature Control

The cabin temperature control valve is a variable position valve that proportions the volume of air that bypasses the cabin heat exchanger. The valve may be positioned manually by the crew, or automatically by one of the two cabin temperature controllers. The cabin temperature controller is a motor-driven actuator that adjusts the cabin temperature control valve to achieve the temperature selected by the *CABIN TEMP* rotary switch on panel L1. The cabin temperature control valve and the two controllers are located in the ECLSS bay below panel MD44F.

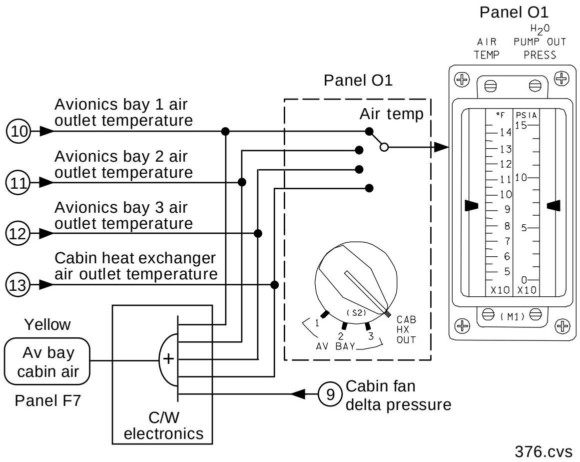
When the *CABIN TEMP CNTLR* switch on panel L1 is positioned to *1*, it enables controller 1. The rotary *CABIN TEMP* switch elects and automatically controls the bypass valve by diverting 0 to 70 percent of the air flow around the cabin heat exchanger, depending on the position of the switch. *Normally, full COOL corresponds to a temperature of approximately 65° F, and full WARM corresponds to about 80° F.*

The controllers are attached to a single bypass valve by an actuator arm. If controller 1 malfunctions, the actuator arm linkage must be removed from controller 1 by the flight crew at panel MD44F and connected manually to controller 2 before the *CABIN TEMP CNTLR* switch on panel L1 is positioned to 2. This enables controller 2 and permits the rotary *CABIN TEMP* switch to control controller 2 and the single bypass control valve. The *CABIN TEMP CNTLR* switch's *OFF* position removes electrical power from both controllers, the rotary switch, and automatic control of the single bypass valve. For ascent and entry, the *CABIN TEMP* is set to full *COOL* to ensure maximum air cooling during these relatively warm phases of flight.

The air from the cabin heat exchanger and the bypassed air come together in the supply duct downstream of the heat exchanger and are exhausted into the crew cabin through the CDR and PLT consoles and through various station duct outlets into the crew cabin.



HUMIDITY SEP, CABIN TEMP, CABIN TEMP CNTLR, and CABIN FAN Switches on panel L1



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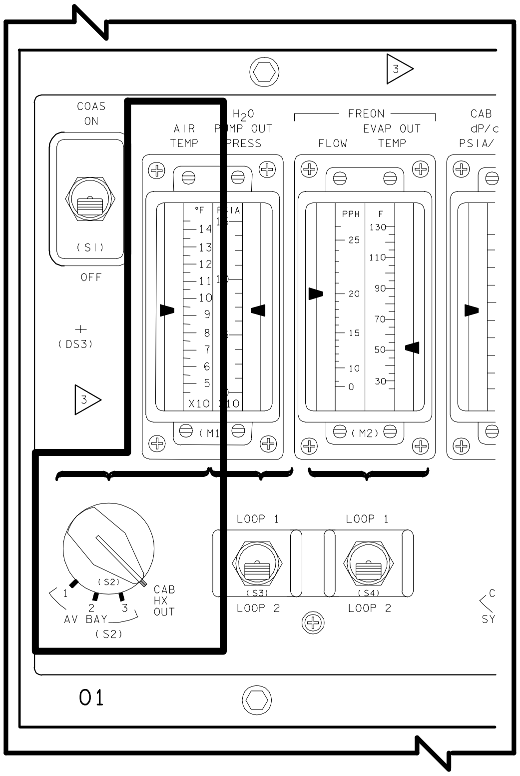
Avionics Bay and Cabin Heat Exchanger Temperature Monitoring and Caution/Warning, Crew Cabin Air

Cabin Temperature Monitoring

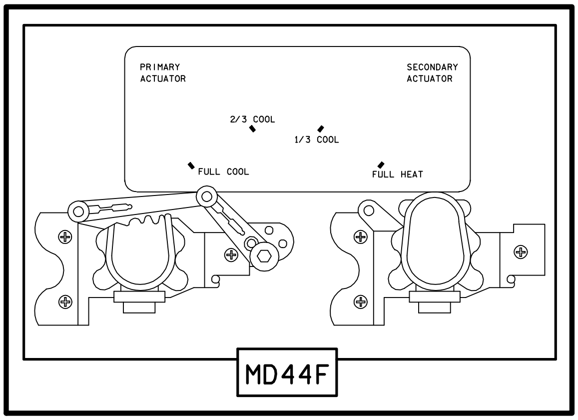
The cabin heat exchanger outlet temperature is transmitted to a rotary switch below the AIR TEMP meter on panel O1. When the switch is positioned to *CAB HX OUT*, the temperature can be monitored on the meter. The cabin heat exchanger outlet temperature provides an input to the yellow *AV BAY/CABIN AIR* caution and warning light on panel F7. The light is illuminated if the cabin heat exchanger outlet temperature is above 145° F, if avionics bay 1, 2, or 3 temperatures exceed 130° F, or if the cabin fan delta pressure is less than 4.2 inches of water or above 6.8 inches of water.



AIR TEMP Meter and Switch on Panel O1

Manual Temperature Control

If cabin temperature controllers 1 and 2 or the *CABIN TEMP* rotary switch on panel L1 are unable to control the single bypass valve, the flight crew can position the single bypass valve actuator drive arm to the desired position and pin the bypass valve arm to one of four fixed holes (*FULL COOL, FULL HEAT*, etc.) on panel MD44F. The *FULL COOL* position establishes the maximum cabin air flow rate to the cabin heat exchanger, the *2/3 COOL* position establishes a flow rate that provides approximately two-thirds of the maximum cooling capability, the *1/3 COOL* position establishes a flow rate that provides approximately one-third of the maximum cooling, and the *FULL HEAT* position establishes the minimum cabin air flow rate to the cabin heat exchanger.



Manual Temperature Controls
on Panel MD44F

Cabin Air Humidity Control

Cabin air is directed to the crew cabin heat exchanger, where heat is transferred to the water coolant loop. Humidity condensation that forms in the heat exchanger is pushed by the air flow to the slurper. One of two humidity separators draws air and water from the slurper. In the humidity separator, centrifugal force separates the water from the air. The fan separator removes *nominally about 1 and* up to approximately 4 pounds of water per hour. The water is routed to the waste water tank, and the air is ducted through the exhaust for return to the cabin. There are two fan separators (A and B) controlled individually by *HUMIDITY SEP A* and *B* switches on panel L1. Normally, only one fan separator is used. The relative humidity in the crew cabin typically is maintained between 30 and 65 percent in this manner.

The orbiters have been modified to *allow* redirect*ing* the *condensate* water from the humidity separator to a contingency water container (CWC) while on orbit. This modification is in support of ISS missions where waste tank dumping will be minimized while docked. Once undocked, the CWC will be dumped overboard through the contingency crosstie waste quick disconnect.

A small portion of the revitalized and conditioned air from the cabin heat exchanger is ducted to the carbon monoxide removal unit *(the ambient temperature catalytic oxidizer, or ATCO)*, which converts carbon monoxide to carbon dioxide. A bypass duct carries warm cabin air around the cabin heat exchanger and mixes it with the revitalized and conditioned air to control the crew cabin air temperature between 65° and 80° F.

Avionics Bay Cooling

Cabin air is also used to cool the three avionics equipment bays and some of the avionics units in the bays. Each of the three avionics equipment bays in the middeck has a closeout cover to minimize air interchange and thermal gradients between the avionics bay and crew cabin; however, the covers are not airtight. For all practical purposes, air circulation is closed loop within the bay. The electronic avionics units in each avionics bay meet outgassing and flammability requirements to minimize toxicity levels.

Each of the three avionics equipment bays has identical air-cooling systems. Two fans per bay are controlled by individual *AV BAY 1, 2, 3 FAN A* and *B* switches on panel L1. Normally, only one fan is used at a time. When the A or B switch for an avionics bay is positioned to *ON*, the fan draws air from the floor of the avionics bay through the applicable air-cooled avionics units and a 300-micron filter into the avionics bay fan.

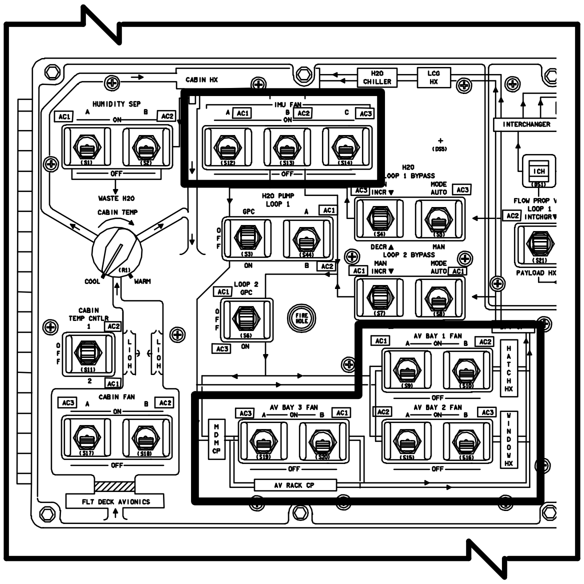
Note: The fan duct work for *Av* Bay 3A has been modified to accept a larger cabin fan for additional middeck cooling for payloads that will be stowed in the middeck for ISS missions. The standard avionics bay fans will be flown until the larger fan is needed.

The avionics bay fan outlet directs the air through that avionics bay heat exchanger, located beneath the middeck crew compartment floor. The water coolant loops flow through the heat exchanger to cool the fan outlet air, and the cooled air is returned to the avionics bay. A check valve in the outlet of the fan that is not operating prevents a reverse flow through that fan.

The air outlet *temperature* from the fan in each avionics bay is monitored and transmitted to a rotary switch on panel O1. When the switch is positioned to *AV BAY 1, 2,* or *3*, that avionics bay's fan outlet temperature can be displayed on the AIR TEMP meter. The air outlet temperature of each avionics bay also provides an input to the yellow *AV BAY/CABIN AIR* caution and warning light on panel F7. This light is illuminated if any of the avionics bay outlet temperatures are above 130° F. The *OFF* position of the *A* or *B* switch removes power from that avionics bay fan.

Inertial Measurement Unit (IMU) Cooling

The three IMUs are cooled by one of three fans drawing cabin air through a 300-micron filter and across the three IMUs. The fans are located in AV Bay 1. The fan outlet air flows through the IMU heat exchanger located on the flight deck and is cooled by the water coolant loops before returning to the crew cabin. Each IMU fan is controlled by the *IMU FAN* switches on panel L1. The *ON* position turns the corresponding fan on, and the *OFF* position turns it off. Normally, one fan is sufficient because one fan cools all three IMUs. A check valve is installed on the outlet of each fan to prevent a reverse airflow through the fans that are not operating.

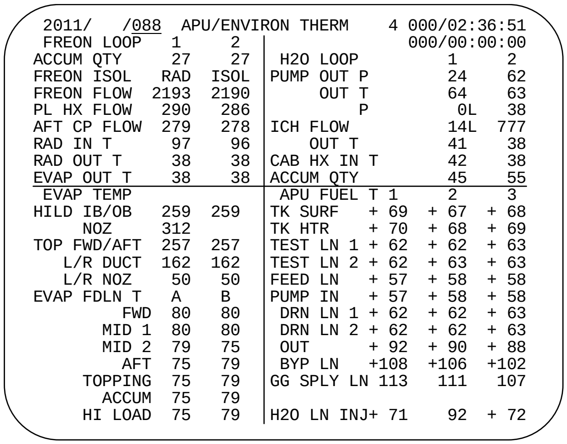


IMU FAN and AV BAY FAN Switches on Panel L1

Water Coolant Loop System

The water coolant loops circulate water through the crew compartment to collect excess heat and transfer it to the Freon coolant loops. Two complete, separate water coolant loops flow side by side and can operate at the same time, although only one is active at any given time. Loop 2 is normally the active loop. The only difference between loops 1 and 2 is that loop 1 (the backup) has two water pumps, and loop 2 has one pump. The water pumps are located in the ECLSS bay below the forward lockers. The pumps are powered by three-phase, 117-volt AC motors.

Some electronic units in each of the avionics equipment bays and in the cabin are mounted on cold plates. The water coolant loops flow through the cold plates, and the heat generated by the electronics unit is transferred to the cold plate and then to the water coolant loop, which carries heat from the electronic unit. The cold plates mounted on the shelves in each avionics bay are connected in a series-parallel arrangement with respect to the water coolant loop flow.



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ACCUM QTY     27    27 | H2O LOOP          1     2
FREON ISOL   RAD  ISOL |PUMP OUT P        24    62
FREON FLOW  2193  2190 |     OUT T        64    63
PL HX FLOW   290   286 |         P         0L   38
AFT CP FLOW  279   278 |ICH FLOW          14L  777
RAD IN T      97    96 |    OUT T         41    38
RAD OUT T     38    38 |CAB HX IN T       42    38
EVAP OUT T    38    38 |ACCUM QTY         45    55
 EVAP TEMP             | APU FUEL T 1      2     3
HILD IB/OB   259   259 |TK SURF   + 69  + 67  + 68
     NOZ     312       |TK HTR    + 70  + 68  + 69
TOP FWD/AFT  257   257 |TEST LN 1 + 62  + 62  + 63
   L/R DUCT  162   162 |TEST LN 2 + 62  + 63  + 63
   L/R NOZ    50    50 |FEED LN   + 57  + 58  + 58
EVAP FDLN T   A     B  |PUMP IN   + 57  + 58  + 58
         FWD  80    80 | DRN LN 1 + 62  + 62  + 63
       MID 1  80    80 | DRN LN 2 + 62  + 62  + 63
       MID 2  79    75 | OUT      + 92  + 90  + 88
         AFT  75    79 | BYP LN   +108  +106  +102
     TOPPING  75    79 |GG SPLY LN 113   111   107
       ACCUM  75    79 |
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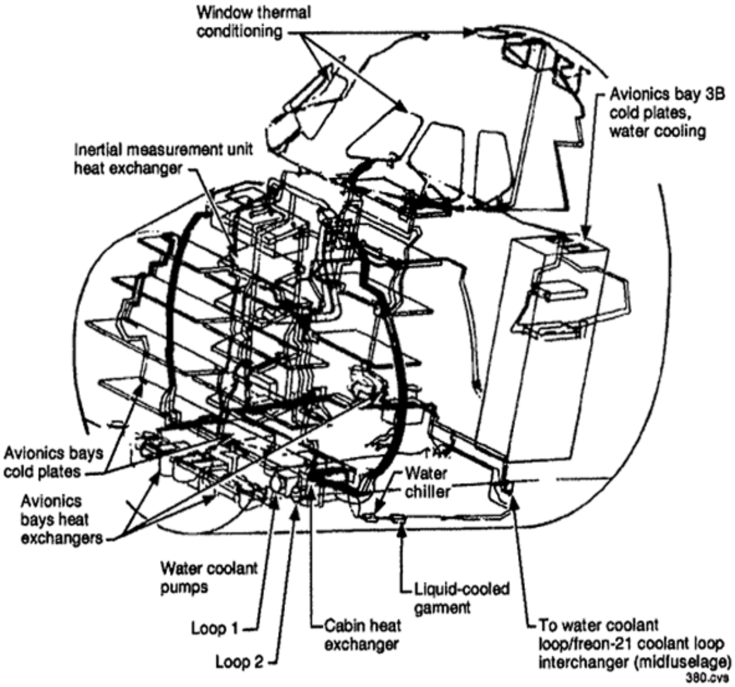
APU/ENVIRON THERM Display (DISP 88)



Crew Cabin Water Coolant Loops

The status of the water loops can be monitored on the APU/ENVIRON THERM display (DISP 88), which is available in SM OPS 2. The information is found in the items under H2O LOOP.

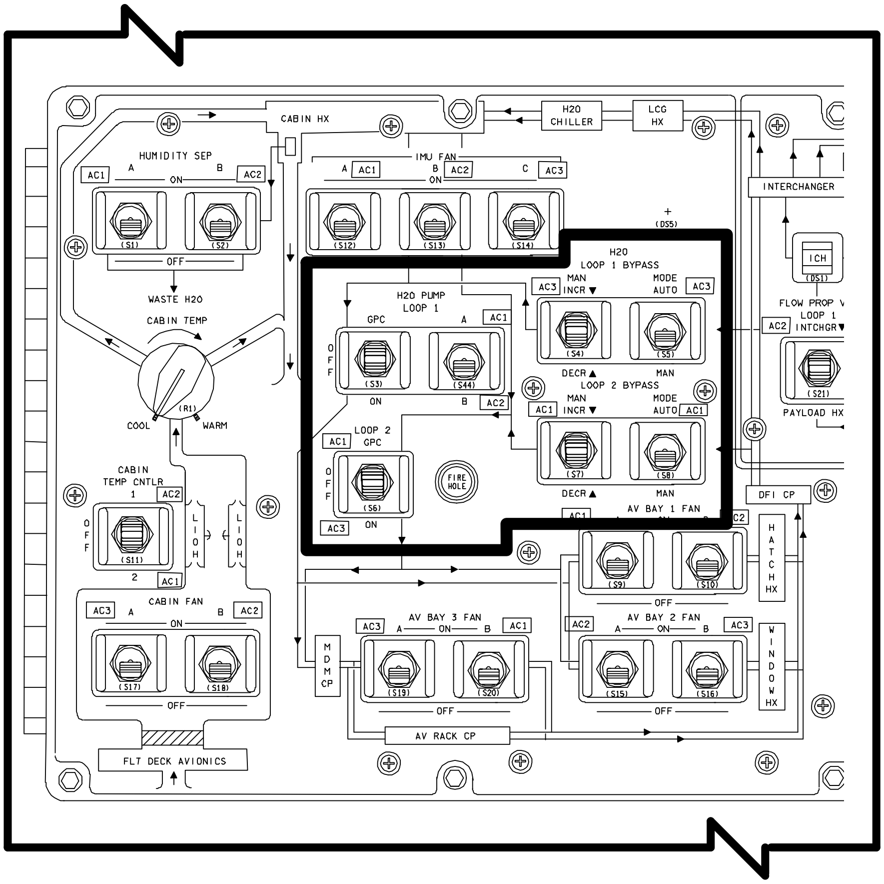
Water Loop Pumps

A ball-type check valve downstream of each water pump in loop 1 prevents reverse flow through the non-operating pump. The water pumps in coolant loop 1 are controlled by the *H_2O PUMP LOOP 1 A* and *B* switch on panel L1 in conjunction with the *H_2O PUMP LOOP 1 GPC, OFF, ON* switch beside it. *The ON position continuously energizes the loop 1 pump.* The *GPC* position enables the general-purpose computer to command the loop 1 pump, which is selected by the *H_2O PUMP LOOP 1 A* or *B* switch, to circulate water through water coolant loop 1 *nominally* for 6 minutes every 4 hours while on orbit *(OPS 2)* to thermally condition the normally static loop. The *OFF* position removes electrical power from both the A and B pumps of loop 1.

The coolant loop 2 water pump is controlled by the *H_2O PUMP LOOP 2* switch on panel L1. The *ON* position energizes *the loop 2* water pump continuously. *In OPS 2, when the switch is positioned to GPC, water pump 2 is commanded by the GPC to circulate water through water coolant loop 2 for 6 minutes every 4 hours. In OPS 1, 3, and 6, the GPC-ON command for the water loop 2 pump stays resident in the BFS, so taking the switch to the GPC position immediately activates the pump (assuming the associated pump power circuit breakers are closed).* The *OFF* position removes electrical power from water coolant loop 2 pump.

Water Loop Flow

Water loops 1 and 2 are routed side by side through the same areas. Downstream of each water pump, water flow splits into three parallel paths. One is through the AV Bay 1 air/water heat exchanger and cold plates. A second is through the AV Bay 2 air/water heat exchanger and cold plates, and thermal conditioning of the crew cabin windows. A third is through the crew cabin MDM flight deck cold plates, the AV Bay 3A air/water heat exchanger and cold plates, and the AV Bay 3B cold plates. The three parallel paths in each coolant loop then rejoin upstream of the Freon/water heat interchanger. The flow path splits again with one parallel path in each water coolant loop flowing through the Freon/water interchanger, where the water loop is cooled.



H_2O Loop Switches on Panel L1

The cooled water then flows through the liquid-cooled garment heat exchanger, potable water chiller, cabin heat exchanger, and IMU heat exchanger to the respective water coolant loop 1 and 2 pump package. The other parallel path in each water coolant loop, containing warm water, bypasses the interchanger and heat exchanger, rejoining the loop at the loop pump package. A valve installed in the bypass path controls the amount of bypass flow, thus controlling the mixed water temperature out of the pump package.

The bypass valve is controlled by bypass controllers either manually or automatically via *H_2O LOOP 1* and *2 BYPASS MODE* switches on panel L1. When the switch is positioned to *AUTO*, the water bypass controller and bypass valve automatically control the amount of water in the coolant loop that bypasses the Freon/water interchanger and heat exchangers *in an attempt to maintain a pump outlet set point temperature of 63.0 ± 2.5° F*. When the water pump's outlet temperature *exceeds the set point temperature*, the loop's bypass valve is *commanded to close*, and *more* loop flow is directed to the Freon/water interchanger to provide *increased* cooling.

When the bypass controller senses that the water pump's outlet temperature is *below the set point temperature*, the controller *increases the* amount of water *bypassed* around the Freon/water interchanger, reducing the heat rejection rate and increasing the water temperature out of the pump outlet. When the *H_2O LOOP BYPASS MODE* switch for the coolant loop is positioned to *MAN*, the flight crew *uses* the corresponding *H_2O LOOP MAN INCR/DECR momentary* switch on panel L1 to manually control the bypass valve *position* in that water coolant loop.

The bypass valve is manually adjusted before launch to provide a flow of approximately 950 pounds per hour through the Freon/water interchanger, and the control system remains in the manual mode until post insertion. On orbit, the active water coolant loop's H_2O LOOP BYPASS MODE switch is set to AUTO and the bypass valve automatically controls the loop so that the water pump's outlet temperature remains at *about* 63° F.

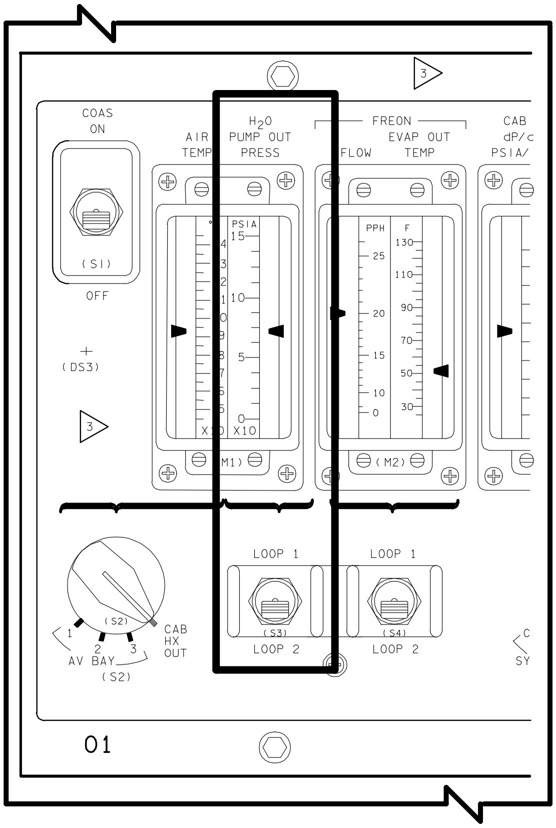
The accumulator in each water coolant loop provides a positive pressure on the corresponding water pump inlet and *accommodates* thermal expansion and dampens pressure surges in that water coolant loop when the pump is turned on or off. Each accumulator is pressurized with gaseous nitrogen at 19 to 35 psi.

The pressure at the outlet of the water pump in each water coolant loop is monitored and transmitted to the H_2O PUMP OUT PRESS meter on panel O1. When the switch *below the meter* is positioned to *LOOP 1* or *LOOP 2*, the corresponding water coolant loop's pressure in psia is monitored on the meter.

NOTE

> For normal operations, only one water loop is active (usually loop 2). Running two water loops for long periods of time is undesirable. Two operating loops will flow too much water through the Freon/water interchanger and result in a significant increase in the cabin temperature. This occurs because two active water loops are capable of picking up more heat than the Freon/water interchanger can transfer to the Freon loops. Over time, the water loops will start to heat up, and cooling efficiency will decrease.

The yellow *H_2O LOOP* caution and warning light on panel F7 will be illuminated if the outlet pressure of the water coolant loop 1 pump is less than 19.5 psia or greater than 79.5 psia, or if the outlet pressure of the loop 2 pump is less than 45 psia or greater than 81 psia. The pump outlet pressure *and delta pressure across the pump* of each coolant loop are monitored and transmitted to the systems management GPC for DPS display readout on the DISP 88 APU/ENVIRON THERM display (PUMP OUT P).



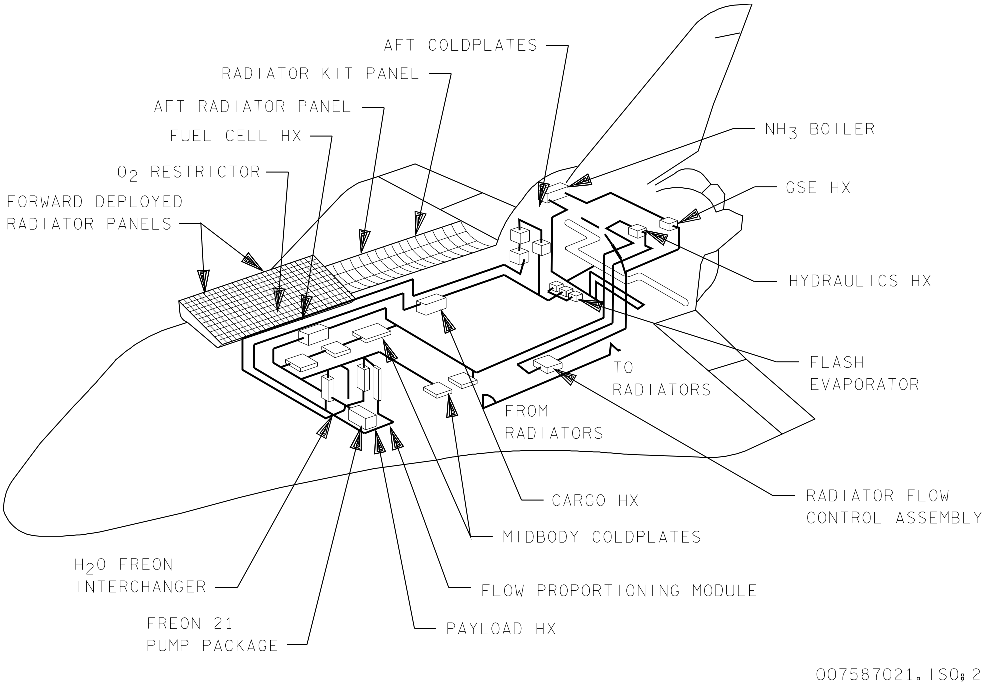
H_2O PUMP OUT PRESS Meter and Switch on Panel O1 (The same transducer feeds SM DISP 88)

Active Thermal Control System

The active thermal control system (ATCS) provides orbiter heat rejection during all phases of the mission after solid rocket booster separation. The system consists of two complete, identical Freon coolant loops, cold plate networks for cooling avionics units, liquid/liquid heat exchangers, and three *onboard* heat sinks: radiators, flash evaporators, and ammonia boilers.

Freon Loops

Two Freon coolant loops transport excess heat from the Freon/water interchanger, fuel cell heat exchanger, payload heat exchanger, and midbody and aft avionics electronic units. The Freon loops then deliver the heat to the heat sinks. Each loop has a pump package consisting of two pumps and an accumulator. The pump package is located in the midbody of the orbiter below the payload bay liner. One pump in each loop is active at all times. The metal bellows-type accumulator in each loop is pressurized with gaseous nitrogen to provide a positive pressure on the pumps and permit thermal *variation* in that coolant loop. When the accumulator bellows is fully extended, approximately 80 lb of Freon is in the accumulator (normally only 20 to 30 percent of this amount is used). A ball check valve downstream of the pumps in each coolant loop prevents a reverse flow through the non-operating pump in the loops. The pumps in each coolant loop are controlled individually by the *FREON PUMP* switches on panel L1. When either switch is positioned to *A* or *B*, the corresponding Freon pump in that loop operates. The *OFF* position of each switch prohibits either Freon pump in that coolant loop from operating.



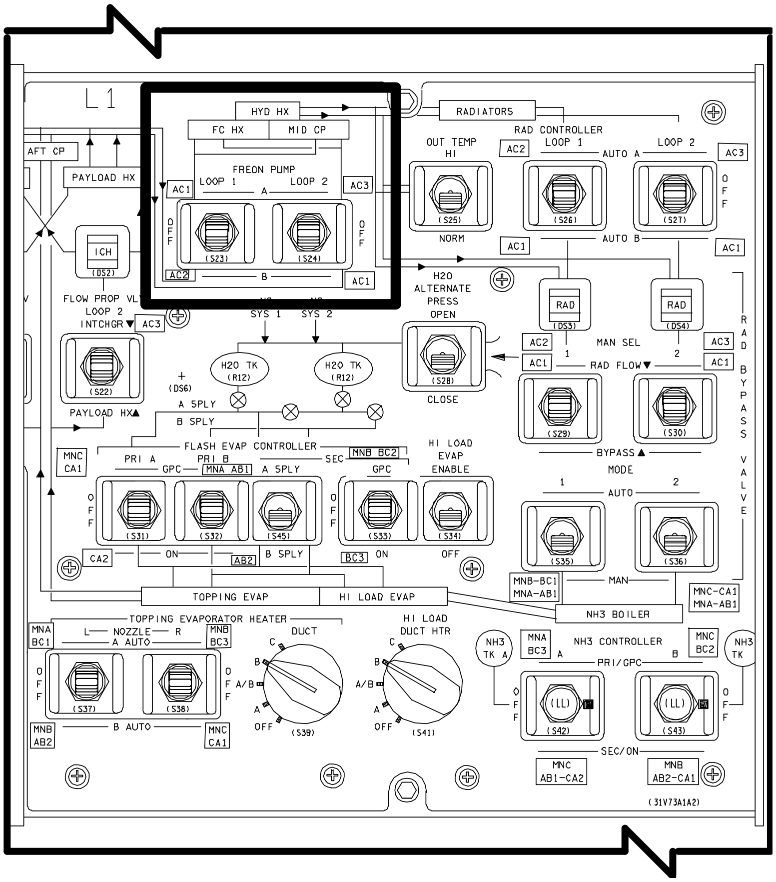
Active Thermal Control System Component Locations

When a Freon pump is operating, Freon is routed in parallel paths through the fuel cell heat exchanger and the midbody cold plate network to cool electronic avionics units*, including the station/shuttle power transfer system (SSPTS) electronics*. The Freon coolant converges to one flow path before entering the hydraulics heat exchanger.

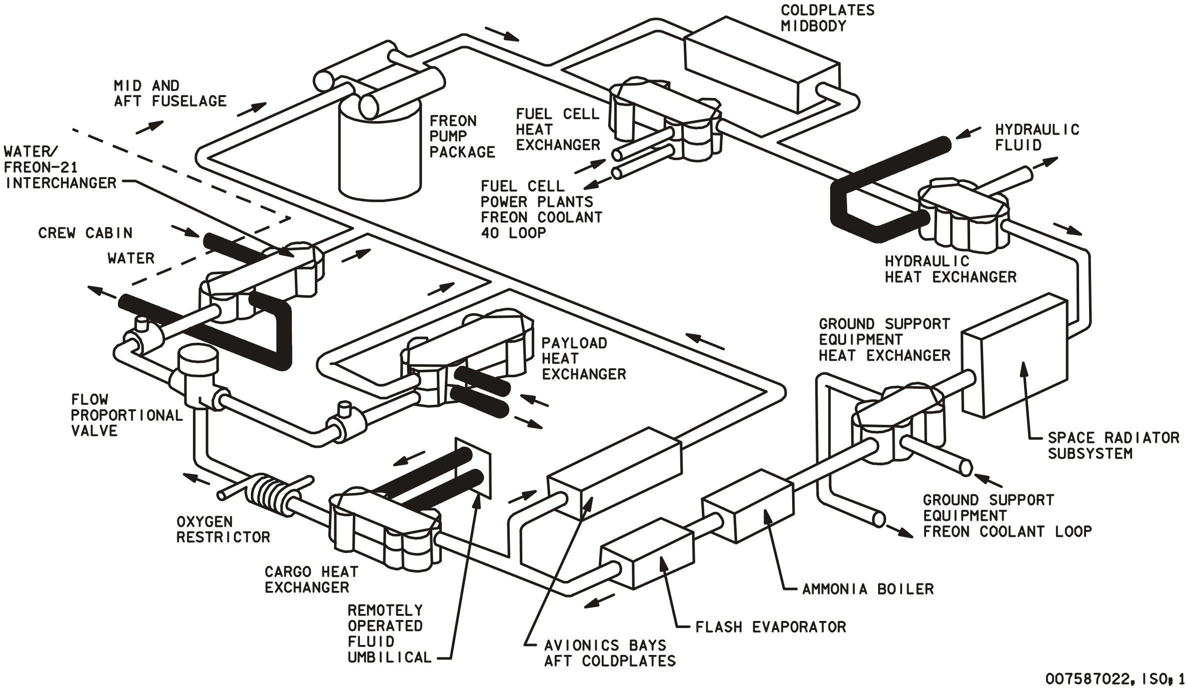
Normally, the warmest portion of the Freon loop is at the outlet of the hydraulic system heat exchanger. The Freon flows from the hydraulic fluid heat exchanger to the radiators, which are bypassed through a bypass valve during ascent and entry unless cold soak cooling from the radiators is being used.

When the payload bay doors are opened on orbit, radiators located on the inside of the payload bay doors are used for heat rejection to space. *After the radiators, t*he Freon coolant flows through the ground support equipment heat exchanger *(*used for *providing prelaunch and post-landing* cooling*)*, ammonia boilers, and flash evaporator located in the aft fuselage. It is then divided into two parallel paths. One path flows through the cargo heat exchanger (located on the left side roughly center of the midfuselage) and continues through the ECLSS oxygen restrictor to warm cryogenic oxygen to *about* 40° F. The flows splits through a flow-proportioning valve module into parallel paths to the payload heat exchanger*,* and atmospheric revitalization system *Freon/water* interchanger (located in the lower forward portion of the midfuselage) and then returns to a series flow. The second path flows in series through aft avionics bays 4, 5, and 6 to cool electronic avionics equipment. The flow continues through cold plates to cool four rate gyro assemblies. The parallel paths combine and return in series to the Freon coolant pump in that Freon coolant loop.

The FREON FLOW meter on panel O1 permits the crew to monitor Freon flow to the Freon/water interchanger. The switch below the meter selects the loop to be monitored. Freon loop status can also be monitored under the FREON LOOP area on the APU/ENVIRON THERM display (DISP 88) and the BFS THERMAL display (FREON Loop 1, 2) in OPS 1. The yellow *FREON LOOP* caution and warning light on panel F7 will illuminate if Freon/water interchanger (ICH) flow in either loop is less than *1186 lbm/hr*. The crew has no insight into total loop flow.



FREON PUMP Switches on Panel L1



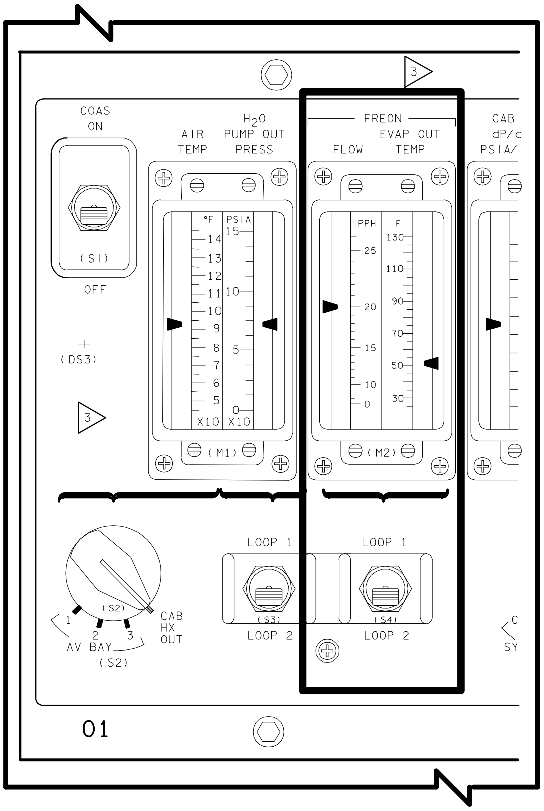
Freon Coolant Loop

Radiators

Radiators act as a heat sink for the coolant loops. The radiator system consists of four radiator panels attached to the inside of each payload bay door. The two forward radiator panels on each payload bay door are deployable when the doors are opened on orbit. The heat rejection requirements of the orbiter for a specific mission will determine if the forward radiators are to be deployed. The third and fourth radiator panels are fixed to the aft underside of the aft right and left payload bay doors and are not deployable.

The maximum heat rejection capability is 61,100 Btu per hour. When the payload bay doors are closed, the radiators are usually bypassed.

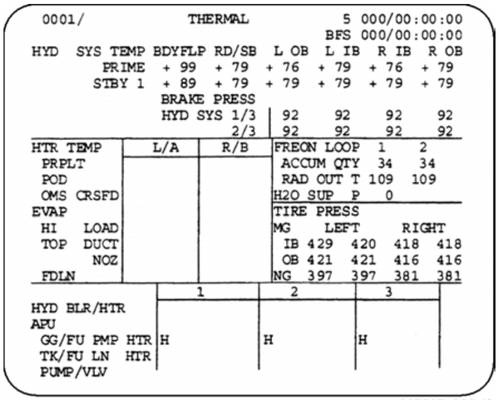
The radiator panels on the left and right sides are *each* configured to flow in series, while flow within each panel is parallel through a bank of tubes connected by an inlet and outlet connector manifold. The radiator panels on the left side are connected in series with Freon coolant loop 1. The radiator panels on the right side are connected in series with Freon coolant loop 2.



FREON FLOW Meter and Switch on Panel O1

The radiator panels provide an effective heat dissipation area of 1,195 square feet on orbit. Each radiator panel is 10 feet wide and 15 feet long. The Freon tubing in the radiator panels is more than 1 mile long.

For ascent, the radiators are normally bypassed since the doors are closed. Radiator flow is established shortly before the doors are opened on orbit. During deorbit preparations, prior to closing the doors, the Freon in the radiators is cold-soaked by positioning the orbiter in a tail Sun attitude *and slowing flow through the radiators by taking the RAD CONTROLLER OUT TEMP switch to the HI position on panel L1*. This cold soak is saved for use as a heat sink during the latter stages of entry.



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                                     BFS 000/00:00:00
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          PRIME  + 99  + 79  + 76  + 79  + 76  + 79
         STBY 1  + 89  + 79  + 79  + 79  + 79  + 79
                 BRAKE PRESS
                 HYD SYS 1/3 | 92    92    92    92
                         2/3 | 92    92    92    92
HTR TEMP  |   L/A   |  R/B   |FREON LOOP  1    2
 PRPLT    |         |        | ACCUM QTY  34   34
 POD      |         |        | RAD OUT T 109  109
 OMS CRSFD|         |        |H2O SUP  P   0
EVAP      |         |        |TIRE PRESS
 HI   LOAD|         |        |MG    LEFT     RIGHT
 TOP  DUCT|         |        | IB 429  420  418  418
       NOZ|         |        | OB 421  421  416  416
 FDLN     |         |        |NG  397  397  381  381
                 |     1     |    2     |    3     |
HYD BLR/HTR      |           |          |          |
APU              |           |          |          |
 GG/FU PMP HTR   |H          |H         |H         |
 TK/FU LN   HTR  |           |          |          |
 PUMP/VLV
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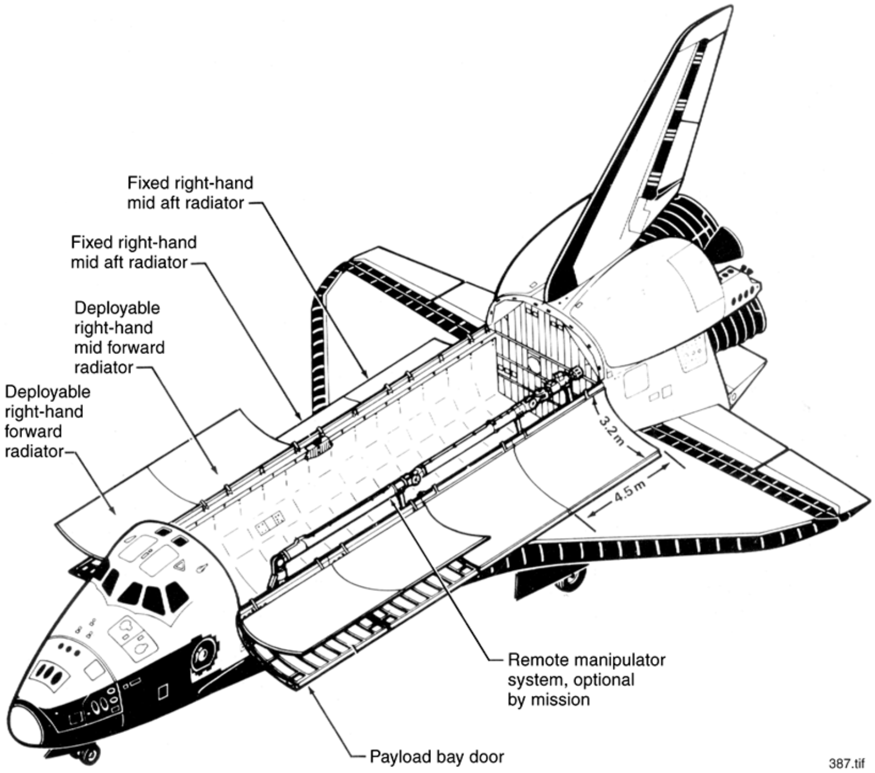
BFS THERMAL DISPLAY

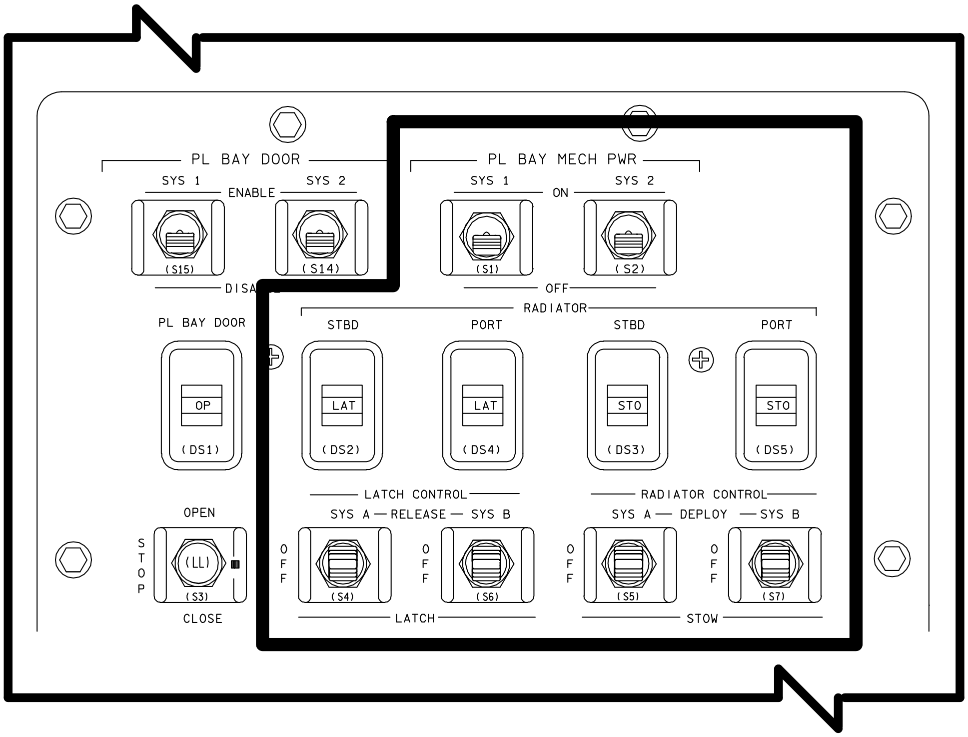
Radiator Mounting and Construction

The deployable radiators are secured to the inside of the right and left payload bay doors by six motor-operated latches. When the payload bay doors are opened on orbit, *if* the mission dictates that the deployable radiators be deployed, *then* the six motor-driven latches unlatch the radiators from the payload bay doors, and a motor-driven torque-tube-lever arrangement deploys the forward radiators at 35.5° from the payload bay doors. Deploying the forward radiators provides more surface area, and thus greater heat rejection.

The aft fixed radiator panels are attached to the payload bay doors by a ball joint arrangement at 12 locations to compensate for movement of the payload bay door and radiator panel caused by the thermal expansion and contraction of each member.



Payload Bay Radiators



RADIATOR DEPLOY and STOW Switches and Talkbacks on Panel R13L

The radiator panels are made of an aluminum honeycomb face sheet 126 inches wide and 320 inches long. The forward deployable radiator panels are two-sided and have a core thickness of 0.9 of an inch. They have longitudinal tubes bonded to the internal side of both face sheets. Each of the forward deployable panels contains 68 tubes spaced 1.9 inches apart.

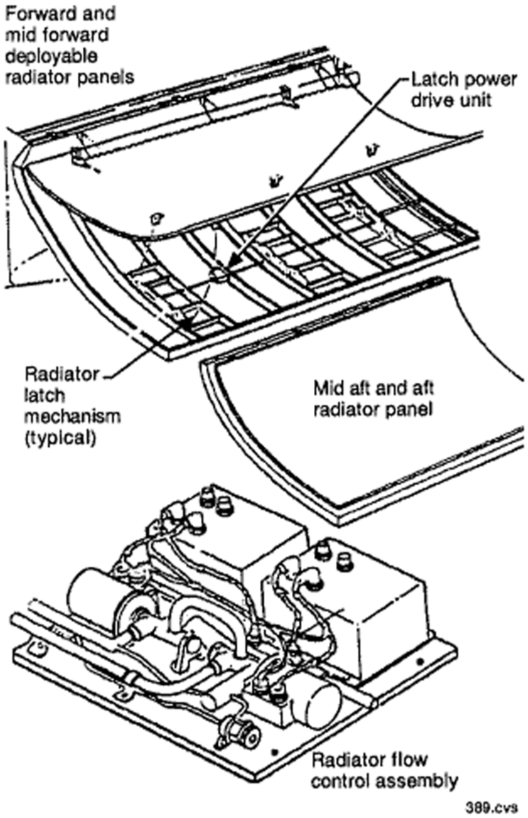
Each tube has an inside diameter of 0.131 inch. Each side of the forward deployable radiator panels has a coating bonded by an adhesive to the face sheet consisting of silver-backed Teflon tape for proper emissivity properties. The aft fixed panels are one-sided, and their cores are 0.5 inch thick. They have tubes only on the exposed side of the panel and a coating bonded by an adhesive to the exposed face sheet. The aft panels contain 26 longitudinal tubes spaced 4.96 inches apart. Each tube has an inside diameter of 0.18 inch. The additional thickness of the forward radiator panels is required to meet deflection requirements when the orbiter is exposed to ascent acceleration.

Radiator Deploy Systems

There are two radiator deploy systems, each of which drives one of two motors on each door. The systems drive the radiator panels away from the payload bay doors (deployed) or to the stowed position, using two reversible three-phase AC motors. It takes 50 seconds to deploy or stow the radiators.

The crew deploys and stows the radiators using switches on panel R13L. To deploy, the *PL BAY MECH PWR SYS 1* and *SYS 2* switches are set to *ON* to provide power to the panel switches. Both *RADIATOR LATCH CONTROL* switches are set concurrently to *RELEASE*; after 30 seconds, they are set to *OFF*. The *RADIATOR CONTROL* switches are then concurrently set to *DEPLOY*; after 50 seconds, they are set to *OFF*. The *PL BAY MECH PWR* switches are then set to *OFF*.

To stow the radiators, the *PL BAY MECH PWR* switches are again positioned to *ON*. The *RADIATOR CONTROL* switches are both concurrently set to *STOW*, and after 50 seconds to *OFF*. The *LATCH CONTROL* switches are then positioned to *LATCH*, and after 30 seconds, to *OFF*. The *PL BAY MECH PWR* switches are then positioned to *OFF*.



Radiators and Radiator Flow Control Valve Assembly

Single Radiator Operations

It is possible to deploy either the port side or the starboard side radiator independently. This cannot be done directly with switches, because each controls motors on both sides. To deploy only one radiator, circuit breakers must be pulled to disable motors on one side. Single radiator operations may be done in case of a contingency situation, such as failure of one radiator or necessary Ku-Band antennae pointing, or a planned situation, such as flying in an attitude such that one door must remain partially closed to protect against debris strikes.

Radiator Flow Control

A radiator flow control valve assembly in each Freon coolant loop controls that loop's temperature via variable flow control, which mixes hot bypassed Freon coolant with the cold Freon coolant from the radiators. The radiator bypass valve allows Freon to flow through the radiator or bypass the radiator completely.

In the automatic mode, the *RAD CONTROLLER LOOP 1* and *LOOP 2* switches on panel L1 are positioned to *AUTO A* or *AUTO B* to apply electrical power to the corresponding radiator flow controller assembly. The *RAD BYPASS VALVE MODE* switch is positioned to *AUTO*, and the *RAD CONTROLLER OUT TEMP* switch on panel L1 is positioned to *NORM* or *HI*.

With the *RAD CONTROLLER OUT TEMP* switch on panel L1 positioned to *NORM*, the radiator *controller* outlet temperature in Freon coolant loops 1 and 2 is automatically controlled at 38° F (±2°); in *HI*, the temperature is automatically controlled at 57° F (± 2°).

NOTE

To achieve the radiator NORM and HI control point temperatures, the radiator panel outlet temperature must be at or below the corresponding control point temperature.

NOTE

If *a primary* flash evaporator system (FES) controller switch on L1 is ON, the FES is activated automatically when the radiator *controller* outlet temperature exceeds 41° F to supplement the radiators' ability to reject excess heat.

The talkback indicators below the *RAD CONTROLLER* switches on panel L1 indicate the position of the bypass valve in that Freon coolant loop. The *RAD BYPASS VALVE LOOP 1 and 2 talkback* indicators show *BYP* when the bypass valve in that Freon coolant loop is in the bypass position, barberpole when the motor-operated bypass valve is in transit, and *RAD* when the bypass valve is in the radiator flow position.

When the *RAD BYPASS VALVE MODE* switch on panel L1 is positioned to *MAN* for the Freon coolant loop selected, automatic control of the radiator bypass valve in that loop is inhibited, and the flight crew controls the bypass valve manually using the *RAD BYPASS VALVE LOOP 1, LOOP 2, MAN SEL* switches on panel L1. When the switch is set to *BYPASS*, the loop's motor-operated bypass valve *causes* that Freon coolant loop *flow* to bypass the radiators. When the switch is positioned to *RAD FLOW*, the valve permits coolant to flow through the radiator *and associated flow control valve*.

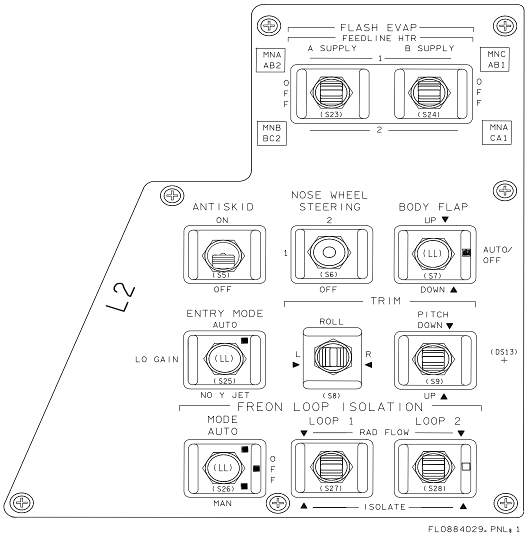
NOTE

*Besides specifying the NORM or HI radiator controller output set point temperature, t*he flow control valve cannot be controlled manually – only automatically via the controller. The bypass valve can be operated manually or automatically.

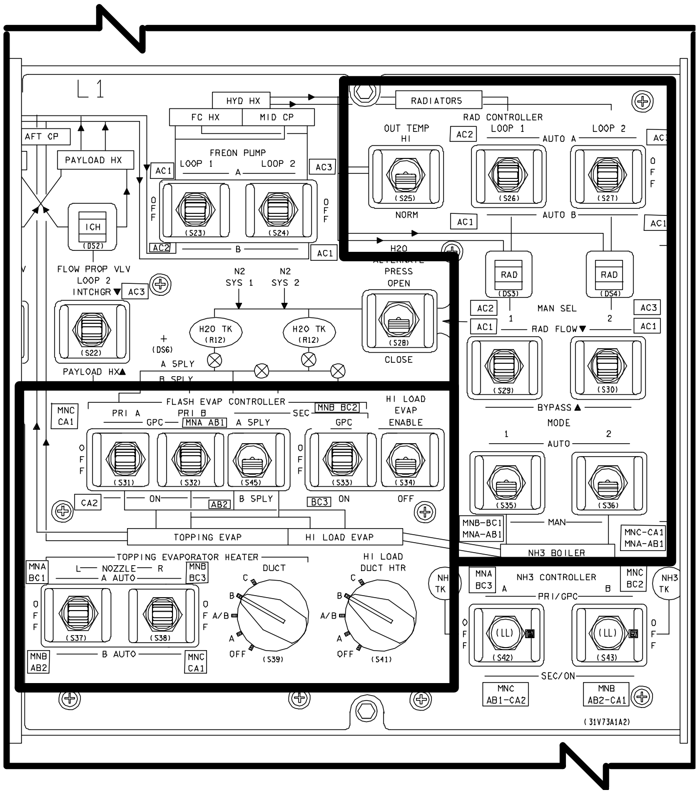
Freon Radiator Isolation Valves

Orbital debris could damage the orbiter Freon loop radiators located on the inner surface of the payload bay doors. Debris striking a Freon coolant line in the radiator could cause loss of Freon in that loop. To preclude this loss, a method was designed to isolate the punctured radiator from the rest of the loop.

To isolate the affected radiator from the Freon loop, *AC*-powered isolation valves and directional-*flow check* valves with associated plumbing were added to the Freon loops. Switches on L2 provide control of the isolation valves. Power to the valves and control logic are provided via circuit breakers on panels L4 and O14. The *AC*-powered isolation valve has automatic and manual controls. *During OPS 2 orbit operations, w*ith the *FREON ISOLATION MODE* switch in *AUTO*, if the affected Freon loop accumulator quantity drops below *a threshold quantity (default is* 12 percent*)* for at least *3*-5 seconds, a class 3 SM alert will annunciate and a command will be sent to the isolation valve on the affected loop to isolate the affected radiator. However, this automatic isolation will not occur if the Freon loop accumulator quantity *shows* less than *-5%* or if the status is "M" due to MDM failures. *(The -5% threshold prevents inadvertent automatic radiator isolation in the event of an accumulator quantity instrumentation failure; off-scale low for Freon loop accumulator quantity is about -11%.)* In MAN, the crew has to isolate the affected radiator manually if a leak is detected by holding the affected loops switch in ISOL*ATE* until the radiator is isolated (~5 sec). Manual control of the valve can override the auto control in “both” directions (RAD FLOW or ISOL) to reset the valve to the normal flow condition for a system test or for a false failure that may have caused the isolation valve to isolate the radiator. *Only manual control of the radiator isolation valves is available during ascent and entry (while the SM is managed by the backup flight system (BFS)).*



Panel L2 - Freon Loop Isolation



RAD CONTROLLER SWITCHES and Talkbacks and FLASH EVAP CONTROLLER Switches on Panel L1

Flash Evaporator System

The FES rejects heat loads from Freon coolant loops 1 and 2 by evaporating supply water in a vacuum. The FES is used during ascent above 140,000 feet, and it supplements the radiators on orbit if required. It also rejects heat loads during deorbit and entry to an altitude of approximately 100,000 feet.

The FES is located in the aft fuselage of the orbiter. There are two evaporators, a high-load evaporator and a topping evaporator. Two major differences are that the high-load evaporator has a higher cooling capacity and only one overboard vent on the left side of the vehicle. The topping evaporator vents steam equally to the left and right sides of the orbiter to minimize propulsiveness. The evaporators are cylindrical shells with dual water spray nozzles at one end and a steam exhaust duct at the other end. The shell is composed of two separate finned packages, one for each Freon loop. The hot Freon from the coolant loops flows around the finned shell, and water is sprayed onto the *inner surface of the* shell by water nozzles from either evaporator. The water vaporizes, cooling the Freon coolant loops. In the low-pressure atmosphere above 100,000 feet, water vaporizes quickly. Changing water liquid to vapor removes approximately 1,000 Btu per hour per pound of water. The water for the evaporators is obtained from the *supply* water storage tanks through FES water supply feedlines A and B.

Flash Evaporator Controllers

The flash evaporators have three controllers: primary A, primary B, and secondary. The primary A and B controllers have two separate, functionally redundant shutdown logic paths (under-temperature and *over-temperature with insufficient* rate of cooling). The secondary *controller* has no *automatic* shutdown *capability*. The flash evaporator controllers are enabled by the *FLASH EVAP CONTROLLER* switches on panel L1. The *PRI A* switch controls primary controller A, the *PRI B* switch controls primary controller B, and the *SEC* switch controls the secondary controller.

When the *PRI A, PRI B,* or *SEC* switch is positioned to *GPC*, the corresponding controller is turned on automatically during ascent by the backup flight system (BFS) computer as the orbiter ascends above 140,000 feet (MM103/SRB SEP). During entry, the BFS computer turns the corresponding controller off as the orbiter descends *below about* 100,000 feet (MM305). The *ON* position of the switch provides electrical power directly to the corresponding flash evaporator controller. The *OFF* position of the switch removes all electrical power and inhibits flash evaporator operation.

The primary A controller controls water flow to the flash evaporator from water supply system A through water feed line A. The primary B controller controls water flow to the flash evaporator from water supply system B through water feed line B.

NOTE

> When a primary controller is enabled, both *High Load and Topping* evaporators can be used simultaneously.

The secondary controller controls water flow to the high load flash evaporator from water supply system A through feed line A if the *FLASH EVAP CONTROLLER SEC* switch on panel L1 is in the *A SPLY* position, and if the *HI LOAD EVAP* switch is in the *ENABLE* position. If the switch is in the *B SPLY* position, and the *HI LOAD EVAP* switch is in the *ENABLE* position, the secondary controller controls water flow to the flash evaporator from water supply system B through feed line B. When the secondary controller is used, and the *HI LOAD EVAP* switch is *OFF*, both the A and B water supply systems will feed the topping evaporator in an alternate pulsing fashion*; the high load evaporator is disabled*. When the secondary controller is used, and the *HI LOAD EVAP* switch is in the *ENABLE* position, the topping evaporator is disabled.

The primary A and B controllers modulate the water spray in the evaporator to keep the Freon coolant loops' evaporator outlet temperature stable at 39 ± 1° F. The secondary controller modulates the water spray in the evaporator to control the Freon coolant loops' evaporator outlet temperature at 62° F. The temperature sensors are located at the outlets of both evaporators.

The applicable FES controller pulses water into the evaporators, cooling the Freon. The steam generated in the topping evaporator is ejected through two sonic nozzles at opposing sides of the orbiter aft fuselage to reduce payload water vapor pollutants on orbit and to minimize venting thrust effects on the orbiter's guidance, navigation, and control system.

The high-load evaporator is used in conjunction with the topping evaporator during ascent and entry when higher Freon coolant loop temperatures impose a greater heat load that requires a higher heat rejection. The *HI LOAD EVAP* switch on panel L1 must be in the *ENABLE* position for high-load evaporator operation. After leaving the high-load evaporator, Freon flows through the topping evaporator for additional cooling. The steam generated by the high-load evaporator is ejected through a single sonic nozzle on the left side of the orbiter aft fuselage. The high-load evaporator normally would not be used on orbit because *the high heat rejection capability of the high load evaporator is not normally needed on orbit when radiator cooling is available, and attempting to use the high-load evaporator under low heat load would likely cause the evaporator controller to shut down. The high load also* has a propulsive vent *(causing unbalanced rates on the vehicle),* and *it* might *contaminate* a payload.

NOTE

> Norm jets are required to control vehicle attitude when the FES high load is used on orbit.

FES Auto Shutdown

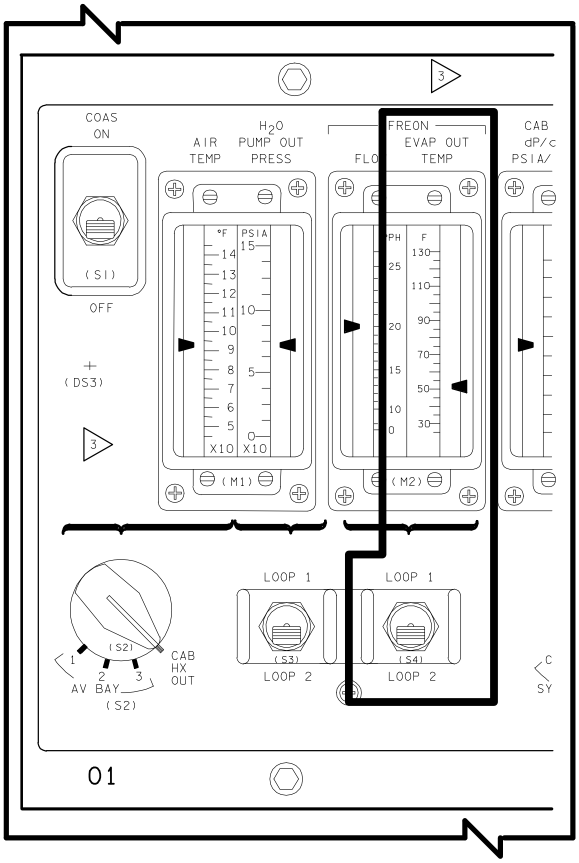
Each primary controller has an automatic shutdown capability to protect the evaporator from over- or undertemperature conditions. The evaporator's outlet temperature is monitored to determine whether a thermal shutdown of the evaporator is warranted. If the evaporator outlet temperature goes below 37° F for 20 seconds or more, an undertemperature shutdown of the evaporator occurs. If the evaporator outlet temperature is greater than 41° F for 55 seconds, the overtemp shutdown logic is enabled. An overtemp shutdown occurs when the cooling rate is less than 2.*1 to 7.8*° F *per minute* from 20 to 40 seconds after the overtemp logic is enabled. If the evaporator is shut down, electrical power to the affected controller must be recycled to re-enable operations.

Temperature Monitoring

The evaporator outlet temperature of Freon coolant loops 1 and 2 is transmitted to panel O1. When the switch below the FREON meter on panel O1 is positioned to *LOOP 1* or *LOOP 2*, the evaporator outlet temperature of Freon coolant loops 1 or 2 can be monitored in degrees Fahrenheit on the FREON EVAP OUT TEMP meter or on the DISP 79 SM SYS SUMM 2 display (EVAP OUT T)*, or on the DISP 88 APU/ENVIRON THERM display*. If the outlet temperature drops below 32.2° F, or rises above 64.8°F *(after post insertion)*, the red *FREON LOOP* caution and warning light on panel F7 will be illuminated. (The upper limit for ascent is
115° F.)

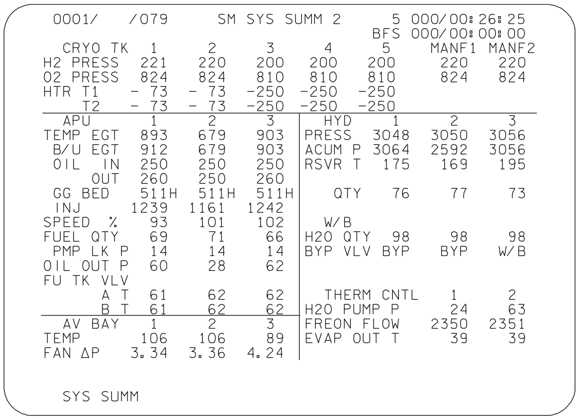
FES Heaters

Electrical heaters are employed on the topping and high-load flash evaporators' steam ducts to prevent freezing. The *HI LOAD DUCT HTR* rotary switch on panel L1 selects the electrical heaters. Switch positions *A* and *B* provide electrical power to the corresponding thermostatically controlled heaters on the high-load evaporator steam duct and steam duct exhaust. The *A/B* position provides electrical power to both thermostatically controlled heaters. The *C* position provides electrical power to both thermostatically controlled C heaters. The *OFF* position removes electrical power from all the heaters.



FREON EVAP OUT TEMP Meter and Switch on Panel O1

The *TOPPING EVAPORATOR HEATER DUCT* rotary switch on panel L1 selects the thermostatically controlled electrical heaters on the topping evaporator. Positions *A* and *B* provide electrical power to the corresponding heaters, while A/B provides electrical power to both A and B heaters. The C position provides power to the C heaters and part of the B heaters. The *OFF* position removes electrical power from all the heaters.



```
 0001/   /079      SM SYS SUMM 2      5 000/00:26:25
                                    BFS 000/00:00:00
  CRYO TK   1      2      3     4      5     MANF1 MANF2
H2 PRESS   221    220    200   200    200     220   220
O2 PRESS   824    824    810   810    810     824   824
HTR T1    - 73   - 73   -250  -250   -250
    T2    - 73   - 73   -250  -250   -250
  APU       1      2      3  |  HYD     1      2      3
TEMP EGT   893    679    903 |PRESS   3048   3050   3056
 B/U EGT   912    679    903 |ACUM P  3064   2592   3056
 OIL   IN  250    250    250 |RSVR T   175    169    195
      OUT  260    250    260 |
 GG BED    511H   511H   511H|   QTY    76     77     73
 INJ      1239   1161   1242 |
SPEED  %    93    101    102 |  W/B
FUEL QTY    69     71     66 |H2O QTY   98     98     98
 PMP LK P   14     14     14 |BYP VLV  BYP    BYP    W/B
OIL OUT P   60     28     62 |
FU TK VLV                    |
       A T  61     62     62 |  THERM CNTL      1      2
       B T  61     62     62 |H2O PUMP P       24     63
  AV BAY    1      2      3  |FREON FLOW     2350   2351
TEMP       106    106     89 |EVAP OUT T       39     39
FAN ΔP    3.34   3.36   4.24 |

  SYS SUMM
```

The SM SYS SUMM 2 display is an SM display (DISP 79) available in the BFS and in PASS SM OPS 2

The topping evaporator's left and right nozzle heaters are controlled by the *TOPPING EVAPORATOR HEATER L(R) NOZZLE* switches on panel L1. When the switches are positioned to *A AUTO* or *B AUTO*, electrical power is provided to the corresponding left and right nozzle heaters, and the corresponding nozzle temperature is maintained between 40° and 70° F. The *OFF* position removes electrical power from both heater systems.

FES Water Dumps

The FES topping evaporator can be used to dump excess water from the supply water storage tanks, if required, on orbit. When the *RAD CONTROLLER OUT TEMP* switch on panel L1 is placed in *HI*, the radiator flow control valve assembly controls that radiator outlet at 57° F. Since the topping evaporator controls to 39° F, water is used up at a rate of about 25 lb/hr, thus dumping excess water.

Ammonia Boilers

The ammonia boiler system acts as a heat sink by using the low boiling point of ammonia (NH_3) to cool the Freon coolant loops when the orbiter is below 400,000 feet during entry or on the ground after landing. The resultant superheated vapor is vented overboard. Two complete, individual ammonia storage and control systems feed one common boiler containing ammonia passages and the individual Freon coolant loops 1 and 2. Each system consists of a storage tank, an isolation valve, an overboard relief valve, two control valves, a controller, three temperature sensors, a pressure sensor and a feedline to the boiler.

The ammonia boiler is a shell-and-tube system with a single pass of ammonia on the ammonia side and two passes of each Freon coolant loop through the boiler. The ammonia flows in the ammonia tubes and the Freon coolant loop flows over the tubes, cooling the Freon coolant loops. When the ammonia flows over the warm Freon coolant lines in the boiler, it immediately vaporizes, and the heat and boiler exhaust are vented overboard in the upper aft fuselage of the orbiter next to the bottom right side of the vertical tail.

The ammonia system is used during entry if the radiators have not been cold-soaked, *as would be the case in the event of an ascent abort*. If radiator *coldsoak* cooling is used during entry, the ammonia system is activated post-landing when radiator outlet temperatures reach 55° F. The ammonia boiler operations are used post-landing until a ground-cooling cart is connected to the ground support equipment *(GSE)* heat exchanger.

Storage Tanks

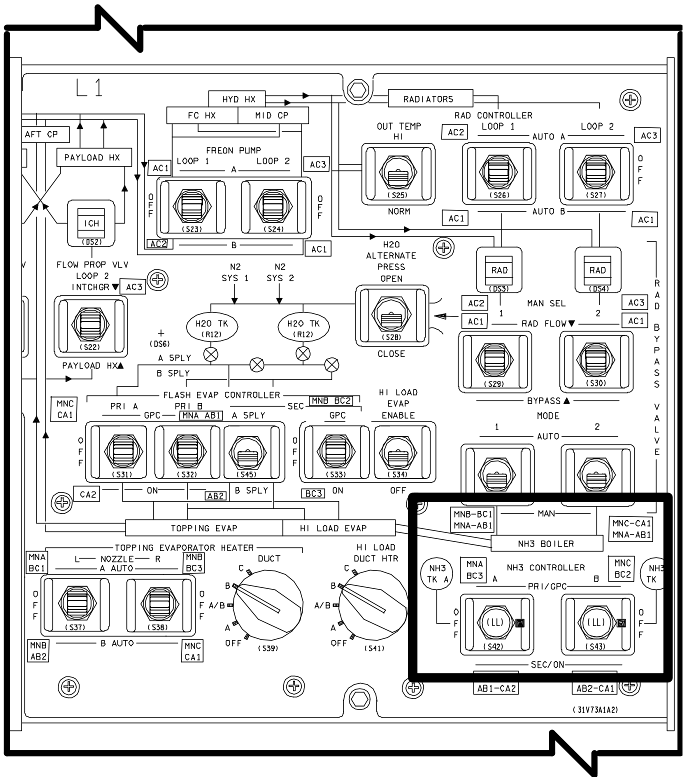
Each ammonia boiler storage tank contains a total of 49 pounds of ammonia (approximately 30 minutes of cooling *under nominal post-landing conditions*), all of which is usable. Each tank is pressurized with gaseous helium at a maximum operating pressure of 550 psia. Downstream of each ammonia storage tank to the common boiler are three control valves: a normally closed isolation valve, a normally open secondary control valve, and a normally open primary control valve. A relief valve in each ammonia boiler storage system provides overpressurization protection of that ammonia storage tank.

Primary Ammonia Boiler Controller

The primary controller in the ammonia system controller energizes the ammonia system isolation valve, permitting ammonia to flow to two motor-operated controller valves. The controller also commands the primary motor-operated valve to regulate the flow to the ammonia boiler. Ammonia boiler supply systems A and B are enabled by the corresponding *NH_3 CONTROLLER* switches on panel L1. *To prepare for the possibility of low altitude cooling in the event of an ascent abort*, one of the *NH_3 CONTROLLER* switches (usually *B*) is positioned to *PRI/GPC* before *launch*, which enables the GPC to control electrical power to the primary and secondary controllers within the ammonia controllers. When the orbiter descends through 120,000 feet *in Major Mode 304 (or upon transition to Major Mode 602 during a return to launch site (RTLS) abort)*, the backup flight system *(BFS)* computer commands the selected ammonia system controller on.

Ammonia Boiler Control Sensors

Three temperature sensors *associated with ammonia system A are affixed to Freon coolant loop 1, and three sensors associated with ammonia system B are affixed to Freon coolant loop 2. For each ammonia system, one sensor's temperature is fed to the primary controller logic to help control ammonia boiler Freon outlet temperatures to 35° ± 3° F if the primary controller is active. Also, for each ammonia system, a different sensor's temperature helps the secondary controller logic control ammonia boiler Freon outlet temperature to 34° ± 3° F if the secondary controller is active. The third sensor feeds temperature data to the controller's fault detection logic. If an ammonia boiler controller is operating in the PRI/GPC configuration and the associated fault detection logic senses temperatures below 31.25° F for longer than 10 seconds*, the fault detection logic automatically inhibits the primary controller, which removes power from the *associated* ammonia system isolation valve and the primary control valve. The logic switches to the secondary controller in the *same* ammonia system controller, which energizes a redundant coil in the ammonia system supply isolation valve and *adjusts* the secondary control valve *to achieve appropriate Freon outlet temperatures*. It commands the isolation valve to full open and allows the secondary controller to control the secondary control valve to regulate the ammonia flow to the ammonia boiler. *This automatic switchover is only from the primary to the secondary controller.*



NH_3CONTROLLER Switches on Panel L1

Secondary Controller

When the *NH_3 CONTROLLER A* or *B* switch on panel L1 is positioned to *SEC/ON*, the A or B ammonia system controller is electrically powered and enabled directly (no computer command is required). The secondary controller in the ammonia system controller energizes the system's isolation valve open, permitting ammonia to flow to two motor-operated controller valves. The secondary controller *also* commands *its* motor-operated *control* valve to regulate the ammonia flow to the ammonia boiler. The three temperature sensors on each Freon coolant loop operate and control Freon coolant loop 1 and 2 temperature in the same manner as in the *PRI/GPC* mode. Fault detection logic does not exist in the secondary controller.

The *OFF* position of the *NH_3 CONTROLLER* switches removes all electrical power from the ammonia system controller, rendering the ammonia system inoperative.

Cargo Heat Exchanger

The cargo heat exchanger was installed on the shuttle in anticipation of a certain type of ISS logistics module that needed active cooling from the orbiter's Freon coolant loops. The proposed logistics modules were demanifested, but OV-103 and OV-105 were already outfitted with the heat exchanger, cooling lines and accumulator (evacuated), and associated coolant line heaters. In these vehicles, switches for the cargo coolant loop heaters are on panel A14. These switches should always be in the OFF position and are never expected to be used.

Supply and Waste Water Systems

The supply water system provides water for flash evaporator system cooling, crew consumption, and hygiene. The supply water system stores water generated by the fuel cells, and the waste water system stores waste from the crew cabin humidity separator and from the flight crew. Four supply water tanks and one waste water tank are located beneath the crew compartment middeck floor.

Data on the supply and waste water system can be monitored on the ENVIRONMENT display (DISP 66) under H2O SUPPLY and WASTE items and on the BFS THERMAL display (H_2O SUP P).

Supply Water System

The supply water system consists of four water tanks that are pressurized with nitrogen from the pressure control system. Each of the four *supply* water tanks has a usable capacity of *165* pounds *of water (plus 3.3 pounds residual)*, is 35.5 inches in length and 15.5 inches in diameter, and weighs 39.5 pounds dry.

The three fuel cells generate a maximum of 25 pounds of *supply* water per hour (about *0.77* pounds of water *per hour* per *generated* kilowatt). The product water from all three fuel cells flows to a single water relief control panel. The water can be directed to potable water tank A or to the fuel cell water relief nozzle. Normally, the water is directed to water tank A.

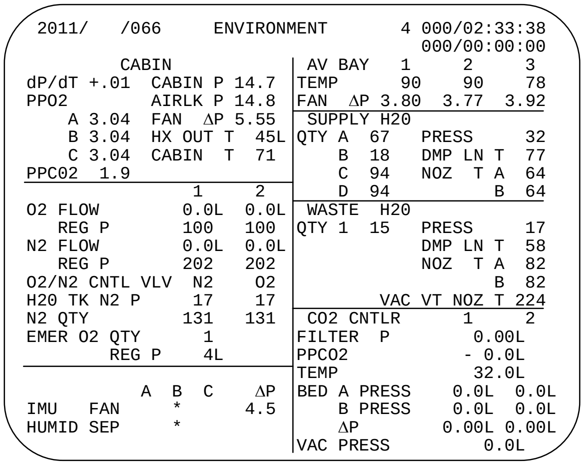
The product water lines from all three fuel cells were modified to incorporate a parallel (redundant) path of product water to *supply* water tank B in the event of a blockage of the primary water path to the tanks. If such a blockage were to occur, pressure would build up and relieve *fuel cell water* through the redundant paths to *the supply* water tank B *inlet manifold*.

Instrumentation

Temperature sensors are installed on each of the redundant paths; in addition, *the primary path* pressure sensor is transmitted to telemetry and can be monitored on the BFS THERMAL display. A pH sensor is located at the common product water outlet of the water relief panel. It provides a redundant measurement of fuel cell health and water purity. A single measurement of water purity in each fuel cell is also provided. If a single fuel cell pH sensor indicated high, the flight crew would be required to sample the potable water to verify the proper pH.

Hydrogen Separators

The hydrogen-enriched water from the fuel cells flows through the single water relief panel through two hydrogen separators to potable water tank A. The separator removes 85 percent of the excess hydrogen. The hydrogen separators consist of a matrix of silver palladium tubes, which have an affinity for hydrogen. The hydrogen is dumped overboard through a vacuum vent. The redundant water line to *the* tank B *inlet manifold* does not pass through the hydrogen separator. Water passing through the hydrogen separators can be stored in all four *supply* water tanks: A, B, C, and D.



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 2011/   /066     ENVIRONMENT       4 000/02:33:38
                                      000/00:00:00
         CABIN                | AV BAY   1     2     3
dP/dT +.01  CABIN P 14.7      |TEMP      90    90    78
PPO2        AIRLK P 14.8      |FAN  ΔP 3.80  3.77  3.92
    A 3.04  FAN   ΔP 5.55     | SUPPLY H2O
    B 3.04  HX OUT T   45L    |QTY A  67    PRESS     32
    C 3.04  CABIN  T   71     |    B  18    DMP LN T  77
PPCO2  1.9                    |    C  94    NOZ  T A  64
                  1     2     |    D  94           B  64
O2 FLOW         0.0L  0.0L    | WASTE  H2O
   REG P        100   100     |QTY 1  15    PRESS     17
N2 FLOW         0.0L  0.0L    |             DMP LN T  58
   REG P        202   202     |             NOZ  T A  82
O2/N2 CNTL VLV   N2    O2     |                    B  82
H2O TK N2 P      17    17     |        VAC VT NOZ T 224
N2 QTY          131   131     | CO2 CNTLR      1     2
EMER O2 QTY       1           |FILTER  P       0.00L
        REG P     4L          |PPCO2         - 0.0L
                              |TEMP            32.0L
           A  B  C     ΔP     |BED A PRESS   0.0L  0.0L
IMU   FAN     *        4.5    |    B PRESS   0.0L  0.0L
HUMID SEP     *               |    ΔP       0.00L 0.00L
                              |VAC PRESS       0.0L
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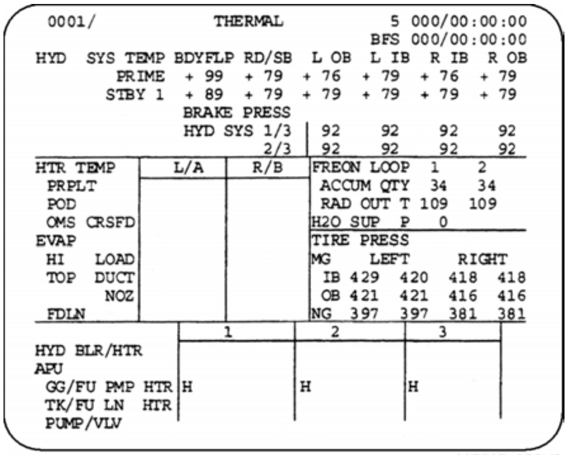
H_2O System Parameters on the ENVIRONMENT Display (DISP 66)



```
 0001/            THERMAL             5 000/00:00:00
                                    BFS 000/00:00:00
HYD  SYS TEMP BDYFLP RD/SB  L OB  L IB  R IB  R OB
          PRIME  + 99  + 79  + 76  + 79  + 76  + 79
         STBY 1  + 89  + 79  + 79  + 79  + 79  + 79
               BRAKE PRESS
               HYD SYS 1/3 | 92    92    92    92
                       2/3 | 92    92    92    92
HTR TEMP  |  L/A  |  R/B   |FREON LOOP  1     2
 PRPLT    |       |        | ACCUM QTY  34    34
 POD      |       |        | RAD OUT T 109   109
 OMS CRSFD|       |        |H2O SUP  P  0
EVAP      |       |        |TIRE PRESS
 HI   LOAD|       |        |MG    LEFT      RIGHT
 TOP  DUCT|       |        | IB 429  420  418  418
       NOZ|       |        | OB 421  421  416  416
 FDLN     |       |        |NG  397  397  381  381
                |     1      |    2     |    3     |
HYD BLR/HTR     |            |          |          |
APU             |            |          |          |
 GG/FU PMP HTR  |H           |H         |H         |
 TK/FU LN  HTR  |            |          |          |
 PUMP/VLV
```

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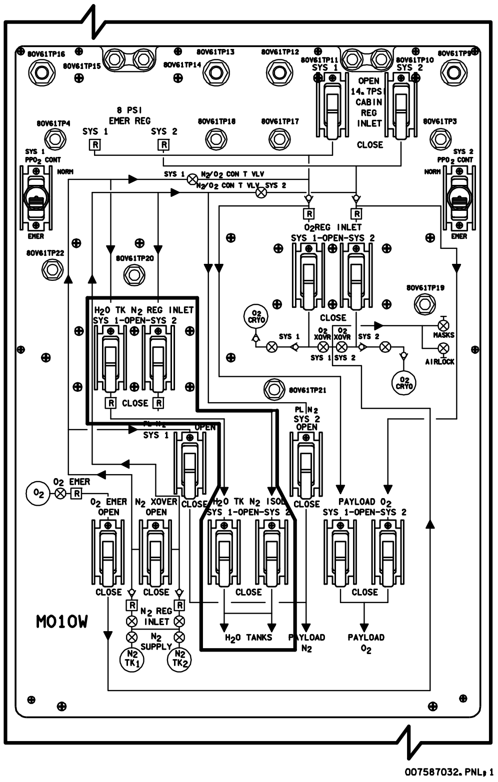
BFS THERMAL Display

Microbial Filter

The water entering tank A, which is sterilized before launch, passes through a microbial filter that adds approximately one-half parts per million iodine to the water to prevent microbial growth. The water stored in tank A is normally used for flight crew consumption; tanks B, C, and D are *commonly* used for flash evaporator cooling. The water from the microbial check valve is also directed to a galley supply valve. If the water tank A inlet valve is closed, or tank A is full, water is directed to tank B through a 1.5 psid check valve where it branches off to tank B. If the tank B inlet valve is closed, or tank B is full of water, the water is directed through another 1.5 psid check valve to the inlets to tanks C and D.

Each *supply* water tank has an inlet and outlet valve that can be opened or closed selectively to use water; however, the tank A outlet valve normally remains closed to isolate the treated water from the untreated water in the other tank.



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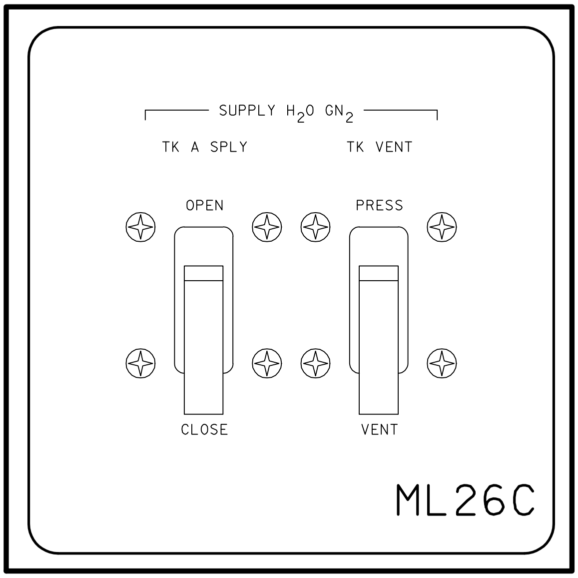
Nitrogen Supply System Valves on Panel MO10W

Tank Pressurization

Each *supply* water and waste water tank is pressurized with gaseous nitrogen from the crew compartment nitrogen supply system. The nitrogen and water are separated by a metal bellows. Nitrogen supply systems 1 and 2 can be used individually to pressurize the water tanks with nitrogen at 15.5 to 17.0 psig. Nitrogen supply system 1 is controlled by the *H_2O TK N_2 REG INLET* and *H_2O TK N_2 ISOL SYS 1* manual valves on panel MO10W. Nitrogen supply system 2 is controlled by the *SYS 2* manual valves on panel MO10W. The regulator in each nitrogen supply system controls the nitrogen pressure to the tanks at 15.5 to 17 psig, and a relief valve in each nitrogen supply system will relieve into the crew cabin if the nitrogen supply increases to 18.5 ± 1.5 psig, to protect the tanks from overpressurization.



Manual Valves on Panel ML26C

Tank Depressurization

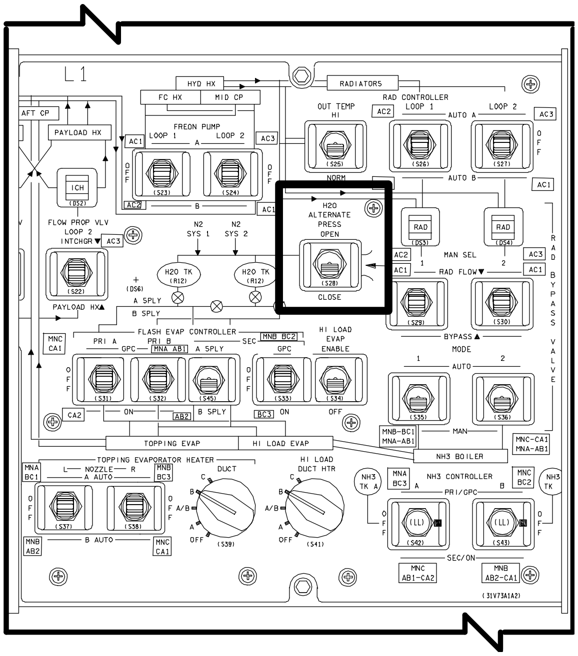
All the tanks can be vented to cabin pressure, but tank A is depressed for ascents, as described here. For only tank A, inlet nitrogen pressure is controlled by the *SPLY H_2O GN_2 TK A SPLY* and *TK VENT* manual valves on panel ML26C. When the tank A supply valve is closed, the tank is isolated from the nitrogen supply. When the tank A *vent* valve is opened, the tank is pressurized *only* by the crew cabin atmosphere. For launch, the tank A supply valve is closed, and the tank vent *valve* is opened, which lowers tank A pressure *by removing back-pressurization from the nitrogen supply system*. The fuel cell water head pressure is lower to help prevent flooding of the fuel cells during ascent. On orbit, the tank A supply valve is opened, and the tank A vent to the cabin is closed, allowing nitrogen supply pressure to tank A.

Alternate Water Pressurization

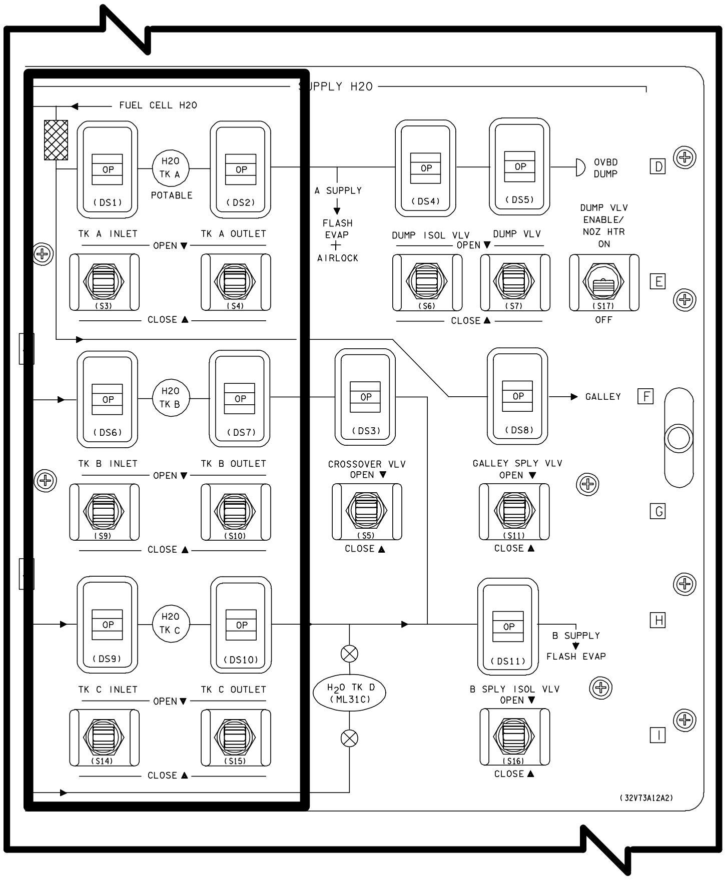
If neither nitrogen supply system 1 nor 2 can be used to pressurize the water tanks, the *H_2O ALTERNATE PRESS* switch on panel L1 can be positioned to *OPEN*, which would apply the crew cabin pressure to the water tanks. Normally, this switch is positioned to *CLOSE* to isolate the cabin pressurization system from the water tank pressurization system.

Supply Water Tank Inlet Valves

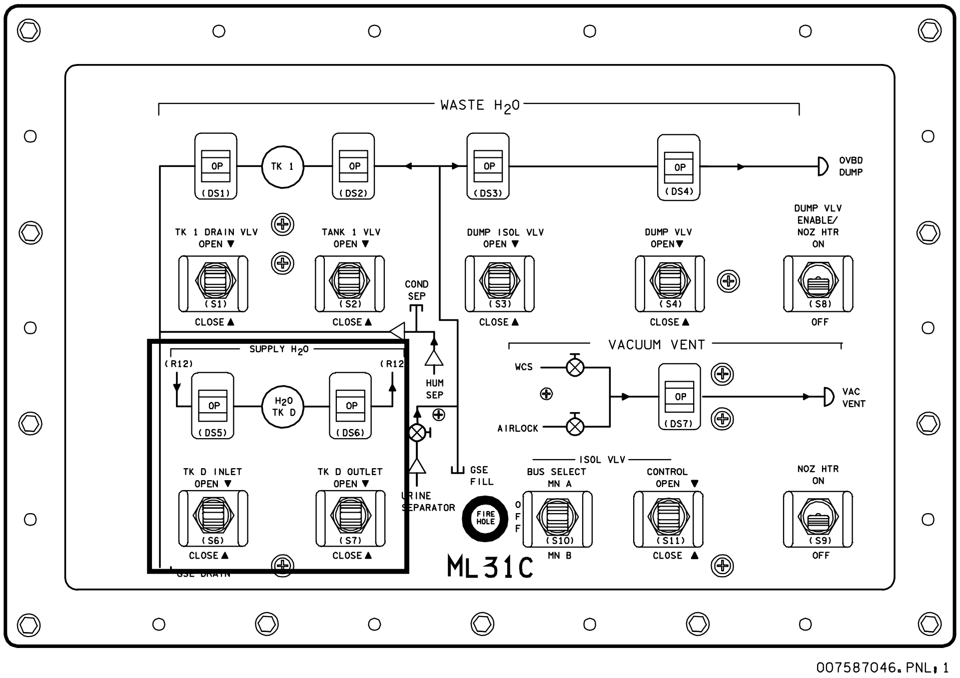
Supply water tank A, B, and C valves are controlled from panel R11L, and tank D valves are controlled from panel ML31C. When the *SUPPLY H2O TK A INLET, TK B INLET,* or *TK C INLET* switch on panel R11L is positioned to *OPEN*, the inlet valve for the tank permits water into that tank. A talkback indicator above the corresponding switch indicates *OP* when the corresponding valve is open, barberpole when the valve is in transit, and *CL* when that valve is closed. When the switch is positioned to *CLOSE*, the water inlet to that tank is isolated from the inlet water supply. The *SUPPLY H_2O TK D INLET* switch and talkback indicator are located on panel ML31C and operate in the same manner as the switches and talkbacks for tanks A, B, and C.



H_2O ALTERNATE PRESS Switch on Panel L1



TK and OUTLET Switches and Talkbacks on Panel R11L



TK INLET and OUTLET Switches and Talkbacks on Panel ML31C

Tank Outlet Valves

Positioning the *SUPPLY H2O TK A, B,* or *C OUTLET* switch on panel R11L to *OPEN* permits water from the corresponding tank to flow from the tank into the water outlet manifold due to the tank nitrogen pressurization system. A talkback indicator above the switch would indicate *OP* when that valve is open, barberpole when it is in transit, and *CL* when it is closed. The *CLOSE* position of each switch isolates that water tank from the water outlet manifold. The *SUPPLY H_2O TK D OUTLET* switch and talkback indicator are located on panel ML31C and operate in the same manner as the tank A, B, and C switches and talkback indicators on panel R11L.

If the *supply* water tank B outlet valve is opened (normally tank A is used only for crew consumption), water from the corresponding tank is directed to the water outlet manifold. The tank A and B water is then available to the extravehicular mobility unit (EMU) fill in the airlock, to the flash evaporator water supply system A, and to the water dump *line*. The tank A outlet valve is normally closed to prevent contamination of the water in tank A. Thus, tank B would supply water to flash evaporator water supply system A and to the EMU fill in the airlock. If it is necessary to provide space for storing water in tank A and/or B, tank A and/or B water can be dumped overboard.

An external airlock water transfer valve and line *are installed in* the orbiters. The valve and line *could* provide capability to transfer water from the orbiter's supply H_2O system to the International Space Station (ISS). *However, there are no current plans to use this water transfer capability.* This configuration is covered in more detail in the ODS section of this document.

If the tank C or D outlet valve is opened, water from either tank is directed to the water outlet manifold. The water is then available to the flash evaporator B water supply.

Supply Water Crossover Valves

A crossover valve installed in the water outlet manifold is controlled by the *SUPPLY H2O CROSSOVER VLV* switch on panel R11L. When the switch is positioned to *OPEN*, the crossover valve opens and allows tank A or B (also C or D) to supply *both* flash evaporator water supply systems A and B, the EMU fill in the airlock, and *the* water dump *line*. A talkback indicator above the switch indicates *OP* when the crossover valve is opened, barberpole when the valve is in transit, and *CL* when the valve is closed. The *CLOSE* position isolates the water manifold between the tank A and B outlets and the tank C and D outlets.

Contingency Water Container Fill Configuration

There is an additional supply H_2O tank configuration for ISS to transfer H_2O to the ISS via contingency water container (CWC) bags. In this configuration, the tank A outlet is OPEN, the tank B inlet is CLOSED, *and* the XOVER valve is closed. The circuit breakers on ML86B that provide power to the tank B inlet and the XOVER *valves* are then pulled to preclude inadvertent valve opening. This configuration allows tanks A and B to be used for potable H_2O transfer and tanks C and D to be used for FES operations. This configuration may remain a *backup* option *if* the supply H_2O transfer lines *become* operational on the ISS.

Supply Isolation Valve

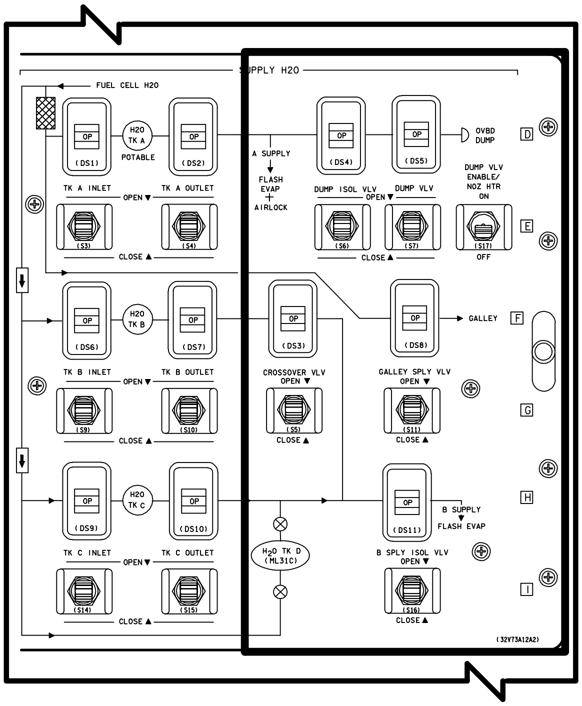
Water from supply system A is routed directly to the flash evaporator. Water from system B is routed to an isolation valve in the system. The valve is controlled by the *SUPPLY H2O B SPLY ISOL VLV* switch on panel R11L. When the switch is positioned to *OPEN*, water from supply system B is directed to the flash evaporator. A talkback above the switch indicates *OP* when the valve is opened, barberpole when it is in transit, and *CL* when the valve is closed. The *CLOSE* position isolates water supply system B from the flash evaporator.

Supply Water Dumps

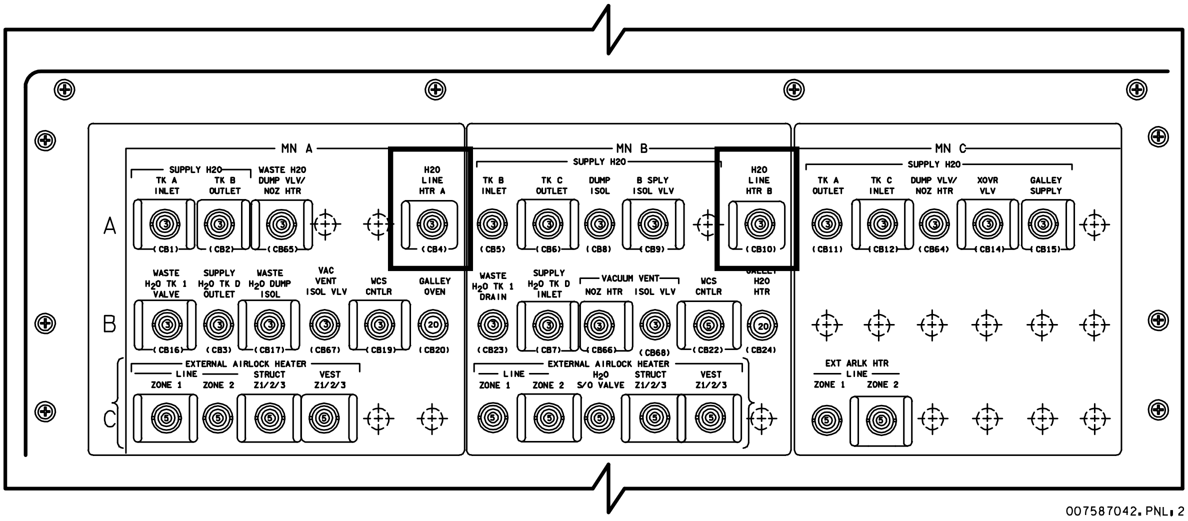
Supply water from all the tanks can be dumped overboard, if necessary, through a dump isolation valve and a dump valve. *Supply* water from tank C or D can also be dumped overboard, if necessary, through the crossover valve and through the dump isolation valve and dump valve. The overboard dump isolation valve is located in the crew cabin, and the dump valve is located in the midfuselage.

The dump isolation valve is controlled by the *SUPPLY H2O DUMP ISOL VLV* switch on panel R11L. The dump valve is controlled by the *SUPPLY H2O DUMP VLV* switch on panel R11L.

The *SUPPLY H2O DUMP VLV ENABLE/NOZ HTR* switch on panel R11L must be positioned to *ON* to supply electrical power to the *SUPPLY H2O DUMP VLV* switch. The *ON* position also applies power to the nozzle heaters, which warm the nozzles to prevent freezing when the dump valve is opened. When the *DUMP VLV* and *DUMP ISOL VLV* switches are positioned to *OPEN*, the corresponding valve is opened, which allows *supply* water to be dumped overboard. A talkback indicator above each switch indicates *OP* when the corresponding valve is open, barberpole when it is in transit, and *CL* when it is closed. Closing either valve inhibits the dumping of *supply* water. At the completion of the dump, each switch is positioned to *CLOSE* to close the corresponding valve. The nozzle heater is then deactivated by placing the *SUPPLY H2O DUMP VLV ENABLE/NOZ HTR* switch to *OFF*.



SUPPLY H2O CROSSOVER VLV, ISOL VLV, and DUMP VLV Switches and Talkback on Panel R11L



H2O LINE HTR Circuit Breakers on Panel ML86B

Contingency Crosstie

There is a contingency crosstie connection in the supply water overboard dump line between the dump isolation valve and dump valve. There is a corresponding crosstie connection in the waste water overboard dump line between the dump isolation valve and dump valve. These crosstie connections permit joining the waste water system through a flexible hose to the supply water system for emergency dumping of waste water through the supply water dump nozzle (and vice versa). CWC bags are also filled through the contingency crosstie for emergency storage of supply or waste water. The CWC bags nominally hold 95 pounds of H_2O and are stowed in the middeck for entry.

Supply H_2O Dump Line Purge Device

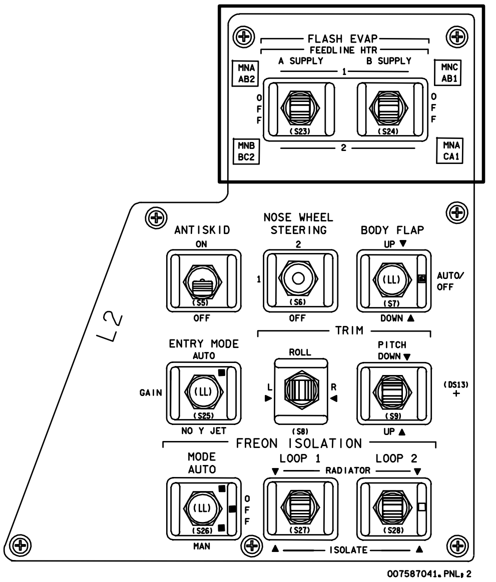
Before beginning a supply H_2O dump, a purge device is installed in the supply H_2O quick disconnect of the contingency crosstie. The purge device allows cabin air at ~3 lb/hr to purge the supply H_2O dump valve of any remaining water droplets to preclude a condition known as “burping” of the dump valve. When the water droplets freeze under the dump valve, they expand and could cause the dump valve to open. Purging the valve post dump alleviates this problem.

Dump Nozzle Heaters

The supply water dump nozzle employs a heater to prevent freezing of the supply water dump nozzle at the midfuselage. The dump nozzle heater is powered when the *SUPPLY H2O DUMP VLV ENABLE/NOZ HTR* switch on panel R11L is positioned to *ON*. When the switch is positioned to *OFF*, it removes electrical power from the nozzle heater, as well as the *SUPPLY H2O DUMP VLV* switch, which causes the dump valve to close.

The supply water line upstream of the water dump nozzle has electrical heaters on the line to prevent supply water from freezing. The A and B heaters on the line are thermostatically controlled and are powered by the *H_2O LINE HTR A* and *B* circuit breakers on panel ML86B. (These circuit breakers also provide power to thermostatically controlled heaters on the waste water line and the waste collection system vacuum vent line.)

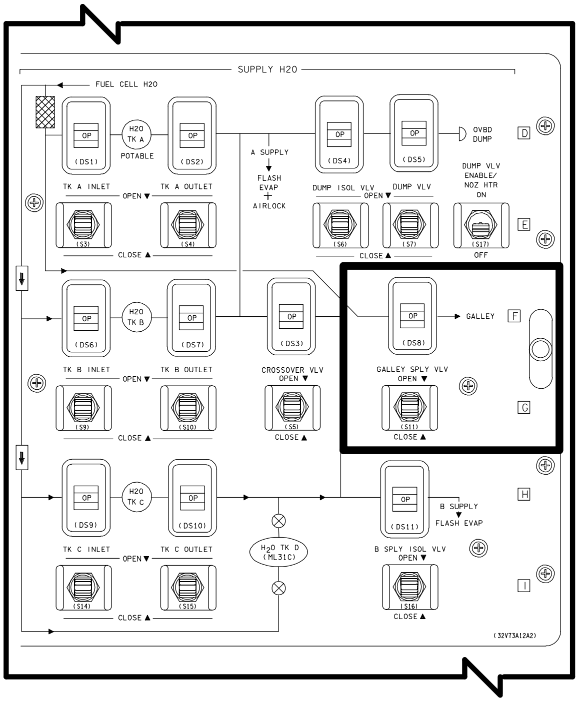
The supply water feed lines to the flash evaporators are approximately 100 feet long. To prevent the water in the lines from freezing, redundant heaters are installed along the length of the water lines. The heaters are controlled by the *FLASH EVAP FEEDLINE HTR A SUPPLY* and *B SUPPLY* switches on panel L2. When a switch is positioned to *1*, it enables the thermostatically controlled heaters on the corresponding supply line to automatically control the temperature on that line. When a switch is positioned to *2*, it enables the redundant thermostatically controlled heater system on the corresponding supply line. The *OFF* position of each switch inhibits heater operation on the corresponding supply line.



FLASH EVAP FEEDLINE HTR Switches on Panel L2

Galley Water Supply

The galley supply valve in the supply water line from the microbial filter of tank A permits or isolates the supply water from the galley or water dispenser. When the *SUPPLY H2O GALLEY SUP VLV* switch on panel R11L is positioned to *OPEN*, supply water is routed through parallel paths: one path flows through the atmospheric revitalization system water coolant loop water chiller for cooling of the supply water, and the other path bypasses the water chiller with ambient temperature water. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. The *CLOSE* position of the switch isolates the potable supply water from the middeck ECLSS supply water panel.



GALLEY Water Supply Switch and Talkback on Panel R11L

If the galley is not available *or* manifested for a flight, the chilled water and ambient water are connected to an Apollo water dispenser to dispense ambient and chilled water for drinking and food reconstitution.

Waste Water System

A single waste water tank receives waste water from the humidity separator and the waste management system. The tank is located beneath the crew compartment middeck floor next to the *supply* water tanks.

The waste water tank holds 165 pounds *of expellable water (plus 3.3 pounds residual)*, is 35.5 inches long and 15.5 inches in diameter, and weighs 39.5 pounds dry. It is pressurized by gaseous nitrogen from the same source as the *supply* water tanks.

Waste water is directed to the waste water tank 1 inlet valve, which is controlled by the *WASTE H_2O TANK 1 VLV* switch on panel ML31C. When the switch is positioned to *OPEN*, waste water is directed to the waste water tank. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. Positioning the switch to *CLOSE* closes the waste water tank inlet, isolating the waste water tank from the waste water collection system. When the valve is open, waste water from the tank can also be directed to the waste water dump *line* for overboard dumping. The waste water tank 1 outlet valve (or drain valve) operates the same as the inlet valve. It is controlled by the WASTE H_2O TK 1 DRAIN VLV switch on panel ML31C. The addition of the condensate quick disconnect (QD) required the humidity separator common outlet to be plumbed to the waste tank via the drain line. When the waste water outlet valve is OPEN, humidity waste will flow into the waste tank. During *condensate* collection, the outlet valve will be closed and humidity waste water will flow into a connected CWC bag to be disposed of later. This valve is also opened for ground draining of the tank.

Waste Water Dumps

The waste water dump isolation valve and waste water dump valve in the waste water dump line allow waste water to be dumped overboard through the waste water dump *nozzle*. The *WASTE H_2O DUMP ISOL VLV* switch on panel ML31C positioned to *OPEN* allows waste water to be directed to the waste water dump valve. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed.

For waste water to be dumped overboard, the waste water dump valve must be opened. It is controlled by the *WASTE H_2O DUMP VLV ENABLE/NOZ HTR* and *WASTE H_2O DUMP VLV* switches on panel ML31C. When the *WASTE H_2O DUMP VLV ENABLE/NOZ HTR* switch is positioned to *ON*, electrical power is supplied to the waste water dump *nozzle* heaters and the *WASTE H_2O DUMP VLV* switch. *The heaters at the waste water dump nozzle* *prevent waste water from freezing at the overboard dump nozzle.*

When the *WASTE H_2O DUMP VLV* switch is positioned to *OPEN*, the dump valve allows waste water to be dumped overboard. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. If waste water is dumped overboard, the *DUMP ISOL VLV* switch is positioned to *CL* upon completion of the dump. The *WASTE H_2O DUMP VLV* is positioned to *CLOSE*, and the *WASTE H_2O DUMP VLV ENABLE/NOZ HTR* switch is set to *OFF*.

CAUTION

If the *DUMP VLV ENABLE/NOZ HTR* switch is positioned to *OFF* before the *DUMP VLV* switch is positioned to *CLOSE*, the dump valve will remain open *and the heaters protecting the dump nozzle from freezing will be deactivated*.

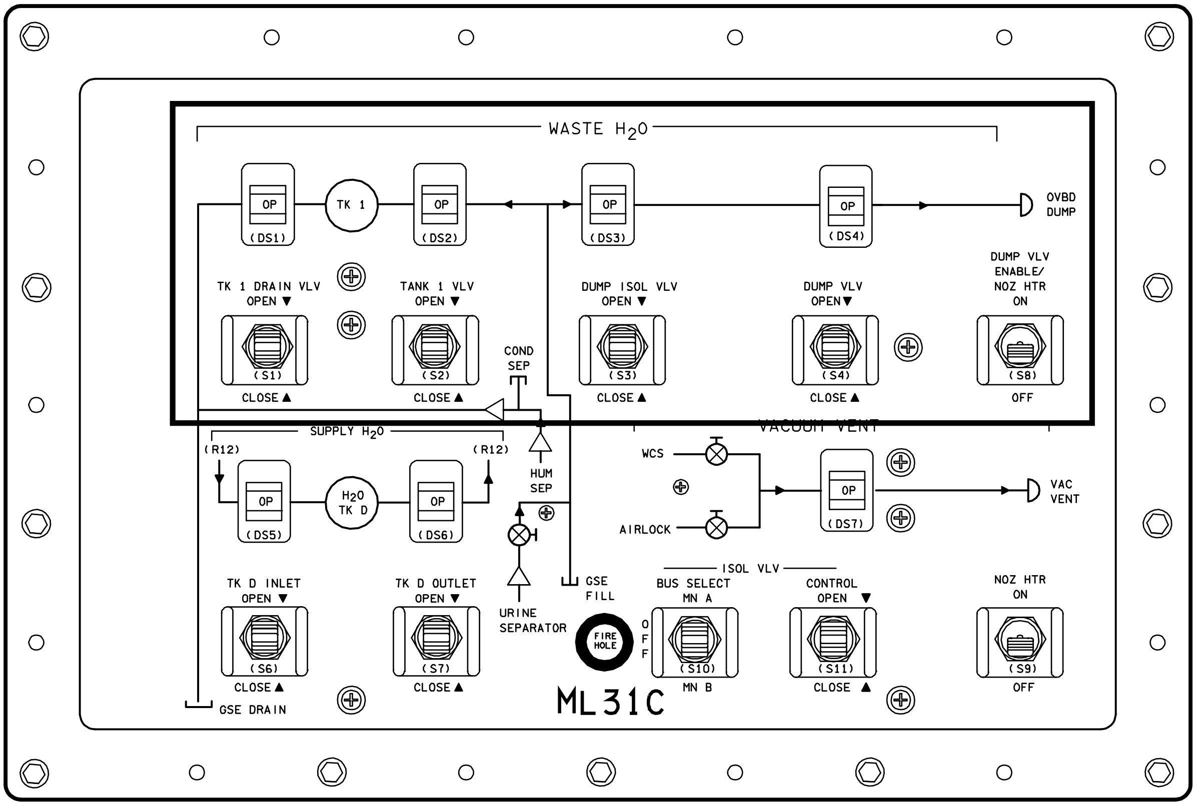
The waste water dump line, upstream of the waste dump nozzle, has electrical heaters on the line to prevent waste water from freezing. The thermostatically controlled A and B heaters are powered by the *H_2O LINE HTR A* and *B* circuit breakers on ML86B. (These circuit breakers also provide power to thermostatically controlled heaters on the supply water line and waste collection system vacuum vent line.)

Contingency Crosstie

The contingency crosstie quick disconnect in the waste water overboard dump line between the dump isolation valve and dump valve permits waste water to be joined with the supply water system through a flexible hose for emergency dumping of supply water through the waste water dump or using waste water for the flash evaporators.

Waste Water Tank Draining

The waste water tank 1 drain valve controls the draining of the waste water tank during ground



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WASTE H_2O System Switches and Talkbacks on Panel ML31C

operations through the ground support equipment flush and drain. When the *WASTE H_2O TK 1 DRAIN VLV* switch on panel ML31C is positioned to *OPEN*, the valve permits the draining and flushing of the waste water tank. The drain line is capped during flight. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed.

Operations

Pressure Control System

For ascent, both 14.7 psia cabin regulator inlet valves are closed to isolate the 14.7 psia cabin regulators. If a cabin leak develops, this configuration conserves nitrogen by not allowing any makeup flow into the cabin until the cabin pressure drops below 8 psia. The O_2 regulator inlet valves are closed, directing all the O_2 to the O_2 crossover manifold to supply the launch and entry suit helmets. The O_2/N_2 control valve on pressure control system 1 is open to allow N_2 to pressurize the O_2/N_2 manifold. The O_2/N_2 control valve on pressure control system 2 is closed. This would normally allow oxygen to flow to the O_2/N_2 manifold, but since the oxygen regulators are closed, nothing is configured to flow through the emergency 8 psia regulators on pressure control system 2. The crew will close the visors of their launch and entry suit helmets shortly before lift-off and breathe 100 percent O_2 until shortly after solid rocket booster separation.

The pressure control system remains in the ascent configuration until early in the flight plan when the orbit pressure control system configuration is performed. The pressure control system configuration to system 1 typically is called for in the flight day 1 EZ activities block. The 14.7 psia cabin regulator inlet valve on the selected pressure control system is opened. This enables the cabin regulator to automatically maintain the cabin pressure at 14.7 psia. The O_2 regulator inlet valve is opened, and the selected system O_2/N_2 control valve is taken to *AUTO*. This enables the O_2/N_2 controller to control whether O_2 or N_2 flows into the O_2/N_2 manifold based on cabin PPO_2 level. During *late Flight Day 1 timeline* activities, *the* O_2 bleed orifice is installed in launch and entry helmet QD-8. The O_2 bleed orifice is sized based on number of crew and compensates for the crew's metabolic O_2 usage by flowing O_2 directly into the cabin. This helps keep the PPO_2 level stable when the cabin pressure is greater than 14.7 psia and the cabin regulators are not flowing. *It also minimizes automatic switchovers of the O_2/N_2 controller and, in doing so*, *lessens the chances for annunciating an O_2 or N_2 high flow alarm.* A reconfiguration to pressure control system 2 *may be* performed halfway through the mission *or post-undocking on flights to the ISS*.

A 10.2 psia cabin protocol was developed by the flight surgeons to minimize the risk of decompression sickness (bends) for crewmembers preparing for an EVA. The EVA crewmembers must prebreathe pure O_2 before they go EVA to help flush N_2 out of their body tissue. The following 10.2 cabin protocol options have been developed:

- Option 1
    - 60-minute initial prebreathe on launch and entry suit helmet
    - 12 hours at 10.2 psia cabin pressure
    - 75-minute final prebreathe in suit
- Option 2
    - 60-minute initial prebreathe on launch and entry suit helmet
    - 24 hours at 10.2 psia cabin pressure
    - 40-minute final prebreathe in suit
- Option 3
    - 4-hour prebreathe in suit

For scheduled EVAs, option 1 or 2 is chosen to minimize the in-suit prebreathe just prior to the EVA. The cabin is depressurized to 10.2 psia using the airlock depressurization valve located in the airlock. Because there is no 10.2 psia cabin regulator, the cabin pressure and the PPO_2 levels must be manually managed during 10.2 psia cabin operations.

NOTE

> If a 10.2 depress is scheduled early in the mission, the PCS 1 configuration may be delayed until 10.2 operations are no longer required. This saves consumables during consumable-critical missions, such as ISS docking missions, where orbiter O_2 and N_2 are used to repress and resupply the ISS.

The pressure control system configuration is the same for entry as it was for ascent.

Atmospheric Revitalization System

The atmospheric revitalization system is already configured for ascent at crew ingress. One cabin fan, one humidity separator, one IMU fan, and one fan in each avionics bay are already operating. The cabin temperature control valve is positioned in the *FULL COOL* position by powering the controller and adjusting the rotary switch to the *COOL* position. Once the *FULL COOL* position is reached, cabin temperature controller 1 is unpowered. The humidity separators and the IMU fan signal conditioners are unpowered to protect against an *AC* to *AC* bus short, which could cause loss of a main engine controller. (The wire bundle that carries power to these signal conditioners had a short on STS-6.) Water loop 2 is on, and water loop 1 is off during ascent. Both water bypass valves are positioned to flow approximately 950 lb/hr through the Freon/water interchanger.

If no failures occur during ascent, no actions are required to manage the atmospheric revitalization system in OVs 103 and 104 (OV-105 if flown without the RCRS), with the exception of scheduled LiOH canister changeouts. During the post insertion period for RCRS configured vehicles, the crew will activate the system. Every 13 minutes, the RCRS will automatically switch chemical beds between regeneration and adsorption as part of a 26-minute full regeneration cycle with no further crew actions for nominal operations. Mid-mission (on 10+ day flights), the activated charcoal canister will be changed out. *Additionally, during deorbit prep for RCRS configured vehicles, the crew will replace the LiOH canister, and deactivate the RCRS.* The operating cabin fan(s) should be turned off for removal and installation of *LiOH and charcoal* canisters.

The orbit fan and pump configuration is the same on orbit as for ascent, except water loop 1 is set to the *GPC* position and the BYPASS controller for water loop 2 is set to the AUTO position. While in SM OPS 2, the *GPC* position enables the inactive water loop to be cycled on periodically. This periodic cycling prevents the inactive water loop from freezing. The cycling sequence is initiated any time an OPS transition is made into SM OPS 2. When an OPS transition is made, the pump will receive a 6-minute *ON* command, then remain off for 4 hours. The pump will *nominally* cycle on for 6 minutes every 4 hours.

The pump on water loop 2 is powered by AC3 when its switch is in the *ON* position. The GPC position of the *WATER PUMP LOOP 2* switch provides an alternate power source for the pump during ascent and entry. When the BFS computer has control of the payload MDMs, the GPC position powers the loop 2 pump with AC1 power. Since water loop 2 has only one pump, this enables the pump to remain powered even if AC3 should fail. However, the circuit breakers that provide AC1 power to the GPC position of H_2O loop 2 and the A pump of H_2O loop 1 are *nominally* pulled for the entire mission. This is because of the possibility of an AC1-to-AC3 short as a result of a relay failure or switch failure. If power is required for the pump to operate, these circuit breakers will need to be pushed in. The *GPC* position of the *WATER LOOP 1 PUMP* switch has no special function during ascent and entry; it acts just like the *OFF* position.

If the situation arises where no PASS SM or BFS computers are available, the water loop pumps can still be commanded on in the GPC position using real-time commands. The real-time commands can be issued by a ground uplink or crew inputs on DPS UTILITY SPEC 1. The real-time commands must be issued through the computer that has control of the payload MDMs. It would take a severe loss of system redundancy for the use of real-time commands to ever be required.

Cooling Management

Depending on the mission phase, the Freon cooling loops are cooled four different ways. Prior to launch, cooling is provided by the ground support equipment. After lift-off, there is no active means of cooling until *about the time of* solid rocket booster separation. It takes the orbiter slightly more than 2 minutes to reach an altitude where water evaporation provides effective cooling. Until that time, sufficient "thermal inertia" is in the Freon loops to limit the temperature increase so that no active heat rejection is required.

At solid rocket booster separation, the flash evaporator system receives a GPC ON command from the BFS and begins providing active cooling. The FES continues to be the primary cooling source through the ascent phase and on into the post insertion timeframe. During the Post Insertion checklist procedures, flow is initiated through the radiators, the payload bay doors are opened, and the radiators become the primary source of cooling. The topping FES may be left on to provide supplemental cooling when necessary. If the orbiter is in a warm attitude, the radiator panels may not be effective enough to provide the desired cooling. The FES can provide the additional cooling necessary to achieve the desired Freon loop temperatures.

During the deorbit prep procedures, the radiators are cold soaked for use later during entry. The radiator coldsoak process stores cool Freon in the radiator panels. This is accomplished by changing the radiator control temperature *set point* from *NORM to HI (*38° to 57° F*)*. The FES is reactivated to cool the Freon loops from 57° to 39° F. Since less cool Freon from the radiator panels is required to achieve the 57° F RAD OUT temperature, the Freon stays in the radiator panels longer and becomes even cooler. After being in this configuration for a little over an hour, the radiators are bypassed, and the FES begins providing all the cooling. The FES provides the cooling during the rest of the deorbit, through entry interface, and on down to *about* V = 12k (approximately 175,000 ft). *Below 100,000 ft, the atmospheric pressure is too high for the FES to cool effectively.* At V = 12k, the radiator *controllers* are *activated and* put through their auto startup sequence, and radiator flow is reinitiated *to utilize the stored Freon coldsoak*. Normally, the radiator coldsoak is used as the primary source of *vehicle* cooling from this point through rollout.

Once *the* radiator coldsoak is depleted, the ammonia boilers are used as the primary cooling source until the ground support equipment cooling cart hookup is complete. Then the ammonia cooling is deactivated, and ground support equipment cooling is initiated.

For ascent aborts, the thermal management of the Freon cooling is somewhat different. The FES still provides the cooling after solid rocket booster separation. The cooling management during the entry portion changes. The ammonia boilers provide the cooling during the lower stages of the abort entry. The ammonia is used for cooling during the entry phase of an ascent abort because the orbiter lifts off without a radiator coldsoak, and the FES functions normally only at low atmospheric pressure (above 100,000 ft).

For a transoceanic abort landing *(TAL)* or an abort once around *(AOA)*, the ammonia boiler receives a GPC "ON" command from the BFS at MM 304 and 120,000 ft. For a return to launch site abort, the ammonia boiler receives a GPC "ON" command from the BFS at external tank separation (MM 602). The ammonia boiler will provide the cooling from this point through landing. The ammonia boilers can provide cooling for approximately *30 to 40 minutes under ascent abort conditions*.

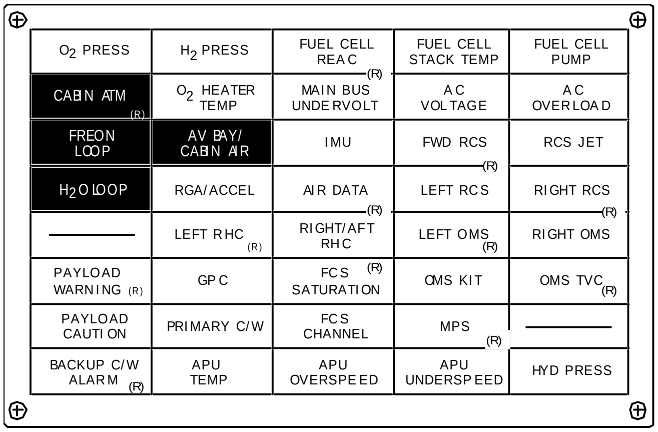
ECLSS Caution and Warning Summary

- The red *CABIN ATM* caution and warning light on panel F7 is illuminated for any of the following monitored parameters: (1) cabin pressure below 13.76 psia *(13.74 psia for OV-104)* or above, 15.36 psia *for OV-103, 15.53 psia for OV-104, and 15.35 for OV-105*, (2) PPO_2 below 2.7 psia or above 3.6 psia, (3) oxygen flow rate above 4.9 pounds per hour, and (4) nitrogen flow rate above 4.9 pounds per hour.

- The yellow *AV BAY/CABIN AIR* C/W light will illuminate for the following conditions: any avionics bay temperature higher than 130° F, the heat exchanger out temperature higher than 145° F, or cabin fan delta P below *4.16* inches of water or greater than 6.8 inches.

- The yellow *H_2O LOOP* C/W light will illuminate if the outlet pressure of water coolant loop pump 1 is less than 19.5 psia or greater than 79.5 psia, or if pump 2 pressure is less than 45 psia or greater than 81 psia.

- The yellow *FREON LOOP* light will illuminate if Freon flow in either coolant loop is less than *1186 lbm/hr*, or if either loop's Evap Out Temperature is less than 32.2° F or greater than 64.8° F (upper limit for ascent is 115° F.)



ECLSS Caution and Warning Lights on Panel F7

ECLSS Summary Data

- The functions of the ECLSS are to maintain the orbiter's thermal stability, provide a pressurized, habitable environment for the crew and onboard avionics, and store water and liquid waste.

- The four components of the ECLSS are the pressure control, atmospheric revitalization, active thermal control, and supply and waste water systems.

- The pressure control system pressurizes the crew cabin at 14.7 psia, pressurizes the supply and waste water tanks, and provides breathing oxygen directly to the launch and entry suit helmets, and emergency breathing masks.

- The main components of the pressure control system are oxygen and nitrogen systems, tanks, and valves.

- The atmospheric revitalization system circulates air through the crew compartment to control relative humidity between 30 and 65 percent, maintain carbon dioxide and carbon monoxide at non-toxic levels, air filtration, control temperature and ventilation in the crew compartment, and provide avionics cooling. The water loop provides cooling for the crew and avionics.

- The atmospheric revitalization system consists of cabin air loops, water coolant loops, fans, and heat exchangers and interchangers.

- The active thermal control system provides orbiter heat rejection during all phases of the mission.

- The active thermal control system consists of two complete, identical Freon coolant loop systems, cold plate networks for cooling avionics units, liquid/liquid heat exchangers, and radiators, flash evaporators, and ammonia boilers.

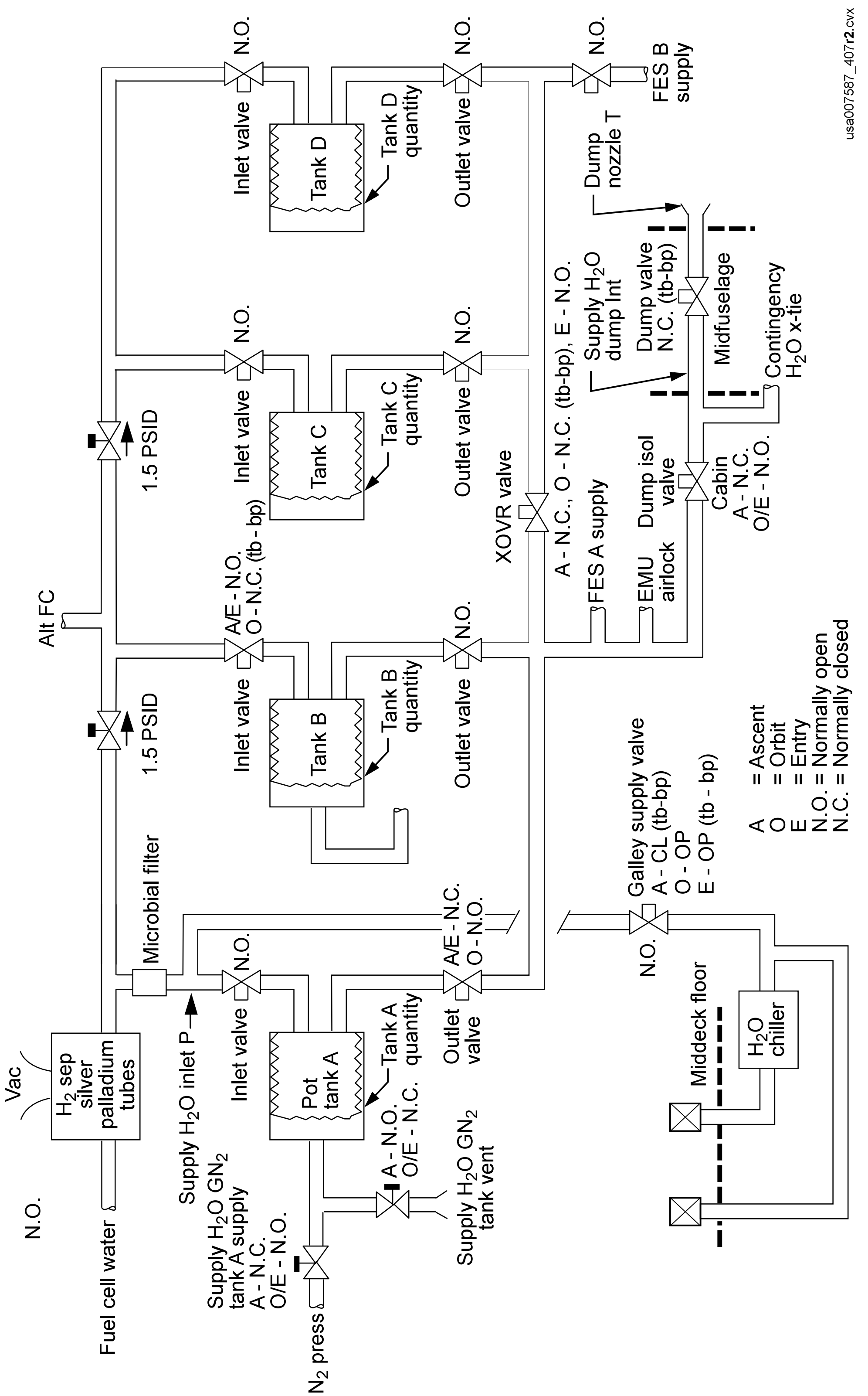
- The supply water system stores water generated by the fuel cells. The supply water is used for flash evaporator system cooling, crew consumption, and hygiene.

- The waste water system stores waste from the crew cabin humidity separator and from the crew.

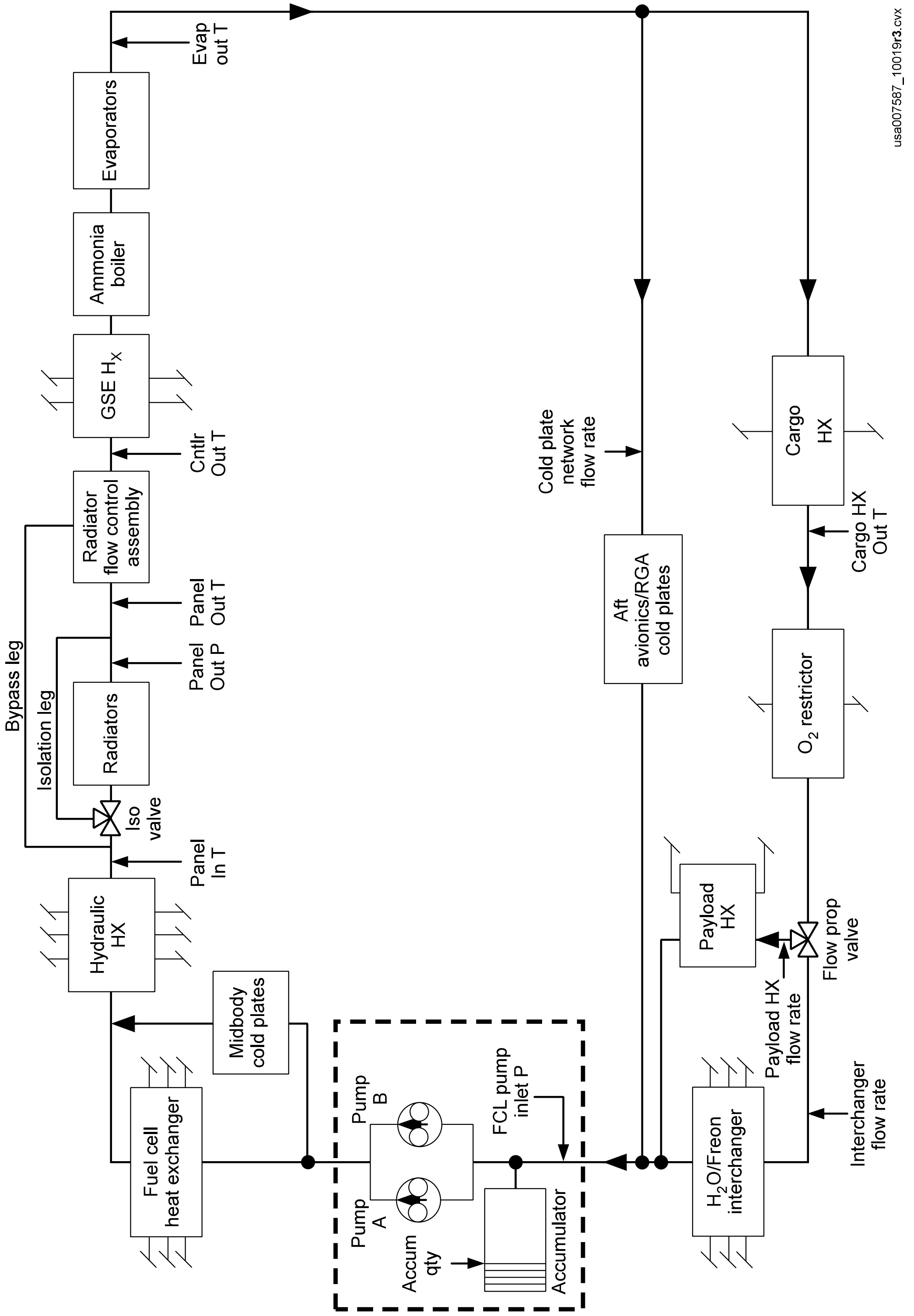
- Four supply water tanks and one waste water tank are located beneath the crew compartment middeck floor.

- Panels that control the major portion of ECLSS functions are panels L1, L2, MO10W, and R11L. Panels ML31C, ML86B, MA73C, R13L, MO51F, and MD44F also control ECLSS functions.

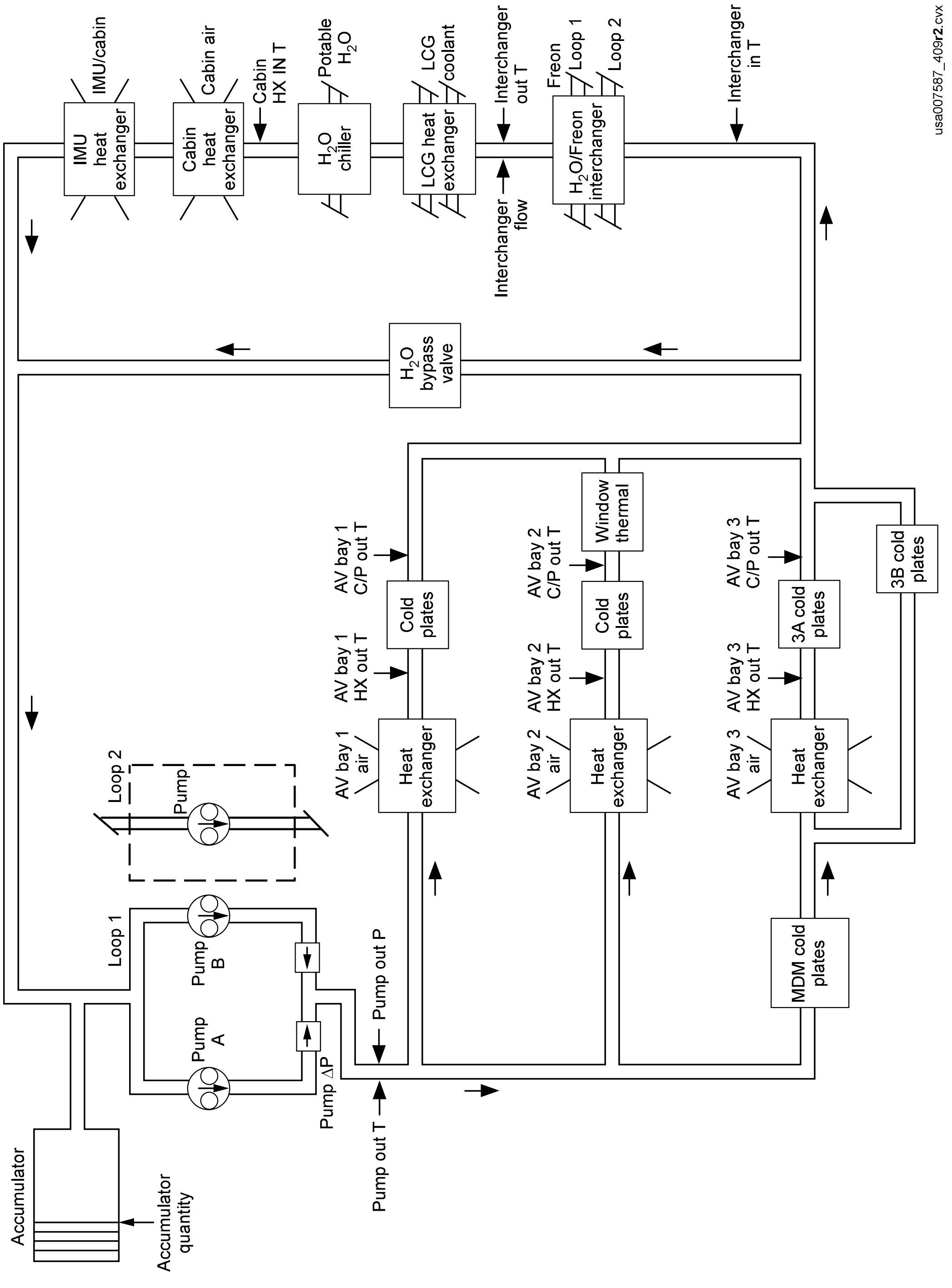
- ECLSS status can be monitored on panel O1 and on the following DPS displays: ENVIRONMENT (DISP 66), SM SYS SUMM 1, SM SYS SUMM 2, APU/ENVIRON THERM (DISP 88), and BFS THERMAL.



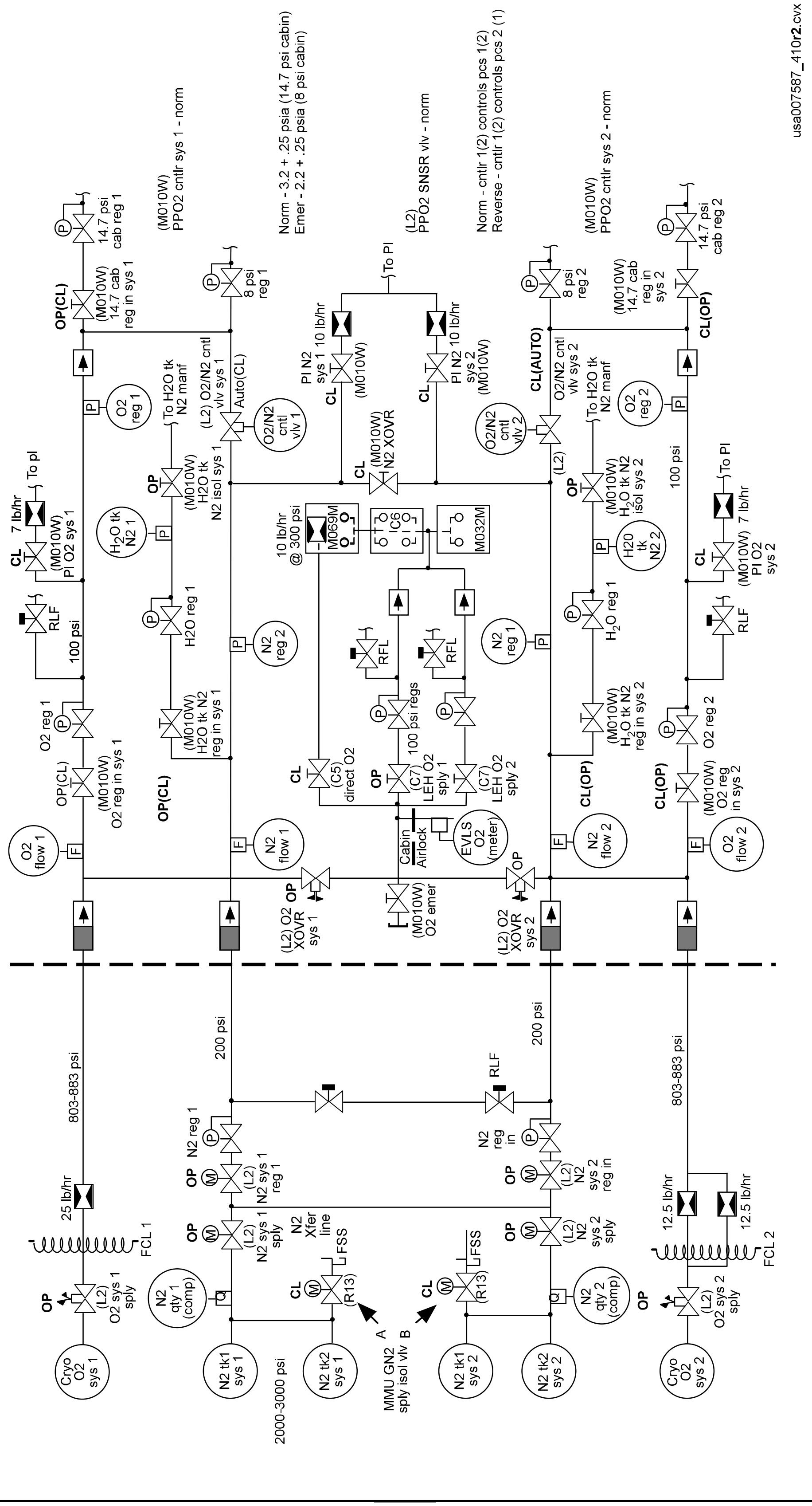
Supply Water Storage System


Evap out T
Evaporators
Ammonia boiler
GSE H_X
Cntlr Out T
Radiator flow control assembly
Panel Out T
Panel Out P
Bypass leg
Isolation leg
Radiators
Iso valve
Panel In T
Hydraulic HX
Midbody cold plates
Fuel cell heat exchanger
Pump B
Pump A
FCL pump inlet P
Accum qty
Accumulator
Cold plate network flow rate
Aft avionics/RGA cold plates
Cargo HX
Cargo HX Out T
O_2 restrictor
Payload HX
Payload HX flow rate
Flow prop valve
H_2O/Freon interchanger
Interchanger flow rate
usa007587_10019r3.cvx

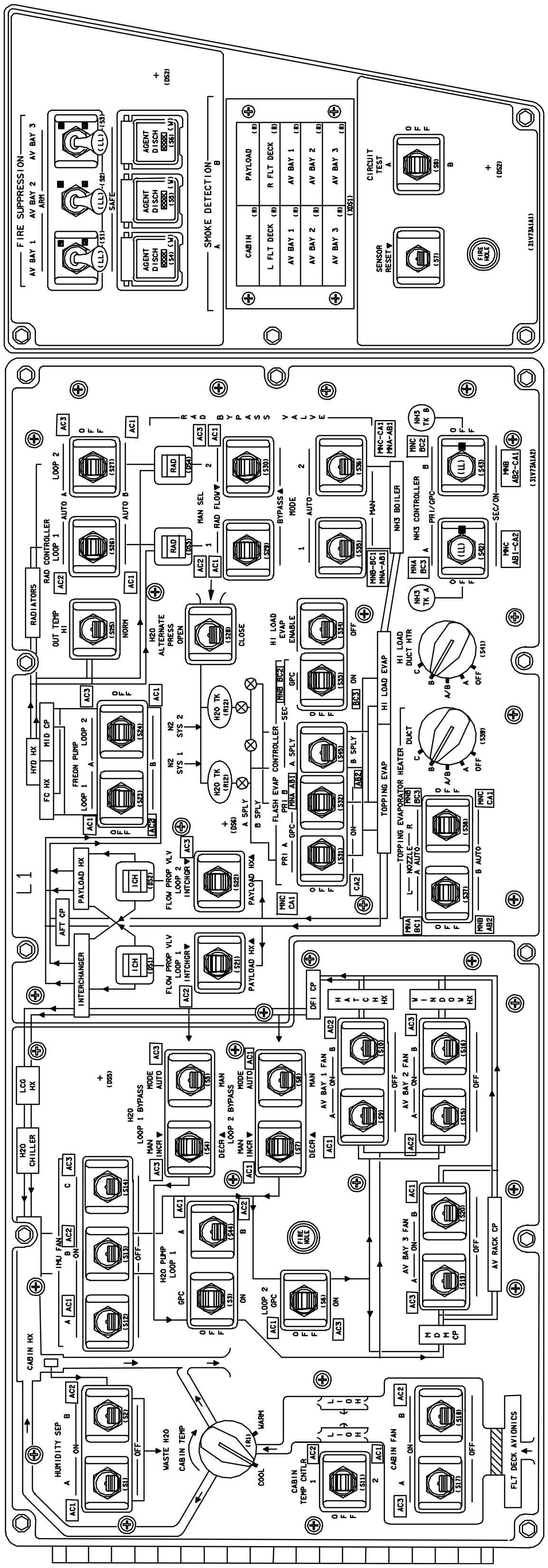
Freon Loops


IMU/cabin
IMU heat exchanger
Cabin air
Cabin heat exchanger
Cabin HX IN T
Potable H_2O
H_2O chiller
LCG coolant
LCG heat exchanger
Interchanger out T
Interchanger flow
Freon Loop 1
Loop 2
H_2O/Freon interchanger
Interchanger in T
usa007587_409r2.cvx
H_2O bypass valve
AV bay 1 C/P out T
AV bay 1 HX out T
AV bay 1 air
Cold plates
Heat exchanger
Window thermal
AV bay 2 C/P out T
AV bay 2 HX out T
AV bay 2 air
Cold plates
Heat exchanger
AV bay 3 C/P out T
AV bay 3 HX out T
AV bay 3 air
3A cold plates
3B cold plates
Heat exchanger
MDM cold plates
Loop 2
Pump
Loop 1
Pump B
Pump A
Pump out P
Pump ΔP
Pump out T
Accumulator
Accumulator quantity

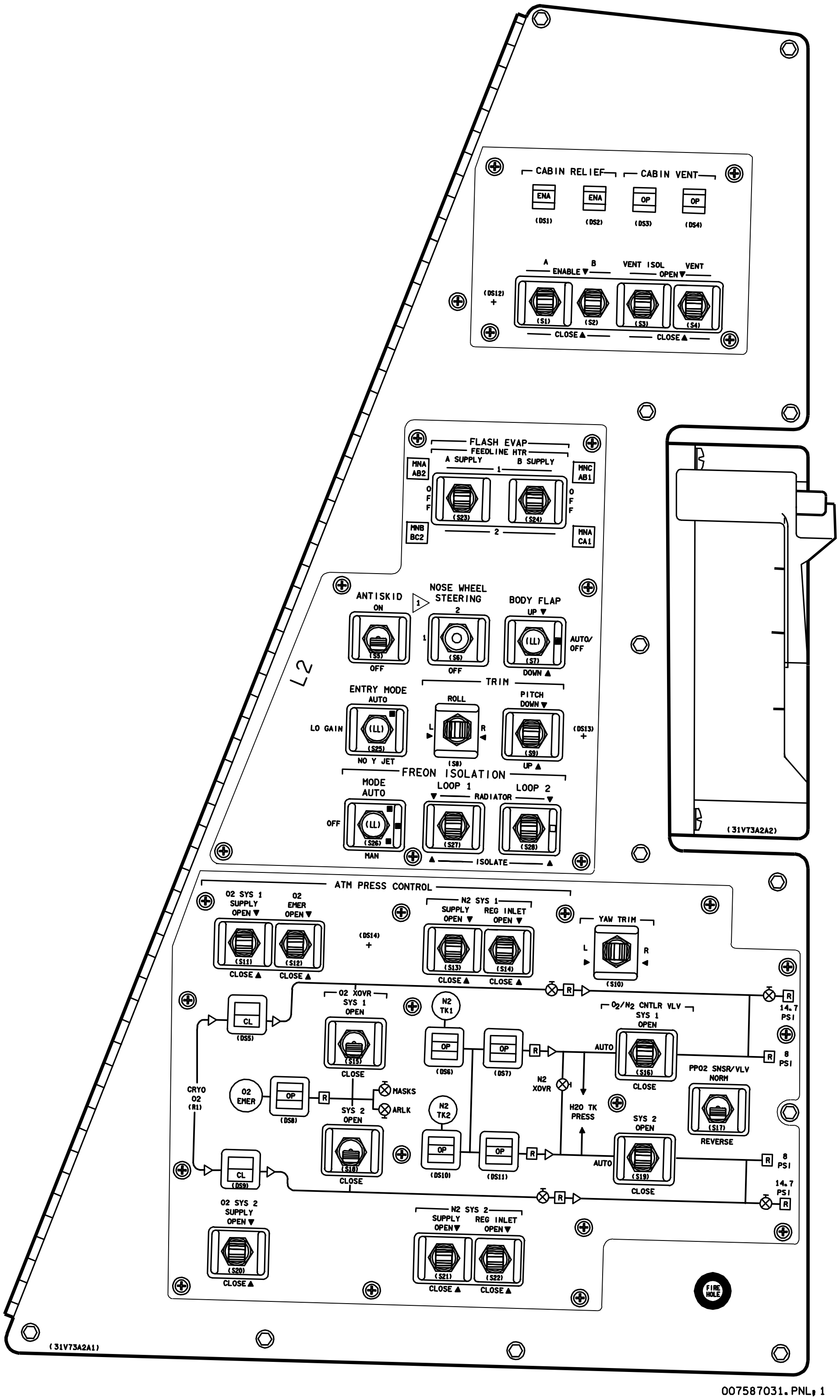
Water **Loops**



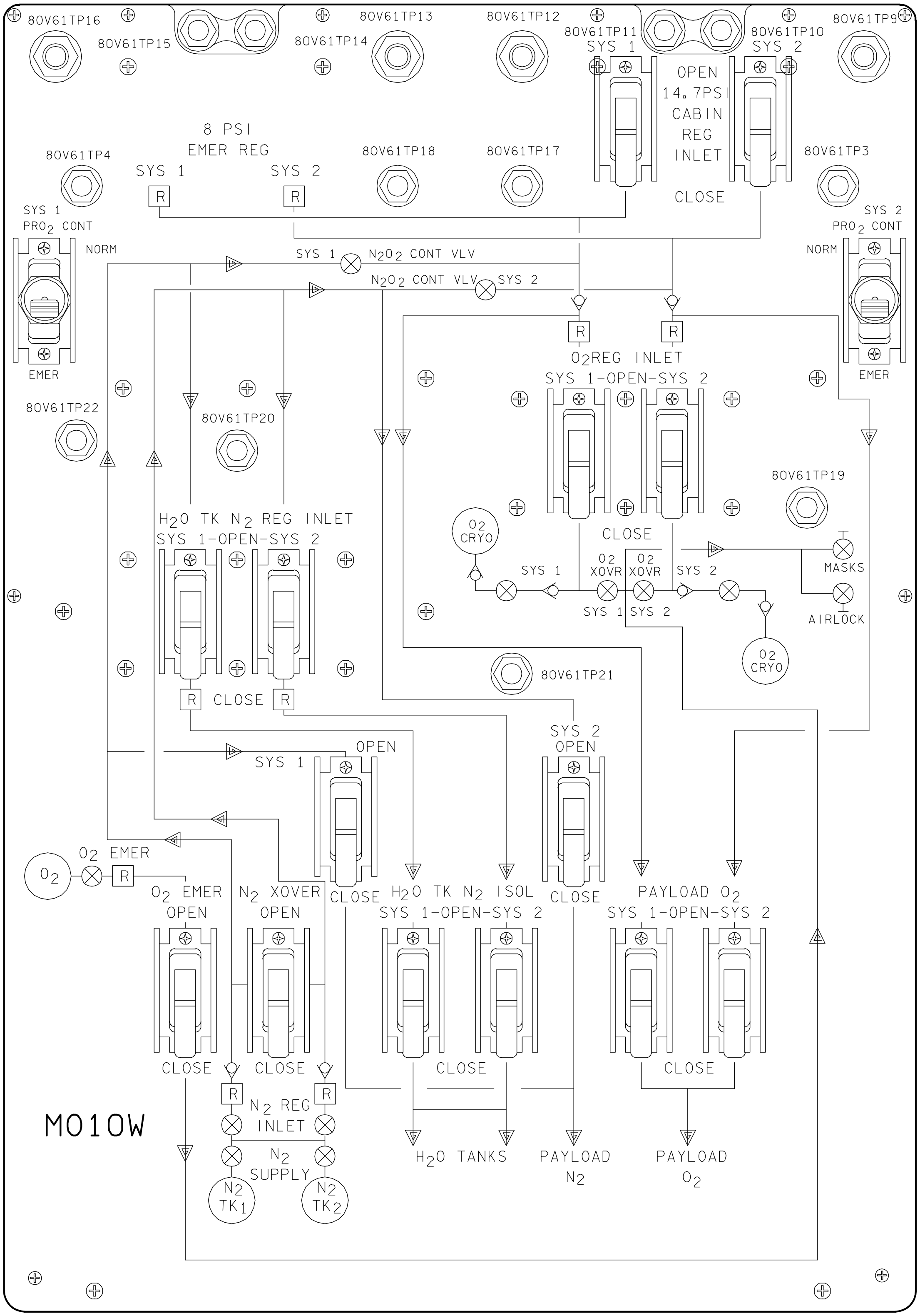
Pressure Control System (Orbit)


FIRE SUPPRESSION
AV BAY 1
AV BAY 2
AV BAY 3
ARM
SAFE
AGENT DISCH
SMOKE DETECTION
CABIN
PAYLOAD
L FLT DECK
R FLT DECK
CIRCUIT TEST
SENSOR RESET
RADIATORS
RAD CONTROLLER
LOOP 1
LOOP 2
AUTO A
AUTO B
OUT TEMP
HI
NORM
RAD BYPASS VALVE
MAN SEL
RAD FLOW
BYPASS
MODE
AUTO
MAN
NH3 BOILER
NH3 CONTROLLER
PRI/GPC
SEC/ON
NH3 TK A
NH3 TK B
H2O ALTERNATE PRESS
OPEN
CLOSE
HI LOAD EVAP ENABLE
HI LOAD DUCT HTR
H2O TK
N2 SYS 1
N2 SYS 2
FREON PUMP
FLASH EVAP CONTROLLER
A SPLY
B SPLY
PRI
GPC
SEC
HI LOAD EVAP
TOPPING EVAP
DUCT
TOPPING EVAPORATOR HEATER
NOZZLE
FC HX
HYD HX
MID CP
PAYLOAD HX
AFT CP
INTERCHANGER
FLOW PROP VLV
INTCHGR
L1
DFI CP
HATCH HX
WINDOW HX
LCG HX
H2O CHILLER
H2O LOOP 1 BYPASS
H2O LOOP 2 BYPASS
MAN
INCR
DECR
AV BAY 1 FAN
AV BAY 2 FAN
AV BAY 3 FAN
AV RACK CP
IMU FAN
H2O PUMP LOOP 1
LOOP 2 GPC
MDM CP
CABIN HX
HUMIDITY SEP
WASTE H2O
CABIN TEMP
COOL
WARM
CABIN TEMP CNTLR
CABIN FAN
FLT DECK AVIONICS
ON
OFF

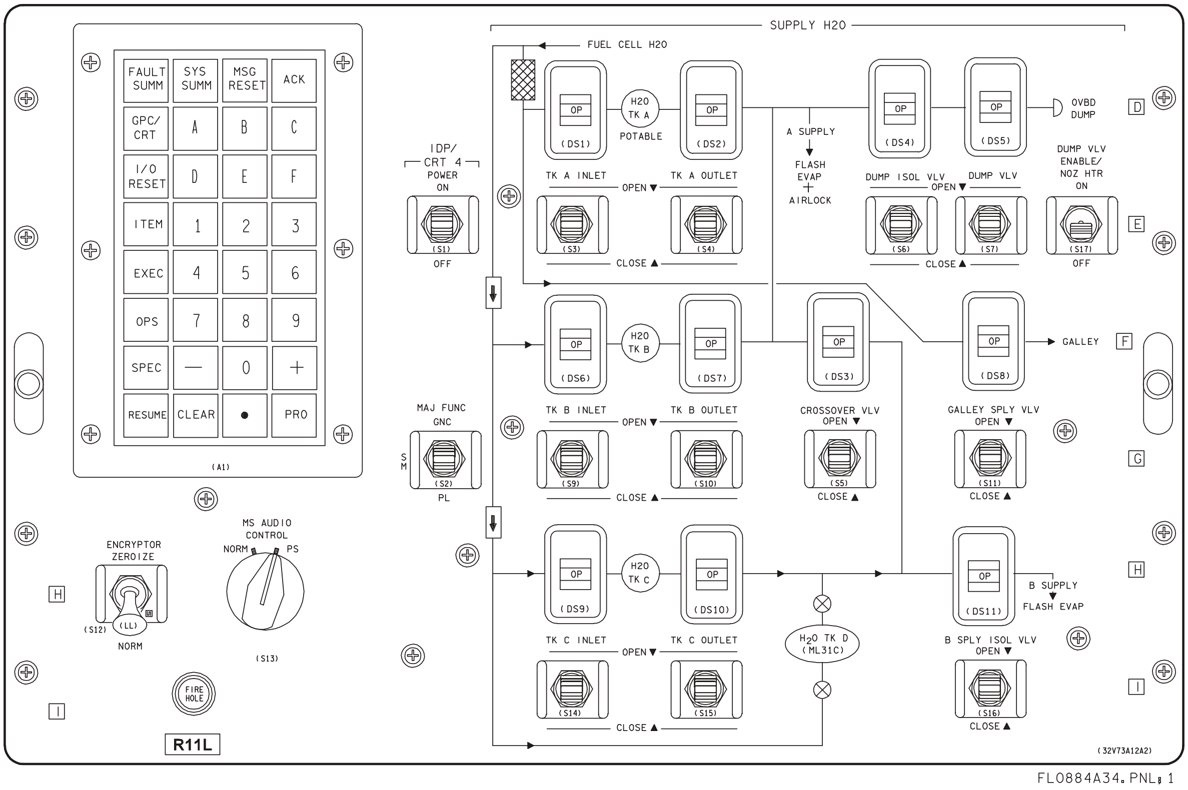
Panel L1


CABIN RELIEF
CABIN VENT
ENA
ENA
OP
OP
(DS1)
(DS2)
(DS3)
(DS4)
A
B
ENABLE ▼
VENT ISOL
VENT
OPEN ▼
(DS12)
+
(S1)
(S2)
(S3)
(S4)
CLOSE ▲
CLOSE ▲
FLASH EVAP
FEEDLINE HTR
A SUPPLY
B SUPPLY
1
2
MNA AB2
MNC AB1
MNB BC2
MNA CA1
OFF
OFF
(S23)
(S24)
L2
ANTISKID
ON
OFF
(S5)
NOSE WHEEL STEERING
2
1
OFF
(S6)
BODY FLAP
UP ▼
AUTO/OFF
(S7)
DOWN ▲
ENTRY MODE
AUTO
LO GAIN
(S25)
NO Y JET
TRIM
ROLL
L
R
(S8)
PITCH
DOWN ▼
(S9)
UP ▲
(DS13)
+
FREON ISOLATION
MODE
AUTO
OFF
(S26)
MAN
LOOP 1
LOOP 2
RADIATOR
(S27)
(S28)
ISOLATE
(31V73A2A2)
ATM PRESS CONTROL
O2 SYS 1 SUPPLY OPEN ▼
O2 EMER OPEN ▼
(S11)
(S12)
CLOSE ▲
CLOSE ▲
(DS14)
+
N2 SYS 1
SUPPLY OPEN ▼
REG INLET OPEN ▼
(S13)
(S14)
CLOSE ▲
CLOSE ▲
YAW TRIM
L
R
(S10)
R
14.7 PSI
CL
(DS5)
O2 XOVR
SYS 1
OPEN
(S15)
CLOSE
N2 TK1
OP
(DS6)
OP
(DS7)
R
O2/N2 CNTLR VLV
SYS 1
OPEN
AUTO
(S16)
CLOSE
R
8 PSI
PPO2 SNSR/VLV
NORM
(S17)
REVERSE
CRYO O2 (R1)
O2 EMER
OP
(DS8)
R
MASKS
ARLK
SYS 2
OPEN
N2 XOVR
H2O TK PRESS
SYS 2
OPEN
N2 TK2
(S18)
CLOSE
OP
(DS10)
OP
(DS11)
R
AUTO
(S19)
CLOSE
R
8 PSI
CL
(DS9)
R
14.7 PSI
R
O2 SYS 2 SUPPLY OPEN ▼
(S20)
CLOSE ▲
N2 SYS 2
SUPPLY OPEN ▼
REG INLET OPEN ▼
(S21)
(S22)
CLOSE ▲
CLOSE ▲
FIRE HOLE
(31V73A2A1)
007587031.PNL, 1

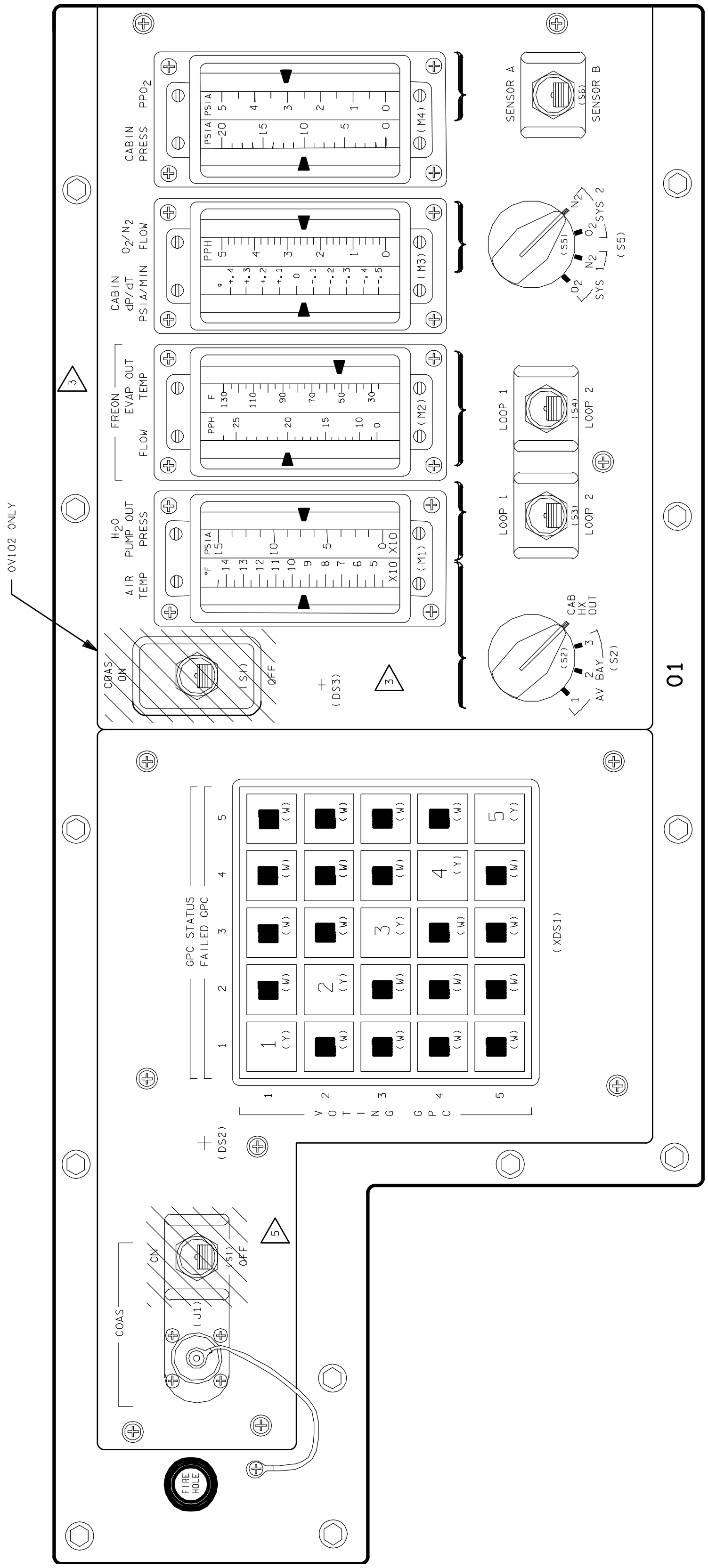
Panel L2


80V61TP16
80V61TP15
80V61TP14
80V61TP13
80V61TP12
80V61TP11
80V61TP10
80V61TP9
SYS 1
SYS 2
OPEN
14.7PSI
CABIN
REG
INLET
CLOSE
8 PSI
EMER REG
SYS 1
SYS 2
80V61TP4
80V61TP18
80V61TP17
80V61TP3
SYS 1
PRO2 CONT
NORM
EMER
SYS 2
PRO2 CONT
NORM
EMER
SYS 1
N2O2 CONT VLV
N2O2 CONT VLV
SYS 2
O2REG INLET
SYS 1-OPEN-SYS 2
80V61TP22
80V61TP20
80V61TP19
H2O TK N2 REG INLET
SYS 1-OPEN-SYS 2
CLOSE
O2 CRYO
SYS 1
O2 XOVR
O2 XOVR
SYS 2
MASKS
AIRLOCK
SYS 1
SYS 2
O2 CRYO
80V61TP21
CLOSE
SYS 1
OPEN
SYS 2
OPEN
O2
O2 EMER
O2 EMER
OPEN
N2 XOVER
OPEN
CLOSE
H2O TK N2 ISOL
SYS 1-OPEN-SYS 2
CLOSE
PAYLOAD O2
SYS 1-OPEN-SYS 2
CLOSE
CLOSE
CLOSE
CLOSE
N2 REG
INLET
N2
SUPPLY
N2 TK1
N2 TK2
H2O TANKS
PAYLOAD
N2
PAYLOAD
O2
MO10W

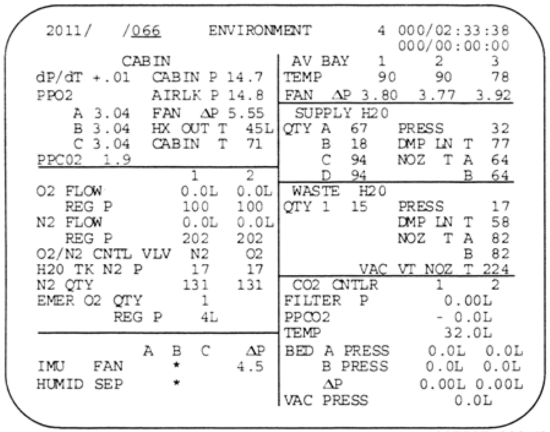
Panel MO10W


FAULT SUMM
SYS SUMM
MSG RESET
ACK
GPC/CRT
A
B
C
I/O RESET
D
E
F
ITEM
1
2
3
EXEC
4
5
6
OPS
7
8
9
SPEC
—
0
+
RESUME
CLEAR
●
PRO
(A1)
IDP/ CRT 4
POWER
ON
(S1)
OFF
MAJ FUNC
GNC
SM
(S2)
PL
ENCRYPTOR ZEROIZE
(S12)
(LL)
NORM
MS AUDIO CONTROL
NORM
PS
(S13)
FIRE HOLE
R11L
SUPPLY H2O
FUEL CELL H2O
OP
(DS1)
H2O TK A
POTABLE
(DS2)
A SUPPLY
FLASH EVAP
AIRLOCK
(DS4)
(DS5)
OVBD DUMP
TK A INLET
OPEN ▼
TK A OUTLET
(S3)
(S4)
CLOSE ▲
DUMP ISOL VLV
DUMP VLV
(S6)
(S7)
DUMP VLV ENABLE/ NOZ HTR
ON
(S17)
OFF
(DS6)
H2O TK B
(DS7)
(DS3)
(DS8)
GALLEY
TK B INLET
TK B OUTLET
(S9)
(S10)
CROSSOVER VLV
(S5)
GALLEY SPLY VLV
(S11)
(DS9)
H2O TK C
(DS10)
(DS11)
B SUPPLY
FLASH EVAP
TK C INLET
TK C OUTLET
(S14)
(S15)
H_2O TK D (ML31C)
B SPLY ISOL VLV
(S16)
D
E
F
G
H
I
(32V73A12A2)
FL0884A34.PNL;1

Panel R11L


PPO2
CABIN PRESS
PSIA
(M4)
SENSOR A
(S6)
SENSOR B
O_2/N_2 FLOW
CABIN dP/dT PSIA/MIN
PPH
(M3)
O_2
N_2
SYS 1
SYS 2
(S5)
FREON
EVAP OUT TEMP
FLOW
(M2)
LOOP 1
(S4)
LOOP 2
H_2O PUMP OUT PRESS
AIR TEMP
°F
X10
(M1)
(S3)
OV102 ONLY
COAS
ON
OFF
(S1)
(DS3)
CAB HX OUT
AV BAY
(S2)
O1
GPC STATUS
FAILED GPC
(W)
(Y)
(XDS1)
VOTING GPC
(DS2)
(J1)
FIRE HOLE

Panel O1



```
 2011/   /066      ENVIRONMENT        4 000/02:33:38
                                        000/00:00:00
          CABIN           | AV BAY    1      2      3
dP/dT +.01  CABIN P 14.7  |TEMP      90     90     78
PPO2        AIRLK P 14.8  |FAN  ΔP 3.80   3.77   3.92
    A 3.04  FAN   ΔP 5.55 | SUPPLY H2O
    B 3.04  HX OUT T  45L |QTY A  67    PRESS      32
    C 3.04  CABIN  T  71  |     B  18    DMP LN T   77
PPC02  1.9                |     C  94    NOZ  T A   64
                  1     2 |     D  94           B   64
O2 FLOW         0.0L  0.0L| WASTE  H2O
   REG P        100   100 |QTY 1  15    PRESS      17
N2 FLOW         0.0L  0.0L|             DMP LN T   58
   REG P        202   202 |             NOZ  T A   82
O2/N2 CNTL VLV   N2    O2 |                    B   82
H2O TK N2 P      17    17 |         VAC VT NOZ T 224
N2 QTY          131   131 | CO2  CNTLR        1      2
EMER O2 QTY       1       |FILTER  P        0.00L
         REG P    4L      |PPCO2            - 0.0L
                          |TEMP              32.0L
            A   B   C   ΔP|BED A PRESS     0.0L   0.0L
IMU   FAN       *      4.5|     B PRESS    0.0L   0.0L
HUMID SEP       *         |      ΔP      0.00L  0.00L
                          |VAC PRESS           0.0L
```

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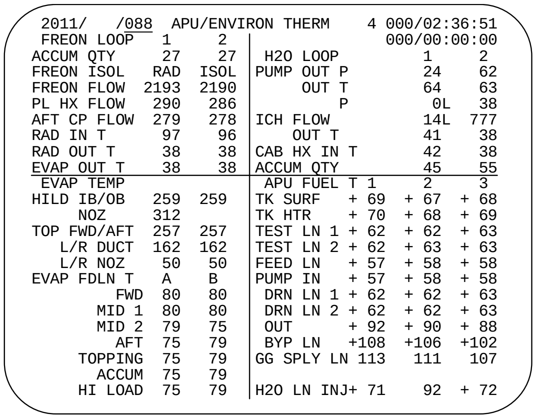
ENVIRONMENT (DISP 66)



```
 2011/   /088  APU/ENVIRON THERM    4 000/02:36:51
 FREON LOOP    1     2 |              000/00:00:00
ACCUM QTY      27    27 | H2O LOOP          1     2
FREON ISOL    RAD  ISOL |PUMP OUT P        24    62
FREON FLOW   2193  2190 |     OUT T        64    63
PL HX FLOW    290   286 |         P         0L   38
AFT CP FLOW   279   278 |ICH FLOW          14L  777
RAD IN T       97    96 |    OUT T         41    38
RAD OUT T      38    38 |CAB HX IN T       42    38
EVAP OUT T     38    38 |ACCUM QTY         45    55
 EVAP TEMP              | APU FUEL T 1      2     3
HILD IB/OB    259   259 |TK SURF   + 69  + 67  + 68
     NOZ      312       |TK HTR    + 70  + 68  + 69
TOP FWD/AFT   257   257 |TEST LN 1 + 62  + 62  + 63
   L/R DUCT   162   162 |TEST LN 2 + 62  + 63  + 63
   L/R NOZ     50    50 |FEED LN   + 57  + 58  + 58
EVAP FDLN T    A     B  |PUMP IN   + 57  + 58  + 58
         FWD   80    80 | DRN LN 1 + 62  + 62  + 63
       MID 1   80    80 | DRN LN 2 + 62  + 62  + 63
       MID 2   79    75 | OUT      + 92  + 90  + 88
         AFT   75    79 | BYP LN   +108  +106  +102
     TOPPING   75    79 |GG SPLY LN 113   111   107
       ACCUM   75    79 |
     HI LOAD   75    79 |H2O LN INJ+ 71    92  + 72
```

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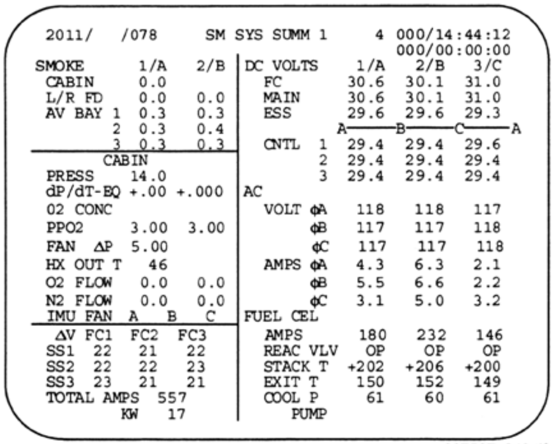
APU/ENVIRON THERM (DISP 88)



```
 2011/   /078      SM SYS SUMM 1      4 000/14:44:12
                                        000/00:00:00
SMOKE        1/A    2/B  |DC VOLTS    1/A    2/B    3/C
 CABIN       0.0         |  FC        30.6   30.1   31.0
 L/R FD      0.0    0.0  |  MAIN      30.6   30.1   31.0
 AV BAY 1    0.3    0.3  |  ESS       29.6   29.6   29.3
        2    0.3    0.4  |           A─────B─────C─────A
        3    0.3    0.3  |  CNTL   1  29.4   29.4   29.6
        CABIN            |         2  29.4   29.4   29.4
 PRESS      14.0         |         3  29.4   29.4   29.4
 dP/dT-EQ +.00  +.000    |AC
 02 CONC                 |  VOLT ϕA   118    118    117
 PPO2       3.00   3.00  |       ϕB   117    117    118
 FAN  ΔP    5.00         |       ϕC   117    117    118
 HX OUT T    46          |  AMPS ϕA   4.3    6.3    2.1
 O2 FLOW     0.0    0.0  |       ϕB   5.5    6.6    2.2
 N2 FLOW     0.0    0.0  |       ϕC   3.1    5.0    3.2
 IMU FAN  A    B     C   |FUEL CEL
  ΔV FC1   FC2   FC3     |  AMPS      180    232    146
 SS1   22    21    22    |  REAC VLV   OP     OP     OP
 SS2   22    22    23    |  STACK T  +202   +206   +200
 SS3   23    21    21    |  EXIT T    150    152    149
 TOTAL AMPS   557        |  COOL P     61     60     61
          KW   17        |     PUMP
```

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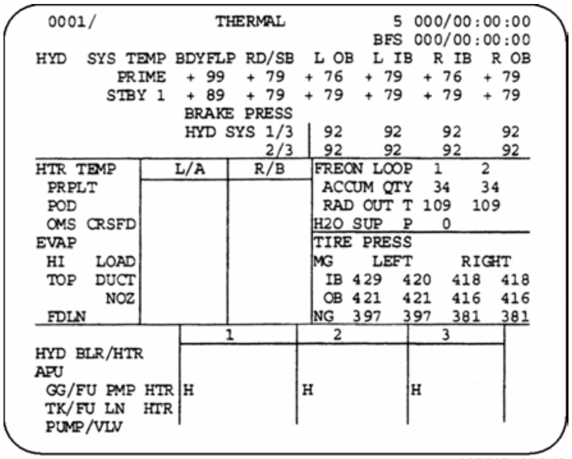
PASS **SM SYS SUMM 1**



```
 0001/             THERMAL            5 000/00:00:00
                                    BFS 000/00:00:00
HYD  SYS TEMP BDYFLP RD/SB  L OB  L IB  R IB  R OB
          PRIME  + 99  + 79  + 76  + 79  + 76  + 79
         STBY 1  + 89  + 79  + 79  + 79  + 79  + 79
                 BRAKE PRESS
                 HYD SYS 1/3 |  92    92    92    92
                         2/3 |  92    92    92    92
HTR TEMP   |   L/A   |   R/B   |FREON LOOP   1     2
 PRPLT     |         |         | ACCUM QTY  34    34
 POD       |         |         | RAD OUT T 109   109
 OMS CRSFD |         |         |H2O SUP  P   0
EVAP       |         |         |TIRE PRESS
 HI   LOAD |         |         |MG     LEFT      RIGHT
 TOP  DUCT |         |         | IB 429   420   418   418
       NOZ |         |         | OB 421   421   416   416
 FDLN      |         |         |NG  397   397   381   381
                |       1       |     2     |     3     |
HYD BLR/HTR     |               |           |           |
APU             |               |           |           |
 GG/FU PMP HTR  |H              |H          |H          |
 TK/FU LN  HTR  |               |           |           |
 PUMP/VLV
```

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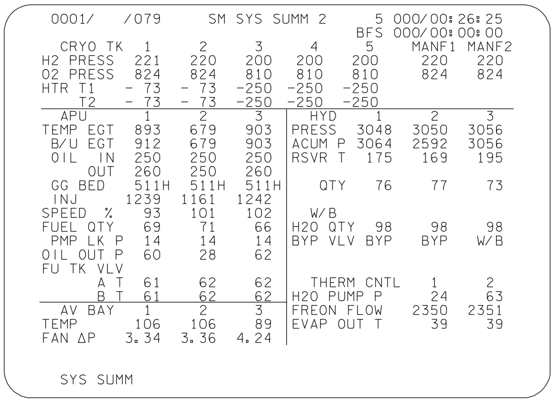
BFS THERMAL



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O2 PRESS   824    824    810   810    810     824   824
HTR T1    - 73   - 73   -250  -250   -250
    T2    - 73   - 73   -250  -250   -250
  APU       1      2      3  |  HYD     1      2      3
TEMP EGT   893    679    903 |PRESS   3048   3050   3056
 B/U EGT   912    679    903 |ACUM P 3064   2592   3056
 OIL   IN  250    250    250 |RSVR T  175    169    195
      OUT  260    250    260 |
 GG BED    511H   511H   511H|   QTY    76     77     73
 INJ      1239   1161   1242 |
SPEED  %    93    101    102 |  W/B
FUEL QTY    69     71     66 |H2O QTY   98     98     98
 PMP LK P   14     14     14 |BYP VLV BYP    BYP    W/B
OIL OUT P   60     28     62 |
FU TK VLV                    |
       A T  61     62     62 |  THERM CNTL    1      2
       B T  61     62     62 |H2O PUMP P     24     63
  AV BAY    1      2      3  |FREON FLOW   2350   2351
TEMP       106    106     89 |EVAP OUT T     39     39
FAN ΔP    3.34   3.36   4.24 |

  SYS SUMM
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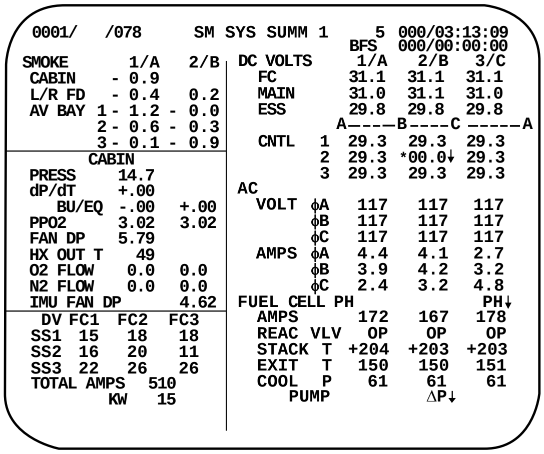
PASS **SM SYS SUMM 2**



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 L/R FD     - 0.4    0.2 |  MAIN      31.0   31.1   31.0
 AV BAY 1 - 1.2 -  0.0   |  ESS       29.8   29.8   29.8
        2 - 0.6 -  0.3   |           A────B────C ─────A
        3 - 0.1 -  0.9   |  CNTL   1  29.3   29.3   29.3
        CABIN            |         2  29.3  *00.0↓  29.3
 PRESS      14.7         |         3  29.3   29.3   29.3
 dP/dT      +.00         |AC
    BU/EQ   -.00    +.00 |  VOLT ϕA   117    117    117
 PPO2       3.02    3.02 |       ϕB   117    117    117
 FAN DP     5.79         |       ϕC   117    117    117
 HX OUT T     49         |  AMPS ϕA   4.4    4.1    2.7
 O2 FLOW     0.0     0.0 |       ϕB   3.9    4.2    3.2
 N2 FLOW     0.0     0.0 |       ϕC   2.4    3.2    4.8
 IMU FAN DP          4.62|FUEL CELL PH                PH↓
  DV FC1   FC2   FC3     |  AMPS      172    167    178
 SS1  15    18    18     |  REAC VLV   OP     OP     OP
 SS2  16    20    11     |  STACK  T +204   +203   +203
 SS3  22    26    26     |  EXIT   T  150    150    151
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          KW   15        |     PUMP          ΔP↓
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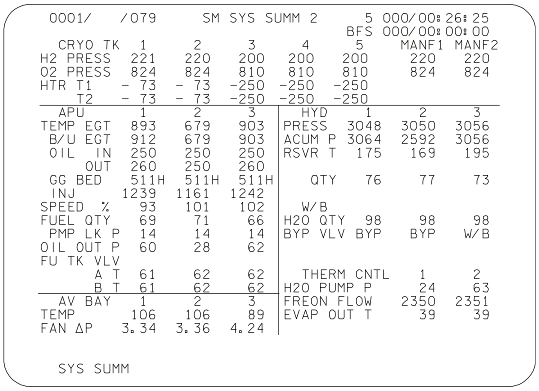

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  CRYO TK  1     2     3     4     5    MANF1 MANF2
H2 PRESS  221   220   200   200   200    220   220
O2 PRESS  824   824   810   810   810    824   824
HTR T1   - 73  - 73  -250  -250  -250
    T2   - 73  - 73  -250  -250  -250
  APU      1     2     3  |  HYD    1     2     3
TEMP EGT  893   679   903 |PRESS  3048  3050  3056
 B/U EGT  912   679   903 |ACUM P 3064  2592  3056
 OIL  IN  250   250   250 |RSVR T  175   169   195
     OUT  260   250   260 |
 GG BED   511H  511H  511H|
                          |   QTY   76    77    73
 INJ     1239  1161  1242 |
SPEED  %   93   101   102 |  W/B
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 PMP LK P  14    14    14 |BYP VLV BYP   BYP   W/B
OIL OUT P  60    28    62 |
FU TK VLV                 |
      A T  61    62    62 |  THERM CNTL  1     2
      B T  61    62    62 |H2O PUMP P    24    63
  AV BAY   1     2     3  |FREON FLOW   2350  2351
TEMP      106   106    89 |EVAP OUT T    39    39
FAN ΔP   3.34  3.36  4.24 |

  SYS SUMM
```

BFS SM SYS SUMM 2

ECLSS Rules of Thumb

NOTE

Numbers presented here are for typical orbit power and heat loads and may vary significantly, depending on attitude and power loading.

- Supply water tanks fill at about *6.5* percent per hour, depending on fuel cell load (*14 kW typical orbit power load * 0.77 lbm/hr/kW ÷ 1.65 lbm per %*).

- *Waste water tank fills at about 4.4 percent per day per crewmember (urine and condensed humidity). Relative contributions from urine and condensate are about equal.*

- *Assuming no concurrent fuel cell water replenishment, supply w*ater tanks empty at about *90* percent per hour for a water dump *(or, about 40 seconds per percent to dump);* about *40* percent per hour when using *full-up* FES *(*high load *and topping* evaporator*)* for cooling with payload bay doors closed, and about *15* percent per hour when using the FES topping evaporator for supply water dumps on orbit with the doors open.

- *Waste water tank empties at about 2 percent per minute.*

- On-orbit cold soak is good for *about 15* minutes of cooling. Prelaunch Freon conditioning is good for 2 to 3 minutes of cooling.

- *Each ammonia* boiler supply is good for *about* 25 *to 35* minutes of ground cooling.

- A single LiOH canister is usable for about 48 man-hours.

- *Typical nitrogen usage rate is about 6 lbm per day (assuming 7 crewmembers, at 14.7 psia).*

- *All of the ECLSS parameters visible on the panel O1 meters come from the same sensor that can be read on the display. They are not redundant and the meter/display pair cannot be used as confirming cues for a reading.*

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2.10 ESCAPE SYSTEMS

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Description

Escape systems refer to equipment and systems intended to facilitate emergency and contingency egress of the flight crew. Escape systems include equipment worn by the crewmembers, hardware built into the orbiter, and external systems located on the launch pad. Types of escape or emergency egress from the orbiter depend upon the mission phase (basically prelaunch, in-flight, and post-landing). The prelaunch phase implies the crew must perform an emergency egress while the orbiter is still positioned on the launch pad.

The in-flight phase requires that the crew can safely bail out of the orbiter during controlled gliding flight at altitudes of 30,000 feet and below. A special in-flight crew escape system is devised for this phase. It includes pressure suits, oxygen bottles, parachutes, life rafts, pyrotechnics to vent the cabin and jettison the orbiter side hatch, and an escape pole to allow the crewmembers to clear the vehicle. The most likely uses of the system would be during a return-to-launch-site (RTLS) abort, transatlantic abort landing (TAL), or abort once-around (AOA) when the orbiter has insufficient energy to achieve a runway landing or after an emergency deorbit made regardless of landing site opportunities.

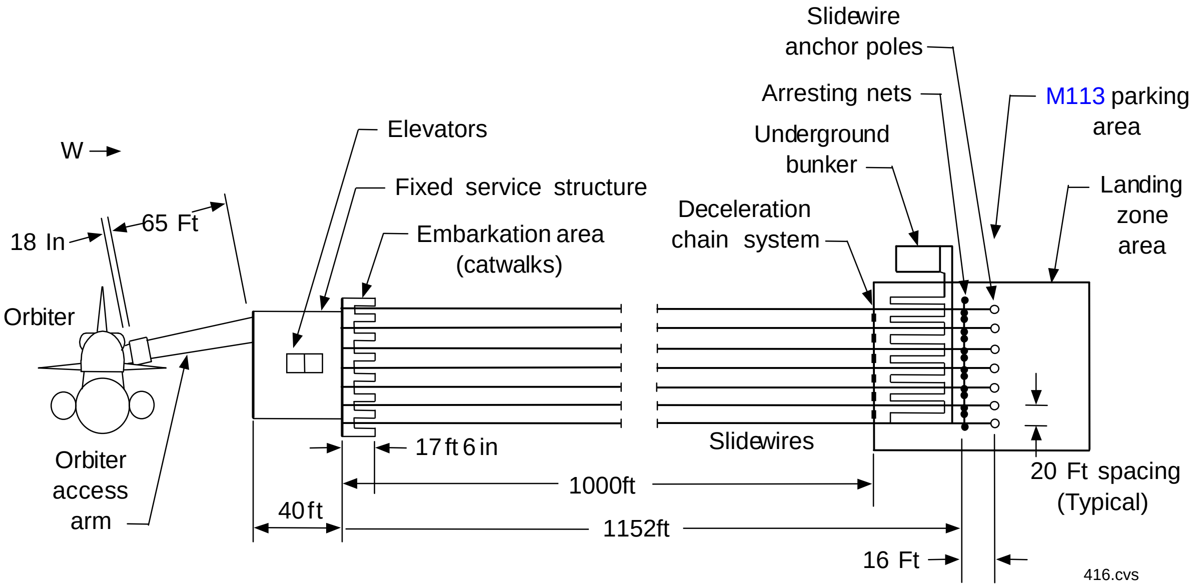
During the post-landing phase, the crew exits the orbiter following an emergency landing or landing at a contingency site. The orbiter will probably not survive a water ditching; therefore, bailout is the primary escape mode over water.

The orbiter-based hardware associated with the in-flight crew escape system was installed after the Challenger accident. Some orbiter modifications were required for the inclusion of the in-flight escape system. The side hatch water coolant lines for side hatch thermal conditioning were modified to accommodate the installation of the pyrotechnic separation system. The flight crewmembers' seats were also modified to accommodate the crew's altitude protection system suit. In addition, a handhold was added in the middeck next to the side hatch to permit the crewmembers to position themselves through the side hatch opening for bailout. The interdeck access ladder was widened, and a handhold was added to the commander's seat to allow easier movement through the interdeck access.

Software adjustments were also required to accommodate the in-flight escape system. Software changes applied to the primary avionics software system for OPS 3 and 6. The changes enable an automatic flight control mode of the orbiter with input by crewmembers by using the ATO abort position on the abort rotary switch in MM 603/305. The automatic mode stabilizes the orbiter by controlling the velocity and angle of attack to the desired bailout conditions, thus allowing the commander to escape.

Launch Pad Egress Systems

In the event of a potential catastrophe on the launch pad, escape by the flight crew is facilitated by descending to a safe area via slidewire baskets. The emergency egress/ escape system uses seven separate slidewires and seven multi-person basket assemblies to effect rapid escape of personnel from the 195-foot level of the fixed service structure to a landing zone. The landing zone is approximately 1,200 feet west of the fixed service structure. The flight crew leaves the slidewire baskets and proceeds to the bunker, which is provided with breathing air, first aid supplies, and communications equipment. The flight crew will only leave the bunker upon instructions by the NASA Test Director.



Launch Pad Emergency Egress System

An M-113 is positioned near the slidewire termination area. The M-113 is a military armored personnel carrier designed to provide protected evacuation from the launch pad area.

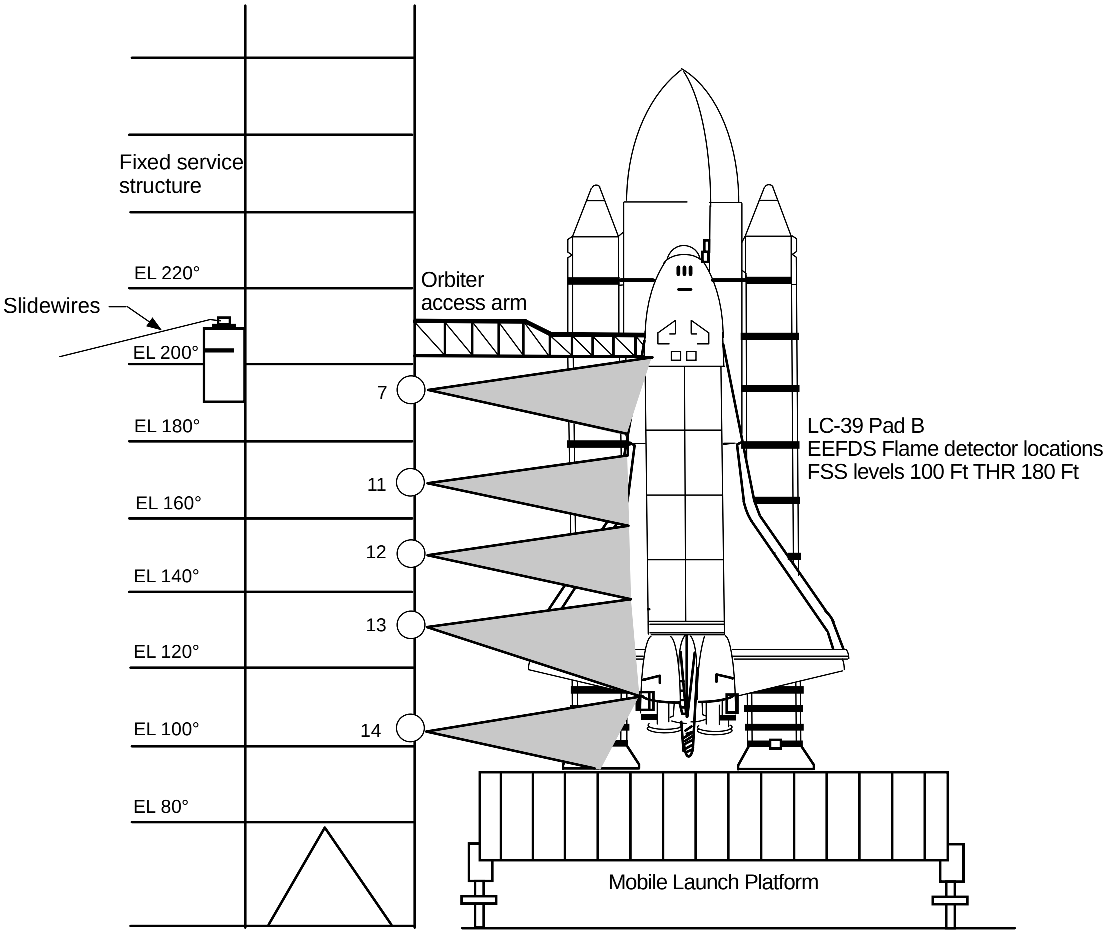
There are four modes of escape from the launch pad area, varying in degrees of egress aid to the crew by the closeout crew or pad fire/rescue crew. In the case of an aided escape, support crews are responsible for opening the side hatch using an emergency hatch opening tool.

The launch pad structure also includes an escape temperature and hydrogen fire-hazard monitoring system, consisting of 10 temperature sensors and 14 ultraviolet (UV) hydrogen fire detectors. Nine UV fire detectors are located in the area of the white room, the orbiter access arm, and the fixed service structure both above and below the fire barrier. Five UV fire detectors are also spaced vertically down the fixed service structure from the 175-foot level to the 95-foot level to view a profile of the orbiter.

The 10 temperature sensors are located along the egress path, from the white room to the slidewire basket embarkation area. The sensors are placed both above and below the fire barrier. The signals from these sensors are displayed on firing room console C-7 in the launch control center.

The Firex spray system provides a water shower to the orbiter access arm and the fixed service structure in the event of a fire. There are 20 water spray nozzles located on the orbiter access arm, approximately 4 feet above the walkway, and 20 on the fixed service structure, 7 to 10 feet overhead. Each nozzle emits 287 gallons of water per minute. Two control modes, local and remote, operate the Firex spray system. The local mode consists of two pairs of activation paddles located outside the white room on the orbiter access arm and on the east side of the elevators directly facing the orbiter access arm. The remote mode is a hard-wire backup control panel located in the launch control center.

FLAME DETECTION (EEFDS)



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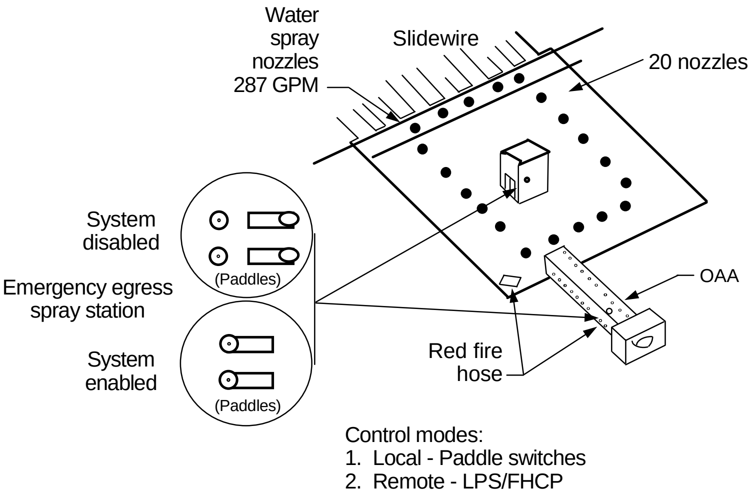

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Emergency Egress Water Spray Control Panels

Advanced Crew Escape Suit

The advanced crew escape suit (ACES) is designed to provide protection to each crewmember for the following off-nominal conditions:

- Loss of cabin pressure
- Environmental extremes
- Effects of prolonged zero gravity
- Contaminated atmosphere

The ACES has an inner pressure bladder that encompasses the crewmember's body and an outer covering. The outer covering is an orange Nomex material that is heat/flame resistant and provides a highly visible target for search and rescue (SAR). The pressure bladder is constructed of Gore-Tex that wicks body moisture and vapor away from the crewmember when unpressurized, yet holds pressure when inflated. The ACES is designed to provide pressure protection indefinitely for total loss of cabin pressure or above 100,000 feet.

The ACES is a full-pressure suit that applies static pressure evenly to the entire body surface. Suit pressure is automatically maintained by a dual suit controller and, at full inflation, provides an absolute pressure of 3.67 psia. Suit pressurization begins when the cabin pressure altitude rises to around 35,000 feet and is "hard pressed" (3.67 psia) above 60,000 feet. Ground testing of the dual suit controller is through the "Dial-to-Test" and "Press-to-Test" manual controls. For either manual or automatic pressurizations, several ACES components must be properly attached.

Detachable gloves are required for the ACES suit to properly provide pressure protection. The gloves attach to the sleeves via metal-mating rings. The rings provide an airtight seal and allow the gloves to swivel for improved mobility. Similarly, a mating-metal ring is provided for the helmet.

The ACES helmet provides a pressurized breathing volume and head protection to the crewmember. A clear, rotating pressure visor is used to seal the helmet cavity for the crewmember's face. Also, an independently mounted sunshade can be rotated as required. Another component is the antisuffocation valve located at the lower right rear of the helmet. If the oxygen supply is lost, inhalation by the crewmember will open the valve, allowing ambient air into the helmet. The helmet also provides an interface for communications between the communications carrier assembly (CCA) and the orbiter.

The CCA, or comm cap, contains all necessary equipment for crewmember voice communication. The comm cap contains dual/redundant microphones and dual/redundant earphones. All comm hardware is connected with comm cables and pass throughs. The ACES also has a pass through for several other reasons.

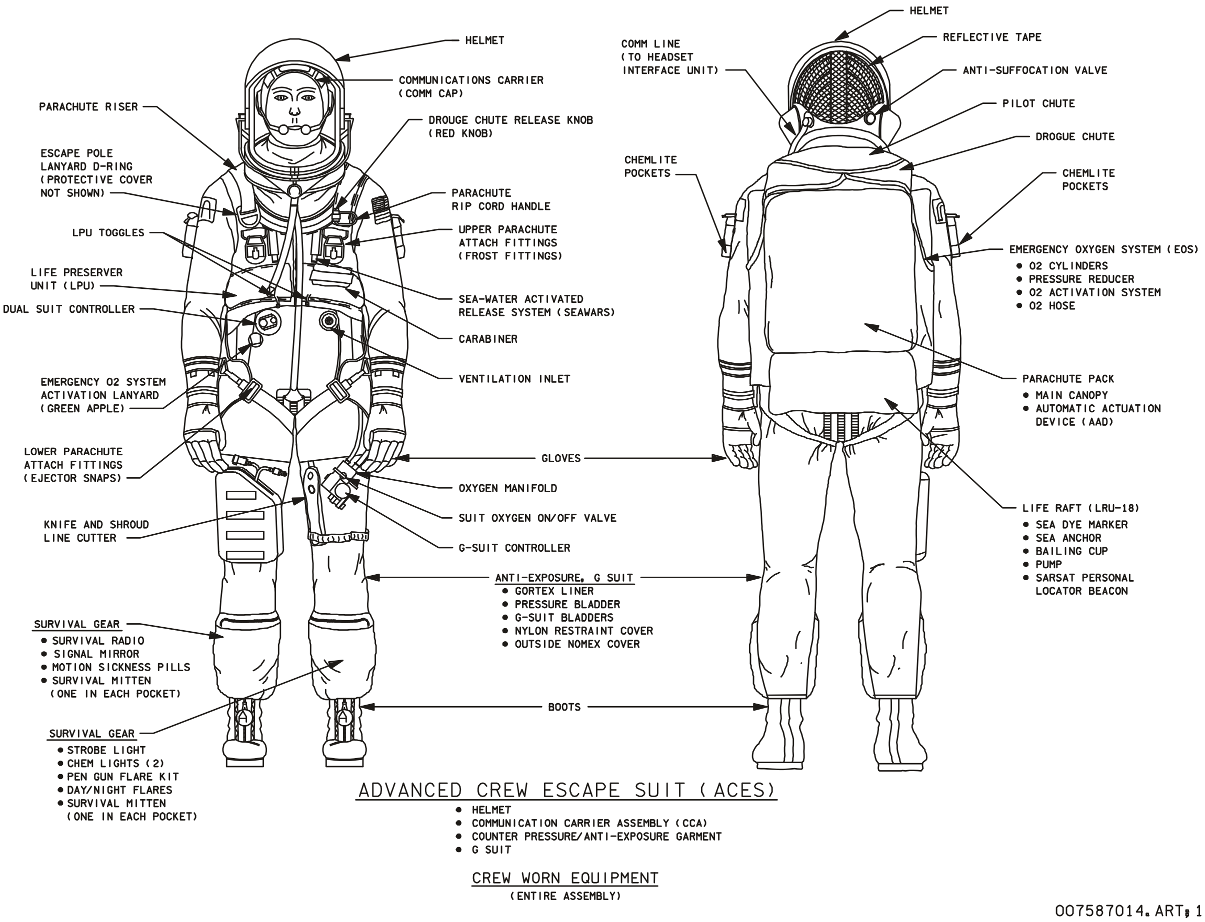
A bioinstrumentation pass-thru (BIP) is located on the upper right leg allowing medical lines and/or water cooling lines to pass into the suit for the crewmember. Crewmembers require cooling for personal comfort while wearing the ACES and receive it from an external source.

WARNING

For the ACES to pressurize, gloves must be worn, helmet pressure visor must be down/locked, and BIP plug must be seated properly.

Each crewmember relies on a closed water loop system to provide personal cooling. Water is cooled in the core of the individual cooling unit (ICU), mounted on crewmembers' seats, using a thermoelectric principle. From the ICU, the water is pumped through water lines into the ACES via the BIP. The cooled water then circulates throughout tubes sewn into a liquid-cooled garment (LCG), worn under the ACES. The water returns back through the BIP to the ICU, where it begins the cycle again. Another item crewmembers wear under the ACES is the anti-g suit.

Each crewmember is issued an anti-g suit to be worn during shuttle reentry and landing. The anti-g suit, or g-suit, is designed to counteract the effects of orthostatic intolerance due to body fluid loss by applying mechanical pressure to the lower abdomen and legs.



Advanced Crew Escape Suit (ACES)

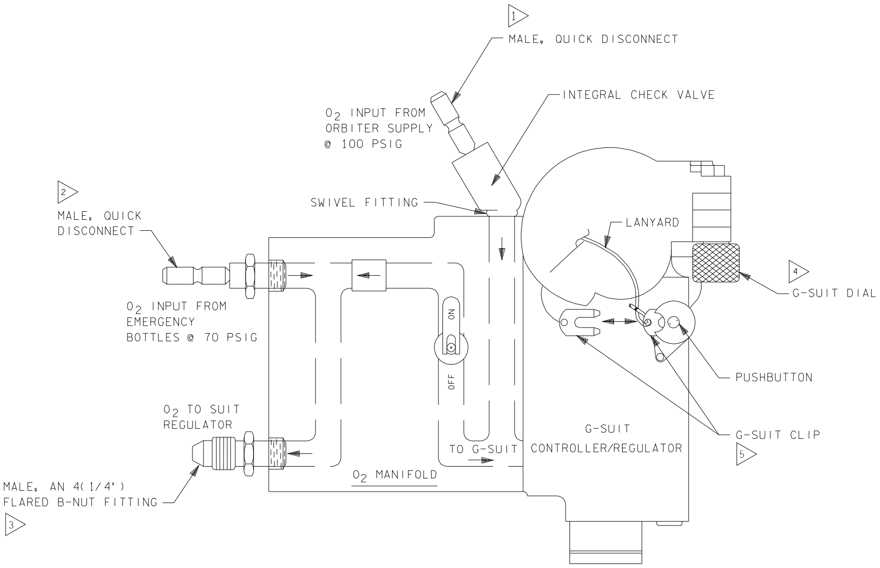
Inflation of the g-suit is controlled at the O_2 manifold/g-suit controller (one piece), located on the upper left leg. This assembly consists of the following components, referenced to the illustration on the next page:

a. A male O_2 hose fitting that connects to the orbiter O_2 supply hose. It is provided with a breakaway fitting to facilitate rapid egress from the vehicle.

b. A second male O_2 hose fitting that connects the manifold with the emergency O_2 bottles in the crewmember's parachute harness.

c. A third (threaded) male O_2 hose fitting that connects the manifold with the oxygen regulator for crewmember respiration.

d. When the manifold is connected to orbiter O_2, rotating the g-suit dial (knurled knob) clockwise, inflates the g-suit bladders 0.5 psi per complete turn, to a maximum pressure of 2.5 psi. A one-way valve inside the manifold prevents the g-suit from inflating with emergency O_2, which is reserved for breathing. Rotation of the knob counterclockwise will deflate the g-suit bladders 0.5 psi per complete turn. Each complete revolution of the knob is indicated by a slight detent. The recommended setting for inflation is 1.5 psia, which is obtained by rotating the red knurled knob three complete turns clockwise.



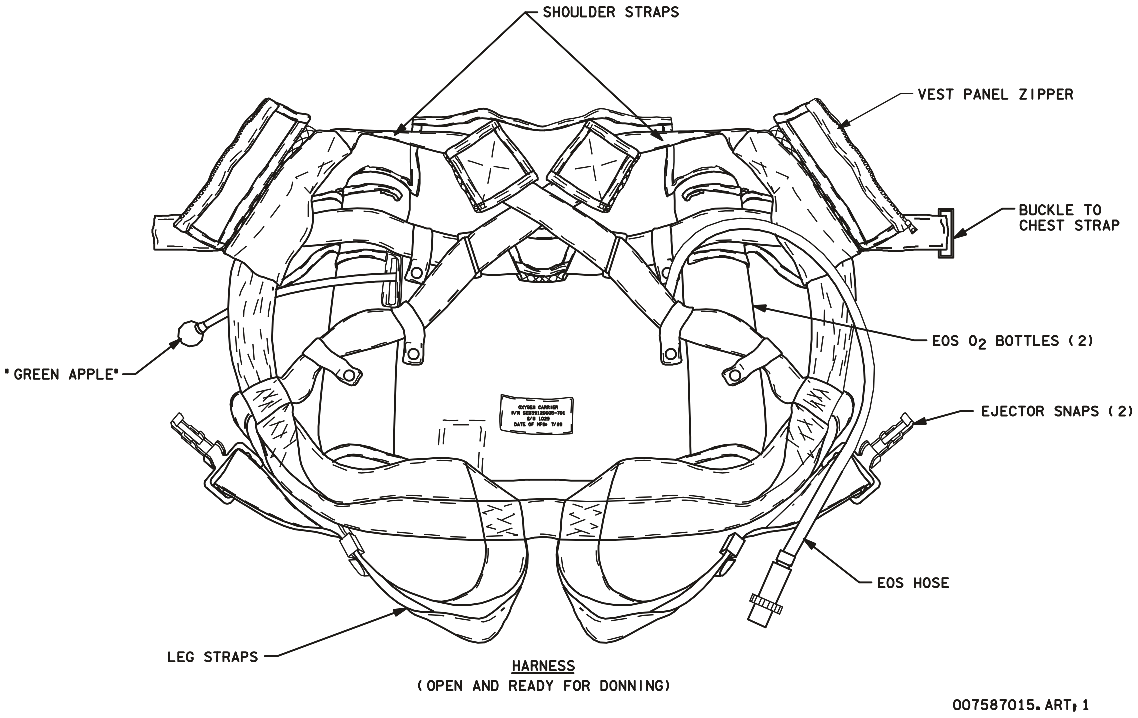
O2 Manifold/G-Suit Controller

e. When the g-suit controller clip is pulled free, the current volume of O_2 will be trapped maintaining g-suit pressure. Reinstallation of the clip will allow a normal deflation of the g-suit bladders.

Parachute Harness and Parachute

The parachute harness contains an interwoven system of nylon straps that attach the personal parachute assembly (PPA) to the crewmember. These straps provide complete body support for crewmembers during bailout, emergency egress, and rescue operations. In addition to the support straps, the harness also includes the following items that may prove necessary in an emergency:

1. The emergency oxygen system (EOS) consists of two high-pressure cylinders containing breathing oxygen. Regulators reduce the 3000 psi pressure of the bottles to a working pressure of 70 psi. A common manifold delivers oxygen from the bottles to the O_2 manifold/g-suit controller. The EOS is activated by a “green apple” on the right side of the harness. Once activated, the EOS can supply a total of 401 liters of oxygen at 14.7 psi. At 38 liters per minute, the EOS will last for at least 10 minutes at sea level and longer at high altitudes.
2. A locking carabiner is attached to the left side of the harness. It is an oval aluminum ring for attaching descent devices used during post-landing emergency egress. It can also be used during rescue operations.
3. A life preserver unit (LPU) encircles the crewmember's upper torso. It inflates automatically via two CO_2 cartridges (FLU-8) when submersed in water. It may also be inflated manually via two inflation toggles on the front of the harness. The unit is designed to keep an unconscious crewmember's head out of the water.
4. Sixteen individual packages contain two liters of emergency drinking water and are stored at the rear of the harness.

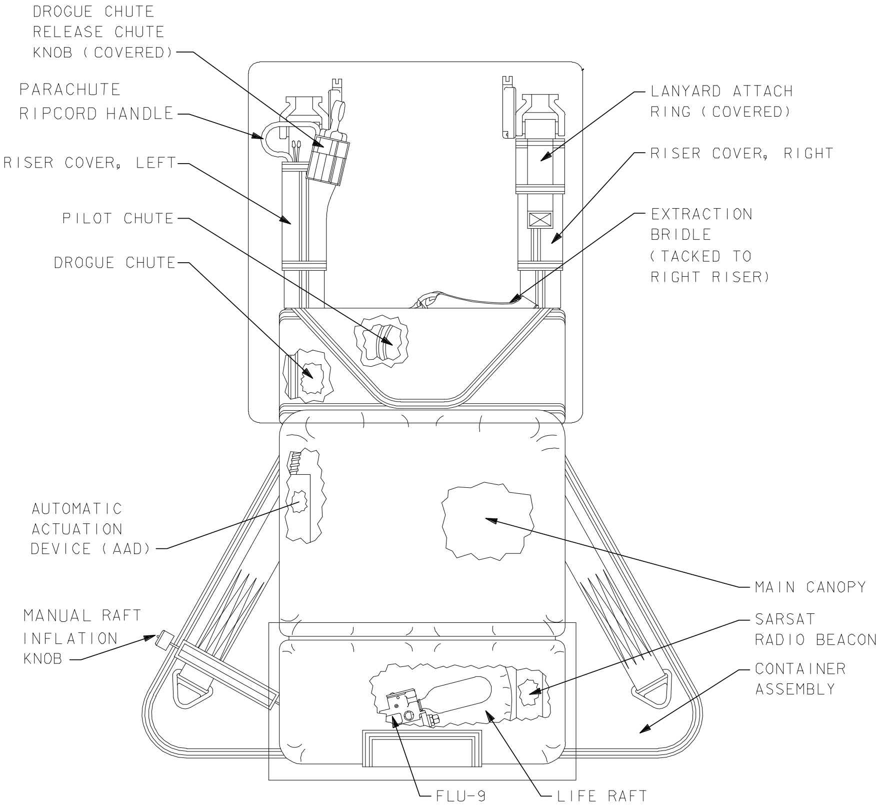


Harness Diagram

The PPA is an integrated pack assembly containing parachutes, risers, and actuation devices required for automatic and manual deployment of the parachutes. The PPA also contains survival equipment in the form of a personal life raft and personal locator beacon. Finally, the PPA doubles as a seat back cushion and is already in the orbiter when the crew ingresses prior to launch. During seat strap-in, the insertion technicians attach the PPA to the harness.

There are four connections between the PPA and the harness; two riser attach fittings (Frost fittings) and two ejector snaps. During an inflight bailout, the crewmember will egress the seat, taking the parachute with him/her. When immersed in salt water, two Seawater Activated Release System (SEAWARS) units, one for each riser, automatically release the risers and canopy from the harness. For a ground egress, the crewmember manually releases the four PPA attach points leaving it in the seat. The PPA contains the following items:

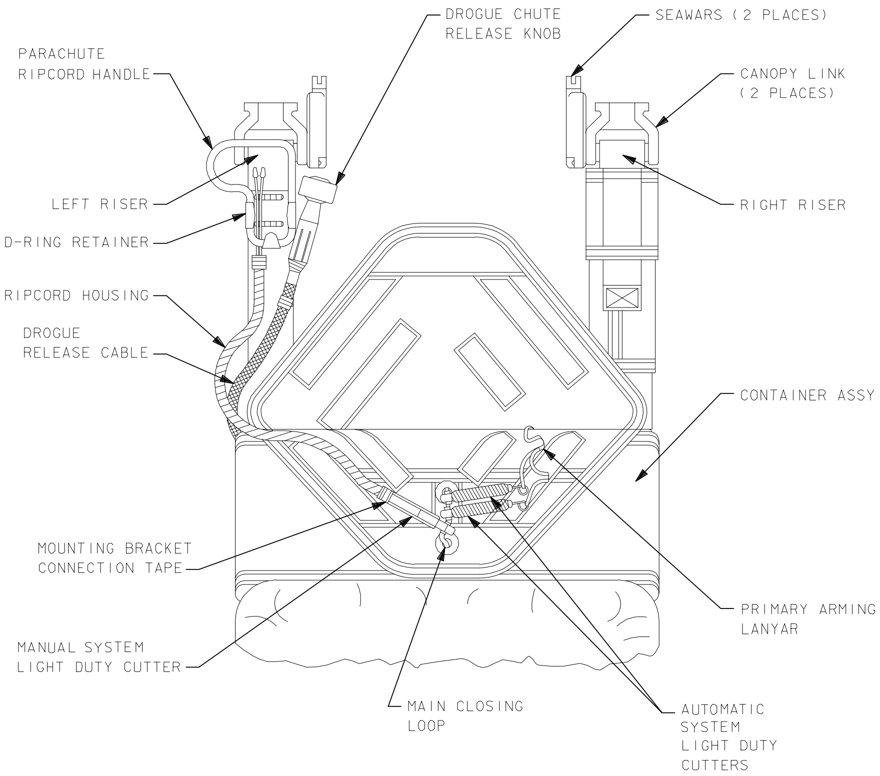
- Automatic and manual pilot chute deployment system
- Drogue chute release knob
- An 18-inch-diameter pilot chute
- A 4.5-foot-diameter drogue chute
- A 26-foot-diameter main canopy
- Deployment sleeve
- Automatic actuation device (AAD)
- Life raft compartment
- Life raft
- SARSAT personnel locator beacon



Parachute Pack (Back)

For an in-flight bailout, crewmembers would use the primary parachute deployment sequence. First, crewmembers connect the extraction bridle to a lanyard on the crew escape pole. As the crewmember descends down the escape pole, the extraction bridle is fully extended initiating the auto sequence. After a 1.5 second delay, the bridle/lanyard are separated from the PPA via two heavy-duty pyrotechnic line cutters. Next, the upper flap of the PPA is opened when two light-duty line cutters release the spring-loaded pilot chute. The 18-inch-diameter pilot parachute immediately pulls out the drogue deployment sleeve.

The 4.5-foot-diameter drogue chute stabilizes the crewmember in a preferred attitude to reduce injury during freefall, and reduce parachute opening deployment damage. When the drogue chute is deployed, the AAD is armed.



Parachute Pack (Back)

The AAD is a pressure-activated pyrotechnic device with an internal aneroid that is sensitive to atmospheric pressure. When the AAD senses a pressure altitude of 14,000 ± 1,000 feet, the pyrotechnic charge releases the drogue chute, which pulls the main parachute canopy out of the pack.

The main parachute is a modified version of the Navy 26-foot conical canopy with Kevlar reinforcement. A discard line reefing system is added to increase the basic strength and reduce the load to the crewmember during opening shock. Four anti-oscillation windows are added at the base of the canopy to reduce oscillation during descent. The canopy is attached to the risers by 22 suspension lines.

NOTE

The parachute is not steerable.

The average descent rate for a crewmember under main canopy is 24-ft/sec.

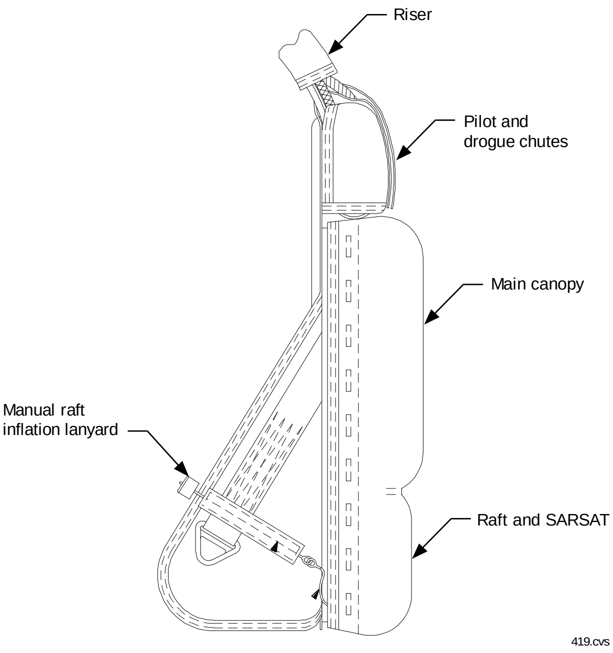
Manual activation can be accomplished by pulling the ripcord handle on the upper left riser. Pulling the ripcord handle performs the same function as the bridle activation by firing a single light duty pyrotechnic cutter, which then deploys the pilot chute. The ripcord handle would be used if the bridle activation failed or the escape pole was not used. The drogue chute release knob is also located on the left parachute riser.

The drogue chute release knob is used if the AAD fails to deploy the main canopy. Pulling the drogue chute release knob disconnects the drogue chute riser from the PPA, allowing it to deploy the main canopy.

WARNING

The drogue chute release knob will not deploy the main canopy unless the drogue chute has been deployed via the bridle/lanyard or the ripcord handle.

For auto or manual main canopy deployment, the Search and Rescue Satellite Aided Tracking (SARSAT) personnel locator beacon will be activated and the liferaft compartment loosened.

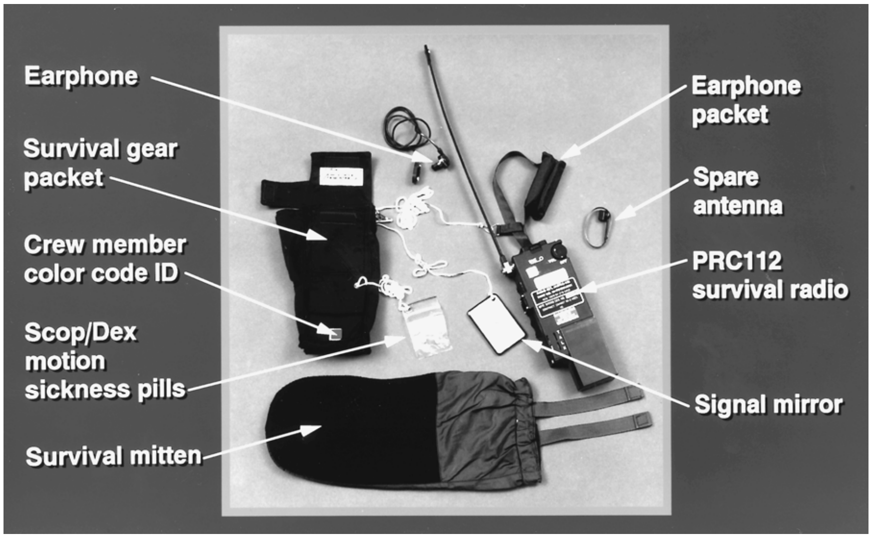


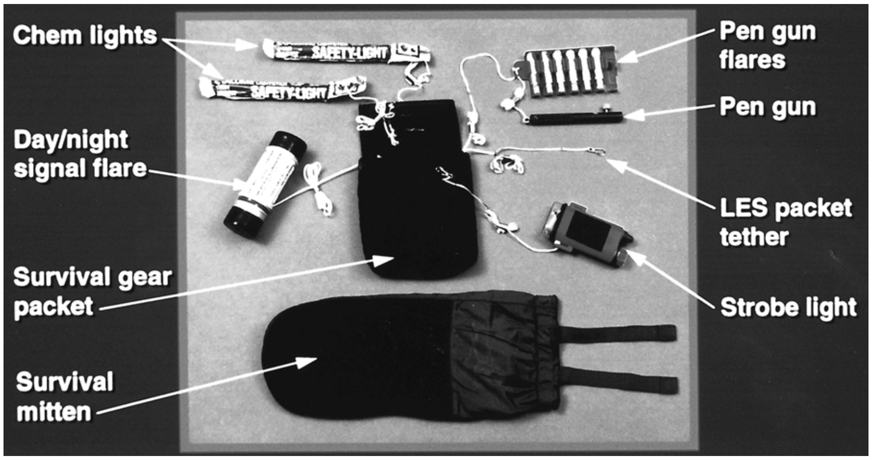
Parachute Pack (Side)

The SARSAT beacon is activated during main canopy deployment. A magnetic plug, pulled out by the canopy riser, activates the SARSAT beacon and begins transmitting during crewmember descent. The beacon has a range of 60 miles to aircraft at a 10,000-foot altitude. The main canopy also fires two redundant light-duty pyrotechnic cutters, loosening the bottom of the PPA where the liferaft is located. However, the liferaft remains stowed in place during descent until water entry.

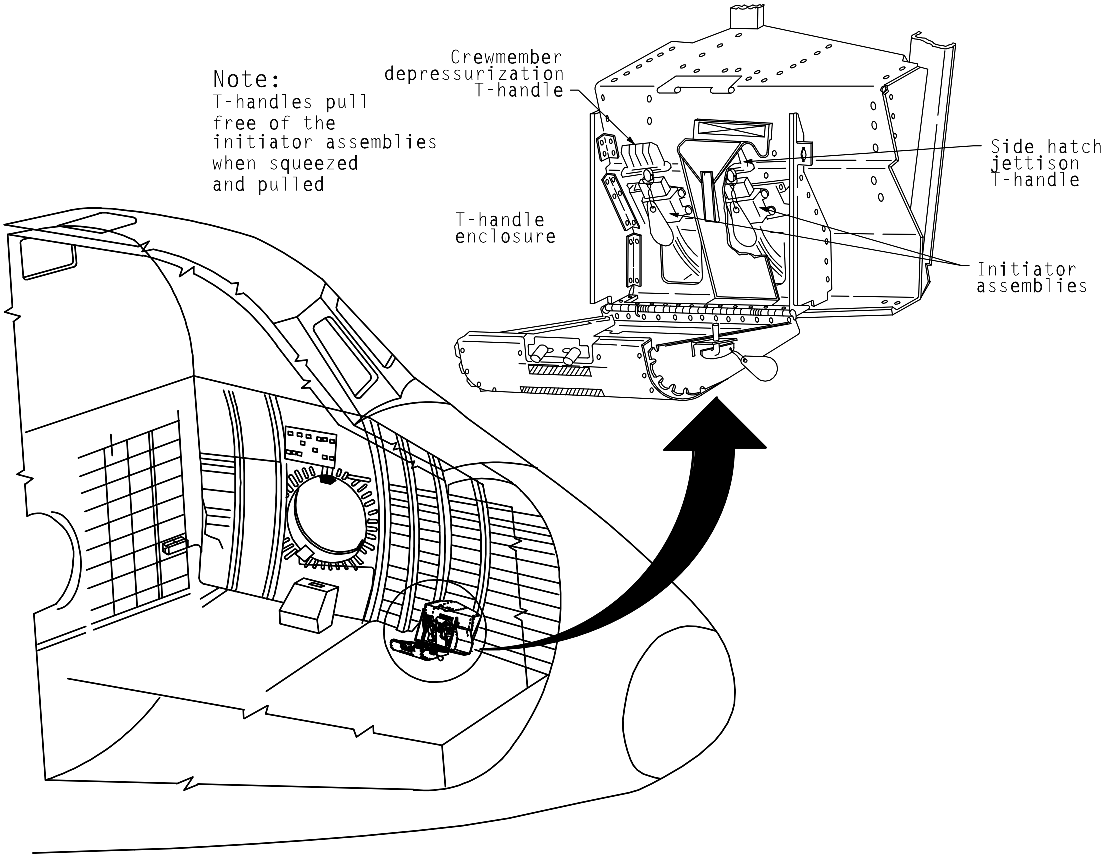
The polyurethane coated nylon life raft automatically inflates upon immersion in water. If required, a manual inflation lanyard is also installed on the left side of the PPA. Once inflated, the life raft is attached to the PPA with a 64-inch tether to keep it within reach of the crewmember. The raft is also equipped with two sea dye markers, a sea anchor, a bailing pump, and a bailing cup. Each crewmember also carries survival gear, located in both of the lower leg pockets of the ACES.

The survival gear includes a PRC-112 survival radio, a strobe light, a pen-gun flare kit, a day/night flare, a signal mirror, two 12-hour stick chem-lights, and motion sickness pills.





Survival Gear



Emergency Crew Module Depressurization and Side Hatch Jettison T-Handles

Cabin Vent and Side Hatch Jettison

The cabin vent system and hatch jettison system allow the flight crew to quickly and safely egress the orbiter during emergency situations. The cabin vent system consists of pyrotechnics and valves that let the crew quickly depressurize the crew cabin to ambient pressure prior to hatch jettison during bailout. Depressurizing the cabin prevents it from structural buckling during hatch jettison. The hatch jettison pyrotechnic system ejects the hatch from the orbiter, allowing the crew to bail out or rapidly egress the orbiter after landing.

NOTE

The pyrotechnics systems use mechanical energy transfer systems and do not require orbiter electrical power.

Separate T-handle initiators, located on the forward port middeck floor, activate the cabin vent and hatch jettison systems. The T-handles are located inside a pyro box accessible to the crewmember seated in seat 5. Squeezing together two latches on the top opens the pyro box. A safing pin is used to secure the box during orbit operations. Pre-launch and prior to deorbit, the pin is removed. Reinstalling the pin safes the side hatch.

NOTE

The convoy crew will not approach the orbiter unless the crew has reported the "side hatch safed."

The pyro vent valve is activated by squeezing and pulling the aft T-handle. The pyro vent valve opens a 15-square-inch hole between the crew compartment and the payload bay. The purpose of the valve is to depressurize the cabin at a controlled rate prior to jettisoning the side hatch in flight. This is necessary to prevent severe buckling of the middeck floor, which would occur if the side hatch were jettisoned without any attempt to equalize the inside and outside pressure. Pyro vent valve initiation at an altitude of 40,000 feet requires approximately 75 seconds to lower the pressure in the cabin to that of the ambient air outside the orbiter. Equalization occurs at approximately 31,000 feet.

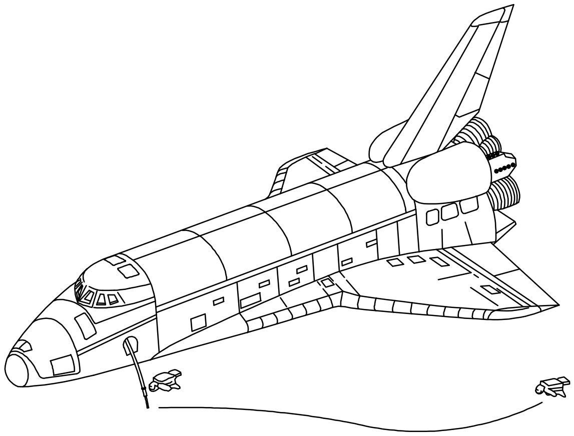
WARNING

The cabin vent pyros are an ignition source in the payload bay and should not be used for post-landing egress.

Three separate sets of pyrotechnics are associated with the side hatch, all of which are activated simultaneously by squeezing and pulling the forward T-handle. A total of four linear-shaped charges (two per hinge for redundancy) cut through hinge arms near the side hatch. Two (redundant) expanding tube assemblies are included to fracture the 70 frangible bolts that hold the hatch adapter ring to the orbiter. Three (partially redundant) thruster packs are used to separate the hatch from the orbiter at a velocity of approximately 45 ft/sec. The hatch jettison features could be used in a landing emergency.

Egress Pole System

The crew escape pole is designed to guide escaping crewmembers on a trajectory that will clear the vehicle's left wing when bailing out of the orbiter. The escape pole consists primarily of a curved, spring-loaded, telescoping steel and aluminum cylinder. The escape pole is contained in an aluminum housing that attaches to the middeck ceiling and side hatch tunnel area. A magazine holding eight lanyards is attached to the port end of the pole housing near the side hatch tunnel. The lanyards are the means by which crewmembers are guided down the pole.



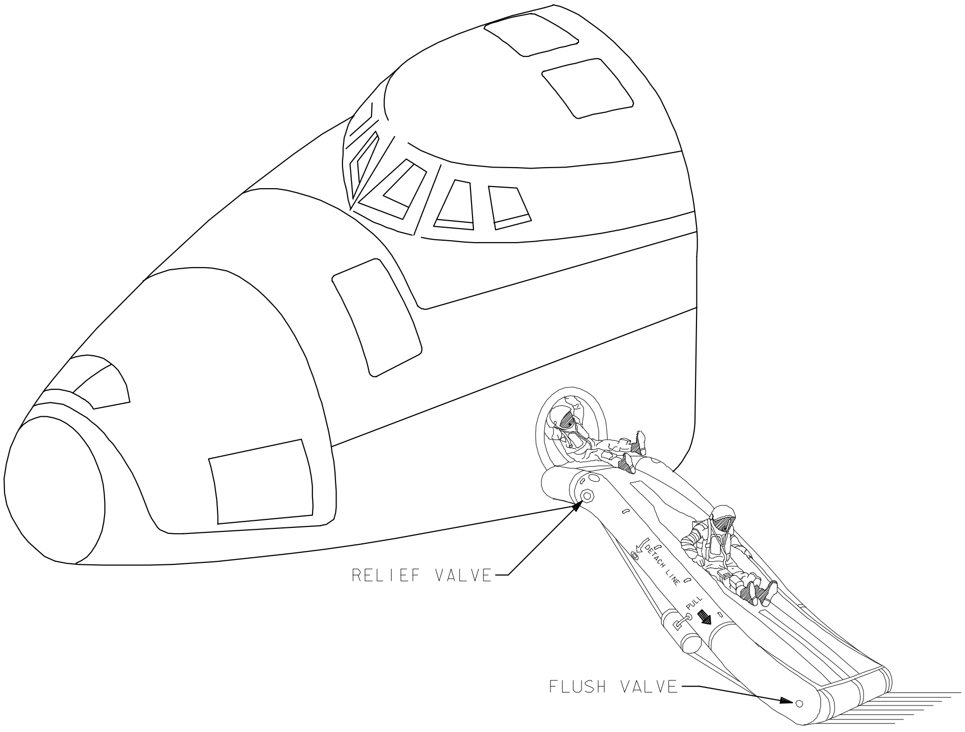
Crew Egress/Wing Clearance

Each lanyard assembly consists of a hook attached to a Kevlar strap that surrounds the escape pole. Four roller bearings on each strap surround the pole and permit the lanyard to roll freely down the pole. The Kevlar thread stitching can break away, providing the crewmember with an energy absorber. The crewmember slides down the escape pole and off the end directing him/her beneath and away from the vehicle.

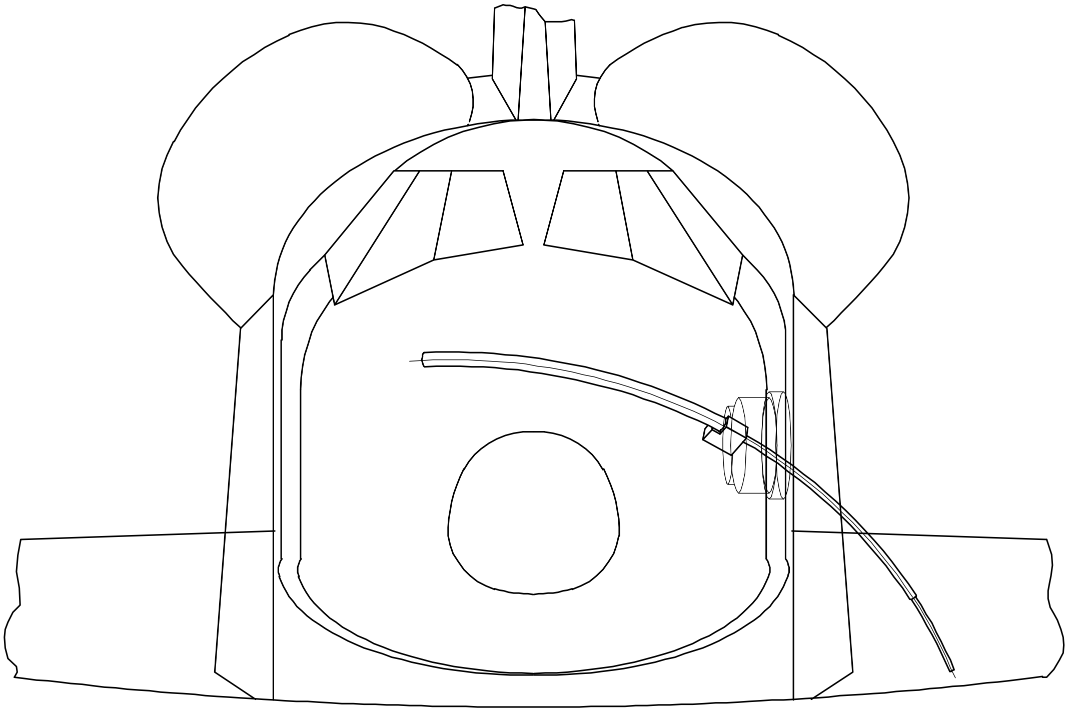
Emergency Egress Slide

The emergency egress slide provides a rapid and safe orbiter egress during post landing contingency and emergency situations. The slide allows the safe egress of the crewmembers to the ground within 60 seconds after the side hatch is fully opened or jettisoned. It also accommodates the egress of incapacitated crewmembers. Equipment consists of an inflatable slide, pressurized Argon bottle, aspirator, girt bracket, and slide cover, all stowed together below the side hatch.

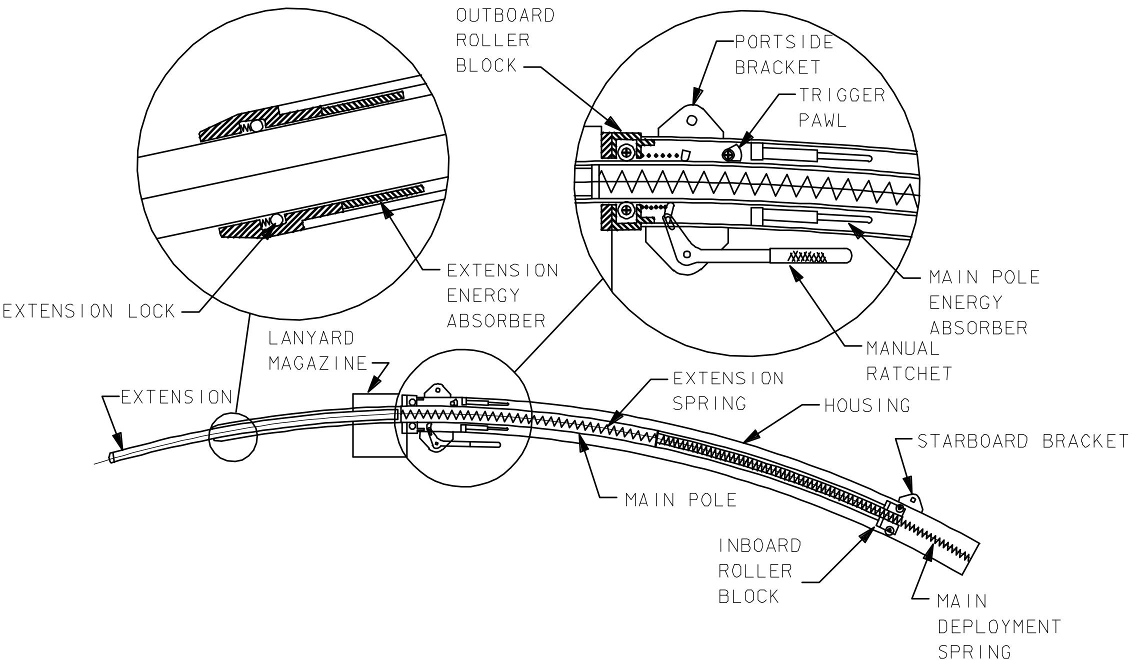
The slide can be deployed by attaching it to the side hatch if the hatch has not been jettisoned or rotating the slide into the opening if the hatch has been jettisoned. The slide is inflated by pulling a lanyard that activates an Argon bottle pressurized to 3,000 psi. The slide inflates to approximately 2.75 psig. A relief valve bleeds off pressures greater than 3.0 psig.



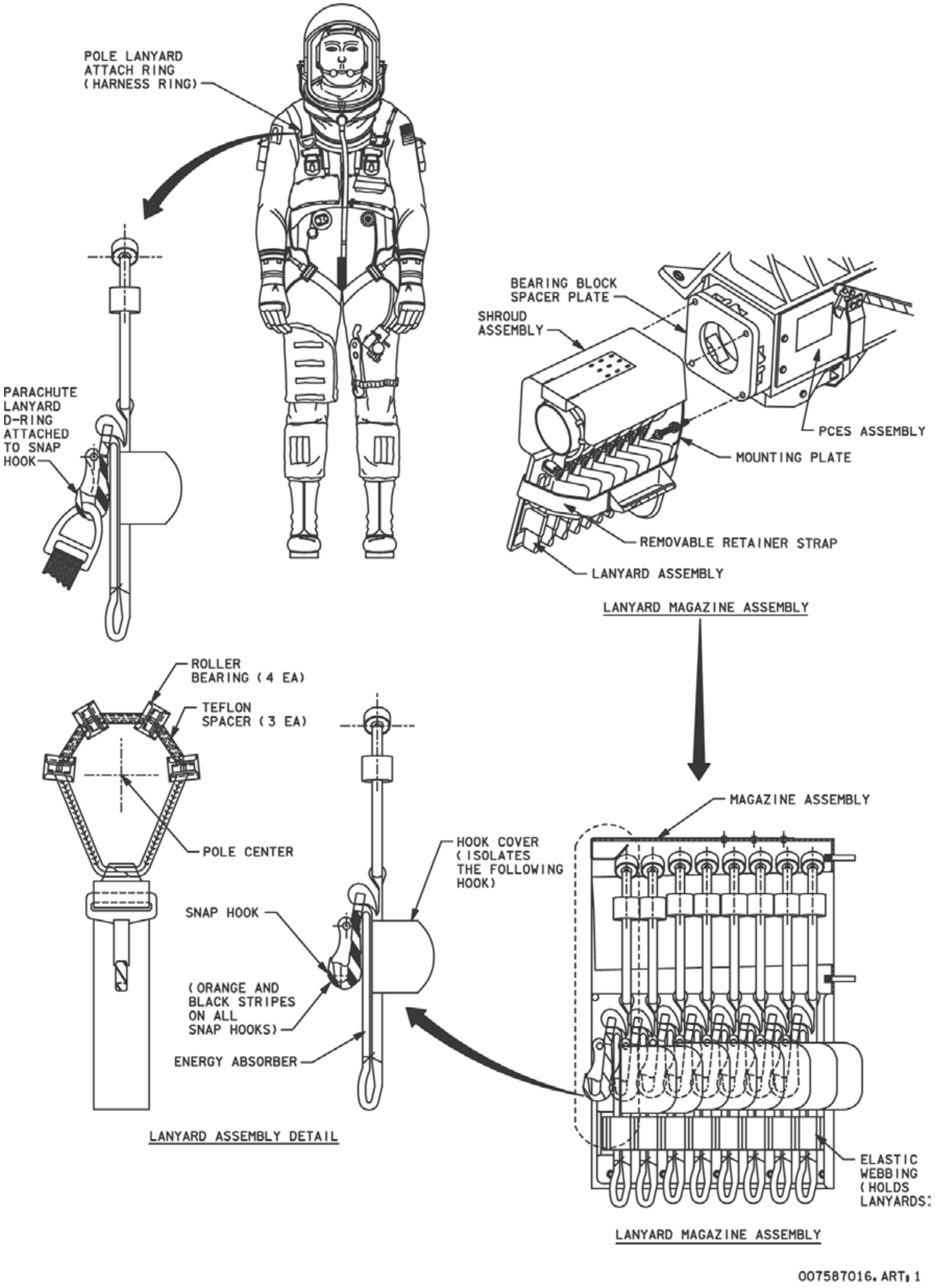
Emergency Egress Slide with Side Hatch Jettison



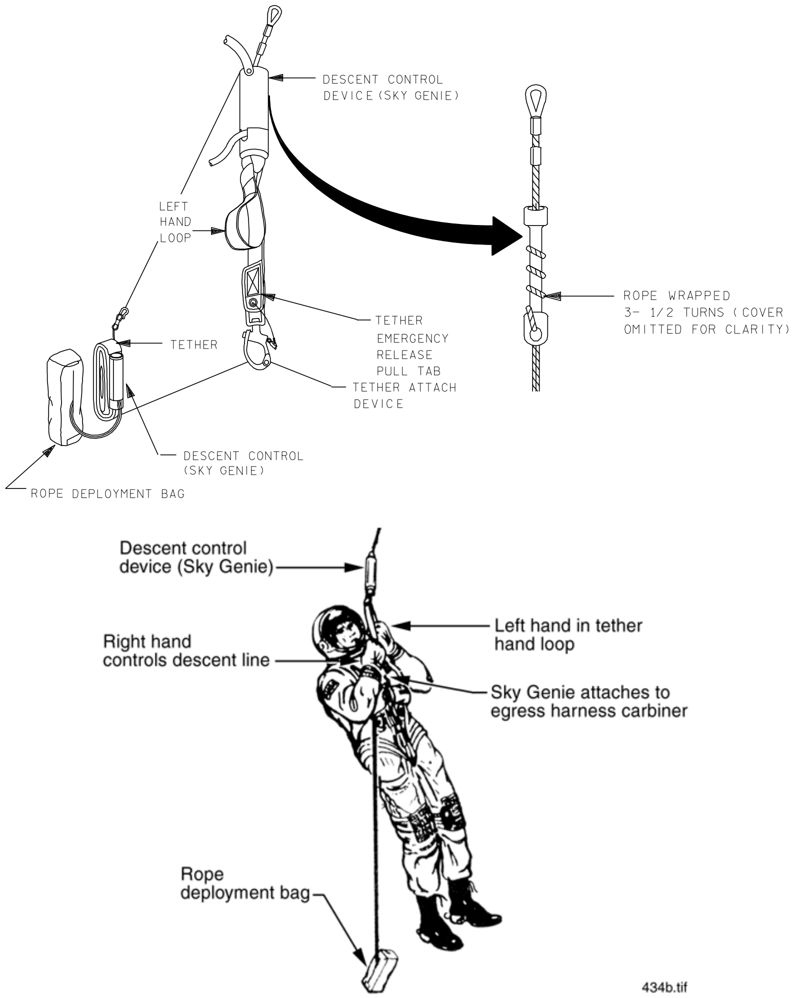
DEPLOYED POLE
(LOOKING AFT)



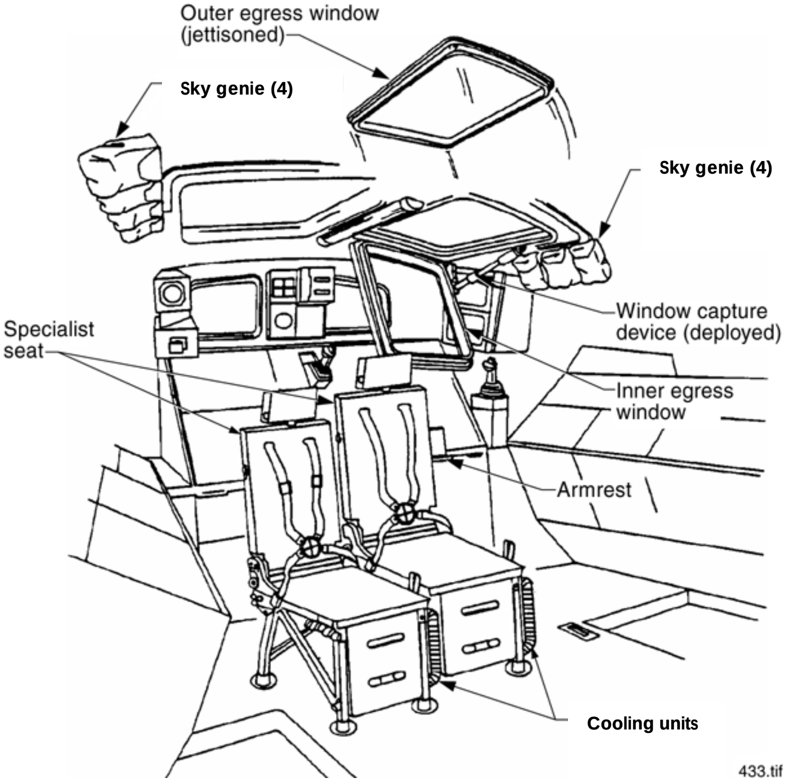
Deployed Pole Assembly



Lanyard Magazine Assembly



Descent Control Device



Overhead Egress Window Jettisoned

Overhead Escape Panel

In the event that egress through the side hatch is not possible, the port side flight deck overhead window (window 8) provides the flight crew with a secondary emergency egress route. This overhead window consists of three panes of glass, two panes attached to the crew compartment and one attached to the upper forward fuselage. The overhead window jettison system consists primarily of expanding tube assemblies, mild detonating fuses, frangible bolts, and associated initiators.

Pulling the ring handle located forward of the flight deck center console (C3) activates the overhead window jettison system. When initiated, the outer pane is jettisoned upward and aft. A time delay in the pyrotechnic firing circuit delays the initiation of the opening of the inner pane 0.3 second after the outer pane is jettisoned. The inner window pane rotates downward and aft into the crew compartment aft flight deck on hinges located at the aft portion of the window frame. A capture device attenuates the opening rate and holds the window in position. This overhead window jettison system can also be initiated by ground personnel from the outside of the orbiter on the starboard side of the forward fuselage.

Crewmembers use the MS2 seat (seat 4) to climb up through the window. Seven emergency ground descent devices (Sky Genies) are stowed on the overhead aft flight deck outboard of each overhead window, one for each flight crewmember. The emergency ground descent device enables crewmembers to lower themselves to the ground over the starboard side of the orbiter.

Procedures for Bailout, Water Survival, and Rescue

When it is determined that a bailout is necessary, the commander places the orbiter in a minimum-sink-rate attitude and engages the autopilot. At 50,000 feet, the commander directs the crew to close and lock their visors and activate emergency oxygen. At 40,000 feet, MS 3 (seated middeck in seat 5) vents the cabin via the pyro vent valve T-handle initiator. At an altitude of 31,000 feet the cabin pressure is about equalized with the outside atmosphere. Shortly thereafter, the commander directs MS3 to jettison the side hatch. As soon as the hatch is jettisoned, all crewmembers disconnect their oxygen and communication connections, and egress their seats.

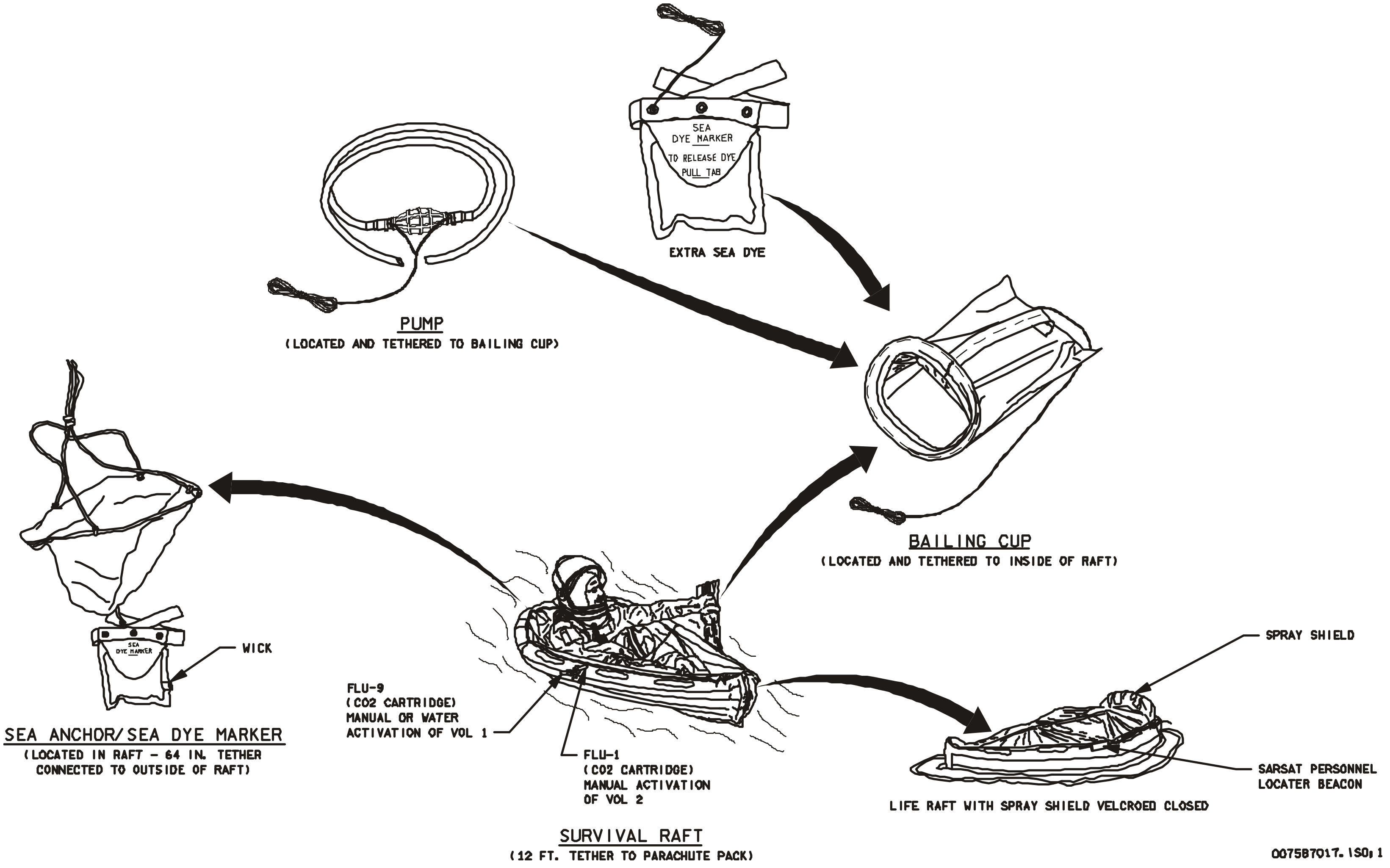
MS3 deploys the egress pole by pulling the safing pin and arming pin and rotating the handle counterclockwise. Should the pole fail to deploy fully, the manual ratchet is used to manually extend the pole. The exit involves each crewmember attaching the lanyard hook assembly to the parachute harness and egressing through the side hatch opening. It takes approximately 2 minutes for a maximum crew of eight to bailout.

As each crewmember exits the orbiter, the force exerted by entering the windstream activates the automatic parachute sequence. Once the crewmember is off the pole and away from the orbiter (1.5 second delay), a pyrotechnic cutter separates the bridle and lanyard. The 18-inch pilot chute is deployed 1.5 seconds later, and immediately deploys the 4.5-foot drogue chute. The drogue chute stabilizes the crewmember down to an altitude of 14,000 feet, then deploys the main canopy.

Prior to a water landing, the crewmember pulls the manual inflation tab for the life preserver unit. The unit is designed to inflate automatically upon immersion in any type of water, but should be activated manually as an additional safeguard. Upon landing in saltwater, the SEAWARS automatically releases the crewmember from the parachute risers. At the same time, the life raft automatically deploys and inflates. The crewmember's first task is to deploy the sea anchor and get into the life raft. Next, the crewmember pulls the activation tab on the upper CO_2 cylinder to inflate the upper chamber. Raft bailing proceeds by either using the spray shield, the bailing cup, or the bailing pump.

The crewmember's next task is to unpack the signaling equipment. The SARSAT personnel locator beacon is the primary signaling device. It is located on the raft spray shield. The telescoping antenna is extended, and the flexible antenna is removed. The PRC-112 is used to monitor 282.8 MHz and establish voice contact with search and rescue forces.

The arrival time of the search and rescue forces depends on where the bailout occurred. The first rescue force to arrive will probably be a C-130 transport aircraft, specially equipped for search and rescue. Two teams are dropped, each consisting of three rescue jumpers in a motorized rescue boat. One team drops to each end of the line of orbiter crewmembers. The C-130 may also drop two 20-person rafts for the assembled crewmembers and rescue personnel to wait in until rescue helicopters arrive.



Survival Gear

Vehicle Loss of Control/Breakup

Although there are no formal requirements for crewmembers to bail out of the orbiter during uncontrolled flight, they may be able to do so under certain circumstances. The pyro vent and hatch jettison pyrotechnics do not require orbiter power to function and can be activated even if orbiter power is lost. Each crewmember is wearing his or her own emergency oxygen bottles and parachute, and if the crew cabin is not tumbling rapidly, at least some crewmembers should be able to get to the side hatch and get out.

In the case involving loss of orbiter control, the crewmembers should activate their emergency oxygen as soon as possible and then evaluate the situation. If the crew module is lofting to altitudes above 50,000 feet, the crew should remain within it until it passes through 40,000 feet on the way back down. If the cabin is depressurized, the ACES and a cabin altimeter on the middeck can be used to judge the bailout altitude of 40,000 feet.

The escape pole is intended for use only during controlled gliding flight, and its use should not be attempted during an uncontrolled bailout. Once out of the orbiter, crewmembers should pull their parachute ripcord handle to activate the automatic opening sequence for their parachutes.

Escape Systems Summary Data

- Escape systems refer to equipment and systems intended to facilitate emergency egress of the flight crew. Escape systems include equipment worn by the crewmembers, hardware built into the orbiter, and external systems located on the launch pad.

- Escape by the flight crew on the launch pad is facilitated by descending to a safe area via slidewire baskets. The launch pad structure also includes an escape temperature and hydrogen fire-hazard monitoring system and a Firex spray system for water shower.

- The ACES is designed to protect crewmembers from (1) loss of cabin pressure and/or orbiter oxygen at altitudes of up to 100,000 feet, (2) cold atmospheric and/or water temperatures after bailing out, (3) pooling of blood in the lower body, and (4) contaminated atmosphere during flight or post-landing procedures.

- The personal parachute assembly is worn by the crew in the event of bailout. It is designed to work automatically with the crew egress pole system or with manual backups as needed.

- The hardware associated with the orbiter for purposes of in-flight crew escape consists of several types of pyrotechnics plus the egress pole.

- Three separate sets of pyrotechnics are associated with jettisoning the side hatch, all of which are activated simultaneously by squeezing and pulling a T-handle.

- The purpose of the egress pole is to guide escaping crewmembers on a trajectory that will clear the orbiter's left wing.

- The emergency egress slide is intended for use after a normal opening of the middeck side hatch or after jettisoning of the side hatch at the nominal end-of-mission landing site or at a remote or emergency landing site.

- In the event that egress through the side hatch is not possible, the port side flight deck overhead window (W8) provides the flight crew with a secondary emergency egress route.

- The commander may decide a bailout is necessary, if the range-to-go exceeds about 50 n. mi. at an altitude of 55,000 feet. The orbiter is placed in a minimum-sink-rate attitude on autopilot.

- Bailout includes using the escape pole to leave the orbiter, deploying the parachute for descent, and inflating the life raft for a water recovery. Special survival gear and procedures are provided in the case of a bailout.

2.11 EXTRAVEHICULAR ACTIVITY (EVA)

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EVA Overview

An EVA occurs when a crewmember leaves the protective environment of a spacecraft's pressurized cabin and ventures out into the vacuum of space in a space suit. An EVA is commonly known as a spacewalk. Two EVAs are available for payload use, with a third reserved for orbiter contingency operations. EVA has been useful in satellite repair, retrieval, and refueling, as well as with space station assembly.

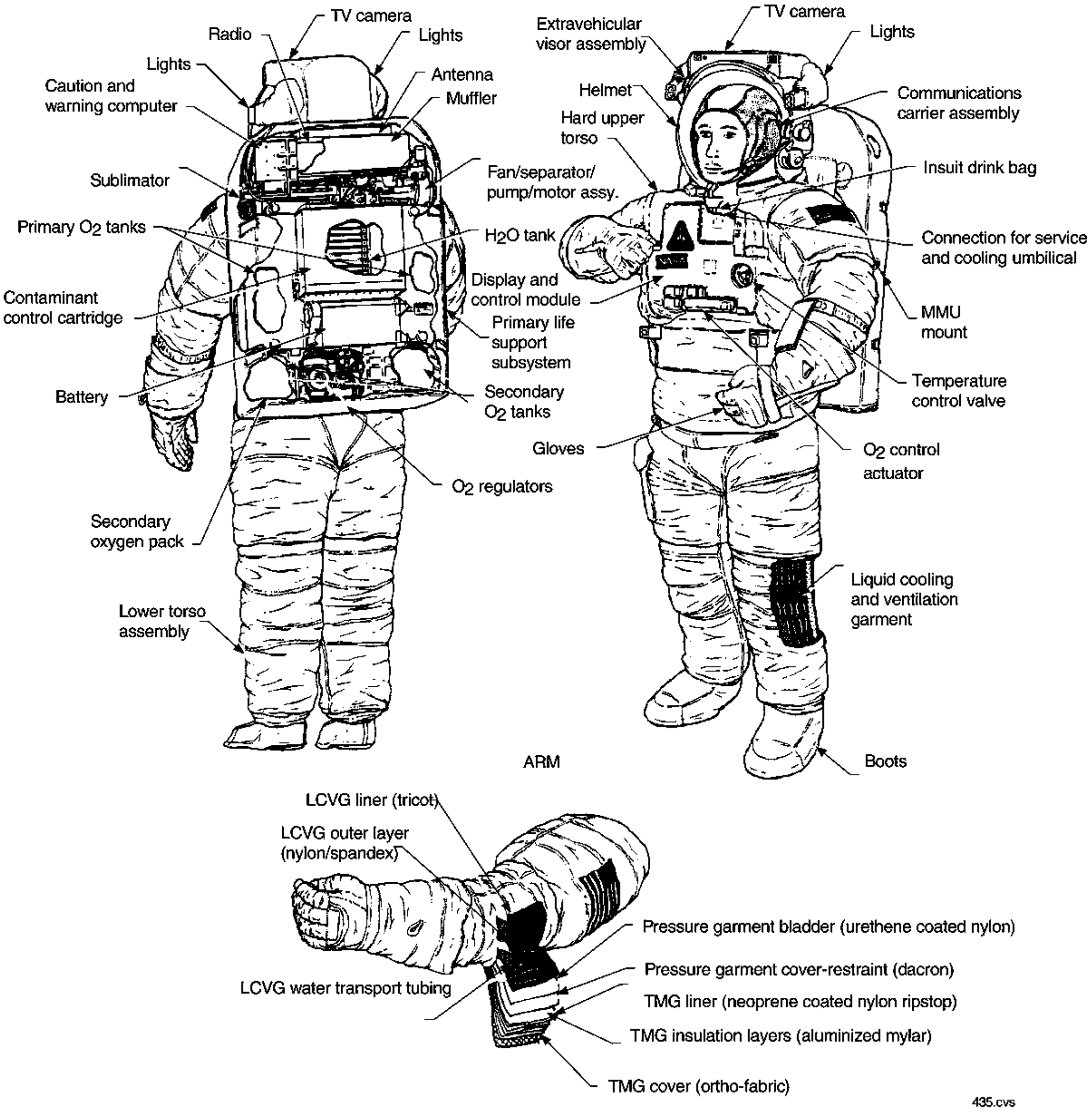
The current space suit, designed for a total maximum time of 7 hours, provides environmental protection, mobility, life support, and communications. Two suits are flown in each baseline orbiter mission, and consumables are provided for three two-person, 6-hour EVAs.

An airlock is used when crewmembers go EVA. The airlock is depressed with the crewmembers within, allowing them to egress into vacuum. The airlock allows a small volume of the shuttle to be depressed, rather than the entire crew cabin. The external airlock provides docking capability with other space vehicles when outfitted with an orbiter docking system (ODS).

There are three basic categories of EVA: scheduled, unscheduled, and contingency. A scheduled EVA is an EVA incorporated into the nominal flight plan to complete a specific mission objective. An unscheduled EVA is not part of the flight plan, but is conducted to achieve payload operation success or to advance overall mission accomplishments. A contingency EVA is also unscheduled, but is required to ensure safe return of the orbiter and crew.

Mission	Date	Purpose of EVA	EVA crew	No. EVA/ mission	Duration, man-hours
STS-6	Apr 4-9, 83	System Functional Demo	Musgrave/Peterson	1	8 hr, 34 min
STS-41B	Feb 3-11, 84	MMU Capability Demo	NcCandless/Stewart	2	23 hr, 14 min
STS-41C	Apr 6-13. 84	Solar Max Satellite Repair	Van Hoften/Nelson	2	20 hr, 12 min
STS-41G	Oct 5-13, 84	Orbiter Fuel Transfer Demo	Leestma/Sullivan	1	6 hr, 58 min
STS-51A	Nov 8-16, 84	Westar/Palapa Satellite Retrieval	Allen/Gardner	2	24 hr, 28 min
STS-51D	Apr 12-19, 85	Syncome F3 Satellite Repair	Griggs/Hoffman	1	6 hr, 20 min
STS-51I	Aug 27-Sep 3, 85	Syncome F3 Satellite Repair	Fisher/Van Hoften	2	23 hr, 42 min
STS-61B	Nov 26-Dec 3, 85	Large Structure Assembly	Spring/Ross	2	24 hr, 40 min
STS-37	Apr 5-10, 91	GRO Satellite Repair/Locomotion Studies	Ross/Apt	2	20 hr, 58 min
STS-49	May 10-14, 92	Intelsat Repair and Assembly of Station by EVA Methods (ASEM)	Thuot, Hieb, Akers, Hornton,	4	59 hr, 51 min
STS-54	Jan 17, 93	First EVA Detailed Test Objective (DTO 1210)	Harbaugh, Runco	1	8 hr, 56 min
STS-57	Jun 25, 93	EURECA Antenna Stow and Second EVA DTO (1210)	Low, Wisoff	1	11 hr, 40 min
STS-51	Sep 16, 93	Third EVA DTO (1210)	Walz, Newman	1	14 hr, 10 min
STS-61	Dec 4-8, 93	Hubble Space Telescope Repair Mission	Musgrave, Hoffman, Akers, Thornton	5	70 hr, 58 min
STS-64	Sep 16, 94	SAFER First Flight	Lee, Meade	1	13 hr, 42 min
STS-63	Feb 9, 95	First EVA Development Flight Test (EDFT) (Spartan Mass Handling)	Foale, Harris	1	13 hr, 18 min
STS-69	Sept 16, 95	Second EDFT (Task board with station EVA interfaces)	Voss, Gernhardt	1	13 hr, 32 min
STS-72	Jan 14-16, 95	Third EDFT (Station assembly and maintenance hardware)	Chiao, Barry, Scott	2	26 hr, 4 min
STS-76	Mar 27, 96	Fourth EDFT (MEEP - Mir Environmental Effects Payload)	Godwin, Clifford	1	12 hr, 4 min

Space Shuttle EVA Chronology



Extravehicular Mobility Unit

Extravehicular Mobility Unit

The extravehicular mobility unit (EMU) is an independent anthropomorphic system that provides environmental protection, mobility, life support, and communications for the crewmember to perform EVA in Earth orbit. For EMU design considerations, an EVA is defined as any time the EMU external environmental pressure is below 4.0 psia. The EMU is designed to accommodate an EVA mission with a total maximum duration of 7 hours, consisting of 15 minutes for egress, 6 hours for useful EVA tasks, 15 minutes for ingress, and a 30-minute reserve. The EMU also accommodates specific metabolic rate limits, including (1) an average metabolic rate not exceeding 1600 Btu/hr in any given EVA hour and not exceeding 1000 Btu/hr for the entire duration, (2) a peak metabolic rate not exceeding 2000 Btu/hr for a period of 15 minutes, and (3) a minimum metabolic rate not less than 400 Btu/hr for a period of 30 minutes. The EMU is an integrated assembly, primarily composed of the space suit assembly, life support system, and numerous items of associated support and ancillary equipment.

Space Suit Assembly

The space suit assembly (SSA) is the anthropomorphic pressure vessel that encloses the crewmember's torso, limbs, and head. The SSA provides a variety of functions while the crewmember performs an EVA, including suit pressure retention, crewmember mobility, crewmember liquid cooling distribution, oxygen ventilation gas circulation, downlink of crewmember's electrocardiogram data via EMU radio, crewmember interface with EMU radio, crewmember in-suit drinking water, and urine containment. The SSA operates under specific pressure requirements and leakage criteria.

The space suit assembly consists of the following:

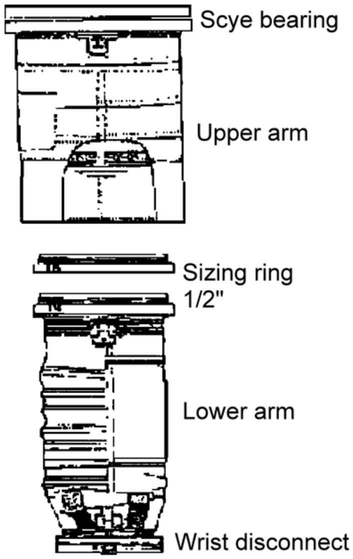
- Hard upper torso/arms
- Lower torso assembly
- Extravehicular gloves
- Helmet/extravehicular visor assembly
- Liquid cooling and ventilation garment
- Operational bioinstrumentation system
- Communications carrier assembly
- Disposable in-suit drink bag
- Maximum absorption garment

The hard upper torso (HUT) provides pressure containment for the upper torso as well as being the central component from which the mechanical, electrical, and fluid interfaces of the EMU branch. The HUT is available in four sizes to accommodate 5th through 95th percentile-sized crewmembers. The planar HUT, which deletes the arm gimbal and bellows assembly, will be available in two sizes. The HUT includes the following components: fiberglass shell (with water tubes and oxygen ducts), assorted mounting brackets, waterline and vent tube assembly, multiple water connector, EMU electrical harness, shoulder bearing assemblies, waist disconnect ring (passive half), helmet disconnect ring, and thermal micrometeoroid garment (TMG). The right and left arm assemblies are flexible, anthropomorphic pressure vessels that encompass the arms. Each arm assembly includes the following components: upper arm assembly, rotating scye bearing, lower arm assembly, rotating arm bearing, wrist disconnect ring, urethane pressure bladders, cloth restraint systems, and TMGs for the upper and lower arm assemblies.

The lower torso assembly (LTA) consists of a flexible anthropomorphic pressure vessel that encompasses the waist, lower torso, legs, and feet. The LTA includes the following components: waist assembly, waist disconnect ring, trouser assembly, rotating waist bearing between the waist and trouser assemblies, boot assembly, urethane pressure bladders, cloth restraint systems, and TMGs for the waist, trouser, and boot assemblies.

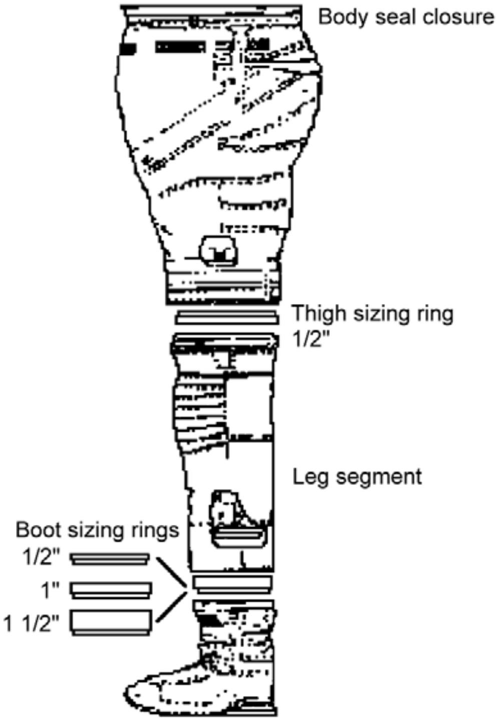
The current sizing of the arm/leg assemblies can be accomplished on the ground using different sizes of each assembly for a particular crewmember. There is also available an on-orbit capability of EMU resizing by using various arm/leg segments and sizing rings. The on-orbit quick-sizing capability, uses threaded quick-disconnects, softgood sizing elements, aluminum sizing rings, and adjustable-length restraint lines. The suit incorporates dual lip seal mobility bearings and low-torque fabric joints.

The extravehicular gloves consist of a detachable, flexible pressure vessel, encompassing each hand for use during EVA. The extravehicular gloves include the following components: urethane pressure bladder and cloth restraint system, wrist disconnect ring with rotating wrist bearing, two wrist gimbal rings, adjustable palm restraint bar/strap, wrist tether strap, fingertip heaters, and TMG with palm restraint bar. The current Phase VI series gloves are customized to fit individual crewmembers. The build process begins with a casting of the crewmember’s hands if a previously cast glove does not fit.



Enhanced Arm Assembly

The helmet, a "one-size-fits-all" model, consists of a detachable, transparent, hard pressure vessel encompassing the head. The helmet includes the following components: hard transparent bubble, helmet disconnect ring, helmet purge valve, and vent pad. Two crew optional items are also available for the helmet. One of these items is the Fresnel lens, which is mounted to the lower front inside of the helmet to improve display control module visibility for the crewmember. The other item is the valsalva device, attached to the inside of the bubble, which allows the crewmember to clear his or her ears during pressure changes. The extravehicular visor assembly (EVVA) attaches to the helmet to provide the crewmember with visual, thermal, impact, and micrometeoroid protection. The EVVA includes the following components: clear protective visor, sun visor, center and side eyeshades, fiberglass shell, and latch mechanisms and supporting structure for the visor and eyeshades.



Enhanced Lower Torso Assembly

The liquid cooling and ventilation garment (LCVG) is a form-fitting elastic garment worn against the crewmember's body. The LCVG includes the following components: outer restraint fabric, inner liner assembly, crew optional comfort pads, biomed pocket, dosimeter pocket, water tubing network, paramanifold assembly, ventilation ducting network, vent plenum assembly, multiple water connector, and full torso zipper. The garment supports a network of tubing that circulates water over the body to provide cooling to the crewmember. It also supports a network of ducting that draws ventilation gas from the suit extremities and routes it back to the primary life support system to complete the suit ventilation loop. Connections to the ducting in the HUT for both cooling water and ventilation flow are made at the LCVG half of the multiple water connector. Various sizing options for the LCVG are available to achieve a good fit for the crewmember.

The communications carrier assembly (CCA) is a cloth aviator-type cap that positions and supports the electronics for interface with the EMU radio for crewmember communications. The CCA contains the microphones and earphones necessary for the EVA crewmembers to communicate with each other or with the orbiter. The CCA also allows the EVA crewmembers to talk to Mission Control via the orbiter communications system. Six sizes allow the CCA to fit 5th through 95th percentile-sized crewmembers. The CCA includes the following components: skull cap, ear cups, ear phones, ear seals, microphone modules, microphone booms, summing module, interconnect wiring, interface cable, neck strap, crew-optional chin strap, and perspiration absorption strap.

The disposable in-suit drink bag (DIDB) is a single use, heat sealed, flexible bladder assembly mounted within a reusable restraint bag. The DIDB holds 32 oz. of water. The restraint bag is mounted to the front interior of the HUT and has a drinking tube extending to the neck area.

The maximum absorption garment (MAG) consists of multiple layers of material designed to rapidly absorb and store urine. The MAG is designed to be worn under the LCVG by male or female crewmembers during EVA. It has the capacity to hold 32 fluid ounces of urine and is disposable after use. The MAG includes multilayer absorbent material and tape attachment straps.

Life Support System

The life support system (LSS) provides a safe living environment inside the EMU. The LSS provides a variety of functions while the crewmember performs an EVA. These include provisions for breathing oxygen, suit pressurization, crewmember cooling, crewmember communications, displays and controls for crewmember operation of the EMU, and monitoring of EMU consumables and operational integrity. The life support system consists of the following:

- Primary oxygen system
- Secondary oxygen pack
- Oxygen ventilation circuit
- Liquid transport cooling system
- Feedwater circuit
- Electrical interfaces
- Extravehicular communicator (EMU radio)
- Display and control module
- Caution and warning system

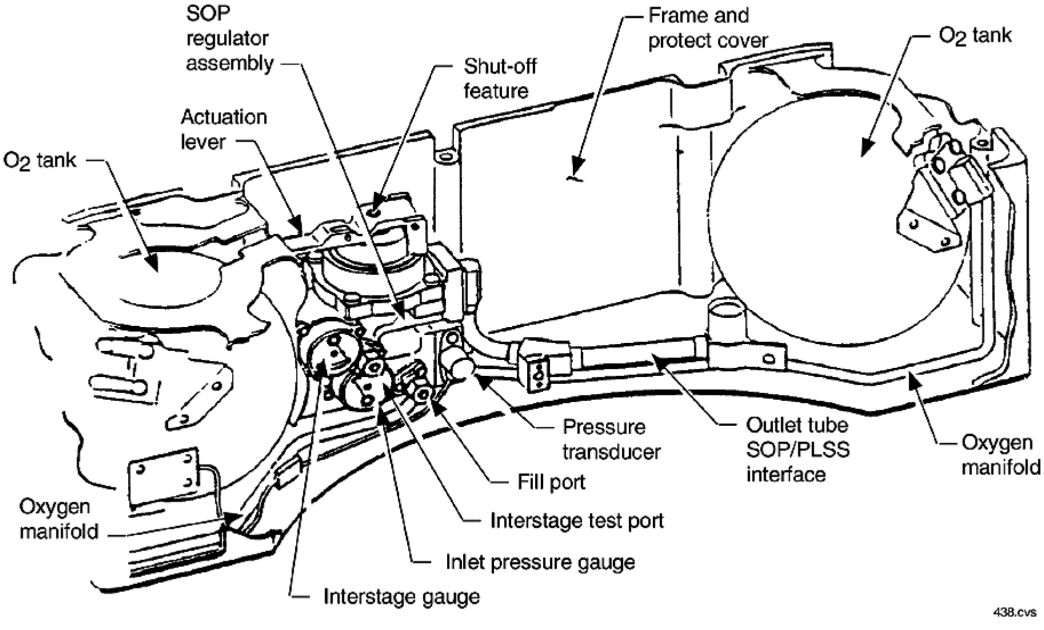
The primary life support subsystem (PLSS) consists of the primary oxygen system, oxygen ventilation circuit, liquid transport system, feedwater circuit, electrical interfaces, extravehicular communicator, and the caution and warning system. The secondary oxygen pack is a separate unit that is attached to the bottom of the PLSS. Together, the PLSS and the secondary oxygen pack make up the backpack of the EMU.

The primary oxygen system provides a crewmember with breathing oxygen and satisfies pressure requirements for EVA. The system stores 1.217 pounds of oxygen at 850 psia and 90° F. It delivers oxygen during EVA at 4.3 ± 0.1 psid, and maintains a metabolic use rate range of 0.02 to 0.33 lb/hr. The system is charged through a servicing and cooling umbilical (SCU) to the orbiter environmental control and life support system. Charging pressure is 850 ± 50 psig. The minimum usable pressure is 60 psi. The system performs various functions, including suit pressurization, provision of breathing oxygen, and water pressurization. The primary oxygen system includes the following components: oxygen tanks, oxygen tank pressure sensor, flow limiter, oxygen shutoff valve, oxygen actuator, suit pressure regulator, water pressure regulator, and dual mode relief valve.

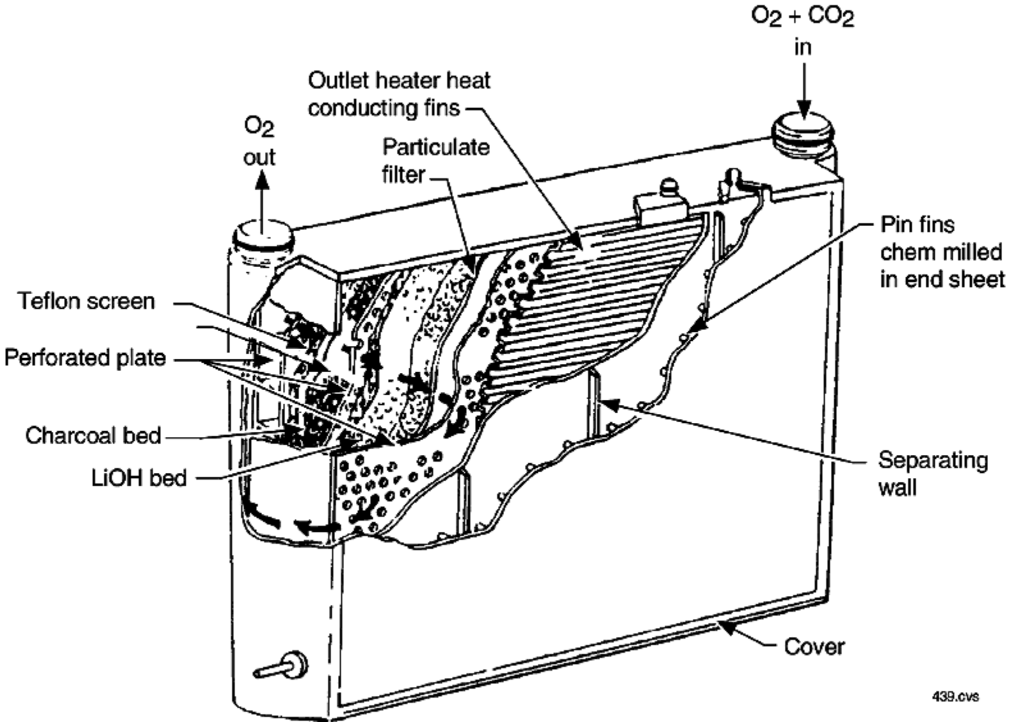
The secondary oxygen system, also known as the secondary oxygen pack (SOP), is the backup assembly to the primary oxygen system. This backup system provides a minimum of 30 minutes of emergency oxygen with the DCM purge valve open. The SOP functions include suit pressurization, provision of breathing oxygen, and some degree of cooling in the purge mode. There is no required crewmember interface to activate the SOP; it automatically activates whenever the oxygen actuator is in the EVA position and suit pressure is less than 3.9 psid. The SOP includes two oxygen tanks, containing a total of 2.65 pounds of oxygen at 5800 psia and 70° F. The system includes the following components: oxygen tanks, SOP inlet pressure gauge, first-stage regulator, interstage gauge, second-stage regulator/shutoff valve/flow restrictor, PLSS/SOP interface connector, and oxygen tank pressure sensor. The SOP is not rechargable on-orbit.

The oxygen ventilation circuit forms a closed loop with the space suit assembly. The circuit provides oxygen for breathing, suit pressurization for intravehicular activity (IVA) and EVA operation, and ventilation for cooling and elimination of exhaled gases. The oxygen flow picks up heat, humidity, carbon dioxide, and other contaminants, which are removed from the EMU by the ventilation circuit components. The system includes the following components: fan/water separator, slurper/sublimator, vent flow sensor/backflow check valve, suit pressure sensor, suit pressure gauge, contaminant control (lithium hydroxide-LiOH) cartridge (CCC), carbon dioxide sensor, display control module purge valve, helmet purge valve, positive pressure relief valve, negative pressure relief valve, and SOP checkout fixture. Ventilation flow is picked up at the body extremities and returned to the upper torso via a vent duct manifold that is part of the LCVG. From the upper torso, the gas is routed back into the PLSS and the CCC. The LiOH CCC is sized to absorb 1.48 pounds of carbon dioxide associated with 7000 Btu of metabolic activity over a 7-hour EVA period. The cartridge is installed in the back of the PLSS and is replaceable on orbit. On the ground, the used LiOH cartridge can be recharged for future use.

The liquid transport system uses the centrifugal pump to circulate approximately 240 lb/hr of water through the LCVG. The function served by the liquid transport system is to provide cooling to the crewmember. The system includes the following components: pump, temperature control valve, LCVG, gas trap, pump priming valve, pump check valve, sublimator temperature sensor, and service and cooling umbilical bypass valve. During IVA operation, the pump circulates water not only through the EMU, but also through the service and cooling umbilical to the orbiter heat exchanger.



Secondary Oxygen Pack



LiOH Cartridge

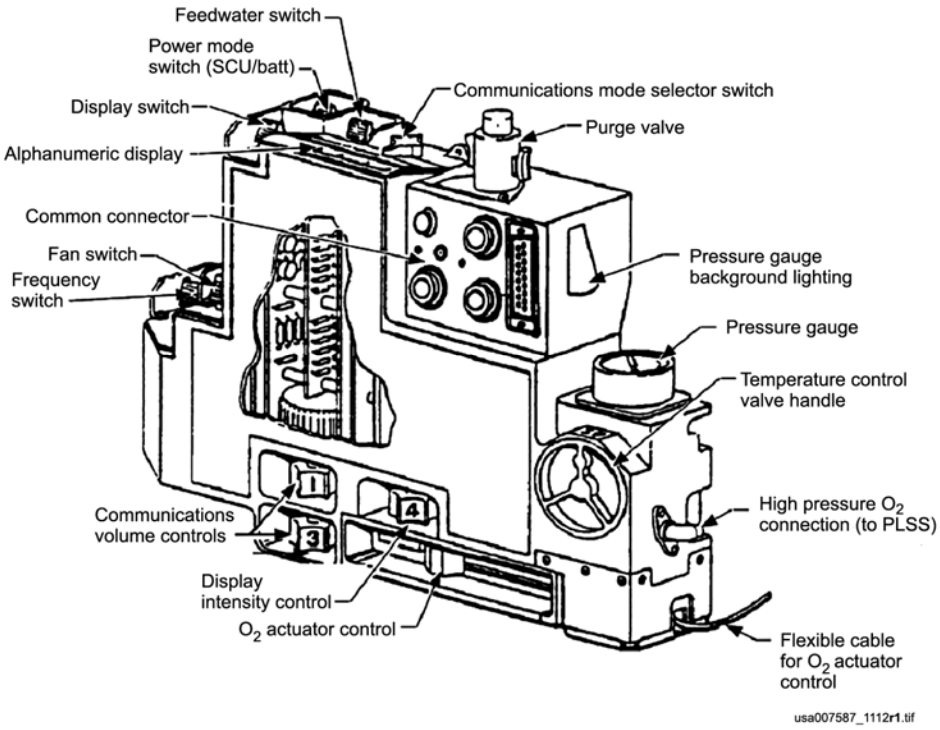
The feedwater circuit contains the equipment and water to dissipate heat loads imposed on the system by the crewmember, the PLSS, and the environment. It also contains equipment to remove moisture from the ventilation circuit and gas from the transport circuit, to separate the water and gas, and to put them back in their respective loops. The feedwater circuit functions involve heat rejection, LCVG water makeup, and vent loop condensate separation and storage. The system includes the following components: feedwater tanks (2 primary/1 reserve), feedwater tank pressure sensors, reserve feedwater tank check valve, feedwater pressure regulator, feedwater shutoff valve, feedwater pressure sensor, sublimator, feedwater relief valve, condensate water relief valve, water separator, and coolant isolation valve. The primary and reserve tanks store approximately 9 pounds of feedwater at 15 psig. The reserve feedwater tank provides 30 minutes of water for EMU cooling in the event that primary feedwater is depleted. Potable water from the orbiter ECLSS is used to fill or recharge the tanks.

The EMU electrical system is composed of the following main components: battery, feedwater shutoff valve, coolant isolation valve, motor, instrumentation, extravehicular communicator, display and control module, and caution and warning system. Electrical interfaces exist between the display and control module and parts of the PLSS, SOP, and C/W. The power supply for operation of all electrical components of the EMU is a battery installed in the back of the PLSS. The EMU battery consists of eleven sealed, silver-zinc, high current density cells connected in series. The battery provides a minimum of 32 amp-hr of power over a 7-hour EVA mission at a full charge voltage between 21.6 and 21.9 V dc.

The extravehicular communicator (EVC) is composed of two parts, the orbiter-based equipment and the EMU-based equipment. The orbiter equipment consists of the EVA/air traffic control transceivers and antennas. This configuration provides communication with the EVA crewmembers and relay between EVA crewmembers and the ground (including downlink ECG and real-time data system (RTDS) telemetry). The EMU equipment consists of the EMU radio and antenna. It provides voice communications with other EVA crewmembers and the orbiter, ECG/RTDS telemetry to the orbiter for recording and/or downlink, and caution and warning tones to alert the EVA crewmember of anomalies or other significant events. The EVC includes the following components: orbiter UHF system, EMU radio, EMU electrical harness, communications carrier assembly, biomed sensors, COMM MODE selector switch, FREQ switch, volume controls, and real-time data system. Orbiter panels O6, A1R, and R10 are the crew communication interfaces. The panels control UHF operation, air-to-air or ground transmission, and biomed data downlink/recording respectively.

The display and control module (DCM) contains all controls and displays necessary for nominal operation and monitoring of EMU systems. The DCM includes the following components: POWER mode switch, DISPL switch, FAN switch, WATER switch, FREQ switch, communications volume controls, display intensity control, oxygen actuator, temperature control valve, pressure gauge, DCM purge valve, alphanumeric display, and COMM mode selector. The DCM is installed on the hard upper torso, with the surfaces covered with a TMG. This TMG contains the labels for the controls and displays.

The EMU caution and warning system (CWS) consists of instrumentation and a microprocessor to obtain, process, and visually display information for use by the EVA crewmember in the operation and management of the EMU. The system contains built-in test equipment (BITE), consisting of software and hardware that verify proper CWS operation. CWS serial data are also routed to the ground by the real-time data system. The CWS functions involve displaying EMU leak check procedures, monitoring and displaying EMU consumables status, monitoring EMU operational integrity, and alerting crewmembers to EMU anomalies. The system includes the following components: alphanumeric display with BITE indicator, display (DISPL) switch, alert/status/warning tones, sensors, and "black box" processor. The CWS receives inputs from EMU sensors and from the DISPL switch located on the DCM. Sensors gather information throughout the EMU system and relay it to the CWS. Information is provided on pressures, temperatures, currents, and voltages.



Display and Control Module

EMU Ancillary Equipment

The EMU ancillary equipment consists of hardware necessary to support the EMU during all phases of EVA (prep/post/operation). The following list itemizes the components with a brief description of their functions.

EMU helmet lights - Attach to the helmet EVVA and provide two functionally independent sets of lights for portable lighting during an EVA task.

EMU scissors - Steel cutters with one serrated edge capable of cutting anything from fabric bags and straps to lightweight steel cable and Kevlar cord.

EMU wrist mirror - Attaches to the wrist of the EVA glove to allow the EVA crewmember to view the controls and displays on the DCM or other areas of the EMU.

EVA cuff checklist - A set of reference cards bound by an aluminum alloy bracket attached to a wrist band. The reference cards, approximately 4 inches by 5 inches in size, contain procedures and reference data for performing EVA tasks and for aiding in the diagnosis and resolution of EMU malfunctions.

*In-suit drink bag syring*e - A device used to remove gas from the water in the drink bag. The needle of the syringe is inserted in the inlet valve of the bag, and gas is suctioned out of the bag with the syringe.

*Thermal mitten*s - An adjustable enclosure composed of several layers of thermal blankets and aluminized Mylar with a layer of Nomex felt on the palm and undersides of the fingers that fit conformally around the EV gloves to provide greater thermal hand protection at extreme high and low temperature worksites.

Lower torso assembly donning handles - Left and right handles that aid in the mating of the hard upper torso and lower torso assembly halves of the waist ring.

Body Seal Closure Contingency tool (LTA prybar) - A pry bar used to disconnect the LTA and HUT halves of the waist ring in the event that the latching mechanism becomes jammed. Operation of the pry bar may damage the latching mechanism; therefore, it should be used only if the waist ring becomes jammed and the crewmember is entrapped in the space suit.

Bends treatment adapter (BTA) - An emergency device that may be used on-orbit in the event an EVA crewmember contracts decompression sickness (bends). The BTA converts the EMU into a hyperbaric treatment chamber, pressurizing the EMU to 8.0 psid over ambient cabin pressure.

SOP checkout fixture - A flight support test item installed on the HUT half of the neck ring during pre-EVA operations.

DCM plug - A cover that attaches to the multiple connector on the DCM in the event that water begins leaking from the connector after the service and cooling umbilical multiple connector is removed.

EMU servicing kit - Items necessary for preparing the EMU for EVA, such as antifog wipes, tissue-type wipes, and scissors. It also contains additional equipment necessary for routine EMU maintenance, including valsalva devices, stericide wipes, and lubricant wipes.

Bio kit - Equipment associated with the biomed instrumentation, including EVA cables, overtapes, electrode placement illustration, alcohol wipes, stoma seals, and electrode paste.

Airlock stowage bag - A Nomex bag used for temporary storage and transfer of items used in prep- and post-EVA operations. When stowed in the airlock over the inner hatch, the bag and its contents are removed from the airlock prior to airlock depressurization.

EVA bag - Used to stow various items (camera, thermal mittens, tool caddy) in the airlock for possible use during EVA. The EVA bag remains in the airlock during the EVA.

External Airlock

The external airlock on the orbiter accommodates astronaut EVA operations. The external airlock permits EVA crewmembers to transfer from the middeck crew compartment into the payload bay in EMUs through a short tunnel, without depressurizing the orbiter crew cabin. The external airlock can stow two EMUs and has the interfaces and associated displays and controls for the orbiter systems that support EMU operation and servicing. Sized to accommodate a two-person EVA, the external airlock dimensions have a diameter of 63 inches, a length slightly longer than 83 inches, and three D-shaped 40-inch-diameter openings. The floor is not solid; it is a cover over the endcone at the bottom of the external airlock. It has an empty volume of 228 cubic feet. The external airlock depresses a total volume of 208 cubic feet with two EMUs. Support functions performed in the external airlock include depressurization and repressurization, EVA equipment recharge, LCVG water cooling, and EVA equipment checkout, donning, and communications. All EVA gear, checkout panel, and recharge stations are located against the internal walls.

External Airlock Hatches

Three pressure-sealing hatches are mounted on the airlock. They are designated as an inner hatch, an EV hatch, and a docking hatch.

The inner hatch is located on the exterior of the external airlock opening into the middeck. The inner hatch isolates the airlock from the crew cabin. The inner hatch is hinged to be pulled first into the middeck and rotated down until it rests with the low-pressure (outer) side facing the airlock floor. The hatch has a hold-open hook that snaps into place over a flange when the hatch is fully open.

The EV hatch isolates the airlock from the unpressurized payload bay when closed and permits the EVA crewmembers to exit from the airlock to the payload bay when open. The EV hatch of the external airlock opens in the same manner as the inner hatch.

The external airlock's third hatch is an additional upper, outer hatch that is used for docking operations. The docking hatch, located on the top of the external airlock (toward the payload bay doors), is hinged to be pulled into the external airlock and then rotated until the low pressure side rests against the airlock wall facing toward the nose of the orbiter.

Each hatch has interconnected latches with gearbox and actuator, a window, a hinge mechanism with hold-open device, a differential pressure gauge on each side, and two equalization valves. The external airlock hatches also have hold-open protection and deployable struts for support against the airlock structure.

External airlock repressurization is controlled from the middeck or inside the external airlock. It is performed by equalizing the external; airlock and cabin pressure with airlock-hatch-mounted equalization valves on the inner hatch. Depressurization of the external airlock is controlled from inside the external airlock. It is depressurized by venting the external airlock pressure overboard. The three D-shaped airlock hatches are installed to open toward the primary pressure source, the orbiter crew cabin, to achieve pressure-assist sealing when closed. Each hatch opening is 40 inches in diameter, yet with one side being flat, the minimum dimension is 36 inches.

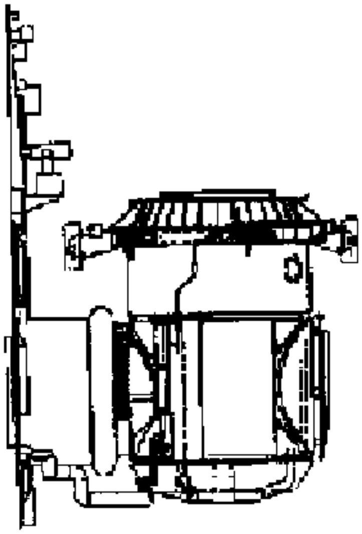
The 4-inch-diameter window in each external airlock hatch is used for crew observation from the cabin to the airlock and the airlock to the payload bay. The dual window panes are made of polycarbonate plastic and are mounted directly to the hatch using bolts fastened through the panes. Each external airlock hatch has dual pressure seals to maintain the external airlock's pressure integrity. One seal is mounted on the external airlock hatch and the other on the external airlock structure. A leak check quick disconnect is installed between the hatch and the airlock pressure seals to verify hatch pressure integrity before flight.

Each airlock hatch has the following design characteristics: (1) capable of being fully locked/ unlocked from either side, (2) designed for 2000 open/close cycles, (3) one-handed operation by astronaut in pressure suit, (4) capable of opening against 0.2 psid maximum, (5) latches capable of withstanding 20 g's in the +X direction, and (6) actuator handle load of 30 pounds maximum.

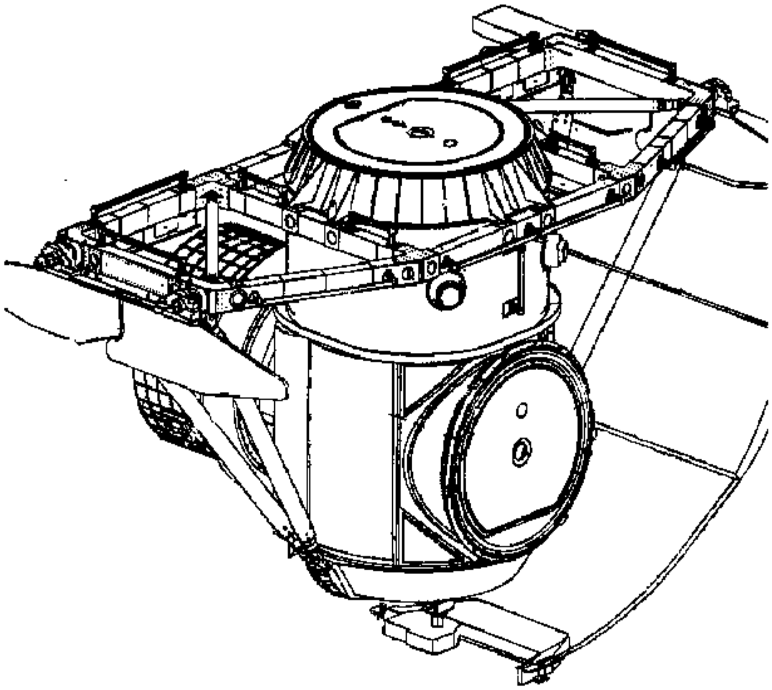
The gearbox with latch mechanisms on each hatch allows the flight crew to open or close the hatch during transfers and EVA operations. The gearbox and the latches are mounted on the low-pressure side of each hatch, with a gearbox handle installed on both sides to permit operation from either side of the hatch. Some of the latches on each hatch are double-acting with cam surfaces that force the sealing surfaces apart when the latches are opened, thereby acting as crew-assist devices. To latch or unlatch the hatch, the gearbox handle must be rotated 440°.

The hatch actuator/gearbox is used to provide the mechanical advantage to open and close the latches. The hatch actuator lock lever requires a force of 8 to 10 pounds through an angle of 180° to unlatch the actuator. A minimum rotation of 440° with a maximum force of 30 pounds applied to the actuator handle is required to operate the latches to their fully unlatched positions.

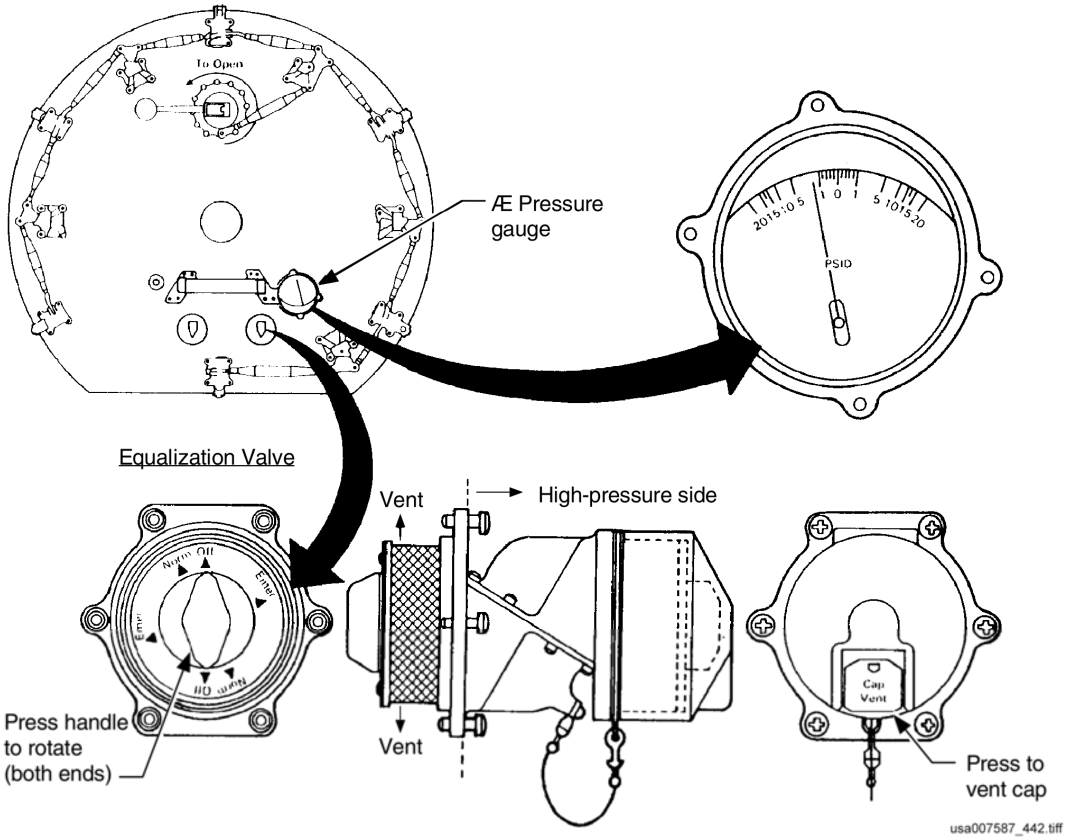
The hinge mechanism for each hatch permits a minimum opening sweep into the airlock or the crew cabin middeck.



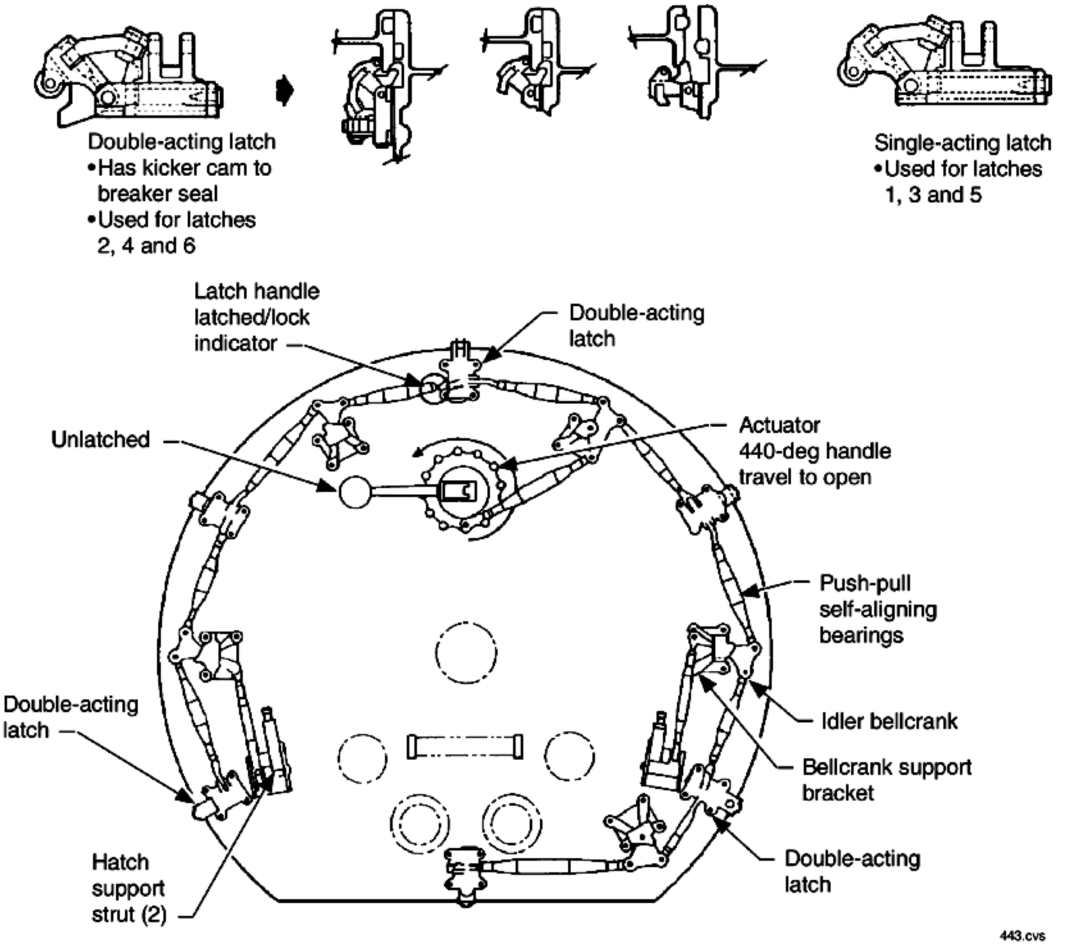
External Airlock
(port side view)



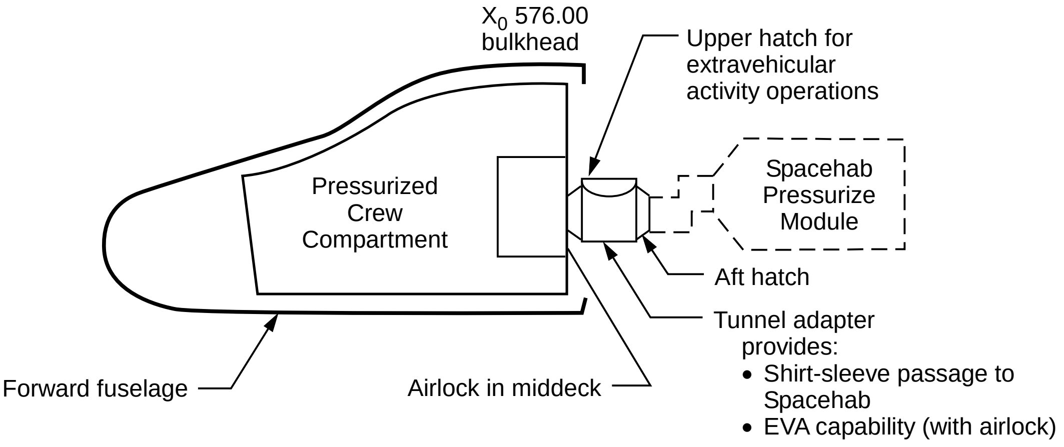
External Airlock ISS Configuration



Airlock Repressurization, Schematic Diagram



Airlock Hatch Latches, Schematic Diagram



Airlock/Tunnel Adapter

External Airlock Subsystems

The external airlock air circulation system provides conditioned air to the external airlock during non-EVA periods. Upon external airlock hatch opening in flight, a duct is installed on the middeck floor fitting by the flight crew through the cabin/airlock hatch and connected to the airlock booster fan. The duct has threaded fittings installed on the end of it which are used to secure it The duct must be removed from the airlock before the cabin/airlock hatch is closed for chamber depressurization.

To assist the crewmember before and after EVA operations, the external airlock incorporates handrails and foot restraints. Handrails are located alongside the avionics and ECLSS panels, with aluminum alloy handholds mounted on each side of the hatches. Each handrail has a clearance of 2.25 inches between the airlock wall and the handrail to allow crewmembers to grip it while wearing a pressurized glove.

External airlock-based EMU support components provide for EMU stowage, EMU operational support, and EMU recharge during intravehicular activity operations. These components include the EMU mount, the service and cooling umbilical, and the lower torso restraint bag. The EMU mount provides a mechanical interface between the EMU and airlock wall for EMU stowage. The mount attaches to the back side of the EMU and engages with three fixtures on the wall of the external airlock. The mount is also used to maintain the EMU in a fixed position on orbit for EMU donning and doffing operations. If necessary, the EMU mount can be removed from the airlock wall while on orbit.

The service and cooling umbilical consists of three water hoses, a high pressure oxygen hose, electrical wiring, water pressure regulators, and a strain relief tether. The system is used to interconnect the EMU and the orbiter airlock for the following major functions: electrical power, hardline communications, oxygen supply, wastewater drainage, water cooling capability and recharge capability for the PLSS oxygen tanks, water reservoir, and battery.

The lower torso restraint bag is attached to the bottom of the EMU mount and covers the lower torso of the EMU to restrain it during launch and entry. Straps on either side of the bag are attached to points on the upper part of the EMU mount and are tightened to ensure that the EMU is fully restrained.

The external airlock is used in conjunction with a tunnel adapter during Spacehab missions when the orbiter is docked to the ISS. The airlock tunnel adapter, hatches, tunnel extension, and tunnel permit the flightcrew to transfer from the orbiter's pressurized middeck compartment to the Spacehab pressurized shirt-sleeve environment. An upper hatch in the tunnel adapter provides egress/ingress for EVA operations. In the event of an EVA, the flightcrew may not be present in the Spacehab.

EVA Support Equipment

A variety of equipment is available to support the EVA crewmember. Depending on the task to be performed, the proper tool is available outside the airlock. The general equipment functions include securing the crewmember to the orbiter/RMS, providing the crewmember with mechanical assistance, and assisting the crewmember in mobility. The following list itemizes the EVA support components with a brief description of their functions.

Crewmember safety tether - Ensures the crewmember is positively tethered to the orbiter while providing access to all areas of the payload bay. Before airlock egress, this safety tether is attached to a waist tether and remains attached at all times during EVA, while the crewmember translates from one area of the payload bay to another.

Slidewires - Facilitate the translation of a crewmember and equipment in the forward and aft directions of the payload bay. Two slide-wires, one on each side of the payload bay, may be installed for a length of approximately 46 feet.

Tethers - Include waist and wrist tethers. Waist tethers are used to attach the crewmember to the orbiter safety tether system and to provide additional crewmember restraint at a worksite when required. Waist tethers use a large hook to be attached to various tether points (including the crewmember safety tether) and a small hook that attaches to an EMU waist tether ring. Wrist tethers are used to secure tools and hardware to the EVA crewmember and to tether points. Wrist tethers are both fixed and adjustable, attaching to loops on the EMU glove.

Handrails - Aluminum tubing strategically located to aid in crewmember translation or restraint to accomplish a specific task. Handrails are located on the forward and aft bulkheads, the hingeline of the payload bay doors, and the RMS end effector. Handrails are designed with tether attach points.

Portable foot restraint - A working platform designed to restrain the EVA crewmember while performing contingency operations on various components of the payload bay systems. The portable foot restraint stabilizes the crewmember by using a system of toe guides and heel clips designed to interface with the EMU boots.

EVA Winch - Allows the EVA crewmember to close the payload bay doors in the event of a payload bay door drive system failure. Prior to launch, the winch is mounted on both the forward and aft payload bay bulkheads. The winch consists of a reel, assisted by spring energy, housing 24 feet of 3/8-inch-diameter Kevlar rope with a hook attached to the free end.

Mini-workstation - A mechanical device that mounts on the front of the EMU to stow tools and to provide a means of tether restraint for an EVA crewmember at a worksite.

Tube cutter - Used for a contingency door-closing operation. The tool consists of spring-loaded retention rollers, a cutter wheel mounted on a slide, a blade ratchet handle, a rotating body, a control lever, and a tube-cutter ratchet handle. It is designed to cut drive door linkages.

General purpose cutter (large cutter) - Designed to cut larger cables, wires, and structural tubes that cannot be cut by the compound cutter. The ratchet direction of the jaws is controlled by an open-and-close lever mounted on the head of the tool.

Payload bay doors disconnect tools - Used to disengage the power drive unit on each payload bay door from the power-drive-unit torque shaft, allowing manual closing of the doors. The tool is approximately 6-3/4 inches long from the tip of the tether ring to the end of the 3/8-inch steel, square drive extension. Additional tools for disconnecting the door drive linkage system include vise-grip, ratcheting box-end wrench, adjustable wrench, loop pin extractor, Velcro/ tape caddy, bolt puller, and trash bag.

Three-point latch tool - Used to compensate for failed bulkhead latches. The tool consists of a stowable ratchet handle, two interchangeable tool handles, a ratchet control selection lever, a spring-loaded compensator, and two fixed-load pickup points.

Centerline latch tool - Used to compensate for a failed payload bay door centerline latch. The tool consists of a fixed-load and a spring-loaded pickup point, plus a reversible ratchet with a stowable handle and a pair of trigger release buttons with a safety that prevents an accidental release.

Airlock latch disconnect tool - A common, EVA-modified, crescent wrench used to force open a jammed latch and/or latches disconnected from the rotary actuator. The other contingency airlock disconnect tool is a drive ratchet with a 7/16-inch hex socket and 4-inch extension.

RMS rope reel - Used with the snatch blocks in case of an RMS joint failure. The reel consists of a rope spool, spool bracket, rope guide, and cam cleats. The rope reel contains approximately 80 feet of 5/16-inch-diameter Kexlon rope.

Snatch block - A common marine device used, in the event of an RMS failure, in conjunction with the RMS rope reel and EVA winch to backdrive the RMS to a stowed position.

Payload retention device (PRD) - Used as an on-orbit temporary tiedown tool so that the article or payload being secured can be repositioned as necessary to prevent damage. It consists of a housing that encloses a 15-foot Kevlar webbing strap on a spring-loaded reel.

RMS manipulator positioning mechanism wrench (RMS MPM wrench) - A double-ended, open-end steel wrench used to deploy or stow the MPMs (in the event the MPM motors fail) by manually turning the drive shaft in the appropriate direction, thus allowing for payload deployment and/or payload bay door closing.

RMS shoulder brace release - A flat steel bar with an angled foot used to disengage the RMS shoulder brace locking mechanism, thus releasing the shoulder brace. If the lock is not released, the RMS is inoperative.

Grapple fixture release tools - Used to remove a grapple fixture shaft should an end effector malfunction, failing to release a payload. The tools include a probe and 1/2-inch ratcheting box-end wrench.

Radiator actuator disconnect tools - A 3/8-inch drive ratchet and 1/4-inch allen wrench extension used to disconnect the radiator actuators and support stowage of the radiators in the event of a failure.

External tank umbilical door tool - Used to override a failed external tank door centerline latch and support ET door closure.

Generic jam removal tools - Compound cutters, needle nose pliers, probe, hammer, prybar, forceps, trash bag. For use in disconnecting or dislodging jams in various orbiter mechanisms, such as PLBD hinges, latches, etc.

Portable foot restraint (PFR) bridge clamp - Provides a PFR socket that mounts on the sill of the PLB in available locations on existing bridge rails.

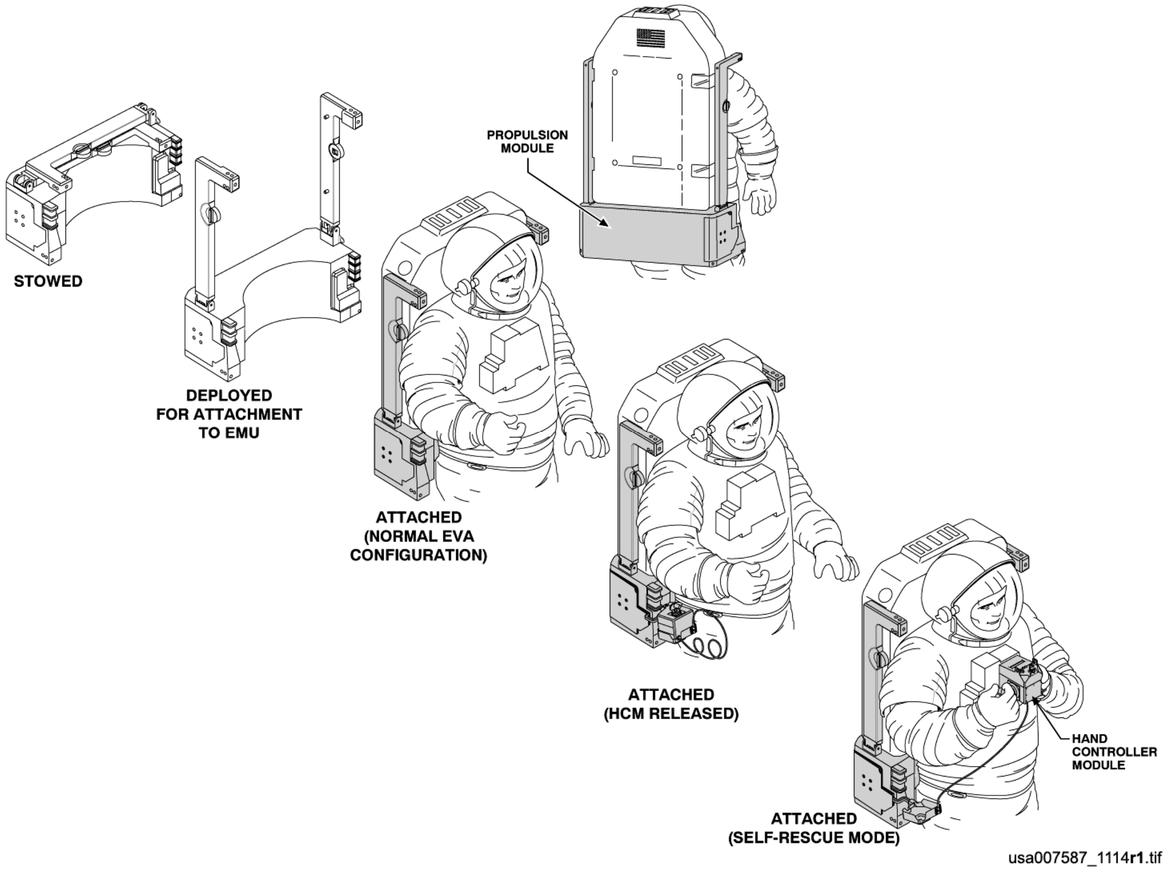
Simplified Aid for EVA Rescue

The simplified aid for EVA rescue (SAFER) is a small, self-contained, propulsive backpack system used to provide a free-flying rescue capability for an EVA crewmember. SAFER is a "simplified," single-string system that fits on the bottom of the EMU PLSS and attaches to existing mounts on the sides of the PLSS.

SAFER is designed to be used as a self-rescue device for a separated EVA crewmember in situations where the orbiter is unavailable to provide rescue capability. Such situations would include when the orbiter is docked to a large payload or structure, such as the ISS. The SAFER will also be used during all future ISS EVA operations where the orbiter might not be present at the ISS during an EVA.

To provide self-rescue capability, the SAFER offers a minimum of 13 minutes of battery power. The SAFER has 24 gaseous-nitrogen (GN_2) thrusters to provide 6 degrees-of-freedom maneuvering control. The SAFER is controlled by a single hand controller housed in a hand controller module box located on the bottom of the unit. The SAFER propulsion subsystem provides a total delta velocity of at least 8 ft/sec with an initial charge. The flight unit weighs approximately 85 pounds and folds for launch, landing, and on-orbit stowage.

The SAFER is the product of a Johnson Space Center (JSC) in-house project to develop, build, and produce a rescue device for when the orbiter cannot provide rescue capability and for ISS EVA operations. An on-orbit SAFER detailed test objective (DTO) conducted on shuttle mission STS-64 was very successful. This DTO demonstrated SAFER's operational capabilities and collected performance data to augment the design and development of the final operational SAFER. The STS-76 SAFER was a transitional unit between the DTO unit flown on STS-64 and the final production unit that was manifested for ISS. SAFER has a limited certification timeframe; however, after use on orbit, the unit will be returned to Earth for refurbishing.



Attachment of SAFER to EMU

Operations

As previously discussed, there are three types of EVA: scheduled, unscheduled, and contingency. A scheduled EVA is defined as any EVA incorporated into the normal flight plan in order to complete a specific mission objective. A subcategory of scheduled EVA is the quick-response EVA, which must be performed within a few hours after a problem is discovered. It is usually associated with payload deployment. Quick-response EVAs are planned pre-flight, and the crew prepares for the EVA even though it may not be performed.

An unscheduled EVA is not part of the flight plan; rather, it is conducted to achieve payload operation success or to advance overall mission accomplishments.

A contingency EVA is also unscheduled, but is required to ensure safe return of the orbiter and flight crew. Contingency EVAs occur if orbiter hardware sustains a malfunction. Procedures, tools, and specified work locations are identified for practice on any STS mission. The recognized failures pertain to the following orbiter systems: radiator actuator, payload bay doors, bulkhead latches, centerline latches, airlock hatch, remote manipulator system (RMS), bulkhead camera, Ku-band antenna, and external tank doors. The corrective actions for each system failure are itemized in the System Failure Corrective Actions Table.

Extravehicular activities are classified according to level of complexity: simple, intermediate, or complex. A simple payload EVA requires minimal unique tools, mockups, or mobility aids. Existing procedures and techniques may be adapted to particular EVA needs, thus requiring minimal crew training. An intermediate payload EVA requires development of new tools and equipment. Some procedure and technique development is required, with more extensive training necessary. A complex payload EVA requires the design and development of complex or elaborate tools and equipment. The tasks require extension of basic capabilities and may pose difficulty in access or restraint. Procedure and technique development is extensive, as are crew training requirements.

Regardless of the EVA type, a series of procedures is required to initiate and terminate an EVA. These procedures cover an integrated timeline sequence from the EVA checklist. The detailed procedures are summarized for reference in the following steps:

1. ***Quick don mask prebreathe*** - Donning of the mask for prebreathe and cabin depressurization.
2. ***Cabin depressurization to 10.2 psi*** - Reducing the cabin pressure from 14.7 psi to 10.2 psi.
3. ***EMU checkout*** - Preliminary checkout of the EMU systems prior to EMU donning.
4. ***Middeck preparation and preparation for donning*** - Configuration of the EMU and its ancillary components for crewmember donning.
5. ***Suit donning*** - Crewmember donning of the EMU and ancillary components, approximately 40 minutes duration.
6. ***EMU check*** - Configuration and checkout of the EMU prior to EMU purge.
7. ***EMU purge*** - Nitrogen purge of the EMU prior to prebreathe.
8. ***Prebreathe*** - Crewmember acclimation to lower chamber pressure, over a period of 40 to 70 minutes.
9. ***Preparation for depressurization*** - Configuration of the airlock and closing the inner hatch prior to airlock depressurization.
10. ***Airlock depressurization*** - Configuration and checkout of the EMU, airlock depressurization to vacuum, and opening of the outer hatch.
11. ***Airlock repressurization*** - Airlock repressurization and opening of the inner hatch.
12. ***Post-EVA*** - Shutdown of the EMU systems and doffing of the EMU and ancillary components.
13. ***EMU maintenance/recharge*** - Change-out or recharge of the EMU battery and lithium hydroxide cartridge and general cleaning of the EMU for subsequent EVA; recharge of the EMU water system.
14. ***Post-EVA entry preparation*** - Reconfiguration and restowage of the EMU and airlock equipment.

A set of procedures are followed when a crewmember has contracted the bends during an EVA. The crewmember discontinues the EVA and returns to the airlock to connect to the service and cooling umbilical. The airlock is repressed to 10.2 psia, and the cabin is repressed to 14.7 psia. The helmet is doffed, and the crewmember drinks a minimum of 32 ounces of fluids. After proper EMU reconfiguration, the bends treatment adapter is installed for bends recovery.

Scheduling an EVA is a very complex and involved task. The following list outlines the general mission constraints regarding EVA, but does not attempt to define the detailed specific activities.

- The maximum scheduled duration for an EVA is 6 hours.
- All scheduled and unscheduled EVAs require two crewmembers.
- No scheduled or unscheduled EVA shall occur on flight day 1 (~24 hours MET).
- No scheduled EVA shall be planned to occur prior to flight day 4 (~72 hours MET) unless:
    i) A specific flight is dedicated to scheduled EVA activity, and

  - ii) That payload customer has specifically negotiated with NASA for the early scheduled EVA capability, and an exemption is processed.

- The latest an EVA may be scheduled in preflight planning is EOM-2.

- No unscheduled EVA shall be planned to occur prior to flight day 3 (~48 hours MET) unless:

  - i) A specific payload has no alternative but to utilize an EVA as its third level of redundancy for the purpose of a critical backup to deploy/operations that would prevent loss of the payload, and

  - ii) That payload customer has been made aware of the inherent risk that the EVA may not be able to be performed due to crew status, and the customer has agreed to accept the risk, and

  - iii) That payload customer has specifically negotiated with NASA for the early unscheduled EVA capability, and an exemption is processed.

- The following are required response times prior to an unscheduled payload EVA:

  - i) Upon the discovery of a failure leading to an EVA, approximately 24 hours are allotted for EVA preparation prior to starting actual EVA maintenance on a failed component.

  - ii) If the case above occurs on launch day, then approximately 44 hours are allotted prior to starting EVA maintenance.

  - iii) If a payload requires a shorter EVA response time, the requirement for that EVA must be negotiated with NASA, and an exemption must be processed.

- Payload activities that could require an unscheduled EVA at the end of a mission may only be scheduled if there are sufficient consumables and landing opportunities to extend the mission to perform the EVA and preserve 2 wave-off days.

- A minimum of 1 flight day must separate two scheduled EVAs, for any given EVA crewmember.

- A contingency EVA will be scheduled in real time whenever it is necessary to restore the orbiter to a configuration for safe return.

FAILURE	CORRECTIVE ACTION
Radiator actuator	Radiator actuator disconnect
Payload bay door system	PDU Winch operations PLBD drive system linkage cut PLBD drive system disconnect Electrical crossover disconnect Jam removal
Bulkhead latch	3-point latch tool installation Jam removal
Centerline latch	Centerline latch tool installation Jam removal
Airlock hatch	Airlock latch disconnect Hinge disconnect
RMS	RMS joint alignment RMS tiedown MPM stow/deploy RMS shoulder brace release Grapple fixture release
Bulkhead camera	Disconnect and remove camera
Ku-band antenna fails to align for stowing	Ku-band antenna gimbal alignment
External tank door	ET door centerline latch release

System Failure Corrective Actions Table

EVA Summary Data

- EVA refers to operations performed outside the spacecraft crew compartment.
- For generic orbiter missions, two suits are included with consumables provided for three, two-person, 6-hour EVAs.
- There are three basic categories of EVA: scheduled, unscheduled, and contingency.
- The extravehicular mobility unit (EMU) is an independent anthropomorphic system that provides environmental protection, mobility, life support, and communications for the crewmember to perform EVA in Earth orbit. An EVA is defined, for EMU design considerations, as any time the EMU external environmental pressure is below 4.0.
- The EMU is an integrated assembly, primarily composed of the space suit assembly, life support system, and numerous items of associated support and ancillary equipment.
- The orbiter's external airlock permits EVA flight crew members to transfer from the middeck crew compartment into the payload bay in EMUs without depressurizing the orbiter crew cabin. The external airlock also provides launch and entry stowage of up to two EMUs.
- The external airlock's support functions include airlock depressurization and repressurization, EVA equipment recharge, LCVG water cooling, EVA equipment checkout, donning, and communications.
- Depending on the task to be performed, the proper tool is available outside the external airlock. The general EVA-support equipment functions include securing the crewmember to the orbiter/RMS, providing the crewmember with mechanical assistance, and assisting the crewmember in mobility.
- A standard series of procedures (pre and post operations) are required to initiate and terminate an EVA, regardless of the EVA type.

EVA Rules of Thumb

- Always use "make before break" tether protocol.
- Do not use the glove as a hammer.
- EVA crewmember and equipment must remain tethered at all times.
- Slow, deliberate motion provides much greater stability than quick, jerky motions.
- Body positioning is 90 percent of the task.
- Each EVA crewmember should check out his or her own EMU.

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2.12 GALLEY/FOOD

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Description

The middeck of the orbiter is equipped with facilities for food stowage, preparation, and dining. The food supply is categorized as either menu food, pantry food, or fresh food. Meals are individually tailored, based on crewmember preference. Menu food consists of three daily meals per crewmember and provides an average energy intake of approximately 2,700 calories per crewmember per day. The pantry food is a 2-day contingency food supply that also contains food for snacks and beverages between meals and for individual menu changes. Pantry food provides an average energy intake of 2,100 calories per crewmember per day. Fresh food items consist of perishable items such as fruits, vegetables and tortillas. The types of food include fresh, thermostabilized, rehydratable, irradiated, intermediate-moisture, and natural-form and rehydratable beverages.

Three 1-hour meal periods are scheduled for each day of the mission. Breakfast, lunch, and dinner are scheduled as close to normal meal times as possible. Dinner is scheduled at least 2 to 3 hours before crewmembers begin their pre-sleep activities.

Galley

The galley is a multipurpose facility that provides a centralized location for one individual to handle all food preparation activities for a meal. The galley has facilities for heating food, rehydrating food, and stowing food system accessories. The galley consists of a rehydration station, oven, hot water tank, and associated controls.

Oven

The oven is divided into two principal compartments: an upper compartment designed for heating up to 14 rehydratable food containers inserted on tracks, and a lower compartment designed to accept up to 7 flexible packages. The *OVEN/RHS ON/OFF* switch provides power to the oven heaters and the control electronics assembly. The oven fan *ON/OFF* switch enables/disables power to three oven fans. These fans circulate warm air over a heat sink, thus providing forced convection heating for the rehydratable packages. The flexible packages are held against the heat sink by three spring-loaded plates, and warmed by conduction. The oven has a heating range of 160° to 185° F. The oven door is operated by a "squeeze" latch requiring only 3 lb of pressure to open.

Rehydration Station Dispensing System

The galley rehydration station dispensing system interfaces directly with food and beverage packages to provide rehydration capability and drinking water for crewmembers.

When both WATER HEATER switches are turned on, 145° - 165° F water is available for rehydration. The *VOLUME/OUNCES* switch selects the volume of water to be dispensed by the rehydration station in 0.5-ounce increments from 0.5 of an ounce to 8 ounces. The yellow *(HOT)* pushbutton indicator allows hot water to be dispensed when it is depressed and is illuminated when energized. When the selected volume of water has been dispensed, the pushbutton will begin to flash on and off. The light will be extinguished when the food package is retracted, releasing the rehydration station lever *ARM/LIMIT* switch.

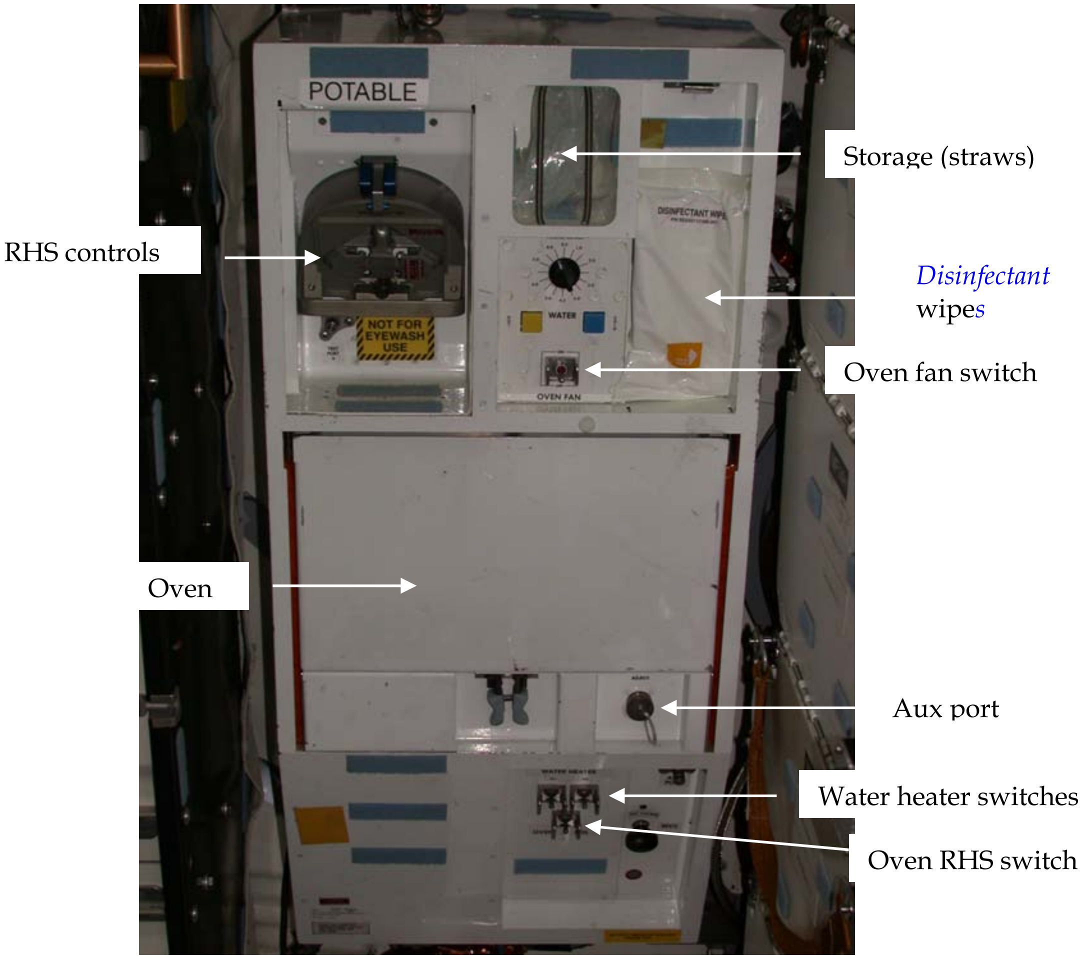
The blue (*COLD)* pushbutton indicator allows cold water (40° - 60° F) to be dispensed when it is depressed and is illuminated when energized.

The rehydration station lever ARM/LIMIT switch serves as an interlock so water can be dispensed only when a food package is connected to the needle. The food package makes contact with the rehydration station lever, which activates the LIMIT switch (note that the flight crew does not physically actuate the lever).

Galley Controls

The galley controls consist of the OVEN/RHS switch, the two *WATER HEATER* switches, the *OVEN FAN* switch, the rehydration station hot and cold pushbuttons and quantity selector dial, and the MV2 valve. Six water heater strips on the hot water tank are energized when the two *WATER HEATER* switches are turned on. The *OVEN/RHS* switch controls power to the oven heaters and rehydration pumps and associated electronics.

On the lower right-hand side of the galley (above the MV2) is an auxiliary port water quick disconnect (AUX PORT QD) that allows the crewmembers to access ambient to hot (70° - 120° F) potable water when a 12-foot flex line and water dispensing valve are attached to the QD. The MV2 valve, located below the AUX PORT QD, allows the crew to control the temperature of water (hot to ambient) out of the AUX PORT. The galley also has a test port (under the rehydration station) and a canon plug (by the oven latch) that are used for ground operations.



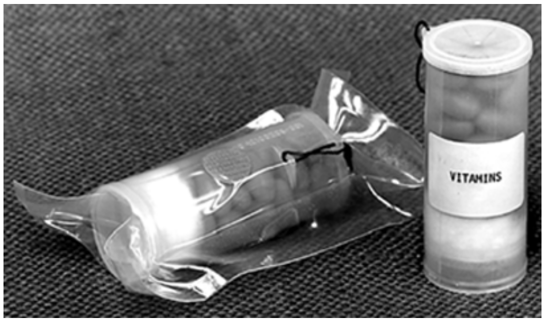
Shuttle Galley

Volume A - Pantry

Volume A holds a hodgepodge of items in two half trays and two quarter trays stowed upside down. Snack foods, such as almonds, dried apricots, butter cookies, candy-coated nuts, candies, granola bars, peanut butter, and dried beef, are stowed in the first tray. This "free-for-all" food is available to anyone at any time and tends to be very popular. The second tray of volume A contains all the entry day weather wave-off entrees. Unlike the menu food that is packed by meals and itemized with labels, this food is stuffed into the tray in a jumble. Crewmembers are free to swap out their planned meals during the mission with items from this tray. The third and fourth trays hold extra drink bags and beverages, straws, condiments and utensils. The extra drink bags are for drinking water. Drinking straws can be removed from this tray and temporarily stowed in the storage compartment of the galley for easy access. Each crewmember is provided with one set of utensils, which includes a knife, fork, tablespoon, and a small pair of scissors, for the entire flight.

About 6 months before a flight, crewmembers attend a food tasting provided by the food systems group (SF3) to sample and rate every food and drink item, including reentry kits. Several weeks later, crewmembers individually meet with a dietitian to develop their personal menus for the flight. Choices are based on the crewmember's preferences from the tasting and on the dietitian's nutritional and caloric recommendation. Generally, the food supply is more than adequate because about 30 to 50 percent of all the food manifested for flight returns unopened. The food systems people make a good effort to accommodate special requests for favorite and ethnic foods.

Utensils



Vitamins

***Disinfectant* Wipes**

Salt, Pepper, and Toothpicks

Food System Accessories

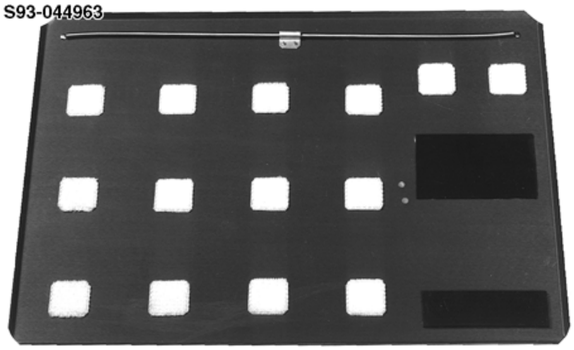
Accessories consist of gum and candy, vitamins, disinfectant wipes, and the galley adapter. The galley adapter is a removable piece of the galley slide/adapter mechanism. The disinfectant wipes are a COTS product that allow crewmembers to clean their eating utensils. Each package contains 26 wipes and is fitted with Velcro patches that allow its installation on the front of the galley. Packages are stowed for launch and noted on the Consumables Cue Card for replenishment, as needed.

Reentry Kits

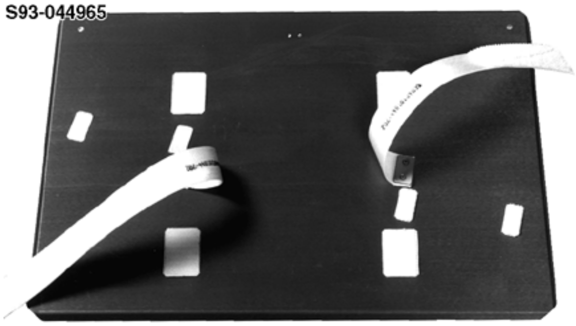
The reentry kits, also known as fluid loading kits, contain either empty drink bags and salt tablets, chicken consommé (drink) packets, or Astroade packets (like Gatorade without sugar). Crewmembers must consume a certain amount of water and salt tablets, depending on their body weight, prior to entry to aid in their readjustment to one g.

Trays

The trays consist of a flat piece of aluminum with magnets and Velcro patches for holding utensils, food, and drink packets. Crewmembers either can Velcro the trays to a wall (ceiling/floor) or can strap the trays to one of their legs for use. The strap on the bottom side has been modified so that it fits over the right or the left thigh (not both).



Top of Tray



Bottom of Tray

2.13 GUIDANCE, NAVIGATION, AND CONTROL (GNC)

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Description

Guidance is the computation of corrective actions to change from the navigation-determined vehicle state to a required vehicle state. The required state depends on particular mission requirements, which usually specify a required present state (e.g., a particular orbit) or an objective (e.g., rendezvous at a point in space) from which the present required state can be computed.

Navigation is the determination of the state of motion of the vehicle; i.e., position, velocity, and attitude. This state is determined with reference to some mission-dependent coordinates suitable for defining the motion of the vehicle.

Control is the application of corrective maneuvers to obtain the changes commanded by guidance. Flight control for the orbiter converts guidance computations into effector commands to point and translate the vehicle. Control software frequently uses navigation data to determine the effectors used and the appropriate system control gains.

State Vector

The basic function of the orbiter navigation system is to maintain an accurate estimate of the inertial position and velocity of the vehicle, called its state vector, with respect to time. In addition, during a rendezvous mission, the navigation system must maintain an estimate of a target's position and velocity. This information is then used by the onboard guidance system to compute the commands required to transfer the vehicle from one position and velocity to another, as well as to point the vehicle at a specified target (Earth, Sun, another orbiting vehicle, etc.). The state vector data are also used by the ground controllers for monitoring the status of the onboard navigation system. Information about the orbiter and target state vectors is displayed to the crew on the dedicated displays and GNC DPS displays.

The navigation system tracks the orbiter's position and velocity with six parameters (X, Y, Z, Vx, Vy, Vz) that define the state vector. A time tag is also associated with this state vector. The X, Y, Z components are the orbiter's position in the Mean of 1950 (M50) coordinate system measured in feet from the center of the Earth. The velocity components are measured in feet per second, and are also in the M50 coordinate system. The time at which the state vector is applicable is based on Greenwich mean time (GMT).

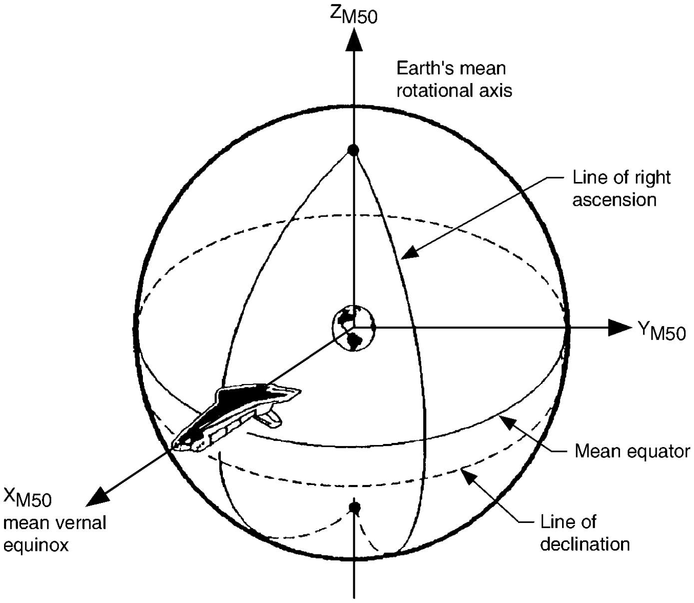
The navigation system uses the standard equations of motion along with the information received from the inertial measurement units, the navigation sensors, and the software models of the forces acting on the orbiter (gravity, drag, vents, etc.) to predict the components of the state vector at each time value. This process is called state vector propagation, a scheme in which errors are inherent. The equations of motion and the propagation technique are approximations, as are the gravity, drag, and vent models. In addition, the acceleration, position, and range rate information received from the inertial measurement units and the navigation sensors is also prone to error. To correct these errors, which increase with time, the ground controllers periodically uplink a new state vector or a delta to the current onboard state based upon the more accurate ground radar tracking data.

The release of OI-27 flight software (FSW) began the process of replacing the orbiter tactical air navigation (TACAN) system with a global positioning system (GPS). GPS provides the navigation system with an alternate source of orbiter state vector data throughout the orbit and entry phases of flight. Currently, there is a mixed fleet of either triple-string GPS or triple string TACAN with a single GPS receiver.

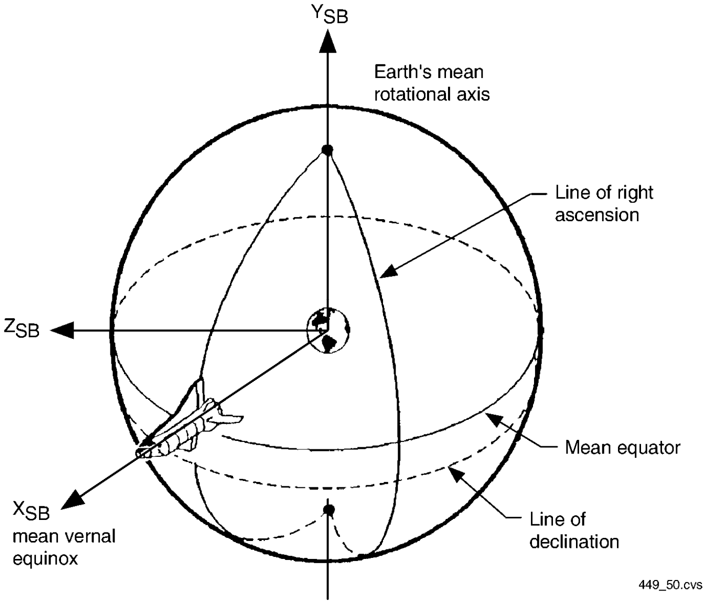
OV-105 *is* the only vehicle *that has* triple-string GPS *installed*. This section addresses both triple-string TACAN and triple-string GPS configurations.

WARNING

Control software uses state vector information to select control effectors and set control gains, especially during entry. Large navigation errors can cause the orbiter to depart controlled flight.



M50 Coordinate System



Starball Coordinate System

Coordinate Systems

The position and velocity of the orbiter must be uniquely defined in terms of an inertial coordinate system - a reference frame that is neither rotating nor accelerating. Such a system ensures that the normal equations of motion are valid. The onboard navigation system uses the M50 inertial system. However, some computations are considerably simpler if performed in other coordinate systems. For example, when landing the orbiter, the position of the vehicle relative to the runway is more meaningful than its position in a coordinate system fixed in space. Therefore, the onboard navigation system uses a number of different coordinate systems to simplify the various inputs, outputs, and computations required. These inputs and outputs can be expressed in any coordinate system by using coordinate transformations resident in the navigation software.

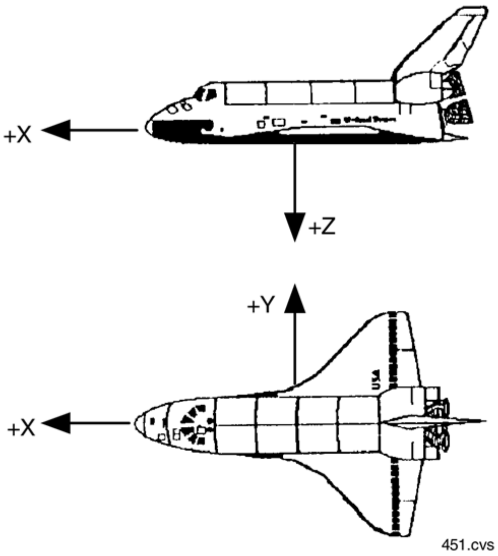
All the coordinate systems referenced are right-handed Cartesian systems. These right-handed systems have three mutually perpendicular axes, sequentially ordered such that each axis satisfies the application of the right-hand rule to the other two axes (XYZ system: applying right-hand rule to X-Y yields Z, to Y-Z yields X, and to Z-X yields Y).

Body Axis Coordinate System

The body axis coordinate system maintains the origin at the orbiter's center of mass with the three axes stemming from that point. The X axis is parallel to the X_o axis of the orbiter structural body (orbiter + external tank + solid rocket boosters) and lies in the orbiter plane of symmetry. The positive direction is toward the nose. The Z axis lies in the orbiter plane of symmetry and is perpendicular to the X axis. The positive direction is opposite the payload bay. The Y axis completes the right-handed orthogonal system and points out of the right wing. Note that vehicle pitch is a rotation about the Y body axis, roll is a rotation about the X body axis, and yaw is a rotation about the Z body axis.

M50 Coordinate System

The inertial coordinate system used by the onboard navigation system is the Aries Mean of 1950 Cartesian system, generally called the M50 system. The M50 system is used to establish and maintain the inertial position and velocity of the orbiter during all flight phases. The X axis points toward the mean vernal equinox (the apparent point on the celestial sphere where the Sun crosses the Earth's equator on its northward journey) of the year 1950. The Z axis points along Earth's mean rotational axis of 1950 with the positive direction toward the North Pole. The Y axis completes the right-handed system, with the corresponding X-Y plane lying in the plane of the equator. Note that this is an inertial system and, although its origin is at the Earth's center, the M50 system is completely independent of the Earth's rotation.



Body Axis Coordinate System

Starball Coordinate System

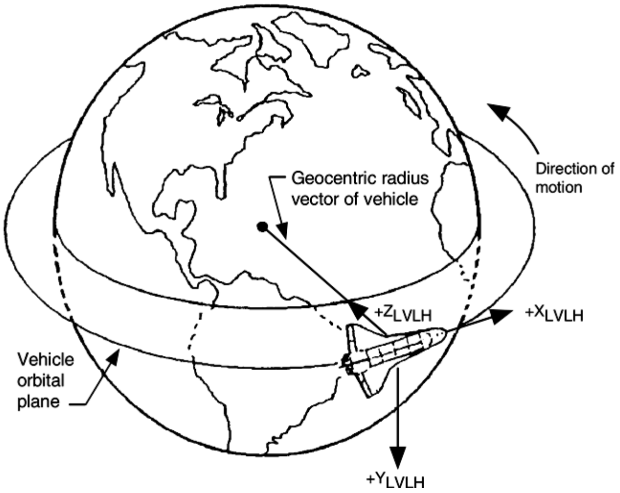
The Starball coordinate system, a variation of the M50 system, is described by rotating the M50 system by 90° about the X axis. The Starball orientation makes the pitch angle equivalent to the right ascension and the yaw angle equivalent to declination, thus simplifying maneuvers to point at stars. This coordinate system is seldom, if ever, used.

Local Vertical/Local Horizontal Coordinate System

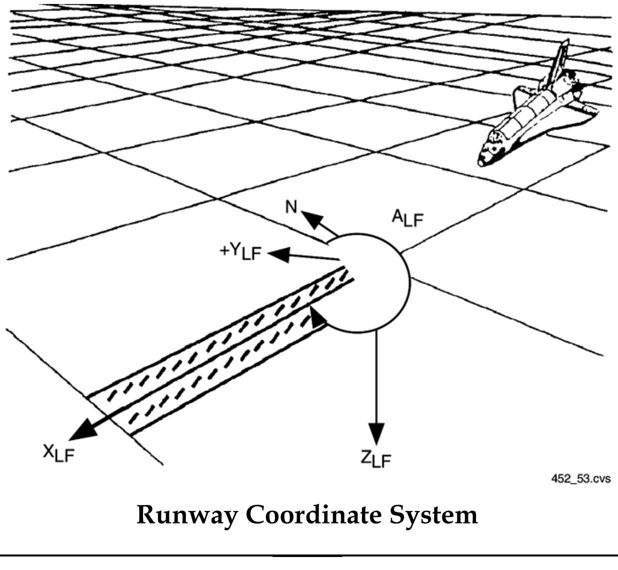
The local vertical/local horizontal (LVLH) coordinate system is an orbiter-centered system. The positive Z axis points toward the center of the Earth along the geocentric radial vector of the vehicle. The positive Y axis points toward the negative angular momentum vector of the vehicle's orbit. The X axis completes the right-hand rule with positive X along the vehicle's direction of motion in the orbital plane. The LVLH system allows the crew to see the attitude of the orbiter in relation to the Earth's surface. It is not an inertial system, because it rotates at approximately 4 deg/min with respect to the inertial frame.

Runway Coordinate System

For launch, landing, and Earth observation, it is advantageous to know the orbiter's position and velocity in coordinate systems fixed to the Earth. These non-inertial systems are related to the M50 system by transformations that depend on time, Earth rotation rate, and the latitude and longitude of the point of interest. The runway coordinate system is a good example of an Earth-fixed reference frame. The origin of the system is placed at the runway center at the approach threshold. The Z axis is normal to the ellipsoid model through the runway centerline and positive toward the center of the Earth. The X axis is perpendicular to the Z axis and lies in a plane containing the Z axis and the runway centerline (positive in the direction of landing). The Y axis completes the right-hand rule. Note that A is the runway azimuth measured in the X-Y plane from true north to the positive X axis (positive clockwise). The runway coordinate system is used by navigation and the crew during ascent, entry, and landing phases of flight.



LVLH Coordinate System



Runway Coordinate System

Guidance, Navigation, and Control Software

Guidance, navigation, and control (GNC) software commands the GNC system to effect vehicle control and to provide sensors and controllers with the data needed to compute these commands. The process involves three steps:

1. Navigation tracks the vehicle's actual location.
2. Guidance equipment and software compute the orbiter location required to satisfy mission requirements.
3. Flight control transports the orbiter to the required location.

During launch and ascent, most of the GNC commands are directed to gimbal the three SSMEs and two SRBs to maintain thrust vector control. The GNC software also controls SSME burns for maximum aerodynamic loading of the vehicle during ascent, referred to as max q. To circularize the orbit and perform on-orbit and deorbit maneuvers, the GNC software commands the orbital maneuvering system (OMS) engines. At external tank separation, on orbit, and during portions of entry, GNC controls commands to the reaction control system (RCS). In atmospheric flight, GNC controls the orbiter aerodynamic flight control surfaces.

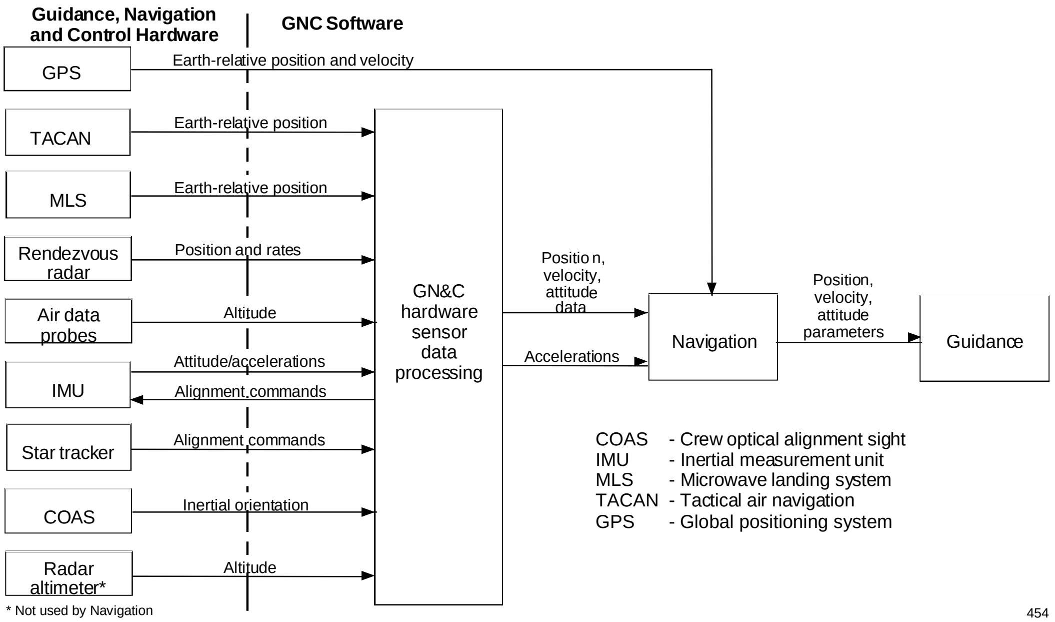
Control Modes

The GNC system consists of two operational modes: automatic and control stick steering (CSS). In the automatic mode, the primary avionics software system (PASS) essentially allows the GPCs to fly the vehicle. The flight crew may control the vehicle in the CSS mode using hand controllers, such as the rotational hand controller. In the CSS mode, flight crew commands must still pass through and be issued by the GPCs. There are no direct mechanical links between the flight crew and the orbiter's various propulsion systems or aerodynamic surfaces. The orbiter is an entirely digitally controlled, fly-by-wire vehicle.

Navigation Hardware

The navigation system uses measurements from onboard sensors to improve its estimate of the state vector. These sensors and the physical data they sense include:

- Inertial measurement unit (IMU) -- Senses vehicle attitude in inertial space and accelerations along inertial axes.
- Star trackers -- Sense vehicle line of sight vectors to stars or orbiting target.



Navigation Interfaces

- Crew optical alignment sight (COAS) -- Allows the crew to visually align the vehicle line of sight to stars or orbiting targets. The head-up display (HUD) test pattern also allows the crew to align the vehicle line of sight to the stars. The HUD serves as the backup to the star trackers.
- Tactical air navigation (TACAN) -- Senses vehicle position with respect to a ground-based TACAN station.
- Air data system -- Senses air temperature and pressure in free stream and air disturbed by vehicle.
- Microwave landing system (MLS) -- Senses vehicle position with respect to ground stations alongside the landing runway.
- Radar altimeters (RA) -- Senses vehicle altitude above the ground.
- GPS - Senses satellite ranging signals to determine position and velocity.

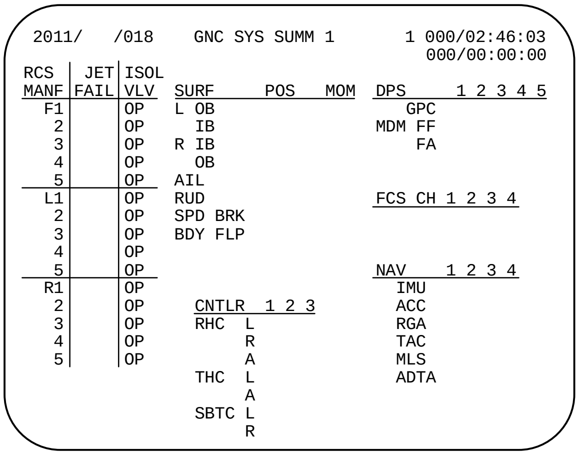
NOTE

Radar altimeter altitude is not used for navigation or guidance. The information is displayed for the crew to monitor.

Each piece of navigation hardware is hard-wired to one of eight flight-critical multiplexer/demultiplexers (MDMs) connected to each of five GPCs. Several navigation system parameters can be monitored at the lower right-hand corner of the GNC SYS SUMM 1 display (DISP 18).

Inertial Measurement Units

There are three IMUs on the orbiter. Each contains three accelerometers and two two-axis gyros mounted on an inertially stabilized four-gimbal platform. The IMUs provide inertial attitude and velocity data to the GNC software functions. Navigation software uses the processed IMU velocity and attitude data to propagate the orbiter state vector. Guidance uses the attitude data, along with the state vector from the navigation software, to develop steering commands for flight control. Flight control uses the IMU attitude data to convert the steering commands into control surface, engine gimbal (thrust vector control), and RCS jet fire commands.



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                                         000/00:00:00
 RCS | JET|ISOL
 MANF|FAIL|VLV  SURF      POS   MOM   DPS      1 2 3 4 5
   F1|    |OP   L OB                      GPC
    2|    |OP     IB                  MDM FF
    3|    |OP   R IB                        FA
    4|    |OP     OB
    5|    |OP   AIL
   L1|    |OP   RUD                   FCS CH 1 2 3 4
    2|    |OP   SPD BRK
    3|    |OP   BDY FLP
    4|    |OP
    5|    |OP                         NAV    1 2 3 4
   R1|    |OP                            IMU
    2|    |OP      CNTLR  1 2 3          ACC
    3|    |OP      RHC  L                RGA
    4|    |OP           R                TAC
    5|    |OP           A                MLS
                   THC  L                ADTA
                        A
                   SBTC L
                        R
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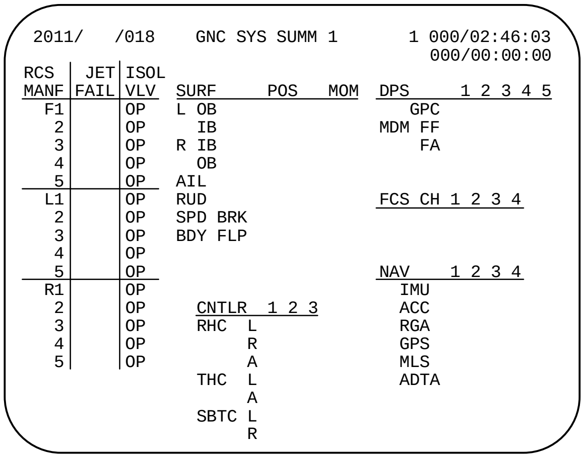
**GNC SYS SUMM 1 Display
(Three-String TACAN Vehicles)**



```
  2011/   /018    GNC SYS SUMM 1       1 000/02:46:03
                                         000/00:00:00
 RCS | JET|ISOL
 MANF|FAIL|VLV  SURF      POS   MOM   DPS      1 2 3 4 5
   F1|    |OP   L OB                      GPC
    2|    |OP     IB                  MDM FF
    3|    |OP   R IB                        FA
    4|    |OP     OB
    5|    |OP   AIL
   L1|    |OP   RUD                   FCS CH 1 2 3 4
    2|    |OP   SPD BRK
    3|    |OP   BDY FLP
    4|    |OP
    5|    |OP                         NAV    1 2 3 4
   R1|    |OP                            IMU
    2|    |OP      CNTLR  1 2 3          ACC
    3|    |OP      RHC  L                RGA
    4|    |OP           R                GPS
    5|    |OP           A                MLS
                   THC  L                ADTA
                        A
                   SBTC L
                        R
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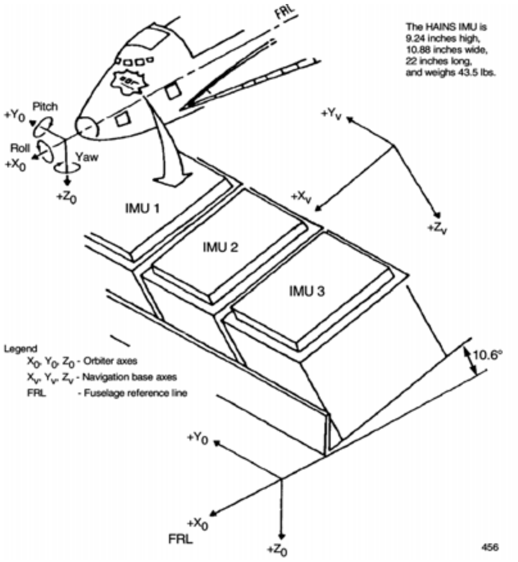
**GNC SYS SUMM 1 Display
(Three-String GPS Vehicles)**



Inertial Measurement Units

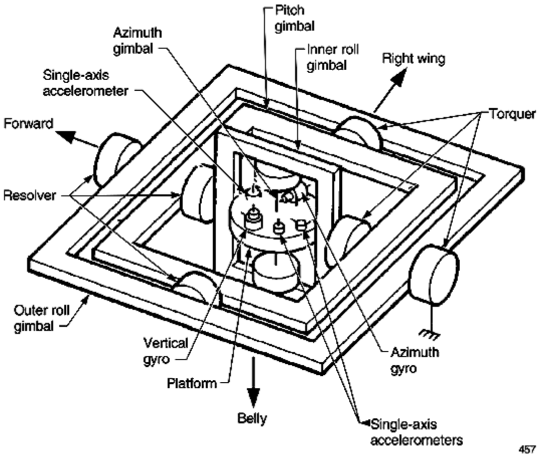
Although flight could be accomplished with only one IMU, three units are installed on the orbiter for redundancy. The IMUs are mounted on the navigation base, which is located inside the crew compartment flight deck forward of the flight deck control and display panels. The base provides a platform on which the IMUs can be repeatedly mounted with great accuracy, enabling the definition of transformations that relate IMU reference frame measurements to any other reference frame.

The IMU consists of a platform isolated from vehicle rotations by four gimbals. Since the platform does not rotate with the vehicle, its orientation remains fixed, or inertial, in space. The gimbal order from outermost to innermost is outer roll, pitch, inner roll, and azimuth. The platform is attached to the azimuth gimbal. The inner roll gimbal is a redundant gimbal used to provide an all-attitude IMU, while preventing the possibility of gimbal-lock (a condition that can occur with a three-gimbal system and can cause the inertial platform to lose its reference). The outer roll gimbal is driven from error signals generated by disturbances to the inner roll gimbal. Thus, the inner roll gimbal will remain at its null position, orthogonal to the pitch gimbal.

The IMUs have three accelerometers, one on each of the X, Y, and Z axes. The accelerometer is basically a force rebalance-type instrument. When the accelerometer experiences an acceleration along its input axes, it causes a pendulum mass displacement. This displacement is measured by a pick-off device, which generates an electrical signal that is proportional to the sensed acceleration. This signal is amplified and returned to a torquer within the accelerometer, which attempts to reposition the mass to its null position.

The acceleration data measured by the accelerometers are the primary sources for the three position and three velocity components of the state vector used during ascent and entry. On orbit, a sophisticated drag model is substituted for IMU velocity information, except during large vehicle accelerations. During large on-orbit accelerations, IMU velocity data are used in navigation calculations.

The inertial sensors consist of two gyros, each with two degrees of freedom, mounted on the cluster platform. Angular motion about any axis perpendicular to the spin axis causes rotation about a third orthogonal axis, which is electrically sensed. In response to this sensed rotation, the appropriate gimbals are torqued to null the gyro rotation. This gimbal torquing in response to vehicle motion results in an inertially stabilized platform. In addition, the gyros may be pulse torqued (small angles) or slewed (large angles) by software, which results in gimbal torquing to position or reposition the platform. Each gimbal has a coarse (one-speed or 1X) resolver and a fine (eight-speed or 8X) resolver. The resolver readouts are sent to the data processing system, which determines the gimbal angles, which in turn determine the attitude of the orbiter.



IMU Platform Assembly

One gyro, the vertical gyro, is oriented so its input axes are aligned with the X and Y platform axes; its input axes provide IMU platform roll and pitch stabilization. The second gyro is oriented so that one input axis lies along the platform's Z axis, and the other lies in the X-Y plane. This gyro, the azimuth gyro, provides platform yaw stabilization with the Z input axis, while the second input axis is used as a platform rate detector for built-in test equipment. Each gyro contains a two-axis pick-off that senses deflection of the rotating wheel. The gyro also contains a pair of two-axis torquers that provide compensation torquing for gyro drift and a means to reposition the platform.

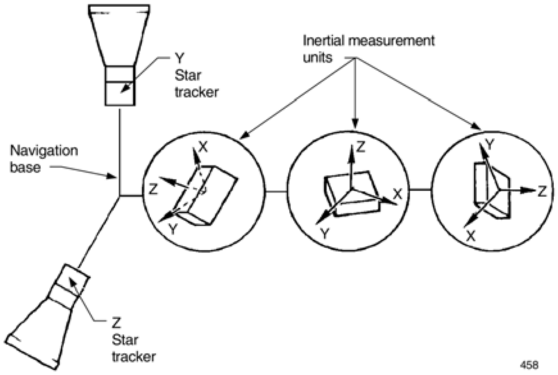
The spin axis of a gyro is its axis of rotation. The inertial stability of the spin axis is a basic property of gyroscopes and is used in stabilization loops, which consist of the gyro pick-off, gimbals, and gimbal torquers. When the vehicle is rotated, the platform also tends to rotate due to friction at the gimbal pivot points. Because the gyro casing is rigidly mounted to the platform, it will also rotate. The gyro resists this rotation tendency to remain inertial, but the resistance is overcome by friction. This rotation is detected by the pick-offs as a deflection of the rotating gyro wheel. A signal proportional to this deflection is sent to the gimbal electronics, which route the signals to the appropriate torquers, which in turn rotate their gimbals to null the pick-off point. When the output is nulled, the loop is closed.

Four resolvers in an IMU are used to measure vehicle attitude. A resolver is located at one of two pivot points between adjacent gimbals. The IMU resolvers are electromechanical devices that apply the principle of magnetic induction to electrically measure the angle between two adjacent gimbals. This electrical signal is then transformed into a mechanical angle by the IMU electronics.

The single gimbal angle measurements are used to determine vehicle attitude. Attitude information is used by flight control for turn coordination and steering command guidance. An attitude director indicator (ADI) displays attitude and navigation data.

Platform attitude can be reoriented by slewing or pulse torquing. Slewing rotates the platform at a high rate (1.2° per second), and pulse torquing rotates it very slowly (.007° per second). Platform reorientation relies on another property of gyroscopes: precession. If a force is applied to a spinning gyroscope, the induced motion is 90° from the input force. In each IMU, a two-axis torquer is located along the input axes of both gyros. Commands are sent to the torquers from the GPC to apply a force along the input axes. The result is a deflection of the gyro spin axis that is detected and nulled by the stabilization loops. Because the gyro spin axis is forced to point in a new direction, the platform has to rotate to null the gyro outputs.

The three IMUs have skewed orientations: their axes are not co-aligned and not aligned with the vehicle axes. This is done for two reasons. First, gimbaled platforms have problems at certain orientations. Skewing ensures that no more than one IMU will have an orientation problem for a given attitude. Second, skew allows resolution of a single-axis failure on one IMU by multiple axes on another IMU since the possibility of multiple-axis failure is more remote. Skewing is also used by redundancy management to determine which IMUs have failures.



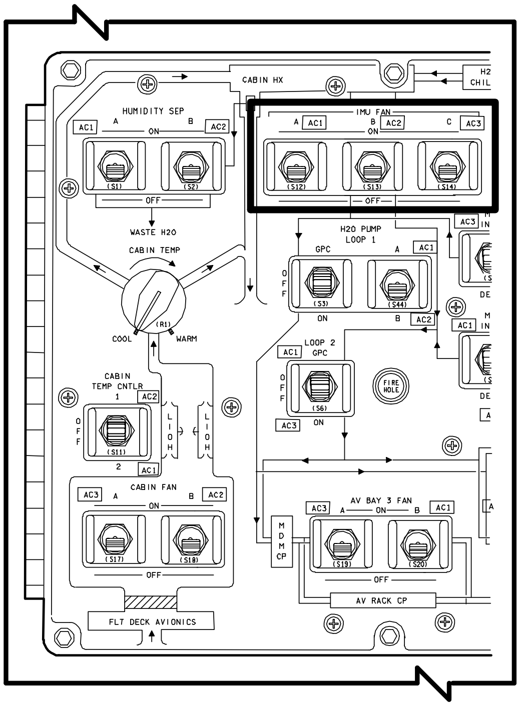
IMU Skew

Each IMU contains heaters, temperature sensors, and built-in test equipment (BITE). Very precise thermal control must be maintained in order to meet IMU performance requirements. The IMU thermal control system consists of an internal heater system and a forced-air cooling system. The internal heater system is completely automatic and is activated when power is initially applied to the IMU. It continues to operate until the IMU is powered down. The forced-air cooling consists of three continues to operate until the IMU is powered down. The forced-air cooling consists of three fans that serve all three IMUs. Each IMU fan is controlled by an individual IMU FAN switch located on panel L1. Only one fan is used at a time; three are provided for redundancy.

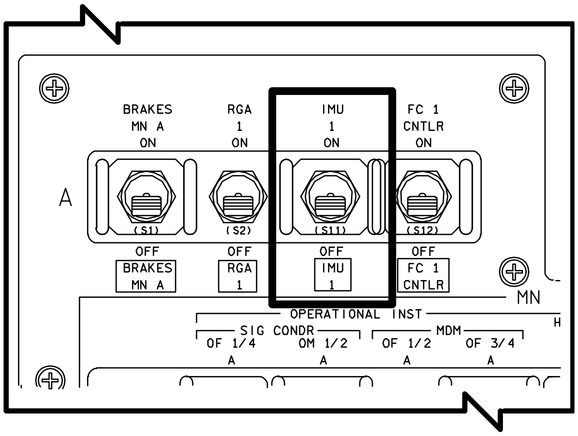
Each IMU is supplied with redundant 28-volt dc power through two separate remote power controllers. The IMU 1, 2, and 3 power switches are located on panels O14, O15, and O16. Loss of one control bus or one main bus will not cause the loss of an IMU.

Each IMU has two modes of operation, a warmup/standby mode and an operate mode. When an IMU switch is positioned to ON, the IMU is powered in the warm-up/standby mode, which applies power only to the heater circuits. It takes approximately 8 hours from cold start for the IMU to reach its operating temperature range, at which time the IMU enters a standby mode. A software command in GNC OPS 2, 3, or 9 transitions the IMU to the operate mode. To mode the IMU to operate, the controlling GPC sends the operate discrete to the IMU through the flight forward MDM. The IMU, upon receiving this command, initiates its run-up sequence.

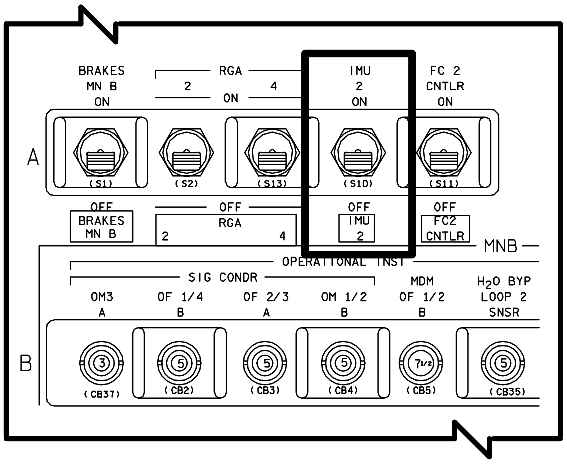
The run-up sequence first cages the IMU, a process of reorienting the IMU gimbals and then mechanically locking them into place so that the gyros may begin to spin. When the IMU is caged, its platform orientation is known when it becomes inertial. The caged orientation is defined as the point at which all resolver outputs are zero. Inner roll and azimuth must always be at 90° angles to each other.



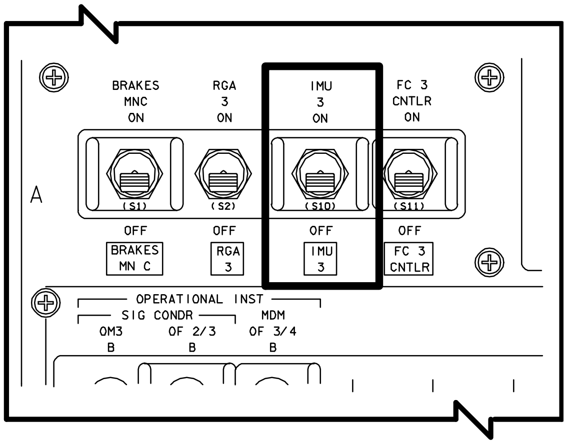
IMU FAN ON/OFF Switches on Panel L1



IMU 1 Power Switch on Panel O14



IMU 2 Power Switch on Panel O15



IMU 3 Power Switch on Panel O16

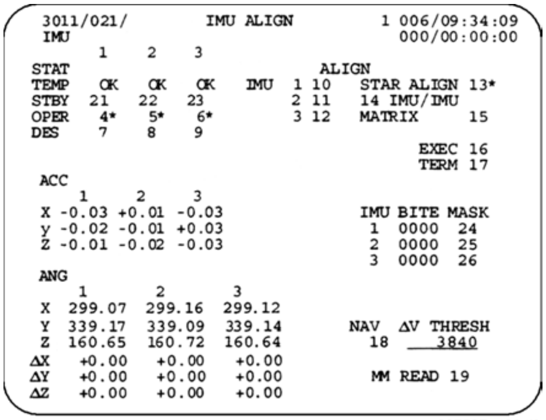
Once the IMU gimbals are caged, the gyros begin to spin, and power is applied to the remaining IMU components. When the gyros have reached the correct spin rate, the stabilization loops are powered, and the IMU becomes inertial. At this time, the IMU returns an in-operate-mode discrete to the GPC, indicating that the run-up sequence is complete. This process requires approximately 85 seconds.

The IMUs are in operate by the time the flight crew enters the vehicle before launch and remain in that state for the duration of the flight, unless powered down to minimize power consumption. While in the operate mode, the IMU maintains its inertial orientation and is used for calibration and preflight, on-orbit, and entry alignments.

During ascent, the IMUs provide accelerometer and resolver data to the GNC software to propagate the state vector, determine attitude, and display flight parameters. During the orbital flight phase, the IMUs provide GNC software with attitude and accelerometer data. On-orbit alignments are necessary to correct platform misalignment caused by uncompensated gyro drift. During entry, IMU operation differs only in the manner in which accelerometer data are used by navigation.

The IMUs can be safely powered off from either the warmup/standby mode or the operate mode. A braking system is used to ensure that the gyros have slowed to a stop.

The IMU software scheme is designed to select the best data for GPC use and to detect system failures. This scheme is referred to as redundancy management. IMU parameters can be accessed using the IMU ALIGN display (SPEC 21) and the GND IMU CNTL/MON display (SPEC 104)(GNC OPS 9 only).



```
 3011/021/         IMU ALIGN          1 006/09:34:09
 IMU                                    000/00:00:00
        1     2     3
STAT                              ALIGN
TEMP    OK    OK    OK    IMU   1 10   STAR ALIGN 13*
STBY   21    22    23           2 11   14 IMU/IMU
OPER    4*    5*    6*          3 12   MATRIX      15
DES     7     8     9
                                              EXEC 16
                                              TERM 17
 ACC
     1      2      3
 X -0.03 +0.01 -0.03                   IMU BITE MASK
 y -0.02 -0.01 +0.03                    1   0000   24
 Z -0.01 -0.02 -0.03                    2   0000   25
                                        3   0000   26
 ANG
     1        2        3
 X  299.07   299.16   299.12
 Y  339.17   339.09   339.14          NAV  ΔV THRESH
 Z  160.65   160.72   160.64           18    ___3840
ΔX    +0.00    +0.00    +0.00
ΔY    +0.00    +0.00    +0.00          MM READ 19
ΔZ    +0.00    +0.00    +0.00
```

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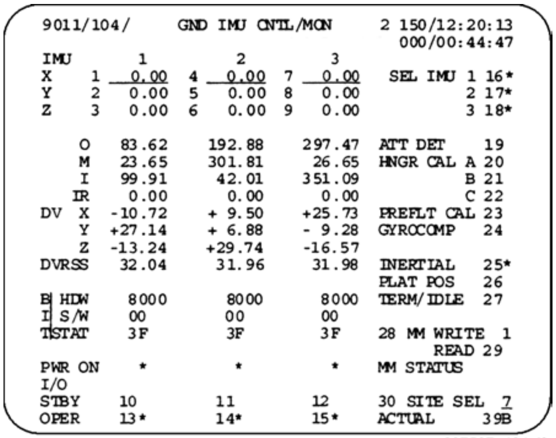
IMU ALIGN Display (SPEC 21)



```
 9011/104/      GND IMU CNTL/MON      2 150/12:20:13
                                        000/00:44:47
 IMU        1          2          3
 X     1 __0.00   4 __0.00   7 __0.00    SEL IMU 1 16*
 Y     2    0.00  5    0.00  8    0.00           2 17*
 Z     3    0.00  6    0.00  9    0.00           3 18*

       O    83.62     192.88     297.47  ATT DET     19
       M    23.65     301.81      26.65  HNGR CAL A 20
       I    99.91      42.01     351.09           B 21
      IR     0.00       0.00       0.00           C 22
 DV   X   -10.72     + 9.50     +25.73  PREFLT CAL 23
      Y   +27.14     + 6.88     - 9.28  GYROCOMP    24
      Z   -13.24     +29.74     -16.57
 DVRSS     32.04      31.96      31.98  INERTIAL    25*
                                        PLAT POS    26
 B HDW      8000       8000       8000  TERM/IDLE   27
 I S/W      00         00         00
 TSTAT      3F         3F         3F    28 MM WRITE  1
                                              READ 29
 PWR ON      *          *          *    MM STATUS
 I/O
 STBY      10         11         12     30 SITE SEL 7
 OPER      13*        14*        15*    ACTUAL     39B
```

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GND IMU CNTL/MON Display (SPEC 104)
(available in OPS 9 only)

In the event of an IMU dilemma, the IMU caution and warning light on panel F7 will be illuminated. (The light will not illuminate for a redundancy management fail.) If temperatures are out of limits or if BITE detects a failure, a fault message (IMU BITE/T X) and SM ALERT will be annunciated.

The accuracy of the IMU deteriorates with time. If the errors are known, they can be physically or mathematically corrected. Software based on preflight calibrations is used to compensate for most of the inaccuracy. The star trackers are used to determine and correct additional errors.

The IMU subsystem operating program (SOP) processes and converts the data from the IMUs. The following computations are performed in the IMU SOP: conversion of velocities to the M50 coordinates; conversion of resolver outputs to gimbal angles; computation of accelerations for displays; performance of additional software BITE checks; support of selection, control, and monitoring of IMU submodes of the operate mode; and computation of torquing commands, based on the misalignment determined by the star trackers or another IMU. Typical misalignments are due to gyro drifts.

Star Trackers

The star tracker system consists of the negative Y axis tracker and the negative Z axis tracker. They are located just forward and to the left of the commander's plus X window in a well outside the crew compartment, an extension of the navigation base on which the IMUs are mounted. The star trackers are slightly inclined off the vehicle axes for which they are named. The star trackers are used to align the IMUs onboard the orbiter, as well as to track targets and provide line-of-sight vectors for rendezvous calculations. The GPC memory contains inertial information for 100 stars in OPS 2 and 50 stars in OPS 3. The stars are chosen for their brightness and their ability to provide complete sky coverage.

The star trackers are oriented so that the optical axis of the negative Z star tracker is pointed approximately along the negative Z axis of the orbiter, and the optical axis of the negative Y star tracker is pointed approximately along the negative Y axis of the orbiter. Since the navigation base provides the mount for the IMUs and star trackers, the star tracker line of sight is referenced to the navigation base and the orbiter coordinate system; thus, the GPC knows the star tracker's pointing direction and its orientation with respect to the IMUs.

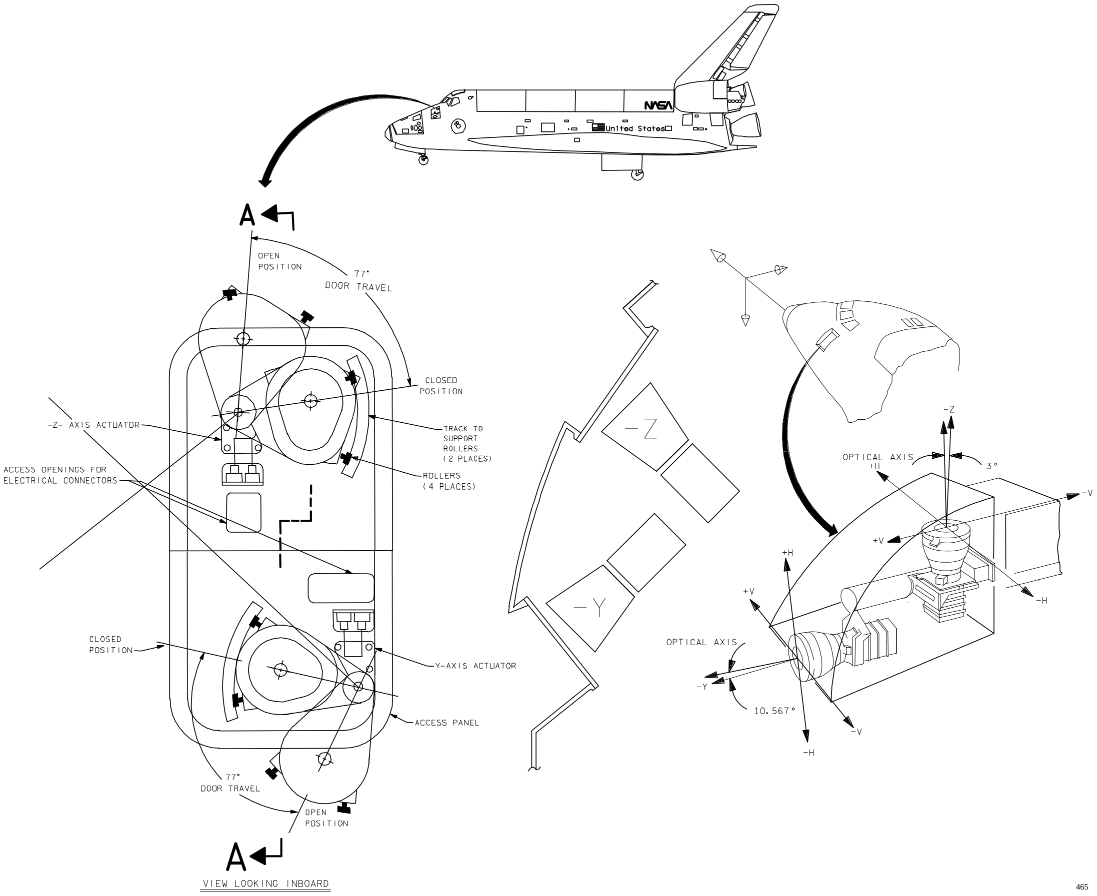
Each star tracker has a door to protect it during ascent and entry. The doors are opened on orbit to permit use of the star trackers. To enable the star tracker doors to open, the STAR TRACKER POWER -Y and -Z switches on panel O6 must be positioned to ON. The STAR TRACKER DOOR CONTROL SYS 1 and SYS 2 switches on panel O6 control two three-phase ac motors on each door. Positioning the SYS 1 switch to OPEN controls motor control logic and drives the -Y and -Z star tracker doors by electromechanical actuators to the open position. Limit switches stop the motors when the doors are open and control talkback indicators above the DOOR CONTROL switches. Setting the SYS 2 switch to OPEN controls redundant ac motors and electromechanical actuators to open both doors. Limit switches stop the motors when the doors are open and control the same two talkback indicators above the DOOR CONTROL SYS 1 and SYS 2 switches. Normally, both the SYS 1 and SYS 2 switches are used together to actuate the star tracker doors.

Positioning the SYS 1 switch to CLOSE drives the system 1 motors and closes the -Y and -Z doors; the talkback indicators above the switches indicate CL. Setting the SYS 2 switch to CLOSE drives the system 2 motors and closes the -Y and -Z doors; the talkback indicators above the switches indicate CL. The indicators are barberpole when a door is between open and closed. The door opening or closing time with two motors is 6 seconds; with one motor, it is 12 seconds.

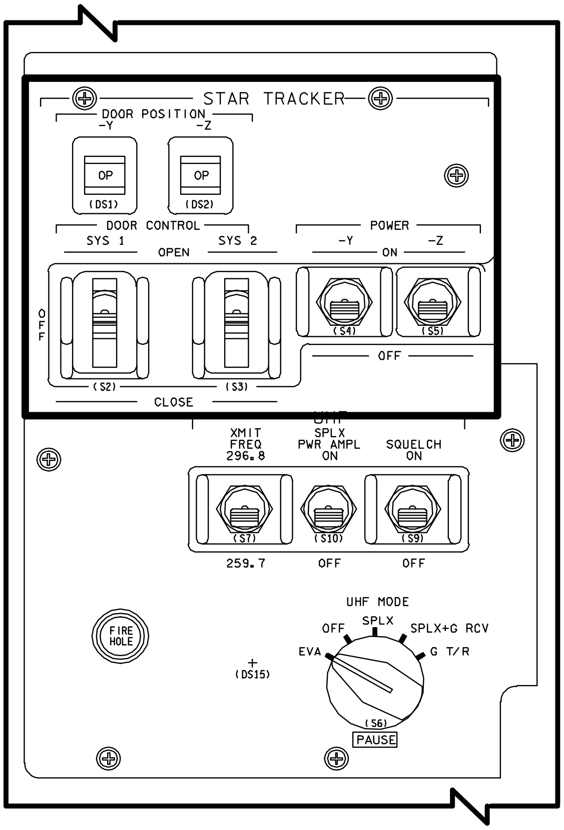
The OFF position of the SYS 1 or 2 switch removes power from the corresponding motor control logic circuitry.

The star trackers are used to align the IMU inertial platforms. A star tracker searches for, acquires, and tracks stars whose approximate position is determined by the IMUs. By knowing the relationship of the star tracker to the orbiter and the location of the star in space, a line-of-sight vector from the orbiter to the star is defined. Two such vectors define the orbiter inertial attitude.

The difference between the inertial attitudes defined by the star tracker and the IMU is processed by software and results in IMU torquing angles. If either the IMU gimbals are physically torqued or the matrix defining its orientation is recomputed, the effects of the IMU gyro drift are removed, and the IMU is restored to its inertial attitude. If the IMU alignment is in error by more than 1.4°, the star tracker may be unable to acquire and track stars. In this case, the HUD must be used to realign the IMUs to within 1.4°; the star trackers can then be used to realign the IMUs more precisely.



Star Trackers



STAR TRACKER Controls and Talkbacks on Panel O6

NOTE

The star tracker cannot be used if the IMU alignment error is greater than 1.4° because the angles the star tracker is given for searching are based on current knowledge of the orbiter attitude, which is based on IMU gimbal angles. If that attitude is greatly in error, the star tracker may acquire and track the wrong star.

In addition to aligning the IMUs, the star trackers can be used to provide angular data from the orbiter to a target. This capability can be used during rendezvous or proximity operations.

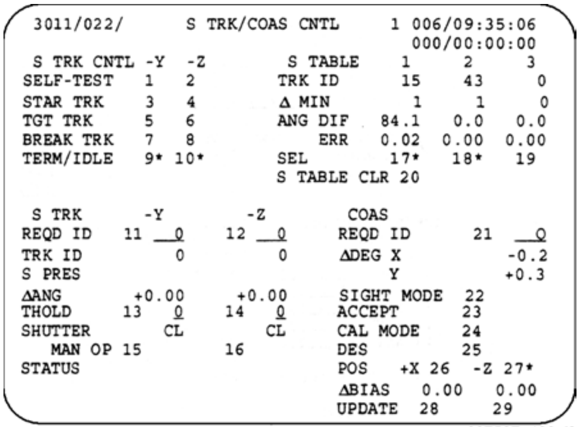
The star tracker includes a light shade assembly and an electronics assembly mounted on top of the navigation base. The light shade assembly defines the tracker field of view (10° square). Its shutter mechanism may be opened manually by the crew using an entry on the S TRK/COAS CNTL display, or it can be opened and closed automatically by a bright object sensor or target suppress software. The bright object sensor reacts to close the shutter before a bright object, such as the Sun or Moon, can damage the star tracker (the sensor has a larger field of view than the star tracker shutter).

There are two types of star trackers used by the space shuttle program, a solid state star tracker (SSST) or an image dissector tube (IDT) star tracker. Currently, there is a mixed fleet of star trackers installed on the three orbiters. Each star tracker contains an electronics assembly mounted on the underside of the navigation base. The star tracker itself does not move; the field of view is scanned electronically. The star tracker may be commanded to scan the entire field of view or a smaller offset field of view (1° square) about a point defined by horizontal and vertical offsets. An object is tracked when the correct location is sensed. Star tracker outputs are the horizontal and vertical position within the field of view of the object being tracked and its intensity.

There is no redundancy management for the star tracker assemblies. They operate independently and can do the entire task. They can be operated either separately or concurrently.

The star tracker SOP supports the modes that are commanded manually from SPEC 22 S TRK/COAS CNTL: self-test, star track, target track, break track, and term/idle. Self-test consists of software and hardware tests. In the star track mode, the star tracker does an offset scan search for the star, acquires it, and tracks it. The star may be selected by the flight crew or GPC; in either case, a field-of-view check is made. Target track is the same as star track, but it tracks a target. Threshold is independent of target track. Break track forces the star tracker to stop tracking a star or target and to perform a search scan from the current location to track the next target it acquires. In the term/idle mode, the star tracker hardware continues operation, but star tracker software processing ceases. In addition, the star tracker SOP maintains the star table. When a star tracker has acquired and tracked a star, and the data have passed software checks, the star identification, time tag, and line-of-sight vector are stored. The identification and time elapsed since time tag are displayed in the star table. When two or three stars are in the table, the angular difference between their line-of-sight vectors is displayed. The difference between the star tracker and star catalog angular differences is displayed as an error. The star tracker SOP selects line-of-sight vectors of two stars in the star table for IMU alignment and outputs an ALIGN ENA discrete. The software selects the star pair whose angular difference is closest to 90°, as long as the difference is between 35° - 145°.

The flight crew may manually override the SOP selection or clear the table if desired. The SOP also determines and displays star tracker status. Star tracker parameters are accessible to the crew on the S TRK/COAS CNTL display (SPEC 22).



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                                       000/00:00:00
  S TRK CNTL -Y  -Z        S TABLE    1     2     3
 SELF-TEST   1   2        TRK ID     15    43     0
 STAR TRK    3   4        Δ MIN       1     1     0
 TGT TRK     5   6        ANG DIF  84.1   0.0   0.0
 BREAK TRK   7   8            ERR  0.02  0.00  0.00
 TERM/IDLE   9* 10*       SEL       17*   18*   19
                          S TABLE CLR 20

  S TRK      -Y        -Z          COAS
 REQD ID   11 __0    12 __0      REQD ID      21  __0
 TRK ID         0         0      ΔDEG X          -0.2
 S PRES                               Y          +0.3
 ΔANG       +0.00     +0.00      SIGHT MODE  22
 THOLD     13   0    14   0      ACCEPT      23
 SHUTTER       CL        CL      CAL MODE    24
   MAN OP 15         16          DES         25
 STATUS                          POS    +X 26   -Z 27*
                                 ΔBIAS    0.00     0.00
                                 UPDATE  28        29
```

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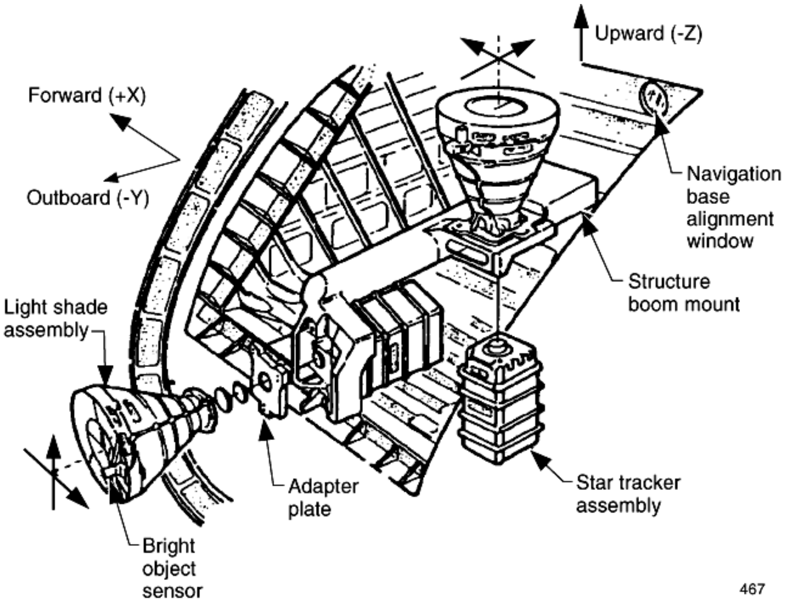
S TRK/COAS CNTL Display (SPEC 22)

Crew Optical Alignment Sight

The COAS is an optical device with a reticle focused at infinity projected on a combining glass. The reticle consists of a 10°-wide circle with 1° marks. A light bulb with variable brightness illuminates the reticle. The COAS requires 115-volt ac power for reticle illumination. The COAS is 9.5 by 6 by 4.3 inches and weighs 2.5 pounds.

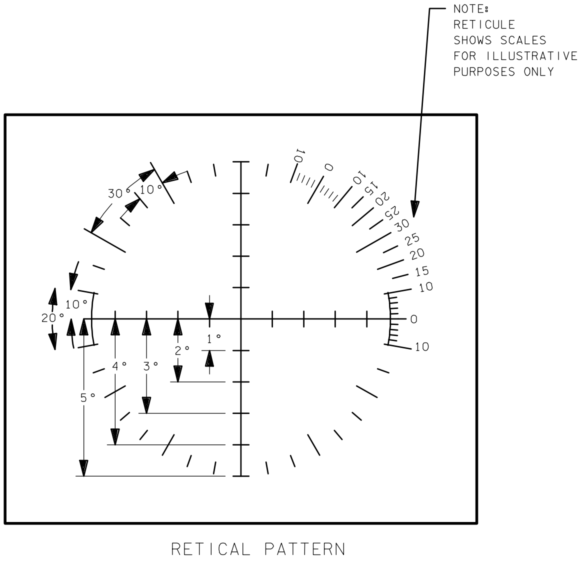
The COAS can be used if IMU alignment is in error by more than 1.4°, rendering the star tracker unable to acquire and track stars, but, primarily, the HUD is used.

The COAS can be mounted at either the commander's station to view along the +X axis or next to the aft flight deck overhead starboard window to view along the -Z axis. To use the COAS or HUD, the flight crewmember must manually maneuver the orbiter until the selected star is in the field of view. The crewmember then maneuvers the orbiter so that the star crosses the center of the reticle or the "P" in the HUD test pattern. At the instant of the crossing, the crewmember enters a mark by depressing the most convenient of the three ATT REF pushbuttons located on panels F6, F8, and A6U. At the time of the mark, software stores the gimbal angles of the three IMUs. This process can be repeated if the accuracy of the star's centering is in doubt. When the crewmember feels a good mark has been taken,



View into Star Tracker Cavity

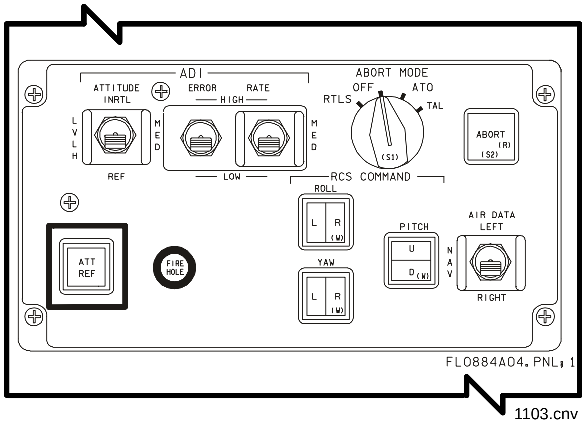
the software is notified to accept it. Good marks for two stars are required for an IMU alignment. The separation between the two stars should be between 60° and 120°.



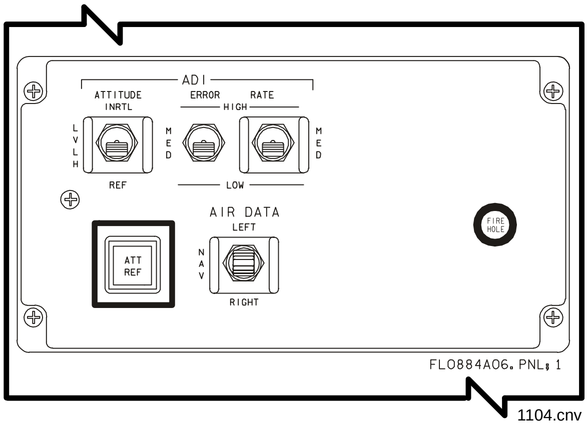
COAS Reticle Pattern

By knowing the star being sighted and the HUD or COAS's location and mounting relationship in the orbiter, software can determine a line-of-sight vector from the HUD/COAS to the star in an inertial coordinate system. Line-of-sight vectors to two stars define the attitude of the orbiter in inertial space. This attitude can be compared to the attitude defined by the IMUs; if an error exists, the IMUs can be aligned to the correct orientation.

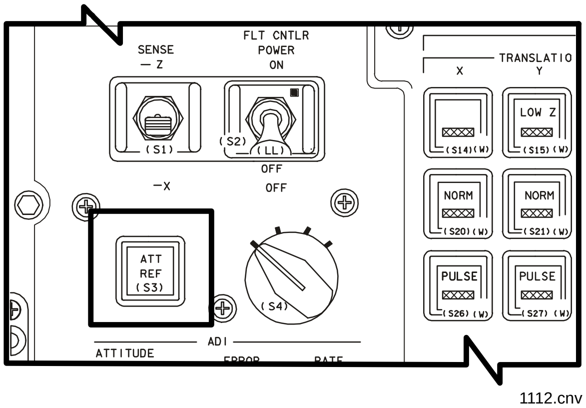
The COAS's mounting, relative to the navigation base on which the IMUs are mounted, is calibrated before launch. The constants are stored in software, and COAS line-of-sight vectors are based on known relationships between the COAS line of sight and the navigation base. These constants are usually updated by the crew on orbit using a calibration mode to mark on a star while the IMUs are known to be correctly aligned. The HUD is consistent and, generally, needs no calibration.



ATT REF Pushbutton on Panel F6



ATT REF Pushbutton on Panel F8



ATT REF Pushbutton on Panel A6U

The COAS can also be used to visually track targets during proximity operations or to visually verify tracking of the correct star by the -Z star tracker.

COAS data processing is accomplished in the star tracker SOP. This SOP accepts and stores crew inputs on COAS location, star identification, or calibration mode, accepts marks, computes and stores the line-of-sight vectors, enables IMU alignment when two marks have been accepted, and computes, updates, and provides display data. COAS parameters may be accessed using the S TRK/COAS CNTL (SPEC 22) display (lower right).

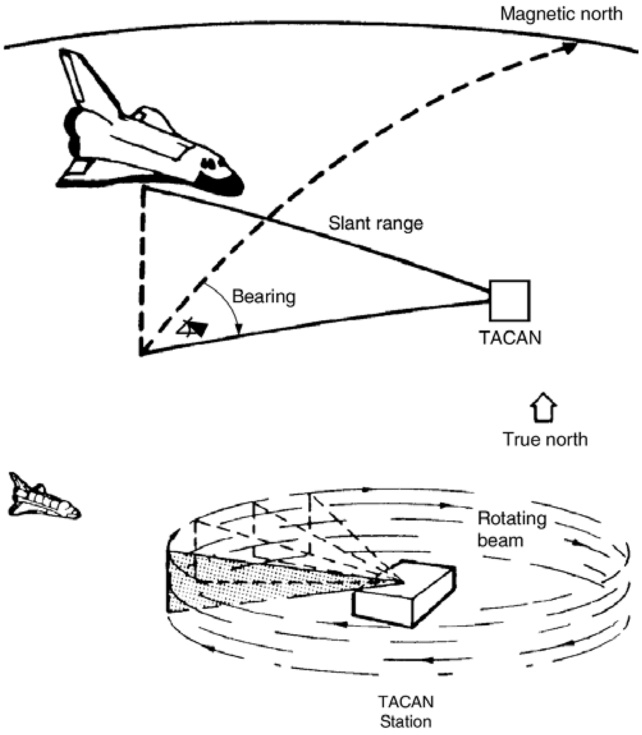
Tactical Air Navigation

The onboard TACAN units determine slant range and magnetic bearing of the orbiter to a TACAN or VHF omnirange tactical air navigation (VORTAC) ground station.

The ground-based TACAN and VORTAC stations constitute a global navigation system for military and civilian aircraft operating at L-band frequencies (1 GHz). The TACAN unit includes a transmitter, a receiver, and a data processor. The data processor decodes the selected channel and sends the frequency to the receiver.

Vehicles without the three-string GPS upgrade are equipped with three TACANs that operate redundantly. Each TACAN has two antennas, one on the orbiter's lower forward fuselage and one on the orbiter's upper forward fuselage. The antennas are covered with thermal protection system tiles. The three passive-cooled TACANs are located in the orbiter crew compartment middeck avionics bays. The onboard TACANs are used to obtain orbiter position data from an external source during entry. TACAN's maximum range is 400 nautical miles (n. mi.). Each set is 7.62 inches high, 7.62 inches wide, and 12.53 inches long and weighs 30 pounds.

Each ground station has an assigned frequency (L-band) and a three-letter Morse code identification. The ground station transmits on one of 252 (126X, 126Y) preselected frequencies (channels) that correspond to the frequencies the onboard TACAN sets are capable of receiving. These frequencies are spaced at 63-MHz intervals. The TACAN ground station beacon continuously transmits pulse pairs on its assigned frequency. The orbiter TACAN receivers pick up these pulse pairs, and the TACAN data processors decode them to compute bearing. The on-



- TACAN station transmits RF burst when beam points to true north.
  - Aircraft receiver times interval from burst to beam impingement and derives bearing.

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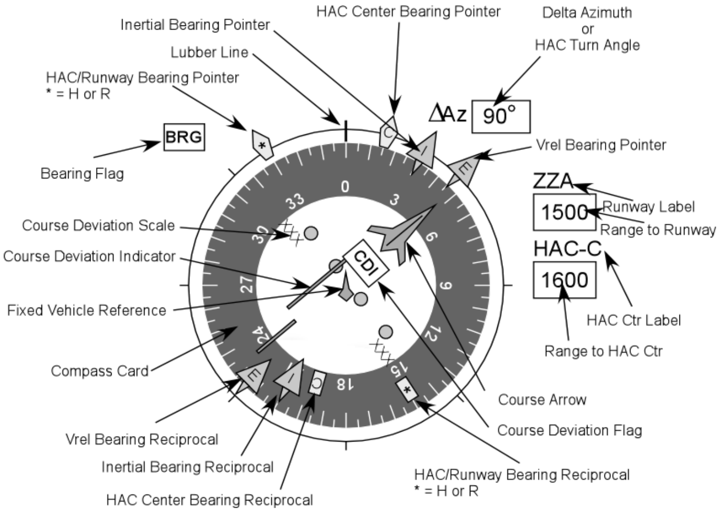
TACAN Operation

board TACAN sets detect the phase angle between magnetic north and the position of the orbiter with respect to the ground station. The ground beacon is omnidirectional. When the orbiter is over the ground station, or nearly so, it is in a cone of confusion. Within this cone, bearing is unusable.

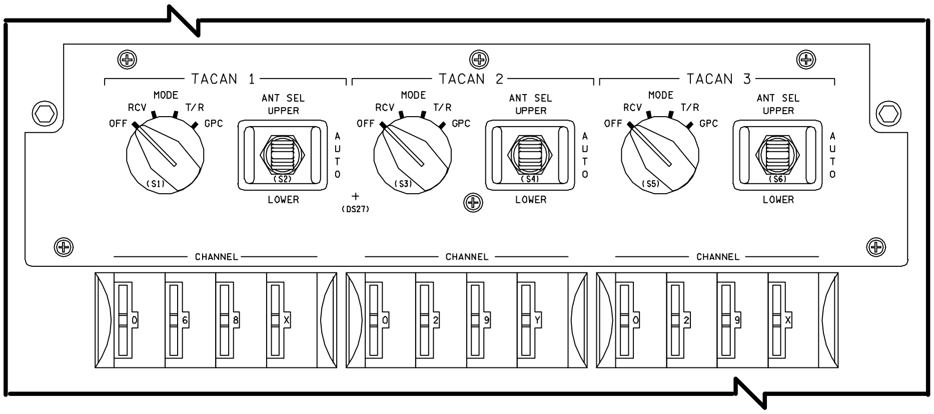
Periodically, the onboard TACAN sets emit an interrogation pulse that causes the selected TACAN ground station to respond with distance-measuring equipment pulses. The slant range (orbiter to ground station) is computed by the onboard TACAN sets by measuring the elapsed time from interrogation to valid reply and subtracting known system delays. As the orbiter approaches a ground TACAN station, the range decreases. After a course has been selected, the onboard TACAN sets derive concise deviation data.

The TACAN range and bearing data are used to update the state vector position components during entry. Range and bearing data are also displayed on the horizontal situation indicators (see section 2.7 for description), as well as on the GNC SPEC 50 HORIZ SIT display.

TACAN controls are located at the top of panel O7. The TACAN 1,2,3 ANT SEL switches control antenna selection. In the AUTO position, the onboard GPCs automatically select the best antenna for that TACAN. The UPPER and LOWER positions of the switches allow the flight crew to manually select the upper or lower L-band antenna.



Horizontal Situation Indicator



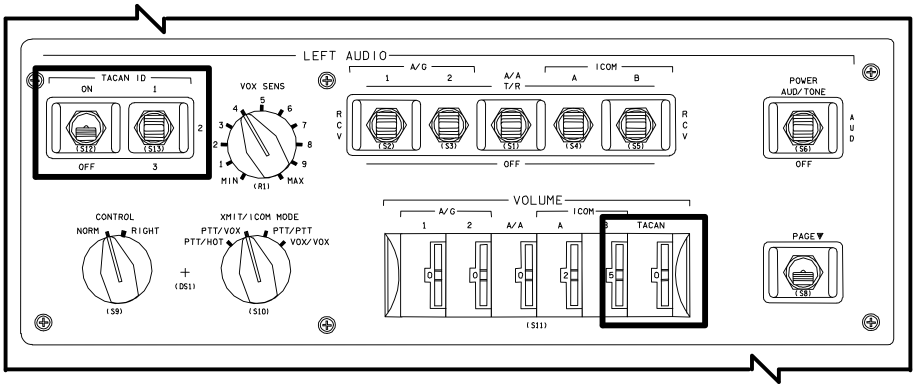
TACAN Switches and Thumbwheels on Panel O7
(Three-string TACAN Vehicles)

Each TACAN also has a MODE rotary switch on panel O7. The modes are OFF, receive (RCV), transmit and receive (T/R), and GPC. In the GPC mode, the onboard GPCs control TACAN ground station channel selection automatically, and both bearing and range are processed by hardware and software. In the T/R mode, both bearing and range are processed by hardware and software, but TACAN ground station channels are selected manually using the four CHANNEL thumbwheels for that TACAN on panel O7. The first three thumbwheels (left to right) select the channel (frequency), and the fourth selects the X or Y. In the RCV mode, only bearing is received and processed by the hardware; the thumbwheels for that TACAN are used to select the channel.

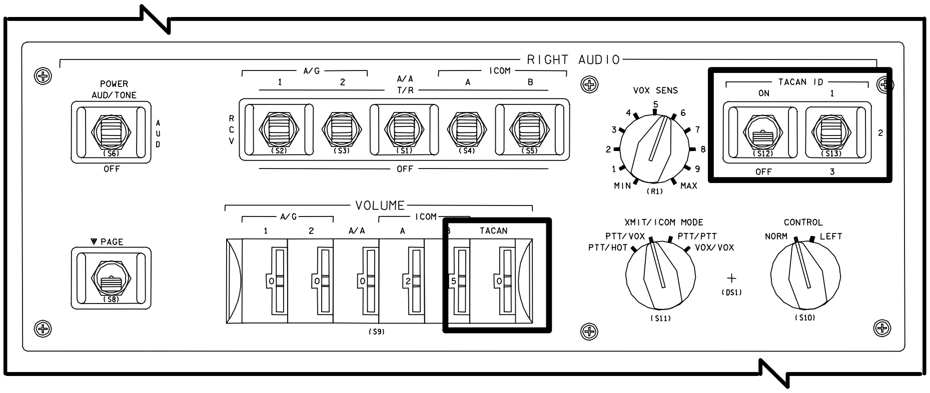
Approximately every 37 seconds, the selected TACAN ground station transmits its three-letter identification to the onboard TACAN. In order for the Morse code identification to be verified by the commander and pilot, TACAN ID audio controls are located on panel O5 (designated LEFT AUDIO) for the commander and panel O9 (designated RIGHT AUDIO) for the pilot. The TACAN ID ON/OFF switch is positioned to ON to receive the TACAN identification. The TACAN ID 1, 2, 3 switch selects the onboard TACAN that will transmit the TACAN identification code. VOLUME TACAN thumbwheels on panels O5 and O9 control the volume setting of the TACAN identification code to the commander and pilot.

During entry, when at least two available TACANs lock on, TACAN range and bearing data are used by navigation software to update the state vector until microwave landing system (MLS) acquisition at approximately 18,000 feet.

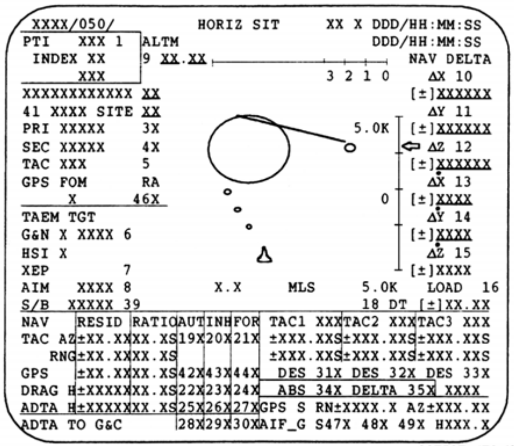
TACAN azimuth and range (TAC AZ, RNG) are provided on the lower left side of the HORIZ SIT display (SPEC 50). TACAN range and bearing data cannot be used to produce a good estimate of the altitude position component, so navigation uses barometric altitude derived from the air data system probes, which are deployed by the fight crew at approximately Mach 5.



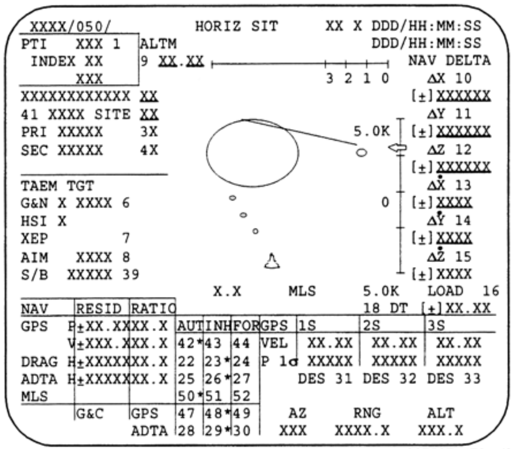
TACAN Controls on Panel O5



TACAN Controls on Panel O9



**HORIZ SIT Display (SPEC 50)
(TACAN Azimuth and Range
Three-String TACAN Vehicles)**



**HORIZ SIT Display (SPEC 50)
(Three-String GPS Vehicles)**

If MLS is not acquired, TACAN data can be used until an altitude of 1,500 feet. When runways with MLS are acquired, MLS operation is automatic. The flight crew is provided with the controls and displays necessary to evaluate MLS performance and take over manually, if required.

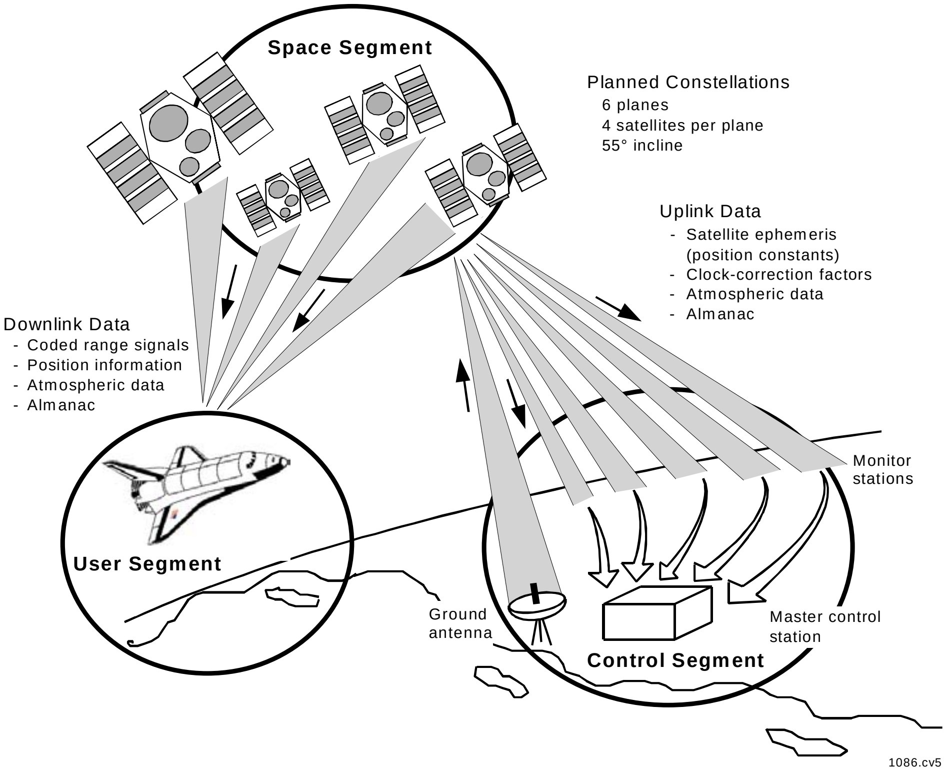
TACAN redundancy management consists of processing and mid-value-selecting range and bearing data. The three TACANs are compared to determine if a significant difference is detected. When all three TACANs are good, redundancy management selects middle values for range and bearing. If a fault is detected, the SM ALERT light is illuminated, and a GPC annunciated fault message occurs for the applicable TACAN parameter.

Global Positioning System

The GPS is a relatively new navigation tool to the shuttle. Because of the anticipated decommissioning of TACAN stations by the Department of Defense (DOD), shuttle program officials decided to use GPS as the replacement for TACANs, which had been a primary navigational tool for entry.

The NAVSTAR GPS is a space-based radio positioning navigation system that provides three-dimensional position, velocity, and time information to suitably equipped users anywhere on or near the surface of the Earth. The GPS constellation consists of 27 NAVSTAR satellites, including 3 active on-orbit spares. The satellites travel in 10,980 n. mi. orbits at velocities of 14,500 km/hr for periods of 12 hours. These satellites are in six planes, each at an inclination of 55° with respect to the equator. NAVSTAR satellites and their support equipment are financed by the DoD, but their navigation signals are available free of charge to anyone. The NAVSTAR satellite constellation control center facility is located at Falcon Air Force Base in Colorado Springs, CO.

The way a GPS receiver interacts with the NAVSTAR satellites to determine position and velocity is fairly straightforward. Each GPS satellite repeatedly transmits a specific sequence of codes. The receiver knows each satellite's code pattern, as well as what time a satellite is supposed to transmit specific parts of the code. After identifying a specific satellite (via code-matching techniques), the GPS receiver compares the time at which it received the specific part of the code to the time at which the satellite was supposed to have sent it. This time delta directly corresponds to how far the receiver is from the given satellite. For a receiver to determine exactly where it is near the Earth, it must make at least three such measurements from three different satellites. For the receiver to accurately measure the time delta, it must have an extremely accurate internal clock. Most receivers do not have an atomic clock; therefore, a fourth measurement is taken from another satellite to help the receiver determine its clock bias and, thus, determine an accurate state vector.

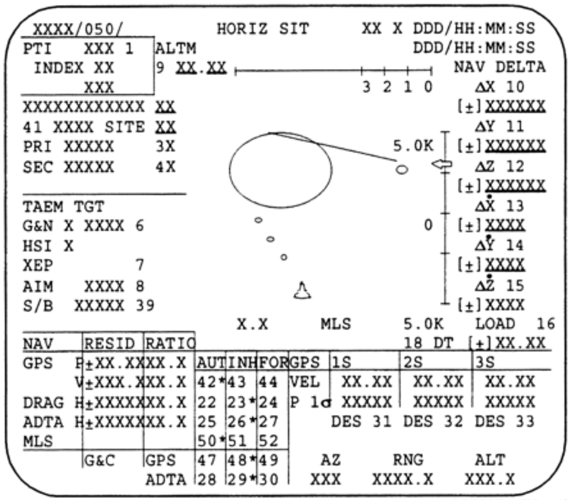


GPS Operation

The NAVSTAR satellites transmit two separate codes, one intended for U.S. military use (called Y-code) and one for civilian use (called coarse/acquisition (C/A) code). The major difference between these two is that the military code is encrypted and requires the military receivers to have a special “key” to decipher the transmitted messages. The orbiter receivers contain the key necessary to use the encrypted Y-code; accuracy is expected to be better than 110 ft. DoD is able to introduce noise into the civilian code to provide less accurate solutions to non-military users. This noise was removed from the civilian signal in 2000, but could be reinstated if the DoD determined it to be necessary.

Starting with OV-105, the orbiter has three GPS receivers that operate redundantly. Each receiver is equipped with two antennas, one on the orbiter’s lower forward fuselage and one on the upper forward fuselage. The antennas are covered with thermal protection system tiles. The satellite signals are received by the antennas, amplified through a preamplifier, and then routed through a combiner to combine the signals from the upper and lower antenna pairs into a single stream of data. From there, the signals are transmitted directly to the associated receiver for processing. The three convection-cooled GPS receivers are in the orbiter forward avionics bays. Each receiver is 6.78 inches high by 3.21 inches wide by 12.0 inches long; each weighs 13 pounds and consumes 40 watts of power.

Unlike air data and MLS, where navigation data are used to update the onboard state vector, the selected GPS vector completely replaces the propagated vectors periodically during orbit (OPS 2 and 8) and entry (OPS 602/603 and OPS 3). For example, during orbit, the FSW will replace its propagated state vector with a selected GPS vector every 90 minutes. This vector will then be propagated forward by the FSW for the next 90 minutes, using the nominal FSW propagation techniques. GPS information is displayed on the horizontal situation indicators (HSIs) on panels F6 and F8, as well as on the HORIZ SIT display (SPEC 50) and the GPS STATUS display (SPEC 55).



```
 XXXX/050/             HORIZ SIT      XX X DDD/HH:MM:SS
PTI    XXX 1  ALTM                         DDD/HH:MM:SS
 INDEX XX     9 XX.XX                       NAV DELTA
       XXX                       3 2 1 0     ΔX 10
XXXXXXXXXXXX XX                            [±]XXXXXX
41 XXXX SITE XX                              ΔY 11
PRI XXXXX    3X                      5.0K  [±]XXXXXX
SEC XXXXX    4X                              ΔZ 12
                                           [±]XXXXXX
TAEM TGT                                     ΔẊ 13
G&N X XXXX 6                          0    [±]XXXX
HSI X                                        ΔẎ 14
XEP         7                              [±]XXXX
AIM   XXXX 8                                 ΔŻ 15
S/B  XXXXX 39                              [±]XXXX
                 X.X       MLS       5.0K  LOAD  16
NAV   RESID  RATIO                   18 DT [±]XX.XX
GPS  P±XX.XXXX.X AUT INH FOR GPS 1S     2S     3S
     V±XXX.XXX.X 42*43  44  VEL  XX.XX  XX.XX  XX.XX
DRAG H±XXXXXXX.X 22  23*24  P 1σ XXXXX  XXXXX  XXXXX
ADTA H±XXXXXXX.X 25  26*27     DES 31 DES 32 DES 33
MLS              50*51  52
      G&C   GPS  47  48*49     AZ     RNG     ALT
           ADTA  28  29*30    XXX   XXXX.X   XXX.X
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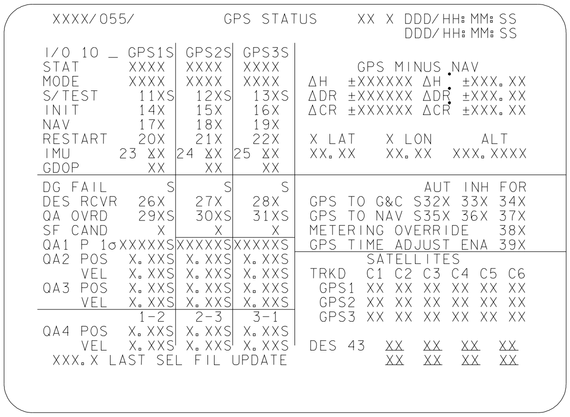
HORIZ SIT Display (SPEC 50)
(Three-String GPS Vehicles)

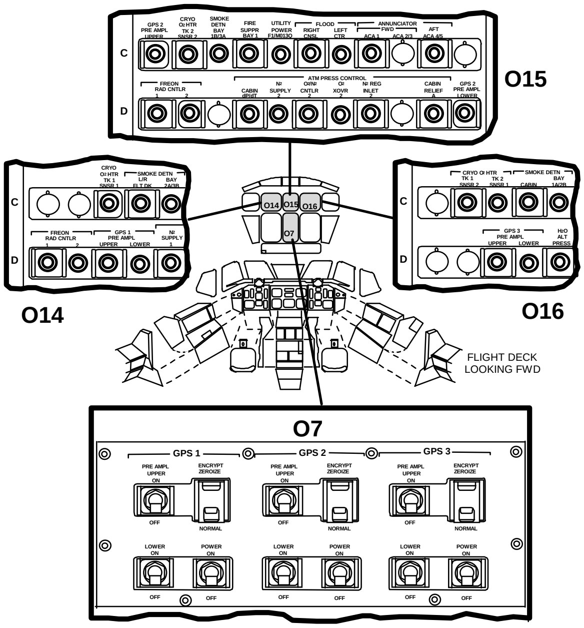


```
 XXXX/055/          GPS STATUS    XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS
I/O 10 _ GPS1S GPS2S GPS3S
STAT      XXXX  XXXX  XXXX        GPS MINUS NAV
MODE      XXXX  XXXX  XXXX    ΔH  ±XXXXXX ΔḢ  ±XXX.XX
S/TEST     11XS  12XS  13XS   ΔDR ±XXXXXX ΔḊR ±XXX.XX
INIT       14X   15X   16X    ΔCR ±XXXXXX ΔĊR ±XXX.XX
NAV        17X   18X   19X
RESTART    20X   21X   22X    X LAT    X LON      ALT
IMU     23 XX 24 XX 25 XX     XX.XX    XX.XX   XXX.XXXX
GDOP        XX    XX    XX
DG FAIL      S     S     S               AUT INH FOR
DES RCVR   26X   27X   28X    GPS TO G&C S32X 33X 34X
QA OVRD    29XS  30XS  31XS   GPS TO NAV S35X 36X 37X
SF CAND      X     X     X    METERING OVERRIDE   38X
QA1 P 1σXXXXXSXXXXXSXXXXXS    GPS TIME ADJUST ENA 39X
QA2 POS  X.XXS X.XXS X.XXS          SATELLITES
    VEL  X.XXS X.XXS X.XXS    TRKD  C1 C2 C3 C4 C5 C6
QA3 POS  X.XXS X.XXS X.XXS     GPS1 XX XX XX XX XX XX
    VEL  X.XXS X.XXS X.XXS     GPS2 XX XX XX XX XX XX
           1-2   2-3   3-1     GPS3 XX XX XX XX XX XX
QA4 POS  X.XXS X.XXS X.XXS
    VEL  X.XXS X.XXS X.XXS    DES 43  XX  XX  XX  XX
 XXX.X LAST SEL FIL UPDATE            XX  XX  XX  XX
```

007587051.CRT;1

GPS STATUS Display (SPEC 55)

GPS hardware controls are located at the top of panel O7. GPS 1,2,3 PRE AMPL UPPER (LOWER) switches provide power to each of the antenna preamplifiers, with circuit breakers located on panels O14, O15, and O16. Each receiver has a POWER switch on panel O7 and is powered through a single energy storage system (ESS) bus/forward power controller (FPC) combination. The ENCRYPT switches located on panel O7 control the integrity of the Y-code key within each receiver. In NORM, the key is kept intact such that it can be used to decode the Y-code signals being sent by the NAVSTAR satellites. If this switch is moved to the ZEROIZE position, the key will be erased from the memory of the receiver and the receiver will only be able to make measurements using the civilian codes. This is a procedure that would be used in the event of a non-U.S. landing to protect the key from being obtained by unauthorized users. A permanent switch guard prevents accidental movement of this switch. All of the new GPS switches on panel O7 will replace the existing TACAN switches.



GPS Controls
(Three-String GPS Vehicles)

Unlike the classical redundancy management (RM) schemes applied to other shuttle sensors, the GPS uses a cyclic quality assessment (QA) process that is more conducive to its performance. Because of the nature of its operation, whereby poor satellite coverage may result in short periods of invalid data, it would not be prudent to "permanently" remove a unit from availability because of these questionable periods.

There are four separate QA checks the software will perform to determine the status of the data from each receiver. These four checks include each receiver's estimate of the error in its own navigation state (QA1), the difference between each receiver's state and the FSW's computed state (QA2), the difference between each receiver's current state and its previous state (QA3), and the differences between each receiver and the other receivers (QA4). If the FSW determines that one of the QA1, QA3, or

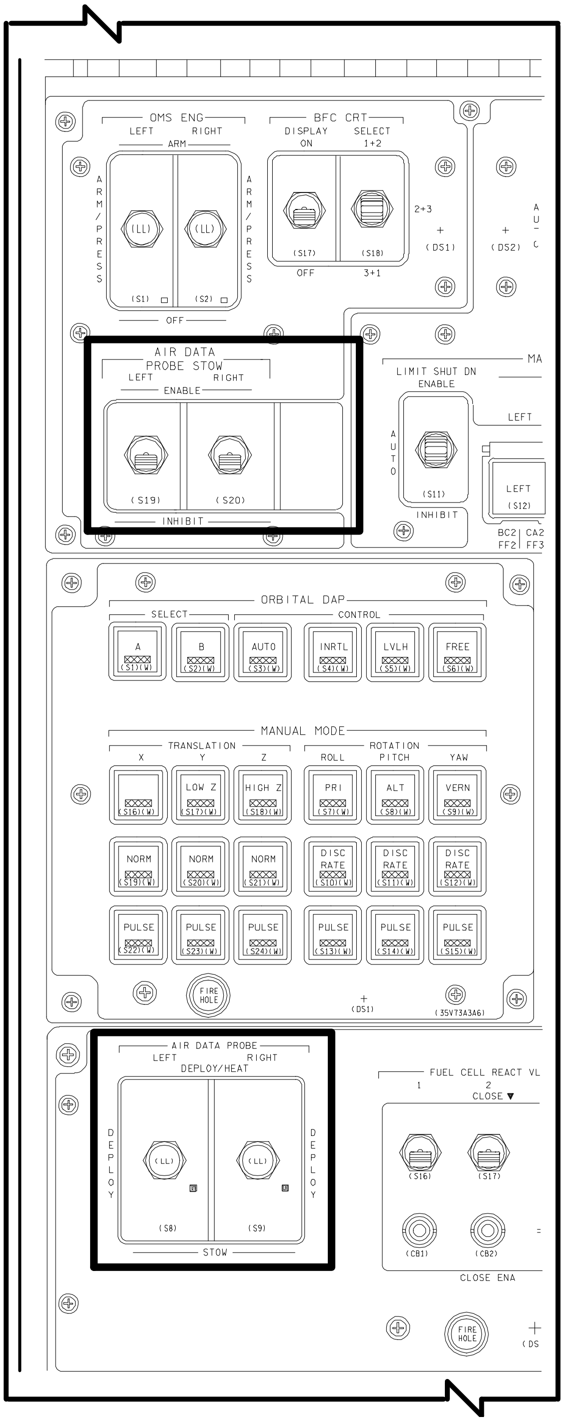
QA4 checks has failed, the associated receiver will not be considered available to the selection filter. A miscompare of the QA2 check does not cause the receiver to be considered unavailable. With three candidates available (three level) to the selection filter, mid-value select (MVS) logic is used to select a unit's state vector for processing. With two candidates available (two level), the candidate data are averaged. With only one receiver available (one level), the single GPS is selected. When no eligible GPS candidates are available, the GPS selection filter will propagate the last valid data for processing. This vector will not be used to update the onboard navigation state if it has been longer than 18 seconds since the selection filter has had valid GPS data.

Air Data System

The air data system provides information on the movement of the orbiter in the air mass (flight environment). There are two air data probes, one on the left and one on the right side of the orbiter's forward lower fuselage. During ascent, on orbit, deorbit, and initial entry phases, the probes are stowed inside the forward lower fuselage. The air data probe is covered by thermal protection system tiles while in the stowed position. At Mach 5, depending on mission requirements, the air data probes are deployed. Each probe is 4.87 inches high, 21.25 inches long, 4.37 inches wide, and weighs 19.2 pounds.

The air data system senses air pressures related to spacecraft movement through the atmosphere to update the navigation state vector in altitude, provide guidance in calculating steering and speed brake commands, update flight control law computations, and provide display data for the commander's and pilot's flight instruments, and various GNC displays. (The flight instruments are detailed in Section 2.7.)

Each air data probe has four pressure-port sensors and two temperature sensors. The pressures sensed include static pressure and angle-of-attack upper, center, and lower pressure. The four pressures are sensed at ports on each probe. The probe-sensed pressures are connected by a set of pneumatic lines to two air data transducer assemblies (ADTAs). The two temperature sensors are installed on each probe and wired to an ADTA. The pressures and temperatures sensed by the left probe are connected by pneumatic tubing to ADTAs 1 and 3. Those sensed by the right probe are connected to ADTAs 2 and 4.



AIR DATA PROBE Switches on Panel C3

Within each ADTA, the pressure signals are directed to four transducers, and the temperature signal is directed to a bridge. The pressure transducer analogs are converted to digital data by digital-processor-controlled counters. The temperature signal is converted by an analog-to-digital converter. The digital processor corrects errors, linearizes the pressure data, and converts the temperature bridge data to temperatures in degrees Centigrade. These data are sent to the digital output device and then to the onboard computers to update the navigation state vector. The computers then send the data for display on various GNC displays and on the commander's and pilot's flight instruments.

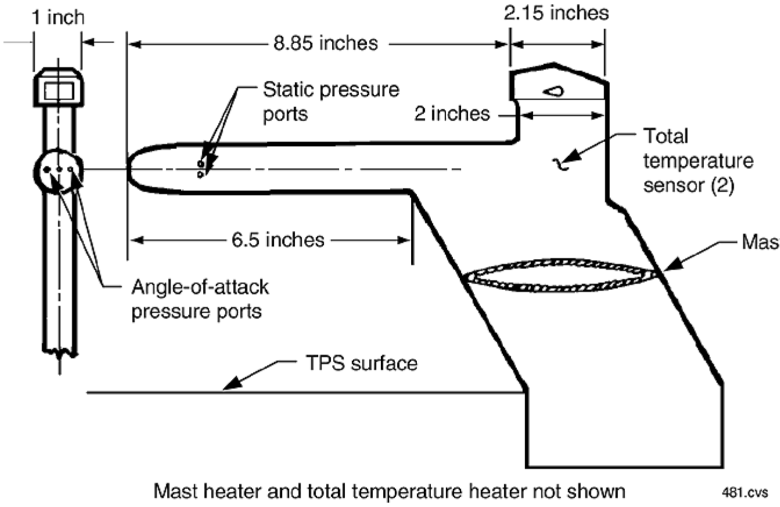
The ADTA SOP uses ADTA data to compute angle of attack, Mach number (M), equivalent airspeed (EAS), true airspeed (TAS), dynamic pressure (qbar), and barometric altitude (h).

The GPCs compare the pressure readings from the four ADTAs. If all the pressure readings compare within a specified value, one set of readings from each probe is averaged and sent to the software. If one or more pressure signals of a set of probe pressure readings fail, the failed set's data flow is interrupted, and the software receives data from the other ADTA on that probe. If both probe sets fail, the software operates on data from the two ADTAs connected to the other probe. The best total temperature from all four ADTAs is sent to the software.

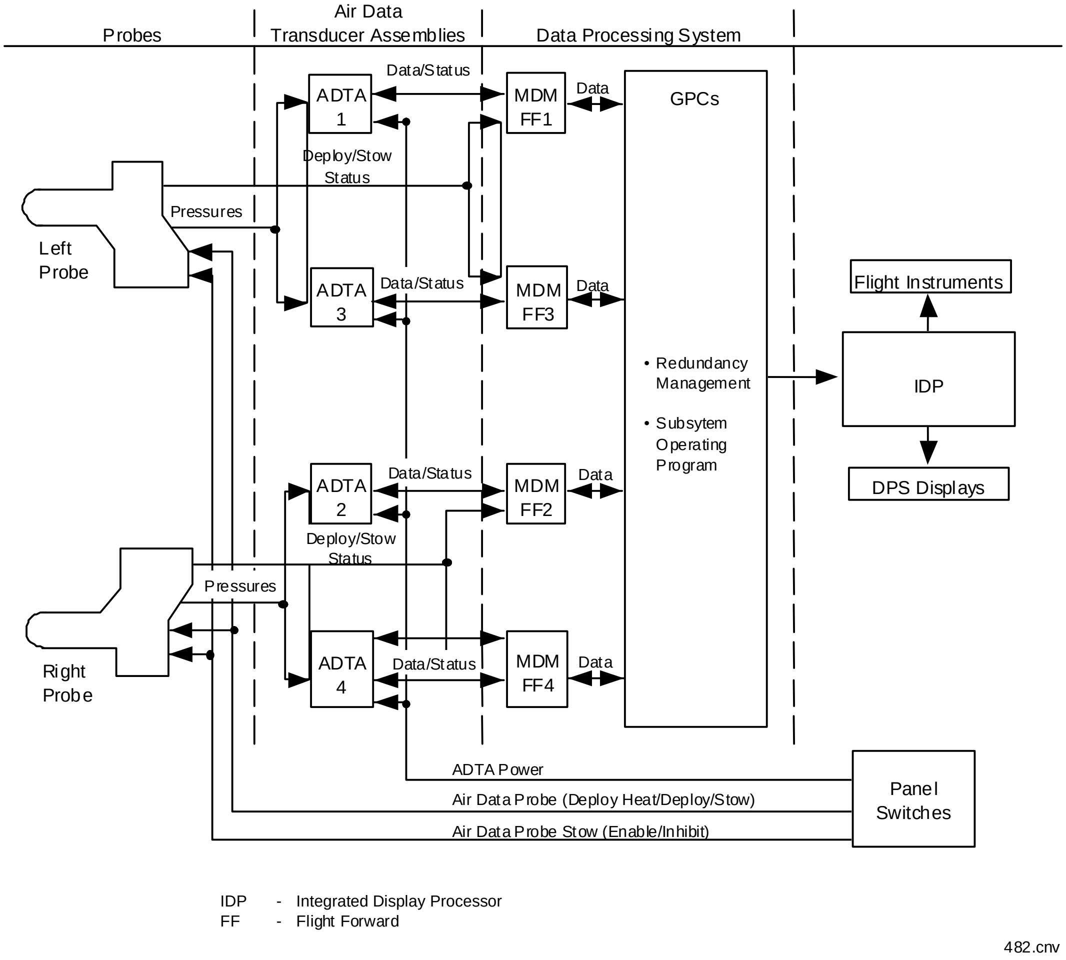
Each probe is independently deployed by an actuator consisting of two ac motors connected to a rotary electromechanical actuator. Each probe is controlled by its AIR DATA PROBE switch on panel C3. To deploy the air data probes, the LEFT and RIGHT switches are positioned to DEPLOY. The redundant motors for each probe drive the probe to the deployed position. When the probe is fully deployed, limit switches remove electrical power from the motors. Deployment time is 15 seconds for two-motor operation and 30 seconds for single-motor operation. The DEPLOY position deploys the probe without electrical heaters; the DEPLOY/HEAT position deploys the air data probes with heaters powered.

The AIR DATA PROBE STOW LEFT and RIGHT switches on panel C3 are used to stow the probes. The stow procedure includes positioning the switches to ENABLE and positioning the corresponding AIR DATA PROBE switch to STOW. The AIR DATA PROBE STOW INHIBIT position opens the ac motor circuits, disables the stow, and protects the microswitches.

The fault detection system illuminates the red AIR DATA and BACKUP C/W ALARM lights on panel F7, and illuminates the MASTER ALARM. A fault also sounds the audible tone and generates a fault message. A communication fault illuminates the SM ALERT light.



Air Data Probe



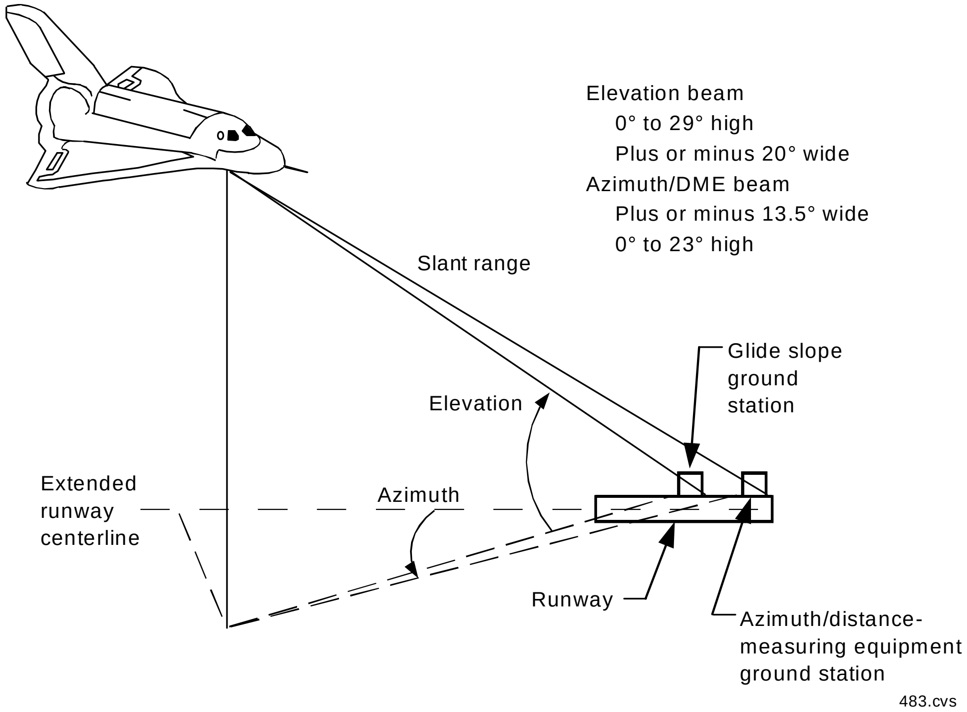
Air Data System Functional Block Diagram

Microwave Landing System

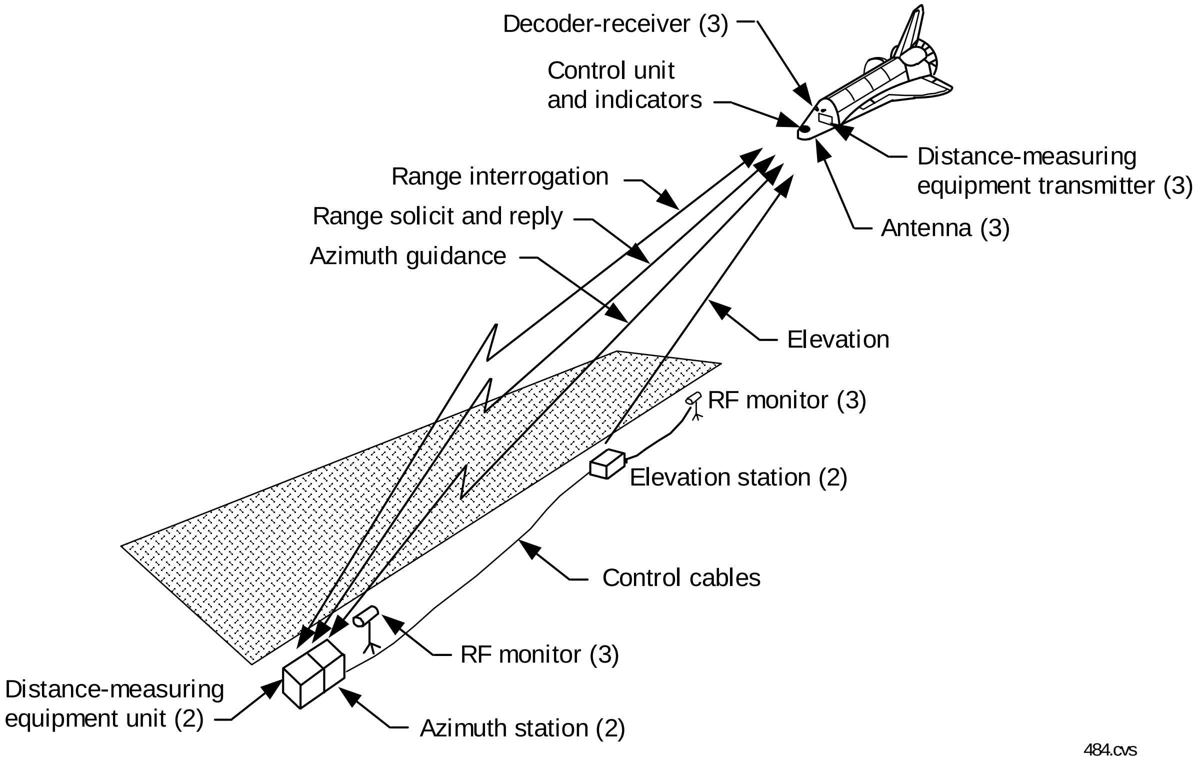
The three onboard MLS units are airborne navigation and landing aids with decoding and computational capabilities. The MLS units determine slant range, azimuth, and elevation to the ground stations alongside the landing runway. MLS is used during the approach and landing flight phases. When the channel (specific frequency) associated with the target runway approach is selected, the orbiter's MLS units receive elevation from the glide slope ground station and azimuth and slant range from the azimuth/distance-measuring equipment ground station.

The orbiter is equipped with three independent MLS sets, each consisting of a Ku-band receiver transmitter and decoder. Data computation capabilities determine elevation angle, azimuth angle, and orbiter range with respect to the MLS ground station. The MLS provides the orbiter highly accurate three-dimensional navigation position information to compute state vector components. The three orbiter Ku-band antennas are located on the upper forward fuselage. The three MLS and decoder assemblies are located in the crew compartment middeck avionics bays. Each MLS decoder assembly is 8.25 inches high, 5 inches wide, 16.6 inches long, and weighs 17.5 pounds. The radio frequency (RF) assembly is 7 inches high, 3.5 inches wide, 10.25 inches long, and weighs 6 pounds.

The ground portion of the MLS consists of two shelters: an elevation shelter and an azimuth/distance-measuring equipment (DME) shelter. The elevation shelter is located near the projected touchdown point, and the azimuth/DME shelter is located at the far end of the runway.



Major Microwave Landing System



Major Microwave Landing System Components and Radio Frequency Links

The MLS ground station signals are acquired when the orbiter is close to the landing site, usually at an altitude of approximately 18,000 feet. Final tracking occurs at the approach and landing interface at approximately 10,000 feet altitude and 8 n. mi. from the azimuth/DME station. (Refer to the Operations section for further information on entry procedures.)

The MLS azimuth, elevation, and range data are used to compute steering commands from acquisition through landing and rollout.

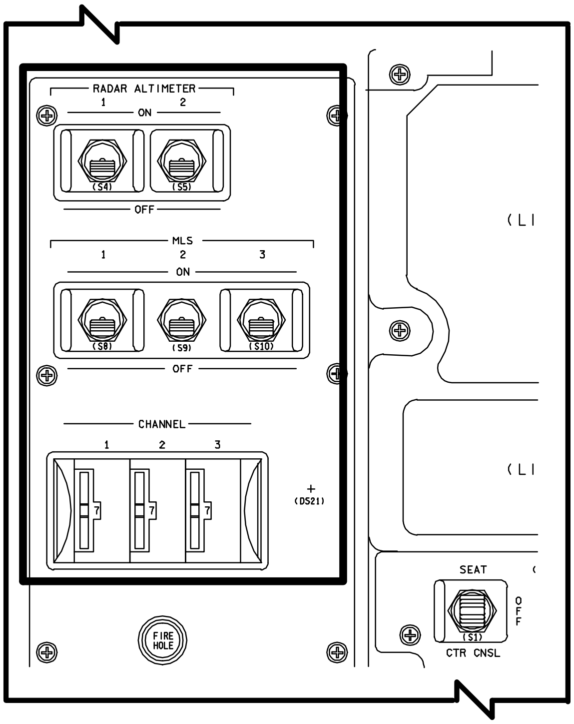
The commander's and pilot's horizontal situation indicators display the orbiter's position with respect to the runway. Elevation with respect to planned glide slope is shown on the glide slope indicator. The course deviation needle displays azimuth information, and range is displayed on a mileage indicator. Azimuth/ DME data are used during the landing rollout.

The three orbiter MLS sets operate on a common channel during the landing phase. The MLS ground station transmits a DME solicit pulse. The onboard MLS receiver responds with a DME interrogation pulse. The ground equipment responds by transmitting a return pulse. A decoder in the onboard MLS decodes the pulses to determine range, azimuth, and elevation. Range is a function of the elapsed time between interrogation pulse transmission and signal return. Azimuth pulses are returned in pairs. The spacing between the two pulses in a pair identifies the pair as azimuth and indicates on which side of the runway the orbiter is situated. Spacing between pulse pairs defines the angular position from the runway centerline. The spacing between the two pulses in a pair identifies the pair as elevation, while the spacing between pulse pairs defines the angular position of the orbiter above the runway.

Each RF assembly routes range, azimuth, and elevation information in RF form to its decoder assembly*, which* processes the information and converts it to digital data for transmission to the onboard GNC software via the MDMs.

Because the azimuth/DME shelters are at the far ends of the runway, the MLS provides useful data until the orbiter stops. Azimuth data provide position in relation to the runway centerline; the DME gives the distance from the orbiter to the end of the runway.

Each MLS has an MLS ON/OFF power switch and a CHANNEL (frequency) selection thumbwheel on panel O8. Positioning the MLS 1, 2, or 3 switch to ON provides power to the corresponding system. MLS 1 receives power from main bus A, MLS 2 from main bus B, and MLS 3 from main bus C. Positioning the CHANNEL 1, 2, and 3 thumbwheels selects the frequency (channel) for the ground station at the selected runway for the corresponding MLS.



RADAR ALTIMETER Switches and MLS Switches and Thumbwheels on Panel O8

Redundancy management selects range, azimuth and elevation angles for processing navigation data. The three MLS sets are compared to identify any significant differences among them. When data from all three MLS sets are valid, redundancy management selects middle values from three ranges, azimuths, and elevations. In the event that only two MLS sets are valid, the two ranges, azimuths, and elevations are averaged. If only one MLS set is valid, its range, azimuth, and elevation are passed for display. During fault detection, the SM ALERT light is illuminated, and a GPC annunciated fault message is shown.

Radar Altimeters

The two RAs onboard the orbiter measure absolute altitude from the orbiter to the nearest terrain within the beam width of the orbiter's antennas. The two independent RAs consist of a transmitter and receiver antenna. The systems can operate simultaneously without affecting each other. The four C-band antennas are located on the lower forward fuselage. The two receiver/transmitters are located in the middeck forward avionics bays. Each radar altimeter receiver/transmitter measures 3.13 inches high, 7.41 inches long, 3.83 inches wide, and weighs 4.5 pounds.

Each RA transmits a C-band (4,300 MHz modulated at 8.5 kHz) pulse through its transmitting antenna. The signal is reflected by the nearest terrain, and the leading edge of the return radar echo is locked on by the RA's receiving antenna. The altitude outputs by the RA are analog voltages, proportional to the elapsed time required for the ground pulse to return. The range output of the RA is from zero to 5,000 feet. The RA may not lock on if large pitch or roll angles are present.

The GPCs process the data for display on the commander's and pilot's altitude tape and head up displays (described further in Section 2.7) from 5,000 feet. Two RADAR ALTIMETER ON/OFF switches are located on panel O8. RA data is not used as input to navigation; it is for crew use only.

Flight Control System Hardware

The flight control system (FCS) ascent and entry hardware provides manual guidance commands to GNC software and responds to effector commands from GNC software in order to effect vehicle and trajectory control.

The following hardware includes sensors responsible for flight control data:

- Accelerometer assembly (AA) -- senses vehicle accelerations along two body axes.
- Rate gyro assembly (RGA) -- senses vehicle rotation rates about three body axes.
- SRB rate gyro assembly (SRB RGA) -- Senses vehicle rotation rates about two body axes during first stage ascent before SRB separation.

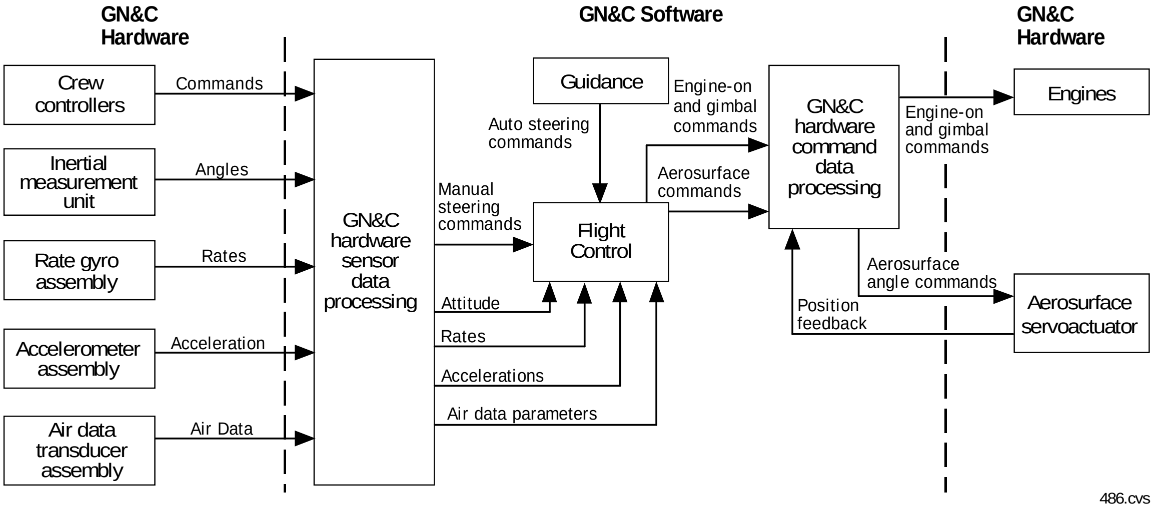
The following hardware provides manual guidance commands:

- Rotational hand controller (RHC) -- Commands rotational rates and accelerations about a body axis.
- Translational hand controller (THC) -- Commands vehicle translations along a body axis (orbit only).
- Rudder pedal transducer assembly (RPTA) -- Generates an electrical output signal which is proportional to the rudder pedal displacement. During glided flight, this signal controls the position of the rudder. During rollout, this signal is used for nose wheel steering.
- Speed brake/thrust controller (SBTC) -- During ascent, commands SSME throttle settings between 67% and 109% (PLT only). During entry commands the position of the speed brake (CDR & PLT).

The following hardware responds to software commands:

- Ascent thrust vector control (ATVC) -- Takes position commands generated by the GPCs during powered flight and converts them into position error commands, which are then used to drive the SSME and SRB nozzles.
- Aerosurface servoamplifier (ASA) -- Takes position commands generated by the GPCs during glided flight and converts them into position error commands, which are then used to drive the aerosurfaces.

Each piece of FCS hardware is hardwired to one of eight flight-critical MDMs connected to each of the five GPCs by data buses. Each GPC is assigned to command one or more data buses.



Flight Control Interfaces

Accelerometer Assemblies

There are four AAs onboard the orbiter, each containing two identical single-axis accelerometers. One senses vehicle acceleration along the lateral (left and right) vehicle Y axis; the other senses vehicle acceleration along the normal (vertical) Z axis. The four AAs are located in the crew compartment middeck forward avionics bays 1 and 2. The AAs are convection cooled.

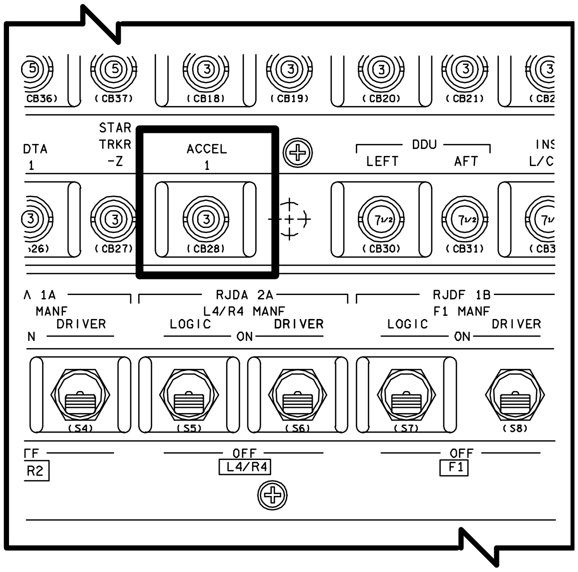
The AAs provide acceleration feedback to the FCS. These accelerations are used to augment stability during first-stage ascent, aborts, and entry, to relieve vehicle load during first-stage ascent, and to compute steering errors for display on the commander's and pilot's attitude director indicators.

The lateral acceleration readings enable the FCS to null side forces during both ascent and entry. The normal acceleration readings augment pitch control and indicate the need to relieve normal loads. During the latter stages of entry, the normal acceleration measurements provide feedback for guidance to control pitch. (In contrast, the accelerometers within the IMUs measure three accelerations used in navigation to calculate state vector changes.)

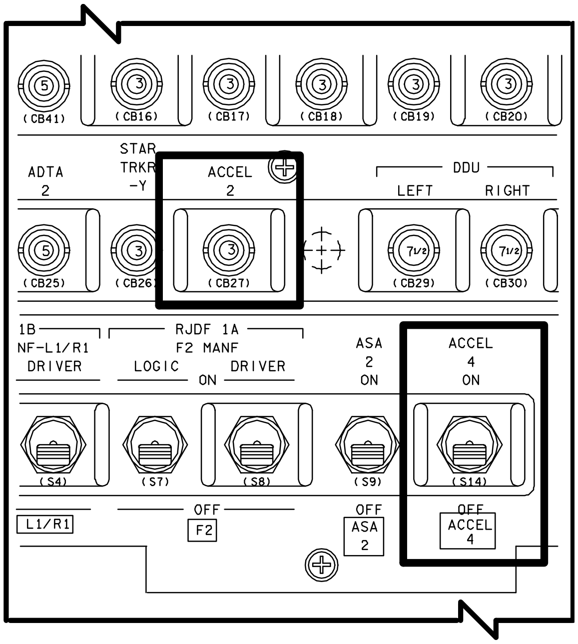
Each accelerometer consists of a pendulum suspended so that its base is in a permanent magnetic field between two torquer magnets. A light beam passes through an opening in one of the torquer magnets; photodiodes are located on both sides of the other torquer magnet. When acceleration deflects the pendulum toward one photodiode, the resulting light imbalance on the two photodiodes causes a differential voltage. This voltage increases the magnetic field on one of the torquer magnets to rebalance the pendulum at an offset position representing the sensed acceleration. The magnitude of the current required to accomplish this is proportional to the acceleration. The polarity of the differential voltage depends on the direction of the pendulum's movement, which is opposite the direction of acceleration. The only difference between the lateral and normal accelerometers is the position in which they are mounted within the assembly. When the acceleration is removed, the pendulum returns to the null position. The maximum output for a lateral accelerometer is plus or minus 1 g; for a normal accelerometer, the maximum output is plus or minus 4 g's.

The accelerations transmitted to the forward MDMs are voltages proportional to the sensed acceleration. These accelerations are sent to the GPCs, where an accelerometer assembly subsystem operating program converts the eight accelerometer output voltages to gravitational units. This data is also sent to the MEDS displays and attitude director indicator during entry.

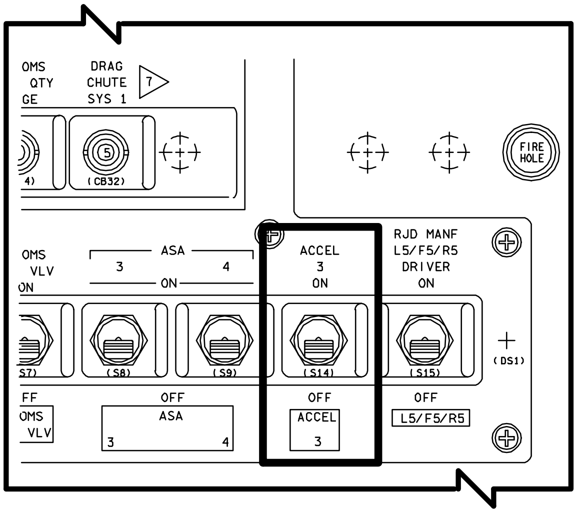
The accelerometer assemblies provide fail-operational redundancy during both ascent and entry. The four assemblies employ an interchangeable mid-value software scheme (IMVS) to select the best data for redundancy management and a reasonableness limit check for failure detection. Software fault detection will operate when all four AAs are operational and will then detect the first failure and deselect that accelerometer assembly. A caution and warning message "RM FAIL ACC" is generated to inform the flight crew of an accelerometer failure. The RGA/ACCEL caution and warning light on panel F7 is not supported.



Accelerometer 1 Power Control on Panel O14



Accelerometer 2 and 4 Power Controls on Panel O15

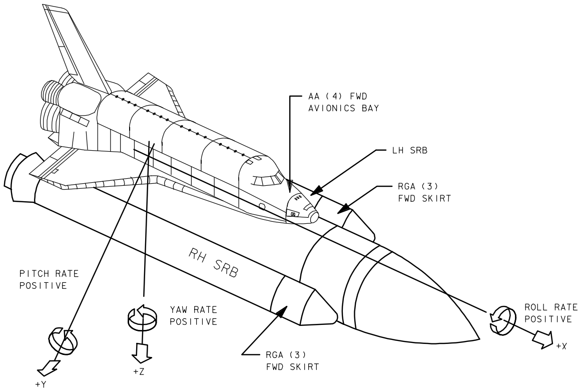


Accelerometer 3 Power Control on Panel O16

Accelerometer 1 is powered from main bus A through the ACCEL 1 circuit breaker on panel O14. Accelerometer 2 is powered from main bus B through the ACCEL 2 circuit breaker on panel O15. Accelerometer 3 is redundantly powered through the ACCEL 3 ON/OFF switch on panel O16. Accelerometer 4 is redundantly powered through the ACCEL 4 ON/OFF switch on panel O15. The accelerometers are turned off once on orbit and on again before entry.

Orbiter Rate Gyro Assemblies

The orbiter has four RGAs. Each RGA contains three identical single-degree-of-freedom rate gyros so that each gyro senses rotation about one of the vehicle axes. Thus, each RGA includes one gyro sensing roll rate (about the X axis), one gyro sensing pitch rate (about the Y axis), and one gyro sensing yaw rate (about the Z axis). These rates are the primary feedback to the FCS during ascent, entry, insertion, and deorbit. The FCS must have good rate feedback in all three axes to maintain control.



Rate Gyro Assembly Location and Rotation Axes

The RGAs are located on the aft bulkhead below the floor of the payload bay. They are mounted on cold plates for cooling by the Freon coolant loops.

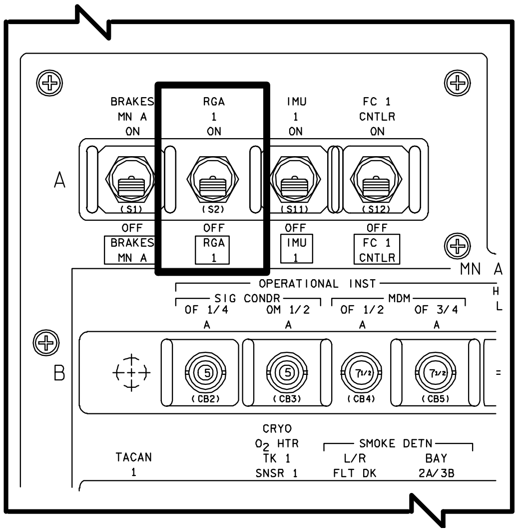
Each gyro has three axes. A motor forces the gyro to rotate about its spin axis. When the vehicle rotates about the gyro input axis, a torque results in a rotation about the output axis. An electrical voltage proportional to the angular deflection about the output axis, representing vehicle rate about the input axis, is generated and transmitted through the flight aft MDMs to the GPCs and RGA SOP. This same voltage is used within the RGA to generate a counteracting torque that prevents excessive gimbal movement about the output axis. The maximum output for roll rate gyros is ±40° per second; for the pitch and yaw gyros, the maximum output is ±20° per second.

The RGA 1, 2, 3, and 4 power switches are located on panels O14, O15, O16, and O15 respectively. The redundant power supplies for RGAs 1 and 4 prevent the loss of more than one rate gyro assembly if main bus power is lost. The RGAs are turned off on orbit, except during flight control system checkout, to conserve power. RGAs are reactivated during deorbit prep, and prior to any transition to OPS 3, when they are required for the transition DAP to control vehicle attitude.

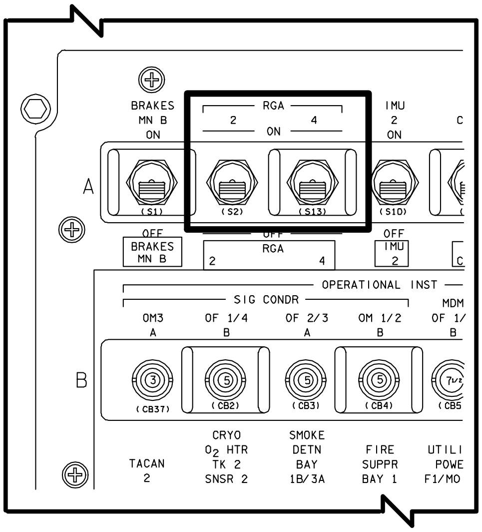
WARNING

A transition to OPS 3 with RGAs off can result in loss of control.

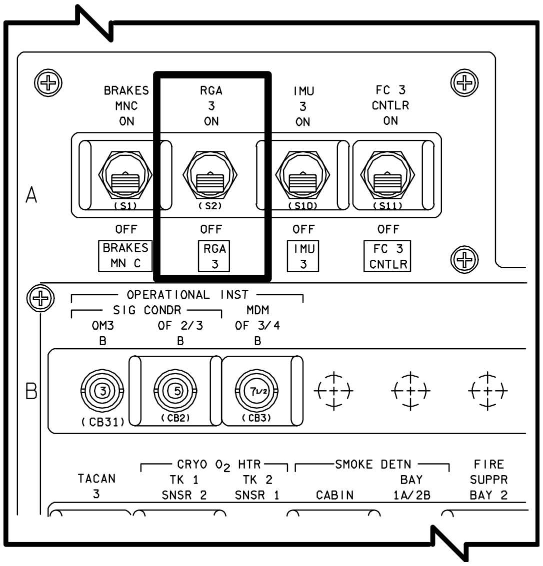
The RGAs afford fail-operational redundancy during both ascent and entry. Redundancy management software employs an interchangeable mid-value scheme (IMVS) to select the best data for flight control use and has two methods of failure detection. A reasonableness limit fault detection operates when all four RGAs are operational and then detects the first failure and deselects that RGA. The RGAs also have power failure fault detection via a spin motor run detector (SMRD), which will deselect any RGA that has lost power up until only one RGA remains. A caution and warning message, "RM FAIL RGA," is generated to inform the flight crew of an RGA failure.



RGA 1 Power Switch on Panel O14



RGA 2 and 4 Power Switches on Panel O15



RGA 3 Power Switch on Panel O16

Solid Rocket Booster Rate Gyro Assemblies

The SRB RGAs are used exclusively during first-stage ascent as feedback to find rate errors before SRB separation. There are two RGAs on each SRB, each containing two identical single-degree-of-freedom rate gyros. These gyros sense rates in the vehicle pitch and yaw axes similar in function to the orbiter RGAs. Because the SRBs are more rigid than the orbiter body, these rates are less vulnerable to errors created by structural bending. They are thus particularly useful in thrust vector control. The two RGAs in each SRB are mounted on the forward ring within the forward skirt near the SRB-external tank attach point.

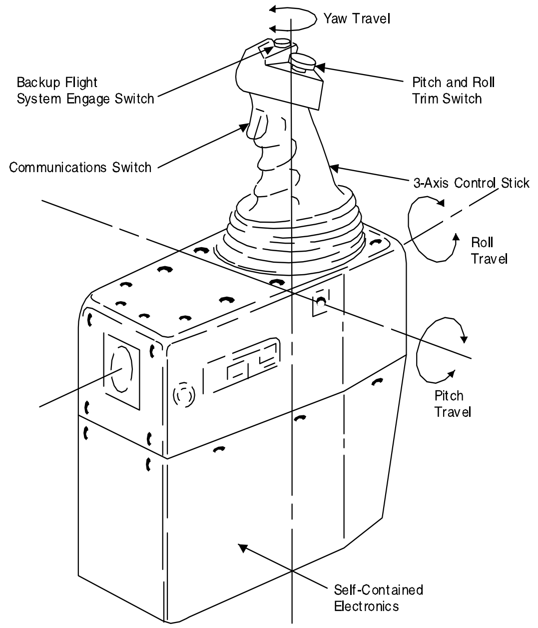
Similar to orbiter RGAs, each SRB RGA generates an electrical voltage that is transmitted through the flight aft MDMs to the GPCs and the SRB RGA SOP. The SRB RGA SOP converts the eight voltages representing a rate into units of degrees per second. The maximum outputs for the SRB RGAs are 10° per second. These rates are used by the flight control system during first-stage ascent as feedback to identify rate errors, which are used for stability augmentation. The pitch and yaw axes and a combination of rate, attitude, and acceleration signals are blended to provide a common signal to the SSMEs and SRB thrust vector control during first stage. In the roll axis, rate and attitude are summed to provide a common signal to the engines and SRB thrust vector control.

The compensated rate signals from the SRB RGA SOP are sent to redundancy management software, where the interchangeable mid-value scheme (IMVS) selects the best data for flight control use and a reasonableness limit check is performed for failure detection. The reasonableness limit fault detection will operate when all four SRB RGAs are operational and will then detect the first failure and deselect that rate gyro assembly. Unlike orbiter RGAs, SRB RGAs do not have fault detection for power failures. In addition, there is no crew insight into SRB RGA fault detection.

The SRB RGAs are commanded to null and released from the flight control system 2 to 3 seconds before SRB separation; SRB yaw and pitch rate data are then replaced with orbiter RGA pitch and yaw data.

Rotational Hand Controller

There are three RHCs on the orbiter flight deck: one at the commander's station, one at the pilot's station, and one at the aft flight deck station. Each RHC controls vehicle rotation about the roll, pitch, and yaw axes. During ascent, the commander's and pilot's RHCs may be used to gimbal the SSMEs and SRBs. For insertion and deorbit, the commander's and pilot's RHCs may be used to gimbal the OMS engines or to command the RCS jets.



Rotational Hand Controller

On orbit, the commander's, pilot's, and aft flight station RHCs may be used to gimbal the OMS engines and command RCS jets. In addition, the commander's and pilot's RHCs may be used to command RCS jets during the early portion of entry, as well as to command the orbiter aerosurfaces during the latter portion of entry. The aft flight station RHC is used only on orbit.

Human factors dictate that an RHC deflection produce a rotation in the same direction as the flight crewmember's line of sight. A SENSE switch on panel A6U selects the line-of-sight reference, either -Z or -X, for the aft station RHC.

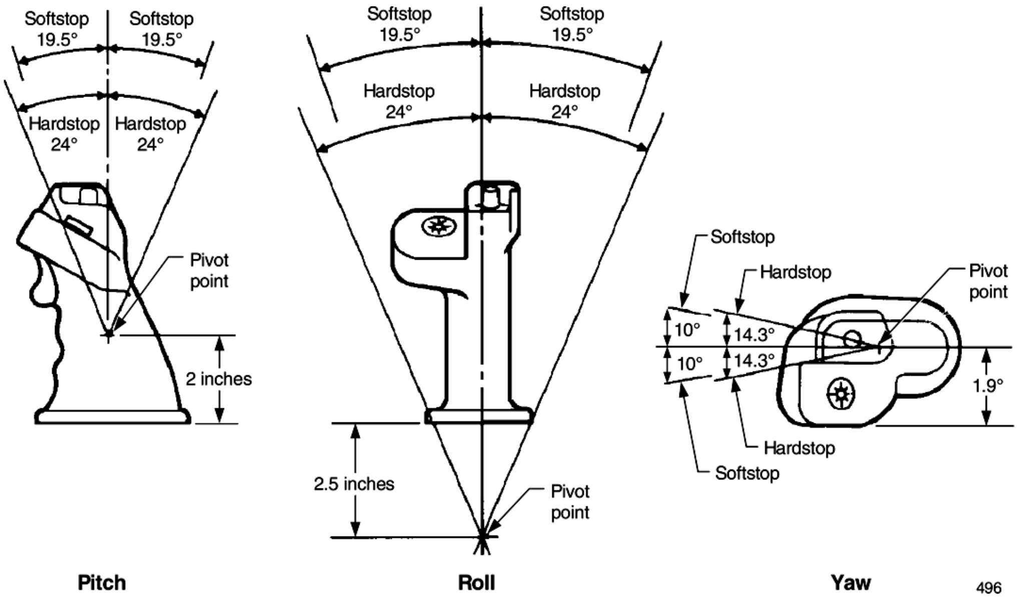
Several switches are located on the RHC. Depressing the red button on the right engages the backup flight system (BFS). The switch to the left trims the RHC by biasing the pitch and roll commands coming from the RHC. (The aft RHC's trim switch is inactive.) The trigger switch on each RHC is a push-to-talk switch that enables voice transmission.

Each RHC contains nine transducers: three transducers sense pitch deflection, three sense roll deflection, and three sense yaw deflection. The transducers produce an electrical signal proportional to the deflection of the RHC. Each channel is powered by a separate power supply in its associated display driver unit. Each controller is triply redundant; thus, only one good signal from a controller is required for the controller to operate.

Each RHC has an initial dead band of 0.25° in all three axes. To move the RHC beyond the dead band, an additional force is required. When the amount of deflection reaches a certain level, called the soft stop, a step increase in the force required for further deflection occurs. The soft stop occurs at 19.5° in the roll and pitch axes, and 9.5° to 10.5° in the yaw axis. The mechanical hard stop is 24.3° in the roll and pitch axes and 14.3° in the yaw axis.

Inputs from the RHCs to the FCS pass through a redundancy management scheme and the RHC SOP before they are passed to the aerojet digital autopilot. The RHC SOP performs four key functions. First, if an RHC is deemed bad, through redundancy management, then all commands from that RHC are set to zero. The SOP is also responsible for compensating and biasing the RHC commands, with the aft RHC commands transformed according to the SENSE switch position. Next the compensated and transformed commands are summed, by axis, to produce rotation commands for the flight control software. Finally, the SOP sets discretes to indicate if an RHC deflection is outside the software detent or beyond the software softstop.

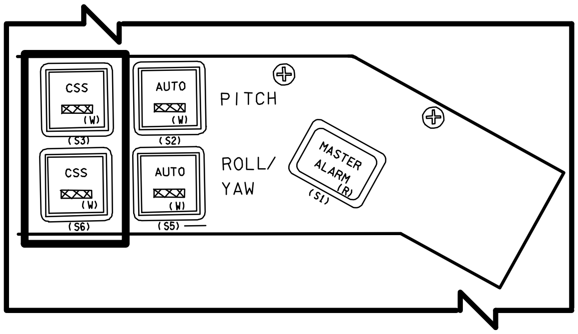
In a nominal mission, the flight crew can make manual inputs using the RHC during every major mode except terminal countdown. During all phases except ascent, when an RHC deflection exceeds the detent in an axis, the RHC SOP downmodes the flight control system from the automatic mode to control stick steering (CSS) in the axis of deflection. (This is referred to as “hot stick downmode”.) During ascent, a CSS PITCH and/or ROLL/YAW pushbutton indicator on panel F2 or F4 must be depressed for manual inputs to be implemented into the flight control system from the commander's or pilot's RHC. On ascent, the CSS light for the pushbutton indicator illuminates, a CSS indicator appears on the Ascent/Entry Flight Display (AFD), and control is downmoded to CSS for all axes. On entry, the CSS light and the AFD CSS indicator appear for only the deflected axis that has downmoded.



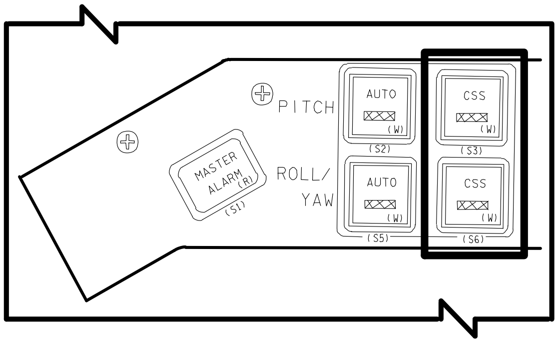
Rotational Hand Controller Mechanical Limits

When the flight crew commands three-axis motion using the RHC, the GPCs process the RHC and motion sensor commands.

The FCS interprets the RHC motions (fore and aft, right and left, clockwise and counter-clockwise) as rate commands in pitch, roll, and yaw. The flight control equations are subsequently processed to provide control response and stability. If conflicting commands are given from more than one RHC, no commands result.



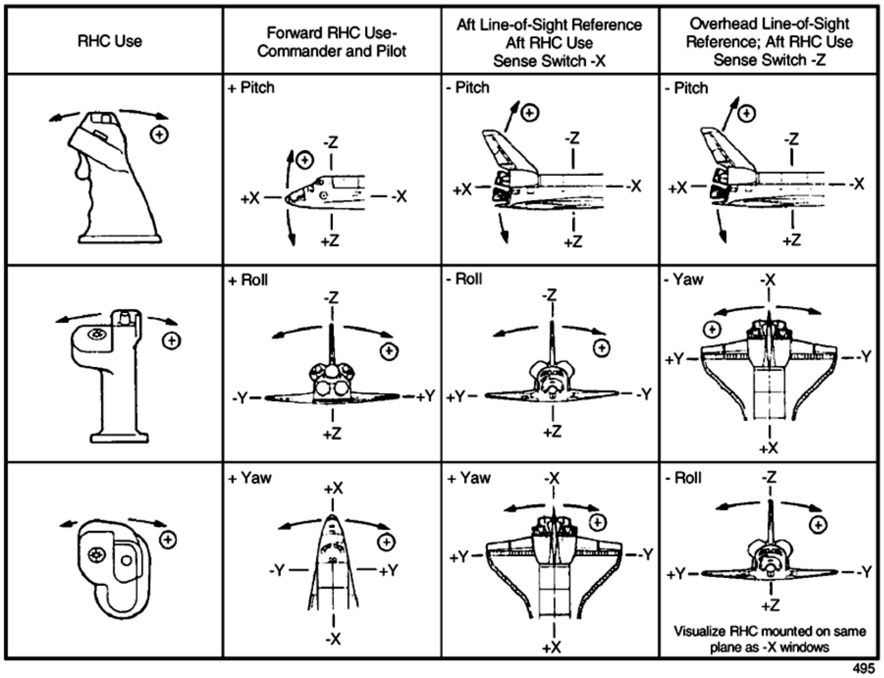
CSS Pushbuttons on Panel F2



CSS Pushbuttons on Panel

During orbital flight, any one of the three stations can input three-axis control commands to the flight control system. During entry and landing, the commander and pilot have two-axis (bank and pitch only) capability. Aerosurface deflection trim, in all three axes, is controlled by the panel trim switches on panels L2 and C3, while bank and pitch vehicle rate trim is controlled with the trim switches on the RHC. For a return-to-launch-site abort, both the com-mander's and pilot's RHC have three-axis capability during powered flight and two-axis capability during gliding flight.

The commander's RHC is powered when the FLT CNTLR POWER switch on panel F7 is positioned to ON. Similarly, the pilot's RHC and the aft RHC are powered when the FLT CNTLR POWER switches on panels F8 and A6U are positioned to ON.



Positive Deflections of the Rotational Hand Controller by Axis

RHC software redundancy management detects malfunctions in roll, pitch, or yaw axes for all three channels. The first malfunction detected will deselect all axes in that channel. For a second malfunction between the remaining two channels, the RHC is put in dilemma and the RHC SOP will no longer accept inputs from that RHC. For any detected malfunction, caution and warning generates an "RHC L," "RHC R," or "RHC A" message and illuminates the corresponding LEFT RHC or R/AFT RHC light on panel F7.

Translational Hand Controller

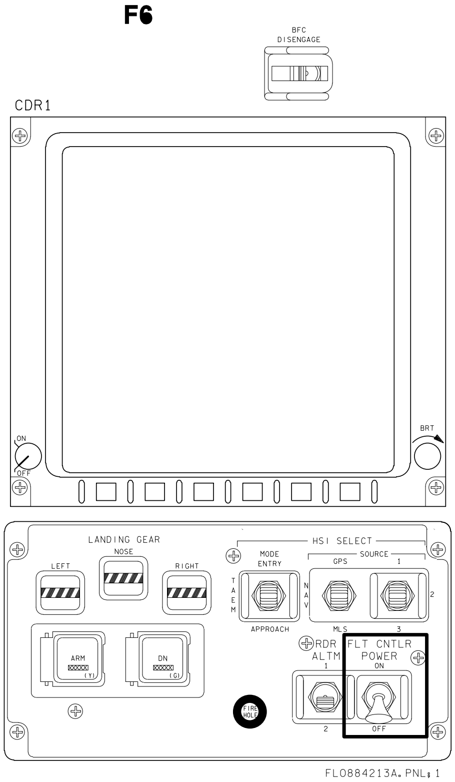
Signals from the THC in FCS command the RCS jets on orbit. There are two THCs, one at the commander's station and one at the aft flight deck station. The commander's THC is active during orbit insertion, on orbit, and during deorbit. The aft flight deck station THC is active only on orbit.

Each THC contains six three-contact switches, one in the plus and minus directions for each axis (+X, -X, +Y, -Y, +Z, -Z). Moving the forward THC to the right closes three switch contacts and commands translation along the plus Y axis.

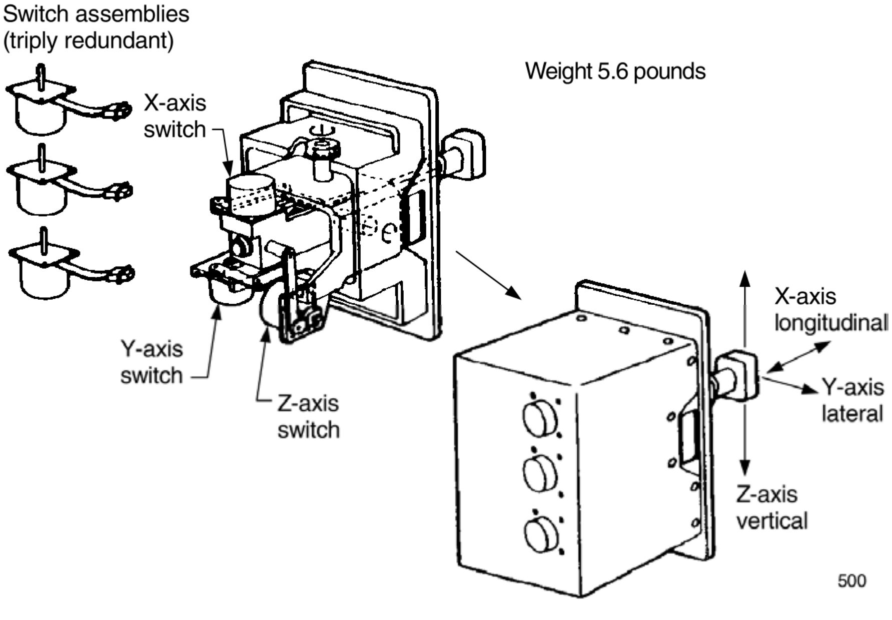
The aft THC is used when the crewmember is looking out the rear or overhead windows. The SENSE switch on panel A6U selects the line-of-sight reference along the -X or -Z axis of the orbiter for the aft THC. The SENSE switch must be in the -X position for aft windows and -Z for the overhead windows for the aft THC commands to be correctly transformed to give the desired orbiter movement.

The THCs are used for manual control of translation along the longitudinal (X), lateral (Y), and vertical (Z) vehicle axes.

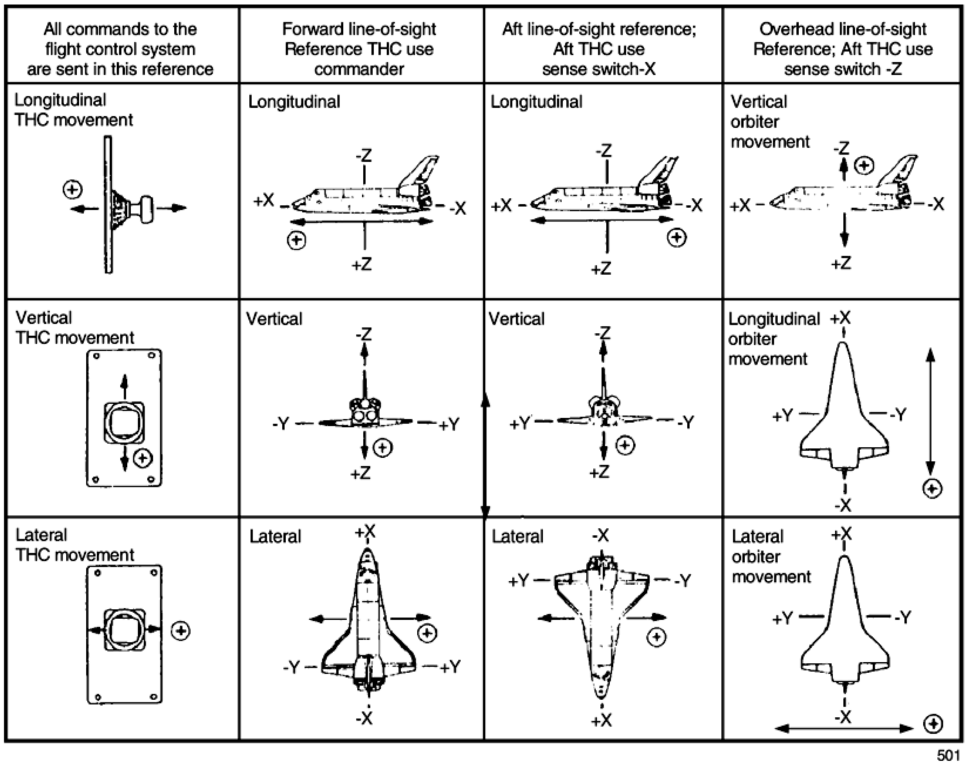
The redundant signals from the forward and aft THC pass through a redundancy management process and SOP before being passed to the flight control system. If the forward and aft THCs generate conflicting translation commands, no output translation command is issued.



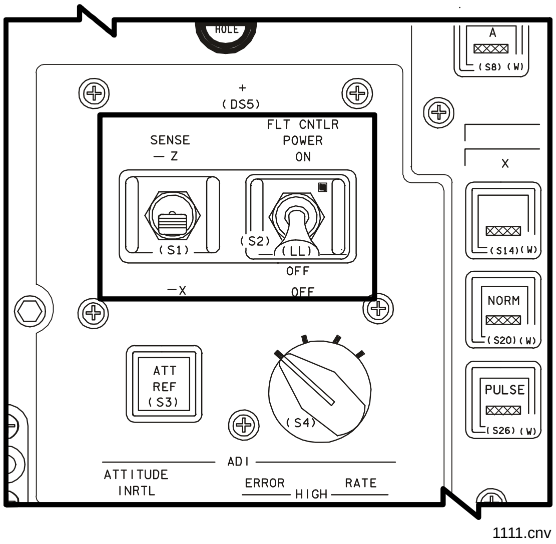
FLT CNTLR POWER Switch on Panel F6



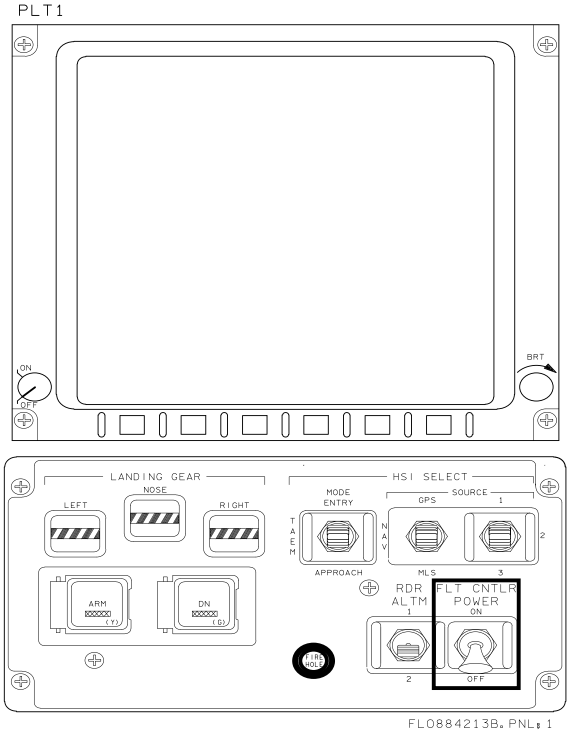
Translational Hand Controller



Positive Deflections of the Translational Hand Controller



FLT CNTRL POWER and SENSE Switches on Panel A6U



FLT CNTRL POWER Switches on Panel F8

THC software redundancy management detects miscompares between the three channels for all six directions of movement. The first miscompare detected deselects only that channel for that direction. A second miscompare between the remaining two channels puts that THC direction in dilemma, so its commands are no longer noted by flight control. For any detected miscompare, caution and warning generates an "SBTC/THC L" or "SBTC THC A" message.

The commander's THC is powered when the FLT CNTLR POWER switch on panel F6 is positioned to ON. The aft THC is powered when the FLT CNTLR POWER switch on panel A6U is positioned to ON.

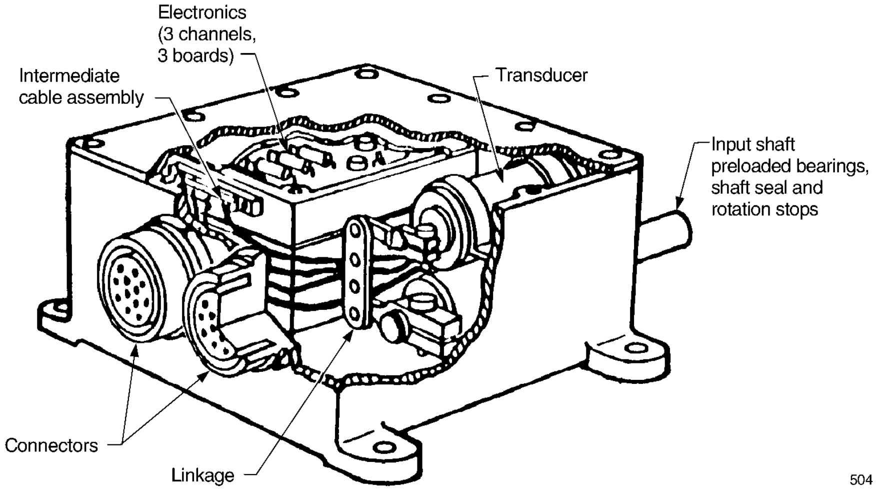
Rudder Pedal Transducer Assembly

There are two pairs of rudder pedals, one pair each for the commander and pilot. The commander's and pilot's rudder pedals are mechanically linked so that movement on one side moves the other side. When depressed, the pedal moves a mechanical input arm in an RPTA. The RPTA contains three transducers, each generating an electrical signal proportional to the rudder pedal deflection.

The rudder pedals command orbiter acceleration in yaw by positioning the rudder during atmospheric flight. However, because the flight control software automatically performs turn coordination during banking maneuvers, the rudder pedals are not operationally used during glided flight. It is not until after touchdown that the crew uses them for nose wheel steering during rollout.

The RPTA SOP maintains many functions in processing the RPTA data. The RPTA SOP converts the selected left and right commands from volts to degrees and selects the larger absolute value of the left and right commands for output to flight control software after applying a deadband. RPTA redundancy management software uses a reasonableness limit check to detect a malfunction among the three channels. When the first malfunction is detected, that channel will be deselected. A second malfunction between the remaining two channels puts the RPTA in dilemma and the RPTA SOP will set that RPTA output to zero. There is no crew insight into RPTA fault detection.

Depressing the upper portion of the rudder pedals provides braking. Differential braking may also be used for directional control during rollout.



Rudder Pedal Transducer Assembly

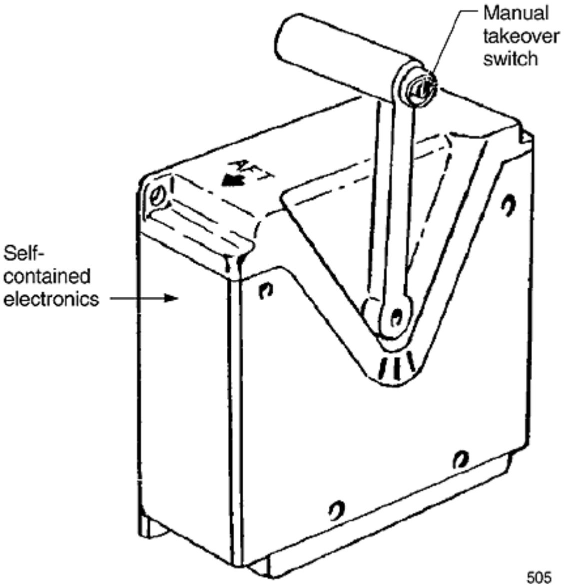
Speed Brake/Thrust Controller

There are two SBTCs, one on the commander's left-hand side on panel L2 and one on the pilot's left-hand side on panel C3. The SBTCs serve two distinct functions. During ascent, the pilot's SBTC may be used to throttle the engines. During entry, either the commander's or pilot's SBTC may be used to control aerodynamic drag (hence airspeed) by opening or closing the speed brake.

At the forward setting, the SSME thrust level is the greatest, or the speed brake is closed. Rotating the SBTC back decreases the SSME thrust level or opens the speed brake.

Each SBTC contains three transducers that produce a voltage proportional to the deflection. Redundancy management uses a mid-value select scheme (MVS) to determine output. It also uses a reasonableness limit check between the channels to detect failures. When the first malfunction is detected, that channel will be deselected. A second malfunction between the remaining two channels puts the SBTC in dilemma and inputs from that SBTC will no longer be accepted. For any detected malfunction, caution and warning generates an "SBTC/THC L" or "SBTC/THC R" message.

In the case of the engine thrust-level setting, the top half (AUTO) of both SPD BK/THROT pushbutton indicators on panels F2 and F4 are illuminated nominally. Only the pilot's SBTC can be enabled for manual throttle control. The pilot depresses the TAKEOVER pushbutton on the SBTC, causing the GPC throttle command to be frozen at its current value. While depressing the TAKEOVER button, the pilot moves the SBTC to match the frozen GPC command. Manual control is established when the SBTC command matches within four percent of the GPC command. When the match is achieved, the pilot's SPD BK/THROT MAN pushbutton indicator on panel F4 is illuminated, and the AUTO light is extinguished on both panels F2 and F4. A manual throttle indicator also appears on the Ascent/Entry Flight Display (AFD).



Speed Brake/Thrust Controller

At this point, the pilot will have manual control of the throttles and the TAKEOVER pushbutton is then released. If the TAKEOVER pushbutton is released before a match is achieved, the system reverts to GPC auto commands. Under manual throttle command, depressing either or both pushbutton indicators on panel F2 and F4 causes the system to revert to the GPC auto commands. Transferring back to auto leaves the throttle at the last-commanded manual setting until a new command is issued.

On entry, if the speed brake mode is in automatic, and the commander or pilot wishes to control the speed brake manually, momentarily depressing the TAKEOVER pushbutton takes manual control of the speed brake. The SPD BK/THROT MAN pushbutton indicator will be illuminated on the side with manual control and the AUTO lights will both be extinguished. A manual speed brake indictor also appears on the AFD. The speed brake is driven to the position currently commanded by the SBTC. To place the speed brake under software control, either or both SPD BK/THROT pushbutton indicators on panels F2 and F4 can be depressed, thus illuminating the AUTO lights on both panels.

The SBTC SOP converts the selected SSME throttle command to a setting in percent and the selected speed brake command from volts to degrees. In addition, the SBTC SOP selects the speed brake command from the SBTC whose TAKEOVER button was depressed last. If both TAKEOVER buttons are depressed simultaneously, the commander's SBTC is given control. If redundancy management declares an SBTC bad, the command is frozen.

The commander's SBTC is powered by the FLT CNTLR POWER switch on panel F7 when positioned to ON. The pilot's SBTC is powered by the FLT CNTLR POWER switch on panel F8.

Body Flap Switches

There are two BODY FLAP switches, one on panel L2 for the commander and one on panel C3 for the pilot. Each switch is lever-locked and spring-loaded to the AUTO/OFF position. The UP and DOWN positions of each switch have two power supplies from separate control buses. In addition, each contact status is sent to the data processing system via an MDM. The switches provide manual control for positioning the body flap for main engine thermal protection and for pitch trim to reduce elevon deflections during the entry phase.

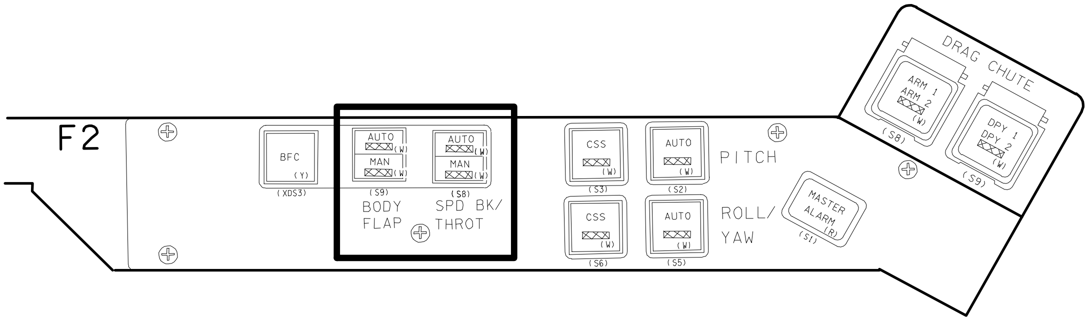
Body flap control is initialized in its automatic mode with both BODY FLAP AUTO pushbutton indicators illuminated on panels F2 and F4. The body flap can be switched to its manual mode by depressing either BODY FLAP pushbutton. The white BODY FLAP MAN pushbutton indicators will then illuminate, indicating manual control of the body flap. To regain automatic control, the BODY FLAP pushbutton indicator on panel F2 or F4 is again depressed, extinguishing the MAN light and illuminating the AUTO light. The pushbutton indicator is triply redundant.

Panel Trim Switches

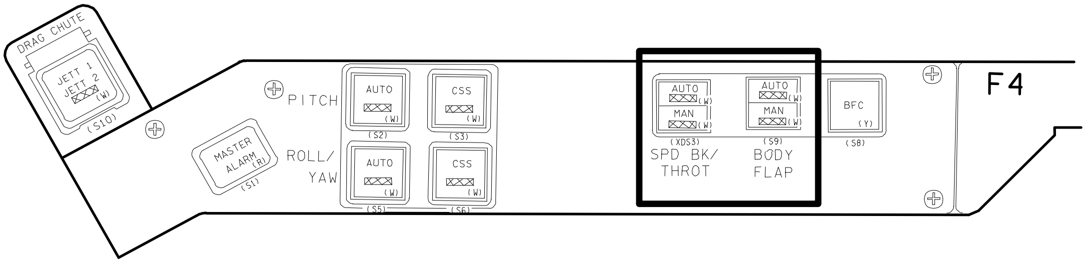
Roll and pitch panel trim switches allow the crew to actually move the aerosurfaces, whereas the yaw panel trim switch inputs an acceleration bias into the yaw channel.

The TRIM PANEL switches on panel F3 enable control bus power to a set of three panel trim switches. The dual-redundant TRIM RHC/PANEL switches on panel F3 provide signals to the GPCs, prohibiting software execution of the associated RHC and panel trim switch inputs while in the INHIBIT position. The ENABLE position permits the RHC and TRIM PANEL switch to be used for trimming.

Six panel switches control roll, pitch, and yaw. The switches, labeled ROLL TRIM, PITCH TRIM, and YAW TRIM, are located on panel L2



BODY FLAP and SPD DK/THROT Pushbuttons on Panel F2



SPD BK/THROT and BODY FLAP Pushbuttons on Panel F4

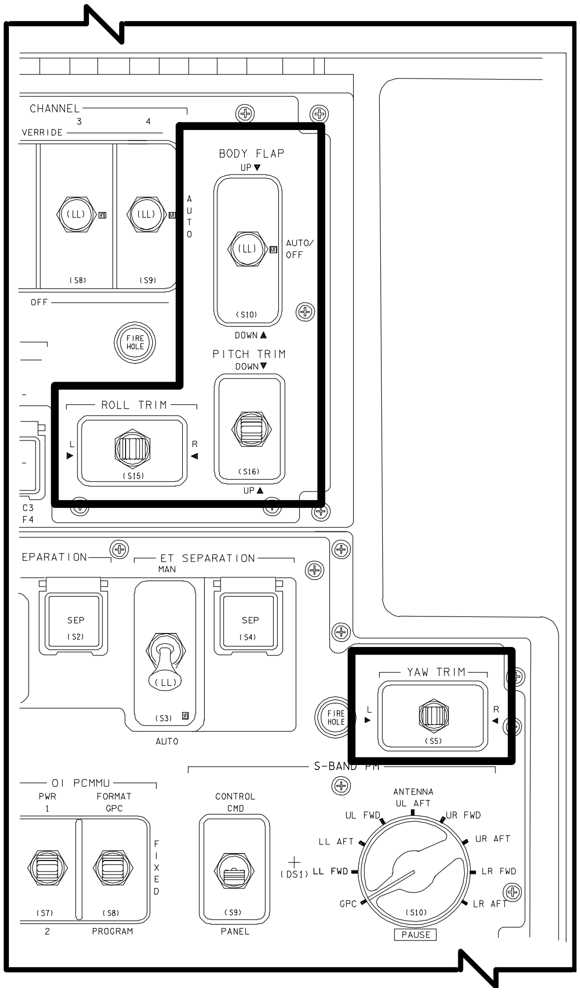
for the commander and panel C3 for the pilot. The commander's trim switches on panel L2 are activated when the TRIM PANEL switch on the left side of panel F3 is positioned to ON. The pilot's trim switches on panel C3 are activated when the TRIM PANEL switch on the right side of panel F3 is positioned to ON. The corresponding TRIM RHC/PANEL switch must be in ENABLE for roll, pitch, and yaw trimming to take place. All the panel trim switches are spring loaded to the OFF position.

RHC Trim Switches

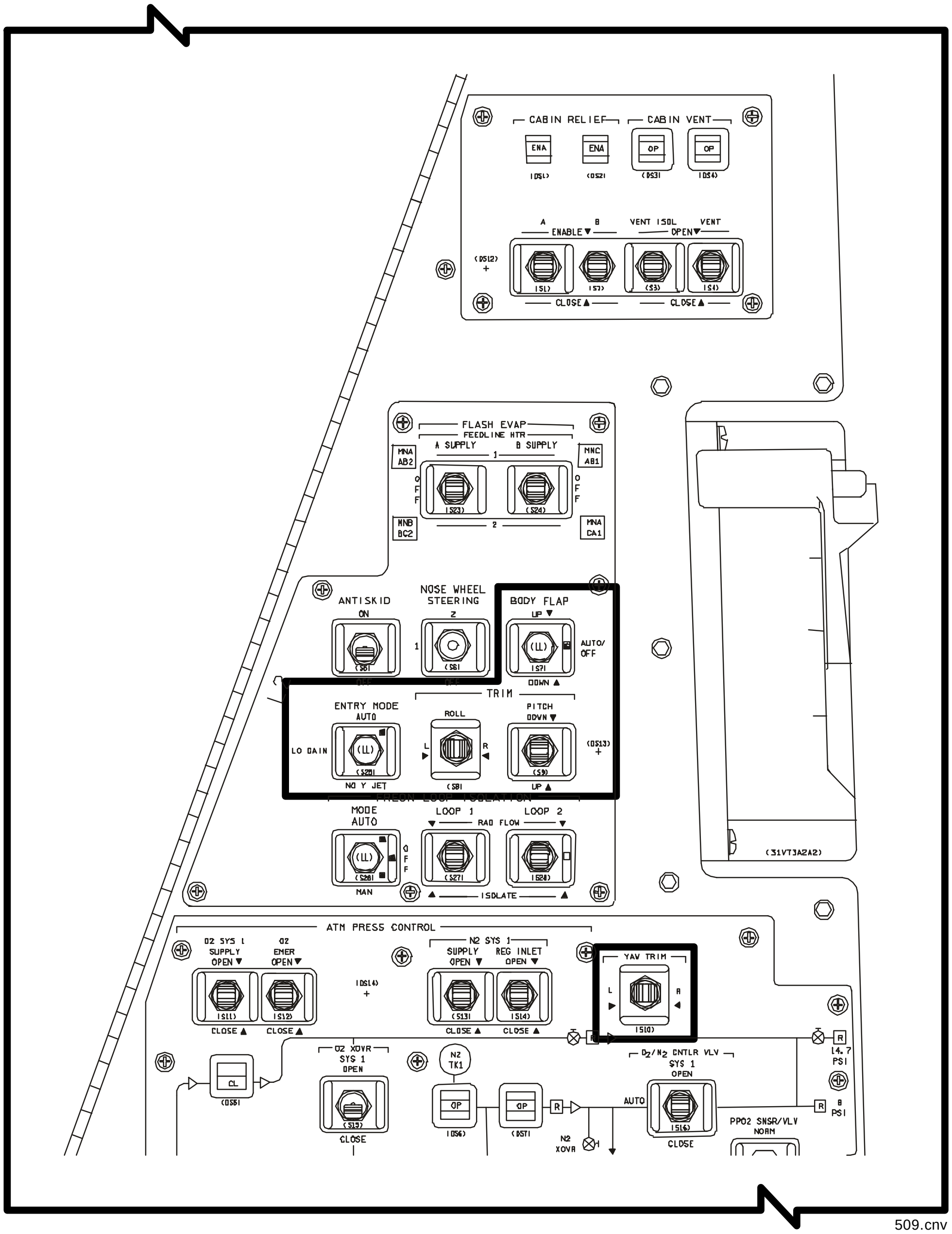
The RHC trim switches bias the rate commands coming from the RHC (up to 1.5 deg/sec in pitch; up to 2.5 deg/sec in roll). The RHC trim is active when the corresponding FLT CNTRL POWER switch on panel F7 or F8 is ON and the corresponding TRIM RHC/PANEL switch on F3 is in ENABLE. Like the panel trim switches, the RHC trim switches are spring loaded to the OFF position.

Trim Switch RM

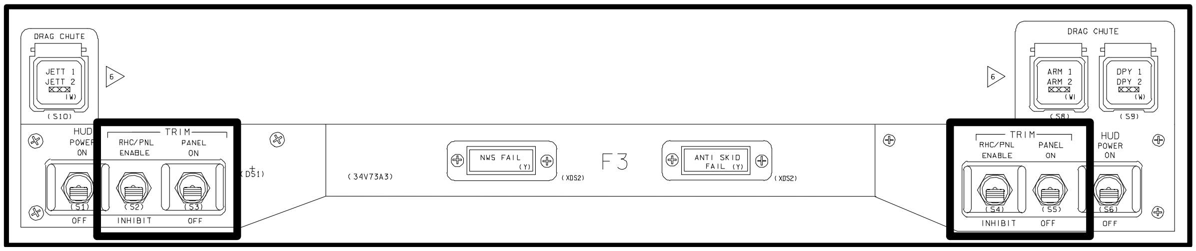
Both the panel trim and the RHC trim switches have two contacts each. In the event of a dilemma as a result of disagreeing contacts, the resultant trim command in that axis is zero.



BODY FLAP and TRIM Switches on Panel C3



BODY FLAP and TRIM Switches on Panel L2



TRIM Switches on Panel F3

Aerosurface Servoamplifiers

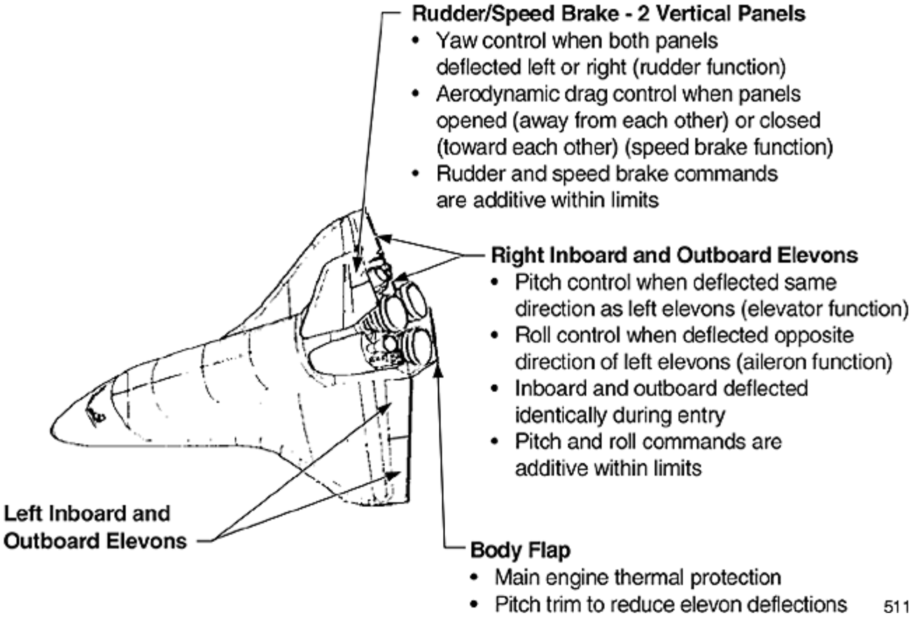
Vehicle control during atmospheric flight is accomplished in the entry phase by deflecting the seven aerosurfaces on the orbiter. Each aerosurface is driven by a hydraulic actuator controlled by a redundant set of electrically driven servovalves. There are four of these valves for each aerosurface actuator (except for the body flap, whose three actuators do not use servovalves and are instead hard-assigned to the three hydraulic systems).

The servovalves are controlled by electronic devices called aerosurface servoamplifiers (ASAs). There are four ASAs located in aft avionics bays 4, 5, and 6. Each ASA commands one valve for each aerosurface. The ASA power switches are *found* on panels O14, O15, and O16.

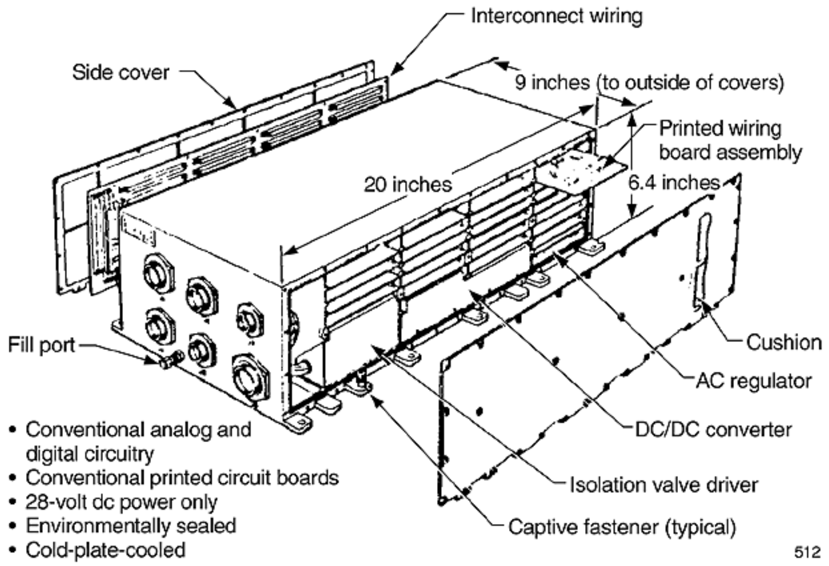
In addition to the command channels from the ASAs to the servovalves, there are data feedback channels to the ASAs from the aerosurface actuators. These feedback channels include position feedback signals and pressure feedback signals. Each aerosurface has four associated position feedback transducers that provide a servoloop closure for each of the four independent servoloops associated with the aerosurfaces.

The path from an ASA to its associated servovalve in the actuators and the path back from the aerosurface feedback transducers to an ASA is called a flight control channel. There are four flight control channels for each aerosurface.

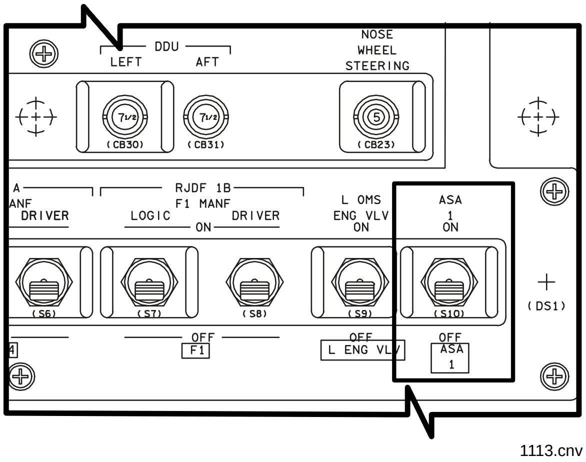
Each of the four elevons located on the trailing edges has an associated servoactuator for positioning. Each servoactuator is supplied with hydraulic pressure from the three orbiter hydraulic systems. A switching valve is used to control the hydraulic system that becomes the source of hydraulic pressure for that servoactuator. The valve allows a primary source of pressure to be supplied to that servoactuator. If the primary hydraulic pressure drops to around 1,200 to 1,500 psia, the switching valve allows the first standby hydraulic pressure to supply that servoactuator. If the first standby hydraulic pressure drops to around 1,200 to 1,500 psia, the secondary standby hydraulic source pressure is supplied to that servoactuator. The yellow HYD PRESS caution and warning light is illuminated on panel F7 if the hydraulic pressure of system 1, 2, or 3 is below 2,400 psia. The red BACKUP C/W ALARM light on panel F7 also illuminates.



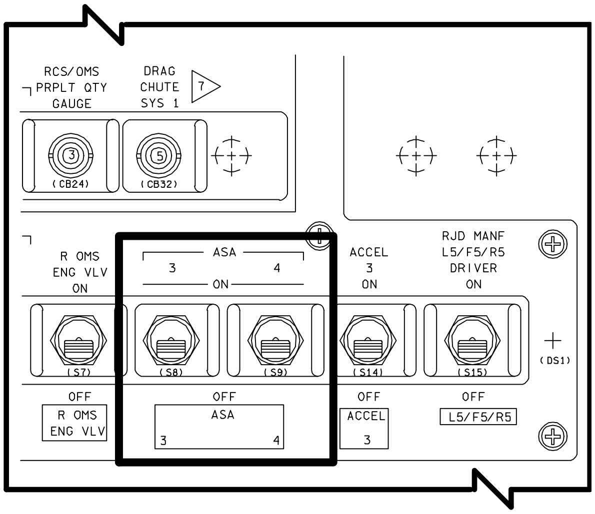
Aerodynamic Surfaces and Associated Control Axes



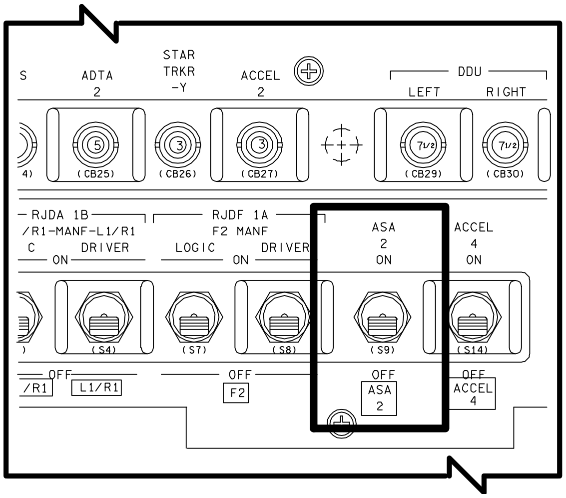
Aerosurface Servoamplifier



ASA 1 Power Switch on Panel O14



ASA 3 and 4 Power Switch on Panel O16



ASA 2 Power Switch on Panel O15

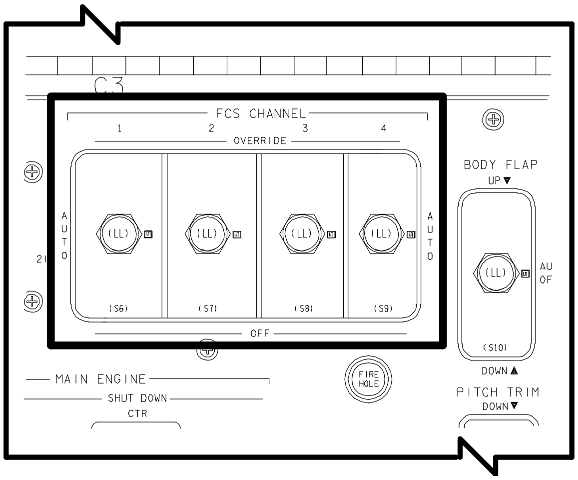
Each elevon servoactuator receives command signals from each of the four ASAs. Each actuator is composed of four two-stage servovalves that drive a modulating piston. Each piston is summed on a common mechanical shaft, referred to as the secondary force-sum actuator. The summed force positions this power spool to control the flow of hydraulic fluid to the actuator power ram, also referred to as the primary actuator. The direction of ram movement is controlled, thus driving the elevon to the desired position. When the desired position is reached, the secondary power spool moves to block the hydraulic pressure to the hydraulically operated ram, thus stopping the ram at that position.

If a problem develops within a servovalve, or it is commanded to a position different than the positions of the other three within an actuator, secondary delta pressure (SEC ΔP), measured for that servovalve off the secondary force-sum actuator, begins to rise. Once the secondary delta pressure is at or above 2,025 psi for more than 120 milliseconds, the corresponding ASA sends an isolation command to bypass that servovalve, effectively removing it from operation.

The FCS CHANNEL yellow caution and warning light on panel F7 is illuminated to inform the flight crew of a bypassed servovalve. Also, an "FCS CH X" caution and warning message is generated, corresponding to which FCS channel (1, 2, 3, or 4) had a bypassed servovalve on one of its actuators. A red FCS SATURATION caution and warning light on panel F7 is illuminated if one of the four elevons is set at more than +12° or less than -15°. This condition also generates an "FCS SAT POS" caution and warning message, informing the crew that elevon movement is becoming saturated. The FCS SATURATION light is also illuminated if any one of the four elevons has a hinge moment greater than 80 percent and an "FCS SAT MOM" message informs the crew that the elevon loading is saturated and flight control is marginal.

There are four FCS CHANNEL switches on panel C3. Each has an OVERRIDE, AUTO, and OFF position. The switch controls the channel's automatic isolation capability for high SEC ΔP for the elevons, rudder, speed brake, and SRB and SSME actuators. When an FCS CHANNEL switch is in AUTO, the isolation capability discussed above can take place. Moving the switch to OVERRIDE and back to AUTO will reset any isolated servovalves on that channel. Leaving the switch in OVERRIDE will prevent the auto isolation due to high SEC ΔP from taking place. When the switch is positioned to OFF, that channel is bypassed on all actuators.

During ascent, the elevons are deflected to reduce wing loads caused by rapid acceleration through the lower atmosphere. In this scheme, the inboard and outboard elevons are deflected separately. By the time the vehicle reaches approximately Mach 2.5, the elevons have reached a null position, where they remain.



FCS CHANNEL Switches on Panel C3

The rudder/speed brake, which consists of upper and lower panels, is located on the trailing edge of the orbiter's vertical stabilizer. One servoactuator positions the panels together to act as a rudder; another opens the panels at the rudder's flared end so it functions as a speed brake.

The rudder and speed brake servoactuators receive four command signals from the four ASAs. Each servoactuator is composed of four two-stage servovalves that function like those of the elevons to drive a secondary force-sum actuator or power spool. The exception is that the rudder's power spool controls the flow of hydraulic fluid to the rudder's three reversible hydraulic motors; the speed brake's power spool controls the flow of hydraulic fluid to the speed brake's three reversible hydraulic motors. Each rudder and speed brake hydraulic motor receives hydraulic pressure from only one of the orbiter's hydraulic systems as determined by switching valves like those of the elevons.

The three rudder hydraulic motors provide output to the rudder differential gearbox, connected to a mixer gearbox that drives rotary shafts. These rotary shafts drive four rotary actuators, which position the rudder panels. The three speed brake hydraulic motors provide power output to the speed brake differential gearbox, connected to the same mixer gearbox as that of the rudder. This gearbox drives rotary shafts, which drive the same four rotary actuators involved with the rudder. Within each of the four rotary actuators, planetary gears blend the rudder positioning with the opening of the speed brake.

If a problem occurs in one of the four rudder or speed brake channels, the corresponding SEC ΔP transducer causes the corresponding ASA to open an isolation valve, bypassing that actuator's servovalve. The FCS CHANNEL switches control the rudder and speed brake channels the same way they control the elevons. If two of the three hydraulic motors fail in the rudder or speed brake, no servovalves are bypassed; however, about half the design speed output results from the corresponding gearbox.

Three servoactuators at the lower aft end of the fuselage are used to position the body flap. Each is separately supplied with hydraulic pressure from one of the three orbiter hydraulic system and has a solenoid-operated enable valve controlled by one of three ASAs. Note that the fourth ASA is not used for the body flap command, but it is still used for position feedback. Each solenoid-operated enable valve supplies hydraulic pressure from one orbiter hydraulic system to two corresponding solenoid-operated up and down pilot valves, which are, in turn, controlled by one of the three ASAs.

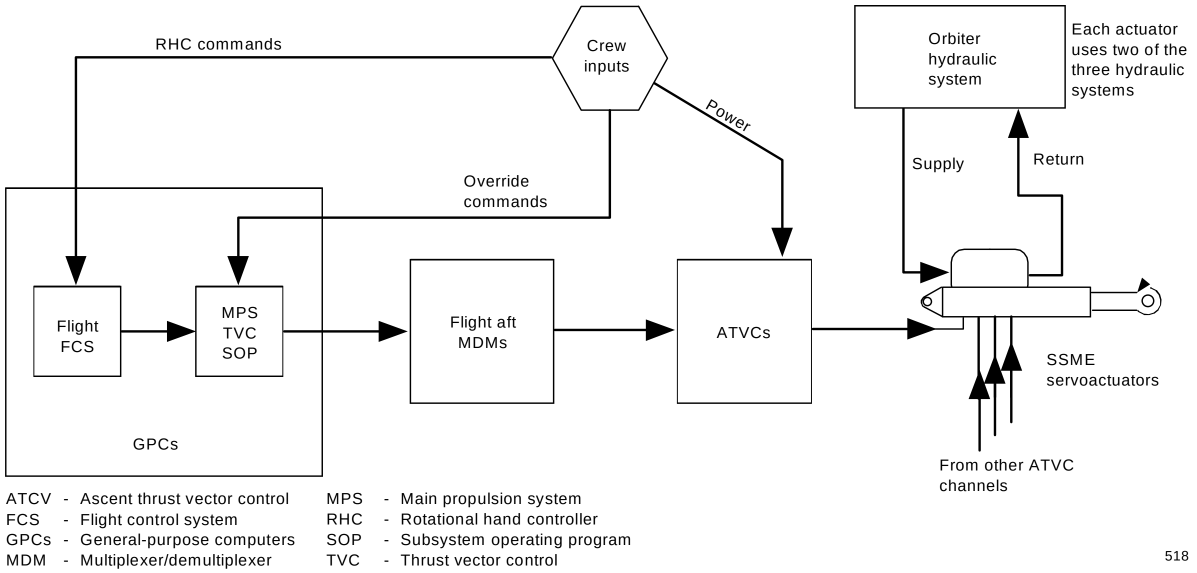
When one of the individual pilot valves receives a command signal from its corresponding ASA, it positions a common mechanical shaft in the control valve, allowing hydraulic pressure to be supplied to the hydraulic motors. The hydraulic motors are reversible, allowing the body flap to be positioned up or down. The hydraulic brake associated with each hydraulic motor releases the hydraulic motor for rotation. When the desired body flap position is reached, the control valves block the hydraulic pressure to the hydraulic motor and apply the hydraulic brake. Each hydraulic motor provides the power output to a differential gearbox, thus driving a rotary shaft and four rotary actuators, which position the body flap. Four rotary position transducers measure the output of the differential gearbox to provide position feedback through all four ASAs to the flight control system software.

There is no channel isolation capability for the body flap. With the FCS CHANNEL switch in OFF, the corresponding ASA's body flap commands are removed from the solenoid valves. If the hydraulic system associated with the hydraulic motor fails, the remaining two hydraulic motors position the body flap, and the HYD PRESS caution and warning light is illuminated.

Each ASA is hardwired to a flight aft MDM. Commands originate from guidance software or from controllers. These inputs go to the flight control software, where they are routed to the ASAs. Several SOP functions associated with the ASA commands and data include:

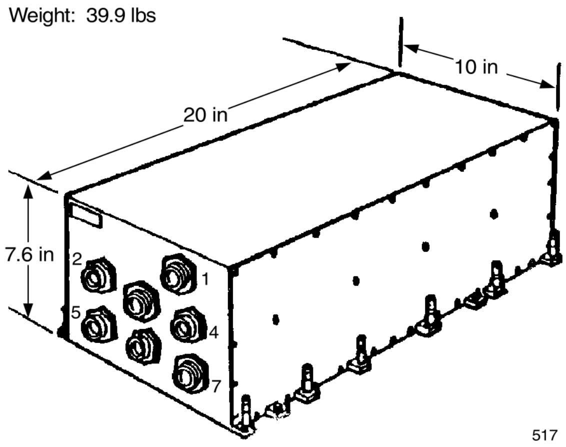
- Converts elevon, rudder, and speed brake commands produced by flight control software from degrees to millivolts
- Sets commands to body flap valves based on an enable command from body flap redundancy management and up/down commands from flight control
- Converts position feedback to degrees for the elevons, rudder, speed brake, and body flap
- Computes body flap and speed brake deflections as percentages
- Calculates elevon and rudder positions for display on the surface position indicator
- Monitors the FCS CHANNEL switches and, if any are positioned to OVERRIDE, sets the override command for that ASA
- Monitors hydraulic system pressures for failures and limits aileron and elevator commands according to the number of failures

Isolation status of the FCS CHANNEL servovalves is displayed on the GNC SYS SUMM 1 display under FCS CH for all actuators, and on the SPEC 53 CONTROLS display in more detail for each aerosurface and SSME actuator.



SSME Thrust Vector Control Interface Flow

Ascent Thrust Vector Control



Ascent Thrust Vector Controller

The orbiter ATVC portion of the FCS controls attitude and trajectory directing the thrust of the three main engines and two solid rocket boosters during lift-off and first-stage ascent, and of the main engines only during second-stage ascent.

ATVC is provided by four avionics hardware packages that supply gimbal commands and fault detection for each hydraulic gimbal actuator. The packages are located in the three aft avionics bays in the orbiter aft fuselage and are cooled by cold plates and the Freon system. The associated flight aft MDMs are also located in the aft avionics bays.

The ATVC command flow starts in the GPCs, in which the flight control system generates the position commands, and terminates at the SSME and SRB servoactuators, where the actuators gimbal the nozzles in response to the commands. All the position commands are issued to the ATVC command SOP. This program processes and transmits the commands to their corresponding flight aft MDMs. The commands are then separated and distributed to the four ATVC channels, which generate equivalent command analog voltages for each command issued. These voltages are, in turn, sent to one of four servovalves on a servoactuator, commanding the SSME and SRB hydraulic actuators to extend or retract, thus gimbaling the nozzles to which they are fastened.

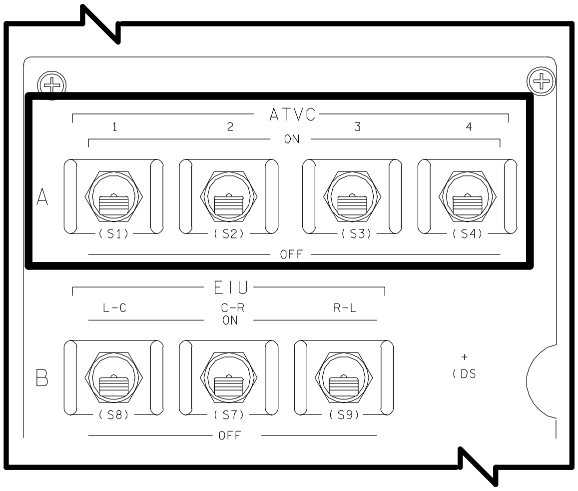
Ten actuators respond to the command voltages issued by four ascent thrust vector control channels. Each FCS channel contains an ATVC that has six SSME drivers and four SRB drivers. Each actuator receives four identical command voltages from four different drivers, each located in one of the four ATVCs.

Both main engine and solid rocket booster servoactuators consist of four independent, two-stage servovalves that receive signals from the drivers. The force of these four servovalves is summed on a secondary force-sum actuator or power spool, which positions an actuator ram and thus the engine to control thrust direction.

The four servovalves in each actuator provide a force-summed majority voting arrangement to position the power spool. With four identical commands to the four servovalves, the actuator's force-sum action prevents a single erroneous command from affecting power ram motion. If the erroneous command persists for more than a predetermined time, differential pressure measured off of the secondary force-sum actuator for that servovalve is sensed in the corresponding ATVC, which activates an isolation driver. This driver energizes an isolation valve that isolates the defective servovalve and removes hydraulic pressure, permitting the remaining channels and servovalves to control the actuator ram spool, provided the FCS CHANNEL 1, 2, 3, or 4 switch on panel C3 is in the AUTO position. A second failure would isolate the defective servovalve and remove hydraulic pressure in the same manner as the first failure, leaving only two channels remaining.

Failure monitors are provided for each channel on the GNC SYS SUMM 1 display and with the yellow FCS CHANNEL and red BACKUP C/W ALARM lights on panel F7 to indicate which channel has a bypassed servovalve for any of the MPS and/or solid rocket boosters. There is more detailed crew information on precisely which MPS actuator has a bypassed servovalve on the SPEC 53 CONTROLS display. If the FCS CHANNEL 1, 2, 3, or 4 switch on panel C3 is positioned to OFF, then that ATVC channel is isolated from its servovalves on all SSME and solid rocket booster actuators. The OVERRIDE position of the switch inhibits the corresponding ATVC from automatically bypassing servovalves on that channel due to high secondary delta pressure problems on the power spool and provides the capability to reset a bypassed servovalve on that channel.

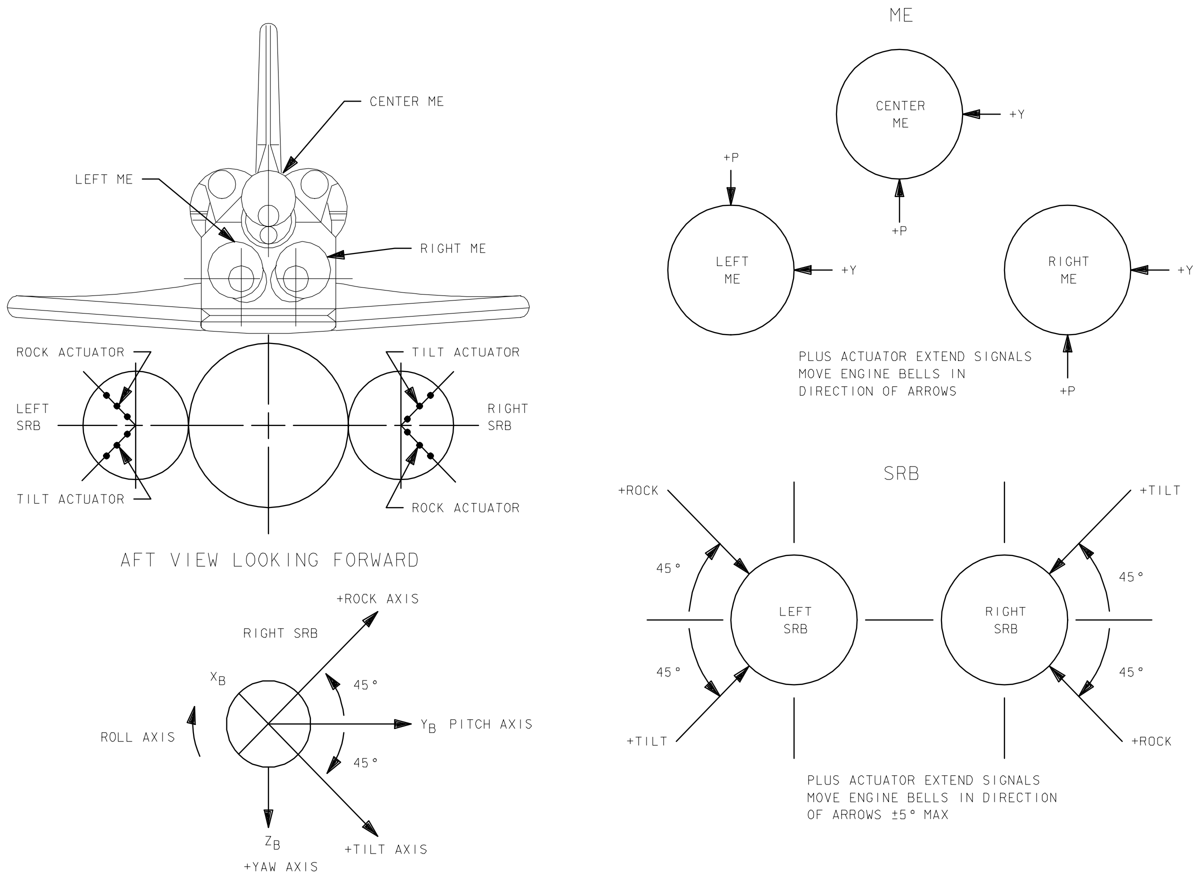
The ATVC 1, 2, 3, 4 power switches are located on panel O17. The ON position enables the ATVC channel selected; OFF disables the channel.



ATVC Power Switches on Panel O17

The SSME servoactuators change each main engine's thrust vector direction as needed during the flight sequence. Each main engine has one pitch actuator and one yaw actuator. The pitch actuator gimbals the engine up or down a maximum of 10.5° from the installed null position. The yaw actuator gimbals the engine left or right a maximum of 8.5° from the installed position. The installed null position for the left and right main engines is 10° up from the X axis and 3.5° outboard from an engine centerline parallel to the X axis. The center engine's installed null position is 16° above the X axis centerline for pitch and on the X axis centerline for yaw. When any engine is installed in the null position, the other engines cannot collide with it.

Each SRB also has two thrust vector control actuators. However, the SRB TVC coordinate axes are called "rock" and "tilt" rather than pitch and yaw. The rock and tilt axes form a 45° angle with the pitch and yaw axes. This allows an equivalent ±7° movement range in pitch and yaw with a rock/tilt gimbal range of ±5°.



SSME and SRB Thrust Vector Control

Digital Autopilot

The digital autopilot (DAP) is the heart of flight control software. It is composed of several software modules that interpret maneuver requests, compare them to what the vehicle is doing, and generate commands for the appropriate effectors. There are different DAPs for different flight phases, particularly insertion and orbit, and various modes and submodes within each.

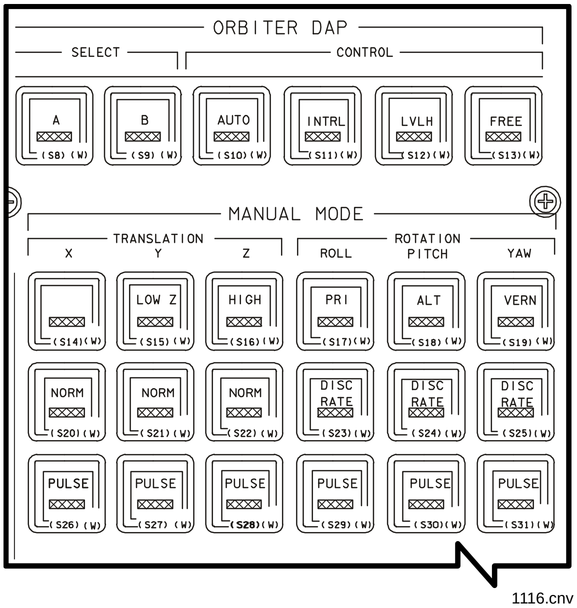
The DAP controls the orbiter in response to automatic or manual commands during insertion and on orbit. The effectors used to produce control forces and moments on the orbiter are the two OMS engines and the 38 primary RCS jets. Six vernier RCS jets are also available on orbit for attitude control. The forward and aft RCS jets also provide attitude control and three-axis translation during external tank separation, insertion, and on-orbit maneuvers, as well as roll control for a single-OMS-engine operation.

The OMS provides propulsive control for orbit insertion, orbit circularization, orbit transfer, and rendezvous.

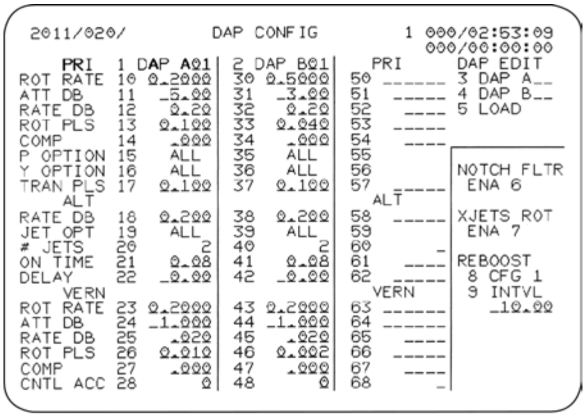
Orbital DAP Panel

There are 24 ORBITAL DAP pushbutton indicators on panels C3 and A6U. Assuming no electrical, computer, or hardware failures affect the operation of the indicators, inputs made to one panel are reflected in the configuration of the other panel. All the pushbuttons are active in the Orbital DAP, whereas only a subset are operational in the Transition DAP or when the backup flight system is engaged. None of the indicators are operational during ascent or entry. As with other aft flight-deck controls, aft panel A6U pushbutton indicators (PBIs) are only supported in OPS 2.

A discussion of the various pushbuttons follows:



ORBITAL DAP Pushbuttons on Panel C3 (Panel A6U identical)



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                                         000/00:00:00
    PRI    1 DAP A01 | 2 DAP B01 |    PRI      DAP EDIT
ROT RATE  10 0.2000  | 30 0.5000 | 50 ______  3 DAP A__
ATT DB    11  _5.00  | 31  _3.00 | 51  _____  4 DAP B__
RATE DB   12   0.20  | 32   0.20 | 52   ____  5 LOAD
ROT PLS   13  0.100  | 33  0.040 | 53  _____
COMP      14   .000  | 34   .000 | 54   ____ ___________
P OPTION  15    ALL  | 35    ALL | 55       |
Y OPTION  16    ALL  | 36    ALL | 56       | NOTCH FLTR
TRAN PLS  17  0.100  | 37  0.100 | 57  _____|  ENA 6
    ALT                          |    ALT   |
RATE DB   18  0.200  | 38  0.200 | 58  _____| XJETS ROT
JET OPT   19    ALL  | 39    ALL | 59       |  ENA 7
# JETS    20      2  | 40      2 | 60      _|
ON TIME   21   0.08  | 41   0.08 | 61   ____| REBOOST
DELAY     22  _0.00  | 42  _0.00 | 62  _____|  8 CFG 1
    VERN                         |    VERN  |  9 INTVL
ROT RATE  23 0.2000  | 43 0.2000 | 63 ______|    _10.00
ATT DB    24 _1.000  | 44 _1.000 | 64 ______|
RATE DB   25   .020  | 45   .020 | 65   ____|
ROT PLS   26  0.010  | 46  0.002 | 66  _____|
COMP      27   .000  | 47   .000 | 67   ____|
CNTL ACC  28      0  | 48      0 | 68      _|
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DAP CONFIG Display (SPEC 20)

The SELECT (A or B) PBIs toggle the Orbital DAP between one of two configurations. These configurations are changed and displayed on the DAP CONFIG display (SPEC 20).

The CONTROL PBIs toggle the Orbital DAP between AUTO, INRTL, LVLH, and FREE. In AUTO the orbiter's attitude is controlled by universal pointing (UNIV PTG) or orbit burn guidance. In this control mode, the Orbital DAP will rotate the orbiter about the shortest angle to the desired attitude. The rate of rotation is determined by ROT RATE items on the DAP CONFIG (SPEC 20) display. Once in attitude, the Orbital DAP will fire jets to maintain the attitude and attitude rates within the deadbands specified on the DAP CONFIG display.

In CONTROL INRTL, the orbiter is in inertial attitude hold (a fixed orbiter attitude relative to an inertial reference), and in CONTROL LVLH the orbiter is in LVLH hold (a fixed orbiter attitude relative to the Earth). The ROTATION DISC RATE pushbutton indicators must be illuminated for INRTL or LVLH to hold attitude.

The CONTROL FREE PBI puts the Orbital DAP into free drift. In this mode, the ROTATION PULSE pushbutton indicators will illuminate, and RCS jets will not fire if the RHC and THC remain in detent.

The first row of the MANUAL MODE TRANSLATION pushbuttons control which of the +Z (up firing) jets will fire. Nominally, none of the pushbutton indicators are illuminated, and the "normal" number of up firing jets will be commanded to fire. If the LOW Z pushbutton indicator is depressed, Orbital DAP will never command an up firing jet to fire. This mode is used to protect a payload or crewmember that is operating close to the orbiter.

In HIGH Z, all the up firing jets will be commanded to fire if a +Z translation is commanded with the THC. All other Orbital DAP maneuvers will result in the "normal" number of up firing jets to fire. This mode is used to quickly separate the orbiter from a payload.

The second and third rows of MANUAL MODE TRANSLATION pushbuttons toggle the Orbtial DAP between NORM and PULSE. In NORM, RCS jets will be continuously commanded to fire if the THC is moved out of detent. In PULSE, Orbital DAP will fire RCS jets to achieve the TRANSLATION PULSE rate specified on the DAP CONFIG display. The PULSE units are feet per second.

The first row of the MANUAL MODE ROTATION portion of the DAP panel toggles the Orbital DAP between primary (PRI), alternate (ALT), and vernier (VERN). In PRI, one or more of the primary RCS jets will be continuously commanded to fire if either the attitude or attitude rate deadbands are exceeded. This mode will not be used for many different RMS and payload operations.

In ALT, the primary RCS jets are still used, but the number of jets, duration of firings, and time between firings can be controlled on the DAP CONFIG display. This extra control of jet firings greatly reduces the stress on a payload and the RMS. The ALT mode allows almost unrestricted payload and RMS operations if the vernier jets are not available. In ALT mode, the Orbital DAP also determines the best jet(s) to fire based on the combined orbiter/payload moments of inertias. These inertias are selected with CNTL ACCEL (item 14) on the DAP CONFIG display.

In VERN, the Orbital DAP uses the six vernier RCS jets for attitude control. Vernier control produces less stress on the RMS/payload, uses less propellant, and can achieve tighter deadbands than either PRI or ALT. Like the ALT mode, the best jet(s) to use are determined by the orbiter/payload moments of inertias.

The second and third rows of the ROTATION pushbutton indicators toggle the Orbital DAP between discrete rate (DISC RATE) and PULSE. For these rows to have any effect, the ORBITAL DAP CONTROL must not be in AUTO. In DISC RATE, if the RHC is taken out of detent, the Orbital DAP will fire RCS jets to achieve and maintain the rate specified by the ROT RATE in the DAP CONFIG display. If the RHC is in detent, the Orbital DAP will fire jets to maintain either INRTL or LVLH attitude hold, depending on the selection of the ORBITAL DAP CONTROL pushbutton indicators.

In ROTATION PULSE, moving the RHC out of detent commands a pulse of jet firings to increase the rotation rate by the ROT PLS rate specified on the DAP CONFIG display. When the RHC is in detent, the Orbital DAP is in free drift for that axis. Pushing the CONTROL FREE pushbutton indicator is functionally equivalent to pushing all three ROTATION PULSE pushbutton indicators.

Continuous rotation RCS jet firings can be obtained by moving the RHC past the soft stop. This continuous firing of jets can be obtained in either DISC RATE or PULSE. Even if CONTROL is in AUTO, moving the RHC out of detent will force the Orbital DAP to INRTL, and further movement past the soft stop will cause continuous jet firings.

Transition DAP

The Transition DAP is used from MECO until transition to OPS 2, and then again in MM 301-303.

At MECO, the Transition DAP first becomes active, firing RCS as needed to null out any residual rates. External tank separation is automatically commanded about 20 seconds after MECO. Here, the Transition DAP sends commands to fire the orbiter's down firing RCS jets, causing the orbiter to translate in the -Z direction. When a rate of 4 feet per second is reached, RCS commands are removed.

Insertion flight control is also accomplished with the Transition DAP. The Transition DAP uses commands from the guidance software for automatic maneuvers to the OMS burn attitude using RCS jets. During the OMS-2 burn (and OMS-1 burn, if required), the Transition DAP uses the OMS engines thrust vector control and RCS jets, as needed. The Transition DAP also receives commands from the commander's THC and the commander's or pilot's RHC. The Transition DAP then takes these commands and converts them into appropriate RCS or OMS TVC commands. The Transition DAP monitors the resultant attitude and attitude rates and sends the necessary commands to achieve the desired attitude and attitude rate within premission-specified deadbands.

The flight crew interfaces directly with the Transition DAP through the forward RHCs and THC and indirectly through entries to the OMS MNVR EXEC display and the ORBITAL DAP pushbuttons on panel C3.

In the Transition DAP, the commander's THC is active and totally independent of the DAP pushbuttons or RHC position or status. Whenever the commander's THC is out of detent in either plus or minus X, Y, or Z, translation acceleration commands are sent directly to the RCS jet selection logic for continuous RCS jet firing. Rotational commands may be sent simultaneously with translation commands within the limits of the RCS jet selection logic. For example, if both plus X and minus Z translations are commanded simultaneously, plus X translation receives priority.

For rotations, the flight crew can select either automatic or manual control via the ORBITAL DAP CONTROL pushbutton indicators (AUTO, INRTL) or manual control by moving the RHC out of detent. In INRTL, the capability exists to rotate about any axis in one of two modes. When the ROTATION PULSE mode is selected, each RHC deflection results in a single burst of jet fire. In DISC RATE mode, RHC deflection results in a specified rate being commanded in that axis for the entire time the RHC is deflected. A free-drift mode (INRTL/PULSE) is also available in which no RCS jets are fired, or an attitude-hold mode, in which the Transition DAP sends commands to maintain the current attitude with null rates within premission-specified deadbands. Also, if the RHC is deflected beyond the soft stop, continuous RCS jet firings result. In translation, movement of the THC results in continuous jet firings. Pulse translation mode is not available in the Transition DAP.

The Transition DAP also involves maintaining the OMS thrust vector control. The OMS processor generates OMS engine gimbal actuator thrust vector control commands to produce the desired spacecraft/engine relationship for the specified thrust direction.

For the OMS burn, the orbital state vector (position and velocity) is produced by navigation using inertial measurement unit delta velocities during powered and coasting flight. This state is sent to guidance, which uses target inputs through the IDP to compute thrust direction commands for flight control and burn parameters for DPS display. Flight control converts the commands into OMS engine gimbal angles (thrust vector control) for the OMS burn.

OMS thrust vector control for a normal two-engine burn is entered by depressing the ORBITAL DAP CONTROL AUTO pushbutton indicator with both RHCs within software detents. OMS manual thrust vector control for both OMS engines is entered by depressing the INRTL pushbutton indicator or by moving the commander's or pilot's RHC out of detent. The flight crew supplies the rate commands to the burn vector control system instead of guidance. The manual RHC rotation requests are proportional to RHC deflections and are converted into gimbal angles. OMS thrust in either case is applied through the spacecraft's center of gravity.

Orbital DAP

The orbital flight control software includes an RCS DAP, an OMS TVC DAP, and an attitude processor module to calculate vehicle attitude, as well as logic to govern the selection of a DAP. The attitudes calculated by the attitude processor are displayed on the attitude director indicator, as well as on the OPS 201 UNIV PTG display, which is available whenever orbit software is active. The vehicle attitude is used by the DAP to determine attitude and rate errors.

RCS DAP

The RCS DAP is used at all times in the on-orbit phase except during an OMS burn. This DAP controls vehicle attitudes and rates through RCS jet fire commands. Either the larger primary jets or the less powerful vernier jets can be used for rotational maneuvers, depending on whether PRI, ALT, or VERN is selected on the panel C3 (or A6U) ORBITAL DAP CONTROL panel. The choice of primary or vernier thrusters depends on fuel consumption considerations, how quickly the vehicle needs to be maneuvered to satisfy a mission objective, and interaction with payloads. ALT mode uses primary jets with fewer jet firings of a small duration and selectable delay between firings to allow attitude control when vernier jet capability is lost.

The rotation rates and deadbands, translation rate, and additional DAP options can be changed by the flight crew during the orbit phase using the DAP CONFIG display. The flight crew loads the DAP with these options in two ways, one option set is accessed by depressing the A pushbutton on the ORBITAL

DAP SELECT panel and the other by depressing the B pushbutton.

Each planned DAP configuration is given a reference number. In general, the A configurations have larger deadbands and slower maneuvering rates than the B configurations. The wider deadbands of the A configurations are used to minimize fuel usage, while the tighter deadbands of the B configurations allow greater precision in executing maneuvers or holding attitude.

The RCS DAP operates in either AUTO or in one of two manual modes (INRTL or LVLH), depending on selections made on the ORBITAL DAP CONTROL panel. The INRTL mode is also accessed when the RHC is moved out of its detent position (i.e., "hot stick downmode"). In both the automatic and manual modes, the rotation rate is controlled by the selection of DAP A or B and the information loaded in the DAP CONFIG display. In addition, in automatic, the DAP determines the required attitude to be achieved from the UNIV PTG display and then computes the RCS jet-fire commands necessary to achieve these requirements within the current set of deadbands.

In the manual rotation mode, the RCS DAP converts flight crew inputs from any of the three RHCs to RCS jet-fire commands, depending on whether PULSE or DISC RATE is selected on the MANUAL MODE ROTATION ROLL, PITCH, and YAW pushbuttons on panel C3 or A6. Simply, when PULSE is selected, a single burst of jet fire is produced with each RHC deflection. The desired rotational rate is specified on the DAP CONFIG display (ROTATION). When DISC RATE is selected, jet firings occur whenever the RHC is out of detent, but inside the soft stop, thus maintaining the rotational rate specified on the DAP CONFIG display. When the RHC is beyond the soft stop, continuous jet firings will result. When the RHC is returned to detent, the current M50 attitude will be maintained within the specified deadbands.

Another manual RCS DAP mode, local vertical/local horizontal (LVLH), is used to maintain the current attitude with respect to the rotating LVLH reference frame. It is selected through the LVLH pushbutton on panel C3 or A6U.

The RCS DAP includes only a manual translation capability, executed through the forward or aft THC. Only the primary RCS jets are used. If in VERN, DAP will automatically upmode to primary RCS (PRCS) when the THC is moved out of detent. The DAP will return to VERN or ALT when the desired rate is achieved or the THC is returned to detent. Deflections of the THC result in RCS jet firings based on the MANUAL MODE TRANSLATION pushbutton indicator selected on the ORBITAL DAP panel. PULSE mode results in a single burst of jet fire. NORM mode results in continuous jet firings as long as the THC is out of detent.

Two additional submodes, HIGH Z and LOW Z, are available for special applications of +Z translations. NORM will fire three up-firing jets when a +Z translation is commanded and is the default. HIGH Z will fire all nine up-firing jets and would be used only for emergency escape from the vicinity of another orbiting body. LOW Z fires two aft-firing and two forward-firing jets for +Z maneuvers. LOW Z is used to maneuver near payloads that can be contaminated or damaged by the plume from an up-firing jet. Selection of NORM, HIGH Z, or LOW Z has no effect on choice of jets for ±X, ±Y, or -Z translations. LOW Z will inhibit upfiring jets for rotations.

OMS TVC DAP

The OMS thrust vector control DAP is available when an OMS burn is executed through the ORBIT MNVR EXEC display. The TVC DAP uses the guidance-generated velocity requirements and converts these into the appropriate OMS gimbal commands, assuming AUTO is selected on the ORBITAL DAP CONTROL panel. The TVC DAP also generates the OMS fire commands, the OMS shutdown commands, and, if necessary, due to OMS engine failure, the required RCS commands to maintain attitude control. Under INRTL selection, the TVC DAP takes inputs from the RHC to control attitude during the burn. When the RHC is in detent, the TVC DAP will maintain the current inertial attitude.

Before OMS ignition, the orbiter is automatically or manually maneuvered to the OMS ignition attitude using the RCS jets. Automatic TVC for one OMS engine is identical for two, except that the RCS processor is responsible for roll control. Single-OMS-engine burn is also through the orbiter's center of gravity, except when pitch or yaw rate commands are non-zero. If the left or right OMS engine fails during a burn, a red LEFT or RIGHT OMS light on panel F7 is illuminated. Since an OMS cutoff is based on time rather than velocity, a velocity residual may exist following the cutoff. The residual can be reduced to zero by the RCS through the THC.

Aerojet DAP

Entry flight control is accomplished using the Aerojet DAP, which generates effector and RCS jet commands to control and stabilize the vehicle during its descent from orbit. During exoatmospheric flight, or flight during which certain aerosurfaces are rendered inefficient due to adverse aerodynamics, a combination of aerosurface and RCS jet commands are used.

The Aerojet DAP has the following characteristics:

(1) Flight adaptive (changes as a function of qbar)

(2) Closed loop (compares feedback with command to generate an error signal)

(3) Rate command (jets and aerosurfaces are commanded as necessary to achieve the desired rate)

Once the desired rate is obtained, forward loop trim integrators maintain the desired rate. The Aerojet DAP is activated by MM 304 transition, usually at EI-5, and runs through wheel stop on the runway. It slowly blends out the use of jets and blends in the use of aerosurfaces as the orbiter makes the transition from a spacecraft to hypersonic glider to subsonic glider to finally a high-speed 100-ton tricycle.

Pitch control is driven by either the auto system via alpha error (MM 304/602) or N_Z error (MM 305/603), which is turned into a rate command, or by CSS via RHC input. This rate command is compared to the pitch RGA output to come up with a rate error that is turned into a jet command until qbar = 40 psf, and/or elevator command after qbar = 2 psf. The body flap is used as a trim device to keep the elevons on or near schedule. This allows the elevons to be in the right position for maximum effectiveness, and to limit hinge moments and thermal effects. The speed brake is opened at V_{REL} = 10,000 fps and is used supersonic as a lateral-directional stability device (speed brake opens causing a pitch-up moment that the elevons counteract by moving down, making the elevons more effective as an elevator and as ailerons). Subsonic, the speed brake is used first as an energy modulator, then as a qbar modulator below 9,000 ft.

Other features of the pitch channel include:

- Pitch panel trim moves the elevons up or down. It requires trim be enabled and on, and either the CDR or PLT use the TRIM switches on panel L2 or C3. There is no current use for this feature, especially with the body flap in AUTO.

- RHC pitch rate trim biases the output of the RHC by inputting a rate command. It requires trim to be enabled and flight controller power on, and the CDR or PLT to use the "beep trim" switch on their RHC. Any input by the RHC rate trim will be zeroed if the pitch axis is returned to AUTO. This switch is used to perform the beep trim derotation during landing rollout.

- Nose-up turn compensation provides a pitch rate as a function of steady state turn yaw rate and bank angle during bank maneuvers in MM 305. This provides a constant flight path angle without the crew having to make a pitch adjustment during turns.

- At nose gear touchdown, the pitch axis will mode to AUTO and auto-load relief will move the elevons down to off-load the main gear. (This is the only entry phase auto flight control feature in the BFS.)

Because of the very high angles of attack (α) that the orbiter flies, there is a large difference in the velocity vector and the body X axis. For conventional airplanes that fly at small α, a body axis roll is very close to a velocity vector bank. (Bank refers to a rotation about the velocity vector, or a stability axis rotation. Roll refers to a rotation about the X axis or a body axis rotation.) But at an α of 90°, a velocity vector bank is a body axis yaw. Therefore, at α=40° (the orbiter's angle of attack from MM 304 transition to V_{REL} = 10,500 fps), a velocity vector bank requires a combination of a body axis roll and body axis yaw.

Another very important feature of the orbiter during early entry (V_{REL} > 4,000 fps) is that the vehicle rolls and yaws due to sideslip (β). Beta can be generated by either yaw jets or the adverse yaw caused by aileron displacement. (Adverse yaw means instead of rolling because of the increased lift caused by moving an aileron down, the vehicle will yaw because of the increased drag caused by moving an aileron down. This yaw produces β.) Therefore, adverse yaw is purposely used during early entry to start a bank by using "reverse aileron" (right aileron down when initiating a bank to the right) along with yaw jets to develop a β to get the vehicle banking. One of the two purposes of a gain called GALR is to determine whether the first output from the roll channel is reverse or proverse aileron, and how big the output should be. (Basically, no initial aileron is used until qbar=10 psf, reverse aileron is used from qbar=10 psf until approximately V_{REL} = 3,800 fps, and steadily increasing proverse aileron from V_{REL} = 3,800 fps.) However, once a β has been induced, it must be controlled. More precisely, the change in β must be made zero when the desired bank rate is achieved. Proverse aileron, used in the proper relationship to compensated body axis yaw and α, is introduced after the bank has been started to control β and maintain the bank rate. This is called "beta dot damping", and GALR controls how much aileron is used for damping and when it is terminated. Beta damping is used from qbar=2 psf until V_{REL} = 900 fps, although it starts ramping down at approximately V_{REL} = 3,800 fps.

Roll channel is driven by either the auto system via bank angle error, which is turned into a bank rate command, or by CSS via RHC input. This bank rate command is multiplied by (1-GALR) to determine if the initial command should be reverse or proverse ailerons. It is converted into a roll rate command and is summed with beta dot damping (which is multiplied by GALR to determine magnitude) and compared with the output from the roll axis RGAs after compensation for roll rates from the steady-state turn. This is the rate error that is turned into jet commands until qbar=10 psf and/or aileron commands after qbar=2 psf.

The Entry Mode Switch, also known as the Roll Mode Switch, on the CDR L2 panel, allows the crew to select one of three Aerojet DAP flight control modes. The switch positions are Auto, Low Gain, and No Yaw Jet. Auto allows selection, via Override SPEC 51, of either the baseline or Wraparound DAP roll modes. Wraparound DAP provides the same GALR terms as the No Yaw Jet mode, which are seven times that of the baseline GALR term for V_{REL} > 4,000 fps. Wraparound DAP is the nominal entry roll mode. With increased GALR, Wraparound DAP decreases RCS propellant usage by using the ailerons as the primary control effectors and the RCS jets as supplemental control effectors.

The No Yaw Jet entry mode eliminates all yaw jet commands. Bank maneuvers are accomplished only with aileron commands. This flight mode is certified for qbar >20 psf (or very soon after the first non-zero bank) to landing. No Yaw Jet will be used in critical entry cases of low aft RCS propellant (<10% total quantity) or loss of aft RCS yaw jets.

The Low Gain position cuts the GALR terms in half, using both yaw jets and ailerons for control. This mode may be selected in off-nominal situations because of airframe vibrations or oscillations.

Other features of the roll channel are:

- Roll channel trim is automatic in AUTO until rollout. Because auto trim in CSS is terminated at Mach 1.25, if CSS is taken at Mach >1 while the vehicle is maneuvering, such as rolling onto the

HAC, the CDR may experience a roll rate on final that must be compensated for by displacing the RHC slightly to the right or left. This is because the automatic trim input during the maneuver is "locked" into the flight control system when CSS is taken. This usually becomes apparent when rolled out on final. The RHC roll trim may be used to trim the RHC.

- RHC roll rate trim is exactly the same as pitch rate trim.
- At main gear touchdown, auto load balance keeps the wings level during rollout and prevents the downwind tire from experiencing excessive loads with crosswinds. After nose gear touchdown, load balance is faded out over 100 seconds.
- Any yaw jet firing causes the ailerons to trim in the proper direction to reduce the number of jet firings (right yaw jet firings will cause right aileron to trim down).

Except during bank maneuvers, DAP attempts to keep β small throughout entry. Until Mach 0.6, the yaw channel is driven by bank angle error, which is turned into a bank rate command. After Mach 0.6, the yaw channel is driven by the roll rate compensated for steady state turn so rudder pedal inputs are not required to maintain coordinated flight. The bank rate command or the compensated roll rate is converted to a body yaw command and summed with a beta compensation term until qbar=20 psf. That is compared with the output from the yaw axis RGAs after compensation for yaw rates from the steady state turn. This yaw rate error is then summed with lateral acceleration (N_Y), RPTA input, and yaw panel trim inputs. This is the rate that is turned into jet commands until Mach 1 and/or rudder commands after Mach 5. This causes the beta during early entry to cause the orbiter to bank, or during late entry (M < 0.6), coordinates the bank.

The rudder is not active for control until M < 5.0 due to the high angle of attack on entry essentially blanking the vertical tail/rudder from the airstream. Once the angle of attack decreases, the rudder is blended into the flight control system.

Other features of the yaw channel are:

- The RPTA does not directly control the rudder, but commands lateral acceleration, and the rudder moves as necessary to maintain that lateral acceleration. Yaw panel trim performs exactly the same function. There is no operational reason to command a non-zero lateral acceleration. The RPTAs are not active until the rudder becomes active at M< 5.0.
- At GSENBL set (WOW set for 2 sec, theta < 0 deg, WONG), if in AUTO R/Y, the yaw channel will provide nose wheel steering commands to maintain runway centerline.

Operations

Ascent

The terminal count phase extends from T-20 minutes through SRB ignition. During this timeframe, the GNC OPS 1 software is loaded into the GPCs and verified by the ground. Guidance and flight control software are not active during terminal count. Navigation software is initialized at T-8 seconds when the onboard state vector is initialized and state vector propagation begins.

First-stage guidance is active from SRB ignition through SRB separation command. In this stage, guidance uses a preflight planned ("canned") table of roll, pitch, and yaw attitudes referenced to relative velocity. In addition to sending commands to flight control to obtain proper attitudes, the guidance software also sends commands to the MPS throttle per a preflight defined throttle schedule. Steering of the vehicle during first stage is accomplished by gimballing primarily the SRB nozzles. First-stage guidance also attempts to relieve vehicle aerodynamic loads based on sensed accelerations.

The navigation software during first stage propagates the vehicle state vector using the Super-G integration scheme using IMU data and a gravity model.

The flight control software during first stage uses commands issued by guidance. If the crew has selected CSS, commands are input through the RHC. Feedback from rate gyro assemblies and accelerometers is used to generate commands to reposition the SRB nozzles and main engine bells. The current vehicle attitude rates and the errors between current and desired attitudes are sent to the attitude director indicator for display to the crew. If the crew does take CSS, the resultant control mode is discrete rate/attitude hold. In this mode, when the rotational hand controller is moved, a specified attitude rate is commanded as long as the RHC is out of its neutral position. When the RHC is in detent, attitude hold commands are generated by flight control.

During first stage, no GNC-related crew actions are planned unless a failure occurs. Following launch, the crew uses the Ascent Flip Book for general procedures. To ensure that the auto flight control system is maintaining the expected ascent profile, the crew can scan the cue cards placed next to the dedicated displays.

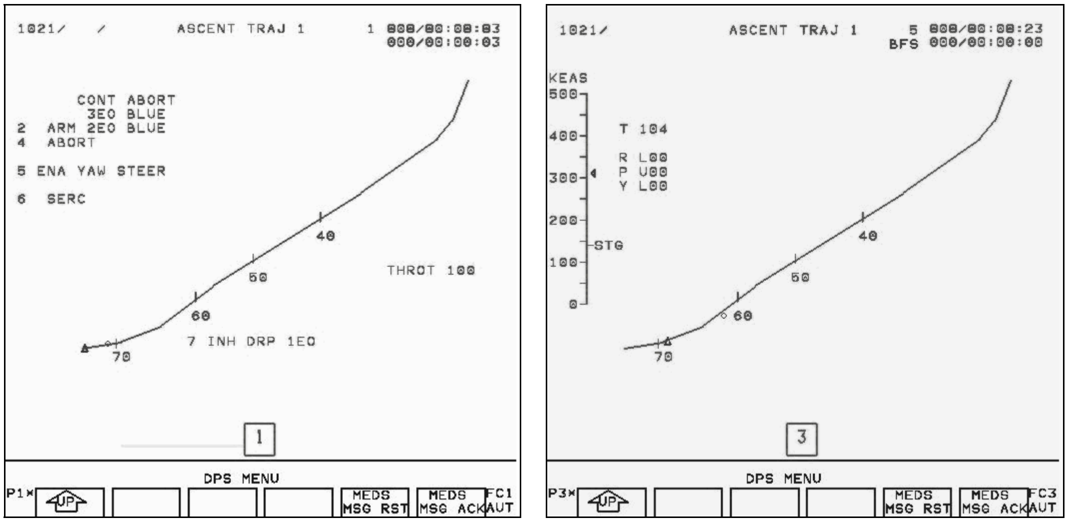
Second-stage ascent begins at SRB separation and extends through MECO and external tank separation. During second stage, the crew monitors the onboard systems to ensure that the major GNC events occur correctly. These events include closed loop guidance convergence, 3-g throttling, MECO, external tank separation, and -Z translation.

The second stage guidance software uses a cyclic, closed loop scheme to calculate the necessary commands to take the mated vehicle to a specified set of target MECO conditions. These conditions include cutoff velocity, radius from the Earth, flight path angle, orbital inclination, and longitude of the ascending node. The name of the targeting scheme is PEG (powered explicit guidance) 1.

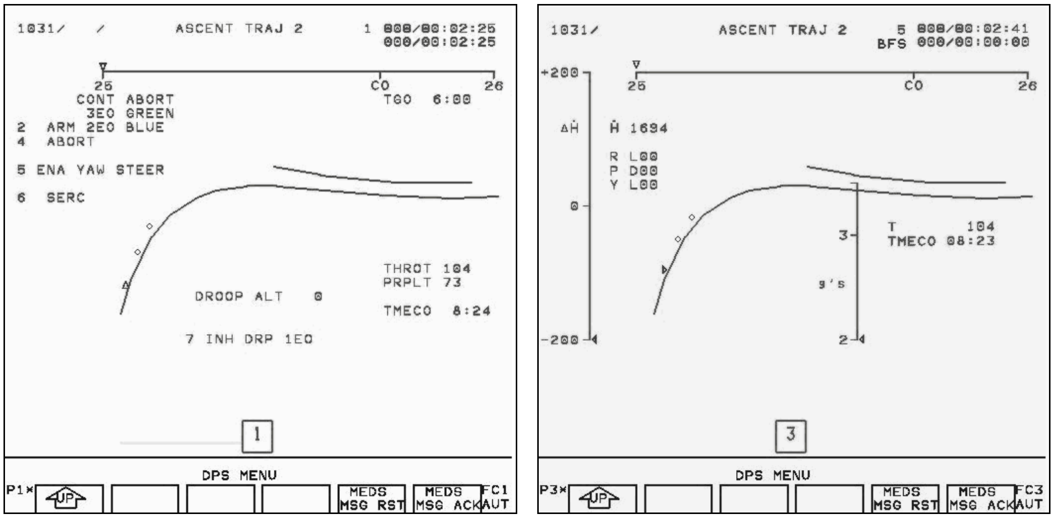
The predicted time of MECO (TMECO) is calculated by both PASS and BFS and displayed on their respective ASCENT TRAJ displays for the crew to evaluate. (Adiscrepancy between PASS and BFS may indicate a guidance error, requiring the crew to take manual control.) Following SRB separation, it may take the PEG 1 guidance algorithm several cycles to converge and for TMECO to become stable. Forty seconds prior to MECO, guidance begins targeting only for the desired cutoff velocity.

Guidance software also governs the main engine throttle commands such that 3 g's are not exceeded. The crew can ensure that 3 g's are not exceeded by monitoring the g-indicator on either the BFS ASCENT TRAJ 2 display or the Ascent/Entry Flight Display.

Second-stage navigation software continues as it did during first stage; i.e., it propagates a state vector using the Super-G integration scheme.



PASS *and BFS* ASCENT TRAJ *1* Display*s*



Pass and* BFS ASCENT TRAJ 2 Display*s

Second-stage flight control software continues through MECO as it did during first stage, with the exception of gimballing the main engines versus the SRBs. After SRB separation, attitude hold is commanded until guidance converges.

At MECO, the transition (or TRANS) DAP, becomes active. Initially it sends attitude hold commands. External tank separation is automatically commanded about 20 seconds after MECO. The DAP immediately sets commands to fire the orbiter -Z RCS jets resulting in the orbiter translating in the -Z direction (away from the external tank). When -4 fps delta velocity is reached, the fire commands are removed.

Orbit Insertion

During the orbit insertion phase, the guidance software is used to target the OMS 2 burn (and OMS 1 burn, if required). The primary targeting scheme used is called PEG 4. This is a cyclic, closed loop scheme that computes the required delta velocity to achieve a specific point in space and a specific flight path angle.

Navigation during the orbit insertion phase is identical in processing to that used in the mainstage whenever the IMU-sensed acceleration is greater than the noise threshold. If the IMU-sensed acceleration drops below the threshold, navigation ignores the IMU data and propagates the state vector using an atmospheric drag model of the orbiter.

Insertion flight control is accomplished using the transition DAP. The transition DAP uses commands from guidance for automatic maneuvers to burn attitude using the RCS jets. During the OMS 1 and 2 burns, it uses the OMS engines and RCS jets as required. It can also receive commands from the crew via the forward THC and RHC. The transition DAP takes these commands and converts them into the appropriate RCS commands. It then monitors the resultant attitude and attitude rates. The necessary commands are sent to achieve the targeted attitude and attitude rate within the pre-mission specified deadbands.

For rotations, the crew selects either AUTO or INRTL control on the ORBITAL DAP panel or by moving the RHC. In translation, movement of the THC results in continuous jet firings.

Orbit GNC

The major GNC-related orbit tasks include achieving the proper position, velocity, and attitude necessary to accomplish the mission's objectives. To do this, the GNC software maintains an accurate state vector, maneuvers to specified attitudes and positions, and points a specified orbiter body vector at a selected target. These activities are planned with several constraints in mind, including fuel consumption, vehicle thermal limits, payload requirements, and rendezvous/proximity operations considerations. The GNC displays for the majority of on-orbit operations are OPS 201 UNIV PTG and MNVR EXEC. Both are available in OPS 2, and MNVR EXEC is available for the orbit portion of OPS 1 and 3.

The navigation software has several important features. As before, it propagates the orbiter state vector using the Super-G integration scheme. During coasting flight, the software uses a model of atmospheric drag acceleration to propagate the state vector. Another navigation option that is available on-orbit is called rendezvous navigation. When this option is enabled by a crew input on the REL NAV display, the software propagates a target state vector, as well as the orbiter state vector. In this mode, navigation can use external sensor data from the star tracker, rendezvous radar or COAS, in computing the orbiter/target relative state vector.

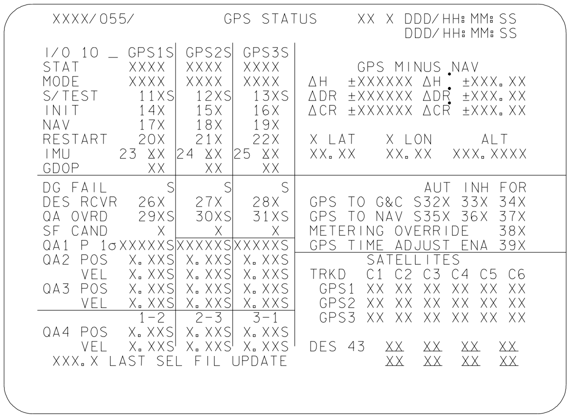
For vehicles equipped with three-string GPS hardware, the navigation software will replace its propagated vector with a selected GPS vector every 90 minutes. This will happen only if the selected GPS state vector falls within the navigation software’s expected error. After the orbiter vector is updated, it will then be propagated for the next 90 minutes using the same techniques as described above (i.e., Super-G, drag model, etc.). This automatic GPS state vector update will be inhibited during rendezvous operations to avoid interfering with the current rendezvous navigation sensor processes.

For vehicles with single-string GPS, periodic updates are sent from Mission Control to correct any errors that develop with the onboard nav state. In the event of no-comm, GPS can be incorporated as described above.

The on-orbit guidance software has several features. Universal pointing is used to compute attitude changes required to "point" a specified orbiter body axis at a specified target, to maneuver to a predetermined attitude, to rotate the orbiter about a specified body axis, or to maintain attitude hold. The crew interacts with this software via the UNIV PTG display.

Another guidance feature is PEG 7, or external ΔV, targeting for OMS or RCS burns. In this mode, guidance sends the commands to flight control to execute a burn specified by an ignition time (TIG) and delta velocities in the local vertical coordinate system at ignition.

Commands continue to be generated until the original ΔV requirement is met. The crew monitors this option with the ORBIT MNVR EXEC display.



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XXXX/055/          GPS STATUS     XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS
I/O 10 _ GPS1S  GPS2S  GPS3S
STAT      XXXX   XXXX   XXXX         GPS MINUS NAV
MODE      XXXX   XXXX   XXXX    ΔH  ±XXXXXX ΔḢ  ±XXX.XX
S/TEST    11XS   12XS   13XS    ΔDR ±XXXXXX ΔḊR ±XXX.XX
INIT       14X    15X    16X    ΔCR ±XXXXXX ΔĊR ±XXX.XX
NAV        17X    18X    19X
RESTART    20X    21X    22X    X LAT    X LON     ALT
IMU     23 XX  24 XX  25 XX     XX.XX    XX.XX  XXX.XXXX
GDOP        XX     XX     XX
DG FAIL      S      S      S                  AUT INH FOR
DES RCVR   26X    27X    28X    GPS TO G&C S32X 33X 34X
QA OVRD   29XS   30XS   31XS    GPS TO NAV S35X 36X 37X
SF CAND      X      X      X    METERING OVERRIDE   38X
QA1 P 1σXXXXXS XXXXXS XXXXXS    GPS TIME ADJUST ENA 39X
QA2 POS  X.XXS  X.XXS  X.XXS             SATELLITES
    VEL  X.XXS  X.XXS  X.XXS    TRKD  C1 C2 C3 C4 C5 C6
QA3 POS  X.XXS  X.XXS  X.XXS     GPS1 XX XX XX XX XX XX
    VEL  X.XXS  X.XXS  X.XXS     GPS2 XX XX XX XX XX XX
           1-2    2-3    3-1     GPS3 XX XX XX XX XX XX
QA4 POS  X.XXS  X.XXS  X.XXS
    VEL  X.XXS  X.XXS  X.XXS    DES 43  XX  XX  XX  XX
 XXX.X LAST SEL FIL UPDATE              XX  XX  XX  XX
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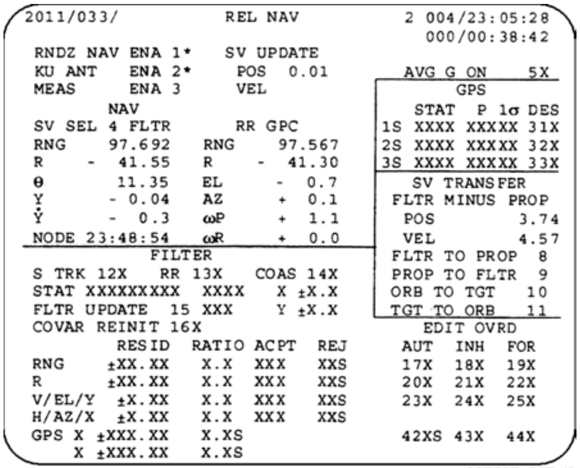
007587051.CRT;1

GPS STATUS Display (SPEC 55)



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2011/033/            REL NAV          2 004/23:05:28
                                        000/00:38:42
 RNDZ NAV ENA 1*   SV UPDATE
 KU ANT   ENA 2*    POS  0.01          AVG G ON    5X
 MEAS     ENA 3     VEL                     GPS
        NAV                              STAT  P 1σ DES
 SV SEL 4 FLTR        RR GPC         1S XXXX XXXXX 31X
 RNG     97.692   RNG    97.567      2S XXXX XXXXX 32X
 R    -   41.55   R   -   41.30      3S XXXX XXXXX 33X
 θ        11.35   EL    -   0.7        SV TRANSFER
 Y       - 0.04   AZ    +   0.1      FLTR MINUS PROP
 Ẏ       -  0.3   ωP    +   1.1       POS         3.74
 NODE 23:48:54    ωR    +   0.0       VEL         4.57
            FILTER                   FLTR TO PROP  8
 S TRK 12X   RR 13X   COAS 14X       PROP TO FLTR  9
 STAT XXXXXXXXX  XXXX    X ±X.X      ORB TO TGT   10
 FLTR UPDATE  15 XXX     Y ±X.X      TGT TO ORB   11
 COVAR REINIT 16X                        EDIT OVRD
          RESID   RATIO ACPT   REJ     AUT  INH  FOR
 RNG     ±XX.XX    X.X  XXX    XXS     17X  18X  19X
 R       ±XX.XX    X.X  XXX    XXS     20X  21X  22X
 V/EL/Y   ±X.XX    X.X  XXX    XXS     23X  24X  25X
 H/AZ/X   ±X.XX    X.X  XXX    XXS
 GPS X  ±XXX.XX    X.XS                42XS 43X  44X
     X  ±XXX.XX    X.XS
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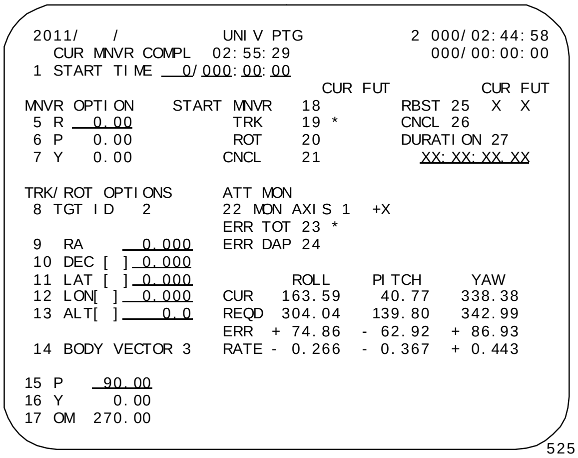
usa007587_527.tif

REL NAV Display (SPEC 33)



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 2011/   /            UNIV PTG            2 000/02:44:58
   CUR MNVR COMPL   02:55:29                000/00:00:00
 1 START TIME __0/000:00:00
                                  CUR FUT          CUR FUT
MNVR OPTION    START MNVR   18          RBST 25   X   X
 5 R  0.00            TRK   19 *        CNCL 26
 6 P  0.00            ROT   20          DURATION 27
 7 Y  0.00          CNCL    21            XX:XX:XX.XX

TRK/ROT OPTIONS     ATT MON
 8 TGT ID   2       22 MON AXIS 1  +X
                    ERR TOT 23 *
 9  RA       0.000  ERR DAP 24
 10 DEC [ ]  0.000
 11 LAT [ ]  0.000            ROLL     PITCH      YAW
 12 LON[ ]   0.000  CUR    163.59     40.77    338.38
 13 ALT[ ]     0.0  REQD   304.04    139.80    342.99
                    ERR  + 74.86   - 62.92   + 86.93
 14 BODY VECTOR 3   RATE - 0.266   - 0.367   + 0.443

15 P   90.00
16 Y    0.00
17 OM 270.00
```
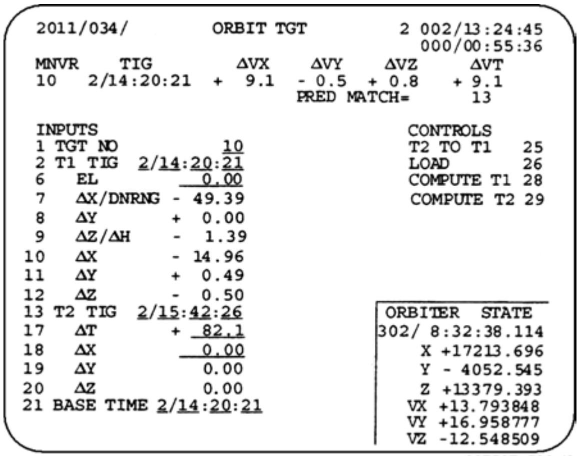

525

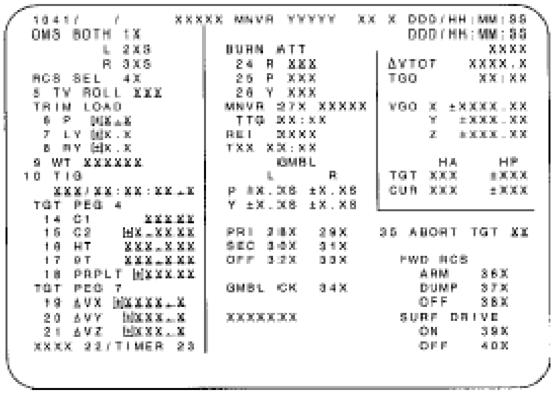
UNIV PTG Display



```
 2011/034/         ORBIT TGT         2 002/13:24:45
                                       000/00:55:36
 MNVR    TIG          ΔVX    ΔVY    ΔVZ     ΔVT
 10   2/14:20:21  +   9.1  - 0.5  + 0.8   + 9.1
                              PRED MATCH=    13

 INPUTS                              CONTROLS
 1 TGT NO            10              T2 TO T1    25
 2 T1 TIG    2/14:20:21              LOAD        26
 6   EL            0.00              COMPUTE T1  28
 7   ΔX/DNRNG  - 49.39               COMPUTE T2  29
 8   ΔY        +  0.00
 9   ΔZ/ΔH     -  1.39
10   ΔX        - 14.96
11   ΔY        +  0.49
12   ΔZ        -  0.50
13 T2 TIG    2/15:42:26            ORBITER  STATE
17   ΔT        +  82.1            302/ 8:32:38.114
18   ΔX            0.00               X +17213.696
19   ΔY            0.00               Y - 4052.545
20   ΔZ            0.00               Z +13379.393
21 BASE TIME 2/14:20:21              VX +13.793848
                                     VY +16.958777
                                     VZ -12.548509
```

usa007587_528.tif

ORBIT TGT Display (SPEC 34)



```
 1041/    /       XXXXX MNVR YYYYY   XX X DDD/HH:MM:SS
 OMS BOTH 1X                              DDD/HH:MM:SS
         L 2XS      BURN ATT                      XXXX
         R 3XS       24 R XXX        ΔVTOT      XXXX.X
 RCS SEL   4X        25 P XXX        TGO         XX:XX
 5 TV ROLL XXX       26 Y XXX
 TRIM LOAD          MNVR 27X XXXXX   VGO X ±XXXX.XX
  6 P  ±XX.X         TTG XX:XX            Y  ±XXX.XX
  7 LY ±X.X         REI  XXXX             Z  ±XXX.XX
  8 RY ±X.X         TXX XX:XX
 9 WT XXXXXX              GMBL                HA    HP
10 TIG                  L       R      TGT XXX    ±XXX
    XXX/XX:XX:XX.X  P ±X.XS  ±X.XS     CUR XXX    ±XXX
 TGT PEG 4          Y ±X.XS  ±X.XS
  14 C1      XXXXX
  15 C2    ±X.XXXX  PRI 28X   29X    35 ABORT TGT XX
  16 HT    XXX.XXX  SEC 30X   31X
  17 θT    XXX.XXX  OFF 32X   33X       FWD RCS
  18 PRPLT ±XXXXX                         ARM    36X
 TGT PEG 7          GMBL CK   34X         DUMP   37X
  19 ΔVX ±XXXX.X                          OFF    38X
  20 ΔVY  ±XXX.X    XXXXXXX             SURF DRIVE
  21 ΔVZ  ±XXX.X                          ON     39X
 XXXX 22/TIMER 23                         OFF    40X
```

MNVR Display

The third guidance capability is an on-orbit targeting scheme used to compute the burn parameters required to move the orbiter to a specified target offset position in a given amount of time. This capability is used to do on-board targeting of rendezvous maneuvers. The crew monitors this feature using the SPEC 34 ORBIT TGT display.

The orbital flight control software includes the RCS DAP, OMS TVC DAP, an attitude processor, and the logic to govern DAP selection. The attitudes calculated by the attitude processor are displayed on the ADI and the UNIV PTG display screen. The vehicle attitude is used by the DAP to determine attitude and rate errors.

Options for the DAP, including the translation rate, rotation rates, and deadbands, are changeable by the crew during the orbit phase using the DAP CONFIG display. The Flight Plan specifies which DAP configurations should be loaded at each time in the mission.

Deorbit

The deorbit phase of the mission includes the deorbit burn preparations, the loading of burn targets, the execution and monitoring of the burn, post-burn reconfiguration, and a coast mode until about 400,000 feet above the Earth's surface. The deorbit and entry flight software is referred to as OPS 3.

During the deorbit phase, navigation uses the Super-G algorithm to propagate the orbiter state vector, based upon a drag model or IMU data. Navigation maintains and propagates three orbiter state vectors, each based upon a different IMU. From these three state vectors, a single orbiter state vector is calculated using an interchangeable mid-value selection process. A single-state vector is passed on for use by guidance, flight control, dedicated display, and DPS display software. Three separate state vectors are propagated to protect the onboard software from problems due to two IMU data failures. This three-state vector system is only used during entry, since that phase is most critical with respect to navigation errors and their effects on vehicle control and an accurate landing. Another feature available during this phase is the software computational capability of a statistical estimate of the error in the state vector propagation, to be used later in flight when external sensor data are available. Also in this phase, it is possible for the crew or Mission Control to input a delta state vector to correct navigation.

Vehicles with three-string GPS hardware will be able to incorporate a selected GPS state vector every 42 seconds throughout the deorbit and entry phases of flight. This will be initialized via crew command upon entering OPS 301. Similar to orbit, the nav software will pick the best available GPS vector to replace the three IMU propagated state vectors. These three updated vectors will continue to be propagated as described above for the next 42 seconds, at which time they will be replaced with a new selected GPS vector and then the process will repeat.

Guidance during the deorbit phase is similar to that used in the orbit insertion phase. The PEG 4 scheme is used again to target the deorbit burn and guide the vehicle during the burn although the required conditions are different. The deorbit burn targets ensure the proper conditions for entry interface, including altitude, position with respect to the Earth (and landing site), and velocity/flight path angle constraints. These deorbit burn targets are specified preflight for a nominal mission, although it is also possible for the ground to uplink changes or for the crew to recompute them onboard. It is also possible to specify OMS fuel "wasted" (burned out of plane) during the deorbit burn in order to establish an acceptable orbiter center of gravity (c.g.) for entry. The crew is responsible for loading these targets on the DEORB MNVR EXEC display.

The display is used to set up and target the OMS burn, to specify fuel to be wasted, to display the required burn attitude, to initiate an automatic attitude maneuver, and to monitor the progress of the burn. The crew's task for deorbit guidance includes ensuring the correct burn targets are entered on the DEORB MNVR EXEC display, "loading" this target for PEG 4 deorbit burn guidance software, and maneuvering to calculated and displayed burn attitude either in AUTO or manually using the RHC. The burn itself is typically executed in AUTO such that the crew's task is to monitor the burn progress in terms of velocities and OMS performance.

Flight control during the deorbit phase is similar to the procedures used during orbit insertion - the transition DAP is again in effect.

Entry

The entry phase of flight is subdivided into three separate subphases because the software requirements for each are different:

- The ENTRY subphase extends from EI-5 to the point at which the vehicle is traveling at 2500 fps (83,000 ft altitude).
- The terminal area energy management (TAEM) subphase begins at 2500 fps and extends to the approach/landing capture zone, defined when the vehicle is on glide-slope, on airspeed, and on runway centerline (below 10,000 ft altitude).
- The approach/landing (A/L) subphase begins at the approach/landing capture zone and extends through wheel stop after touchdown.

The guidance software during the entry portion of flight performs different tasks during each of the ENTRY, TAEM, and A/L subphases. During the ENTRY subphase, guidance attempts to keep the vehicle on a trajectory that provides protection against excessive temperature, dynamic pressure, and normal acceleration (Nz) limits. To do this, the software sends commands to flight control to fly a drag/acceleration determined profile, which guides the vehicle through a tight corridor limited on one side by altitude and velocity requirements for ranging (in order to make the runway), and on the other side by the thermal, qbar, and Nz constraints. Ranging is accomplished by adjusting drag acceleration to velocity such that the vehicle stays in that corridor. Drag acceleration can be adjusted by modifying the angle of attack, which changes the vehicle's cross sectional area with respect to the airstream, or by adjusting the vehicle bank angle, which affects lift and thus the vehicle's sink rate into denser atmosphere. The vehicle's angle of attack is maintained at a high value (α=40°) during most of this phase to protect the upper surfaces from extreme heat. It is ramped down to a lower value at the end of this phase for vehicle controllability. Using bank angle to adjust drag acceleration results in the vehicle turning off course. Therefore, at certain times, the vehicle must be rolled back toward the runway. This is called a roll reversal and is commanded as a function of azimuth error from the runway.

During the entry phase of flight, the crew uses IDP displays, dedicated displays, certain panel switches (such as TRIM switches), the RHC, and the SBTC to control the vehicle. Between the ENTRY interface and the TAEM interface, five ENTRY TRAJ displays sequentially become available. These displays are used to monitor autoguidance and the vehicle's trajectory compared to the planned entry profile. The five displays are identical with the exception of the central plot, which shows vehicle velocity versus range or energy/weight versus range with a changing scale as the vehicle approaches the landing site. This central plot also includes static background lines that allow the crew to monitor the vehicle's progression compared to planned entry profiles.

Once TAEM interface is reached, the VERT SIT 1 display becomes available. This display includes a central plot of vehicle altitude with respect to range. The plot has three background lines that represent the nominal altitude versus range profile, a dynamic pressure limit profile, and a maximum lift-over-drag profile. At 30,000 feet altitude, the scale and titles on the display change to VERT SIT 2. This second display is used through landing. When the A/L interface conditions are met, a flashing A/L is displayed on the VERT SIT 2 display.

Guidance software during TAEM generates the necessary commands to enable the vehicle to achieve the proper A/L conditions by following an energy/weight versus range profile. During TAEM, as the name implies, the goal is to manage the vehicle's energy while the orbiter travels around an imaginary arc called the heading alignment cone (HAC). A HAC is an imaginary cone that when projected on the Earth, lies tangent to the extended runway centerline.

The guidance software performs the TAEM function as follows:

- S-Turns: If the vehicle is high on energy, it dissipates the excess by turning away from the HAC until the proper energy conditions are met.
- HAC Acquisition: Turns the vehicle toward the targeted tangent point on the HAC and flies to this point.
- Heading Alignment: Flies the vehicle around the HAC to the point at which the HAC is tangent to the runway centerline, called the nominal energy point (NEP).
- Prefinal: From the NEP, flies the vehicle down the runway centerline until the proper A/L conditions (airspeed, altitude, flight path angle, distance off centerline) are met.

Within the above steps, TAEM guidance makes the necessary adjustments to account for various energy conditions.

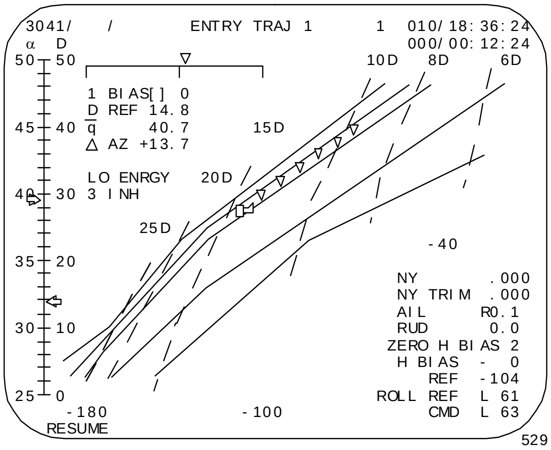
Approach/landing guidance software commences when the vehicle is about 10,000 feet altitude (at 5.8 or 6.3 nm range from the runway threshold) and near the proper altitude, airspeed, and flight path angle for the outer glide slope (20° or 18°, depending on orbiter weight). The guidance software sends commands to keep the vehicle tracking the runway centerline and on the steep glide slope until approximately 2000 feet, at which point a preflare maneuver is performed to put the orbiter on a shallow glide slope (1.5°). Final flare is initiated between 30 and 80 feet (based on sink rate), reducing the sink rate to 3 fps for touchdown. At this point, guidance software generates commands directing the vehicle to the runway centerline.

In the entry phase, navigation software functions similarly to the deorbit phase (i.e., three-state vectors computed using the Super-G algorithm corresponding to each inertial measurement unit) with the exception that additional external sensor data are sequentially incorporated. This information is used to provide the accuracy necessary to bring the orbiter to a pinpoint landing and to some extent to maintain vehicle control. The TACAN system provides slant range and magnetic bearing to various fixed stations around the landing site and becomes available at about 160,000 feet altitude until 1500 feet above ground level. The ADTA system provides pressure data to compute angle of attack, Mach number, equivalent airspeed, true airspeed, dynamic pressure, barometric altitude, and altitude rate. Only barometric altitude is used for the navigation software. The microwave landing system precisely determines slant range, azimuth, and elevation to the ground stations located along the side of the landing runway. When landing at runways with microwave landing system ground stations, data become available at 18,000 feet for processing by navigation.

Another tool used by the navigation software is a "software sensor" called drag altitude, which uses a model of the atmosphere to correlate the drag acceleration measured by the inertial measurement units to altitude. The drag altitude data are important in keeping downrange and altitude errors bounded until TACAN data is available.

The navigation software also maintains a statistical estimate of the expected error in the state vector. When an external sensor, such as TACAN, becomes available to the navigation software, a check is made to see if the data lays within the current expected range of error. Crew controls are provided on the HORIZ SIT display to force the software to accept or inhibit the external sensor data regardless of whether they lie within this expected range. There is also a control on the display that may be selected to allow the software to use the external sensor data to update its state vector as long as the data lie within the expected range. This scheme is part of what is called Kalman filtering and is used to prevent navigation from being polluted by bad sensor data. The navigation parameters computed as a result of this filter can be seen by the crew on the dedicated displays when NAV is selected as the data source. In addition to providing insight and control over navigation parameters, the HORIZ SIT display supplies the crew with spacecraft position and heading information.

GPS-equipped vehicles will not have TACAN data to incorporate into the three-state vectors corresponding to each IMU. Similar to the other navigation sensors, GPS data are constantly checked to make sure they lie within an expected error range. Crew controls (via the HORIZ SIT display) allow the navigation software to automatically incorporate a GPS vector if the vector falls within the expected range or to force the software to accept or inhibit the data regardless of whether the information lies within the expected range. As described in the Deorbit subsection, navigation software will select and incorporate a GPS vector every 42 seconds up to 17,000 feet and then every 9 seconds thereafter to allow for smoother updates to navigation software in the event that MLS is not available. If MLS is available, MLS will update navigation software as described above and GPS updates will automatically be inhibited by the navigation software.



3041/ / ENTRY TRAJ 1 1 010/18:36:24
000/00:12:24

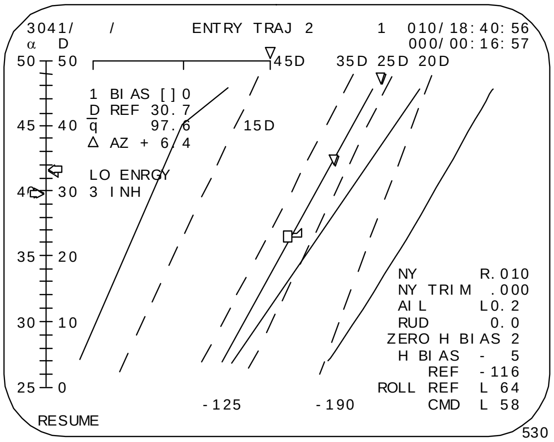
1 BIAS[ ] 0
D REF 14.8
q̄ 40.7
Δ AZ +13.7

LO ENRGY
3 INH

NY .000
NY TRIM .000
AIL R0.1
RUD 0.0
ZERO H BIAS 2
H BIAS - 0
REF -104
ROLL REF L 61
CMD L 63

RESUME

ENTRY TRAJ 1 Display



3041/ / ENTRY TRAJ 2 1 010/18:40:56
000/00:16:57

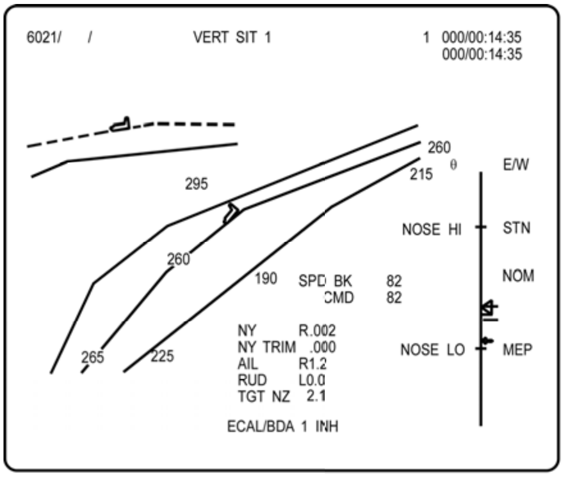
1 BIAS [ ] 0
D REF 30.7
q̄ 97.6
Δ AZ + 6.4

LO ENRGY
3 INH

NY R.010
NY TRIM .000
AIL L0.2
RUD 0.0
ZERO H BIAS 2
H BIAS - 5
REF -116
ROLL REF L 64
CMD L 58

RESUME

ENTRY TRAJ 2 Display



6021/ / VERT SIT 1 1 000/00:14:35
000/00:14:35

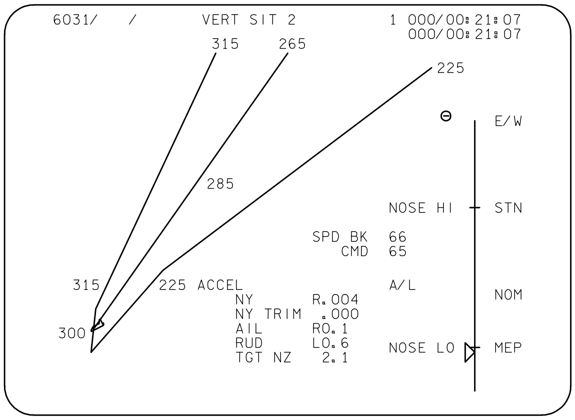
SPD BK 82
CMD 82

NY R.002
NY TRIM .000
AIL R1.2
RUD L0.0
TGT NZ 2.1

ECAL/BDA 1 INH

usa007587_1106r2.cvx

VERT SIT 1



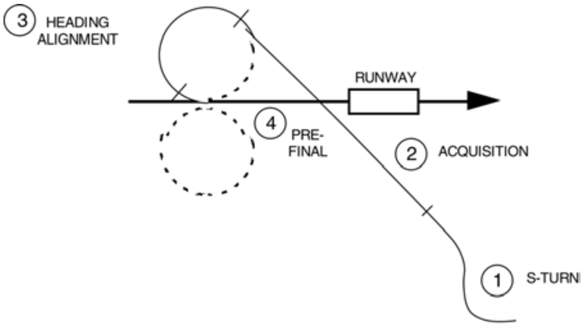
6031/ / VERT SIT 2 1 000/00:21:07
000/00:21:07

SPD BK 66
CMD 65

NY R.004
NY TRIM .000
AIL R0.1
RUD L0.6
TGT NZ 2.1

007587024.CRT;1

VERT SIT 2



TAEM Guidance Subphases

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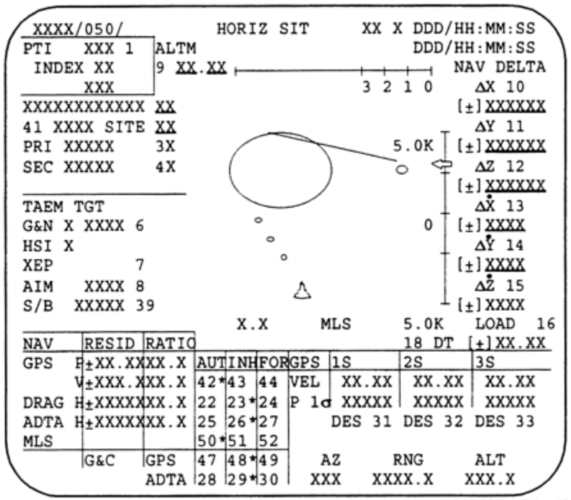

```
 XXXX/050/          HORIZ SIT     XX X DDD/HH:MM:SS
PTI    XXX 1  ALTM                     DDD/HH:MM:SS
 INDEX XX     9 XX.XX                    NAV DELTA
       XXX                  3 2 1 0       ΔX 10
XXXXXXXXXXXX XX                         [±]XXXXXX
41 XXXX SITE XX                           ΔY 11
PRI XXXXX    3X                  5.0K   [±]XXXXXX
SEC XXXXX    4X                           ΔZ 12
                                        [±]XXXXXX
TAEM TGT                                  ΔẊ 13
G&N X XXXX 6                        0   [±]XXXX
HSI X                                     ΔẎ 14
XEP        7                            [±]XXXX
AIM   XXXX 8                              ΔŻ 15
S/B  XXXXX 39                           [±]XXXX
               X.X      MLS      5.0K    LOAD  16
NAV    RESID RATIO               18 DT  [±]XX.XX
GPS   P±XX.XXXX.X AUT INH FOR GPS  1S     2S     3S
      V±XXX.XXX.X 42*43  44  VEL  XX.XX  XX.XX  XX.XX
DRAG  H±XXXXXXX.X 22  23*24  P 1σ XXXXX  XXXXX  XXXXX
ADTA  H±XXXXXXX.X 25  26*27     DES 31 DES 32 DES 33
MLS               50*51  52
       G&C   GPS  47  48*49     AZ     RNG      ALT
             ADTA 28  29*30    XXX   XXXX.X    XXX.X
```

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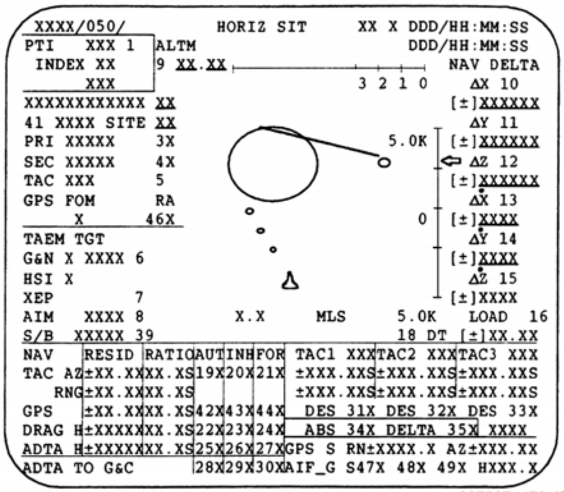
HORIZ SIT Display (SPEC 50)
(Three-String GPS Vehicles)



```
 XXXX/050/          HORIZ SIT     XX X DDD/HH:MM:SS
PTI    XXX 1  ALTM                     DDD/HH:MM:SS
 INDEX XX     9 XX.XX                    NAV DELTA
       XXX                  3 2 1 0       ΔX 10
XXXXXXXXXXXX XX                         [±]XXXXXX
41 XXXX SITE XX                           ΔY 11
PRI XXXXX    3X                  5.0K   [±]XXXXXX
SEC XXXXX    4X                           ΔZ 12
TAC XXX      5                          [±]XXXXXX
GPS FOM      RA                           ΔẊ 13
     X      46X                     0   [±]XXXX
TAEM TGT                                  ΔẎ 14
G&N X XXXX 6                            [±]XXXX
HSI X                                     ΔŻ 15
XEP        7                            [±]XXXX
AIM   XXXX 8          X.X      MLS      5.0K    LOAD  16
S/B  XXXXX 39                           18 DT [±]XX.XX
NAV    RESID  RATIOAUTINHFOR TAC1 XXXTAC2 XXXTAC3 XXX
TAC AZ±XX.XXXX.XS19X20X21X ±XXX.XXS±XXX.XXS±XXX.XXS
   RNG±XX.XXXX.XS          ±XXX.XXS±XXX.XXS±XXX.XXS
GPS   ±XX.XXXX.XS42X43X44X  DES 31X DES 32X DES 33X
DRAG H±XXXXXXX.XS22X23X24X  ABS 34X DELTA 35X XXXX
ADTA H±XXXXXXX.XS25X26X27XGPS S RN±XXXX.X AZ±XXX.XX
ADTA TO G&C       28X29X30XAIF_G S47X 48X 49X HXXX.X
```

usa007587_479.tif

HORIZ SIT Display (SPEC 50)
(Three-String TACAN Vehicles)

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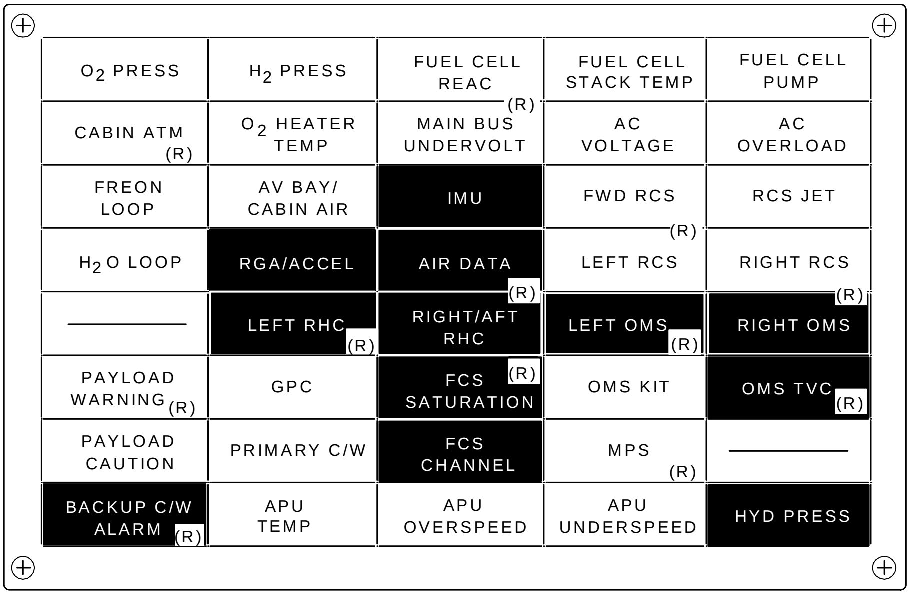
GNC Caution and Warning Summary

- IMU overheating or BITE-detected failures display a fault message and annunciate an SM ALERT. An IMU failure illuminates the SM ALERT and displays a fault message, while a dilemma illuminates the IMU C/W light on panel F7.
- A TACAN, GPS, or microwave scanning beam landing system (MSBLS) fault will illuminate the SM ALERT and display a fault message.
- Fault detection in the air data system illuminates the SM ALERT for a failure or the red AIR DATA and BACKUP C/W ALARM lights on panel F7 for a dilemma, in addition to sounding an alarm and generating a fault message.
- The RGA/ACCEL light on panel F7 is not supported. RGA or AA failure will sound an alarm and generate a DPS fault message.
- A malfunction in the commander's RHC will illuminate the LEFT RHC light on panel F7; a malfunction in the pilot's RHC or the aft RHC will illuminate the RIGHT/AFT RHC light.
- If the hydraulic system pressure drops below 2,800 psi, the HYD PRESS and BACKUP C/W ALARM lights will illuminate.
- The yellow FCS CHANNEL light illuminates to indicate a failed channel; the red FCS SATURATION light is illuminated if one of the four elevons is set at more than +12° (down) or less than -15° (up).
- The OMS TVC light illuminates if the left or right OMS gimbal fails, or if software detects a TVC failure.
- The LEFT or RIGHT OMS light illuminates if the left or right OMS engine fails.



O_2 PRESS	H_2 PRESS	FUEL CELL REAC	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O_2 HEATER TEMP	(R) MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS	RCS JET
H_2O LOOP	RGA/ACCEL	AIR DATA (R)	(R) LEFT RCS	RIGHT RCS
———	LEFT RHC (R)	RIGHT/AFT RHC	LEFT OMS (R)	(R) RIGHT OMS
PAYLOAD WARNING (R)	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	———
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

GNC Caution and Warning Lights on Panel F7

GNC Summary Data

- GNC systems determine the current state of motion of the vehicle, compute actions to change its state of motion, and apply corrective maneuvers to achieve the change.

- GNC elements are navigation and flight control system hardware and digital autopilot software.

- A bad orbiter navigation state can degrade flight control, since navigation data are used to set control gains and choose control effectors.

- Navigation hardware includes: (1) IMUs, which sense vehicle orientation and accelerations; (2) star trackers, which sense vehicle line of sight vectors; (3) COAS, which allows the crew to manually determine line of sight vectors; (4) TACAN, which senses vehicle position with respect to a ground based station; (5) GPS, which senses satellite ranging signals to determine orbiter position and velocity; (6) air data system, which senses temperature and pressure; (7) MLS, which senses vehicle position with respect to a ground-based station along the runway; and (8) radar altimeters.

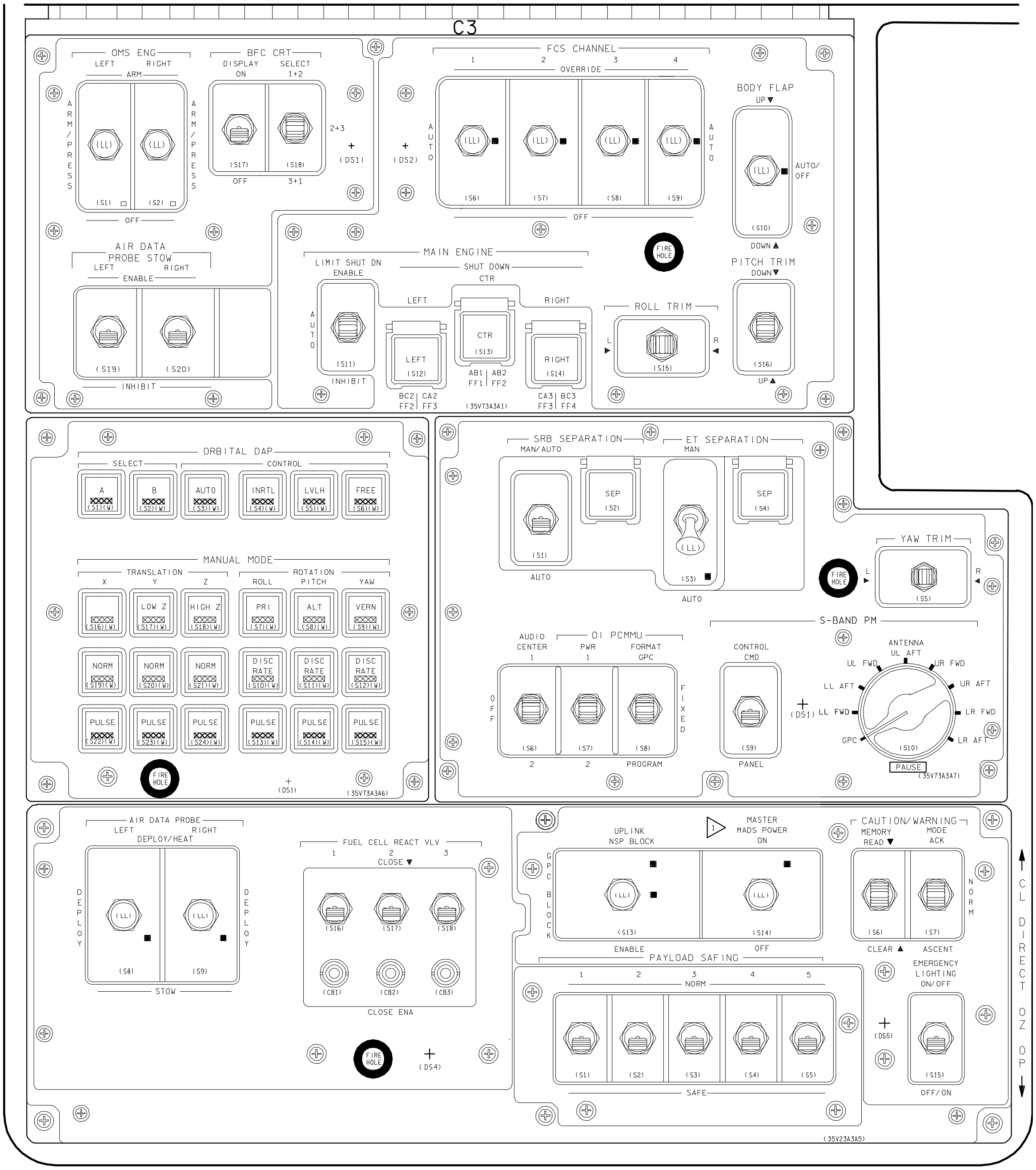
- The flight control system hardware includes four accelerometer assemblies, four orbiter rate gyro assemblies, four SRB rate gyro assemblies, rotational and translational hand controllers, rudder pedal transducer assemblies, two speed brake/thrust controllers, two body flap switches, panel trim switches, aerosurface servoamplifiers, and ascent thrust vector control.

- DAP software interprets maneuver requests, compares them to what the vehicle is doing, and generates commands for the appropriate effectors.

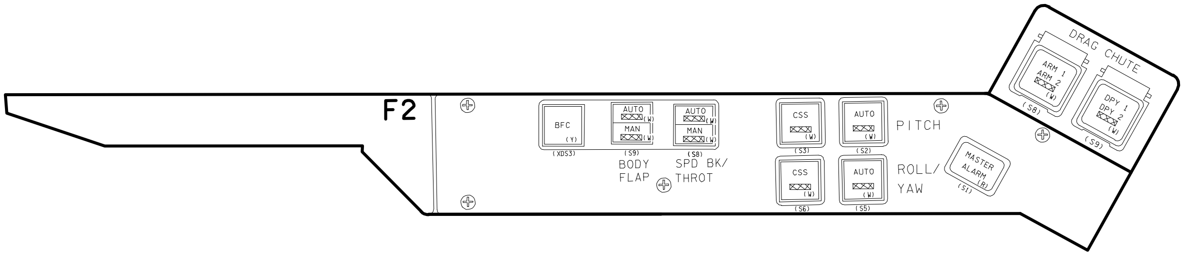
- Different DAPs function during different flight phases. Transition DAP (TRANSDAP) becomes active at MECO; orbit DAP includes an RCS DAP, an OMS TVC DAP, and an attitude processor module. TRANSDAP is used again for the deorbit burn until EI-5 minutes. Aerojet DAP is used from EI-5 until wheel stop on landing.

- Primary GNC-related switches and pushbuttons are located on panels C3, A6U, F2, F3, and F4. Other switches, pushbuttons, and circuit breakers are located on the following: F6, F7, F8, O5, O6, O7, O8, O9, O14, O15, O16, O17, and L1.

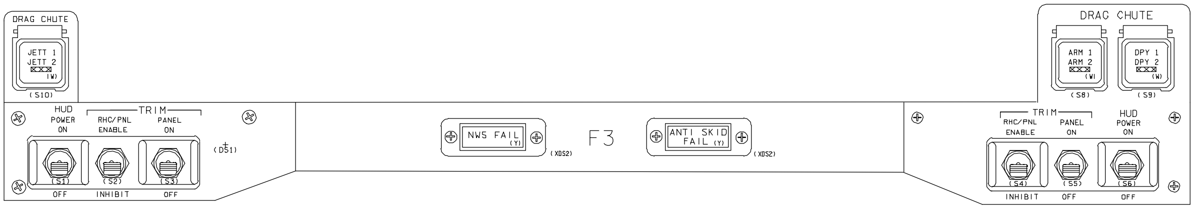
- GNC-related information and crew access are provided by several displays: GNC SYS SUMM 1, IMU ALIGN, GND IMU CNTL/MON, S TRK/COAS CNTL, HORIZ SIT, MNVR, UNIV PTG, DAP CONFIG, PASS ASCENT TRAJ 1, *PASS ASCENT TRAJ 2, BFS ASCENT TRAJ 1,* BFS ASCENT TRAJ 2, REL NAV, ORBIT TGT, ENTRY TRAJ 1-5, VERT SIT 1, VERT SIT 2, and GPS STATUS.


C3
OMS ENG
LEFT
RIGHT
ARM
ARM/PRESS
(LL)
(S1)
(S2)
OFF
BFC CRT
DISPLAY
ON
SELECT
1+2
2+3
3+1
(S17)
(S18)
(DS1)
(DS2)
FCS CHANNEL
1
2
3
4
OVERRIDE
AUTO
(S6)
(S7)
(S8)
(S9)
BODY FLAP
UP
AUTO/OFF
(S10)
DOWN
AIR DATA
PROBE STOW
ENABLE
(S19)
(S20)
INHIBIT
MAIN ENGINE
LIMIT SHUT DN
SHUT DOWN
CTR
LEFT
RIGHT
(S11)
(S12)
(S13)
(S14)
BC2 FF2
CA2 FF3
AB1 FF1
AB2 FF2
CA3 FF3
BC3 FF4
(35V73A3A1)
FIRE HOLE
ROLL TRIM
L
R
(S15)
PITCH TRIM
(S16)
ORBITAL DAP
SELECT
CONTROL
A
B
AUTO
INRTL
LVLH
FREE
MANUAL MODE
TRANSLATION
X
Y
Z
ROTATION
ROLL
PITCH
YAW
LOW Z
HIGH Z
PRI
ALT
VERN
NORM
DISC RATE
PULSE
(35V73A3A6)
SRB SEPARATION
MAN/AUTO
SEP
ET SEPARATION
MAN
YAW TRIM
(S5)
OI PCMMU
AUDIO CENTER
PWR
FORMAT
GPC
OFF
FIXED
PROGRAM
S-BAND PM
CONTROL
CMD
PANEL
ANTENNA
UL AFT
UL FWD
UR FWD
LL AFT
UR AFT
LL FWD
LR FWD
GPC
LR AFT
PAUSE
(35V73A3A7)
AIR DATA PROBE
DEPLOY/HEAT
DEPLOY
STOW
FUEL CELL REACT VLV
CLOSE
CLOSE ENA
(CB1)
(CB2)
(CB3)
(DS4)
UPLINK
NSP BLOCK
GPC BLOCK
MASTER MADS POWER
ON
ENABLE
OFF
CAUTION/WARNING
MEMORY READ
MODE ACK
NORM
CLEAR
ASCENT
PAYLOAD SAFING
SAFE
EMERGENCY LIGHTING ON/OFF
OFF/ON
(DS5)
CL DIRECT OZ OP
(35V23A3A5)

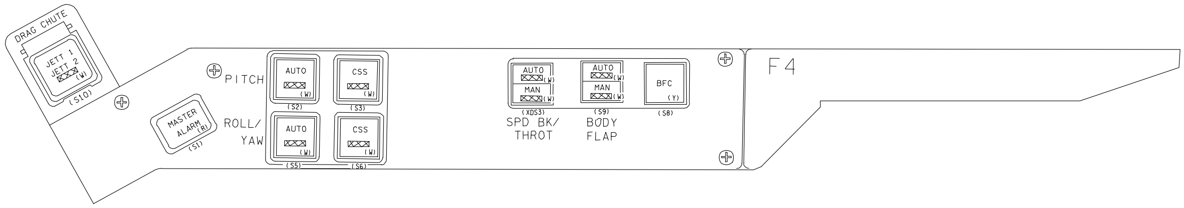
Panel C3



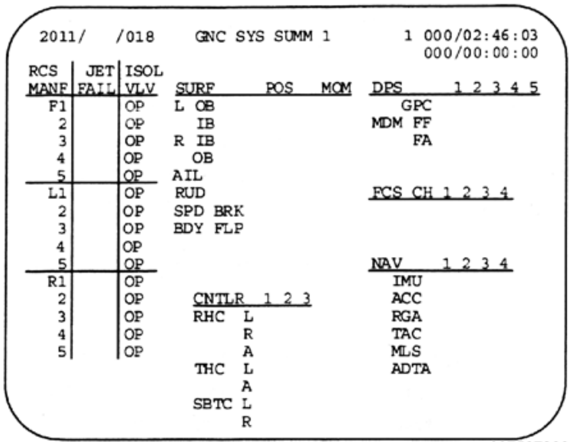
Panel F2



Panel F3



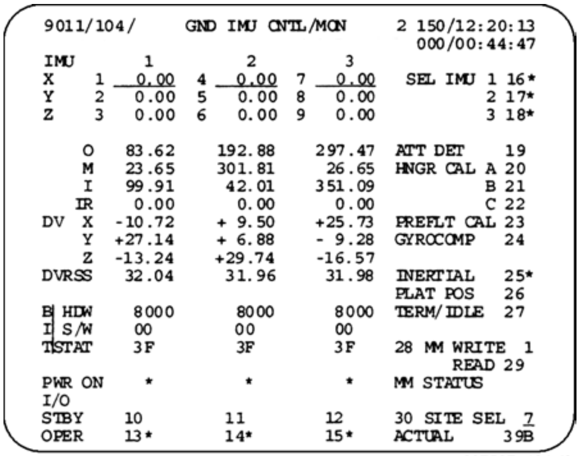
Panel F4



```
2011/   /018    GNC SYS SUMM 1        1 000/02:46:03
                                        000/00:00:00
RCS | JET|ISOL
MANF|FAIL|VLV  SURF      POS  MOM   DPS       1 2 3 4 5
  F1|    |OP   L OB                    GPC
   2|    |OP     IB                 MDM FF
   3|    |OP   R IB                       FA
   4|    |OP     OB
   5|    |OP   AIL
  L1|    |OP   RUD                  FCS CH 1 2 3 4
   2|    |OP   SPD BRK
   3|    |OP   BDY FLP
   4|    |OP
   5|    |OP                        NAV     1 2 3 4
  R1|    |OP                          IMU
   2|    |OP     CNTLR  1 2 3         ACC
   3|    |OP     RHC  L               RGA
   4|    |OP          R               TAC
   5|    |OP          A               MLS
                 THC  L               ADTA
                      A
                 SBTC L
                      R
```

usa007587203

GNC SYS SUMM 1 Display

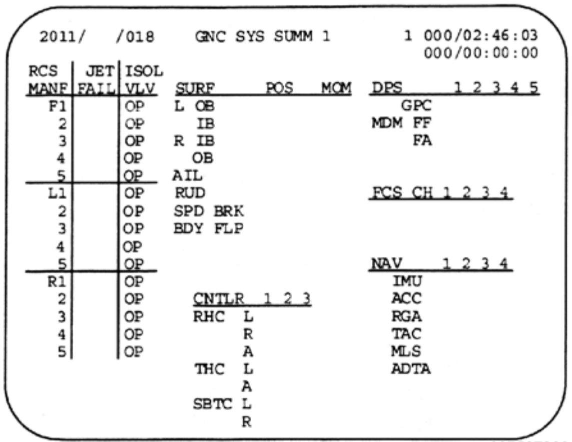


```
9011/104/      GND IMU CNTL/MON      2 150/12:20:13
                                       000/00:44:47
IMU          1          2          3
X     1 __0.00  4 __0.00  7 __0.00   SEL IMU 1 16*
Y     2   0.00  5   0.00  8   0.00           2 17*
Z     3   0.00  6   0.00  9   0.00           3 18*

     O    83.62     192.88     297.47  ATT DET     19
     M    23.65     301.81      26.65  HNGR CAL A 20
     I    99.91      42.01     351.09             B 21
    IR     0.00       0.00       0.00             C 22
DV   X   -10.72     + 9.50     +25.73  PREFLT CAL 23
     Y   +27.14     + 6.88     - 9.28  GYROCOMP   24
     Z   -13.24     +29.74     -16.57
DVRSS     32.04      31.96      31.98  INERTIAL   25*
                                       PLAT POS   26
B|HDW     8000       8000       8000   TERM/IDLE  27
I|S/W     00         00         00
TSTAT     3F         3F         3F     28 MM WRITE  1
                                             READ 29
PWR ON     *          *          *     MM STATUS
I/O
STBY      10         11         12     30 SITE SEL  7
OPER      13*        14*        15*    ACTUAL     39B
```

usa007587_464.tif

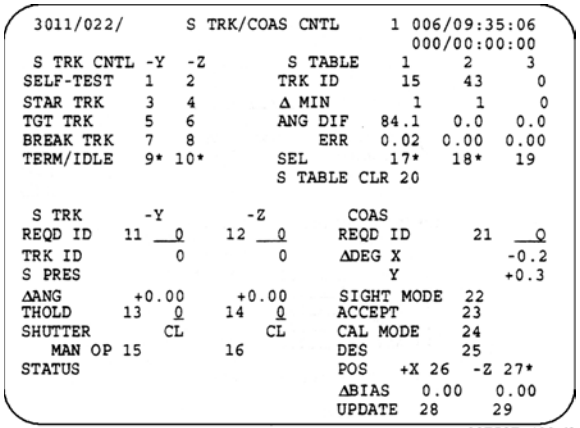
GND IMU CNTL/MON Display (SPEC 104)
(available on OPS 9 only)



```
2011/   /018    GNC SYS SUMM 1        1 000/02:46:03
                                        000/00:00:00
RCS | JET|ISOL
MANF|FAIL|VLV  SURF      POS  MOM   DPS       1 2 3 4 5
  F1|    |OP   L OB                    GPC
   2|    |OP     IB                 MDM FF
   3|    |OP   R IB                       FA
   4|    |OP     OB
   5|    |OP   AIL
  L1|    |OP   RUD                  FCS CH 1 2 3 4
   2|    |OP   SPD BRK
   3|    |OP   BDY FLP
   4|    |OP
   5|    |OP                        NAV     1 2 3 4
  R1|    |OP                          IMU
   2|    |OP     CNTLR  1 2 3         ACC
   3|    |OP     RHC  L               RGA
   4|    |OP          R               TAC
   5|    |OP          A               MLS
                 THC  L               ADTA
                      A
                 SBTC L
                      R
```

usa007587203

GNC SYS SUMM 1 Display
(Three-String GPS Vehicles)

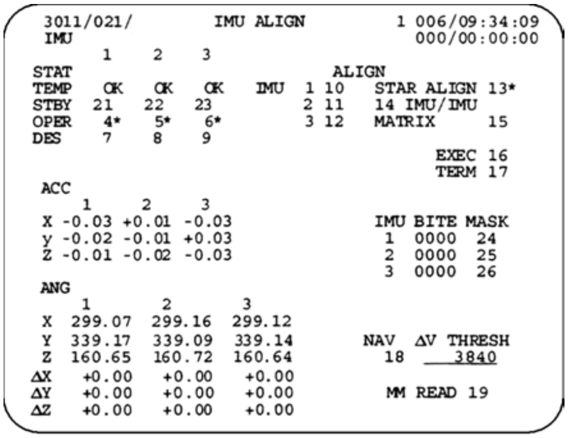


```
3011/022/      S TRK/COAS CNTL     1 006/09:35:06
                                     000/00:00:00
 S TRK CNTL -Y  -Z        S TABLE    1     2     3
SELF-TEST   1   2        TRK ID     15    43     0
STAR TRK    3   4        Δ MIN       1     1     0
TGT TRK     5   6        ANG DIF  84.1   0.0   0.0
BREAK TRK   7   8            ERR  0.02  0.00  0.00
TERM/IDLE   9* 10*       SEL       17*   18*    19
                         S TABLE CLR 20

 S TRK      -Y         -Z       COAS
REQD ID   11 __0    12 __0     REQD ID     21  __0
TRK ID          0          0   ΔDEG X            -0.2
S PRES                              Y            +0.3
ΔANG        +0.00      +0.00   SIGHT MODE  22
THOLD     13  0     14  0      ACCEPT      23
SHUTTER        CL         CL   CAL MODE    24
  MAN OP 15         16         DES         25
STATUS                         POS    +X 26  -Z 27*
                               ΔBIAS   0.00    0.00
                               UPDATE  28      29
```

usa007587_468.tif

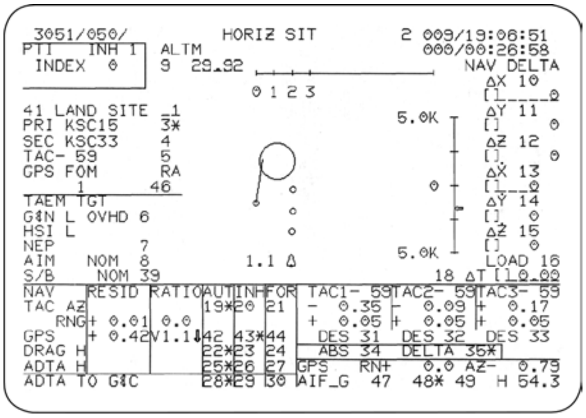
S TRK/COAS CNTL Display



```
3011/021/          IMU ALIGN         1 006/09:34:09
IMU                                    000/00:00:00
        1     2     3
STAT                             ALIGN
TEMP    OK    OK    OK    IMU  1 10   STAR ALIGN 13*
STBY   21    22    23          2 11   14 IMU/IMU
OPER    4*    5*    6*         3 12   MATRIX       15
DES     7     8     9
                                            EXEC 16
                                            TERM 17
 ACC
      1      2      3
 X -0.03 +0.01 -0.03                  IMU BITE MASK
 y -0.02 -0.01 +0.03                   1  0000  24
 Z -0.01 -0.02 -0.03                   2  0000  25
                                       3  0000  26
 ANG
      1        2        3
 X  299.07   299.16   299.12
 Y  339.17   339.09   339.14         NAV  ΔV THRESH
 Z  160.65   160.72   160.64          18  ___3840
ΔX    +0.00    +0.00    +0.00
ΔY    +0.00    +0.00    +0.00          MM READ 19
ΔZ    +0.00    +0.00    +0.00
```

usa007587_463.tif

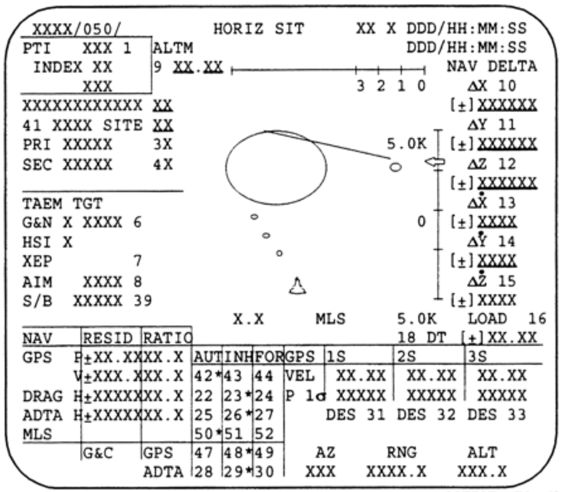
IMU ALIGN Display (SPEC 21)



```
3051/050/            HORIZ SIT         2 009/19:06:51
PTI   INH 1  ALTM                        000/00:26:58
 INDEX  0    9  29.92                       NAV DELTA
                                              ΔX 10
                    0 1 2 3                   [1_____0
41 LAND SITE _1                               ΔY 11
PRI KSC15     3*                   5.0K       []      0
SEC KSC33     4                               ΔZ 12
TAC- 59       5                               []      0
GPS FOM       RA                              ΔẊ 13
   1         46                      0        [1___0
TAEM TGT                                      ΔẎ 14
G&N L  OVHD 6                                 []   0
HSI L                                         ΔŻ 15
NEP           7                               []   0
AIM    NOM  8            1.1 Δ     5.0K       LOAD 16
S/B     NOM 39                            18 ΔT [10.00
NAV     RESID  RATIO AUT INH FOR  TAC1- 59 TAC2- 59 TAC3- 59
TAC AZ               19* 20  21   -  0.35  -  0.09  +  0.17
    RNG + 0.01  0.0                +  0.05  +  0.05  +  0.05
GPS     + 0.42 V1.1↓ 42  43* 44    DES 31   DES 32   DES 33
DRAG H               22* 23  24    ABS 34   DELTA 35*
ADTA H               25* 26  27   GPS   RN+    0.0 AZ-  0.79
ADTA TO G&C          28* 29  30   AIF_G  47   48*  49  H 54.3
```

10013.tif

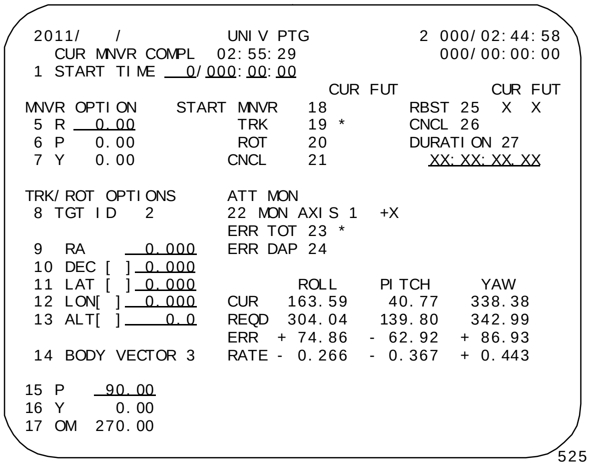
HORIZ SIT Display (SPEC 50)
(Three-String TACAN Vehicles)



```
 XXXX/050/            HORIZ SIT      XX X DDD/HH:MM:SS
PTI   XXX 1 ALTM                          DDD/HH:MM:SS
 INDEX XX   9 XX.XX                         NAV DELTA
      XXX                      3 2 1 0        ΔX 10
XXXXXXXXXXXX XX                             [±]XXXXXX
41 XXXX SITE XX                               ΔY 11
PRI XXXXX    3X                       5.0K  [±]XXXXXX
SEC XXXXX    4X                               ΔZ 12
                                            [±]XXXXXX
TAEM TGT                                      ΔẊ 13
G&N X XXXX 6                             0  [±]XXXX
HSI X                                         ΔẎ 14
XEP         7                               [±]XXXX
AIM   XXXX 8                                  ΔŻ 15
S/B  XXXXX 39                               [±]XXXX
                   X.X       MLS      5.0K   LOAD   16
NAV    RESID RATIO                    18 DT  [±]XX.XX
GPS   P±XX.XXXX.X AUTINHFORGPS 1S        2S        3S
      V±XXX.XXX.X 42*43 44 VEL  XX.XX    XX.XX    XX.XX
DRAG  H±XXXXXXX.X 22 23*24 P 1σ XXXXX    XXXXX    XXXXX
ADTA  H±XXXXXXX.X 25 26*27     DES 31   DES 32   DES 33
MLS               50*51 52
       G&C   GPS  47 48*49     AZ       RNG       ALT
            ADTA  28 29*30     XXX     XXXX.X     XXX.X
```

usa007587_479a.tif

HORIZ SIT Display (SPEC 50)
(Three-string GPS Vehicles)



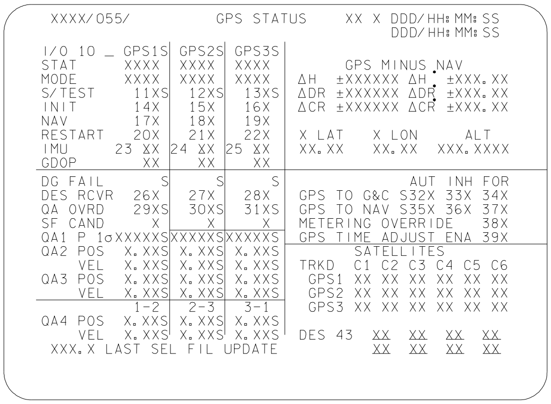
```
 2011/    /                 UNIV PTG              2 000/02:44:58
   CUR MNVR COMPL  02:55:29                         000/00:00:00
 1 START TIME    0/000:00:00
                                     CUR FUT                CUR FUT
MNVR OPTION    START MNVR    18               RBST 25   X   X
 5 R    0.00         TRK     19 *             CNCL 26
 6 P    0.00         ROT     20               DURATION 27
 7 Y    0.00        CNCL     21                 XX:XX:XX.XX

TRK/ROT OPTIONS     ATT MON
 8 TGT ID   2       22 MON AXIS 1   +X
                    ERR TOT 23 *
 9  RA      0.000   ERR DAP 24
 10 DEC [ ] 0.000
 11 LAT [ ] 0.000            ROLL      PITCH      YAW
 12 LON[ ]  0.000   CUR    163.59      40.77    338.38
 13 ALT[ ]    0.0   REQD   304.04     139.80    342.99
                    ERR  + 74.86   - 62.92   + 86.93
 14 BODY VECTOR 3   RATE - 0.266   - 0.367   + 0.443

15 P     90.00
16 Y      0.00
17 OM   270.00
```

525

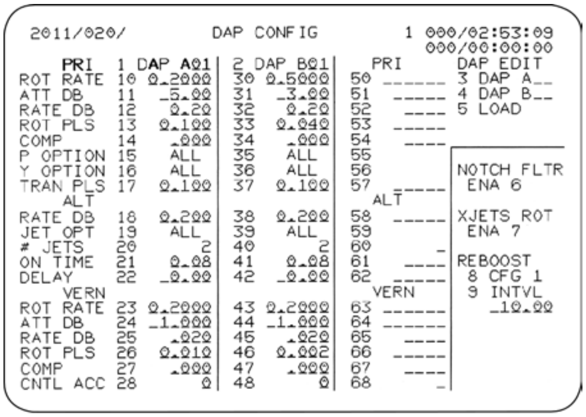
UNIV PTG Display



```
  XXXX/055/           GPS STATUS    XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS
 I/O 10 _ GPS1S GPS2S GPS3S
 STAT      XXXX  XXXX  XXXX          GPS MINUS NAV
 MODE      XXXX  XXXX  XXXX    ΔH  ±XXXXXX ΔḢ  ±XXX.XX
 S/TEST     11XS  12XS  13XS   ΔDR ±XXXXXX ΔḊR ±XXX.XX
 INIT       14X   15X   16X    ΔCR ±XXXXXX ΔĊR ±XXX.XX
 NAV        17X   18X   19X
 RESTART    20X   21X   22X    X LAT   X LON     ALT
 IMU     23 XX 24 XX 25 XX     XX.XX   XX.XX   XXX.XXXX
 GDOP        XX    XX    XX
 DG FAIL      S     S     S                AUT INH FOR
 DES RCVR   26X   27X   28X    GPS TO G&C S32X 33X 34X
 QA OVRD   29XS  30XS  31XS    GPS TO NAV S35X 36X 37X
 SF CAND      X     X     X    METERING OVERRIDE   38X
 QA1 P 1σXXXXXSXXXXXSXXXXXS    GPS TIME ADJUST ENA 39X
 QA2 POS   X.XXS X.XXS X.XXS          SATELLITES
     VEL   X.XXS X.XXS X.XXS   TRKD  C1 C2 C3 C4 C5 C6
 QA3 POS   X.XXS X.XXS X.XXS    GPS1 XX XX XX XX XX XX
     VEL   X.XXS X.XXS X.XXS    GPS2 XX XX XX XX XX XX
             1-2   2-3   3-1    GPS3 XX XX XX XX XX XX
 QA4 POS   X.XXS X.XXS X.XXS
     VEL   X.XXS X.XXS X.XXS   DES 43  XX  XX  XX  XX
  XXX.X LAST SEL FIL UPDATE            XX  XX  XX  XX
```

007587051.CRT;1

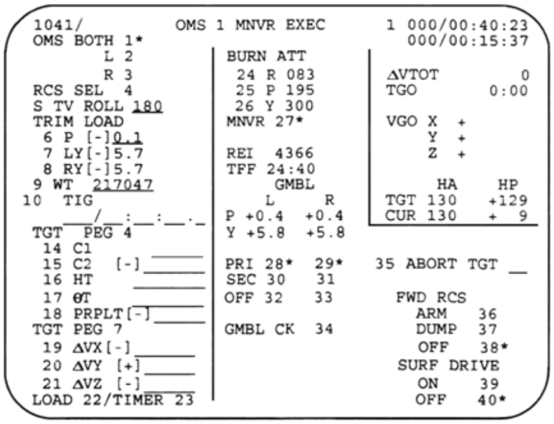
GPS STATUS Display (SPEC 55)



```
 2011/020/           DAP CONFIG          1 000/02:53:09
                                           000/00:00:00
      PRI    1 DAP A01 | 2 DAP B01 |    PRI       DAP EDIT
ROT RATE  10  0.2000 | 30  0.5000 | 50 ______  3 DAP A__
ATT DB    11   _5.00 | 31   _3.00 | 51  _____  4 DAP B__
RATE DB   12    0.20 | 32    0.20 | 52   ____  5 LOAD
ROT PLS   13   0.100 | 33   0.040 | 53  _____
COMP      14    .000 | 34    .000 | 54   ____
P OPTION  15     ALL | 35     ALL | 55
Y OPTION  16     ALL | 36     ALL | 56          NOTCH FLTR
TRAN PLS  17   0.100 | 37   0.100 | 57  _____    ENA 6
     ALT                               ALT
RATE DB   18   0.200 | 38   0.200 | 58  _____  XJETS ROT
JET OPT   19     ALL | 39     ALL | 59           ENA 7
# JETS    20       2 | 40       2 | 60      _
ON TIME   21    0.08 | 41    0.08 | 61   ____  REBOOST
DELAY     22   _0.00 | 42   _0.00 | 62  _____   8 CFG 1
     VERN                              VERN      9 INTVL
ROT RATE  23  0.2000 | 43  0.2000 | 63 ______     _10.00
ATT DB    24  _1.000 | 44  _1.000 | 64 ______
RATE DB   25    .020 | 45    .020 | 65   ____
ROT PLS   26   0.010 | 46   0.002 | 66  _____
COMP      27    .000 | 47    .000 | 67   ____
CNTL ACC  28       0 | 48       0 | 68      _
```

522.tif

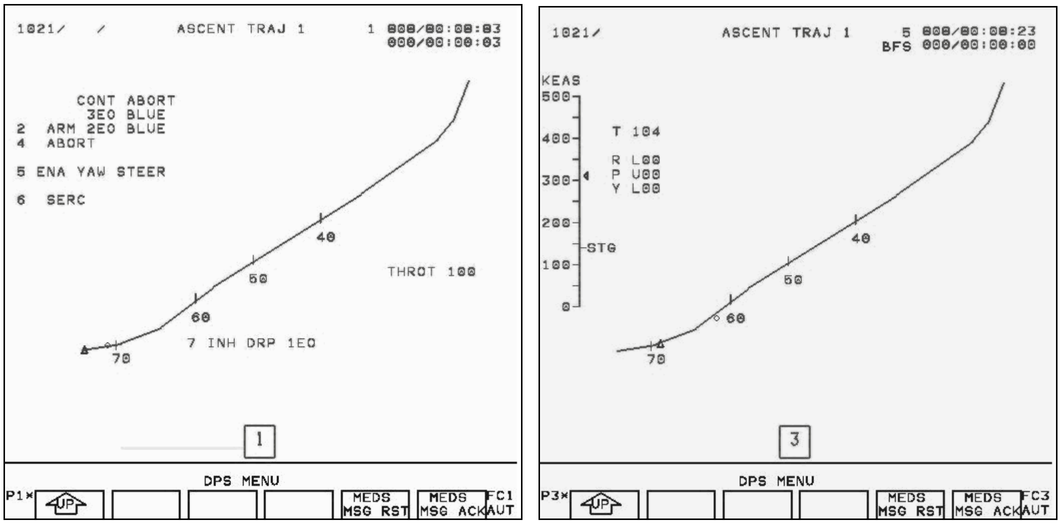
DAP CONFIG Display



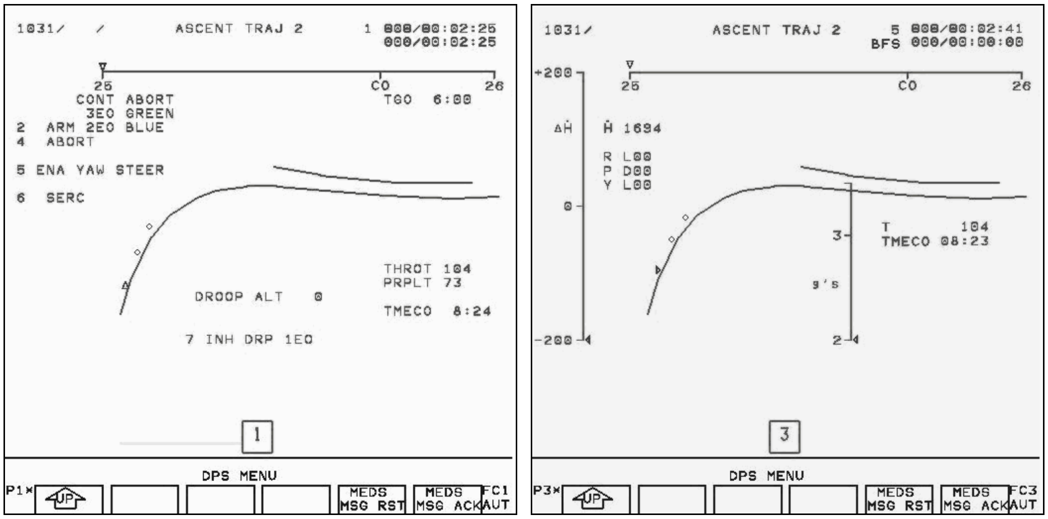
```
 1041/          OMS 1 MNVR EXEC         1 000/00:40:23
 OMS BOTH 1*                              000/00:15:37
        L 2       BURN ATT
        R 3        24 R 083        ΔVTOT          0
 RCS SEL  4        25 P 195        TGO         0:00
 S TV ROLL 180     26 Y 300
 TRIM LOAD        MNVR 27*         VGO X  +
  6 P [-]0.1                           Y  +
  7 LY[-]5.7      REI   4366           Z  +
  8 RY[-]5.7      TFF 24:40
 9 WT  217047           GMBL              HA     HP
10  TIG                 L      R   TGT 130    +129
     ____/__:__:__._  P +0.4  +0.4  CUR 130    +  9
 TGT  PEG 4         Y +5.8  +5.8
  14 C1       ______
  15 C2  [-]________  PRI 28*  29*   35 ABORT TGT __
  16 HT     ________  SEC 30   31
  17 θT     ________  OFF 32   33       FWD RCS
  18 PRPLT[-]_______                      ARM    36
 TGT PEG 7            GMBL CK  34         DUMP   37
  19 ΔVX[-]_______                        OFF    38*
  20 ΔVY [+]______                     SURF DRIVE
  21 ΔVZ [-]______                        ON     39
 LOAD 22/TIMER 23                         OFF    40*
```

usa007587_526.tif

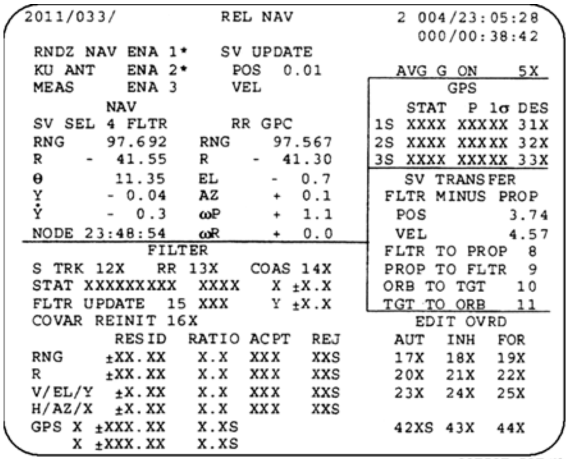
MNVR Display



PASS and BFS ASCENT TRAJ 1 Displays



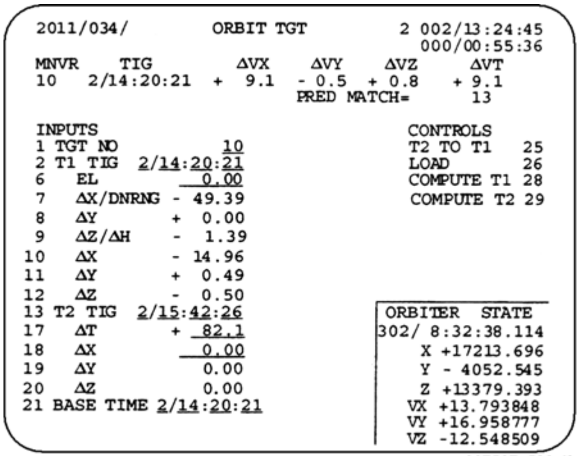
PASS and BFS ASCENT TRAJ 2 Displays



```
2011/033/           REL NAV           2 004/23:05:28
                                        000/00:38:42
 RNDZ NAV ENA 1*    SV UPDATE
 KU ANT   ENA 2*     POS  0.01        AVG G ON    5X
 MEAS     ENA 3      VEL                   GPS
        NAV                             STAT  P 1σ DES
 SV SEL 4 FLTR       RR GPC           1S XXXX XXXXX 31X
 RNG     97.692   RNG     97.567      2S XXXX XXXXX 32X
 R    -  41.55    R    -  41.30       3S XXXX XXXXX 33X
 θ       11.35    EL      -  0.7        SV TRANSFER
 Y      - 0.04    AZ      +  0.1       FLTR MINUS PROP
 Ẏ      -  0.3    ωP      +  1.1        POS         3.74
 NODE 23:48:54    ωR      +  0.0        VEL         4.57
            FILTER                     FLTR TO PROP  8
 S TRK 12X   RR 13X   COAS 14X         PROP TO FLTR  9
 STAT XXXXXXXXX   XXXX    X ±X.X       ORB TO TGT   10
 FLTR UPDATE  15 XXX      Y ±X.X       TGT TO ORB   11
 COVAR REINIT 16X                         EDIT OVRD
          RESID   RATIO ACPT   REJ       AUT  INH  FOR
 RNG     ±XX.XX    X.X  XXX    XXS       17X  18X  19X
 R       ±XX.XX    X.X  XXX    XXS       20X  21X  22X
 V/EL/Y   ±X.XX    X.X  XXX    XXS       23X  24X  25X
 H/AZ/X   ±X.XX    X.X  XXX    XXS
 GPS X  ±XXX.XX    X.XS                  42XS 43X  44X
     X  ±XXX.XX    X.XS
```

usa007587_527.tif

REL NAV Display

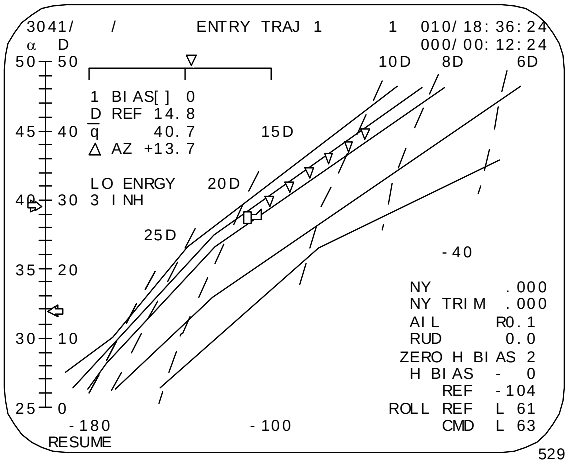


```
 2011/034/        ORBIT TGT        2 002/13:24:45
                                     000/00:55:36
 MNVR    TIG         ΔVX     ΔVY     ΔVZ      ΔVT
 10   2/14:20:21  +  9.1   - 0.5   + 0.8     + 9.1
                            PRED MATCH=       13

 INPUTS                                CONTROLS
 1 TGT NO               10             T2 TO T1    25
 2 T1 TIG   2/14:20:21                 LOAD        26
 6   EL               0.00             COMPUTE T1  28
 7   ΔX/DNRNG  -  49.39                COMPUTE T2  29
 8   ΔY        +   0.00
 9   ΔZ/ΔH     -   1.39
10   ΔX        -  14.96
11   ΔY        +   0.49
12   ΔZ        -   0.50
13 T2 TIG   2/15:42:26                ORBITER  STATE
17   ΔT        +  82.1               302/ 8:32:38.114
18   ΔX           0.00                   X +17213.696
19   ΔY           0.00                   Y - 4052.545
20   ΔZ           0.00                   Z +13379.393
21 BASE TIME 2/14:20:21                 VX +13.793848
                                        VY +16.958777
                                        VZ -12.548509
```

usa007587_528.tif

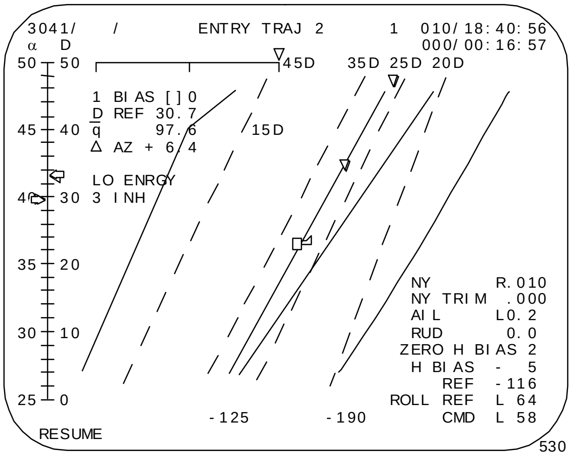
ORBIT TGT Display



```
3041/    /        ENTRY TRAJ 1       1  010/18:36:24
 α  D                                   000/00:12:24
   1 BIAS[ ] 0
   D REF 14.8
   q̄       40.7
   Δ AZ +13.7

   LO ENRGY
   3 INH
                                  NY          .000
                                  NY TRIM     .000
                                  AIL         R0.1
                                  RUD          0.0
                                ZERO H BIAS 2
                                  H BIAS  -    0
                                      REF   -104
                               ROLL REF   L 61
                                      CMD   L 63
 RESUME
```

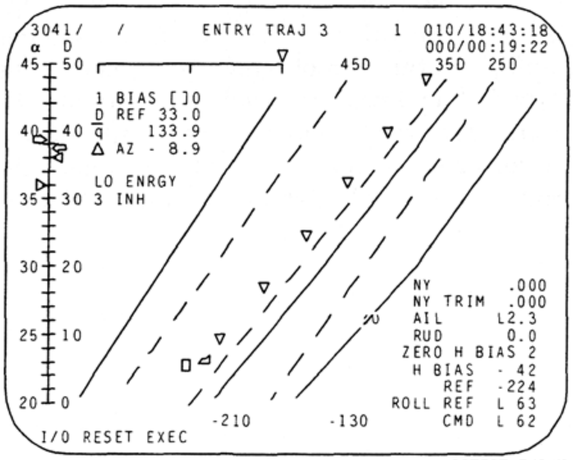
ENTRY TRAJ 1 Display



```
3041/    /        ENTRY TRAJ 2       1  010/18:40:56
 α  D                                   000/00:16:57
   1 BIAS [ ]0
   D REF 30.7
   q̄       97.6
   Δ AZ + 6.4

   LO ENRGY
   3 INH
                                  NY         R.010
                                  NY TRIM     .000
                                  AIL         L0.2
                                  RUD          0.0
                                ZERO H BIAS 2
                                  H BIAS  -    5
                                      REF   -116
                               ROLL REF   L 64
                                      CMD   L 58
 RESUME
```

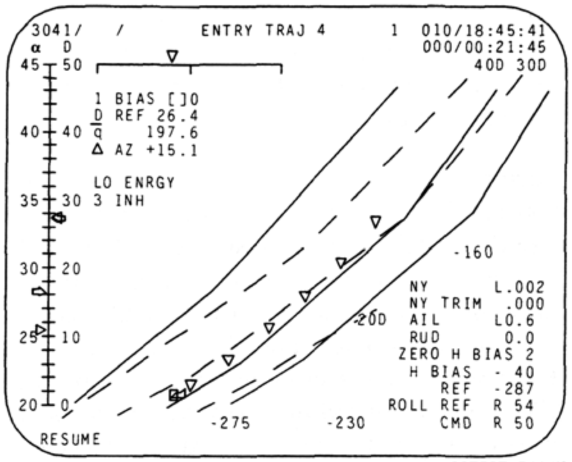
ENTRY TRAJ 2 Display



```
3041/    /        ENTRY TRAJ 3       1  010/18:43:18
 α  D                                   000/00:19:22
   1 BIAS [ ]0
   D REF 33.0
   q̄      133.9
   Δ AZ - 8.9
   LO ENRGY
   3 INH
                                  NY          .000
                                  NY TRIM     .000
                                  AIL         L2.3
                                  RUD          0.0
                                ZERO H BIAS 2
                                  H BIAS  -   42
                                      REF   -224
                               ROLL REF   L 63
                                      CMD   L 62
 I/O RESET EXEC
```

usa007587_540.tif

ENTRY TRAJ 3 Display



```
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                                       000/00:21:45
     1 BIAS []0
     D REF 26.4
     q      197.6
     Δ AZ +15.1

     LO ENRGY
     3 INH
                                   NY          L.002
                                   NY TRIM      .000
                                   AIL         L0.6
                                   RUD          0.0
                                   ZERO H BIAS 2
                                   H BIAS      - 40
                                   REF         -287
                                   ROLL REF    R 54
                                   CMD         R 50
RESUME
```
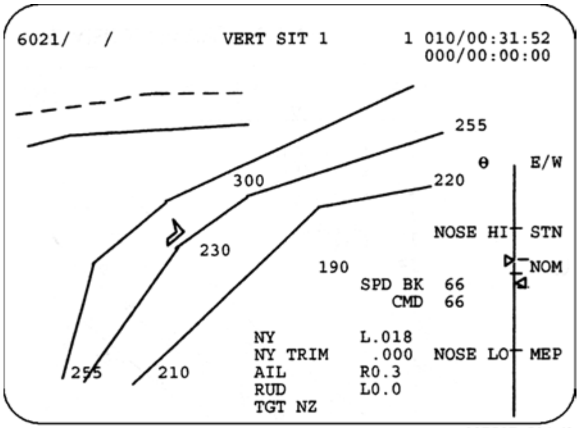

usa007587_541.tif

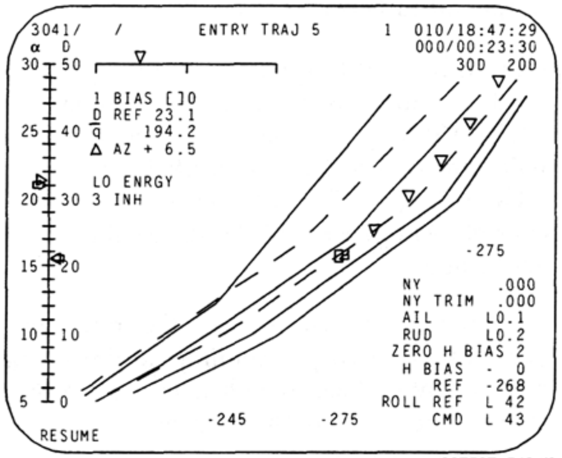
ENTRY TRAJ 4 Display



```
6021/   /          VERT SIT 1       1 010/00:31:52
                                      000/00:00:00
                                SPD BK  66
                                   CMD  66
                   NY          L.018
                   NY TRIM      .000
                   AIL         R0.3
                   RUD         L0.0
                   TGT NZ
```

usa007587_531.tif

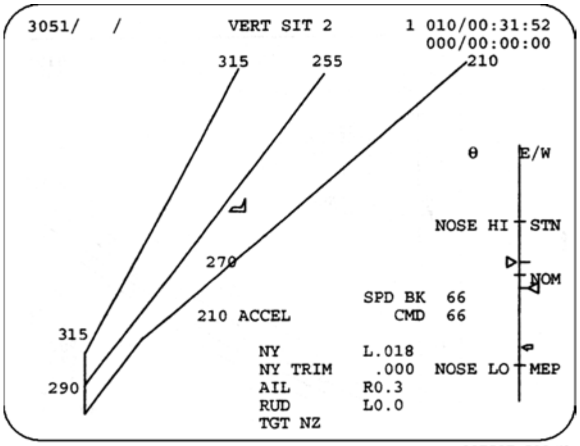
VERT SIT 1 Display



```
3041/   /        ENTRY TRAJ 5       1  010/18:47:29
                                       000/00:23:30
     1 BIAS []0
     D REF 23.1
     q      194.2
     Δ AZ + 6.5

     LO ENRGY
     3 INH
                                   NY           .000
                                   NY TRIM      .000
                                   AIL         L0.1
                                   RUD         L0.2
                                   ZERO H BIAS 2
                                   H BIAS      -  0
                                   REF         -268
                                   ROLL REF    L 42
                                   CMD         L 43
RESUME
```

usa007587_542.tif

ENTRY TRAJ 5 Display



```
3051/   /          VERT SIT 2       1 010/00:31:52
                                      000/00:00:00
               210 ACCEL        SPD BK  66
                                   CMD  66
                   NY          L.018
                   NY TRIM      .000
                   AIL         R0.3
                   RUD         L0.0
                   TGT NZ
```

usa007587_532.tif

VERT SIT 2 Display

GNC Rules of Thumb

- The PASS FDIR for the RGAs, AAs, and aerosurfaces terminates after the first failure. After the first failure, crew management of the selection filter is required. However, PASS has an RGA SMRD FDIR that will continue to deselect any power failed RGAs. For the BFS selection filter, crew management is always required. Proper selection filter management is required for proper control.

- For FCS channel management:

  - Never have more active channels on one GPC than another.

  - If there are two failures on the same actuator, take the remaining FCS channels to OVERRIDE.

  - Always maintain two good commands and one good feedback on each aerosurface.

  - Delay 2 seconds between switch throws when moving FCS CHANNEL switches. Port bypass, or port pop, is a mechanical means to avoid force fights; feedback deselection is a software means to avoid a bad input into the selection filter.

- For ascent, only the pilot's SBTC is active. To get manual throttles, the pilot must depress the TAKEOVER button and then match the commanded throttle setting. Manual rotational control is available only in PASS and must be both pitch and roll/yaw.

- For entry, both SBTCs are active. To get manual speed brake, the CDR or pilot must depress the TAKEOVER button. Manual rotational control is available in either pitch or bank in PASS and is required in both axes in BFS.

- For TACAN and ADTA management, talk to MCC before incorporating.

2.14 LANDING/DECELERATION SYSTEM

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Landing/Deceleration System Rules of Thumb 2.14-17

Description

The orbiter, unlike previous space vehicles, lands on a runway using a conventional type of landing system. Once the orbiter touches down, the crew deploys the drag chute, begins braking, and starts nose wheel steering operations.

The orbiter drag chute, first used on the maiden flight of OV-105, improves the orbiter's deceleration and eases the loads on the landing gear and brakes.

Braking is accomplished by a sophisticated system that uses electrohydraulic disk brakes with an anti-skid system. Only the two main gear sets have braking capability, and each can be operated separately.

Three primary steering options are available. The crew can use the rudder to assist steering while at higher ground speeds. By selecting nose wheel steering, the crew can use the rudder pedal assembly to operate a hydraulic steering actuator incorporated in the nose landing gear. By applying variable pressure to the brakes, the crew can steer the vehicle by a method called differential braking.

Landing Gear

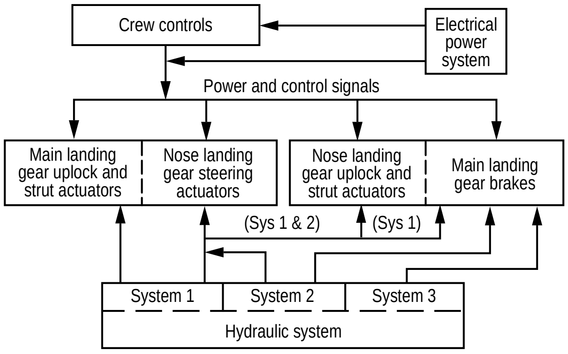
The orbiter landing gear system is a tricycle configuration consisting of a nose landing gear and a left and right main landing gear. The nose landing gear is located in the lower forward fuselage, and the main landing gear is in the lower left and right wing area adjacent to the midfuselage. Each landing gear includes a shock strut with two wheel and tire assemblies. Each main landing gear wheel is equipped with a brake assembly with anti-skid protection.

Landing Gear Doors

The nose landing gear has two doors, and each main gear has one door. When the crew commands gear deployment, the doors open automatically as the gear is dropped. This is accomplished by the door extend/retract mechanism, which is actuated by the dropping gear. The nose landing gear doors have two door hooks that hold the doors closed, and the main gear doors have four door hooks.

In addition, the doors have door-assist bungee assemblies. These assemblies exert additional force on the inside of the doors to assist in door deployment to overcome the aerodynamic forces acting against the doors and/or in case the pressure inside the wheel wells is less than the outside pressure. The nose landing gear bungee assist assemblies exert 2,000 pounds of force on the doors; the main landing gear bungee assist assemblies exert approximately 5,000 pounds of force on the doors over the first 2 inches of travel.

The nose landing gear also contains a pyro boost system to further assure nose gear door and gear extension in case high aerodynamic forces on the nose gear door are present. This pyro system is fired each time the landing gear is deployed.



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Landing/Deceleration Interfaces

Each of the landing gear doors has high-temperature reusable surface insulation tiles on the outer surface and a thermal barrier or door seal to protect the landing gear from the high temperatures encountered during reentry.

Gear Retraction

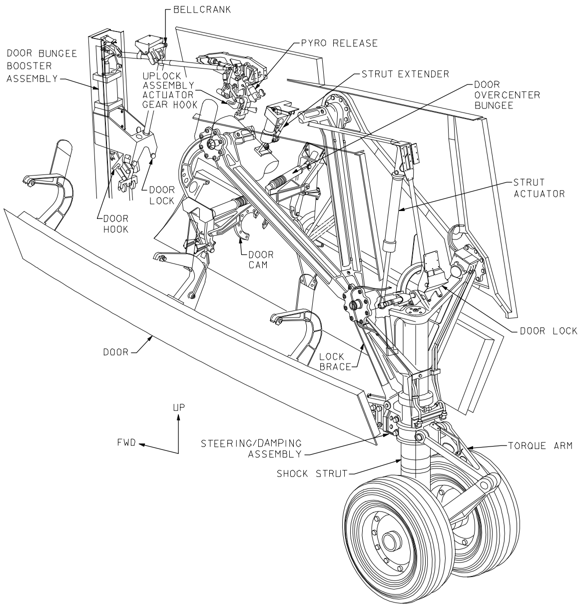
During retraction, each gear is hydraulically rotated forward and up by ground support equipment until it engages an uplock hook for each gear in its respective wheel well. The uplock hook locks onto a roller on each strut. A mechanical linkage driven by each landing gear mechanically closes each landing gear door.

The nose landing gear is retracted forward and up into the lower forward fuselage and is enclosed by two doors. The main landing gear is also retracted forward and up into the left and right lower wing area, and each is enclosed with a single door. The nose and main landing gear can be retracted only during ground operations.

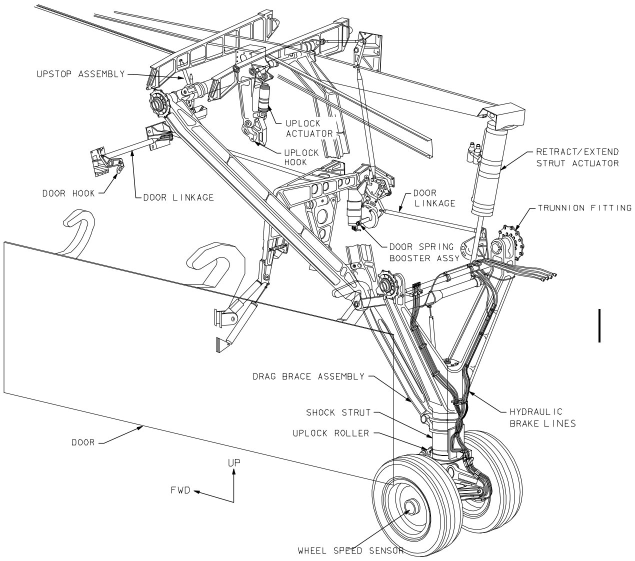
Gear Deployment

When deployment of the landing gear is commanded by the crew, the uplock hook for each gear is unlocked by hydraulic system 1 pressure. (See Section 2.1 for more information on orbiter hydraulic systems.) Once the hook is released from the roller on the strut, the gear is driven down and aft by springs, hydraulic actuators, aerodynamic forces, and gravity. A mechanical linkage released by each gear actuates the doors to the open position. The landing gear *reaches* the full-down and extended position within 10 seconds and are locked in the down position by spring-loaded downlock bungees. If hydraulic system 1 pressure is not available to release the uplock hook, a pyrotechnic initiator at each landing gear uplock hook automatically releases the uplock hook on each gear 1 second after the flight crew has commanded gear down.

The landing gear is deployed at 300 ± 100 feet and at a maximum of 312 knots equivalent airspeed (KEAS).



Nose Landing Gear Deployed



Main Landing Gear Deployed

Shock Struts

The shock strut of each landing gear is the primary source of impact attenuation at landing. The struts have air/oil shock absorbers to control the rate of compression/extension and prevent damage to the vehicle by controlling load application rates and peak values.

Each landing gear shock strut assembly is constructed of high-strength, stress- and corrosion-resistant steel alloys, aluminum alloys, stainless steel, and aluminum bronze. The shock strut is a pneumatic-hydraulic shock absorber containing gaseous nitrogen and hydraulic fluid. Because the shock strut is subjected to zero-g conditions during space flight, a floating piston separates the gaseous nitrogen from the hydraulic fluid to maintain absorption integrity.

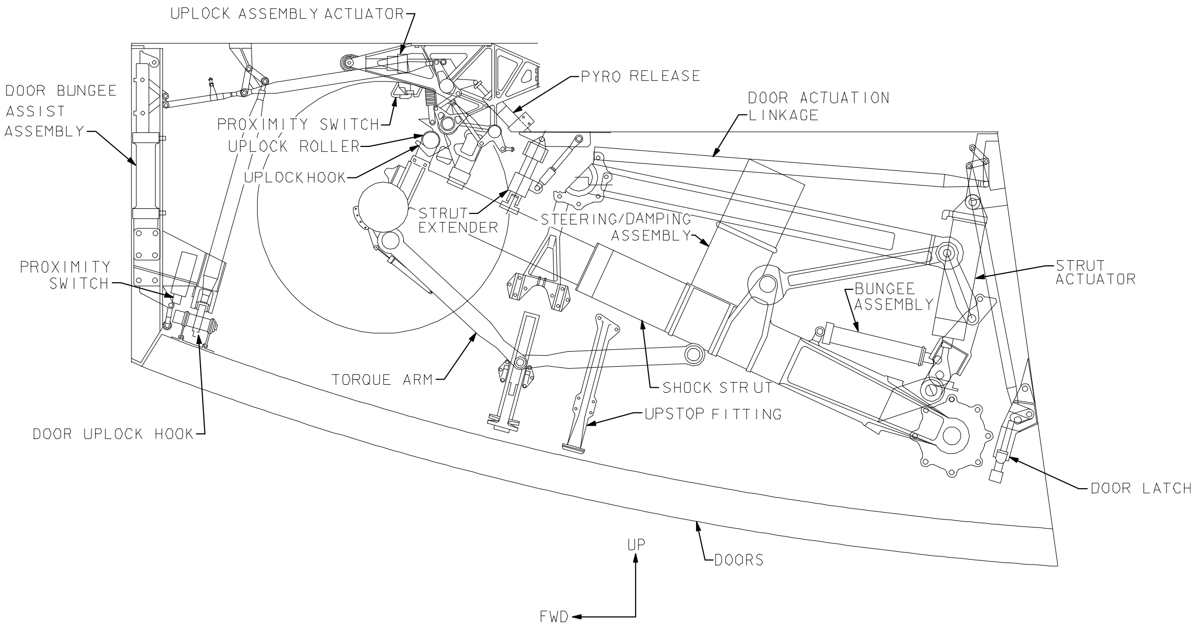
The nose landing gear shock strut has a 22-inch stroke. The maximum allowable derotation rate is approximately 9.9° per second or 11.5 feet per second, vertical sink rate.

The main landing gear shock strut stroke is 16 inches. The allowable main gear sink rate for a 211,000-pound orbiter is 9.6 feet per second; for a 240,000-pound orbiter, it is 6 feet per second. With a 20-knot crosswind, the maximum allowable gear sink rate for a 211,000-pound orbiter is 6 feet per second; for a 240,000-pound orbiter, it is approximately 5 feet per second. (Current maximum operational crosswind is limited to 15 knots.)

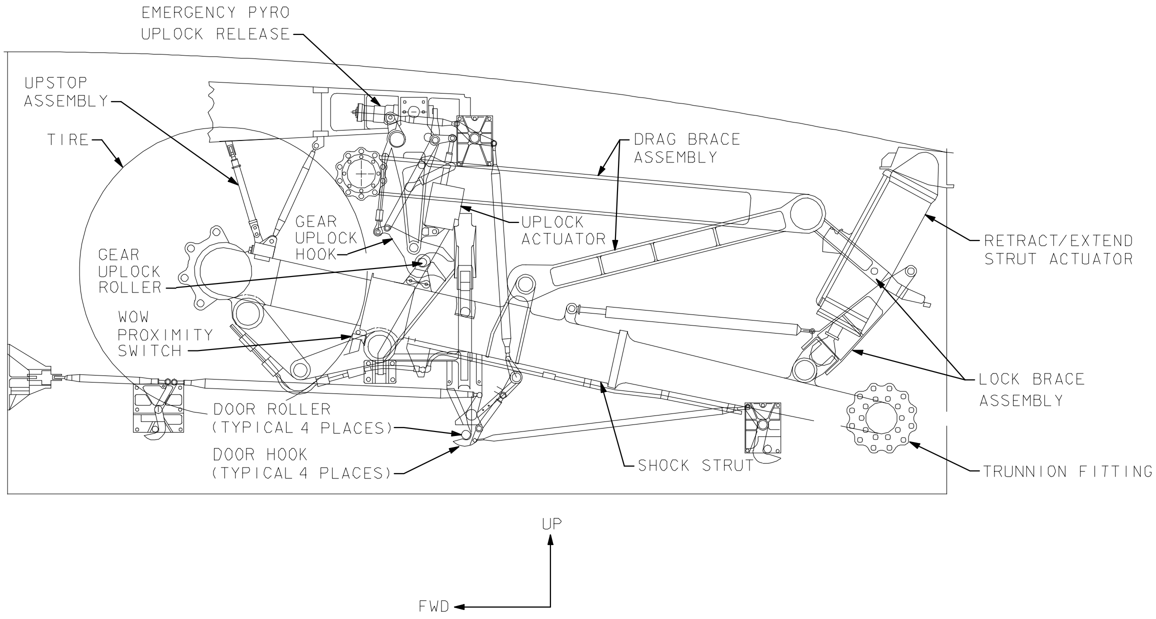
Wheels and Tires

Landing gear wheels are made in two halves from forged aluminum. The nose landing gear tires are 32 by 8.8 inches and have a normal nitrogen inflation pressure of 350 psi prior to launch. The maximum allowable load per nose landing gear tire is approximately 45,000 pounds. Nose landing gear tires are rated for 217 knots maximum landing speed. They may be reused once.

The main landing gear tires are 44.5 by 21 inches and have 16 cord layers in a bias-ply design. They are normally inflated with nitrogen to a pressure of 370 *pounds per square inch* (psi). The maximum allowable load per main landing gear tire is 132,000 pounds. With a 60/40 percent tire load distribution, the maximum tire load on a strut is 220,000 pounds. The main gear tires are rated at 225 knots maximum ground speed and have a life of one landing.



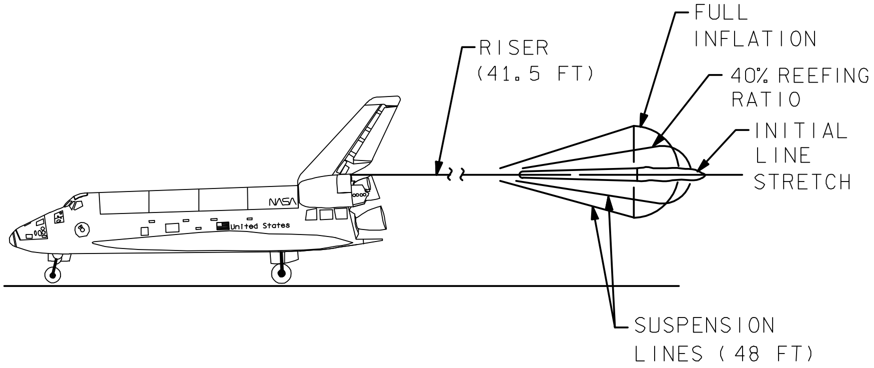
Nose Landing Gear Stowed



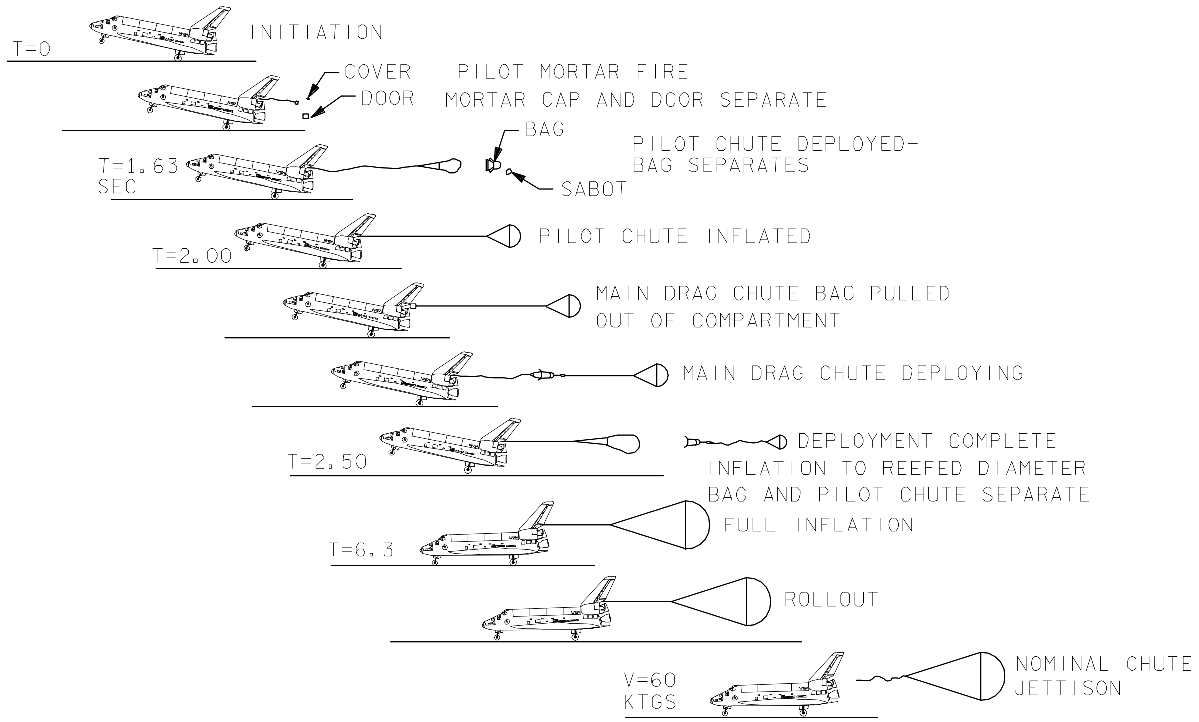
Main Landing Gear Stowed

Drag Chute

The orbiter drag chute was designed to assist the deceleration system in safely stopping the vehicle on the runway at end of mission (EOM) and abort weights. Design requirements included the ability to stop a 248,000 lb *transoceanic abort landing* (TAL) orbiter in 8,000 feet with a 10 knot tailwind on a hot (103° F) day and maximum braking at 140 knots ground speed or one half runway remaining. The drag chute, housed at the base of the vertical stabilizer, is manually deployed by redundant commands from the *commander* (CDR) or *pilot* (PLT) prior to derotation. The drag chute is jettisoned at 60 (±20) knots ground speed to prevent damage to the main engine bells. The drag chute will be used on lake bed and concrete runways except with crosswinds greater than 15 knots or in the presence of main engine bell repositioning problems. The drag chute may be deployed without engine bell repositioning if landing/rollout control problems exist.



Drag Chute Configuration



Nominal Sequence of Drag Chute Deployment, Inflation, and Jettison

Pilot and Main Chutes

When drag chute deployment is initiated, the door is blown off of the chute compartment by pyros and a mortar fires deploying a nine foot pilot chute. The pilot chute in turn extracts the 40 foot, partially reefed conical main chute. The main chute is reefed to 40 percent of its total diameter for about 3.5 seconds to lessen the initial loads on the vehicle. The main chute trails the vehicle by 89.5 feet on a 41.5 foot riser.

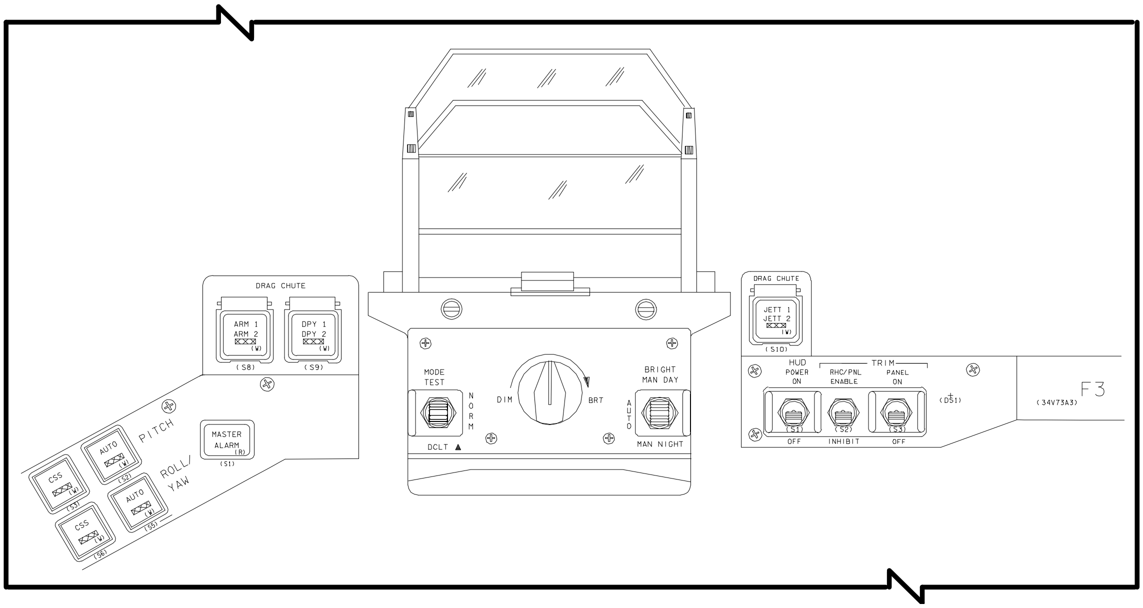
Drag Chute Controls

The drag chute deployment and jettison pushbuttons, ARM 1(2), DPY 1(2), and JETT 1(2) are installed on either side of both the CDR's and PLT's *heads-up displays* (HUD). Activation of each lighted pushbutton initiates a signal through the primary and redundant paths simultaneously. The deployment sequence requires that both the ARM and DPY pushbuttons be activated simultaneously. The JETT pushbutton signal will only be effective when the ARM command has previously been initiated. Circuit breakers for the drag chute controls are located on panels O15 and O16.

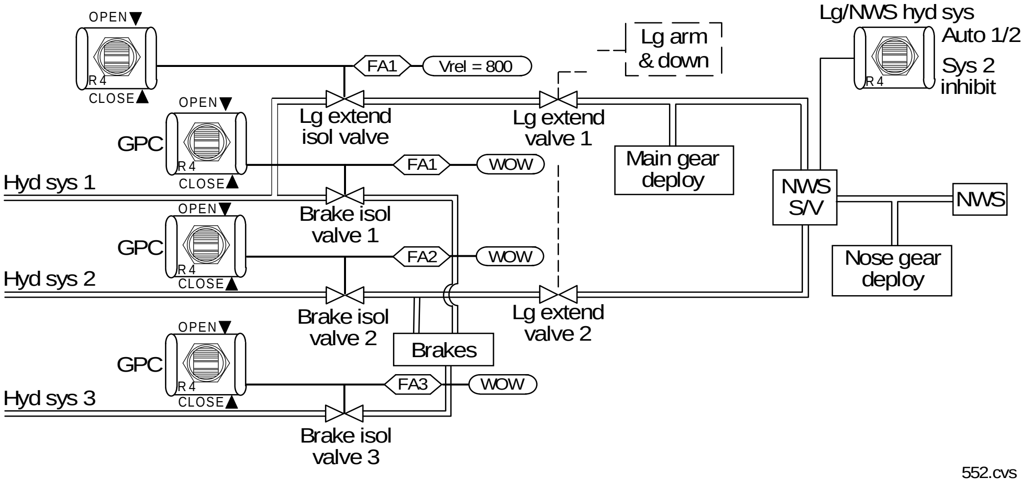
Main Landing Gear Brakes

Each of the orbiter's four main landing gear wheels has electrohydraulic disc brakes and an associated anti-skid system. The disc brake assembly consists of nine discs, five rotors, four stators, a backplate, and a pressure plate. The carbon-lined rotors are splined to the inside of the wheel and rotate with the wheel. The carbon-lined stators are splined to the outside of the axle assembly and do not rotate with the wheel.

The brakes are controlled by the commander or pilot applying toe pressure to the upper portion of the rudder pedals; electrical signals produced by rudder pedal toe pressure control hydraulic servovalves at each wheel and allow hydraulic system pressure to actuate braking. Brakes cannot be applied until about 1.9 seconds after weight on the main gear has been sensed. The anti-skid system monitors wheel velocity and controls brake pressure to prevent wheel lock and tire skidding. The braking/anti-skid system is redundant in that it utilizes system 1 and 2 hydraulic pressure as the active system with system 3 as standby, and it also utilizes all three main *direct current (DC)* electrical systems.



Panels F2, F3



Landing Gear Hydraulics

Brake System Hydraulic Power

Each of the four main landing gear wheel brake assemblies is supplied with pressure from two different hydraulic systems. Each brake hydraulic piston housing has two separate brake supply chambers. One chamber receives hydraulic source pressure from hydraulic system 1 and the other from hydraulic system 2. There are eight hydraulic pistons in each brake assembly. Four are manifolded together from hydraulic system 1 in a brake chamber. The remaining four pistons are manifolded together from hydraulic system 2. When the brakes are applied, the eight hydraulic pistons press the discs together, providing brake torque.

When hydraulic system 1 or 2 source pressure drops below approximately 1,000 psi, switching valves provide automatic switching to hydraulic system 3. Loss of hydraulic system 1, 2, or both would have no effect on braking capability, because standby system 3 would automatically replace either system. Loss of hydraulic system 3 and either 1 or 2 would cause the loss of half of the braking power on each wheel, and additional braking distance would be required.

The brake isolation valves in hydraulic systems 1, 2, and 3 must be open to allow hydraulic pressure to the brakes. All three valves are automatically commanded open after weight on the main landing gear is sensed. The 3,000 psi hydraulic pressure is reduced by a regulator in each of the brake hydraulic systems to 2,000 psig.

Anti-Skid

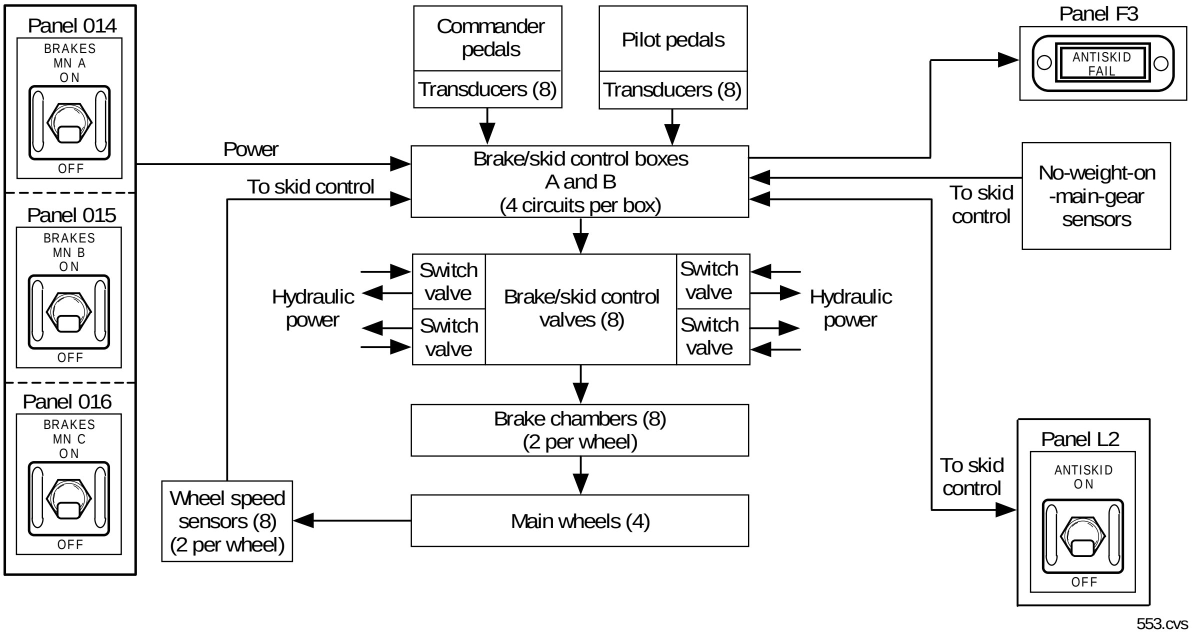
The anti-skid portion of the brake system provides optimum braking by preventing tire skid or wheel lockup and subsequent tire damage.

Each main landing gear wheel has two speed sensors that supply wheel rotational velocity information to the skid control circuits in the brake/skid control boxes. The velocity of each wheel is continuously compared to the average wheel velocity of all four wheels. Whenever the wheel velocity of one wheel is 60 percent below the average velocity of the four wheels, skid control removes brake pressure from the slow wheel until the velocity of that wheel increases to an acceptable range.

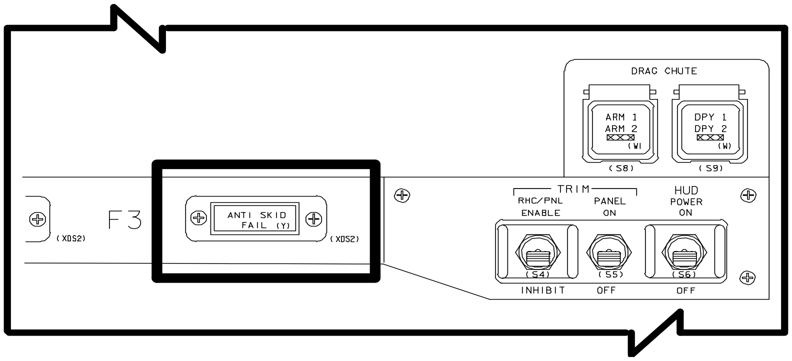
The brake system contains eight brake/skid control valves. Each valve controls the hydraulic brake pressure to one of the brake chambers. The brake/skid control valves contain a brake coil and a skid coil. The brake coil allows hydraulic pressure to enter the brake chambers. The skid coil, when energized by the skid control circuit, provides reverse polarity to the brake coil, preventing the brake coil from allowing brake pressure to the brake chamber.

Anti-skid control is automatically disabled below approximately 10 to 15 knots to prevent loss of braking for maneuvering and/or coming to a complete stop.

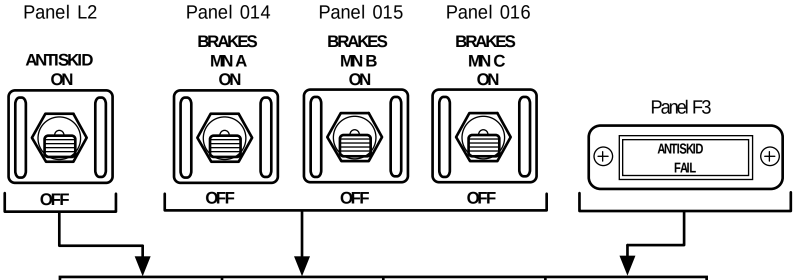
The anti-skid system control circuits contain fault detection logic. The yellow ANTI SKID FAIL caution and warning light on panel F3 will be illuminated if the anti-skid fault detection circuit detects an open circuit or short in a wheel speed sensor or control valve servocoil, or a failure in an anti-skid control circuit. A failure of these items will only deactivate the failed circuit, not total anti-skid control. If the BRAKES switches on panels O14, O15, and O16 are ON, and the ANTISKID switch on panel L2 is OFF, the ANTISKID FAIL caution and warning light will also be illuminated.



Brake/Skid Control System Overview



ANTI SKID FAIL Caution and Warning Light on Panel F3



Anti-skid Switch		Brake Power Switch		Anti-skid Failure*		Anti-skid** Fail Light	
ON	OFF	ON	OFF	YES	NO	ON	OFF
			●				●
	●	●				●	
●		●			●		●
●		●		●		●	

* Anti-skid fault detection circuits detect any of the following failures:
- Open or short in a wheel speed sensor circuit
- Open or short in a skid control servovalve circuit
- Failure in an anti-skid control circuit

** Applies only if brake power switches MN B, MN C or both are activated.

Note: A failure will deactivate only the failed circuit and not total anti-skid control.

555.cvs

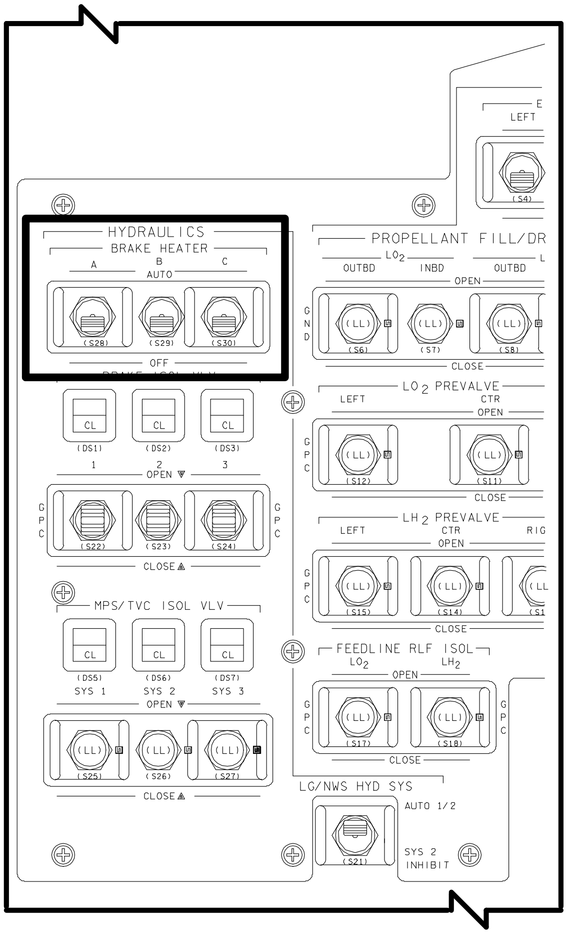
Anti-Skid Fail Light Status

Temperature Control

Insulation and electrical heaters are installed on the portions of the hydraulic systems that are not adequately thermally conditioned by the individual hydraulic circulation pump system because of stagnant hydraulic fluid areas.

Redundant electrical heaters are installed on the main landing hydraulic flexible lines located on the back side of each main landing gear strut between the brake module and brakes. These heaters are required because the hydraulic fluid systems are dead-ended, and fluid cannot be circulated with the circulation pumps. The hydraulic system 1 lines to the nose landing gear are located in a tunnel between the crew compartment and forward fuselage. The passive thermal control systems are attached to the crew compartment, which leaves the hydraulic system 1 lines to the nose landing gear exposed to environmental temperatures, thus requiring electrical heaters on the lines in the tunnel.

The *HYDRAULICS BRAKE HEATER* A, B, and C switches on panel R4 enable the heater circuits. The *HYDRAULICS BRAKE HEATER* switches A, B, and C provide electrical power from the corresponding main buses A, B, and C to the redundant heaters on the main landing gear flexible lines and the hydraulic system 1 lines in the tunnel between the crew compartment and forward fuselage leading to the nose landing gear.



HYDRAULICS BRAKE HEATER Switches on Panel R4

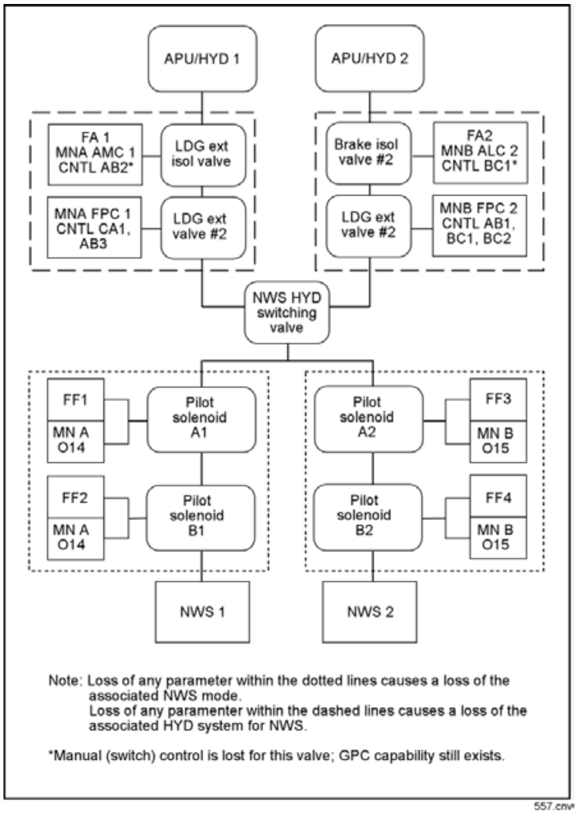
Nose Wheel Steering

The nose landing gear contains a hydraulic steering actuator that responds to electronic commands from the commander's or pilot's rudder pedals. Two types of operation are available, GPC and caster. The GPC mode is supported by hydraulic systems 1 and 2 through the selection of nose wheel steering (NWS) system 1 or 2. This provides redundant avionics modes regardless of hydraulic system support. NWS 1 or 2 will work with either hydraulic system 1 or 2.

In the GPC modes, the flight control software uses accelerometer assembly feedback to modify commands from the rudder pedal transducer assemblies (RPTAs) to automatically counter hardovers or large lateral accelerations due to gear or tire malfunctions. If GPC 1 or 2, or FF1 or 2 is inoperative, steering downmodes to caster if NWS 1 is selected. Similarly, the loss of GPC 3 or 4, or FF3 or 4 will prevent the use of NWS 2 and cause a downmode. The loss of either NWS system will only cause a downmode to castor. The other NWS system must be selected if required. In caster, no positive control over the nose wheel position is available, and differential braking and rudder are used for directional control.

A hydraulic servoactuator mounted on the nose strut permits orbiter NWS up to 9° left or right after system activation. Hydraulic systems 1 and 2 provide redundant hydraulic pressure to either NWS 1 or 2. If NWS is not activated, or if hydraulic systems 1 and 2 fail, the NWS actuator acts as a nose wheel shimmy damper in the caster mode.

NWS can only be enabled after certain preconditions are met. Among these preconditions are three major milestones: weight-on-wheels (WOW), pitch angle (θ) less than 0°, and weight-on-nose-gear (WONG). There are three sensors on each main gear designed to sense when main gear touchdown (MGTD) occurs so that WOW can be set. One sensor is a proximity sensor and the other two are wheel speed sensors (one per tire). Once WOW is set, the speed brake is commanded full open, flat turn discrete is set, half gain RHC is enabled, and the HUD format downmodes. After WOW is set on one strut, brakes are also enabled.



Note: Loss of any parameter within the dotted lines causes a loss of the associated NWS mode.
Loss of any paramenter within the dashed lines causes a loss of the associated HYD system for NWS.

*Manual (switch) control is lost for this valve; GPC capability still exists.

OI-21 NWS Functional Drawing

WONG can be set by either of two proximity sensors located on the nose gear. Once WONG is set (presupposing WOW is already set and the vehicle attitude (theta) is less than zero), the ground speed enable "flag" is set. This enables NWS and the I-loaded downward deflection of the elevons for tire load relief. As a backup to the WOW and WONG discretes, the crew nominally selects SRB SEP MAN/AUTO and presses the associated pushbutton. This will manually bypass the WOW/WONG discretes and set the ground speed enable "flag." Per the entry procedure, this should be accomplished just after nose gear touchdown. Taking the F7 SEP Switch to MAN and pressing the associated pushbutton is an alternate method of manually backing up WOW/WONG.

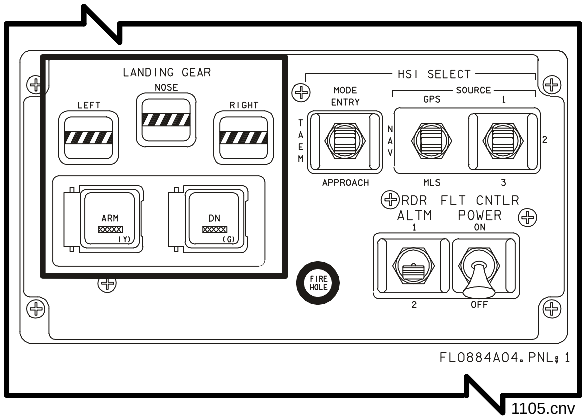
Operations

Landing Gear

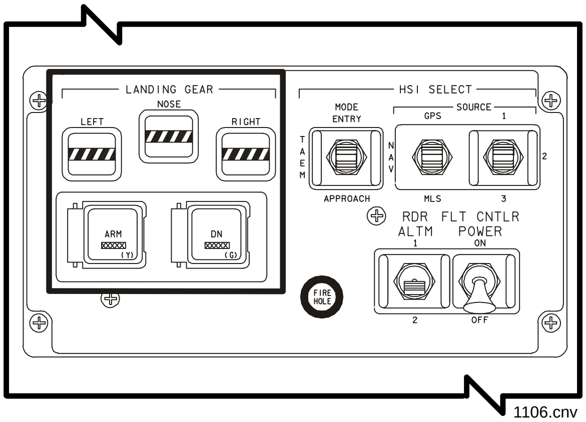
Landing gear deployment is initiated when the commander (on panel F6) or pilot (on panel F8) depresses the guarded *LANDING GEAR ARM* pushbutton and then the guarded DN pushbutton.

NOTE

Deploying the landing gear at equivalent airspeeds greater than 312 knots may result in high aerodynamic loads on the doors and interference with the normal opening sequence.



Commander's LANDING GEAR Controls on Panel F6



Pilot's LANDING GEAR Controls on Panel F8

Depressing the ARM pushbutton energizes latching relays for the landing gear extend valves 1 and 2 in preparation for gear deploy. It also arms the nose and main landing gear pyrotechnic initiator controllers and illuminates the yellow light in the ARM pushbutton. This is normally performed by the pilot at approximately 2,000 feet *above ground level* (AGL).

The DN pushbutton is then depressed. This energizes latching relays that open the hydraulic system 1 extend valve 1 and hydraulic system 2 landing gear extend valve 2.

Fluid in hydraulic system 1 flows to the landing gear uplock and strut actuators and the NWS switching valve. The green light in the *DN* pushbutton indicator is illuminated. Normally, the DN pushbutton is pressed at least 15 seconds before touchdown at an altitude of 300 feet ± 100 feet and at an airspeed no greater than 312 KEAS.

The proximity switches on the nose and main landing gear doors and struts provide electrical signals to control the *LANDING GEAR NOSE, LEFT*, and *RIGHT* indicators on panels F6 and F8. The output signals of the landing gear and door uplock switches drive the landing gear *UP* position indicators and the backup pyrotechnic release system. The output signals of the landing gear downlock switches drive the landing gear *DN* position indicators. The landing gear indicators are barberpole when the gear is in transit.

The left and right main landing gear WOW switches produce output signals to the guidance, navigation, and control software to reconfigure the flight control system for landing and rollout gains.

The two WONG signals, along with WOW and theta (pitch angle) less than 0°, allow the GNC software to issue a nose wheel steering enable signal. This signal is then sent to the steering control box to enable nose wheel steering.

Six gear proximity switches are signal conditioned by the landing gear proximity sensor electronics box 1, located in avionics bay 1. Six additional gear proximity switches are signal conditioned by the landing gear proximity sensor electronics box 2, located in avionics bay 2. All WOW proximity switches are redundant through two signal conditioners.

Hydraulic system 1 source pressure is routed to the nose and main landing gear uplock actuators, which releases the nose and main landing gear and door uplock hooks. As the uplock hooks are released, the gear begins its deployment. During gear extension, a camming action opens the landing gear doors. The landing gear free falls into the extended position, assisted by the strut actuators and airstream in the deployment. The hydraulic strut actuator incorporates a hydraulic fluid flowthrough orifice (snubber) to control the rate of landing gear extension and thereby prevent damage to the gear's downlock linkages.

The *BRAKE ISOL 1, 2*, and *3* are opened via a GPC command sent after weight on the main gear is sensed. The landing gear isolation valves cannot be opened or closed with hydraulic pressures less than approximately 100 psi. Hydraulic systems 1 and 2 share the braking duties, each providing hydraulic pressure to one-half of the braking pucks. Hydraulic system 3 provides the backup pressure for all the braking pucks. Landing gear extend valve 2 is located downstream of brake isolation valve 2. Since brake isolation valve 2 is opened after weight on wheels is present, hydraulic system 2 can only be used for redundant nose gear deploy if the brake isol 2 is manually opened early.

The *BRAKE ISOL VLV 2* and *3* switches on panel R4 positioned to *CLOSE* isolate the corresponding hydraulic system from the main landing gear brake control valves. The adjacent talkback indicator would indicate *CL*. When switches 2 and 3 are positioned to *OPEN*, the corresponding hydraulic system source pressure is available to the main landing gear brake control valves. The corresponding talkback indicator would indicate *OP*. Landing gear extend valve 2 is located downstream of brake isolation valve 2. This valve further isolates hydraulic system 2 supply pressure from the nose wheel steering and nose landing gear deploy actuators and is opened by a *LANDING GEAR DN* command.

When the nose and main *LANDING GEAR DN* command is initiated, hydraulic system 1 pressure is directed to the nose and main landing gear uplock hook actuators and strut actuators to actuate the mechanical uplock hook for each landing gear. This will allow the gear to be deployed and provide hydraulic system 1 pressure to the nose wheel steering actuator. The landing gear/nose wheel steering hydraulic system switching valve will automatically select hydraulic system 2 supply pressure if system 1 should fail, thereby providing redundant hydraulics for NWS actuation and nose gear deploy.

NOTE

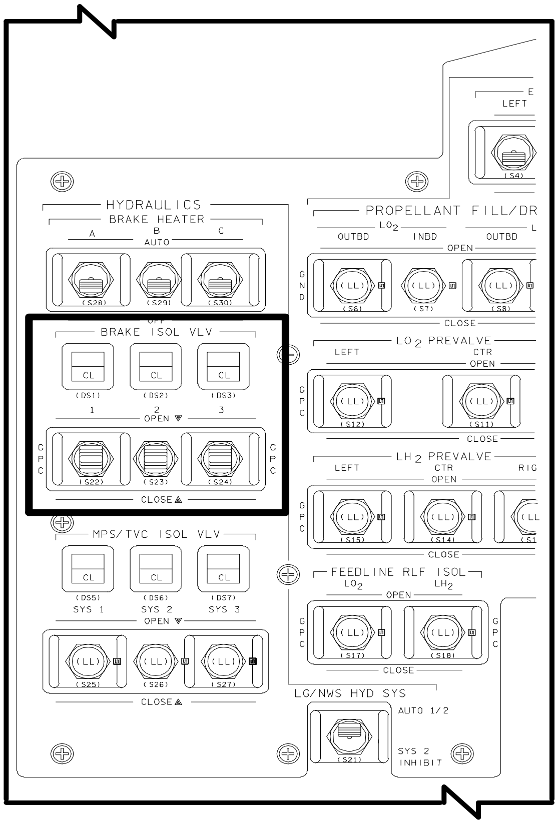
> Hydraulic system 1 is the only hydraulic system for deploy of the main landing gear.

If the hydraulic system fails to release the landing gear within 1 second after the *DN* pushbutton is depressed, the nose and left and right main landing gear uplock sensors (proximity switches) will provide inputs to the pyro initiator controllers (PICs) for initiation of the redundant NASA standard initiators (pyro system 1 and 2). They release the same uplock hooks as the hydraulic system. As mentioned earlier, the nose landing gear, in addition, has a PIC and redundant NASA standard initiators that initiate a pyrotechnic power thruster 2 seconds after the *DN* pushbutton is depressed to assist gear deployment. This "nose gear pyro assist" pyro fires every time the gear are deployed.

The landing gear drag brace overcenter lock and spring-loaded bungee lock the nose and main landing gear in the down position.

Two series valves, landing gear retract control valve 1 and 2, prevent hydraulic pressure from being directed to the retract side of the nose and main landing gear uplock hook actuators and strut actuators if the retract/circulation valve fails to open during nose and main landing gear deployment.

During the landing sequence, GNC software commands the landing gear extend isolation valve OPEN at 0.8 Mach. The crew will verify the valve is open at 0.7 Mach, ARM the gear at 2000 ft, and passing 300 feet, DEPLOY the gear. Brake ISO VLV 1, 2, and 3 are automatically opened after weight on the main gear is sensed with GPC commands via MDM FA1, FA2, and FA3, respectively. NWS is activated once weight is sensed on the nosewheel. The pilot verifies that the brake isolation valves are open for landing rollout. Should the gear or brake isolation valves fail to automatically OPEN, the pilot manually opens them using switches on panel R4.



BRAKE ISOL VLV Switches and Talkbacks on Panel R4

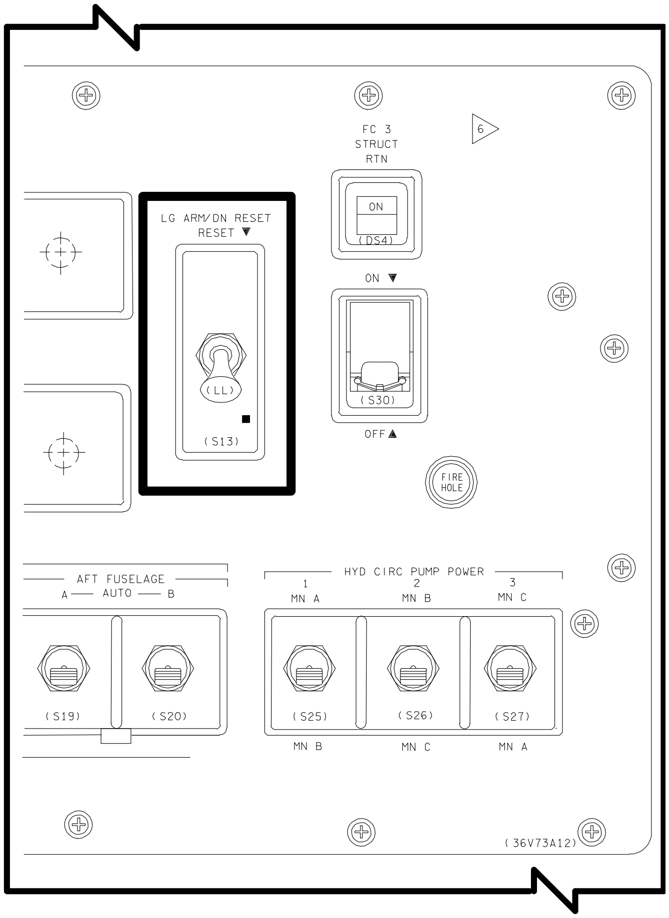
Ground Reset

Landing gear reset is a post landing function, which will be performed by the crew.

The *LG ARM/DN RESET* switch on panel A12 positioned to RESET unlatches the relays that were latched during landing gear deployment by the *LANDING GEAR ARM* and *DN* pushbutton indicators. The primary function of this procedure is to remove power to the PIC circuits that are still charged as a backup landing gear deploy method. The *RESET* position also will extinguish the yellow light in the *ARM* pushbutton indicator and the green light in the *DN* pushbutton.

Drag Chute

During entry, at a velocity between 8000 to 3500 fps, the main engine bells are repositioned 10° below the nominal to preclude damage during drag chute deployment. The crew cannot monitor the bell repositioning but can determine that the system is enabled at item 19



LG ARM/DN RESET Switch on Panel A12

on the SPEC 51 OVERRIDE display. The crew can inhibit the repositioning while in MM 301-304 by toggling item 19 in SPEC 51. Nominal EOM drag chute deployment will be initiated only if main engine bell repositioning is enabled.

Although the drag chute may be deployed at speeds up to 230 KEAS, current EOM procedures call for its deployment at 195 KEAS with a crosswind component no greater than 15 knots. If the drag chute is deployed above 230 KEAS, the drag chute pivot pin is designed to fail, resulting in the chute being jettisoned. Approximately one second after the CDR or PLT presses the ARM 1(2) and DPY 1(2) pushbuttons simultaneously, the pilot chute deploys. Within 1 second, the pilot chute extracts the main chute, which deploys to its 40 percent reefed diameter. After about 3.5 seconds of reefed deployment, two cutters sever the reefing ribbon allowing the main chute to inflate to its full 40-foot diameter.

WARNING

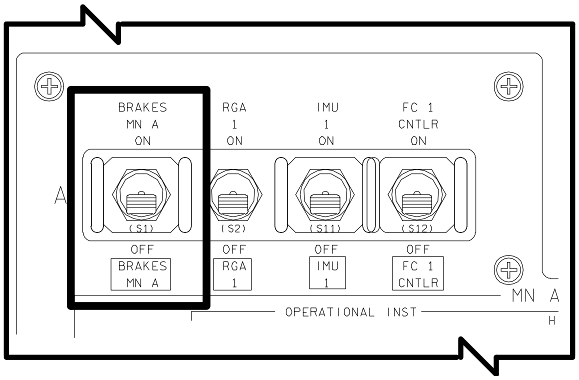
Deployment of the drag chute between 135 and 40 ft AGL can cause loss of control of the vehicle. Drag chute jettison must be initiated immediately to prevent loss of the vehicle and crew.

At 60 (±20) KGS, the drag chute will be jettisoned. Below 40 KGS, if drag chute jettison has not been initiated, the chute will be retained until the orbiter has stopped to minimize damage to the main engine bells.

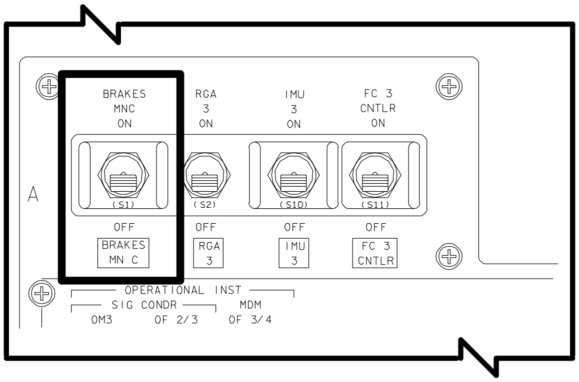
Brake Controls

The BRAKES MN A, MN B, and MN C switches are located on panels O14, O15, and O16. These switches allow electrical power to brake/anti-skid control boxes A and B. The ANTISKID switch located on panel L2 provides electrical power for enabling the anti-skid portion of the braking system boxes A and B. The BRAKES MN A, MN B, and MN C switches are positioned to ON to supply electrical power to brake boxes A and B, and to OFF to remove electrical power. The ANTISKID switch is positioned to ON to enable the anti-skid system, and OFF to disable the system.

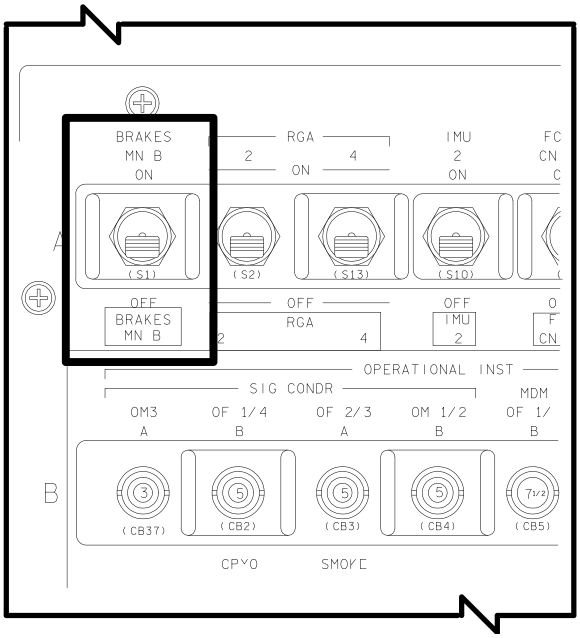
When weight is sensed on the main landing gear, the brake/anti-skid boxes A and B are enabled and brake isolation valves 1, 2, and 3 are opened, permitting the main landing gear brakes to become operational.



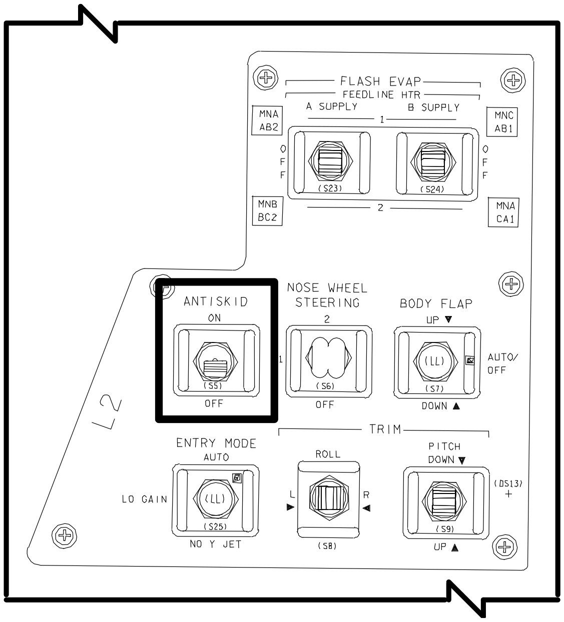
BRAKES Switch on Panel O14



BRAKES Switch on Panel O16



BRAKES Switch on Panel O15



ANTISKID Switch on Panel L2

The main landing gear brakes controlled by the commander's or pilot's brake pedals are located on the rudder pedal assemblies at the commander's and pilot's stations. Pressure on the toe of the adjustable brake/rudder pedals results in a command to the wheel braking system.

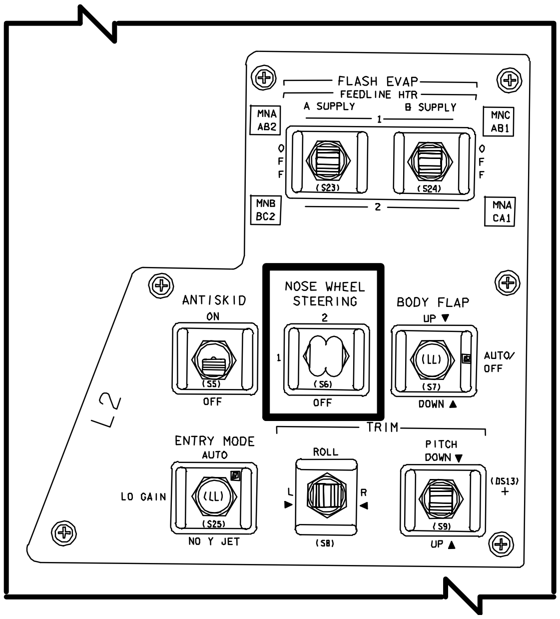
Each brake pedal has four transducers. The left pedal transducer unit outputs four separate braking signals through the brake/skid control boxes for braking control of the two left main wheels. The right pedal transducer unit does likewise for the two right main wheels. When the brake pedal is deflected, the transducers transmit electrical signals of 0 to 5 volts DC to the brake/anti-skid control boxes.

If both right pedals are moved, the pedal with the greatest toe pressure becomes the controlling pedal through electronic OR circuits. The electrical signal is proportional to the toe pressure. The electrical output energizes the main landing gear brake coils proportionately to brake pedal deflection, allowing the desired hydraulic pressure to be directed to the main landing gear brakes for braking action. The brake system bungee at each brake pedal provides the artificial braking feel to the crewmember.

Nose Wheel Steering

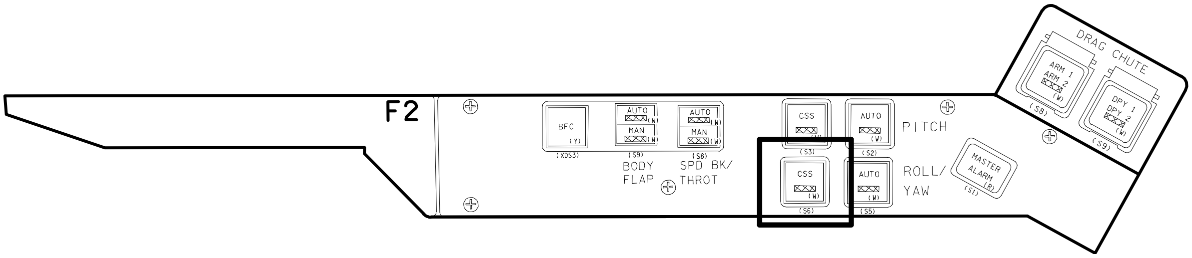
GPC Mode

The *NOSE WHEEL STEERING* switch on panel L2 positioned to *NWS 1(2)* enables the corresponding NWS (avionics) system. In addition to the NWS mode selections of the switch, the *FLIGHT CNTLR POWER* switch on panel F8 must be positioned to *ON*, and the flight control system *ROLL/YAW CSS* pushbutton on panel F2 or F4 must be depressed to enable the GPC for nose wheel steering. When either pushbutton is depressed, a white light illuminates the pushbutton.

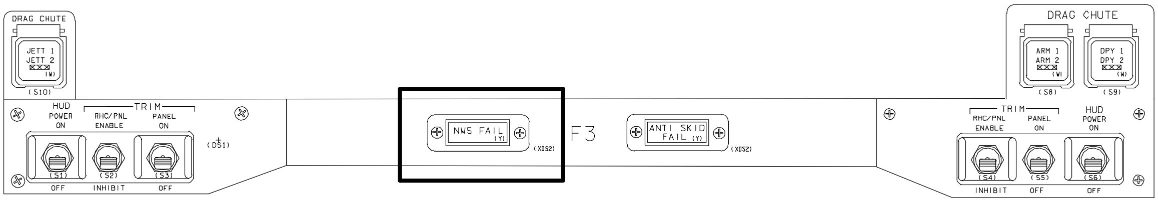


NOSE WHEEL STEERING Switch on Panel L2

When the commander or pilot makes an input to the rudder pedals in the NWS 1(2) mode, the rudder pedal command position is appropriately scaled within the GPC's software and transmitted to a summing network, along with lateral accelerometer inputs from within the flight control system. The accelerometer inputs are utilized to prevent any sudden orbiter lateral deviation. From this summing network, a nose wheel steering command is sent to comparison network, as well as to the steering servo system.



ROLL/YAW CSS Pushbutton on Panel F2



NWS FAIL Light on Panel F3

Steering position transducers on the nose wheel strut receive redundant electrical excitation from the steering position amplifier, which receives redundant electrical power from data display *unit 2*.

Each of the three transducers transmits nose wheel position feedback to a redundancy management mid-value-select software. It then transmits a nose wheel position signal to the comparison network. The orbiter nose wheel commanded and actual positions are compared for position error and for rates to reduce any error. Absence of an error condition will allow nose wheel steering to be enabled after WOW, WONG, and theta less than 0° are sensed in the software. The enable signal permits hydraulic system 1(2) pressure to be applied to the nose wheel steering actuator from the NWS switching valve. If hydraulic system 1 is lost, hydraulic system 2 provides the pressure for nose wheel steering. If both systems' pressures drop below approximately 1,325 psi, the actuator remains in the caster mode and a failure is annunciated to the NWS FAIL C/W yellow light on panel F3.

Landing/Deceleration System Summary Data

- The orbiter has the capability of landing on a runway using a tricycle type of landing gear system. Once the orbiter touches down, the crew begins braking and steering operations.
- The landing gear consists of a nose landing gear and a left and right main landing gear. Each landing gear includes a shock strut with two wheel and tire assemblies.
- The nose wheels are co-rotating through a common axle, whereas the main gear wheels rotate independently.
- Each of the four main landing gear wheels has electrohydraulic brakes and an anti-skid system. Each gear wheel brake assembly is supplied with pressure from two different hydraulic systems. Systems 1 and 2 are the primary hydraulic systems for brake pressure; system 3 can back up either or both systems.
- Redundant electrical heaters are installed on the main landing hydraulic flexible lines located on the back side of each main landing gear strut between the brake module and brakes.
- The orbiter nose wheel is steerable after nose wheel touchdown at landing.
- ANTI SKID FAIL and NWS FAIL caution and warning lights are located on panel F3.
- Landing/deceleration controls are located on panels F6, F8, R4, L2, F2, F4, A12, O14, O15, and O16.

Landing/Deceleration System Rules of Thumb

- Landing gear should not be deployed at equivalent airspeeds greater than 312 knots.
- ±1 knot of touchdown speed corresponds to ±90 feet of distance. This is often rounded up to 100 feet for convenience.

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2.15 LIGHTING SYSTEM

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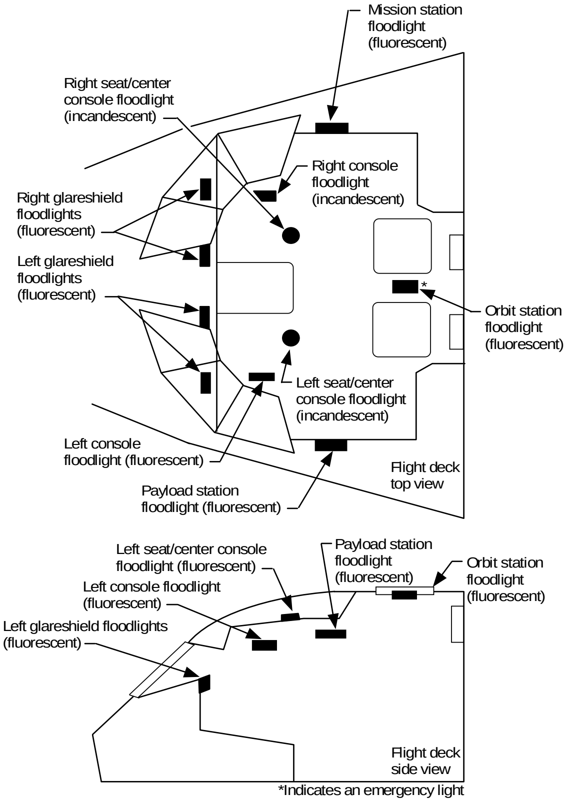


*Indicates an emergency light

568.cvs

**Floodlight Locations -
Flight Deck Forward and Aft**

Description

The lighting system provides both interior and exterior lighting. Interior lighting encompasses display and control visibility and general crew station and crew equipment operations. Exterior lighting provides illumination for payload bay door operations, EVA, remote manipulator system operations, stationkeeping, and docking. Interior lighting consists of floodlights, panel lights, instrument lights, numeric lights, and annunciator lights. Exterior lighting includes floodlights, spotlights, and docking lights.

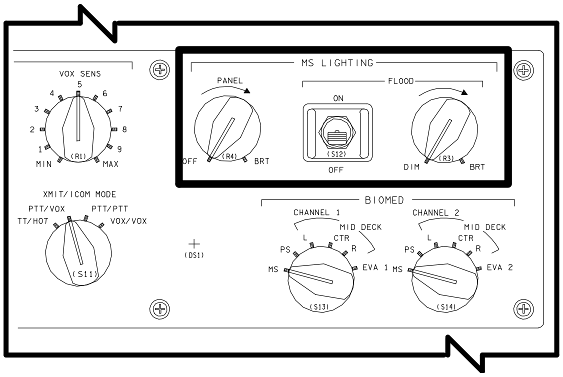
Interior Lighting

Interior floodlights provide general illumination throughout the crew cabin and allow the crew to function within the flight deck, middeck, airlock, tunnel adapter, and Spacehab (if installed). Circuit breakers, switches, and variable controls are used to operate the lights. Both fluorescent and incandescent lamps are used.

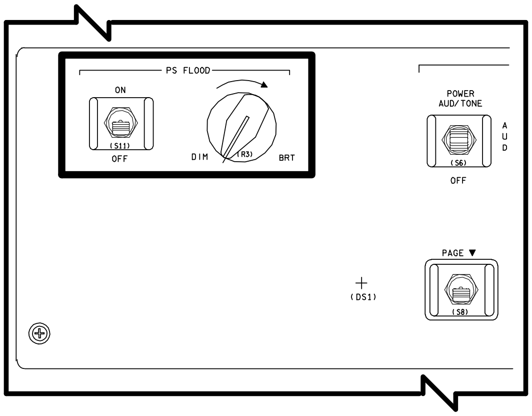
Emergency lighting is provided by selected fixtures that are powered via a separate power input from an essential bus. Existing floodlights are used, but a separate input powers the lights.

Dual fluorescent lamp fixtures provide lighting for the glareshield, mission station, and payload station floodlights. The mission station lighting is controlled by the *MS LIGHTING FLOOD ON/OFF* switch on panel R10; the adjacent rotary control *DIM/BRT* switch controls brightness. The payload station lighting is controlled by the *PS FLOOD ON/OFF* switch on panel L9, which also has an adjacent *DIM/BRT* rotary switch to control brightness.

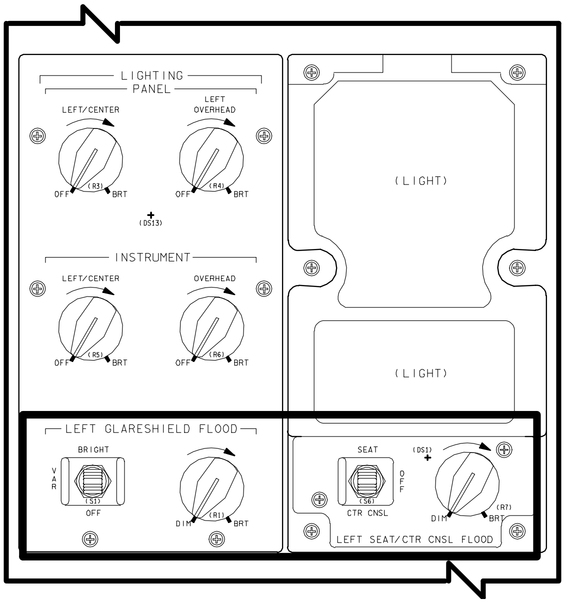
A single fluorescent lamp fixture with an integral off/variable-on is employed on each side of the commander's and pilot's side consoles and the orbit station. The commander's glareshield light, which consists of left inboard (dual lamp) and left outboard (dual lamp), is controlled by the *LIGHTING LEFT GLARESHIELD FLOOD BRIGHT, VAR, OFF* switch and a *DIM, BRT* rotary control on panel O6. (The *DIM, BRT* rotary control operates in conjunction with the *VAR* position.) The pilot's glareshield light functions the same as the commander's, except the controls *(LIGHTING RIGHT GLARESHIELD FLOOD* and *DIM, BRT)* are on panel O8.



MS LIGHTING Controls on Panel R10

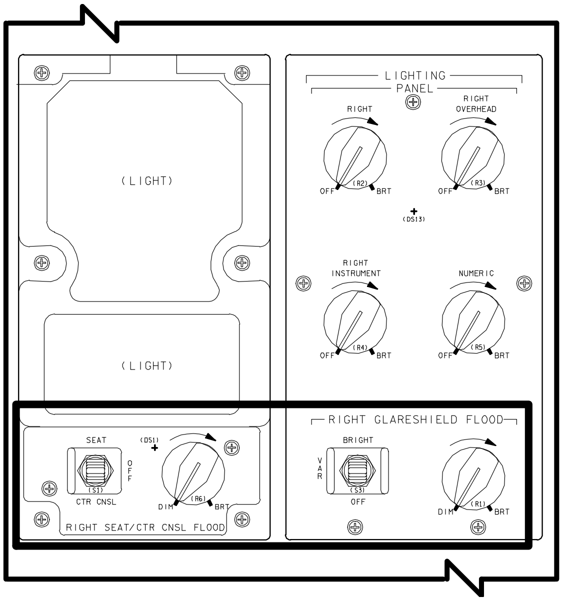


PS FLOOD Lighting Controls on Panel L9



CDR LIGHTING Controls on Panel O6

The commander's side console light is controlled by an integral off/variable-on control switch on the fixture. The pilot's side console light is controlled by the same type of control switch on the fixture. The orbit station light is controlled by the *ORBIT STATION LIGHTING FLOOD ON/OFF* switch and *DIM, BRT* rotary control on panel A6U. There are two seat/center console floodlights: one for the commander and one for the pilot. Each light has two incandescent bulbs: the left one illuminates the commander's lap or the center console, and the other illuminates the pilot's lap or the center console. The commander or pilot can select either the lap or center console, but not both at once. The commander's seat or console light is controlled by the *LEFT SEAT/CTR CNSL FLOOD, SEAT/OFF/CTR CNSL* switch and the *DIM, BRT* rotary control on panel O6. The pilot's seat or console light is controlled by the *RIGHT SEAT/CTR CNSL FLOOD, SEAT/OFF/CTR CNSL* switch and the *DIM, BRT* rotary control on panel O8.



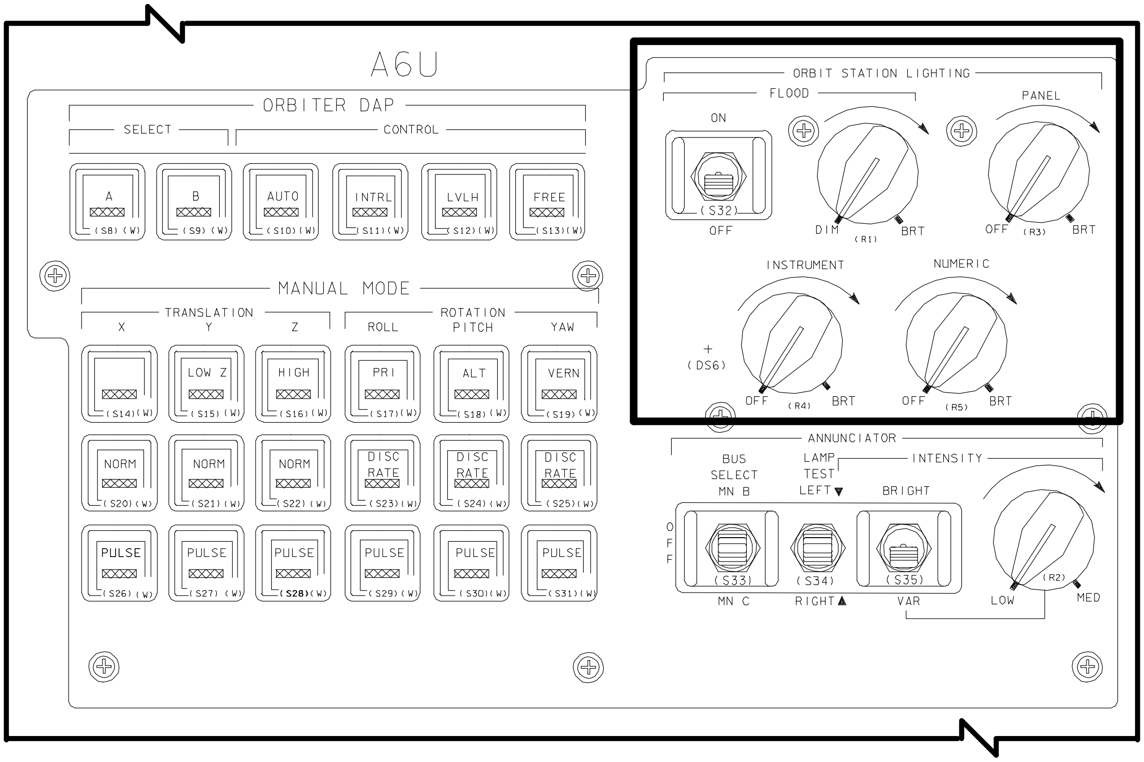
Pilot's Light Controls on Panel O8

Eight middeck ceiling floodlight fixtures are located behind a translucent polycarbonate material. They are the same fixtures as those at the orbit station and are individually controlled by *MID DECK FLOODS ON/OFF* switches on panel MO13Q. The middeck panel MO13Q is lighted by a small fluorescent lamp at each end of the recessed panel and is controlled by the *MO13Q LTG ON/OFF* switch on the panel.

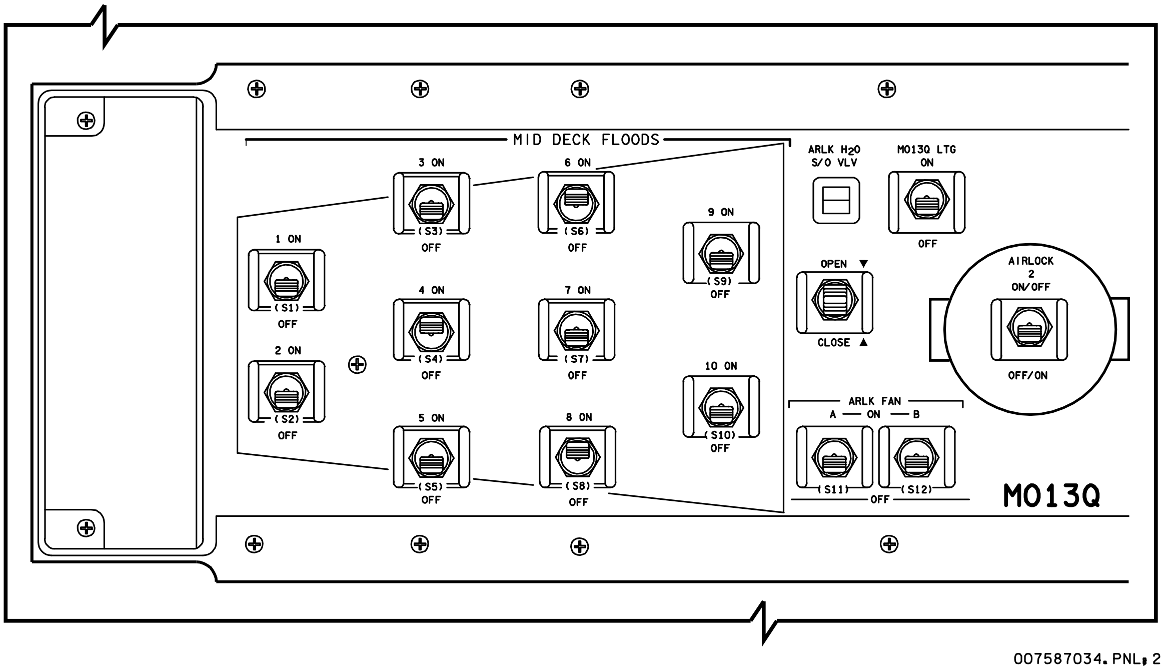
The waste management compartment floodlight is also the same as the orbit station fixture and is controlled by the *WASTE MANAGEMENT COMPARTMENT FLOOD ON/OFF* switch on panel ML18F.

The middeck sleep station bunks (if installed) use the same floodlights as the commander's and pilot's flight deck consoles and are also controlled individually.

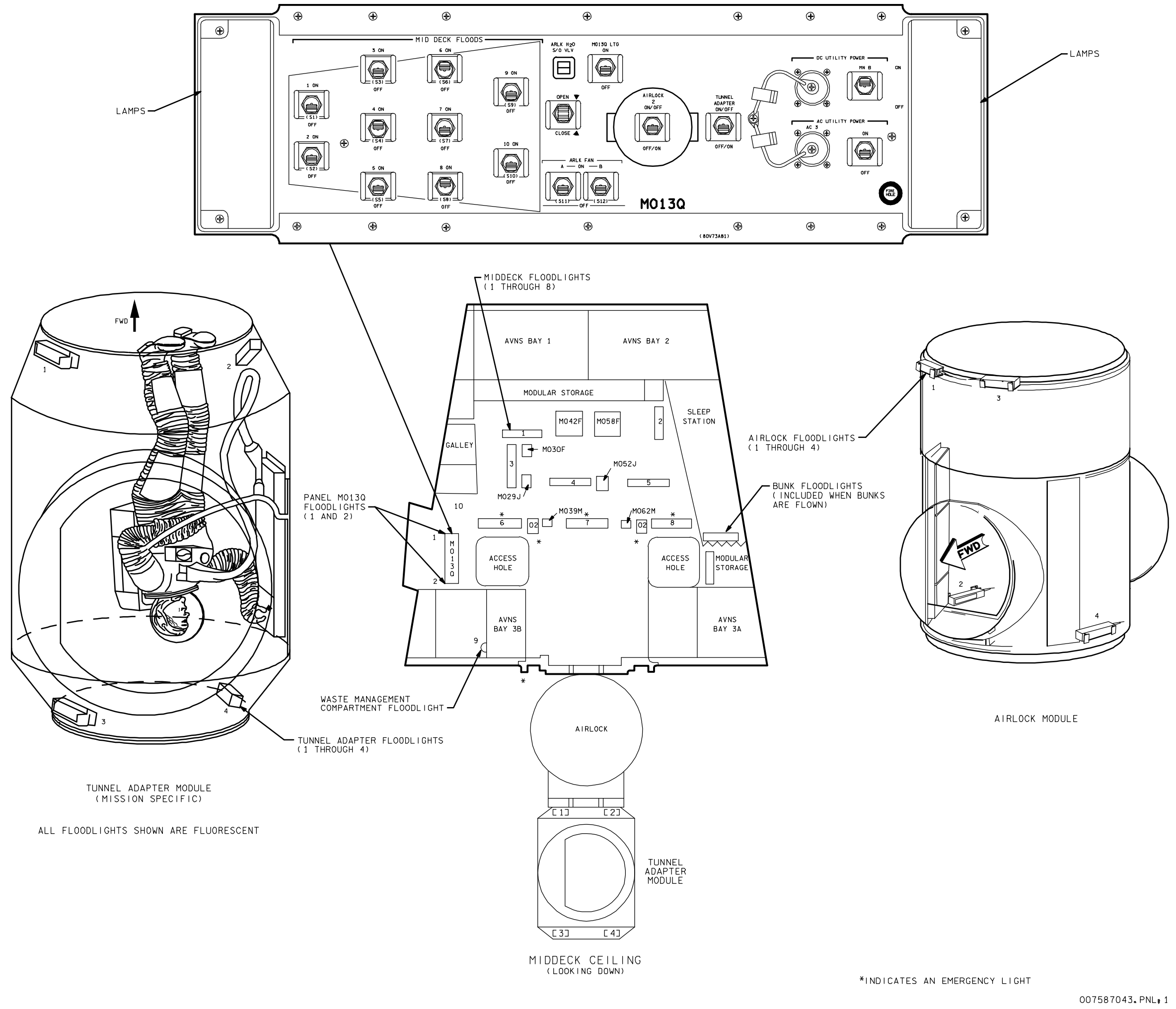
The airlock floodlights are similar to those at the commander's and pilot's flight deck side consoles, except they are controlled by *LIGHTING FLOOD* switches on panel AW18A and an *AIRLOCK 2* switch on panel MO13Q.



ORBIT STATION LIGHTING Controls on Panel A6U



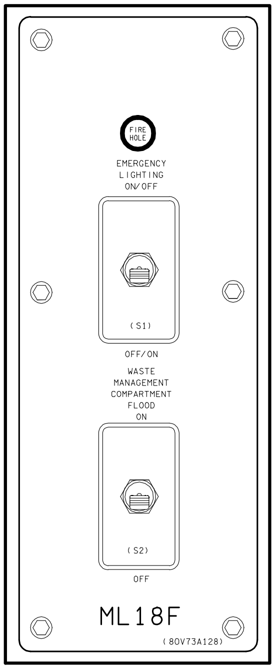
MID DECK FLOODS Controls on Panel MO13Q



ALL FLOODLIGHTS SHOWN ARE FLUORESCENT

*INDICATES AN EMERGENCY LIGHT

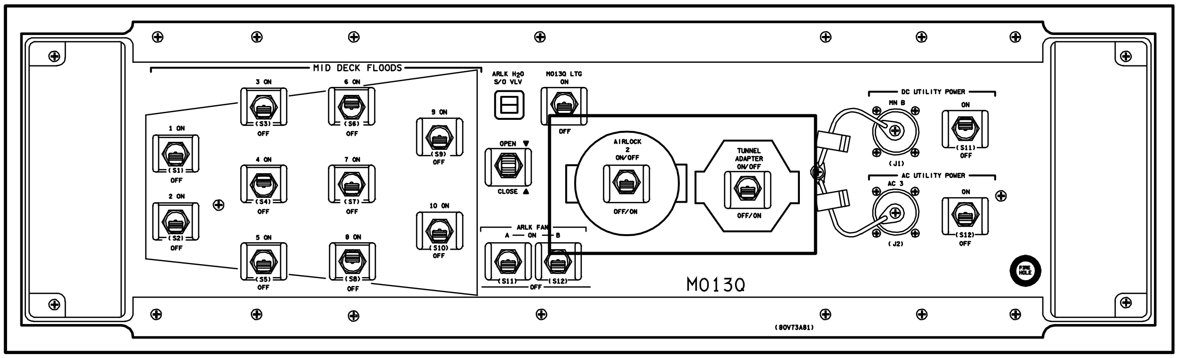
Floodlight Locations - Middeck and Airlock



EMERGENCY LIGHTING and WASTE MANAGEMENT COMPARTMENT FLOOD Lighting Control Switches on Panel ML18F

If the tunnel adapter is installed, the floodlights are similar to those at the commander's and pilot's side consoles. Tunnel adapter lights 2, 3, and 4 are controlled by individual *ON/OFF* switches on the tunnel adapter panel TW58T. Tunnel adapter light 1 is controlled by the *TUNNEL ADAPTER 1 ON/OFF* switch on panel MO13Q and the *ON/OFF 1* switch on the tunnel adapter panel.

The Spacehab (if installed) can accommodate different flight configurations, either a single module or a double module configuration. Each module has four overhead floodlights. The fixtures are single-lamp floodlights with an integral dimmer control on three. There is a main switch located on the monitor and control panel (MCP) at the entrance of the module that powers three floodlights per module. The emergency lighting system powers the remaining one floodlight per module in the event of a power failure. The Spacehab has a caution and warning (C&W) system that enables the master alarm light switch closure. The C&W luminaries are located on the MCP in the Spacehab.



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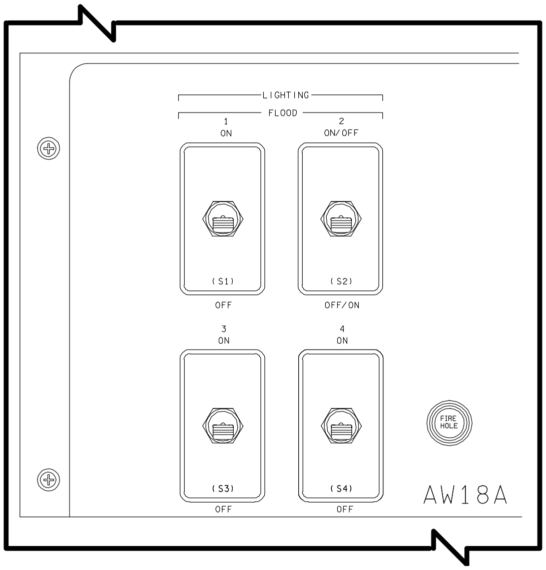
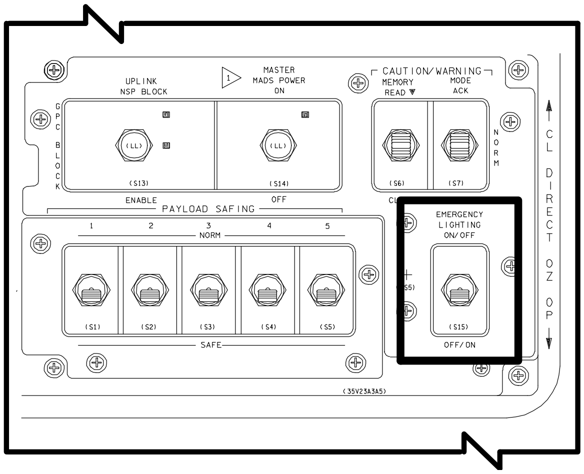
AIRLOCK 2 and TUNNEL ADAPTER Lighting Controls on Panel MO13Q



Airlock Flood LIGHTING Switches on Panel AW18A (Switches on Tunnel Adapter Panel TW58T are in Identical Configuration)



EMERGENCY LIGHTING Switch on Panel C3

The emergency floodlights for the crew module are controlled by *EMERGENCY LIGHTING ON/OFF* switches on either panel C3 or ML18F. The emergency lighting system is powering the floodlights when both panel switches are in the same position. When the emergency system is turned on, a relay is activated that configures the lights to full bright. Chem lights are available for crewmembers during minimum floodlight operations.

Panel Lighting

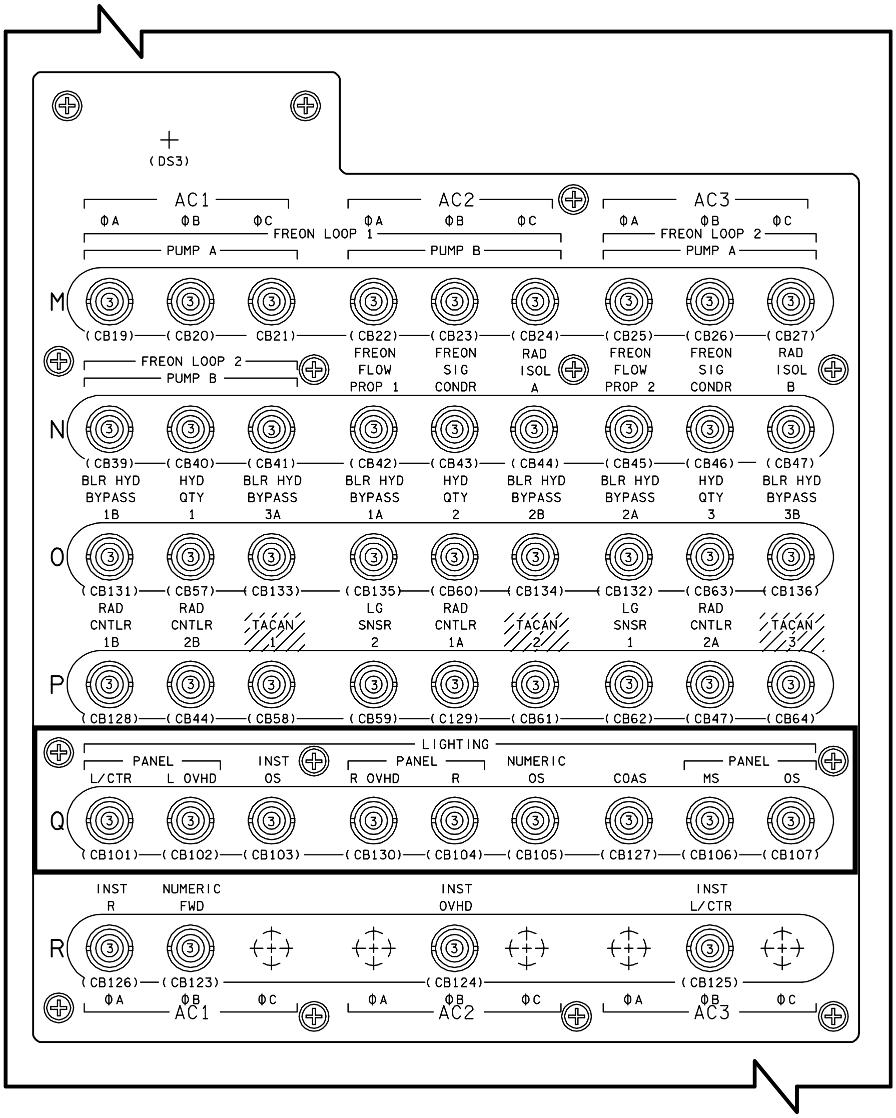
Many flight deck instrument panels have integral lighting that illuminates the panel nomenclature and markings on the displays and controls. This illumination aids the flight crew in locating displays and controls while operating the orbiter. Panel lighting is transmitted from behind a panel overlay through the panel nomenclature, making it appear white-lighted. It is also transmitted to the edges of the displays and controls for general illumination.

The lighting source consists of small incandescent, grain-of-wheat lamps mounted between the metal panel face and the plastic panel overlay. The overlay has a layer of white paint and a layer of gray paint on the top surface. The panel nomenclature is formed by etching the letters and symbols into the gray paint, leaving the white layer underneath.

On panel L4, panel lighting circuit breakers are found in the Q row: *PANEL L/CTR, L OVHD; PANEL R OVHD, R*; and *PANEL MS, OS*. The lighting circuit breakers are generally out for day launches. *LIGHTING PANEL LEFT/CENTER* and *LEFT OVERHEAD OFF/BRT* rotary switches are found on panel O6. *LIGHTING PANEL RIGHT* and *RIGHT OVERHEAD OFF/BRT* rotary switches are located on panel O8. A *LIGHTING PANEL OFF/BRT* rotary switch is located on panel R10. An *ORBIT STATION LIGHTING PANEL OFF/BRT* rotary switch is located on panel A6U.

Instrument Lighting

The flight deck instruments have internal integral lighting that illuminates the face to enable the flight crew to read the displayed data. Lighting is provided by incandescent lamps located behind the face of the instruments. Prisms are used to distribute the light evenly over the face. Circuit breakers labeled *INST OS, INST R, INST OVHD*, and *INST L/CTR* are located in rows Q and R on panel L4. *LIGHTING INSTRUMENT LEFT/CTR* and *OVERHEAD OFF/BRT* rotary switches are located on panel O6. A *LIGHTING PANEL RIGHT INSTRUMENT OFF/BRT* rotary switch is located on panel O8. An *ORBIT STATION LIGHTING INSTRUMENT OFF/BRT* rotary switch is located on panel A6U.



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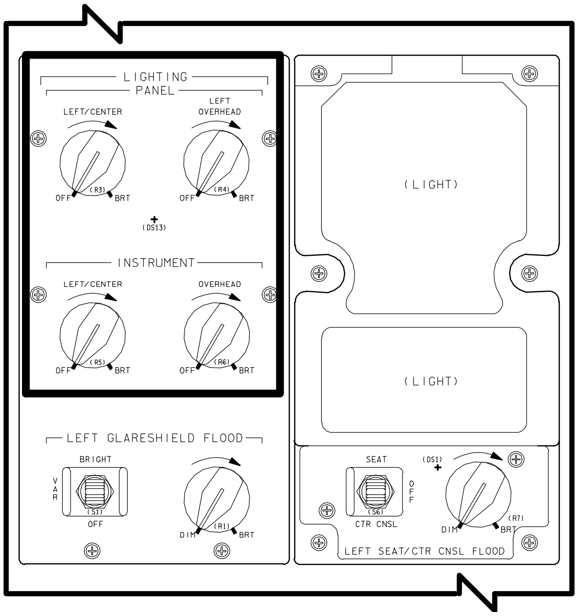
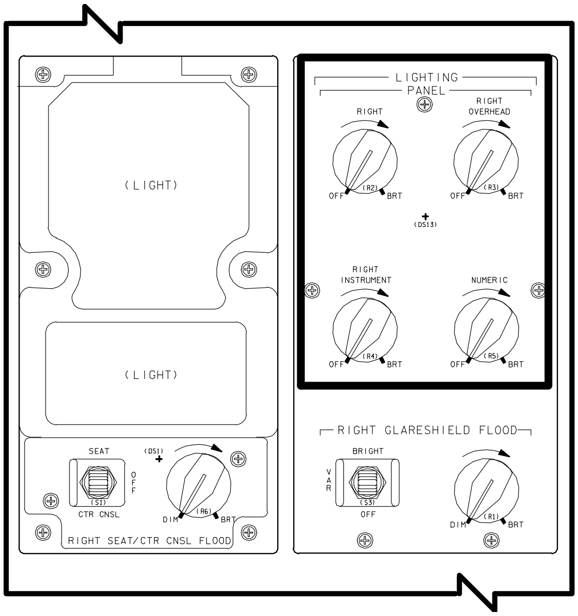
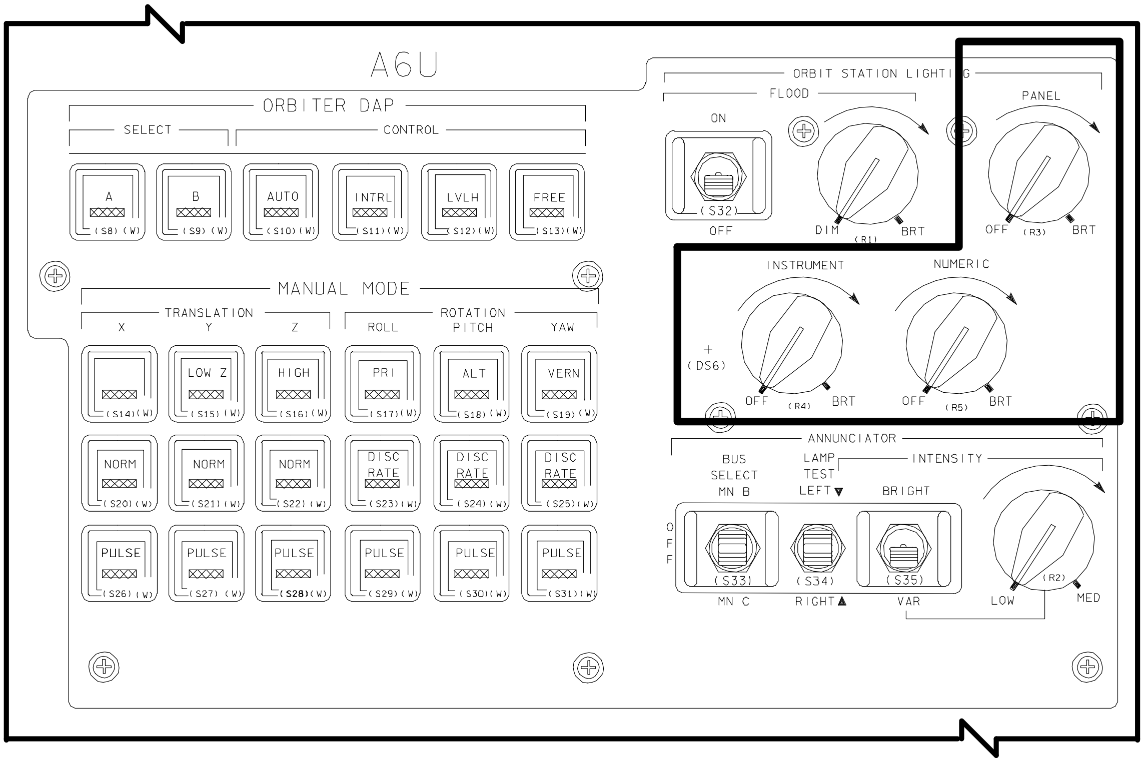
PANEL INST and NUMERIC Circuit Breakers on Panel L4



PANEL and INSTRUMENT LIGHTING
Controls on Panel O6



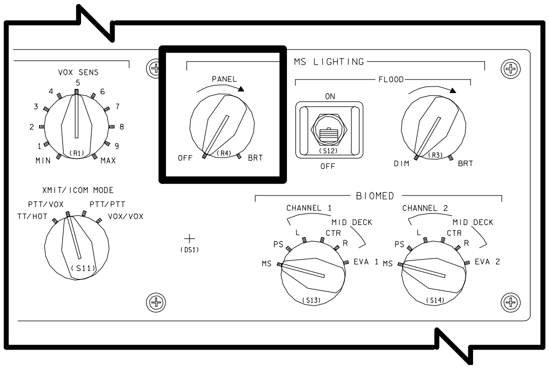
PANEL, INSTRUMENT, and NUMERIC
Lighting Controls on Panel O8



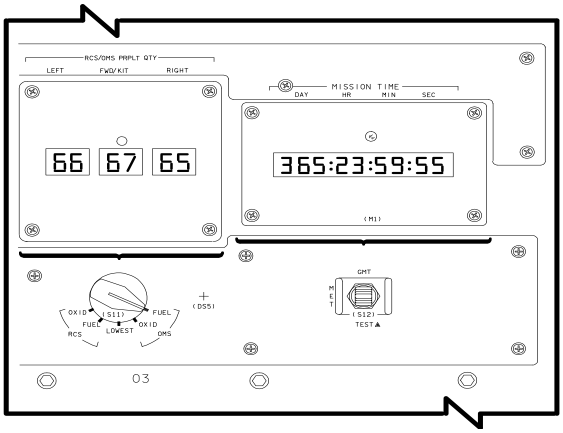
PANEL, INSTRUMENT, and NUMERIC Lighting on Panel A6U

Numeric Lighting

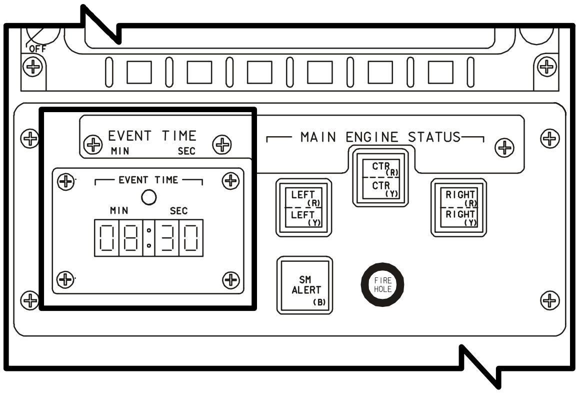
Indicators on the flight deck use illuminated numeric (digital) readouts to display data. The illumination is provided by a single incandescent lamp in each segment of a digit. Seven segments are required to generate the numbers zero through nine. Each numeric indicator has a red light to indicate failures in the indicator and will be illuminated when any lamp in the indicator fails. The numeric (digital) indicators are *EVENT TIME* (panels F7 and A4), *MISSION TIME* (panels O3 and A4), *RCS/OMS PRPLT QTY* (panel O3), and *RANGE/ELEVATION* and *RANGE RATE/AZIMUTH* (rendezvous radar) on panel A2. The *LIGHTING NUMERIC OS* circuit breaker is located in row Q on panel L4. A *LIGHTING NUMERIC OFF/BRT* rotary switch is located on panel O8, and an *ORBIT STATION LIGHTING NUMERIC OFF/BRT* rotary switch is located on panel A6U. The RMS (if installed) has numeric readouts on panel A8U.



PANEL Lighting Control on Panel R10



RCS/OMS PRPLT QTY and MISSION TIME Numeric (Digital) Indicators on panel O3



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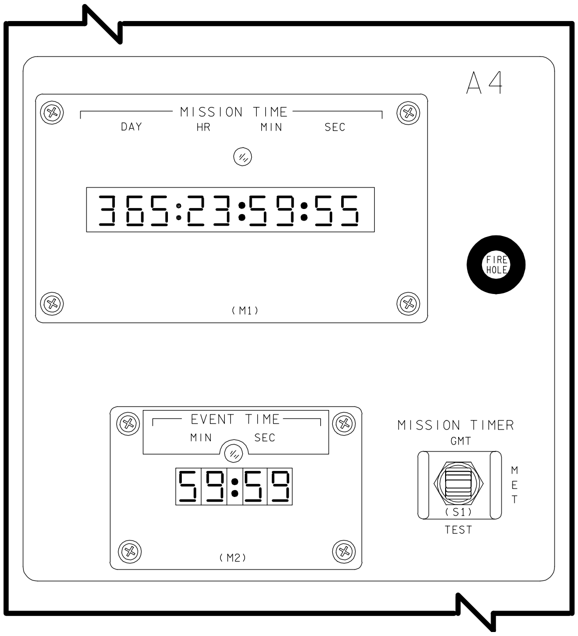
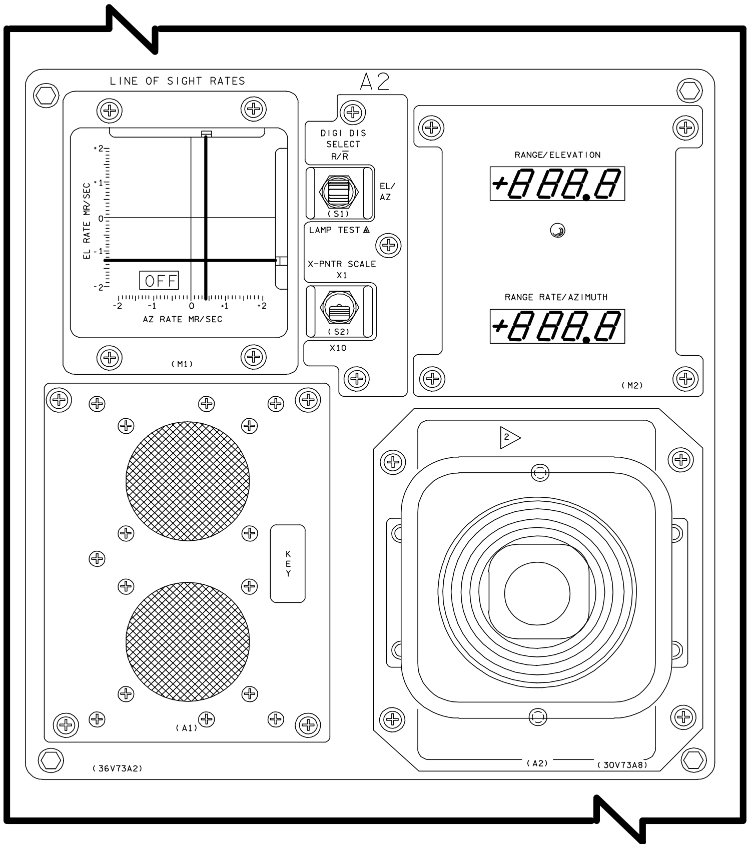
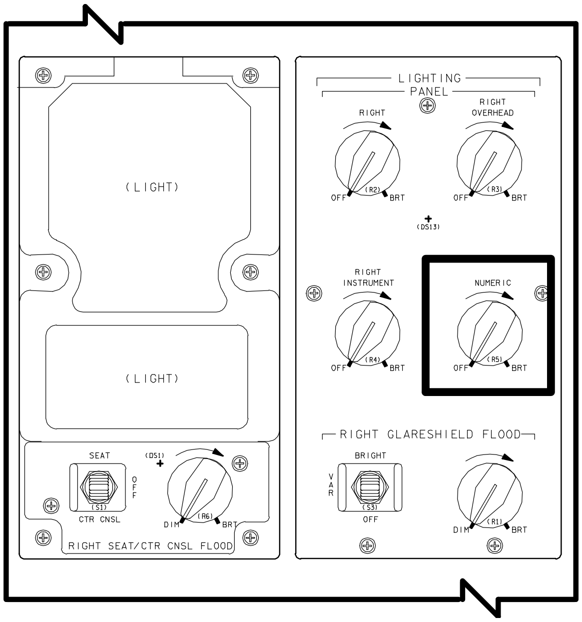
EVENT TIME Numeric (Digital) Indicator on Panel F7



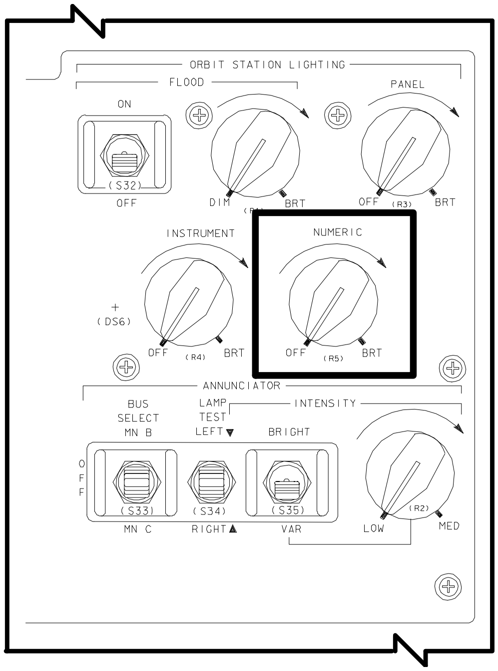
MISSION TIME and EVENT TIME Numeric (Digital) Indicators on A4



RANGE/ELEVATION AND RANGE RATE/AZIMUTH
Numeric (Digital) Indicators on Panel A2



LIGHTING NUMERIC Rotary Switch on Panel O8



ORBIT STATION LIGHTING NUMERIC Rotary Switch on Panel A6U

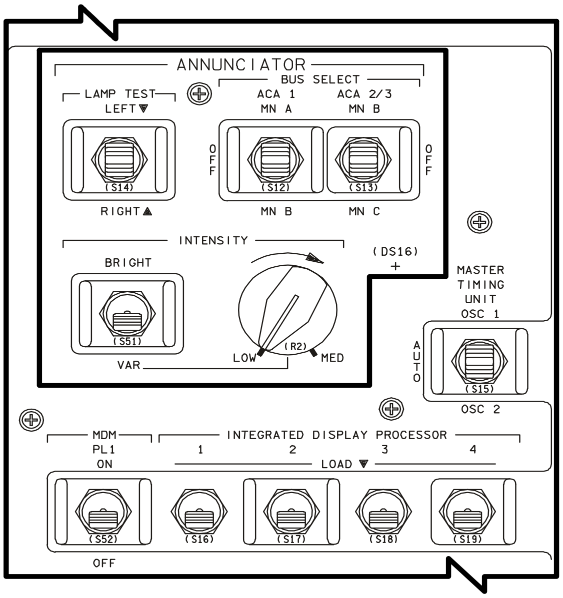
Annunciator Lights

Annunciators provide visual indications of vehicle and payload systems status. The annunciator lights are classified as emergency, warning, caution, and advisory. Emergency and warning annunciators are red, and cautions are yellow. Advisory annunciators may be white (status), green (normal configuration), yellow (alternate configuration), or blue (special applications).

Annunciator lighting is provided by incandescent lamps that illuminate the lens area of the annunciators. Most annunciators are driven by an annunciator control assembly, which controls the illumination of the lights during a "normal" or "test" input and also controls the brightness level. The caution and warning status lights on panel F7 and the *GPC STATUS* lights on panel O1 have separate electronic units for lighting control. Some annunciator lighting is provided by directly driven light emitting diodes (LEDs).

Three different lens configurations exist for the pushbutton indicators and indicator lights. One configuration has illuminated nomenclature in the appropriate color on an opaque black background. The nomenclature cannot be seen until it is illuminated. Another configuration has non-illuminated white nomenclature on an opaque black background and a bar that illuminates in the appropriate color. The nomenclature in this configuration is always visible. The third configuration has a bar that illuminates on an opaque black background and no nomenclature on the lens, but nomenclature is available as part of the panel.

The forward flight deck *ANNUNCIATOR BUS SELECT ACA 1* and *ACA 2/3* switches on panel O6 provide electrical power to enable the corresponding AC power supplies. (Section 2.8 has details on the power system and associated terminology.) ACA 1 is enabled by positioning *BUS SELECT ACA 1* to either the *MN A* or *MN B* position, and thus the annunciator lights associated with ACA 1. *BUS SELECT ACA 1* also provides electrical power to the *ANNUNCIATOR INTENSITY BRIGHT, VAR* switch and the *LOW, MED* rotary switch on panel O6, controlling the intensity of the annunciator lights associated with ACA 1. ACAs 2 and 3 are enabled by positioning the *BUS SELECT ACA 2/3* switch to either the *MN B* or *MN C* position, and thus the annunciator lights associated with ACAs 2 and 3. *BUS SELECT ACA 2/3* also provides electrical power to the annunciator light *INTENSITY BRIGHT, VAR* switch on panel O6 and the *LOW, MED* rotary control on panel O6, thus controlling the intensity of the annunciator lights associated with ACAs 2 and 3. The *OFF* position of the *BUS SELECT ACA 1* switch removes power from ACA 1, disabling the annunciator lights associated with it. The *OFF* position of the *BUS SELECT ACA 2/3* switch removes power from ACAs 2 and 3, disabling the annunciator lights associated with them.



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ANNUNCIATOR Lighting Controls on Panel O6

Illuminated nomenclature (Nomenclature is black when not illuminated).

Illuminated bar-white nomenclature

Illuminated bar-no nomenclature

(Bars appear black when not illuminated).

All backgrounds are opaque black.

592.cvs

Typical Annunciator Configurations

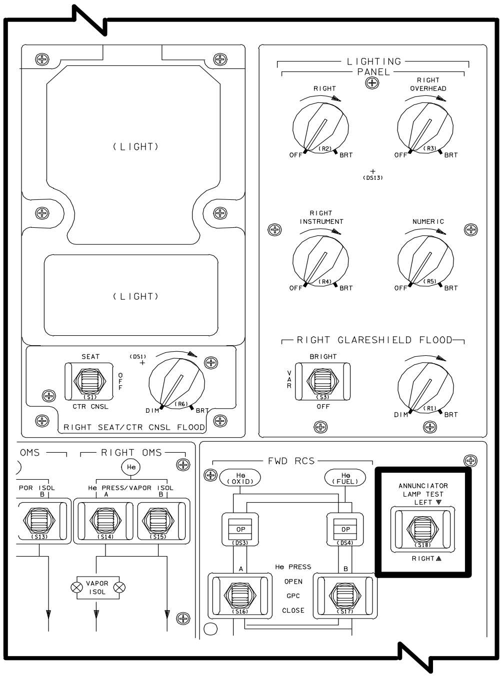
The *ANNUNCIATOR INTENSITY* switch on panel O6 positioned to *BRIGHT* bypasses the *INTENSITY LOW, MED* rotary control. The *ANNUNCIATOR INTENSITY* switch positioned to *VAR* permits the *INTENSITY LOW, MED* rotary control to control annunciator light intensity.

The *ANNUNCIATOR LAMP TEST* switch on panel O6 or O8 positioned to *LEFT* applies power to the ACA 1, 2, and 3 annunciator lamp test circuits, illuminating annunciator lights on panels F2 (*MASTER ALARM*), F6, L1 (*SMOKE DETECTION*), O1 (*GPC STATUS*), and M029J, the left 20 C/W lights on panel F7, and the *SM ALERT* on panel F7. Positioning the *LAMP TEST* switches to *RIGHT* applies power to the ACA 1, 2, and 3 annunciator lamp test circuits, illuminating the annunciator lights on panels C3, F4 (*MASTER ALARM*), F8, and M052J (*MASTER ALARM*), the right 20 C/W lights on panel F7, and the *MAIN ENGINE STATUS* lights on panel F7.

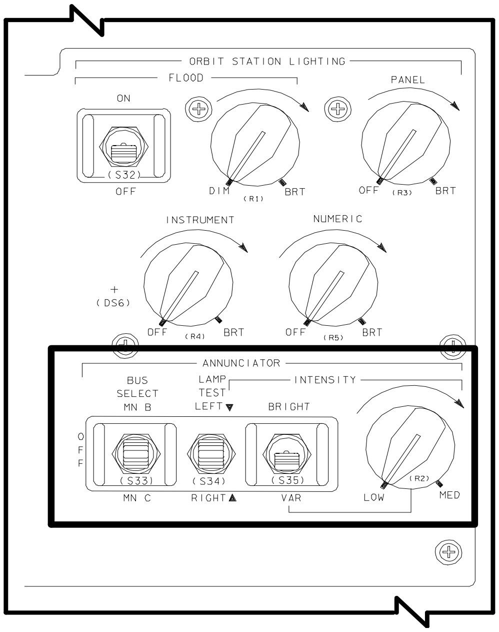
The aft flight deck *ANNUNCIATOR BUS SELECT* switch on panel A6U provides electrical power to enable ACAs 4 and 5. ACAs 4 and 5 are enabled by positioning *BUS SELECT* to either the *MN B* or *MN C* position, and thus the annunciator lights associated with ACAs 4 and 5. The *BUS SELECT* switch also provides electrical power to the annunciator light *INTENSITY BRIGHT, VAR* switch and the *LOW, MED* rotary control on panel A6U, thus controlling annunciator light intensity associated with ACAs 4 and 5. The *OFF* position of the *BUS SELECT* switch removes power from ACAs 4 and 5, disabling the annunciator lights associated with them.

The *ANNUNCIATOR INTENSITY* switch on panel A6U, when positioned to *BRIGHT*, bypasses the *INTENSITY LOW, MED* rotary control on panel A6U. Positioned to *VAR*, it permits the *INTENSITY LOW, MED* rotary control to vary annunciator light intensity.

The *ANNUNCIATOR LAMP TEST* switch on panel A6U, when positioned to *LEFT*, applies power to the ACA 4 and 5 annunciator lamp test circuits, illuminating the annunciator lights on panels A2 and A6U, the *VIDEO INPUT* pushbuttons on panel A7U, and columns 0 through 4 on panel R13U. Positioning the switch to *RIGHT* applies power to the ACA 4 and 5 annunciator lamp test circuits, illuminating the annunciator lights (*MASTER ALARM*) and *VIDEO OUTPUT* and *ALC/GAMMA* pushbuttons on panel A7U and columns 5 through 9 on panel R13U.



ANNUNCIATOR LAMP TEST Switch on Panel O8



ANNUNCIATOR Lighting Controls on Panel A6U

Exterior Lighting

The exterior floodlights improve visibility for the crew during payload bay door operations, EVA operations, RMS operations, stationkeeping, and docking.

Metal halide lamps light the payload bay. These lamps are gas discharge arc tubes similar to mercury vapor lamps.

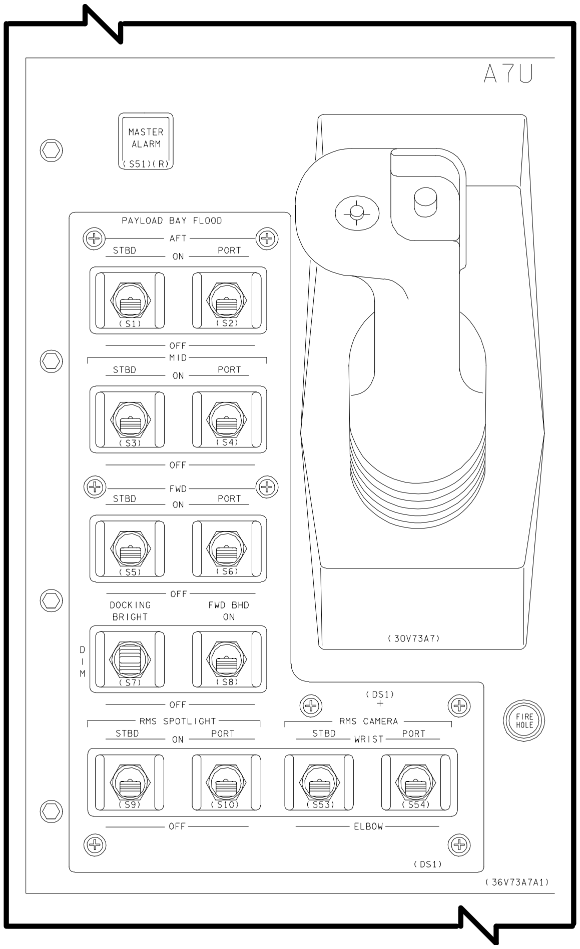
After a floodlight is turned on, it takes 2 to 3 minutes to reach full brightness. It is recommended by the manufacturer that payload bay floodlights remain powered for a minimum of 10 minutes before being turned off. The only exception is if a floodlight fails to illuminate. If a light does not reach full brightness in 5 minutes, it should be unpowered. Also, when a light is turned off, it should not be repowered for 10 to 16 minutes, depending on the amount of payload blocking of the light. These time constraints will help prolong floodlight life.

The premature failure of the lamps on a previous flight may have been caused by not waiting the required time before repowering the lamps. It is better to leave the lamps powered until the task is finished than to try to save power by turning them off.

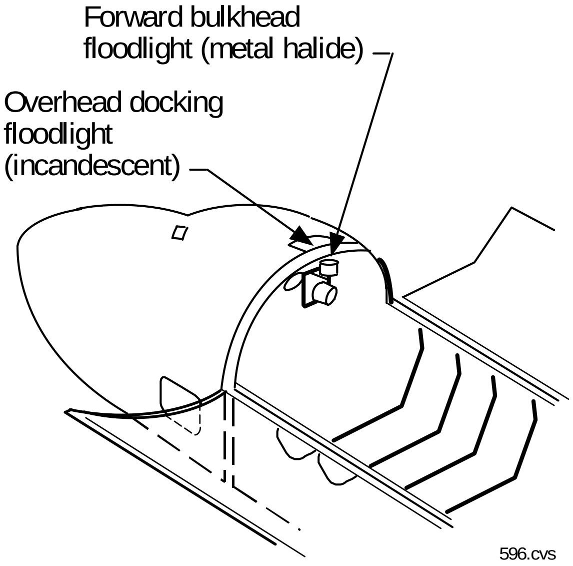
Each lamp has a separate DC/DC power supply that produces the higher voltage required to operate the lamps. Power for the lamps is supplied by the mid power control assemblies, using 10-amp remote power controllers to control the lights.

The power supplies for the metal halide lamps are mounted to the floodlight electronics assemblies, which are cooled by the Freon loops. The floodlight used for docking and the forward bulkhead floodlight use a cold plate cooled by the water loops. *These two lights are present only on OV-104, and have been removed from OV-103 and OV-105 due to issues with the water loop cold plate.*

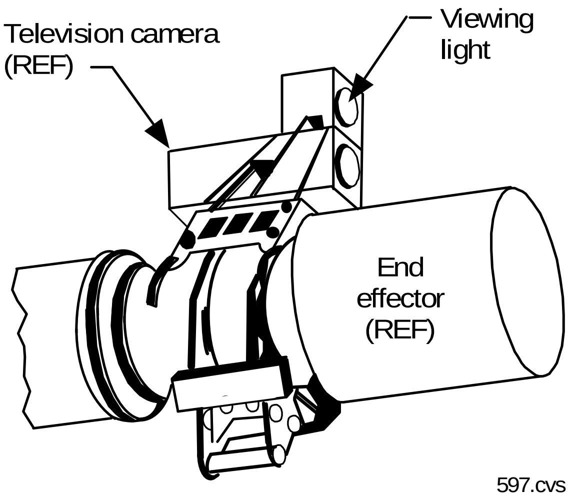
The payload bay floodlights are controlled by switches on panel A7U. The panel contains *PAYLOAD BAY FLOOD AFT, MID,* and *FWD* sets of switches, with a *STBD* and *PORT* switch in each set. The *DOCKING* light switch is below the payload bay flood controls on panel A7U; it has *BRIGHT, DIM,* and *OFF* settings. The RMS floodlight is controlled by *RMS SPOTLIGHT STBD* and *PORT* switches on panel A7U. *The DOCKING and FWD BHD switches are only active for OV-104, where the lights are still installed. The switches are physically present on OV-103 and -105, but do not do anything.*



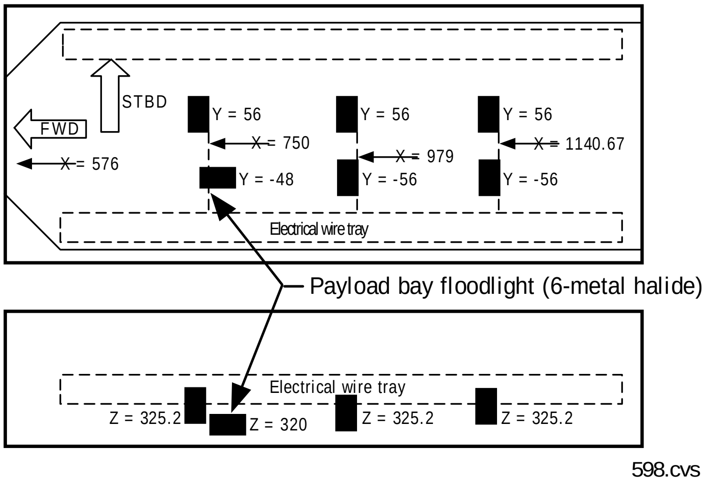
PAYLOAD BAY FLOOD, DOCKING, and RMS Lighting Controls on Panel A7U



Bulkhead Floodlights *(OV-104 only)*



Remote Manipulator System Wrist Floodlight



Payload Bay Forward/Mid/Aft Floodlights

Lighting System Summary Data

- Interior lighting consisting of floodlights, panel lights, instrument lights, numeric lights, and annunciator lights provides general illumination throughout the crew cabin.
- Exterior floodlights and spotlights improve visibility for the flight crew during payload bay door operations, EVA operations, RMS operations, stationkeeping, and docking.
- Emergency lighting is provided by separate fixtures powered by a separate power input from an essential bus. Emergency lighting is controlled by switches on panels C3 and ML18F.
- Switches controlling the lighting system are distributed over panels R10, L9, O6, O8, A6U, A7U, MO13Q, ML18F, and AW18A.
- Lighting system circuit breakers are located on panel L4.

Lighting System Rules of Thumb

- Power consumption of cockpit lighting can be as much as 1 to 2 kW with all lights on.
- When payload bay floodlights are powered, they should be left on for a minimum of *10* minutes.
- When payload bay floodlights are turned off, they should remain unpowered for 10 to 16 minutes prior to repowering.
- If a payload bay floodlight does not reach full brightness within 5 minutes of being powered, it should be turned off.

2.16 MAIN PROPULSION SYSTEM (MPS)

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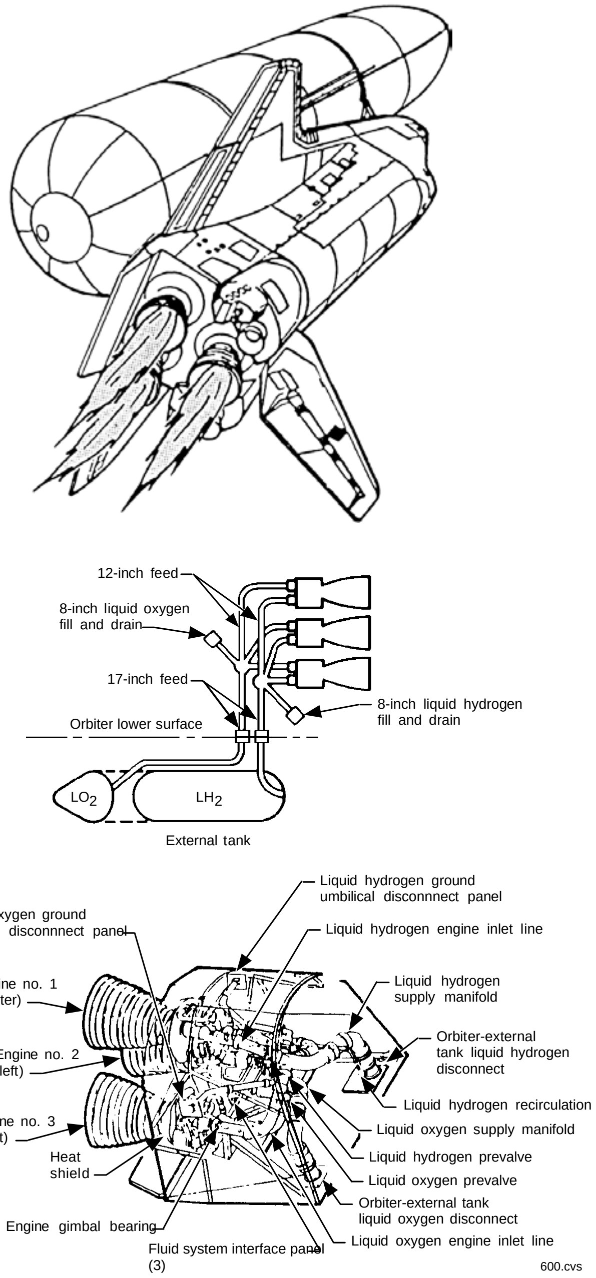
Description

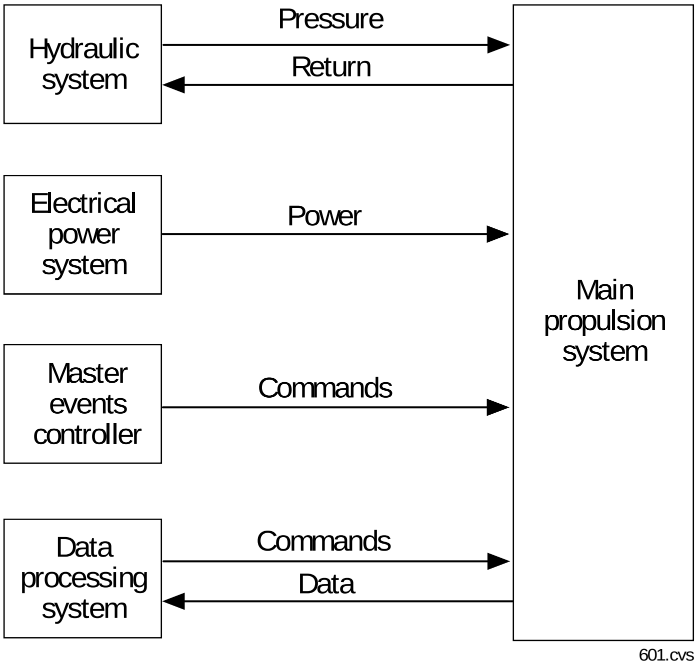
The space shuttle main engines (SSMEs), assisted by two solid rocket motors during the initial phases of the ascent trajectory, provide vehicle acceleration from lift-off to main engine cutoff (MECO) at a predetermined velocity.

The MPS has critical interfaces with the orbiter hydraulic system, electrical power system, master events controller, and data processing system. The hydraulic system supplies hydraulic pressure to operate the main engine valves and gimbal actuators. The electrical power system furnishes ac power to operate the main engine controllers and dc power to operate the valves and transducers in the propellant management and helium systems. The master events controller initiates firings of pyrotechnic devices to separate the SRBs from the external tank and the external tank from the orbiter. The data processing system controls most of the MPS functions during ascent and entry.

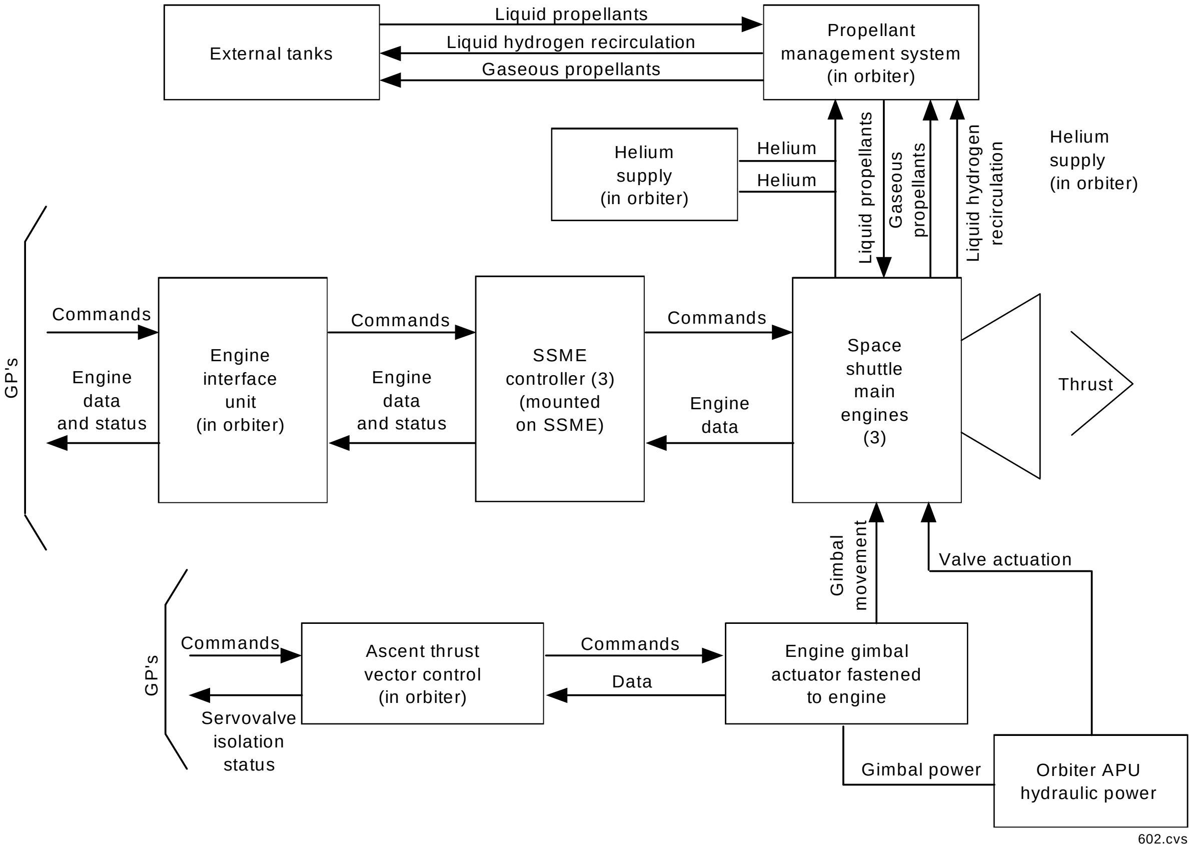
The MPS has three SSMEs, three SSME controllers, the ET, the orbiter MPS propellant management system and helium subsystem, four ascent thrust vector control units, and six SSME hydraulic TVC servoactuators. (The external tank is described in detail in Section 1.3.) Most of the MPS is located in the aft fuselage beneath the vertical stabilizer.



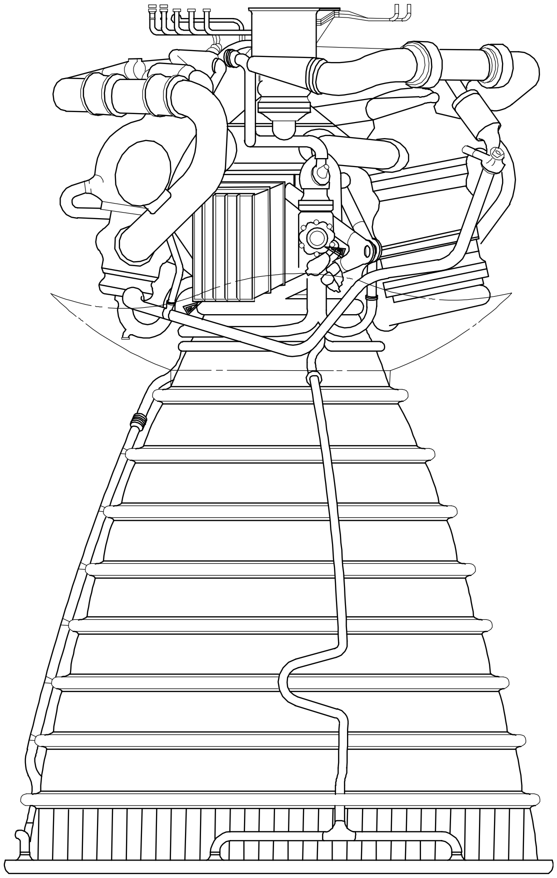
Main Propulsion System



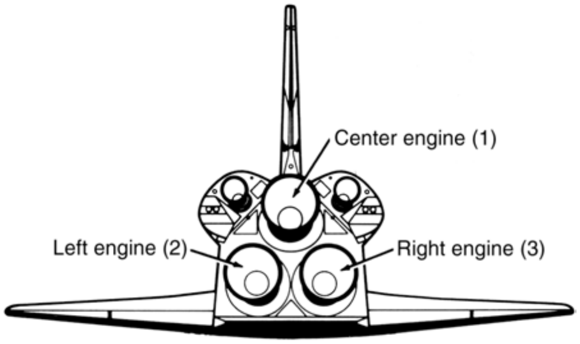
Critical Interfaces with the Main Propulsion System



Main Propulsion System Subsystem



Space Shuttle Main Engine



Main Engine Numbering System

Space Shuttle Main Engines (SSMEs)

The three SSMEs are reusable, high-performance, liquid propellant rocket engines with variable thrust. The engines use liquid hydrogen for fuel and cooling and liquid oxygen as an oxidizer. The propellant is carried in separate tanks within the external tank and is supplied to the main engines under pressure. Using a staged combustion cycle, the propellants are partially burned at high pressure and relatively low temperature in two preburners, then completely burned at high pressure and high temperature in the main combustion chamber.

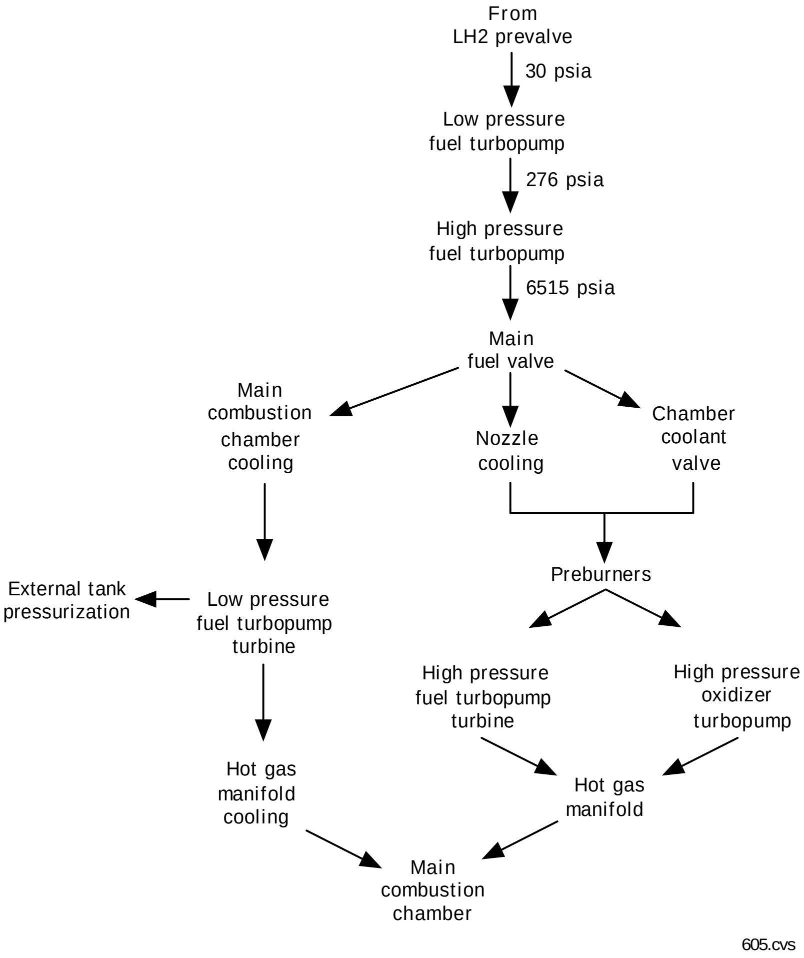
The engines are generally referred to as the center (engine 1), left (engine 2), and right (engine 3). Each engine is designed for 15,000 seconds of operation over a life span of 30 starts. Throughout the throttling range, the ratio of the liquid oxygen to liquid hydrogen mixture is 6:1. Each nozzle area ratio is 77.5:1. The engines are 14 feet long and 7.5 feet in diameter at the nozzle exit. Overall, a space shuttle main engine weighs approximately 7,000 pounds.

The main engines can be throttled over a range of 67 to 109 percent of their rated power level in 1-percent increments. A value of 100 percent corresponds to a thrust level of 375,000 pounds at sea level and 470,000 pounds in a vacuum; 104 percent corresponds to 393,800 pounds at sea level and 488,800 pounds in a vacuum; 109 percent corresponds to 417,300 pounds at sea level and 513,250 pounds in a vacuum.

At sea level, flow separation in the nozzle reduces the engine throttling range, prohibiting operation of the engine at its minimum 67-percent throttle setting. All three main engines receive the same throttle command at the same time. Normally, these come automatically from the orbiter general-purpose computers (GPCs) through the engine controllers. During certain contingency situations, engine throttling may be controlled manually through the pilot's speedbrake/thrust controller. SSME throttling reduces vehicle loads during maximum aerodynamic pressure and limits vehicle acceleration to a maximum of 3 g's during ascent.

Hydraulically powered gimbal actuators allow each engine to be gimbaled in the pitch and yaw axes for thrust vector control.

The SSME major components are the fuel and oxidizer turbopumps, preburners, a hot gas manifold, main combustion chamber, nozzle, oxidizer heat exchanger, and propellant valves.



Main Engine Fuel Flow

Fuel Turbopumps

Low-Pressure Fuel Turbopump

The low-pressure fuel turbopump is an axial-flow pump driven by a two-stage axial flow turbine powered by gaseous hydrogen. It boosts liquid hydrogen pressure from 30 psia to 276 psia and supplies the high-pressure fuel turbopump. During engine operation, this pressure increase allows the high-pressure fuel turbopump to operate at high speeds without cavitating. The low-pressure fuel turbopump operates at approximately 16,185 rpm, measures approximately 18 by 24 inches, and is flange-mounted to the SSME at the inlet to the low-pressure fuel duct.

High-Pressure Fuel Turbopump

The high-pressure fuel turbopump, a three-stage centrifugal pump driven by a two-stage, hot-gas turbine, boosts liquid hydrogen pressure from 276 psia to 6,515 psia. It operates at approximately 35,360 rpm. The discharge flow from the high-pressure turbopump is routed through the main fuel valve and then splits into three flow paths. One path is through the jacket of the main combustion chamber, where the hydrogen is used to cool the chamber walls, and then to the low-pressure fuel turbopump to drive its turbine. The second flow path, through the chamber coolant valve, supplies liquid hydrogen to the preburner combustion chambers and also cools the hot gas manifold.

The third hydrogen flow path is used to cool the engine nozzle. It then joins the second flow path from the chamber coolant valve. The high-pressure fuel turbopump is approximately 22 by 44 inches and is flanged to the hot-gas manifold.

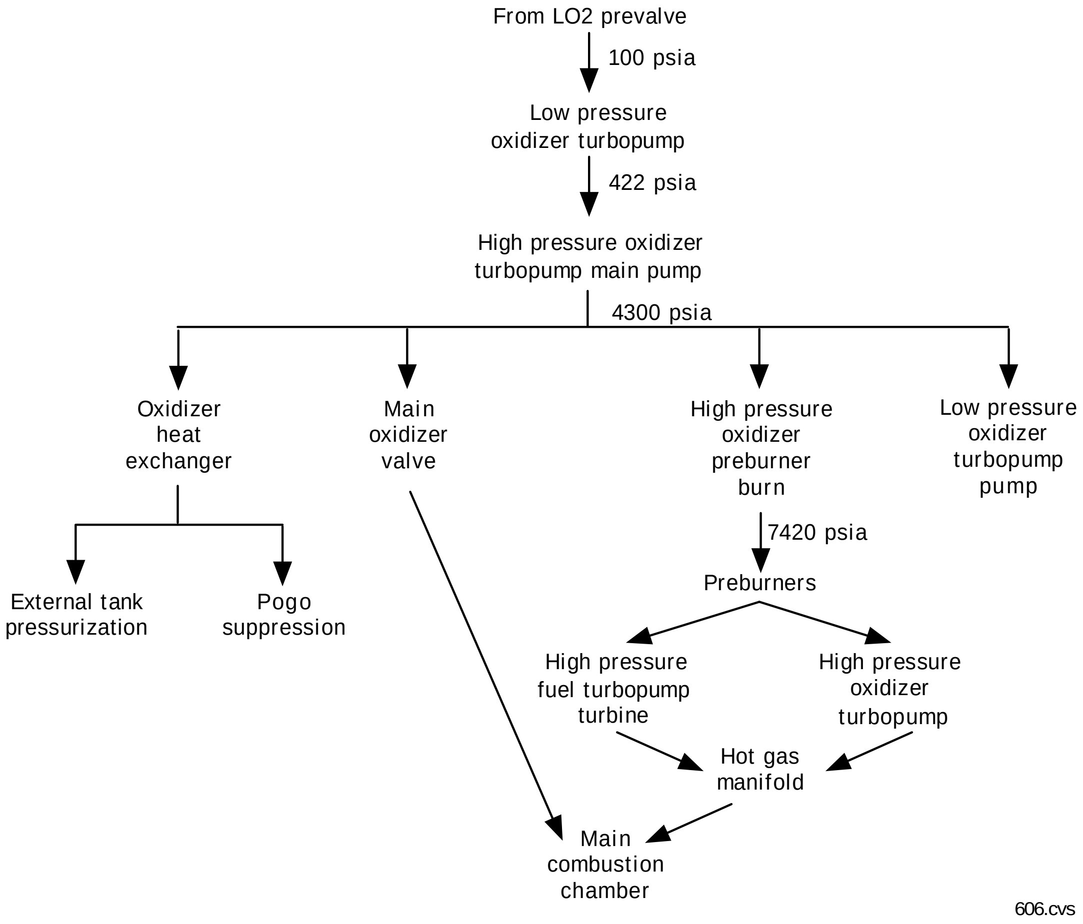
Oxidizer Turbopumps

Low-Pressure Oxidizer Turbopump

The low-pressure oxidizer turbopump is an axial-flow pump driven by a six-stage turbine powered by liquid oxygen. It boosts the liquid oxygen pressure from 100 psia to 422 psia. The flow is supplied to the high-pressure oxidizer turbopump to permit it to operate at high speeds without cavitating. The low-pressure oxidizer turbopump operates at approximately 5,150 rpm, measures approximately 18 by 18 inches, and is flange-mounted to the orbiter propellant ducting.

High-Pressure Oxidizer Turbopump

The high-pressure oxidizer turbopump consists of two single-stage centrifugal pumps (a main pump and a preburner pump) mounted on a common shaft and driven by a two-stage, hot-gas turbine. The main pump boosts liquid oxygen pressure from 422 psia to 4,300 psia while operating at approximately 28,120 rpm. The high-pressure oxidizer turbopump discharge flow splits into several paths, one of which is routed to drive the low-pressure oxidizer turbopump turbine. Another path is routed through the main oxidizer valve and enters the main combustion chamber. Another small flow path is tapped off and sent to the oxidizer heat exchanger, where it is vaporized



Main Engine Oxidizer Flow

and then used to pressurize the external tank. The final path enters the preburner boost pump to raise the liquid oxygen's pressure from 4,300 psia to 7,420 psia at the inlet to the liquid oxygen preburner. The high-pressure oxidizer turbopump measures approximately 24 by 36 inches. It is flanged to the hot-gas manifold.

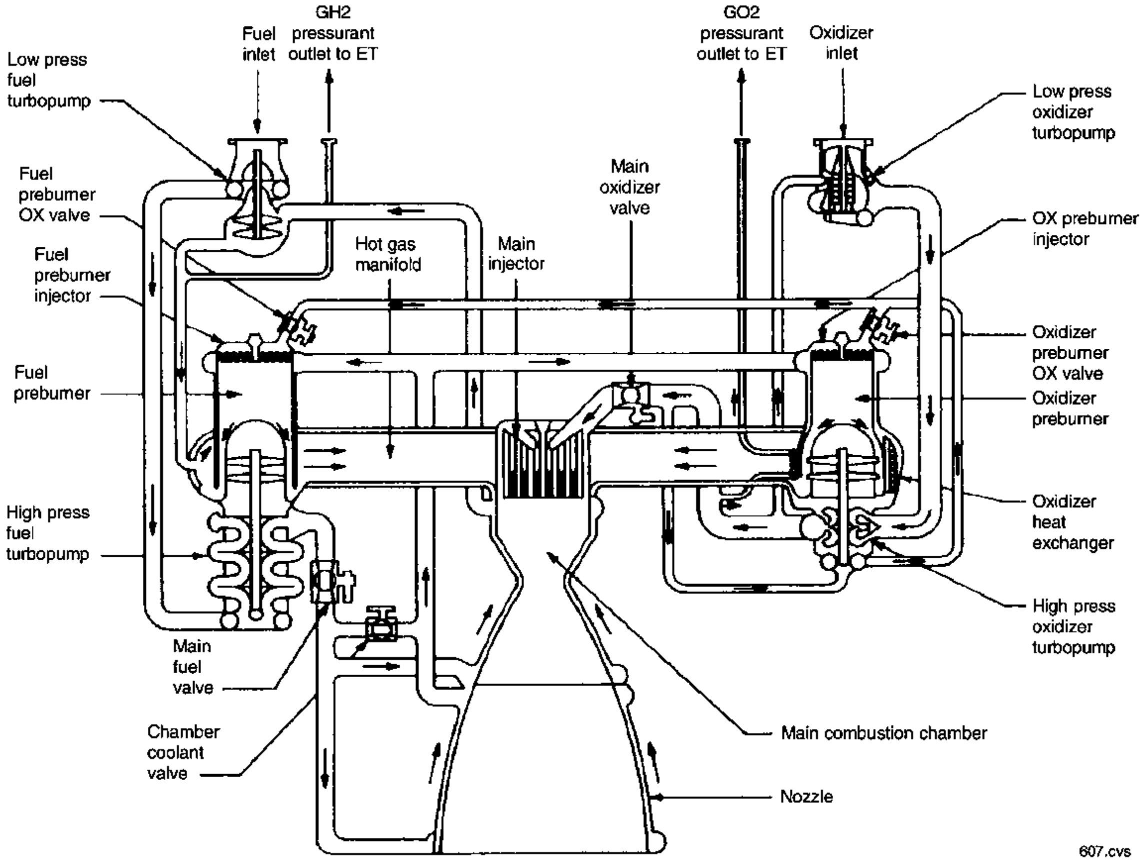
Bellows

The low-pressure oxygen and low-pressure fuel turbopumps are mounted 180° apart on the engine. The lines from the low-pressure turbopumps to the high-pressure turbopumps contain flexible bellows that enable them to flex when loads are applied. This prevents them from cracking during engine operations.

Helium Purge

Because the high-pressure oxidizer turbopump turbine and pumps are mounted on a common shaft, mixing the fuel-rich hot gas in the turbine section and the liquid oxygen in the main pump could create a hazard. To prevent this, the two sections are separated by a cavity that is continuously purged by the MPS engine helium supply during engine operation. Two seals, one located between the turbine section and the cavity, and the other between the pump section and cavity, minimize leakage into the cavity.

Should this cavity experience a drop in helium pressure below opertating limits, the main engine controller will initiate an automatic engine shutdown, rather than risk the possibility of the propellants leaking through the seals, mixing in the cavity, and resulting in catastrophic engine shutdown.



Main Engine Schematic

WARNING

Catastrophic shutdown may occur if low helium pressure occurs in the cavity while the operating limits are inhibited. The same is true if there is a rapid loss of helium pressure (e.g. both MPS helium isolation valves are closed). In either case, the propellants could possibly leak through the seals and mix in the cavity, resulting in catastrophic shutdown.

Hot Gas Manifold

The hot-gas manifold is the structural backbone of the engine. It supports the two preburners, the high-pressure turbopumps, and the main combustion chamber. Hot gas generated by the preburners, after driving the high-pressure turbopumps, passes through the hot-gas manifold on the way to the main combustion chamber.

Preburners

The oxidizer and fuel preburners are welded to the hot-gas manifold. Liquid hydrogen and liquid oxygen from the high-pressure turbopumps enter the preburners and are mixed so that efficient combustion occurs. The preburners produce the fuel-rich hot gas that passes through the turbines to generate the power to operate the high-pressure turbopumps. The oxidizer preburner's outflow drives a turbine that is connected to the high-pressure oxidizer turbopump and the oxidizer preburner boost pump. The fuel preburner's outflow drives a turbine connected to the high-pressure fuel turbopump.

Main Combustion Chamber

Each engine main combustion chamber receives fuel-rich hot gas from the fuel and oxidizer preburners. The high-pressure oxidizer turbopump supplies liquid oxygen to the combustion chamber where it is mixed with fuel-rich gas by the main injector. A small augmented spark igniter chamber is located in the center of the injector. The dual-redundant igniter is used during the engine start sequence to initiate combustion. The igniters are turned off after approximately 3 seconds because the combustion process is self-sustaining. The main injector and dome assembly are welded to the hot-gas manifold. The main combustion chamber is bolted to the hot-gas manifold. The combustion chamber, as well as the nozzle, is cooled by gaseous hydrogen flowing through coolant passages.

The nozzle assembly is bolted to the main combustion chamber. The nozzle is 113 inches long, with an exit plane of 94 inches. The physical dimension of the nozzle creates a 77.5:1 expansion ratio. A support ring welded to the forward end of the nozzle is the engine attach point to the engine heat shield. Thermal protection is provided for the nozzles to protect them from the high heating rates experienced during the launch, ascent, on-orbit, and entry phases. The insulation consists of four layers of metallic batting covered with a metallic foil and screening.

Oxidizer Heat Exchanger

The oxidizer heat exchanger converts liquid oxygen to gaseous oxygen for tank pressurization and pogo suppression. The heat exchanger receives its liquid oxygen from the high-pressure oxidizer turbopump discharge flow.

Pogo Suppression System

A pogo suppression system prevents the transmission of low-frequency flow oscillations into the high-pressure oxidizer turbopump and, ultimately, prevents main combustion chamber pressure (engine thrust) oscillation. Flow oscillations transmitted from the vehicle are suppressed by a partially filled gas accumulator, which is attached by flanges to the high-pressure oxidizer turbopump's inlet duct.

The system consists of a 0.6-cubic-foot accumulator with an internal standpipe, helium precharge valve package, gaseous oxygen supply valve package, and four recirculation isolation valves.

During engine start, the accumulator is charged with helium 2.4 seconds after the start command to provide pogo protection until the engine heat exchanger is operational and gaseous oxygen is available. The accumulator is partially chilled by liquid oxygen during the engine chill-down operation. It fills to the overflow standpipe line inlet level, which is sufficient to preclude gas ingestion at engine start. During engine operation, the accumulator is charged with a continuous gaseous oxygen flow.

The liquid level in the accumulator is controlled by an internal overflow standpipe, which is orificed to regulate the gaseous oxygen overflow at varying engine power levels. The system is sized to provide sufficient supply of gaseous oxygen at the minimum flow rate and to permit sufficient gaseous oxygen overflow at the maximum pressure transient in the low-pressure oxidizer turbopump discharge duct. Under all other conditions, excess gaseous and liquid oxygen are recirculated to the low-pressure oxidizer turbopump inlet through the engine oxidizer bleed duct.

The pogo accumulator is also pressurized with MPS helium at engine shutdown to provide a positive pressure at the high-pressure oxidizer turbopump inlet. Without this positve pressure, the sudden loss of acceleration that accompanies main engine cutoff (MECO) causes the turbine to cavitate before the blades have had a chance to spin down. The positive pressure provided by the accumulator prevents the turbine from cavitating, flying apart, and causing vehicle damage.

CAUTION

In situations where there is insufficient helium to charge the pogo accumulator (e,g, a helium supply leak), a manual engine shutdown may be required pre-MECO, while the vehicle is still under acceleration.

Valves

Each engine has five propellant valves (oxidizer preburner oxidizer, fuel preburner oxidizer, main oxidizer, main fuel, and chamber coolant) that are hydraulically actuated and controlled by electrical signals from the engine controller. They can be fully closed by using the MPS engine helium supply system as a backup actuation system.

The turbine speeds of the high-pressure oxidizer turbopump and the high-pressure fuel turbopump depend on the position of the oxidizer and fuel preburner oxidizer valves. The engine controller uses the preburner oxidizer valves to control engine thrust by regulating the flow of liquid oxygen to the preburners. The oxidizer and fuel preburner oxidizer valves increase or decrease the liquid oxygen flow into the preburner, thereby increasing or decreasing preburner chamber pressure and, consequently, turbine speed. This directly affects liquid oxygen and gaseous hydrogen flow into the main combustion chamber which, in turn, can increase or decrease engine thrust. The fuel preburner oxidizer valve is used to maintain a constant 6:1 propellant mixture ratio.

The main oxidizer valve controls liquid oxygen flow into the engine combustion chamber. The main fuel valve controls the total liquid hydrogen flow into the engine cooling circuit, the preburner supply lines, and the low-pressure fuel turbopump turbine. When the engine is operating, the main valves are fully open.

A chamber coolant valve on each engine combustion chamber coolant bypass duct regulates the amount of gaseous hydrogen allowed to bypass the nozzle coolant loop to control engine temperature. The chamber coolant valve is 100 percent open before engine start, and at power levels between 100 and 109 percent. For power levels between 67 and 100 percent, the valve's position will range from 68.3 to 100 percent open.

Propellant Dump

After MECO, the main oxidizer valves in all three engines are opened to allow residual liquid oxygen to be dumped through the engine nozzles. Also after MECO, both liquid hydrogen fill/drain valves, as well as the fuel bleed valve, are opened to allow residual liquid hydrogen to drain over the left wing of the orbiter.

Space Shuttle Main Engine Controllers

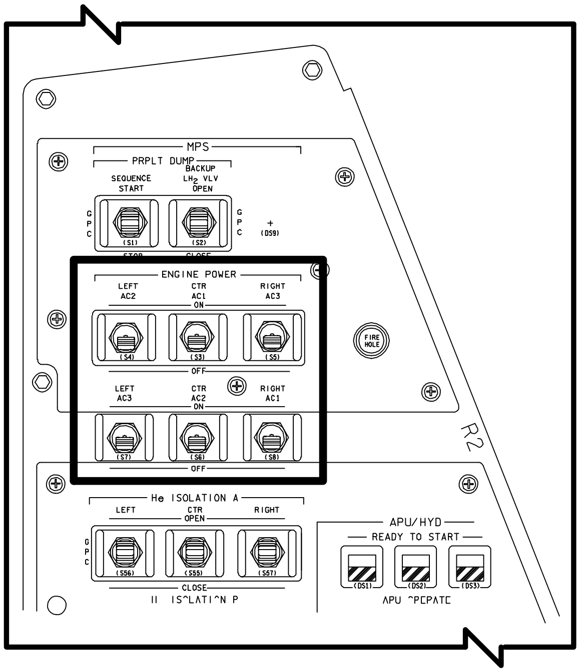
The controller is a pressurized, thermally conditioned electronics package attached to the thrust chamber and nozzle coolant outlet manifolds on the low-pressure fuel turbopump side of the engine. Each controller contains two redundant digital computer units (DCUs), referred to as DCU A and DCU B. Normally, DCU A is in control, while DCU B electronics are active but not in control. Instructions to the engine control elements are updated 50 times per second (every 20 milliseconds). Engine reliability is enhanced by a dual-redundant system that allows normal DCU operation after the first failure and a fail-safe shutdown after a second failure. High-reliability electronic parts are used throughout the controller. The digital computer is programmable, allowing engine control equations and constants to be modified by changing the software.

The controller is packaged in a sealed, pressurized chassis and is cooled by convection heat transfer through pin fins as part of the main chassis. The electronics are distributed on functional modules with special thermal and vibration protection.

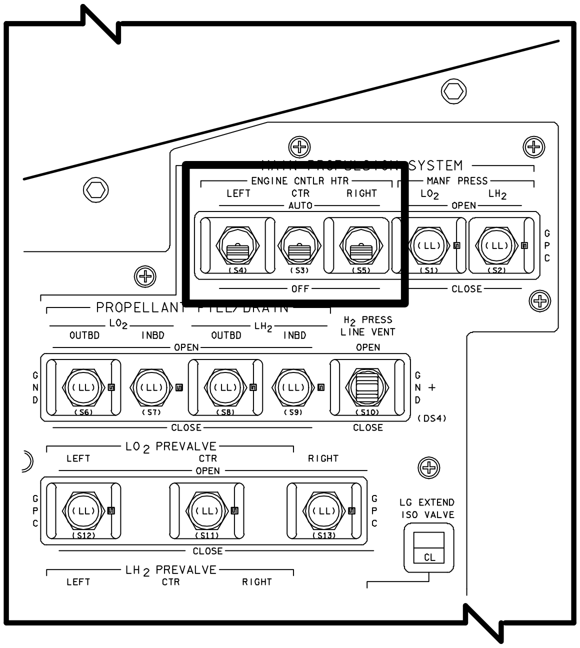
Operating in conjunction with engine sensors, valves, actuators, and spark igniters, the controllers form a self-contained system for engine control, checkout, and monitoring. The controller provides engine flight readiness verification, engine start and shutdown sequencing, closed-loop thrust and propellant mixture ratio control, sensor excitation, valve actuator and spark igniter control signals, engine performance limit monitoring, and performance and maintenance data. The controller also provides onboard engine checkout, response to vehicle commands, and transmission of engine status.

Controller power is supplied by the three ac buses in a manner that protects their redundancy. Each computer unit within a controller receives its power from a different bus. The buses are distributed among the three controllers such that the loss of any two buses will result in the loss of only one engine. The digital computer units require all three phases of an ac bus to operate. There are two MPS ENGINE POWER switches on panel R2 for each engine controller (LEFT, CTR, RIGHT); the top switch is for DCU A, and the bottom switch is for DCU B. Cycling an MPS ENGINE POWER switch to OFF and back to ON will cause the affected digital computer unit to stop processing.

Switches for engine controller heaters are found on panel R4, but these are nonfunctional. Heaters were once thought to be needed to keep the controllers thermally conditioned. This later turned out not to be the case. Since then, the heaters have not been installed.



MPS ENGINE POWER Switches on Panel R2



MAIN PROPLSION SYSTEM ENGINE CNTLR HTR Switches on Panel R4

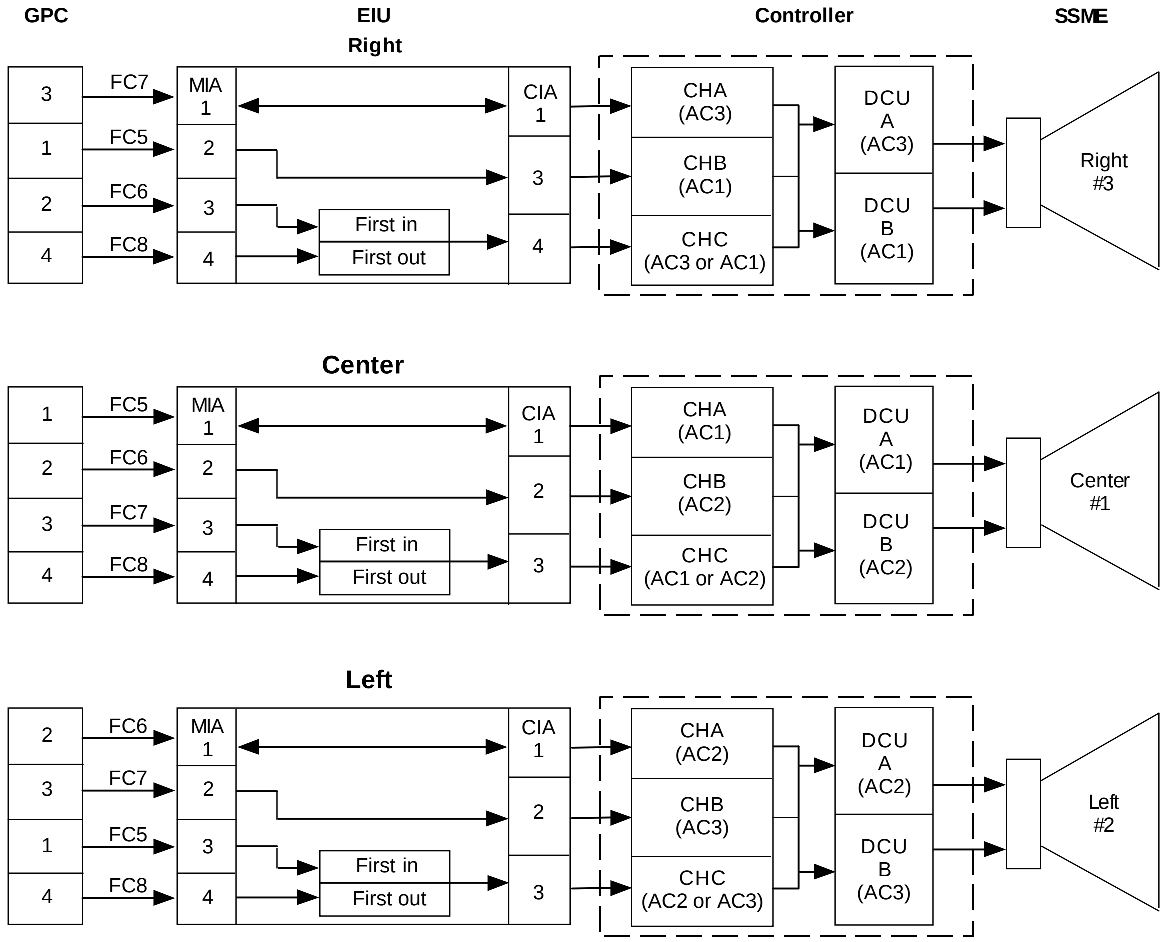
Command and Data Flow

Command Flow

Each controller receives commands transmitted by the GPCs through its own engine interface unit (EIU), a specialized multiplexer/demultiplexer (MDM) that interfaces with the GPCs and with the engine controller. When engine commands are received by the unit, the data are held in a buffer until the GPCs request data. The unit then sends the data to each GPC. Each engine interface unit is dedicated to one SSME and communicates only with the engine controller that controls its SSME. The three units have no interface with each other.

The engine interface units are powered through the EIU switches on panel O17. If a unit loses power, its corresponding engine cannot receive any throttle, shut down, or dump commands, and will not be able to communicate with the GPCs. As a result, the controller will maintain the last valid command until it is shut down manually via the MPS ENGINE POWER switches on panel R2.

Each orbiter GPC, operating in a redundant set, issues engine commands from resident SSME subsystem operating programs to the EIUs for transmission to their corresponding engine controllers. Engine commands are output over the GPC's assigned flight-critical data bus (a total of four GPCs outputting over four flight-critical data buses). Therefore, each EIU will receive four commands. The nominal ascent configuration has GPCs 1, 2, 3, and 4 outputting on flight-critical data buses 5, 6, 7, and 8, respectively. Each data bus is connected to one multiplexer interface adapter in each EIU.



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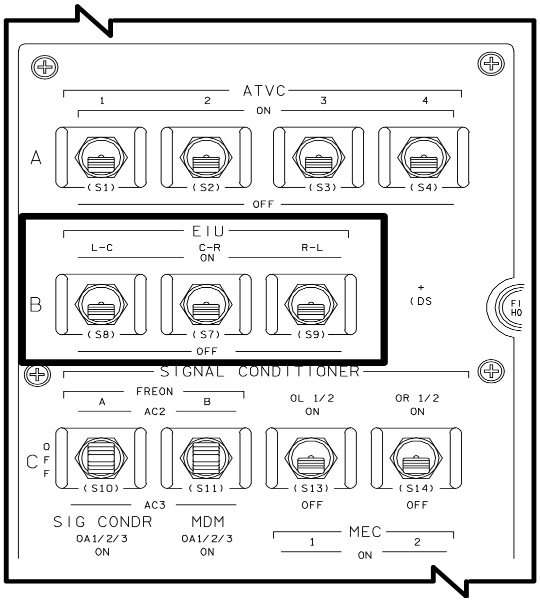
Main Engine Command Flow



EIU Switches on Panel O17

The EIU checks the received engine commands for transmission errors. If there are none, the EIU passes the validated engine commands on to the controller interface assemblies (CIAs), which output the validated engine commands to the engine controller. An engine command that does not pass validation is not sent to the CIA. Instead, it is dead-ended in the multiplexer interface adapter (MIA). Commands that come through MIA 1 and MIA 2 are sent to CIA 1 and CIA 2, respectively. Commands that come to MIA 3 and MIA 4 pass through CIA 3 data-select logic. This logic outputs the command that arrives at the interface first. The other command is dead-ended. The selected command is output through CIA 3. In this manner, the EIU reduces the four input commands to three output commands.

The engine controller vehicle interface electronics receive the three engine commands, check for transmission errors (hardware validation), and send controller hardware-validated engine commands to the controller channel A and B electronics. Normally, channel A electronics are in control, with channel B electronics active but not in control. If channel A fails, channel B will assume control. If channel B subsequently fails, the engine controller will shut the engine down. If two or three commands pass voting, the engine controller will issue its own commands to accomplish the function requested by the orbiter GPCs. If command voting fails, and two or more commands fail, the engine controller will maintain the last command that passed voting.

Whenever the controller does not receive two of three valid inputs, it creates a command path failure. The GPCs will issue an “MPS CMD C(L,R)” fault message and light the yellow MAIN ENGINE STATUS light on panel F7.

The backup flight system (BFS) computer, GPC 5, contains SSME hardware interface program applications software. When the four primary GPCs are in control, GPC 5 does no commanding. When GPC 5 is in control, the BFS sends commands to, and requests data from, the engine interface unit. The BFS, when engaged, allows GPC 5 to command flight-critical buses 5, 6, 7, and 8 for main engine control through the SSME hardware interface program, which performs the same main engine command functions as the SSME subsystem operating program. The command flow through the engine interface units and engine controllers is the same when GPC 5 is engaged as for the four-GPC redundant set.

Data Flow

The engine controller provides all the main engine data to the GPCs. Sensors in the engine supply pressures, temperatures, flow rates, turbopump speeds, valve positions, and engine servovalve actuator positions to the engine controller. The engine controller assembles these data into a vehicle data table and adds other status data. The vehicle data tables output via channels A and B to the vehicle interface electronics for transmission to the engine interface units. The vehicle interface electronics output data over both the primary and secondary data paths.

The vehicle data table is sent by the controller to the engine interface unit. There are only two data paths versus three command paths between the engine controller and the engine interface unit. The data path that interfaces with CIA 1 is called primary data. Primary data consist of the first 32 words of the SSME vehicle data table. Secondary data is the path that interfaces with CIA 2. Secondary data consist of the first six words of the vehicle data table. Primary and secondary data are held in buffers until the GPCs send a primary and secondary data request command to the engine interface units. Primary data are output only through MIA 1 on each engine interface unit. Secondary data are output only through MIA 4 on each engine interface unit.

At T minus zero, the orbiter GPCs request both primary and secondary data from each engine interface unit. For no failures, only primary data are looked at. If there is a loss of primary data (which can occur between the engine controller channel A electronics and the SSME subsystem operating procedure), only the secondary data are transmitted to the GPCs.

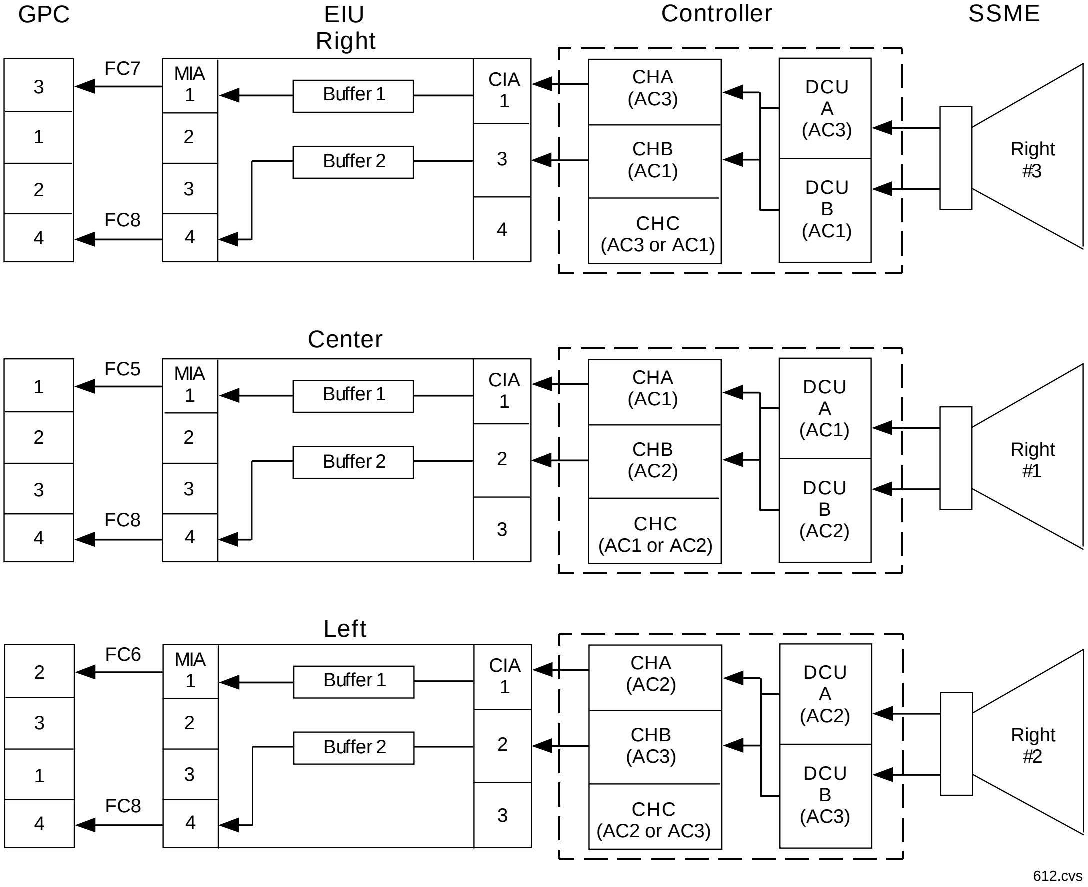
Loss of both primary and secondary data creates a data path failure. This causes the GPCs to issue an "MPS DATA C(L,R)" fault message and light the appropriate yellow MAIN ENGINE STATUS light on panel F7

NOTE

Unlike powered flight, loss of either primary or secondary data prelaunch will result in a data path failure. This will either inhibit engine ignition or result in a launch pad shutdown of all three main engines.

Electric Lockup

An electric lockup occurs when the engine controller loses data from either the LH2 flowmeters or the main combustion chamber pressure sensors, both of which are needed to set the proper mixture ratio. Because the mixture ratio can no longer be controlled, the controller will actively hold the engine valves at their last commanded position. This puts the



Main Engine Data Flow

engine in "lockup"; that is, it will no longer throttle. The engine will still shutdown when commanded. However, shutdown will now occur from a different throttle setting than normal. A manual shutdown of the engine pre-MECO may be required (see section 6.8).

Controller Software

The two primary engine controller programs are the flight operational program and the test operational program. The flight operational program is a real-time, process-control program that processes inputs from engine sensors, controls the operation of the engine servovalves, actuators, solenoids, and spark igniters, accepts and processes vehicle commands, provides and transmits data to the vehicle, and provides checkout and monitoring capabilities.

The test operational program supports engine testing prior to launch. Functionally, it is similar to the flight operational program but differs in implementation. The programs are modular and are defined as computer program components. Each consists of a data base organized into tables. During application of the computer program components, the programs perform data processing for failure detection and status of the vehicle. As system operation progresses through an operating phase, combinations of control functions are operative at different times. These combinations within a phase are defined as operating modes.

The checkout phase initiates active control monitoring or checkout. The standby mode in this phase puts the controller on pause while active control sequence operations are in process. Monitoring functions that do not affect engine hardware status are continually active during this mode. Such functions include processing vehicle commands, updating engine status, and self-testing the controller. During checkout, data and instructions can be loaded into the engine controller's computer memory, permitting updates to the software and data as necessary to proceed with engine-firing or checkout operations. Component checkout is also performed during this mode.

The start preparation phase consists of system purges and propellant conditioning to prepare for engine start. The first, purge sequence 1 mode, includes oxidizer system and intermediate seal purge operation. This is followed by purge sequence 2 mode, which includes fuel system purge operation and the continuation of purges initiated during purge sequence 1. Purge sequence 3 mode includes propellant recirculation (bleed valve operation). Purge sequence 4 mode includes fuel system purges and indicates that the engine is ready to enter the start phase. The engine-ready mode occurs when proper engine thermal conditions for start have been attained, and other criteria for start have been satisfied, including a continuation of the purge sequence 4 mode.

The start phase covers engine ignition operations and scheduled open-loop operation of the propellant valves. The start initiation mode includes all functions before ignition confirm and the closing of the thrust control loop. During thrust buildup, the main combustion chamber pressure is monitored to verify that closed-loop sequencing is in progress.

Main stage is automatically entered upon successful completion of the start phase. Mixture ratio control and thrust control are active.

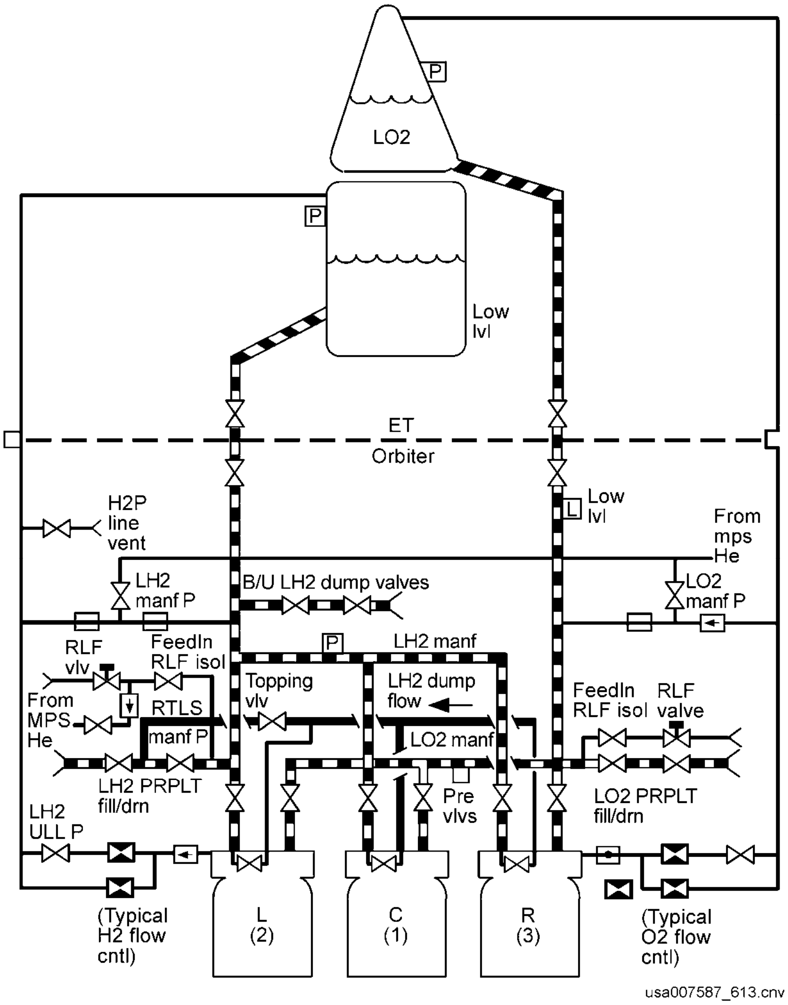
The shutdown phase covers operations to reduce main combustion chamber pressure and drive all valves closed to effect full engine shutdown.

The post-shutdown phase starts at completion of SSME shutdown. During the terminate sequence, all propellant valves are closed, and all solenoid and torque motor valves are de-energized.

Propellant Management System (PMS)

Liquid hydrogen and liquid oxygen pass from the ET to the PMS, which consists of manifolds, distribution lines, and valves. It also contains lines needed to transport gases from the engines to the external tank for pressurization.

During prelaunch activities, this subsystem is used to load liquid oxygen and liquid hydrogen into the external tank. After MECO, the PMS is used to complete a liquid oxygen and liquid hydrogen dump and vacuum inerting. It is also used for manifold repressurization during entry.

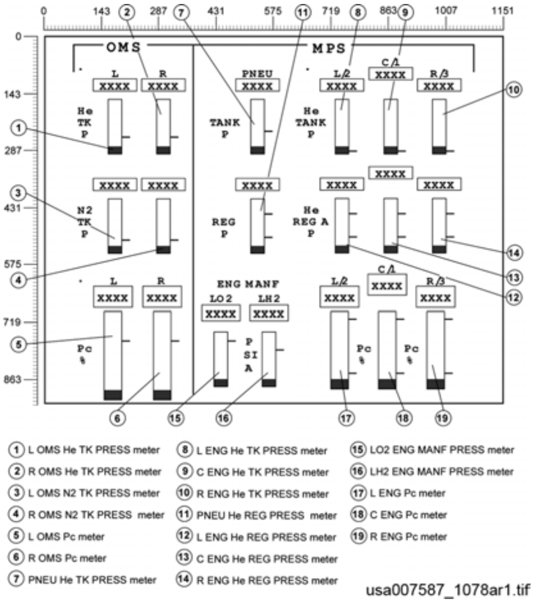


MPS PMS Schematic (Ascent Pocket Checklist)

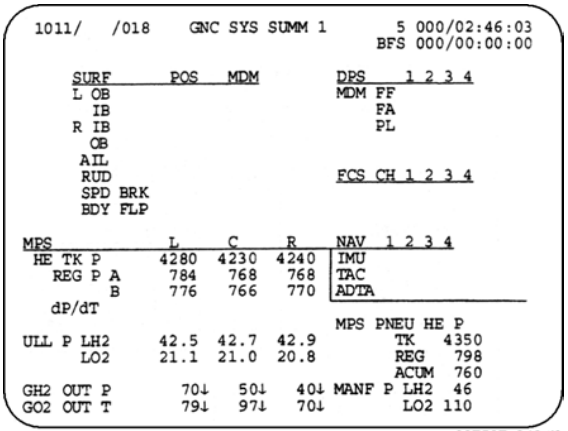
Propellant Manifolds

Two 17-inch-diameter MPS propellant feedline manifolds are in the orbiter aft fuselage, one for liquid oxygen and one for liquid hydrogen. Each manifold interfaces with its respective line on the ET. Both manifolds interface with an 8-inch fill/drain line containing an inboard and outboard fill/drain valve in series. Inside the orbiter, the manifolds diverge into three 12-inch SSME feedlines, one for each engine.

Fluid pressures within the LO2 and LH2 feedline manifolds can be monitored on the two MPS PRESS ENG MANF meters on the OMS/MPS MEDS display or on the BFS GNC SYS SUMM 1 display (MANF P LH2, LO2).



OMS/MPS Display.



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 1011/   /018    GNC SYS SUMM 1          5 000/02:46:03
                                       BFS 000/00:00:00

      SURF         POS   MDM          DPS      1 2 3 4
      L OB                            MDM FF
        IB                                FA
      R IB                                PL
        OB
       AIL
       RUD                            FCS CH 1 2 3 4
       SPD BRK
       BDY FLP

 MPS              L     C     R       NAV  1 2 3 4
  HE TK P        4280  4230  4240    |IMU
    REG P A       784   768   768    |TAC
          B       776   766   770    |ADTA
   dP/dT
                                      MPS PNEU HE P
 ULL P LH2       42.5  42.7  42.9          TK    4350
       LO2       21.1  21.0  20.8          REG    798
                                           ACUM   760
 GH2 OUT P         70↓   50↓   40↓  MANF P LH2    46
 GO2 OUT T         79↓   97↓   70↓           LO2 110
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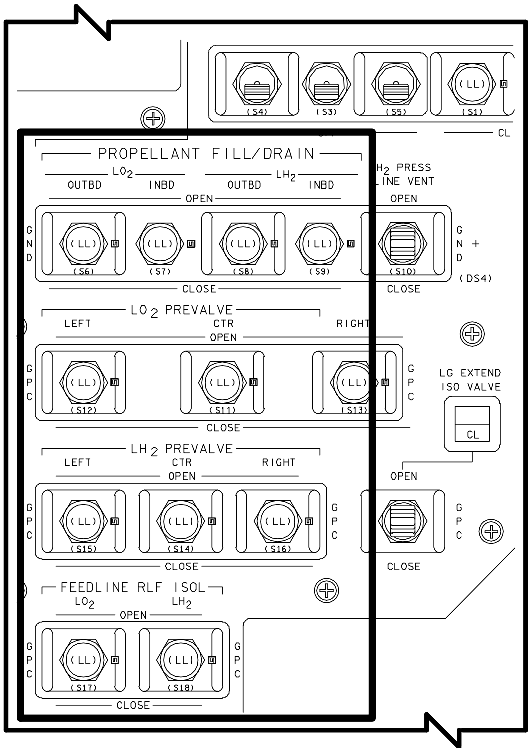
GNC SYSTEM SUMMARY 1



PROPELLANT FILL/DRAIN, REVALVE and FEEDLINE RLF ISOL Switches on Panel R4

Feedline Disconnect Valves

Two disconnect valves are found in each feedline where the orbiter meets the external tank. One is on the orbiter side of the manifold, and the other is on the external tank side. All four are closed automatically prior to external tank separation.

Fill/Drain Valves

Two (outboard and inboard) 8-inch-diameter liquid oxygen and liquid hydrogen fill/drain valves are connected in series. They are used to load the external tank before launch to perform the post-MECO MPS propellant dump. The valves can be manually controlled by the PROPELLANT FILL/DRAIN LO2, LH2 OUTBD, INBD switches on panel R4. Each switch has OPEN, GND, and CLOSE positions

Relief Valves

Each 8-inch liquid hydrogen and liquid oxygen manifold has a 1-inch-diameter line that is routed to a feedline relief isolation valve and then to a feedline relief valve. When the feedline relief isolation valve is opened automatically after MECO, the corresponding manifold can relieve excessive pressure overboard through its relief valve. The relief isolation valves can also be manually controlled by the MAIN PROPULSION SYSTEM FEEDLINE RLF ISOL LO2 and LH2 switches on panel R4. The switches have OPEN, GPC, and CLOSE positions.

Backup Liquid Hydrogen Dump Valves

The backup liquid hydrogen dump line connects the feedline manifold to an overboard port above the left wing of the orbiter. The line, designed primarily for a post-MECO liquid hydrogen dump during a return-to-launch site (RTLS) abort, is also used to vent the liquid hydrogen manifold after a nominal MECO. Since liquid hydrogen evaporates quickly, this vent is used to prevent pressure buildup in the hydrogen manifold from repeatedly cycling the relief valve before the propellant dump begins. It is also used for two post-dump vacuum inerts, nominally.

Flow through the lines is controlled by two valves in series, which are normally commanded by the GPCs. However, during OPS 1, they can be manually controlled by the MPS PRPLT DUMP BACKUP LH2 VLV switch on panel R2, which has OPEN, GPC, and CLOSE positions. In an RTLS abort dump, liquid hydrogen is dumped overboard through a port at the outer aft fuselage's left side between the OMS/RCS system pod and the upper surface of the wing. These valves are also known as the LH2 RTLS Dump valves.

Topping Valve

This valve controls the flow of liquid hydrogen through the tank topping manifold, which is used for prelaunch liquid hydrogen tank topping and thermal conditioning. During thermal conditioning, propellants flow through the engine components to cool them for engine start.

Liquid hydrogen is loaded through the outboard fill/drain valve, circulates through the topping valve to the engines for thermal conditioning, and is pumped into the external tank for tank topping. (The part of the topping recirculation line that goes to the external tank is not shown on the pocket checklist schematic.) The topping valve can be controlled indirectly by the crew via the LH2 inboard FILL DRAIN switch on panel R4. When this switch is taken to OPEN, both the LH2 inboard fill/drain and topping valves open.

There is no topping valve for liquid oxygen. Since liquid oxygen is harmless in the atmosphere, it is not circulated back to the external tank during thermal conditioning. Rather, it is dumped overboard through the engine liquid oxygen bleed valves and out the overboard bleed valve.

Liquid Hydrogen and Liquid Oxygen Bleed Valves

Three liquid hydrogen bleed valves, one in each engine, connect the engine internal liquid hydrogen line to the topping valve manifold. The valves are used to route liquid hydrogen through the engines during prelaunch thermal conditioning and to dump the liquid hydrogen trapped in the engines post-MECO.

There are also three liquid oxygen bleed valves that are not shown on the pocket checklist schematic. They connect the engine internal liquid oxygen lines to an overboard port and are used only during prelaunch thermal conditioning.

Prevalves

The prevalve in each of the three 12-inch feedlines to each engine isolates liquid oxygen and liquid hydrogen from each engine or permits liquid oxygen and liquid hydrogen to flow to each engine. Most of the prevalve functions are automatic, but they can also be controlled by the LO2 and LH2 PREVALVE, LEFT, CTR, RIGHT switches on panel R4. Each switch has OPEN, GPC, and CLOSE positions.

Ullage Pressure System

Ullage refers to the space in each tank not occupied by propellants. The ullage pressure system consists of the sensors, lines, and valves needed to route gaseous propellants from the three main engines and supply them to the external tank to maintain propellant tank pressure during engine operation.

There are two external tank pressurization manifolds, one for gaseous oxygen and one for gaseous hydrogen. During prelaunch, the manifolds are used to supply ground support pressurization of the ET using helium routed through the T-0 umbilical. Self-sealing quick disconnects are provided at the T-0 umbilical for separation at lift-off.

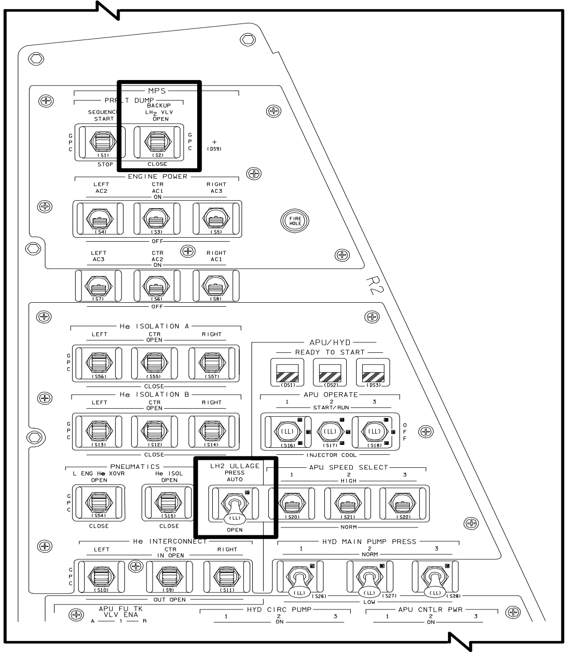
Each manifold contains three 0.63-inch-diameter pressurization lines, one from each engine. The three lines join in a common manifold prior to entering the ET.

In each SSME, a small portion of liquid oxygen from the high-pressure oxidizer turbopump main pump is diverted into the engine's oxidizer heat exchanger. The heat generated by the engine's high-pressure oxidizer turbopump converts the liquid oxygen into gaseous oxygen and directs it through a check valve to a fixed orifice and then to the ET. During ascent, the liquid oxygen tank pressure is maintained between 20 and 25 psig by the fixed orifice. If the tank pressure is greater than 30 psig, it is relieved through the liquid oxygen tank's vent and relief valve.

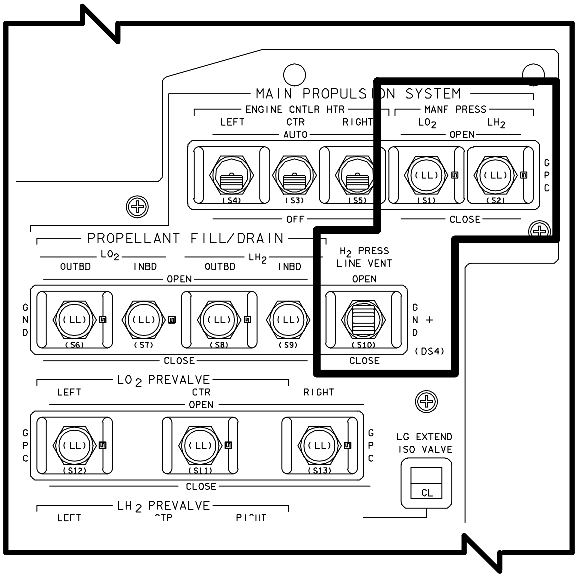
In each SSME, a small portion of gaseous hydrogen from the low-pressure fuel turbopump is directed through two check valves, two orifices, and a flow control valve before entering the ET. During ascent, the liquid hydrogen tank pressure is maintained between 32 and 34 psia using both a variable and a fixed orifice in each SSME supply system. The active flow control valve is controlled by one of three liquid hydrogen pressure transducers. When the tank pressure decreases below 32 psia, the valve opens; when the tank pressure increases to 33 psia, the valve closes. If the tank pressure exceeds 35 psia, the pressure is relieved through the liquid hydrogen tank's vent and relief valve. If the pressure falls below 28 psia, the MPS LH2 ULL PRESS switch on panel R2 is positioned from AUTO to OPEN, causing all three flow control valves to go to full open.

The three liquid hydrogen and three liquid oxygen ullage pressures are displayed on the BFS GNC SYS SUMM 1 display (ULL P).

The SSME/ET liquid hydrogen pressurization system also contains a line that is used to vent the liquid hydrogen pressurization manifold during post-MECO inerting. It is controlled by the H_2 PRESS LINE VENT switch on panel R4. This valve is normally closed. Post-MECO, however, this valve is opened for about one minute to allow for vacuum inerting. The GND position allows the launch processing system to control the valve during ground operations.



MPS PRPLT DUMP BACKUP LH2VLV Switch and LH2ULLAGE PRESS Switch on Panel R2



MAIN PORPULSION SYSTEM MANF PRESS and H2 PRESS LINE VENT Switches on Panel R4

Manifold Repress Valves

The liquid hydrogen and liquid oxygen manifold repress valves route helium from the MPS helium system into the feedline manifolds. The helium pressure is used to expel propellants during the MPS propellant dump and to repressurize the propellant lines during entry. The valves can be controlled manually using the MAIN PROPULSION SYSTEM MANF PRESS switches on panel R4.

MPS Valve Types

All the valves in the MPS are either electrically or pneumatically operated. Pneumatic valves are used where large loads are encountered, such as in the control of liquid propellant flows. Electrical valves are used for lighter loads, such as the control of gaseous propellant flows.

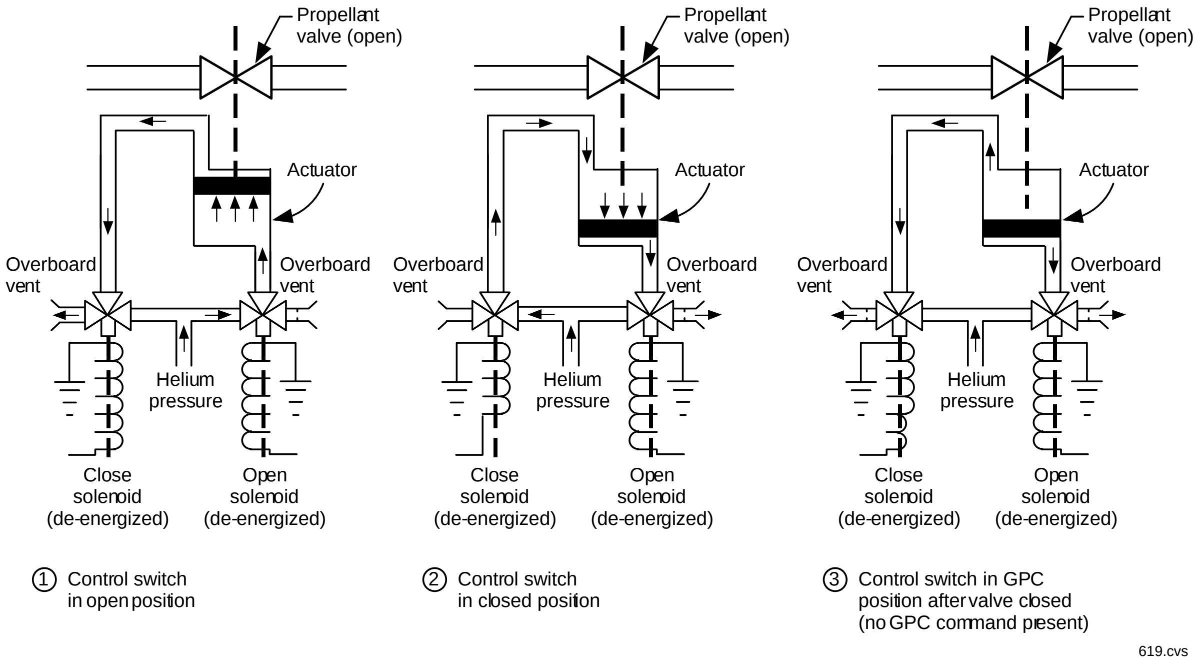
The pneumatically actuated valves are divided into two types: type 1, which requires pneumatic pressure to open and close the valve, and type 2, which is spring-loaded to one position and requires pneumatic pressure to move to the other position.

Each type 1 valve actuator is equipped with two electrically actuated solenoid valves, which control helium pressure to an "open" or "close" port on the actuator. Energizing the solenoid valve on the open port allows helium pressure to open the pneumatic valve. Energizing the solenoid on the close port allows helium pressure to close the pneumatic valve. Removing power from a solenoid valve removes helium pressure from the corresponding port of the pneumatic actuator and allows the helium pressure trapped in that side of the actuator to vent into the aft compartment. Removing power from both solenoids allows the pneumatic valve to remain in the last commanded position. This is known as a bi-stable valve.

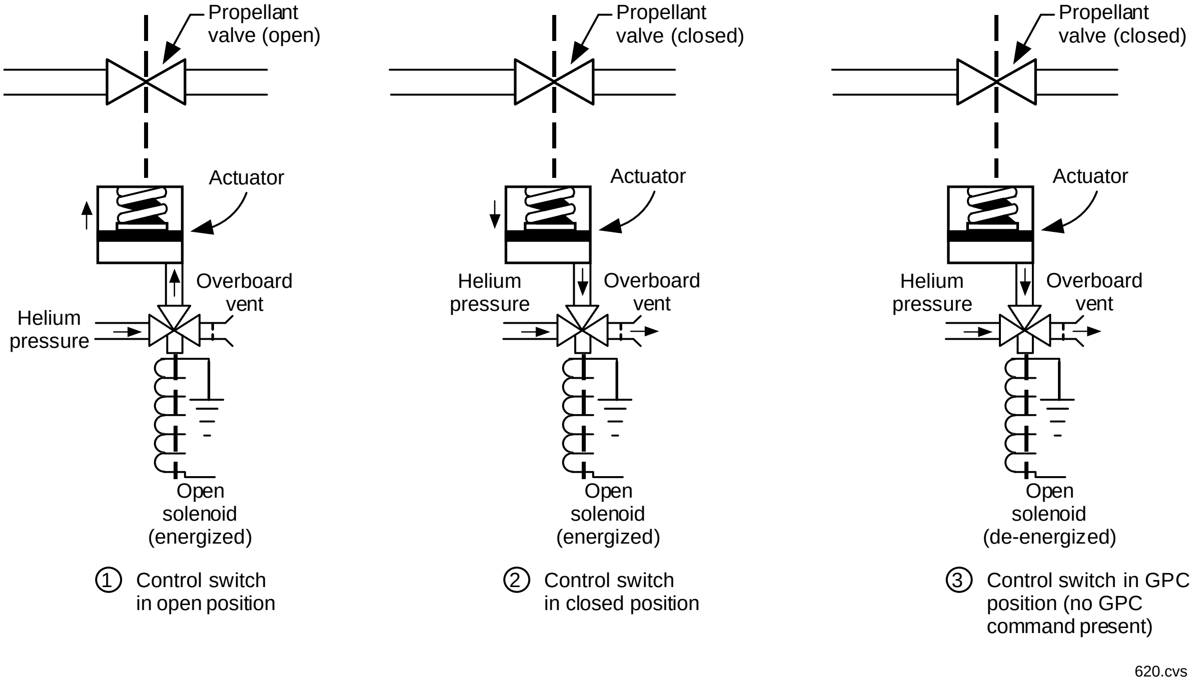
Type 1 valves are used for the liquid oxygen and liquid hydrogen feedline 17-inch umbilical disconnect valves, the liquid oxygen and liquid hydrogen prevalves, the liquid hydrogen and liquid oxygen inboard and outboard fill and drain valves, and the liquid hydrogen 4-inch recirculation disconnect valves.

Each type 2 valve is a single electrically actuated solenoid valve that controls helium pressure to either an open or a close port on the actuator. Removing power from the solenoid valve removes helium pressure from the corresponding port of the pneumatic actuator and allows helium pressure trapped in that side of the actuator to vent overboard. Spring force takes over and drives the valve to the opposite position. If the spring force drives the valve to the open position, the valve is referred to as a normally open (NO) valve. If the spring force drives the valve to a closed position, the valve is referred to as a normally closed (NC) valve.

Type 2 pneumatic valves are used for the liquid hydrogen RTLS inboard dump valve (NC), the liquid hydrogen RTLS outboard dump valve (NC), the liquid hydrogen feedline relief shutoff valve (NO), the liquid oxygen feedline relief shutoff valve (NO), the three liquid hydrogen engine recirculation valves (NC), the two liquid oxygen pogo recirculation valves (NO), the liquid hydrogen topping valve (NC), the liquid hydrogen high-point bleed valve (NC), and the liquid oxygen overboard bleed valve (NO).



Propellant Management Subsystem Typical Type 1 Pneumatically Actuated Propellant Valve



**Propellant Management Subsystem Typical Type 2
Pneumatically Actuated Propellant Valve Helium System**

The electrically actuated solenoid valves are spring-loaded to one position and move to the other position when electrical power is applied. These valves also are referred to as either normally open or normally closed, depending on their position in the de-energized state. Electrically actuated solenoid valves are the gaseous hydrogen pressurization line vent valve (NC), the three gaseous hydrogen pressurization flow control valves (NO), and the three gaseous oxygen pressurization flow control valves (NO).

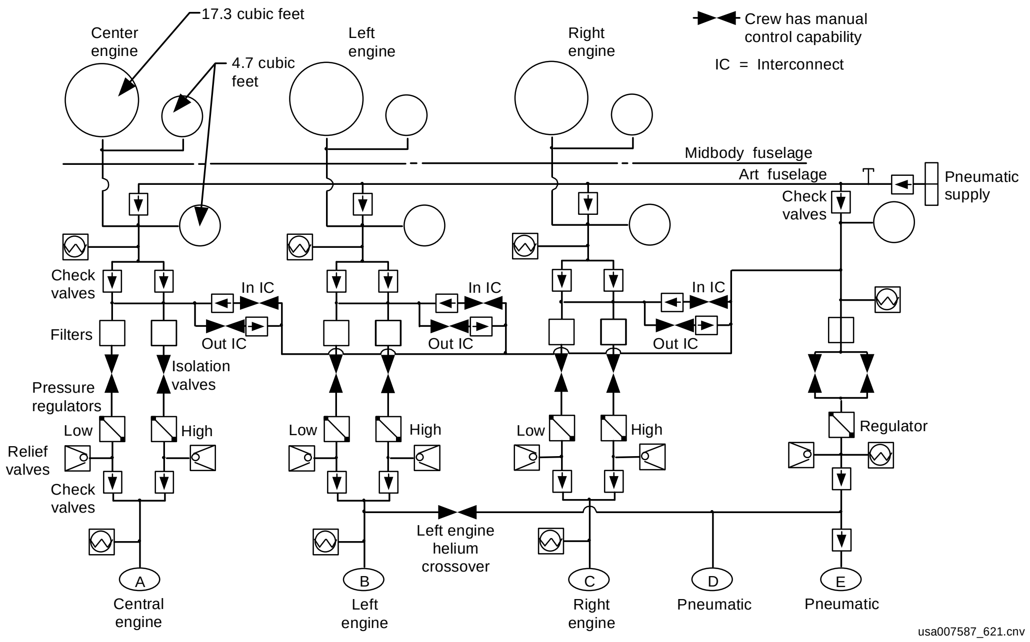
Helium System

The MPS helium system consists of seven 4.7-cubic-foot helium supply tanks, three 17.3-cubic-foot helium supply tanks, and associated regulators, check valves, distribution lines, and control valves.

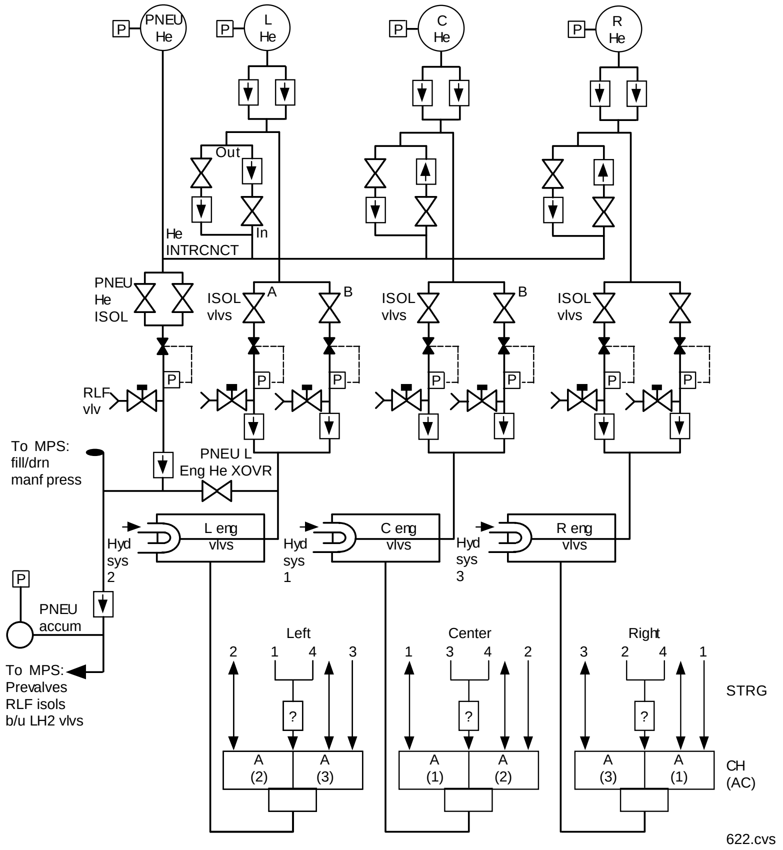
The MPS helium system is used for in-flight purges within the engines, and it provides pressure for actuating engine valves during emergency pneumatic shutdowns. It also supplies pressure to actuate the pneumatically operated valves within the propellant management system. During entry, the remaining helium is used for the entry purge and repressurization. (Unlike the orbital maneuvering system and reaction control system, the MPS does not use helium to pressurize propellant tanks.)

The MPS helium supply system is divided into four separate subsystems, one for each of the three main engines and a fourth pneumatic system to operate the propellant valves.

All the valves in the helium subsystem are spring-loaded to one position and electrically actuated to the other position. The supply tank isolation valves are spring-loaded to the closed position and pneumatically actuated to the open position. Valve position is controlled via electrical signals either generated by the onboard GPCs or manually by the flight crew. All the valves can be controlled automatically by the GPCs, and the flight crew can control some of the valves.



Helium System Storage and Supply



Main Propulsion System Helium Schematic from the Ascent Pocket Checklist

Helium Tanks

The tanks are composite structures consisting of a titanium liner with a fiberglass structural overwrap. The large tanks are 40.3 inches in diameter and have a dry weight of 272 pounds. The smaller tanks are 26 inches in diameter and have a dry weight of 73 pounds. The tanks are serviced before lift-off to a pressure of 4,100 to 4,500 psi.

Four of the 4.7-cubic-foot helium supply tanks are located in the aft fuselage, and the other three are located below the payload bay in the midfuselage. The three 17.3-cubic-foot helium supply tanks are also located below the payload bay in the midfuselage.

Each of the larger supply tanks is plumbed to two of the smaller supply tanks (one in the midbody, the other in the aft body), forming three clusters of three tanks. Each set of tanks normally provides helium to only one engine and is commonly referred to as left, center, or right engine helium, depending on the engine serviced. Each set normally provides helium to its designated engine for in-flight purges and provides pressure for actuating engine valves during emergency pneumatic shutdown.

The remaining 4.7-cubic-foot helium tank is referred to as the pneumatic helium supply tank. It provides pressure to actuate all the pneumatically operated valves in the propellant management subsystem.

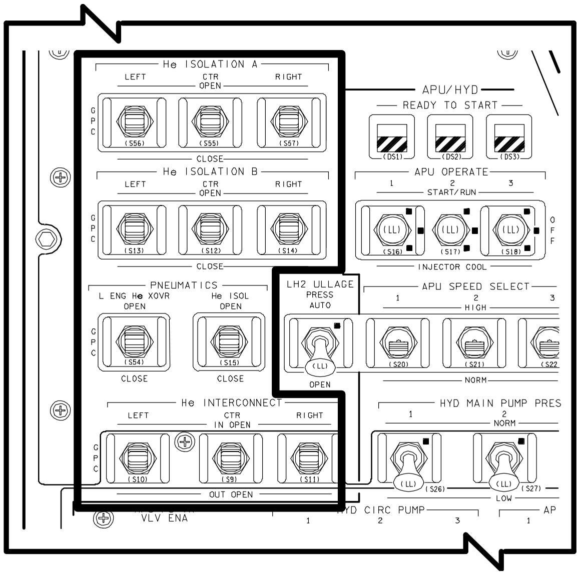
The helium pressure of the pneumatic, left, center, and right supply systems can be monitored on the MPS PRESS HELIUM, PNEU, L, C, R meters on panel F7 by positioning the switch below the meters to TANK. Left, center, right, and pneumatic tank pressures can be monitored on the BFS GNC SYS SUMM 1 display (MPS L, C, R HE TK P, and MPS PNEU HE P TK).

Helium Isolation Valves

Eight helium supply tank isolation valves grouped in pairs control the flow of helium from the tanks. One pair of valves is connected to each of the three tank clusters, and one pair is connected to the pneumatic supply tank. In the engine helium supply tank system, each pair of isolation valves is connected in parallel, with each valve in the pair controlling helium flow through one leg of a dual-redundant helium supply circuit. Each helium supply circuit contains two check valves, a filter, an isolation valve, a regulator, and a relief valve.

The two isolation valves connected to the pneumatic supply tanks are also connected in parallel. The rest of the pneumatic supply system consists of a filter, the two isolation valves, a regulator, a relief valve, and a single check valve.

Each engine helium supply isolation valve can be individually controlled by the He ISOLATION A LEFT, CTR, RIGHT, and He ISOLATION B LEFT, CTR, RIGHT switches on panel R2. The switches have OPEN, GPC, and CLOSE positions. The two pneumatic helium supply isolation valves are controlled by a single PNEUMATICS He ISOL switch on panel R2, which also has OPEN, GPC, and CLOSE positions.



He ISOLATION, PNEUMATICS L ENG He XOVR and He ISOL, and He INTERCONNECT Switches on Panel R2

Helium Pressure Regulators

Each engine helium supply tank has two pressure regulators operating in parallel. Each regulator controls pressure to within 730 to 785 psia in one leg of a dual-redundant helium supply circuit and is capable of providing all the helium needed by the main engines.

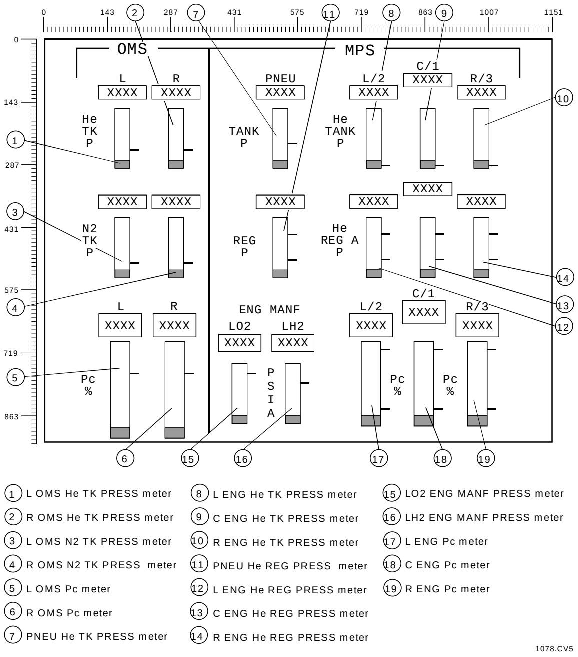
The pressure regulator for the pneumatic helium supply system is not redundant and regulates outlet pressure between 715 to 770 psig. Downstream of the pneumatic regulator are the liquid hydrogen manifold pressure regulator and the liquid oxygen manifold pressure regulator. These regulators are used only during MPS propellant dumps and manifold pressurization. Both regulators are set to provide outlet pressure between 20 and 25 psig. Flow through the regulators is controlled by the appropriate set of two normally closed manifold pressurization valves.

Downstream of each pressure regulator, with the exception of the two manifold repressurization regulators, is a relief valve. The valve protects the downstream helium distribution lines from overpressurization if the associated regulator fails fully open. The two relief valves in each engine helium supply are set to relieve at 790 to 850 psig and reseat at 785 psig.

The regulated pressure of the left, center, right, and pneumatic systems can be monitored on the BFS GNC SYS SUMM 1 display (MPS L, C, R REG P and MPS PNEU REG). They are also displayed on the OMS/MPS MEDS Display. The MEDS display, however, only displays the REG A pressure, unlike BFS GNC SYS SUMM 1 which displays both REG A and REG B.

Pneumatic Left Engine Helium Crossover Valve

The crossover valve between the pneumatic and left engine helium systems serves as a backup for the nonredundant pneumatic pressure regulator system. In the event of a pneumatic helium regulator failure or a leak in the pneumatic helium system, the left engine helium system can provide regulated helium through the crossover valve to the pneumatic helium distribution system. The PNEUMATICS L ENG He XOVR switch is on panel R2.



OMS/MPS MEDS Display

Helium Interconnect Valves

During ascent, the four helium supply systems operate independently. However, during dumps and purges, and in the event of system leaks, one system can draw helium from another via the helium interconnect valves.

Each engine helium supply has two interconnect valves associated with it: one designated “IN OPEN”; the other, “OUT OPEN”. Check valves ensure that helium flows in only one direction through the IN OPEN and OUT OPEN interconnect valves. Through the IN OPEN valve, helium is drawn into the affected engine from a pressure line common to all three engine helium systems. This common line is normally fed by the pneumatic helium supply. The OUT OPEN valve, on the other hand, routes the affected engine’s helium to the common line where other engines can access it.

Each pair of interconnect valves is controlled by a single switch on panel R2. Each He INTERCONNECT LEFT, CTR, RIGHT switch has three positions: IN OPEN, GPC, and OUT OPEN. With the switch in GPC, the interconnect valves are controlled by the orbiter software.

Manifold Pressurization

Manifold pressurization valves, located downstream of the pneumatic helium pressure regulator, are used to control the flow of helium to the LO2 propellant manifold for a nominal LO2 propellant dump and for LH2 and LO2 manifold repressurization on entry. There are four of these valves grouped in pairs. One pair controls helium pressure to the liquid oxygen propellant manifold, and the other pair controls helium pressure to the liquid hydrogen propellant manifold.

There are additional regulators just past the manifold repress valves that regulate the pneumatic helium from the normally regulated pressure of 750 psi to a lower, usable pressure. The LH2 manifolds are pressurized to 17 to 30 psig and the LO2 manifolds are pressurized to 20 to 25 psig during the MPS dump and entry manifold repressurization.

Additionally, on the LH2 propellant manifold, there are manifold pressurization valves that open during propellant dumps to remove LH2 from the manifold while executing return-to-launch-site (RTLS) or transoceanic abort landing (TAL) profiles.

Pneumatic Control Assemblies

There is one pneumatic control assembly on each SSME. The assembly is essentially a manifold pressurized by one of the engine helium supply systems and contains solenoid valves to control and direct pressure to perform various essential functions. The valves are energized by discrete ON/OFF commands from the output electronics of the SSME controller. Functions controlled by the pneumatic control assembly include the high-pressure oxidizer turbopump intermediate seal cavity and preburner oxidizer dome purge, pogo system postcharge, and pneumatic shutdown.

MPS Hydraulic Systems

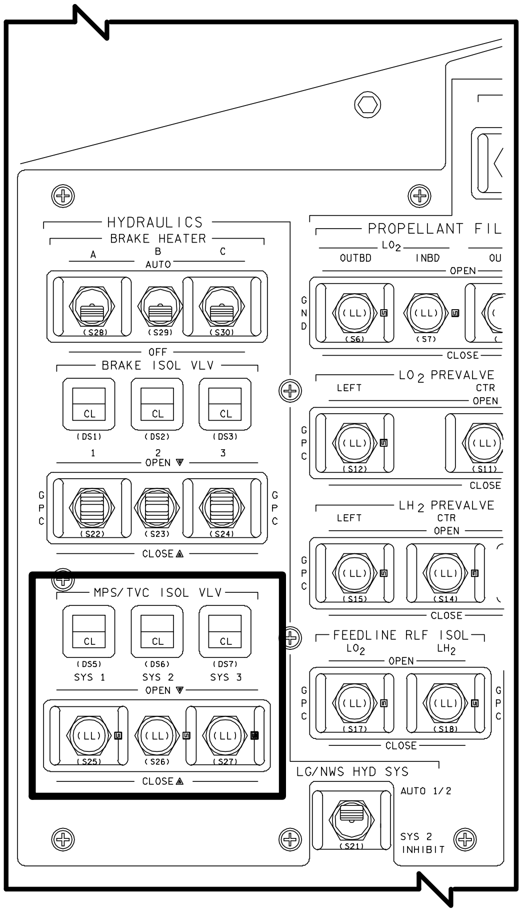
Hydraulic System Operation

The three orbiter hydraulic systems (see section 2.1 for more on the hydraulic system) supply hydraulic pressure to each SSME to actuate the engine valves and to provide thrust vector control. The three hydraulic supply systems are distributed to the thrust vector control (TVC) valves. These valves are controlled by HYDRAULICS MPS/TVC ISOL VLV switches (one for each of the three hydraulic systems) on panel R4. A valve is opened by positioning its switch to OPEN. The talkback indicator above each switch indicates OP when the valve is open and CL when it is closed.

When the three MPS/TVC ISOL valves are opened, hydraulic pressure is applied to the five hydraulically actuated engine valves (the main fuel valve, the main oxidizer valve, the fuel preburner oxidizer valve, the oxidizer preburner oxidizer valve, and the chamber coolant valve). All hydraulically actuated engine valves receive hydraulic pressure from the same hydraulic system: HYD SYS 1 for the center engine valves; HYD SYS 2 for the left engine valves; HYD SYS 3 for the right engine valves. Each engine valve actuator is controlled by dual-redundant signals: channel A/engine servovalve 1 and channel B/engine servovalve 2 from that engine's controller electronics. In the event of a hydraulic system failure, all the hydraulically actuated engine valves can be blown closed with helium pressure from the affected engine’s helium supply.

Hydraulic Lockup

Hydraulic lockup occurs when the engine controller senses any one of the five hydraulically actuated engine valves outside the limits of where it is expected to be. This may be due to a hydraulic system failure or a failure of the engine valve itself. Consequently, the controller will hydraulically isolate all five engine valves at their last position. This minimizes, but does not prevent, the valve from drifting. The valve could still deviate further and possibly cause a loss of performance and even an engine failure. The engine is now in “lockup”; that is, the engine will no longer to throttle. The engine will still shutdown when commanded. However, shutdown will now occur from a different throttle setting than normal. A manual shutdown of the engine pre-MECO may be required (see section 6.8). Whether commanded or manual, a shutdown will be done pneumatically via engine helium.

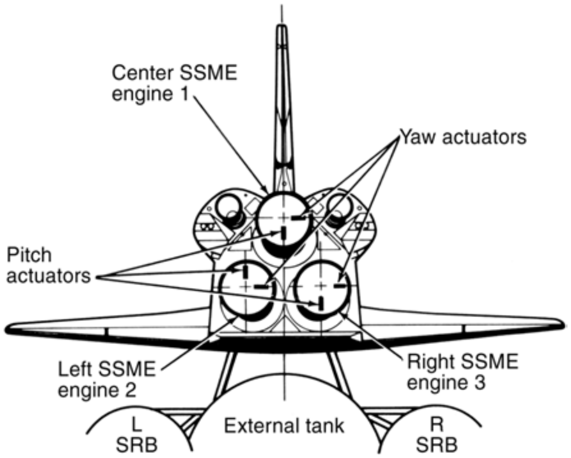


MPS/TVC ISOL VLV Switches and Talkbacks on Panel R4

Thrust Vector Control

The three MPS/TVC ISOL valves on panel R4 must also be opened to supply hydraulic pressure to the six main engine TVC actuators. There are two servoactuators per SSME: one for yaw and one for pitch. Each actuator is fastened to the orbiter thrust structure and to the powerheads of the three SSMEs.

Two actuators per engine provide attitude control and trajectory shaping by gimbaling both the SSMEs and SRBs during first-stage and the SSMEs alone during second-stage. Each SSME servoactuator receives hydraulic pressure from two of the three orbiter hydraulic systems; one system is the primary system, and the other is a standby secondary system. Each servoactuator has its own hydraulic switching valve. The switching valve receives hydraulic pressure from two of the three orbiter hydraulic systems and provides a single source to the actuator.



Main Engine Gimbal Actuators

Normally, the primary hydraulic supply is directed to the actuator. However, if the primary system were to fail and lose hydraulic pressure, the switching valve would automatically switch over to the secondary system, and the actuator would continue to function.

The following tables summarizes the hydraulic system assignments for the SSME actuators:

	Pitch		Yaw	
	PRI	SEC	PRI	SEC
Center	Hyd Sys 1	Hyd Sys 3	Hyd Sys 3	Hyd Sys 1
Left	Hyd Sys 2	Hyd Sys 1	Hyd Sys 1	Hyd Sys 2
Right	Hyd Sys 3	Hyd Sys 2	Hyd Sys 2	Hyd Sys 3

Detailed information about ascent thrust vector control is provided in section 2.13.

Hydraulic System Isolation On Orbit

The HYDRAULICS MPS/TVC ISOL VLV SYS 1, SYS 2, and SYS 3 switches on panel R4 are positioned to CLOSE during on-orbit operations to protect against hydraulic leaks downstream of the isolation valves. In addition, there is no requirement to gimbal the main engines from the stow position. During on-orbit operations when the MPS/TVC ISOL valves are closed, the hydraulic pressure supply and return lines within each MPS/TVC component are interconnected to enable hydraulic fluid to circulate for thermal conditioning.

Malfunction Detection

There are three separate means of detecting malfunctions within the MPS: SSME redlines, the hardware caution and warning (C/W) system, and the software C/W system.

SSME Redlines

The SSME controller processes numerous engine operating parameters, four of which are critical to safely operating the engine. The controller closely monitors these four parameters to see whether they remain within the main engine limits (or "redlines") specified by the Flight Rules:

- The high-pressure fuel turbopump's discharge temperature not to exceed 1860° R.
- The high-pressure oxidizer turbopump's discharge temperature not to exceed 1660° R or fall below 720° R.
- The high-pressure oxidizer turbopump's intermediate seal purge pressure not to fall below 159 psia.
- During steady state operation, the main combustion chamber's pressure not to fall more than 200 psia (400 psia, during throttling) below the reference chamber pressure.
- *The high-pressure fuel and oxidizer turbopumps' vibration levels not to exceed 8 g and 4 g, respectively.*

Assuming main engine limits are enabled, a redline violation sensed by the controller will cause the controller to automatically shut down the engine to guard against uncontained SSME damage. Certain situations, however, call to have main engine limits inhibited. In this case, the engine will continue to run, though at increased risk of undergoing a catastrophic shutdown.

WARNING

An engine failure with limits inhibited will probably result in vehicle damage. Further, as the controller will probably be damaged as well, the engine failure would go unrecognized by the GPCs.

The flight crew can control whether main engine limits are enabled or inhibited via the MAIN ENGINE LIMIT SHUT DN switch on panel C3. The switch has three positions:

ENABLE -- Enables main engine limits.

AUTO -- Enables main engine limits. However, immediately after one engine has shut down (either automatically or manually), main engine limits are inhibited on the remaining engines.

INHIBIT -- Inhibits main engine limits.

SSME Status Lights

The MAIN ENGINE STATUS lights (CTR, LEFT, RIGHT) on panel F7 each have a red half and an amber half.

The red half illuminates for an engine in shutdown or post-shutdown phase or for an engine that is running with a redline violation.

The amber half illuminates for an engine experiencing any of the following failures:

- Command path failure
- Hydraulic lockup
- Electric lockup
- Data path failure

Hardware C/W

Operating limits have been given to certain pieces of MPS hardware:

- MPS He REG P (Reg A only) not to exceed 810 psia or fall below 680 psia.
- MPS He TK P not to fall below 1150 psia.
- MPS LH2 MANF P not to exceed 65 psia.
- MPS LO2 MANF P not to exceed 249 psia.

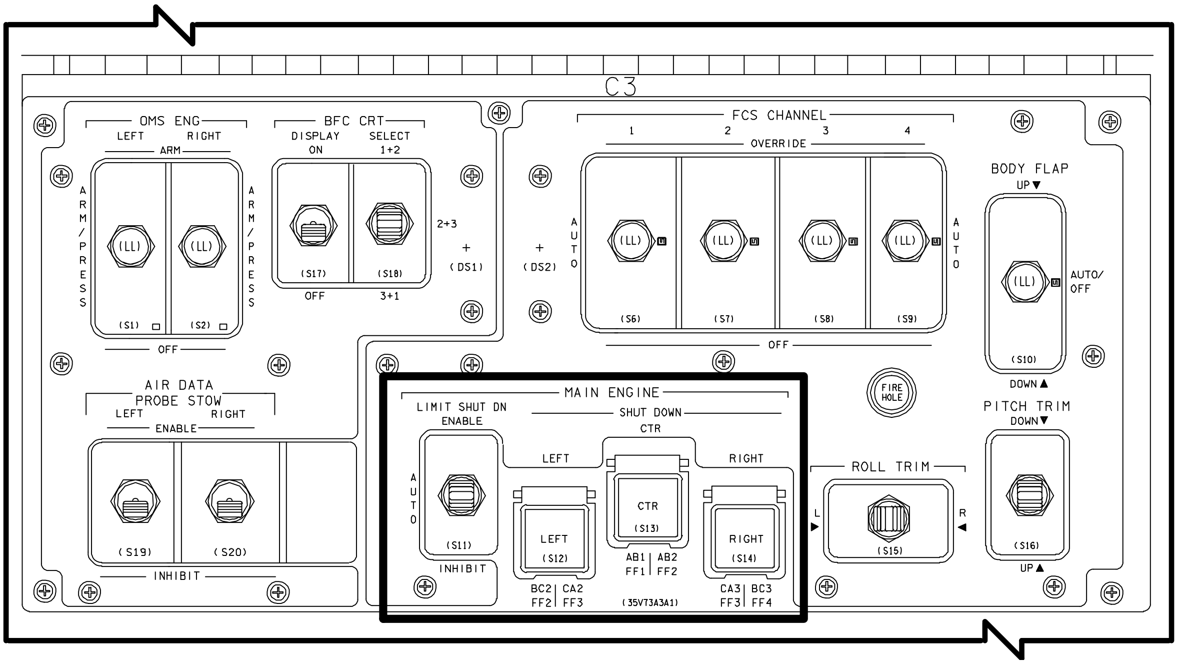
A violation of any of those limits will illuminate the red MPS light on the C/W matrix, found on panel F7. (Violations in the He TK P and LH2/LO2 MANF P will also illuminate the Backup C/W Alarm light.).

Software C/W

For certain MPS out-of-limit or fault conditions detected by the GPCs, the following fault messages appear on the PASS and/or BFS DPS displays.

Generated by both PASS and BFS:

- "SSME FAIL C(L,R)" - Premature main engine shutdown.
- "MPS CMD C(L,R)" - Command path failure occurs, when the main engine controller does not receive 2/3 valid inputs from the GPCs. (message from PASS only pre-engage).
- "MPS HYD C(L,R)" - Hydraulic lockup occurs, whenever the main engine controller senses any one of the five engine valves out of position.
- "MPS ELEC C(L,R)" - Electric lockup occurs, whenever the main engine controller loses all Pc data or all fuel flow rate data from the engine.
- "MPS DATA C(L,R)" - Data path failure occurs, due to loss of both primary and secondary data from the main engine controller to the GPCs.
- "ET SEP INH" - Message triggered by either vehicle rates greater than 0.7 deg/sec post-MECO or feedline disconnect failures. (During RTLS, also triggered when either angle of attack or sideslip angle exceeds limits post-MECO.)
    - NOM/ATO -- ET separation inhibited until the flight crew either nulls the rates or manually initiates ET separation.



MAIN ENGINE LIMIT SHUT DN Switch and MAIN ENGINE SHUT DOWN Pushbuttons on Panel C3

  - – TAL -- ET separation inhibited only for excessive rates (which flight crew must null). Otherwise, automatic separation after a brief delay to allow for venting.
  - – RTLS -- Automatic ET separation after a brief delay to allow for venting.

Generated by PASS only:

- "ET SEP MAN" - The ET SEPARATION switch on panel C3 is in dilemma. Function has defaulted to MANUAL. ET separation must be manually initiated by the flight crew.
- "ET SEP AUTO" - Like “ET SEP MAN”, this also means that the ET SEPARATION switch on panel C3 is in dilemma. However, function has defaulted to AUTO instead, and ET separation will occur as expected.
- "ME SHDN SW C(L,R)" - MAIN ENGINE SHUT DOWN pushbutton on panel C3 is in dilemma and no longer functional.

Generated by BFS only:

- "MPS H2 OUT P C(L,R)" - SSME GH_2 outlet pressure less than 1050 psia (indication of a premature engine shutdown).
- "MPS HE P C(L,R)" -
  - + MPS He TK P is less than 1150 psi.
  - + Change in He TK P is greater than 20 psi over 3 seconds (indication of a helium leak).
  - + MPS He REG P is less than 679 psi or more than 810 psi.
- "MPS LH2/O2 ULL" - ET LH2 ullage pressure is less than 28 psig or greater than 48.9 psig; ET LO2 ullage pressure is 0 or more than 29.0 psig.
- "MPS O2 OUT T C(L,R)" - SSME GO_2 outlet temperature less than 125° F (indication of a premature engine shutdown).
- "MPS PNEU P ACUM" - MPS pneumatic accumulator pressure is less than 700 psia.
- "MPS PNEU P REG" - MPS pneumatic regulator pressure is less than 700 psia or greater than 810 psia.
- "MPS PNEU P TK" - MPS pneumatic tank pressure is less than 3800 psia.

These failures have messages that are annunciated in OPS 1 and 6. Also, the BFS does all processing of the MPS helium and ullage pressure systems.

In OPS 3, the MPS parameters on the BFS SYS SUMM 1 will be blanked, except for helium REG A and B pressure.

In OPS 2, there is no software caution and warning for the MPS. Therefore, if either manifold pressure (LO2 or LH2) violates limits while on orbit, the only indication the crew will see is hardware caution and warning (MPS light and master alarm.) There will be no message on the DPS display.

Operations

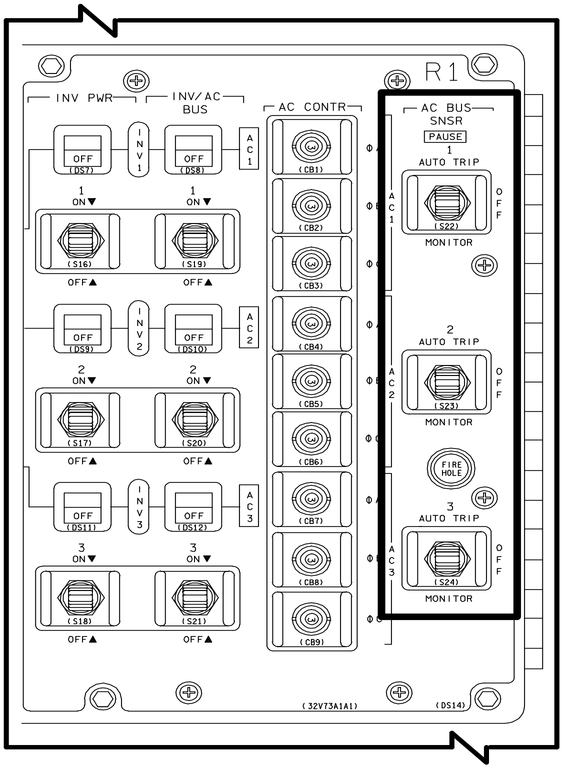
Prelaunch

At T minus 5 hours 50 minutes, the launch processing system initiates the SSME liquid hydrogen chill-down sequence in preparation for liquid hydrogen loading. At T minus 5 hours 15 minutes, the fast-fill portion of the liquid oxygen and liquid hydrogen loading sequence begins, and the liquid hydrogen recirculation pumps are started shortly thereafter. At T minus 3 hours 45 seconds, the fast fill of the liquid hydrogen tank to 98 percent is complete, and a slow topping off process that stabilizes to 100 percent begins. At T minus 3 hours 30 minutes, the liquid oxygen fast fill is complete. At T minus 3 hours 15 minutes, liquid hydrogen replenishment begins, and liquid oxygen replenishment begins at T minus 3 hours 10 minutes.

During prelaunch, the pneumatic helium supply provides pressure to operate the liquid oxygen and hydrogen prevalves and outboard and inboard fill and drain valves. The three engine helium supply systems are used to provide anti-icing purges.

The MPS helium tanks are pressurized from 2,000 psi to their full pressure at T minus 3 hours 20 minutes. This process is gradual to prevent excessive heat buildup in the supply tank. Regulated helium pressure is between 715 and 775 psi.

At this time, the MPS He ISOLATION A and B switches, the MPS PNEUMATICS L ENG He XOVR and He ISOL switches, and the MPS He INTERCONNECT LEFT, CTR, RIGHT switches on panel R2 are in the GPC position. With the switches in this position, the eight helium isolation valves are open, and the left engine crossover and the six helium interconnect valves are closed.



AC BUS SNSR Switches on Panel R1

At T minus 16 minutes, one of the first actions by the flight crew (the pilot) is to place the six MPS He ISOLATION A and B switches and the MPS PNEUMATICS He ISOL switch on panel R2 in the OPEN position. This procedure will not change the position of the helium isolation valves, which were already open, but it inhibits launch processing system control of valve position.

During prelaunch, liquid oxygen from ground support equipment is loaded through the ground support equipment liquid oxygen T-0 umbilical and passes through the liquid oxygen outboard fill and drain valve, the liquid oxygen inboard fill and drain valve, and the orbiter liquid oxygen feedline manifold. The liquid oxygen exits the orbiter at the liquid oxygen feedline umbilical disconnect and enters the liquid oxygen tank in the external tank.

During loading, the liquid oxygen tank's vent and relief valves are open to prevent pressure buildup in the tank due to liquid oxygen loading. The MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LO_2 OUTBD and INBD switches on panel R4 are in the GND (ground) position, which allows the launch processing system to control the positions of these valves. Just prior to lift-off, the launch processing system will first command the liquid oxygen inboard fill and drain valve to close. The liquid oxygen in the line between the inboard and outboard fill and drain valves is then allowed to drain back into the ground support equipment, and the launch processing system commands the outboard fill and drain valve to close.

Also during prelaunch, liquid hydrogen supplied through the ground support equipment liquid hydrogen T-0 umbilical passes through the liquid hydrogen outboard fill and drain valve, the liquid hydrogen inboard fill and drain valve, and the liquid hydrogen feedline manifold. The liquid hydrogen then exits the orbiter at the liquid hydrogen feedline umbilical disconnect and enters the liquid hydrogen tank in the external tank. During loading, the liquid hydrogen tank's vent valve is left open to prevent pressure buildup in the tank due to boiloff. The MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LH_2 OUTBD and INBD switches on panel R4 are in the GND position, which allows the launch processing system to control the position of these valves.

During the T minus 3 hour hold the pilot positions the three AC BUS SNSR switches on panel R1 to MONITOR to protect the main engine controllers. Each engine controller is powered by two of the three ac buses, one for each digital computer unit. The loss of one bus would result in a loss of controller redundancy on two engines, and the loss of any two buses would cause the associated engine to shut down. With the AC BUS SNSR switches positioned to MONITOR, the sensors will provide caution and warning for a potential over/undervoltage or overload condition, but they will not trip a bus off line before the crew can verify whether a true failure exists.

Engine Start

At T minus 4 minutes, the fuel system purge begins. It is followed at T minus 3 minutes 25 seconds by the beginning of the engine gimbal tests, during which each gimbal actuator is operated through a canned profile of extensions and retractions. If all actuators function satisfactorily, the engines are gimbaled to a predefined position at T minus 2 minutes 15 seconds. The engines remain in this position until engine ignition.

At T minus 2 minutes 55 seconds, the launch processing system closes the liquid oxygen tank vent valve, and the tank is pressurized to 21 psig with ground support equipment-supplied helium. The liquid oxygen tank's pressure can be monitored as MANF P LO2 on both the BFS GNC SYS SUMM 1 DPS display and on the OMS/MPS MEDS display. The 21-psig pressure corresponds to a liquid oxygen engine manifold pressure of 105 psia.

At T minus 1 minute 57 seconds, the launch processing system closes the liquid hydrogen tank's vent valve, and the tank is pressurized to 42 psig with ground support equipment-supplied helium. The pressure can be monitored as MANF P LH2 on both the BFS GNC SYS SUMM 1 DPS display and the OMS/MPS MEDS display.

At T minus 31 seconds, the onboard redundant set launch sequence is enabled by the launch processing system. From this point on, all sequencing is performed by the orbiter GPCs in the redundant set, based on the onboard clock time. The GPCs still respond, however, to hold, resume count, and recycle commands from the launch processing system.

At T minus 16 seconds, the GPCs begin to issue arming commands for the solid rocket booster ignition pyro initiator controllers, the hold-down release pyro initiator controllers, and the T-0 umbilical release pyro initiator controllers.

At T minus 9.5 seconds, the engine chill-down sequence is complete, and the GPCs command the liquid hydrogen prevalves to open. (The liquid oxygen prevalves are open during loading to permit engine chill-down.) The MAIN PROPULSION SYSTEM LO_2 and LH_2 PREVALVE LEFT, CTR, RIGHT switches on panel R4 are in the GPC position.

At T minus 6.6 seconds, the GPCs issue the engine start command, and the main fuel valve in each engine opens. Between the opening of the main fuel valve and MECO, liquid hydrogen flows out of the external tank/orbiter liquid hydrogen disconnect valves into the liquid hydrogen feedline manifold. From this manifold, liquid hydrogen is distributed to the engines through the three engine liquid hydrogen feedlines. In each line, liquid hydrogen passes through the prevalve and enters the main engine at the inlet to the low-pressure fuel turbopump.

When the GPCs issue the engine start command, the main oxidizer valve in each engine also opens. Between the opening of the main engine oxidizer valve and MECO, liquid oxygen flows out of the external tank and through the external tank/orbiter liquid oxygen umbilical disconnect valves into the liquid oxygen feedline manifold. From this manifold, liquid oxygen is distributed to the engines through the three engine liquid oxygen feedlines. In each line, liquid oxygen passes through the prevalve and enters the main engine at the inlet to the low-pressure oxidizer turbopump.

If all three SSMEs reach 90 percent of their rated thrust by T minus 3 seconds, then at T minus 0, the GPCs will issue the commands to fire the solid rocket booster ignition pyro initiator controllers, the hold-down release pyro initiator controllers, and the T- 0 umbilical release pyro initiator controllers. Lift-off occurs almost immediately because of the extremely rapid thrust buildup of the solid rocket boosters. The three seconds prior to T minus 0 allow the vehicle base bending loads to return to minimum by T minus 0. If one or more of the three main engines do not reach 90 percent of their rated thrust at T minus 3 seconds, all SSMEs are shut down, the solid rocket boosters are not ignited, and a pad abort condition exists.

Ascent

Beginning at T minus 0, the SSME gimbal actuators, which were locked in their special preignition position, are first commanded to their null positions for solid rocket booster start and then are allowed to operate as needed for thrust vector control.

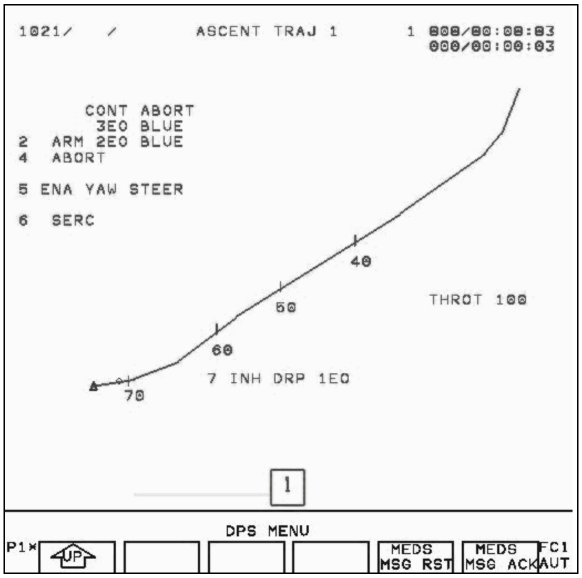
Between lift-off and MECO, as long as the SSMEs perform nominally, all MPS sequencing and control functions are executed automatically by the GPCs. During this period, the flight crew monitors MPS performance, backs up automatic functions, if required, and provides manual inputs in the event of MPS malfunctions.

During ascent, the liquid hydrogen tank's pressure is maintained between 32 and 34 psig by the orifices in the two lines and the action of the flow control valve.

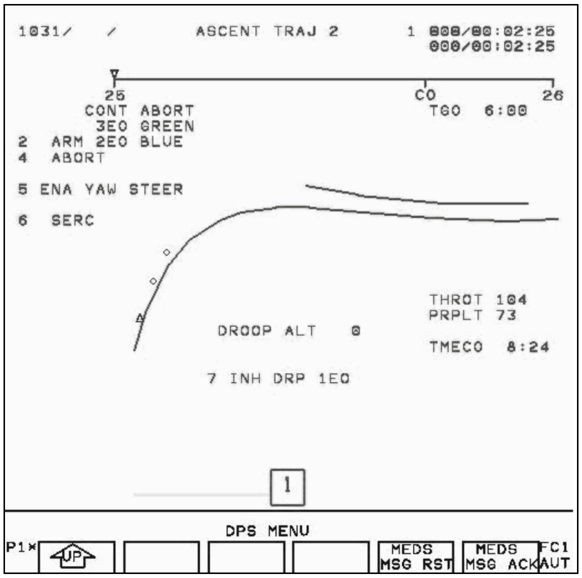
The liquid oxygen tank's pressure is maintained between 20 and 25 psig by fixed orifices in the ET to SSME pressurization lines. A pressure greater than 30 psig will cause the tank to relieve through its vent and relief valve.

The SSME thrust level depends on the flight: it is usually 104 percent, but the maximum setting of 109 percent may be required for emergency situations. *PASS commanded thrust (THROT) is displayed in PASS ASCENT TRAJ 1 and TRAJ 2 displays. The throttle level that would be commanded by the BFS (T) is displayed on the BFS ASCENT TRAJ 1 and TRAJ 2 displays. Actual throttle levels are read on the OMS/MPS MEDS display.* As dynamic pressure rises, the GPCs throttle the engines to a lower power level (typically 72 percent) to minimize structural loading while the orbiter is passing through the region of maximum aerodynamic pressure. This is called the "thrust bucket" because of the way the plot looks like a bucket on a graph of thrust versus mission elapsed time (MET). Although the bucket duration and thrust level vary, a typical bucket runs from about 30 to 65 seconds MET. The solid rocket booster propellant is also shaped to reduce thrust. At approximately 65 seconds MET, the engines are once again throttled up to the appropriate power level (typically 104 percent) and remain at that setting for a normal mission until 3-g throttling is initiated.

SRB separation is the next major event on ascent. The SRBs burn out after about 2 minutes of flight. Appearance of an overbright "Pc < 50" (SRB chamber pressure is less than 50 psi) on the trajectory display indicates to the crew that the SRB separation sequence has begun. Actual separation occurs about 5 seconds later to allow for SRB thrust tailoff.



PASS ASCENT TRAJ 1 DISPLAY
(throttle commanded by the PASS)



PASS ASCENT TRAJ 2 DISPLAY

Liquid oxygen manifold pressure is greatly affected by acceleration from the SRBs, but because of its low density, liquid hydrogen is not. At SRB separation, the liquid oxygen manifold pressure will drop from well over 100 psia to approximately 50 psia. Pressure rises again as the vehicle approaches 3 g's. The crew can monitor the manifold pressures (MANF P) on both the BFS GNC SYS SUMM 1 display and on the OMS/MPS MEDS display.

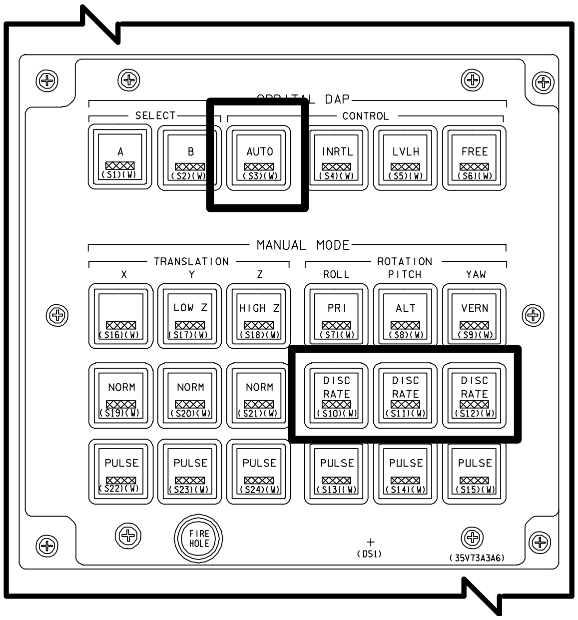
Beginning at approximately 7 minutes 30 seconds MET, the engines are throttled back as necessary to maintain vehicle acceleration at 3 g's or less. Three g's is an operational limit devised to prevent excessive physical stress on the flight crew and vehicle. Approximately six seconds before MECO (the period known as "fine count), the engines are throttled back to the minimum 67 percent in preparation for shutdown.

Main Engine Cutoff (MECO)

Normally, the GPCs command MECO once the vehicle has attained a specified velocity. *The cutoff bugs on the PASS ASCENT TRAJ 2 and the BFS ASCENT TRAJ 2 displays march* across the top of the display leading up to MECO and reach the "CO" tick mark at MECO.

The engines can also be shut down due to a "low-level cutoff," where the liquid oxygen or liquid hydrogen are depleted before the specified MECO velocity is reached. Liquid oxygen depletion is sensed by four sensors in the orbiter liquid oxygen feedline manifold. Liquid hydrogen depletion is sensed by four sensors in the bottom of the liquid hydrogen tank. If any two of the four sensors in either system indicate a dry condition (assuming the propellant mass has dropped to the point where the sensors have been armed), the GPCs will issue a MECO command to the engine controllers. This allows the engines to safely shutdown while there is still enough propellant to avoid cavitating the turbopumps.

The crew observes MECO through the illumination of the three red MAIN ENGINE STATUS lights on panel F7 and the Pc indicators on the OMS/MPS MEDS display dropping to 0 percent. Four of the ORBITAL DAP pushbutton lights on panel C3 illuminate, indicating that the Trans DAP has been activated and that the MECO CONFIRMED software flag has been set. This flag must be set to enter the ET separation sequence. (NOTE: the DAP lights will not illuminate on an RTLS abort since the Trans DAP is not activated at MECO. The MECO CONFIRMED flag, however, is still set.)



ORBITAL DAP CONTROL AUTO Light on Panel C3

Once MECO has been confirmed at approximately 8 minutes 30 seconds MET, the GPCs execute the external tank separation sequence. The sequence takes approximately 20 seconds to complete and includes opening the feedline relief isolation valves, arming the external tank separation pyro initiator controllers, closing the liquid hydrogen and liquid oxygen feedline 17-inch disconnect valves, turning the external tank signal conditioners' power off (deadfacing), firing the umbilical unlatch pyrotechnics, retracting the umbilical plates hydraulically, and gimbaling the SSMEs to the MPS dump sequence position.

At this point, the computers check for external tank separation inhibits. If the vehicle's pitch, roll, and yaw rates are greater than 0.7 degree per second, or the feedline disconnect valves fail to close, automatic external tank separation is inhibited. If these inhibit conditions are met, the GPCs issue the commands to the external tank separation pyrotechnics. The crew has the capability to override the external tank separation with the ET SEPARATION switch located on panel C3. Also, a deflection of the forward translational hand controller (THC) will interrupt the separation sequence.

At ET separation, the gaseous oxygen and gaseous hydrogen feedlines are sealed at the umbilicals by self-sealing quick disconnects.

Post-MECO

Ten seconds after MECO, the backup liquid hydrogen dump valves are opened for two minutes to ensure that the liquid hydrogen manifold pressure does not result in operation of the liquid hydrogen feedline relief valve.

After external tank separation, approximately 1,700 pounds of propellant are still trapped in the SSMEs, and an additional 3,700 pounds of propellant remain trapped in the orbiter's MPS feedlines. This 5,400 pounds of propellant represents an overall center-of-gravity shift for the orbiter of approximately 7 inches. Non-nominal center-of-gravity locations can create major guidance problems during entry. The residual liquid oxygen, by far the heavier of the two propellants, poses the greatest impact on center-of-gravity travel.

A hazard from the trapped liquid hydrogen occurs during entry, when any liquid or gaseous hydrogen remaining in the propellant lines may combine with atmospheric oxygen to form a potentially explosive mixture. In addition, if the trapped propellants are not dumped overboard, they will sporadically outgas through the orbiter liquid oxygen and liquid hydrogen feedline relief valves, causing slight vehicle accelerations.

The MPS propellent dumps (LO2 and LH2) occur simultaneously. Both dumps are completely automatic. The helium subsystem is used during the MPS dump to help expel the liquid oxygen from the LO2 manifold. To support this, at MECO plus 20 seconds, the GPCs interconnect the pneumatic helium and engine helium supply system by opening the center and right out/open interconnect valves and the left in/open interconnect valve if the MPS He INTERCONNECT LEFT, CTR, RIGHT switches on panel R2 are in the GPC position. This connects all 10 helium supply tanks to a common manifold, and it ensures that sufficient helium is available to perform the liquid oxygen and liquid hydrogen propellant dumps.

The MPS dump starts automatically at MECO plus 2 minutes. The MPS dump may be started manually by taking the MPS PRPLT DUMP SEQUENCE switch to START. The earliest that the manual MPS dump can be performed is MECO plus 20 seconds. The only reason that the crew may need to start the dump prior to MECO plus 2 minutes is if the LO2 or LH2 manifold pressure rises unexpectedly. The MPS dump will start automatically prior to MECO plus 2 minutes if the LH2 manifold pressure is greater than 60 psi. The dump takes 2 minutes to complete. The STOP position of the MPS PRPLT DUMP SEQUENCE switch prevents the automatic dump from starting during the ET separation sequence if it is delayed by an RCS leak or feedline disconnect valve failure.

For the LO2 dump, the GPCs command the two liquid oxygen manifold repressurization valves to open (the MAIN PROPULSION SYSTEM MANF PRESS LO2 switch on panel R4 must be in the GPC position), command each engine controller to open its SSME main oxidizer valve (MOV), and command the three liquid oxygen prevalves to open (the LO2 PREVALVE LEFT, CTR, RIGHT switches on panel R4 must be in the GPC position). The liquid oxygen trapped in the feedline manifolds is expelled under pressure from the helium subsystem through the nozzles of the SSMEs. This dump is propulsive and typically provides a change in orbital velocity of about 9 to 11 fps.

The pressurized liquid oxygen dump continues for 90 seconds. At the end of this period, the GPCs automatically terminate the dump by closing the two liquid oxygen manifold repressurization valves, wait 30 seconds, and then command the engine controllers to close their SSME main oxidizer valve. The three liquid oxygen prevalves remain open during the orbit phase of the flight.

Concurrent with the liquid oxygen dump, the GPCs automatically initiate the MPS liquid hydrogen dump. The GPCs command the two liquid hydrogen fill and drain valves (inboard and outboard) to open, the topping valve to open, and the three LH2 prevalves to open.

The liquid hydrogen trapped in the orbiter feedline manifold is expelled overboard without pressure from the helium subsystem. The liquid hydrogen flows overboard through the inboard and outboard fill and drain valves, and the topping valve for two minutes. The GPCs automatically stop the dump by closing the liquid hydrogen outboard fill and drain valve and the topping valve.

At the end of the liquid oxygen and liquid hydrogen dumps, the GPCs close the helium out/open and in/open interconnect valves, provided the He INTERCONNECT LEFT, CTR, RIGHT switches on panel R2 are in the GPC position. After the MPS dump is complete, the SSMEs are gimballed to their entry stow position with the engine nozzles moved inward (toward one another) to reduce aerodynamic heating. Although the gimbals move to an MPS dump position during the external tank separation, the I-loads are currently the same as the entry stow position. At this time, the BODY FLAP lights on panel F2 and F4 turn off. This is the crew's indication that the MPS dump is complete.

In the post OMS-1 procedures, the pilot positions all six MPS ENGINE POWER switches on panel R2 to OFF, which removes all power to the main engine controllers. Once power is removed from the controllers, the main oxidizer valves (through which the residual liquid oxygen is dumped) can no longer be operated.

The pilot also positions the six He ISOLATION switches and the PNEUMATIC He ISOLATION switch to GPC at this time. When this is done, the helium isolation valves automatically close. This cuts off helium to the helium regulators, which then begin to bleed down.

NOTE

> As the helium regulators bleed down, they trigger multiple MASTER ALARMS, which the crew can expect.

The external tank gaseous hydrogen pressurization manifold is manully vacuum inerted by opening the hydrogen pressurization line vent valve by placing the MAIN PROPULSION SYSTEM H2 PRESS LINE VENT switch on panel R4 to OPEN. After about one minute, the switch is taken back to the GND position, which closes the valve. The hydrogen pressurization vent line valve is electrically activated; however, it is normally closed (spring-loaded to the closed position). Removing power from the valve solenoid closes the valve.

Vacuum Inerting

Fifteen minutes after the MPS dump stops, the GPCs initiate the sequence for vacuum inerting the orbiter's liquid oxygen and liquid hydrogen manifolds. Vacuum inerting allows traces of liquid oxygen and liquid hydrogen trapped in the propellant manifolds to be vented into space.

The LO2 vacuum inerting is accomplished by the GPCs opening the LO2 inboard and outboard fill and drain valves. The LH2 vacuum inerting is accomplished by the GPCs opening the backup LH2 dump valves.

The liquid oxygen and hydrogen lines are inerted simultaneously for two minutes. At the end of the sequence, the GPCs close the LO2 outboard fill drain valve and the LH2 backup dump valves. The LO2 and LH2 inboard valves are left open to prevent a pressure buildup between the inboard and outboard valves.

Any GPC or FA MDM failure that will not allow the automatic vacuum inert to function properly will require the crew to perform a manual vacuum inerting procedure.

Following the OMS 2 burn, upon transition to MM 106, the LH2 system goes through a second vacuum inerting to evacuate all of the residual liquid hydrogen. Residual hydrogen ice sublimates quickly after the OMS 2 burn (and the LH2 manifold pressure rises) due to the vibrations induced by the firing of the OMS engines. This second inert takes about three minutes to complete.

Post Insertion

In the post insertion portion of the flight, the MPS is essentially unpowered.

On panel L4, the 18 circuit breakers connecting ac power to the main engine controllers are all opened to reduce the risk of a short.

Via switches on panel O17, the four ascent thrust vector control (ATVC) units, the three engine interface units (EIUs), and the two master events controllers (MECs) are all powered OFF.

The hardware C/W system is reconfigured to inhibit caution and warning on the helium tank pressures and the "A" regulators, since the helium system is secured and no longer used. In the event of an incomplete MPS dump, the LH2 and LO2 manifold pressure caution and warning is left enabled to alert the crew to a possible high manifold pressure while on orbit.

Orbit

All main propulsion systems have been secured by the time post insertion is complete. The MPS orbit procedures deal with off-nominal manifold pressures and are not normally performed. The concern on orbit is possible high manifold pressures due to an incomplete vacuum inert or MPS dump. If high manifold pressures were detected during orbit, the MCC would advise the crew to perform a manual vacuum inert. If the MCC were not available, the manifold pressure caution and warning parameter (left enabled during post insertion) would alert the crew of the high manifold pressure and the malfunction procedure would be performed, relieving the pressure or deducing a manifold pressure transducer failure.

Deorbit Prep

During the deorbit prep timeframe, the MPS hardware C/W is reconfigured in preparation for entry. First, the MPS helium "A" regulators are re-enabled. Helium will be used for the entry purge and manifold repressurization. The hardware C/W will help the crew identify a regulator that has failed high before it over-pressurizes the aft compartment. Next, the manifold pressure is inhibited. The manifolds are at a vacuum state and do not need to be monitored during entry.

Also during deorbit prep, the ATVC switches are powered back on. This will allow the main engine nozzles, which may have drifted out of position while on orbit, to return to their entry stow positions. Activating the ATVCs also supports SSME repositioning for drag chute deploy, which automatically occurs during glided flight.

Entry

The GPCs reconfigure the MPS helium system in preparation for the entry repressurization and purge at the MM 303 transition.

NOTE

> Expect the F7 MPS light to be on until MM 303.

Once MM 303 is entered, the GPCs command the PNEUMATIC ISOLATION A and B, and the L ENG He XOVR to OPEN provided the switch is in the GPC position. At the same time, the MPS He INTERCONNECTS CTR and RIGHT are commanded out/open, while the MPS He INTERCONNECT LEFT is commanded in/ open. This feeds all the MPS helium through the left engine, through the PNEUMATICS L ENG He XOVR, and through the pneumatic isolation valves. Also at this time, the LH2

RTLS dump valves go open to insure the LH2 manifold is completely vented prior to entry.

At a ground-relative velocity (V_{REL}) of 8000 fps (around an altitude of 151,000 feet), the ATVCs pitch down the main engine bells out of the way of the drag chute when it is deployed after touchdown.

At a V_{REL} of 5300 fps (between 130,000 and 110,000 feet altitude, depending on the entry trajectory), the helium blowdown valves open which allows helium to continuously purge the aft compartment, OMS pods, and the LH2 umbilical cavity area. There is no manual control of the blowdown valves. The blowdown purge continues for 650 seconds and typically ends a few minutes after touchdown.

Also at a V_{REL} of 5300 fps, the MAIN PROPULSION SYSTEM MANF PRESS LH2 & LO2 valves are commanded OPEN, provided the switches on panel R4 are in the GPC position. This allows the LH2 and LO2 manifolds to be pressurized, preventing contaminants from entering the manifolds during entry. Removing contamination from the manifolds or feedlines can be a long and costly process since it involves disassembly of the affected parts. The manifold repress continues until the ground crews install the throat plugs in the main engine nozzles. Further, the LH2 backup dump valves and the LO2 prevalves go closed.

RTLS Abort Propellant Dump Sequence

For RTLS abort, immediately post-MECO, the valve sequencing is the same as for a nominal MECO. After approximately 25 seconds, the vehicle enters MM 602 and the RTLS dump begins. The RTLS entry dump differs only slightly from the nominal entry dump.

During the RTLS dump, liquid oxygen is initially dumped through the LO2 prevalves and through the main oxidizer valves (MOVs) in the SSMEs. When the dynamic pressure is above 20 psf (plus an I-load), there is a subsequent venting through the liquid oxygen fill and drain valves. This dump is done without helium pressurization and relies on the self-boiling properties of the liquid oxygen. In the RTLS liquid oxygen dump, the GPCs terminate the dump whenever the ground relative velocity drops below 3,800 feet-per-second. The liquid oxygen system is repressurized when V_{REL} is 3800 fps, and repressurization continues as in a nominal entry.

LH2 manifold is expelled in the same manner as the nominal post-MECO dump (with one exception) until V_{REL} is 3800 fps, at which time the valves are closed. The only exception is that the RTLS LH2 dump is assisted by helium pressurization through the RTLS manifold pressurization valves for two minutes, beginning at RTLS dump start.

The entry repressurization and the aft compartment surge also occur during the RTLS. The helium blowdown valves are opened at V_{REL} of 5300 fps, followed by the manifold repress valves opening at a V_{REL} of 3800 fps. As with the nominal entry, the blowdown valves remain open until a few minutes after landing.

TAL Abort Propellant Dump Sequence

For a TAL abort, the entire dump sequence is the same as that for RTLS. On the TAL, the dump begins at the transition to MM 304.

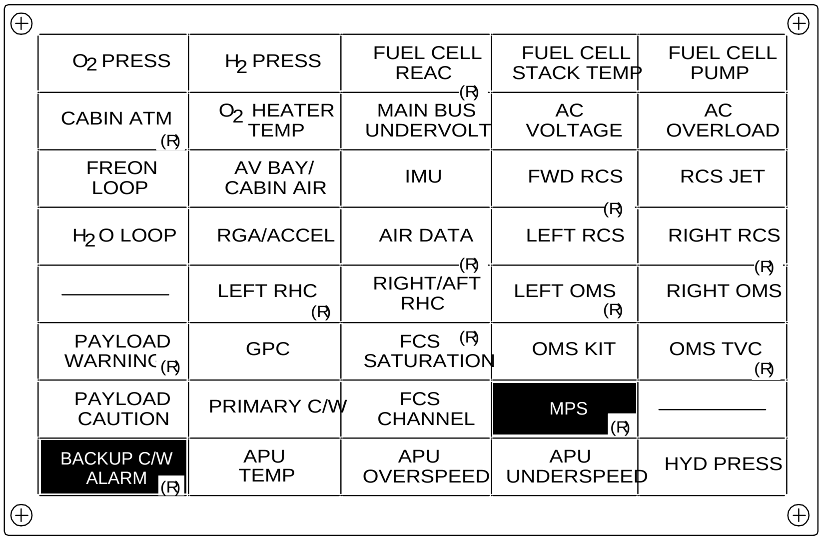
The LO2 is also dumped at the MM 304 transition through the LO2 prevalves and then out the MOVs, just as in the nominal dump. To assist in removing the LO2 propellants, the LO2 inboard and outboard fill drains are opened at a V_{REL} of 20,000 fps if the LO2 manifold pressure is less than 30 psi.

MPS Caution and Warning Summary

- **Data path failure** is the loss of both primary and secondary data paths between the engine controller and the GPCs. Data path failure indications include an *SM ALERT* light and audio tone, an amber *MAIN ENGINE STATUS* light on panel F7, the engine Pc meter on the OMS/MPS MEDS display driven to zero, and an "MPS DATA L (C, R)" message.
- **Command path failure** is when the engine controller does not receive 2/3 valid inputs from the GPCs. The engine will not respond to any commands, such as throttling or shutdown. Indications include an *SM ALERT* light on panel F7 and audio tone, an amber *MAIN ENGINE STATUS* light on panel F7, no change in the Pc meter during throttling, and an "MPS CMD L (C, R)" message. This message will only annunciate on the PASS pre-BFS engage.
- **Hydraulic lockup** occurs when the engine controller senses any of the five hydraulically actuated engine valves out of position. The engine will no longer throttle. Indications are an *SM ALERT* light and audio tone, an amber *MAIN ENGINE STATUS* light on panel F7, no change in Pc meter during throttling, and an "MPS HYD L (C, R)" message.
- **Electric lockup** occurs when the controller loses all Pc or all fuel flow rate data from the engine. The engine will no longer throttle. Indications are *SM ALERT* light and audio tone, an amber *MAIN ENGINE STATUS* light on panel F7, no change in Pc meter during throttling, and "MPS ELEC L (C, R)" message.
- **Engine failure** indications are a visual and audible *MASTER ALARM*, a red *MAIN ENGINE STATUS* light, engine Pc meter reading of zero, a Backup C&W Alarm light on the F7 C/W matrix, and an "SSME FAIL L (C, R)" message on the DPS display. A drop in acceleration also occurs but may be hard to detect (especially in MM 102, pre SRB SEP).
- **ET SEP** switch failures are shown by an SM alert light and an "ET SEP MAN" or "ET SEP AUTO" message. MAN is the default software position for NOM/ATO; AUTO, for RTLS/TAL. This is annunciated by the PASS only (since BFS has no switch RM).
- Main engine shutdown pushbutton failures cause an "ME SHDN SW C(L,R)" message and an SM alert light and tone that is annunciated by the PASS only (since BFS has no switch RM).
- **Liquid hydrogen ullage pressure below 28.0** psia is indicated by an *SM ALERT* light and audio tone, one or more down arrows by the LH2 pressure readings on the BFS GNC SYS SUMM 1 display, and an "MPS LH2/O2 ULL" message on the BFS DPS display.
- **High liquid hydrogen or liquid oxygen manifold pressure** indications are: a visual and audible *MASTER ALARM*, out of limits indications by the applicable MANF P reading on both the BFS GNC SYS SUMM 1 display and the OMS/MPS MEDS display, and an "MPS LH2/LO2 MANF" message on the DPS display. The limits are 249 psia for liquid oxygen, and 65 psia for liquid hydrogen.
- **Helium tank leaks** or regulator failure are indicated by an *SM ALERT* light and audio tone, an up arrow by the applicable dP/dT or regulator on the BFS GNC SYS SUMM 1 display, and an "MPS He P C (L, R)" message.
- **ET separation inhibit** is indicated by an *SM ALERT* light and audio tone and an "ET SEP INH" message.
- **The MPS** light on panel F7 illuminates (red) if liquid hydrogen manifold pressure exceeds 65 psia on orbit or liquid oxygen manifold pressure exceeds 249 psia on orbit. *A MASTER ALARM* also illuminates, an audio alarm sounds, and the red *BACKUP C/W ALARM* on panel F7 is lit as well. The light will also illuminate for helium pressure below 1,150 psia or regulated helium pressure below 680 or above 810 psia on the "A" regulators only.
- **The red upper half of the MAIN ENGINE STATUS** lights on panel F7 will be illuminated for an engine in shutdown or post-shutdown phase or exceeding redline limits with limits inhibited.

MPS Caution and Warning Summary (continued)

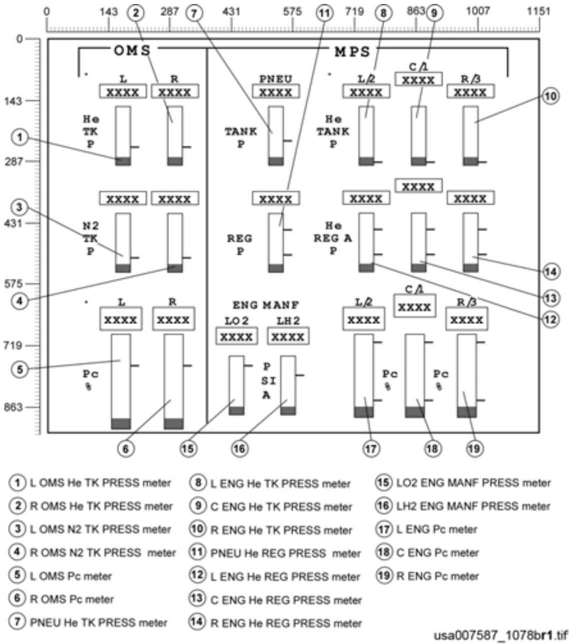
- **MPS** pneumatic system anomalies are annunciated by an SM alert light and audio tone, and an applicable message on the BFS DPS display. The following pneumatic system messages are annunciated along with an SM alert light and audio tone for the given condition. MPS PNEU TK, pneumatic tank pressure drops below 3800 psi. MPS PNEU ACUM, pneumatic accumulator pressure drops below 700 psi. MPS PNEU REG, pneumatic regulator pressure drops below 700 psi or goes above 810 psi.



O_2 PRESS	H_2 PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O_2 HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H_2O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS	RIGHT RCS (R)
————	LEFT RHC (R)	RIGHT/AFT RHC	LEFT OMS (R)	RIGHT OMS
PAYLOAD WARNING (R)	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	————
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

633.cvs

MPS Caution and Warning Lights on Panel F7



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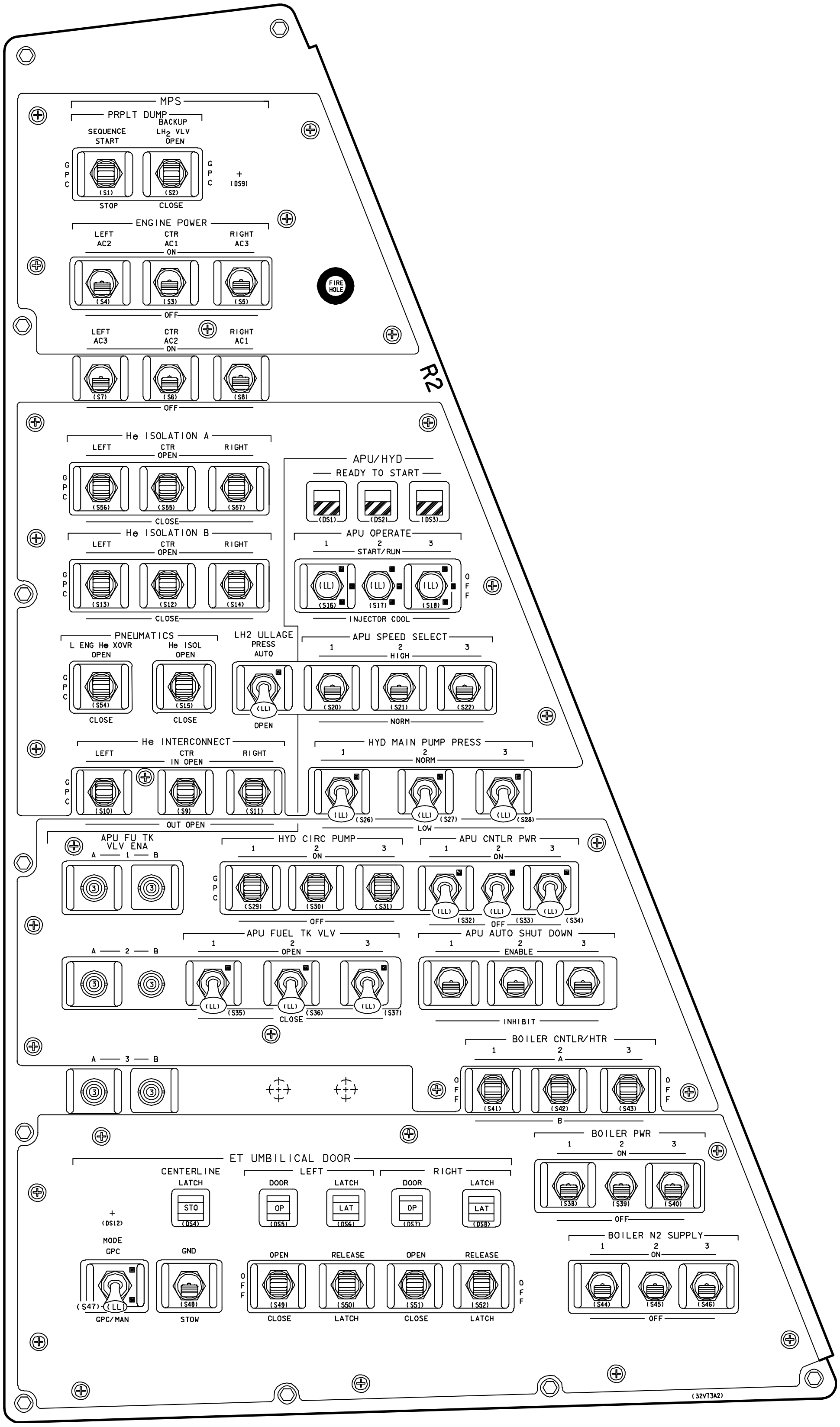
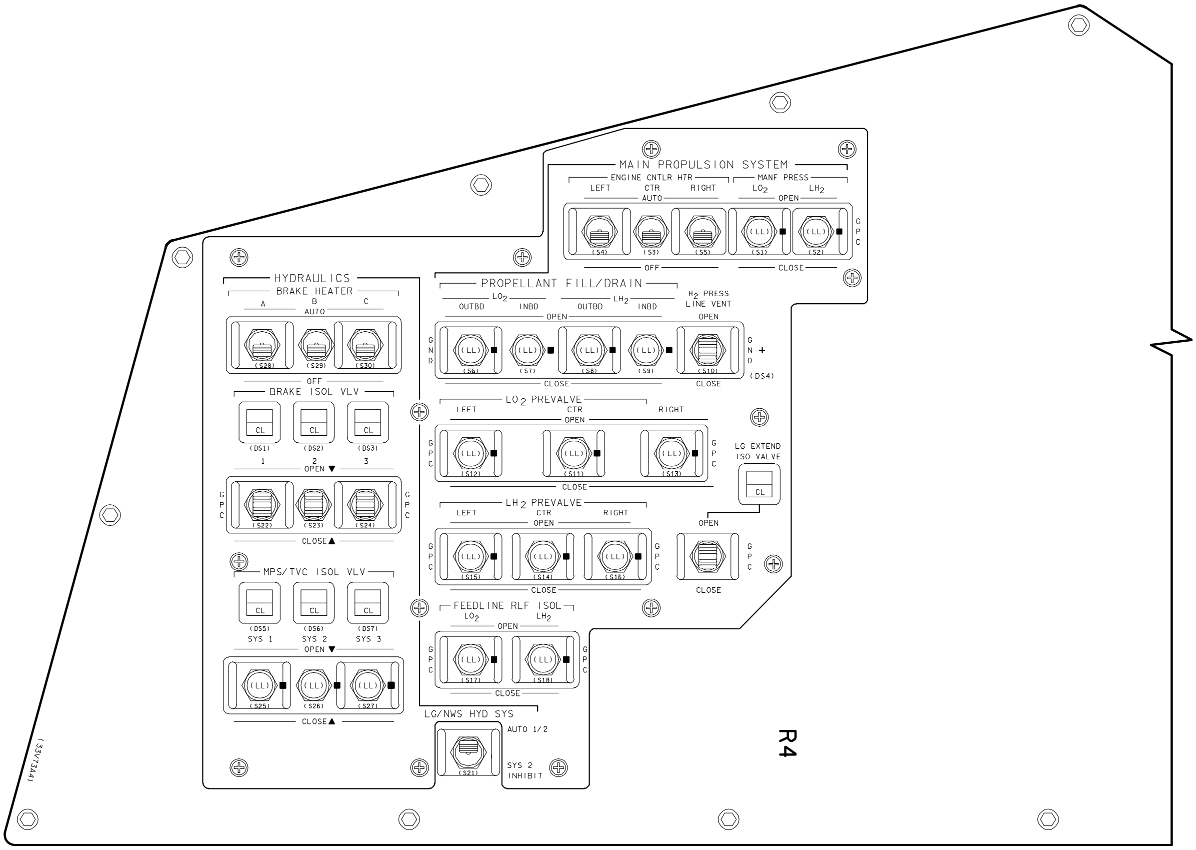
OMS/MPS Display

MPS Summary Data

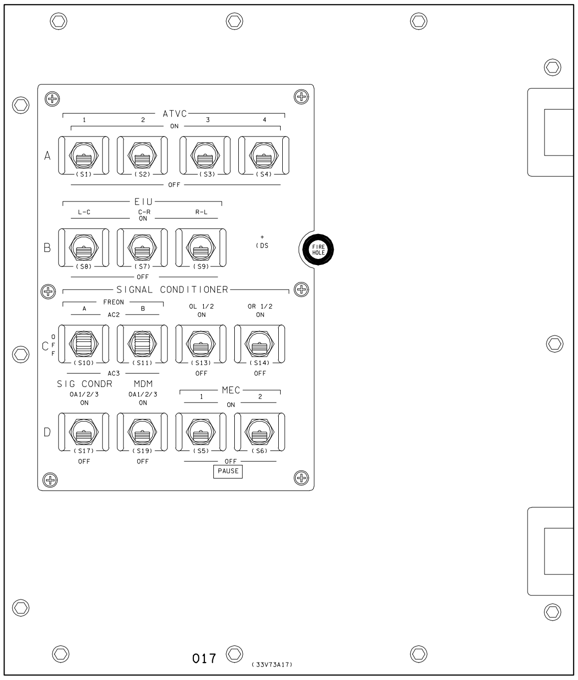
- The main engines, assisted by two solid rocket motors during the initial phases of the ascent trajectory, provide the vehicle acceleration from lift-off to MECO at a predetermined velocity.
- Most of the MPS is located at the aft end of the orbiter beneath the vertical stabilizer.
- The MPS consists of three SSMEs and controllers, the external tank, propellant management and helium systems, four ascent thrust vector control units, and six hydraulic servoactuators.
- The SSMEs are reusable, high-performance engines that use liquid hydrogen for fuel and cooling and liquid oxygen as an oxidizer.
- The SSMEs can be throttled 67 to 109 percent in 1 percent increments. Thrust level values are: 100 percent = 375,000 pounds at sea level, 470,000 pounds in a vacuum; 104 percent = 393,800 pounds at sea level, 488,000 pounds in a vacuum; 109 percent = 417,300 pounds at sea level, 513,250 pounds in a vacuum.
- Major SSME components are fuel and oxidizer turbopumps, preburners, a hot gas manifold, main combustion chamber, nozzle, oxidizer heat exchanger, and propellant valves.
- Each SSME has a controller with two redundant digital computer units. Operating in conjunction with engine sensors, valves, actuators, and spark igniters, the controllers form a self-contained system for engine control, checkout, and monitoring.
- The propellant management system consists of manifolds, distribution lines, and valves that transport propellant from the external tank to the three main engines for combustion, and gases from the engines to the external tank for pressurization.
- The helium system consists of 10 supply tanks and associated regulators, check valves, distribution lines, and control valves.
- The helium system is used for: (1) in-flight engine purges, (2) pressure for emergency closing of engine valves, (3) pressure to actuate pneumatically operated propellant valves, (4) expelling the propellants during the MPS dump and (5) entry purge and repressurization.
- There is one helium system per engine, plus a fourth pneumatic system to operate the propellant valves.
- The three orbiter hydraulic systems supply hydraulic pressure to the MPS to actuate engine valves and provide engine gimballing for thrust vector control.
- MPS controls are located primarily on panels R2 and R4, and C3 with a few on panels F7, O17, and R1.
- MPS system status indicators appear *on several displays, which include OMS/MPS MEDS, BFS GNC SYS SUMM 1, and both PASS and BFS ASCENT TRAJ 1 and 2.*


MPS
PRPLT DUMP
SEQUENCE START
BACKUP LH2 VLV OPEN
GPC
(S1)
(S2)
STOP
CLOSE
(DS9)
ENGINE POWER
LEFT AC2
CTR AC1
RIGHT AC3
ON
(S4)
(S3)
(S5)
OFF
FIRE HOLE
LEFT AC3
CTR AC2
RIGHT AC1
ON
(S7)
(S6)
(S8)
OFF
R2
He ISOLATION A
LEFT
CTR OPEN
RIGHT
(S56)
(S55)
(S57)
CLOSE
He ISOLATION B
LEFT
CTR OPEN
RIGHT
(S13)
(S12)
(S14)
CLOSE
APU/HYD
READY TO START
(DS1)
(DS2)
(DS3)
APU OPERATE
1
2 START/RUN
3
(LL)
(S16)
(S17)
(S18)
OFF
INJECTOR COOL
PNEUMATICS
L ENG He XOVR OPEN
He ISOL OPEN
(S54)
(S15)
CLOSE
LH2 ULLAGE PRESS AUTO
OPEN
APU SPEED SELECT
1
2 HIGH
3
(S20)
(S21)
(S22)
NORM
He INTERCONNECT
LEFT
CTR IN OPEN
RIGHT
(S10)
(S9)
(S11)
OUT OPEN
HYD MAIN PUMP PRESS
1
2 NORM
3
(S26)
(S27)
(S28)
LOW
APU FU TK VLV ENA
A — 1 — B
HYD CIRC PUMP
1
2 ON
3
(S29)
(S30)
(S31)
OFF
APU CNTLR PWR
1
2 ON
3
(S32)
(S33)
(S34)
OFF
APU FUEL TK VLV
A — 2 — B
1
2 OPEN
3
(S35)
(S36)
(S37)
CLOSE
APU AUTO SHUT DOWN
1
2 ENABLE
3
INHIBIT
BOILER CNTLR/HTR
1
2 A
3
A — 3 — B
OFF
(S41)
(S42)
(S43)
B
OFF
BOILER PWR
1
2 ON
3
(S38)
(S39)
(S40)
OFF
ET UMBILICAL DOOR
CENTERLINE LATCH
LEFT
DOOR
LATCH
RIGHT
DOOR
LATCH
STO
(DS4)
OP
(DS5)
LAT
(DS6)
OP
(DS7)
LAT
(DS8)
(DS12)
MODE GPC
GND
(S47)
(S48)
GPC/MAN
STOW
OPEN
RELEASE
OPEN
RELEASE
OFF
(S49)
(S50)
(S51)
(S52)
OFF
CLOSE
LATCH
CLOSE
LATCH
BOILER N2 SUPPLY
1
2 ON
3
(S44)
(S45)
(S46)
OFF
(32VT3A2)

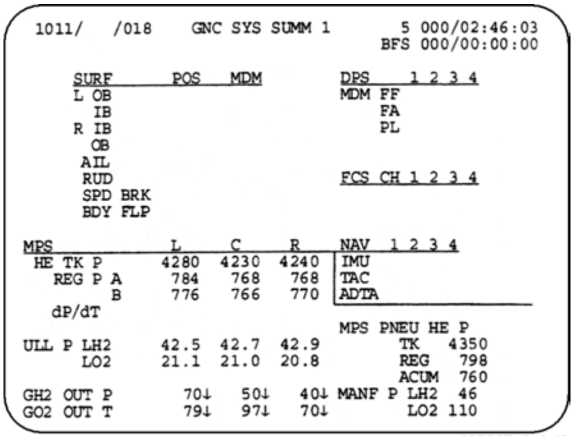
Panel R2



Panel R4



Panel O17



```
1011/  /018   GNC SYS SUMM 1        5 000/02:46:03
                                    BFS 000/00:00:00

     SURF      POS   MDM           DPS    1 2 3 4
     L OB                          MDM FF
       IB                              FA
     R IB                              PL
       OB
      AIL
      RUD                          FCS CH 1 2 3 4
      SPD BRK
      BDY FLP

MPS            L     C     R       NAV  1 2 3 4
 HE TK P     4280  4230  4240      IMU
    REG P A   784   768   768      TAC
          B   776   766   770      ADTA
   dP/dT
                                   MPS PNEU HE P
ULL P LH2    42.5  42.7  42.9          TK   4350
      LO2    21.1  21.0  20.8          REG   798
                                       ACUM  760
GH2 OUT P     70↓   50↓   40↓  MANF P LH2  46
GO2 OUT T     79↓   97↓   70↓          LO2 110
```

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BFS GNC SYS SUMM 1

MPS Rules of Thumb

- Direct insertion MECO is usually close to 8 minutes 30 seconds MET.

- An SSME will consume approximately 4 percent propellant per engine per minute at 104 percent. Propellant remaining is displayed on the *PASS* ASCENT TRAJ 2 display and is a guidance-calculated number.

- When an engine fails, the helium dP/dT is greater than 40 for several seconds, due to engine shutdown purges, and then it goes to zero. This is a good crosscheck to confirm engine shutdown.

- Two automatic ways to set MECO confirm are: three Pc's < 30% or two Pc's <30% and a data path failure on the third SSME. Three manual ways to set MECO confirm are: push the three SSME PB's, OPS 104 PRO, or FAST SEP.

- Both PASS and BFS do not require all three MAIN ENGINE SHUT DOWN pushbuttons simultaneously to set MECO confirmed.

- To shut down an engine, both contacts on the MAIN ENGINE SHUT DOWN pushbutton must be good. If one contact is commfaulted, the button can only be used to set the safing flag on an engine that failed under a data path failure. If, however, a contact is power-failed, the button is totally inoperative.

- In the BFS, if a contact on the MAIN ENGINE SHUT DOWN pushbutton is either commfaulted or power-failed, the button is totally inoperative.

- An SSME command path failure must always be shut down manually with the A/C switches and PBs.

- Shutdown with A/C switches will always cause a data path failure.

- An “SSME FAIL C (L, R)” message indicates that the GNC software has recognized an engine shut down.

- An engine in data path failure will never display a red MAIN ENGINE STATUS light.

- There are no direct indications to the crew of limit shutdown enable/inhibit status. The status is available to the MCC, or it can be deduced by the crew.

- Limits must be enabled on an engine when the helium regulator pressure begins to decay due to a helium leak. An SSME will fail catastrophically if there is insufficient helium, and limit shutdown is inhibited.

- Loss of an APU in powered flight will result in a hydraulic lockup.

- An SSME in hydraulic or electric lockup may require a pre-MECO shutdown.

- Actual throttle levels on the first stage throttle bucket can vary due to SRB thrust level dispersions. This is an artifact of "first stage adaptive guidance."

- Manual SSME shutdown typically occurs about 30 seconds before MECO. This corresponds to: V_I = 23K (3-eng uphill), V_I = 24.5K (2-eng uphill), and V_I = 22.5K (TAL).

- MPS ENGINE POWER switches look very similar to He ISOLATION switches and are located close together on panel R2. **Use caution.**

- Loss of ALC 1, 2, 3 (APC 4, 5, 6) will cause SSME helium isolation A to close on the C, L, R SSME, respectively. Do not attempt subsequent helium leak isolations.

2.17 MECHANICAL SYSTEMS

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Description

The orbiter's mechanical systems are those components that must be deployed, stowed, opened, or closed. An electrical or hydraulic actuator physically moves each of these components.

The mechanical systems include the active vent system, external tank *(ET)* umbilical doors, payload bay doors, deployable radiator system, and the landing and deceleration system. The landing and deceleration system is discussed in Section 2.14, and the radiators are included in Section 2.9. Descriptions of the remaining systems, as well as their operations are discussed in this section.

There are other orbiter systems that use mechanical actuators but they are not considered mechanical systems. These systems are not discussed in this section. Instead, they are covered in the following sections: Section 2.4, Ku-band Antenna; Section 2.13, Star Tracker Doors and Air Data Probes; and Section 2.19, Payload Retention Latches.

Electromechanical Actuators

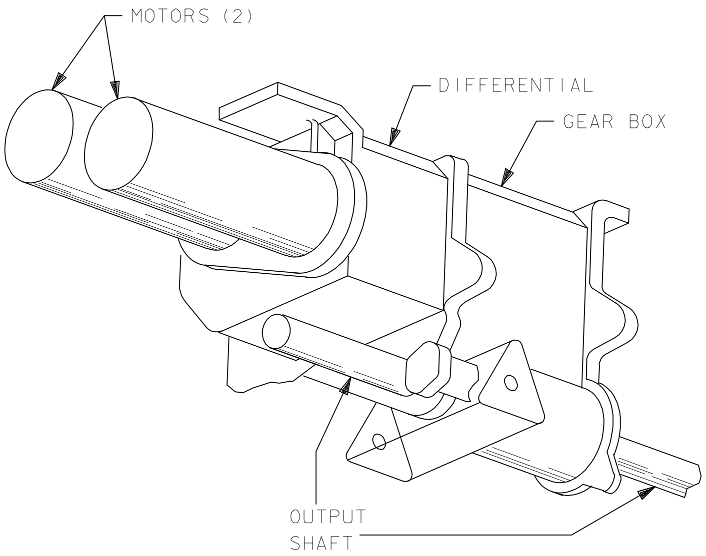
The orbiter's electromechanical actuators, also called power drive units (PDUs), contain two three-phase *alternating current (AC)* motors, brakes, a differential assembly, a gearbox, and limit switches. Except for the ET door centerline latches, all actuator assemblies also contain torque limiters.

Power for the actuator motors and limit switches is provided by the orbiter's motor control assemblies (MCAs). The MCAs are powered via *MCA LOGIC* switches and circuit breakers on panel MA73C.

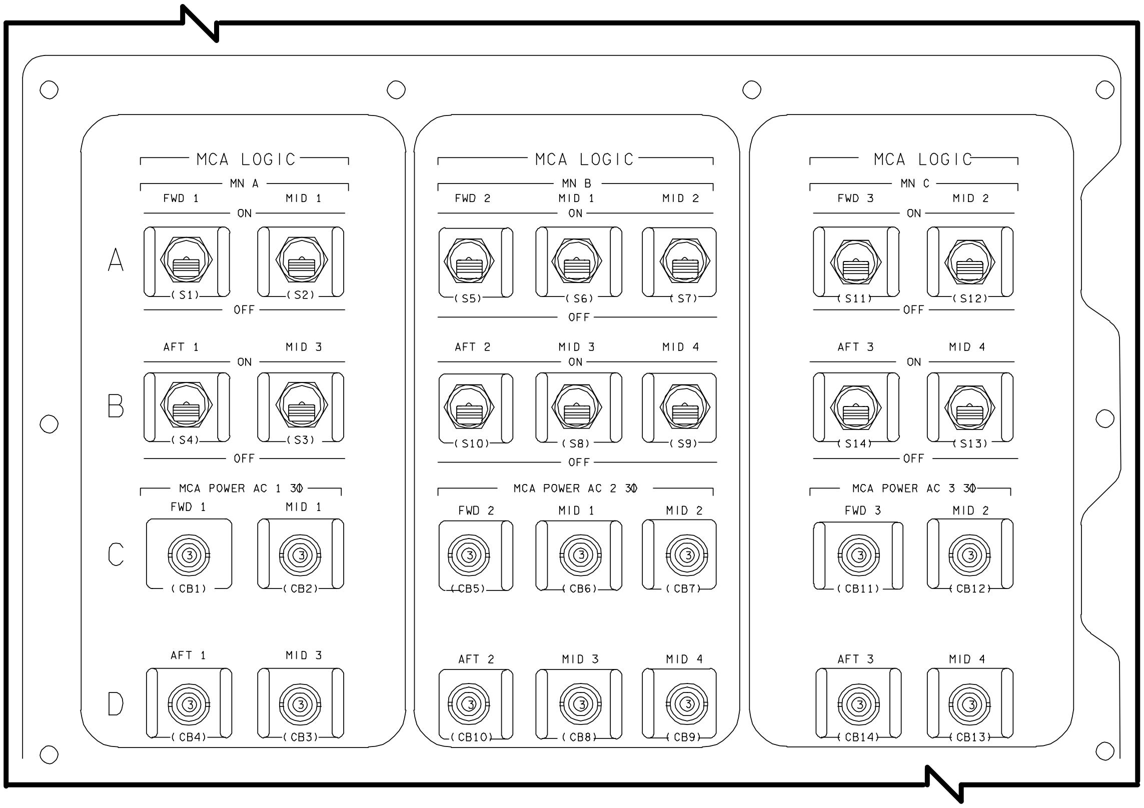
Nominally, both of an actuator's AC motors will drive at the same time, which is referred to as dual motor drive. If only one motor is driving, it is called single motor drive. If a mechanism is being driven with single motor drive, it will take twice as long to reach the desired position than it would with dual motor drive.

Commands are sent to the MCAs to turn the AC motors on and off. Commands can originate from the *general purpose computers* (GPCs), *data processing system* (DPS) item entries, or hardwired switches. These commands are sent via multiplexer/demultiplexers (MDMs). Each actuator motor is commanded through a separate MDM; therefore, the loss of one MDM will not cause the loss of an entire actuator.

The AC motors are reversible so that mechanisms may be driven in both directions (open or closed, stowed or deployed, latched or released). When a mechanism reaches the commanded position, the limit switches send signals back to the MCA to open relays that remove the AC power to the associated motors. These limit switch signals also provide feedback through telemetry, DPS displays, and talkbacks in the crew compartment.



Electromechanical Actuator



MCA Controls on Panel MA73A

Active Vent System

The active vent system (AVS) equalizes the orbiter's unpressurized compartments to the ambient environment as the orbiter travels from the pressurized atmosphere of Earth to the vacuum of space.

The AVS consists of *14* vent ports (*7* on each side) in the orbiter fuselage. For identification, each door is numbered forward to aft.

Originally, there were a total of 18 vents. An engineering analysis showed that vent ports 3, 5, and 6 provide sufficient venting of the payload bay and mid-fuselage compartments. Because of this, vent ports 4 and 7 were permanently capped shut on both sides of Atlantis and Discovery. The associated actuators and linkages also were removed. Endeavour did not have the equipment installed.

Each vent door has a pressure seal and a thermal seal, and is driven inward by its associated electromechanical actuator. The vent openings are sized according to the volume to be vented.

The doors for the vent ports are opened and closed during the mission to perform the functions of the AVS. Normal opening or closing time is 5 seconds for each vent door, with dual motor drive.

Some of the vent doors (1, 2, 6, 8, and 9) also have intermediate positions to provide the capability to purge the unpressurized compartments with dry air or nitrogen. Purge operations are performed on the ground to provide thermal conditioning, moisture control, and to exclude hazardous gases or contaminants.

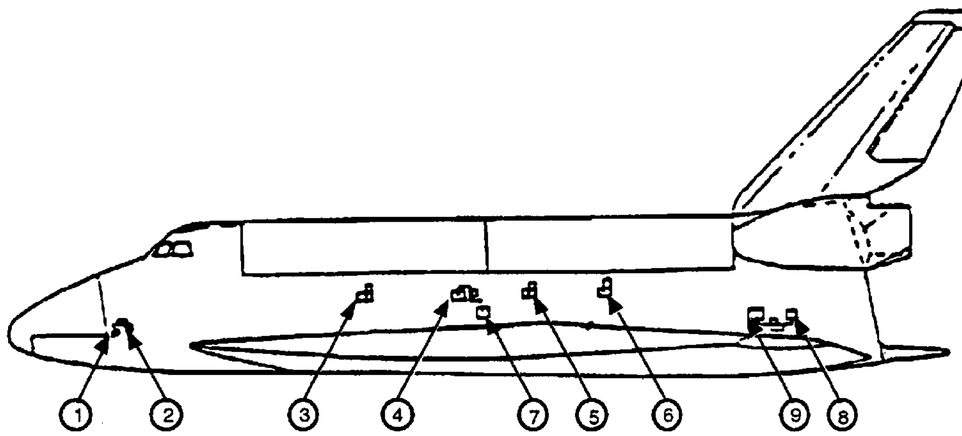
Vent Operations

The vent doors are controlled by a GNC software sequence that can be started by a master timing unit, major mode transition, velocity, or DPS item entry.

When commanded via item entry by the crew, they will use GNC SPEC 51 OVERRIDE in the PASS. There are similar capabilities in the BFS, but the item entries on the BFS page are only legal if BFS is engaged.

During countdown, the vent doors are in their purge positions until T-28 seconds, when the OPEN sequence is automatically called by the redundant set launch sequencer (RSLS). The vent doors are commanded open in a staggered sequence at approximately 2.5-second intervals.

The vent doors remain open during ascent, orbital insertion, and all on-orbit phases. During entry preparation, the crew performs a DPS item entry on GNC SPEC 51 OVERRIDE to close the vent doors. At this time, all the vent doors are commanded closed and then port vents 1, 2, 8, and 9 are automatically reopened. These vents are left open to vent any hazardous gases during the deorbit burn and to prevent vehicle overpressurization should a rapid *orbital maneuvering system (*OMS*)*/*reaction control system (*RCS*)* leak occur. These vents are automatically closed at the MM304 transition.



Vent	Area Vented	Positions	Type Actuator
1, 2	FWD RCS and fuselage	OPEN/CLOSE/PURGE	Common
3, 5	Midbody, payload	OPEN/CLOSE	Single
6	Midbody, payload	OPEN/CLOSE/PURGE	Single
4, 7	Midbody, payload/wing *	SEALED	Removed
9, 8	Aft fuselage/OMS PODS	OPEN/CLOSE/PURSE	Common

* OV-105 and others after Orbiter Maintenance Down Period (Major Mod) J-1.

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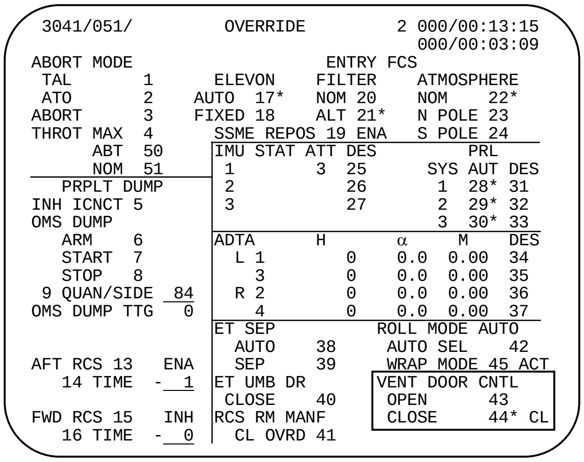
Vent Locations

When the relative velocity of the orbiter reaches 2400 ft/s on entry, all the vent doors are automatically commanded open, allowing the unpressurized compartments to equalize with the ambient atmosphere.

Postlanding, once in OPS 9, the crew will perform DPS item entries on GNC SPEC 105 TCS CONTROL to configure the AVS for purge operations.

Nominally, the AVS operates automatically except for the preentry and postlanding configuration, which are commanded by the orbiter crew at the appropriate times. In the return-to-launch site (RTLS) abort, the vent doors are automatically commanded closed at MM 602. For a transoceanic abort landing (TAL), the vent doors are automatically commanded closed at ET separation.



```
 3041/051/         OVERRIDE         2 000/00:13:15
                                      000/00:03:09
ABORT MODE                   ENTRY FCS
 TAL       1      ELEVON    FILTER    ATMOSPHERE
 ATO       2    AUTO  17*   NOM 20    NOM    22*
ABORT      3    FIXED 18    ALT 21*   N POLE 23
THROT MAX  4      SSME REPOS 19 ENA   S POLE 24
      ABT  50     IMU STAT ATT DES         PRL
      NOM  51      1        3  25      SYS AUT DES
   PRPLT DUMP      2           26       1  28* 31
INH ICNCT 5        3           27       2  29* 32
OMS DUMP                                3  30* 33
   ARM    6       ADTA      H       α     M     DES
   START  7         L 1        0    0.0  0.00   34
   STOP   8           3        0    0.0  0.00   35
 9 QUAN/SIDE  84    R 2        0    0.0  0.00   36
OMS DUMP TTG   0      4        0    0.0  0.00   37
                  ET SEP            ROLL MODE AUTO
                    AUTO    38       AUTO SEL    42
AFT RCS 13   ENA    SEP     39       WRAP MODE 45 ACT
   14 TIME  -  1  ET UMB DR         VENT DOOR CNTL
                   CLOSE    40       OPEN      43
FWD RCS 15   INH  RCS RM MANF        CLOSE     44* CL
   16 TIME  -  0    CL OVRD 41
```

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OVERRIDE Display (SPEC 51)

PASS/BFS		
Major Mode (RTLS)	**Command**	
	OPEN ITEM 43	**CLOSE ITEM 44**
301	All doors open	All doors close; then port 1, 2, 8, 9 Auto reopen
302	*All doors open*	*All doors close*
303	All doors open	All doors close
304	Port 1, 2, 8, 9 open	All doors close
305	All doors open	Command not available until rollout flag set
(602)	All doors open	All doors close
(603)	All doors open	Command not available until rollout flag set

Manual Vent Door Command Capability during Entry

External Tank Umbilical Doors

Electrical and fuel umbilicals between the external tank and the orbiter enter the shuttle through two aft umbilical openings located on the underside of the orbiter. These umbilical cavities contain the orbiter/ET attachment points and the fuel and electrical disconnects. The left cavity contains the liquid hydrogen umbilical, and the right cavity contains the liquid oxygen umbilical.

Each umbilical cavity has an associated ET door. During ascent, this door is open to allow the umbilical connections between the orbiter and the ET. After the ET separates from the orbiter, the two aft umbilical openings are exposed. The ET doors are closed to cover these exposed areas and to shield them from entry heating.

A closeout curtain is installed at each of the orbiter/external tank umbilicals. After ET separation, the residual liquid oxygen in the main propulsion system is dumped through the three SSMEs and the residual liquid hydrogen is dumped overboard. The umbilical curtain prevents hazardous gases (gaseous oxygen and hydrogen) from entering the orbiter aft fuselage through the umbilical openings before the umbilical doors are closed.

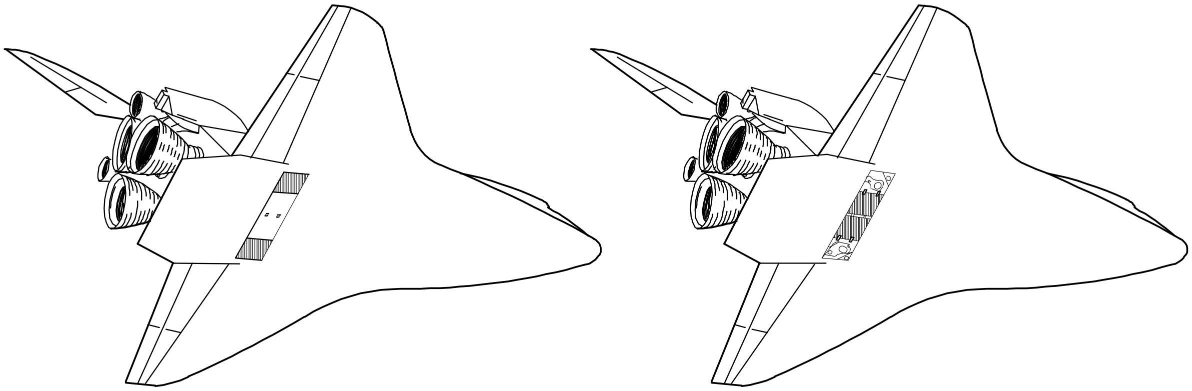
Each umbilical door, which is approximately 50 in^2, is covered with reusable thermal protection system tiles. Additionally, each door has an aerothermal barrier that requires approximately 6 psi to seal it with adjacent thermal protection tiles.

There are two types of latches associated with the ET doors, centerline latches and uplock latches. The centerline latches hold the ET doors open during ascent, and the uplock latches secure the doors when they are closed.

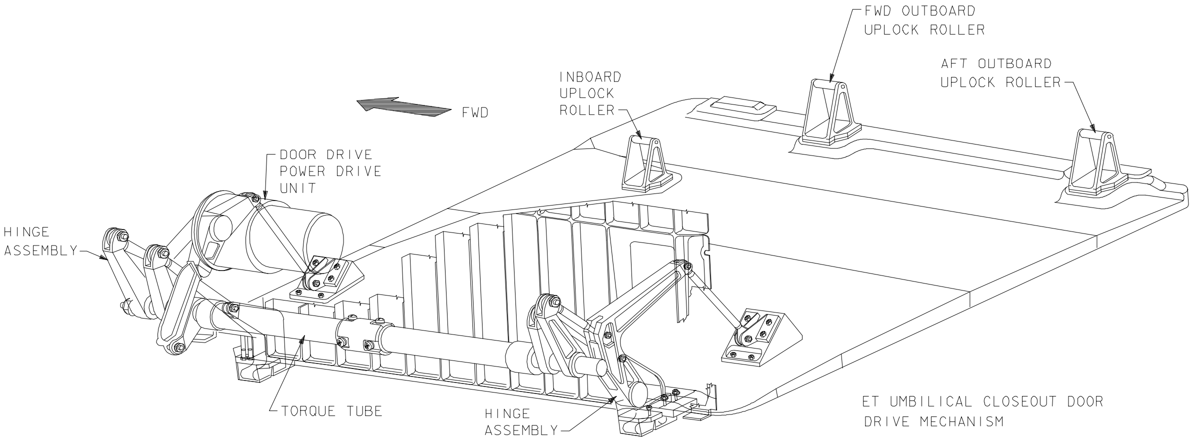
The centerline latches must be disengaged from the doors before both ET doors can be closed. In the latched position, each centerline latch fits into a notch on the outer edge of the left and right ET doors. When stowed, the two centerline latches rotate and retract into the body of the orbiter so that they are flush with the orbiter thermal protection system mold line.

After the ET doors are closed, uplock latches pull the doors fully closed, compressing them against aerothermal seals and positioning them flush with the orbiter body. These latches secure each door closed and prevent them from vibrating or opening during reentry.

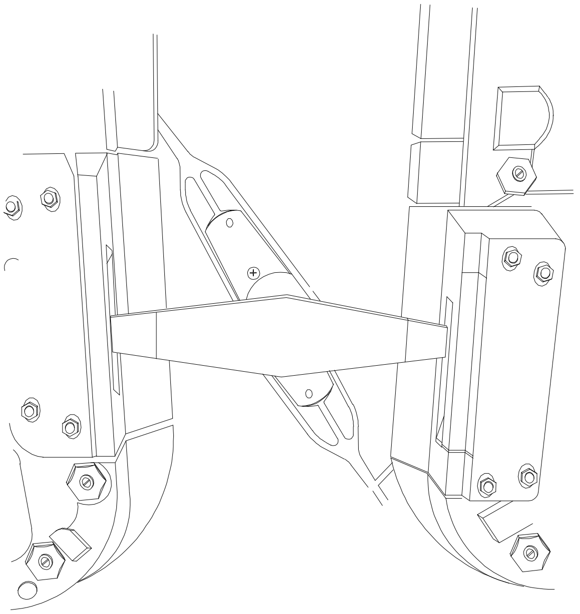
Three uplock latches are located inside each umbilical cavity. The latches engage three uplock rollers located on each ET door. The latches can engage the rollers as long as the ET door is within 2 inches of being closed.



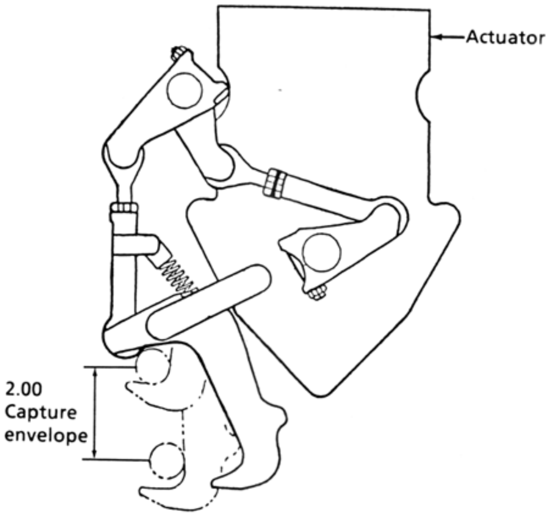
ET Door Positions



Right Side ET Umbilical Door



Centerline Latch Movement



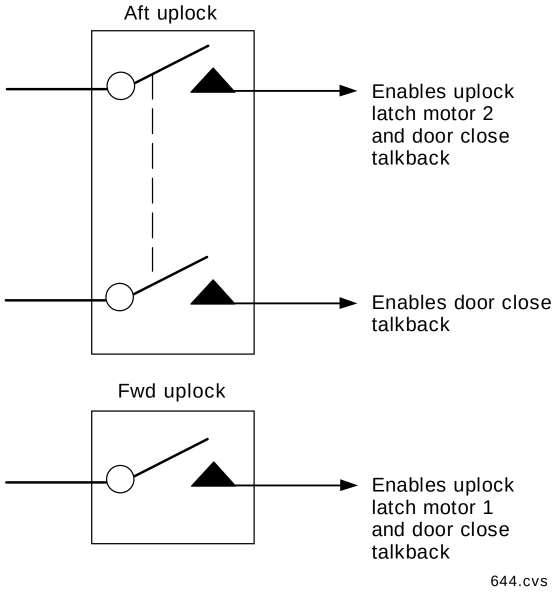
Door Uplock Latch and Roller

> **CAUTION**
>
> Thermal damage will occur if the ET doors are not fully latched flush with the orbiter body.

ET Door Operations

The ET doors are closed post OMS-1 burn after MPS vacuum inerting. The doors and latches must be sequenced in an orderly manner to prevent damage. First, the centerline latches are stowed, then the doors are closed, and finally the doors are latched.

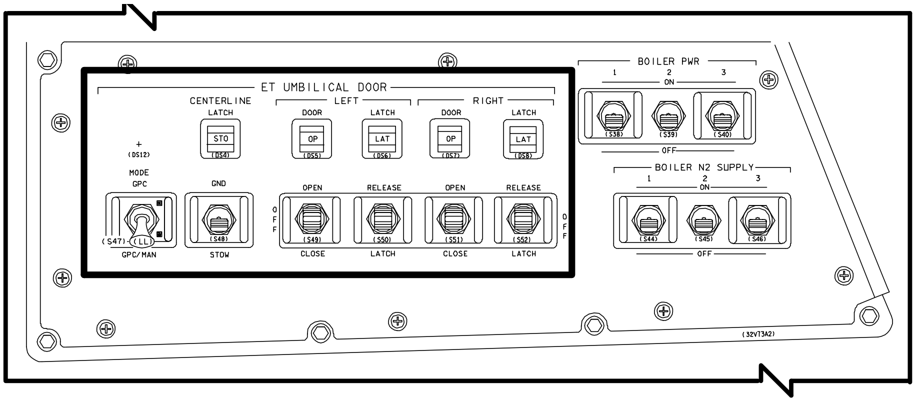
The doors are nominally closed by the crew with the *ET UMBILICAL DOOR* switches located on panel R2. The *MODE* switch must be in the *GPC/MAN* position to enable manual crew control with the panel R2 switches.



Uplock Latch Limit Switches

The crew stows the centerline latches by taking the *CENTERLINE LATCH* switch to the *STOW* position. Each centerline latch is driven by one electromechanical actuator. Nominally, 6 seconds are required to stow the centerline latches with dual motor drive. The *GND* position of this switch removes commands from the centerline latch motors.

The talkback above the *CENTERLINE LATCH* switch has two positions. The microswitches that drive the talkback are located within the centerline latch drive mechanisms and are activated based on the position of the latches. The talkback will be barberpole when the latches are deployed or in transit, and will be *STO* when the latches are stowed.



ET UMBILICAL DOOR Controls on Panel R2

Once stowed, the crew cannot redeploy the centerline latches. This task can be performed only on orbit by real-time commands from MCC or postlanding by ground crews.

The crew uses the *LEFT DOOR* and *RIGHT DOOR* switches on panel R2 to close the ET doors. When the crew positions the switches to *CLOSE,* commands are sent to electromechanical actuators to drive the doors closed through a system of bellcranks and pushrods. Each door has its own actuator and will close in approximately 24 seconds with the dual motor drive.

As the doors move within 2 inches of being closed, two rollers mounted on the outboard edge of each door contact two ready-to-latch (RTL) paddles located in the umbilical cavity. The two RTL paddles drive three RTL microswitches that enable the uplock latch motors and drive the *CL* position of the *DOOR* talkback. Two of the three microswitch indications are needed to provide a *CL* indication on the door drive talkback. Each door also has two open microswitches that drive the *OP* position of the door talkback.

The crew uses the *LEFT LATCH* and *RIGHT LATCH* switches on panel R2 to close the ET door uplock latches. When the crew positions the switches to *LATCH,* commands are sent to electromechanical actuators that drive the uplock latches through a system of pushrods. Each set of three uplock latches is driven by one actuator. Nominally, it takes 6 seconds to open or close the uplock latches with dual motor drive. Onboard talkbacks will indicate *LAT* once the uplock latches close.

When the uplock latches engage the rollers that are located on the inside face of the ET door, the doors are pulled closed approximately 1 to 2 inches, providing the 6 psi required to compress the aerothermal barrier. Compression of the aerothermal barrier results in a seal that protects the umbilical cavity from reentry heating.

The *RELEASE* position of the *LEFT* and *RIGHT LATCH* switches is used postlanding to open the uplock latches in preparation for ET door opening. The latch talkbacks indicate *REL* once the uplock latches are fully opened.

As mentioned previously, the door RTL microswitches drive the door *CL* talkback and enable the uplock latch motors. If an ET door closes but microswitch failures prevent the uplock latches from being enabled, an override is available.

The system is designed so that the *LEFT LATCH* switch can override the right RTL microswitches, and the *RIGHT LATCH* switch can override the left RTL microswitches. The override is performed by placing both the *LEFT LATCH* and *RIGHT LATCH* switches in the *LATCH* position. By doing this, one switch overrides the missing microswitch indications, enabling the uplock latch motors, while the other switch sends its latch command.

Mission Control has additional telemetry to determine if missing RTL indications have prevented the uplock latches from being enabled. The crew should not attempt this override until the ground has verified that this is the case.

During RTLS and TAL aborts, transition into MM 602 or 304 will automatically initiate an ET door software closure sequence. When the sequence starts, GPC commands are sent for 12 seconds to stow the centerline latches. Six seconds from the initial centerline latch command, commands are sent to close the ET doors. After single motor time for the doors has elapsed (48 seconds), close commands are sent to the uplock latches for 12 seconds.

Note that the automatic closure sequence doubles the normal drive times on the doors and uplock latches, thus allowing for a single motor failure in any of the actuators. The sequence does not allow single motor drive time on the centerline latches before sending the ET door close commands. If one of the centerline latches does have a motor failure, it still should have rotated far enough in 6 seconds to disengage the ET doors and allow them to close.

The panel R2 talkbacks remain active throughout the software closure sequence; they may be used by the flight crew for insight into the completion of the sequence.

During MM 104, 105, and 106, the crew can initiate the ET door software closure sequence with an item entry on GNC SPEC 51

OVERRIDE. However, because the sequence sends commands based on times rather than on microswitch indications, crew initiation of the automatic sequence should only be considered as a backup method during an AOA.

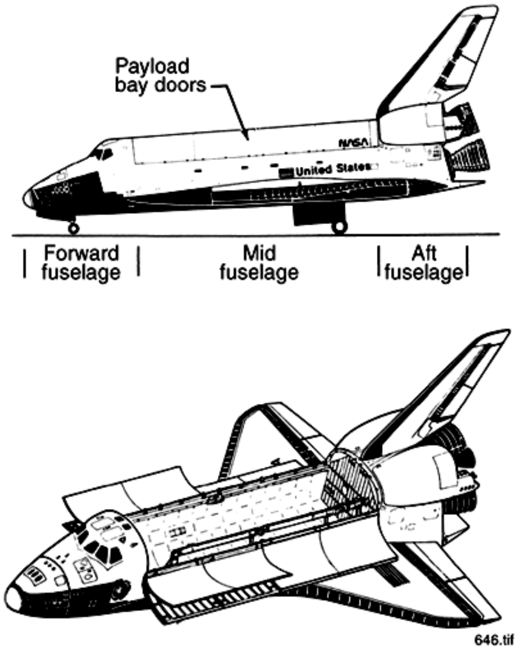
Postlanding, the crew opens the ET umbilical doors using the panel R2 switches, which gives the ground crews access to the umbilical cavities.

Payload Bay Door System

The payload bay doors provide an opening for payload deployment from and retrieval into the payload bay. The doors provide structural support for the orbiter midbody, and they house the *environmental control and life support system* (ECLSS) radiators that transfer heat from the vehicle to space.

There are two doors, port and starboard. Each door consists of five segments interconnected by expansion joints. The port door with attached systems weighs approximately 2,375 pounds, and the starboard door weighs about 2,535 pounds. The starboard door contains the centerline latch active mechanisms, which accounts for the weight difference. These weights do not include the deployable radiator system, which adds 833 pounds per door. The doors are approximately 60 feet long with a combined area of 1,600 square feet. Thermal and pressure seals are used to close the gaps at the forward and aft fuselage interface, door centerline, and expansion joints. The starboard door overlaps the port door to form the pressure and thermal seal on the centerline.

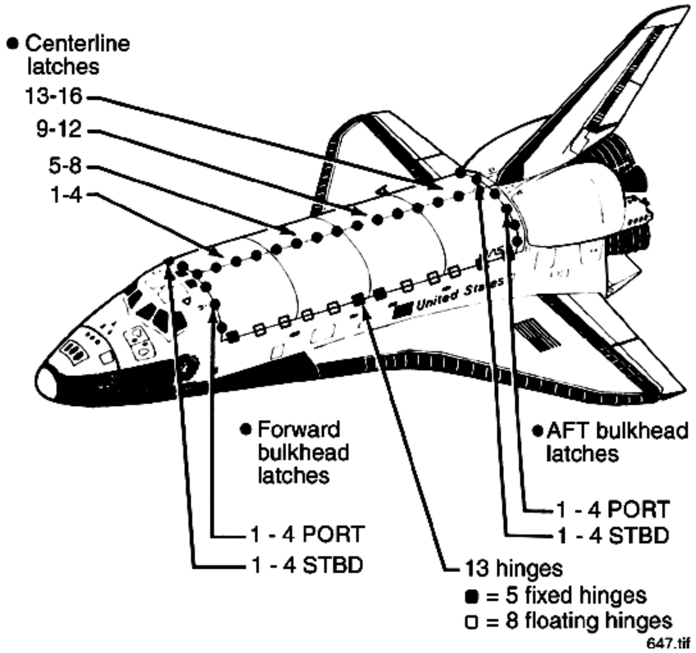
The starboard door must be opened first and closed last because of the arrangement of the centerline latch mechanism and the structural and seal overlap.



Payload Bay Doors Location

Each door is connected to the midfuselage by 13 hinges; i.e., 5 shear hinges (nonmoving hinges) and 8 floating hinges (moving hinges that allow for thermal expansion and contraction of the doors). Each door is driven open and closed by a single electromechanical actuator, each of which has two three-phase *AC* motors.

The doors are held closed by a total of 32 latches, 16 centerline latches that secure the doors to each other on the centerline and 8 forward and 8 aft bulkhead latches that secure the doors on the bulkheads.



Payload Bay Door Latch Locations

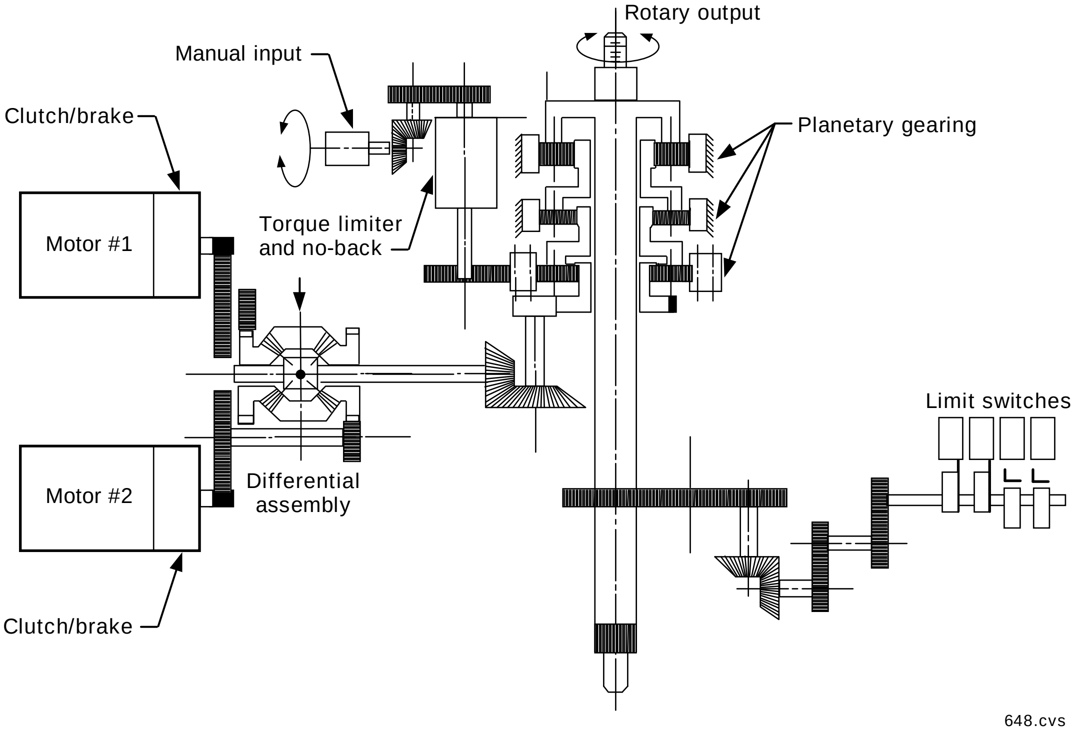
Centerline Latches

The centerline latches are grouped in four sets of four latches each, or four centerline latch "gangs." The latches are numbered from 1 to 16, starting forward and moving aft. Each latch gang is driven by a single typical orbiter electromechanical actuator using two three-phase AC motors. The motors are reversible, which allows the crew to latch or unlatch the doors from each other at the centerline.

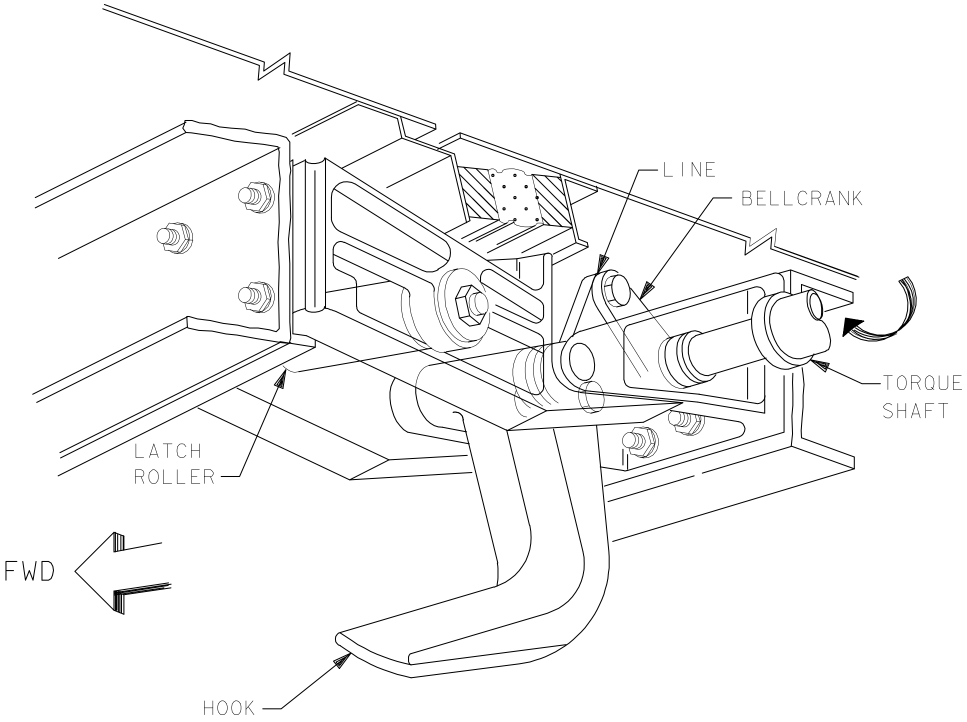
The starboard door contains the centerline latch hooks, and the port door contains the centerline latch rollers. The hooks are the active portion of the centerline latch system; they rotate to grasp the latch rollers.

As the electromechanical actuator torque shaft rotates, the bellcrank and link cause the hook to rotate closed or open, engaging the latch roller on the port door. It takes 20 seconds to open or close a gang of centerline latches (dual motor time).

The status of the centerline latch gang is provided by limit switches. Two open and two closed limit switches are associated with each centerline latch gang. These limit switch indicators relay the position of the latch gang (i.e., latch gang is open or closed). They also provide a method for enabling and disabling latch drive motors.



Payload Bay Door Centerline Latch Actuator Schematic



Payload Bay Door Centerline Latch

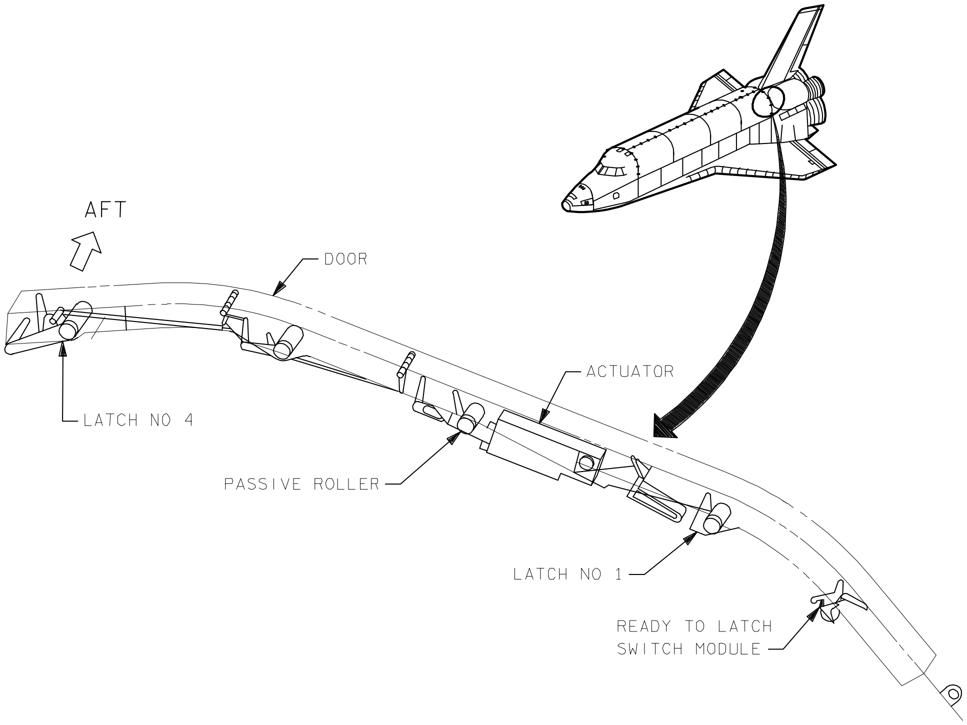
Bulkhead Latches

The bulkhead latches are grouped in four sets of four latches each, comprising the starboard and port forward and aft bulkhead latch gangs. Each latch gang is driven by a single typical electromechanical actuator using two three-phase AC motors. The motors are reversible, which allows the crew to latch or unlatch the doors from the forward and aft bulkheads. The latches are numbered 1-4, starting with the latch closest to the door hinge line.

The latch hooks for the bulkhead latches are located on the forward and aft edges of each door, and the latch rollers are located on the forward and aft bulkheads. The hooks are the active portion of the bulkhead latch system; they rotate to grasp the latch roller.

As the electromechanical actuator torque shaft rotates, the linkage connecting the latches begins to move. The linkage design causes a staggered latch open or close sequence; latch 1 closes first, then latches 2, 3, and 4 close. It takes 30 seconds to open or close a group of bulkhead latches (dual motor time). The staggered sequence results in latch 1 being nearly closed as latch 4 is just starting to close.

The status of the bulkhead latch groups is provided by limit switches similar to those used by the centerline latches. There are two open and two closed limit switches for each bulkhead latch gang relay the position of the latch gang (i.e., open or closed). They also provide a method for enabling or disabling the latch drive motors and the payload bay door drive motors.



Payload Bay Door Bulkhead Latches

Doors

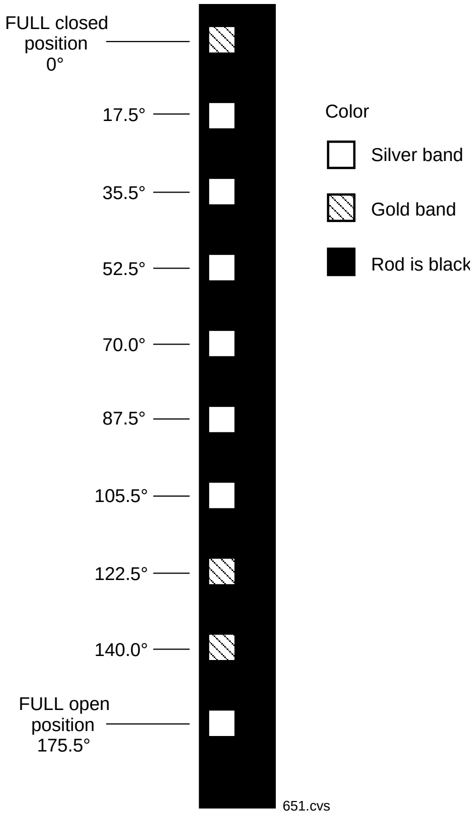
Each of the payload bay doors is driven open or closed by a single electromechanical actuator with two three-phase AC motors per drive unit. Torque limiters are incorporated in the rotary actuators to avoid damaging the door drive motors or mechanisms in the event of jamming or binding during operation. It takes 63 seconds to open or close each door (dual motor time). The doors open through an angle of 175.5°.

The electromechanical actuator drives a 55-foot-long torque shaft that turns the rotary actuators, causing the push rods, bellcranks, and links to push the doors open. The same arrangement pulls the doors closed.

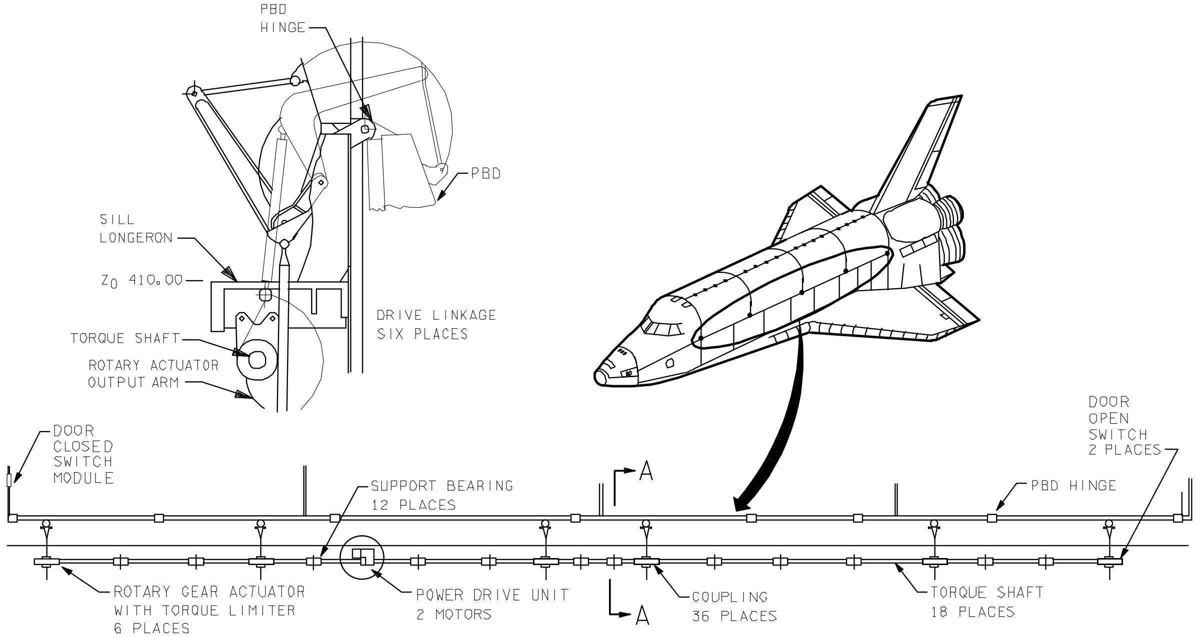
The push-pull rod is color-coded with silver and gold bands to assist the crew in determining how far open the door is*, since there is no telemetry to the ground*. As the push rod opens or closes the door, certain colors are displayed. Each band, gold or silver, represents the amount the doors are open or closed in degrees of rotation; the distance between stripes indicates about 17.5° of motion. The crew can use this information to determine if the door is warped or jammed by seeing if any push rod has more or less stripes visible than the others. If the door is completely open, nine colored bands should be visible (one gold, six silver, and two gold bands; the final silver stripe indicating full open is, at best, only partially visible to the crew). If the door is completely closed, one gold band at the top of the push rod should be partially visible.

There are six push-pull rods per door. They can be located by looking along the sill longeron that runs along the entire length of the payload bay. The pushrod closest to the crew compartment is not *visible* from the aft flight deck; to see it, the closed circuit television (CCTV) system must be used.

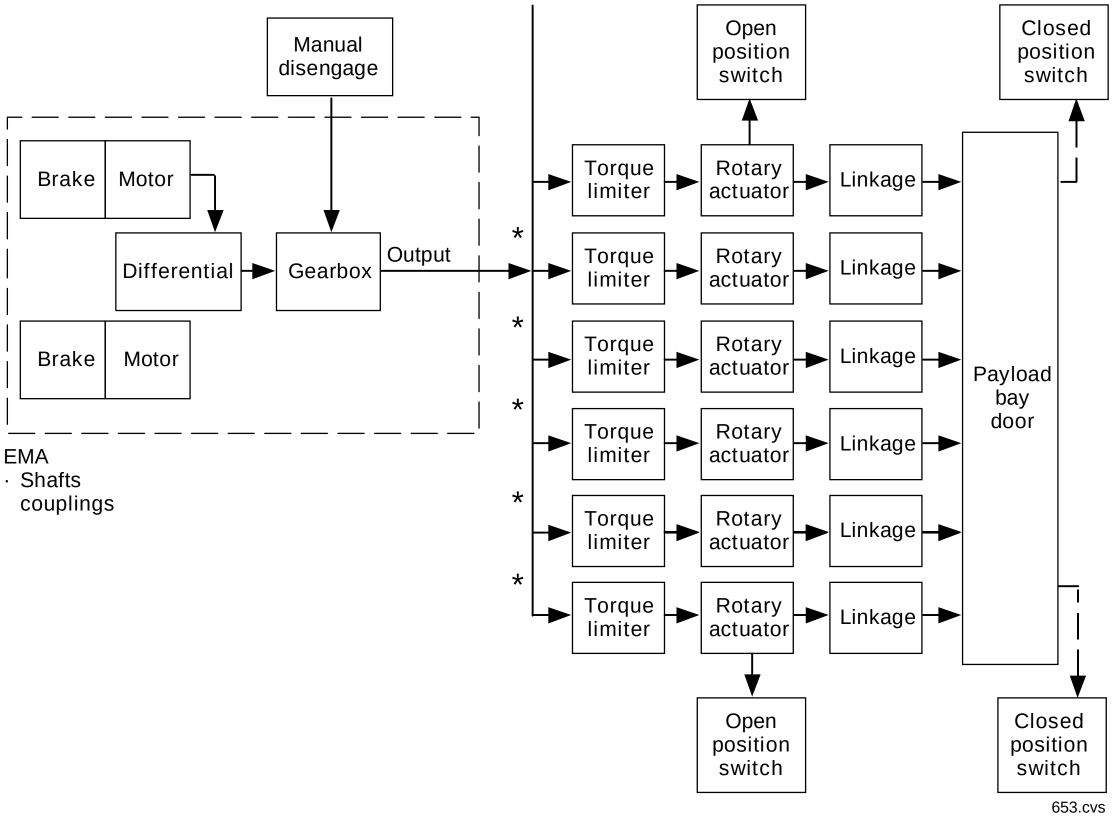
The status of the doors is provided by limit switches; these, however, are slightly different from the centerline latch and bulkhead latch limit-switch indicators. Each door has two limit-switch modules, one each on the forward and aft bulkhead. Each switch module contains four limit switches; i.e., three RTL indicators and one closed indicator. The RTL indicators determine when the door is within 4° of being closed. This is important because the forward and aft bulkhead latches are then within reach to latch the door closed. The closed micro-switches indicate when the door is completely closed. Each door also has two open limit switches located on the torque shaft. These limit switches determine when the door drive unit has driven to the full open position.



Push-Pull Rod Markings



Payload Bay Door Drive System



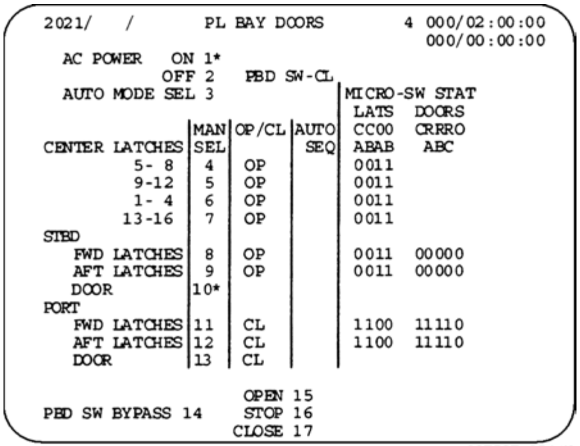
Payload Bay Door Drive System Mechanical Block Diagram

Payload Bay Door Operations: Opening

The crew can use either the Auto or Manual mode to open the payload bay doors. Both sequences are controlled by software. In either mode, the crew makes item entries to the PL BAY DOORS display, which provides the interface between the crew and the doors. The display can be called up as PASS SM OPS 202 (or 402) or as BFS SM SPEC 63. Nominally, the doors are opened and closed using PASS in OPS 202, but when the primary software is not in OPS 2, and payload bay door operations are needed, the BFS is used. This occurs when the doors must be opened early (loss of cooling, for example) or when the doors are closed late in preparation for entry. *Operations in PASS and BFS are identical, except for the Warning below, which only applies to BFS.* In addition, the crew uses control switches and talkbacks on panel R13L.

> **WARNING**
>
> *When in BFS, unless specifically directed by MCC or Flight Data File procedures, do not go back to AUTO mode if mechanisms have been commanded in MANUAL mode. There is a possibility of driving mechanisms out of order.*

The PL BAY DOORS display has 17 manual item entries and several columns of status data. When selected, Item 1, AC POWER ON, applies AC power to the latch and door drives. Item 2, AC POWER OFF, removes the AC power. Items 1 and 2 are mutually exclusive. Item 3, AUTO MODE SEL, allows the user to select the Auto mode to open and close the doors and latches. Items 4 through 13 select a latch or door to move manually (listed in the order in which they will be performed from the top of the page to the bottom for opening the doors, from the bottom up for closing the doors). Item 14, PBD SW BYPASS, manually bypasses the *PL BAY DOOR* switch on panel R13L in case it has failed or if the crew cannot get to the switch for some reason; the status of this hardware switch is indicated at the top right of the display as the PBD-SW status (which will read OP, CL, STOP, or FAIL). If the switch is manually bypassed with an Item 14, Items 15 through 17 are used to "move" the switch to its various locations. The OP/CL status column reflects the state of the mechanism, based on how the software interprets the microswitch status. The AUTO SEQ column shows any Auto Sequence failures. Finally, the right side of the display represents the microswitches as seen by the software; a 1 means that the indication "C" (closed) or "O" (open) is present, a 0 means it is not present. For the latches, two positive indications are required for a confirmed state of the latch, which is then reflected in the OP/CL column. For the doors, a combination of open, closed, and RTL indications is required for the software to determine the state of the door.



```
 2021/    /          PL BAY DOORS           4 000/02:00:00
                                              000/00:00:00
   AC POWER     ON 1*
               OFF 2    PBD SW-CL
   AUTO MODE SEL 3                 |MICRO-SW STAT
                                   |  LATS   DOORS
                  |MAN|OP/CL|AUTO  |  CC00   CRRRO
 CENTER LATCHES   |SEL|     |  SEQ |  ABAB    ABC
           5- 8   | 4 | OP  |      |  0011
           9-12   | 5 | OP  |      |  0011
           1- 4   | 6 | OP  |      |  0011
          13-16   | 7 | OP  |      |  0011
 STBD             |   |     |      |
    FWD LATCHES   | 8 | OP  |      |  0011   00000
    AFT LATCHES   | 9 | OP  |      |  0011   00000
    DOOR          |10*|     |      |
 PORT             |   |     |      |
    FWD LATCHES   |11 | CL  |      |  1100   11110
    AFT LATCHES   |12 | CL  |      |  1100   11110
    DOOR          |13 | CL  |      |

                          OPEN 15
 PBD SW BYPASS 14         STOP 16
                         CLOSE 17
```

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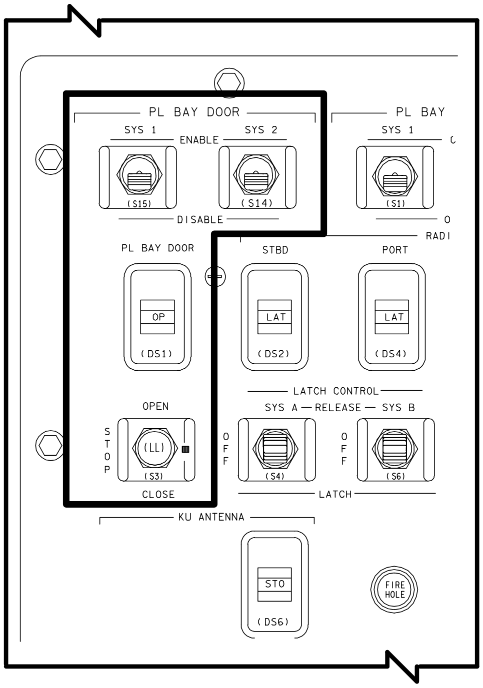
PL BAY DOORS Display

An "active group" is that group of items that is currently being or are about to be commanded to drive. Typically, an active group consists of two latch gangs (centerline latches 5-8 and 9-12, 1-4 and 13-16, starboard bulkhead latches, or port bulkhead latches) or a single door (starboard or port).

The software monitors the latches and door drives for premature and out-of-sequence operation during the Auto mode only (i.e., making sure that door opening doesn't occur before it is unlatched). If any of the latches or doors are out of configuration, the Auto mode stops, removes AC power to all the payload bay door (PLBD) motors, and generates a fault message, PBD CONFIG, with an *SM ALERT*. If any latch or door drive exceeds its single-motor drive time, the Auto sequence will stop, remove AC power to all the PLBD motors, terminate all drive commands, and generate a fault message, PBD SEQ FAIL, with an *SM ALERT*. These safety devices prevent door and latch damage.



PL BAY DOORS Controls on Panel R13L

The *PL BAY DOOR SYS 1* and *SYS 2* switches on panel R13L close DC powered relays that allow AC power to reach the motors in the electromechanical actuators. The third switch on panel R13L used for PLBD operations is the *PL BAY DOOR* switch, which has three positions (open, stop, close) to initiate the opening and closing sequences.

The status of the sequence as it proceeds should be monitored both on the display and visually out the window. Crewmembers should time the various mechanism motions to verify dual motor time.

Payload Bay Door Operations: Opening

The payload bay doors are opened approximately 1 hour 25 minutes into a nominal flight. Certain conditions must be met before the doors can be opened. The following table lists the failures that will require the crew to leave the doors closed and deorbit to the first day primary landing site (PLS).

If none of these conditions exists, Mission Control will give the crew the go-ahead to open the doors. The doors and latches must be opened in an orderly manner to prevent possible damage. The doors and latches are normally opened in Auto mode, though they may be opened in Manual mode based on crew preference, various failures, or as specified by the procedures.

RAD/PLBD OPS NO GO FOR FOLLOWING FAILURES			
OMS/RCS	GNC	ECLS/EPS	MECH
2 OMS Engs 1 OMS Eng and 1 +X RCS Jet 1 OMS Inlet line OMS Prop TK Leak Aft RCS He or Prop Leak COMM No Voice and No CMD	2 IMUs 3 RGAs 3 AAs 3 ADTAs 3 Elevon or BF Pos Fdbks (same surface) 2 FCS CH (same surface)	1 H2O or Freon Loop Both RFCAs Both Cab Fans 3 OF 6 Av Bay Fans 2 FCs Any Mn or 3 phase AC Bus Any CNTL or MPC Bus 3 IMU Fans	2 LG deploy methods Pressure or redundant window pane failure DPS 3 GPCs 2 PL MDMs 2 FF or FA MDMs APU/HYD 2 APU/HYD/WSB

Opening Doors in Auto Mode

In Auto mode, the software controls the sequence of opening the latches and doors, commanding the next group only after the previous group has completely moved to its end of travel open.

The crew will first configure the AC and DC power sources and select the Auto mode on the DPS display. They have no active role in the sequence of opening other than to monitor times and microswitches and to take manual action if a failure occurs.

First, centerline latch groups 5-8 and 9-12 open. These groups secure the mid-centerline region of the doors. When the orbiter is exposed to the cold environment of space, warping of the doors is likely. Opening these two groups first relieves the tension in the doors caused by thermal expansion and contraction.

Next to open are centerline latch groups 1-4 and 13-16, which secure the centerline near the forward and aft bulkheads. Opening these groups next helps relieve the tension in the door caused by thermal warping. Centerline latches must be opened before the bulkhead latches to decrease tension in the doors.

When all the centerline latches are open, the starboard forward and aft bulkhead latches open. This removes any tension in the starboard door due to the latches and thermal warping. The starboard door is then opened. It is opened first because it overlaps the port door and contains the centerline latch mechanisms. The port forward and port aft bulkhead latches on the port door are opened next, followed last by the port door.

When OP/CL status of the port door shows OP, the *PL BAY DOOR* switch and the *PL BAY DOOR SYSTEM* switches on panel R13L are set to their unpowered positions, item 2 on the DPS display (AC POWER OFF) is executed, and the payload bay floodlights are turned off.

Opening Doors in Manual Mode

The software does not monitor the latch and door opening during the Manual mode as it does in the Auto mode. The crew must monitor the limit-switch indications and motor drive times very carefully to determine if the doors and latches are opening properly. Any latch or door can be driven out of sequence (i.e., the bulkhead latches can be opened first). The major difference between Auto and Manual modes is that in Manual, the crew must select which item(s) to drive and then cause the mechanism(s) to drive using the switch or bypass; in Auto, the software controls which items are selected and driven. For nominal operations using Manual mode, the sequence of the latches and doors matches that of the Auto mode.

Payload Bay Doors: Closing

The payload bay doors are closed approximately 2 hours 45 minutes before the deorbit burn. The door closing sequence is the direct reverse of the sequence for opening them. The port door is closed first, followed by the port forward and port aft bulkhead latches. The starboard door is closed next, followed by the starboard forward and aft bulkhead latches. Finally, the centerline latch groups are closed in the following order: 1-4 and 13-16, then 5-8 and 9-12.

The crew can use Auto or Manual mode to close the doors. The difference in monitoring between the two modes is the same as it is to open the doors. Panel R13L and the PL BAY DOORS display are also used for closing the doors. The payload bay doors are normally closed using the Auto mode, typically via the OPS 202 display in PASS (SM SPEC 63 display in BFS).

Closing Doors in Auto Mode

To close the doors using the Auto mode, the crew configures the *AC* and *DC* power sources, selects the Auto mode, and then initiates the auto sequence by taking the *PL BAY DOOR* switch to *CLOSE*. The status of the sequence is displayed on the DPS display. One manual step is taken during the Auto procedures: after the port door has been closed and latched, and the starboard door is as close as possible to the port door before contacting it (about 3-4 feet apart), the crew performs a fit check by taking the *PL BAY DOOR* switch to *STOP* and visually comparing the centerline latches to a diagram. The sequence is continued in Auto mode when this is verified. When the sequence is complete, the *PL BAY DOOR* switch is set to *STOP* and the *AC* and *DC* power sources are removed.

Closing Doors in Manual Mode

To close the doors using the Manual mode, the crew first configures the *AC* and *DC* power sources. The manual sequence is initiated by selecting the individual mechanism item(s) and driving them taking the *PL BAY DOOR* switch to *CLOSE*, then deselecting the items, and proceeding to the next active group.

First to close are the port door and then the bulkhead latches, followed by the starboard door. As in the Auto mode, when the starboard door is as close as possible to the port door before contacting it (approximately 3-4 feet apart), the crew performs a fit check by taking the *PL BAY DOOR* switch to *STOP* and visually comparing the centerline latches to a diagram. Afterwards, the starboard door is completely closed and the bulkhead latches are closed. The centerline latches are then closed in the following sequence: 1–4 and 13–16, and 5–8 and 9–12.

When the last of the latches is closed, the *PL BAY DOOR* switch is set to *STOP* and the *AC* and *DC* power sources are removed.

Mechanical Systems Summary Data

- Orbiter mechanical systems are those components that must be deployed, stowed, opened, or closed. Each is physically moved by an electrical or hydraulic actuator.

- All orbiter electromechanical actuators contain two three-phase *AC* motors, brakes, a differential, a gearbox, and limit switches. With the exception of the ET door centerline latches, all actuator assemblies also contain torque limiters.

- Power for actuator motors and limit switches is provided by motor control assemblies that are controlled by panel MA73C.

- The active vent system equalizes the unpressurized orbiter compartments and controls the orbiter's internal environment by opening and closing vent doors in orbit or on the ground.

- The active vent system operates automatically, except for preentry when the crew uses the GNC SPEC 51 OVERRIDE display to open or close the vent doors.

- The external tank umbilical doors shield the two aft umbilical openings on the underside of the orbiter. The doors are closed post-OMS 1 burn after MPS vacuum inerting.

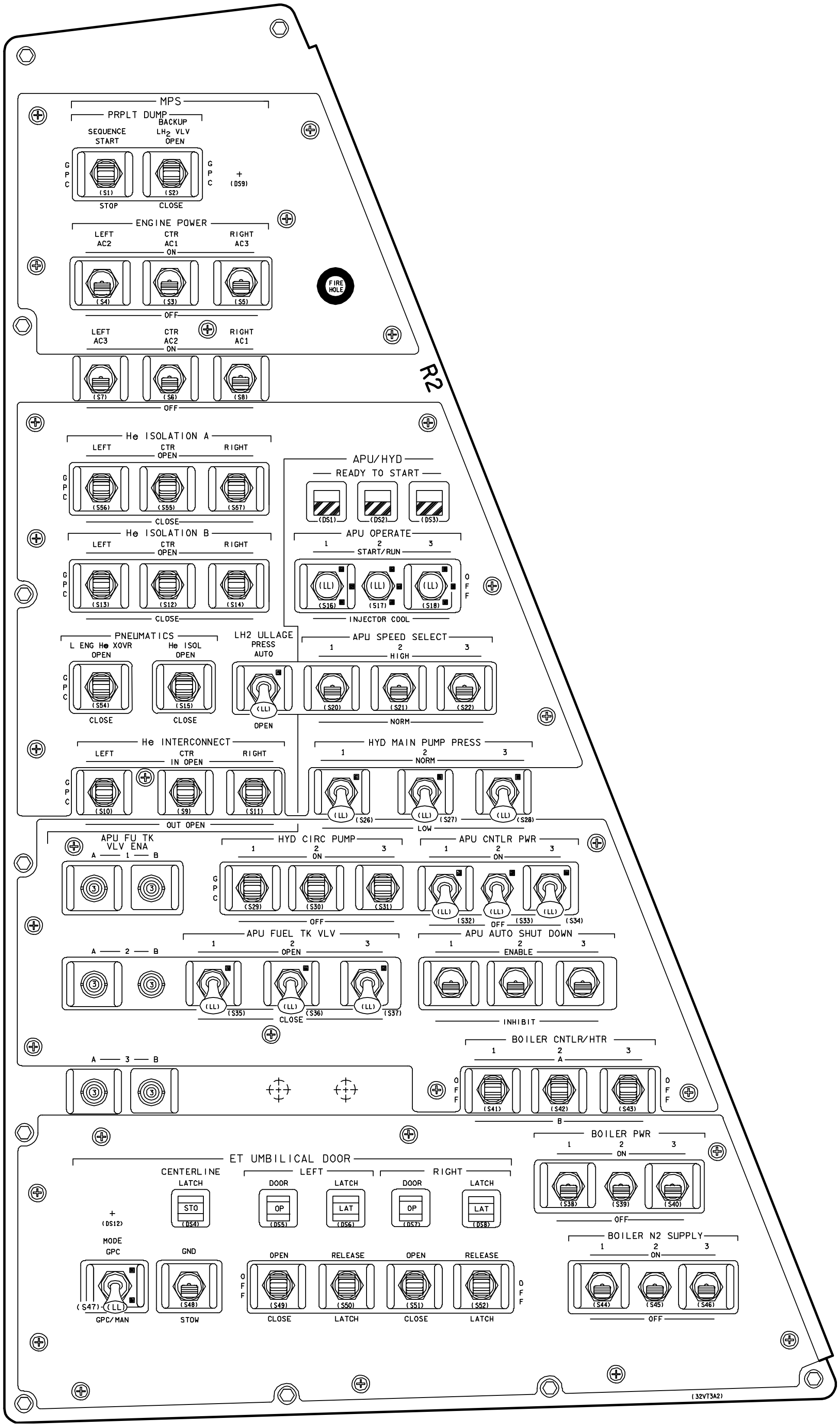
- ET umbilical doors are controlled by the flight crew with switches on panel R2 or item entry on the GNC SPEC 51 OVERRIDE display.

- The payload bay doors provide an opening for payload deployment from and retrieval into the payload bay.

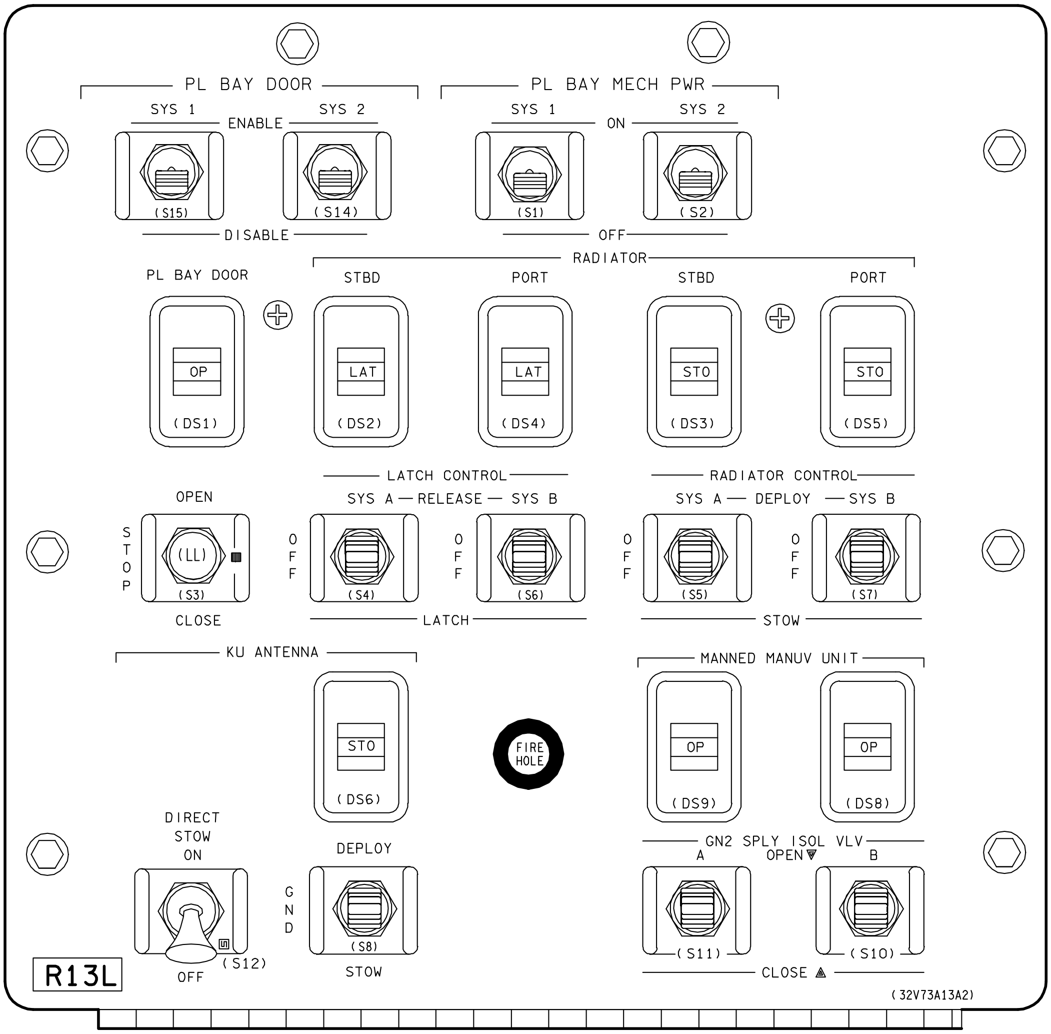
- Two doors, port and starboard, are connected to the midfuselage. They are held closed by groups of centerline and bulkhead latches.

- Payload bay doors are opened approximately 1 hour 25 minutes into a nominal flight and closed about 2 hours 45 minutes before the deorbit burn.

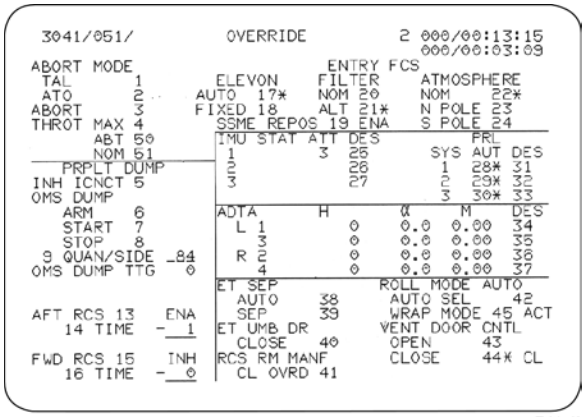
- Payload bay doors displays and controls are on panel R13L and the PL BAY DOORS display.


MPS
PRPLT DUMP
SEQUENCE START
BACKUP LH2 VLV OPEN
GPC
(S1)
(S2)
STOP
CLOSE
GPC
+ (DS9)
ENGINE POWER
LEFT AC2
CTR AC1
RIGHT AC3
ON
(S4)
(S3)
(S5)
OFF
FIRE HOLE
LEFT AC3
CTR AC2
RIGHT AC1
ON
(S7)
(S6)
(S8)
OFF
R2
He ISOLATION A
LEFT
CTR OPEN
RIGHT
GPC
(S56)
(S55)
(S57)
CLOSE
He ISOLATION B
LEFT
CTR OPEN
RIGHT
GPC
(S13)
(S12)
(S14)
CLOSE
APU/HYD
READY TO START
(DS1)
(DS2)
(DS3)
APU OPERATE
1
2 START/RUN
3
(LL)
(S16)
(S17)
(S18)
OFF
INJECTOR COOL
PNEUMATICS
L ENG He XOVR OPEN
He ISOL OPEN
GPC
(S54)
(S15)
CLOSE
CLOSE
LH2 ULLAGE PRESS AUTO
(LL)
OPEN
APU SPEED SELECT
1
2 HIGH
3
(S20)
(S21)
(S22)
NORM
He INTERCONNECT
LEFT
CTR IN OPEN
RIGHT
GPC
(S10)
(S9)
(S11)
OUT OPEN
HYD MAIN PUMP PRESS
1
2 NORM
3
(S26)
(S27)
(S28)
LOW
APU FU TK VLV ENA
A — 1 — B
HYD CIRC PUMP
1
2 ON
3
GPC
(S29)
(S30)
(S31)
OFF
APU CNTLR PWR
1
2 ON
3
(S32)
OFF
(S33)
(S34)
A — 2 — B
APU FUEL TK VLV
1
2 OPEN
3
(S35)
CLOSE
(S36)
(S37)
APU AUTO SHUT DOWN
1
2 ENABLE
3
INHIBIT
A — 3 — B
BOILER CNTLR/HTR
1
2 A
3
OFF
(S41)
(S42)
(S43)
B
OFF
ET UMBILICAL DOOR
CENTERLINE LATCH
STO
(DS4)
LEFT
DOOR
OP
(DS5)
LATCH
LAT
(DS6)
RIGHT
DOOR
OP
(DS7)
LATCH
LAT
(DS8)
+ (DS12)
MODE GPC
(S47)
(LL)
GPC/MAN
GND
(S48)
STOW
OPEN
RELEASE
OPEN
RELEASE
OFF
(S49)
(S50)
(S51)
(S52)
OFF
CLOSE
LATCH
CLOSE
LATCH
BOILER PWR
1
2 ON
3
(S38)
(S39)
(S40)
OFF
BOILER N2 SUPPLY
1
2 ON
3
(S44)
(S45)
(S46)
OFF
(32VT3A2)

Panel R2


PL BAY DOOR
SYS 1
ENABLE
SYS 2
(S15)
(S14)
DISABLE
PL BAY MECH PWR
SYS 1
ON
SYS 2
(S1)
(S2)
OFF
RADIATOR
PL BAY DOOR
STBD
PORT
STBD
PORT
OP
(DS1)
LAT
(DS2)
LAT
(DS4)
STO
(DS3)
STO
(DS5)
LATCH CONTROL
RADIATOR CONTROL
OPEN
STOP
(LL)
(S3)
CLOSE
SYS A
RELEASE
SYS B
OFF
(S4)
OFF
(S6)
LATCH
SYS A
DEPLOY
SYS B
OFF
(S5)
OFF
(S7)
STOW
KU ANTENNA
STO
(DS6)
FIRE HOLE
MANNED MANUV UNIT
OP
(DS9)
OP
(DS8)
DIRECT STOW ON
(S12)
OFF
DEPLOY
GND
(S8)
STOW
GN2 SPLY ISOL VLV
A
OPEN
B
(S11)
(S10)
CLOSE
R13L
(32V73A13A2)

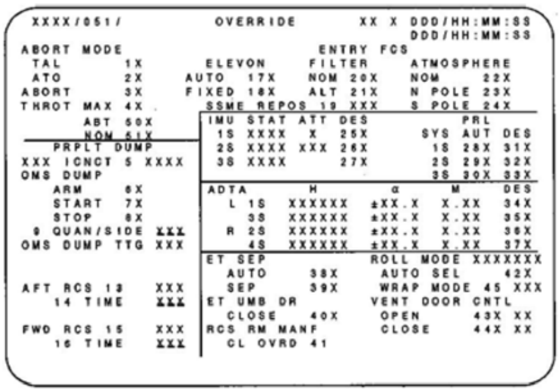
Panel R13L



```
 3041/051/          OVERRIDE          2 000/00:13:15
                                        000/00:03:09
ABORT MODE                     ENTRY FCS
 TAL        1         ELEVON    FILTER    ATMOSPHERE
 ATO        2       AUTO  17*   NOM 20    NOM     22*
ABORT       3       FIXED 18    ALT 21*   N POLE 23
THROT MAX 4           SSME REPOS 19 ENA   S POLE 24
        ABT 50      |IMU STAT ATT DES            PRL
        NOM 51      | 1        3   25       SYS AUT DES
   PRPLT DUMP       | 2            26         1 28* 31
INH ICNCT 5         | 3            27         2 29* 32
OMS DUMP            |                         3 30* 33
   ARM      6       |ADTA      H       α     M     DES
   START    7       |  L 1         0   0.0  0.00   34
   STOP     8       |    3         0   0.0  0.00   35
 9 QUAN/SIDE _84    |  R 2         0   0.0  0.00   36
OMS DUMP TTG    0   |    4         0   0.0  0.00   37
                    |ET SEP          ROLL MODE AUTO
                    |  AUTO     38     AUTO SEL     42
AFT RCS 13     ENA  |  SEP      39     WRAP MODE 45 ACT
   14 TIME    -__1  |ET UMB DR         VENT DOOR CNTL
                    |  CLOSE    40     OPEN       43
FWD RCS 15     INH  |RCS RM MANF       CLOSE      44* CL
   16 TIME    -__0  |  CL OVRD 41
```

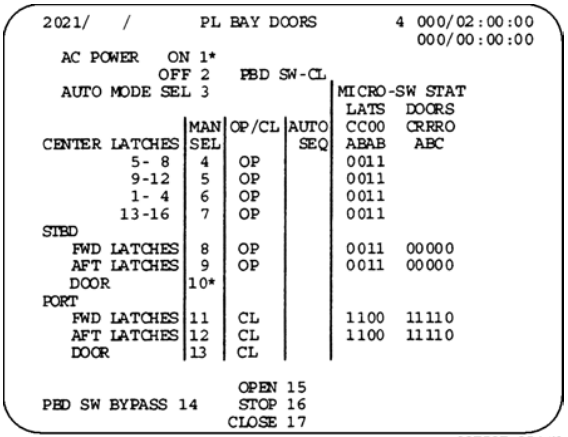
741.tif

PASS **OVERRIDE Display (SPEC 51)**



```
 XXXX/051/          OVERRIDE        XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS
ABORT MODE                      ENTRY FCS
 TAL        1X        ELEVON    FILTER    ATMOSPHERE
 ATO        2X      AUTO  17X   NOM 20X   NOM     22X
ABORT       3X      FIXED 18X   ALT 21X   N POLE 23X
THROT MAX 4X          SSME REPOS 19 XXX   S POLE 24X
        ABT 50X     |IMU STAT ATT DES            PRL
        NOM 51X     | 1S XXXX  X  25X       SYS AUT DES
   PRPLT DUMP       | 2S XXXX XXX 26X        1S 28X 31X
XXX ICNCT 5 XXXX    | 3S XXXX     27X        2S 29X 32X
OMS DUMP            |                        3S 30X 33X
   ARM      6X      |ADTA      H       α      M     DES
   START    7X      |  L 1S  XXXXXX  ±XX.X  X.XX    34X
   STOP     8X      |    3S  XXXXXX  ±XX.X  X.XX    35X
 9 QUAN/SIDE XXX    |  R 2S  XXXXXX  ±XX.X  X.XX    36X
OMS DUMP TTG XXX    |    4S  XXXXXX  ±XX.X  X.XX    37X
                    |ET SEP          ROLL MODE XXXXXXX
                    |  AUTO     38X    AUTO SEL     42X
AFT RCS 13     XXX  |  SEP      39X    WRAP MODE 45 XXX
   14 TIME     XXX  |ET UMB DR         VENT DOOR CNTL
                    |  CLOSE    40X    OPEN       43X XX
FWD RCS 15     XXX  |RCS RM MANF       CLOSE      44X XX
   16 TIME     XXX  |  CL OVRD 41
```

BFS OVERRIDE Display (SPEC 51)



```
2021/   /        PL BAY DOORS         4 000/02:00:00
                                        000/00:00:00
  AC POWER    ON 1*
             OFF 2   PBD SW-CL
  AUTO MODE SEL 3                 |MICRO-SW STAT
                                  | LATS   DOORS
                 |MAN|OP/CL|AUTO| CC00   CRRRO
CENTER LATCHES   |SEL|     | SEQ| ABAB    ABC
          5- 8   | 4 | OP  |    | 0011
          9-12   | 5 | OP  |    | 0011
          1- 4   | 6 | OP  |    | 0011
         13-16   | 7 | OP  |    | 0011
STBD             |   |     |    |
   FWD LATCHES   | 8 | OP  |    | 0011   00000
   AFT LATCHES   | 9 | OP  |    | 0011   00000
   DOOR          |10*|     |    |
PORT             |   |     |    |
   FWD LATCHES   |11 | CL  |    | 1100   11110
   AFT LATCHES   |12 | CL  |    | 1100   11110
   DOOR          |13 | CL  |    |

                       OPEN 15
PBD SW BYPASS 14       STOP 16
                      CLOSE 17
```

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PASS **PL BAY DOORS Display**
(BFS is identical except for Major Mode notation at the top)

Mechanical Systems Rules of Thumb

Always use a timer when operating mechanical systems, noting either dual or single motor time. Do not continue to command driving if greater than the single motor time has elapsed without the mechanism reaching the desired state.

2.18 ORBITAL MANEUVERING SYSTEM (OMS)

CONTENTS

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Description

The OMS provides propulsion for the orbiter during the orbit phase of flight. The OMS is used for orbit insertion, orbit circularization, orbit transfer, rendezvous, and deorbit. It may provide thrust above 70,000 feet altitude. Each OMS pod can provide more than 1,000 pounds of propellant to the RCS. Amounts available for interconnect depend on loading and number of OMS starts during the mission.

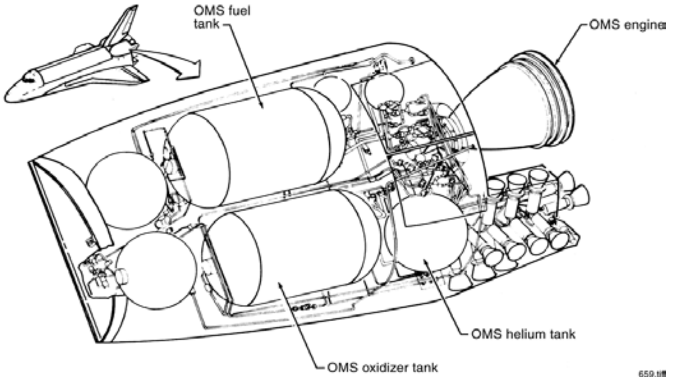
The OMS is housed in two independent pods on each side of the orbiter's aft fuselage. The pods, which also house the aft reaction control system (RCS), are referred to as the OMS/RCS pods. Each pod contains one OMS engine and the hardware needed to pressurize, store, and distribute the propellants to perform OMS engine burns. Normally, OMS maneuvers are done using both OMS engines together; however, a burn can be performed using only one OMS engines. For velocity changes less than 6 fps, RCS is used. For velocity changes greater than 6 fps, a single OMS engine burn is preferred, because engine lifetime concerns make it desirable to minimize engine starts. Two OMS engines are used for large velocity changes or for critical burns. Propellant from one pod can be fed to the engine in the other pod through crossfeed lines that connect the left and right OMS pods.

The OMS has important interfaces with the data processing system and the electrical power system. The OMS valves and gimbal actuators receive commands, and the system returns some data to the GPCs through multiplexer/ demultiplexer units. Electrical power is supplied to the OMS through main buses, control buses, and alternating current buses to operate switches, valves, instrumentation, gimbal actuators, and heaters.

The OMS/RCS pods are designed to be reused for up to 100 missions with only minor repair, refurbishment, and maintenance. The pods are removable to facilitate orbiter turnaround, if required.

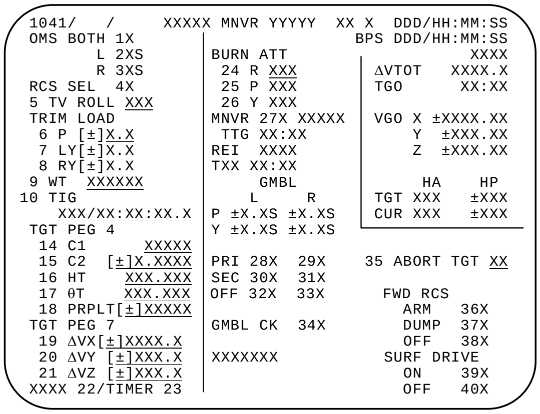
NOTE

At one time, there were plans to provide additional capability by including an OMS kit. It is now unlikely that OMS kits will ever be used, but OMS kit switches and gauges appear throughout the orbiter. They currently are inoperative and are likely to remain so.



Orbital Maneuvering System

Maneuver Display



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 1041/   /     XXXXX MNVR YYYYY  XX X  DDD/HH:MM:SS
 OMS BOTH 1X                       BPS DDD/HH:MM:SS
        L 2XS       BURN ATT                   XXXX
        R 3XS        24 R XXX        ΔVTOT   XXXX.X
 RCS SEL  4X         25 P XXX        TGO      XX:XX
 5 TV ROLL XXX       26 Y XXX
 TRIM LOAD          MNVR 27X XXXXX   VGO X ±XXXX.XX
  6 P [±]X.X         TTG XX:XX           Y  ±XXX.XX
  7 LY[±]X.X        REI  XXXX            Z  ±XXX.XX
  8 RY[±]X.X        TXX XX:XX
 9 WT  XXXXXX            GMBL             HA    HP
10 TIG                  L     R      TGT XXX   ±XXX
    XXX/XX:XX:XX.X  P ±X.XS ±X.XS    CUR XXX   ±XXX
 TGT PEG 4          Y ±X.XS ±X.XS
  14 C1      XXXXX
  15 C2  [±]X.XXXX  PRI 28X  29X    35 ABORT TGT XX
  16 HT    XXX.XXX  SEC 30X  31X
  17 θT    XXX.XXX  OFF 32X  33X      FWD RCS
  18 PRPLT[±]XXXXX                      ARM   36X
 TGT PEG 7          GMBL CK  34X        DUMP  37X
  19 ΔVX[±]XXXX.X                       OFF   38X
  20 ΔVY [±]XXX.X   XXXXXXX           SURF DRIVE
  21 ΔVZ [±]XXX.X                       ON    39X
 XXXX 22/TIMER 23                       OFF   40X
```

usa007587_526**r2**.cvx

Items 1 through 4 (OMS BOTH, L, R, and RCS SEL) are used to select both OMS engines, one engine, or RCS jets for an OMS burn and are mutually exclusive item entries. This information is used by guidance and the OMS software.

Item 5 (TV ROLL) is the roll attitude for OMS burns. Normally, it is 180°, corresponding to a heads-down attitude. A different number can be entered in MM 202 only, but is seldom changed.

Items 6 through 8 (TRIM LOAD P, LY, RY) are used to enter gimbal trim angles for OMS burns.

Item 9 (WT) is the current weight of the orbiter in pounds, which is computed and used by guidance. It can be changed when a more accurate weight is known.

Item 10 (TIG) is the time of ignition for an OMS burn in days/hours:minutes:seconds of mission elapsed time (MET). It is entered as part of a burn target.

Target parameters for powered explicit guidance (TGT PEG 4) are entered with items 14 to 18. PEG 4 guidance puts the orbiter on course for a specific point in space and is normally used for OMS 1, OMS 2, and deorbit burns. PEG 4 targets are only used in OPS 1 and 3.

Items 19 to 21 (TGT PEG 7) are where the target parameters are entered for another type of guidance, known as PEG 7 or External ΔV guidance. It is used to add or subtract orbital velocity and does not target the vehicle for a specific point in space. PEG 7 targets can be used in OPS 1, 2, or 3. PEG 7 delta velocities are in the LVLH coordinate frame.

Executing item 22 (LOAD) causes guidance to compute a burn solution on the basis of the target parameters that have been entered under PEG 4 or PEG 7. Executing item 23 (TIMER) sets up a timer that counts down to time of ignition and is displayed on the second line at the upper right corner of the display.

Items 24 through 26 (BURN ATT) are the desired inertial attitude for the OMS burn, which guidance computes as part of the burn solution. Executing item 27 (MNVR) causes an automatic maneuver to this attitude.

The TTG field displays the time to attitude in the current DAP. When in attitude the “mm:ss” field will blank. If the “in-attitude” time is less than TIG -30 seconds (and not in attitude), mm:ss will be displayed over bright. The fields next to the ITEM 27 display the current DAP mode (AUTO, INRTL, LVLH or FREE).

The GMBL L, R items on the display are the actual gimbal position angles. Items 28 through 33 (PRI, SEC, OFF) permit selection of primary or secondary gimbal motors or turn off both gimbal motors.

Executing item 34 (GMBL CK) starts an automatic gimbal check sequence.

The EXEC item flashes on the screen 15 seconds before TIG; it remains there until the EXEC key is depressed, which enables OMS burn ignition.

ΔV TOT is the total change in velocity needed to satisfy the target requirements. TGO is the expected duration of the burn. Below that are the X, Y, and Z components of ΔV TOT. All of this is computed by Guidance when a target is loaded. These delta velocities are in the body axis coordinate frame.

TGT HA and HP are the altitudes in nautical miles (n. mi.) of the apogee and perigee for the orbit that will result from the successful completion of the targeted OMS burn. CUR HA and HP are the current apogee and perigee altitudes. Mileages are from the Earth’s surface.

Item 35 (ABORT TGT) permits entry of a stored PEG 4 target for OMS 1 or OMS 2 with a single keystroke. It is used primarily for calling up ATO and AOA targets.

Flight software is divided into operational sequences (OPS) that are subdivided into major modes (MMs). Operational sequences and major modes are discussed in detail in Section 2.6; however, it should be noted that OMS burns can only be performed in MM 104, 105, 202, and 302. OMS dumps can be performed in MM 102, 103, 304, 601, and 602.

The maneuver (MNVR) display appears automatically in MM 104, 105, 106, 202, 301, 302, and 303. The title has a prefix and a suffix that vary according to major mode. The BFS version of the display is identical to the primary display.

Major mode	Title	Mission phse
MM 104	OMS 1 MNVR EXEC	OMS 1 burn
105	OMS 2 MNVR EXEC	OMS 1 burn
106	OMS 2 MNVR COAST	Post-OMS 2 coast
202	ORBIT MNVR EXEC	Orbital maneuvers
301	DEORB MNVR COAST	Pre-deorbit coast
302	DEORB MNVR EXEC	Deorbit burn
303	DEORB MNVR COAST	Pre-deorbit coast

Maneuver Display Titles Associated with Major Mode

Engines

The OMS engines are designated left and right, descriptive of location. The engines are located in gimbal mounts that allow the engine to pivot left and right (yaw) and up and down (pitch) under the control of two electromechanical actuators. This gimbal system provides for vehicle steering during OMS burns by controlling the direction of the engine thrust in pitch and yaw (thrust vector control) in response to commands from the digital autopilot or from the manual controls.

The OMS engines can be used singularly by directing the thrust vector through the orbiter center of gravity or together by directing the thrust vector of both engines parallel to the X axis. During a two-OMS-engine burn, the RCS will come into operation only if the attitude or attitude rate limits are exceeded. However, during a one-OMS-engine burn, RCS roll control is required. Section 2.22 has more information about the RCS and its interaction with the OMS.

Each of the two OMS engines produces 6,087 pounds of thrust. For a typical orbiter weight, both engines together create an acceleration of approximately 2 ft/sec^2 or 0.06 g's. Using up a fully loaded tank, the OMS can provide a total velocity change of approximately 1,000 ft/sec. Orbital insertion burns and deorbit burns each typically require a velocity change of about 100–500 ft/sec. The velocity change required for orbital adjustment is approximately 2 ft/sec for each nautical mile of altitude change.

Each OMS engine is capable of 1,000 starts and 15 hours of cumulative firing. The minimum duration of an OMS engine firing is 2 seconds.

The OMS engines use monomethyl hydrazine as the fuel and nitrogen tetroxide as the oxidizer. These propellants are hypergolic, which means that they ignite when they come in contact with each other; therefore, no ignition device is needed. Both propellants remain liquid at the temperatures normally experienced during a mission, however, electrical heaters are located throughout the OMS pods to prevent any freezing of propellants during long periods in orbit when the system is not in use.

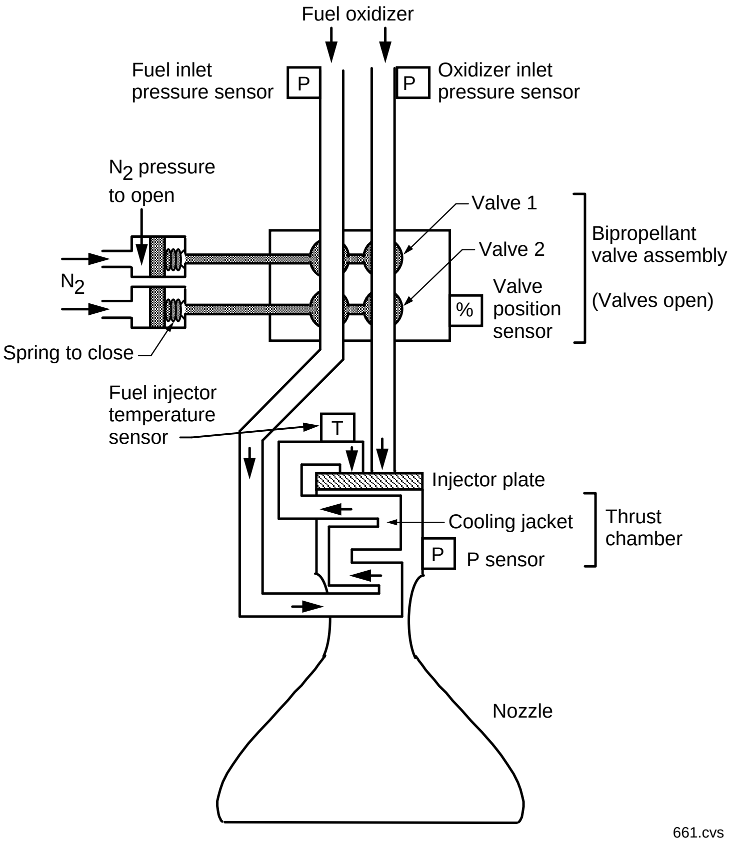
Each OMS engine has a gaseous nitrogen tank that provides pressurized nitrogen to operate the engine valves. The OMS engine does not have propellant pumps; propellant flow to the engines is maintained by pressurizing the propellant tanks with helium.

In the OMS engine, fuel is burned with oxidizer to produce thrust. The major elements of the OMS engine are the bipropellant valve assembly, the injector plate, the thrust chamber, and the nozzle.

Bipropellant Valve Assembly

Each OMS engine receives pressure-fed propellants at a bipropellant valve assembly, which regulates the flow of propellants to the engine to start and stop engine burns. The valve assembly consists of two fuel valves in series and two oxidizer valves in series. Having two valves in series for each propellant provides redundant protection against leakage, but it also means that both valves must open to allow propellant flow to the engine.

Each fuel valve is mechanically linked to an oxidizer valve so that they open and close together. The name bipropellant valve means that each linked set of valves controls the flow of both propellants.



Orbital Maneuvering System Engine

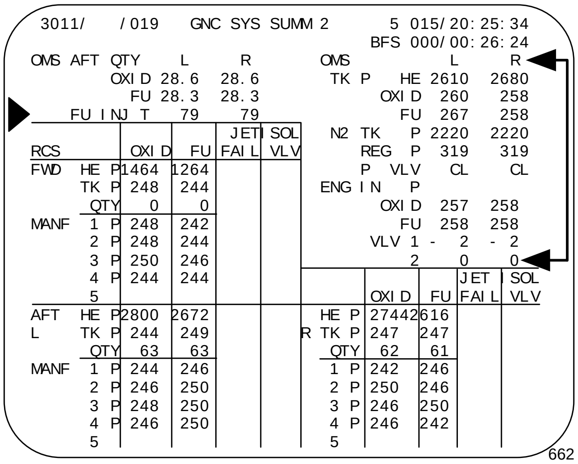
The bipropellant valves are ball valves that rotate from fully closed (0 percent) to fully open (100 percent). The crew can read the valve position in percent for each set on the GNC SYS SUMM 2 display. The VLV 1 and 2 position indicators on the display should read approximately 100 percent for both valve 1 and valve 2 at the start of an OMS burn and remain there throughout the burn. If the valve position is less than 70 percent for either valve, there will probably be insufficient propellant flow, and ignition may not occur. Also, ignition may occur with the possibility of engine hard start or combustion instability resulting in structural failure and/or chamber burnthrough.

The bipropellant valves are driven open and closed by pneumatic pistons. There is one piston for each set of bipropellant valves. The pistons are normally held in the closed position by springs. Pressurized nitrogen is used to fill the piston, which then mechanically opens the bipropellant valves. The engine control valves regulate the flow of nitrogen to the pistons and thereby control the opening and closing of the bipropellant valves. The engine control valve is a solenoid valve that responds to commands from the GPCs. Both engine control valves must operate in order for the bipropellant valves to open.

The engine control valves are discussed in more detail in the next section on the nitrogen system.

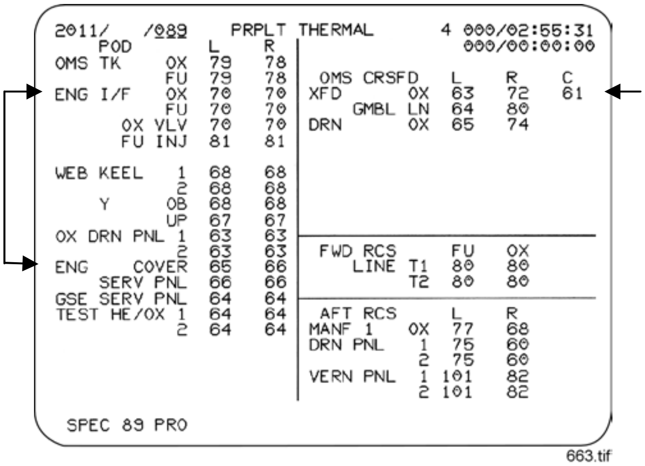
Injector Plate

After passing through the bipropellant valves, the oxidizer line runs directly to the engine injector plate. The fuel, however, is used to cool the engine, and so it is routed through a cooling jacket around the thrust chamber before it reaches the injector plate. A temperature sensor is located near the fuel inlet to the injector, and the reading from this sensor can be viewed by the crew in the FU INJ T entry on the BFS GNC SYS SUMM 2 display. This parameter does not appear on the PASS GNC SYS SUMM 2 display, but can be found on SM SPEC 89 PRPLT THERMAL in OPS 2.



```
3011/    /019    GNC SYS SUMM 2          5 015/20:25:34
                                       BFS 000/00:26:24
OMS AFT QTY     L      R        OMS             L      R
          OXID 28.6   28.6       TK P    HE  2610   2680
            FU 28.3   28.3              OXID  260    258
    FU INJ T    79     79                 FU  267    258
                       JET ISOL     N2 TK     P  2220   2220
RCS          OXID    FU FAIL VLV        REG   P   319    319
FWD  HE  P 1464  1264                   P  VLV    CL     CL
     TK  P  248   244               ENG IN    P
        QTY   0     0                     OXID   257   258
MANF  1  P  248   242                       FU   258   258
      2  P  248   244                    VLV 1 -   2  -  2
      3  P  250   246                        2     0     0
      4  P  244   244                                JET  ISOL
      5                                    OXID   FU FAIL VLV
AFT  HE  P 2800  2672               HE  P 27442616
L    TK  P  244   249             R TK  P 247   247
        QTY  63    63                QTY  62    61
MANF  1  P  244   246                1  P 242   246
      2  P  246   250                2  P 250   246
      3  P  248   250                3  P 246   250
      4  P  246   250                4  P 246   242
      5                              5
```

OMS Parameters on BFS GNC SYS SUMM 2 Display



```
2011/   /089    PRPLT THERMAL      4 000/02:55:31
     POD           L     R               000/00:00:00
OMS TK       OX   79    78
             FU   79    78   OMS CRSFD     L     R     C
ENG I/F      OX   70    70   XFD       OX  63    72    61
             FU   70    70        GMBL LN  64    80
        OX VLV    70    70   DRN       OX  65    74
        FU INJ    81    81

WEB KEEL      1   68    68
              2   68    68
     Y       OB   68    68
             UP   67    67
OX DRN PNL    1   63    63
              2   63    63   FWD RCS       FU    OX
ENG       COVER   65    66       LINE T1   80    80
     SERV PNL     66    66            T2   80    80
GSE SERV PNL      64    64
TEST HE/OX    1   64    64   AFT RCS       L     R
              2   64    64   MANF 1    OX  77    68
                             DRN PNL    1  75    60
                                        2  75    60
                             VERN PNL   1 101    82
                                        2 101    82

 SPEC 89 PRO
```

OMS Parameters on SM SPEC 89 PRPLT THERMAL Display

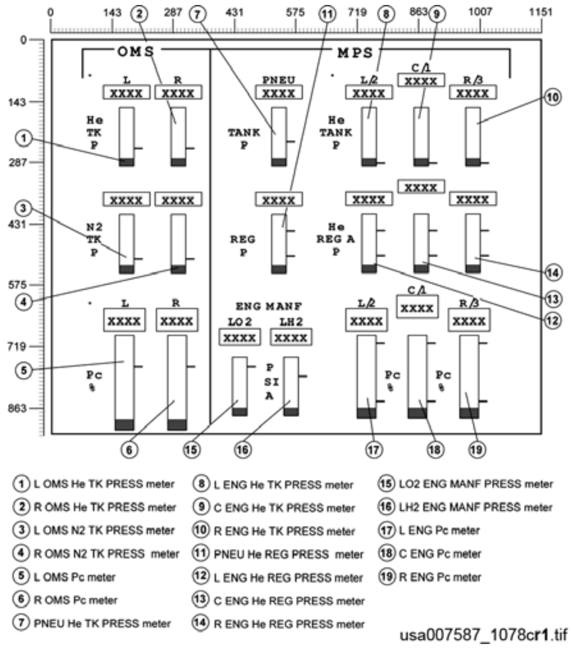
Since the fuel injector temperature is the temperature of the fuel after it has passed through the chamber cooling jacket, it provides an indirect indication of the temperature of the thrust chamber walls. A high fuel injector temperature indicates that the engine may be sustaining thermal damage. The fuel normally flows to the engine at a temperature between 30° and 125° F. During engine operation, when the fuel is cooling the chamber, the fuel injector temperature should be approximately 218° F. The temperature limit for safe operation is 260° F.

Thrust Chamber

The fuel and oxidizer are mixed at the injector plate in the thrust chamber. When the fuel reaches the thrust chamber, it is directed through 120 cooling channels in the combustion chamber walls, providing regenerative cooling to the combustion chamber walls, and then to the injector of the engine. The oxidizer is routed directly to the injector.

The fuel and oxidizer orifices are positioned so that the propellants will impinge and atomize, causing the fuel and oxidizer to ignite because of hypergolic reaction. The resulting hot gas creates thrust as it exits the chamber and expands through the engine nozzle. The contoured nozzle extension is bolted to the aft flange of the combustion chamber.

The pressure in the thrust chamber (P_c) is measured by a sensor that is wired directly to the OMS P_c meter on the MEDS MPS/OMS display. The meter is calibrated in percent. The normal P_c during a burn is between 100 and 105 percent, which corresponds to a pressure of approximately 131 psia. For an off-scale high condition, the MEDS OMS Pc meter will display the maximum (160) value in the digital box in red with an empty red box for the tape. For an off-scale low condition, the minimum (0) value will be displayed instead. For Analog Digital Converter (ADC) failures, the display is blanked with an empty red box. The *LEFT* or *RIGHT OMS* red caution and warning light on panel F7 will illuminate if P_c is less than 80 percent when the engine should be on, or greater than 80 percent when the engine should be off.



OMS Pc N2 and He TANK Meters on the MEDS MPS/OMS Display

Pressure sensors in the fuel and oxidizer lines are located just above the bipropellant valves. These inlet pressures for each engine are shown on the GNC SYS SUMM 2 display as ENG IN P, one for oxidizer, one for fuel. When the OMS engines are not burning, the inlet pressures should match the propellant tank pressures, which are normally 254 psi. During OMS burns, propellant flow into the thrust chamber causes the inlet pressure to drop to approximately 220 to 235 psi for the fuel and to 200 to 206 psi for the oxidizer, but the propellant tank pressures remain higher. The exact inlet pressures are engine dependent.

The inlet pressures are an indirect indication of propellant flow rates. If they are abnormal, problems should be anticipated. An imbalance in the flow rates for fuel and oxidizer will result in an incorrect mixture ratio in the thrust chamber. If the mixture becomes fuel-rich, the chamber pressure and temperature will decrease, and combustion will eventually be choked off. If the mixture becomes fuel-lean, the chamber temperature will increase, and engine damage could result. If the fuel-lean condition is the result of a low fuel flow rate, the situation is especially serious, since the fuel is used to cool the outside of the thrust chamber.

Nitrogen System

Gaseous nitrogen is used to operate the engine control valves and also to purge the fuel lines at the end of each burn. The nitrogen system consists of a storage tank, engine pressure isolation valve, regulator, relief valve, check valve, accumulator, engine purge valves, bipropellant solenoid control valves, and actuators that control the bipropellant ball valves.

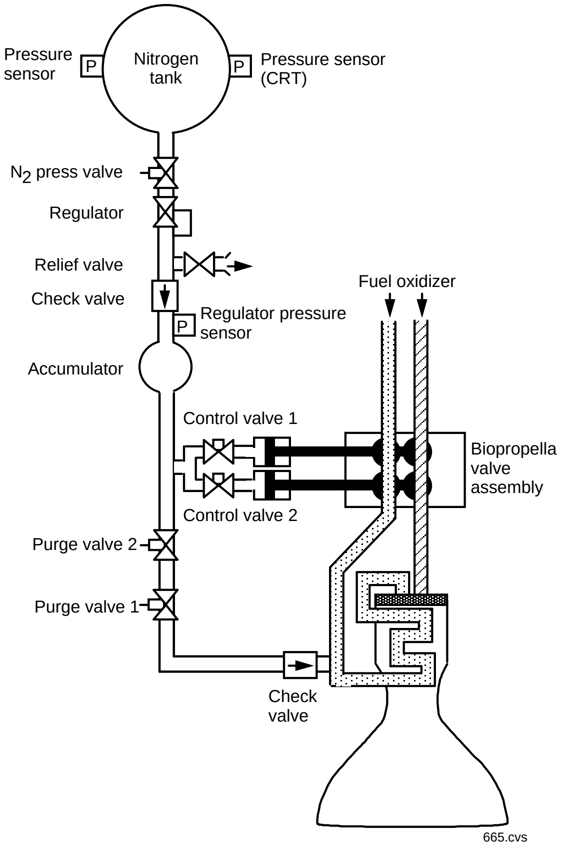
A spherical gaseous nitrogen storage tank is mounted next to the combustion chamber in each of the two engines to supply pressure to its engine pressure isolation valve. The tank contains enough nitrogen to operate the ball valves and purge the engine 10 times.

Two sensors monitor each tank's pressure. One sensor displays the tank pressure on the MEDS MPS/OMS display. The other sensor displays the tank pressure on the GNC SYS SUMM 2 display. Both pressures are downlisted by telemetry.

A dual-coil, solenoid-operated nitrogen pressure isolation valve (sometimes called the engine pressure valve) is located in each gaseous nitrogen system. The valve is energized open and spring-loaded closed. It must be open for nitrogen to reach the OMS engines. The valve permits gaseous nitrogen flow from the tank to the regulator, accumulator, bipropellant ball valve control valves, and purge valves 1 and 2 when energized open and isolates the nitrogen tank from the gaseous nitrogen supply system when closed.

The nitrogen pressure valves in each system are controlled by the *OMS ENG LEFT, RIGHT* switches on panel C3. Placing the switch in the *ARM/PRESS* position opens the nitrogen pressure valve. The switch is placed in the *ARM/PRESS* position by the crew before each OMS burn and is left in the *OFF* position at all other times. When one of the *OMS ENG* switches is placed in the *ARM/PRESS* position, the respective OMS engine pod's pressure isolation valve is energized open. When the switches are in any other position (*ARM* or *OFF*), the valve remains closed.

The gaseous nitrogen engine pressure isolation valve, when energized open, allows gaseous nitrogen supply pressure to be directed into a regulator, through a check valve and an in-line accumulator, and to a pair of valves. The status of the nitrogen pressure valve can be seen on the GNC SYS SUMM 2 display: the P VLV parameter reads OP for open and CL for closed. When the position of the *OMS ENG* switch on panel C3 is changed, the display should be checked to see that the valve is in the proper position.



Nitrogen System

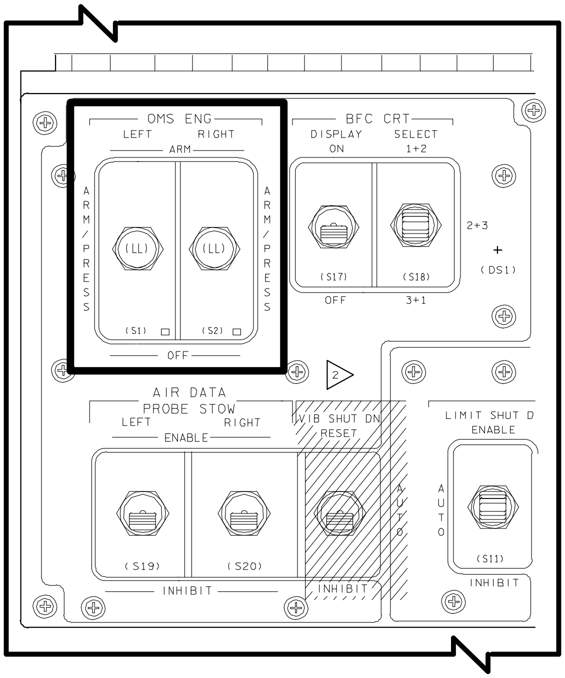
A single-stage regulator is installed in each gaseous nitrogen pneumatic control system between the gaseous nitrogen engine pressure isolation valve and the engine bipropellant control valves. The regulator reduces nitrogen pressure from its tank pressure, which can be as high as 3,000 psig, to a desired working pressure of 315 to 360 psig. A pressure sensor downstream of the regulator monitors the regulated pressure and transmits it to telemetry and to the GNC SYS SUMM 2 display (REG P).

A pressure relief valve downstream of the regulator limits the pressure to the engine bipropellant control valves and actuators if a regulator malfunctions. The relief valve opens between 450 and 500 psig and reseats at 400 psig minimum.

The check valve located downstream of the regulator will close if gaseous nitrogen pressure is lost on the upstream side of the check valve and will isolate the remaining gaseous nitrogen pressure on the downstream side of the check valve.

The 19-cubic-inch gaseous nitrogen (GN_2) accumulator downstream of the check valve and upstream of the bipropellant control valves provides enough pressure to operate the engine bipropellant control valves at least one time with the engine pressure isolation valve closed (ARM position), or in the event of loss of pressure on the upstream side of the check valve. The accumulator is protected from upstream leaks by the one-way check valve. From the accumulator, the nitrogen flows to the engine control valves where it can be used to operate the bipropellant valve pistons.

Two solenoid-operated control valves on each OMS engine allow nitrogen to control the bipropellant control valve actuators and bipropellant ball valves. Control valve 1 controls the no. 1 actuator and the first set of fuel and oxidizer ball valves. Control valve 2 controls the no. 2 actuator and the second set of fuel and oxidizer ball valves, in series with the no. 1 system. Each control valve contains two solenoid coils, either of which, when energized, opens the control valve.



OMS ENG Switches on Panel C3

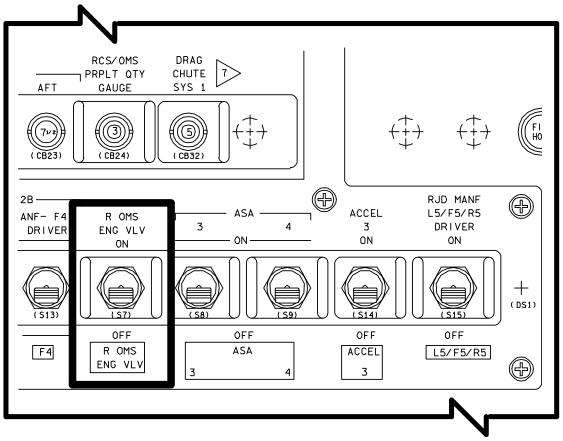
The right OMS engine GN_2 solenoid control valves 1 and 2 are energized open by computer commands if the *OMS ENG RIGHT* switch on panel C3 is in the *ARM* or *ARM/PRESS* position and the *R OMS ENG VLV* switch in the bottom row on panel O16 is *ON*; the valves are de-energized normally when the thrust is commanded off or if the *OMS ENG RIGHT* switch on panel C3 is positioned to *OFF*. The left OMS engine GN_2 solenoid control valves 1 and 2 are controlled in the same manner, using the *OMS ENG LEFT* switch on panel C3 and the *L OMS ENG VLV* switch in the bottom row on panel O14.

Check valves are installed in the vent port outlet of each GN_2 solenoid control valve on the spring pressure side of each actuator to protect the seal of these from atmospheric contamination.

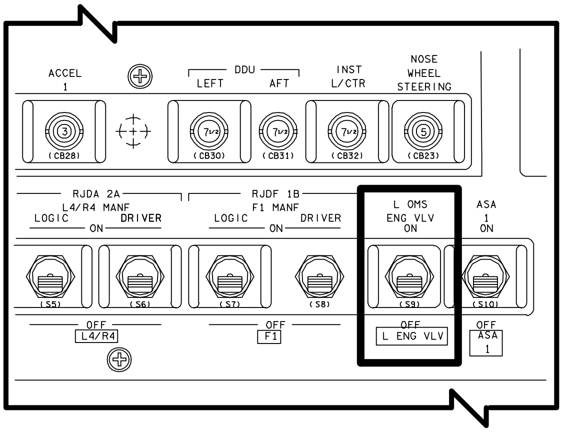
Ball Valve Actuation

When the GN_2 solenoid control valves are energized open, pressure is directed into the two actuators in each engine. The nitrogen acts against the piston in each actuator, overcoming the spring force on the opposite side of the actuators. Each actuator has a rack-and-pinion gear; the linear motion of the actuator connecting arm is converted into rotary motion, which drives two ball valves, one fuel and one oxidizer, to the open position. Each pair of ball valves opens simultaneously. Fuel and oxidizer are then directed to the combustion chamber of the engine, where the propellants atomize and ignite upon contact.

When the computer commands thrust off, or when an engine's *OMS ENG* switch on panel C3 or the *L* or *R OMS ENG VLV* switch on panel O14/O16 is positioned *OFF*, the solenoid control valves are de-energized, removing GN_2 pressure from the actuators. The GN_2 pressure in the actuators is vented overboard through the solenoid control valve. The spring in the actuator forces the actuator's piston to move in the opposite direction, and the actuator drives the fuel and oxidizer ball valves closed simultaneously. The series-redundant arrangement of ball valves ensures engine burn is terminated.



R OMS ENG VLV Switch on Panel O16



L OMS ENG VLV Switch on Panel O14

OMS Purge

The nitrogen subsystem also purges the fuel lines following OMS burns. After an OMS burn, some fuel and oxidizer will be left in the engine inlet lines and will be subject to cold temperatures. The oxidizer does not present a problem, but the fuel could freeze, especially in the cooling jacket around the thrust chamber. The frozen fuel will eventually sublimate. But for the first 10 minutes or so following a burn, it might be dangerous to start another burn, since forcing more fuel into already frozen lines could cause damage.

This situation is avoided by forcing nitrogen through the fuel lines immediately after the engine shuts down. This purge is part of the automatic OMS burn sequence and takes about 2 seconds. When a burn ends, the control valves close, and the purge valves open. Nitrogen can then flow into the fuel line below the bipropellant valves where it forces the remaining fuel through the inlet lines and cooling jacket and out through the engine.

Each engine has two gaseous nitrogen purge valves in series. These valves are solenoid-operated open and spring-loaded closed. They are normally energized open by the GPCs after each burn unless the purge is inhibited by having the *OMS ENGINE* switches on panel C3 in *ARM*. The two purge valves of an engine are energized open 0.36 second after OMS engine thrust has been commanded off. Opening the purge valves permits gaseous nitrogen to flow through the valves and check valve into the fuel line downstream of the ball valves. It then flows out through the combustion chamber and engine injector to space for 2 seconds. This purges the residual fuel from the combustion chamber and injector of the engine, permitting safe engine restart. The purge valves are then de-energized and spring-loaded closed. When the purge is completed, the gaseous nitrogen tank pressure isolation valve is closed by placing the respective *OMS ENG* switch on panel C3 to *OFF*. The check valve downstream of the purge valves prevents fuel from flowing to the engine purge valves during engine burns.

The automatic software will perform the purge only if the *OMS ENG* switch on panel C3 is in the *ARM/PRESS* position; that is, when the nitrogen pressure valve is open. For that reason, the crew should leave both *OMS ENG* switches in *ARM/PRESS* for at least 2 seconds after an OMS burn so that the purge can be completed. When the nitrogen pressure valve is open, nitrogen for the purge is supplied by the tank. If the valve were closed, the purge would deplete the accumulator, and the OMS start capability of the accumulator would be lost. This is not normally a problem since the accumulator can be repressurized. But if the valve were closed because of an upstream leak, it would be important to save the nitrogen in the accumulator. The purge is not as important as the need to preserve the engine restart capability. With the *OMS ENG* switch in *ARM* or *OFF*, the valve is closed, and the engine purge is automatically inhibited.

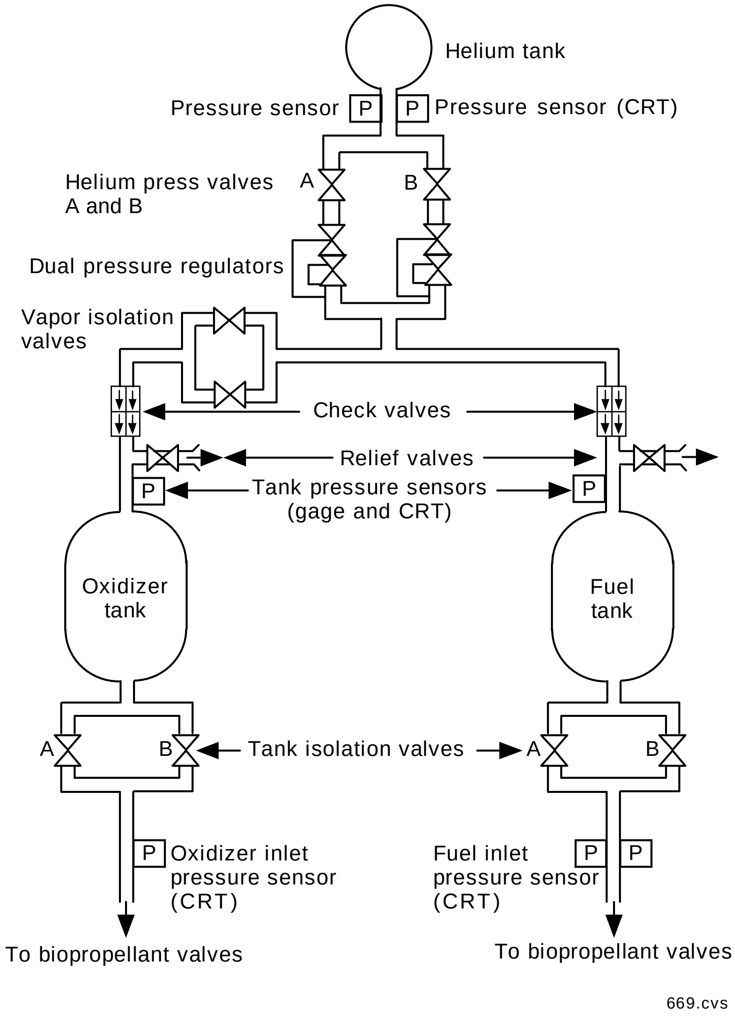
Helium System

Each OMS pod helium pressurization system consists of a high-pressure gaseous helium storage tank, two helium pressure isolation valves, two dual pressure regulator assemblies, parallel vapor isolation valves on the regulated helium pressure to the oxidizer tank only, dual series-parallel check valve assemblies, and pressure relief valves.

Helium Tanks

Oxidizer and fuel are supplied to each OMS engine by separate sets of propellant tanks. The OMS engine does not have fuel or oxidizer pumps; propellant flow must be maintained by keeping the tanks pressurized with helium. A single helium tank provides pressurization to both fuel and oxidizer tanks. One advantage to having a single helium tank in each pod is that it helps ensure that the two propellant tanks remain at the same pressure and thus avoids incorrect mixture ratios. The helium tank's operating pressure range is 4,800 to 390 psia.

Two pressure sensors downstream of each helium tank in each pod monitor the helium source pressure. One sensor displays the pressure on the MEDS MPS/OMS display. The reading from the other sensor appears on the GNC SYS SUMM 2 display (OMS TK P HE).



Propellant and Helium Supply

NOTE

Below a certain propellant quantity, there is enough residual helium pressure in the propellant tank to effectively use all the propellant in that tank. This quantity is referred to as “max blowdown.” Max blowdown for an OMS tank is approximately 39 percent.

Helium Pressure Valves

Two helium pressure valves in each pod isolate the helium tank from the propellant tanks. The valves are in a parallel arrangement, and are labeled A and B. This arrangement provides redundant paths for the helium to reach the propellant tanks. These valves are held closed by springs and are opened by electrical solenoids.

The valves are controlled by the *LEFT* and *RIGHT OMS He PRESS/VAPOR ISOL* switches on panel O8. The switches have manual *OPEN* and *CLOSE* positions as well as a *GPC* position that allows automatic control. These valves are normally closed at all times except during OMS burns. If the switches are in the *GPC* position, the automatic OMS burn sequence opens the helium pressure valves at the start of a burn and closes them at the end of a burn.

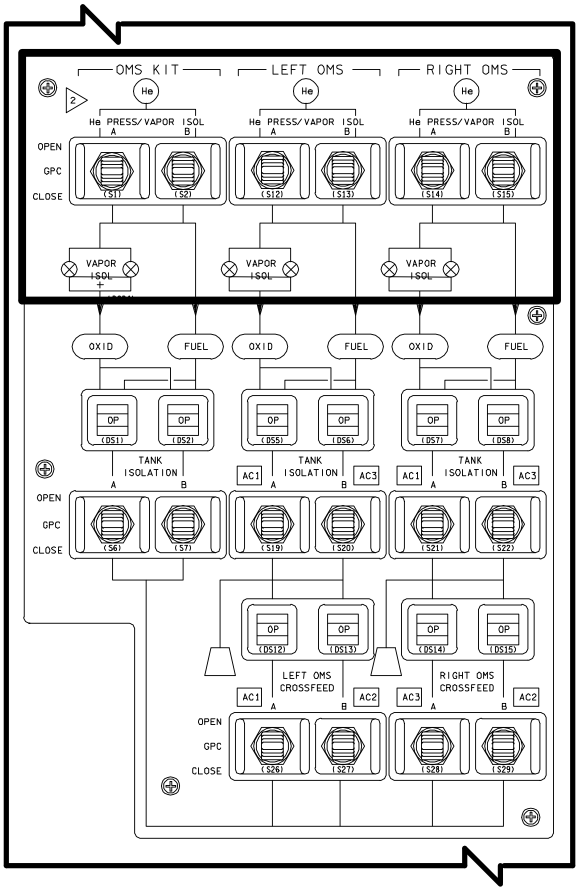
NOTE

When manually opening the *He PRESS/VAPOR ISOL* switches, delay 2 seconds between opening the A and B valves. This will prevent a possible water hammer effect due to a large and sudden pressure change.

Helium Pressure Regulators

Below each helium pressure valve is a pressure regulator that reduces the helium source pressure from its value in the tank, which can be as high as 4,800 psi (at launch), to the desired working pressure of approximately 250 psig. Each pressure regulator assembly contains a flow limiter and primary and secondary regulators in series. Normally, the primary regulator is the controlling regulator. Should the primary regulator fail, the secondary one will continue to provide pressure control.

The primary regulator pressure at normal flow is 252 to 262 psig, while the secondary regulator pressure at normal flow is 259 to 269 psig.



OMS He PRESS/VAPOR ISOL Switches on Panel O8

Vapor Isolation Valves

Over a long period of time, it is possible for small amounts of propellant vapors to diffuse through the check valves and into the helium lines. The vapor isolation valves in the helium pressurization line to the oxidizer tank prevent oxidizer vapor from migrating upstream and over into the fuel system, causing a hypergolic reaction. The vapor isolation valves are low-pressure, two-position, solenoid-operated valves that are energized open and spring-loaded closed. They can be commanded by the positioning of the *LEFT* and *RIGHT OMS He PRESS/VAPOR ISOL* switches on panel O8. When either the *A* or *B* switch is in the *OPEN* position, both vapor isolation valves are energized open; when both switches are in the *CLOSE* position, both vapor isolation valves are closed. When the switches are in the *GPC* position, the GPC opens and closes the valves automatically.

Check Valves

The check valve assembly contains four independent check valves connected in a series-parallel configuration to provide a positive checking action against a reverse flow of propellant liquid or vapor. The parallel path permits redundant paths of helium to the propellant tanks, while the series arrangement provides redundant backflow protection. Filters are incorporated into the inlet of each check valve assembly.

Relief Valves

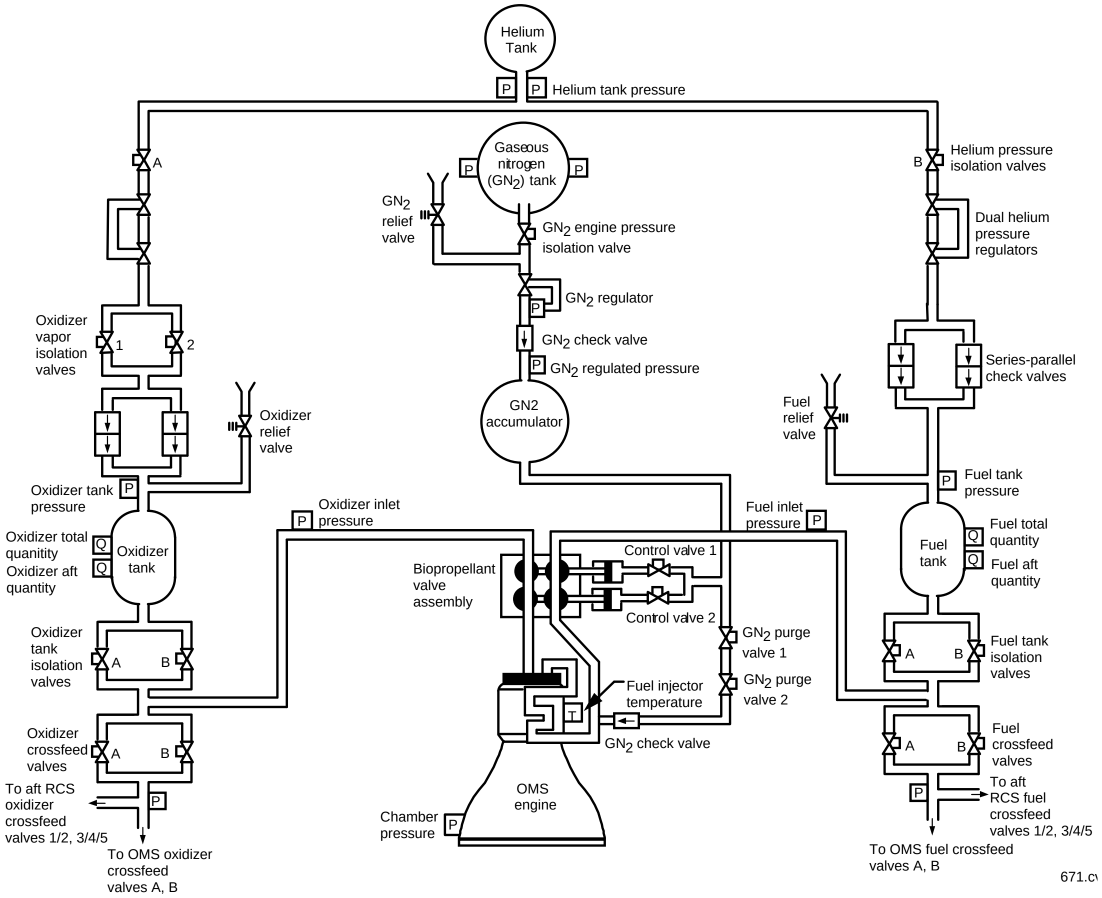
Below the check valves are the relief valves that protect the propellant tanks from over pressurization. Each pressure relief valve contains a burst diaphragm and filter. If excessive pressure is caused by helium or propellant vapor, the diaphragm will rupture, and the relief valve will open and vent the excessive pressure overboard. The filter prevents particulates from the non-fragmentation-type diaphragm from entering the relief valve seat. The relief valve will close and reseat after the pressure has returned to the operating level. The burst diaphragm is used to provide a more positive seal of helium and propellant vapors than the relief valve. The diaphragm ruptures between 303 and 313 psig, while the relief valve opens at 286 psig and reseats at 280 psig.

Propellant Storage and Distribution

The OMS propellant storage and distribution system consists of one fuel tank and one oxidizer tank in each pod. It also contains propellant feed lines, crossfeed lines, isolation valves, and crossfeed valves. The OMS propellant in both pods enables the orbiter to perform a 1,000-foot-per-second velocity change with a 65,000-pound payload in the payload bay. The OMS pod crossfeed lines allow the propellants in the pods to be used to operate either OMS engine.

Fuel (monomethyl hydrazine) and oxidizer (nitrogen tetroxide) are stored in domed cylindrical titanium tanks within each pod. The propellant tanks, which are pressurized by the helium system, are divided into forward and aft compartments. Each tank contains a propellant acquisition and retention assembly in the aft end. This assembly consists of a mesh screen dividing the fore and aft compartments and an acquisition system. Surface tension created by the screen retains propellant in the aft compartment during zero-gravity conditions.

The acquisition assembly consists of four stub galleries and a collector manifold. The stub galleries acquire wall-bound propellant at OMS start and during RCS burns to prevent gas ingestion. The stub galleries have screens that allow propellant flow and prevent gas ingestion. The collector manifold is connected to the stub galleries and also contains a gas arrestor screen to further prevent gas ingestion, which permits OMS engine ignition without the need of a propellant-settling maneuver employing RCS engines. The propellant tank's nominal operating pressure is 250 psi, with a maximum operating pressure limit of 313 psia.



Orbital Maneuvering System Pressurization and Propellant Feed System for One Engine (other Engine Identical

Each propellant tank has one pressure sensor wired directly to the RCS/OMS/PRESS meters on panel O3. Selecting the *OMS PRPLT* position of the rotary switch below the bank of meters enables the crew to read fuel and oxidizer tank pressures. The same measurement is also displayed on the GNC SYS SUMM 2 display (TK P OXID, FU entries). If the tank pressure is lower than 232 psia or higher than 284 psia, the *LEFT* or *RIGHT OMS* red caution and warning light on panel F7 will be illuminated.

OMS Quantity Gauging

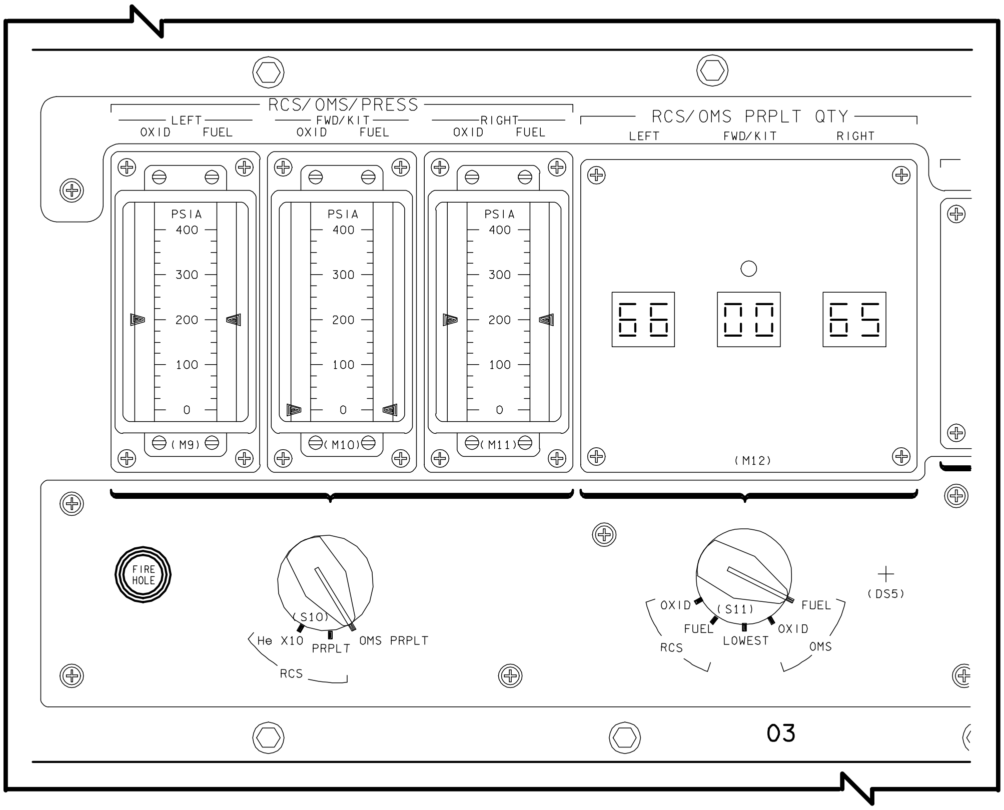
A capacitance gauging system in each OMS propellant tank measures the propellant in the tank. The system consists of a forward and aft probe and a totalizer. The fluid in the area of the communication screens cannot be measured and is called the "ungaugeable region."

The totalizer receives OMS valve operation information and inputs from the forward and aft probes in each tank and outputs total and aft quantities and a low level quantity. The inputs from the OMS valves allow control logic in the totalizer to determine when an OMS engine is burning and which tanks are being used. The totalizer begins an engine flow rate/time integration process at the start of the OMS burn, which reduces the indicated amount of propellants by a preset estimated rate for the first 14.8 seconds. After 14.8 seconds of OMS burn, which settles the propellant surface, the probe capacitance gauging system outputs are enabled, which permits the quantity of propellant remaining to be displayed. The totalizer outputs are displayed on the RCS/OMS PRPLT QTY LEDs on panel O3 when the rotary switch below the LEDs is positioned to the *OMS FUEL* or *OXID* position. In addition, the GNC SYS SUMM 2 display has a readout of the aft probe quantity (OMS AFT QTY). Quantity gauging is updated when at least one OMS engine is burning.

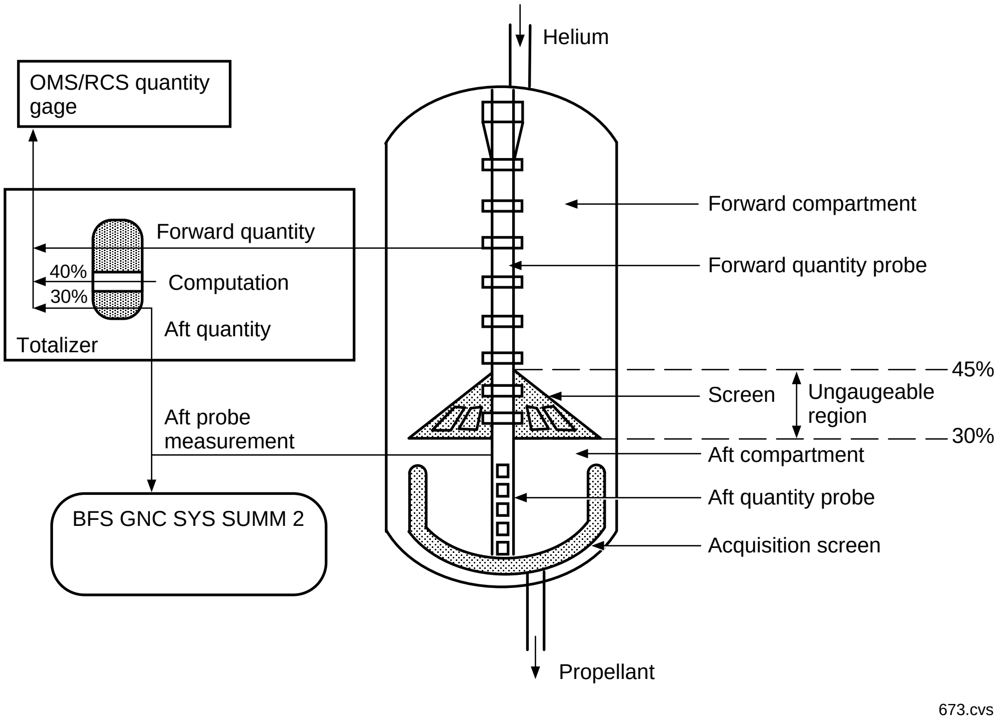
When the forward probe is dry (quantity approximately 45 percent), the ungaugeable propellant in the region of the intermediate bulkhead is added to the aft probe output quantity, decreasing the total quantity at a preset rate for 108 seconds, and updates from the aft probes are inhibited. After 108 seconds of burning (quantity approximately 30 percent), the aft probe output inhibit is removed, and the aft probe updates the total quantity. When the quantity decreases to 5 percent, the low-level signal is output.

NOTE

> Erroneous temperature and/or pressure transducer readings will cause erroneous propellant quantity calculations.



RCS/OMS/PRESS Meters and PRPLT QTY LEDs on Panel O3



Orbital Maneuvering System Quantity Gauging

Tank Isolation Valves

Parallel tank isolation valves (A and B) are located in each pod between the propellant tanks and the OMS engine and the OMS crossfeed valves and permit propellant to be isolated from the rest of the downstream systems. The valves are driven open and closed by ac motors that normally use three-phase ac power but can operate on two-phase power.

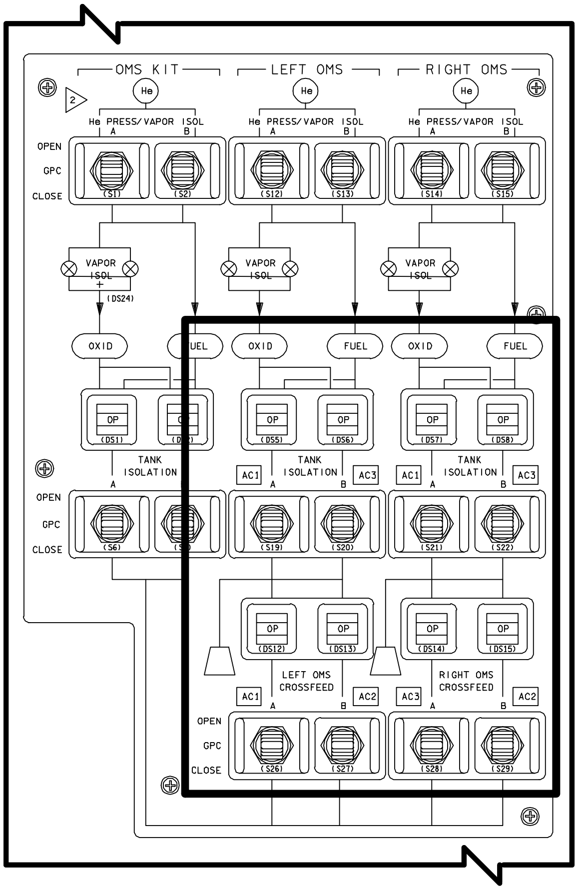
The *LEFT* and *RIGHT OMS TANK ISOLATION A* switches on panel O8 control the A fuel and A oxidizer valve in that pod, and the *B* switches control the B fuel and B oxidizer valve in that pod. The switches have manual *OPEN* and *CLOSE* positions and a *GPC* position that enables automatic control of the valves. When the *LEFT* or *RIGHT OMS TANK ISOLATION* switches in a pod are positioned to *GPC*, valves are automatically opened or closed upon command from the orbiter computer. When a pair of valves is opened, fuel and oxidizer from the propellant tanks are allowed to flow to that OMS engine and OMS crossfeed valves.

The switch positions *OPEN*, *GPC*, and *CLOSE* are permanent-position switches. Electrical power is provided to an electrical motor controller assembly, which supplies power to the ac-motor-operated valve actuators. Once the valve is in the commanded position, logic in the motor controller assembly removes power from the ac-motor-operated valve actuator. A talkback indicator above each *LEFT* or *RIGHT OMS TANK ISOLATION* switch on panel O8 indicates the status of the fuel valve and oxidizer valve. The talkback indicator is controlled by microswitches in each pair of valves. The talkback indicator indicates *OP* when that pair of valves is open, barberpole when the valves are in transit or one valve is open or closed, and *CL* when that pair of valves is closed.

Crossfeeds and Interconnects

An OMS engine in one pod may be fed with propellant from the other pod. This is called an OMS crossfeed and would be done to balance the propellant weight in each pod or in situations where an OMS engine or a propellant tank had failed.

Crossfeed lines connect the left and right OMS propellant lines at a point between the tank isolation valves and the bipropellant valves. Each crossfeed line has two crossfeed valves arranged in parallel to provide redundant paths for propellant flow. The *LEFT* and *RIGHT OMS CROSSFEED* switches are on panel O8, and each controls a pair of fuel and oxidizer valves in the crossfeed lines.



OMS TANK ISOLATION and CROSSFEED Switches and Talkbacks

When a crossfeed is set up, the tank isolation valves on the receiving side are closed. (The OMS propellant tanks on each side should not be directly connected in most cases.) The OMS crossfeed valves are then opened for the feeding and receiving side to establish a flow path from the OMS propellant tanks on one side to the engine on the other side.

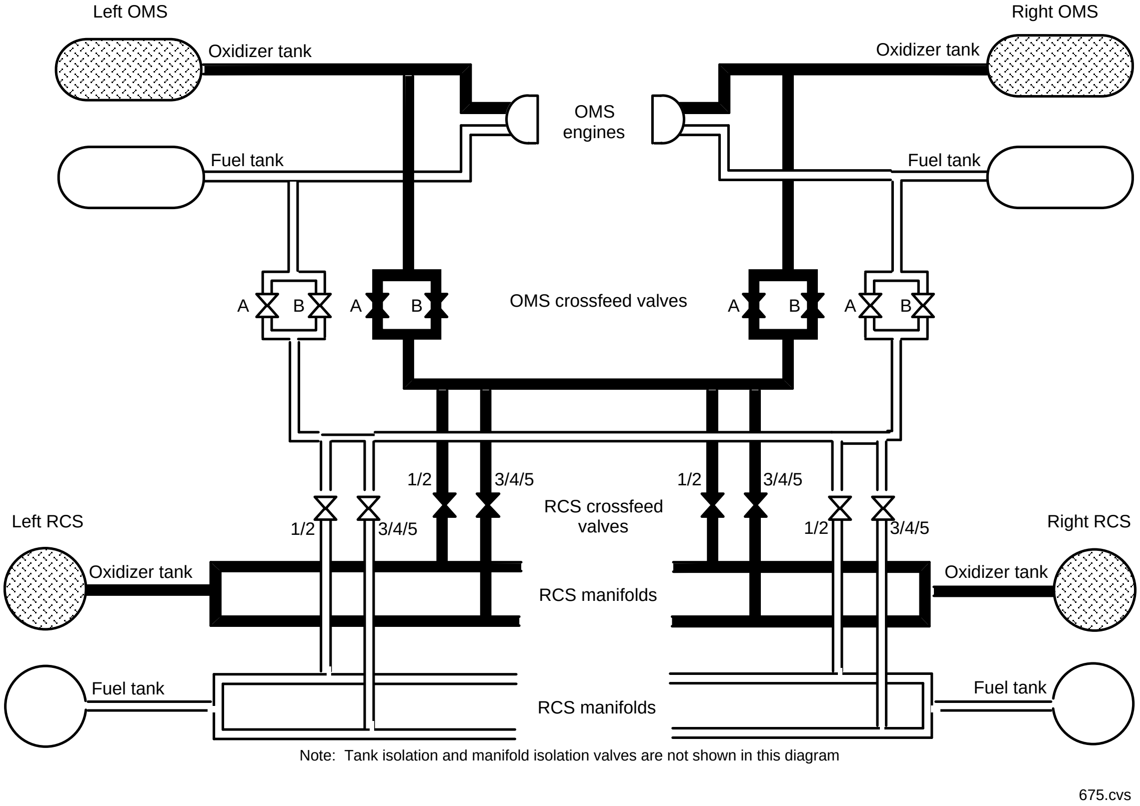
OMS propellant can also be fed to the aft RCS jets using OMS propellant from either OMS pod in orbit. This is called an OMS-to-RCS interconnect, and it provides the capability to operate the aft RCS using OMS propellant for orbital maneuvers. The RCS has its own crossfeed valves, similar to the OMS crossfeed valves, that are used to connect the RCS propellant lines to the crossfeed lines. The same crossfeed lines are used for OMS crossfeeds, RCS crossfeeds, and OMS-to-RCS interconnects.

When an OMS-to-RCS interconnect is set up, the RCS tank isolation valves are closed with *AFT LEFT RCS* and *AFT RIGHT RCS TANK ISOLATION* switches on panel O7. The RCS crossfeed valves are opened, and then one of the OMS crossfeed valves (B crossfeed valve) is opened. The OMS crossfeed valves on the non-feeding side are kept closed. This sequence prevents a direct connection between the OMS and RCS tanks. Normally, an interconnect involves one OMS pod feeding the RCS on both sides. This type of interconnect is used during orbit operations and is set up manually. The most important use of an OMS-to-RCS interconnect would be during an ascent abort, when the interconnect setup is automatic.

In each pod, parallel left or right OMS crossfeed valves are controlled by the *LEFT* and *RIGHT OMS CROSSFEED A, B* switches on panel O8. The *A* switch controls the A fuel and A oxidizer ac-motor-operated valve actuators in the pod selected, and the *B* switch controls the B fuel and B oxidizer valve in the pod selected. When the *A* or *B* switch in a pod is positioned to *GPC*, the A or B pair of fuel and oxidizer valves is automatically opened or closed upon command from the orbiter computer.

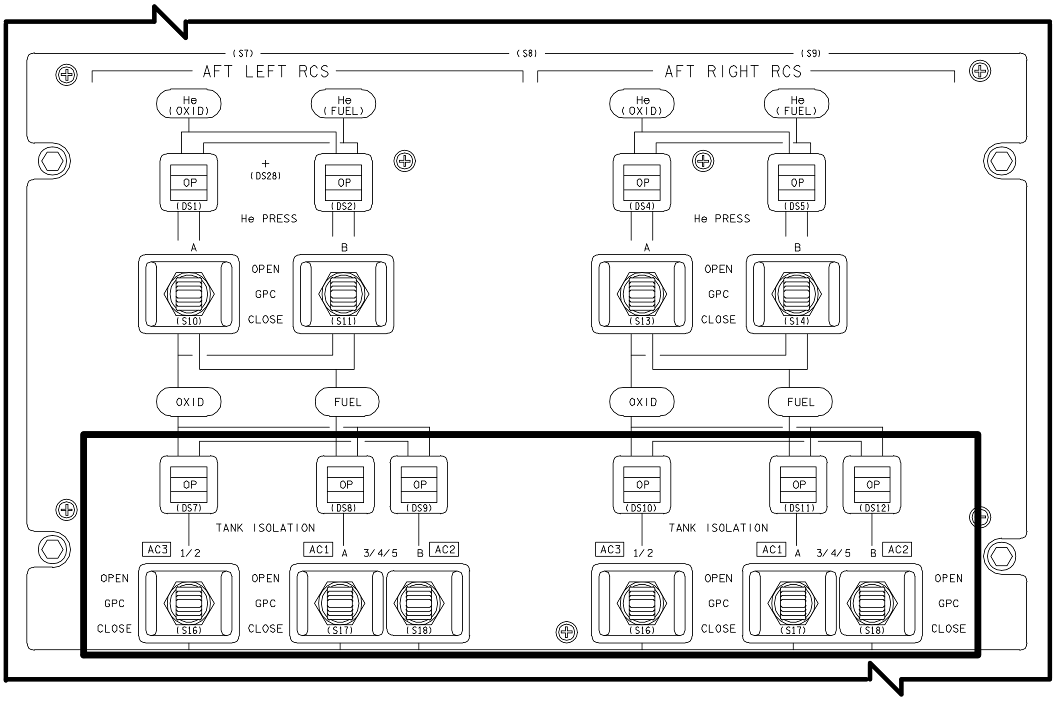
For example, when the A or B pair of crossfeed valves in the left pod is opened, fuel and oxidizer from the left pod are routed to the OMS crossfeed valves of the right pod; thus, a pair of A or B crossfeed valves in the right pod must be opened to permit the left pod fuel and oxidizer to be directed to the right OMS pod engine.

A talkback indicator above the crossfeed switches on panel O8 indicates the status of the selected pair's fuel and oxidizer valves. The talkback indicator indicates *OP* when both valves are open, barberpole when the valves are in transit or one valve is open and one closed, and *CL* when both valves are closed. The *LEFT* and *RIGHT OMS CROSSFEED A* and *B* switches on panel O8 permit manual control of the corresponding pair of fuel and oxidizer valves.



Note: Tank isolation and manifold isolation valves are not shown in this diagram

Orbital Maneuvering System and Reaction Control System Crossfeed Valves (OMS and RCS Tank Isolation Valves Not Shown)



RCS TANK ISOLATION Switches and Talkbacks on Panel O7

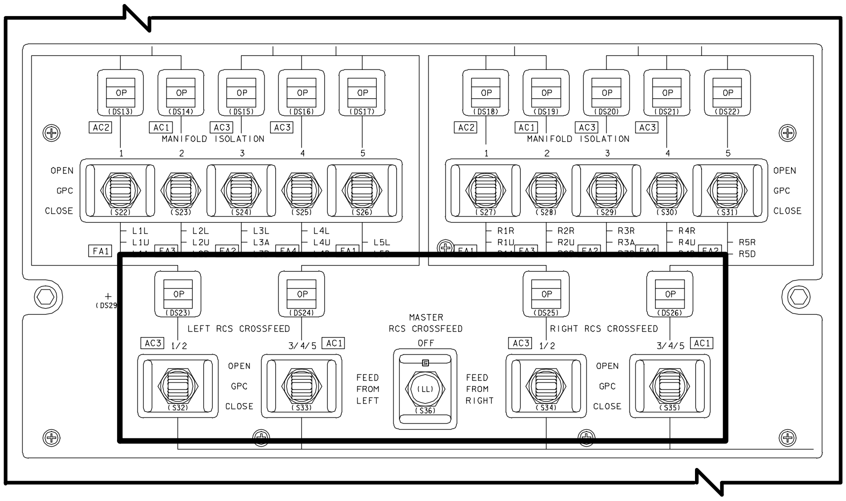
The *LEFT* and *RIGHT OMS CROSSFEED A* and *B* switches also provide the capability to supply OMS propellants to the left and right aft RCS engines. The left and right aft RCS will not be used to supply propellants to the OMS because the RCS tanks cannot support the flow rate required by the OMS engines.

The OMS crossfeed fuel and oxidizer line pressures are monitored on telemetry and are transmitted to the RCS SPEC 23 display.

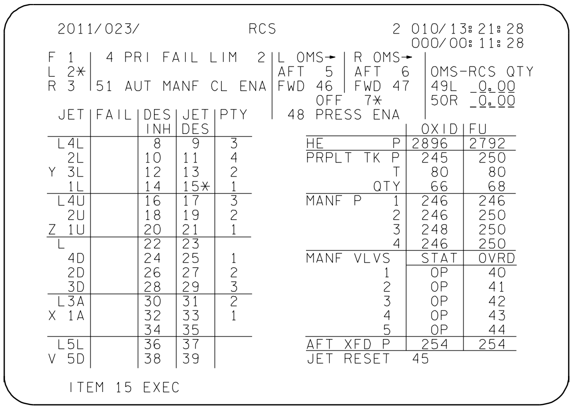
In summary, to perform an OMS to RCS interconnect on orbit, the flight crew must first select *FREE* on the *ORBITAL DAP* controls on panel C3, then configure the following switches (using a feed from the left OMS as an example):

1. Position the aft AFT LEFT RCS TANK ISOLATION 1/2, 3/4/5A and 3/4/5B and AFT RIGHT RCS TANK ISOLATION 1/2, 3/4/5A and 3/4/5B switches on panel O7 to CLOSE.
2. Check that the talkback indicator above these switches indicates *CL*, and position the *AFT LEFT RCS CROSSFEED 1/2, 3/4/5* and *AFT RIGHT RCS CROSSFEED 1/2, 3/4/5* switches to *OPEN*. The crew can then check for a propellant leak in the crossfeed lines.
3. Check that the left *OMS He PRESS/VAPOR ISOL VALVE A* and *B* switches on panel O8 are in the *CL* position.
4. Check that the *LEFT OMS TANK ISOLATION A* and *B* valves (panel O8) are open, and verify that the talkback indicators show *OP*.
5. Check the *RIGHT OMS CROSSFEED A* and *B* valves on panel O8 and verify that the indicators show *CL*.
6. Open the *LEFT OMS CROSSFEED B* valve on panel O8 and verify the talkback indicator shows *OP*. Check the A valve is closed and verify the indicator shows CL.
7. The left OMS-to-aft RCS interconnect quantity gauging can then be initiated by entering OMS PRESS ENA item entry (ITEM #5) on the RCS SPEC 23 display. The crew can then select the desired DAP.

There is software that automatically repressurizes the left OMS propellant tanks. If the *LEFT OMS He PRESS/VAPOR ISOL VALVE A* switch is in *GPC* and the OMS PRESS ENA item entry (item no. 48) is done on RCS SPEC 23, the left OMS helium pressure vapor isolation valve A is commanded open when the left OMS tank (ullage) pressure drops to 236 psig, and the open commands are terminated 30 seconds later. If the left OMS tank (ullage) pressure remains below 236 psia, the sequence sest an OMS/RCS valve miscompare flag and sets a Class 3 alert and DPS fault message. This feature is not used nominally because it would feed any OMS or RCS leaks.



RCS CROSSFEED Switches and Talkbacks on Panel O7



```
 2011/023/              RCS              2 010/13:21:28
                                           000/00:11:28
F 1 |  4 PRI FAIL LIM  2|L OMS→ |R OMS→ |
L 2*|                   |AFT  5 |AFT  6 |OMS-RCS QTY
R 3 |51 AUT MANF CL ENA |FWD 46 |FWD 47 |49L  0.00
                        |   OFF  7*     |50R  0.00
 JET|FAIL|DES|JET|PTY   |  48 PRESS ENA |
         |INH|DES|                 |OXID|FU
  L4L    |  8|  9| 3    HE        P|2896|2792
   2L    | 10| 11| 4    PRPLT TK P | 245| 250
Y  3L    | 12| 13| 2              T|  80|  80
   1L    | 14|15*| 1            QTY|  66|  68
  L4U    | 16| 17| 3    MANF P    1| 246| 246
   2U    | 18| 19| 2              2| 246| 250
Z  1U    | 20| 21| 1              3| 248| 250
  L      | 22| 23|                4| 246| 250
   4D    | 24| 25| 1    MANF VLVS  |STAT|OVRD
   2D    | 26| 27| 2             1 |  OP|  40
   3D    | 28| 29| 3             2 |  OP|  41
  L3A    | 30| 31| 2             3 |  OP|  42
X  1A    | 32| 33| 1             4 |  OP|  43
         | 34| 35|               5 |  OP|  44
  L5L    | 36| 37|      AFT XFD P  | 254| 254
V  5D    | 38| 39|      JET RESET  45

   ITEM 15 EXEC
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RCS Display (GNC SPEC 23)

The flight crew can terminate the sequence and inhibit the OMS-to-RCS gauging sequence by use of the L/R OMS "OFF" item entry (item no. 7) on the RCS display. The valves can then be reconfigured to their normal positions on panels O7 and O8. The OMS-to-aft-RCS interconnect gauging sequence is not available in the backup flight control software, or in OPS 1 or 3.

The OMS-to-aft-RCS propellant quantities are calculated by burn time integration. Once each cycle, the accumulated aft RCS jet cycles are used to compute the OMS propellant used since the initiation of gauging. The number of RCS jet cycles is provided by the RCS command subsystem operating program to account for minimum-impulse firing of the RCS jets. The gauging sequence is initiated by L/R OMS "AFT" item entry of the OMS left (item 5) or OMS right (item 6) interconnect on the RCS SPEC 23 display and is terminated by the return to normal item entry (L/R OMS "OFF", item 7).

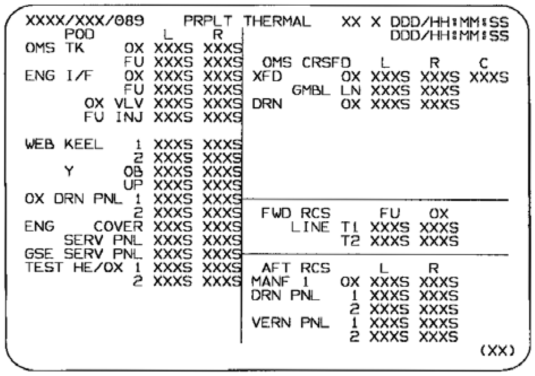
The gauging sequence maintains a cumulative total of left and right OMS propellant used during OMS-to-aft-RCS interconnects and displays the cumulative totals as a percentage of left and right OMS propellant on the RCS display (OMS→RCS QTY). The flight crew may manually update the OMS(RCS quantity by entering item 49 for the Left OMS or item 50 for the Right OMS interconnect quantity.

Valve Actuators

There are 64 ac-motor-operated valve actuators in the OMS/RCS nitrogen tetroxide and monomethyl hydrazine propellant systems. An electrical microswitch in each of the ac-motor-operated valve actuators signals the respective valves' position (open or closed) to the onboard flight crew displays and controls as well as telemetry. An extensive improvement program was implemented to reduce the probability of floating particulates in the electrical microswitch portion of each ac-motor-operated valve actuator. Particulates could affect the operation of the microswitch in each valve and, thus, the position indication of the valves to the onboard displays and controls and telemetry.

Thermal Control

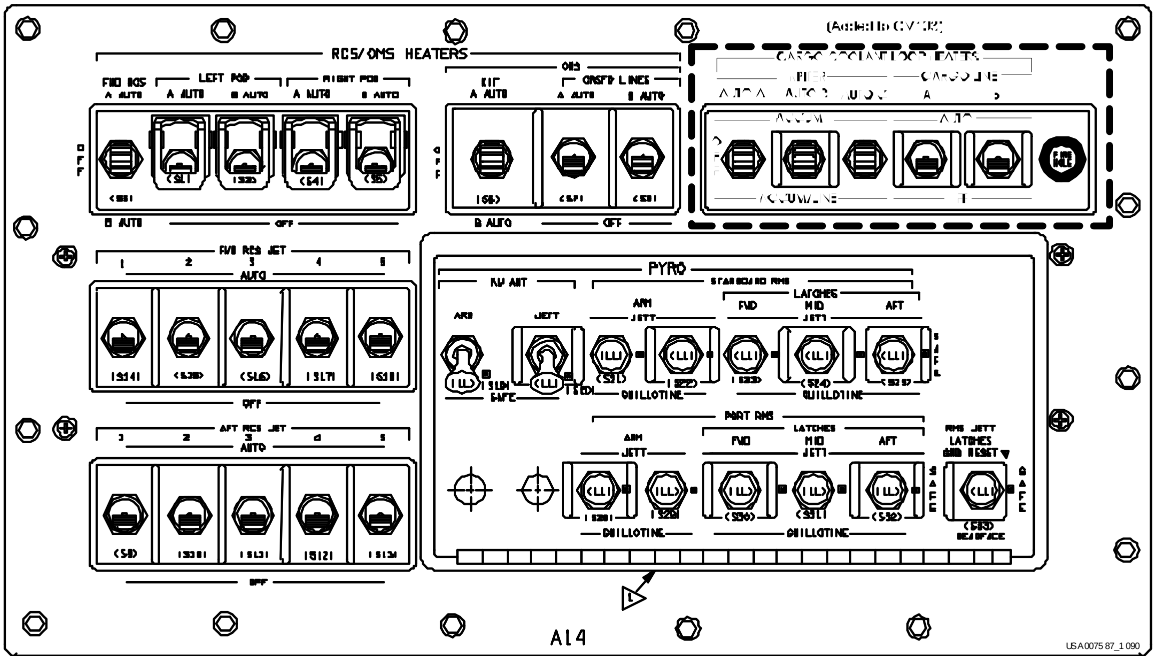
OMS thermal control is achieved by the use of strip heaters and insulation on the interior surface of the pods that enclose the OMS hardware components. Wraparound heaters and insulation condition the crossfeed lines. The heaters prevent propellant from freezing in the tank and lines. The OMS heaters are divided into three segments: left pod, right pod, and crossfeed lines.



```
XXXX/XXX/089     PRPLT THERMAL     XX X DDD/HH:MM:SS
    POD           L    R |              DDD/HH:MM:SS
OMS TK       OX XXXS XXXS|
             FU XXXS XXXS| OMS CRSFD   L    R    C
ENG I/F      OX XXXS XXXS|XFD       OX XXXS XXXS XXXS
             FU XXXS XXXS|     GMBL LN XXXS XXXS
       OX VLV XXXS XXXS  |DRN       OX XXXS XXXS
       FU INJ XXXS XXXS  |
                         |
WEB KEEL      1 XXXS XXXS|
              2 XXXS XXXS|
    Y        OB XXXS XXXS|
             UP XXXS XXXS|
OX DRN PNL    1 XXXS XXXS|-------------------------
              2 XXXS XXXS| FWD RCS     FU   OX
ENG       COVER XXXS XXXS|    LINE T1 XXXS XXXS
      SERV PNL  XXXS XXXS|         T2 XXXS XXXS
GSE SERV PNL    XXXS XXXS|-------------------------
TEST HE/OX    1 XXXS XXXS| AFT RCS     L    R
              2 XXXS XXXS|MANF 1    OX XXXS XXXS
                         |DRN PNL    1 XXXS XXXS
                         |           2 XXXS XXXS
                         |VERN PNL   1 XXXS XXXS
                         |           2 XXXS XXXS
                                               (XX)
```

SM SPEC 89 PRPLT THERMAL Display

Each OMS/RCS pod is divided into eight heater areas. Each of the heater areas in the pods contains an A and B element, and each element has a thermostat that controls the temperature from 55° to 75° F. These heater elements are controlled by the RCS/OMS HEATERS LEFT POD and RIGHT POD A AUTO and B AUTO



RCS/OMS HEATERS Switches on Panel A14

switches on panel A14. Sensors located throughout the pods supply temperature information to the SPEC 89 PRPLT THERMAL display (items listed under POD) and telemetry.

The crossfeed line thermal control in the aft fuselage is divided into 11 heater areas. Each area is heated in parallel by heater systems A and B, and each area has a control thermostat to maintain temperature at 55° F minimum to 75° F maximum. Each circuit also has an over-temperature thermostat to protect against a failed-on heater. These heater elements are controlled by the RCS/OMS HEATERS OMS CRSFD LINES A AUTO and B AUTO switches on panel A14. Temperature sensors near the control thermostats on the crossfeed lines supply temperature information on the SM SPEC 89 PRPLT THERMAL display (OMS CRSFD items) and telemetry.

Thrust Vector Control (TVC)

The OMS engines are attached to the orbiter in gimbal mounts that allow the engines to pivot up and down and from side to side. The OMS TVC system consists of a gimbal ring assembly, two gimbal actuator assemblies, and two gimbal actuator controllers. The engine gimbal ring assembly and gimbal actuator assemblies provide OMS TVC by gimbaling the engines in pitch and yaw. Each engine has a pitch actuator and a yaw actuator. Each actuator is extended or retracted by one of a pair of dual-redundant electric motors and is actuated by general-purpose computer control signals.

The gimbal ring assembly contains two mounting pads to attach the engine to the gimbal ring and two pads to attach the gimbal ring to the orbiter. The ring transmits engine thrust to the pod and orbiter.

The pitch and yaw gimbal actuator assembly for each OMS engine provides the force to gimbal the engines. Each actuator contains a primary and secondary motor and drive gears. The primary and secondary drive systems are isolated and are not operated concurrently. Each actuator consists of two redundant brushless dc motors and gear trains, a single jackscrew and nut-tube assembly, and redundant linear position feedback transducers. A GPC position command signal from the primary electronic controller energizes the primary dc motor, which is coupled with a reduction gear and a no-back device.

The output from the primary power train drives the jackscrew of the drive assembly, causing the nut-tube to translate (with the secondary power train at idle), which causes angular engine movement. If the primary power train is inoperative, a GPC position command from the secondary electronic controller energizes the secondary dc motor, providing linear travel by applying torque to the nut-tube through the spline that extends along the nut-tube for the stroke length of the unit. Rotation of the nut-tube about the stationary jackscrew causes the nut-tube to move along the screw. A no-back device in each drive system prevents backdriving of the standby system.

The electrical interface, power, and electronic control elements for active and standby control channels are assembled in separate enclosures designated the active actuator controller and standby actuator controller. These are mounted on the OMS/RCS pod structure. The active and standby actuator controllers are electrically and mechanically interchangeable.

The gimbal assembly provides control angles of (6° in pitch, and (7° in yaw with clearance provided for an additional 1 (for snubbing and tolerances.

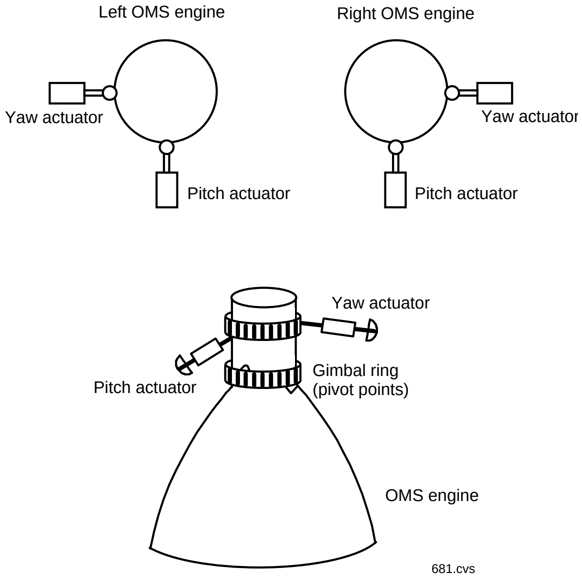
The thrust vector control command subsystem operating program (SOP) processes and outputs pitch and yaw OMS engine actuator commands and the actuator power selection discretes. The OMS TVC command SOP is active during the following operational sequences: orbit insertion (OMS-1 and OMS-2), orbit coast, deorbit, deorbit coast, and return-to-launch-site abort (major modes 104, 105, 201, 301, 302, 303, and 601).

The flight crew can select either the primary or secondary motors of the pitch and yaw actuators by item entry (PRI 28,29 and SEC 30,31 on the MNVR display), or they can turn the actuator motors off. The actuator command outputs are selected by the TVC command SOP, depending on the flag that is present; i.e., major modes, deorbit maneuver, orbit coast, RTLS abort, center-of-gravity trim, and gimbal check. The deorbit maneuver coast flag causes the TVC command SOP to output I-loaded values to command the engines to the entry stowed position.

The presence of the RTLS abort and center-of-gravity trim flags causes the engines to be commanded to a predefined position with the thrust vector through the center of gravity. The major mode RTLS flag by itself will cause the engines to be commanded to a stowed position for return-to-launch-site entry.

The gimbal check flag causes the engines to be commanded to plus 7° yaw and 6° pitch, then to minus 7° yaw and 6° pitch, and back to zero° yaw and pitch. In the absence of these flags, the TVC command SOP will output the digital autopilot gimbal actuator commands to the engine actuators. The backup flight control system allows only manual TVC during a burn, but it is otherwise similar.

The OMS TVC feedback SOP monitors the primary and secondary actuator selection discretes from the MNVR display and performs compensation on the selected pitch and yaw actuator feedback data. These data are output to the OMS actuator fault detection and identification and to the MNVR display. The OMS TVC feedback SOP is active during orbit insertion (OMS-1 and OMS-2), orbit coast, deorbit maneuver, and deorbit maneuver coast. The present OMS gimbal positions can be monitored on the MNVR display when this SOP is active, and the primary or secondary actuator motors are selected.



Orbital Maneuvering System Gimbal Actuators

Fault Detection and Identification

OMS Engine

The OMS engine fault detection function detects and identifies off-nominal performance of the OMS engine, such as off-failures during OMS burns, on-failures after or before a burn, and high or low engine chamber pressures.

Redundancy management software performs OMS engine fault detection and identification. It is assumed that the flight crew arms only the OMS engine to be used; the OMS engine not armed cannot be used for burns. Fault detection is initialized at solid rocket booster ignition and terminated after the OMS-1 burn or, in the case of an RTLS abort, at the transition from RTLS entry to the RTLS landing sequence program. Fault detection also is initiated 15 seconds before each OMS burn and terminated after the OMS burn is complete.

The PASS OMS engine fault detection uses both a velocity comparison and a chamber pressure comparison method to determine a failed-on or failed-off engine. The velocity comparison is used only after MECO since the OMS thrust is small compared to MPS thrust before MECO. The BFS OMS engine fault detection uses only a chamber pressure comparison method.

The measured velocity increment is compared to a predetermined one-engine and two-engine acceleration threshold value by the redundancy management software to determine the number of engines actually firing. This information, along with the assumption that an armed engine is to be used, allows the software to determine if the engine has low thrust or has shut down prematurely.

The chamber pressure comparison test compares a predetermined threshold chamber pressure level to the measured chamber pressure to determine a failed engine (on, off, or low thrust).

The engine-on command and the chamber pressure are used before MECO to determine a failed engine. The velocity indication and the chamber pressure indication are used after MECO to determine a failed engine. If the engine fails the chamber pressure test but passes the velocity test after MECO, the chamber pressure transducer will be considered failed. Such a failure would illuminate the red RIGHT OMS or LEFT OMS caution and warning light on panel F7, sound the master alarm, and produce a fault message, but the engine is still burning. If an engine fails the chamber pressure and velocity tests, the engine is considered failed, and a down arrow next to the failed engine appears on the MNVR display, in addition to illumination of the light on F7 and master alarm.

When the flight crew disarms a failed engine by turning the appropriate ARM/PRESS switch on panel C3 to OFF, a signal is sent to the OMS burn sequence to shut down the engine and to signal guidance to reconfigure. Guidance reconfigures and downmodes from two OMS engines, to one OMS engine, to four plus X RCS jets.

OMS Gimbal Fault Detection

The OMS gimbal actuator fault detection indicator detects and identifies off-nominal performance of the pitch and yaw gimbal actuators of the OMS engines.

The OMS gimbal actuator fault detection is divided into two processes. The first determines if the actuators should move from their present position. If the actuators must move, the second part determines how much they should move and whether the desired movement has occurred.

The first part checks the actuators' gimbal deflection error (the difference between the commanded new position and the actuators' last known position) and determines whether the actuators should extend or retract or if they are being driven against a stop. If the actuators are in the desired position or being driven against a stop, the first part of the process will be repeated. If the first part determines that the actuator should move, the second part of the process is performed.

The second part of the actuator fault detection process checks the present position of each actuator against its last known position to determine whether the actuators have moved more than a threshold amount. If the actuators have not moved more than this amount, an actuator failure is incremented by one. Each time an actuator fails this test, the failure is again incremented by one. When the actuator failure counter reaches an I-loaded value of four, the actuator is declared failed, and a fault message is output. The actuator failure counter is reset to zero any time the actuator passes the threshold test.

The first and second parts of the process continue to perform in this manner. The process can detect full-off gimbal failures and full-on failures indirectly. The full-on failure determines that the gimbal has extended or retracted too far and commands reverse motion. If no motion occurs, the actuator will be declared failed. The flight crew's response to a failed actuator is to select the secondary actuator electronics by item entry on the MNVR display. Gimbal failure on the left or right OMS will illuminate the red OMS TVC caution and warning light on panel F7.

Operations

The OMS burn sequence commands the OMS engines on or off and commands the engine purge function. The flight crew can select, via item entry on the MNVR display, a one or two-engine burn.

The sequence determines which engines are selected and then provides the necessary computer commands to open the appropriate helium vapor isolation valves and the engine gaseous nitrogen solenoid control valves and sets an engine-on indicator. The sequence will monitor the OMS engine fail flags and, if one or both engines have failed, issue the appropriate OMS shutdown commands as soon as the crew has confirmed the failure by placing the OMS ENG switch on panel C3 in the OFF position. This will then terminate the appropriate engine's control valve commands.

In a normal OMS burn, when the OMS cutoff flag is true, the sequence terminates commands to the helium pressurization/vapor isolation valves, and two gaseous nitrogen engine control valves. If the engine purge sequence is not inhibited, the sequence will check for the left and right engine ARM/PRESS signals, and open the engine gaseous nitrogen purge valves for two seconds for the engines that have the ARM/PRESS signals present.

The ascent profile for a mission uses a single OMS burn, and is referred to as direct insertion. In a direct-insertion ascent profile, the OMS-1 burn after main engine cutoff is normally not required unless there is an underspeed. The OMS-2 burn is then used to achieve orbit circularization. The direct-insertion ascent profile allows the main propulsion system to provide more energy for orbit insertion.

Additional OMS burns using one or both OMS engines are performed on orbit according to the mission's requirements to modify the orbit for rendezvous, payload deployment, or transfer to another orbit.

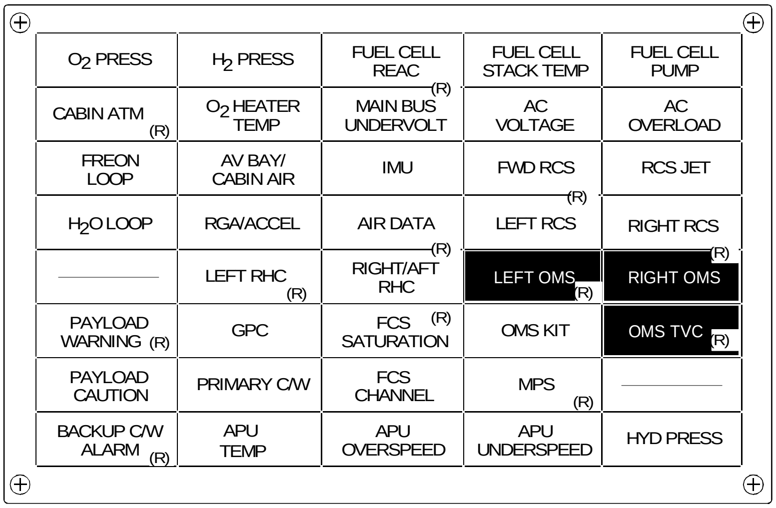
The two OMS engines are used to deorbit. Target data for the deorbit maneuver are computed by the ground and loaded in the onboard GPCs via uplink. These data are also voiced to the flight crew for verification of loaded values. After verification of the deorbit data, the flight crew initiates an OMS gimbal test on the DPS keyboard unit.

Before the deorbit burn, the flight crew maneuvers the spacecraft to the desired deorbit burn attitude manually using the rotational hand controller, or automatically with an item entry on the MNVR display. Upon completion of the OMS burn, the RCS is used to null any residual velocities, if required.

The aft RCS plus X jets can be used to complete any planned OMS burn in the event of an OMS engine failure. In this case, the OMS-to-RCS interconnect would feed OMS propellants to the aft RCS.

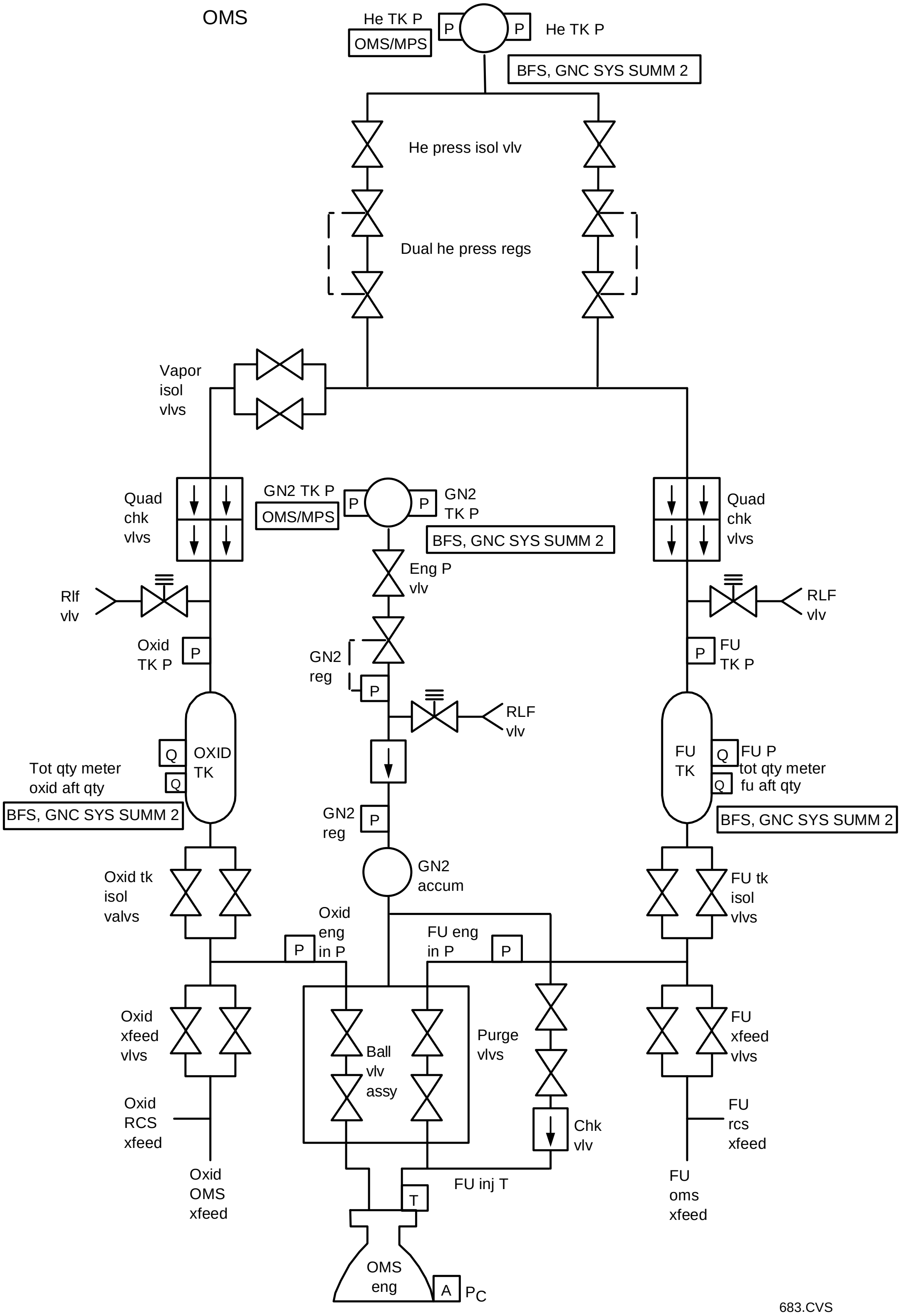
OMS Caution and Warning Summary

- There are class 2 and class 3 alerts for the OMS.
- Class 2 alerts can occur in all OPS and generate a MASTER ALARM light and tone and a light on the caution and warning matrix on panel F7.
- A class 3 alert is generated by the primary GNC or SM software in OPS 2 and 8 or by the BFS software in other OPS. Class 3 alerts include an SM ALERT light and tone and a fault message.
- The red LEFT OMS and RIGHT OMS lights on panel F7 will illuminate under the following conditions:
  - Left or right OMS oxidizer tank pressure is less than 232 or greater than 288 psi.
  - Left or right OMS fuel tank pressure is less than 232 or greater than 288 psi.
  - Left or right OMS engine Pc is less than 80 percent when the engine should be on or greater than 80 percent when the engine should be off.
- The red OMS TVC light will illuminate when there is gimbal failure on the left or right OMS.
- An L (R) OMS GMBL fault message will be displayed when there is a 2° difference between command and feedback position for an OMS gimbal actuator.
- An L (R) OMS PC fault message will be displayed when OMS engine Pc is less than 80 percent.
- An L (R) OMS QTY fault message will be displayed when OMS propellant tank quantity is less than 5 percent.
- An L (R) OMS TK P fault message will be displayed when OMS oxidizer or fuel tank pressure is below 234 or above 288 psi; when OMS helium tank pressure is below 1,500 psi; OMS N2 tank pressure is below 1,200 psi; or OMS N2 regulator pressure is above 434 or below 299 psi.
- An L (R) OMS VLV fault message will be displayed when OMS helium pressure valve and vapor isolation valve positions do not agree.
- An L (R) OMS TEMP fault message will be displayed when OMS engine fuel injector temperature is above 260° F.

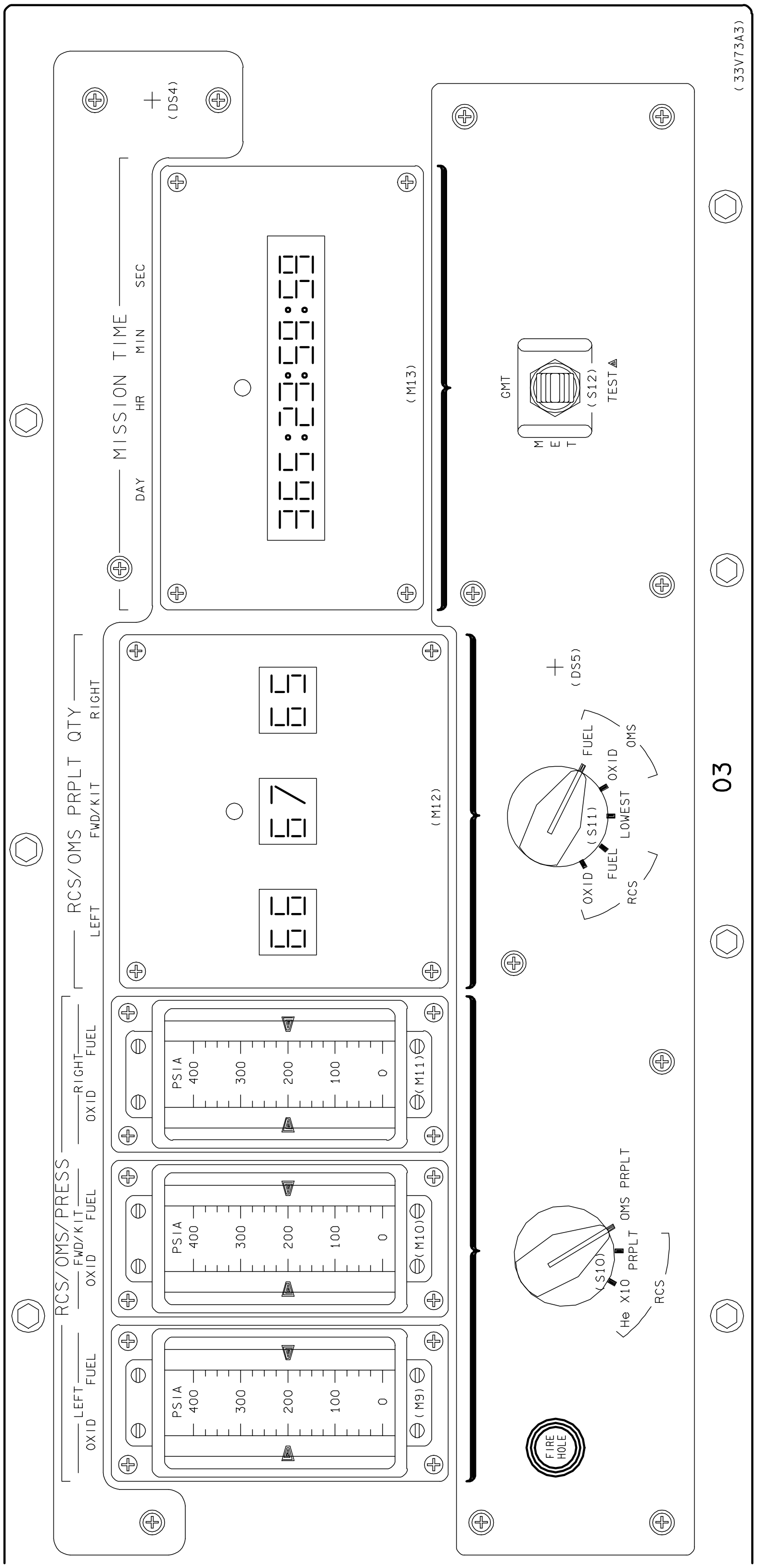


O_2 PRESS	H_2 PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O_2 HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H_2O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS	RIGHT RCS (R)
———	LEFT RHC (R)	RIGHT/AFT RHC	LEFT OMS (R)	RIGHT OMS
PAYLOAD WARNING (R)	GPC	FCS SATURATION (R)	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	———
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

OMS Caution and Warning Lights on Panel F7

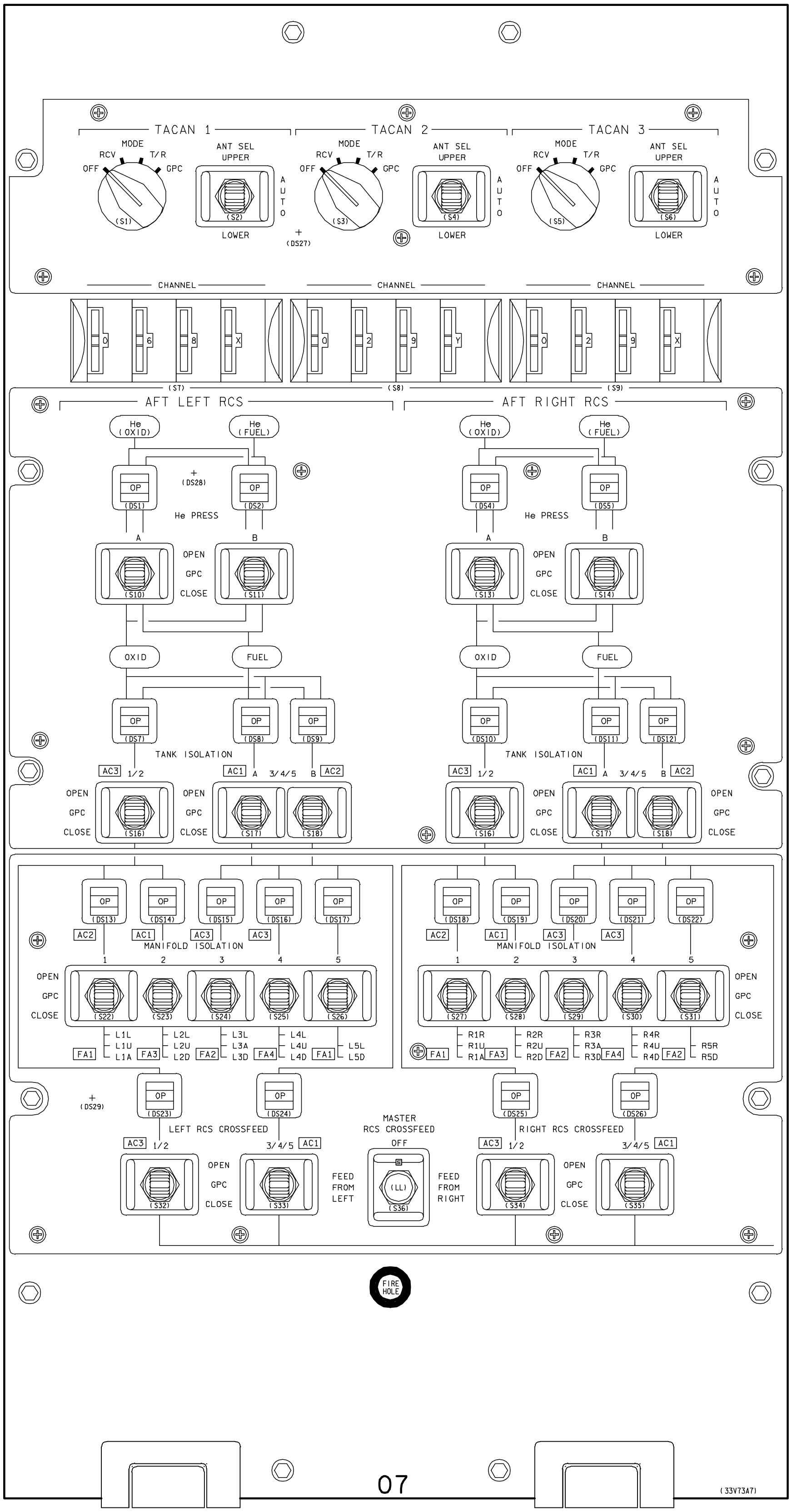


Orbital Maneuvering System

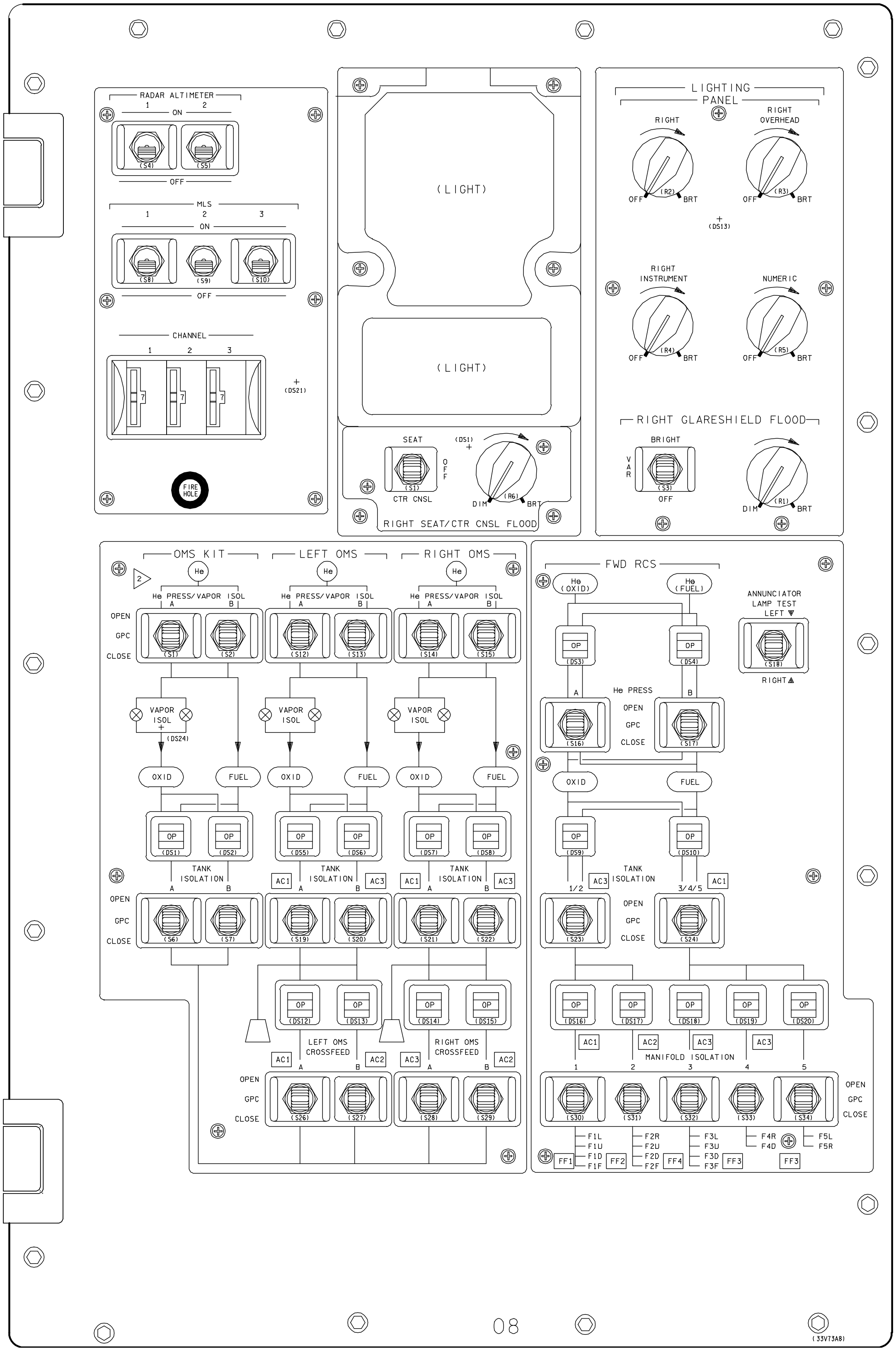


Panel O3

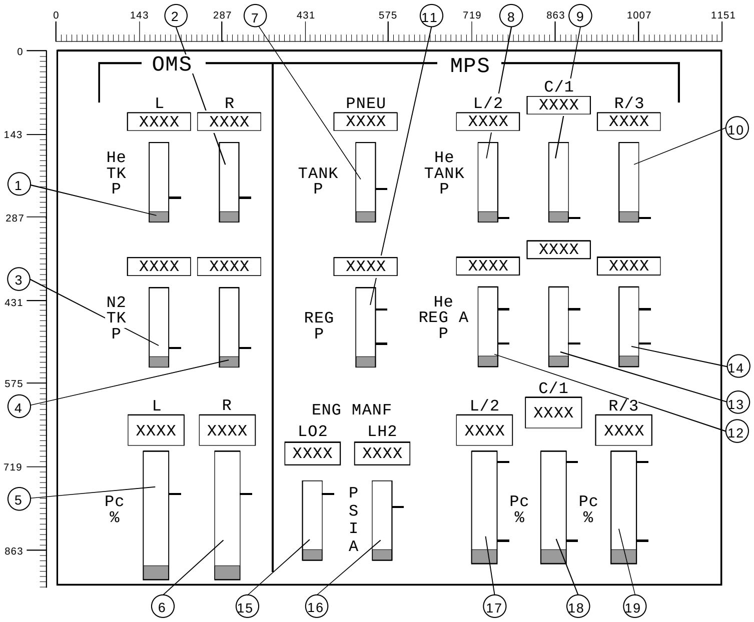
Panel O3


TACAN 1
TACAN 2
TACAN 3
MODE
OFF
RCV
T/R
GPC
ANT SEL
UPPER
LOWER
AUTO
(S1)
(S2)
(S3)
(S4)
(S5)
(S6)
(DS27)
CHANNEL
(S7)
(S8)
(S9)
AFT LEFT RCS
AFT RIGHT RCS
He (OXID)
He (FUEL)
OP
(DS1)
(DS2)
(DS4)
(DS5)
(DS28)
He PRESS
A
B
OPEN
GPC
CLOSE
(S10)
(S11)
(S13)
(S14)
OXID
FUEL
(DS7)
(DS8)
(DS9)
(DS10)
(DS11)
(DS12)
TANK ISOLATION
AC1
AC2
AC3
1/2
3/4/5
(S16)
(S17)
(S18)
(DS13)
(DS14)
(DS15)
(DS16)
(DS17)
(DS18)
(DS19)
(DS20)
(DS21)
(DS22)
MANIFOLD ISOLATION
1
2
3
4
5
(S22)
(S23)
(S24)
(S25)
(S26)
(S27)
(S28)
(S29)
(S30)
(S31)
L1L L1U L1A
L2L L2U L2D
L3L L3A L3D
L4L L4U L4D
L5L L5D
R1R R1U R1A
R2R R2U R2D
R3R R3A R3D
R4R R4U R4D
R5R R5D
FA1
FA2
FA3
FA4
(DS29)
(DS23)
(DS24)
(DS25)
(DS26)
LEFT RCS CROSSFEED
RIGHT RCS CROSSFEED
MASTER RCS CROSSFEED
OFF
FEED FROM LEFT
FEED FROM RIGHT
(LL)
(S32)
(S33)
(S34)
(S35)
(S36)
FIRE HOLE
O7
(33V73A7)

Panel O7

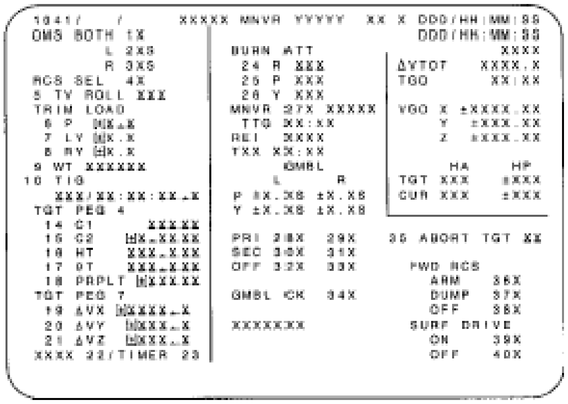

RADAR ALTIMETER
1 2
ON
OFF
MLS
1 2 3
ON
OFF
CHANNEL
1 2 3
(DS21)
FIRE HOLE
(LIGHT)
(LIGHT)
SEAT
OFF
CTR CNSL
DIM BRT
RIGHT SEAT/CTR CNSL FLOOD
LIGHTING PANEL
RIGHT
RIGHT OVERHEAD
OFF BRT
(DS13)
RIGHT INSTRUMENT
NUMERIC
RIGHT GLARESHIELD FLOOD
BRIGHT
VAR
OFF
DIM BRT
OMS KIT
LEFT OMS
RIGHT OMS
He
He PRESS/VAPOR ISOL
A B
OPEN
GPC
CLOSE
VAPOR ISOL
(DS24)
OXID
FUEL
OP
TANK ISOLATION
AC1
AC2
AC3
LEFT OMS CROSSFEED
RIGHT OMS CROSSFEED
FWD RCS
He (OXID)
He (FUEL)
ANNUNCIATOR LAMP TEST
LEFT ▼
RIGHT ▲
He PRESS
1/2
3/4/5
MANIFOLD ISOLATION
1 2 3 4 5
F1L F1U F1D F1F
F2R F2U F2D F2F
F3L F3U F3D F3F
F4R F4D
F5L F5R
FF1
FF2
FF3
FF4
O8
(33V73A8)

Panel O8



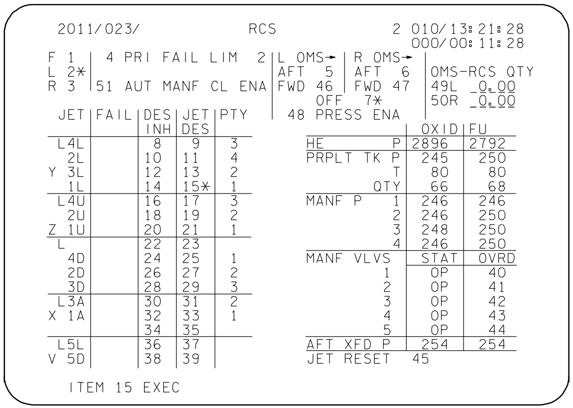
① L OMS He TK PRESS meter
② R OMS He TK PRESS meter
③ L OMS N2 TK PRESS meter
④ R OMS N2 TK PRESS meter
⑤ L OMS Pc meter
⑥ R OMS Pc meter
⑦ PNEU He TK PRESS meter
⑧ L ENG He TK PRESS meter
⑨ C ENG He TK PRESS meter
⑩ R ENG He TK PRESS meter
⑪ PNEU He REG PRESS meter
⑫ L ENG He REG PRESS meter
⑬ C ENG He REG PRESS meter
⑭ R ENG He REG PRESS meter
⑮ LO2 ENG MANF PRESS meter
⑯ LH2 ENG MANF PRESS meter
⑰ L ENG Pc meter
⑱ C ENG Pc meter
⑲ R ENG Pc meter

OMS/MPS Display



```
1041/     /      XXXXX MNVR YYYYY  XX X DDD/HH:MM:SS
OMS BOTH 1X                               DDD/HH:MM:SS
        L 2XS     | BURN ATT                      XXXX
        R 3XS     |  24 R XXX       | ΔVTOT    XXXX.X
RCS SEL  4X       |  25 P XXX       | TGO       XX:XX
5 TV ROLL XXX     |  26 Y XXX       |
TRIM LOAD         | MNVR 27X XXXXX  | VGO X ±XXXX.XX
 6 P  ±X.X        |  TTG XX:XX      |       Y  ±XXX.XX
 7 LY ±X.X        | REI  XXXX       |       Z  ±XXX.XX
 8 RY ±X.X        | TXX XX:XX       |
9 WT XXXXXX       |      GMBL       |       HA      HP
10 TIG            |    L      R     | TGT XXX     ±XXX
  XXX/XX:XX:XX.X  | P ±X.XS ±X.XS   | CUR XXX     ±XXX
TGT PEG 4         | Y ±X.XS ±X.XS   
 14 C1      XXXXX |
 15 C2   ±X.XXXX  | PRI 28X  29X     35 ABORT TGT XX
 16 HT   XXX.XXX  | SEC 30X  31X
 17 θT   XXX.XXX  | OFF 32X  33X       FWD RCS
 18 PRPLT ±XXXXX  |                      ARM    36X
TGT PEG 7         | GMBL CK  34X         DUMP   37X
 19 ΔVX ±XXXX.X   |                      OFF    38X
 20 ΔVY  ±XXX.X   | XXXXXXX            SURF DRIVE
 21 ΔVZ  ±XXX.X   |                      ON     39X
XXXX 22/TIMER 23  |                      OFF    40X
```

MNVR Display

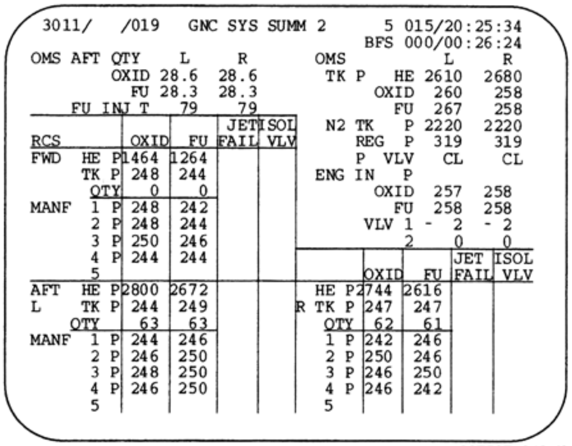


```
2011/023/              RCS              2 010/13:21:28
                                          000/00:11:28
F 1 | 4 PRI FAIL LIM  2|L OMS→ |R OMS→ |
L 2*|                  |AFT  5 |AFT  6 |OMS-RCS QTY
R 3 |51 AUT MANF CL ENA|FWD 46 |FWD 47 |49L _0.00
                       |    OFF   7*   |50R _0.00
JET|FAIL|DES|JET|PTY   | 48 PRESS ENA
   |    |INH|DES|                     |OXID|FU
L4L|    |  8|  9| 3      HE          P|2896|2792
 2L|    | 10| 11| 4      PRPLT TK P   | 245| 250
Y 3L|   | 12| 13| 2                 T |  80|  80
 1L|    | 14|15*| 1               QTY |  66|  68
L4U|    | 16| 17| 3      MANF P     1 | 246| 246
 2U|    | 18| 19| 2                 2 | 246| 250
Z 1U|   | 20| 21| 1                 3 | 248| 250
L  |    | 22| 23|                   4 | 246| 250
 4D|    | 24| 25| 1      MANF VLVS     |STAT|OVRD
 2D|    | 26| 27| 2                 1 | OP |  40
 3D|    | 28| 29| 3                 2 | OP |  41
L3A|    | 30| 31| 2                 3 | OP |  42
X 1A|   | 32| 33| 1                 4 | OP |  43
   |    | 34| 35|                   5 | OP |  44
L5L|    | 36| 37|        AFT XFD P    | 254| 254
V 5D|   | 38| 39|        JET RESET  45

ITEM 15 EXEC
```

00616308.CRT;1
usa007587_678r1.cvx

SPEC 23 RCS Display



```
3011/   /019   GNC SYS SUMM 2       5 015/20:25:34
                                  BFS 000/00:26:24
OMS AFT QTY     L      R        OMS          L      R
        OXID 28.6   28.6         TK P   HE 2610   2680
          FU 28.3   28.3               OXID  260    258
   FU INJ T   79     79                  FU  267    258
                       |JET|ISOL  N2 TK    P 2220   2220
RCS        |OXID|  FU |FAIL|VLV      REG   P  319    319
FWD  HE P|1464|1264 |    |         P  VLV    CL     CL
     TK P| 248| 244 |    |      ENG IN    P
      QTY|   0|   0 |    |            OXID  257    258
MANF  1 P| 248| 242 |    |              FU  258    258
      2 P| 248| 244 |    |          VLV 1 -  2   -  2
      3 P| 250| 246 |    |                2   0      0
      4 P| 244| 244 |    |                        |JET |ISOL
      5  |    |     |    |        |OXID|  FU |FAIL|VLV
AFT  HE P|2800|2672 |    |    HE P|2744|2616 |    |
L    TK P| 244| 249 |    |  R TK P| 247| 247 |    |
      QTY|  63|  63 |    |     QTY|  62|  61 |    |
MANF  1 P| 244| 246 |    |    1 P |242 | 246 |    |
      2 P| 246| 250 |    |    2 P |250 | 246 |    |
      3 P| 248| 250 |    |    3 P |246 | 250 |    |
      4 P| 246| 250 |    |    4 P |246 | 242 |    |
      5  |    |     |    |    5   |    |     |    |
```

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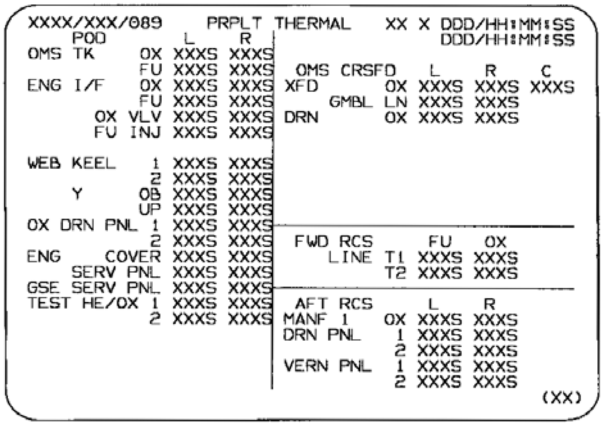
GNC SYS SUMM 2 Display



```
XXXX/XXX/089    PRPLT THERMAL    XX X DDD/HH:MM:SS
    POD          L     R |                DDD/HH:MM:SS
OMS TK       OX XXXS XXXS|
             FU XXXS XXXS| OMS CRSFD    L    R    C
ENG I/F      OX XXXS XXXS|XFD       OX XXXS XXXS XXXS
             FU XXXS XXXS|     GMBL LN XXXS XXXS
      OX VLV XXXS XXXS   |DRN       OX XXXS XXXS
      FU INJ XXXS XXXS   |
                         |
WEB KEEL      1 XXXS XXXS|
              2 XXXS XXXS|
    Y        OB XXXS XXXS|
             UP XXXS XXXS|
OX DRN PNL    1 XXXS XXXS|______________________________
              2 XXXS XXXS| FWD RCS      FU   OX
ENG       COVER XXXS XXXS|     LINE T1 XXXS XXXS
    SERV PNL    XXXS XXXS|          T2 XXXS XXXS
GSE SERV PNL    XXXS XXXS|______________________________
TEST HE/OX    1 XXXS XXXS| AFT RCS      L    R
              2 XXXS XXXS|MANF 1    OX XXXS XXXS
                         |DRN PNL    1 XXXS XXXS
                         |           2 XXXS XXXS
                         |VERN PNL   1 XXXS XXXS
                         |           2 XXXS XXXS
                                                   (XX)
```

SM SPEC 89 PRPLT THERMAL Display

OMS Summary Data

- The OMS provides propulsion for orbit insertion, orbit circularization, orbit transfer, rendezvous, and deorbit.
- The OMS engines are collocated with the aft RCS in two independent OMS/RCS pods on each side of the orbiter's aft fuselage. Each engine produces 6,087 pounds of thrust and specific impulse of 313 seconds.
- The OMS engines use monomethyl hydrazine as fuel and nitrogen tetroxide as oxidizer. The propellants are hypergolic.
- Gaseous pressurized nitrogen operates the OMS engine valves and is also used to purge the fuel lines at the end of each burn. Propellant flow to the engines is maintained by a helium pressurization system.
- Each OMS/RCS pod contains one OMS fuel tank and one OMS oxidizer tank. Crossfeed lines allow propellants to be used to operate either engine. OMS propellant can also be fed to aft RCS jets using OMS propellant from either or both pods.
- OMS engines are attached to the orbiter in gimbal mounts that allow the engines to pivot up and down and from side to side (±6° pitch, ±7° yaw).
- Switches that the crew uses to operate the OMS are located on panels C3, O14, O16, O7, O8, and A14. Panels that display OMS parameters are F7 and O3.
- The MNVR display is used by the crew to enter burn targeting parameters. Other displays on which OMS data appear are GNC SYS SUMM 2, SPEC 23 RCS, and SM SPEC 89 PRPLT THERMAL

OMS Rules of Thumb

- 1 percent of OMS propellant

  = 6 fps

  = 3 n. mi.

  130 lb (80 lb oxidizer, 50 lb fuel) uses 400 psi of helium for long burns.
- One OMS engine causes approximately 1 fps^2 acceleration.
- For OMS ignition, there must be power and command to at least one coil on both control valves.
- OMS TVC requires an enable discrete from the FF MDM, and commands from the FA MDM.
- FUEL INJECTOR TEMP message may be a signature of a bad temperature transducer or a fuel blockage.
- CHAMBER PRESSURE message may be a signature of a bad pressure transducer or an oxidizer blockage.
- There are several failures that inop OMS FDI (FA MDM commfault or Pc transducer failing high during the burn).
- Always check redundant sources to confirm any malfunction.
- Max blowdown on the OMS is approximately 39 percent.
- 1,000 lbs of OMS (approximately 8 percent) moves the X c.g. 1.5 inches aft and the Y c.g. 0.5 inches left or right.
- Max OMS quantity for landing = 22 percent/ side.

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2.19 ORBITER DOCKING SYSTEM

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Truss Assembly 2.19-2
Androgynous Peripheral Docking System.. 2.19-2
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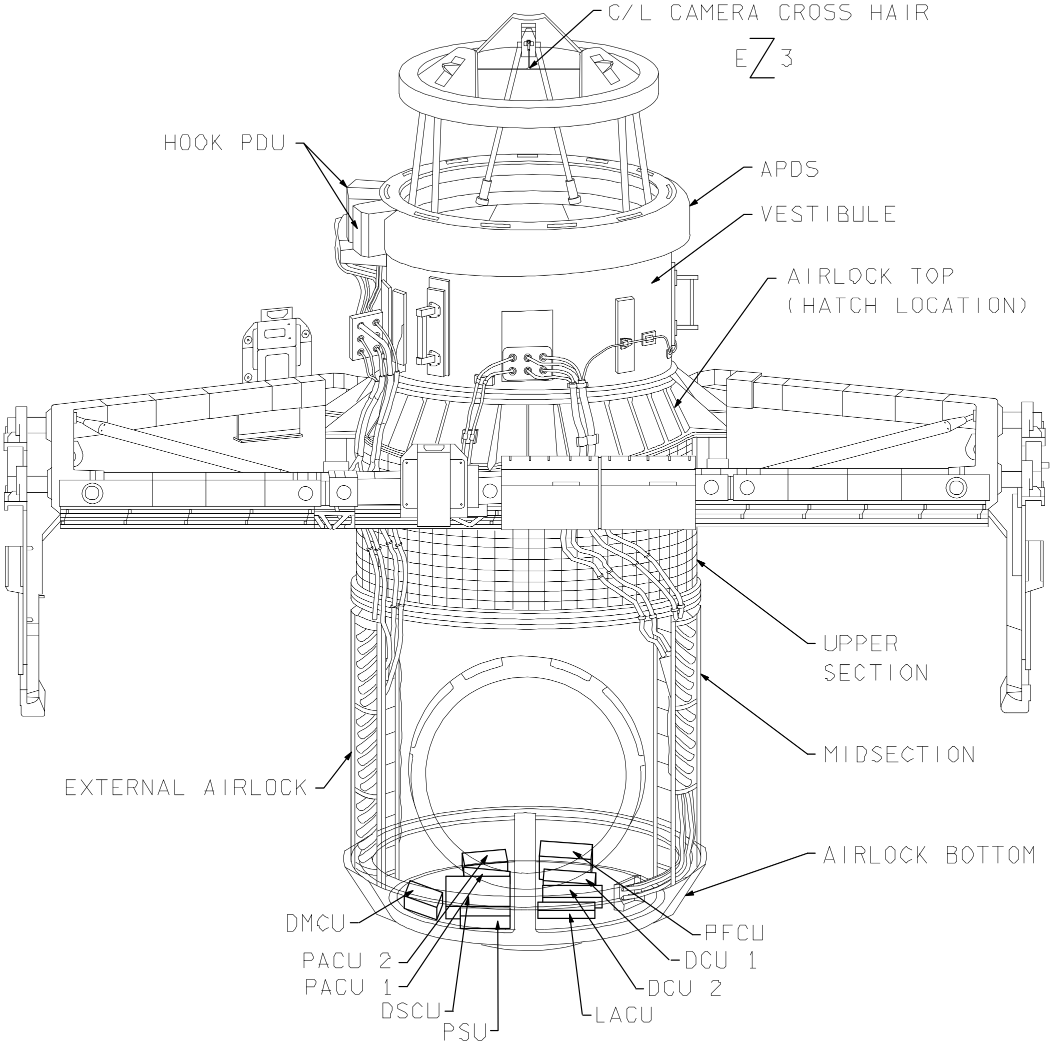
APDS Operational Sequences (OPS) 2.19-6
Operational Notes of Interest 2.19-8

Description

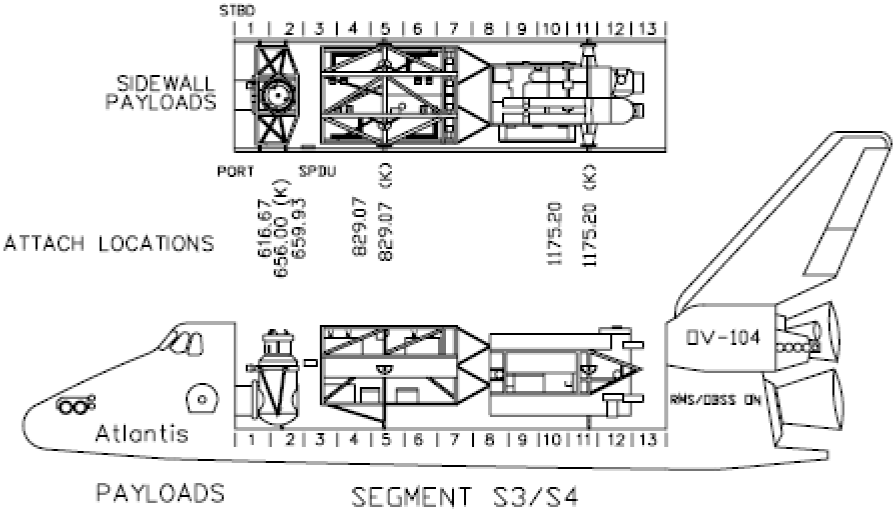
The orbiter docking system (ODS) will be used to dock the shuttle to the International Space Station (ISS). The ODS has three major components:

- External airlock
- Truss assembly
- Androgynous Peripheral Docking System

The ODS is located in the payload bay aft of the 576 bulkhead, behind the tunnel adapter.



Orbiter Docking System View Looking Aft



ODS Configuration in the Payload Bay on STS-*117*

External Airlock

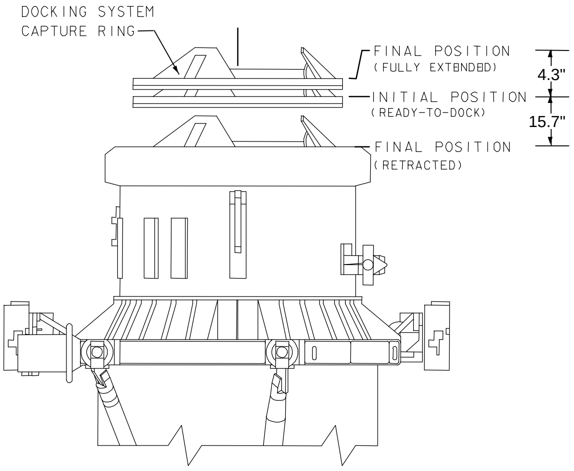
The external airlock provides an airtight, internal tunnel between the two spacecraft after docking.

Truss Assembly

The truss assembly provides a sound structural base within which the components of the docking system are housed. The truss assembly is physically attached to the payload bay and houses rendezvous and docking aids, such as camera/light assemblies and trajectory control systems.

Androgynous Peripheral Docking System

The Androgynous Peripheral Docking System (APDS), manufactured by RSC-Energia in Kaliningrad, Russia, is designed to achieve the capture, dynamic attenuation, alignment, and hard docking of spacecraft by using essentially identical docking mechanisms attached to each vehicle. The primary components of each docking mechanism are a structural base ring housing 12 pairs of structural hooks (1 active, 1 passive per pair), an extendable guide (active) ring with 3 petals, a motor-driven capture latch within each guide petal, 3 ball screw/nut mechanism pairs connected via a common linkage, 6 electromagnetic brakes (dampers), and 5 fixer mechanisms (that allow for only z-axis movement of the active ring). Two control panels in the aft flight deck and nine avionics boxes in the subfloor of the external airlock provide power and logic control of the mechanical components. The docking mechanism on the rendezvousing spacecraft (orbiter) is intended to be active, while the corresponding mechanism on the target spacecraft (ISS) is typically passive.



Extendable Guide Ring Positions

APDS Avionics Overview

Aft Flight Deck Panels

The docking system power panel (A6L) is a Rockwell-built panel that provides power for the various components of the ODS. This panel includes circuit breaker (cb) protection for all the ODS-related bus sources, as well as switches for application of logic and drive power to the APDS control panel, the APDS avionics boxes, the docking lights, and the vestibule depress valves.

The APDS control panel (A7L) is supplied by RSC-Energia and is used to control the docking mechanism operation. On the left of the panel are nine circuit breakers (cb's) that are operated as switches. The three control panel power cb's supply logic bus power to the control panel functions. The heater/data collection units (DCU) cb's provide power to heaters located around the docking ring. The H2/DCU and H3/DCU cb's also provide redundant power to each of the two DCUs. The APDS power switches supply logic power to the power switching unit (PSU). Activating these cb's also illuminates indicator lights below each cb. Eighteen status lights are located in the middle of the panel and provide the prime feedback on the operation of the docking mechanism. The right side of the panel includes the functional controls of the mechanism that allow for manual operation of the various motor-driven components. Also on the right are the controls of the backup pyro separation system.

SPEC 167 provides an alternate (backup) set of telemetry from the system. Information from the *display* is used to help monitor docking system operations. SPEC 167 details can be found in the Generic Reference Data Book.

Power Switching Unit

The PSU contains several relays with the sole purpose of distributing power, both logic and drive, to the other avionics boxes operating in the nominal docking sequence. These boxes include the docking system control unit (DSCU), docking mechanism control unit (DMCU), pressure actuation control units (PACUs), and latch actuation control unit (LACU). The DCUs are powered through the heater/DCU switches on panel A7L. The pyro firing control unit (PFCU) is powered through several other switches on both A6L and A7L panels.

When the POWER ON pushbutton is depressed, it activates a momentary relay in the PSU and begins a chain reaction of relay operations. The result is that several latching relays are set, providing the circuit flow paths for logic and drive power to be distributed to the other avionics boxes.

Docking System Control Unit

The DSCU contains extensive logic control circuits that interface with each of the remaining avionics boxes, except the PFCU. These circuits control the timing and sequencing of the automatic docking sequence. The DSCU also receives the inputs from any manual pushbutton command from the APDS control system panel and routes the inputs to the appropriate control box for execution. The DSCU is responsible for providing all feedback to the STATUS lights on the control panel as well.

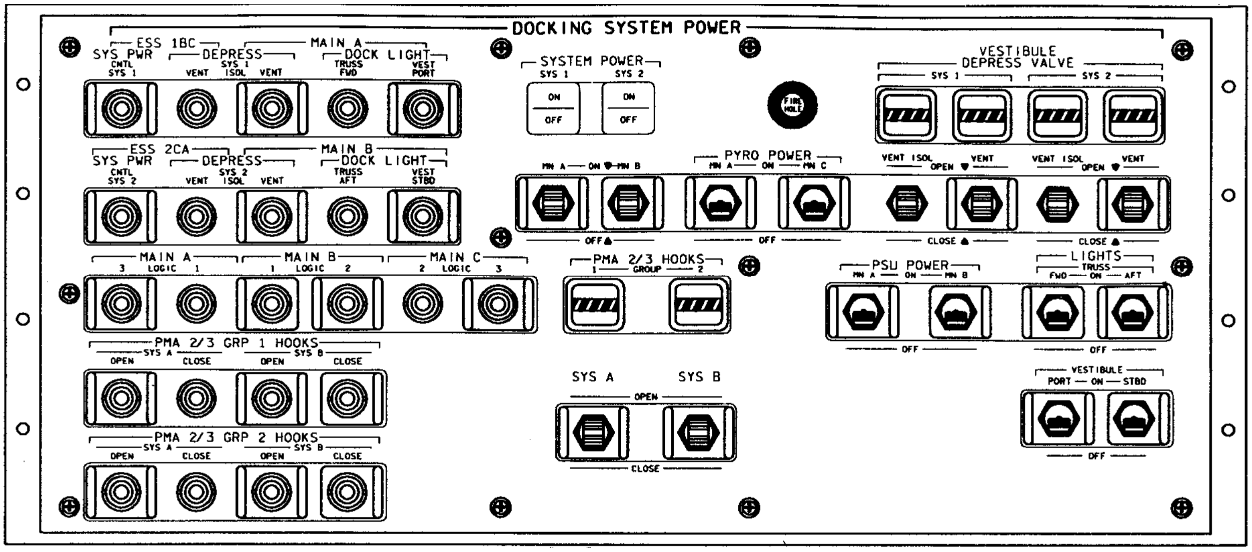
During docking, the initial contact and capture indications are routed into the DSCU. To receive a capture indication, at least one of two series of three "short" capture contacts (one contact from each of the three sensors) must be made, in addition to one of the six "long" capture contacts. When this condition is met, a latched logic loop is created, which in turn creates the capture ground buses. The latched loop can be broken only by a POWER OFF command, loss of at least two of three APDS bus powers, or loss of all six long capture contacts.

The manual commands for RING OUT, UNDOCKING, OPEN HOOKS, and OPEN LATCHES require the creation of a dedicated ground bus. This is done using the APDS CIRC PROT OFF pushbutton. All other manual commands can be accomplished without removing the circuit protection.

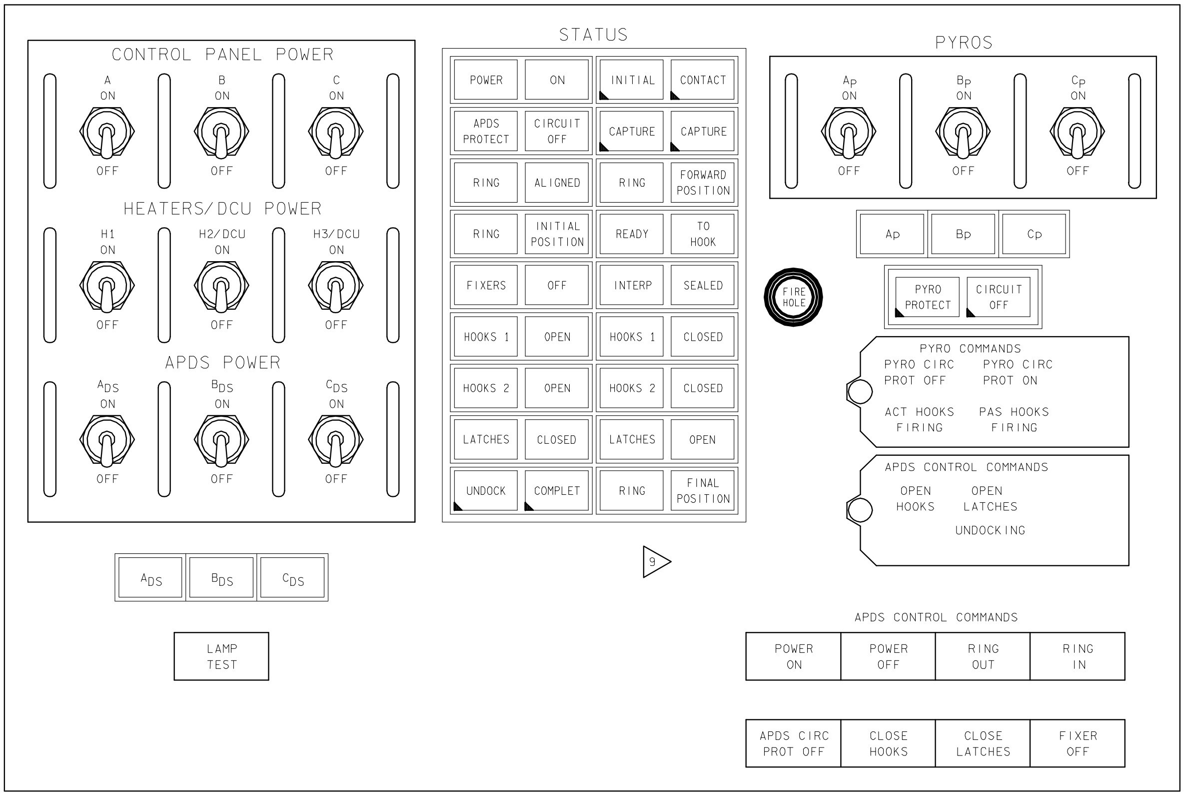
The DSCU also directly powers the fixers and the electromagnetic brakes (dampers). The fixers are energized whenever the ring is retracted during the auto sequence, and whenever the ring is manually driven in either direction. (An unwanted fixers ON command can be avoided with the FIXERS OFF pushbutton command on the control panel.) The dampers are activated 5 seconds after the capture latching logic loop is created and are deactivated with a POWER ON command in the Docking Sequence Cue Card.

Docking Mechanism Control Unit

The DMCU provides power to each of the two extend/retract actuator motors when commanded from the DSCU. The motors are single winding dc motors. The DMCU essentially has two similar halves, one to drive the ring in, and the other to drive the ring out. Instead of using latching logic, the DMCU uses mechanically latching relays to provide power to the motors. Therefore, the relays must be energized to the reset position to stop the ring drive. To accomplish this, the DSCU issues both ring drive and ring drive stop commands at the appropriate times. A ring drive stop command must be issued before a drive command in the opposite direction will be accepted because of inhibits built into the logic.



Docking System Power Panel, Panel A6L



APDS Control Panel, Panel A7L

Pressure Actuation Control Units

PACUs 1 and 2 control the operation of the active hooks, which are separated into two gangs of six each (hook gangs 1 and 2, respectively). Again, the DSCU issues the hooks open and close commands to the PACUs, based on the appropriate signals it receives. Each PACU uses latching logic to supply power to the two dc motors per actuator. The hook gangs are commanded simultaneously with one set of commands from the DSCU; i.e., they cannot be operated separately. However, if the hooks are driving in one direction, the opposing command can be issued, and the motors will reverse direction.

Latch Actuation Control Unit

The capture latch motors, one motor per latch, are continuous drive motors controlled by the LACU. The capture latches are not redundantly powered (one motor per latch with latch 1 powered via APDS POWER A_{DS}, latch 2 via APDS POWER B_{DS}, and latch 3 via APDS POWER C_{DS}). The motors are dc motors, but they drive in one direction only, rotating an eccentric cam inside the capture latch. There are 10 sensor contacts per latch that provide feedback. There are two redundant open/close contacts for motor control, two redundant open/close contacts for panel feedback, and one open/close contact for SPEC 167 telemetry per latch. For the motor to operate; for example, in the close direction, one of the two open contacts must be mated, which provides a ground path for the motor current. When the closed position is reached, the closed contacts mate, but it is the loss of the open contact shortly thereafter that causes the motor to stop driving. With the closed contacts mated, it is now ready to drive in the open direction when the proper relays in the LACU are energized. All the relays in the LACU serve to provide power and a ground path to each latch motor.

Pyro Firing Control Unit

The pyro power switches on panel A6L, and the PYRO A_P, B_P, C_P cb's on panel A7L provide the main bus and logic power to the PFCU. With these switches powered, the PYRO CIRC PROT OFF pushbutton will remove one inhibit from the logic by energizing several relays within the PFCU. This will allow the ACTIVE or PASSIVE HOOKS FIRING command from the control panel to be transmitted to each pyrobolt in the hook mechanisms. There is only one pyrobolt per hook, but there are two redundant initiators per charge.

APDS Operational Sequences (OPS)

Docking System Initialization

Configuring the SYSTEM POWER SYS 1, 2 switches on A6L panel provides three logic power buses to the Russian A7L panel. These switches also provide MN A/B power to the A6L panel for the docking lights, depress valves, etc.

Docking Mechanism Powerup

First, the PSU power switches on panel A6L are turned on to feed MNA and MNB bus power to the PSU avionics box. Next, the three HEATER/DCU cb's are turned on to activate heaters on elements of the docking mechanism. The H2 and H3 cb's also power the two DCU avionics boxes that provide telemetry data for SPEC 167 and downlink. Now, on A7L, the three control panel power cb switches are activated to provide logic power to the control panel pushbuttons and status lights. The three APDS power cb's provide logic power from the control panel to the PSU avionics box. The POWER ON momentary pushbutton activates numerous relays within the PSU to distribute logic power to the following avionics boxes: the DSCU, the DMCU, the LACU, and both PACUs. This also enables the feedback circuitry from the various mechanism microswitches, which illuminate their respective status lights on the A7L panel. The control panel also has a lamp test pushbutton that is used to test all 18 pairs of status lights and the 2 pyro circuit protect off lights.

Docking Ring Extension

The docking system is launched with the active docking ring fully retracted and aligned in its final position, the structural hooks open, and the capture latches closed. In preparation for docking, the ring must be extended to its ready-to-dock or ring INITIAL position. To do this, it is necessary to remove the inhibit that exists for manual operation of the mechanism. This is accomplished by depressing the APDS CIRC PROT OFF pushbutton. This pushbutton activates several relays that enable the logic for the manual RING OUT, OPEN HOOKS, OPEN LATCHES, and UNDOCKING pushbuttons. Without this step, these four pushbuttons are not operative.

With the inhibit removed, the RING OUT command is sent to the DMCU avionics box. This command activates two dc motors to drive the ring out to its initial position (15.7 inches from final position) at a rate of approximately 4.3 in/min. As the ring is driving, the fixers are also activated to keep the ring aligned while it drives. One second after the ring reaches its initial position, the ring motors and the fixers are automatically commanded off. The system is then powered down.

Docking

Once the orbiter is on the Vbar (or Rbar) for final approach, the docking system is powered back on. When the POWER ON pushbutton is depressed, the docking system will be ready for docking. In this timeframe, it is also necessary to close the inner airlock hatch, check the function of the airlock fan, and turn on the docking lights and cameras.

At contact, the initial contact light on A7L *may* temporarily illuminate and the ring aligned light may go off. This will cue the crew to activate the preset postcontact thrusting (PCT) sequence, using the spare digital autopilot (DAP) pbi. The PCT is designed to provide the force required to attain capture with the APDS while not exceeding dynamic loads. To enhance the probability of success, the PCT should be initiated within 2 seconds of initial contact. To prevent exceeding loads, it should not be initiated once capture is achieved.

The following steps are found in the Docking Sequence Cue Card. Once capture is achieved, the capture light illuminates. The electromagnetic brakes (dampers) are automatically energized 5 seconds post-capture to dampen relative motion between the two vehicles. When relative motion has ceased, the crew performs a

POWER ON pushbutton command to disable the dampers. When relative motion has again ceased, the docking sequence cue card calls for a set of actions to release any dampers that may still be mechanically engaged. This is accomplished by first executing a FIXERS OFF pushbutton, followed by a RING IN pushbutton to start the ring driving in. Five seconds later, the ring drive is terminated by a POWER ON pushbutton. The FIXERS OFF pushbutton is necessary to inhibit the FIXERS ON command that would automatically be issued with a ring drive command. The fixers are disabled to prevent them from engaging the ring in a potentially misaligned configuration. Once the 5-second RING IN is terminated and relative motion has ceased, an APDS CIRC PROT OFF pushbutton is executed to enable the RING OUT pushbutton. A RING OUT pushbutton is then initiated to start the ring out motion. The RING OUT is terminated 5 seconds later by a POWER OFF pushbutton followed immediately by a POWER ON pushbutton. This power cycle stops the ring drive and resets the APDS CIRC PROT and FIXERS OFF logic. Once the disable and release damper steps in the docking sequence cue card has been executed, an MCC GO is required to proceed with the next RING IN pushbutton. Conditions for MCC GO are *ring alignment and* no relative motion .

Automatic Docking Sequence

With the RING IN pushbutton and subsequent ring retraction, a FIXERS ON command is automatically initiated. The retracting ring will eventually pull the structural rings close enough together to activate the ready-to-hook sensors (three of four required to indicate RDY). The RDY signal activates the CLOSE HOOKS close command and the hooks begin driving closed. About 10 seconds after the hooks begin driving, they reach an in between sensor that stops the ring from retracting further. As the hooks drive closed, the mating surfaces will compress the pressure seals and activate three INTERFACE SEALED sensors (two of three required to indicate). Once the sets of hooks are closed, the docking sequence cue card calls for actions to load relieve the capture latches, open the capture latches, and retract the ring to the final position. An APDS CIRC PROT OFF *pushbutton*, followed by a RING OUT pushbutton is executed to extend the ring slightly (10-second drive) to relieve loads on the capture latches. The capture latches are opened with an OPEN LATCHES pushbutton, and the ring is retracted to its FINAL position with a RING IN pushbutton. The docking is then complete, and the system is powered down.

Failed Capture

For failed capture cases that result in a bounce off, it is necessary to check out the mechanism before conducting another attempt. This can be simply accomplished by fully extending the ring to the FORWARD position (20.4 inches) to verify function and realign it, and either retracting it to the INITIAL position or fully retracting it to the FINAL position and then reextending it to the INITIAL position. If the mechanism appears functional, and the cause of the failed capture is apparent, it is not necessary to delay a second attempt (from the mechanism perspective only). For cases where the mechanism captures, but either the orbiter or the ISS does not get the signal (i.e., the orbiter does not get active damping or the ISS does not go to free drift), the response can be more complicated. If the crew can determine that the relative motion appears stable and will not bottom out the mechanism, the preferred approach is to hang on and wait it out. If motion ever appears unstable or excessive, the crew may be required to open the capture latches and back away.

Manual Docking Sequence

With the exception of the active damping, the entire docking sequence can be completed manually by the crew. Pushbuttons are available to command the ring in or out, open or close the hooks, open or close the capture latches, and disengage the fixers.

Undocking Timeline

Prior to undocking, the external airlock and internal airlock hatches must be closed and the ISS verified ready for undock, including the release of any PMA hooks (located on the ISS docking ring) used for structural margin. Again, the docking lights and cameras will be turned on. The airlock vestibule will be depressed using the switches on A6L, and leak checks will be performed. With that complete, the docking system will be powered up for undocking.

The APDS circuit protect acts as an inhibit to using several other pushbuttons, as mentioned earlier. When the APDS CIRC PROT OFF pushbutton is depressed, the UNDOCKING, OPEN HOOKS, OPEN LATCHES, and RING OUT pushbuttons are enabled. The undocking sequence nominally requires just the APDS CIRC PROT OFF and UNDOCKING pushbuttons to be pushed. (In certain failure cases, the OPEN HOOKS and OPEN LATCHES pushbuttons could be required.) By depressing the UNDOCKING pushbutton, the hooks are commanded open. As they release, four spring plungers compressed between the mating surfaces, with a combined spring force of approximately 700 lb, impart a small separating velocity on the ISS/orbiter. The sep burns are then performed, and the docking system is powered off.

Contingency Undock

This procedure assumes the orbiter hooks have failed closed during a previous undocking attempt. This would require use of the pyro system to separate. If the failed hooks are on the ISS side, the pyro system for the passive hooks can be used from the orbiter side to effect undocking. The pyro power switches on A6L energize four buses to the PFCU avionics box. The pyro cb’s on A7L enable three logic power buses to the PFCU. Depressing the PYRO CIRC PROT OFF pushbutton activates numerous relays within the PFCU and essentially enables the active and passive HOOKS FIRING pushbuttons.

If the firing of the hook pyro bolts does not result in separation of the two vehicles, the only remaining option is for the crew to perform an extravehicular activity (EVA) to remove the 96 bolts that attach the vestibule to the external airlock. The interface is held via specially designed quick-release clamps while the bolts are removed.

Operational Notes of Interest

IFM Workarounds

Because of the number of unknowns with the Russian avionics, an in-flight maintenance (IFM) procedure was deployed that would bypass the avionics and directly drive any motor on the APDS. The procedure has the crew access the American-made feedthrough connectors in the external airlock; the connectors are located in "bubbles" behind closeout panels. The connector required for the intended operation is demated and jumpers from the IFM pin kit are attached between the power and ground sockets in the connector and the IFM breakout box. When the breakout box is activated, the motors drive in the intended direction. With this procedure, however, feedback is lost due to the demated connector and must be accounted for before the procedure is accomplished. The IFM was originally intended as a backup to open the hooks should there be a power or avionics problem during undocking. However, the procedure was expanded to include the capability to drive any motor in any direction.

Power On Time Constraints

The avionics boxes have a power on time constraint of 2 hours, after which they must be off for 30 minutes before being repowered. This is due to heat buildup concerns of continuously energized relays within the boxes.

Pushbutton Operation

The manual pushbuttons on the APDS control panel should not be depressed for any more than 2-3 seconds. This is because pushing those pushbuttons activates momentary relays inside the DSCU, and the relays could overheat if they are energized for too long.

In addition, each pushbutton on the A7L panel covers a set of electrical contacts. To ensure a positive electrical connection when depressing a pushbutton, the standard Russian training procedure is to instruct crews to use a “two fingers for two seconds” rule. This rule ensures that the pushbutton is fully and evenly depressed, making a good electrical connection.

Electrical Bus Failures

The Russian design philosophy within the avionics utilizes three separate electrical paths; two of the three are required to activate any particular function. For feedback from sensors external to the avionics boxes, the three paths typically are combined into two paths to the sensors with the APDS A logic bus common to both paths; i.e., A and B complete through one sensor contact, A and C through the other. In this way, with any two buses powered, the system can complete its function. Conversely, however, if any one contact shorts to ground, two of the three paths associated with that function will be activated and possibly disrupt the system operation. This is the basis for all the avionics single-point failures.

With this design, a workaround was implemented such that with any single sensor contact shorted to ground, the APDS A logic bus can be powered off to regain full manual functionality of the system. It does not, however, work very well when the DMCU is involved (ring position sensors), because the removal of one power leg must occur within a short time if commanding ring drive. The relays in the DMCU are not powered symmetrically like the other boxes, so the 2-of-3 voting scheme is not entirely valid. Two commands are still required to activate the ring drive motors, but only one path (A or C) needs to be satisfied to stop the ring drive. There are workarounds for this scenario, but they are not as simple or straightforward.

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2.20 PAYLOAD AND GENERAL SUPPORT COMPUTER

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Description

The payload and general support computer (PGSC) is a laptop portable computer used either as a standalone computer or as a terminal device for communicating with other electronic systems. The PGSC is one element of the command and data services provided by the Space Shuttle Program (SSP). These computers are used in many different activities.

Experiments

PGSCs are used in the middeck or flight deck to interface with flight-specific experiments that may be located in the cabin or payload bay. The PGSCs are used to monitor experiment data and/or issue commands to payloads or experiments in the payload bay.

Orbiter Communications Adapter

The orbiter communications adapter (OCA) is a card that is installed in the expansion tray to provide an interface to either the orbiter S-band PM system or the Ku-band system. While in the S-band mode, the OCA acts as a modem and allows electronic file transfers via one of the air-to-ground (A/G) audio loops, usually A/G 2 through the payload specialist (PS) audio panel. The A/G 2 loop provides a bandwidth of 32 kbps. The Ku-band system is capable of using a bandwidth of 128 kbps, in addition to one A/G loop for uplinks, thus enabling a higher data rate transfer. In the Ku mode, the downlink bandwidth could be in either 2 or 4 Mbps. Electronic file transfers include personal mail to individual crewmembers; Flight Data File (FDF) procedures; drawings; whiteboard, which is a real-time system of displaying what a person in MCC is sketching on a board; and video conferencing, which provides real-time video to and from MCC and displays the video on the PGSC screen.

Spacehab

With Spacehab module missions, PGSCs in the Spacehab provide an interface to Spacehab systems data and to experiments in Spacehab.

PDRS

On missions with RMS operations, PGSCs are loaded with two RMS Situational Awareness applications. The RMS situational awareness display (RSAD) provides current joint angle information in relation to reach limits and singularities. It also has options to display other information such as position and attitude. Dynamic Onboard Ubiquitous Graphics (DOUG) provides an artificial simulated bird’s eye view of the shuttle and Space Station from any perspective.

Rendezvous

During missions that will deploy/rendezvous with a payload or that will dock with Space Station, PGSCs are used as a tool to aid the crew’s situational awareness about the orbiter's approach/separation to/from the target. Other tools used in conjunction with the PGSCs include:

- Handheld LIDAR (HHL)
- Pulse code modulation master unit (PCMMU) decommutation software (PCDECOM).
- Rendezvous proximity operations program (RPOP)
- Trajectory control sensor (TCS)

The above are used for the tools for rendezvous and docking (TRAD) system.

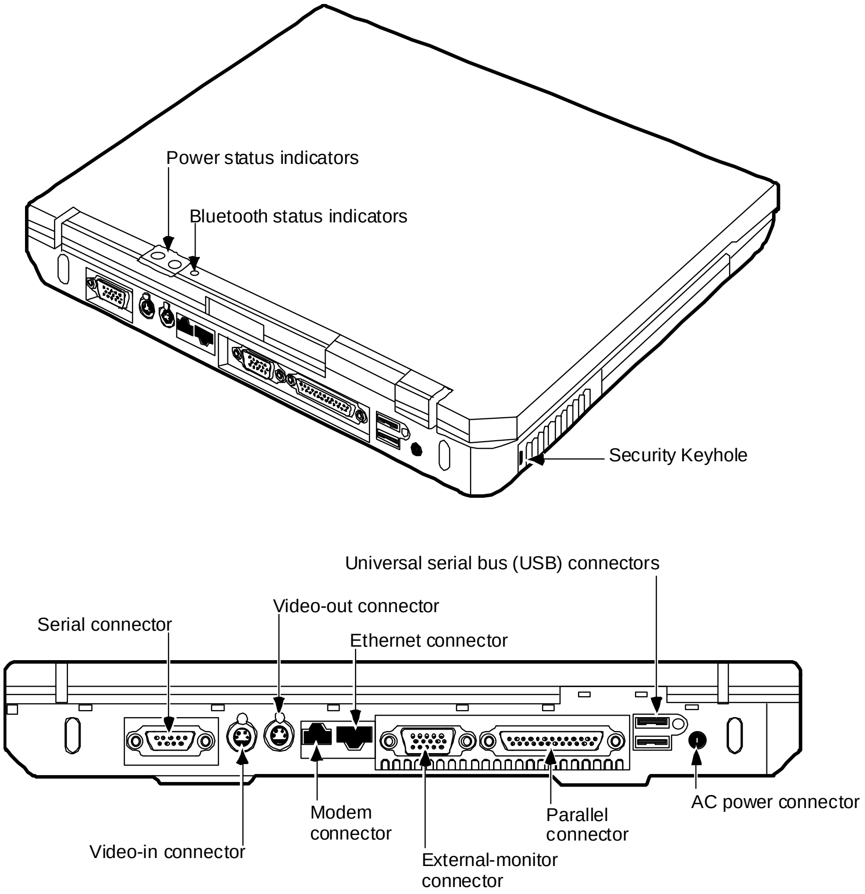
Deorbit

The Deorbit Manager application can be used to determine landing opportunities, deorbit targeting information, deorbit footprint information, as well as entry and landing c.g. data. This application is used in the event that a contingency deorbit is necessary with no communication with the ground.

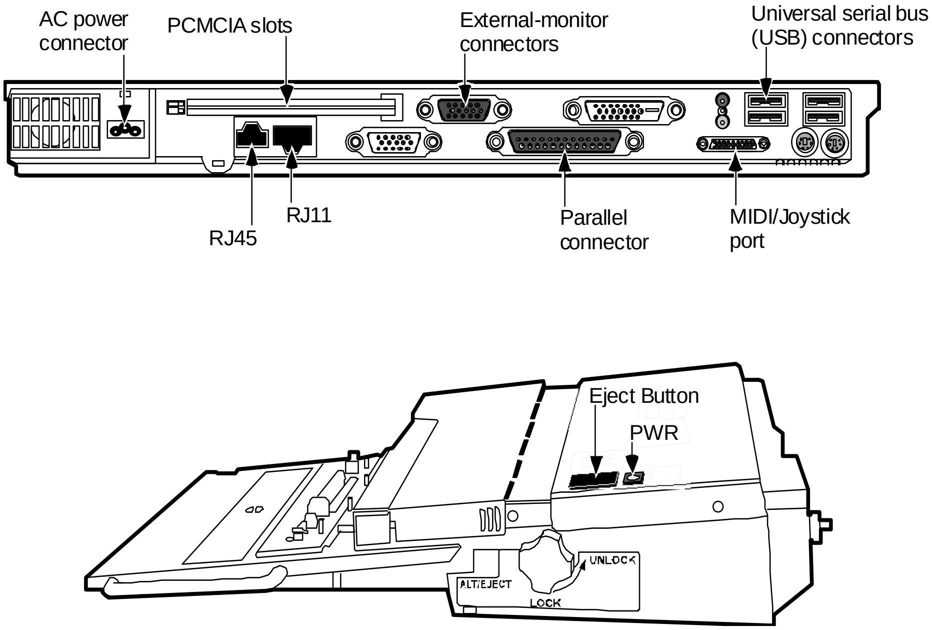
Equipment

Equipment flown to support PGSC activities includes:

- IBM 760XD laptop
- RS-422 and RS-232 Y - cables to interface multiple PGSCs
- PCMMU data cable to interface the orbiter PCMMU data to the PGSC
- RS-422 PDIP cables to interface PGSC with equipment located in the payload bay
- Cables to interface an HHL or TCS to a PGSC
- Expansion tray to provide additional ports to the PCMMU payload bay equipment
- OCA card to interface with orbiter communications systems
- TV tuner to interface orbiter CCTV signals to a PGSC



A31P PGSC without Expansion Unit



A31P Expansion Unit

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2.21 PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM (PDRS)

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Description

The PDRS consists of the hardware, software, and interfaces required to remotely hold and control the movements of a specified object, usually a payload, and to remotely observe or monitor objects or activities.

The PDRS includes the remote manipulator system (RMS), the manipulator positioning mechanisms (MPMs), the manipulator retention latches (MRLs), the manipulator controller interface unit (MCIU), and dedicated displays and controls. The PDRS also interfaces with other orbiter systems, such as the SM GPC, the electrical power distribution system (EPDS), and the CCTV.

Remote Manipulator System

The RMS is the mechanical arm portion of the PDRS. The arm can perform several tasks, such as deploying and retrieving a payload, providing a stable platform for EVA crewmember foot restraints or workstations, mating space station components, and taking payload bay surveys. The RMS is capable of maneuvering up to 586,000 pounds.

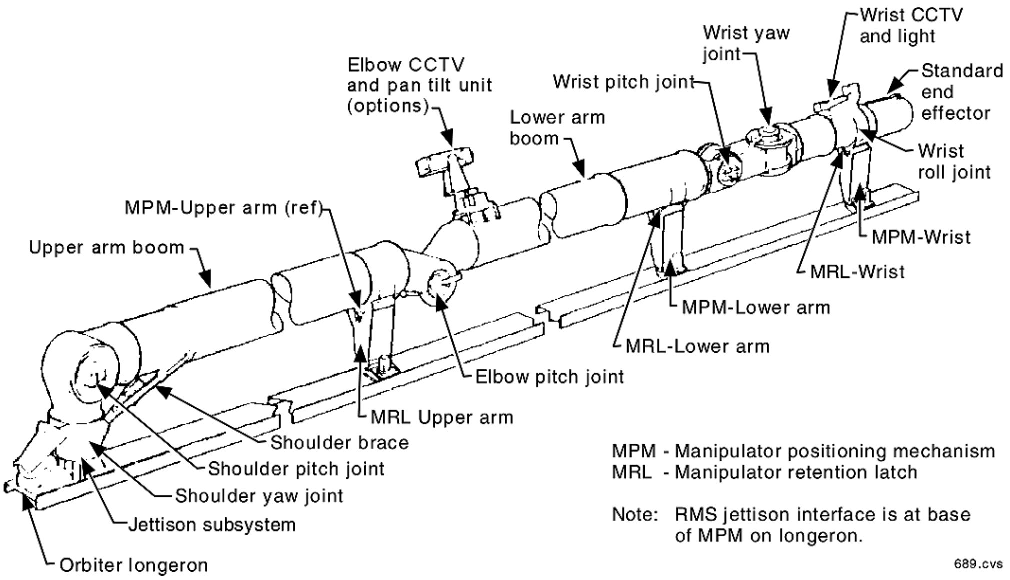
The RMS is installed on the port longeron of the payload bay for those missions requiring it. Some deployable payloads do not require use of the RMS.

NOTE

> Original concepts called for an optional second arm to be placed along the starboard longeron. It is no longer under consideration; however, there are still residual references to the starboard arm on orbiter panels and controls.

The available starboard infrastructure *is* used for the orbiter boom sensor system (OBSS) that will be employed for *all* missions to inspect the orbiter thermal protection system.

When cradled, the arm rests on three MPM pedestals that contain MRLs to secure the arm during launch, entry, and periods of inactivity. When the payload bay doors are closed,

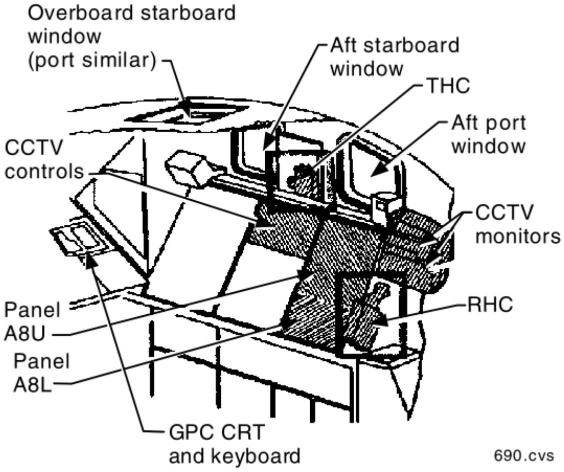


MPM - Manipulator positioning mechanism
MRL - Manipulator retention latch

Note: RMS jettison interface is at base of MPM on longeron.

RMS-Stowed Position and General Arrangement including during launch and entry, the MPM is in the rolled in, or stowed, position. After the doors are opened on orbit, the MPM must be rolled out, or deployed, to not interfere with payload clearances.

The arm has six joints connected via structural members (booms) and a payload capture/ release device (end effector) on the end. The arm is 50 feet 3 inches long and 15 inches in diameter. The arm has 6 degrees of freedom, three translational (X, Y, and Z) and three rotational (P, Y, and R). They are in reference not only to the orbiter but also to the end effector or the payloads it can carry. It weighs 905 pounds; the total system weighs 994 pounds.



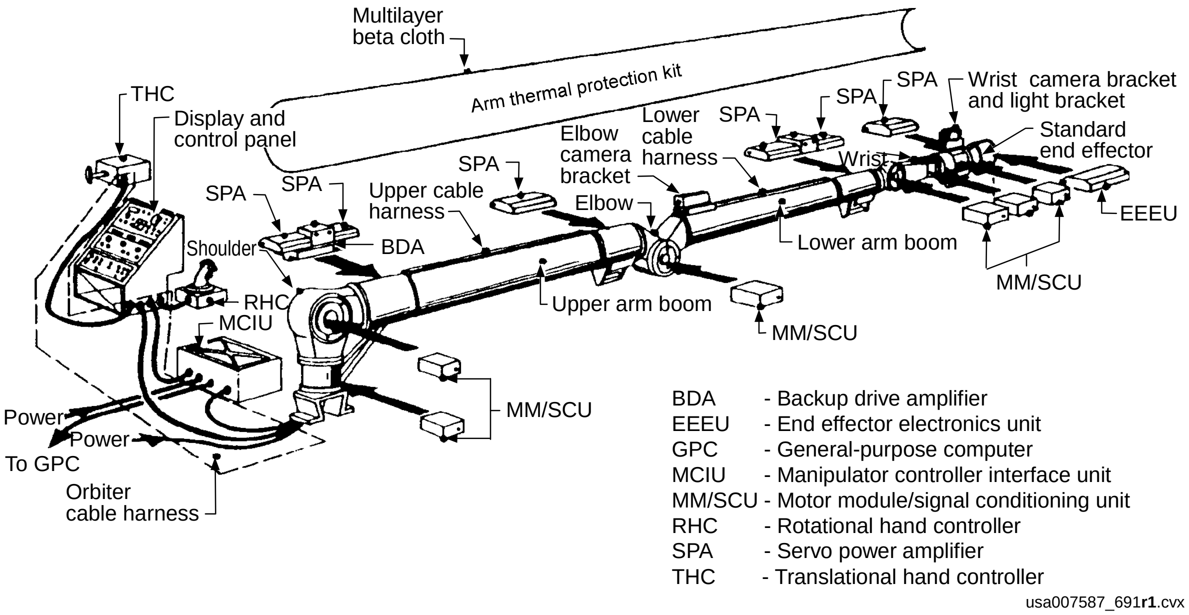
RMS Displays and Controls, Aft Station

On-orbit RMS operations are performed by a team of two arm operators, R1 and R2. R1 controls the actual RMS trajectories and is stationed on the port aft flight deck. R2 is stationed on the starboard aft flight deck and controls DPS inputs, payload retention latch assemblies (PRLAs), and cameras.

The RMS has a built-in test capability to detect and display critical failures. It monitors the arm-based electronics (ABE), displays and controls (D&C), and the manipulator controller interface unit (MCIU) firmware checks. Failures are displayed on a light matrix on panel A8U and on the DPS display and are available for downlink through orbiter telemetry.

All the major systems of the ABE are monitored. The MCIU checks the integrity of the communications link between itself and the ABE, D&C, and the orbiter SM GPC. The MCIU also monitors end effector functions, thermistor circuit operation, and its own internal integrity. The computer checks include an overall check of each joint's status via the consistency check, encoder data validity, and the proximity of the arm to reach limits, soft stops, and singularities.

The RMS can be operated only in a weightless environment because the arm motors are unable to move the arm's weight under the influence of Earth's gravity. Each of the six joints has an extensive range of motion, allowing the arm to reach across the payload bay, over the crew compartment, or to areas on the undersurface of the orbiter. Arm joint travel limits are annunciated to the flight crew arm operator before the actual mechanical hard stop for a joint is reached.



RMS Components

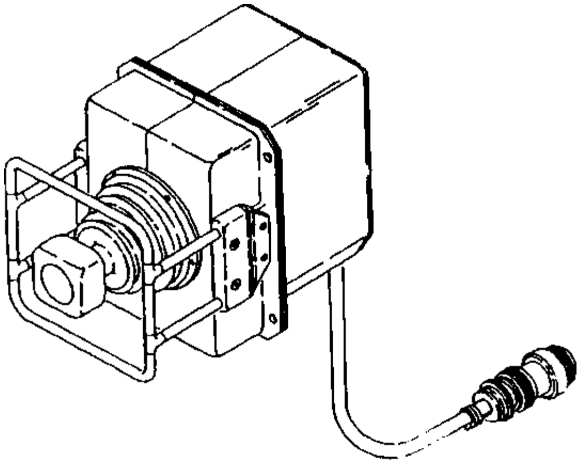
Manipulator Controller Interface Unit

The principal function of the MCIU is to handle and evaluate the exchange of information between itself and the SM GPC, the displays and controls, and the RMS. The MCIU manipulates data, analyzes and responds to failure conditions, and controls the end effector auto capture/release and rigidization/derigidization sequence logic.

A spare MCIU is usually flown on RMS flights and can be changed out with a failed MCIU in flight. Procedures for changing out the MCIU are contained in the All Vehicle IFM Checklist.

Translational Hand Controller

The THC allows an operator to control the three-dimensional linear motion of the RMS point of resolution (POR) by means of manual inputs. The POR is a software-defined point about which all translations and rotations occur. For an unloaded arm, the POR is at the tip of the EE. For a loaded arm, the POR is usually defined to be at or near the payload geometric center, but can also be defined at a berthing interface or the payloads center of gravity. The POR rate commands are proportional to the deflection of the controller.



Translational Hand Controller

The hand controller provides three independent electrical inputs to the MCIU, one for each axis. The THC incorporates in each axis a spring and viscous damper, which provide suitable force feel characteristics to aid the operator.

Rotational Hand Controller

The RHC is a three-axis controller that provides electrical control signals for pitch, yaw, and roll control of the RMS. Control signals are proportional to manual input displacements in each of the three mutually perpendicular axes. The RHC also provides additional RMS controls through three switches located on the handgrip. The three switches are:

- ***RATE HOLD*** pushbutton. This pushbutton is mounted on the top of the grip assembly and is thumb-operated. The pushbutton is used to maintain the POR translational and rotational rates at a commanded value. Rate hold is engaged when the pushbutton is depressed momentarily. Rate hold is disengaged when the pushbutton is again depressed momentarily. The rates can be biased once rate hold has been actuated and the hand controllers have been returned to detent by deflecting a hand controller a second time.
- ***RATE*** switch. The *VERNIER/COARSE RATE* switch is a slide switch that produces the signal used by the RMS software to determine the POR rate limits when operating in resolved-rate modes and the joint rate limits when operating in *SINGLE* mode. The switch is configured to produce coarse (faster) rates when pushed away from the operator and vernier (slower) rates when pushed toward the operator.
- ***CAPTURE/RELEASE*** switch. This rocker switch is mounted on the aft part of the grip assembly and is used to capture and release payloads. The lower part of the switch sends the capture signal to the end effector, and the upper part sends the release signal. A finger-operated guard is provided over the release part of the switch to prevent inadvertent actuation during normal operation of the RHC.

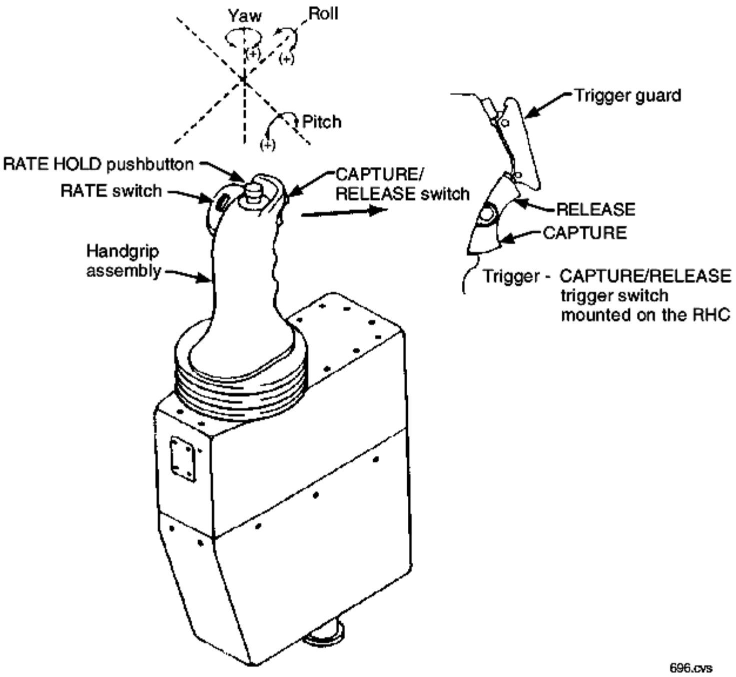
Manipulator Arm Drive System

Each joint of the manipulator arm is driven electromechanically, and the drive trains for all joints are similar, except for gear ratio. Each of the six joints has an identical reversible, brushless DC motor that is used in both prime and backup modes of operation. Motor shaft position is provided by a commutation scanner assembly consisting of two optical commutators on the input side of each motor. One commutator electronically interfaces with the primary motor drive amplifier and one electronically interfaces with the backup drive amplifier.

The drive motor is held in a quiescent state by the brakes, which apply a brake pad to a contact surface on the motor shaft. Continuous application of 28 V DC to the brake is required to disengage the brake.

Each joint contains a gear train that differs in gearing ratios. Dry lubrication is used throughout the gear trains. Backlash is minimized by the use of close tolerance gears and a backlash control device.

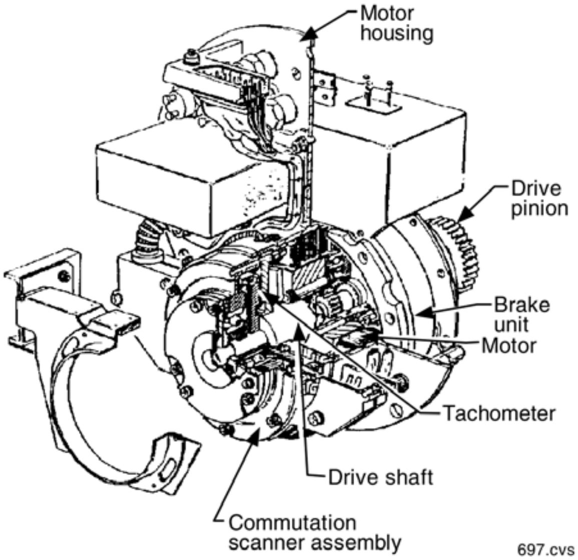
An electro-optical encoder is fitted to the gear box output of each joint. The encoder is used to sense the angular position of the joint. The encoder uses an LED light source and a single disk. The encoder in the wrist roll joint has a hole in the center to allow cables to pass through.



Rotational Hand Controller

Each joint in the arm contains a digital servo power amplifier (SPA). The SPA is associated with the motor module and position encoder for that joint. The major function of the SPA is to provide a drive signal to the motor. The SPA conditions incoming +28 V DC MN A power to the appropriate level needed to drive the joint, and regulates power to the other components of the motor module. The SPA also performs several built-in test equipment (BITE) checks to ensure it is functioning properly. Should one of these tests fail, a master alarm and SM message will be generated.

One backup drive amplifier is located in the shoulder. The backup drive amplifier conditions +28 V dc MN B power for arm use and provides drive signals to the selected joint motor.



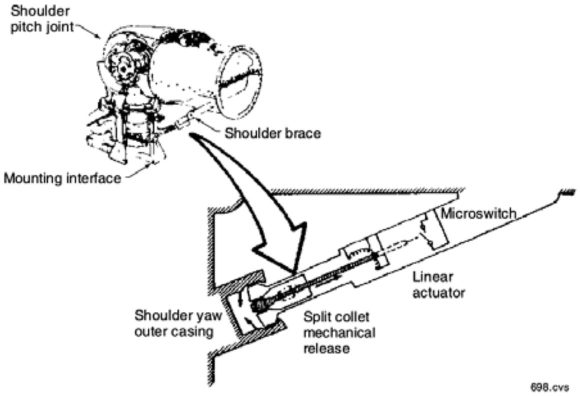
Motor Module

Mechanical Arm Assembly

The manipulator arm drive system components, the arm cable harness, and arm structural components form the mechanical arm assembly. The structural components consist of joint housings, electronic housings, and arm booms.

Each joint is fitted with a mechanical stop that is capable of stopping the joint from moving. This mechanical stop is known as the hard stop

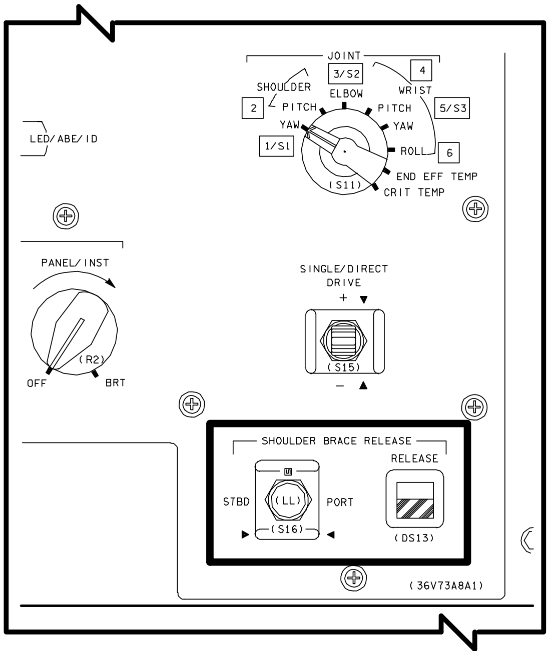
The shoulder brace is designed to minimize the high-pitch-axis moment loading on the shoulder pitch gear train during the launch environment. On orbit, the brace is released to allow RMS operations. The shoulder brace is designed to enable ground engagement of the release mechanism using an external power source. It cannot be relatched on orbit, but there is no requirement to relatch the brace before reentry and landing. A plunger is extended between two pieces of tapered metal, pushing the ends of the pieces outward, wedging the ends of the receptacle on the outer casing of the shoulder yaw joint, and engaging the shoulder brace.



Shoulder Brace

Shoulder brace release is controlled by the lever-locked *SHOULDER BRACE RELEASE* switch on panel A8U. Positioning the switch to *PORT* releases the brace, which withdraws the plunger by an electrical linear actuator. This allows the tapered metal pieces to relax and move toward each other, which permits the brace to slide out of the shoulder yaw outer casing, unlatching the brace. The switch must be held 2 seconds after the *RELEASE* talkback indicator on panel A8U indicates gray because the microswitch indicating release is not at the end of the plunger's travel. A barberpole indication shows that the shoulder brace is not released.

The arm boom assemblies are two thin-walled tubular sections called the upper and lower arm booms. The arm booms are structures designed to meet stiffness criteria. To achieve an efficient stiffness/weight design and to maintain simplicity of construction, a circular section graphite/epoxy composite design has been implemented. End flanges are made of aluminum alloy and are bonded and bolted to the graphite/epoxy tubular sections. Provisions are made for the installation of electrical cable harness assemblies along the length of each arm.



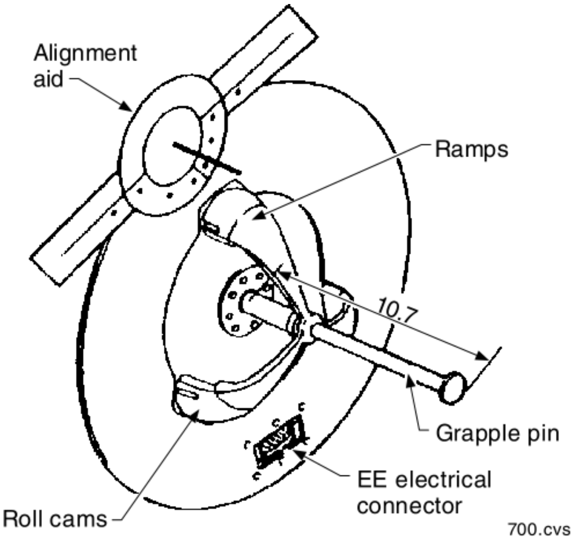
SHOULDER BRACE RELEASE Switch and Talkback Indicator on Panel A8U

On top of the lower arm and immediately below the elbow joint interface is a mount for installation of an elbow CCTV camera and pan/tilt unit.

Wire arm cable harnesses are designed to minimize electrical cross-talk and electromagnetic interference. They are of a weight-efficient design and are installed on the outside of the upper and lower arm booms, utilizing a lightweight mounting technique with adhesive Kapton tape. Sufficient slack is allowed for relative thermal expansion and contraction between the cables and arm booms and for movement of the joints.

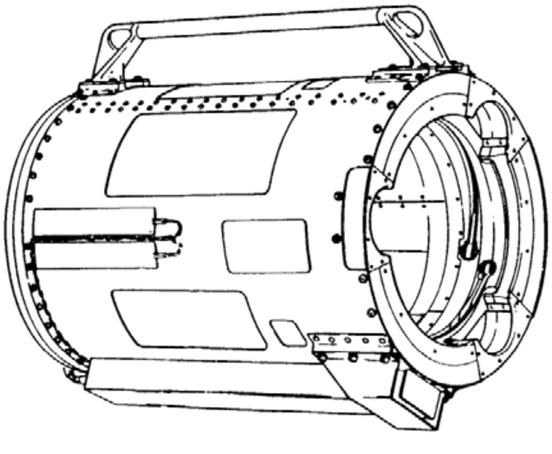
End Effectors

The RMS can operate with standard or special-purpose end effectors. The standard end effector can grapple a payload, keep it rigidly attached as long as required, and then release it. Special-purpose end effector designs are available and can be built and installed on the RMS during ground turnaround in place of the standard end effector. A male plug on the optional electrical flight grapple fixture can receive electrical power through a female connector located in the special purpose end effector.



Electrical Flight Grapple Fixture

The standard end effector drive system captures or releases a payload using a rotating ring at the open end of the unit to close three wire snares around the payload-mounted grapple fixture. The entire snare ring is then pulled into the end effector until the grapple fixture base plate is flush against the tip of the end effector. This process is called rigidizing the end effector. To release a payload, the carriage is extended or derigidized to a point where there is no axial tension on the grapple fixture probe, and the snares are then opened.



Standard End Effector

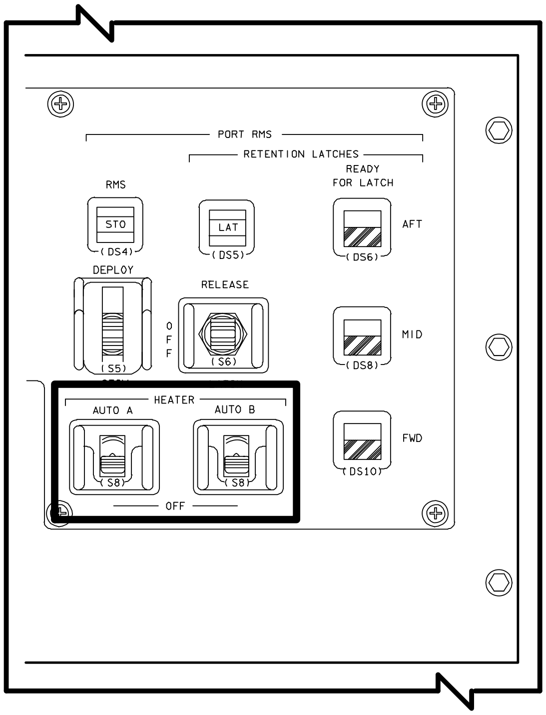
Thermal Protection

The RMS has both passive and active thermal control systems. The passive system consists of multilayer insulation blankets and thermal coatings that reflect solar energy away from the arm and aid in controlling the temperature of the hardware. The blankets are attached to the arm structure and to each other with Velcro. Exposed areas around the moving parts are painted with a special white paint.

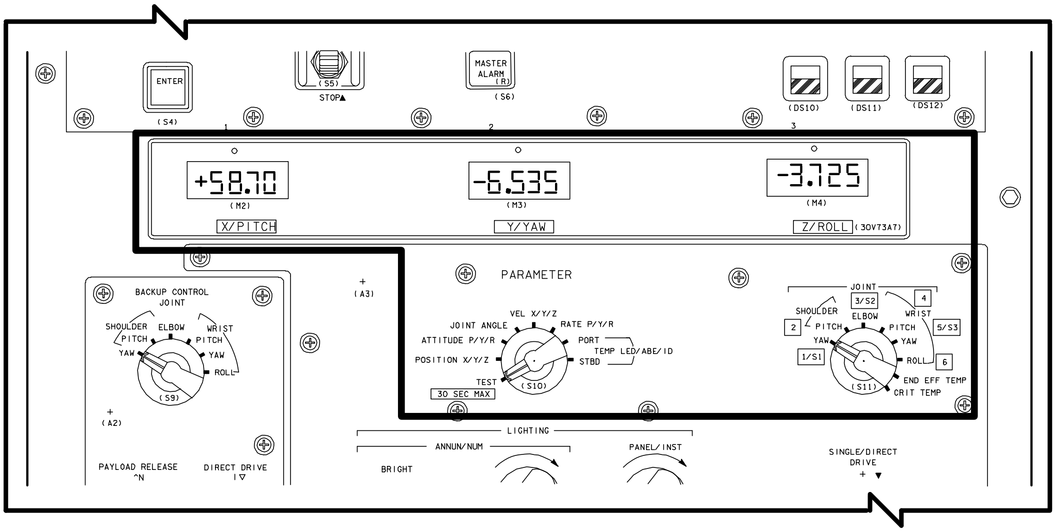
To maintain the arm's temperature within predetermined operating limits, an active system of 26 heaters on the arm *consumes* up to 525 watts of power at 28 V DC. There are two redundant heater systems, one powered from the orbiter's MN A DC bus and the other from the MN B DC bus. Only one system is required for proper thermal control. The heaters in each system are concentrated at the arm's joint and end effector to heat the electronics and ac motor modules. The heaters are enabled by the *PORT RMS HEATER A* and *B* guarded switches on panel A8L. When the switches are positioned to *AUTO*, the heaters are thermostatically controlled *by 12 thermistors located along the arm. The joint thermistors turn the heaters* on at 14° F and off at 43° F. The therm*istor* in the end effector turns the heaters on at 23° F and off at 52° F.

LED numerical displays 1, 2, and 3 in the middle of panel A8U can be used in conjunction with the *JOINT* and *PARAMETER* rotary switches to display arm temperatures in degrees Fahrenheit along with identification numbers.

For example, when the *JOINT* switch is positioned to *END EFF TEMP* and the *PARAMETER* switch is positioned to *PORT TEMP*, LED 1 displays the commutator's temperature, LED 2 displays the end effector electronics' temperature, and LED 3 identifies the location *as* the end effector.



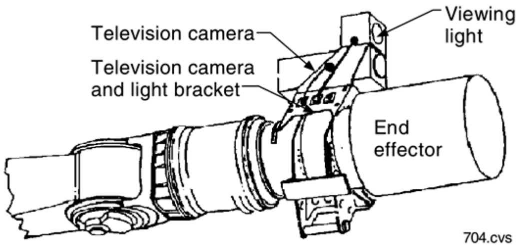
PORT RMS HEATER Switches on Panel A8L



LEDs and Rotary Switches on Panel A8U

CCTV

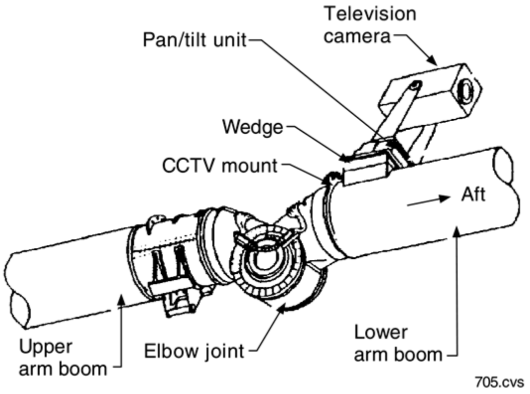
The orbiter's CCTV aids the flight crew in monitoring PDRS operations. Mounted on the end effector are a spotlight and a fixed CCTV camera that can be zoomed. A CCTV with pan and tilt capability is located below the elbow. In addition, four CCTV cameras in the payload bay can be panned, tilted, and zoomed. Keel cameras, which look up from the bottom of the payload bay, may be provided, depending on the mission tasks. LED illuminators normally are mounted around the lens of all of the CCTV cameras to add additional lighting when required. The two CCTV monitors at the aft flight deck station can each display any two of the CCTV camera views simultaneously with split screen capability. Two views show on the same monitor, which allows crewmembers to work with four different views at once. Crewmembers can also view payload operations through the aft flight station overhead and payload bay viewing windows. (See Section 2.3 for CCTV operations.)



Wrist CCTV and Light Configuration

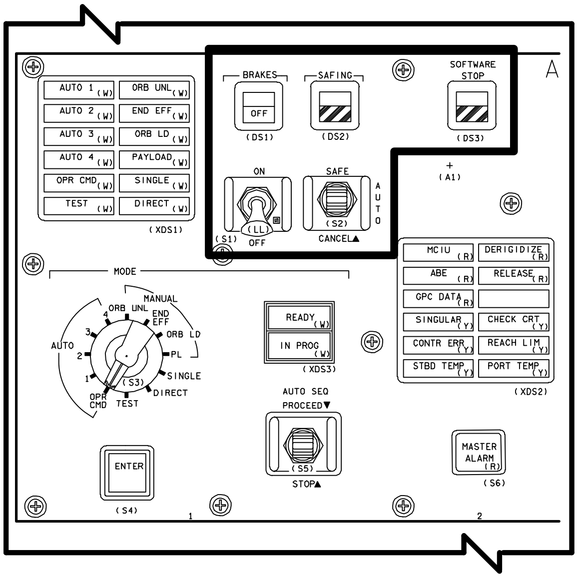
Reach Limits, Soft Stops, and Hard Stops

Each RMS joint has travel limits. As an example, the wrist pitch joint can be physically moved positive or negative 121.4° to the mechanical hard stop. At positive or negative 114.4°, software warns the RMS operator that the arm is approaching its end of travel by activating the yellow *REACH LIM* light and the red *MASTER ALARM* pushbutton indicator on panel A8U, sounding the master alarm, displaying a computer fault message, sounding an SM tone, and displaying a REACH LIMIT indication on the DPS display.



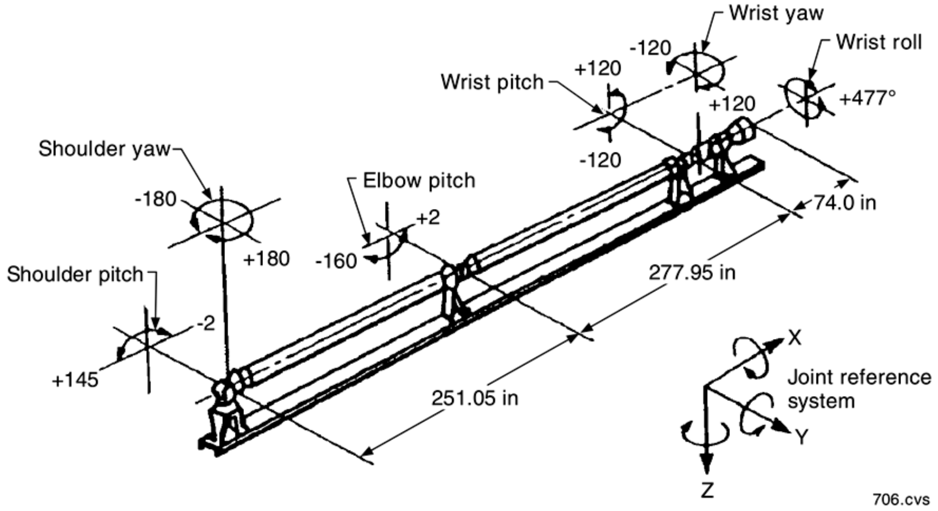
Elbow CCTV System

If the operator continues driving the joint past the reach limit, the next warning is the soft stop. At this point (positive or negative 116.4° for the wrist pitch joint), the *SOFTWARE STOP* talkback on panel A8U (top center) will indicate barberpole. The arm can only be operated in *SINGLE, DIRECT*, or *BACKUP* modes once it reaches a soft stop. If the operator continues to drive the joint in this direction, motion will stop at positive or negative 121.4°. All joint angles equal 0° when the arm is cradled.



BRAKES and SAFING Switches and Talkbacks and SOFTWARE STOP Talkback on Panel A8U

Joint	Reach limit	Soft Stop	Mechanical stop
Shoulder yaw	+175.4°	+177.4°	+180°
	-175.4°	-177.4°	-180°
Shoulder pitch	+2.6°	+0.6°	-2°
	+140.4°	+142.4°	+145°
Elbow pitch	-2.4°	-0.4°	+2.4°
	-155.6°	-157.6°	-161°
Wrist pitch	-114.4°	-116.4°	-121.4°
	+114.4°	+116.4°	+121.4°
Wrist yaw	-114.6°	-116.6°	-121.3°
	+114.6°	+116.6°	+121.3°
Wrist roll	-440.0°	-442°	-447°
	+440.0°	+442°	+447°



Joint Travel Limits

Safing and Braking

Safing and braking are the two methods available for bringing the arm to rest. Safing can be accomplished by positioning the *SAFING* switch at the top of panel A8U to *SAFE*, which brings the arm to rest using the servocontrol loops. When the switch is positioned to *AUTO*, safing is initiated by the MCIU when certain critical built-in test equipment failures are detected *or communication with the SM GPC is lost*. The *CANCEL* position removes the safing state. The *SAFING* talkback indicator indicates gray when safing is not in progress and barberpole when safing is in progress.

In the initial stages of PDRS operations development, safing was considered the primary method whereby the MCIU could quickly respond to a failure condition and arrest the motion of the arm. MCIU initiations of auto brakes was added later to respond to certain failure conditions in the SPA. The *BRAKES ON/OFF* switch and talkback indicator are located on panel A8U. The brakes are manually disengaged by moving the switch to the *OFF* position. This setting sends a hardwired signal to the brake logic function in the MCIU. The MCIU then commands the brakes to be lifted or removed from restraining the joints on the arm. The operator may reapply the brakes by placing the switch in the *ON* position. The arm operator is trained to respond to any suspected *RMS* failure condition by immediately placing the *BRAKES* switch to the *ON* position while operating in any mode except *DIRECT DRIVE* and *BACKUP*. In *DIRECT DRIVE* the operator responds by moving the *MODE* rotary switch to a non-*DIRECT DRIVE* position. In *BACKUP* the proper response is to place the *RMS SELECT* switch to *OFF*. Use of the *SAFING* switch is not recommended.

Manipulator Positioning Mechanism

The MPM is composed of a torque tube, the MPM pedestals, which are mounted on the torque tube, the MRLs, and the jettison system.

MPM Pedestals

The *port MPM* houses the separation system and *provides* the cradling units upon which the arm rests. There are four support assemblies. One is a shoulder attach point located at an orbiter
X-value of 679.5. The support assembly at the *port* shoulder attach point is unique. Since the RMS is attached to the orbiter at this point, it does not contain an MRL, but does contain a separation system that is part of the MPM.

The port MPM pedestals are located at X-values of 911.05, 1189, and 1256.5. The three pedestals are similar. Each contains two 45° saddle interfaces for cradling the arm and a retention latch to lock the arm in place. The mating hardware for the arm consists of two 45° mating plates to rest on the support saddle and a latch striker held by the retention latch.

The support assembly also contains redundant sensors or microswitches to indicate ready-to-latch and latched/release conditions.

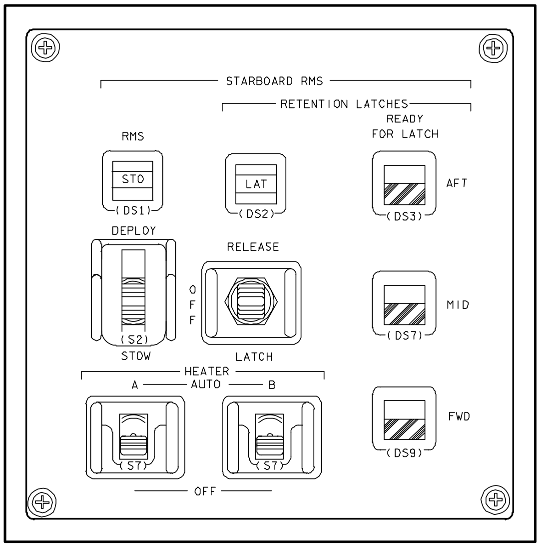
The starboard *pedestals* for the OBSS are located at X values of 679.5, 911.05, and 1256.5. All three of these contain MRLs. The OBSS has additional bracing at the forward MPM attach point to help with loads in the X direction. A power connector is engaged in the forward MPM when the MRL is latched. This provides heater power to the OBSS while it is latched in the MPMs.

MPM Torque Tube

The MPM drive system consists of dual redundant motors rotating a torque tube that in turn drives the rotary actuators that move the RMS pedestals. The torque tube rotates the arm from its stowed position to its operational position outside the payload bay. The drive mechanism has two overcenter lock components, one of which locks in the deployed position and the other which locks in the stowed position. The drive system contains microswitches needed for stow/deploy indications. Current flight rules prohibit loaded arm operations from the stowed configuration.

The *PORT RMS DEPLOY/STOW* switch is on panel A8L. The talkback above the switch indicates *STO* when the MPMs are in the stowed position, *DPY* when they are deployed, and barberpole in transit. The status of the shoulder MPM can be monitored on the SPEC 94 PDRS CONTROL display (MPM STO/DPLY).

The *STBD RMS DEPLOY/STOW* switch is also located on panel A8L. The talkback and microswitch operate the same as the Port MPM. An item entry on SPEC 94 PDRS CONTROL is used to select Port or Starboard MPM data for display.



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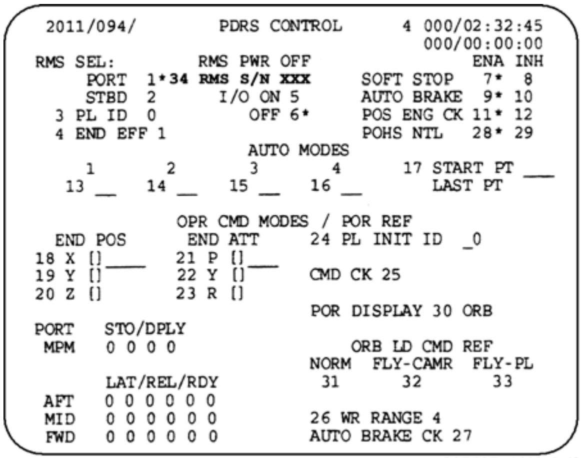
STBD RMS Controls on Panel A8L



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 2011/094/          PDRS CONTROL       4 000/02:32:45
                                         000/00:00:00
RMS SEL:          RMS PWR OFF                 ENA INH
    PORT  1*34 RMS S/N XXX     SOFT STOP    7*   8
    STBD  2       I/O ON 5     AUTO BRAKE   9*  10
  3 PL ID  0         OFF 6*    POS ENG CK  11*  12
  4 END EFF 1                  POHS NTL    28*  29
                     AUTO MODES
     1        2        3        4       17 START PT ___
   13 __    14 __    15 __    16 __         LAST PT

                 OPR CMD MODES / POR REF
  END POS         END ATT      24 PL INIT ID  _0
18 X []____     21 P []___
19 Y []         22 Y []        CMD CK 25
20 Z []         23 R []
                               POR DISPLAY 30 ORB
PORT    STO/DPLY
 MPM    0 0 0 0                    ORB LD CMD REF
                               NORM   FLY-CAMR   FLY-PL
        LAT/REL/RDY             31       32         33
 AFT    0 0 0 0 0 0
 MID    0 0 0 0 0 0            26 WR RANGE 4
 FWD    0 0 0 0 0 0            AUTO BRAKE CK 27
```

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PDRS CONTROL Display (SPEC 94)

Manipulator Retention Latches

The arm is latched in three locations (aft, mid, and forward) along the port longeron to secure it for launch and entry loads. The retention latches are dual rotating surfaces that are driven by redundant motors. When the three ready-to-latch indications are received, the operator positions the *PORT RMS RETENTION LATCHES* switch on panel A8L to *LATCH,* and the retention hooks catch the striker bars on the RMS and secure them firmly in place. All three latches are controlled by the switch. The MRL system contains microswitches for ready to latch, latched, and released indications. The microswitch status can be viewed via panel A8L (*AFT, MID, FWD*) talkbacks and the SPEC 94 PDRS CONTROL display (LAT/REL/RDY).

The OBSS is latched in three locations along the starboard longeron. The retention latches operate the same as described for the port side. The only difference is that the STARBOARD RMS RETENTION LATCHES switch was changed to a lever lock switch to prevent inadvertent release of the OBSS.

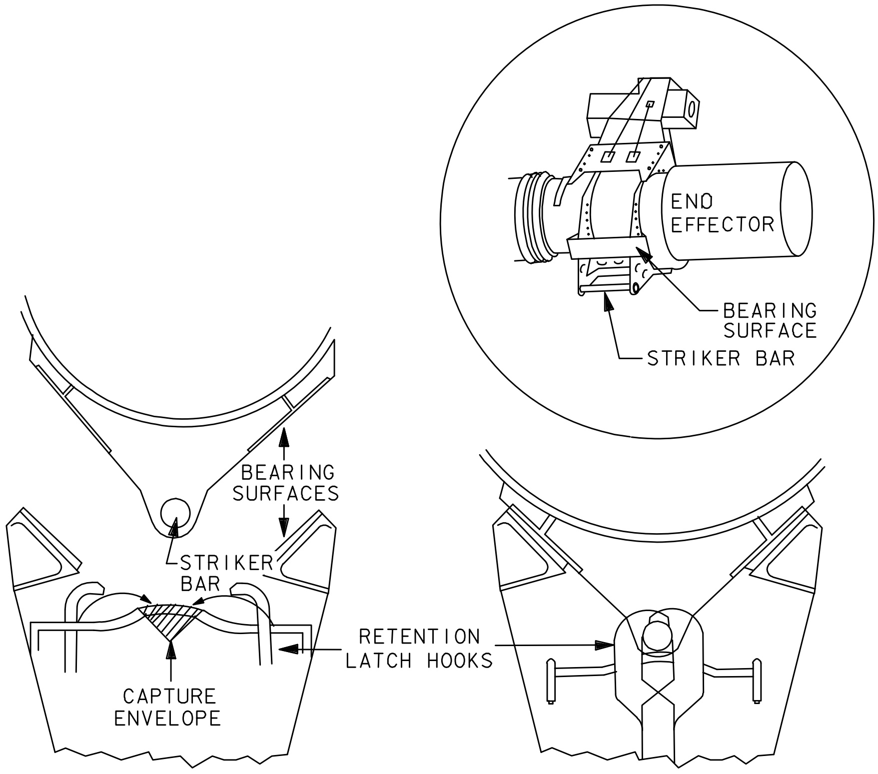
Jettison System

If for any reason the arm *or OBSS* cannot be recradled and restowed, *they* can be jettisoned so that the payload bay doors can be closed. There are four separation points, *on the port side,* one at the shoulder and one at each of the three pedestals. *The starboard side has separation points at each of the three pedestals.* Each of the separation points is individually actuated. The separation system is designed to cause a non-impulsive separation.

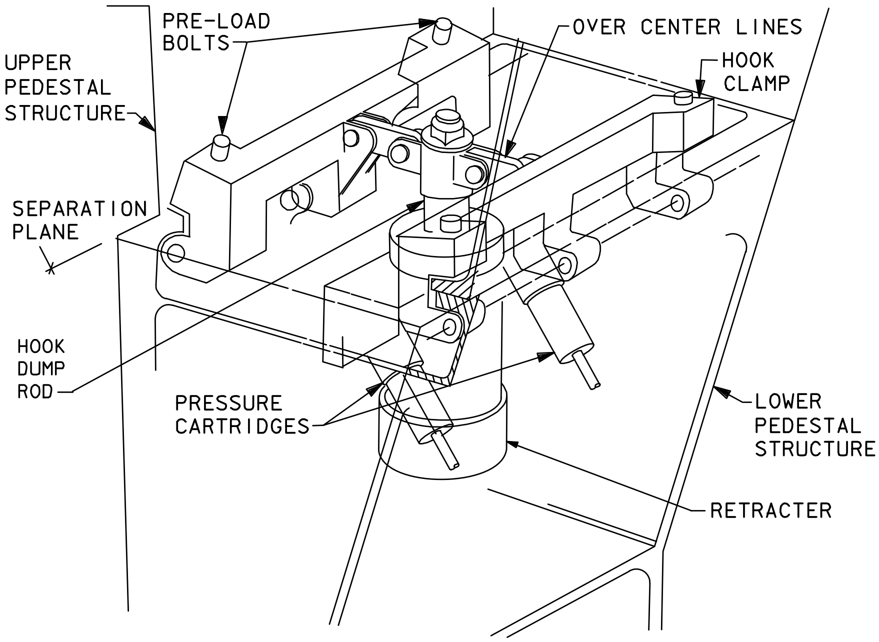
The shoulder attach point has a wire bundle that must be separated prior to shoulder support separation. The wire bundle is severed by a redundant pyro-operated guillotine prior to the activation of the support jettison system.

The jettison system works by redundant pressure cartridges firing to force down a retractor that pulls back four overcenter tie-down hooks, releasing the arm *or OBSS* at the *selected* support.

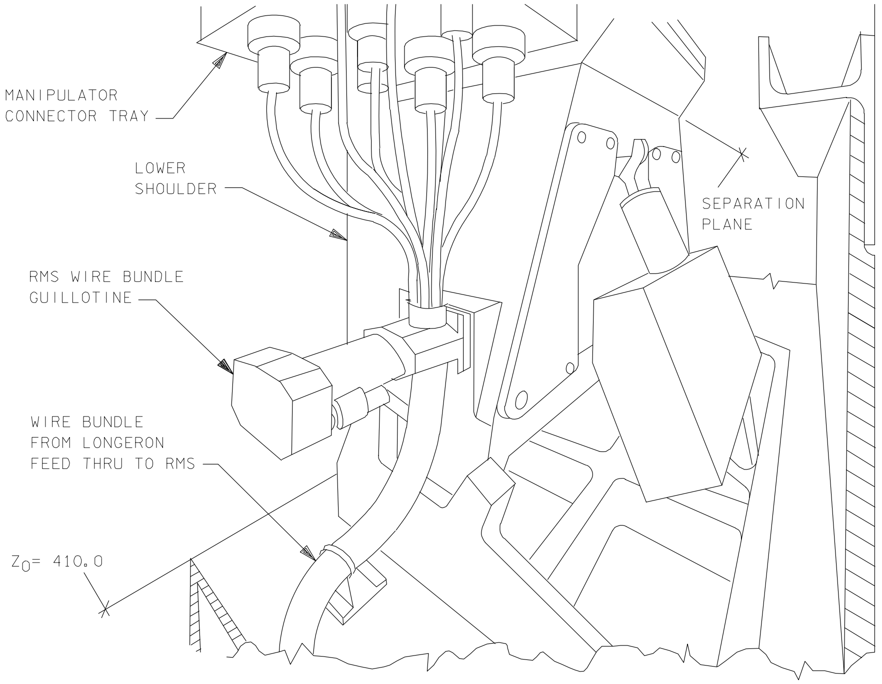
The *GUILLOTINE* switches for the RMS are located on panel A14.



RMS Retention Mechanism

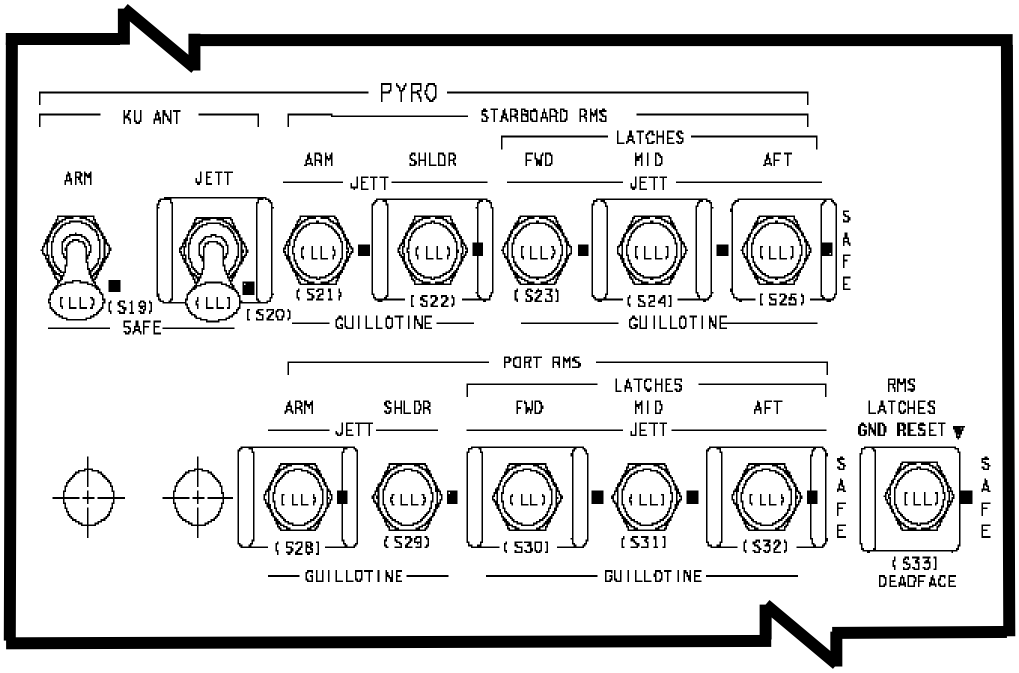


Jettison System

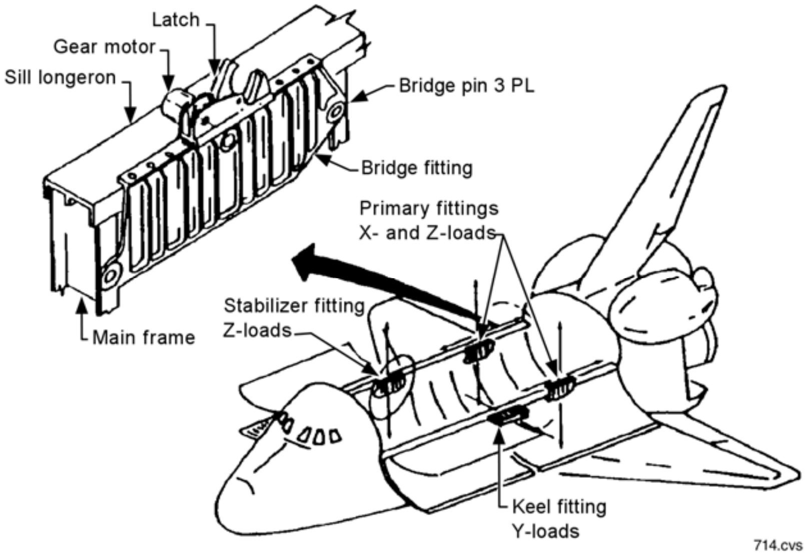


NOTE: THE MPM WIRES ARE NOT SEVERED BY GUILLOTINE

RMS Shoulder Wire Bundle



RMS Jettison Controls on Panel A14



Active Payload Retention System

Payload Retention Mechanisms

Non-deployable payloads are retained by bolted passive retention devices, and deployable payloads are secured by motor-driven, active retention devices. Payloads are secured in the orbiter payload bay with the payload retention system or are equipped with their own unique retention systems. The orbiter payload retention system provides three-axis support for up to three payloads per flight. The payload retention mechanisms secure the payloads during all mission phases and allow installation and removal of the payloads when the orbiter is either horizontal or vertical.

Attachment points in the payload bay are in 3.933-inch increments along the left- and right-side longerons and along the bottom centerline of the bay. Of the potential 172 attach points on the longerons, 48 are unavailable because of the proximity of spacecraft hardware. The remaining 124 may be used for deployable payloads. Along the centerline keel, 89 attach points are available, 75 of which may be used for deployable payloads.

Bridge Fittings

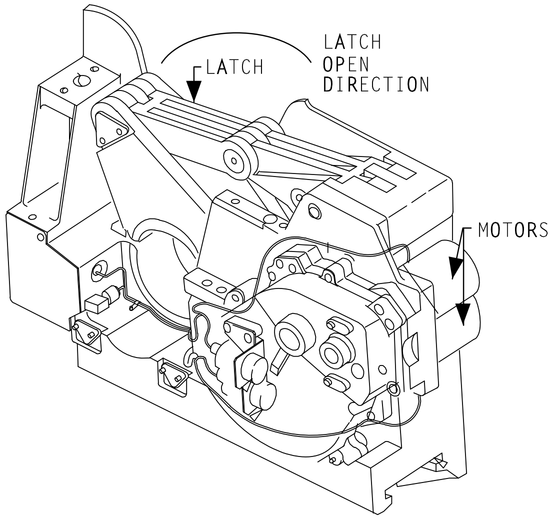
Bridge fittings are used to react to the loads imparted to the orbiter structure by the payload, and provide a structural interface for both the payload retention latch assemblies (PRLAs) and active keel actuators (AKAs). Bridge fittings fall into standard and lightweight categories, just as the PRLAs and AKAs do, and, of course, differ in type when used to interface longeron versus keel latches.

The keel bridge has a T-slot that accepts the T-bar fitting of the AKA; the two mated members are bolted in place. Contrastingly, the longeron bridge fitting incorporates a T-bar rail onto which the PRLA T-slot slides.

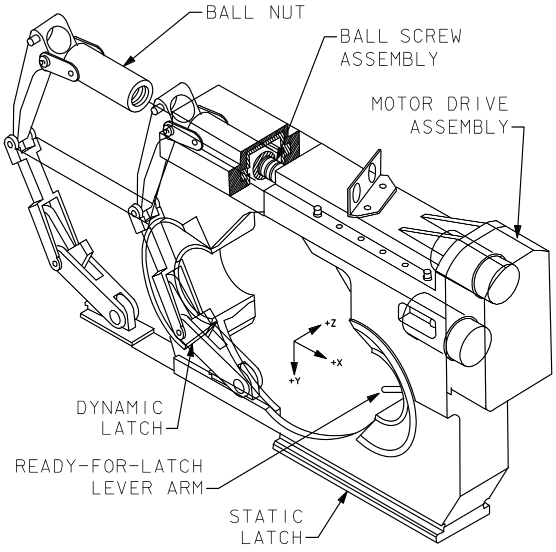
The standard and lightweight bridge fittings differ in both cross-sectional thickness and material. The standard fittings are made of titanium and are thicker than their lightweight aluminum counterparts. Bridge fittings, whether standard or lightweight, longeron or keel type, are compatible with the hole patterns and wiring routes for a particular bay only. Therefore, each fitting is unique dimensionally for any given bay.

There are 13 longeron bridges per side and 12 keel bridges available per flight. Only the bridges required for a particular flight are flown. The bridges are not interchangeable because of main frame spacing, varying load capability, and subframe attachments.

The longeron bridge fittings attach to the payload bay frame at the longeron level and at the side of the bay. Keel bridge fittings attach to the payload bay frame at the bottom of the payload bay.



Payload Retention System



Active Keel Actuator

Latches

There are normally three or four longeron latches per payload. Two primary latches are required to take the X- and Z-loads, and one or two stabilizing latches are required to take Z-loads. The stabilizing latches float free in the X-X direction. The latches are driven by dual-redundant motors.

A payload may also require a keel latch that takes the side loads. The keel latch centers the payload in the Y direction in the payload bay when it closes; the keel latch must be closed prior to closing the longeron latches. The keel latch can float plus or minus 2.75 inches in the X direction.

Trunnions

The payload trunnions are the cylindrical portion of the payload that interfaces with the payload retention system. The trunnions that interface with the longeron are 3.24 inches in diameter and 7 or 8.75 inches long, depending on their position in the payload bay. The keel trunnions are 3 inches in diameter and vary in length from 4 to 11.5 inches, depending on where they fit in the payload bay.

Payload Guides/Scuff Plates

Payload guides and scuff plates assist in deploying and berthing payloads in the payload bay. The payload is constrained in the X direction by guides and in the Y direction by scuff plates and guides. Bright yellow and black striped markings are painted on the guides to enhance visual cues during payload berthing. The guides are mounted to the inboard side of the payload latches and interface with the payload trunnions and scuff plates. The scuff plates are attached to the payload trunnions and interface with the payload guides.

The guides are V-shaped, and one part of the V is 2 inches taller than the other. Parts are available to make either the forward or aft guide taller.

This difference enables the operator monitoring the berthing or deployment operations through the aft bulkhead CCTV cameras to better determine when the payload trunnion has entered the guide. The top of the taller portion of the guide is 24 inches above the centerline of the payload trunnion when it is all the way down in the guide. The top of the guide has a 9-inch opening. These guides are mounted to the 8-inch guides that are a part of the longeron payload retention latches.

Payload Retention System Controls

The *PAYLOAD RETENTION LOGIC POWER SYS 1* switch on panel A6U positioned to *ON* provides MN A bus power to the *PAYLOAD SELECT* rotary switch. The *SYS 2* switch positioned to *ON* provides MN B bus power to the *PAYLOAD SELECT* switch.

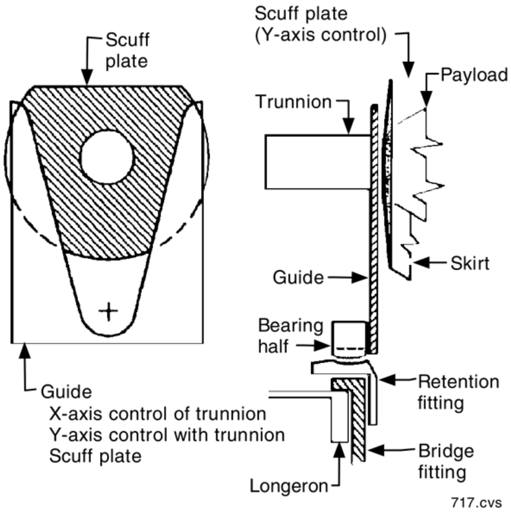
Positioning the *PAYLOAD SELECT* switch to *1* provides power-on logic for the dual actuator motors of up to five latches for one payload, the latch status for that payload on DISP 97 PL RETENTION, and the talkback indications associated with the payload. Position *2* of the switch provides power-on logic for the dual actuator motors of up to five latches for the second payload, the latch status for that payload on DISP 97, and the talkback indications associated with that payload. Position *3* provides power-on logic for the dual actuator motors of up to five latches for the third payload, the latch status for that payload on DISP 97, and the talkback indications associated with up to five latches. In addition, two monitor settings are available. These positions allow the crewmember to monitor all payload retention latches at once on DISP 97, but inhibit all latch control commands. Talkback indicators are also inhibited when in the monitor position and indicate barberpole.

The *PAYLOAD RETENTION LATCHES 1, 2, 3, 4,* and *5* switches on panel A6U are enabled by the *PAYLOAD SELECT* rotary switch. Positioning the *PAYLOAD SELECT* switch to *1* enables up to five retention latches for payload 1, and each of the five retention latches for payload 1 would be controlled by the individual *1*, *2*, *3*, *4*, and *5* switches. Positioning the *PAYLOAD SELECT* switch to *2* or *3* has the same effect for payloads 2 and 3.

NOTE

Payload retention latch wiring configurations are mission-dependent.

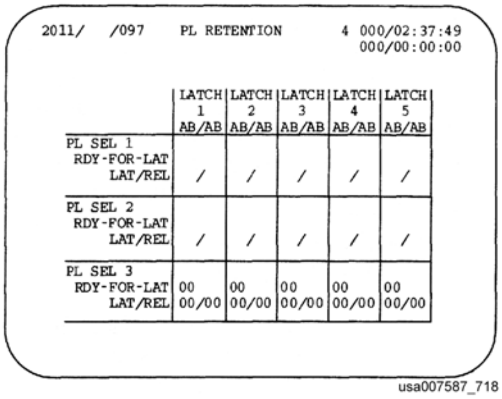
Positioning a *PAYLOAD RETENTION LATCHES* switch to *RELEASE* enables AC power to the dual electric motors associated with the retention latches designated by the position of the *PAYLOAD SELECT* switch, driving the retention latch open. The operating time of the latch with both motors operating is 30 seconds; with only one motor operating it is 60 seconds. The talkback indicator immediately above the switch indicates *REL* when the latch is fully open. There are two microswitches for the *REL* talkback indication; however, only one is used to control the talkback indicator (the "A" indication). The talkback is barberpole when the payload latch is between latch and release. There are two microswitches for the ready-for-latch talkback indication; however, as above, only the "A" indication controls the talkback indicator.



Orbiter Payload Guide, Active Retention Fitting

NOTE

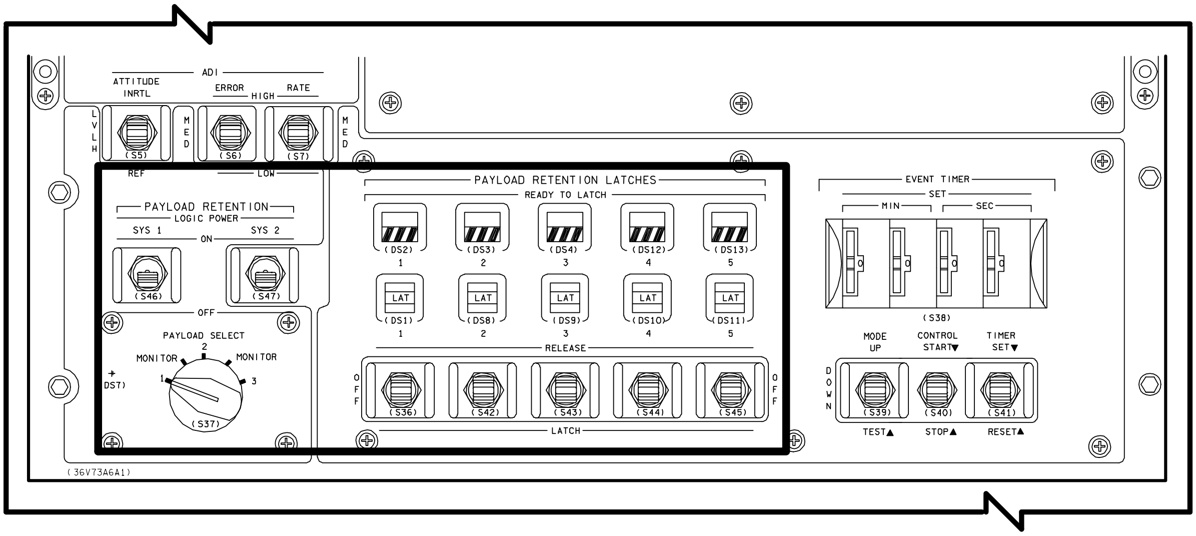
When driving the *PAYLOAD RETENTION LATCHES* to *RELEASE*, do not continue to command a release for longer than 60 seconds if no *REL* indication is received. If the "A" release microswitch has failed whereby no indication is present, the latch will continue to drive against the fully open position as long as *RELEASE* is selected, which could quickly lead to actuator damage.



```
2011/   /097     PL RETENTION          4 000/02:37:49
                                         000/00:00:00

                  |LATCH|LATCH|LATCH|LATCH|LATCH|
                  |  1  |  2  |  3  |  4  |  5  |
                  |AB/AB|AB/AB|AB/AB|AB/AB|AB/AB|
 PL SEL 1
   RDY-FOR-LAT
        LAT/REL     /     /     /     /     /
 PL SEL 2
   RDY-FOR-LAT
        LAT/REL     /     /     /     /     /
 PL SEL 3
   RDY-FOR-LAT  00    00    00    00    00
        LAT/REL  00/00 00/00 00/00 00/00 00/00
```

DISP 97 PL RETENTION Display



PAYLOAD RETENTION Switches and Talkbacks on Panel A6U

Positioning a *PAYLOAD RETENTION LATCHES* switch to *LATCH* provides AC power to the dual electric motor associated with the latches designated by the position of the *PAYLOAD SELECT* switch, driving the retention latch closed. The operating time of one or both motors is the same as for releasing a payload. A gray *READY* talkback indicates that latch is ready to latch. The indicator shows *LAT* when the latch is closed. There are two microswitches for the *LAT* indication; however, only system A is required to control the talkback indicator.

Operations

The RMS can perform a wide range of operations. This section gives an overview of these operations, as well as the actions required to configure the arm to support these operations.

On-Orbit Initialization

Prior to any planned RMS operations, the shoulder brace must be released, and for any loaded operations, the MPM must be deployed. This procedure contains both of these activities, *as well as the deployment of the starboard MPM. T*he status of some of the panel lights, talkbacks, and switches *is also checked*. The PDRS CONTROL SPEC 94 display is called up, and the interface with the SM GPC is established. This operation is usually scheduled at about 2.5 hours MET.

RMS Powerup

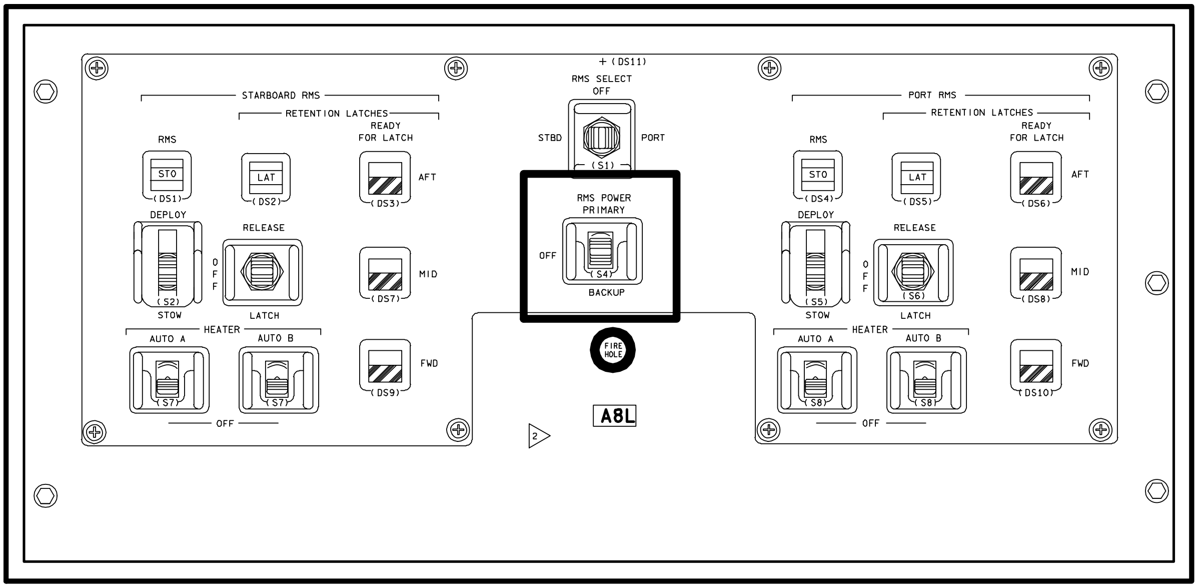
This procedure releases the MRLs and gets the arm out of the cradle to a "pre-cradle" configuration. This procedure *may be* performed several times during a flight, as the arm is usually powered down when not in use. The *RMS POWER* switch is on panel A8L.

NOTE

> Placing the *RMS POWER* switch to *PRIMARY* generates an RMS master alarm. This alarm is generated because the panel powers up faster than the MCIU, thereby causing the *MASTER ALARM* light and tone to annunciate before the MCIU can respond with the proper master alarm flag. This is a normal condition and will occur every time the *RMS POWER* switch is cycled *OFF* and back to *PRIMARY*.

RMS Checkout

This procedure verifies in exacting detail that all the arm hardware and the panel switches and functions are in good operating condition. This is about an hour-long procedure and is done only once per flight. It is usually scheduled as early as possible in order to allow plenty of time for any problems to be worked around.



RMS POWER Switches on Panel A8L

Flight-Specific Operations

The arm can perform nine different types of operations. One or more may be done per flight. These operations are broken down as described below.

Contingency-Only Unloaded Operations

These unscheduled operations will only be performed if a problem arises in another orbiter system. The training for these operations is very minimal, and the tasks performed would involve surveys of some parts of the orbiter.

Unloaded Operations

These scheduled operations involve maneuvering the arm to various positions or along various trajectories. An example of this would be a payload survey. There is no payload attached to the arm during these maneuvers.

Loaded Operations

These operations involve grappling a payload that is berthed in the payload bay, releasing the payload latches, unberthing the payload, maneuvering the payload, reberthing and relatching the payload, and ungrappling the payload.

Deploy Operations

These operations involve grappling a payload that is berthed in the payload bay, releasing the payload latches, unberthing the payload, maneuvering the payload to the release position and orientation, and releasing the payload.

Retrieve Operations

These operations involve capturing a free-flying payload, maneuvering the payload to a hover position (aligned with the berthed position, but about 10 feet over the bay), berthing and latching the payload, and ungrappling it.

Deploy and Retrieve Operations

These operations apply to one payload that is both deployed and retrieved, as in the steps listed above. The order of deploy and retrieve operations is flight specific.

Station Build Operations

These operations apply to taking a station element such as an MPLM and then either installing it on to the ISS or handing it off to the SSRMS for subsequent installation. These tasks could also involve removing a station element and relocating it to another port.

RMS/EVA Operations

These operations involve using the RMS as a portable work platform with an EVA crewmember attached to the end of the arm with a foot restraint. The EVA crewmember can be moved around via the RMS because it provides access to worksites where the tasks would be made more difficult if they had to be performed free floating.

OBSS Operations

While undocked, these operations involve grappling the OBSS, unberthing the OBSS, and using auto sequences to inspect the orbiter thermal protection system (TPS). When docked to ISS, the operations also include a handoff of the OBSS from the SSRMS.

RMS Powerdown

This procedure returns the arm to the cradled configuration and relatches the MRLs. This is usually done any time arm operations are not required. However, there are occasions when the arm will be left uncradled to meet mission-specific objectives (e.g., when the RMS cameras are used to view an ISS mechanism overnight). The power to the ABE is deactivated, but the MCIU remains powered up and in contact with the SM GPC. For the final flight powerdown, the MPM will be stowed as part of this procedure.

RMS Deactivation

This procedure removes power from the RMS heaters and turns off the MCIU. This will only be done after all arm operations scheduled for the flight have been completed.

RMS Jettison

This is a contingency procedure that is used to jettison the arm only, the arm plus MPM pedestals, or the arm/payload combination. Jettison causes a non-impulsive separation of the arm, and then the orbiter pilot performs an orbiter separation from the jettisoned unit. Should the jettison have to be done in an expedited manner, a QUICK RESPONSE JETTISON procedure has been created and is located in the contingency deorbit checklist.

OBSS Jettison

This is a contingency procedure that is used to jettison the OBSS plus the starboard MPM pedestals. The berthed OBSS is grappled prior to pedestal jettisoning, then the OBSS with attached pedestals is maneuvered to a jettison position and released. The orbiter pilot performs an orbiter separation from the jettisoned unit.

Operating Modes

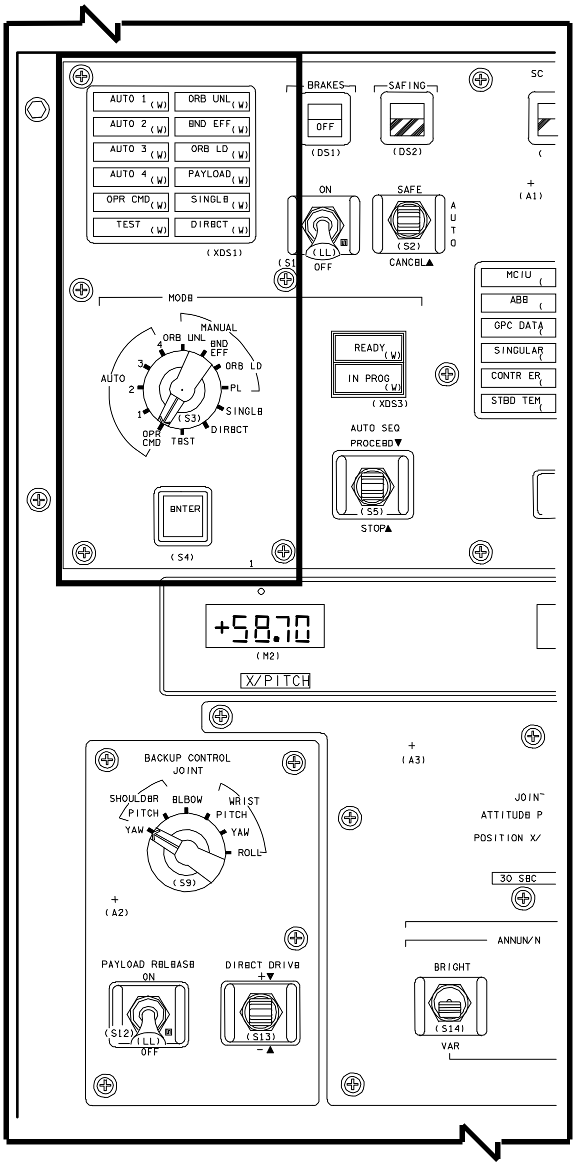
The RMS can be operated in a variety of modes. These modes are detailed below.

Single Joint Modes

Operating the arm in a single joint mode allows only one joint at a time to be driven. Single joint operations are very painstaking and time consuming, and so are only used when absolutely necessary. Uncradling and cradling must be done via a single joint mode, since the arm is in the soft stop region for two joints. The single joint modes are *SINGLE*, which is a computer-supported mode; *DIRECT*, which commands the joints via hardwired signals and uses MN A (primary) power; and *BACKUP*, which commands the joints via hardwired signals and uses MN B (backup) power.

Manual Augmented Modes

The manual augmented modes are computer-supported modes that use the RMS hand controllers (HCs) to control the arm trajectories. The modes that fall into these categories are orbiter unloaded, orbiter loaded, end effector, and payload modes. They are selected by corresponding positions of the *MODE* rotary switch on panel A8U: *ORB UNL, ORB LD, END EFF, PL.*



Mode Selection Rotary Switches and Lights on Panel A8U

In standard RMS operations, the manual augmented modes are supplemented with the position/orientation hold select (POHS) mode. POHS mode is a software improvement that has greatly increased the ability of the RMS operator to control the arm trajectory. The POHS mode is used to improve RMS performance in the manual augmented modes by correcting unwanted motion of the point of resolution. POHS mode can be selected on SPEC 94. When POHS is enabled (SPEC 94, ITEM 28), POR position hold is used to prevent POHS reference drift. When POHS is disabled (SPEC 94, ITEM 29), joint position hold is used. The POHS reference position and attitude are displayed on SPEC 169. The resultant POHS errors for translation and rotation are also displayed on SPEC 169.

ORB UNL. Orbiter unloaded mode uses the unloaded POR and defines the HC inputs to coincide with the desired arm trajectory as viewed out the aft windows. For example, to translate the arm to the left as you are looking out the aft window (toward the starboard side of the vehicle), the THC would be deflected to the left. To move the arm out of the payload bay (up), the THC would be deflected up. To bring the arm toward you, the THC would be pulled out. RHC inputs are similar. To pitch the arm or payload up with respect to you as you are looking out the aft window, the RHC would be tilted back toward you. To yaw the arm/payload as you are viewing it, the RHC would be twisted left or right about its long axis. To roll with respect to your view, the RHC would be deflected left and right.

ORB LD. Orbiter loaded mode is usually used for a loaded arm. The HC inputs in orbiter loaded mode are identical to those in *ORB UNL*; however, the POR is defined to be at a point within the grappled payload.

In the orbiter loaded mode, there are three types of HC references: normal, fly-to (also referred to as fly-camera), and fly-from (also referred to as fly-payload). These command references are mutually exclusive and can be enabled or disabled via SPEC 94. Fly-payload is used the same way orbiter loaded mode is used; however, any orbiter-based camera or window view can be used. Fly-camera is the same as fly-payload with all commands reversed.

END EFF. End effector mode allows the HC inputs to reflect motion desired when viewed through the end effector camera. The sense the operator has is that he or she is “sitting” on the end of the end effector. When the arm is aligned parallel to the longeron, and the wrist joint angles are all zero, HC inputs in *END EFF* coincide with those in *ORB UNL/LD*. If the wrist is then pitched down in that configuration, the motion to take the arm down into the payload bay would be a THC downward deflection in *ORB UNL/LD,* but would be a push inward on the THC in *END EFF* mode.

PL. Payload mode uses the software-predefined POR and coordinate system and applies the HC inputs as follows: THC-in will cause motion in the +X axis of the software-defined PL coordinate system; THC-out corresponds to motion along the -X axis of the PL coordinate system. THC-right will cause motion along the PL +Y axis, while THC-left will cause motion along the PL -Y axis. THC-down will cause motion along the PL +Z axis, and THC-up will cause motion in the PL -Z axis. RHC P will cause motion about the PL Y axis, RHC Y will cause rotation about the PL Z axis, and RHC R will cause rotation about the PL X axis.

TEST. Test mode, while not strictly speaking a manual-augmented mode, uses the same POR and coordinate system definition as *ORB UNL*. Test mode allows the arm operator to monitor and verify the HC commands without causing any arm motion. This is done by cutting off the joint drive current at each joint.

AUTO Modes

There are two types of auto modes, auto-commanded auto sequences and operator-commanded auto sequences. In either case, the SM GPC controls the arm trajectory.

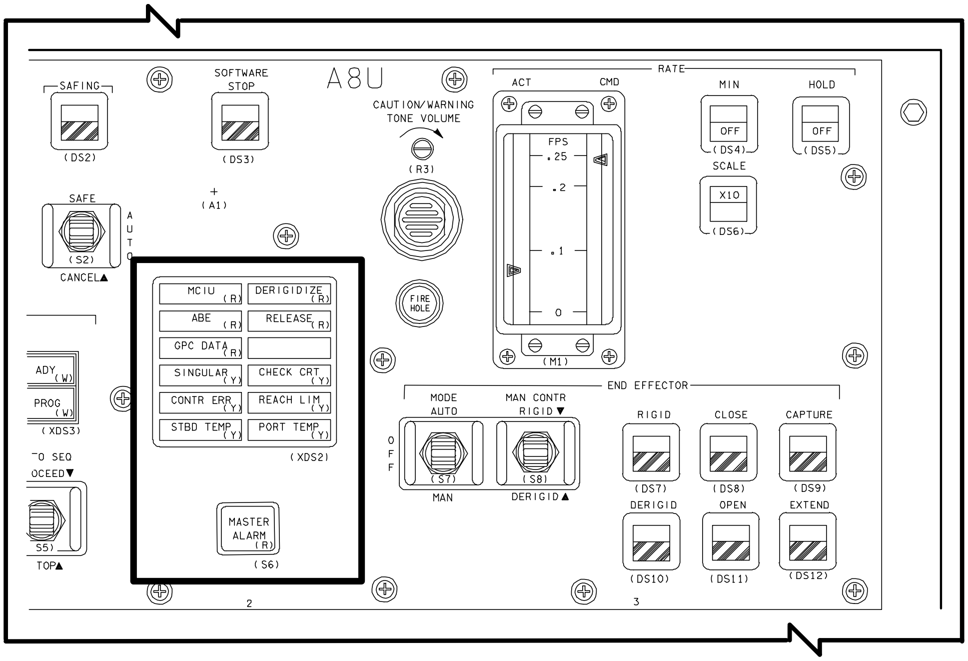
OBSS operations require many long Auto trajectories. POHS was added to Auto modes to better detect sluggish joints that may cause the arm to deviate from the planned trajectory.

<u>Auto-Commanded Auto Sequences</u>. These sequences consist of up to 200 pre-defined points that can be grouped in up to 20 sets, or sequences. To use an auto-commanded auto sequence, the operator enters the desired sequence number on the PDRS CONTROL SPEC for one of AUTO 1, 2, 3, or 4 slots, then selects *AUTO 1, 2, 3*, or *4* via the *MODE* rotary switch on panel A8U. The arm is then commanded to start via the *AUTO SEQ* switch, and will fly through that predefined trajectory.

<u>Operator-Commanded Auto Sequences</u>. For these, the arm operator must manually enter a desired POR end position and attitude via the PDRS CONTROL SPEC. The operator then selects *OPR CMD* mode via panel A8U and starts the sequence. The arm will fly from its current position to the desired end point and then stop. Should another sequence be desired, the operator would have to enter the new end point on the SPEC.

PDRS Caution and Warning Summary

- The RMS has a separate C/W matrix on panel A8U. This system is not associated with the orbiter's C/W system.
- The red *MCIU* light indicates that the MCIU has failed a self-test.
- The red *DERIGIDIZE* light indicates that the end effector has derigidized without command.
- The red *ABE* light indicates that a failure has occurred in the ABE of any joint.
- The red *RELEASE* light indicates that the end effector has released the grapple fixture without command.
- The red *GPC DATA* light indicates invalid data transmitted from the orbiter computer to the MCIU and detected by the MCIU BITE.
- The yellow *CHECK CRT* light indicates an RMS failure message is on the orbiter DPS display.
- The yellow *CONTR ERR* light indicates the presence of abnormal conditions in an arm-joint that may not be detected by BITE and may cause a joint runaway (software automatically applies the brakes when such a condition occurs).
- The yellow *REACH LIM* light indicates that one of the joints is close to its travel limit.
- The yellow *PORT TEMP* light indicates that the temperature of the port arm has exceeded its predetermined caution threshold.
- The yellow *SINGULAR* light indicates that the arm is in one of three singularity configurations.
- The red *MASTER ALARM* signals the RMS operator that an RMS C/W light was activated. The light and tone are canceled by depressing the pushbutton.
- The RMS C/W tone volume may be adjusted by the *CAUTION/WARNING TONE VOLUME* knob.



RMS Caution and Warning Lights on Panel A8U

PDRS Summary Data

- The PDRS is used to maneuver itself or an attached payload in orbit. It consists of the RMS, MPM, and MRLs, and interfaces with other orbiter systems such as the SM GPC, the EPDS, and the CCTV.

- The RMS consists of the arm itself and the controls and interfaces needed to maneuver it. It is located on the port longeron.

- The MPM*s* consist of the torque tube, the pedestals, the MRLs, and the jettison system. The MPM*s* must be stowed whenever the payload bay doors are closed. *The port MPM* must be deployed for any loaded operations. *The starboard MPM differs from the port in having a pedestal where the port has the shoulder, and in the omission of the mid-pedestal.*

- The pedestals contain the MRLs and the jettison electronics and mechan*ism. They are* the supports on which the RMS rests while it is cradled *and the OBSS rests while it is berthed*.

- The MRLs latch the arm *and OBSS* to the*ir respective* MPM*s* and restrain *them when not in use*.

- The jettison *system* allows the arm, the arm and pedestals, the arm/payload combination*, and/or the OBSS and pedestals* to be non-impulsively separated from the orbiter if the arm cannot be cradled and stowed prior to payload door closure.

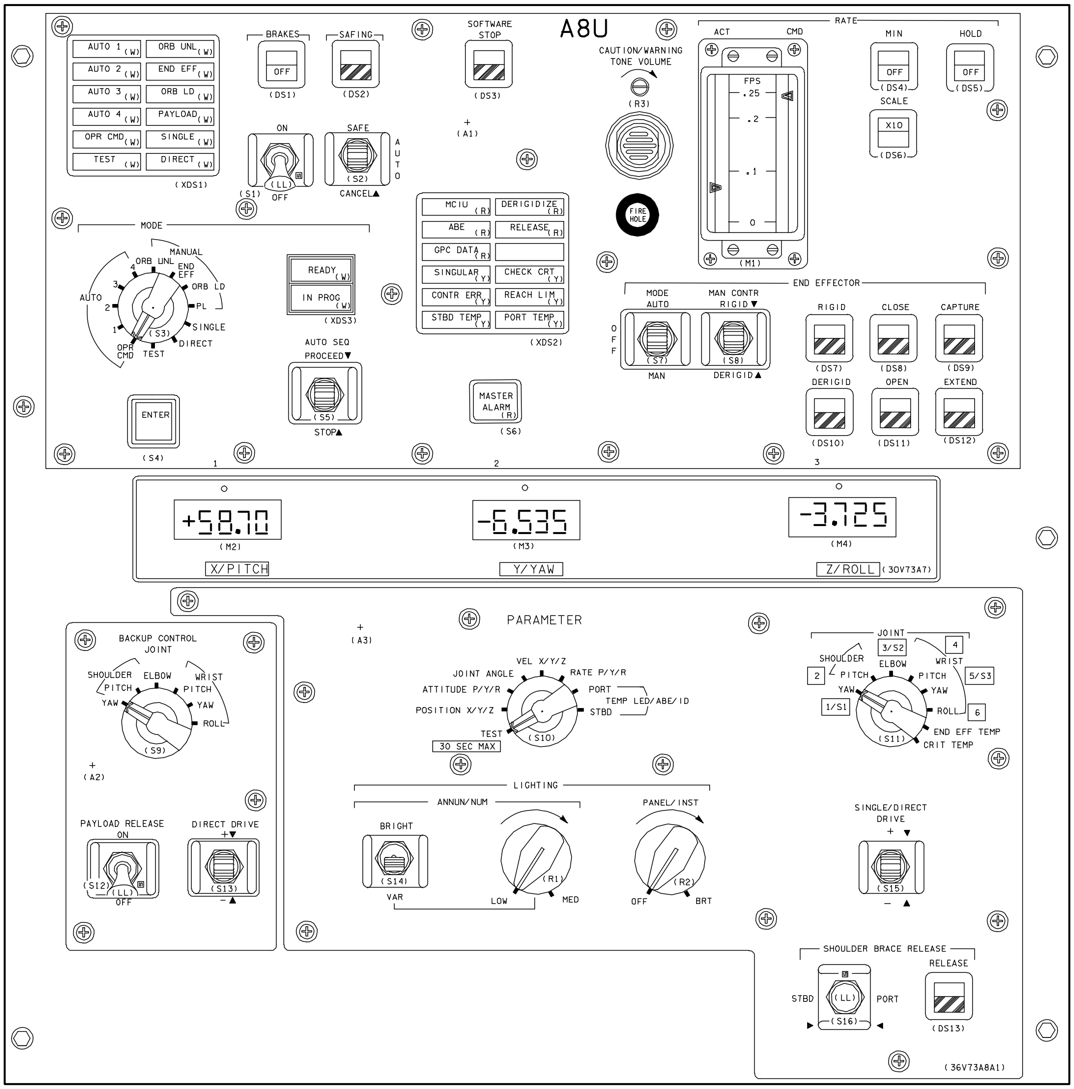
- The on-orbit arm operations fall into nine categories: contingency-only unloaded operations, unloaded operations, loaded operations, deploy operations, retrieve operations, deploy and retrieve operations, station build operations, RMS/EVA operations, and OBSS operations.

- The arm has three basic modes of operation: single joint modes, manual-augmented modes, and auto modes.

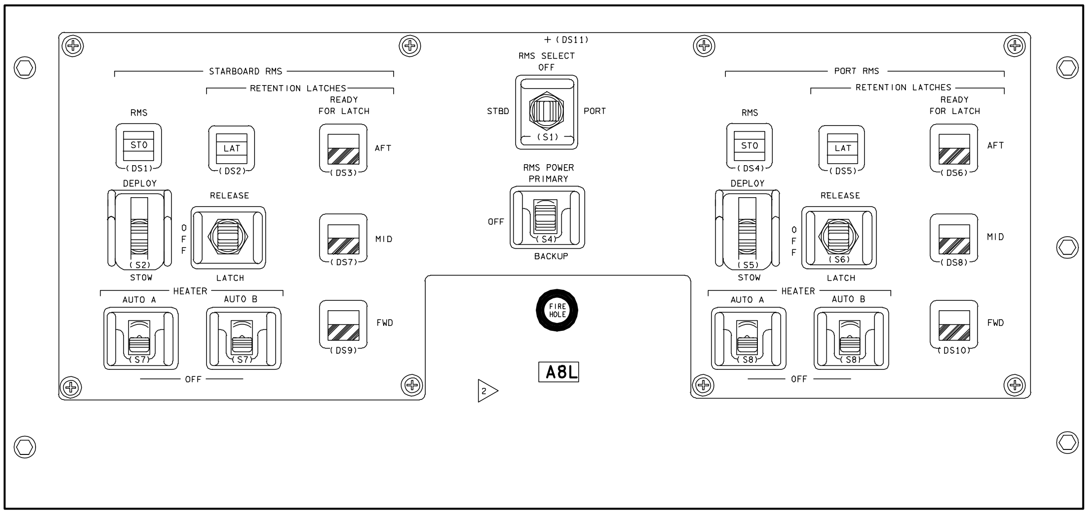
- All RMS operations involve a two-person operator team. Each member is vital to the success of the mission.

- The PDRS controls are located primarily on panels A8U and A8L. Other panels that affect the RMS are ML86B, A14, A7U, A6, and R13.

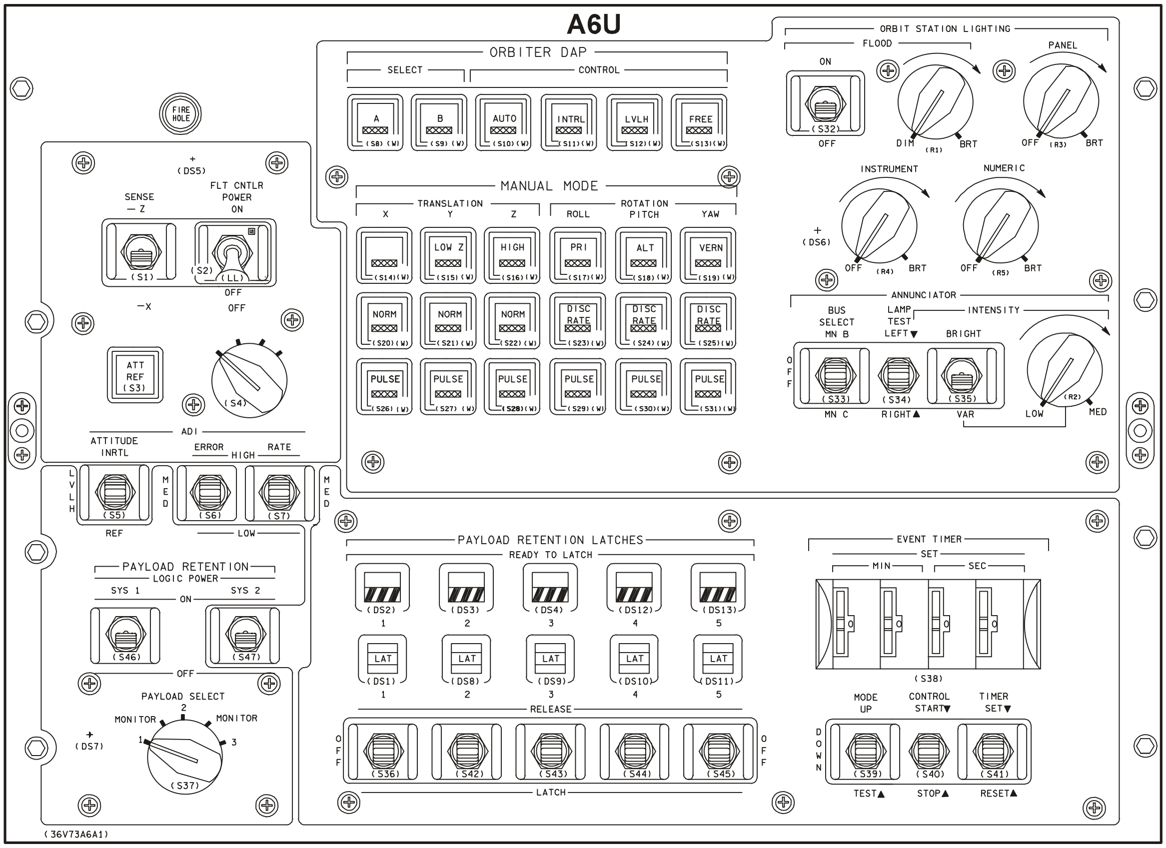
- The major PDRS DPS display is SPEC 94 PDRS CONTROL. PDRS OVERRIDE SPEC 95, PDRS STATUS DISP 169, and PDRS FAULTS SPEC 96 also control and monitor the RMS. DISP 97 PL RETENTION monitors payload retention device status.



Panel A8U



Panel A8L



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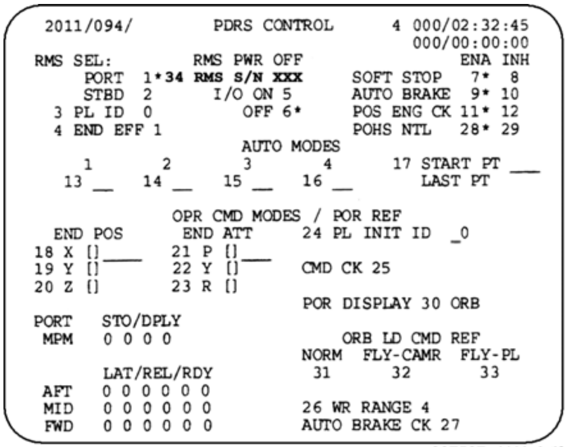
Panel A6U



```
 2011/094/        PDRS CONTROL       4 000/02:32:45
                                       000/00:00:00
RMS SEL:         RMS PWR OFF                ENA INH
     PORT  1*34 RMS S/N XXX     SOFT STOP    7*  8
     STBD  2        I/O ON 5    AUTO BRAKE   9* 10
  3 PL ID  0           OFF 6*   POS ENG CK 11* 12
  4 END EFF 1                   POHS NTL    28* 29
                    AUTO MODES
     1        2          3          4      17 START PT ___
   13 __    14 __     15 __     16 __         LAST PT

                OPR CMD MODES / POR REF
  END POS         END ATT      24 PL INIT ID  _0
18 X []____     21 P []___
19 Y []         22 Y []        CMD CK 25
20 Z []         23 R []
                               POR DISPLAY 30 ORB
PORT    STO/DPLY
 MPM    0 0 0 0                    ORB LD CMD REF
                               NORM   FLY-CAMR  FLY-PL
        LAT/REL/RDY             31       32        33
 AFT    0 0 0 0 0 0
 MID    0 0 0 0 0 0            26 WR RANGE 4
 FWD    0 0 0 0 0 0            AUTO BRAKE CK 27
```

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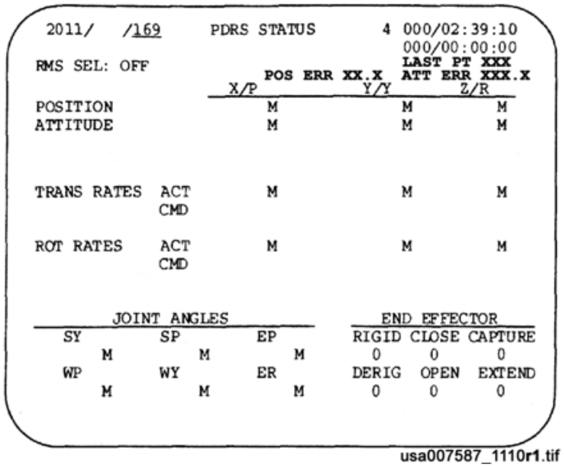
SPEC 94 PDRS CONTROL Display



```
 2011/   /169      PDRS STATUS        4 000/02:39:10
                                        000/00:00:00
RMS SEL: OFF                            LAST PT XXX
                        POS ERR XX.X   ATT ERR XXX.X
                     X/P            Y/Y         Z/R
POSITION                M             M           M
ATTITUDE                M             M           M


TRANS RATES   ACT       M             M           M
              CMD

ROT RATES     ACT       M             M           M
              CMD


         JOINT ANGLES                END EFFECTOR
   SY          SP          EP       RIGID CLOSE CAPTURE
       M           M           M      0     0      0
   WP          WY          ER       DERIG  OPEN  EXTEND
       M           M           M      0     0      0
```

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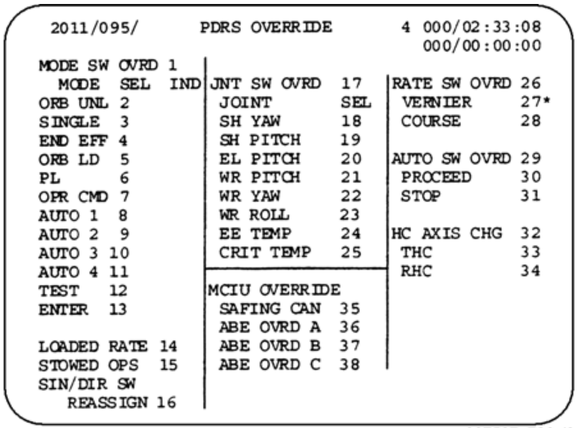
DISP 169 PDRS STATUS Display



```
 2011/095/       PDRS OVERRIDE          4 000/02:33:08
                                          000/00:00:00
MODE SW OVRD 1 |
  MODE  SEL  IND|JNT SW OVRD   17  |RATE SW OVRD 26
ORB UNL  2      | JOINT         SEL |  VERNIER     27*
SINGLE   3      | SH YAW        18  |  COURSE      28
END EFF  4      | SH PITCH      19  |
ORB LD   5      | EL PITCH      20  |AUTO SW OVRD 29
PL       6      | WR PITCH      21  |  PROCEED     30
OPR CMD  7      | WR YAW        22  |  STOP        31
AUTO 1   8      | WR ROLL       23  |
AUTO 2   9      | EE TEMP       24  |HC AXIS CHG  32
AUTO 3  10      | CRIT TEMP     25  |  THC         33
AUTO 4  11      |-------------------|  RHC         34
TEST    12      |MCIU OVERRIDE      |
ENTER   13      | SAFING CAN    35  |
                | ABE OVRD A    36  |
LOADED RATE 14  | ABE OVRD B    37  |
STOWED OPS  15  | ABE OVRD C    38  |
SIN/DIR SW      |
   REASSIGN 16  |
```

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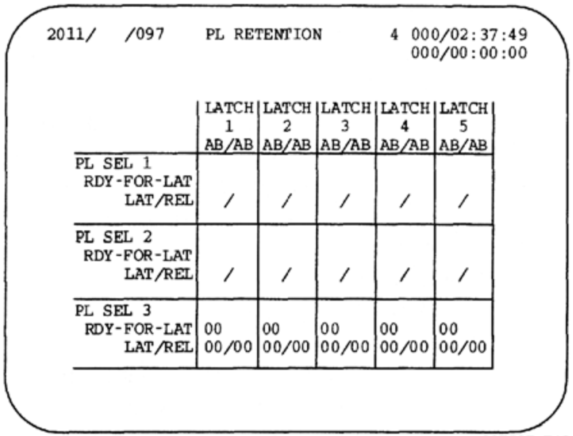
SPEC 95 PDRS OVERRIDE Display



```
 2011/   /097     PL RETENTION        4 000/02:37:49
                                        000/00:00:00


                 |LATCH|LATCH|LATCH|LATCH|LATCH|
                 |  1  |  2  |  3  |  4  |  5  |
                 |AB/AB|AB/AB|AB/AB|AB/AB|AB/AB|
  PL SEL 1       |     |     |     |     |     |
   RDY-FOR-LAT   |     |     |     |     |     |
       LAT/REL   |  /  |  /  |  /  |  /  |  /  |
  PL SEL 2       |     |     |     |     |     |
   RDY-FOR-LAT   |     |     |     |     |     |
       LAT/REL   |  /  |  /  |  /  |  /  |  /  |
  PL SEL 3       |     |     |     |     |     |
   RDY-FOR-LAT   |00   |00   |00   |00   |00   |
       LAT/REL   |00/00|00/00|00/00|00/00|00/00|
```

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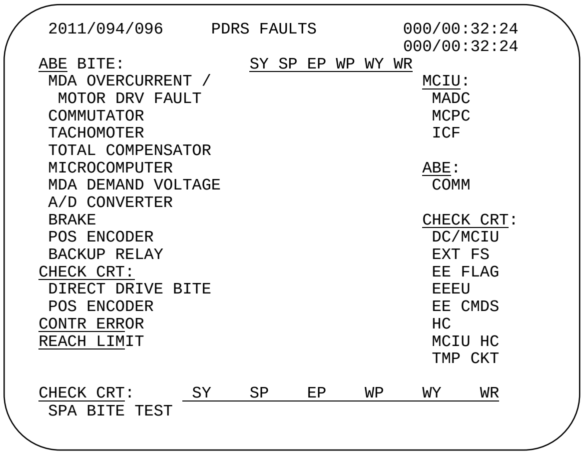
DISP 97 PL RETENTION Display



```
 2011/094/096     PDRS FAULTS         000/00:32:24
                                      000/00:32:24
ABE BITE:              SY SP EP WP WY WR
 MDA OVERCURRENT /                     MCIU:
  MOTOR DRV FAULT                       MADC
 COMMUTATOR                             MCPC
 TACHOMOTER                             ICF
 TOTAL COMPENSATOR
 MICROCOMPUTER                         ABE:
 MDA DEMAND VOLTAGE                     COMM
 A/D CONVERTER
 BRAKE                                 CHECK CRT:
 POS ENCODER                            DC/MCIU
 BACKUP RELAY                           EXT FS
CHECK CRT:                              EE FLAG
 DIRECT DRIVE BITE                      EEEU
 POS ENCODER                            EE CMDS
CONTR ERROR                             HC
REACH LIMIT                             MCIU HC
                                        TMP CKT

CHECK CRT:      SY    SP    EP    WP    WY    WR
 SPA BITE TEST
```

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SPEC 96 PDRS FAULTS Display

PDRS Rules of Thumb

- Whenever there are both talkbacks and DPS displays that reflect microswitch status, they should ALWAYS both be checked during any operation affecting them.

- Whenever troubleshooting RMS malfunctions in the long-form MAL book, always READ AHEAD. The MALs sometimes may require an operator response after the execution of the block which is listed in the next block, depending on the path that is taken.

- The hand controllers are rate-proportional and are extremely sensitive. They should be held in such a way that you can control the full range of inputs without ever stopping to rearrange your hand. Care must be taken to not overcontrol the inputs. A good practice is to slowly and steadily input a desired command, wait patiently until you see the reactions of that command on the arm, and as the desired motion is achieved, slowly back off the input. Ideally, you should reach the axis detent at the same time the arm achieves the desired position and attitude.

- *Visible* MPM motion may cease during deployment or stowage before the expected microswitches *indications are received*. This is because the last part of travel in either direction is when the affected overcenter lock is locking. Therefore, do not turn off the PORT RMS switch when visible motion stops. Wait for the microswitches or max time, whichever occurs first.

- Practice safety habits, the most important of which are brakes on, then *RMS Select* off (if required) for abnormal joint response, and use *the* EE CC for abnormal EE ops during the specified conditions.

- During arm cradling, periodically check all joint angles to make sure that joints that you have already aligned to 0 have not moved.

- At least two good camera views should be set up to aid in RMS operations. However, CCTV cameras have a tendency to malfunction at the most inconvenient times. Expect this and know how to perform all operations with alternate cameras or without the use of certain cameras. Use the Grapple Target overlay during EE grapple operations.

- Develop a scan pattern that encompasses window, CCTV, and panel status.

- Always remember what the DAP should be for the operation you are performing. In addition, keep in mind the down mode option for the DAP in case the arm enters an unexpected singularity or reach limit.

- Never rotate the MODE switch through DIRECT while the brakes are on. This actually puts the arm in mode, and sets you up for a possible runaway if a SINGLE/DIRECT DRIVE switch failure occurs or is present.

- Verify the RATE switch setting by feel <u>and</u> talkback status. This should be done EVERY TIME prior to moving the arm, regardless of mode.

- Make sure you know the proper definitions of “cradling,” “stowing,” “berthing,” “mating,” and “installing.”

- Rates for berthing/unberthing: Usually maintain rates at about 0.01 to 0.02 ft/sec between Z = 414 and -438. For Z < -438 (away from the bay), rates can be increased somewhat.

- For berthing or unberthing of payloads with keel trunnions: the keel pin enters/exits the AKA when the longeron trunnions are at the top of the built-in 8-inch PRLA guides.

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2.22 REACTION CONTROL SYSTEM (RCS)

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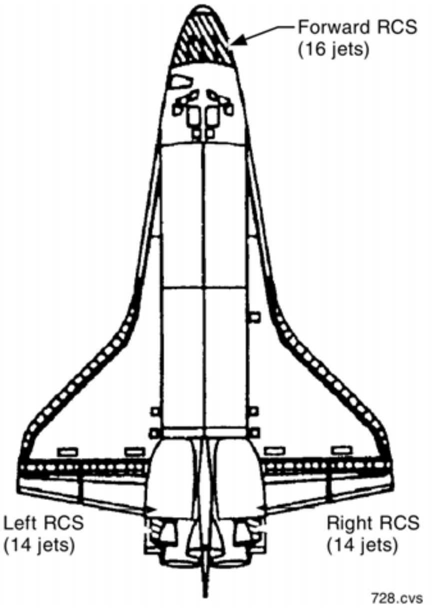
Description

The orbiter’s RCS consists of forward and aft control jets, propellant storage tanks, and distribution networks located in three vehicle modules: forward, left, and right. The forward module is contained in the nose area, forward of the cockpit windows. The left and right (aft) modules are collocated with the orbital maneuvering system (OMS) in the left and right OMS/RCS pods near the tail of the vehicle. Each RCS consists of high-pressure gaseous helium storage tanks, pressure regulation and relief systems, a fuel and oxidizer tank, a propellant distribution system, reaction control jets, and electrical jet and pod heaters.

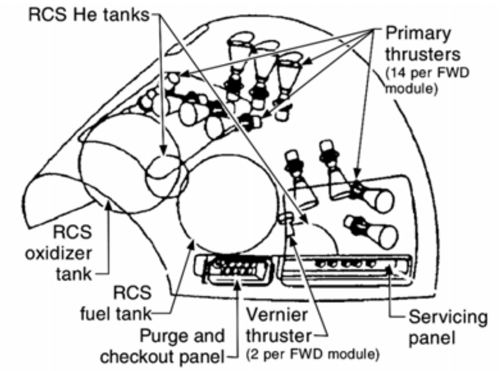
The RCS units provide propulsive forces from a collection of jet thrusters to control the orbiter’s motion. Each jet is permanently fixed to fire in a general direction: up, down, left, right, forward, or aft. The selective firing of individual jets or specific combinations of jets provides thrust for:

- Attitude control
- Rotational maneuvers (pitch, yaw, roll)
- Small velocity changes along the orbiter axes (translational maneuvers)

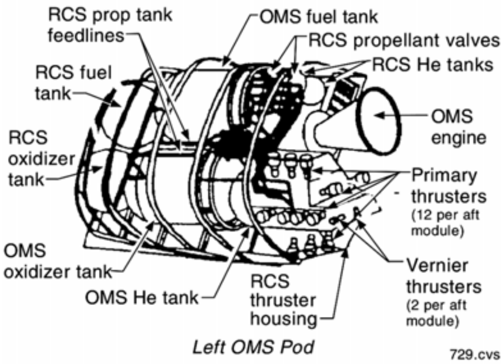
Each RCS jet is identified by the propellant manifold that supplies the jet and by the direction of the jet plume. The first identifier designates a jet as forward (F), left aft (L), or right aft (R) RCS. The second identifier, number 1 through 5, designates the propellant manifold. The third identifier designates the direction of the jet plume: A (aft), F (forward), L (left), R (right), U (up), D (down). For example, jets F2U, F3U, and F1U are forward RCS jets receiving propellants from forward RCS manifolds 2, 3, and 1, respectively; the jet plume direction is up.



Forward, Left, and Right RCS Modules



Forward RCS Module



Left OMS Pod

Left and Forward RCS Modules

Manual RCS use is accomplished through the rotational and translational hand controllers, and automatic use is handled by the digital autopilot (DAP) and the general purpose computers (GPCs).

Nominal uses of the RCS occur during ascent, orbit, and entry. During ascent, the RCS is used for rotational control during mated coast with the external tank. It is also used to provide –Z translation at external tank separation, using all 10 down (–Z) primary jets. This is the only RCS translational maneuver done automatically. The RCS is also used during ascent to maneuver to OMS burn attitude and to trim residuals post-burn, if required.

During orbit, the RCS provides attitude control, including pointing and attitude hold, and rendezvous maneuvers.

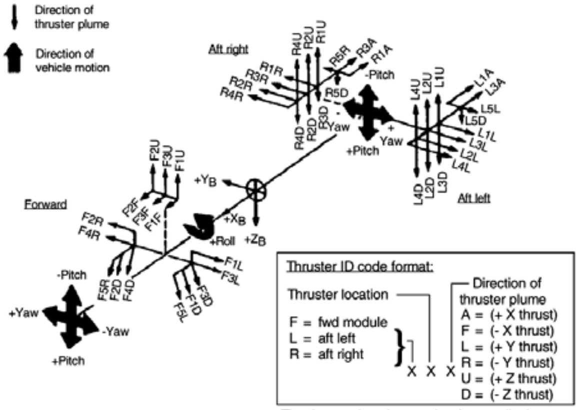
During entry, the RCS provides for center of gravity (c.g.) management through the forward propellant dump. Also during entry, yaw, roll, and pitch control is provided by the aft left/right (Y) and up/down (Z) jets.

The RCS is also used during off-nominal situations. In the case of loss of two SSMEs on ascent, the OMS-to-RCS interconnect is automatically commanded, and the RCS provides single-engine roll control. If the OMS gimballing system is not performing adequately to control vehicle attitude during an OMS burn, RCS jets are used to help maintain attitude. This is also known as "RCS wraparound." The RCS is also used to adjust an orbit if the OMS fails prematurely. During aborts, the RCS may be used to assist with ascent propellant dumps to decrease vehicle weight, improve performance, and control center of gravity.

NOTE

> RCS jets assist in OMS and/or RCS dumps by burning propellant in either propulsive or non-propulsive (null) burns.

There are a total of 44 RCS jets; 38 primary and 6 vernier. The vernier jets are only used on orbit for fine attitude control. The forward RCS has 14 primary and 2 side-firing vernier jets. The aft RCS has 12 primary and 2 vernier jets in each pod for a total of 28. One set of aft vernier jets is side-firing, and the other set is down-firing. The primary RCS jets provide 870 pounds of vacuum thrust each, and the vernier RCS jets provide 24 pounds of vacuum thrust each for precise maneuvering. The vernier jets are used for tight attitude dead bands and fuel conservation.



The thruster location number is actually the propellant manifold number. Manifold 5 jets are verniers.

730.cvs

RCS Jet Identification

NOTE

> The loss of one down-firing vernier jet results in the loss of the entire vernier mode due to the loss of control authority. If one side-firing vernier jet is lost, control can be maintained, except for some RMS-loaded operations.

Two helium tanks supply gaseous helium pressure to the oxidizer and fuel tanks. The oxidizer and fuel are then supplied under pressure to the RCS jets. Nitrogen tetroxide (N_2O_4) is the oxidizer, and monomethyl hydrazine (MMH) is the fuel. The propellants are toxic, liquid at room temperature, and hypergolic (they ignite upon contact with each other). The propellants are supplied to the jets, where they atomize, ignite, and produce a hot gas and thrust.

CAUTION

On-orbit leak of MMH fuel may cause a module fire on entry when MMH mixes with atmospheric oxygen.

The primary jets are operable in a maximum steady-state mode of 1 to 150 seconds, with a maximum single-mission contingency of 800 seconds for the RCS aft (+X) jets and 300 seconds maximum for the RCS forward (–X) jets. The multiple primary jets provide redundancy. A single steady-state vernier firing of up to 275 seconds in any 2-hour period is allowed. Vernier jets are used for finite maneuvers and stationkeeping (long-time attitude hold). The vernier jets are not redundant.

The forward RCS module and OMS/RCS pods can be removed to facilitate orbiter turnaround, if required.

Jet System

The jet system combines fuel and oxidizer to produce hypergolic combustion (hot gas thrust). The system's major components are the reaction jet driver, fuel and oxidizer valves, injector head assembly, combustion chamber, nozzle, and electrical junction box.

The reaction jet driver converts GPC fire commands into the required voltage for opening the bipropellant valves, thus initiating the combustion process. The driver also generates chamber pressure discretes and sends them to redundancy management as an indication of actual jet firings.

Each primary and vernier RCS jet has one fuel and one oxidizer solenoid-operated pilot poppet valve that is energized open by an electrical thrust-on command, permitting the propellant hydraulic pressure to open the main valve poppet and allow the respective propellant to flow through the injector into the combustion chamber. When the thrust-on command is terminated, the valves are deenergized and closed by spring and pressure loads.

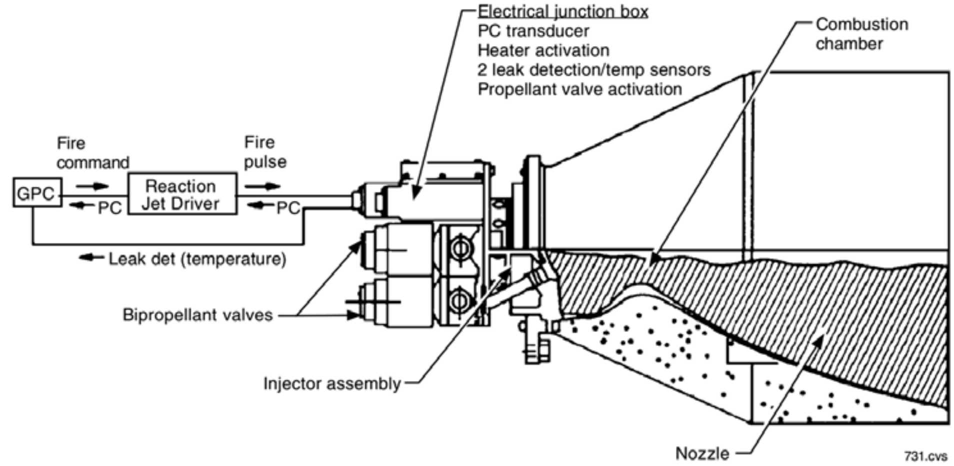
The injector assembly directs the flow of propellants to the combustion chamber. The primary thrusters have injector hole pairs (one fuel, one oxidizer), called doublets, canted toward each other for stream impingement of the propellants in the combustion chamber. Each primary jet has 84 doublets arranged in a "showerhead" circular pattern in the combustion chamber. Additional fuel holes are provided near the outer edge of the injector assembly for cooling the combustion chamber walls.

Each of the six vernier RCS jets has a single pair of fuel and oxidizer injector holes canted to cause impingement of the fuel and oxidizer streams for combustion.

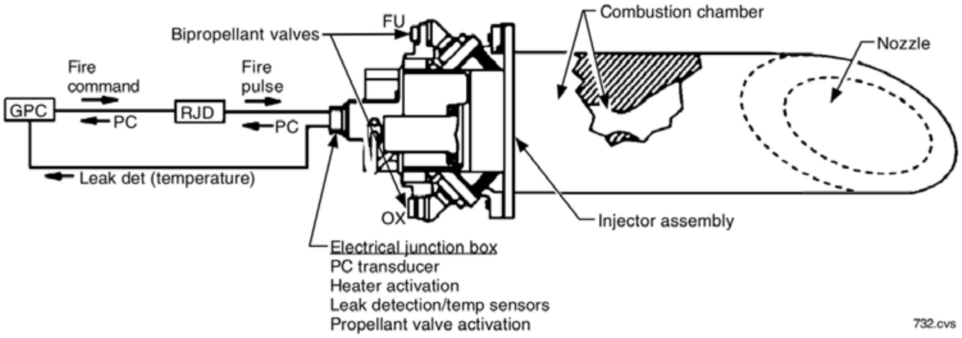
The combustion chamber of each RCS jet is constructed of columbium with a columbium disilicide coating to prevent oxidation. The nozzle of each RCS jet is tailored to match the external contour of the forward RCS module or the left and right aft RCS pods. The nozzle is radiation-cooled, and insulation around the combustion chamber and nozzle prevents the excessive heat of 2,000° to 2,400° F from radiating into the orbiter's structure.

The electrical junction box for each RCS jet has electrical connections for an electrical heater, a chamber pressure transducer, oxidizer and fuel injector temperature transducers (to detect propellant leaks) for each valve, and the propellant valves.

There is a small possibility of random but infrequent combustion instability of the primary RCS jets, causing a burnthrough in the combustion chamber wall of an RCS primary jet in a very few seconds. An instability protection system is incorporated into each of the 38 primary RCS jets. The electrical power wire of each primary RCS jet fuel and oxidizer valve is wrapped around the outside of each primary RCS jet combustion chamber wall. If instability occurs within a primary RCS jet, the burnthrough would cut the electrical power wire to that primary RCS jet's valves, remove electrical power to the valves, close the valves, and render the jet inoperative for the remainder of the mission.



Primary Jet



Vernier Jet

Propellant System

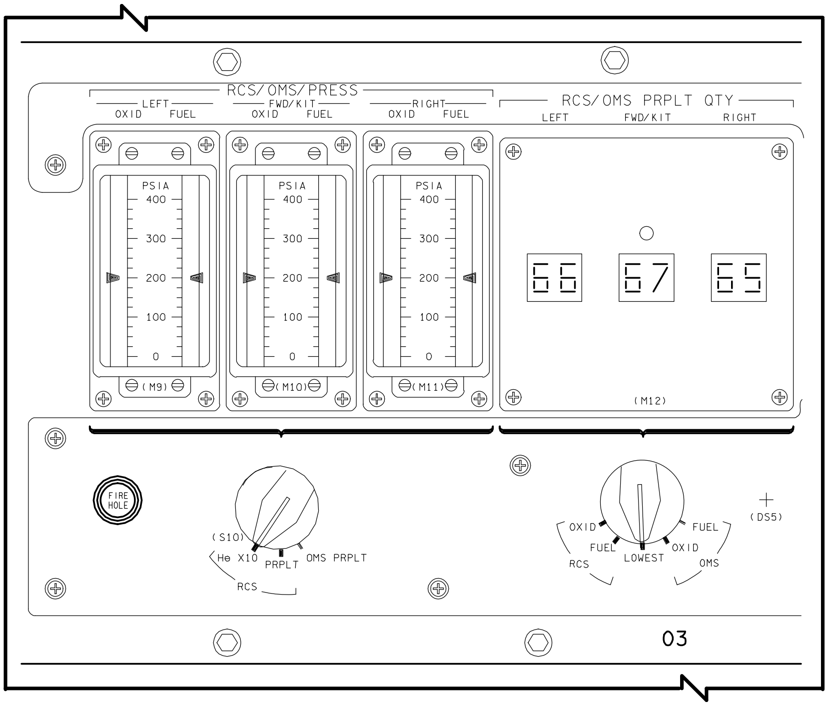
The system that distributes the propellants to the RCS jets consists of fuel and oxidizer tanks, tank isolation valves, manifold isolation valves, crossfeed valves, distribution lines, and filling and draining service connections.

Propellant Tanks

Each RCS module contains two propellant tanks, one for fuel and one for oxidizer. The nominal full load of the forward and aft RCS tanks in each pod is 1,464 pounds in the oxidizer tanks and 923 pounds in the fuel tanks.

Each tank is pressurized with helium, which expels the propellant into an internally mounted, surface-tension, propellant acquisition device that acquires and delivers the propellant to the RCS jets. The propellant acquisition device is required because of the orbiter's orientation during ascent, on orbit, and during entry. The device is also needed to deal with the various accelerations, which range from very high during ascent, entry, or abort to very low during orbital operation. The forward RCS propellant tanks have propellant acquisition devices designed to operate primarily in a low-gravity environment, whereas the aft RCS propellant tanks are designed to operate in both high and low gravity, ensuring adequate propellant flow during all phases of flight. A compartmental tank with individual wire mesh screen devices in both the upper and lower compartments supplies propellant independent of tank load or orientation. A barrier separates the upper and lower compartments in each tank.

The aft RCS propellant tanks incorporate an entry collector, sumps, and gas traps to ensure proper operation during abort and entry mission phases.



RCS/OMS/PRESS Meters and Rotary Switch and RCS/OMS PRPLT QTY LEDs and Switch on Panel O3 (Note: Information on these meters is from a different source than the information on PASS GNC SYS SUMM 2)

The left, forward, and right RCS fuel and oxidizer tank ullage pressures (pressures within an RCS propellant tank used for expelling propellant and calculating propellant volume) can be monitored on panel O3. When the left-hand rotary switch on panel O3 is positioned to *RCS PRPLT*, the pressures are displayed on the three RCS/OMS/PRESS meters. The *LEFT RCS*, *FWD RCS,* or *RIGHT RCS* red caution and warning light on panel F7 will illuminate if a module's tank ullage pressure is less than 200 psia or higher than 300 psia.

RCS Propellant Quantity

The RCS quantity monitor uses the GPC to calculate the usable percent of fuel and oxidizer in each RCS module. The quantities are computed based on the pressure, volume, and temperature method, which requires that pressure and temperature measurements be combined with a unique set of constants to calculate the percent remaining in each of the six propellant tanks. Correction factors are included for residual tank propellant at depletion, gauging inaccuracy, and trapped line propellant. The computed quantity represents the usable (rather than total) quantity for each module and makes it possible to determine if the difference between each pair of tanks exceeds a preset tolerance (leak detection).

The sequence assumes that helium flows to the propellant tanks to replace propellant leaving. As a result, the computed quantity remaining in a propellant tank will be decreased by normal usage, propellant leaks, or helium leaks.

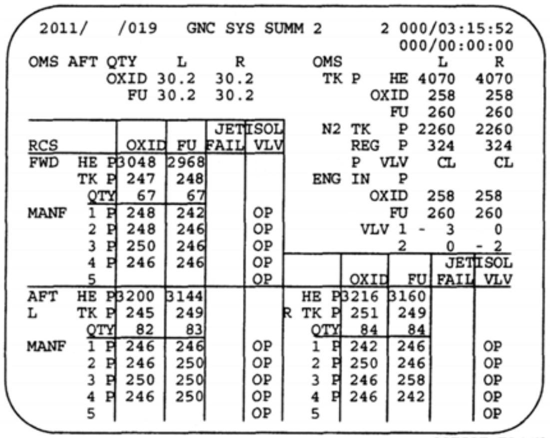
NOTE

> Erroneous temperature and/or pressure transducer readings will cause erroneous propellant quantity calculations.

The left, right, and forward RCS fuel and oxidizer quantities are displayed to the flight crew by the RCS/OMS PRPLT QTY LEDs on panel O3. When the rotary switch on panel O3 below the LEDs is positioned to the *RCS FUEL* or *OXID* position, the LEDs will indicate, in percent, the amount of fuel or oxidizer. If the switch is positioned to *RCS LOWEST*, the gauging system selects whichever is lower (fuel or oxidizer) for display on the LED.

The left, right, and forward RCS quantities also are sent to PASS GNC SYS SUMM 2 (RCS L QTY, R QTY, FWD QTY), and in the event of failures, substitution of alternate measurements and the corresponding quantity will be displayed. If no substitute is available, the quantity calculation for that tank is suspended with a fault message.

The sequence also provides automatic closure of the high-pressure helium isolation valves on orbit when the propellant tank ullage pressure is above 300 psia. When the tank ullage pressure returns below these limits, the close command is removed.



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 2011/   /019   GNC SYS SUMM 2       2 000/03:15:52
                                       000/00:00:00
OMS AFT QTY     L      R          OMS          L      R
        OXID 30.2   30.2           TK P   HE 4070   4070
          FU 30.2   30.2                OXID  258    258
                                          FU  260    260
                           JET ISOL   N2 TK    P 2260   2260
RCS          OXID   FU   FAIL VLV        REG   P  324    324
FWD   HE P   3048 2968                    P  VLV   CL     CL
      TK P    247  248                ENG IN   P
       QTY     67   67                     OXID  258   258
MANF   1 P    248  242         OP            FU  260   260
       2 P    248  246         OP          VLV 1 -  3     0
       3 P    250  246         OP              2    0   - 2
       4 P    246  246         OP                           JET ISOL
       5                       OP          OXID    FU  FAIL VLV
AFT   HE P   3200 3144               HE P  3216  3160
L     TK P    245  249             R TK P   251   249
       QTY     82   83                QTY    84    84
MANF   1 P    246  246         OP      1 P  242   246          OP
       2 P    246  250         OP      2 P  250   246          OP
       3 P    250  250         OP      3 P  246   258          OP
       4 P    246  250         OP      4 P  246   242          OP
       5                       OP      5                       OP
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PASS GNC SYS SUMM 2 Display

Exceeding a preset absolute difference of 9.5 percent between the fuel and oxidizer propellant quantities will illuminate the respective *LEFT RCS*, *RIGHT RCS*, or *FWD RCS* red caution and warning light on panel F7, activate the *BACKUP C/W ALARM*, and cause a fault message to be sent to the DPS display. A bias of 9.5 percent is added when a leak is detected so that subsequent leaks in that same module may be detected in the PASS. BFS will annunciate a leak only once.

Tank Isolation Valves

The valves located between the propellant tanks and the manifold isolation valves isolate the propellant tanks from the remainder of the propellant distribution system. The isolation valves are ac-motor-operated and consist of a lift-off ball flow control device and an actuator assembly that contains a motor, gear train, and actuator gear. One pair of valves (one fuel and one oxidizer) isolates the propellant tanks from the 1/2 manifold (manifolds are referenced by number: 1/2/3/4/5) in the forward and aft left and right RCS. One pair of valves isolates the propellant tanks from the 3/4/5 manifold in the forward RCS. Two pairs of valves, in parallel, identified as A and B, isolate the propellant tanks from the 3/4/5 manifold in the aft left and right RCS.

The forward RCS tank isolation valves are controlled by the *FWD RCS TANK ISOLATION 1/2* and *3/4/5* switches on panel O8. The aft left RCS tank isolation valves are controlled by the *AFT LEFT RCS TANK ISOLATION 1/2* and *3/4/5 A* and *B* switches on panel O7, and the aft right tank isolation valves are controlled by the *AFT RIGHT RCS TANK ISOLATION 1/2* and *3/4/5 A* and *B* switches on panel O7. These permanent-position switches have three settings: *OPEN*, *GPC*, and *CLOSE.*

When the *FWD RCS TANK ISOLATION 1/2* and *3/4/5* switches on panel O8 are positioned open, fuel and oxidizer from the propellant tanks are allowed to flow to the corresponding manifold isolation valves. Electrical power is provided to an electrical motor controller assembly that supplies power to the ac-motor-operated valve actuators. Once the valve is in the commanded position, logic in the motor controller assembly removes power from the actuator.

Microswitches in each pair of valves control talkback indicators above each tank's isolation switch on panel O8. The talkback indicator shows *OP* or *CL* when that pair of valves is open or closed and barberpole when the valves are in transit, or one valve is open, and the other is closed, or for some microswitch failures. The *OPEN* and *CLOSE* positions of the *FWD RCS TANK ISOLATION 1/2* and *3/4/5* switches on panel O8 permit manual control of the corresponding pair of valves. The GPC position is not supported in the Forward RCS.

The *OPEN*, *GPC*, and *CLOSE* positions of the *AFT LEFT RCS TANK ISOLATION 1/2* and *3/4/5 A* and *B* and *AFT RIGHT RCS TANK ISOLATION 1/2* and *3/4/5 A* and *B* switches on panel O7 are the same type as those of the forward RCS tank isolation switches and are controlled electrically in the same manner. A talkback indicator above each switch indicates the position of the pair of valves as in the forward RCS. The *3/4/5 A* and *B* switches control parallel fuel and oxidizer tank isolation valves to permit or isolate propellants to the respective aft left and aft right RCS manifold isolation valves 3, 4, and 5.

The aft tank isolation valves can be commanded open or closed when in the GPC position in OPS 1, 3 and 6 for auto-crossfeed purposes.

Manifold Isolation Valves

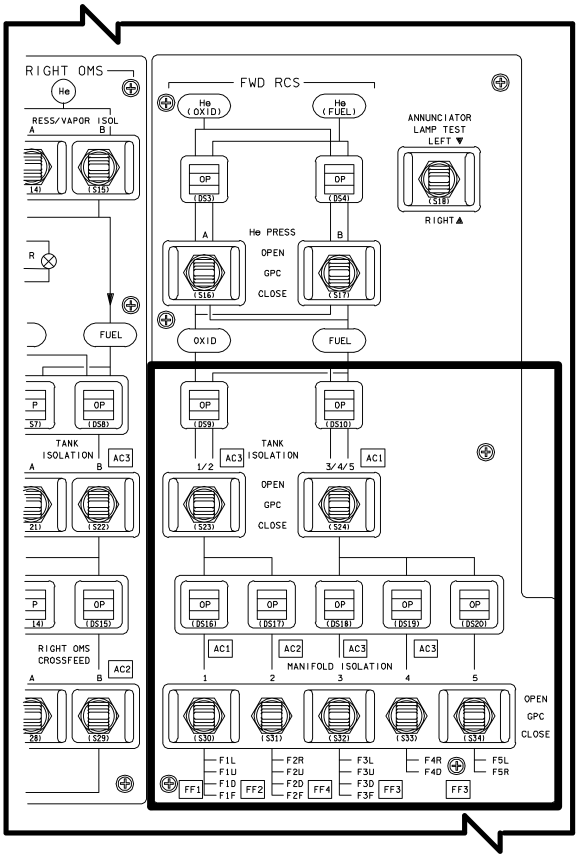
The forward RCS manifold isolation valves are between the tank isolation valves and the forward RCS jets. The valves for manifolds 1, 2, 3, and 4 are the same type of ac-motor-operated valves as the propellant tank isolation valves and are controlled by the same type of motor-switching logic. The forward RCS manifold valve pairs are controlled by the *FWD RCS MANIFOLD ISOLATION 1, 2, 3, 4,* and *5* switches on panel O8. Each MANIFOLD ISOLATION switch controls a pair of valves (one fuel and one oxidizer), which allow propellant to flow to the jets on the corresponding manifold. A talkback indicator above each of the five switches on panel O8 indicates the status of that pair of valves. The talkback indicator is controlled in the same manner as the tank isolation valve indication. The *OPEN* and *CLOSE* positions of the switch permit control the corresponding oxidizer and fuel valves. The GPC position is only supported in OPS 2 and 8.

When the Shuttle is docked to the ISS (or any large payload) in OPS 2, a jet fail on could cause structural failure at the "joints" or to the less robust portions of the docked "stack." The GPCs can automatically close the affected manifold in OPS 2 or 8 if a jet fail on is annunciated, PROVIDED the AUTO MANF CL capability has been enabled via SPEC 23 and the switch is in the GPC position.

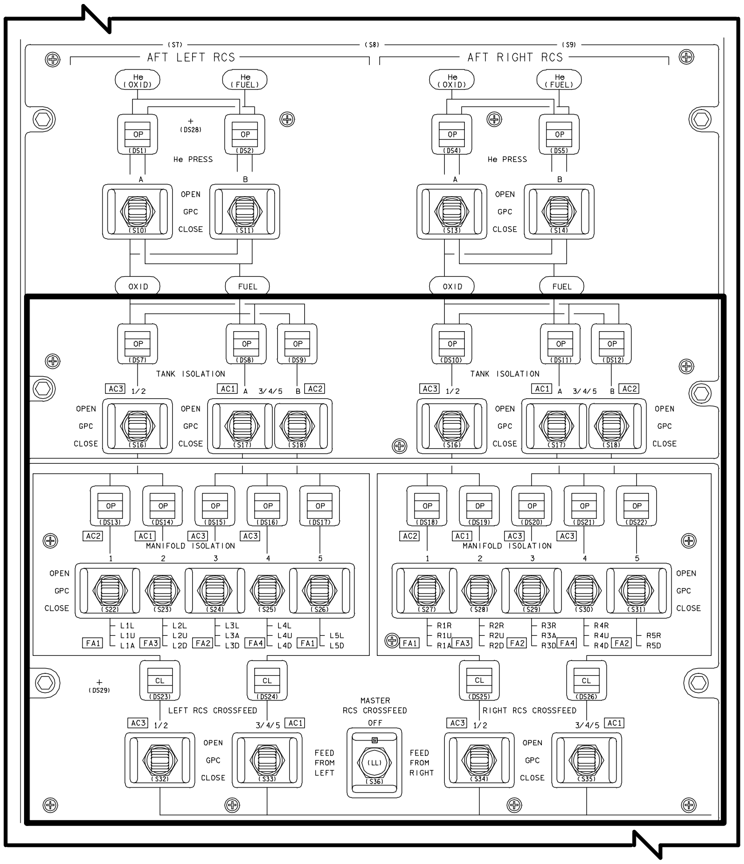
NOTE

> The manifold isolation valves have a backflow capability when the manifold is closed, and the manifold pressure is 30 to 50 psi higher than the tank leg.

The *FWD RCS MANIFOLD ISOLATION 5* switch on panel O8 controls the manifold 5 fuel and oxidizer valves, which control propellants for the forward vernier RCS jets only. The switch is spring-loaded in the *GPC* position. When the switch is moved to the *OPEN* position, electrical power is momentarily applied through logic in an electrical load controller assembly to energize the solenoid valves open and magnetically latch the valves. To close the valves, electrical power is momentarily applied to energize the solenoids surrounding the magnetic latches of the valves, which allows spring and propellant pressure to force the valves closed. A position microswitch in each valve indicates valve position to an electrical controller assembly and controls a talkback indicator above the switch. When both valves are open, the indicator shows *OP*; when both are closed, it indicates *CL*. If one valve is open, and the other is closed, the talkback indicator shows barberpole.



FWD RCS TANK ISOLATION and MANIFOLD ISOLATION Switches and Talkbacks on Panel O8



AFT TANK ISOLATION, AFT MANIFOLD ISOLATION, and RCS CROSSFEED Switches and Talkbacks on Panel O7

The *AFT LEFT RCS MANIFOLD ISOLATION 1, 2, 3, 4, 5* and *AFT RIGHT RCS MANIFOLD ISOLATION 1, 2, 3, 4, 5* switches are on panel O7. The *OPEN, GPC,* and *CLOSE* positions of each switch are the same type as the forward switches and are controlled electrically in the same manner. The OPS 2 and 8 auto-manifold close capability for jet fail on is identical to the Forward RCS. The *AFT LEFT* and *AFT RIGHT RCS MANIFOLD 1, 2, 3,* and *4* switches provide corresponding tank propellants to the applicable primary RCS jets or isolate the propellants from the jets. The *AFT LEFT* and *AFT RIGHT RCS MANIFOLD 5* switches provide corresponding tank propellants to the applicable vernier RCS jets or isolate the propellants from the jets.

RCS Crossfeed Valves

If either aft RCS pod's propellant system must be isolated from its jets, the other aft RCS propellant system can be configured to crossfeed propellant. The aft RCS crossfeed valves that tie the crossfeed manifold into the propellant distribution lines below the tank isolation valves can be configured so that one aft RCS propellant system can feed both left and right RCS jets. The aft RCS crossfeed valves are ac-motor-operated valve actuators and identical in design and operation to the propellant tank isolation valves. The aft RCS crossfeed valves are controlled by the *AFT LEFT* and *AFT RIGHT RCS CROSSFEED 1/2* and *3/4/5* switches on panel O7. The positions of the four switches are *OPEN, GPC,* and *CLOSE*. The *GPC* position allows the orbiter computer to automatically control the crossfeed valves, and the *OPEN* and *CLOSE* positions enable manual control. The *OPEN* position of the *AFT LEFT RCS CROSSFEED 1/2* and *3/4/5* switches permits the aft left RCS to supply propellants to the aft right RCS crossfeed valves, which must be opened by placing the *AFT RIGHT RCS CROSSFEED 1/2* and *3/4/5* switches to the *OPEN* position for propellant flow to the aft right RCS jets. (Note that the *AFT RIGHT* receiving *RCS TANK ISOLATION 1/2* and *3/4/5 A* and *B* valves must be closed.) The *CLOSE* position of the *AFT LEFT* and *AFT RIGHT RCS CROSSFEED 1/2* and *3/4/5* switches isolates the crossfeed capability. The crossfeed of the aft right RCS to the left RCS would be accomplished by positioning the *AFT RIGHT* and *LEFT RCS CROSSFEED* switches to *OPEN* and positioning the *AFT LEFT RCS TANK ISOLATION 1/2* and *3/4/5 A, B* switches to *CLOSE*.

Helium System

Each RCS has two helium storage tanks, four helium isolation valves, four pressure regulators, two check valves, two relief valves, and servicing connections for draining and filling.

Helium Tanks

The two helium tanks in each RCS supply gaseous helium individually, one to the fuel tank and one to the oxidizer tank.

NOTE

> The helium tanks provide ullage pressure for the propellant tanks. Each propellant tank has a specific quantity where, should the helium tank fail, the nominal ullage pressure would result in the maximum delta V. This quantity is referred to as max blowdown. Max blowdown for the forward RCS is 22 percent; for the aft RCS, it is 24 percent propellant quantity remaining.

Helium Isolation Valves

Two parallel helium isolation valves are located between the helium tanks and the pressure regulators in each RCS. When open, the helium isolation valves permit the helium source pressure to flow to the propellant tank. The helium isolation valves are controlled by the *FWD RCS He PRESS A* and *B* switches on panel O8 and the *AFT LEFT RCS He PRESS A* and *B* and *AFT RIGHT RCS He PRESS A* and *B* switches on panel O7. Each switch controls two helium isolation valves, one in the oxidizer helium line and one in the fuel helium line. The switch positions are *OPEN, GPC,* and *CLOSE*. When the switch is positioned to *GPC*, the pair of valves can be closed automatically upon command from the orbiter computer. The *OPEN/CLOSE* positions permit manual control of that pair of valves.

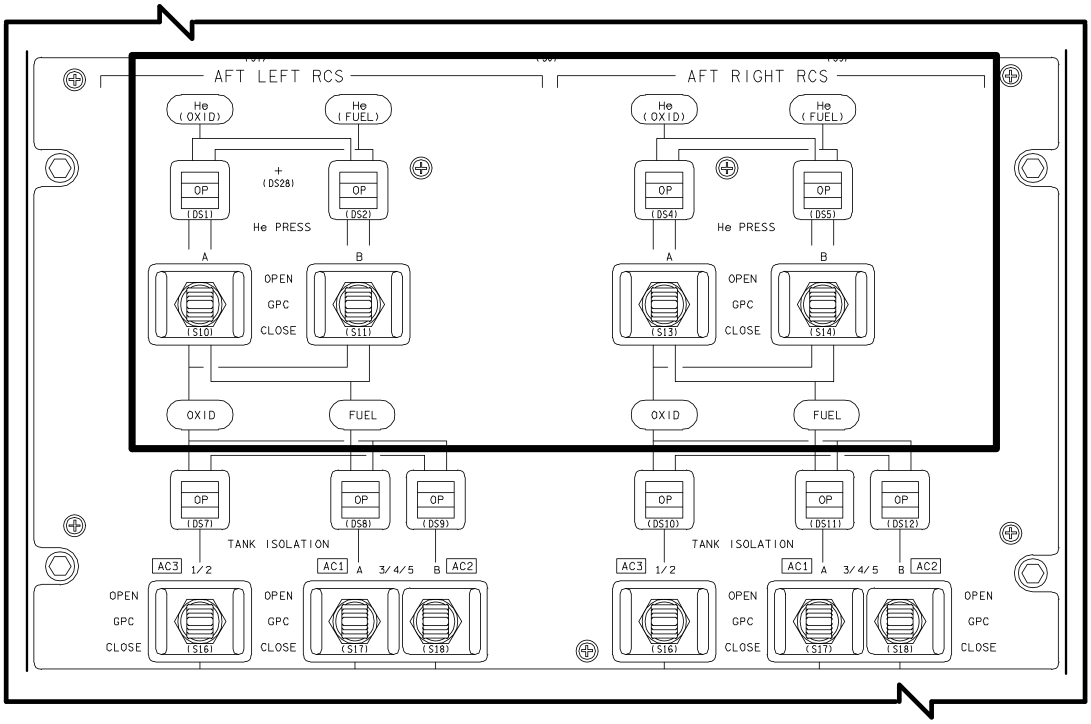
Electrical power is momentarily applied through logic in an electrical load controller assembly to energize the two helium isolation solenoid valves open and to magnetically latch the valves open. To close the two helium isolation valves, electrical power is momentarily applied through the load controller to energize a solenoid surrounding the magnetic latch of the two helium isolation valves, which allows spring and helium pressure to force the valve closed.

A position microswitch in each valve indicates valve position to an electrical controller assembly and controls a position indicator (talkback) above each switch on panels O7 and O8. When both valves (helium fuel and helium oxidizer) are open, the talkback indicates *OP*; when both valves are closed, the talkback indicates *CL*. If one valve is open, and the other is closed, the talkback indicates barberpole.

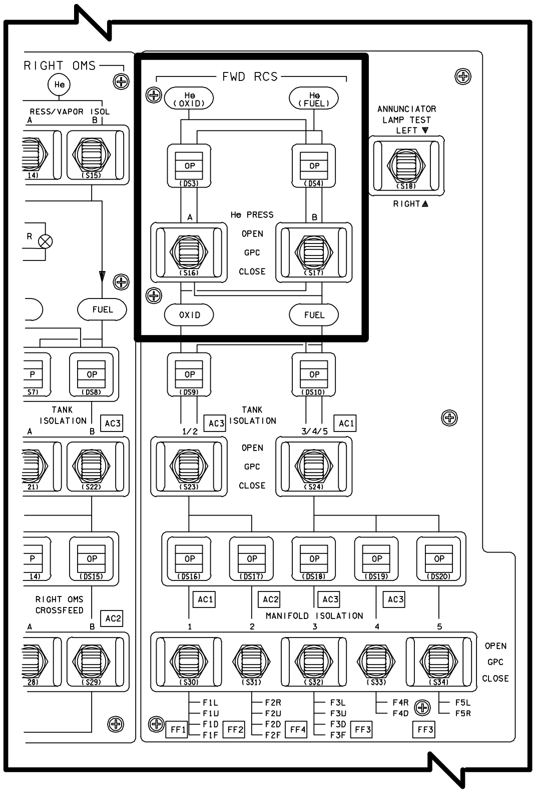
The RCS helium supply pressure is monitored on panel O3. When the rotary switch on panel O3 is positioned to *RCS He X10*, the forward and aft RCS helium pressures are displayed on the RCS/OMS/PRESS OXID and FUEL meters on panel O3.

Helium Pressure Regulators

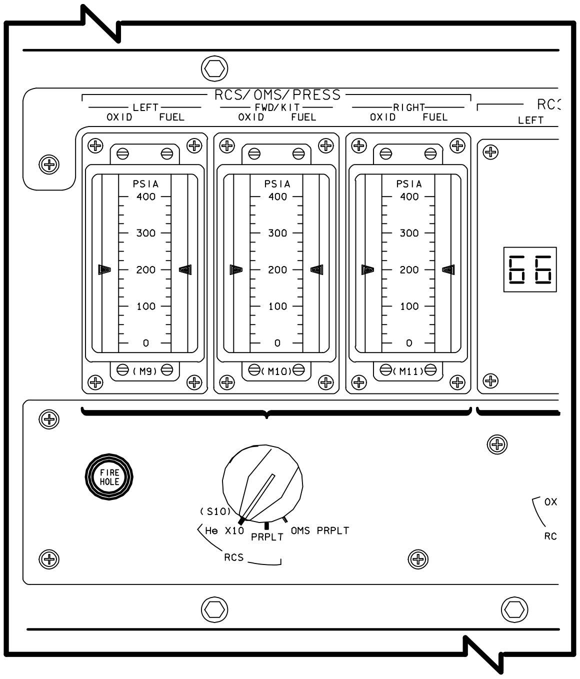
Helium pressure is regulated by two regulator assemblies, connected in parallel, downstream of the helium isolation valves. Each assembly contains two stages, a primary and a secondary, connected in series. If the primary stage fails open, the secondary stage regulates the pressure. The primary regulates the pressure at 242 to 248 psig, the secondary at 253 to 259 psig.



AFT RCS He PRESS Switches and Talkbacks on Panel O7



FWD RCS He PRESS Switches and Talkbacks on Panel O8



RCS/OMS Meters and Rotary Switch on Panel O3
(Note: Information on these meters is the same as the information on SPEC 23 and BFS GNC SYS SUMM 2)

Check Valves

The check valve assembly, which consists of four poppets in a series-parallel arrangement, is located between the pressure regulator assemblies and the propellant tank. The series arrangement limits the backflow of propellant vapor and maintains propellant tank pressure integrity in the event of an upstream helium leak. The parallel arrangement ensures the flow of helium pressure to the propellant tank if a series check valve fails in the closed position.

Pressure Relief Valve

A helium pressure relief valve assembly located between the check valve assemblies and propellant tank will vent excessive pressure overboard before it reaches the propellant tank. Each valve consists of a burst diaphragm, filter, and relief valve. The non-fragmentation diaphragm, which provides a positive seal against helium leakage, will rupture between 324 and 340 psig. The filter prevents any particles of the burst diaphragm from reaching the relief valve seat. The relief valve relieves at 315 psig minimum and reseats at 310 psig. The relief valve is sized to handle, without damaging the propellant tank, helium pressure flow volume if a regulator malfunctions to a full-open position.

Thermal Control

Electrical heaters are provided in the forward RCS module and the OMS/RCS pods to maintain the propellants in the module and pods at safe operating temperatures and to maintain safe operating temperatures for the injector of each primary and vernier RCS jet.

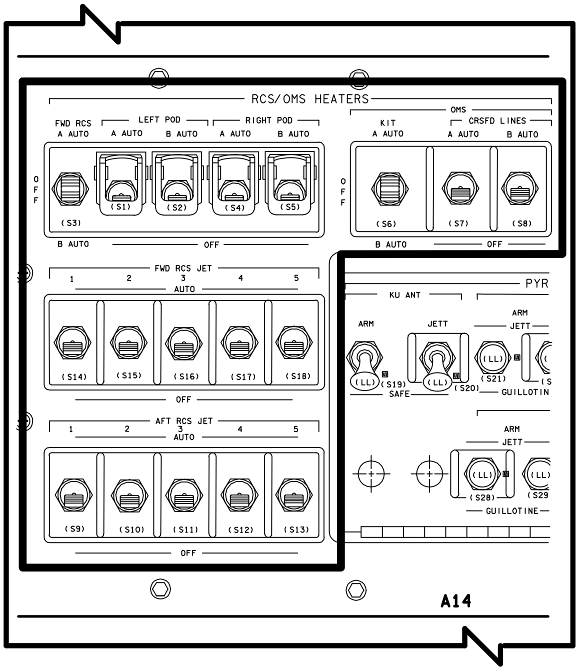
Each primary RCS jet has a 20-watt heater, except the four aft-firing jets, which have 30-watt heaters. Each vernier RCS jet has a 10-watt heater.

The forward RCS has six heaters mounted on radiation panels in six locations. Each OMS/RCS pod is divided into nine heater zones. Each zone is controlled in parallel by an A and B heater system. The aft RCS jet housing contains heaters for the yaw, pitch up, pitch down, and vernier jets in addition to the aft OMS/RCS drain and purge panels.

The forward RCS panel heaters are controlled by the *FWD RCS* switch on panel A14. When the switch is positioned to *A AUTO* or *B AUTO*, thermostats on the forward left-side panel and right-side panel automatically control the respective forward RCS heaters. When the respective forward RCS panel temperature reaches a minimum of approximately 55° F, the respective panel heaters are turned on. When the temperature reaches a maximum of approximately 75° F, the heaters are turned off. The *OFF* position of the switch removes all electrical power from the forward RCS heaters.

The aft RCS heaters are controlled by the *LEFT POD A AUTO* and *B AUTO* and *RIGHT POD A AUTO* and *B AUTO* switches on panel A14. When the switches are positioned to either *A AUTO* or *B AUTO*, thermostats automatically control the nine individual heater zones in each pod. Each heater zone is different, but generally the thermostats control the temperature between approximately 55° F minimum to approximately 75° F maximum. The *OFF* position of the respective switch removes all electrical power from that pod heater system.

The forward and aft RCS primary and vernier jet heaters are controlled by the *FWD* and *AFT RCS JET 1, 2, 3, 4,* and *5* switches on panel A14. When the switches are positioned to *AUTO*, individual thermostats on each jet automatically control the individual heaters on each jet. The primary RCS jet heaters turn on between approximately 66° to 76° F, and they turn off between approximately 94° to 109° F. The vernier RCS jet heaters turn on between approximately 140° to 150° F and off between approximately 184° to 194° F. The *OFF* position of the switches removes all electrical power from the jet heaters. The 1, 2, 3, 4 and 5 designations refer to propellant manifolds. There are two to four jets per manifold.



RCS/OMS HEATERS Switches on Panel A14

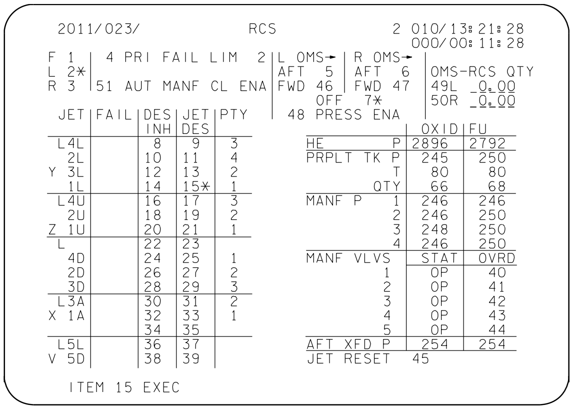
RCS Redundancy Management

RCS redundancy management (RM) software includes RCS jet failure detection and annunciation, jet availability, SPEC 23 RCS, SPEC 51 BFS OVERRIDE, and manifold status processing.

Jet failure modes detected and annunciated are fail-off, fail-on, and fail-leak. Fault annunciation is a class 2 alarm consisting of a master alarm, illumination of the yellow *RCS JET* and red *BACKUP C/W ALARM* lights on panel F7, and a fault summary message (F (L,R) RCS A (D, R, U) JET).

All statuses, flags, counters, and related RCS RM data are carried across OPS transitions. However, when BFS is engaged, all flags, statuses, and counters are cleared and reinitialized.

The jet parameters used in RM are the Pc discrete, CMD B, driver out discrete, and the oxidizer and fuel injector temperatures. Pc discrete is turned on when the jet chamber pressure reaches 36 psi and remains on until the chamber pressure falls below 26 psi. Individual fail detection and response parameters are as follows.



```
 2011/023/            RCS           2 010/13:21:28
                                      000/00:11:28
F 1 | 4 PRI FAIL LIM  2|L OMS→ |R OMS→ |
L 2*|                  |AFT  5 |AFT  6 |OMS-RCS QTY
R 3 |51 AUT MANF CL ENA|FWD 46 |FWD 47 |49L  _0.00
                       |  OFF   7*     |50R  _0.00
 JET|FAIL|DES|JET|PTY  | 48 PRESS ENA  |
    |    |INH|DES|                  |OXID|FU
 L4L|    |  8|  9| 3      HE       P|2896|2792
  2L|    | 10| 11| 4      PRPLT TK P| 245| 250
Y 3L|    | 12| 13| 2               T|  80|  80
  1L|    | 14|15*| 1             QTY|  66|  68
 L4U|    | 16| 17| 3      MANF P   1| 246| 246
  2U|    | 18| 19| 2               2| 246| 250
Z 1U|    | 20| 21| 1               3| 248| 250
 L  |    | 22| 23|                 4| 246| 250
  4D|    | 24| 25| 1      MANF VLVS | STAT|OVRD
  2D|    | 26| 27| 2              1 |  OP | 40
  3D|    | 28| 29| 3              2 |  OP | 41
 L3A|    | 30| 31| 2              3 |  OP | 42
X 1A|    | 32| 33| 1              4 |  OP | 43
    |    | 34| 35|                5 |  OP | 44
 L5L|    | 36| 37|        AFT XFD P | 254 | 254
V 5D|    | 38| 39|        JET RESET  45

  ITEM 15 EXEC
```

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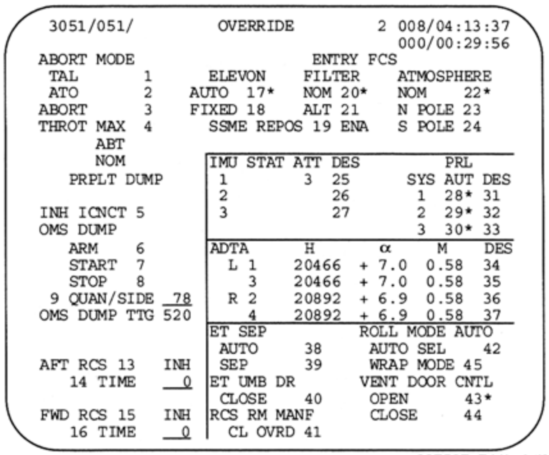
SPEC 23 RCS Display



```
 3051/051/          OVERRIDE        2 008/04:13:37
                                      000/00:29:56
ABORT MODE                     ENTRY FCS
 TAL        1      ELEVON    FILTER    ATMOSPHERE
 ATO        2    AUTO  17*   NOM 20*   NOM     22*
ABORT       3    FIXED 18    ALT 21    N POLE 23
THROT MAX   4      SSME REPOS 19 ENA   S POLE 24
      ABT
      NOM       IMU STAT ATT DES             PRL
   PRPLT DUMP    1        3  25        SYS AUT DES
                 2           26          1  28* 31
INH ICNCT 5      3           27          2  29* 32
OMS DUMP                                 3  30* 33
   ARM      6   ADTA     H      α      M     DES
   START    7     L 1  20466  + 7.0  0.58    34
   STOP     8        3 20466  + 7.0  0.58    35
 9 QUAN/SIDE _78  R 2  20892  + 6.9  0.58    36
OMS DUMP TTG 520     4 20892  + 6.9  0.58    37
                ET SEP            ROLL MODE AUTO
                 AUTO      38      AUTO SEL    42
AFT RCS 13   INH SEP       39      WRAP MODE 45
   14 TIME   __0 ET UMB DR         VENT DOOR CNTL
                 CLOSE     40      OPEN       43*
FWD RCS 15   INH RCS RM MANF       CLOSE      44
   16 TIME   __0   CL OVRD 41
```

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SPEC 51 BFS OVERRIDE Display

Jet Fail-Off

Detection:

- CMD B present with no Pc Discrete for three consecutive cycles.
- RM is suspended for an MDM or LRU commfault.
- RM is unable to detect a fail-off jet when the Pc transducer is failed high.

RM Response:

- Fail-off flag is set.
- Message is annunciated.
- Jet is deselected unless the pod limit has been reached.

Jet Fail-On

Detection:

- Driver out discrete is present when a CMD B is not issued for three consecutive cycles.
- RM is suspended for an MDM or LRU commfault.
- RM is unable to detect a fail-on jet when the driver out discrete is failed low.

RM Response:

- Fail-on flag is set.
- Message is annunciated.
- In OPS 2 (8) a closed command is sent to the affected manifold valves if AUT MANF CL is enabled.

Jet Fail-Leak

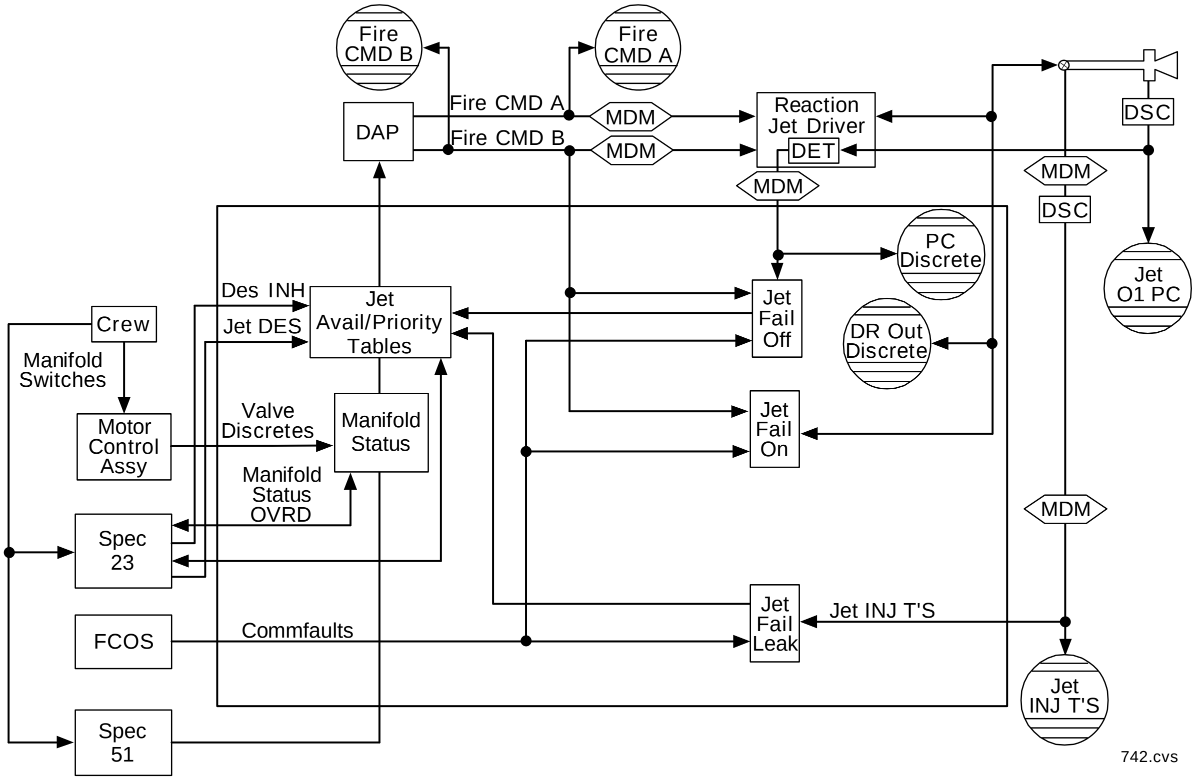
Detection:

- Either oxidizer or fuel injector temperature is below the RCS RM injector temperature limit for three consecutive cycles.
- RM is suspended for an MDM or LRU commfault.
- RM is unable to detect a fail-leak jet for a failed-high temperature transducer.
- A failed-low injector temperature transducer will trip RM.

RM Response:

- Fail-leak flag is set.
- Message is annunciated.
- Jet is deselected unless the pod limit has been reached.

Once RM has annunciated a failure for a jet, that failure will not be reannunciated until the fail flag is reset. The remaining failure modes that were not detected can be annunciated. Vernier jet failures are annunciated in OPS 2 and 8 only.



RCS Redundancy Management Schematic

Nomenclature

To clarify nomenclature, a few RCS RM definitions are listed below.

Deselected Jet – A jet that is not available and will not be commanded to fire.

Reselected Jet – A jet that was previously not available and is now available and could be commanded to fire.

Auto-Deselected Jet – A jet that has been deselected by RCS RM software. RM will auto-deselect a jet for fail-off and fail-leak detection.

Manually Deselected Jet – A jet that has been deselected by SPEC 23 item entry.

Manually Reselected Jet – A jet that is reselected via SPEC 23 item entry. This is the only method to reselect an individual jet that was auto-deselected by RCS RM. (A whole manifold of jets can be reselected via SPEC 51 and SPEC 23 item entry.)

Pod Counter – The internal RCS RM counter that counts the number of jets per pod that have been auto-deselected by RCS RM.

Pod (Fail) Limit – The PRI JET FAIL LIM on SPEC 23 (item 4) that limits the number of primary jets that can be auto-deselected per pod.

Pod Counter is Full – Pod counter equals pod fail limit. Typically, this means two jets have failed and have been auto-deselected in a pod.

Override a Manifold Open (Closed) – An action performed via item entry on SPEC 23 that toggles the RCS RM manifold status to open (closed). The RCS RM manifold status is an independent variable that may differ from the actual manifold valve position. Overriding a manifold closed will deselect all the jets on that manifold.

Deselection Candidate – Any jet that is annunciated fail-off or fail-leak by RCS RM becomes a deselection candidate, unless the jet has been deselect inhibited.

Jet Availability Table — An array that contains a bit for each jet. The bit is on if the associated jet is available and may be commanded to fire by DAP. The bit is off when the jet is not available as determined by RCS RM. Unavailable jets will not be commanded to fire.

Jet Pod Counter and Pod Limit

RCS SPEC 23 displays the PRI JET FAIL LIM. This limit is the number of primary jets that RCS RM will deselect for the pod (forward, left, or right) currently displayed on SPEC 23. This number is I-loaded to 2 and can be changed via SPEC 23.

RCS RM will auto-deselect primary jets until the pod counter equals the pod limit. RM will continue to annunciate all jet failures not previously annunciated when the pod counter is full; however, no new jets will be auto-deselected.

Manually reselecting an auto-deselected jet will reduce the pod counter by one. Manually reselecting a jet that was manually deselected via SPEC 23 will not have an impact on the pod counter.

The pod counter is not affected by subsequent jet failures on a previously deselected jet. Decreasing the pod limit does not reselect jets. If the pod limit is at two, and two jets are currently auto-deselected, changing the limit to one will not reselect one of the auto-deselected jets.

Once a jet is annunciated fail-off or fail-leak, that jet is a deselection candidate. Assume the pod limit is two. If the pod counter is full, and a third (or more) jet becomes a deselect candidate, this jet will not be auto-deselected, as expected. If one of the jets on the same pod is then manually reselected, the pod counter is decremented to one, also as expected. However, the deselection candidate that could not previously be auto-deselected since the pod counter was at the limit will now be auto-deselected, and the pod counter will be incremented to two again. All deselect candidates remain "deselectable" until their fail-flags are cleared.

RCS Manifold RM

RCS RM contains an independent evaluation of RCS manifold valve status. Input to this processing includes the actual manifold valve status, commfault protection, and crew display item entry processing. The RCS RM manifold status can differ from the actual valve positions. Manifold status is reevaluated when valve discretes change, a commfault occurs, or manifold status is changed by crew display item entries. A commfault is declared when the data path for the manifold valve microswitch discrete is failed. A commfault occurs when an MDM or GPC fails, or a BCE BYPASS is declared.

If RCS RM sets the manifold status to closed, all jets on the affected manifold will be removed from the availability table. Manifold status is set to closed by RCS RM in four cases: manually closing the valve, commfault, crew display item entry, and some dilemma cases.

RCS RM will set the manifold status to closed for MDM commfaults on the associated microswitch channelization. An I/O RESET will force RCS RM to reevaluate the manifold status. Thus, if an I/O RESET clears the commfault, the manifold status will be set to open.

Crew item entries on SPEC 23 can toggle a manifold status open or closed.

RCS Manifold RM can detect two failure modes: power fail and dilemma. Input to these failure detection processes are the four manifold microswitch discretes: OX OP, OX CL, FU OP, and FU CL.

Actual electrical bus voltages are not used in power fail determination. The manifolds are paired by common microswitch buses, and power fails are issued only if both manifolds indicate loss of power to their microswitches.

RCS RM Manifold Dilemma

Detection — Three cases of microswitch indications result in an RCS RM manifold dilemma:

- 1 OP indication + 1 or 0 CL indications
- 2 OP indications + 2 CL indications

- 0 OP indications + 0 CL indications (FRCS manifolds 1, 2, 4, and 5 only)

Indications can be OX and/or FU microswitches. These conditions must exist for three consecutive passes.

RM Response — Issue "RCS RM DLMA" message.

In summary, if the number of open indications is greater than the number of closed indications, the manifold status is open; otherwise, the manifold status is closed.

RCS Manifold Power Fail

Detection — All four manifold microswitch discretes are 0 for six consecutive passes. Power fail processing is performed on the following manifold pairs: FRCS M3/4, ARCS L1/R1, L2/R2, L3/R3, L4/R4, and L5/R5.

RM Response — Issue "RCS PWR FAIL" message. Manifold status is unchanged.

Forward manifolds 1, 2, and 5 are not analyzed for power fail conditions. If these manifolds suffer a power fail to their microswitches, an "RCS RM DLMA" will be issued, rather than an "RCS PWR FAIL."

Forward manifold 3 microswitches are redundantly powered by MN A FPC1 and MN C FMC3. Forward manifold 4 microswitches are powered only by MN C FMC3. Both MN A FPC1 and MNC FMC3 must be lost for RCS RM to issue a power fail for this manifold pair. Because of the low probability of this case, forward manifold 3/4 power fails are rarely detected. However, for the loss of MN C FMC3, an "RCS RM DLMA" message is annunciated, FRCS manifold 4 is declared closed, and the associated jets are declared unavailable.

Jet Selection

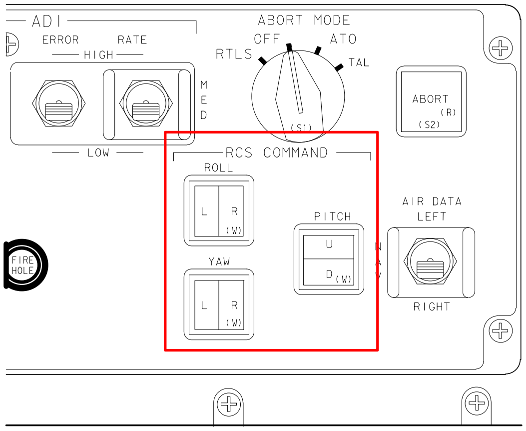
The DAP jet-select module contains default logic in certain instances. When the orbiter is mated to the ET, roll rate default logic inhibits roll rotation, and yaw commands are normally in the direction of favorable yaw-roll coupling. During insertion, a limit of seven aft RCS jets per tank set applies for ET separation and for return-to-launch-site aborts. If negative Z and plus X translation commands are commanded simultaneously, both will be degraded. A limit of four aft RCS jets per tank set normally applies. If plus X and negative Z translations are commanded simultaneously, plus X is given priority. Multi-axis translation and rotation commands may require more jets than allowed and result in degraded control and excessive propellant usage. The DAP jet-select module determines which aft RCS jets (right, left, or both) must be turned on in response to the pitch, roll, and yaw jet commands from the entry flight control system. The forward RCS jets are not used during entry. After entry interface, only the four Y-axis and six Z-axis RCS jets on each aft RCS pod are used. No X-axis or vernier jets are used. The DAP sends the discretes that designate which aft RCS jets are available for firing (a maximum of four RCS jets per pod may be fired). During reconfiguration, or when the RCS crossfeed valves are open, the DAP determines the maximum combined total number of yaw jets available during certain pitch and roll maneuvers.

During ascent or entry, the DAP jet-select logic module in the flight control system receives both RCS rotation and translation commands. By using a table lookup technique, the module outputs 38 jet on/off commands to the RCS command subsystem operating program, which then generates dual fire commands A and B to the individual RCS reaction jet drivers to turn each of the 38 primary RCS jets on or off. The fire commands A and B for each of the 38 primary RCS jets are set equal to the digital autopilot RCS commands. Commands are issued to the six RCS vernier jets similarly on orbit.

Jet Fire Indications

ROLL, *PITCH*, and *YAW* white indicator lights on panel F6 indicate the presence of an RCS command during orbit and early entry. The indicators are *L* and *R* for roll and yaw left or right and *U* and *D* for pitch up and down.

From entry interface until the dynamic pressure is greater than 10 pounds per square foot, the *ROLL L* and *ROLL R* lights indicate that left or right roll commands have been issued by the digital autopilot. The minimum light-on duration is extended to allow the light to be seen even for a minimum impulse firing. When a dynamic pressure of 10 pounds per square foot has been sensed, neither *ROLL* light will be illuminated until 50 pounds per square foot has been sensed, and more than two RCS yaw jets are commanded on.



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Jet Fire Indicator Lights on Panel F6

The *PITCH* lights indicate up and down pitch jet commands until a dynamic pressure of 20 pounds per square foot is sensed, after which the pitch jets are no longer used. When 50 pounds per square foot is sensed, the *PITCH* lights assume a new function. Both *PITCH* lights will be illuminated whenever the elevon surface drive rate exceeds 20° per second (14° per second if only one hydraulic system is remaining).

The *YAW* lights function as yaw jet command indicators throughout entry until the yaw jets are disabled at Mach 1 (approximately 45,000 feet). The *YAW* lights have no other function.

Operations

After main engine cutoff, the forward and aft jets are used to maintain attitude hold until external tank separation. Then the RCS provides a negative Z translation maneuver of about 4 feet per second to move the orbiter away from the external tank. Upon completion of the maneuver, the RCS holds the orbiter attitude until it is time to maneuver to the OMS-2 burn attitude. Although the targeting data for the OMS-2 burn are selected before launch, the target data in the onboard general-purpose computers can be modified by the flight crew via the DPS and keyboard, if necessary, before the OMS burn.

The OMS-2 burn uses both OMS engines to raise the orbiter to a predetermined circular orbit. (OMS-1 burns are only planned for standard insertions.) During the OMS-2 burn, vehicle attitude is maintained by gimbaling (swiveling) the OMS engines. The RCS normally does not operate during an OMS burn. If, during an OMS burn, the gimbal rate or gimbal limits are exceeded, RCS roll control would be required; or if only one OMS engine is used during a burn, RCS roll control may be required.

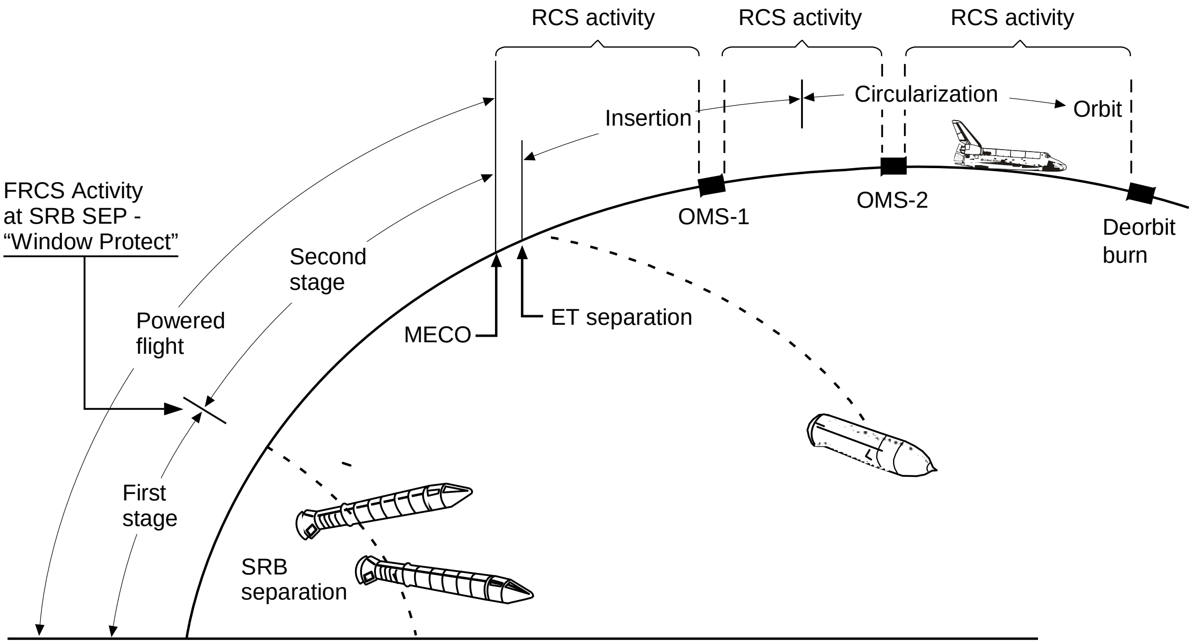
Upon completion of the OMS-2 burn, the RCS can be used to null any residual velocities, if required. It is then used for attitude hold and minor translation maneuvers as required for on-orbit operations. The flight crew can select primary or vernier RCS jets for attitude control in orbit. Normally, the vernier jets are selected for on-orbit attitude hold.

On orbit, the vernier jets are used for fine attitude control, and the primary jets are used for coarse attitude control and minor translations.

Before the deorbit burn, the flight crew maneuvers the spacecraft to the desired attitude using RCS jets. After the OMS burn, the RCS is used to null any residual velocities, if required. The spacecraft is then maneuvered to the proper entry interface attitude using the RCS. The remaining propellants aboard the forward RCS may be dumped by burning the propellants through the forward RCS yaw jets before entry interface if orbiter center-of-gravity control is necessary.

The RCS aft (+ X) jets can be used to complete any OMS deorbit burn if an OMS engine fails. In this case, the OMS-to-aft-RCS interconnect can be used to feed OMS propellant to the aft RCS.

From an entry interface of 400,000 feet, the orbiter is controlled in roll, pitch, and yaw with the aft RCS jets. The orbiter's ailerons are used starting at a dynamic pressure (q-bar) of 2 pounds per square foot (psf), and the aft RCS roll jets are deactivated at a q-bar of 10 psf. At a q-bar of 2 psf, the orbiter's elevons are active, and the aft RCS pitch jets are deactivated at a q-bar of 40 psf. The rudder is activated at Mach 5.0, and the aft RCS yaw jets are deactivated at Mach 1 (approximately 45,000 feet).



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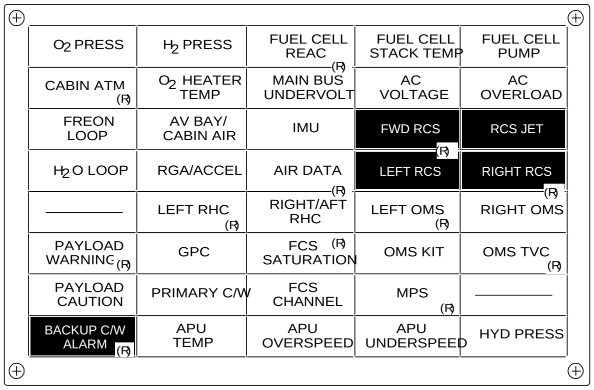
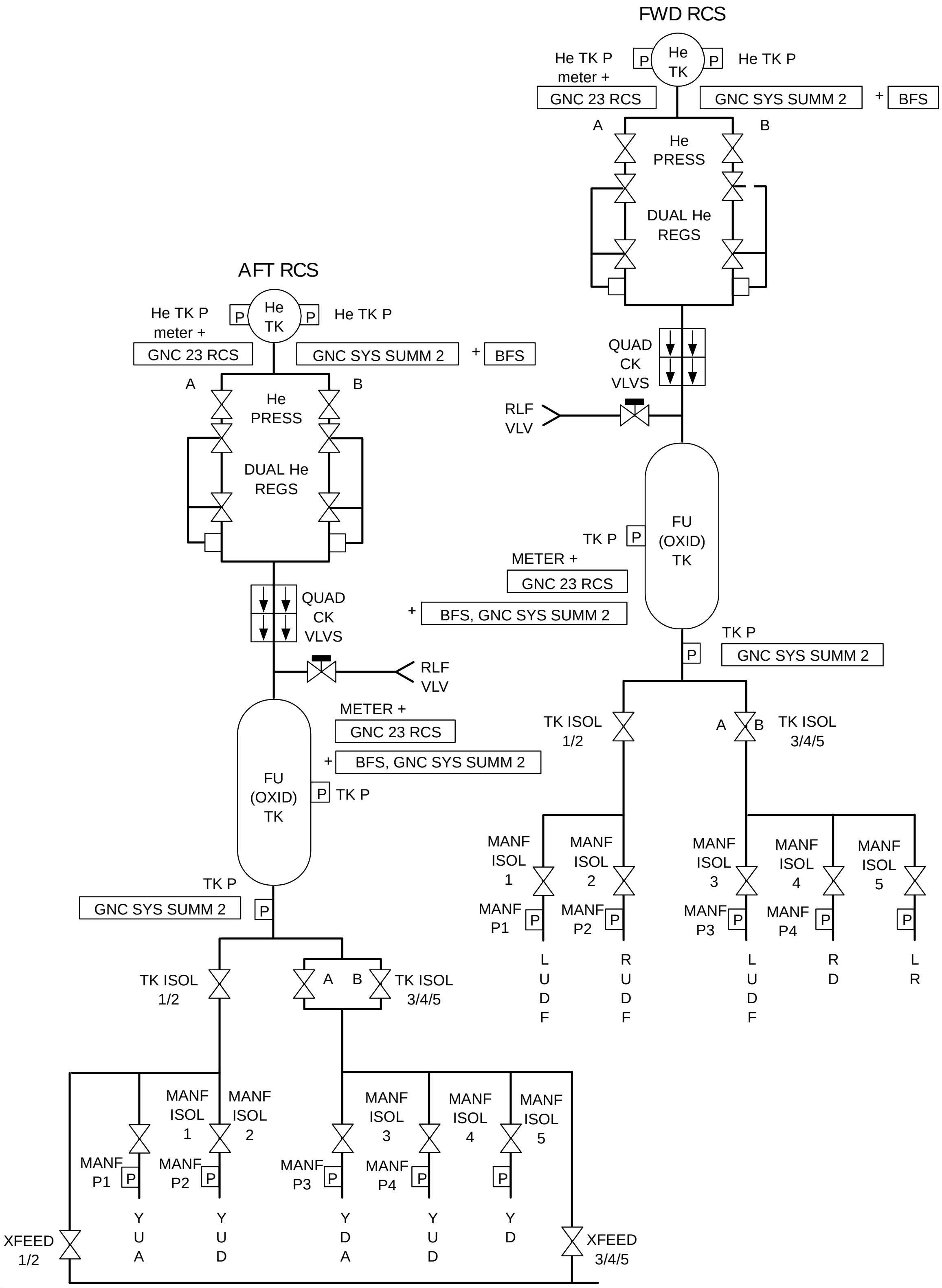
Nominal Ascent Profiles

RCS Caution and Warning Summary

- There are class 2 and 3 alerts for the RCS.
- Class 2 alerts can occur in all the OPS and generate a MASTER ALARM light and tone and a light on the Caution and Warning matrix on panel F7.
- A class 3 alert is generated by the primary GNC or SM software in OPS 2 and 8 or by the BFS software in other OPS.
- The red *LEFT RCS, FWD RCS,* or *RIGHT RCS* light will illuminate if propellant tank ullage pressure is less than 200 psia or higher than 312 psia. Exceeding a preset difference of 9.5 percent between fuel and oxidizer propellant quantities will also illuminate the appropriate one of these lights, activate the *BACKUP C/W ALARM,* and send a fault message to the DPS display.
- RCS jet failure illuminates the yellow *RCS JET* and red *BACKUP C/W ALARM* lights and sends a fault message to the DPS display.
- An F(L,R) RCS X JET (where X=U,D,L,R,F or A) fault message will be displayed in the PASS when a jet fail ON, jet fail OFF, or jet fail LEAK occurs. (OPS 1,2,3,6,8)
- An F(L,R) JET fault message will be displayed in the BFS when a jet fail ON or jet fail OFF occurs when the BFS is engaged. (OPS 1,3,6)
- An F(L,R) He P fault message will be displayed when helium pressure (FU or OX) in the affected pod is below 500 psi. (PASS OPS 2,8; BFS OPS 1,3,6)
- An F(L,R) RCS LEAK fault message will be displayed when propellant quantities (FU and OX) in any one pod differ by more than 9.5 percent. (PASS OPS 2,3,8; BFS OPS 1,3,6)
- An F(L,R) RCS PVT fault message will be displayed in the PASS when there is loss of pressure or temperature data that is needed for RCS quantity calculations. (OPS 2,3,8)
- An F(L,R) RCS TK P fault message will be displayed when propellant tank pressure exceeds upper (312 psi) or lower (200 psi) limits. (PASS OPS 2,8; BFS OPS 1,3,6)
- A G23 RCS SYSTEM F(L,R) fault message will be displayed in the PASS when propellant tank outlet pressure exceeds upper (300 psi) or lower (220 psi) limits or propellant tank temperature exceeds upper (90° F) or lower (50° F) limits. (OPS 2,8)
- An RCS PWR FAIL fault message will be displayed in the PASS when there is loss of valve logic power to the manifold isolation valves. (OPS 1,2,3,6,8)
- An RM DLMA MANF fault message will be displayed in the PASS when a dilemma is detected in the manifold valve status (FU and OX valve positions disagree). (OPS 1,2,3,6,8)
- An S89 PRPLT THRM RCS fault message will be annunciated when the temperature in the affected structure exceeds I-loaded upper or lower limits. (OPS 2)

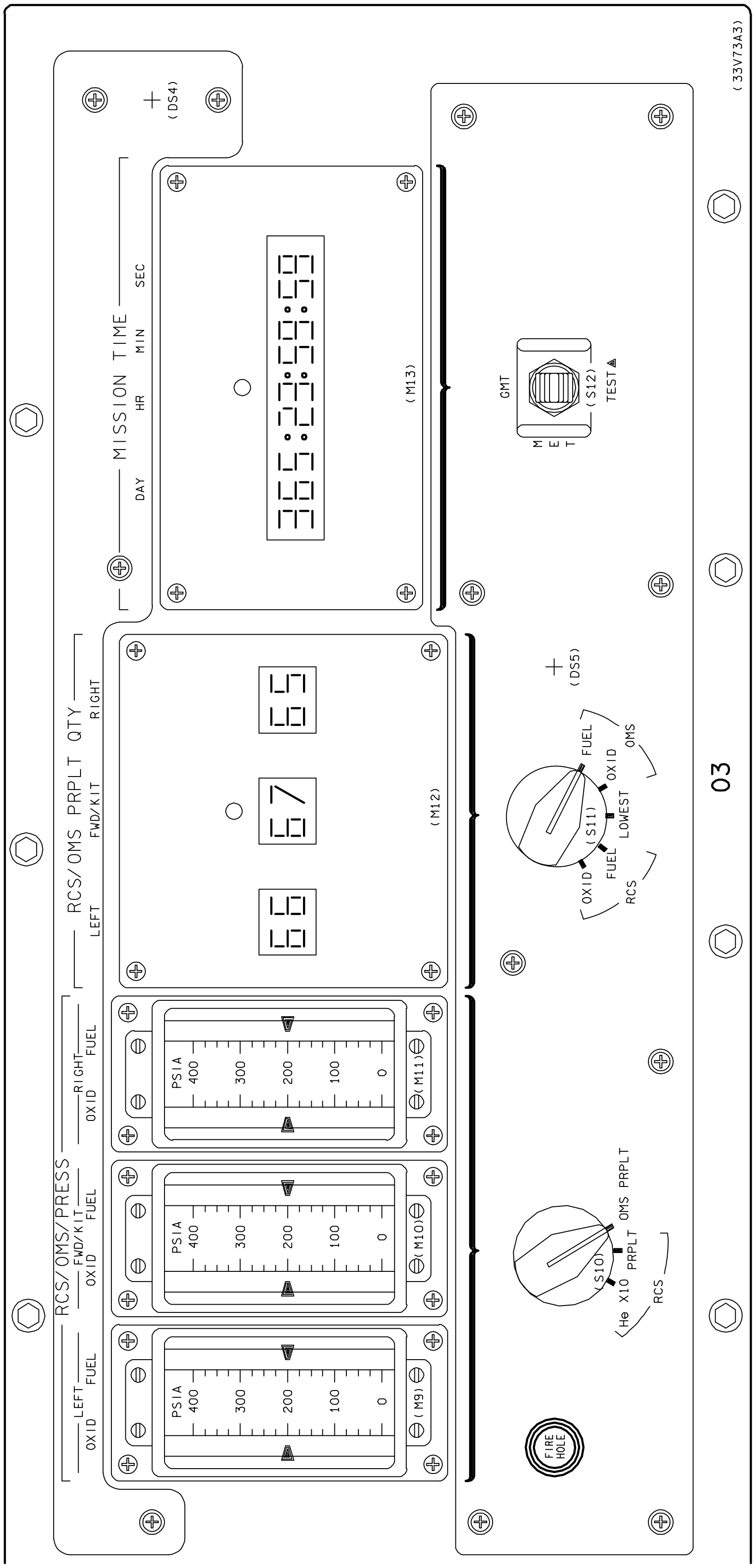


RCS Caution and Warning Lights on Panel R7

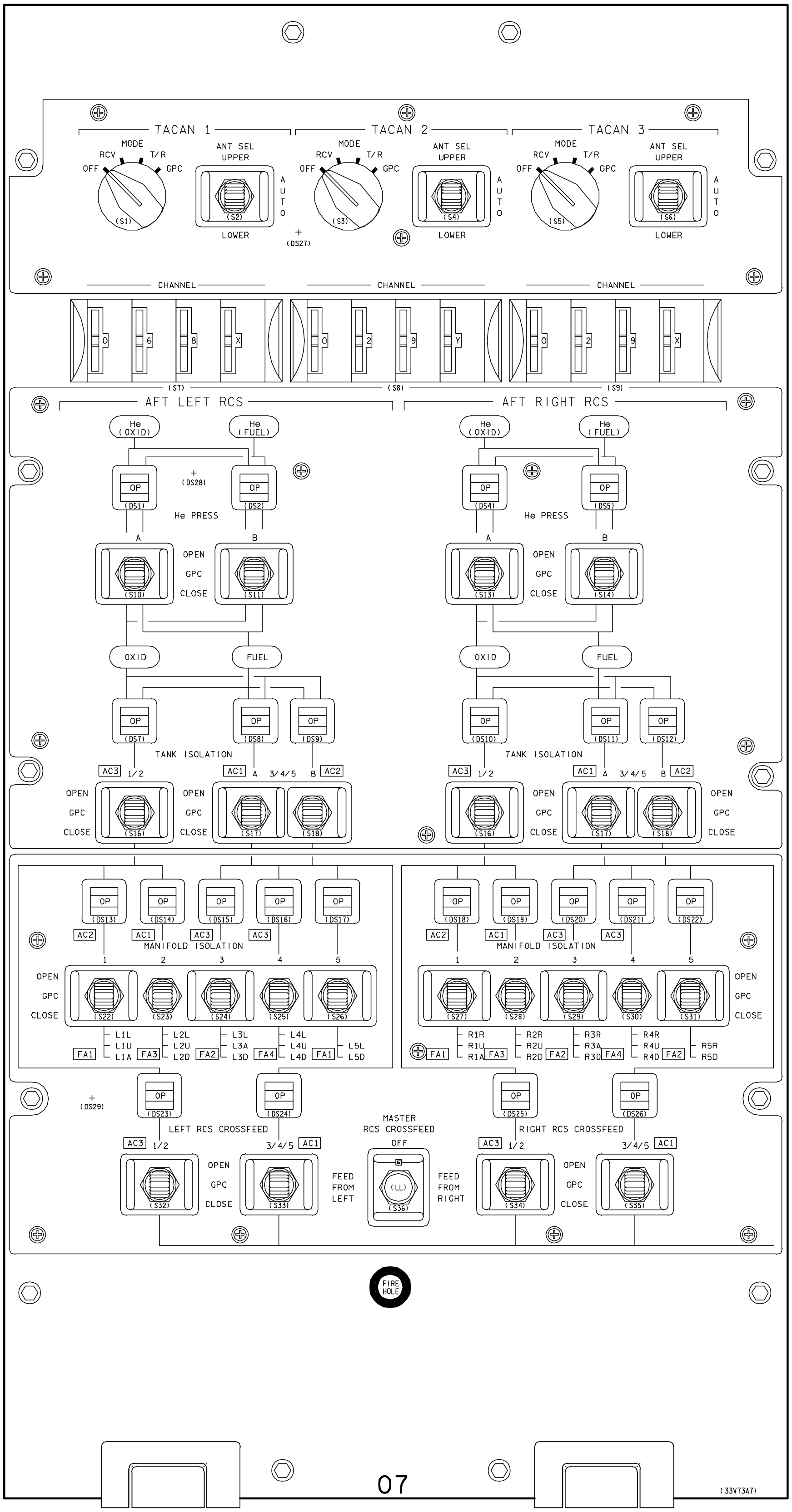


F7

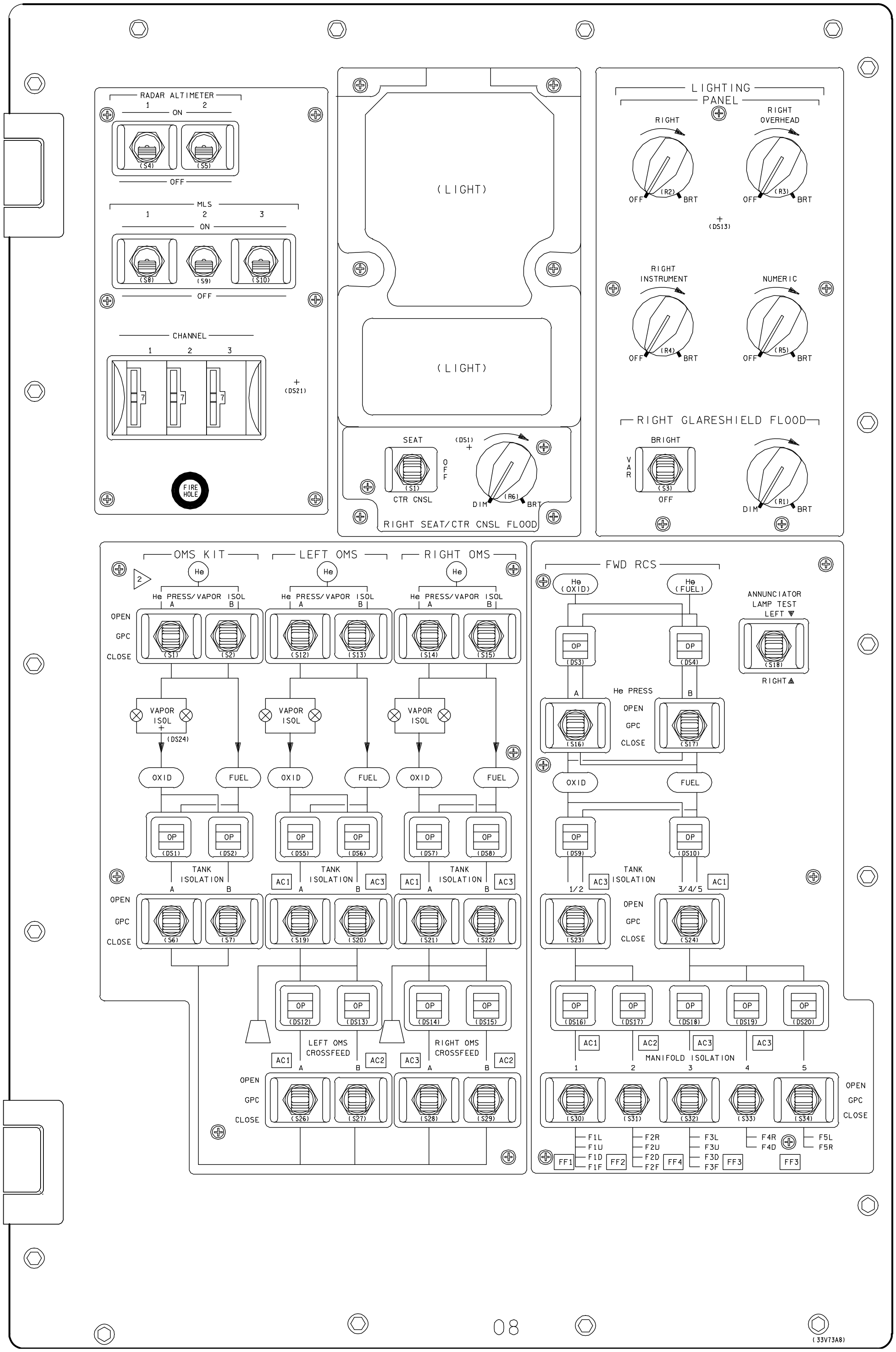
Reaction Control System


(33V73A3)
(DS4)
MISSION TIME
DAY
HR
MIN
SEC
365:23:59:59
(M13)
GMT
M
E
T
(S12)
TEST
RCS/OMS PRPLT QTY
LEFT
FWD/KIT
RIGHT
66
67
65
(M12)
(DS5)
FUEL
OXID
OMS
LOWEST
(S11)
OXID
FUEL
RCS
O3
RCS/OMS/PRESS
LEFT
FWD/KIT
RIGHT
OXID
FUEL
PSIA
400
300
200
100
0
(M9)
(M10)
(M11)
(S10)
He X10
PRPLT
OMS PRPLT
RCS
FIRE HOLE

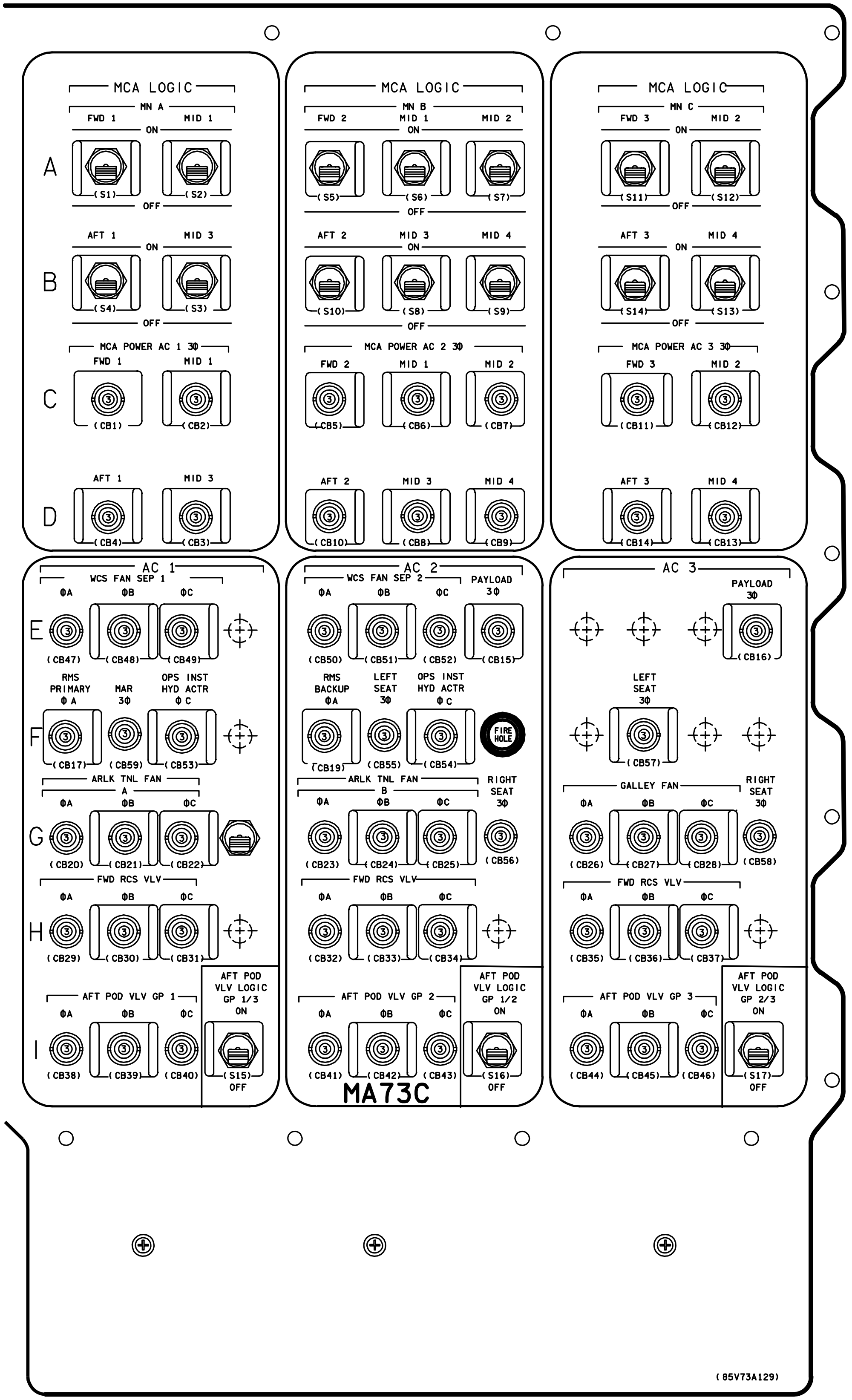
Panel O3


TACAN 1
TACAN 2
TACAN 3
MODE
OFF
RCV
T/R
GPC
ANT SEL
UPPER
LOWER
AUTO
(S1)
(S2)
(S3)
(S4)
(S5)
(S6)
(DS27)
CHANNEL
(S7)
(S8)
(S9)
0
6
8
X
0
2
9
Y
0
2
9
X
AFT LEFT RCS
AFT RIGHT RCS
He (OXID)
He (FUEL)
OP
(DS1)
(DS2)
(DS4)
(DS5)
(DS28)
He PRESS
A
B
OPEN
GPC
CLOSE
(S10)
(S11)
(S13)
(S14)
OXID
FUEL
(DS7)
(DS8)
(DS9)
(DS10)
(DS11)
(DS12)
TANK ISOLATION
AC1
AC2
AC3
1/2
3/4/5
(S16)
(S17)
(S18)
(DS13)
(DS14)
(DS15)
(DS16)
(DS17)
(DS18)
(DS19)
(DS20)
(DS21)
(DS22)
MANIFOLD ISOLATION
1
2
3
4
5
(S22)
(S23)
(S24)
(S25)
(S26)
(S27)
(S28)
(S29)
(S30)
(S31)
L1L
L1U
L1A
L2L
L2U
L2D
L3L
L3A
L3D
L4L
L4U
L4D
L5L
L5D
R1R
R1U
R1A
R2R
R2U
R2D
R3R
R3A
R3D
R4R
R4U
R4D
R5R
R5D
FA1
FA2
FA3
FA4
(DS29)
(DS23)
(DS24)
(DS25)
(DS26)
LEFT RCS CROSSFEED
RIGHT RCS CROSSFEED
MASTER
RCS CROSSFEED
OFF
FEED FROM LEFT
FEED FROM RIGHT
(LL)
(S32)
(S33)
(S34)
(S35)
(S36)
FIRE HOLE
O7
(33V73A7)

Panel O7


RADAR ALTIMETER
1
2
ON
(S4)
(S5)
OFF
MLS
1
2
3
ON
(S8)
(S9)
(S10)
OFF
CHANNEL
1
2
3
(DS21)
FIRE HOLE
(LIGHT)
(LIGHT)
SEAT
(DS1)
OFF
(S1)
CTR CNSL
DIM
(R6)
BRT
RIGHT SEAT/CTR CNSL FLOOD
LIGHTING PANEL
RIGHT
RIGHT OVERHEAD
OFF
(R2)
BRT
OFF
(R3)
BRT
(DS13)
RIGHT INSTRUMENT
NUMERIC
OFF
(R4)
BRT
OFF
(R5)
BRT
RIGHT GLARESHIELD FLOOD
BRIGHT
VAR
(S3)
OFF
DIM
(R1)
BRT
OMS KIT
LEFT OMS
RIGHT OMS
He
He PRESS/VAPOR ISOL
A
B
OPEN
GPC
CLOSE
(S1)
(S2)
(S12)
(S13)
(S14)
(S15)
VAPOR ISOL
(DS24)
OXID
FUEL
OP
(DS1)
(DS2)
(DS5)
(DS6)
(DS7)
(DS8)
TANK ISOLATION
AC1
AC3
(S6)
(S7)
(S19)
(S20)
(S21)
(S22)
(DS12)
(DS13)
(DS14)
(DS15)
LEFT OMS CROSSFEED
RIGHT OMS CROSSFEED
AC1
AC2
AC3
AC2
(S26)
(S27)
(S28)
(S29)
FWD RCS
He (OXID)
He (FUEL)
ANNUNCIATOR LAMP TEST
LEFT ▼
(S18)
RIGHT ▲
(DS3)
(DS4)
He PRESS
A
B
OPEN
GPC
CLOSE
(S16)
(S17)
OXID
FUEL
(DS9)
(DS10)
1/2
3/4/5
AC3
TANK ISOLATION
AC1
(S23)
(S24)
(DS16)
(DS17)
(DS18)
(DS19)
(DS20)
AC1
AC2
AC3
AC3
MANIFOLD ISOLATION
1
2
3
4
5
(S30)
(S31)
(S32)
(S33)
(S34)
F1L
F1U
F1D
F1F
F2R
F2U
F2D
F2F
F3L
F3U
F3D
F3F
F4R
F4D
F5L
F5R
FF1
FF2
FF4
FF3
FF3
O8
(33V73A8)

Panel O8



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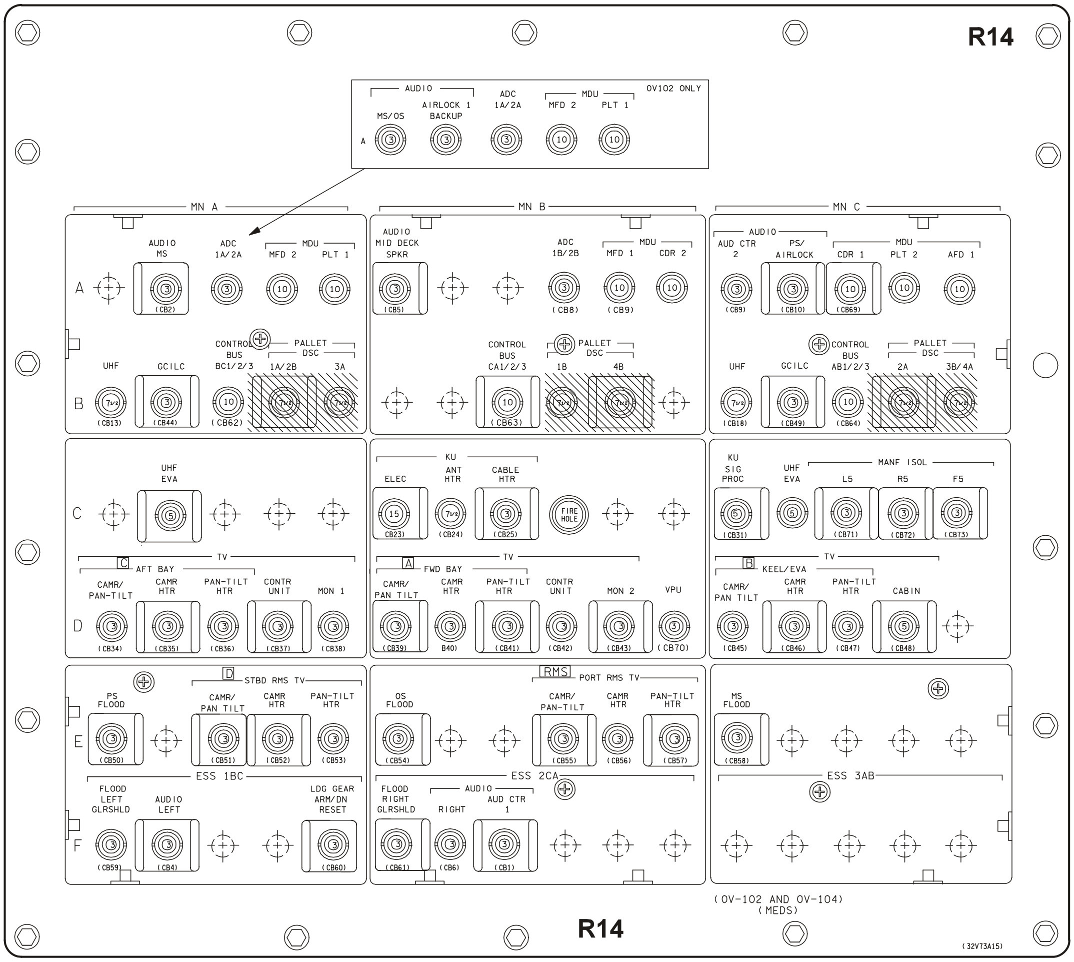
Panel MA73C



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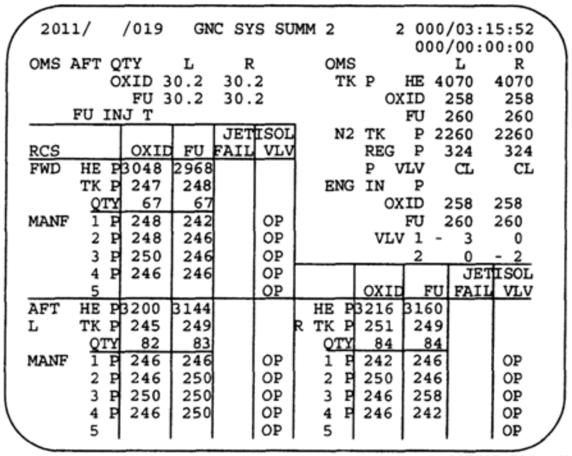
Panel R14


```
 2011/   /019   GNC SYS SUMM 2       2 000/03:15:52
                                       000/00:00:00
OMS AFT QTY     L     R       OMS            L     R
        OXID 30.2  30.2        TK P    HE 4070  4070
          FU 30.2  30.2               OXID  258   258
    FU INJ T                            FU  260   260
                        JET ISOL   N2 TK     P 2260  2260
RCS           OXID  FU FAIL VLV       REG   P  324   324
FWD   HE P 3048 2968                  P   VLV   CL    CL
      TK P  247  248              ENG IN     P
       QTY   67   67                  OXID  258   258
MANF  1 P   248  242      OP              FU  260   260
      2 P   248  246      OP            VLV 1 -   3     0
      3 P   250  246      OP                2     0   - 2
      4 P   246  246      OP                          JET ISOL
      5                   OP               OXID   FU FAIL VLV
AFT   HE P 3200 3144            HE P 3216 3160
L     TK P  245  249          R TK P  251  249
       QTY   82   83             QTY   84   84
MANF  1 P   246  246      OP     1 P  242  246          OP
      2 P   246  250      OP     2 P  250  246          OP
      3 P   250  250      OP     3 P  246  258          OP
      4 P   246  250      OP     4 P  246  242          OP
      5                   OP     5                      OP
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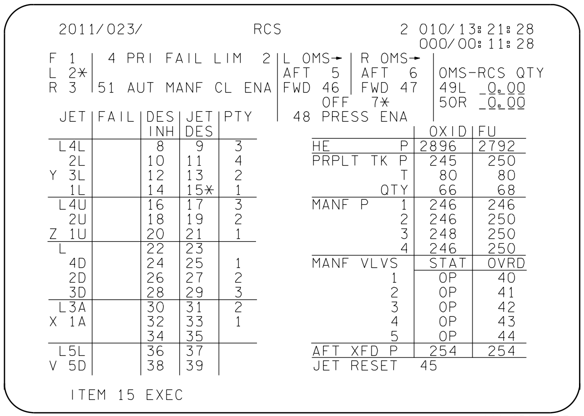
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  2011/023/             RCS           2 010/13:21:28
                                        000/00:11:28
F 1 |  4 PRI FAIL LIM  2|L OMS→ |R OMS→ |
L 2*|                   |AFT  5 |AFT  6 |OMS-RCS QTY
R 3 |51 AUT MANF CL ENA |FWD 46 |FWD 47 |49L  _0.00
                        |    OFF   7*   |50R  _0.00
 JET|FAIL|DES|JET|PTY   | 48 PRESS ENA  |
         |INH|DES|                      |OXID|FU
 L4L     |  8|  9| 3        HE         P|2896|2792
  2L     | 10| 11| 4        PRPLT TK P | 245| 250
Y 3L     | 12| 13| 2                  T|  80|  80
  1L     | 14|15*| 1                QTY|  66|  68
 L4U     | 16| 17| 3        MANF P    1| 246| 246
  2U     | 18| 19| 2                  2| 246| 250
Z 1U     | 20| 21| 1                  3| 248| 250
 L       | 22| 23|                    4| 246| 250
  4D     | 24| 25| 1        MANF VLVS  |STAT|OVRD
  2D     | 26| 27| 2                  1|  OP|  40
  3D     | 28| 29| 3                  2|  OP|  41
 L3A     | 30| 31| 2                  3|  OP|  42
X 1A     | 32| 33| 1                  4|  OP|  43
         | 34| 35|                    5|  OP|  44
 L5L     | 36| 37|          AFT XFD P  | 254| 254
V 5D     | 38| 39|          JET RESET   45

   ITEM 15 EXEC
```

00616308.CRT;1
usa007587_678r1.cvx

PASS GNC SYS SUMM 2 Display

SPEC 23 RCS DisplayRCS Summary Data

RCS Summary Data

- The RCS consists of forward and aft systems of control jets, propellant storage tanks, and distribution networks located in three separate vehicle modules.
- The forward module is in the nose area, and the left and right aft modules are in the left and right OMS/RCS pods near the tail of the vehicle.
- The forward RCS has 14 primary and two vernier jets; the aft RCS has 12 primary and two vernier jets per pod.
- Primary jets provide 870 pounds each of vacuum thrust; vernier 24 each. The vernier jets are only used on orbit for fine attitude control.
- Each jet is permanently fixed to fire in a general direction. The selective firing of individual jets or combinations of jets provides thrust for attitude control, rotational maneuvers, and translational maneuvers.
- Manual RCS use is through the rotational and translational hand controllers, and automatic use is handled by the digital autopilot and the general purpose computers.
- Nominal uses of the RCS include mated coast, ET separation, and trim residuals during ascent; attitude control and maneuvers in orbit; and entry flight control and center of gravity management.
- Off-nominal uses include single-engine roll control, RCS wraparound during OMS burn, OMS completions, and abort dumps.
- RCS jets are fueled with N_2O_4 and MMH. The propellants are liquid at room temperature and hypergolic.
- Propellant quantities are monitored on panel O3.
- Most RCS control switches are distributed over panel O7 and O8.
- Thermal control switches are located on panel A14.
- RCS information display and control is through the GNC SYS SUMM 2 and SPEC 23 RCS displays.

RCS Rules of Thumb

- 1% RCS prop = 1 fps ΔV.
- 1% RCS prop = 22 lb.
- 1,000 lbs of ARCS prop moves X c.g. 1.2. in, Y c.g. ± 0.4 in.
- 1,000 lbs of FRCS prop moves X c.g.-3.5 in.
- ARCS max blowdown qty 24%.
- FRCS max blowdown qty 22%.
- Loss of a single downfiring vernier jet is loss of vernier mode.
- If fuel tank pressure is 20 psi higher than the oxidizer tank pressure, then verniers are no-go.
- Always secure the RCS from the manifolds up to the helium tanks.
- Always open the RCS from the helium tanks down to the manifolds.
- A momentary barberpole talkback may be seen when adjacent "A" or "B" RCS helium isolation valves are operated due to vibration form the operating valve.

2.23 SPACEHAB

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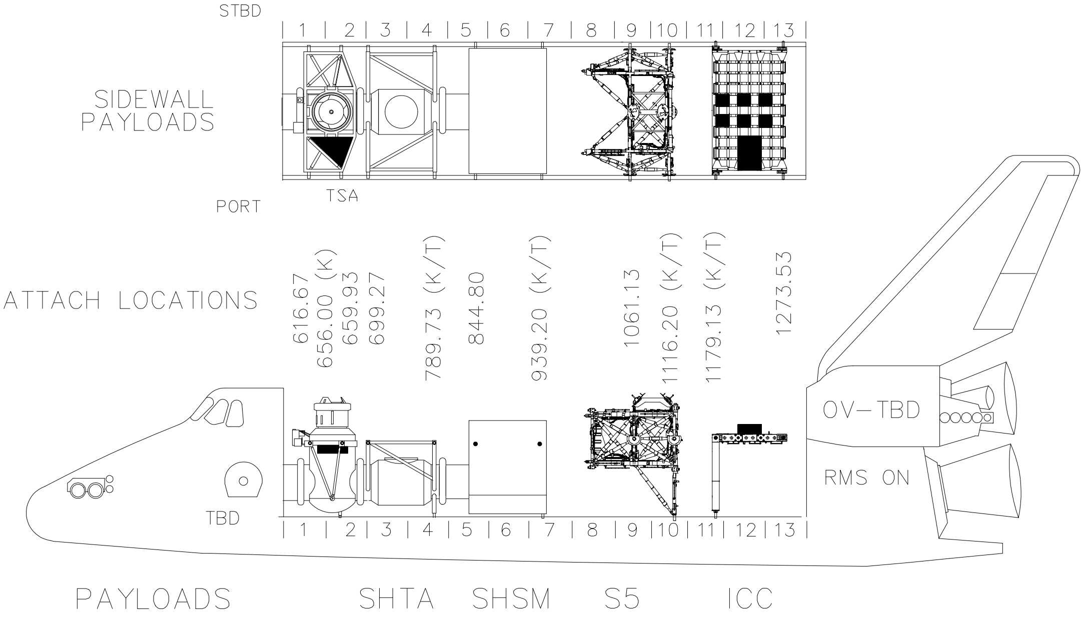
Description

The Spacehab module is a pressurized experiment carrier designed to augment space shuttle middeck experiment accommodations and to provide a pressurized volume for logistics transfer to the International Space Station (ISS). The Spacehab system consists of a module flown in the orbiter payload bay that is configured with middeck-type lockers, racks, and/or the logistics transportation system (LTS) to accommodate a variety of experiments and equipment. The Spacehab module provides space for crewmembers to work on experiments in a shirt-sleeve environment. Spacehab offers the Space Shuttle Program several module configurations to accommodate mission-specific requirements.

Configurations

All Spacehab configurations are connected to the orbiter with standard orbiter payload support resources from the cabin and payload bay. The Spacehab module provides crewmembers with a place to carry logistics and/or experiments and contains cooling, power, and command and data provisions, in addition to Spacehab housekeeping systems (i.e., power distribution and control, lighting, fire and smoke detection, fire suppression, atmosphere control, status monitoring and control, and thermal control).

The Spacehab configuration for logistics mission to the ISS allows the Spacehab single module to be mounted in a trunnion location to accommodate the orbiter docking system (ODS) in the forward payload bay. The module is connected to the ODS using a Spacehab tunnel adapter with extravehicular activity (EVA) hatch, and a Spacehab tunnel segment.



Spacehab Configuration -- Typical ISS Mission

Flight Deck Interfaces

Several panels located on the flight deck allow the crew to control and monitor Spacehab subsystems operations. Those interfaces are listed below with brief descriptions of their primary functions.

R1 Panel

- The R1 panel controls the connection of main dc power to the Spacehab via the primary payload bus.
- The R1 panel controls the connection of essential and emergency power to the Spacehab via auxiliary payload bus and aft payload B bus.
- The R1 panel controls the connection of aft flight deck dc power (cabin payload) to the Spacehab for system operations.

L1 Panel

- The L1 panel controls the distribution of orbiter Freon flow to the payload heat exchanger to support Spacehab thermal load requirements.

C3A5

- The C3A5 panel provides controls to activate the Spacehab fire suppression subsystem (FSS) and H_2O line heaters.

IDP

- The orbiter DPS display allows the crew to monitor and control Spacehab subsystems via the Spacehab displays and SPECs (BFS display 206 SH Launch/Entry, SM SPEC 214 SH ACT/DEAC, and SM SPEC 215 SH ECS).

L12 Panel

- The L12 panel consists of the standard switch panel (SSP) configurations to support Spacehab activation, control, and monitoring.

Command and Data Subsystem

The Spacehab command and data subsystem (CDS) receives hardwired commands from the orbiter SSP and Spacehab monitor and control panel (MCP). The CDS can receive commands for Spacehab subsystem and experiment activation and deactivation from either ground uplink or the orbiter DPS via the payload signal processor (PSP) link. The Spacehab can also receive commands from an orbiter-provided microcomputer, the payload general support computer (PGSC). The PGSC commanding capability can be used only to command the Spacehab video switching unit (VSU).

The data management unit (DMU) is the major element of the Spacehab CDS. The DMU provides data acquisition and command functions for the Spacehab module. The DMU also provides all serial interfaces required for data transmission between the Spacehab module and the orbiter.

The payload data interleaver (PDI) interface to the DMU gives ground controllers the capability to monitor Spacehab subsystem and experiment telemetry.

Caution and Warning

The orbiter caution and warning (C&W) system and Spacehab subsystems work together to alert the crew if Spacehab subsystem equipment is failing. When an alarm condition is detected, the orbiter provides a signal that activates the master alarm light in the Spacehab module.

The Spacehab C&W subsystem is defined in three groups:

- Class 1, Emergency C&W
- Class 2, Hardware C&W/software C&W
- Class 3, Fault detection annunciation (FDA)

Electrical Power Subsystem

The Spacehab electrical power subsystem (EPS) distributes direct current, alternating current, and emergency current sources to subsystems and experiment equipment. Main power is distributed via the power distribution unit (PDU).

The PDU is the major component of the Spacehab EPS. The PDU receives and distributes main dc, secondary dc, and 3-phase 115-volt ac power from the orbiter. Also, the PDU distributes Spacehab inverter-generated, 3-phase 115-volt ac power to subsystem and experiment equipment.

The emergency power received from both the orbiter auxiliary A and aft payload B buses is routed to the Spacehab fire suppression control unit (FSCU) and the monitoring and control panel (MCP).

Control and monitoring of the Spacehab EPS is provided by hardwired interfaces to the SSP, payload multiplexer/demultiplexer (PL MDM), and by discrete inputs and outputs to the DMU.

Environmental Control Subsystem

The Spacehab environmental control subsystem (ECS) controls the habitable environment and provides heat rejection for subsystem and experiment thermal control. The ECS provides this capability during prelaunch, launch, on orbit, entry, and postlanding mission phases. The ECS controls atmospheric temperature control and pressure limitation, contingency depressurization, equipment thermal control, smoke detection, fire suppression, experiment vacuum venting, atmospheric monitoring, trace contaminate removal, and emergency egress breathing capability.

Audio Communication Subsystem

The audio communication subsystem (ACS) is no longer flown on Spacehab missions to the ISS. Crew communications from inside Spacehab are provided by the battery powered speaker microphone unit (BPSMU). The BPSMU provides the Spacehab crew with an audio communication link to the orbiter/ISS and to the flight controllers in the Mission Control Center (MCC).

The BPSMU has the following audio channels:

- Air-to-ground 1 (A/G1)
- Air-to-ground 2 (A/G2)
- Intercommunication A (ICOM A)
- Intercommunication B (ICOM B)
- Page
- Alarm tone

The channels can be configured independently to talk/listen, listen only, or off.

Fire Suppression Subsystem

The FSS includes both smoke sensors and fire suppression equipment. Detection of fire/ smoke is annunciated through the orbiter C&W electronics unit (CWEU) to crewmembers in both the orbiter and Spacehab module. The fire suppression bottles can be discharged using controls located on the SSP, on the payload safing panel (C3A5), on the Spacehab MCP, or by Spacehab SPEC commanding via the orbiter DPS display. Fire suppression firing circuits, smoke detector data circuits, and test/checkout provisions are provided by the FSCU and the MCP.

Activation of the FSS is single fault tolerant during all mission phases. A handheld fire extinguisher is provided for extinguishing localized fires.

Closed Circuit Television Subsystem

The closed circuit television (CCTV) cameras or orbiter-provided camcorders may be located in the Spacehab module for video downlink of Spacehab experiment operations. In the standard configuration, orbiter-provided camcorders are used to provide video recording of Spacehab experiment operations.

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2.24 STOWAGE

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Description

Various provisions are available for stowing loose onboard equipment and trash/waste materials during different phases of the flight. Provisions consist primarily of rigid and flexible containers.

Rigid containers include:

- Modular lockers
- Floor compartments
- Volume B return trash containers

The flexible containers are as follows:

- Flight deck stowage bags
- Helmet stowage bag
- Seat FDF containers
- Soft stowage containers
- Trash containers
- Jettison stowage bags
- In-flight stowage bags
- Middeck retention net
- Airlock stowage bags
- Airlock retention net

Stowage areas in the orbiter crew compartment are located on the flight deck, the middeck, in the airlock, and lower equipment bay.

Rigid Containers

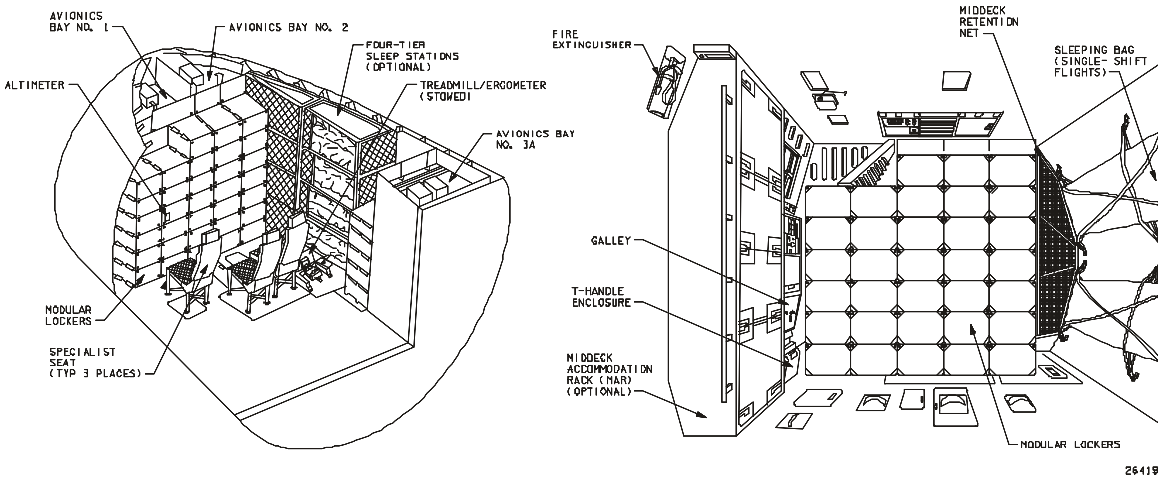
Modular Lockers

Some equipment onboard the orbiter is stowed in lockers with insertable trays. The trays can be adapted to accommodate a wide variety of soft goods, loose equipment, and food. The lockers are interchangeable and attach to the orbiter with spring-loaded captive bolts. The lockers can be removed or installed in flight by the crewmembers. There are four sizes of trays: a single tray (two of which fit inside a locker), a double tray, a half-length single tray (four of which fit inside a locker), and a half-length double tray. Approximately 150 cubic feet of stowage space is available, almost 95 percent of it on the middeck.

The lockers are made of lightweight carbon fiber composite material much like fiberglass. The mounting frame at the rear of the locker and locker door are milled aluminum. Guides for installation tools and Teflon spacer pads are bonded on the composite using epoxy. Lockers hold 2 cubic feet of contents that can weigh no more than 68 pounds.

Foam inserts are used in the trays to provide a friction fit for zero-g retention. In addition, straps, snaps, and mesh retention nets are used in some trays. Soft containers are used in orbiter spaces too small for the fixed lockers.

In the aft flight deck, stowage lockers are located below the rear payload control panels in the center of the deck. A trash container is nominally mounted on the port and starboard side of the flight deck, near the interdeck access opening. These side containers are interchangeable.



Middeck Forward Modular Lockers and Floor Compartment

In the middeck, lockers can be attached to the forward avionics bay. Provisions for 33 lockers are available in this area. In addition, there is an area to the starboard side of the airlock module where 11 lockers can be attached.

To obtain access to the locker interior, the crewmember needs to rotate two quarter-turn, self-aligning ball latches inboard to release the locker door.

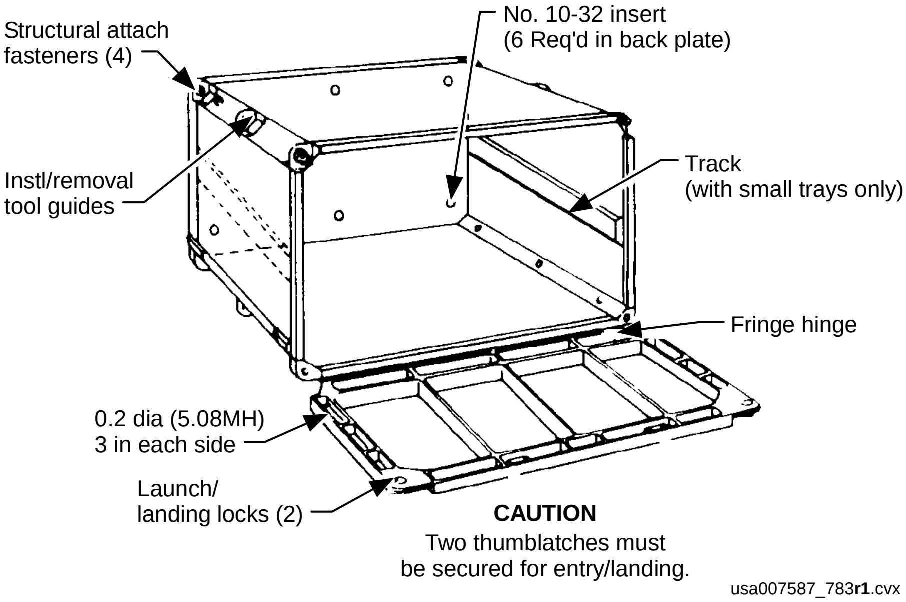
The crewmember can open the door a full 180°. By using the standard hole pattern of the locker, straps and brackets can be attached to the locker faces via pip pins for restraining equipment.

In addition, a crewmember can remove lockers in flight in order to gain access to the floor compartments or the avionics bays.

In the event the locker door cannot be closed or latched because of misalignment problems, the crewmembers can remove the locker and use turnbuckles to provide structural support.

Floor Compartments

Seven floor compartments are available. Volume F (MD76M), the wet trash compartment, provides 8 cubic feet of stowage under the middeck floor. The CO_2 absorbers are manifested at MD52M, with the in-use position at MD54G. Two other compartments (volumes G (MD80R) and H (MD23R)) are used to store contingency hygiene equipment and EVA accessories respectively. Volume D (MD52C) is beneath the forward lockers and holds approximately 8 cubic feet. The remaining floor compartment, volume E (MD76C), is used primarily to store official flight kits and personal preference kits.



Schematic of Modular Lockers

Wet Trash Compartment

To deposit any trash or waste materials into the wet trash compartment, the crewmember merely lifts the latch handle and opens the circular door, deposits the material through a rubber grommet into the trash bag, and closes the door. Air in the wet trash volume is vented overboard at the rate of approximately 3 lb/day.

NOTE

> The WCS vacuum vent valve must be opened to allow the waste gases to be vented overboard.

The types of wet trash to be stowed in the compartment are:

- Medical kit items (no Sharps)
- Emesis bags
- Urine collection devices
- Fecal bags
- WCS odor/bacteria filter
- Discarded food packages

Volume D (MD52C)

Partially blocked by middeck forward lockers, Volume D is used for EVA Tools, G-suits and miscellaneous storage. The door is not hinged.

The compartment door has a spring-loaded latch mechanism. To open, the spring-loaded latch mechanism is squeezed between the thumb and forefinger to release the latch. Then the door is subsequently lifted open. To close, the door can be pushed shut without squeezing the latch mechanism.

Volume E (MD76C)

To gain access to this compartment, two lockers (MF71M and MF71O) have to be removed. Official flight kits and personal preference kits are nominally stowed here. The compartment door has the same type of spring-loaded latch mechanism used in volume D.

Volume G (MD80R)

To gain full access to this compartment, lockers (MA16L and MA16N) have to be removed. Contingency hygiene equipment (urine collection devices, diapers, Apollo fecal bags, wet wipes, etc.), and a spare odor bacteria filter are stowed here. The compartment door has the same type of spring-loaded latch mechanism used in volume D.

Volume H (MD23R)

This floor compartment has the same type of spring-loaded latch mechanism as used in volumes E and G. EVA accessories (liquid-cooled ventilation garments, EMU batteries and lights, tools, etc.) are stowed in this compartment, located at the base of the interdeck ladder on the port side of the middeck.

Volume A (MF57A)

This volume installs above the forward lockers near the middeck ceiling. With 3 cubic feet of stowage, this volume is used as a food pantry.

Volume B

This volume is installed just outboard of the aft lockers on the starboard side of the middeck. To deposit any dry trash, towels, or dirty laundry in this compartment, the crewmember simply inserts the dry trash material through a door located on the inboard side of the compartment.

Volume 3B (MA73J)

This stowage volume originated as a printer closet built into the closeout of the avionics bay near the WCS compartment. With the printer no longer used, the volume houses a cabin air cleaner and emergency breathing masks for launch and return.

Flexible Containers

Flight Deck Stowage Bag

For flight deck stowage, a flight deck stowage bag is mounted on the back of the CDR and PLT seats. Each bag has built-in pockets for stowing loose items on orbit. Also called a VW bag, the bag must be stowed for launch/return.

Helmet Stowage Bag

A Nomex-mesh bag with a drawstring is provided for stowing unnecessary FDF material or other onboard loose equipment on orbit. The bag is located in the CDR's FDF stowage container. In addition, one helmet stowage bag is manifested for each crewmember, which is used to stow the ACES helmet on orbit.

The task of inserting desired FDF items into the mesh bag consists of simply opening the bag, placing items in the bag, and drawing the string tight to close.

Seat FDF Containers

A soft fabric container, called a saddlebag, is available for each seat to store FDF or other small loose items.

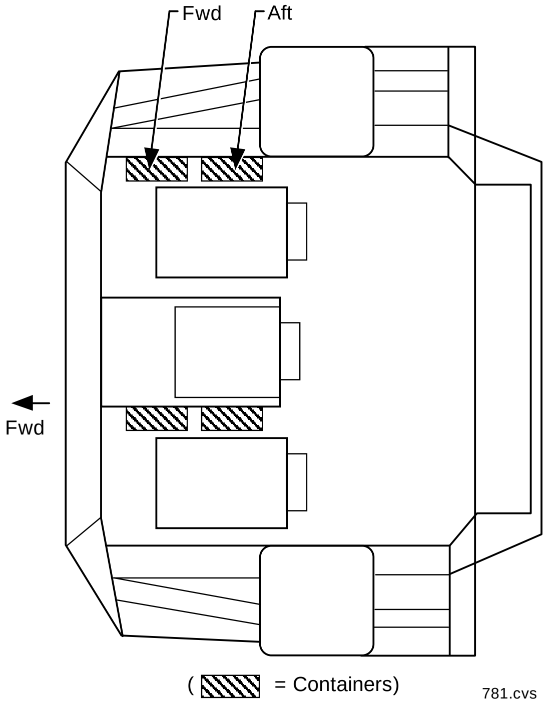
Specialist Seat Saddlebag - To remove the container from the seat requires the following steps:

- Pull up on container release handle to disengage the container attachments from seat.
- Unwrap the container Velcro straps from seat leg support structure to remove container.

The specialist seat FDF container is installed on the right side as follows:

- Attach container Velcro straps around right side leg support structure.
- Insert container attachments to seat attach point.

CDR/PLT Seat Saddlebag - These saddlebags are Nomex fabric with Velcro closures mounted via frame to the panels on the starboard side of the CDR and PLT seats. Two bags on each seat are used for ascent stowage of CDR and PLT FDF as well as helmet bags and headsets.



Flight Deck FDF Containers

Trash Containers

Four trash containers are flown. Two containers are mounted in the middeck area, one on the inside surface of the waste management compartment door and one on AV bay 3B. The flight deck containers are located on the port and starboard flight deck. Each container contains a disposable trash bag plastic liner, with spares located in the bottom of the container (outside the installed liner).

The crewmember deposits trash into the container disposable plastic liner through the alligator clamp opening. Once the plastic liner is full, the top of the trash bag liner is closed with its Velcro closure. The trash bag zipper is opened, and the full liner is removed through the side opening. The top of the liner can be further rolled and secured with gray tape. The liner is then stowed in Volume B. A new liner is inserted through the trash bag top opening and secured to the trash bag mating surfaces using the Velcro strips on the liner.

Only particular types of trash should be stowed in these containers, as follows:

- Drink containers
- Wipes used for nonwaste collection system purposes
- Batteries
- Printer paper
- Vacuum cleaner residue/bag
- No wet or odor producing trash

NOTE

> Absolutely ***no*** human waste materials (fecal, urine, or emesis) are to be stowed in these trash bags/liners.

The starboard trash bag is flown on panel R15 on the starboard flight deck. The bag is used to hold Photo TV equipment and batteries for temporary restraining, stowage, or transporting on orbit.

Jettison Stowage Bags

Teflon-coated Nomex cloth bags are provided to stow equipment and materials on orbit. Each bag has a drawstring for sealing the opening of the bag.

At least one of these bags is used as a return-to-Houston bag. It contains items (such as videocassettes, audio cassettes, film, and notes) that must be flown to Houston immediately following a mission.

In-Flight Stowage Bags

Nomex green or gold colored mesh bags of the same approximate dimensions as the jettison stowage bags are stowed in a middeck stowage locker. The bags are used for stowing the crewmembers' launch equipment such as ACES, boots, and harness. Each bag has a drawstring to seal the opening of the bag.

Middeck Retention Net

The middeck retention net, a polybenzine imidazole brown-colored mesh net with caribiners, is manifested on non-sleepstation flights. This net is used to restrain items such as seats, launch/entry suits, boots, and helmets on orbit. It is located on the starboard forward middeck and attaches to the MF71 row of lockers and the starboard wall.

Middeck Stowage Bag

Made of white Nomex, these bags come in 5 MLE (middeck locker equivalent) and 10 MLE sizes and are used for generic stowage and transfer. For launch and return, these bags are secured via Kevlar straps to composite pallets that are bolted to the middeck aft area.

Airlock Stowage Bag

The airlock stowage bag, when manifested, is mounted to the external airlock floor. This bag is made of white Nomex material and provides an alternate stowage location, primarily for SAFER.

Tunnel Retention Net

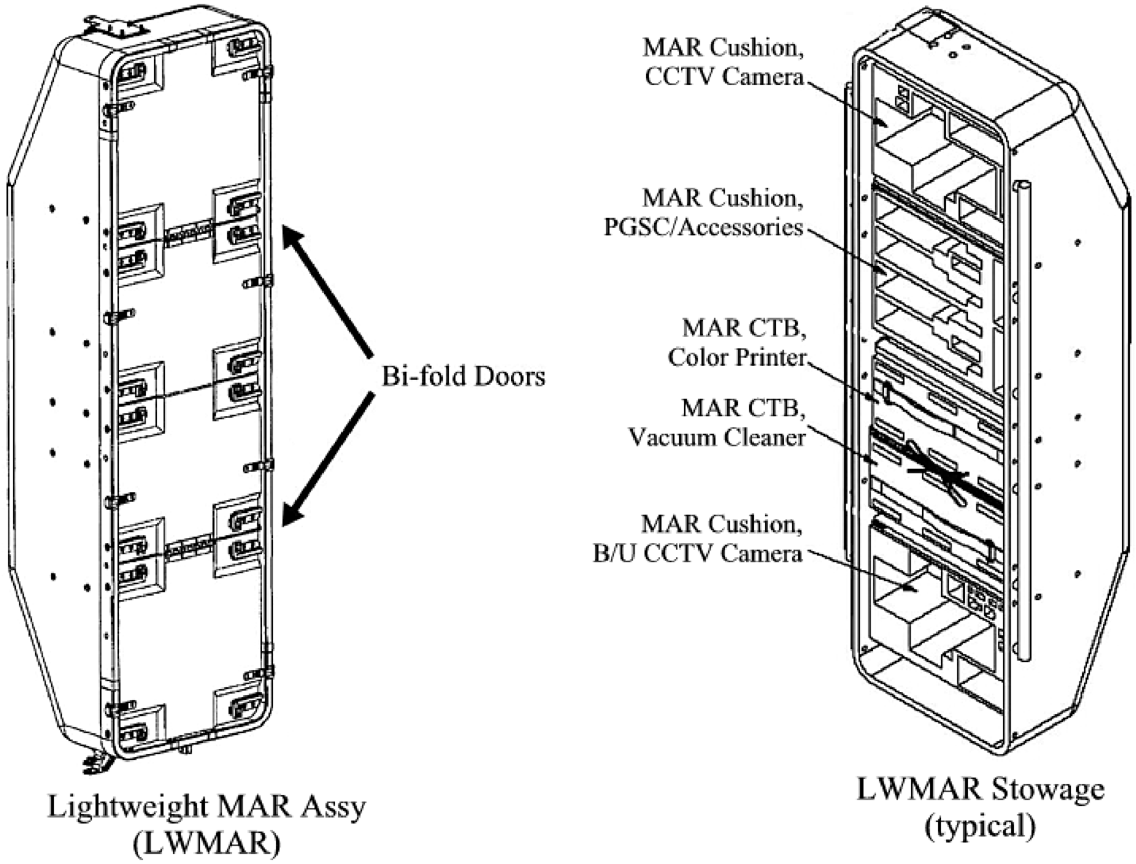
The tunnel retention net is used to restrain equipment in the Spacehab tunnel. It is a brown polybenzine imidazole mesh net that covers the EVA hatch and is used only for on-orbit stowage.

Middeck Accommodations Rack

The middeck accommodations rack (MAR) permits stowage of small payloads and experiments in the middeck of the orbiter. The MAR is installed just forward of the side hatch in the area aft of the galley. The MAR provides approximately 15 cubic feet of internal volume with a maximum payload weight of about 340 pounds.

The lightweight middeck accommodations rack (LWMAR) is usually flown in place of the MAR in the absence of a powered payload. The LWMAR is a carbon-fiber composite structure which offers approximately the same stowage volume as the MAR, but at a much lighter weight and can hold a maximum weight of about 390 pounds.

The LWMAR has two bi-fold doors that swing upward and downward to provide access to the shelves inside. Each door is held in place with eight latches. These doors are opened half at a time by retracting four latches. Internal shelves, also made of composite carbon fiber material, are bolted in place and can be relocated, reconfigured or removed by ground personnel to satisfy mission stowage requirements.



Lightweight MAR Assy
(LWMAR)

LWMAR Stowage
(typical)

Lightweight Middeck Accommodations Rack (LWMAR)

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2.25 WASTE MANAGEMENT SYSTEM (WMS)

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Operations 2.25-4

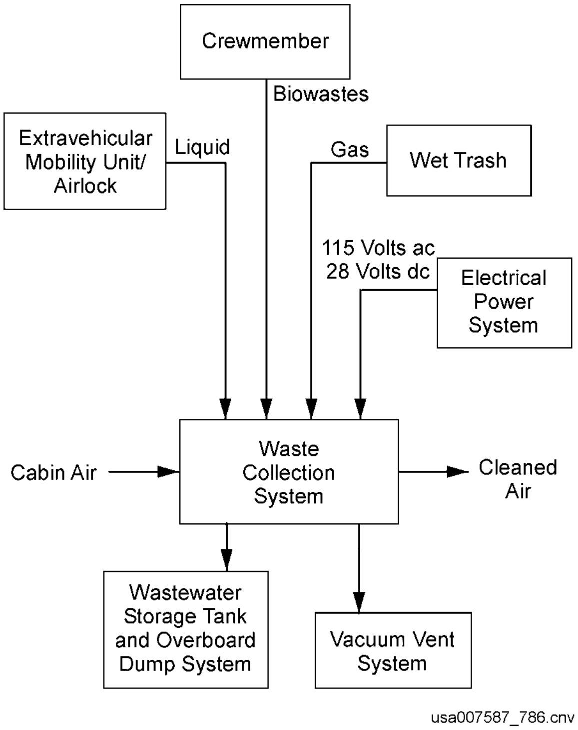
Description

The waste management system (WMS) is an integrated, multifunctional system used primarily to collect and process crew biological wastes. The WMS is located in the middeck of the orbiter crew compartment in a 29-inch-wide area immediately aft of the crew ingress and egress side hatch.

The system collects, stores, and dries fecal wastes. It processes urine and transfers it to the wastewater tank and processes EMU condensate water from the airlock and transfers it to the wastewater tank if an EVA is required on a mission. The system also provides an interface for venting trash container gases overboard and dumping atmospheric revitalization wastewater overboard in a contingency situation, and it transfers atmospheric revitalization system wastewater to the wastewater tank.

A waste management compartment door and two privacy curtains attached to the inside of the door provide privacy. One curtain is attached to the top of the door and interfaces with the edge of the interdeck access, and the other is attached to the outer edge of the door and interfaces with the middeck accommodations rack (MAR), if installed. The door also serves as an ingress platform during prelaunch (vertical) operations since the flight crew must enter the flight deck over the waste management compartment. The door has a friction hinge and must be open to gain access to the waste management compartment.

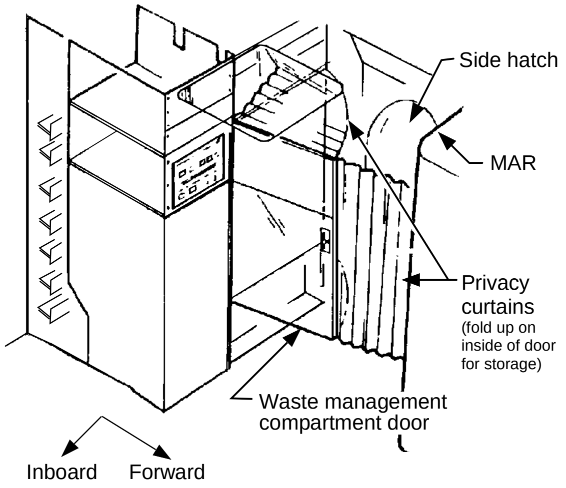
The WMS consists of a commode, urinal, fan separators, odor/bacteria filter, vacuum vent quick disconnect, and controls. The commode is 27 by 27 by 29 inches, and it is used like a standard toilet. The commode contains a single multilayer hydrophobic porous bag liner for collecting and storing solid waste. When the commode is in use, it is pressurized, and transport air flow is provided by the fan separator. When the commode is not in use, it is depressurized for solid waste drying and deactivation.



Waste Management System

The urinal is essentially a funnel attached to a hose and provides the capability to collect and transport liquid waste to the wastewater tank. The fan separator provides transport air flow for the liquid. The fan separators separate the waste liquid from the air flow. The liquid is drawn off to the wastewater tank, and the air returns to the crew cabin through the odor/bacteria filter. The filter removes odors and bacteria from the air that returns to the cabin. The vacuum vent quick disconnect is used to vent gases directly overboard from equipment connected to the quick disconnect through the vacuum line.

The urinal assembly is a flexible hose with attachable funnels that can accommodate both men and women. The assembly can be used in a standing position.



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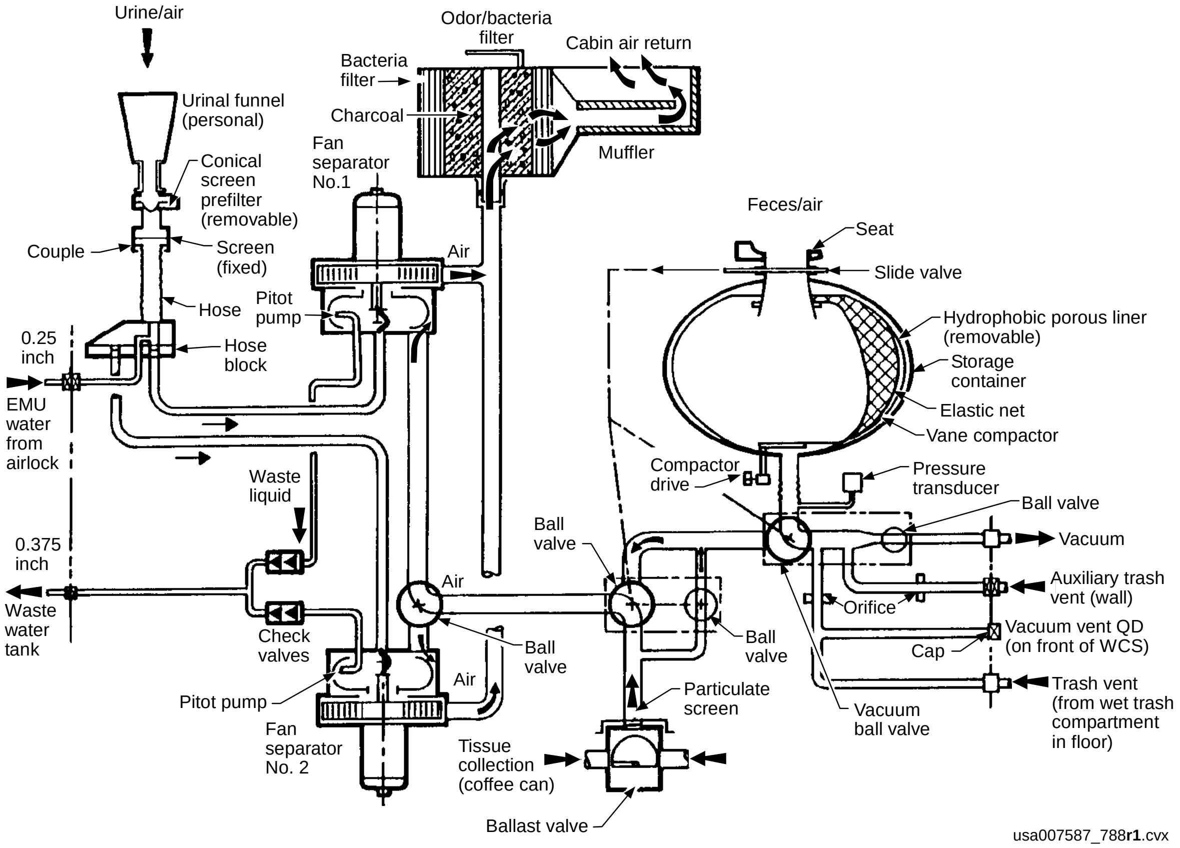
Waste Management System Privacy Curtains



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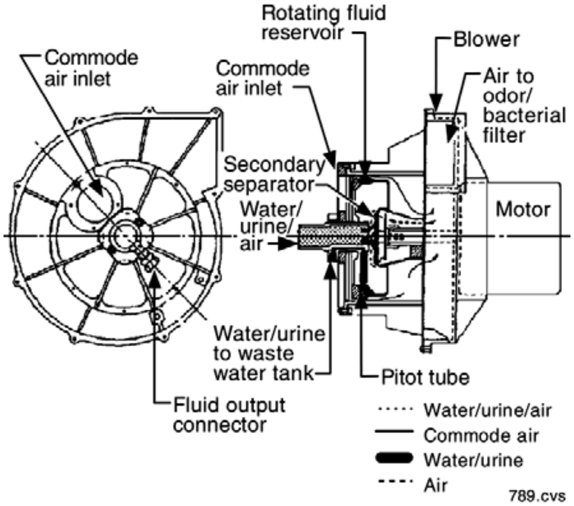
Waste Management System

All waste management system gases are ducted from the fan separator into the odor/bacteria filter and then mixed with cabin air. The filter can be removed for in-flight replacement.

Various restraints and adjustments enable the crew to achieve the proper body positioning to urinate or defecate in a zero-gravity environment. Two foot restraints are provided. A toe bar is located at the commode base and is used for standing urination. It consists of two flexible cylindrical pads on a shaft that can be adjusted to various heights by releasing two locking levers that are turned 90° counterclockwise. The crewmember is restrained by slipping his or her feet under the toe bar restraint.



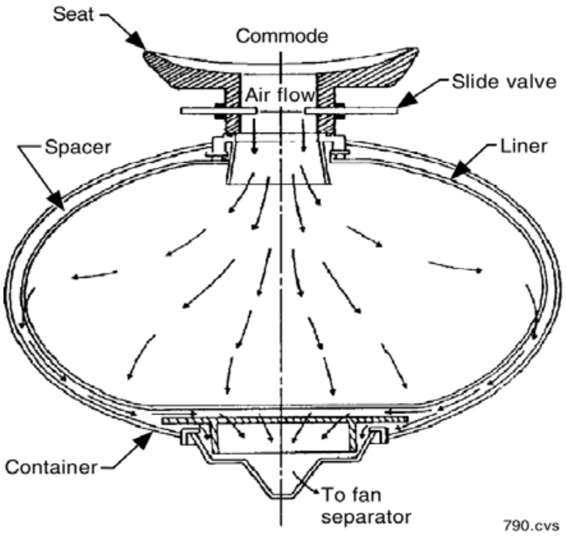
Waste Management System Fan Separator

A footrest restrains the feet of a crewmember sitting on the commode. The footrest consists of an adjustable platform with detachable Velcro straps for securing the feet. The Velcro straps are wrapped crosswise over each foot and secured around the back. The footrest can be adjusted to various angles and heights. Two locking handles pulled outward adjust the angle; two other locking levers adjust the height of the footrest.

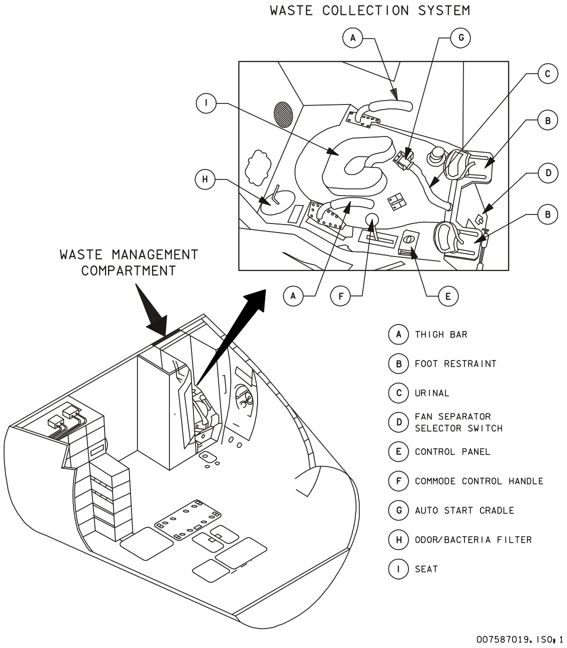
Two body restraints are provided for when crewmembers are seated on the commode. This restraint is a thigh bar that the crewmember lifts up out of the detent position, rotates over the thigh, and releases. The thigh bar exerts a preloaded force of approximately 10 pounds on each thigh.

Handholds are used for positioning or stabilizing the crewmember and form an integral part of the top cover of the waste management collection system assembly.

The WMS compartment is stocked with gloves, trash bags, tissues, and wet wipes. Rubber grommets in the compartment allow crewmembers to restrain their towels and washcloths.



Waste Management System Container Liner



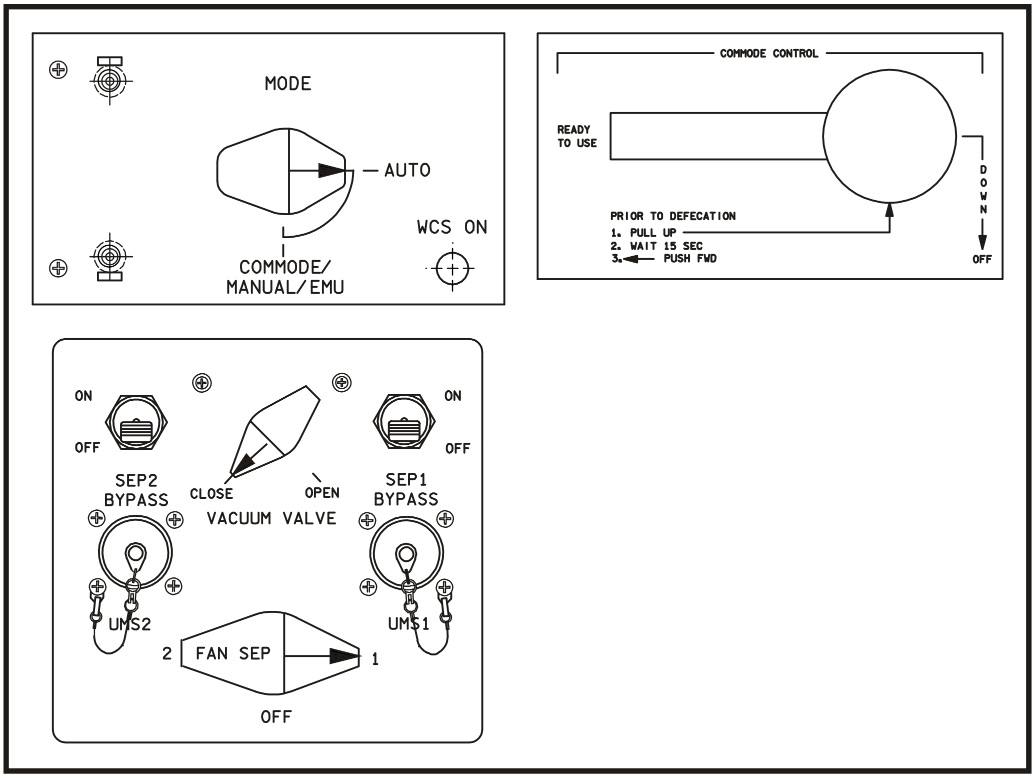
Waste Management System – Middeck

Operations

The controls on the waste collection system (WCS) are the VACUUM VALVE, FAN SEP select switch, MODE switch, fan separator bypass switches, and COMMODE CONTROL handle. The system uses dc power to control the fan separators and ac power for fan separator operations. The MODE switch and the COMMODE CONTROL handle are mechanically interlocked to prevent undesirable system configurations. The remaining controls operate independently. The fan separator bypass switches allow the crewmember to manually override a fan separator limit switch failure.

For launch and entry, the VACUUM VALVE switch is set to CLOSE. During on-orbit operations, when the WCS is not in use, the vacuum valve is set to OPEN. This exposes the commode overboard via the vacuum vent system, and any solid wastes in the commode are dried. This also allows venting of the auxiliary wet trash and the volume F wet trash compartment. The hydrophobic bag liner in the commode allows gas from the commode to vent overboard, but does not allow the passage of free liquid.

In the urine collection mode, the VACUUM VALVE remains in OPEN. The FAN SEP switch is positioned to 1 or 2. When the switch is positioned to 1, main bus A dc power is supplied to fan separator 1; when it is positioned to 2, main bus B dc power is supplied to fan separator 2. The MODE switch positioned to AUTO energizes a microswitch in the Auto cradle for the selected fan separator (dependent on FAN SEP position). When the urinal hose is removed from the cradle, the active fan separator pulls cabin air flow through the urinal at a minimum of 10 cubic feet per minute and cabin air through the coffee can at 30 cubic feet per minute.



Waste Management System Controls

The coffee can air mixes with the urine transport air flow in the fan separator. Liquid check valves at the wastewater outlet from each fan separator prevent backflow through the non-operating separator during separator operation and prevent backflow to the urinal and air outlet when the separators are off. The liquid and air mixture from the urinal line enters the fan separator axially and is carried to a rotating chamber. The mixture first contacts a rotating impact separator that throws the liquid to the outer walls of the rotating fluid reservoir. This centrifugal force causes the liquid to separate and draws it into a stationary pitot tube in a reservoir and directs the liquid through the dual check valves and into the wastewater tank. Air is drawn out of the rotating chamber and passes through the odor/bacteria filter, where it mixes with cabin air and re-enters the crew cabin.

In the EMU water drain mode, a guard is rotated over the *MODE* switch to preclude deactivation during the EMU and airlock water collection mode. The urinal cannot be used during the EMU dump because of possible separator flooding. EMU condensate water is drained only if an EVA is required on a mission. The EMU wastewater is dumped through wastewater valves in the airlock. Other than these requirements, EMU dump is the same as the urine collection mode.

In the urine and feces collection mode, the *MODE* switch is moved to the *COMMODE/MANUAL/EMU* position, the *COMMODE CONTROL* handle is pulled up, and the commode is pressurized with cabin air through the debris screen and flow restrictor in approximately 15 seconds.

NOTE

> If the *MODE* switch is positioned to *AUTO*, the handle cannot be pulled up because of a mechanical interlock. At the top of the handle is a pop off ball that will come off at 40 lb of force to prevent damage to the linkages inside the unit.

The *COMMODE CONTROL* handle is positioned to *PUSH FWD* after 15 seconds (it cannot be pushed forward until after 15 seconds because of the delta pressure across the slide valve, and it cannot be pushed forward unless the *MODE* switch is positioned all the way to the *COMMODE/MANUAL/EMU* position). When the *COMMODE CONTROL* handle is pushed forward, the slide valve on the commode is opened.

The WCS is used like a normal toilet. The commode seat is made of a contoured, hard Ultem plastic material that provides proper positioning and is sealed to minimize air leakage. Feces enter the commode through the 4-inch-diameter seat opening and are drawn in by cabin air flowing through holes under the seat at 30 cubic feet per minute. Fecal matter is deposited into the porous bag liner, and the air is drawn through the hydrophobic material to the fan separator. The hydrophobic liner material prevents free liquid and bacteria from leaving the collector. All paper is deposited in a WCS canister bag and then placed in the WCS auxiliary wet trash compartment. It is recommended that no tissues be placed in the commode, since they tend to block airflow and cause more bulk in the commode. Urine is processed as in the urine collection mode. The *BACK/DOWN* position of the *COMMODE CONTROL* handle closes the slide valve and depressurizes the commode for deactivation and solid waste drying. If the handle were left partially up, it would cause loss of cabin air through the vacuum vent.

NOTE

> The *COMMODE CONTROL* handle must be completely down (in *BACK/DOWN* position) upon completion of WMS usage, or loss of cabin air through the vacuum vent valve will occur.

After usage, the WCS should be cleaned with wet w*ip*es to maintain an odorless and sanitary environment. The seat can be lifted for cleaning. *T*he WCS should be *sanitized* once a day with a *disinfectant wipe*. *U*rinal funnels *may be sanitized daily with the disinfectant wipe as well*.

Alternate Fan Separator Operations

If fan separator 1 is inoperative or fails to achieve proper operational speed (which can be verified by a reduced noise level or lack of air flow), the *FAN SEP* switch is positioned from *1* to *2*, and hose block from 1 to 2, then operate as normal.

The lever-locked *FAN SEP 1 BYPASS* and *FAN SEP 2 BYPASS* switches permit the crew to manually override a fan separator limit switch failure in either the *FAN SEP* or *MODE* switches. When either switch is positioned to *ON*, dc power is applied to the corresponding relay, energizing it and providing ac power to activate the corresponding fan separator. Both BYPASS switches should not be *ON* at the same time. Before the *SEP* 1 or *2 BYPASS* switch is activated, the *FAN SEP* select switch and hose block should be positioned in the corresponding fan separator position to preset the fan separator inlet valve.

Vacuum Vent System

The vacuum vent system provides a pathway for removal of hydrogen (off-gassed by the fuel cells), for venting odors, and for drying solid waste material in the commode when the commode is not in use.

The vacuum vent line T's off from the WCS line at the WCS three-way ball valve. When the commode is not in use, it is exposed to vacuum through this vent line. A manual valve that is downstream of the commode serves to isolate the WCS from the vacuum vent system, if required. One situation in particular where this would be necessary would be if the WCS failed and created a cabin leak. The vacuum vent isolation valve is located downstream of the vacuum valve. It is controlled by the *WASTE* H_2O *VACUUM VENT ISOL VLV CONTROL* switch on panel ML31C. This switch receives electrical power from the *VACUUM VENT* ISOL *VLV BUS SELECT* switch on panel ML31C when the switch is positioned to *MNA* or *MNB*.

When the *WASTE* H_2O *VACUUM VENT ISOL VLV CONTROL* switch is positioned to *OPEN*, the vacuum vent isolation valve is opened, allowing the vacuum vent line to be open to vacuum. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. The unpowered position closes the valve.

Even if the vacuum vent isolation valve could not be opened, vacuum vent functions would not be lost. A small hole in the valve plate allows proper venting overboard in such a contingency.

Alternate Vacuum Venting

Between the WCS ball valve and the vacuum vent valve is a vacuum vent quick disconnect (QD). For a failure of the vacuum vent system, vacuum venting can be regained by connecting a transfer hose from this QD to the contingency wastewater crossite QD, which allows venting through the wastewater dump line.

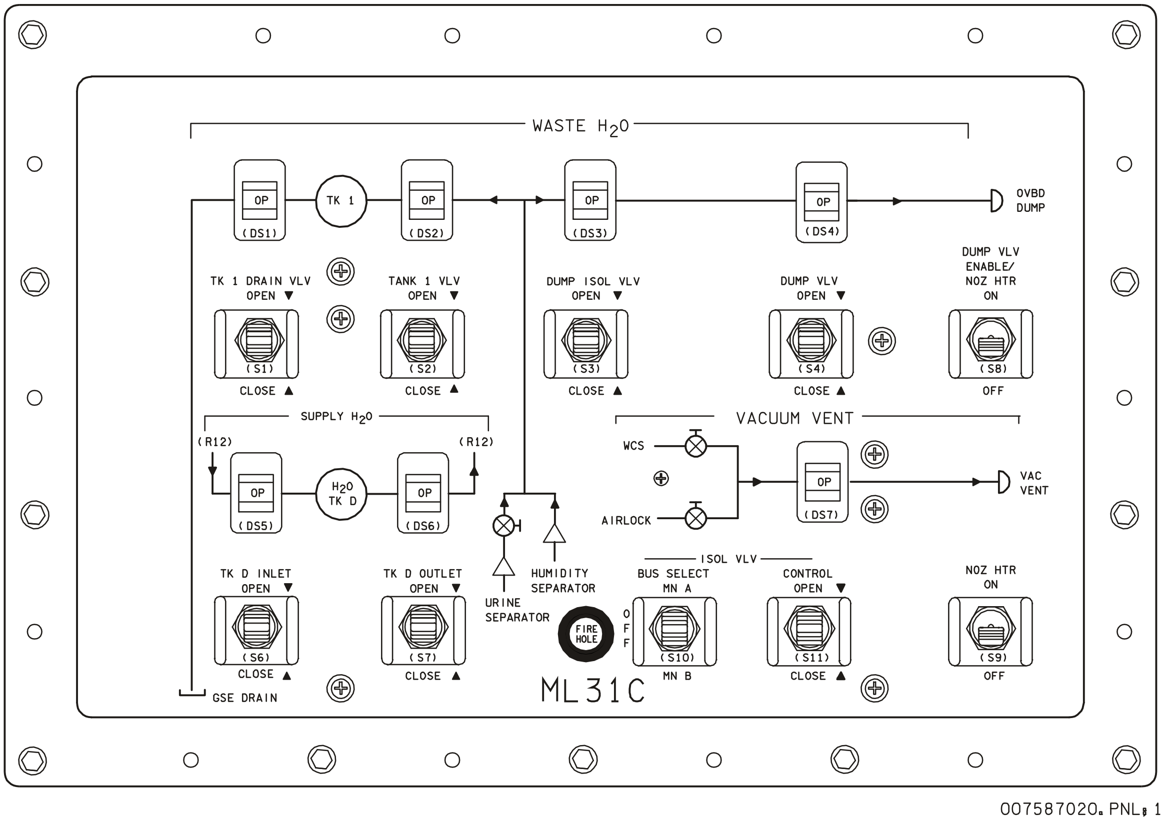
Heaters

Thermostatically controlled heaters are installed on the vacuum vent line. Electrical power for the A and B heaters is supplied on *the* H_2O *LINE HTR A* and *B* circuit breakers on panel ML86B. (These circuit breakers also supply electrical power to supply water dump line A and B heaters and wastewater line A and B heaters.)

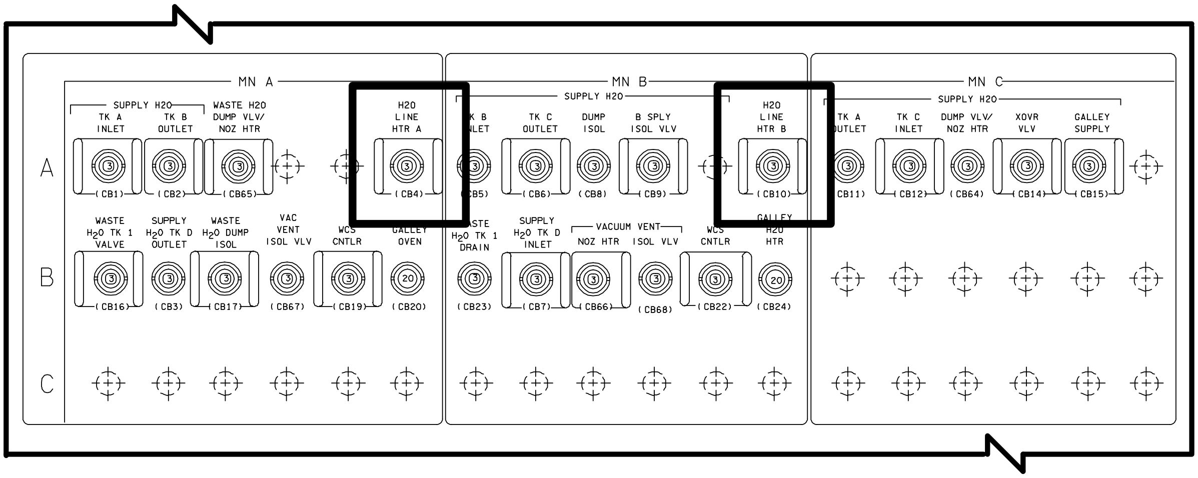
Heaters are also installed on the vacuum vent nozzle and are controlled by the *WASTE* H_2O *VACUUM VENT NOZ HTR* switch on panel ML31C. Electrical power is supplied to the vacuum vent nozzle heaters when the switch is positioned to *ON*. The *OFF* position removes electrical power from the vacuum vent nozzle heaters.

Alternative Waste Collection

For a non-operational WCS, contingency waste collection devices are available. Fecal collection is accomplished by using an Apollo fecal bag. Apollo fecal bags can be stowed inside the WCS commode or in the wet trash (volume F) compartment. For men, the urine collection device (UCD) is used for urine collection. A UCD consists of a collection bag, a restraint assembly, and a roll-on cuff. For women, urine collection is accomplished via absorbent pants (Pull-Ups). The Pull-ups are a modified version of adult diapers.



VACUUM VENT Switches and Talkback on Panel ML31C



H_2O LINE HTR A and B Circuit Breakers on Panel ML86BThis page intentionally left blank

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3. FLIGHT DATA FILE

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3.5 OPERATIONAL USE................ 3.5-1

The Flight Data File (FDF) is the total onboard complement of documentation and related crew aids available to the crew for flight execution. The FDF consists of procedural checklists, timelines, schematics, charts, cue cards, portable onboard computer software, teleprinter/ graphics messages, and accessories. The FDF also includes office-type supplies, such as pens, pencils, markers, Velcro, and rubber bands. The FDF used in training is essentially identical to the material used on orbit, except where trainer-unique characteristics require differences.

The Crew Procedures Control Board (CPCB) is the governing body for establishing guidelines and policies pertaining to the development, publication, fabrication, and validation of FDF under the authority of the Director of Mission Operations. The management process, policies, and guidelines under which the FDF is developed are contained in the Crew Procedures Management Plan (CPMP), USA-005466. This plan and its Annexes A-E detail the development of crew procedures and activities as well as the fabrication and processing of the FDF material. Crew procedures and activities are documented in a variety of books and checklists. Time-critical or frequently used procedures are documented on cue cards and in flip books (a series of cue cards that are ringed together). These documents are categorized into four groups:

- **Control documents** — The FDF books that provide the schedule of crew activities for an entire flight. There is one controlling document for every phase of a flight (i.e., Ascent, Post Insertion, Orbit, Deorbit, and Entry). These documents are time oriented and refer to other FDF documents as required.

FDF Products

- **Support documents –** Used on orbit to accomplish various objectives scheduled in the Control documents, such as flight-specific payload procedures, EVA, or rendezvous and proximity operations. The CPCB may occasionally designate a Support book as the controlling document for that specific phase of the flight.

- **Off-Nominal documents** – Contain contingency procedures for all phases of flight.

- **Reference documents** – Provide data not normally required for a particular task, but useful to the crew. Documents include DPS displays, caution and warning (C/W) parameters, landing site charts, and stowage locations for crew use items.

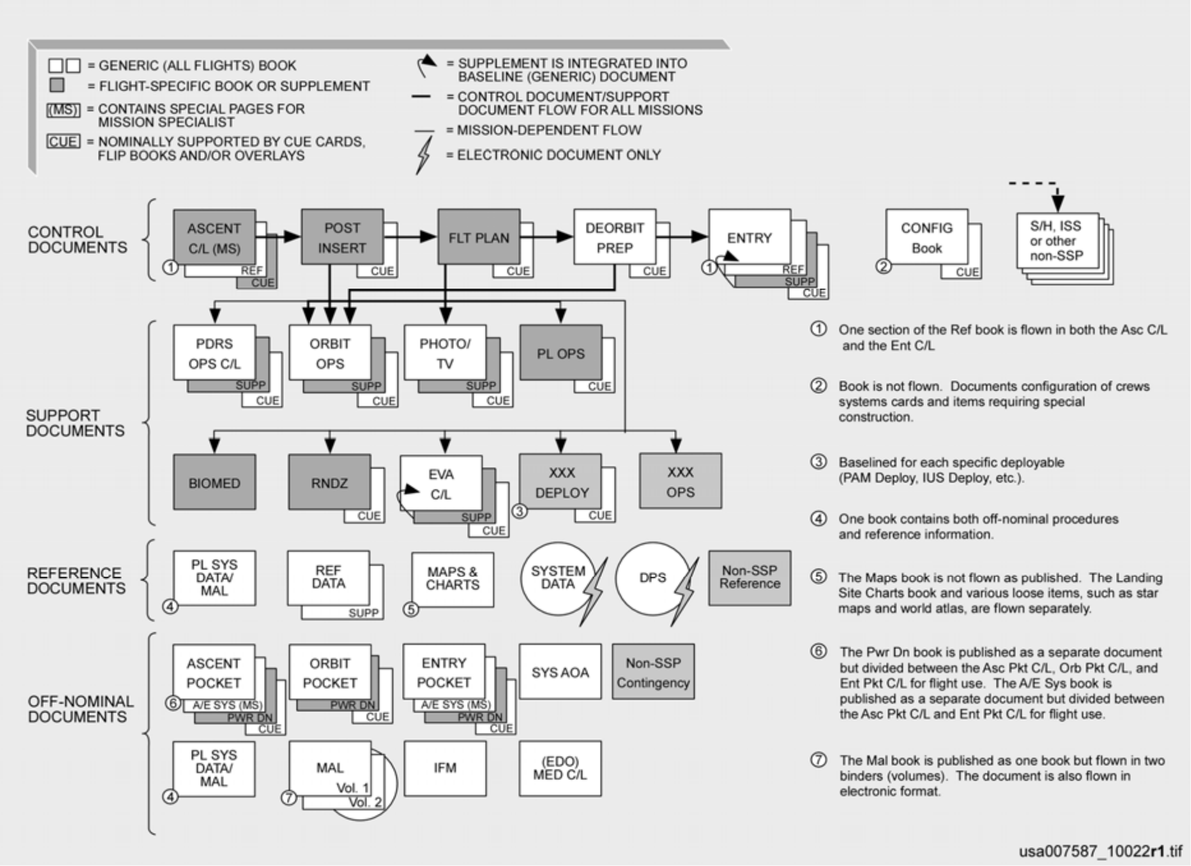
Each FDF book within the four main groups can also be categorized into one of three subgroups:

- **Generic documents** – Reflown from flight to flight since they usually do not contain flight-specific data. Temporary pages may occasionally be added to Generic documents to account for vehicle or mission-specific data.

- **Flight-Specific documents** – Contain flight-specific data used in conjunction with Generic publications. Flight-specific documents contain data for a single mission and have no generic companion document.

- **Standby Supplements** – Contain procedures that are not flown because they have a very low probability of being needed. The data are available on console in Mission Control and can be uplinked if required.

Certain pages of Control, Support, and Off-Nominal documents are labeled “Not Flown.” These pages are included in the books sent to the various recipients on the distribution list, including Mission Control, but are not included in the “flight quality” copies used in the trainers or in flight. Cue cards are also included in the body of the distribution copies but may not be flown as part of a book or checklist; exceptions are Ascent and Entry Cue Cards and flip book pages that are provided to mission specialist 2.



SSP FDF Structure (Typical Books)

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3.1 CONTROL DOCUMENTS

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Ascent Checklist 3.1-1
Post Insertion Book 3.1-1
Flight Plan 3.1-1
Deorbit Preparation Book 3.1-1
Entry Checklist 3.1-2

Ascent Checklist

The Ascent Checklist is a flight-specific document. This checklist contains the nominal procedures for prelaunch through the post-OMS 2 burn, aborts, weather preliminary advisory data (PADs), and prelaunch switch configurations (not flown). Abort entry related material is included in this checklist because of the time critical nature of ascent aborts. Ascent Cue Cards are also controlled by the Ascent Checklist.

#	CARD	CARD FRONT	CARD BACK
1	• Contingency abort • RTLS Contingency	X	 X
2	• OMS 2/orbit OMS burn • OPS 1 RCS burn	X	 X
3	• OMS burn monitor • OMS failures	X	 X
4	• ADI err/rate switch (ASC) • ADI err/rate switch (ENT)	X	 X
5	• Ascent/entry spec	X	
6	• Speedbrake command	X	
7	• Entry alpha • Ascent ADI-nominal	X	 X
8	• AOA deorbit burn (2 engine) * • AOA deorbit burn (1 engine) *	X	 X
9	• AOA deorbit burn (RCS0 *	X	
10	• (XXX) TAL redesignation • (XXX) TAL redesignation	X	 X
11	• (XXX) TAL redesignation	X	
12	• Ascent/abort summary	X	
	• Emergency Egress • Escape Panel Egress • GPC/FCS Channel config • Panel R14 • LOC Breakup	 X X	 X X
* Hinged Card			

Ascent Cue Card

There are five Ascent and Entry Flip Books that are controlled by the Ascent/Entry Systems Procedures Book in the Off-Nominal group of FDF.

Post Insertion Book

The Post Insertion Book is a flight-specific document that includes summary and detailed timelines and procedures to prepare the orbiter, crew, and payload for on-orbit operations. Additionally, it contains on-orbit switch pictorials and abort to orbit (ATO) post insertion data. There are no Post Insertion Cue Cards; however, during the post insertion phase, cue cards for various on-orbit activities are unstowed and utilized.

Flight Plan

The Flight Plan is a flight-specific book that contains summary timelines for the orbiter (launch through landing) and payloads. It also contains the detailed nominal and contingency timelines for the overall mission, including key ground support, crew, orbiter, and payload systems operations. The Flight Plan may also contain the Attitude Timeline if the number of attitude changes warrants its inclusion. There are no Flight Plan cue cards. The Flight Plan is the controlling document for the Digital Autopilot (DAP) Book, which is stowed in one of the pilot's FDF lockers.

Deorbit Preparation Book

The Deorbit Preparation Book (Deorbit Prep) contains a summary and detailed timeline for nominal deorbit preparation procedures that begin about 4 hours prior to the deorbit burn. The book also contains contingency modifications to these procedures and the steps to back out of deorbit preparation should a waveoff be required. Additionally, this book contains a pictorial of the entry switch list, nominal and contingency deorbit preparation procedures for payload bay door closure, and backup flight system (BFS) deorbit preparation notes. There are no cue cards controlled by the Deorbit Prep book.

Entry Checklist

The Entry Checklist (Generic and Flight Supplement) becomes the controlling document about 43 minutes prior to the deorbit burn. This checklist contains pre-deorbit burn, post-burn, entry, and post-landing procedures. Entry Cue Cards are also controlled by the Entry Checklist.

#	CARD	CARD FRONT	CARD BACK
1	Deorbit burn flight rules • One orbit late available • RTLS Contingency	X	X
2	• Deorbit burn monitor • OMS failures	X	X
3	• Deorbit burn (RCS) *	X	
4	• Deorbit burn (2 engine) * • Deorbit burn (1 engine) • Deorbit burn (mixed xfeed) *	X	X X
5	Unbalanced propellant deorbit burn	X	
6	• Entry control	X	X
7	• Entry maneuvers (EI-5 - V=10K) • Entry maneuvers (V=7K - STOP)/ Orbiter Xwind limits	X	X
8	• Entry no/go checklist • ADTA mgmt; no comm TACAN mgmt; nav delta pad; bailout mode 8; postlanding mode 5	X	X
9	• Mach/alpha	X	
	•		
	•		

* Hinged Card

Entry Cue Cards

3.2 SUPPORT DOCUMENTS

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Orbit Operations Checklist 3.2-1
Photo/TV Checklist 3.2-1
Payload Deployment and Retrieval
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Extravehicular Activity Checklists 3.2-1
Rendezvous Checklist 3.2-1
Payload Operations Checklist 3.2-2
Deploy Checklist 3.2-2
Additional Support Documents 3.2-2

The generic documents and flight supplements within this group are bound together for training and flight rather than integrated.

Orbit Operations Checklist

The Orbit Operations (Orbit Ops) Checklist contains the procedures for on-orbit operation of orbiter systems, pre-sleep and postsleep periods, detailed test objectives (DTOs), and separation maneuvers. Cue cards are controlled by the Orbit Ops Checklist, which provide procedures for saving data in the modular memory units (MMUs), a directory of general purpose computer (GPC) specialist function (SPEC) and display (DISP) assignments, and procedures for fuel cell purging.

Photo/TV Checklist

The Photo/TV Checklist contains the procedures for still, motion picture, and closed circuit television (CCTV) camera configuration (including camcorder). It also contains camera setup, activation, and deactivation procedures for photo/TV scenes, camera displays and controls, and camera malfunctions. Photo/TV Cue Cards detail nominal procedures for the use of the CCTV system, video tape recorder (VTR), ET photography and film use. (Examples of cue cards are in Section 2.3.)

Payload Deployment and Retrieval System Operations Checklist

The Payload Deployment and Retrieval System (PDRS) Operations Checklist Generic and Flight Supplement documents fly only on shuttle missions that have the remote manipulator system (RMS) manifested. These documents contain the RMS and RMS/payload nominal, backup, and contingency procedures. They also contain CCTV data for the RMS television cameras (along with the Photo/TV Checklist) and RMS-related EVA procedures. The PDRS document controls two standard cue cards. Their purpose is to quickly safe the payload, orbiter, or RMS from failures that affect end effector operations and, if possible, to complete successfully the mission deploy or retrieval objective.

Extravehicular Activity Checklists

The Extravehicular Activity (EVA) Generic and Flight Supplement Checklists are flown for planned EVAs or for payloads that have EVA backup procedures. These checklists contain all the procedures for EVA preparation through post-EVA. Also included are extravehicular mobility unit (EMU) maintenance, recharging, and malfunction procedures, plus EMU contingency data and airlock nominal and emergency procedures. Two cue cards are controlled through the EVA Checklist. They contain procedures for orbiter airlock depressurization/repressurization and EMU leak check data. The EVA Checklist also controls the EVA cuff checklist worn on the EMU sleeve.

Rendezvous Checklist

A Rendezvous (RNDZ) Checklist is flown for missions involving a planned rendezvous and for flights that involve an RMS deploy with a planned contingency rendezvous revisit. This checklist contains a rendezvous flight profile diagram, a flight rules summary, a deploy timeline (if appropriate), a rendezvous timeline, contingency operations, rendezvous OMS burn procedures, and reference data regarding the DAP, relative motion, targeting, and operation of onboard piloting tools. For missions to the ISS, the Androgynous Peripheral Docking System (APDS) nominal procedures, off-nominal procedures, and docking sequence cue card are included. The Rendezvous Checklist also controls several cue cards: RCS burn, RNDZ propellant PAD, Proximity Operations Procedures, Ku Radar Rendezvous Operations, Nominal Radar Angles & Camera Angles Ranging Chart, and an RMS End Effector

Camera Overlay (for aid in flyaround of the free-flying payload.)

During the rendezvous phase of a flight (typically the three orbits immediately before and including) grapple or docking, the Rendezvous Checklist is the primary controlling document. For use during RMS deploys, the Rendezvous Checklist contains the deploy timeline, which includes references to the PDRS Checklist.

Payload Operations Checklist

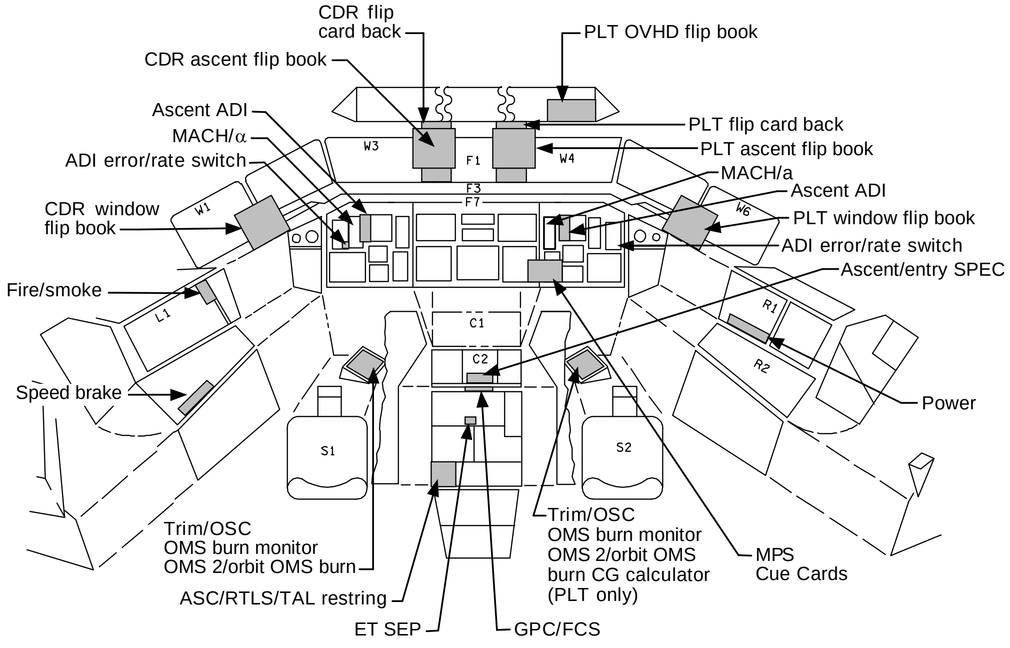
The Payload Operations (PL OPS) Checklist is a flight-specific document that contains payload systems procedures for on-orbit operations through deorbit preparation. There may be mission/payload-specific cue cards associated with this book. For complex payload missions, a Payload Systems Data and Malfunction (PL SYS) Book may be flown. This book contains payload-specific malfunction procedures, reference information, and payload drawings requested by the crew.

Deploy Checklist

The Deploy Checklist is also a flight-specific book with the payload identified in the title. This document covers all phases of deploy from payload checkout through deploy (including RMS procedures), and orbiter separation activities. The checklist also contains deploy flight rules, backup, contingency, and jettison procedures, forward RCS data, and payload-critical action responses. The number and types of Deploy cue cards flown are payload specific.

Additional Support Documents

There may be additional support documents and associated cue cards flown to support unique mission requirements. The Cue Cards and Procedural Decals Book is published and distributed for ground use. It does not fly on the orbiter. It is the controlling document for decals and cue cards that do not reside in other publications. Additionally, this document dictates guidelines and constraints for the fabrication of all cue cards and CCTV overlays and provides diagrams for the placement of flight deck cue cards for various mission phases.



Not shown: Escape PNL egress (back of CDR seat)
Mode 1 and 5 egress (back of PLT seat and on middeck)
Teleprinter (above L9 if flown)
Contingency Abort

798.cvs

Flight Deck Ascent Cue Card Placement

3.3 OFF-NOMINAL DOCUMENTS

CONTENTS

Pocket Checklists.................................. 3.3-1
Ascent/Entry Systems Procedures Book.. 3.3-1
Systems Abort Once Around Book.... 3.3-1
Malfunction Procedures Book............ 3.3-1
In-Flight Maintenance Checklist........ 3.3-1
Payload Systems Data and Malfunction Procedures Book. 3.3-1
Medical Checklist................................. 3.3-2
Contingency Deorbit Preparation Book... 3.3-2

Pocket Checklists

Some of the documents in the Off-Nominal section of the FDF contain critical procedures that must be performed within 5 minutes. The three pocket checklists (PCLs) (Ascent, Orbit, and Entry) and associated cue cards contain these critical data. The PCLs are readily distinguished by the yellow card stock used for the pages. The Ascent PCL contains procedures that safe systems for continued flight. It also contains orbiter systems powerdown procedures.

At the initiation of the post insertion phase, the Orbit PCL is utilized. This PCL contains critical orbiter systems malfunction responses and powerdown procedures. The orbit PCL often refers to the orbiter Malfunction Procedures (MAL) Book for detailed troubleshooting.

The Entry PCL contains critical contingency systems malfunction responses that allow safe continuation of the pre-deorbit through early entry phases along with orbiter systems powerdown procedures.

Ascent/Entry Systems Procedures Book

The Ascent/Entry Systems Procedures Book does not fly as a standalone document. It is the control source for the CDR and PLT Ascent/ Entry Flip Books and Cue Cards. The first nine sections of this document are replications of all the Ascent/Entry Flip Books (excluding Ascent Flip Books) and Cue Cards. They are added to the front of the MS2's Ascent PCL and again to the Entry PCL (minus the ascent-specific pages) to assist MS2 in supporting the CDR/PLT during these critical phases of flight. These pages are printed on white stock to differentiate them from the PCL data.

Systems Abort Once Around Book

The Systems Abort Once Around (SYS AOA) Book contains time-critical steps for the loss of two Freon or water loops precipitating an AOA. Initial steps for the loss of Freon loops or water loops are in the CDR's Flip Book and in the front of the MS2's Ascent PCL. This document also contains deorbit burn monitor procedures, post-burn actions, entry maneuver procedures, and panel configurations.

Malfunction Procedures Book

The MAL Book is a large document dealing with diagnostic steps used to identify, isolate, and correct orbiter systems malfunctions subsequent to quick response procedures or noncritical system problems. For orbiter malfunctions not covered in the Orbit PCL, the MAL Book is the prime reference. The procedures in the MAL Book are applicable for on-orbit operations only. They may be flown electronically or in hardcopy.

In-Flight Maintenance Checklist

The In-Flight Maintenance (IFM) Checklist contains repair/reconfiguration procedures for critical systems, and layouts of orbiter system components. There is also a Standby Supplement available in Mission Control that contains additional procedures.

Payload Systems Data and Malfunction Procedures Book

The Payload Systems Data and Malfunction Procedures (PL SYS DATA) Book is a flight-specific document that contains both off-nominal procedures and reference information for the mission's payloads; it includes DPS displays, systems schematics, malfunction diagnostic flow, critical equipment lost with multiplexer/demultiplexer (MDM) failures, and photographs of payloads in the PLB.

Medical Checklist

The Medical (MED) Checklist Generic contains emergency medical procedures, medical techniques with illustrations, and equipment/ medicine stowage. There are two cue cards associated with the MED Checklist. They are the MEDICATION DATA LOG, which is used to track medication usage from the Shuttle Orbiter Medical System (SOMS) and the AIRWAY "ILMA" (Intubating Laryngeal Mask Airway) cue card. The ILMA cue card provides procedures on how to establish an open airway on an incapacitated crewmember.

Contingency Deorbit Preparation Book

The Contingency Deorbit Preparation (CONT Deorbit PREP) Book contains procedures and the switch list for emergency deorbit during orbits 2 or 3. It also contains the deorbit procedures used for loss of the flash evaporator, two fuel cells, two water loops, or two Freon loops. Although this document has no cue cards, landing site charts and other appropriate data are added to flight copies for crew convenience.

3.4 REFERENCE DOCUMENTS

CONTENTS

Reference Data Book........................... 3.4-1
Systems Data Book.............................. 3.4-1
Data Processing System Dictionary.................................. 3.4-1
Payload Systems Data/ Malfunction Book...................... 3.4-1
Maps and Charts Book........................ 3.4-1

Reference Data Book

The Reference Data (REF DATA) Book contains lists of critical inoperative equipment with the loss of a bus or subbus and an ac/dc power outlet chart. There are also lists of input/output (I/O) GPC parameters lost when selective MDMs are inoperative. Additionally, there is a list of all fault messages, C/W and fault detection and annunciation (FDA) tables, and a complete stowage list for crew equipment, clothing, and Flight Data File (FDF). User notes that were formerly a part of the DPS Dictionary have also been added.

Systems Data Book

The Systems Data Book (SYS DATA) is a large document containing selected schematics of most orbiter systems and structures taken directly from the Space Shuttle Systems Handbook. These schematics are augmented by photographs of major components and structures.

Data Processing System Dictionary

The Data Processing System Dictionary (DPS DICT) contains a compendium and explanation of all DPS displays onboard the orbiter. It also has program notes on software limitations and peculiarities with corrective instructions. It is no longer flown as a piece of FDF, but is still updated for use on the ground.

Payload Systems Data/Malfunction Book

The Payload Systems Data/Malfunction (PL SYS DATA/MAL) Book, detailed in the Off-Nominal section, can also be considered a reference document because of some of the payload-related data it contains.

Maps and Charts Book

The Maps and Charts Book contains landing charts, an orbit map (with a movable 3-revolution groundtrack), star charts, and a World Atlas. The World Atlas also contains a list of Earth sites for observation and photography. Although the Maps and Charts Book controls these media, they are stowed as separate items on the flight deck and middeck.

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3.5 OPERATIONAL USE

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FDF Fabrication 3.5-1
Preliminaries 3.5-1
Basic 3.5-1
482 .... 3.5-2
Final 3.5-3
Flight 3.5-3

FDF Fabrication

Materials acquired for the fabrication of Flight Data File (FDF) articles or for in-flight supplies fall under four categories:

- Printed material (print shop products, photos, maps)
- Commercial materials (paper boards, pens, markers, ring binders)
- JSC components (edge labels, map frames, accessory bags)
- Certified and approved materials with Federal Stock Numbers purchased through the JSC Stores Stock Catalog

These items used by FDF Operations must be in compliance with current safety, reliability, and quality assurance (QA) standards, or in receipt of a Material Usage Agreement (MUA) waiver. Annex E of the CPMP identifies the documents containing these standards and describes the physical dimensions of all JSC fabricated FDF items used onboard the orbiter.

Considering the tremendous volume of critical information being presented in the shuttle FDF, it is essential that special symbols be used to abbreviate procedures.

Preliminaries

Development of the FDF for a mission normally starts about 1 year prior to the launch date. The preliminary work for payloads may start as much as 2 years prior to launch. The earliest FDF official publications (typically the Flight Plan and payload related books) are designated as Preliminary documents. These books are published approximately 8 months prior to the launch date, after the Cargo Integration Review (CIR). Preliminary documents are not under the formal change control of the CPCB. Accordingly, they are under continual development, and changes may be made informally by any cognizant individual by working through the book manager.

,	comma—read“..and...”
/	slash—read“..and/or...”
( )	parentheses—read”...or...”
>>	or chevron — read “exit”
✓	checkmark—read “verify ...” or “check...” or “check with...”
+	plus followed by space then value—read as ‘add”
+	plus followed by value without space—read as “positive”
–	minus followed by space then value—read as mathematical “subtract”
–	minus followed by value without space—read as “negative”
↑	up arrow—upper limit exceeded
↓	down arrow—lower limit exceeded
∆	delta—read ”change”
••	double dot—indicates that preceding data is to be highlighted in flight book
|	vertical line—read “...or...”between alternate conditional statements
|	vertical bar—in page margin to indicate change in procedure since last publication
⬚	dotted box—encloses alternate or optional steps
* * * * * *	vertical stars—brackets contingency steps
☐	box— DPS display callout
$\boxed{n}$	box—read “block n” which refers to corresponding block of procedures

FDF Symbols

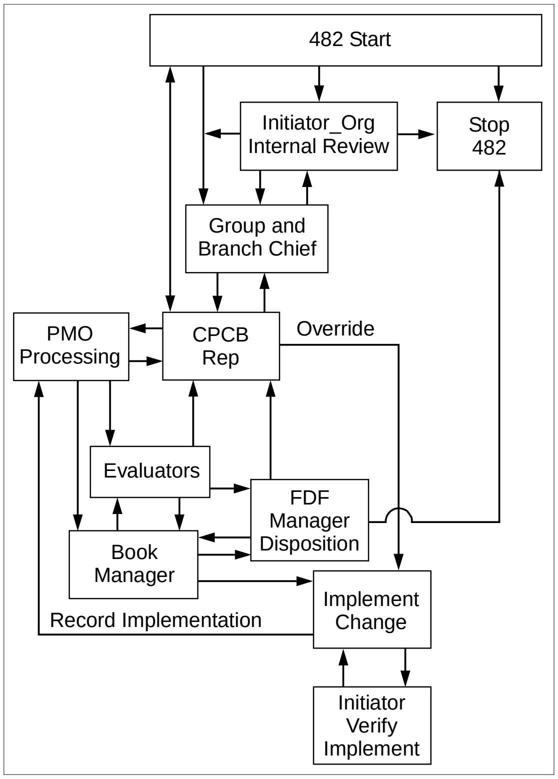
Basic

Approximately 4 months prior to the launch date, the Basic editions of all flight-specific/ supplement FDF are published. The documents are now under the configuration control of the CPCB and all changes must be requested through formal channels that include approval by cognizant personnel. Generic documents are also subject to these formal change requirements, although their publication cycles are independent of mission cycles. Only those Generic books that incorporate temporary flight-specific pages will normally require changes during the FDF preparation for a specific mission. About 3 weeks after the publication of the Basic FDF document, a Flight Operations Review (FOR) is held at JSC. The FOR is a formal review of payload related documents that the flight crew and ground controllers will use for training and flight. It also provides a forum to verify that authorized customer requirements have been met and that safety and shuttle operational requirements related to payload operations are correct. Representatives from the Flight Crew Operations and Mission Operations Directorates, Shuttle Integration and Operations Office, customer personnel, and other NASA personnel, as required, are invited to attend. These representatives may submit Discrepancy Notice (DN) forms regarding additions (for existing requirements), deletions, or modifications to any FDF document under review for that specific flight. The DNs are evaluated by the book manager who recommends approval, disapproval, or withdrawal to the FOR "preboard." DNs recommended for disapproval or withdrawal will be reviewed in "splinter" meetings as required. Final action on all of the DNs is taken by the formal FOR board, which is chaired by the Manager, Space Shuttle Integration and Operations, and made up of management personnel representing the mission payload(s) and NASA directorates. DNs receiving an approval will usually be incorporated into the next publication cycle of the appropriate document. If the data are critical to crew training, the material will be immediately incorporated into all pertinent training documents via simulation packages (Sim Pacs).

482

Subsequent to the FOR, changes to FDF must be made via a Crew Procedures Change Request, JSC Form 482-B. The 482 process is detailed in CPMP Annex B. As before, anyone may submit a 482 requesting a change to a particular FDF document. The 482 will be reviewed by cognizant personnel and approved or disapproved. Disapproval by anyone in the review process causes the 482 to be dispositioned by the CPCB. There is an appellate process for 482s disapproved at the CPCB through the appropriate Level II board. An alternative method of changing minor FDF material is available via an EZ 482. This form requires much less review and fewer signatures, but its use is quite limited and only available from the book manager.

Approximately 4 months prior to flight, the crew determines the allowable additions and deletions to the quantities of FDF documents and supplies they wish to have onboard.



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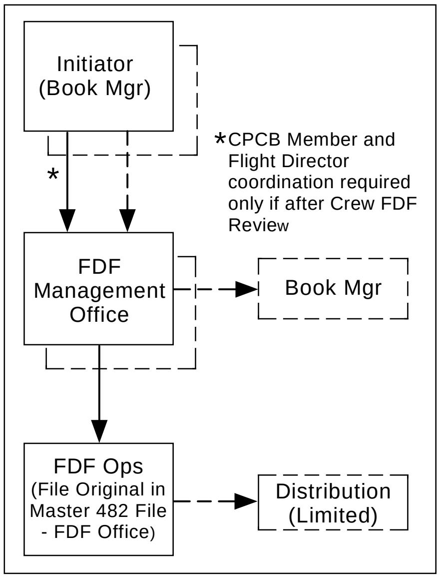
482 Flow



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EZ 482 Flow

Final

Approximately 6 weeks prior to flight, the Final versions of flight-specific/supplement FDF documents are published. Changes can still be made to the FDF after publication of the Final version via a 482. Changes that affect a small percentage of the pages in a book will normally be implemented with a Page Change Notice (PCN). When more than one half of the pages must be reprinted, or many affected pages are scattered throughout a book, a complete revision (REV) will be printed. Other authorized changes may be implemented via an Errata Pack. These changes may be pen and ink modifications or reprints of a particular page. Technical modifications of the flight documents by the crew during their review will be promulgated in an Errata Pack subsequent to the completion of a 482. A duplicate copy of the FDF is available to the crew while they are in quarantine at JSC. The prime and an identical backup set of the FDF are configured for flight and shipped to KSC separately.

Flight

The crew has access to the backup copy of the FDF while in the crew quarters at KSC. On launch day, FDF representatives turn over the carry-on FDF to the astronaut support person (ASP), who installs the appropriate FDF documents for launch. The suit technicians lay out the other carry-on FDF for the crew to stow in their FDF bags. After the crew has ingressed, the ASP makes the final installations and adjustments of the cue cards, flip books, and checklists. Although the number can vary slightly for a particular mission or crew, at launch there are about 7 copies of the 3 ascent related checklists, 5 flip books, and 34 cue cards out/mounted for the crew's use. The checklists are attached to lanyards, while the cue cards and flip books are affixed with Velcro. Additional cue cards and checklists are readily available to the crew in the CDR/PLT's FDF containers and the MS's FDF bags for certain low probability contingencies. The CDR and PLT post insertion checklists are also stowed in the FDF containers.

Approximately 1 hour after launch, when the crew transitions to the Post Insertion Checklist, MS 3 retrieves selected FDF from a middeck locker. Items not needed right away are usually placed in a stowage bag on the back of the CDR or PLT's seat. At this time, ascent-related material is stowed in a helmet bag and placed into a "return to Houston" stowage bag. Subsequent to Mission Control's "GO for orbit ops," the crew may unstow additional FDF as required. FDF control during the on-orbit phase of the mission is basically a crew decision. There are certain contingency FDF documents (CONT Deorbit, Entry, Entry PCL) that should be readily available. Others may be mounted in a convenient place in the orbiter, stowed in a temporary location, or stowed in the FDF locker. Prior to the last sleep cycle, the crew will begin the stowage of on-orbit oriented FDF. During the deorbit preparation phase, the crew stows the remainder of their on-orbit FDF and installs the Deorbit and Entry Cue Cards, Flip Books, and Checklists.

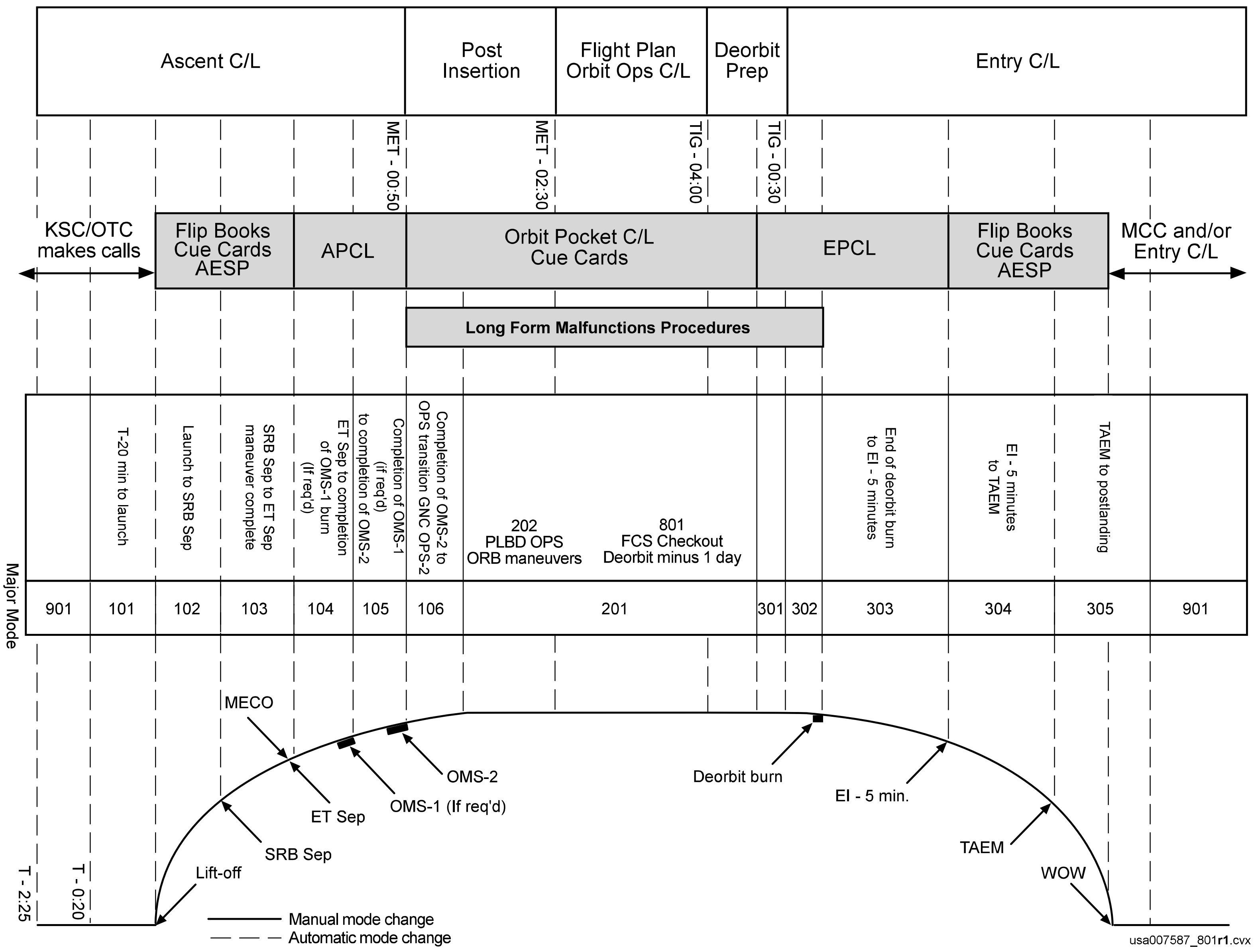
After landing, the ASP enters the orbiter and collects the Deorbit and Entry FDF and places them in "return to Houston" bags with the other FDF. They are returned to Houston with the crew. Kneeboard cards and other items of importance to the crew are collected by the suit technicians and returned to Houston as soon as possible. During postflight debriefings, the crew has access to the flown FDF, kneeboard cards, and microcassettes to help reconstruct events of the mission. The flown FDF is copied onto microfiche and after 6 months it is transferred to the National Archives in Washington, DC. The backup copies are reused if feasible, or destroyed. The crew may request portions of the backup material as mementos.

FLIGHT PHASE	EVENT	SOFTWARE			FLIGHT DATA FILE	
			MAJOR MODE * *			
		MEMORY CONFIG	GNC	SYSTEMS MGMT	FLIGHT PROCEDURE	TROUBLESHOOTING PROCEDURES*
ASCENT	Precount	9	901	--	Ascent Checklist	
	Terminal Count	1	101	--		
	First Stage	1	102	--	Ascent Flip Book Cue Cards	CDR Flip Book Pilot Flip Book Pilot Overhead Flip Book Cue Cards
	Second Stage	1	103	--		
	Orbital Insertion	1	104	--	Ascent Checklist Cue Cards	Ascent Pocket Checklist
	Orbit Circularization	1	105	--		
	Post-Insertion Coast	1	106	--	Post-Insertion Checklist	Orbit Pocket Checklist STS Malfunction Procedure
	RTLS 2nd Stage	1	601	--	Ascent Flip Book	CDR Flip Book Pilot Flip Book Pilot Overhead Flip Book Cue Cards
	Glide RTLS-1	1	602			
	Glide-RTLS-2	1	603	--		
ORBIT	Orbit Coast	2	201	--	Post Insertion Checklist Flight Plan Orbit Operations Checklist Payload Checklists Deorbit Preparation Checklist	Orbit Pocket Checklist Cue Cards STS Malfunction Procedures
	Orbital Maneuver	2	202	--		
	On-Orbit Checkout	8	801	--		
	Orbit Operations	4, 5	--	201, 401		
	Payload Bay Door Operations	4, 5	--	202, 402		
ENTRY	Predeorbit Coast	3	301	--	Deorbit Preparation Checklist Entry Checklist	Entry Pocket Checklist Cue Cards CDR Flip Book Pilot Flip Book
	Deorbit Maneuver	3	302	--	Entry Checklist Cue Cards Cue Cards	
	Preentry Monitor	3	303	--		
	Early Entry	3	304	--		
	TAEM/Landing	3	305	--		
	Post-Landing	9	901	--	Entry Checklist	Pilot Overhead Flip Book Cue Cards

* During ascent and entry, the Mission Specialist uses the Ascent/Entry Systems procedures.

** Major modes separated by a dashed line have automatic transitions from one to the next. Major Mode discussion is in Section 2.6, Data Processing System

Shuttle Mission Overview



Shuttle Mission Overview

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4. OPERATING LIMITATIONS

CONTENTS

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4.3 AIRSPEED LIMITATIONS 4.3-1
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4.8 CENTER OF GRAVITY LIMITATIONS........................... 4.8-1
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4.10 WEATHER LIMITATIONS...... 4.10-1

This section delineates limitations for selected orbiter systems, equipment, and operations. It is not all inclusive. Limitations that the flight crew should be aware of have been emphasized. It must be noted that operations up to and including the given limits for one system may cause a violation of the limits for another. An example would be flying at the flight control system maximum allowable knots equivalent airspeed (KEAS). This KEAS would overspeed the landing gear with a lower maximum allowable KEAS.

> *"Limitations are those measurable or detectable operational limits, which if exceeded, will affect crew safety or result in performance degradation."*

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4.1 INSTRUMENT MARKINGS

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Description 4.1-1
Panel F9 Meters 4.1-5
Panel O1 Meters 4.1-6
Panel O2 Meters 4.1-9
Panel O3 Meters 4.1-11

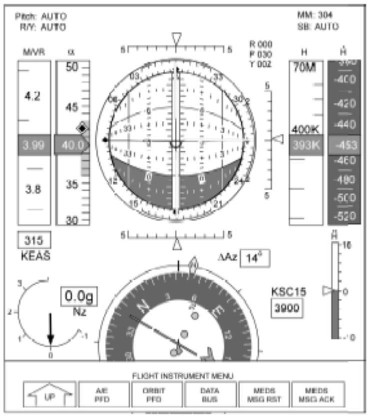
Description

Instrument markings reflect the normal range (green) and upper/lower limits (red). Caution and warning alarms/tones will normally sound at the points marked in red. In some cases an SM alert will sound prior to the limits on the meters being reached. The meter indications in this section are arbitrary and are not intended to reflect actual flight conditions. For MEDS, vehicles, see section 2.18, MEDS for OMS/MPS, HYD/APU, SPI, and Flight Instruments.

Alpha/Mach Indicator

The MEDS alpha tape displays a maximum lift-to-drag (L/D) diamond. The diamond position is a linear interpolation of table values. For Mach ≤0.95, the diamond is fixed at 10.5°.

The MEDS alpha tape also displays a green bar indicating maximum and minimum alpha limits on entry. The maximum and minimum positions are a linear interpolation of a table of values based on the current flight rule limits.



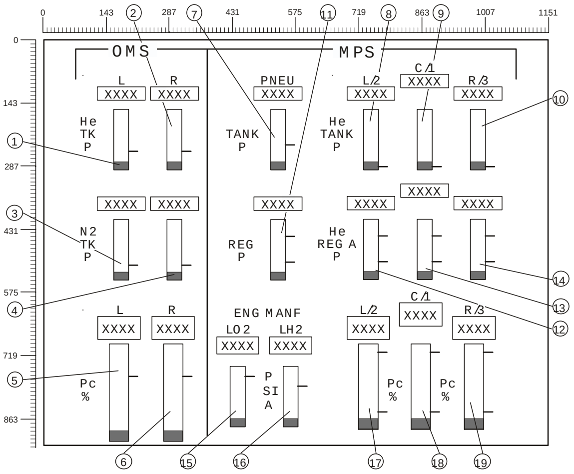
Entry PFD
with Alpha Tape Markings

Subsystem Status MEDS Display

The meters on panels F7 and F8 have been removed and replaced with a MEDS display. The following parameters can be viewed by depressing the SUBSYSTEM STATUS key on the MEDS toolbar and then selecting the appropriate subsystem (OMS/RCS, HYD/APU, SPI).

Normal operating ranges are indicated by: ▨ = GREEN

High/low limits are indicated by: ■ = RED



① L OMS He TK PRESS meter
② R OMS He TK PRESS meter
③ L OMS N2 TK PRESS meter
④ R OMS N2 TK PRESS meter
⑤ L OMS Pc meter
⑥ R OMS Pc meter
⑦ PNEU He TK PRESS meter
⑧ L ENG He TK PRESS meter
⑨ C ENG He TK PRESS meter
⑩ R ENG He TK PRESS meter
⑪ PNEU He REG PRESS meter
⑫ L ENG He REG PRESS meter
⑬ C ENG He REG PRESS meter
⑭ R ENG He REG PRESS meter
⑮ LO2 ENG MANF PRESS meter
⑯ LH2 ENG MANF PRESS meter
⑰ L ENG Pc meter
⑱ C ENG Pc meter
⑲ R ENG Pc meter

1078.CNV

OMS/MPS MEDS Display

OMS PRESS Pc Meter

The left and right Pc (thrust chamber pressure) is measured by a sensor that is routed through a dedicated signal conditioner (DSC) before being displayed on the OMS/MPS display and sent to the GPCs.

OMS PRESS N2/He Tank Meter

Separate N2 and He pressure sensors (left and right) are wired through a DSC to the OMS/MPS display and GPCs. Redundant pressure sensors provide the pressure readings for N2 and He on the GNC SYS SUMM 2 display.

Meter	Meter Marking(s)	Marking Explanation(s)
OMS He TK P (L, R)	<1500 psia (red)	Low limit (Class 3 C/W)
OMS N2 TK P (L, R)	<1200 psia (red)	Low limit (Class 3 C/W)
OMS Pc % (L, R)	95 - 110% Pc (white)	Normal operating range
	<80% Pc (red)	Low limit (Class 2 C/W) 72% Pc allowed during ullage blowdown
	>116% (appx)	Off-scale high (Class 2 C/W) A value of 160 is displayed in red and the Pc box goes red
MPS HE TANK P (C, L, R)	<1150 psia (red)	Low limit (Class 2 C/W)
MPS HE REG A P (C, L, R)	>810 psia (red)	High limit (Class 2 C/W)
	<680 psia (red)	Low limit (Class 2 C/W)
MPS Pc % (C, L, R)	65 - 109% Pc (white)	Normal operating range (104% Pc is the nominal maximum with power available up to 109% Pc)
MPS PNEU TANK P	<3800 psia (red)	High limit (Class 3 C/W)
MPS PNEU REG P	>810 psia (red)	High limit (Class 3 C/W)
	<700 psia (red)	Low limit (Class 3 C/W)
MPS ENG MANF LO2	>249 psia (red)	High limit (Class 2 C/W)
	45-175 psia (green)	Normal operating range for LO2
MPS ENG MANF LH2	>60 psia (red)	High limit (Class 2 C/W)
	30-45 psia (green)	Normal operating range for LH2

MPS PRESS Pc Meter

The left, center, and right Pc (thrust chamber pressure) are measured by a sensor that is wired via the GPCs through flight forward (FF) multiplexer/demultiplexer (MDM) 2, 1, or 3 respectively, to the OMS/MPS display. Power failure of an FF MDM or a data path failure will cause the affected Pc meter to drop to zero. GPC failure and some FF MDM failures can cause the affected Pc reading to freeze.

WARNING

MPS performance has not been verified in flight beyond a power level of 104 percent.

WARNING

MDM power failure can cause MPS Pc indication to drop to zero. Confirm engine failure with acceleration cues, MPS He consumption, or MCC call.

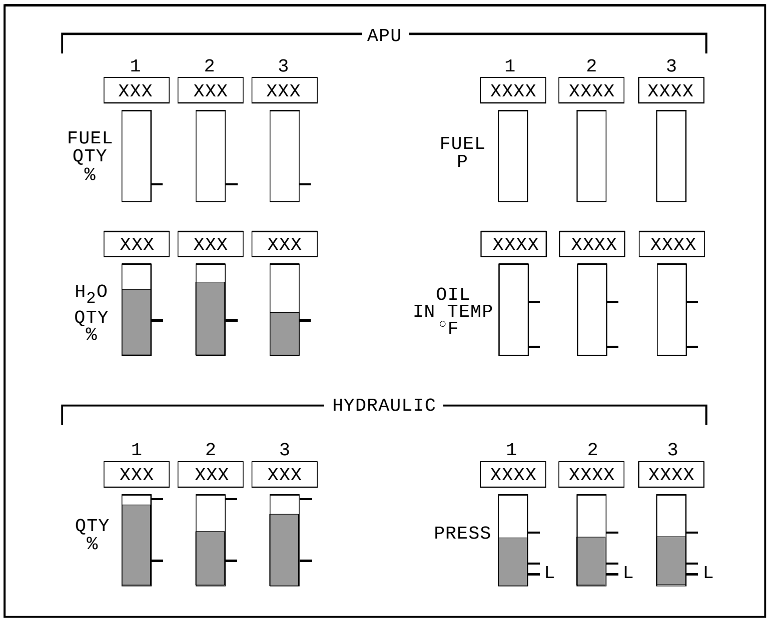
MPS PRESS ENG MANF Meter

The LO_2 and LH_2 manifold pressures are measured by a single transducer in each LO_2 and LH_2 line between the ET and SSMEs. The data are sent directly to the OMS/MPS display and through an MDM to the BFS GNC SYS SUMM 1 display.

MPS PRESS HELIUM and PNEU Meters

The pneumatic, left, center, and right He tank pressures are measured by a single sensor in each system manifold. Data are sent directly to the OMS/MPS display and through an MDM to the GPCs for display on BFS GNC SYS SUMM 1.

The Pneumatic regulator, Left, Center, and Right He Regulator A pressures are measured by a single sensor downstream of each regulator. Data are sent directly to the OMS/MPS display and through an MDM to the GPCs for display on BFS GNC SYS SUMM 1.



HYD/APU MEDS Display

Meter	Meter Marking(s)	Marking Explanation(s)
Hydraulic Pressure	2900 - 3200 psia (green) 2400 psia (red) 500 - 1000 psia (green)	Normal operating range Low limit (Class 2 C/W) Normal "low pressure" operating range
Hydraulic Quantity	40 - 80% (green) >95 or <40% (red)	Normal operating range SM alert sounds
Fuel Quantity	>20% (green) <20% (red)	Normal operating range SM alert sounds at 20%
Fuel Pressure	50 - 370 (green) 110 psia (red)	Normal operating range; however, it would require multiple failures before the pressure could reach 50. SM alert sounds at 100 and 350 psia Low limit for hot restart
Water Quantity	>40% (green) <40% (red)	Normal operating range SM alert sounds at 40%

Hydraulic Pressure Meter

Three sensors in each hydraulic system measure the fluid pressure. The "A" sensor is wired through a DSC to the HYDRAULIC PRESSURE meter (HYD/APU MEDS display), while the "B" sensor provides inputs for the SM SYS SUMM 2, SPEC 87 APU/HYD, and SPEC 87 HYD THERMAL displays. Mission Control has access to the data from the "C" sensor via downlist data. All three sensors are used for priority rate limiting (PRL). PRL status is available on the OVERRIDE (SPEC 51) display.

Hydraulic Quantity Meter

A sensor located in each of the three hydraulic reservoirs provides the information displayed on the HYDRAULIC QUANTITY meter and on the SM SYS SUMM 2 and SPEC 86 APU/HYD displays. Data is sent to the meter and GPCs via a DSC. It is also sent to the GPCs via an orbiter instrumentation MDM.

Fuel Quantity

Fuel quantity is determined by a pressure/volume/temperature (PVT) calculation performed by the onboard computers. The calculated quantity is output to the HYD/APU display and to DPS displays SM SYS SUMM 2 and SPEC 86 APU/HYD.

Fuel Pressure

There are two sensors: one on the N_2 side and one on the fuel side. Both go to the SPEC 86 APU/HYD display, but only the N_2 side sensor goes to the meter via a DSC.

WSB H2O Quantity

The H_2O quantity is determined by a PVT calculation based on H_2O tank pressure and temperature transducer readings as well as GN_2 tank pressure and temperature transducer readings. The calculated quantity is output to the HYD/APU display and to the SM SYS SUMM 2 and SPEC 86 APU/HYD displays.

Oil Temperature

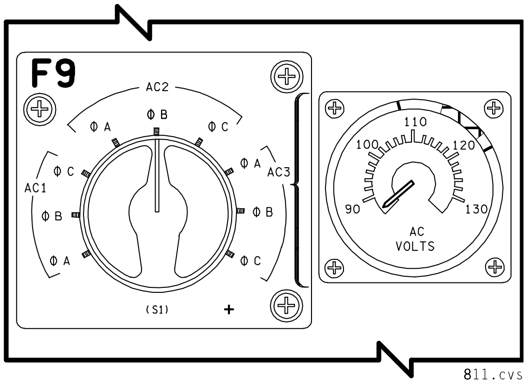
Oil temperature in the three APUs is measured by sensors located upstream and downstream of the water spray boilers. Data from the downstream sensor (OIL IN T) is routed to the OIL IN TEMP meter (HYD/APU MEDS display) via a DSC. The SM SYS SUMM 2 and SPEC 86 APU/HYD displays show data from both sensors (OIL IN T and OIL OUT T).

METER MARKINGS(S)	MARKING EXPLANATION(S)
50° - 70° F (green)	Normal operating range when APUs are off
200° - 270° F (green)	Normal operating range when APUs are off
290° F (red)	High limit (Class 2 C/W)

Panel F9 Meters

AC VOLTS Meter

AC phase voltage (A, B, and C) is read directly at each of the three buses. There is no AC AMPS meter for the AC system that monitors AC current. The data is sent to this meter and to the SM SYS SUMM 1 and SM SPEC 67 ELECTRIC displays.

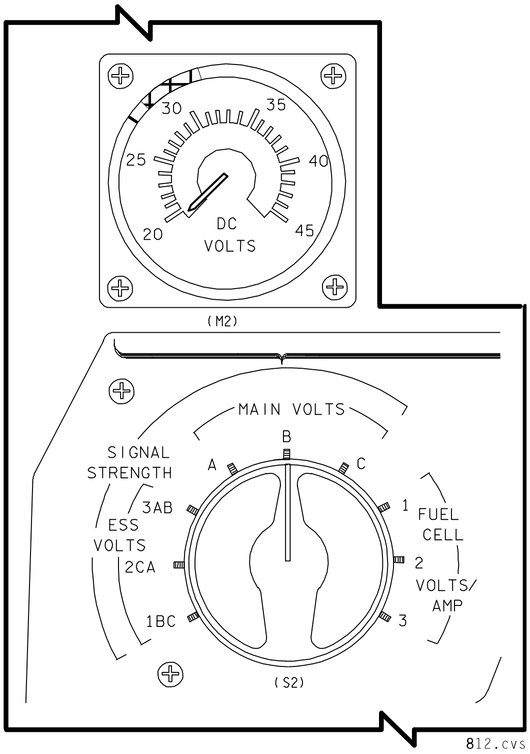


AC VOLTS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
115 — 119 (green)	Normal operating range
123 (red)	High limit (Class 2 C/W)
108 (red)	Low limit (Class 2 C/W)

DC VOLTS Meter

DC voltage is read directly at each fuel cell, main bus, and essential bus. The data is routed to the meter and to the SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS displays.

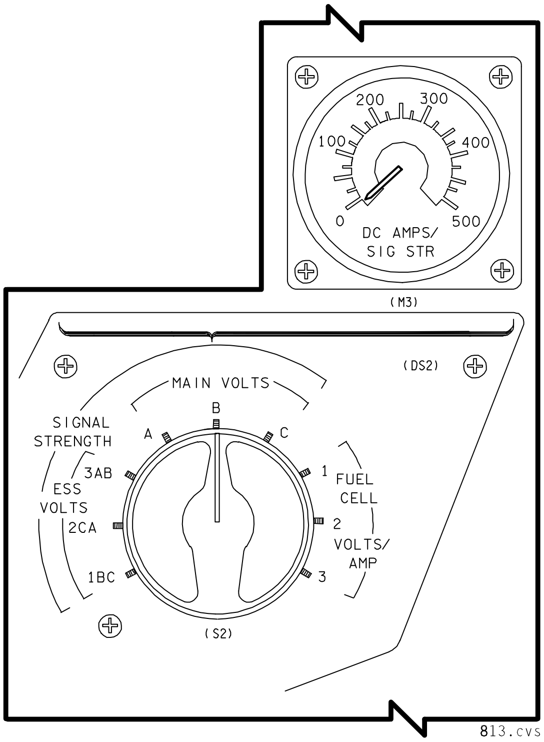


DC VOLTS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
28 — 32 (green)	Normal operating range (SM alert at 32.5)
26.4 (red)	Low limit (Class 2 C/W)

DC AMPS/SIG STR Meter

A current sensor for each of the three fuel cells provides an input to the DC AMPS/SIG STR Meter. ("SIG STR" refers to S-band signal strength that is also monitored on this meter.) Essential and main bus current are not monitored. The data also appear on the SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS displays.



DC AMPS/SIG STR Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
90 — 350 A (green)	Normal operating range

Panel O1 Meters

AIR TEMP, H_2O PUMP OUT PRESS Meter

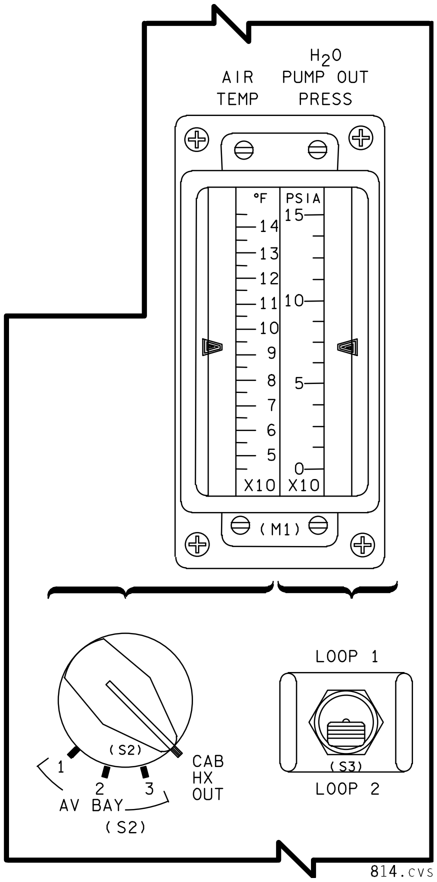
Cabin Heat Exchanger Air Temperature

Temperature data from a sensor downstream from the cabin heat exchanger are sent directly to the dual function AIR TEMP Meter and are also available on the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays.

Avionics Bay Air Temperature

Temperature data from a sensor located downstream of the avionics bay fans are sent directly to the AIR TEMP Meter. These data are also available on the SM SYS SUMM 2 and SPEC 66 ENVIRONMENT displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)
75° — 110° F (green) 130° F (red)	Normal operating range High limit for avionics bay air temp (Class 2 C/W)



AIR TEMP, H_2O PUMP OUT PRESS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
50° — 60° F (green)	Normal operating range

H_2O Pump Out Pressure

Sensors in water loops 1 and 2 send data to this meter via a DSC and to the SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM displays via an MDM. Certain preconditions must exist for the C/W system to activate at the values listed below. Those preconditions are found in the FDF Reference Data book.

METER MARKINGS(S)	MARKING EXPLANATION(S)
Loop 1	
55 — 65 psia (green)	Normal operating range
79.5 (unmarked)	High limit (Class 2 C/W)
19.5 Psia (red)	Low limit (Class 2 C/W)
Loop 2	
55 — 65 psia (green)	Normal operating range
81 psia (red)	High limit (Class 2 C/W)
45 psia (red)	Low limit (Class 2 C/W)

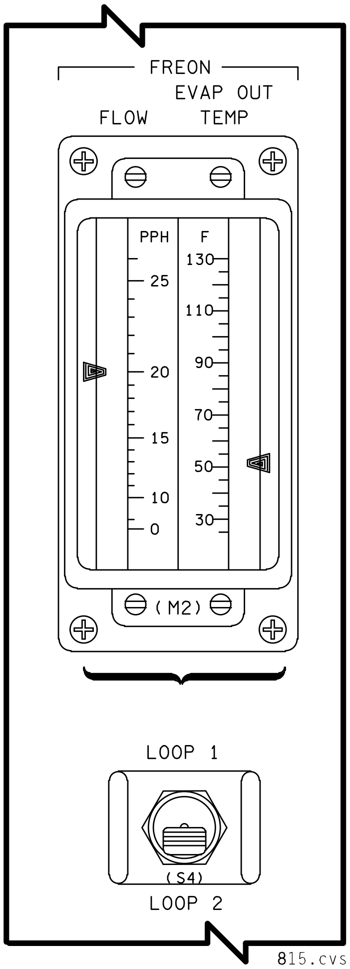
NOTE

SM alerts will occur at 75 psia (high) and 50 or 20 psia (low), depending on pre-conditions for both loops.

FREON FLOW, EVAP OUT TEMP Meter

Flow

A sensor located upstream from the H2O/ Freon Interchanger in Freon Loops 1 and 2 provides a readout of Freon interchanger flow directly to the meter and to the SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM displays.



FREON FLOW, EVAP OUT TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
2300 — 2500 psia (green)	Normal operating range (Flow Proportioning Valve in Payload (PL), SM alert at 1300 psia)
1400 — 2200 psia (green)	Normal operating range (Flow Proportioning Valve in Interchanger (ICH), SM alert at 1950 psia) [Change pending to meter markings to reflect C/W limits]
1200 psia (red)	Low limit (Class 2 C/W)
B	Bypass
R	Radiator

Evaporator Out Temperature

A sensor located downstream from the flash evaporator in each Freon Loop 1 and 2 provides data directly to the meter and to the SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)
38° — 40° F (green)	Normal operating range
65° F (red)	High limit (Class 2 C/W)
32° F (red)	Low limit (Class 2 C/W)

CABIN dP/dT PSIA/MIN, O2/N2 FLOW Meter

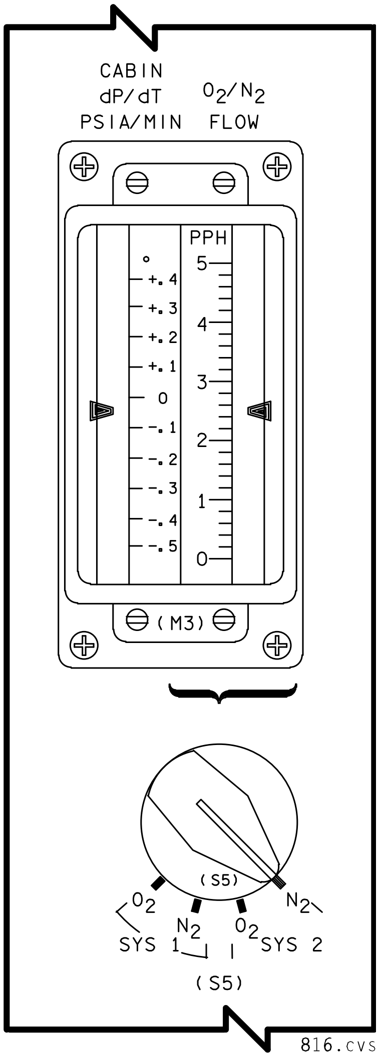
Cabin dP/dT

The indication on this meter is a direct readout of the dP/dT sensor. The data are also transmitted to the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays. The DPS displays also contain an additional backup dP/dT supplied by computations.

O2/N2 Flow

An O2 and N2 flow sensor in the two pressure control systems (four total) send data directly to the O2/N2 FLOW Meter. The readings are also available on the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)
0.0 — 0.75 pph (green)	Normal operating range
4.9 pph (red)	High limit (Class 2 C/W)



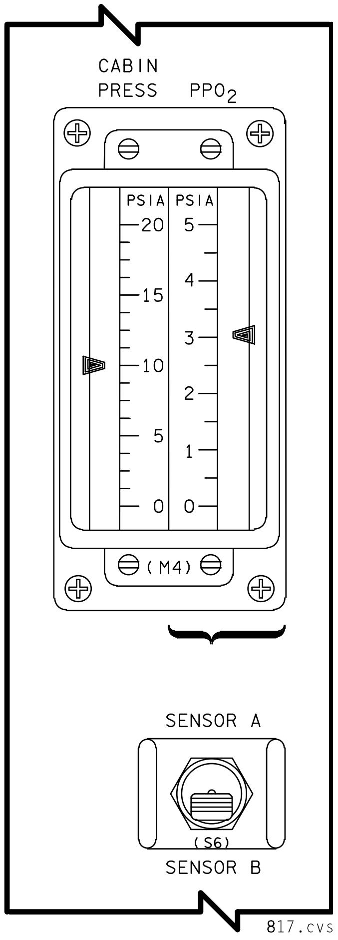
CABIN dP/dT PSIA/MIN,
O2/N2 FLOW Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
0.0 psia (green)	Normal operating range
-0.08 psia (red)	Low limit (Class 2 C/W)

CABIN PRESS, PPO_2 Meter

Cabin Pressure

A cabin pressure sensor provides a direct indication for this meter and for the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays. (The airlock pressure on the CRT ENVIRONMENT display can be used as a backup.)



CABIN PRESS, PPO_2 Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
14.3 — 14.7 psia (green)	Normal operating range
15.2 psia (red)	High limit (Class 2 C/W)
13.8 psia (red)	Low limit (Class 2 C/W)

PPO_2

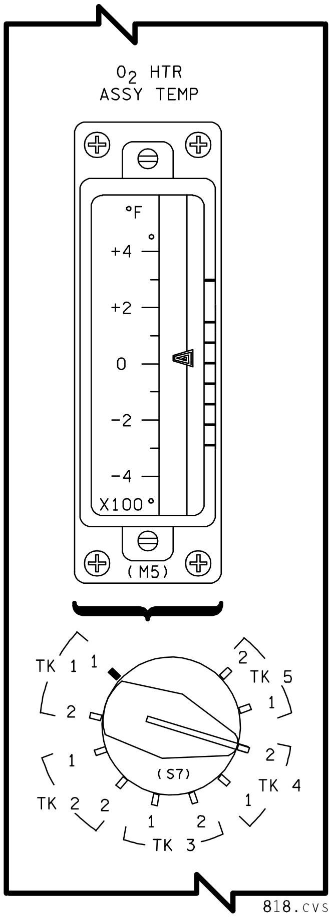
Dual selectable sensors (A or B) send data directly to this meter and for the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)
2.95 — 3.45 psia (green)	Normal operating range
3.6 psia (red)	High limit (Class 2 C/W)
2.7 psia (red)	Low limit (Class 2 C/W)

Panel O2 Meters

CRYO O_2 HTR ASSY TEMP Meter

A temperature sensor in each of the eight O2 tank heater assemblies monitors the temperature of warmed O2 and sends the data via a DSC to this meter and the SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM displays.



CRYO O_2 HTR ASSY TEMP Meter

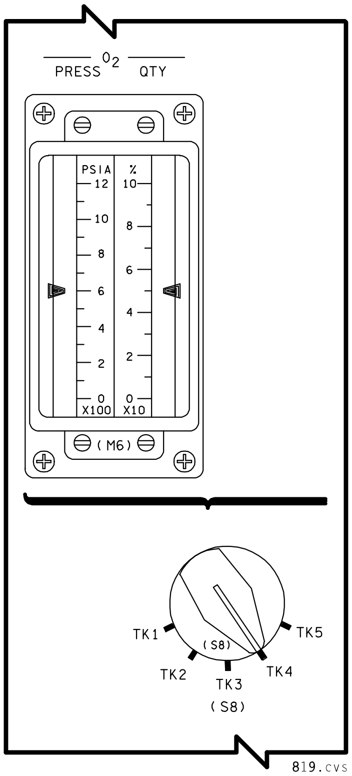
METER MARKINGS(S)	MARKING EXPLANATION(S)
-300° — +200° F (green)	Normal operating range
+349° F (red)	High limit (Class 2 C/W)

NOTE

For OV-105, the *METER TANK SELECT* switch will show HTRS 1 and 2 for tank 5 as well.

CRYO O_2 PRESS Meter

One sensor for each of the O_2 tanks provides pressure data via a DSC to the meter and SM program while another sensor (heater controller) sends data to the SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM displays.



CRYO O_2 PRESS Meter

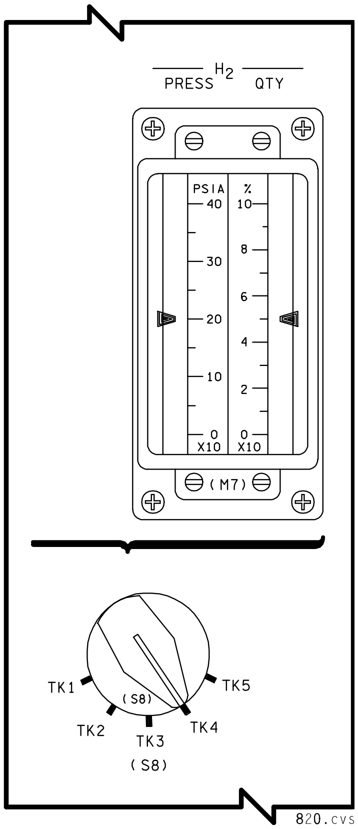
METER MARKINGS(S)	MARKING EXPLANATION(S)
802 — 930 psia (green)	Normal operating range
985 psia (red)	High limit (Class 2 C/W)
540 psia (red)	Low limit (Class 2 C/W)

NOTE

SM alerts occur at 960 psia (high) and 575 psia (low), with heaters not in AUTO or 740 psia (low) with A or B heater in AUTO.

CRYO H_2 PRESS Meter

One sensor for each H_2 tank provides pressure data to the meter via a DSC and SM software, while another sensor (heater controller) sends data to the SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM displays.



CRYO H_2 PRESS Meter

NOTE

Tank 5 *SELECT* position is included on OV-105.

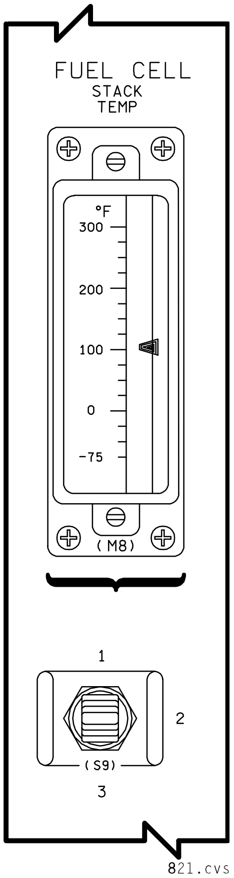
METER MARKINGS(S)	MARKING EXPLANATION(S)
200 — 250 psia (green)	Normal operating range
293.8 psia (red)	High limit (Class 2 C/W)
153 psia (red)	Low limit (Class 2 C/W)

NOTE

SM alerts occur at 283 psia (high) and 165 psia (low) with heaters not in AUTO, or 189.8 psia (low) with A or B heater in AUTO.

CRYO FUEL CELL STACK TEMP Meter

A sensor in each of the three fuel cell systems measures the temperature of the coolant leaving the fuel cell stack and sends the data via a DSC to this meter and the SM SYS SUMM 1 and SPEC 69 FUEL CELLS displays.



CRYO FUEL CELL STACK TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
190° — 225° F (green)	Normal operating range
243.7° F (red)	High limit (Class 2 C/W)
172.5° F (red)	Low limit (Class 2 C/W)

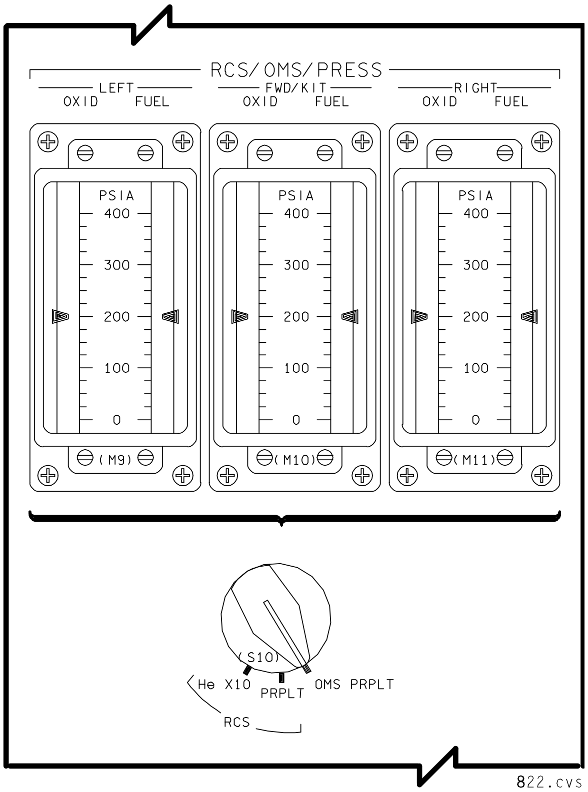
NOTE

SM alerts occur at:

	High	Low	If FC Output is:
(1)	212° F	180° F	Less than 3.5 kW
(2)	222° F	190° F	3.5 - 7.5 kW
(3)	238° F	198° F	More than 7.5 kW

Panel O3 Meters

RCS/OMS PRESS LEFT/FWD/ RIGHT OXID, FUEL Meter



RCS/OMS PRESS LEFT/FWD/RIGHT OXID, FUEL Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
235 — 255 psia (green)	Normal operating range
312 psia (red)	High limit (Class 2 C/W)
200 psia (red)	Low limit (Class 2 C/W)

RCS Pressure

RCS oxidizer, fuel, and helium (X10) pressures are displayed for the left, forward, and right systems by way of dual sensors. One sensor sends data via a DSC to the meter and the SPEC 23 RCS display, while the other routes data via a DSC to the GNC SYS SUMM 2 display. RCS pressure limits/normal ranges are marked on the left side of the meters and are identical for oxidizer and fuel.

NOTE

There are no He limits marked on the meters. An SM alert is generated if He pressure reaches 500 psia (low).

OMS Pressure

OMS oxidizer and fuel pressures are displayed for the left and right systems by way of a single sensor in each tank. The sensors send data via a DSC to the meters and the GNC SYS SUMM 2 display. OMS limits/normal ranges are marked on the right side of the meters and are identical for oxidizer and fuel.

METER MARKINGS(S)	MARKING EXPLANATION(S)
245 — 255 psia (green)	Normal operating range
284 psia (red)	High limit (Class 3 C/W; Class 2 and BFS C/W at 288 psia)
232 psia (red)	Low limit (Class 2 hardware C/W; software 234 psia)

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4.2 ENGINE LIMITATIONS

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Orbital Maneuvering System (OMS) Engines 4.2-2
Reaction Control System (RCS) Jets .. 4.2-3

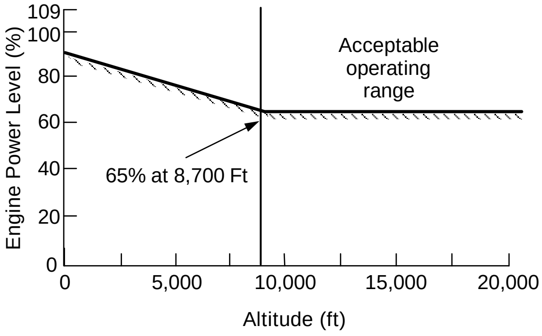
Space Shuttle Main Engines (SSMEs)

Power

The SSMEs are designed to operate from 65 percent Pc to 109 percent Pc above 8,700 MSL. The GPCs can command the engines only within this Pc range. The following chart shows minimum Pc's for altitudes below 20,000 ft. MSL. The engines are limited to 736 seconds of operation in the range of 65 percent to 104 percent Pc.

WARNING

Shuttle MPS in flight performance has not been verified beyond a power level of 104 percent Pc.



Minimum throttle vs. Altitude constraint

Minimum main engine power level (%RPL)	Altitude above sea level (ft)
90.0	0
82.0	2,500
76.0	5,000
68.0	7,500
65.0	≥ 8,700

823.cvs

Pc Chart

SSME Temperature

Mission Control Center (MCC) personnel monitor three critical engine temperatures: high pressure fuel turbopump (HPFT) high temperature, high pressure oxidizer turbopump (HPOT) high temperature, and HPOT low temperature. Temperatures exceeding any of their limits will result in a main engine shutdown, unless the crew has manually inhibited the shutdown limits via the MAIN ENGINE LIMIT SHUTDN switch. The red Main Engine STATUS light will illuminate, regardless of the position of the switch, if any one of these limits is exceeded. The crew has insight into the GO2 OUT T (outlet temperature), which is found on BFS GNC SYS SUMM 1. This temperature varies directly with engine power levels and can be used by the crew to determine if the engine is failed. An SM alert is annunciated when this value drops below 125°.

Propellant Pressure

MCC personnel monitor two critical pressures that are not available on crew displays: HPOT intermediate seal purge pressure-low and main combustion chamber pressure-low. Pressures exceeding any of their limits will result in a main engine shutdown, unless the crew has manually inhibited the shutdown limits; the red ME STATUS light will illuminate regardless of the position of the switch. In addition to the main propulsion system (MPS) manifold LH2 and LO2 pressure limits indicated on the ENG MANF meter (MEDS OMS/MPS display), an SM alert will sound if MPS ULL P (ullage pressure), on BFS GNC SYS SUMM 1, for LH2 or LO2 reaches the indicated maximums/minimums: LH2 34.0 psi/28.0 psi, LO2 29 psi/0 psi. The crew has insight into the GH2 OUT P (outlet pressure), which is found on BFS GNC SYS SUMM 1. This pressure varies directly with the engine power level and can be used by the crew to determine if the engine is failed. An SM alert is annunciated when this value drops below 1050 psi.

Engine Nozzle Position

The MPS nozzles have sufficient dynamic envelope such that they can collide with one another, OMS engine nozzles or pods (upper SSME), or the body flap (lower SSMEs). The crew cannot monitor this envelope. Post MECO, the GPCs will position the nozzles to prevent interference and control entry heating on the lower engine nozzles. SODB Vol 1, section 3, and The Shuttle Performance Analysis Databook (SPAD), Chapter 6, graphically depict the nozzle envelopes.

MPS He Pressure

The first indication of a He leak will be an SM alert annunciated when the He dp/dt exceeds 20 psi for three BFS cycles. The He dp/dt, along with other MPS He pressures, is available on BFS SYS SUMM 1 (He dp/dt is only available in OPS 1). In addition, MPS He TK P (tank pressures) and REG P. A (regulator A pressures) are also available on the MEDS OMS/MPS display.

C&W for Main Engine He Pressure

ME He Tanks low — 1150
Regs low — 679
Regs high — 810
Pneu He tank low — 3800
Accum low — 700

SSME AC Power

SSME controller operation requires that all three ac phases and voltages must not fall below 100 volts RMS (root mean square) for longer than 500 msec. Should this happen, channel switchover (A to B) or engine shutdown will occur.

Engine Electric Lockup

An electric lockup will occur if the main engine controller loses both channels of Pc or fuel flow meter data. This will cause the controller to maintain the last commanded throttle position. The crew will see the corresponding amber MAIN ENGINE STATUS light illuminate and an MPS ELEC (L,R,C) message.

Engine Hydraulic Lockup

The engine design specifications state that the engine must operate if hydraulic pressure is greater than 1500 psia and that it must go into hydraulic lockup below 1100 psia. The loss of hydraulic pressure (any pressure below 1500 psia) will initially send the engine valves into "soft lockup." Soft lockup implies that none of the five engine valves has failed their channel A and B actuator position checks. If no new throttle commands are being executed, it may take up to 1 minute for the valves to fail their actuator checks. If hydraulic pressure is recovered prior to failure of the position checks, the engine can come out of soft lockup and normal engine operation can resume. A "hard hydraulic lockup" will occur when any of the five engine valves fail their channel A and B actuator position checks. The controller software will then command all the valves to their last commanded position before the lockup occurred. The crew will see the corresponding amber MAIN ENGINE STATUS light illuminate and an MPS HYD (L,C,R) message.

Orbital Maneuvering System (OMS) Engines

Engine Chamber Pressure

There is no maximum Pc for the OMS engines due to the stoichiometry of the fuel/oxidizer mixture. Except during ullage blowdown, the OMS Pc should never fall below 80 percent. Operation with low Pc may cause engine damage or combustion instability.

Engine Operations

The engines are not rated for use below 70K feet due to exhaust flow separation and damage to the nozzles. With normal engine shutdown purge the following limitations apply: (1) engine firings of less than 2 seconds are prohibited due to possible propellant freezing or hard starts; (2) the minimum engine off-time between firings is 240 seconds for normal operations and 30 seconds for launch abort operations (15-second minimum burn) due to possible propellant freezing or hard starts. Without normal engine shutdown purge, the off-time increases to 10 minutes (for burns more than 10 seconds).

CAUTION

OMS engines must never be interconnected to use RCS propellant during OMS burns due to the smaller volume of the RCS tanks and the large propellant flow required by the OMS engines. RCS propellant tank damage will result.

Engine Temperature

The only OMS temperature monitored is the fuel injector temperature. This temperature is used to assess engine burn stability.

A fault message will be generated if the fuel injector temperature in either OMS pod exceeds 260° F (indicative of low or high fuel inlet pressure).

Engine Propellant

If the OMS propellant quantity is less than 11 percent, an RCS settling burn should be accomplished prior to OMS ignition. OMS propellant quantity should be less than 22 percent to remain within the structural limit for landing.

Engine Nozzle Position

If a nozzle moves more than 0.7° from its stowed position, a fault message will be generated to the ground and crew. If MCC is satisfied that it has moved more than 1.5° inboard or up during the maximum q-bar regime of ascent, the OMS engine will not be fired.

Engine N2 Pressure

The minimum nitrogen pressure for starting an OMS engine is 299 psi (254 psi for contingencies though abnormal start could occur). The maximum number of starts that can be supported with the N2 system is 17.

Reaction Control System (RCS) Jets

Jet Operations

The maximum nominal firing duration for forward and aft primary jets is 150 seconds, or 300 (-X forward RCS) and 800 (+X aft RCS) seconds for contingencies. Verniers are limited to 275 seconds in any 24-hour period. The GPC's will limit the number of simultaneous jet firings. The limit varies from 4 to 7 jets per pod, depending on propellant quantity, flight phase (mated coast, ET Sep, dump, etc.), and abort mode (norm, RTLS, TAL, etc.). A nominal ET separation requires the use of RCS from all three pods. On entry, the aft RCS roll jets are deactivated at a q-bar of 10 psf, the pitch jets at q-bar of 40 psf, and the yaw jets at Mach 1.

ET SEPARATION RCS REQUIREMENTS

Jet Group	Minimum Requirements	
	Nominal	RTLS
FWD down	1	3
AFT left	1	3
AFT right	1	3
AFT up	1/side	2/side
AFT down	1/side	2/side
FWD yaw	—	1/side

ET Separation Chart

Jet Propellant

The propellant tanks are not usable if pressure is less than 185 psi. During ascent and orbit (also entry when g-load is low) the maximum allowable pressure differential between tanks prior to initiating a crossfeed is 80 psi. When acceleration is between 0 and 1.5 g's, the maximum differential is 55 psi. The maximum acceleration for initiating a crossfeed is 1.5 g. A minimum of 1175 lb , or 53 percent total aft RCS, is required for entry with a c.g. ≤1095 in. For c.g. >1095, 1375 lb, or 62 percent total ARCS, is redlined.

RCS He Tank Pressure

The He tanks are considered lost if pressure is less than 456 psi.

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4.3 AIRSPEED LIMITATIONS

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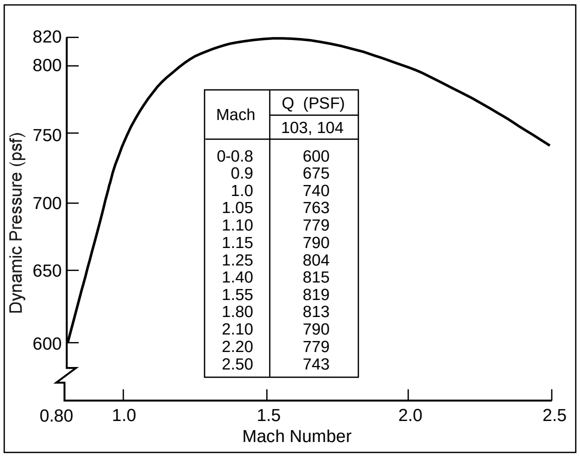
Entry 4.3-1
Landing... 4.3-2

Ascent

The maximum airspeed (based on the q-bar limit of 819 psf) for the shuttle fleet is 492 knots equivalent airspeed (KEAS) where KEAS = $\sqrt{q - \text{bar}}$ x 17.18 (see figure below). These limits are based on thermal protection system (TPS) constraints. Flight design planning for each mission keeps the vehicle's airspeed (via q-bar) below about 475 KEAS.

There is no official minimum airspeed for ascent.



Mach	Q (PSF)
	103, 104
0-0.8	600
0.9	675
1.0	740
1.05	763
1.10	779
1.15	790
1.25	804
1.40	815
1.55	819
1.80	813
2.10	790
2.20	779
2.50	743

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Source: NSTS 08934, SODB, Vol. I

Dynamic Pressure vs. Mach Number

Entry

The maximum certified airspeed during entry is also a function of q-bar, which varies during the descent profile. It reaches a maximum value at 350 psf or 321 KEAS. This protects for the actual limit of 333 KEAS by accounting for air data system and gauge tolerances. If the maximum flight control limit is exceeded, it is possible for the orbiter to go unstable in roll/yaw. For contingency aborts, the maximum airspeed limit is 486 KEAS. This is the ultimate limit for both flight control and the orbiter structure.

The minimum guidance and control airspeed for Mach less than 5.0 is 163 KEAS. The minimum practical airspeed below Mach 2.5 is based on not flying on the back side of the L/D curve. Although control is acceptable on the back side of the L/D curve, there is no reason to fly in this region. The only reason to fly slow is to stretch to the runway if low energy, and flying on the back side is not optimum for stretching. Minimum airspeed (max L/D), which is a function of weight and Mach, is about 190 to 220 KEAS. The minimum airspeed is available on the bottom line of the VERT SIT display; however, a better technique is to monitor maximum L/D alpha (diamond on the alpha tape).

CAUTION

On a TAL, the VERT SIT may give the lightweight minimum airspeed when the TAL weight is heavy. This is because there is only one set of OPS 3 VERT SITs and flight software is always set to the EOM weight.

TAEM guidance will limit minimum airspeed. Unlike maximum airspeed, the gains for minimum airspeed are not set so low that the minimum airspeed will never be reached. TAEM guidance will very effectively fly maximum L/D if it needs to stretch to reach a runway.

WARNING

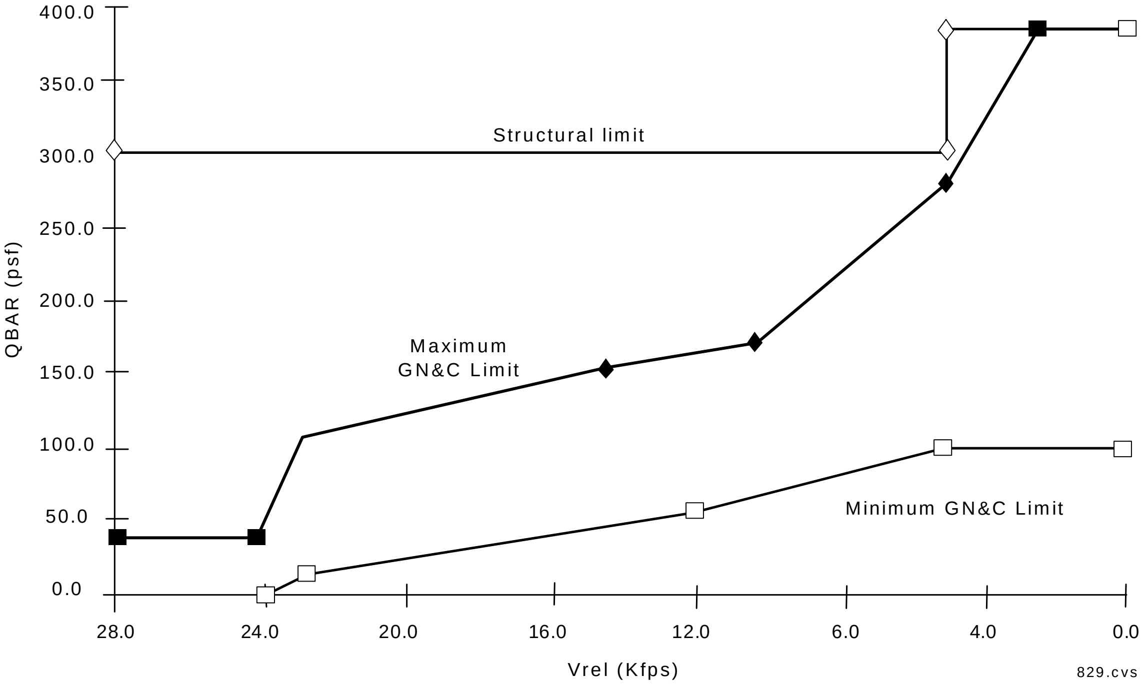
TAEM guidance must have air data to perform airspeed limiting. If air data is not incorporated to TAEM (G&C on SPEC 50), the crew must fly pitch attitude limits (theta limits) to avoid violating airspeed limits. See section 7.4 for more details.

Minimum airspeed is further limited by an uncontrollable pitch-up divergence. This pitch-up divergence always occurs at a slower speed than maximum L/D; however, at Mach 1.5 the limit is close to maximum L/D. The airspeed pitch-up divergence is not available onboard. Alpha must be monitored to avoid a pitch-up divergence. See section 4.4.

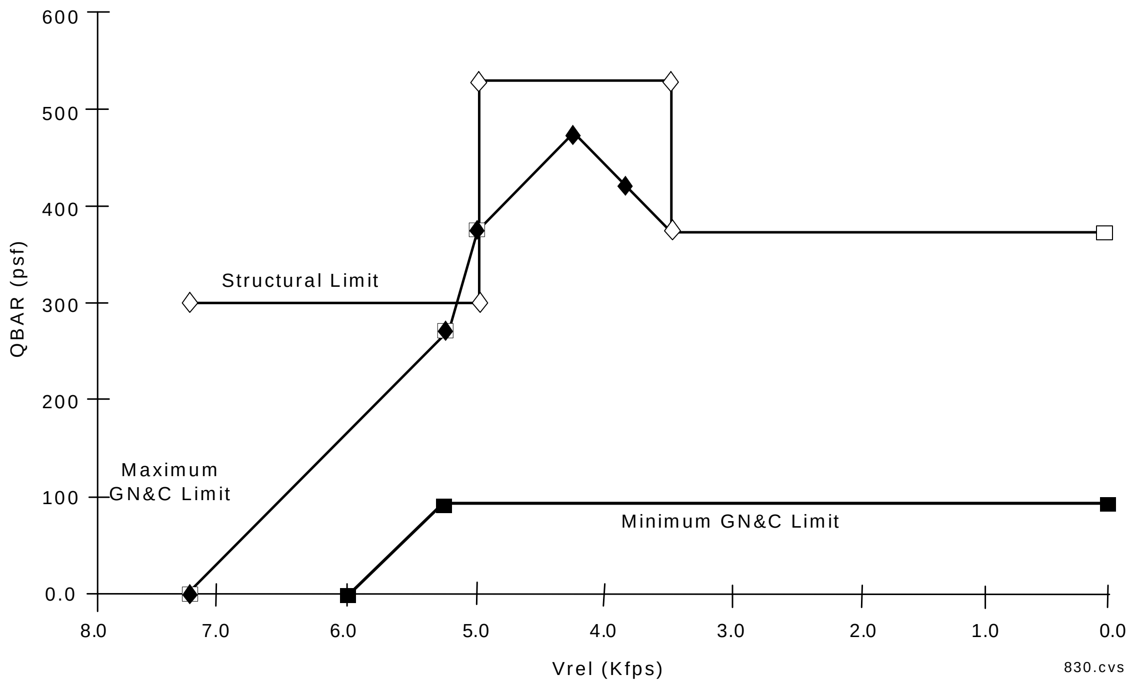
Landing

Maximum airspeed for lowering the gear is 312 KEAS, based on landing gear structural limits.

Maximum speed at landing is based on the 225 knots ground speed (KGS) certified tire speed limit. To protect against this tire limit, the maximum predicted ground speed at the T/D evaluation velocity should not exceed 214 kt. Short field speed brake may be used to achieve the 11 kt pad. This pad was based on errors in the air data system, changing winds, and landing dispersions. Full 3 sigma protection does not always exist for this limit, nor does it exist for the minimum airspeed associated with the tailscrape.



Entry Dynamic Pressure Envelope



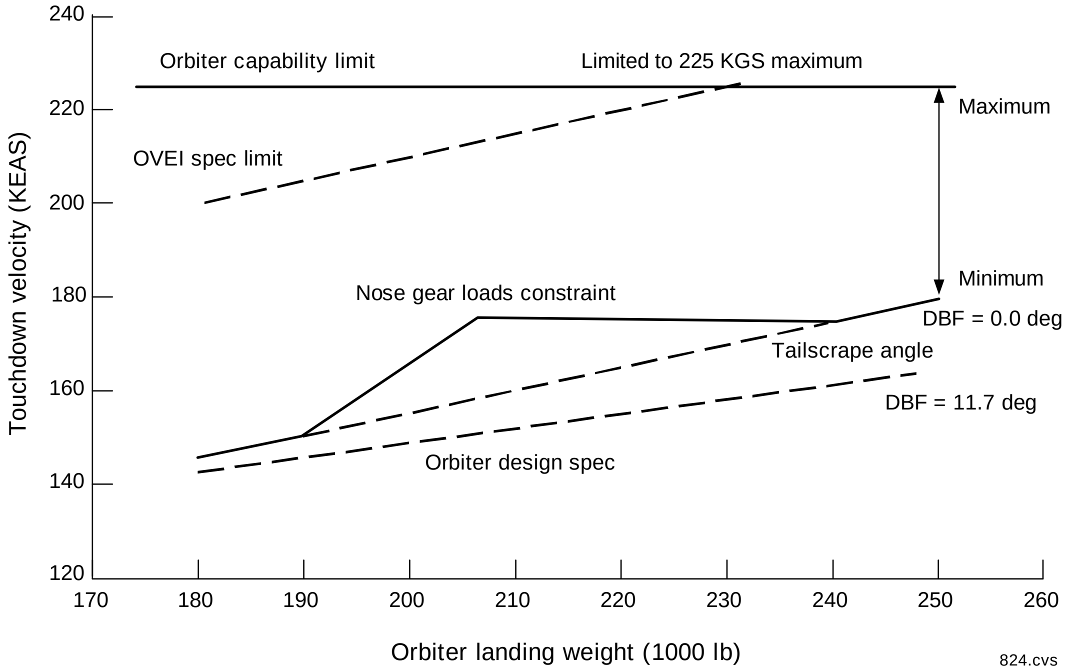
RTLS Dynamic Pressure Envelope

Minimum airspeed at touchdown is limited by body flap scrape. This limit is protected by not landing slower than the targeted landing speed. For minimum airspeed, flight design protects for the crew landing 10 knots slow. The term "energy reserve" is often used to indicate the amount of time that the crew can delay touchdown and not scrape the body flap. See orbit landing speed restrictions chart.

Derotation speed is limited by main gear loading for maximum speed and nose gear loading for minimum airspeed. The current technique is to derotate at 185 KGS using the beep trim on the RHC. Beep trim derotation may be delayed to no slower than 165 KEAS.

Maximum airspeed for drag chute deploy is 230 KEAS. Above this velocity, the drag chute shear pin will fail. This protects the orbiter from an inadvertent deploy on final. Minimum deploy speed is 80 KEAS.

Nominal drag chute jettison speed is 60 KGS; however, the drag chute must be jettisoned by 40 KGS to protect the main engine nozzle. If ground speed goes below 40 knots, the drag chute should not be jettisoned



OVEI = Orbiter vehicle end item.

Orbiter Landing Speed Restrictions

4.4 ANGLE OF ATTACK LIMITATIONS

CONTENTS

Entry 4.4-1

Entry

The maximum alpha for the orbiter during entry is designed to protect the TPS, maintain control in the three axes, meet structural requirements during venting, ensure aerosurface hinge moments remain within limits, and keep the orbiter within guidance limits. Consequently, the alpha limits may be well below the maximum/minimum usable alphas.

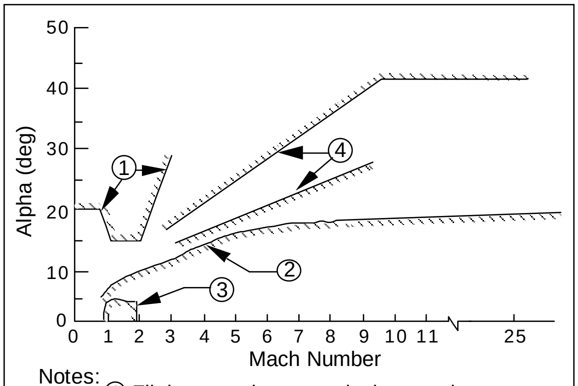
The maximum L/D alphas for various Mach numbers are:

Mach	Max L/D α
3	17
2	15
1	12
Subsonic	10.5

The MEDS alpha tape displays the maximum L/D alpha as a magenta and black diamond for Mach ≤3.0. The tape also displays a green band denoting the maximum/minimum alpha range for Mach 2.5.

The Mach 1, 2, and 3 values are listed on the Entry Alpha cue card. The subsonic value is not listed in the FDF.

The following tables from Flight Rule A4-207, Entry Limits, list the normal angle of attack limits for the orbiter during entry.



Notes:
① Flight control system design requirement
② Cn_β dynamic
③ Venting, hinge moment
④ Guidance requirement

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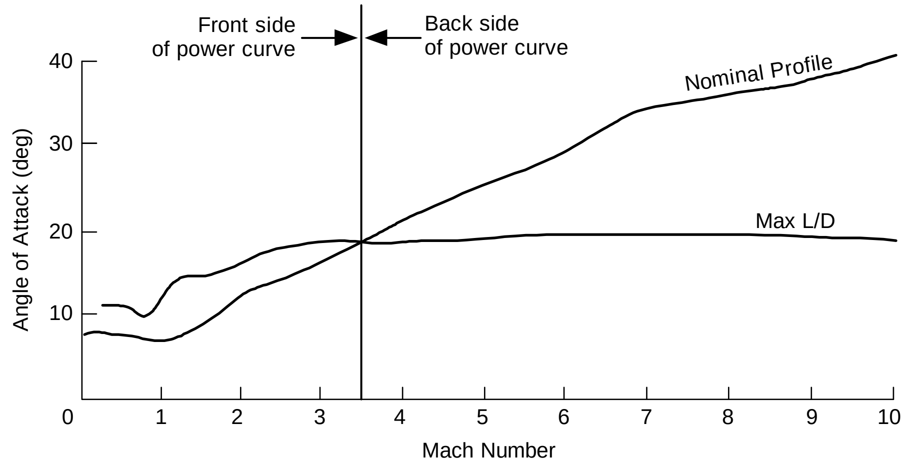
Orbiter Design Angle of Attack Limits



- Orbiter flies back side of power curve (increasing alpha implies increasing L/D) at Mach > 3.5
- Orbiter flies front side of power curve at Mach < 3.5
- Thermal or q-bar constraints prevent flying max L/D alphas until Mach 3

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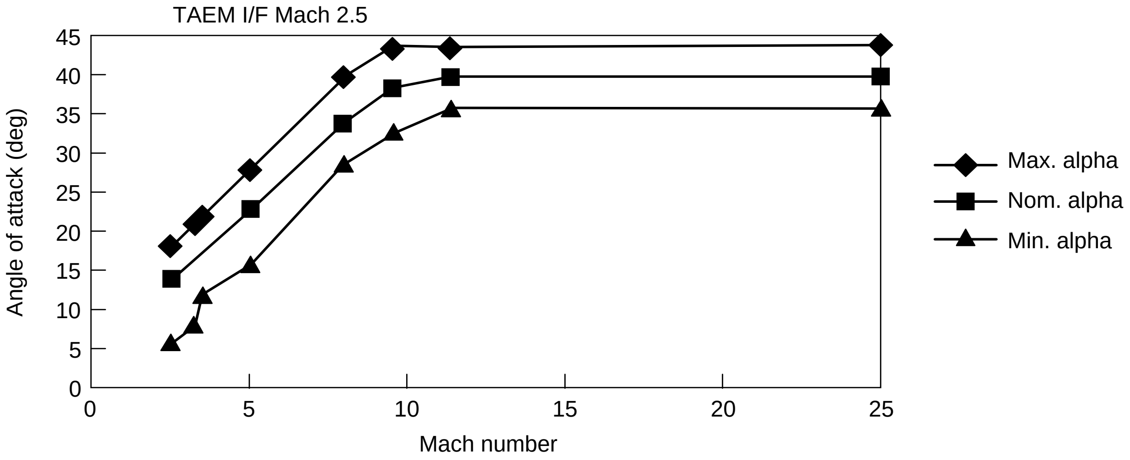
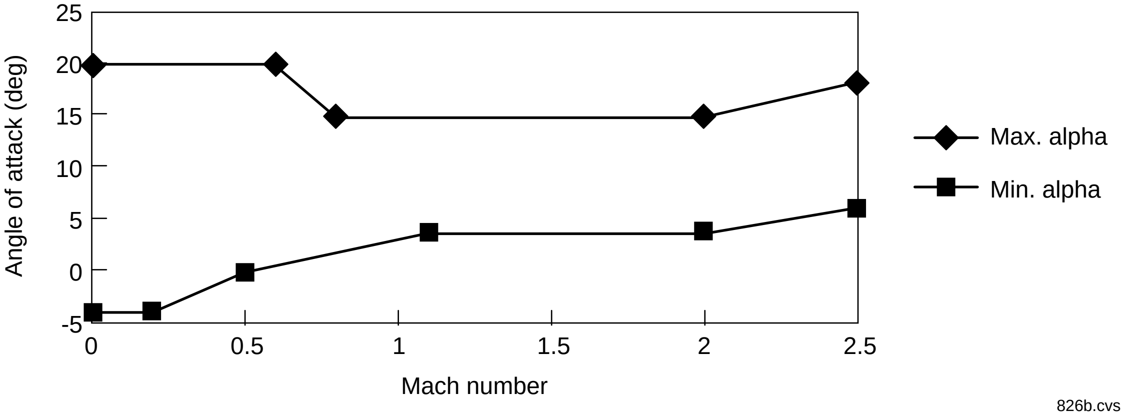
Orbiter Nominal Angle of Attack Profile



Angle of Attack Boundaries - MM 304 Only



Angle of Attack Boundaries - MM 305 Only

Mach	Max Alpha	Min Alpha		Mach	Max Alpha	Min Alpha
2.5	18.0	6.0		0.0	20.0	-4.0
3.2	20.8	8.2		0.2		-4.0
3.5	22.0	12.0		0.		0.0
5.0	28.0	16.0		0.6	20.0	
8.0	40.0	28.9		0.8	15.0	
9.6	44.0	33.0		1.1		4.0
11.4	44.0	36.0		2.0	15.0	4.0
25.0	44.0	36.0		2.5	18.0	6.0

4.5 SIDESLIP LIMITATIONS

Numerous sideslip, β, limitations for the various ascent flight phases (SRB separation, ET separation, aborts, etc.) are available in the Shuttle Performance Assessment Databook (SPAD). During the high dynamic pressure phase of the ascent, the maximum sideslip angle is also a function of angle of attack. Typically, the maximum β allowable ranges from ±3° to ±6°.

During entry, the maximum sideslip angle is ±5°. Also during entry ($2 <$ Mach <12), the crew, by using the Roll Trim switch, will manually trim to reduce RCS jet firings if steady state sideslip exceeds 2°, one or more yaw jets fire continuously, or if scaled Ay (sensed lateral acceleration) exceeds the two-jet capability.

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4.6 LANDING WEIGHT LIMITATIONS

CONTENTS

Maximum Landing Weight 4.6-1

Maximum Landing Weight

Landing weight limits are reduced for higher inclination flights because of orbiter thermal restrictions. Any flight with a manifest that results in an intact abort or end of mission (EOM) landing weight greater than the certified limits must have a waiver specifying the limit for that flight. Approval of the waiver will be based on a case-by-case thermal analysis of the entry trajectory.

The following table lists orbiter maximum landing weights for ascent aborts and EOM.

	Inclination			
Flight Phase	28.5°	39.0°	51.6°	57.0°
RTLS	248k lb	248k lb	245k lb	242k lb
TAL	248k lb	248k lb	244k lb	241k lb
AOA/ATO	248k lb	248k lb	242k lb	239k lb
EOM	233k lb	233k lb	233k lb	233k lb

Source: NSTS 07700, Vol. X, Book 1

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4.7 DESCENT RATE LIMITATIONS

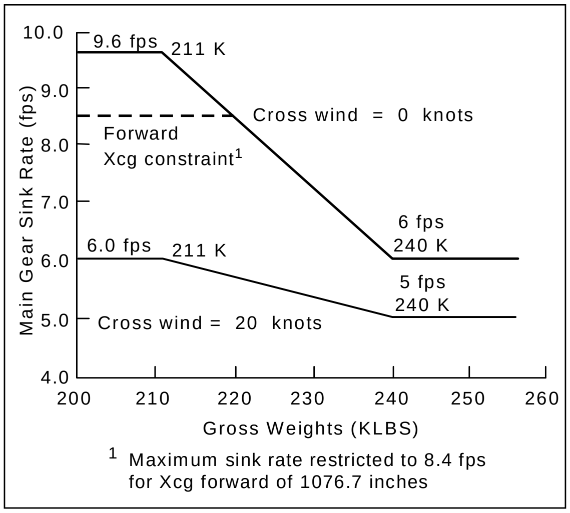
CONTENTS

Main Gear Touchdown 4.7-1
Nose Gear Touchdown........................ 4.7-1

Main Gear Touchdown

The orbiter was designed to withstand the loads developed from landing at the maximum sink rates shown in the following figure. The maximum allowable sink rate is a function of orbiter gross landing weight and crosswind. Crosswinds reduce the allowable sink rate.

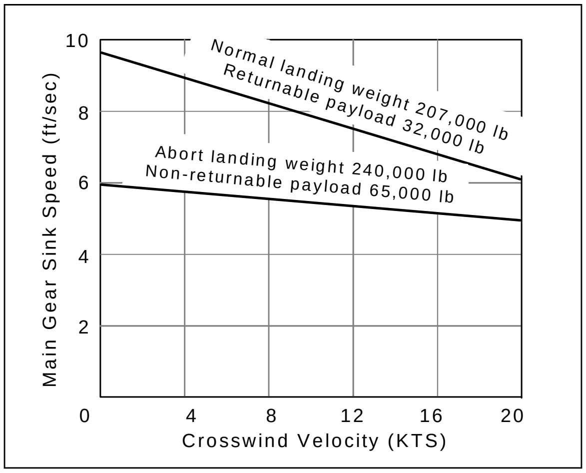
The type of payload returned in the payload bay also establishes the maximum allowable sink rate at main gear touchdown. The second graph shows the limit for crosswind and sink speed for the main gear for returnable and non-returnable payloads.



[1] Maximum sink rate restricted to 8.4 fps for Xcg forward of 1076.7 inches

Source: NSTS 08934, SODB, Vol. V

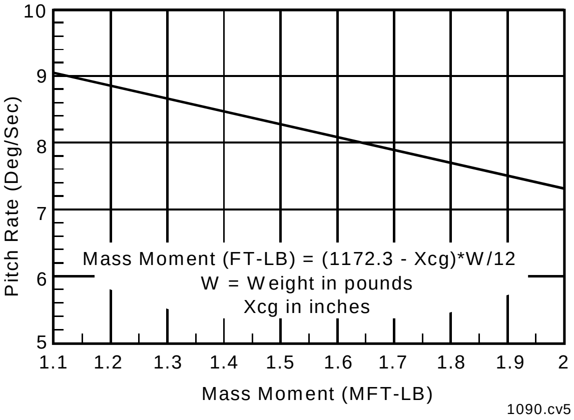
Main Gear Sink Rate



Landing Sink Rate vs. Crosswind Velocity

Nose Gear Touchdown

The maximum rate of descent at nose gear touchdown must not exceed 11.5 fps (9.9° per second) or the rate needed to prevent nose gear vertical loads in excess of 90,000 lb. (Operational rates of descent average 5 fps.)



Nose Gear Slapdown Pitch Rate Limit

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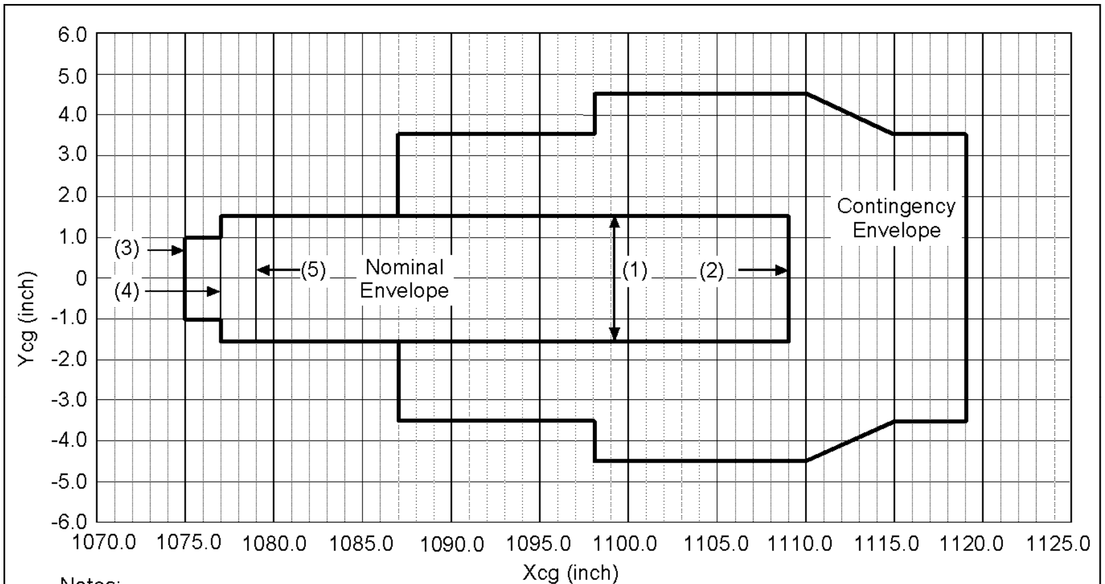
4.8 CENTER OF GRAVITY LIMITATIONS

The orbiter X and Y c.g. limits are shown in the following figure. Mission planning for abort propellant dumps will ensure an adequate c.g. margin for intact aborts. Real-time mission management of orbiter consumables; i.e., cryo, propellant, water, will ensure the EOM c.g. is within limits. This is most easily accomplished via the forward RCS propellant dump and OMS propellant wasting during the deorbit burn.

The Z axis c.g. must be within the limits of 360.0 to 384.0 inches at entry interface (approximately 400,000 ft).



Notes:
(1) Verified aero boundary.
(2) Design envelope aft limit.
(3) Forward limit for EOM, ATO, and AOA (X = 1075.2 inches).
(4) Forward limit for GRTLS for angle of attack <30° and for TAL (X=1076.7 inches).
(5) Forward limit for GRTLS for angle of attack >30° (X = 1079.0 inches).
(6) Nominal cg envelope reflects a 1-inch uncertainty for Xcg and a 0.5-inch uncertainty for Ycg ® [091098-6715].

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Source: Flight Rule A4.1.4-3

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4.9 ACCELERATION LIMITATIONS

CONTENTS

Ascent 4.9-1
Entry 4.9-1
Vn Diagrams 4.9-1

Ascent

The orbiter is constrained to the following translational accelerations during ascent.

Nx =	+3.11 g/-0.00 g
Ny =	+0.18 g/-0.18 g
Nz =	+0.73 g/-0.06 g

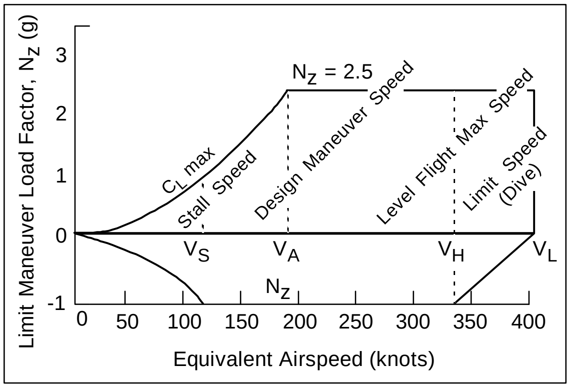
Entry

For orbiter Mach numbers less than 5.0 and weights less than, or equal to 211,000 lb, the maximum symmetrical Nz is 2.5 g. The following graph shows the allowable Nz for various gross weights. The negative acceleration limit is -1.0 g for Mach numbers less than 3.0 and is 0.0 g for Mach numbers greater than 3.0.

For rolling maneuvers, the maximum normal load factor is reduced by approximately 1 percent for every degree per second of roll rate, down to a maximum of Nz of 80 percent of the symmetrical load limit at 20 deg/sec roll rate. For example, at 5 deg/sec roll rate, the Nz maximum is 95 percent of the symmetrical load limit.

Vn Diagrams

The following Vn diagram demonstrates the acceleration limits in the TAEM region of entry.



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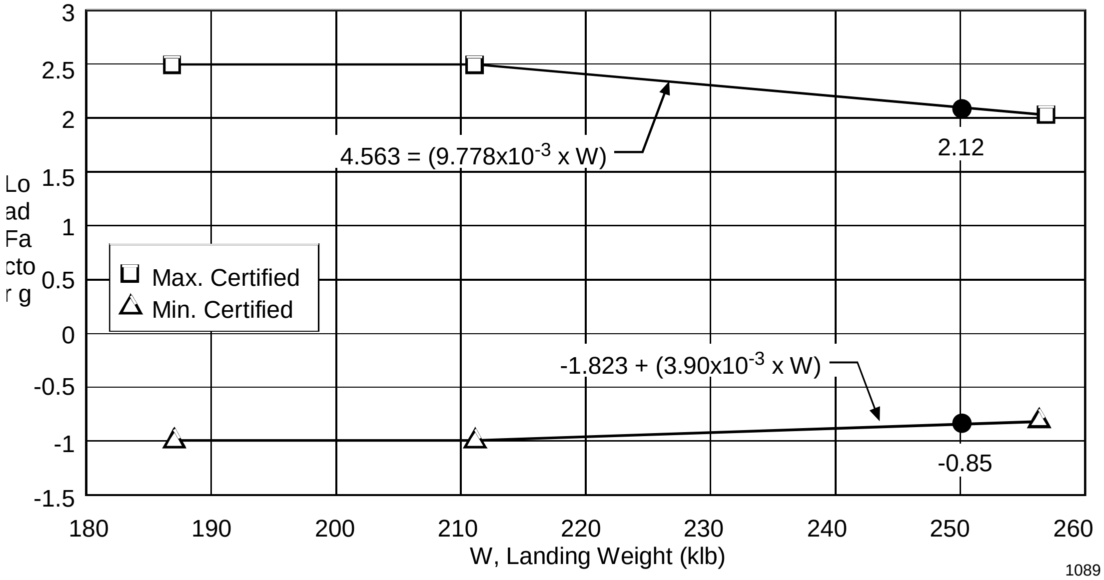

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Orbiter Operational Maneuver Limits

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4.10 WEATHER LIMITATIONS

Weather limitations for launch, abort landing, and end of mission landing are presented below (Ref. FR A2-6).

Ceiling/Visibility (k ft)/(SM)			**Redundant MLS**	**Single-String MLS**	**No MLS**
KSC, EDW, NOR, AOA Daily PLS selection (all sites)	Concrete	Day	≥8/5 (WX recon required)	≥10/7	
		Night		NO-GO	
	Lakebed	Day			≥10/7
		Night		≥15/7	NO-GO
RTLS, TAL	Concrete	Day	≥5/4 RTLS ≥5/5 TAL (WX recon required)	≥10/7	
		Night		NO-GO	
ACLS/ECAL/ELS			0/0		≥8/5
Predeorbit: One APU failed or attempt two APUs procedure			≥10/7		

Ceiling and Visibility Limits

Surface Wind (Knots) and Turbulence		**Cross Peak**	**Head Peak**	**Tail AVG**	**Tail Peak**	**Gust**	**Turb**
RTLS		≤15*	≤25	≤10	≤15	≤10	≤MOD
Day	EOM, TAL, AOA, daily PLS selection	≤15					
Night	EOM, TAL, AOA, daily PLS selection	≤12					
Crosswind DTO		≥10 ≤15					
Nominal drag chute deploy		≤15					
Landing ≥ CDR FD19		≤12					
Predeorbit: One APU failed or attempt two APUs procedure		≤10					≤LGT
ECAL/ELS		≤15	N/A				

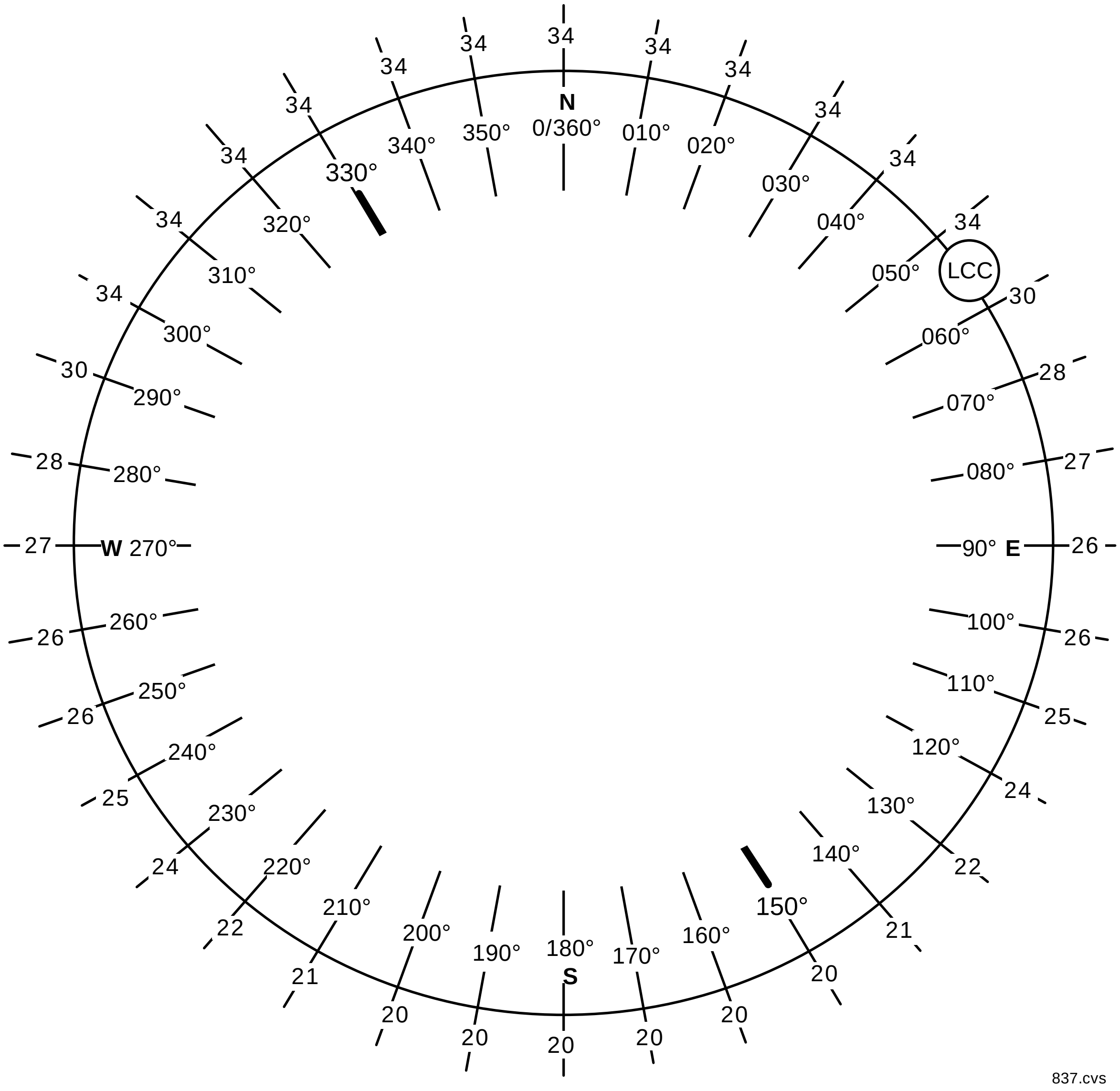
*Requires an STA evaluation to 17 knots and a GO from the STA pilot.

Surface Winds and Turbulence Limits

Thunderstorm, Lightning, and Precipitation Proximity Limits (n. mi.)		**Prelaunch (RTLS, TAL)**	**Predeorbit (EOM Daily PLS) Prelaunch (AOA)**	**Redesig Criteria**	**ELS, ECAL, ACLS**
Tstorm (including attached nontransparent anvils) and lightning	Radial from center of prime runway	>20	>30	>15	None at site
	Lateral along approach path out to 30 n. mi.	>10	>20	>5	
	Vertical from top of cloud	>2			
Detached nontransparent anvil <3 hours old	Radial from center of prime runway	>15	>20	>15	N/A
	Lateral along approach path out to 30 n. mi.	>5	>10	>5	
	Vertical from top of cloud	>2			
Precipitation	Radial from center of prime runway	>20	>30	>15	N/A
	Lateral along approach path out to 30 n. mi.	>10	>20	>5	
	Vertical from top of cloud	>2			
Cumulus clouds produced by smoke/fire up to 1 hour after detaching	Lateral along approach path	>0			N/A

Thunderstorm, Lightning, and Precipitation

Shuttle Launch Wind Limits



Launch Commit Constraint (60-ft winds at the pad)

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5. NORMAL PROCEDURES SUMMARY

CONTENTS

5.1 PRELAUNCH 5.1-1
5.2 ASCENT 5.2-1
5.3 ORBIT.. 5.3-1
5.4 ENTRY 5.4-1
5.5 POSTLANDING 5.5-1

This section summarizes nominal procedures for a generic space shuttle mission. More detailed procedures may be found in the Astronaut Support Personnel Book, the various Flight Procedures Handbooks (FPH), and Flight Data File (FDF) documents. The FPH documents also contain rationales for the various procedures listed herein. For flight-specific training, refer to the applicable FDF checklists/ cue cards.

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5.1 PRELAUNCH

CONTENTS

Prelaunch Procedures.......................... 5.1-1

Prelaunch Procedures

Hr:Min (approx)

L-33:00	Astronaut support personnel (ASP) conduct communications checks with the launch team. Caution and warning (C/W) volumes are adjusted so the air-to-ground communication can be heard over the C/W tone. UHF Guard is checked, and headset interface units (HIUs) are checked for proper operation, along with intercom (ICOM) loops A and B. If the ICOM recorder has been manifested, it is installed and tested.
L-18:30	ASP ensures crew module has been vacuumed and performs ascent switch list configuration.
L-16:30	The backup ASP conducts a check of the middeck and flight deck and installs certain cue cards, flipbooks, and checklists.
L-12:45	The backup ASP adjusts CDR and PLT seats to the full down and aft position and then configures all seats for launch. Rotational hand controllers (RHCs) are adjusted, and SBTCs are set full forward.
L- 8:15	Pad is cleared for tanking.
L-5:35	ASP reports panel *ABORT* light status when initiated by the Flight Director.
L-5:30	ASP Checklist is initiated. Checklist includes communications check, potable/supply water quantity adjustment, LiOH canister installation, air sample, pre-ingress switch reconfiguration, ECLSS Freon coolant loop "payload" heat exchanger flow verification, navigation aids activation, and C/W memory clearing.
L-4:55	Crew wakeup.
L-4:25	Crew breakfast and photo opportunity.
L-3:55	CDR, PLT, MS2 get weather briefing. MS1/3 (PSs) don flight clothing and equipment.
L-3:45	CDR, PLT, MS2 don flight clothing and equipment.
L-3:15	Crew departs for the Pad.
L-2:45	Crew arrives at the White Room; ASP verifies CDR and PLT launch/entry suit (LES)/flight equipment is properly configured before seat ingress, assists with ingress and installation of ascent FDF, monitors CDR/PLT communication air-to-ground checks, assists with post-ingress switch reconfiguration, and coordinates the C/W and intercom volume adjustment; as the MSs ingress, the ASP verifies their LES/flight equipment configuration and assists ingress and communication hook up and checks.
L-1:45	ASP verifies all non-flight equipment is removed from the crew compartment, terminates communication with the Launch Control Center (LCC), and egresses.
L-2:00	After the hatch is closed, a cabin leak check is performed. The cabin is pressurized to 16.7 psi and then vented to ambient when the check is complete over the next 48 minutes.

L-1:22	CDR prepares for the primary avionics software system (PASS)/backup flight system (BFS) transfer. The LCC will perform the transfer via uplink.
L-1:20	CDR places the *OMS ENG* switches to *ARM/PRESS* for GN2 pressurization. The PLT takes the WSB GN2 supply to OPEN to provide N2 pressurization to the WSB.
L-1:15	All crewmembers conduct an A/G voice check with MCC and receive updates to ascent/abort data.
L-1:10	Planned 10-minute launch hold at T-20 min
L-1:00	PASS OPS 1 load is initiated and GNC FAULT is displayed on IDP 1 while C/W is cleared.

Min:Sec (approx)

L-58:30	CDR transitions BFS to OPS 1.
L-57:00	PLT conducts horizontal situation configuration for TAL sites and RTLS to KSC. When this activity is complete, the PLT configures for OMS interconnect with PASS and BFS.
L-56:00	PLT performs the MPS He reconfiguration by opening He and pneumatic isolation valves.
L-49:00	Planned 40-minute launch hold at T-9 min.
L-30:00	A ground-controlled fuel cell purge takes place about this time.
L-25:00	The OMS/RCS crossfeed valves are configured for launch by the Launch Processing System.
L-17:00	PLT clears the F7 C/W lights with the C/W MEM switch on C3.
T-9:00	GO for launch given, and event timers started.
T-8:00	PLT connects essential buses to the fuel cells.
T-7:30	Access arm retracts. Crew makes final checks on seat positions, suit closures, and restraints.
T-6:15	PLT performs APU prestart and verifies three gray “*READY TO START*” talkbacks. IDP 1-3 displays are GNC LAUNCH TRAJ, GNC SYS SUMM 1, AND BFS, SM SYS SUMM 2. IDP 4 typically displays BFS SM SYS SUMM 2.
T-5:00	Pilot starts APUs and verifies normal pressure. CDR turns off flash evaporator feedline heaters.
T-3:25	Main engine nozzles are gimbaled during the next 30 sec. The crew may feel the motion/vibration.
T-2:30	PLT clears the hardware and software.
T-2:00	All crewmembers start O2 flow and close their visors.
T-0:07	Ignition sequence for main engines begins. Crew monitors Pc’s increase.
T-0:03	Crew monitors main engines, which should have Pc’s above 90 percent.

5.2 ASCENT

CONTENTS

Powered Flight 5.2-1
OMS Burns 5.2-3
Post Insertion 5.2-5

Powered Flight

Min:Sec (approx)

T-0:00 SRB ignition, software transitions to MM 102, main engines at ~100 percent Pc, and event timer counts up from zero. Throughout ascent phase, the crew monitors vehicle performance using DPS and dedicated displays intervening as required/directed by MCC. The crew also uses the Flight Instruments, ADI, No-Comm Ascent Abort Mode Boundaries, and Contingency Abort cue cards, to monitor the ascent trajectory and maintain awareness of abort options. Cue cards are used for malfunctions procedures.

Typical displays *used during* ascent are *PASS and BFS* ASCENT TRAJ *1/2, PASS and BFS* GNC SYS SUMM 1. BFS GNC *SYS SUMM 2* and *BFS* SM SYS SUMM 1/2 are used as required.

Mission Elapsed Time (MET)

Min:Sec (approx)

0:01 Ensure that FCS (pitch and roll/yaw) are still in Auto. If not, select Auto. Otherwise BFS Engage may be required for roll program at 0:07.

0:04 If 104 percent is programmed for launch, at a velocity of 60 fps, the main engines are commanded to that level.

0:07 At a velocity ≥127 fps, the vehicle rolls, yaws, and pitches to the heads-down ascent attitude. Crew monitors and engages the BFS if maneuver not begun when required or not properly completed. CDR/PLT select LVLH on ADI ATTITUDE switch.

0:20 or 0:30 (flight specific) Crew monitors main engines' throttling down to limit maximum flight dynamic pressure and to adjust for off-nominal performance. Throttle level can vary, depending on flight design and SRB performance.

1:00 Crew monitors main engines throttling back up to ~104 percent. Manual throttle may be selected if required.

1:30 Maximum q-bar phase is passed. Control stick steering (CSS) may now be selected in lieu of BFS Engage if PASS guidance is not nominal.

2:00 ASCENT TRAJ display will indicate PC <50 when both SRB Pc's drop below 50 psi. SRB separation should occur shortly thereafter (no later than MET 2:20). *During SRB separation*, *all three upfiring jets in the forward RCS fire to protect the cockpit windows from SRB debris (Forward Window Protect).* When the SRBs are separated, GNC changes to MM 103. BFS commands flash evaporator system (FES) on via payload buses.

Post-SRB separation, the crew checks that PASS and BFS TMECOs converge to expected values to verify performance of Ascent Guidance.

OMS Assist

MM 103 transition + 10 seconds	An OMS assist burn during nominal ascent may be manifested on some performance-critical missions. A 4000-lb OMS assist burn takes about 1:42 to complete and provides a 250-lb performance gain. For OMS assist flights, SPEC 51 will display the manual dump quantity and timer until the OMS assist initiates. Then, the OMS assist information will be displayed. For a 4000-lb OMS assist, SPEC 51 will display 15% for the Item 9 quantity and 1:42 for the initial dump time to go (*OMS DUMP T*TG). The crew should verify the OMS assist by monitoring the OMS Pc *on the OMS/MPS display* and OMS quantity. When the OMS assist completes, *T*TG should display 0. For OMS assist missions, if an ATO abort is selected pre-MECO, the Item 9 quantity will reflect the calculated ATO abort dump quantity plus the OMS assist quantity. However, *T*TG will reflect any amount of OMS assist completed. In other words, if the OMS assist completed, *T*TG would only reflect the ATO dump because the dump time during the OMS assist has already been decremented.
3:00	Crew verifies the flash evaporator is working properly (T < 60° F and decreasing on EVAP OUT T overhead meter).
Roll to Heads Up (RTHU)	28.5° inclination RTHU at VI = 13.6 K (Vrel 12,200 fps) 39.0° inclination RTHU at VI = 13.4 K (Vrel 12,200 fps) 51.6° inclination RTHU at VI = 13.2 K (Vrel 12,200 fps) K (Vrel 12,200 fps) Beginning with STS-87, an RTHU is performed during nominal ascent to allow an early handup from MILA to TDRS east in anticipation that the Bermuda ground station will close. The I-loaded RTHU relative velocity of 12,200 fps is converted to inertial velocity for use in the checklist because this is the cue card available onboard. The roll maneuver is performed at 5 deg/sec and is accompanied by a pitch attitude change of 20° to 30° as the vehicle rolls about the X-body axis, changing the thrust vector direction.
7:30	S-band PM communications is reconfigured from STDN-HI to TDRS mode via a stored program command in the BFS GPC.
~8:*25*	Main engine cutoff (MECO) occurs. Crew cues are that the main engine Pc *on the OMS/MPS display* drop to zero, the MAIN ENGINE STATUS lights illuminate red, and the cutoff bug on the *PASS and* BFS ASCENT TRAJ 2 indicates MECO velocity. MECO time may vary, depending on flight profile, but should match simulation time.

Post MECO The MECO velocity should be approximately 25,820 fps. The crew verifies ORBITAL DAP lights illuminated, indicating MECO confirmed. The crew also verifies external tank (ET) separation (MAIN ENGINE STATUS lights extinguish). If ET separation is inhibited, the crew must null rate(s) (if >0.7°/sec). If rates are null and the ET SEP inhibit remains, the crew must assume a feedline disconnect failure. The ascent checklist will cleanly direct this operation. Meanwhile, a -Z translation occurs and GNC transitions to MM 104 at completion of this -Z translation. At MM 104 plus 2 seconds (if a prescribed HA has been achieved), the crew will translate in the plus X direction for a prescribed length of time to assist external tank photography.

Once in MM 104, the crew refers to the Ascent Pocket Checklist for malfunction procedures. The crew verifies OMS 1/2 targeting, using current orbit HA and HP displayed on GNC OMS 1 MNVR EXEC, to determine if an OMS 1 burn is required.

For a nominal MECO (OMS 1 not required), the crew proceeds to the POST OMS 1 tab in the Ascent Pocket Checklist. From there, FDF assists the crew in stepping through procedures required during the transition from powered flight to the OMS 2 Burn. Required steps during this timeframe include the ET PHOTO MANEUVER and powered flight systems management steps, all of which are orchestrated in the Ascent Pocket Checklist.

OMS Burns

SI OMS 1 targets appear on GNC OMS 1 MNVR EXEC displays. The burn is executed for SI OMS 1 and available for DI OMS 1 if required due to a large underspeed. The OMS 1 Burn cue card and the OMS 1 Burn Monitor cue card are referenced for normal OMS 1 burn procedures and malfunctions that occur during the burn.

Crew selects *INRTL* on *ADI ATTITUDE* switch and begins the automatic maneuver to burn attitude if OMS 1 burn is required. When in the proper attitude, the error needles should be centered and ADI inertial attitude should match burn attitude on the MNVR display. VGOs should be crosschecked for proper burn attitude and guidance.

MECO

Min:Sec (approx)

+1:45 EXEC key must be pressed on CDR/PLT keyboard within 15 sec of OMS TIG to enable burn.

IDP 1 in GNC OMS 1 MNVR EXEC, IDP 2 in SYS SUMM 1, and IDP 3 BFS, GNC SYS SUMM 2.

+2:00 OMS 1 ignition. Crew monitors burn (OMS Pc ~100 percent, engine control valves ~100 percent, He pressure decreasing slowly, engine inlet pressure drops to ~200 psi, OMS quantity decreases ~15 sec after ignition, delta VTOT decrementing nominally) and prepares to respond in case of an off-nominal burn; burn duration ~2:30. Two seconds after end of burn, the CDR places the *OMS ENG* switches to *OFF* and trims out any delta V residuals in the X and Z directions using the THC.

If DI (or if OMS 1 is MECO +6 min or more), the MPS propellant dump is automatically initiated at MECO +2 min.

DI or SI Post OMS 1 The crew performs the tasks in the Post OMS 1 procedures section of the Ascent Checklist. CDR and

PLT turn *FLT CNTLR POWER* switches (2) *OFF* to prevent inadvertent inputs to the RHCs (which can initiate manual DAP).

NOTE

Taking *FLT CNTLR POWER* switches to *ON* or *OFF* may cause the DAP to downmode from Auto to Manual. Power surges in the system can be confused with an RHC input, causing the DAP to downmode.

MET

Min:Sec (approx)

12:55 PLT verifies the *BODY FLAP* pushbutton light is out (light extinguishes at the end of a timer). During that time, the MPS dump should have completed (~2:00 duration). *The hydraulic MPS/TVC isolation valves are closed, and* APU shutdown is then performed after checking with MCC.

CDR takes the FES Primary Controller to ON from the GPC position and reenables the FES feedline heaters prior to the OPS 2 transition and securing BFS. PLT takes the cryo O2 tank 1 and 2 B heaters to AUTO.

MS1 takes the APU tank, fuel line, and H2O line heaters to "A" auto for freeze protection.

PLT sets the *AC BUS SNSR* switches to the *AUTO TRIP* position. They were in MONITOR during ascent to prevent SSME loss due to inadvertent bus trip.

CDR/PLT modes GPCs to MM 105 for the OMS 2 burn.

CDR/PLT loads OMS 2 targets as required and OMS gimbal trim data (OMS 1 trim remains until changed. Gimbals do not move until 15 sec before burn); OMS targets verified (PASS and BFS).

PLT secures MPS engine power and performs GH2 inerting.

PLT closes the ET umbilical doors.

CAUTION

ET centerline latches must be stowed prior to door closure to prevent door drive mechanism damage. *GH2 inerting must be done prior to ET umbilical closure because the GH2 is vented into the ET door cavity.*

PLT prepares OMS for the burn by verifying proper valve configurations.

CDR, PLT set *ADI ATTITUDE* to *INRTL* position and maneuver to the burn attitude.

OMS 2 Burn
TIG

Min:Sec (approx)

-5:00 Crew transitions to OMS 2 Burn and Burn Monitor cue cards for procedural reference.

CDR, PLT make final verification of burn attitude, engine selection, DAP selection, OMS gimbal trim, He PRESS/VAP ISOL valve positions, and activate their *FLT CNTLR POWER*.

TIG

Min:Sec (approx)

-2:00 CDR/PLT set *OMS ENG* switches to *ARM/PRESS* and verify the engine press valves are open.

-0:15 CDR/PLT initiates EXEC command to perform burn. There is no need for the crew to correct attitude errors prior to OMS 2 ignition because OMS engine thrust vector control (TVC) will fly the vehicle to the proper

	attitude. OMS TVC can be used to take out attitude errors up to the maximum error limit for OMS ignition to occur. (Limit is variable as a function of remaining ΔV and attitude error; however, an attitude error ≥90° guarantees ignition cutoff.)
00:30-00:60 (00:42 nominal for DI)	CDR, PLT monitor OMS 2 burn, Pc's (~100 percent), delta VTOT and time to go (TGO) decreasing, bipropellant valves (100 percent), and perigee increasing. Crew prepares to complete burn with single engine or RCS if failures occur. Burn duration is ~2 min for 160 n. mi. circular orbit (based on nominal ascent).

OMS 2 Cutoff

+2 sec	CDR/PLT secure OMS engines (2 sec delay for purge) and trim all axes residuals <2 fps (<0.2 fps for orbit critical burns).
Post OMS 2	The crew returns to the Ascent Post OMS 2 section of the Ascent Checklist for nominal procedures and the Ascent Pocket Checklist for malfunctions. CDR/PLT secure *FLT CNTLR POWER* and verify the *DAP* is in *AUTO*. CDR performs an OMS TVC gimbal check (secondary then primary checks are conducted to verify operations prior to on-orbit use). PLT reconfigures OMS and RCS valves for on-orbit operations. CDR/PLT change to MM 106. Crew stows ascent related FDF and unstows the Post Insertion Checklist, Orbit Operations Checklist and Pocket Checklist, cue cards, and the orbiter Malfunction Book.

Post Insertion

The Post Insertion Checklist is used for nominal procedures. The Orbit Pocket Checklist and Malfunction Book are references for malfunctions. During post insertion the following activities must be accomplished to prepare for on-orbit operations:

(1) Reconfigure to on-orbit software and GPC configuration.

(2) Activate radiators.

(3) Open payload bay doors.

(4) Doff and stow LES, reconfigure cockpit for orbit operations.

MET Day/Hr:Min (approx)	
0/0:55	CDR/PLT reconfigure the GPCs. Guidance, Navigation, and Control On-orbit software (GNC OPS 2) is loaded into GPCs 1 and 2. Systems management (SM) software is loaded into GPC 4. GNC OPS 2 data are loaded into GPC 3 and "freeze dried" (taken off line to preserve an independent source of data) while GPC 5 retains BFS software but is placed in *HALT*. With SM software loaded, uplink control for S-band and TDRSS is given to the SM computer. Because only three IDPs can be assigned to the PASS, IDP 3 is de-assigned, and IDP 4 (powered up during MS aft flight deck configuration) is assigned to 4. Pulse-code modulation master unit (PCMMU) formats are loaded for on-orbit high and low data rate telemetry. Displays are called up as required, but the crew must be careful to avoid assigning all three IDPs to the same GPC; e.g., do not use all three IDPs for SM. Mission/payload specialists egress seats during this period.

MSs perform the following functions on the middeck:

- Install UV filter on hatch window.
- Repressurize water supply tank A and activate the airlock heaters.
- Unstow and configure headsets and microphones.
- Configure middeck audio distribution unit (ADU) and speaker box.
- Stow ascent FDF in "return to Houston" bags and unstow on-orbit FDF.
- Close appropriate circuit breakers.

These activities may be accomplished piecemeal during the next hour.

0/0:59 An MS begins flight deck configuration to include: open cabin vent and cabin vent isolation cb's (to preclude accidental venting), activate the OMS and RCS heaters, which will keep them at 55° to 90° F (A-heater in AUTOMATIC, B-heater OFF), and activate APU lube oil heaters. Although the APU gas generator bed temperatures will remain warm until about MET 6:00, a caution is included at this point to monitor the APU fuel pump outlet and bypass line temperatures and activate the gas gen/fuel pump heaters if required. Aft flight deck communication configuration is accomplished, S-band communication is configured for TDRSS at the high rate, R15 cb's are closed as required, ascent thrust vector control, engine interface units, and master event controllers for the main engines are secured, and the display driver units (DDUs) cb's for the aft flight controllers and displays are closed.

MET

Day/Hr:Min (approx)

0/1:00 MSs unstow and activate the payload general support computers (PGSCs).

0/1:05 PLT *configures* the payload electrical bus*es on the flight deck* (payload dependent) *while other buses are powered via the middeck panels*.

0/1:08 Crew configures and activates the galley and waste containment system (WCS).

0/1:10 Flight deck audio is reconfigured from headsets to speaker and handheld mic operations.

0/1:12 PLT executes an automatic maneuver to the PLBD opening attitude -ZLV with a flight-specific bias. This is a time critical action; *DAP A/AUTO/ALT* are selected.

0/1:18 CDR activates the radiators by placing both the *RADIATOR BYPASS VALVE MODE* and *RADIATOR CONTROLLER LOOP 1* and *2* switches (two each) to *AUTO, AUTO A*. CDR then takes the Freon *RADIATOR ISOLATION MODE* switch to *AUTO*. *It takes 90 seconds for the radiator startup sequence.*

0/1:20 An MS sets up the aft panel *PAYLOAD BAY FLOOD* switches as required (given possible payload limitations) for PLBD opening. Lights require ~3 min for full bright). If the CCTV is to be used for PLBD opening, it will be activated at this time.

0/1:28 MS2 initiates automatic PLBD opening with the SM PL BAY DOORS display and switch*es* on panel R13L. Centerline latches take ~20 sec, forward and aft bulkhead latches take ~30 sec, and each door (starboard then port) opens in ~63 sec. After the doors are open and power removed from them, display SM ANTENNA is usually selected for IDP 4 when other displays are not required. The MCC will uplink table maintenance block updates (TMBU) as required.

0/1:36 If there are no known problems with the major orbiter systems, the MCC will issue a GO for orbit operations. Ku-band antenna is deployed (~23 sec) and activated. Ku-band signal strength is shown on the SM OPS 201 Antenna display and panel A1U meter.

0/1:37 CDR, PLT egress seats; all crew doff and stow launch/entry suits (LES). During this time, the MCC uplinks the orbiter state vector and RCS quantity compensations.

0/1:*45* The crew installs the quick-don masks (QDMs) into the various O2 quick disconnects now that the LES are no longer used.

0/1:52 CDR selects the SM 88 APU/ENVIRON THERM display, and if Freon loops are operating nominally as they should by this point (Freon loop radiator out temp <60° F), secures the flash evaporator and turns the high load evaporator off.

0/1:56 The CDR powers on the star trackers and both star tracker doors are opened (6 to 12 sec.). CDR selects GNC 22 S TRK/COAS CNTL display and activates the star trackers. SPEC 21 is then called up to initiate the calculations for the IMU delta angles, and then returned to GNC UNIV PTG display.

0/1:57 *An MS* opens the supply H2O dump isolation valve to ensure redundant dump *path, and then configures other* tank valves as needed for mission requirements (water transfer, etc.).

0/*2:02* MS on the middeck configures the airlock for ingress. Ductwork and booster fans are set up to provide air flow into the airlock.

0/2:*03* PLT activates the APU steam vent heaters to remove any possible ice formation on the water spray boiler (WSB) vent openings.

MET

Day/Hr:Min (approx)

0/0:2:05 MS/PS seats are removed and stowed.

0/2:10 After go for vernier operations from MCC, CDR verifies use of vernier jets is safe (radiators operating and FES hi-load off) and activates verniers on MCC call. DAP selection is typically *A/AUTO/VERN*.

0/2:12 Crew configures controls for on-orbit operations by using panel diagrams in the Post Insertion Checklist that depict switch positions.

0/2:21 PLT performs the hydraulic thermal conditioning enable steps in the Orbit Operations Checklist, which allows the GPCs to operate hydraulic circulation pumps when pressures or temperatures are below set limits.

Note: Payload electrical constraints may alter this activity.

0/2:24	MS resets C/W system from ascent to on-orbit operations. Limits for some systems are changed while others are inhibited.
0/2:29	Fuel cell performance is plotted using the FUEL CELL *VI PERFORMANCE PLOT*.

5.3 ORBIT

CONTENTS

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Orbit Operations

This section summarizes typical orbit operations for METs 0/2:30 through 0/22:00. Activities occurring after 0/6:30 are representative of subsequent flight days until the last full on-orbit day.

Note: Actual activities and times will vary from mission to mission.

D/H:M (approx)	
0/2:30	Crew completes post insertion activity. Post Insertion Checklist is stowed, and crew refers to the Flight Plan for nominal activities. FD1 EZ activities are begun; i.e., lamp test, smoke detection circuit test, pressure control system (PCS) setup, Compound Specific Analyzer - Combustion Products (CSA-CP) ops, and orbiter cabin air cleaner (OCAC) filter cleaning. The Photo/TV Checklist is unstowed, and camera assembly is begun. Other equipment required for flight day (FD) 1 activities is unstowed and set up. The assembly power converter units (APCUs) are activated, if needed.
0/2:35	If the remote manipulator system (RMS) is flown, initial activation procedures begin at about this time. RMS AC cb's are closed, power is applied to the manipulator controller interface unit, RMS shoulder brace is released, heaters are activated, and, if required by payload operations or constraints, the arm is deployed.
0/2:45	IMU alignment (S TRK) using Star Data is accomplished. GNC UNIVERSAL POINTING, GNC 21 IMU ALIGN, and GNC 22 S TRK/COAS CNTL displays are used for this activity.
0/3:10	Aft controller checkout initiated in each axis with the output verified on the GNC 25 RM ORBIT display.
0/3:45	APU steam vent heaters are secured (initiated at MET 2 hr). APU gas generator and fuel pump heaters (A) are placed in AUTO at panel A12 to keep the generator bed 360° to 425° F and the fuel pump 80° to 95° F (the B heaters are used mid-mission to exercise the redundant system).
0/3:50	CRYO O2 tank heater sensor check is accomplished to verify short circuit protection for the O2 tank heaters (SM 68 CRYO SYSTEM display).
0/4:00	Unless there is an FD1 deploy or other mission-specific requirement, the first on-orbit meal is prepared and eaten at this time.
(various times)	Crew begins payload activities. These activities may include payload deploy, Spacehab activation, or secondary experiment activation, depending on the type of mission.
0/8:00	Presleep activities begin 3 hr (2:15 for dual-shift operations) before the sleep period (can be shortened to 2 hr for single shift and 1:30 for dual-shift operations if required). Presleep activities on the flight deck include: • Configure cryo heaters and manifold valves as directed by MCC.

- Install O2 bleed orifice. Note: This may be done postsleep, depending on PPO2 levels.
- Update SM checkpoints.
- Set CRT timer for crew wake up and C/W alert tone duration.
- Adjust the cabin temperature control as required.
- Configure active PCS O2/N2 controller to OPEN to avoid nuisance "FLOW" alarms while sleeping (14.7 config only).
- Power down unnecessary electrical equipment (IDPs, TV power, TV cameras, VTR, cabin and PLB lights, DDUs).
- Install window shades/filters.
- Remove power from primary reaction jet drivers (8) to preclude primary jet ON failures.
- Maneuver to sleep attitude.

Minor payload or experiment related activity can be scheduled during the presleep, if required.

Presleep activities on the middeck include:

- Food preparation and cleanup for the evening meal.
- CO2 absorber (LiOH) replacement (one of two canisters is replaced).
- General housekeeping and WCS cleaning.
- Set up next day's equipment (if practical).
- Write/record mission notes.
- Configure communications panels and lighting.

0/9:50 APU gas generator and fuel pump heaters (A) are activated at panel A12 along with the APU tank/fuel line/H2O system (A) heaters (3) (B heaters off).

0/11:00 Sleep period is scheduled to begin no later than 16 hr after the crew's launch day wakeup (4:55 prior to launch) but can be extended up to 2 hr if unexpected launch holds occur. The sleep period is scheduled for 8 hr but can be shortened to 6 hr if required.

0/19:00 The postsleep period begins about 8 hr after the start of the sleep period and extends for 3 hr for single-shift operations (1:30 for dual shift) but may be shortened to 2 hr (1:15 dual shift) if required.

Middeck postsleep activities include:

- Reconfigure lighting and communications panels.
- Replace CO2 absorber (one of two canisters is replaced).
- Install O2 bleed orifice (first postsleep) to increase O2 to the middeck, if not installed presleep.
- Prepare meals and clean up.
- General housekeeping.

Postsleep flight deck activities include:

- Reconfigure lighting, window shades, communications panels and instruments, and the SM Alert tone duration.
- Power on IDPs (3).

- Adjust cabin temperature (if required).
- Reonfigure active PCS O2/N2 controller back to AUTO.
- Configure OMS/RCS interconnect as required to preserve aft RCS propellant.
- Power primary RJD drivers (8) ON.
- Configure cryo heater/manifold valves per MCC instructions.

0/22:00 The crew begins a full workday on orbit with their flight-specific activities. Each day, photo/TV scenes are activated per the P/TV Checklist. Normally, the crew downlinks live TV of flight deck or middeck activities once each day. At a minimum, a VTR dump of crew activities is downlinked. When the PLB cameras are not required for flight requirements, MCC occasionally asks to control the cameras and conduct Earth viewing. MCC will not activate cabin cameras without prior crew coordination. Once during a 4-day mission (twice for longer flights) the avionics filters are cleaned. Also, the operating humidity separator is checked for water accumulation about every 12 hours during the first few on-orbit days. Once each flight day (the morning of likely/scheduled EVAs and entry day), each crewmember has an opportunity to communicate privately with a flight surgeon during a private medical conference (PMC).

1/00:00 Manually purge fuel cells (FD 1 only to save ground turn-around time). Use SM 69 FUEL CELLS display to monitor purge. All other purges will be uplinked from MCC.

1/01:00 The day prior to docking, the crew performs a series of procedures to intialize, verify, and configure the docking system. When the procedures are complete, the system is powered back down.

1/5:00 PLT runs the Fuel Cell Monitoring System (FCMS), a PGSC program that monitors the health of the fuel cells to a level of detail that Mission Control cannot see. The data is collected into a text file and downlinked for analysis.

3/00:00 Conduct supply and/or waste water dump, monitored using SM 66 ENVIRONMENT display (purges and dumps are not accomplished during star tracker use due to possible contamination). The dumps make room for new water that is being produced.

4/00:00 Mid-mission, the crew will reconfigure various systems for even usage, including heaters (water, hydraulic, etc.) from A to B, PCS from 1 to 2, and cabin temperature controller from 1 to 2.

OMS (RCS) Burns

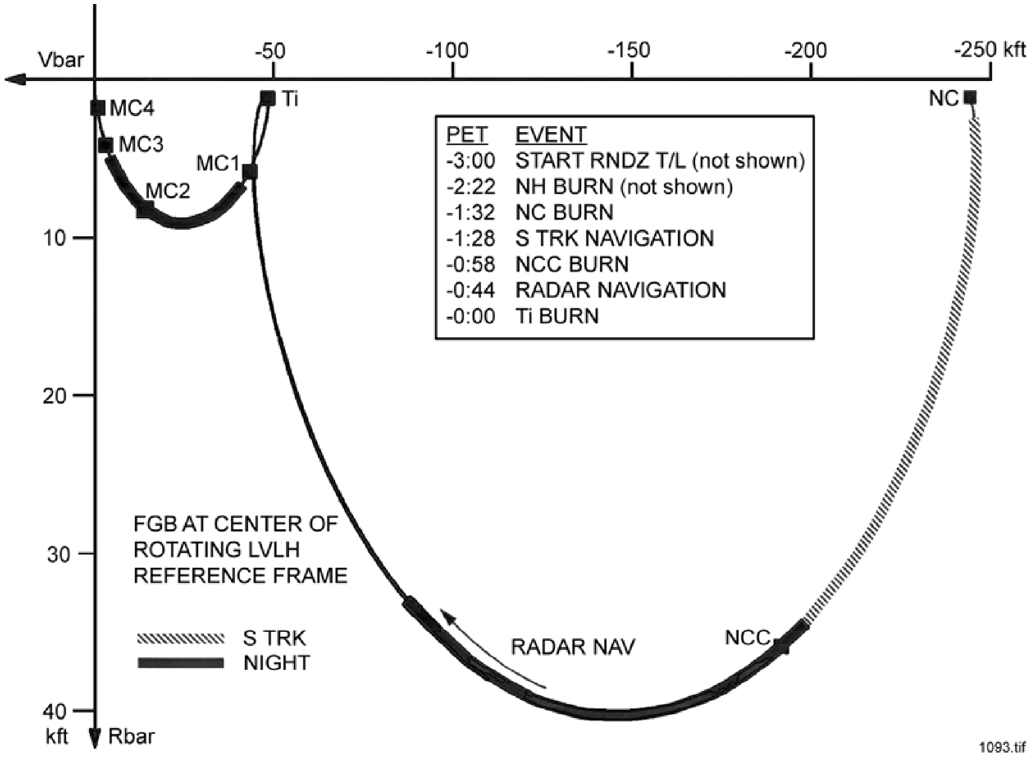
OMS/RCS burns are used on orbit to raise or lower the orbital altitude, for rendezvous phasing, and deorbit. The burn may be done with one or both OMS engines or the RCS, depending on the delta V required. Propellant for the burn can come from either OMS pod or the RCS system. OMS BURN cue cards (OMS-2/ORBIT OMS BURNS (2) and OMS BURN MONITOR (2)) are installed on the forward panels for the burn. On-orbit burns require OPS 202 (302 for entry) with GNC ORBIT MNVR EXEC and GNC SYS SUMM 2 displays. Procedures for on-orbit OMS/RCS burns are similar to those discussed in the OMS 2 section. Burn target data is normally uplinked by MCC and loaded automatically. If delta V total >6 fps, an OMS burn will be required. If delta V total is ≥4 and ≤6 fps, a +X RCS burn is used (thereby limiting the amount of forward RCS burned). If the delta V total <4 fps, the burn is multi-axis (RCS) with no maneuver to burn attitude.

Rendezvous

This section summarizes the major events that occur during the final phases of a rendezvous. Flight-specific rendezvous procedures are located in the Rendezvous Checklist. The phase elapsed time (PET) below is referenced to target intercept (Ti) TIG. PET is used to track rendezvous events and normally is displayed on the DPS display. Actual times will vary, depending on flight profile.

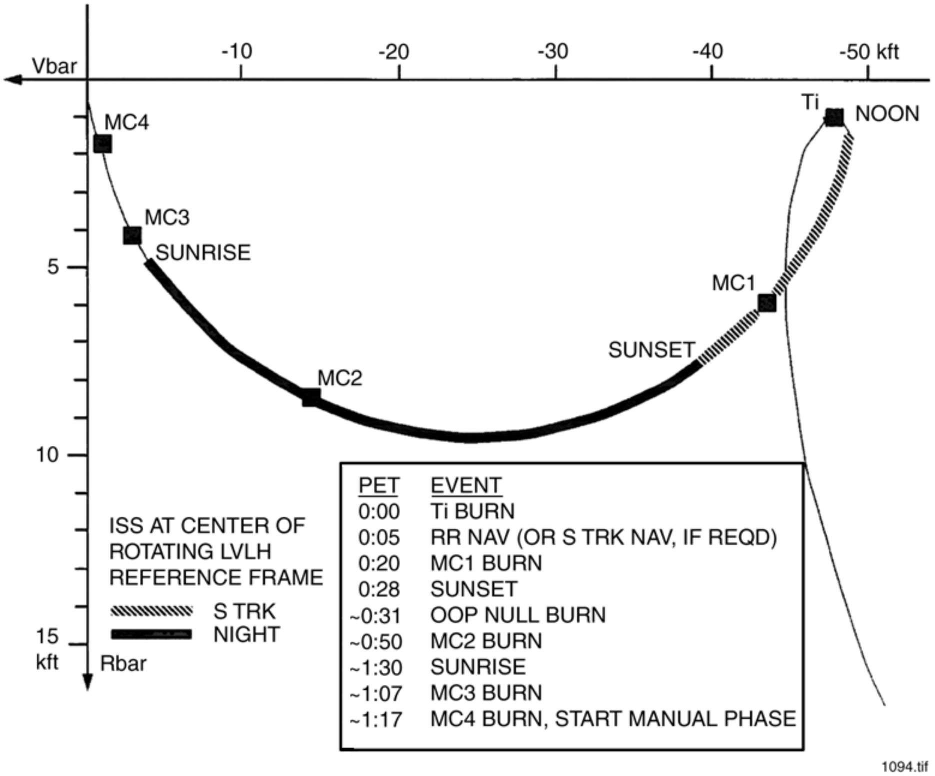
NH Burn (not shown) – NH is a ground-targeted height adjust burn. This burn is accommodated in the checklist, if necessary on the day of rendezvous. (This burn may be executed prior to the day of rendezvous).

NC Burns – The NC burns are phasing maneuvers used to initiate or modify the rendezvous approach (closing rate). They are ground-targeted burns, the last of which is designed to place the orbiter 8 n. mi. behind the target (Ti point) in one (or two) revs.



PET	EVENT
-3:00	START RNDZ T/L (not shown)
-2:22	NH BURN (not shown)
-1:32	NC BURN
-1:28	S TRK NAVIGATION
-0:58	NCC BURN
-0:44	RADAR NAVIGATION
-0:00	Ti BURN

Orbit Rendezvous Profile



PET	EVENT
0:00	Ti BURN
0:05	RR NAV (OR S TRK NAV, IF REQD)
0:20	MC1 BURN
0:28	SUNSET
~0:31	OOP NULL BURN
~0:50	MC2 BURN
~1:30	SUNRISE
~1:07	MC3 BURN
~1:17	MC4 BURN, START MANUAL PHASE

Orbit Post Ti Profile

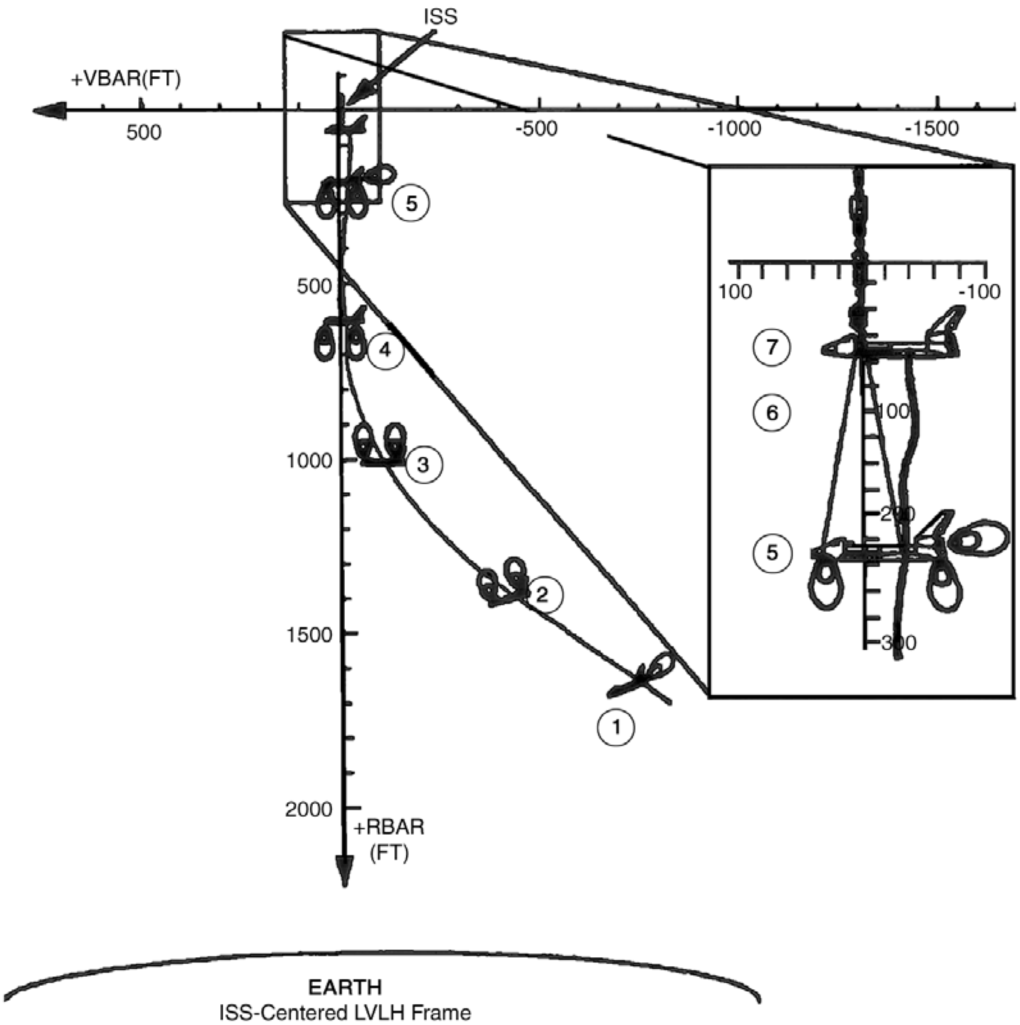
Star Tracker NAV – After the final NC burn, the crew maneuvers the orbiter to a -Z (-Y) target track attitude, which will point the desired Star Tracker (ST) at the target to provide relative navigation data. The ST angle data will be used to improve the onboard filter (FLTR) state vector.

NCC Burn – This is the first onboard targeted burn. It uses the filter state vector updated by the star tracker data. This is a corrective combination burn that will try to create a node at and correct the transfer to the Ti point, 1200 feet below and 48,600 feet (8 n. mi.) behind the target.

Radar NAV – The rendezvous radar is expected to lock on at a range of approximately 150 kft. The radar provides range and range rate data, in addition to the angle data. The FLTR vector with the ST data is saved to the propagated vector (FLTR to PROP transfer) prior to taking the Radar data to nav. This will protect the vector with the star tracker data from possible problems with the radar data.

Ti Burn – The Ti burn initiates the final (transition) phase of rendezvous. It is targeted onboard using the updated FLTR vector. Ti is primarily a posigrade phasing burn designed to place the orbiter at the MC4 position (900 feet behind and 1800 feet below the target). Targeting to MC4 has been shown to reduce the dispersions at MC4 and, therefore, reduce the dispersions at manual takeover.

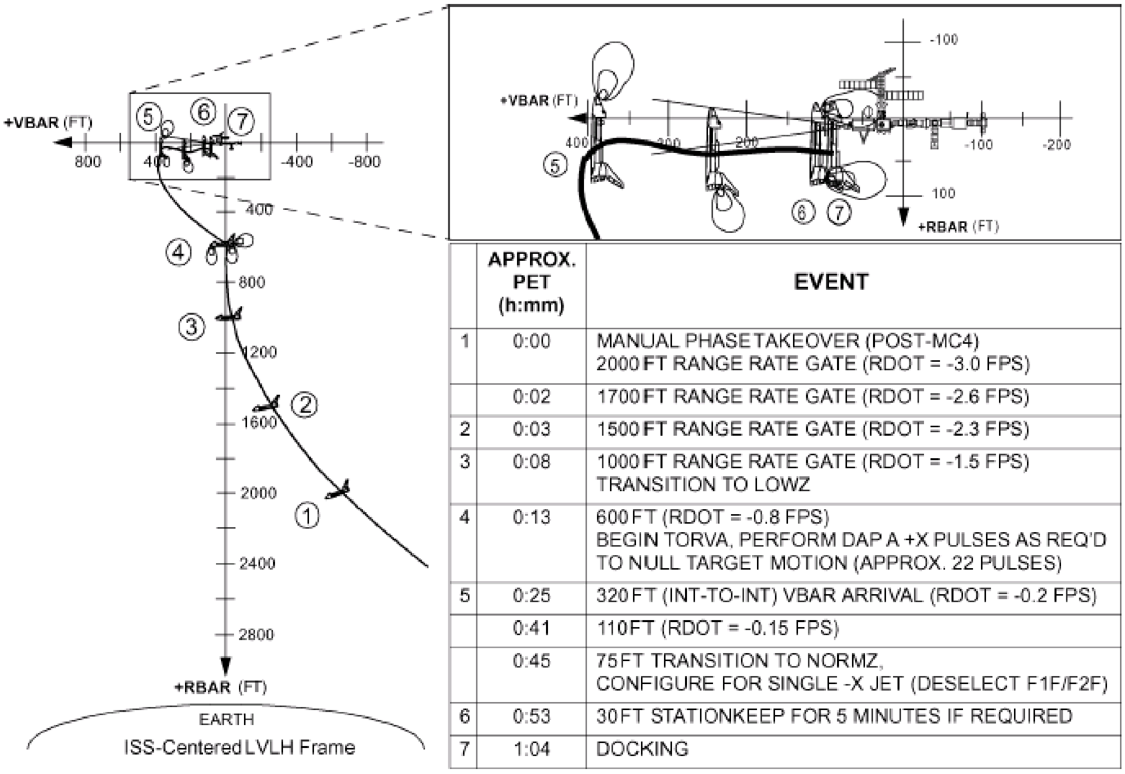
RADAR/S TRK NAV – During this portion of the profile, the orbiter will be in a -Z (-Y) target track attitude. NAV will be updated with radar or ST data. This data will be used to target the four midcourse correction burns and perform the out-of-plane null.



	APPROX. PET (h:mm)	EVENT
1	0:00	MANUAL PHASE TAKEOVER (POST MC4) 2000 FT BRAKING GATE (Rdot = -3.0 fps)
2	0:03	1500 FT BRAKING GATE (Rdot = -2.3 fps)
3	0:08	1000 FT BRAKING GATE (Rdot = -1.5 fps) SWITCH TO LOWZ
4	0:13	600 FT BRAKING GATE (Rdot = -0.8 fps) RBAR ARRIVAL
5	0:35	ARRIVE AT 170 FT STATIONKEEPING
	0:50	RE-ESTABLISH APPROACH
6	1:11	STATIONKEEPING AT 30 FT
	1:16	RE-ESTABLISH APPROACH
7	1:22	DOCKING

1095a.tif

Orbit Terminal Phase and R-bar Approach



	APPROX. PET (h:mm)	EVENT
1	0:00	MANUAL PHASE TAKEOVER (POST-MC4) 2000 FT RANGE RATE GATE (RDOT = -3.0 FPS)
	0:02	1700 FT RANGE RATE GATE (RDOT = -2.6 FPS)
2	0:03	1500 FT RANGE RATE GATE (RDOT = -2.3 FPS)
3	0:08	1000 FT RANGE RATE GATE (RDOT = -1.5 FPS) TRANSITION TO LOWZ
4	0:13	600 FT (RDOT = -0.8 FPS) BEGIN TORVA, PERFORM DAP A +X PULSES AS REQ'D TO NULL TARGET MOTION (APPROX. 22 PULSES)
5	0:25	320 FT (INT-TO-INT) VBAR ARRIVAL (RDOT = -0.2 FPS)
	0:41	110 FT (RDOT = -0.15 FPS)
	0:45	75 FT TRANSITION TO NORMZ, CONFIGURE FOR SINGLE -X JET (DESELECT F1F/F2F)
6	0:53	30 FT STATIONKEEP FOR 5 MINUTES IF REQUIRED
7	1:04	DOCKING

Orbit Terminal Phase and V-bar Approach

MC1 Burn – The MC1 burn will trim any dispersions left over from the Ti burn, taking advantage of more sensor data. MC1 targets to the MC4 position.

Planar Null – The next task is to monitor the GNC 33 REL NAV display closely to watch for the point when the out-of-plane distance between the two orbits (Y) becomes zero (nodal crossing).The NODE time on SPEC 33 will give the crew an estimate of when this will occur. At this point, the crew will null the rate (Y-DOT), which will put the orbiter in the same orbital plane as the target.

MC2 Burn – This is a special burn because it is based upon the elevation angle to the target, not on a time. The burn TIG can change so the burn will occur at the desired elevation angle. The MC2 burn sets up the standard trajectory and reduces the dispersions at MC3. **MC3 and MC4 Burns** – The MC3 burn also targets to MC4 and, typically, is just a "trim burn" similar to MC1.

The MC4 burn targets to 600 feet on the +R-bar. This burn should "coast" the orbiter to the desired range on the +R-bar. In the nominal case, MC4 will be mostly a non-zero +X burn.

Manual Phase – Post-MC4, the orbiter is on a coasting trajectory to the 600-foot point on the +R-bar. An attitude maneuver will be performed to put the orbiter in the +R-bar attitude by the time it reaches the R-bar. R-dot corrections (braking gates) will be performed.

Flight-Specific Final Approaches – (Covered in detail during Prox Ops lessons)

> **R-bar**: Fly up the +R-bar from the 600-foot point.
>
> **TORRA**: Fly to the +R-bar until 600 feet, then transition to the –R-bar at twice orbit rate.
>
> **TORVA**: Fly to the +R-bar until 600 feet, then transition to the +V-bar at twice orbit rate.
>
> **INERTIAL**: Orbiter maintains inertial attitude hold during final approach to target.

NOTE

For a more detailed overview of rendezvous, see the "RNDZ CONCEPTS" computer based training lesson.

Last Full On-Orbit Day

The last full on orbit day includes nominal flight day activities plus general cabin stowage, FCS checkout, RCS hot fire, and those unique procedures that must be accomplished prior to transition to the Deorbit Prep Checklist (-04:00 TIG). Before presleep activities, the crew conducts entry planning and stows the Ku-band antenna.

Presleep and postsleep activities are nominal, with the exception of the continuation of general cabin stowage. Additionally, fluid loading preparation (four 8 oz containers per person) and cabin air samples may be accomplished in the postsleep period or deorbit preparation. The flight control system is checked for proper entry operation (also saves ground test time). The test (conducted in two parts) is accomplished with an APU (MCC designated), but may be done with a circulation pump, if required.

FCS Checkout, Part 1

FCS checkout Part 1 consists of the following activities:

- Power on FCS sensors and controls prior to the transition to OPS 8. Aerosurface amplifiers (ASAs) must be ON prior to GNC OPS 8 if an APU is used and OFF if a circulation pump is used.
- Event timer is set to count up (to track APU ON time).
- Hydraulic thermal conditioning is terminated and the APU is prepared for operation.
- ON MCC GO, the selected APU is brought on line in low pressure and event timer is started.

- If APU operation is nominal, normal pressure is selected for actuator checkout (SM 87 HYD THERMAL display).
- Proper elevon switching valve operation should be noted.
- Surface drive is initiated (some surfaces may not drive properly right away due to cold hydraulic fluid). Test should be complete in about 30 sec.
- A secondary actuator check is initiated to test the bypass feature of the actuators. When the test is complete, the APU is shut down and hydraulic thermal conditioning is re-enabled (if required). Expect a marked structural vibration when ports pop during the secondary actuator check.

FCS Checkout, Part 2

Part 2 of the FCS checkout begins with a sensor test (GNC 40 SENSOR TEST). The orbiter is placed in free drift. The crew then initiates the sensor tests (accelerometer assemblies (AAs), microwave landing system (MLS), Tactical Air Navigation (TACAN), radar altimeter, rate gyro assemblies (RGA), and air data transducer assemblies (ADTA)). Sensors failing the test will be deselected for entry.

Following the sensor test, the FCS mode/ channel switch test is conducted. These procedures verify FCS switch contacts and all entry-critical switches (flight controller power required). Next a test of the nose wheel steering system is performed. The next series of procedures verify proper operation of controllers and their associated switches (left and right). Finally the DDUs and head-up displays (HUDs) are tested and adjusted for entry. When the FCS checkout is complete, the DPS is returned to GNC OPS 2 (G8 to G2 transition), and all entry equipment is secured.

RCS Hot Fire

This test is conducted to verify the operation of seldom used RCS jets (thereby decreasing ground turnaround time). Manual DAP is selected and the orbiter is verified/placed in free drift. Each RCS jet is tested (GNC 23 RCS display) and the results noted (3 sec delay between pulses to allow time for a fault message and 30 sec delay if a failure is annunciated). When the Hot Fire test is complete, the vehicle is placed in inertial hold to allow damping of rates before returning to the required attitude. RJDs, DDUs, and MDMs are then secured as required.

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5.4 ENTRY

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Deorbit Preparation

TIG

Hr:Min (approx)

-4:00 The crew transitions to the Deorbit Prep Checklist for nominal procedures. PLT sets CRT timer for deorbit TIG using the GNC 2 TIME display and SM timer.

-3:56 CDR initiates radiator coldsoak by placing *RAD CNTLR OUT TEMP* switch to the *HI* position and activating topping FES to minimize propulsive venting. Vehicle is maneuvered to "tail sun" attitude (-X SI) for the coldsoak. The H2O Loop Bypass controllers are checked out and the H2O loops are configured for entry.

-3:50 MSs continue entry stowage along with entry airlock configuration.

-3:48 Ku-band antenna is stowed (if not already accomplished in last presleep period).

-3:45 Radiators are stowed (if deployed).

-3:42 Compute N2 quantity (for entry cabin leaks) and identify depleted H2 tanks (for burn cards).

-3:35 Specialists install seats and FDF containers.

-3:30 to -2:30 MS performs payload deactivation/entry preparation in this timeframe, as required.

-3:27 DPS is configured for deorbit preparation. The BFS is woken up to ensure it has interface to the forward IDPs.

-3:25 PLT activates APU water boiler steam vent heaters (at least 2 hr before APU start) and terminates hyd thermal conditioning. PLT prepares for hydraulic repressurization of the main engine thrust vector controls (engine bells must be properly stowed to prevent thermal damage).

-3:15 CDR, PLT power up FCS, DDUs and navigation aids for entry (RGAs and ASAs must be on prior to OPS 3 transition).

-3:10 Crew begins Entry Switch List verification by comparing crew compartment switch positions with diagrams in the Deorbit Prep book.

-2:55 CDR initiates radiator bypass to retain Freon coldsoak. Alternate FES controllers are checked out to save ground test time. PLBDs will not be closed until this checkout and until Freon temperatures are down to 39° F. Primary RCS jets are used because FES Hi Load vent forces are too strong for vernier jets. H2O crossover valve is *verified open* to allow all water tanks to feed the FES equally.

-2:51 MS prepares for PLBD closing: PLB lights activated (as required), cameras/video recorder readied, RMS TV camera positioned and RMS heaters secured (if RMS flown).

-2:40 *Crew* closes PLBDs using SM PL BAY DOORS display on IDP 4 (SM OPS 2).

TIG

Hr:Min (approx)

-2:25 MS performs post-PLBD closing procedures, which include securing PLB lights, deactivating/stowing cameras, and taping down foot restraints (to prevent tripping during egress).

-2:23 CDR monitors auto maneuver to attitude suitable for S-band communications if required. Crew may go to deorbit attitude, depending on flight profile and TDRS position.

--2:16 CDR, PLT configure DPS (three phases) to place GPCs 1, 2, 3, and 4 in PASS OPS 3 and GPC 5 in BFS OPS 3. Prior to OPS 3 transition, entry TFLs are loaded and SM Checkpoint Initiate is performed to update the FDA in case a wave-off is required. Once in OPS 3, the crew refers to the Entry Pocket Checklist for malfunction procedures.

-1:58 MS deactivates star tracker and closes doors.

-1:55 CDR, PLT, MSs perform entry switch list configuration and verification at this time. The following items will be performed or verified:

Forward Flight Deck

- Electrical power to brakes, brake heaters, anti-skid, and nose wheel steering (NWS) is applied.
- Verniers are secured.
- FES control is given to the BFS. Freon loop RADIATOR ISOLATION MODE switch is taken to OFF. Cb's for HUM SEP and IMU FAN signal conditioners are opened.
- One O2/N2 valve is opened in case of a cabin leak.
- Communications panels are configured to provide maximum redundancy.

Aft Flight Deck

- Secure hydraulic heaters.
- Set up DTV for entry.
- Connect an LES communications cable (dC Utility Power MN C).
- Open Ku-band circuit breakers.

Middeck

- Configure communications panel for entry.
- Pressure control system (PCS) is configured for N2 water tank ullage pressure.
- Close 14.7 cabin regulators (protects N2 if leak occurs)
- Close O2 regulators (so O2 flow goes only to LES).
- Remove and stow bleed orifice.

-1:42 CDR receives MCC readup of PADs (OMS propellant PAD, deorbit/ entry/land PAD, and deorbit maneuver PAD). The current state vector, and deorbit targets are also uplinked. Crew can use PGSC (SPOC) to determine targets and c.g. if required.

-1:40 MS enables MPS helium system pressure C/W (assists crew in isolating failed open regulator). Hydraulic system C/W parameters for low pressure are activated (alarm will sound immediately since APUs are OFF).

-1:39 Crew conducts entry review as required (15 min alloted).

-1:24 CDR, PLT don LESs.

TIG

Hr:Min (approx)

-1:10 Specialists don LESs.

-1:06 Final IMU alignment is performed by CDR to reset RM threshold prior to deorbit burn. This maximizes IMU RM, two-level attitude failure detection.

-1:04 Crew begins fluid loading (containers filled in post-sleep). This helps prevent orthostatic intolerance upon exposure to gravity.

-0:59 CDR, PLT ingress seats.

-0:57 CDR, PLT remove HUD covers.

-0:53 Crew performs LES pressure integrity check.

-0:50 Crew doffs and stows on-orbit communications headsets.

-0:33 MS deactivates WCS and galley.

Deorbit Burn

-1:03 All begin fluid loading per individual prescription.

-0:55 CDR, PLT perform LES pressure integrity check.

-0:47 CDR, PLT stow all unnecessary FDF items and transition to the Entry Checklist for the nominal procedures.

-0:46 CDR, PLT receive final deorbit update/uplink. Deorbit flight rules are verified with MCC. Exact time may vary.

-0:40 CDR performs OMS TVC gimbal check (during AOS), using OMS MNVR EXEC display.

PLT initiates APU pre-start procedures (during AOS). BFS, SM SYS SUMM 2 is used to check APU status.

CDR, PLT conduct horizontal situation configuration using GNC 50 HORIZ SIT; BFS GNC 50 HORIZ SIT; and GNC 51 OVERRIDE for both PASS and BFS.

PLT initiates OMS burn preparation, which includes checking engine trims and placing OMS and RCS valve switches in the pre-burn configuration.

MS3 removes and stows side hatch UV filter, locking device, and Pyro Box Safing pin.

-0:25 PLT performs vent door closure with the GNC 51 OVERRIDE display.

CDR, PLT receive final deorbit update/uplink if required. MS1 and MS2 ingress their seats.

CDR proceeds to OPS 302 and GO/NO-GO is given for deorbit burn.

-0:15 CDR initiates maneuver to deorbit burn attitude on OMS MNVR EXEC display. CDR, PLT verify *ADI* switches in proper positions. MS places OMS/RCS heater switches in proper configuration for entry.

-0:05 PLT performs single APU start. One APU must be operating in low pressure prior to the burn. First APU start procedures vary, depending on weather. CDR verifies orbiter is in the deorbit burn attitude ±5°. The crew transitions to the Deorbit Burn cue card for nominal procedures, and the Burn Monitor cue card for malfunction procedures. The Deorbit Burn Flight Rules cue card should be consulted prior to executing the burn.

Deorbit Burn
TIG
Min:Sec (approx)

-5:00 Once on the Deorbit Burn cue cards, CDR and PLT ensure OMS He switches, ADI switches, and FLT CNTRL PWR are in the proper burn configuration.

-2:00 CDR takes OMS ENG switches to ARM/PRESS in preparation for the burn.

-0:15 CDR hits EXEC key to trigger OMS ignition.

0:00 Deorbit burn TIG. CDR, PLT monitor the burn using delta VTOT, VGO, TGO, and Hp from GNC OMS MNVR EXEC. BFS GNC SYS SUMM 2 display is used for OMS systems data. Section 7 discusses deorbit burn monitoring and downmoding.

As burn termination nears (TGO going to 0), crew monitors current perigee (HP) approaching targeted HP and delta VTOT approaching 0. Deorbit OMS burn time varies with orbital altitude. Typical burn times are 2-3 minutes. During the burn, the Deorbit Burn Monitor cue card is used for malfunction procedures.

OMS Cutoff

+2 sec If nominal burn, CDR secures OMS engines following the automatic purge and trims residual X and Z velocities (<2 fps for steep targets and -0.5 fps for shallow ones). The crew returns to the Entry Checklist Post Deorbit Burn section for nominal procedures and to the Entry Pocket Checklist for malfunction procedures.

PLT performs OMS/RCS reconfiguration by verifying the proper position of RCS switches and closing OMS HE and crossfeed valves; MS stows PGSC (SPOC).

CDR proceeds to OPS 303, verifies the proper attitude, and initiates maneuver to the EI -5 min attitude. CDR also conducts OMS gimbal powerdown verifying after gimbals have driven to the proper entry position.

EI

Min:Sec (approx)

-20:00 CDR starts a secondary actuator check, if not already done during FCS checkout and time allows, using GNC 53 CONTROLS, BFS SM SYS SUMM 2, and GNC DEORB MNVR COAST displays.

-18:00 PLT performs forward RCS dump with GNC 23 RCS, GNC DEORB MNVR COAST, and GNC SYS SUMM 2 displays. Dump times for various forward RCS quantities are listed in the Entry Checklist. It takes 90 seconds to dump 50 percent forward RCS with 4 jets (twice as long using a 2 jet dump).

The forward RCS is always dumped unless needed for c.g. control. This reduces the hazard to the crew if a hard landing is made.

CDR, PLT perform entry switch checks (using GNC 51 OVERRIDE) and exercise brake pedals.

-13:00 PLT starts remaining two APUs, verifies nominal performance, then switches all three APUs to normal pressure in preparation for the SSME hydraulic repress.

PLT performs main engine hydraulic system repressurization to ensure the nozzles are properly stowed.

-11:00 If required, PLT initiates hydraulic fluid conditioning on MCC's call and monitors surface position indicators for aerosurface cycling.

Crew makes burn report to MCC and updates new state vector if required. All crew members inflate anti-g suits if desired.

-6:00 The crew transitions to the Entry Maneuver cue card for nominal entry procedures.

-5:00	CDR transitions GPCs to OPS 304 when verified at EI-5 attitude. Crew switches to AESP for malfunction procedures. Program test inputs (PTIs) are enabled on SPEC 50 when applicable.
-3:00	PLT verifies *FWD RCS MANIFOLD ISOLATION* valve switches (4) are closed (unless forward RCS PTIs are scheduled).

Entry Interface

\+ = Time from EI
– = Time to touchdown
Min:Sec (approx)

+0:00 -32:14	Orbiter reaches EI (400,000 ft) at an Earth relative velocity (V) of ~24,600 fps and descent rate (H-dot) of ~500 fps. The crew compares ADI, AMI, and AVVI data to Entry cue card data. ENTRY TRAJ (1 - 5), HORIZ SIT, and GNC SYS SUMM 1 displays are monitored. The BFS ENTRY TRAJ display is available to compare PASS and BFS guidance. The PLT can call up BFS SYS SUMM displays as desired to check system operation.
+2:39 -29:35	Automatic elevon trim begins at a q-bar = 0.5 psf.
+3:32 -28:42	Aerosurface control begins at q-bar = 2.0 psf. CDR, PLT monitor elevon and aileron deflection angles on surface position indicator.
+4:45 -27:29	Closed loop guidance initiated (CLG Init) at q-bar = ~8 psf or drag = ~3 fps^2. Guidance box appears on ENTRY TRAJ to indicate closed loop guidance.
+5:00 27:14	Roll RCS jets deactivated at q-bar = 10 psf.
+5:18 -26:56	First non-zero bank command issued by guidance at H-dot -240 ft/sec (CLG Init plus 15 to 30 sec).
+6:10 -26:04	Maximum surface temperature region begins (Mach 24 to 19). Actual drag should be within .5 fps^2 of orbiter bug drag.
+8:04 -24:10	Pitch RCS jets deactivated at q-bar = 40.
+11:49 -20:25	At drag = 11 fps^2, drag H updates begin in NAV filter. Crew monitors data on GNC 50 HORIZ SIT display.
+13:40 -18:34	First roll reversal is issued by guidance when azimuth error (delta AZ) = ±10.5°. Occurs at a flight-specific velocity between 23,000 and 6,200 fps, depending on crossrange.

<u>Note</u>: 1 k fps = Mach 1.0

+14:42 -17:32 V_{REL} = 19 k fps (Mach = 19) Alt = 215 k ft	The PLT checks that the MPS TVC isolation valves are closed. Pitch and roll RCS activity lights are reconfigured when q-bar = 50 psf to indicate RCS saturation.
+15:51 -16:23 V_{REL}=17 k fps (Mach = 17) Alt = 200 k ft	PASS and BFS TRAJ displays mode to ENTRY TRAJ 2.
+17:00 -15:14 V_{REL} = 15 k fps (Mach = 15) Alt = 185 k ft	NAVAID power is verified and I/O RESET performed. This ensures NAVAIDs will warm up before they are required (in case they were off due to a powerdown).
+17:57 -14:17 V_{REL}=14 k fps (Mach = 14) Alt = 182 k ft	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 3. Drag is up to 33 fps^2 and Gs up to 1.5.

+18:57 -13:17 V_{REL}=12 k fps (Mach = 12) Alt = 176 k ft	Radiator coldsoak usage is initiated in preparation for the FES becoming inactive: Radiator bypass valves (2) are placed in automatic and radiator controller loops (2) are put in AUTO B(A). CDR and PLT begin monitoring for aileron saturation.
+19:20 -12:54 V_{REL}=10.5 k fps (Mach = 10.5) Alt = 167 k ft	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 4. Alpha and drag start to ramp down, but Gs stay up over 1.3.
+20:03 -12:11 V_{REL}=10 k fps (Mach = 10) Alt = 150 k ft	Speedbrake opens to 81 percent.
+21:00 -11:14 V_{Rc}= 8.0 k fps (Mach = 8)	SSME repositioning for drag chute deploy. If GPC annunciates SSME REPOS FAIL, drag chute is emergency deploy only.
+21:34 -10:40 V_{REL}=7.5 k fps (Mach = 7.5) Alt = 144 k ft	MCC has sufficient tracking for state vector update. This time can vary depending on ground track and tracking station performance.
+22:00 -10:14 V_{REL}=7 k fps (Mach = 7) Alt = 138 k ft	MCC and the crew compare TACAN data to NAV. If acceptable, MCC tells the crew to take TACAN. GNC 50 HORIZ SIT display is used to check TACAN errors and accept TACAN data for use by the NAV filter.
+22:41 -09:33 V_{REL}=6 k fps (Mach = 6) Alt = 131 k ft	PASS and BFS ENTRY TRAJ displays mode to GNC ENTRY TRAJ 5.
+23:30 -08:44 V_{REL} = 5 k fps (Mach = 5) Alt = 120 k ft	Air data probes are deployed. CDR, PLT begin aileron and rudder trim monitoring. The crew can check for good probe deploy discretes by noting the absence of OFF flags on the AMI and AVVI tapes when the *AIR DATA* select switch is taken from NAV to LEFT then RIGHT. This does not apply if the BFS is engaged. The BFS does not support OFF flags. Air data information will not be valid until Mach is <3.5.
+25:00 -07:14 (Mach = 3.4) Alt = 95 k ft	Using GNC 51 OVRD, GNC 50 HORIZ SIT, and instrument tapes the crew checks air data is close to NAV. MCC will give a GO to take air data to NAV and/or G&C using Items 25 and 28 on GNC 50 HORIZ SIT.
+25:30 -06:44 (Mach = 2.6) Alt = 83 k ft	PLT *ensures* APUs operating *in the best possible configuration for landing based on any previous failures*. CDR, PLT activate HUDs.

Terminal Area Energy Management (TAEM)

+25:40 -06:34 (Mach = 2.5) Alt = 81 k ft	PLT verifies air data incorporated into guidance. If not, the CDR must take CSS control to avoid a transient when air data is incorporated. Software transitions automatically to OPS 305. Guidance enters TAEM phase. VERT SIT 1 displays replace PASS and BFS ENTRY TRAJ displays.
+25:55 -06:19 (Mach = 2.4) Alt = 80 k ft	*Forward, aft, and midbody compartment* vents open.

+26:50 -05:24 (Mach = 2.0) Alt = 75 k ft	Air data must be incorporated to Guidance and Control or the crew must stay within theta limits as shown on the ADI or on the VERT SIT display.

WARNING

If low energy, or flying a big heading alignment cone (HAC) (>~325°) and air data is not incorporated, TAEM guidance will command an uncontrollable pitch up between Mach 1.0 and 1.5. The CDR will fly pitch CSS at M <2.0 and monitor theta limits.

+27:53 -04:21 (Mach = 1.0) Alt = 54 k ft	RCS yaw jets are deactivated.
+28:17 -03:57 (Mach = 0.9) Alt = 46 k ft	CDR selects pitch, roll, and yaw (R/Y) CSS. Speedbrake "commanded" versus "actual" position is verified. Speed brake is now controlling energy. PLT flight controller is verified ON. This switch must be on for NWS to work. NWS is verified in system 1.
+29:00 -03:14 (Mach = 0.7) Alt = 32 k ft	PLT verifies landing gear extend isolation valve is open *(occurs at M=0.8)*. PASS and BFS VERT SIT displays transition to VERT SIT 2. PLT and CDR monitor PASS and BFS GNC 50 HORIZ SIT for HAC acquisition. The glide slope indicator (GSI) is now accurate enough to use.
+30:00 -02:14 280 KEAS Alt = 15 k ft	MS2 monitors MLS acquisition. All residuals and ratios disappear from PASS GNC 50 HORIZ SIT upon MLS acquisition and an overbright MLS will appear in the middle right of the display. CDR and PLT check PAPIs and HUD overlays on runway to evaluate NAV state. De-clutter HUDs as required. Crew starts landing comm protocol.

Approach and Landing

+31:00 -1:14 300 KEAS (18° and 20° OGS) Alt = 12 k ft	CDR and PLT monitor outer glide slope (OGS) and verify with the PAPIs. At 10,000 ft crew verifies Approach and Landing guidance (flashing A/L on VERT SIT display), body flap to TRAIL, and LES visors down (KSC).
+31:24 -0:50 300 KEAS Alt = 5 k ft	PLT compares radar ALT 1 vs. 2.
+31:35 -0:39 300 KEAS Alt = 3 k ft	MS2 checks speed brake command percent (actual will lag).
31:41 -0:33 300 KEAS Alt = 2 k ft	CDR initiates preflare and begins transition onto ball bar. PLT arms landing gear on call from CDR.
+31:51 -00:23 297 KEAS Alt = 500 ft	Shuttle will be lined up on ball bar. MS2 checks speed brake command percent (second smart speed brake reset).
+31:54 -0:20 288 KEAS Alt = 300 ft	PLT deploys the landing gear on call from CDR. PLT/MS2 check gear indications down.

+32:04 -0:10 261 KEAS Alt = 30-80 ft	Final flare begins.
+32:14 -00:00 195 or 205 KEAS	Main gear touchdown (195 KEAS GW <220,000 lb). CDR controls drift with rudder, maintains wings level with RHC. PLT and MS check speed brake opening. PLT checks HUD display for WOW lock on (WOWLON) (HUD reconfigures and airspeed moves to upper left corner of the display). Also, the velocity vector disappears.
+32:15 +00:01 195 KEAS	PLT deploys drag chute on call from CDR. 195 KEAS.
+32:16 +00:02 185 KEAS	CDR initiates beep trim derotation, which targets 1.5 deg/sec.
+32:24 +00:10 145 to 155 KEAS	Nose gear touchdown (HUD reconfigures with a "G" showing up by the groundspeed). MS2 selects *SRB SEP* to *AUTO/MAN* or *ET SEP* to *MAN* and depresses the corresponding pushbutton to backup automatic discretes for elevon load relief, NWS, and anti-skid circuitry. CDR maintains or slowly and judiciously corrects to centerline with NWS. MS checks elevons down (makes sure they have load relief) and *NWS FAIL* and anti-skid fail lights off. MS calls "NWS FAIL" as necessary. (If no load relief, RHC full forward. If *NWS FAIL* light comes on, steer with rudder, RHC, and brakes. NWS2 may be available.)
+32:34 +00:20	CDR checks ground speed and decel on HUD. Post midfield, CDR applies brakes at 140 knots ground speed (KGS) or 5000 feet runway remaining, whichever occurs first. If 140 KGS is reached first, nominal braking profile is used This deceleration profile is typically 8 to 10 ft/sec^2. At 5000 feet of runway remaining, if groundspeed is greater than 140 knots, CDR applies maximum braking.
+32:46 +00:32 60 KGS (±20 kts)	PLT jettisons drag chute on CDR call.
+32:50 00:36 40 KGS	CDR reduces braking to less than 6 ft/sec^2 until wheelstop.
+32:56 +00:42	Orbiter stops; CDR reports “wheels stop” to MCC. Crew transitions to Post Landing Procedures in the Entry Checklist. At wheel stop, speed brake is closed.

5.5 POSTLANDING

- CDR takes NWS, flight controller power, and HUD power off. PLT checks that APU auto shutdown is enabled and speed select is in norm. PLT takes HUD power off.

- CDR and PLT safe RCS/OMS, and deactivate air data probe heaters.

- CDR, PLT, and MS safe the *drag chute and* landing gear.

- PLT, after notifying MCC, opens the ET umbilical doors. PLT initiates hydraulic load test on MCC call.

- CDR performs DPS transition to GNC OPS 901 on MCC call.

- CDR performs the radiator reconfig and activates the NH3 boiler, as required (MCC call or C/W). *Typically, this is done out of order from the rest of the postlanding procedures based on cooling requirements and frequently is done very early in the postlanding time frame.*

- PLT sets body flap to trail and performs main engine reposition with PASS OPS 9 display GNC 105 TCS CONTROL. PLT also performs APU/HYD shutdown after main engine repositioning is complete.

- CDR performs PCS deactivation. With a GO for extended powerup from MCC, CDR/PLT begin system deactivation. CDR secures GPCs 2-4 reassigning strings to GPC 1 and informs MS to proceed with MS System Deactivation Procedures (LRU and APU heater deactivation, RCS/OMS heaters turned OFF).

- PLT performs vent door purge positioning and RCS/OMS valve test.

- Convoy personnel open hatch.

- Flight Surgeon enters cabin for health check. ASP, suit tech, and Shuttle Processing Contract Spacecraft Operator (SPC SCO) enter the cabin to assist with egress and removal of experiments and early return items.

- CDR, MS, (PS) egress seats. MS, PS retrieve "return to Houston bags."

- CDR, PLT, MS, (PS) egress orbiter to begin postlanding activities. After medical evaluations, showers, visits with family and postlanding medical data collection, the crew returns to Houston. Normal return to Houston occurs 6 to 9 hours after landing.

- ASP removes special FDF but retains some entry related FDF until handover to KSC.

- ASP hands vehicle over to SPC SCO when MCC (Houston flight) hands off to Orbiter Test Conductor (OTC).

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6. EMERGENCY PROCEDURES

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This section covers critical failures to which the crew must react expeditiously. Both performance-related and system failures are presented. Critical system failures are those requiring a response within 5 minutes to safe the system or restore its function. Performance-related failures may result in an abort, depending upon the severity. Launch and ascent aborts are discussed in detail.

The emergency procedures in this section are designed to be general in nature and not flight specific. Detailed procedures are available in Flight Data File (FDF) checklists. It is very important that crewmembers learn to recognize failures and react properly. Failure identification is the key. Only through study, training, and practice will a crewmember achieve the desired degree of proficiency prior to flight.

In some areas, actual crew operations are described, along with monitoring and control devices. This is particularly important for aborts, where dynamic flight cues, instruments, and cue cards must be rapidly interpreted. Some abort rationale is also included to ensure the crewmember understands various abort modes.

The key to most emergencies is to utilize all information available, including inputs from the Launch Control Center (LCC) while on the pad and postlanding, and from the Mission Control Center (MCC) during all flight phases. Both the LCC and MCC have an enormous amount of data at their disposal. With the highly trained Launch Team and Flight Team working together with the crew, most emergencies can be quickly identified and proper actions started.

There are three levels of protection to prevent loss of a shuttle because of failures: component failure prevention, vehicle design, and training.

Component failure prevention is accomplished through a stringent process of equipment design, qualification tests, maintenance, checkout, quality control, and proper operation.

The shuttle is designed to a "fail-ops/fail-safe" philosophy. This means that loss of any one component can be tolerated without compromising the mission, and loss of a second component will not result in loss of vehicle or crew. Obviously, this requires redundant systems and system components. Managing this redundancy adds to shuttle complexity.

The third level of protection is the human element: crew, MCC, and LCC training. In order to quickly and correctly respond to performance or systems problems, as well as complex multiple failures, the flight crew and ground crews must be experts on shuttle systems and how to control them. Prior to flight, both the ground teams and the crew participate in many hours of intense simulations to improve their teamwork and knowledge of shuttle systems. A stringent certification process is also in place to ensure qualified and current personnel in all disciplines.

Failures tend to fall into two general categories, single component and multiple.

For single-component failures, patience is important. Shuttle design should allow time to properly analyze what has happened and what steps are necessary to regain the lost component or to optimize remaining systems to protect against additional failures. A common error among inexperienced personnel is to act too quickly, do the wrong thing, and make the situation worse.

Multiple failures are more difficult to deal with, because reaction time must be short, and procedures may not be explicit. Most FDF procedures are written considering a maximum of two failures. To avoid burdensome complexity and to maintain credibility, this is the only way to realistically tailor procedures to a vehicle as complex as the shuttle. The result is that a specific procedure may not be available to guide the crew, or several procedures must be combined or executed in rapid succession. For these cases, the crew and ground teams must rely on their knowledge and training. Once again, reacting too quickly can jeopardize vehicle integrity.

To cope with potential failures in a dynamic environment, such as ascent or entry, the flight crew must constantly keep in mind their current status and mentally prepare for potential additional failures before they occur. This "staying ahead of the airplane" philosophy, along with system reconfiguration for optimization and built-in graceful degradation of systems, enhances the chances of a successful outcome when multiple failures are encountered.

6.1 LAUNCH ABORT MODES AND RATIONALE

CONTENTS

Mode 1 – Unaided Egress/Escape...... 6.1-1
Mode 2 – Aided Escape........................ 6.1-1
Mode 3 – Aided Escape........................ 6.1-2
Mode 4 – Aided Escape........................ 6.1-2

A shuttle launch may be scrubbed or aborted up to solid rocket booster (SRB) ignition. Normally, launch scrubs prior to space shuttle main engine (SSME) start are followed by an orderly safing procedure and crew egress, assisted by the closeout crew. A fully fueled shuttle on the launch pad may present an extremely hazardous situation if toxic vapors, fire, or structural damage are present. A launch abort after SSME start is automatically controlled by the ground launch sequencer (GLS). The most serious hazard here is the presence of excess hydrogen, resulting in a hydrogen fire, which is invisible to the eye and very dangerous. This situation occurred during a launch attempt for STS-41D.

In the event of an emergency at the launch pad, the NASA Test Director (NTD), who mans a console in the Launch Control Center (LCC) firing room, is in command. Priority is flight and ground crew egress and escape, followed by preventing destruction of the shuttle, facilities, complex, and support equipment.

Should an abnormal event occur that terminates a flight or prelaunch operation and results in substantial damage to the shuttle and/or injury to personnel, the NTD will declare a contingency situation. This alerts fire and rescue personnel and puts in motion pre-planned procedures to minimize further damage and injuries.

The NTD may also initiate action if an emergency condition exists that requires immediate action to prevent loss of life or destruction of equipment. In preparation for a potential emergency condition, a hazardous condition may be declared if there is a threat to personnel health or safety. A hazardous condition may develop into an emergency condition.

Depending upon the severity of the situation on the launch pad, an emergency egress/escape may be required to evacuate personnel. The shuttle program has classified four launch pad escape modes that are preplanned and rehearsed by the flight crew, closeout crew, and all launch pad personnel. Defining these modes prior to the development of an emergency condition or contingency situation ensures standard procedures can be followed and minimizes risk of additional injury and damage.

Mode 1 – Unaided Egress/Escape

This escape mode may be initiated by the NTD or flight crew. The NTD will direct that the orbiter access arm (OAA) be returned to its position at the crew module hatch. The fire/rescue crew will be dispatched if the NTD decides it is safe to do so. Escape from the shuttle vehicle and the pad is performed by the crew. This procedure is practiced in trainers and mockups in Houston and rehearsed during terminal countdown demonstration test (TCDT) at KSC. Because crew complement varies from flight to flight, each crew must develop their own particular procedures. Using a buddy system is strongly recommended. Egressing the shuttle along the OAA and across the pad 195 ft level to the slidewire baskets through the water deluge fire suppression system is a hazardous operation. Given the very real potential of fire, toxic vapors, and explosion, flight crews must be well-trained and prepared.

Mode 2 – Aided Escape

Aided escape is initiated by the NTD, flight crew, or closeout crew. This mode is used when the closeout crew is still on the pad. The closeout crew leader is responsible for ensuring that all personnel egress from the shuttle and proceed along the prescribed escape route to a safe area. The NTD will also alert the fire/rescue crew. Injured personnel will be assisted/carried along the escape route, and basic first aid will be rendered if required. The closeout crew leader keeps the NTD informed of medical conditions and egress/escape progress.

Mode 3 – Aided Escape

Initiated by the NTD or flight crew, this mode is used after the closeout crew has departed, and a contingency occurs that requires assistance. The OAA is repositioned, and the fire/rescue crew proceeds to the pad to assist the flight crew. The actual egress/escape is similar to the Mode 2 operation, except the fire/rescue crew substitutes for the closeout crew.

Mode 4 – Aided Escape

This mode is initiated by the NTD, closeout crew, or flight crew. It involves a contingency where one or more members of the closeout crew or flight crew are trapped or injured. Rescue and escape are performed by the fire/rescue crew, assisted by the closeout crew and flight crew. Use of all seven slidewire baskets may be required. Personnel accountability is critical.

In summary, launch aborts may range from a scrub/turnaround to a complex rescue scenario. Crews must be very familiar with all hardware and procedures. This requires training and practice. Prior to any launch pad evolution, a careful review of emergency procedures is warranted.

6.2 ASCENT ABORTS

CONTENTS

Performance Aborts................................ 6.2-1
Systems Aborts.. 6.2-4
Range Safety 6.2-4

Events that require an ascent abort can be generally grouped into performance and systems failures. Flight Rules that govern these two types of scenarios are incorporated into various real-time MCC calls, along with the NO COMM MODE BOUNDARIES and the SYS FLIGHT RULES cue cards.

Performance Aborts

The amount of performance lost when a shuttle engine loses thrust or fails is directly related to the time of the problem. Early engine degradation or failure while the shuttle is heavy with fuel may preclude achieving a safe orbit. Late engine problems may result in no underspeed at all. Fortunately, it is not necessary to fly all the way to main engine cutoff (MECO) to find out how large the underspeed will be. By using a computer program called the abort region determinator (ARD), MCC can predict the underspeed that will result from any performance problem. Thus, the MCC can immediately determine whether the desired or even a safe orbit can be achieved. If a safe orbit cannot be achieved, some type of abort will be required.

There are two basic types of ascent abort modes, intact and contingency. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed to permit crew survival following more severe failures when an intact abort is not possible. A contingency abort could result in either a landing at an East Coast Abort Landing (ECAL) site or in a crew bailout over the ocean.

The intact aborts will be discussed here. Contingency aborts are discussed in section 6.7.

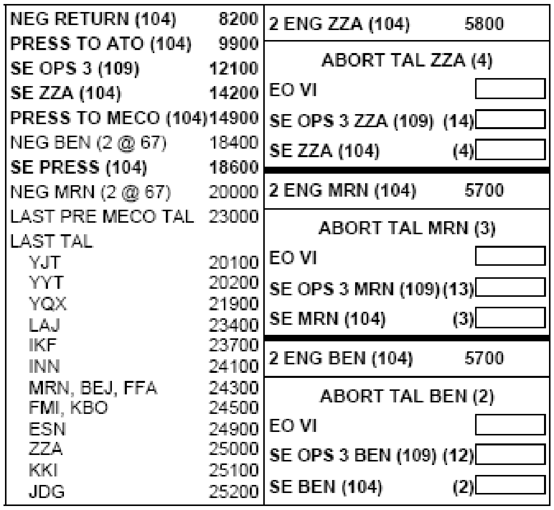
For cases where the orbiter comes close to achieving normal orbit, the abort might simply consist of going to a lower, but perfectly safe, orbit. This is called an abort to orbit (ATO).

If even a low orbit cannot be achieved, an abort once around (AOA) may be used. The orbiter is placed into a suborbital trajectory leading to a landing after a single revolution around the Earth.

The next available abort mode, if performance does not permit an AOA, is a transoceanic abort landing (TAL), which results in landing on a runway in Europe or Africa.

Finally, for intact aborts, if an engine fails after lift-off and before TAL is possible, a return to launch site (RTLS) abort would be performed.

During powered flight, the crew tracks vehicle present abort capability by MCC voice calls. If communications are lost, the NO COMM MODE BOUNDARIES card provides a summary of ascent abort mode capability.



NEG RETURN (104)	**8200**
PRESS TO ATO (104)	**9900**
SE OPS 3 (109)	**12100**
SE ZZA (104)	**14200**
PRESS TO MECO (104)	**14900**
NEG BEN (2 @ 67)	18400
SE PRESS (104)	**18600**
NEG MRN (2 @ 67)	20000
LAST PRE MECO TAL	23000
LAST TAL	
YJT	20100
YYT	20200
YQX	21900
LAJ	23400
IKF	23700
INN	24100
MRN, BEJ, FFA	24300
FMI, KBO	24500
ESN	24900
ZZA	25000
KKI	25100
JDG	25200

2 ENG ZZA (104)	**5800**	
ABORT TAL ZZA (4)		
EO VI		☐
SE OPS 3 ZZA (109)	**(14)**	☐
SE ZZA (104)	**(4)**	☐
2 ENG MRN (104)	**5700**	
ABORT TAL MRN (3)		
EO VI		☐
SE OPS 3 MRN (109)	**(13)**	☐
SE MRN (104)	**(3)**	☐
2 ENG BEN (104)	**5700**	
ABORT TAL BEN (2)		
EO VI		☐
SE OPS 3 BEN (109)	**(12)**	☐
SE BEN (104)	**(2)**	☐

FB 2-4 ASC/116/FIN

NO COMM MODE BOUNDARIES Cue Card

This card does not reflect off-nominal performance such as a stuck throttle. Only the ARD can calculate abort mode boundaries based on actual performance. The ARD takes real-time performance into account when predicting real-time mode boundaries.

The abort mode boundaries are flight specific. Times change significantly because of differences in mass properties, environmental modeling, and performance characteristics. Boundary names may also change. For example, some missions will not have a Press to ATO boundary. Also, TAL sites are mission specific. Higher inclination flights require a different philosophy of calls and checklist mode boundaries than lower inclination flights.

What follows is a generic discussion of mode boundaries. Flight-specific data is available from the Flight Dynamics Officers (FDO).

Two-Engine TAL

TWO-ENGINE TAL is the earliest inertial velocity (V_I), at which AUTO guidance, using only two SSMEs, will achieve the desired MECO targets to the designated TAL landing site.

An engine failure prior to this point will most likely mean an RTLS.

Even after this point, RTLS capability is still available. TAL, however, is typically preferred for engine failures in this overlap region. Single-engine completion capability is attained much earlier for TAL than RTLS, and the TAL profile is not as dynamic as the RTLS profile. On the other hand, in cases of severe systems failures that require the crew to land as soon as possible, an RTLS may be preferred over TAL.

Negative Return

NEGATIVE RETURN represents the last opportunity to abort RTLS and still achieve the desired MECO targets. Past this V_I, the orbiter will have too much downrange energy to successfully return to KSC.

An engine failure past Negative Return will most likely mean a TAL.

Press to ATO

This boundary represents the earliest V_I at which AUTO guidance can achieve the design underspeed at MECO with only two SSMEs. This typically requires having to abort ATO and performing a pre-MECO OMS dump to reduce vehicle weight and improve ascent performance.

An engine failure prior to this point will most like mean a TAL.

The constraints on design underspeed are ET impact, minimum performance, minimum altitude, contingency c.g. envelope protection, and minimum net positive suction pressure (NPSP) for the main engines.

Press to MECO

Like Press to ATO, this boundary also represents the earliest V_I at which AUTO guidance can achieve the design underspeed at MECO with only two SSMEs. The difference here is that the vehicle now has enough velocity that no abort is necessary and a pre-MECO OMS dump will not be required.

An engine failure prior to this point will most likely mean an ATO.

SE OPS 3 109

The single-engine (SE) OPS 3 boundary represents the point in the ascent where two engines can fail and the flight will continue the ascent to MECO for an OPS 3 entry instead of an OPS 6 entry. It also represents the dividing line between two Contigency Abort procedures: CONT 2 OUT SECOND and CONT 2 OUT DROOP (see section 6.7).

The SE OPS 3 boundary is a function of Bermuda/east coast abort landing (BDA/ ECAL) capability, emergency landing site (ELS) capability, and the ability to target a TAL or ELS without descending below 265,000 feet during powered flight (minimum droop altitude). Going below the minimum droop altitude violates ET heating constraints, and loss of vehicle is expected. Although European ELSs can be used for determining the SE OPS 3 boundary, typical ELSs are islands well short of the planned TAL site, such that single-engine runway capability occurs as early as possible in the powered trajectory. Depending on inclination, the island runways used are Lajes, Azores; Las Palmas, Canary Islands; and Amilcar Cabral, Cape Verde Islands.

In case droop capability comes before the last possible BDA/ECAL opportunity, SE OPS 3 will be called on at the earliest of the following: last BDA/ECAL, first ELS, or single-engine limits to an augmented contingency landing site (ACLS).

In any case, capability to a runway exists for all these boundaries.

If BDA/ECAL capability does not overlap droop capability or there is no BDA/ECAL capability, the SE OPS 3 boundary may not ensure runway capability because the boundary will be called solely on the minimum droop altitude, without regard to TAL/ELS runway capability. A bailout likely will be necessary.

Single Engine TAL (104)

This boundary represents the earliest V_I where AUTO guidance can achieve the desired TAL targets line after two simultaneous engine failures.

Two engines failing prior to this point will most likely mean a Contingency Abort.

Single Engine Press

This boundary represent the earliest V_I after which AUTO guidance can achieve the critical underspeed after two simultaneous engine failures.

Two engines failing prior to this point will most likely mean a TAL.

Critical underspeed is the same as design underspeed, excluding the ET impact and NPSP constraints. Other criteria may be found in the Flight Rules.

Last Pre-MECO TAL

This boundary (not normally called out by MCC) represents the last opportunity to abort TAL pre-MECO and still achieve the proper TAL targets.

If a TAL is desired after this point, the crew will need to manually command MECO before a certain V_I (mission dependent), and then perform a post-MECO TAL.

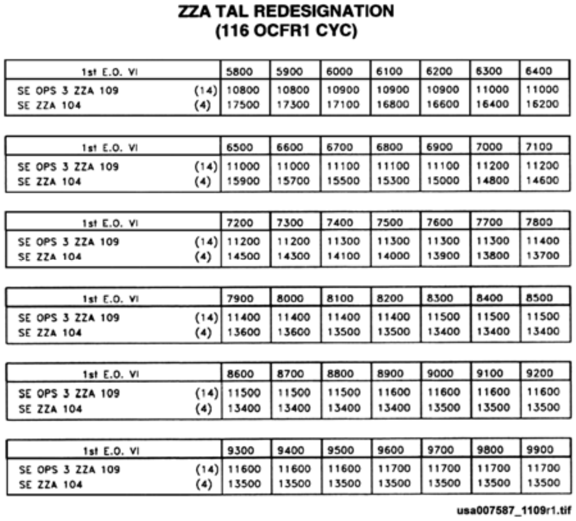
Last TAL

This boundary (also not normally called out by MCC) represents the highest MECO velocity after which a TAL or ELS site is no longer an option. After this point, an AOA or certain high-energy procedures may be invoked.

TAL REDEZ

SE OPS 3 and SINGLE ENGINE TAL both assume simultaneous engine failures. With staggered engine failures, these mode boundaries shift, depending on when the failures occur.

The flight crew uses the TAL REDESIGNATION cue card to determine the new mode boundaries after the first SSME failure.



ZZA TAL REDESIGNATION
(116 OCFR1 CYC)

1st E.O. VI		5800	5900	6000	6100	6200	6300	6400
SE OPS 3 ZZA 109	(14)	10800	10800	10900	10900	10900	11000	11000
SE ZZA 104	(4)	17500	17300	17100	16800	16600	16400	16200

1st E.O. VI		6500	6600	6700	6800	6900	7000	7100
SE OPS 3 ZZA 109	(14)	11000	11000	11100	11100	11100	11200	11200
SE ZZA 104	(4)	15900	15700	15500	15300	15000	14800	14600

1st E.O. VI		7200	7300	7400	7500	7600	7700	7800
SE OPS 3 ZZA 109	(14)	11200	11200	11300	11300	11300	11300	11400
SE ZZA 104	(4)	14500	14300	14100	14000	13900	13800	13700

1st E.O. VI		7900	8000	8100	8200	8300	8400	8500
SE OPS 3 ZZA 109	(14)	11400	11400	11400	11400	11500	11500	11500
SE ZZA 104	(4)	13600	13600	13500	13500	13400	13400	13400

1st E.O. VI		8600	8700	8800	8900	9000	9100	9200
SE OPS 3 ZZA 109	(14)	11500	11500	11500	11600	11600	11600	11600
SE ZZA 104	(4)	13400	13400	13400	13400	13500	13500	13500

1st E.O. VI		9300	9400	9500	9600	9700	9800	9900
SE OPS 3 ZZA 109	(14)	11600	11600	11600	11700	11700	11700	11700
SE ZZA 104	(4)	13500	13500	13500	13500	13500	13500	13500

usa007587_1109r1.tif

ZZA TAL REDESIGNATION Cue Card

For example:

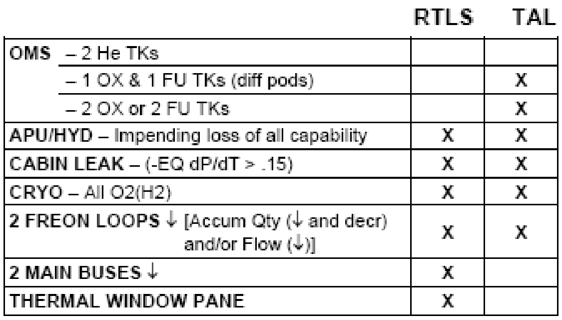
> With three engines running, SE OPS 3 and SE TAL will occur at a V_I of 12,100 fps and 14,200 fps, respectively.
>
> If an engine fails at a V_I = 6000 fps, the new SE OPS 3 and SE TAL boundaries would be at a V_I of 10,900 fps and 17,100 fps, respectively.

These velocities assume a 109% or 104% throttle, as specified in parentheses.

Systems Aborts

The SYS FLIGHT RULES cue card summarizes the Flight Rules requiring RTLS and TAL selection in response to critical systems failures.

In most cases, additional insight provided by MCC is necessary to accurately and fully diagnose a failure and select the best response. In the event of sudden multiple failures, help by MCC is critical. For COMM loss, however, only the SYS FLIGHT RULES cue card is available.



	RTLS	TAL
OMS – 2 He TKs		
– 1 OX & 1 FU TKs (diff pods)		X
– 2 OX or 2 FU TKs		X
APU/HYD – Impending loss of all capability	X	X
CABIN LEAK – (-EQ dP/dT > .15)	X	X
CRYO – All O2(H2)	X	X
2 FREON LOOPS ↓ [Accum Qty (↓ and decr) and/or Flow (↓)]	X	X
2 MAIN BUSES ↓	X	
THERMAL WINDOW PANE	X	

SYS FLIGHT RULES Card

OMS Capability

A severe loss of OMS capability (e.g. leaking propellant or helium) can make it impossible to continue uphill and subsequently deorbit. If total OMS capability is lost while still in powered flight, a TAL would be required.

APU/HYD

With the impending loss of all hydraulics, a trajectory option with minimum time to the ground is desired. This enhances the potential to land prior to a complete loss of hydraulics.

Cabin Leak

Loss of cabin pressure integrity impacts both breathing oxygen and equipment cooling. A minimum time to the ground option is required.

Cryo

Loss of cryo O2 or H2 will result in a loss of fuel cells and all electrical power. A minimum time to the ground option is required.

Freon Loops

Losing both Freon loops will eventually result in loss of all three fuel cells due to lack of cooling. Since this is time critical, RTLS is preferable over TAL.

Main Buses

Two main bus failures preclude ET door closure. Since TAL entry trajectories are thermally severe, RTLS is preferred. If RTLS is no longer possible (past NEGATIVE RETURN), pressing uphill is preferable to TAL.

Thermal Window Pane

An abort is required for the outer forward windshield or side hatch thermal window pane. An RTLS abort is selected to minimize the thermal stresses on the remaining windowpanes and surrounding structure. Entry heat loads are less on an RTLS than on other abort modes or during a normal landing. This choice provides a better chance of the remaining panes and surrounding structure surviving entry.

Range Safety

Launch vehicles convert vast amounts of chemical potential energy into equally vast amounts of kinetic energy to put their payloads into orbit. Despite all planning, design, and tests, the possibility that a malfunction could cause a vehicle to fly out of control toward a populated area must be considered. Range Safety's function is to terminate flights that are far enough out of normal bounds to endanger populated areas. During first stage, this is accomplished by remotely detonating explosive charges aboard the SRBs. During second stage, the responsibility for range safety is on the MCC/crew, with inputs from Range Safety at KSC.

To protect populated areas, impact limit lines are drawn around them. No lethal piece of a vehicle can land behind an impact limit line. Since termination would have to occur well before an impact limit line is reached, destruct lines are drawn inside the boundaries of the impact limit lines. A vehicle passing outside the boundaries of the destruct line would be subject to termination.

Controllability

During first-stage, trajectory deviations may lead to a violation of a destruct line by a shuttle that is still under control. It may be possible to return the vehicle toward its nominal trajectory or to safely execute an abort. Therefore, the Flight Director (FD) and Flight Dynamics Officer (FDO) are in voice communication with the Flight Control Officer (FCO) (formerly Range Safety Officer) during ascent. If the FCO detects a violation, the FDO and FD are immediately informed. The FD must determine whether the shuttle is controllable or uncontrollable, and inform the FCO. As long as the FD declares the shuttle controllable, the FCO takes no action to terminate the flight for trajectory deviations alone.

Range Safety Limit Avoidance

A deviation from nominal trajectory that is large enough to warrant FCO action must be corrected. First-stage options are:

- State vector update
- Select CSS (after 90 seconds MET)
- Engage BFS

In second stage, the options are:

- State vector update
- ATO selection
- Select CSS
- TAL or RTLS selection
- Engage BFS
- SSME manual cutoff. For loss of comm, FCO will send the ARM command as a cue for manual MECO

Options are listed in order of priority. The priorities are established such that higher priority options preserve lower priority options and involve fewer new dangers to the crew and shuttle when possible.

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6.3 RETURN TO LAUNCH SITE

CONTENTS

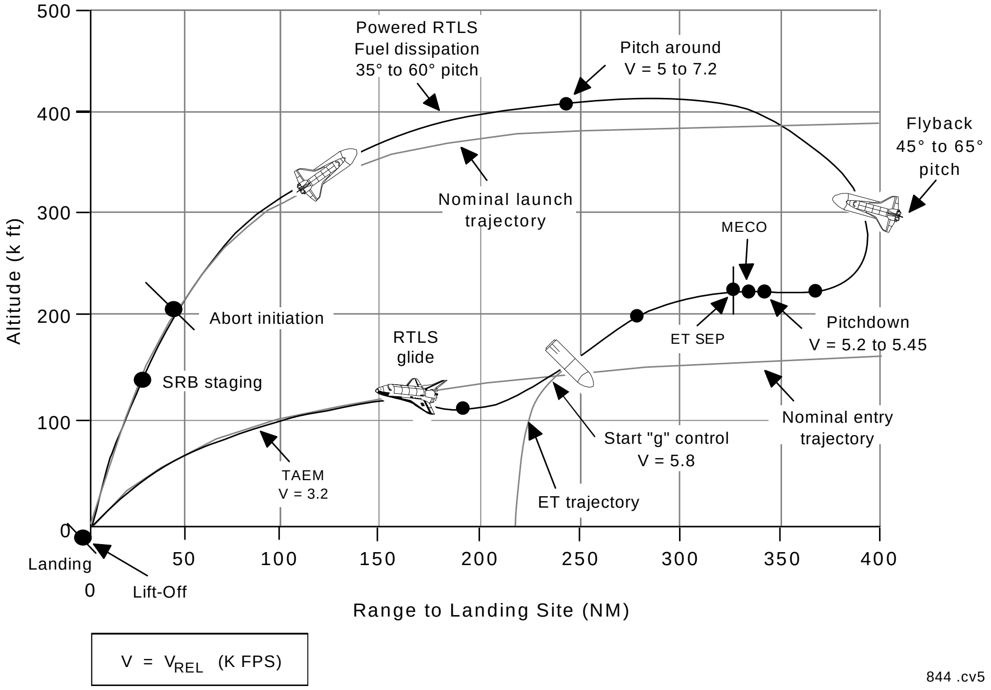
Powered RTLS 6.3-2
Gliding RTLS 6.3-6

RTLS abort is designed to provide intact abort capability for a suborbital return of the shuttle to the KSC Shuttle Landing Facility (SLF). An RTLS abort may be declared for an engine failure after lift-off and prior to NEGATIVE RETURN.

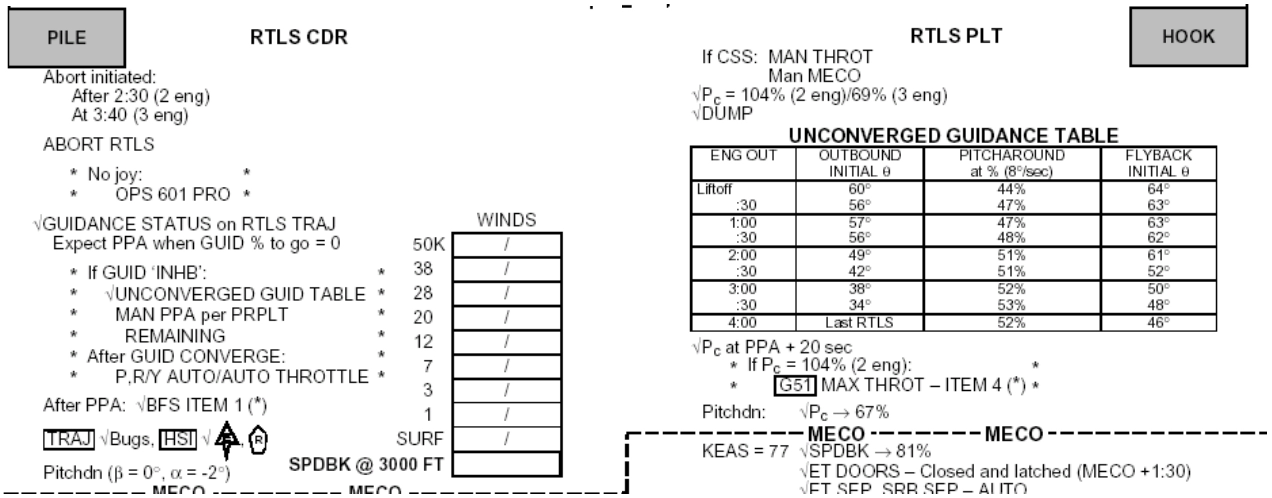
In order to reach the SLF, the shuttle must reverse course and fly back the way it came. The turn to reverse course is called powered pitch around (PPA). Timing of this maneuver is critical. Engines must be shut down when the shuttle has exactly enough speed and altitude to glide to the SLF runway. Also, for safe separation, the ET must have no more than 2% propellant remaining. Excessive propellant will slosh and could cause the ET and shuttle to collide.

Selection of an RTLS abort is driven by several factors. Heat loading on the ET restricts RTLS selection to no earlier than 2 minutes 30 seconds (2+30) after lift-off. For RTLS systems aborts, selection occurs at 3 minutes 40 seconds. Abort overlap allows either an RTLS or a TAL to be selected. When RTLS/TAL overlap exists, TAL may be the preferred mode, since a second engine failure can be accepted much earlier and still make the runway. Also, the powered flight phase of RTLS is several minutes longer, causing more exposure to some types of MPS/SSME failures. An RTLS however, gets the orbiter back on the ground sooner and is not as thermally stressful as a TAL.

Once the decision is made to initiate an RTLS abort, MCC will direct the crew to "Abort RTLS." The FD will also turn on the *ABORT* light on panel F6, using a switch on their console, as a backup to the voice call. Onboard, moving the *ABORT MODE* rotary switch to *RTLS* and depressing the Abort pushbutton reconfigures GNC software to RTLS. As a backup, the crew can enter OPS 601 PRO on any PASS keyboard.



Typical RTLS Profile



PILE **RTLS CDR**

Abort initiated:
After 2:30 (2 eng)
At 3:40 (3 eng)

ABORT RTLS

* No joy: *
* OPS 601 PRO *

√GUIDANCE STATUS on RTLS TRAJ
Expect PPA when GUID % to go = 0

* If GUID ‘INHB’: *
* √UNCONVERGED GUID TABLE *
* MAN PPA per PRPLT *
* REMAINING *
* After GUID CONVERGE: *
* P,R/Y AUTO/AUTO THROTTLE *

After PPA: √BFS ITEM 1 (*)

TRAJ √Bugs, HSI √

Pitchdn (β = 0°, α = -2°)

WINDS	
50K	/
38	/
28	/
20	/
12	/
7	/
3	/
1	/
SURF	/
SPDBK @ 3000 FT	

MECO MECO

RTLS PLT **HOOK**

If CSS: MAN THROT
Man MECO
√P_c = 104% (2 eng)/69% (3 eng)
√DUMP

UNCONVERGED GUIDANCE TABLE

ENG OUT	OUTBOUND INITIAL θ	PITCHAROUND at % (8°/sec)	FLYBACK INITIAL θ
Liftoff	60°	44%	64°
:30	56°	47%	63°
1:00	57°	47%	63°
:30	56°	48%	62°
2:00	49°	51%	61°
:30	42°	51%	52°
3:00	38°	52%	50°
:30	34°	53%	48°
4:00	Last RTLS	52%	46°

√P_c at PPA + 20 sec
* If P_c = 104% (2 eng): *
* G51 MAX THROT – ITEM 4 (*) *

Pitchdn: √$P_c \rightarrow$ 67%

MECO **MECO**

KEAS = 77 √SPDBK → 81%
√ET DOORS – Closed and latched (MECO +1:30)
√ET SEP, SRB SEP – AUTO

RTLS Pre-MECO Procedures

Powered RTLS

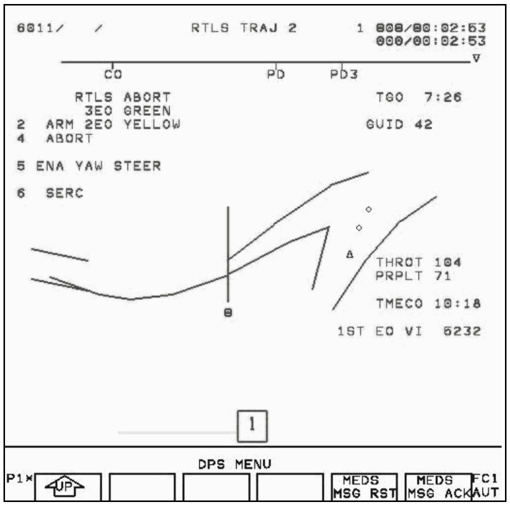
Powered RTLS (PRTLS) begins when the abort is initiated and terminates at MECO. PRTLS guidance is designed to deliver the shuttle to a MECO location at the proper altitude (I-load), flight path angle, and speed (function of range).

Guidance during PRTLS is closed loop. Computed MECO conditions are compared to desired MECO targets to determine a miss vector. This vector is then used to compute corrections in steering and throttle commands.

The crew monitors guidance using cue cards and DPS displays.

Should guidance not converge, the crew will see “GUID INHB” on the RTLS TRAJ display. MCC, in conjunction with the crew, will request CSS takeover if guidance does not converge within a reasonable time.

The primary display for PRTLS is RTLS TRAJ. Some of the information on this display comes directly from NAV and is independent of guidance.



```
6011/    /          RTLS TRAJ 2          1 000/00:02:53
                                           000/00:02:53
       CO                    PD     PD3
       RTLS ABORT                           TGO   7:26
        3EO GREEN
2  ARM 2EO YELLOW                          GUID 42
4  ABORT

5 ENA YAW STEER

6  SERC
                                          THROT  104
                                          PRPLT  71

                                          TMECO  10:18

                                       1ST EO VI   5232
```

PASS **RTLS TRAJ Display**

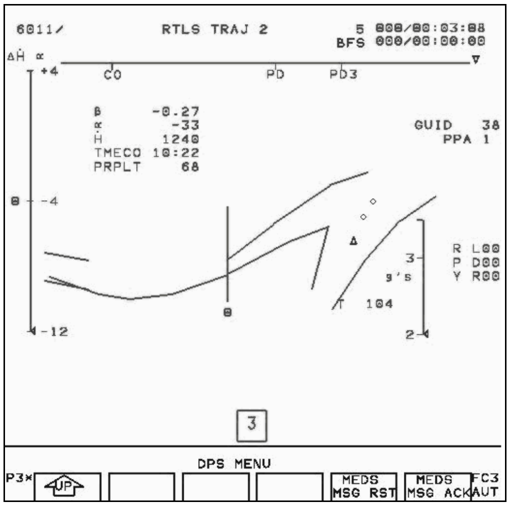
The central portion of the display is a plot of altitude versus horizontal component of V_{REL}, with the zero-velocity point at the end of the top trajectory line to the left of the screen midpoint. Shuttle position is plotted with a triangle. Predictors are generated to show 30- and 60-second positions. Trajectory lines are approximations of a generic set of high and low dispersed trajectories for an engine out at lift-off and just before negative return.

On the left side of the BFS ASC TRAJ, there is a scale for delta H dot and angle of attack (α). The delta H dot scale is not used operationally and is not trained. The scale is intended to provide a “fly to” indication for controlling altitude rate during the RTLS profile. However, this scale is referenced to a canned RTLS profile and, therefore, is not useful in most cases. The alpha scale is just a graphical representation of the NAV-derived angle of attack. This scale also is not used operationally and, therefore, is not trained. The middle of the scale has a mark at -4°, which was intended to provide a reference during ET SEP while trying to maintain an AOA of -4° for separation. However, the desired angle of attack for ET SEP is now -2°, so the scale does not provide a good visual cue for the separation.

Two guidelines at the left end of the lower TRAJ line depict the q-bar limit for ET SEP. The shuttle symbol should be between these two lines, while approaching MECO. The lower line represents q-bar at 1 psf and the upper line represents q-bar at 2 psf.

A delta range scale at the top of the display represents current glide range. Near MECO, the cutoff bug moves from right to left, passing the pitchdown points for 3-engine (PD3) and 2-engine (PD) PRTLS. The cutoff (CO) point indicates where MECO should occur to obtain proper glide range to the runway.

Digital readouts present useful data for monitoring performance. Additional readouts on the BFS RTLS TRAJ present computed values of sideslip (beta), angle of attack (alpha), total vehicle acceleration, attitude errors, and computed throttle command.


6011/ RTLS TRAJ 2 5 000/00:03:08
BFS 000/00:00:00

β -0.27
α -33
Ḣ 1240
TMECO 10:22
PRPLT 68

GUID 38
PPA 1

R L00
P D00
Y R00

T 104

BFS RTLS TRAJ 2 Display

To function properly, guidance needs to know the shuttle’s speed and time when an engine fails. Normally, the GPCs will capture this data, but the crew should also note the time. This becomes important later to determine key trajectory parameters.

NOTE

> If CSS flight control is selected, manual throttle control must also be selected. This will require manual throttle down and shutdown.

Fuel Dissipation

After abort selection, the first phase is fuel dissipation. During fuel dissipation, the shuttle continues heading downrange at a fixed inertial thrust direction. Cyclical computations are performed to determine the proper time to initiate turnaround. Should the abort be declared near the NEGATIVE RETURN boundary, pitch-around may occur immediately with no fuel dissipation.

For the crew to fly fuel dissipation phase in CSS, they must know the proper pitch angle (theta) and when to pitch around. Using the engine fail time, the RTLS cue card UNCONVERGED GUIDANCE TABLE is entered and the appropriate theta and pitcharound propellant remaining are determined. Theta is chosen to minimize altitude loss while heading away from the runway. Once set, it remains constant through the fuel dissipation phase.

Powered Pitch Around

This turn changes shuttle attitude from heads-down going away from the launch site to heads-up pointing toward the launch site by an approximately 60° to 70° pitchdown maneuver. Until zero relative velocity is reached, the shuttle is still moving away from the launch site. Powered pitch around is performed at 10° per second pitch rate in AUTO. This is a dramatic maneuver and is designed to prevent lofting while passing through vertical orientation.

Timing of powered pitch around is critical and must occur within a certain interval to ensure the shuttle arrives at MECO with the proper amount of fuel remaining and the proper energy. The crew monitors guidance using the GUID % to go on the RTLS TRAJ 2 display. The percentage displayed is the percent deviation of the predicted final mass from the RTLS mass target. When the percentage equals zero, PPA should occur.

Should guidance be unconverged, the crew should select CSS and manual throttle control and pitch around manually at the appropriate propellant remaining cue.

NOTE

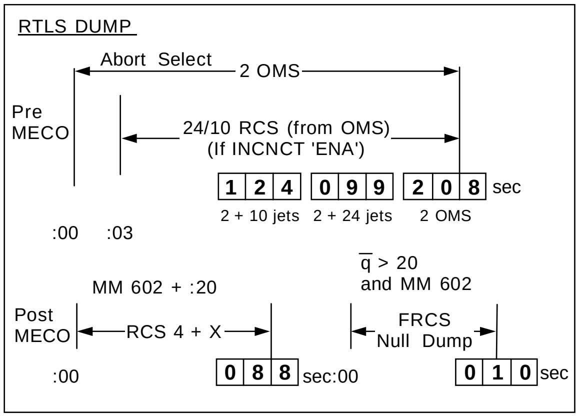
> It is much better to pitch around slightly early than slightly late as late pitch-arounds may result in not reaching a nominal RTLS MECO state.

OMS Dump

OMS propellant onboard at launch is mission specific. Because the propellant is stored in tanks located near the back end of the shuttle, it causes the c.g. to be considerably aft of the point at which the shuttle is designed to fly. For aborts such as RTLS, this excess propellant is dumped.

The dump is actually a burn, using the OMS engines and possibly the aft RCS jets. For interconnected dumps, valves are reconfigured by the GPCs to allow OMS propellant to be burned through the RCS jets. When RTLS is selected, the OMS engines begin burning immediately. Smart Interconnect takes approximately 3 seconds to reconfigure and check the valves. Some missions have interconnected-inhibited dumps where the dump is through the OMS engines only.

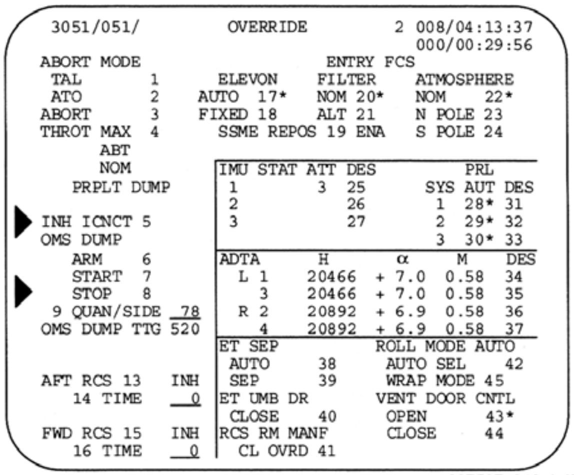
Normally, RTLS dumps are a combination of 2 OMS engines and 24 aft RCS jets. The jets used are 4 +X jets and 20 null jets. The +X jets fire directly aft and produce no significant rotational movement. Null jets fire in opposite directions so that they cancel each other out. Dump times are mission specific and are depicted on the RTLS/TAL DUMPS cue card.



RTLS/TAL Dumps

When the dump is complete, OMS/RCS valves are automatically reconfigured by the GPCs in preparation for MECO. If required procedurally, the crew can secure one or both OMS engines by placing the *ARM/PRESS* switch in *OFF*.

Dump time-to-go (TTG) counts down to zero during RTLS dumps. During the dump, the interconnect can be inhibited or enabled by toggling ITEM 5.



```
  3051/051/          OVERRIDE          2 008/04:13:37
                                         000/00:29:56
 ABORT MODE                     ENTRY FCS
  TAL        1      ELEVON    FILTER    ATMOSPHERE
  ATO        2    AUTO  17*   NOM 20*   NOM    22*
 ABORT       3    FIXED 18    ALT 21    N POLE 23
 THROT MAX   4      SSME REPOS 19 ENA   S POLE 24
       ABT
       NOM        IMU STAT ATT DES         PRL
    PRPLT DUMP     1        3  25      SYS AUT DES
                   2           26        1  28* 31
▶INH ICNCT 5       3           27        2  29* 32
 OMS DUMP                                3  30* 33
    ARM     6     ADTA      H      α      M    DES
    START   7      L 1    20466  + 7.0  0.58   34
▶   STOP    8        3    20466  + 7.0  0.58   35
  9 QUAN/SIDE  78    R 2    20892  + 6.9  0.58   36
 OMS DUMP TTG 520      4    20892  + 6.9  0.58   37
                  ET SEP            ROLL MODE AUTO
                   AUTO      38      AUTO SEL    42
 AFT RCS 13    INH  SEP       39      WRAP MODE 45
    14 TIME     0 ET UMB DR          VENT DOOR CNTL
                   CLOSE     40      OPEN        43*
 FWD RCS 15    INH RCS RM MANF        CLOSE       44
    16 TIME     0   CL OVRD 41
```

usa007587_849r1.tif

OVERRIDE Display

Onboard failures, such as electrical or DPS problems, can cause serious OMS/RCS valve reconfiguration problems. "Smart Interconnect" Software should reconfigure the valves or inhibit some or all of the jets to prevent any serious problems.

Shuttle abort dumps are complex procedures and must be executed correctly in a time-critical situation. Consult the Ascent/Aborts Flight Procedures Handbook for additional information.

Flyback

This phase is part of PRTLS where the shuttle points back toward the runway. Guidance computes steering and throttle commands that direct the shuttle along the proper trajectory.

Should CSS control be required, the crew should stop the PPA maneuver at the initial flyback theta, as determined from the RTLS PLT UNCONVERGED GUIDANCE TABLE. The shuttle pitch attitude must then be adjusted to fly back along or parallel to the guidelines on the RTLS TRAJ display.

> **WARNING**
>
> Do not allow the predictors to fall below the lower guideline during flyback. Recovery from this low altitude condition may be impossible.

In the area of high q-bar, the guidelines are very important to avoid structural overload or ET SEP problems. As the predictors reach the left edge of the display, control theta to fly between the guidelines until the delta-R bug begins to move.

Powered Pitchdown

To satisfy altitude and flight path angle constraints at MECO, a positive angle of attack of about 30° is required. However, to safely separate the ET, an alpha of -2° is necessary. The transition between these attitudes is called powered pitchdown.

The maneuver must be completed rapidly (5° to 8° per second) to avoid large sink rates, which could cause overheating or overstressing. Engines are throttled back to reduce trajectory impact. Should CSS be required when the bug reaches the appropriate pitchdown mark (PD3 or PD), the shuttle should be pitched down at 5° to 8° per second to alpha = -2°. At this point the crew should null beta. Simultaneously, the engines are manually throttled to 67 percent. These procedures are summarized on the RTLS CDR and PLT cue cards.

MECO and ET SEP

Because the MECO time has been fixed by the GPCs, an attitude of alpha = -2 must be held until the delta-R bug reaches the CO mark, and the engines are shut down either by the GPCs or manually. After shutdown, a mated coast phase occurs for approximately 13 seconds. During this phase, valves are closed, umbilicals retracted, and electrical connections deadfaced. The RCS jets control attitude.

The shuttle is then ready for ET SEP, which will occur automatically, provided certain constraints are within limits.

	DESIGN TARGET	DESIGN TOLERANCES	VEHICLE LIMITS
Roll rate, P	0°	±1.25°/sec	20 > P > -20
Pitch rate, Q	-.25°/sec	±0.5°/sec	+.25 > Q > -20
Yaw rate, R	0°/sec	±0.5/sec	+20 > R > -20
Angle of attack, α	-2°	±.05°	-1.5° > α > -89°
Side slip angle, β	0	±2°	+20 > β > -20
Roll angle ∅	0	±5°	None

RTLS ET Auto Separation Limits

These limits prevent separation in an unsafe attitude, which might cause shuttle/ET collision. If the parameters are not within limits, an ET SEP inhibit suspends the separation sequence until the out-of-limits is corrected or 6 seconds expire, whichever occurs first. The timer is necessary because of rapid q-bar buildup, which makes a safe separation impossible, regardless of attitude. Separation can be commanded manually using the ET *SEPARATION* switch and *ET SEP* pushbutton on panel C3.

Immediately after ET SEP, the DAP performs a translation and pitch maneuver to fly the shuttle away from the ET. This is accomplished by firing all of the shuttle's downfiring jets. The combination of four forward and six aft downfiring jets results in a simultaneous translation and rotation, which moves the shuttle up and away from the ET. Once the shuttle achieves an alpha ≥ +10° and time from ET SEP ≥ 10 seconds, the GPCs mode to MM 602 and the glide portion of RTLS (GRTLS) begins.

In CSS and manual throttle, a manual MECO must be performed using the *MAIN ENGINE*

SHUT DOWN pushbuttons on panel C3. The alpha = -2 degree attitude must be maintained until ET SEP. This will require a small negative pitch rate due to H-dot increase, which causes alpha to become more positive. The -Z translation maneuver will occur automatically unless the CDR intervenes by moving the THC out of detent. If this is done, a manual -Z maneuver should be performed to ensure safe separation, and the pitch up maneuver to alpha ≥ +10° must also be manually performed. Generally, it is preferable to allow the DAP to perform these maneuvers automatically.

Gliding RTLS

The gliding portion of RTLS is very similar to the final portions of entry, which are discussed in detail in Section 7. Only significant differences are presented here.

Post-MECO Dumps

After MECO and ET SEP, the remaining MPS propellants must be dumped to assist in c.g. control and, for the liquid hydrogen, to reduce potential fire hazard. The MPS dump sequences are very similar for the nominal, TAL, and RTLS modes. The LO2 and LH2 are dumped simultaneously to save time.

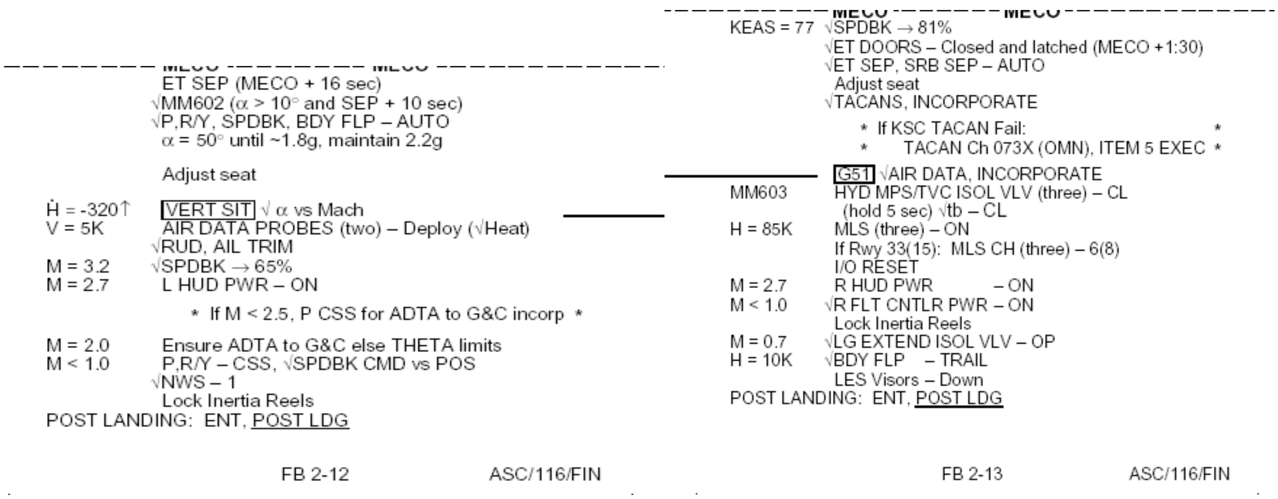
The RTLS MPS dump starts immediately upon transition to MM 602. LO2 is dumped through the main oxidizer valves in the main engines and the 8-inch fill/drain line on the starboard side of the orbiter. LH2 is dumped through the 1.5-inch backup dump line and the 8-inch fill/drain line on the orbiter port side aft. To ensure a rapid LH2 dump, the LH2 manifold is pressurized with helium.

The onboard software also allows a post-MECO dump of RCS propellant through the RCS jets to satisfy maximum tank landing weight constraints and c.g. control.

Guidance

During GRTLS, guidance manages the shuttle's energy state to arrive at the runway with sufficient energy to complete a safe landing. GRTLS guidance is divided into five phases:

- Alpha Recovery
- N_Z Hold
- Alpha Transition
- S-Turn
- GRTLS TAEM



```
---------- MECO --------- MECO ----------------
           ET SEP (MECO + 16 sec)
          √MM602 (α > 10° and SEP + 10 sec)
          √P,R/Y, SPDBK, BDY FLP – AUTO
           α = 50° until ~1.8g, maintain 2.2g

           Adjust seat

Ḣ = -320↑  VERT SIT √ α vs Mach
V = 5K     AIR DATA PROBES (two) – Deploy (√Heat)
          √RUD, AIL TRIM
M = 3.2   √SPDBK → 65%
M = 2.7    L HUD PWR – ON

              *  If M < 2.5, P CSS for ADTA to G&C incorp  *

M = 2.0    Ensure ADTA to G&C else THETA limits
M < 1.0    P,R/Y – CSS, √SPDBK CMD vs POS
          √NWS – 1
           Lock Inertia Reels
POST LANDING:  ENT, POST LDG

                    FB 2-12                ASC/116/FIN
```

```
------------- MECO -------- MECO ---------------
KEAS = 77  √SPDBK → 81%
           √ET DOORS – Closed and latched (MECO +1:30)
           √ET SEP, SRB SEP – AUTO
            Adjust seat
           √TACANS, INCORPORATE

               *  If KSC TACAN Fail:                    *
               *      TACAN Ch 073X (OMN), ITEM 5 EXEC  *

            G51 √AIR DATA, INCORPORATE
MM603       HYD MPS/TVC ISOL VLV (three) – CL
             (hold 5 sec) √tb – CL
H = 85K     MLS (three) – ON
            If Rwy 33(15):  MLS CH (three) – 6(8)
            I/O RESET
M = 2.7     R HUD PWR         – ON
M < 1.0    √R FLT CNTLR PWR – ON
            Lock Inertia Reels
M = 0.7    √LG EXTEND ISOL VLV – OP
H = 10K    √BDY FLP   – TRAIL
            LES Visors – Down
POST LANDING:  ENT, POST LDG

                    FB 2-13                ASC/116/FIN
```

RTLS Post-MECO Procedures

These phases provide for transition from a ballistic trajectory, through hypersonic gliding flight, to an energy management scheme designed to make the runway.

Alpha Recovery

Pullout from the ET SEP attitude must be accomplished quickly before aerodynamic forces build up to uncontrollable levels. To accomplish this, the shuttle maneuvers to a high (alpha = 50°) angle of attack using both RCS jets and aerodynamic controls.

Increasing dynamic pressure caused by the shuttle falling into the atmosphere causes more lift to be generated by the wings. The resultant lift produces a Z–axis acceleration (N_z). At about 1.65 g, the DAP starts to reduce alpha to hold an N_z of 2.2 g's. The shuttle N_z limit for RTLS is 2.0 – 2.5 g's (based on the vehicle's weight).

Roll jets are secured at q-bar = 10. Pitch jets are secured at q-bar = 40. Yaw jets are required until Mach = 1.0. When KEAS = 77, the speed brake is ramped open to about 81 percent to enhance lateral stability by allowing the elevons to be trimmed down. Below Mach = 0.95, the speed brake position is modulated by GRTLS TAEM guidance.

N_Z Hold

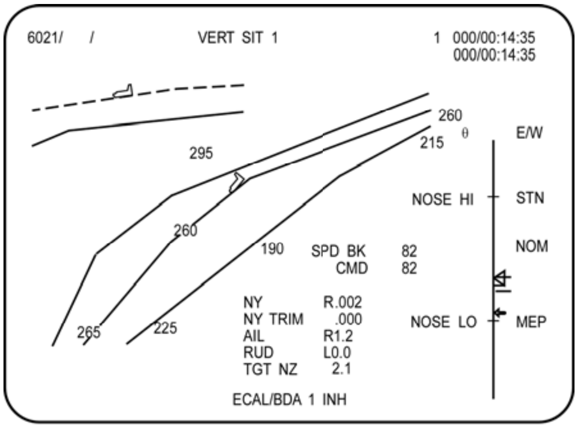
Alpha is smoothly decreased to maintain the 2.2 g limit until H-dot is greater than -320 ft/sec. Excessive g-loading could cause structural damage and also dissipate excessive energy. The ADI pitch error needle displays N_z error during this phase.

Alpha Transition

Upon termination of N_z hold, alpha is changed to conform to a profile that is a function of Mach number. This profile provides the best vehicle control until active ranging begins in GRTLS TAEM. Also, a bank maneuver is performed, either to null any heading errors to the heading alignment cone (HAC) tangency point, or to dissipate excess energy by turning (S-turn) away from the HAC. The maximum bank angle is 45°. The ADI pitch error needle displays alpha error during alpha transition phase. Guidance can be manually downmoded to the straight-in or minimum entry point (MEP) HAC if required due to low energy.

To fly the alpha transition in CSS, the display in the upper left corner of VERT SIT 1 is used. The shuttle symbol initially appears in this portion of the display, which represents an alpha versus Mach number profile. The dashed line is the nominal profile, and the solid line is the q-bar limit.

The ENTRY ALPHA cue card can also be used for alpha transition. Since there are no procedures to initiate S-turns manually, ranging is accomplished by exercising the OTT options described in Section 7. The MCC can also request a GCA and accomplish S-turns by asking the crew to fly appropriate bank angles or headings.



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GRTLS Vertical Situation 1 Display

Note: Shuttle symbol appears only at one location on the display at a time

S-Turn

An S-turn can be initiated in GRTLS TAEM or while still in alpha transition. S-turns increase the distance to be flown, thus decreasing energy. It is possible that more than one S-turn would be required. Starting and stopping of S-turns can be monitored using the E/W scale on VERT SIT 1.

GRTLS TAEM

This phase is essentially identical to normal entry TAEM, which is discussed in detail in Section 7. The main differences are that GRTLS TAEM starts at Mach = 3.2 and an alpha limiting corridor exists.

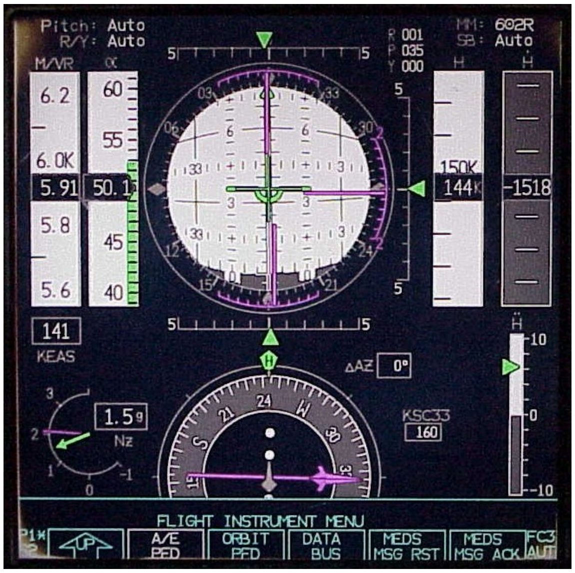
The MPS/TVC ISOL valves must be closed by the crew before the low altitude/high maneuvering regions of GRTLS TAEM to prevent PRL. These valves must remain open until MPS dump completion at approximately Mach = 4.5.

To conserve power during ascent, the MLS LRUs are powered off. They must be turned on and communication established (I/O RESET) at about 85 k ft during GRTLS.

Postlanding procedures are the same as nominal end of mission, except that the hydraulic load test is not performed.

RTLS Flight Displays

RLS MM 601



RLS MM 601

RTLS Ascent Specific Notes

- **RTLS** abort verified by letter “R” adjacent to MM field in upper-right corner

E **Earth-Relative Velocity** bearing pointer and **Beta** digital readout are displayed on an RTLS ascent (Inertial Velocity is blanked)

R **Runway bearing pointer** appears at RTLS selection indicating bearing to the selected abort runway

R Tail of Runway bearing pointer shows when heading away from the RTLS site

- SPEC 50 **Runway** selection, **Range** to runway in nm, and **ΔAz** appear at RTLS abort select
- **Compass Card** displays magnetic heading on a N, E, S, W reference
- **X-Trk, ΔInc** and **CDI** are also blanked at RTLS abort select
- **Mach/Velocity** tape displays VI prior to PPA, then VR post PPA

6.4 TRANSOCEANIC ABORT LANDING

CONTENTS

Nominal Transoceanic Abort Landing 6.4-1
Post MECO Transoceanic Abort Landing 6.4-3

The purpose of a transoceanic abort landing (TAL) is to provide an intact abort capability for single-engine failures between 2 ENGINE TAL and PRESS TO ATO (MECO). It also offers an intact option for two engine failures much earlier than SINGLE ENGINE PRESS. TAL also supports system aborts that occur after NEGATIVE RETURN such as cabin leaks, cooling problems, or OMS propellant loss.

During a TAL abort, the shuttle flies an entry trajectory across the ocean to land on a mission-specific runway. Landing occurs approximately 40 minutes after launch. Powered flight guidance has the capability to target 13 different landing sites, which are selected based on runway length, weather, and orbital inclination. Landing sites near the nominal ascent ground-track are more efficient since crossranging requirements are reduced. Typically, only three TAL sites are supported for possible use on each mission.

Nominal Transoceanic Abort Landing

TAL is selected prior to MECO by placing the *ABORT MODE* rotary switch on panel F6 in *TAL* and pressing the *ABORT* pushbutton. Item entries on the OVERRIDE display (SPEC 51) may also be used to select TAL should the *ABORT MODE* switch fail. The crew should note the title of the ASCENT TRAJ display changes to TAL TRAJ and the MM 103T (flight instruments upper right corner) as confirmation that the TAL flag has been set. The shuttle indicator (triangle) and predictors should follow the upper trajectory line on *the PASS and* BFS TAL TRAJ 2 *displays*.

Abort Dump

When TAL is selected, an abort dump begins immediately. OMS propellant is usually dumped through the OMS engines plus 24 aft RCS jets interconnected to the OMS propellant tanks. The OMS/RCS interconnects are determined preflight via I-loads for each abort scenario. They may be enabled or inhibited by the crew if required. Some OMS propellant will be dumped in MM 304 prior to 0.05 g. This dump is performed primarily to increase separation from the ET.

If a TAL is initiated after an I-loaded velocity (dependent on two or three engines remaining), there will not be enough time to complete the OMS dump. For these cases, the remaining engines will be throttled down automatically to 67% to gain extra dump time.

The OMS dump should be stopped if helium pressure decreases to 2,000 psi to ensure helium will not be ingested into the RCS lines.

Guidance

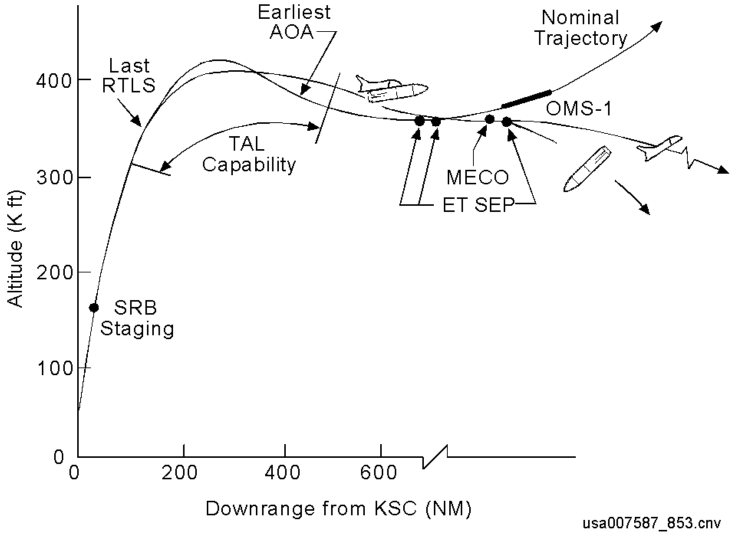
At abort selection, TAL guidance begins steering the shuttle toward the selected landing site plane. Variable I-Y steering is used to bring crossrange to the TAL site within acceptable limits (approximately 500 n. mi.) at MECO.

The crew monitors guidance during TAL aborts using the TAL CDR and TAL PLT cue cards.

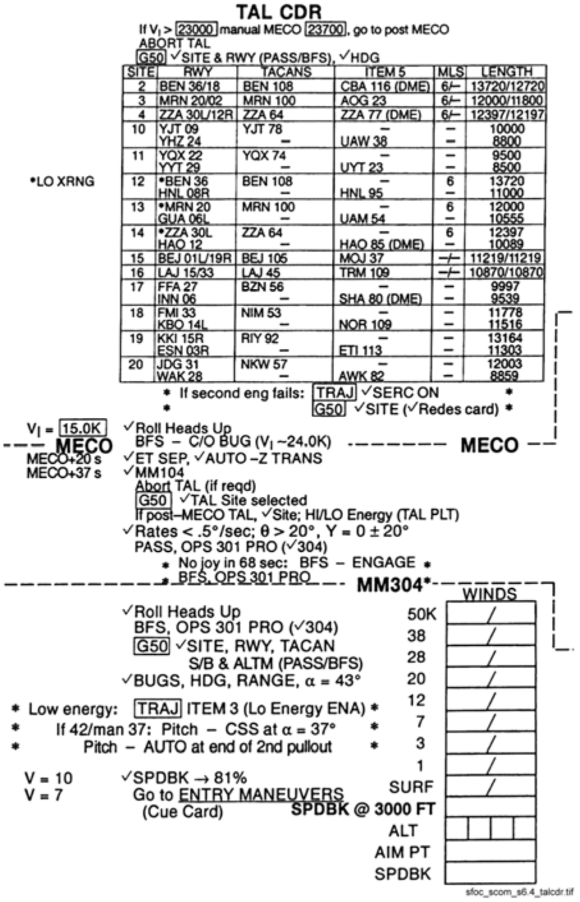
It is important to verify, using SPEC 50, that the correct landing site is selected.

Should a second engine fail during a TAL, the OMS dump will continue through the OMS engines, but the dump through the RCS will be terminated. The crew must push the two failed engine *MAIN ENGINE SHUT DOWN* pushbuttons on panel C3 to set the safing flag. The contingency dump must also be started using SPEC 51.

Trajectory droop, along with guidance convergence and main engine performance, are the deciding factors in defining the earliest single-engine TAL capability. Drooping below the 265 k ft limit will result in either an explosion due to ET heating or a loss of control. If two engines fail near the SE OPS 3 109 boundary, the crew should throttle up to 109 percent. Droop guidance will engage and pitch up to 60° on the ADI to minimize sink rate and enable the shuttle to remain above 265 k ft. When thrust-to-weight is greater than 1, the shuttle will begin to climb and accelerate downrange.



TAL versus nominal Ascent



TAL CDR

If $V_I >$ $\boxed{23000}$ manual MECO $\boxed{23700}$, go to post MECO ABORT TAL

$\boxed{G50}$ ✓SITE & RWY (PASS/BFS), ✓HDG

SITE	RWY	TACANS	ITEM 5	MLS	LENGTH
2	BEN 36/18	BEN 108	CBA 116 (DME)	6/–	13720/12720
3	MRN 20/02	MRN 100	AOG 23	6/–	12000/11800
4	ZZA 30L/12R	ZZA 64	ZZA 77 (DME)	6/–	12397/12197
10	YJT 09 YHZ 24	YJT 78 –	– UAW 38	– –	10000 8800
11	YQX 22 YYT 29	YQX 74 –	– UYT 23	– –	9500 8500
12	•BEN 36 HNL 08R	BEN 108 –	– HNL 95	6 –	13720 11000
13	•MRN 20 GUA 06L	MRN 100 –	– UAM 54	6 –	12000 10555
14	•ZZA 30L HAO 12	ZZA 64 –	– HAO 85 (DME)	6 –	12397 10089
15	BEJ 01L/19R	BEJ 105	MOJ 37	–/–	11219/11219
16	LAJ 15/33	LAJ 45	TRM 109	–/–	10870/10870
17	FFA 27 INN 06	BZN 56 –	– SHA 80 (DME)	– –	9997 9539
18	FMI 33 KBO 14L	NIM 53 –	– NOR 109	– –	11778 11516
19	KKI 15R ESN 03R	RIY 92 –	– ETI 113	– –	13164 11303
20	JDG 31 WAK 28	NKW 57 –	– AWK 82	– –	12003 8859

•LO XRNG

* If second eng fails: $\boxed{TRAJ}$ ✓SERC ON *
* $\boxed{G50}$ ✓SITE (✓Redes card) *

V_I = $\boxed{15.0K}$ ✓Roll Heads Up
BFS – C/O BUG (V_I ~24.0K)

--- MECO -------- MECO ---

MECO+20 s ✓ET SEP, ✓AUTO –Z TRANS
MECO+37 s ✓MM104
Abort TAL (if reqd)
$\boxed{G50}$ ✓TAL Site selected
If post–MECO TAL, ✓Site; HI/LO Energy (TAL PLT)
✓Rates < .5°/sec; θ > 20°, Y = 0 ± 20°
PASS, OPS 301 PRO (✓304)
* No joy in 68 sec: BFS – ENGAGE *
* BFS, OPS 301 PRO

---------- MM304* ----------

✓Roll Heads Up
BFS, OPS 301 PRO (✓304)
$\boxed{G50}$ ✓SITE, RWY, TACAN
S/B & ALTM (PASS/BFS)
✓BUGS, HDG, RANGE, α = 43°

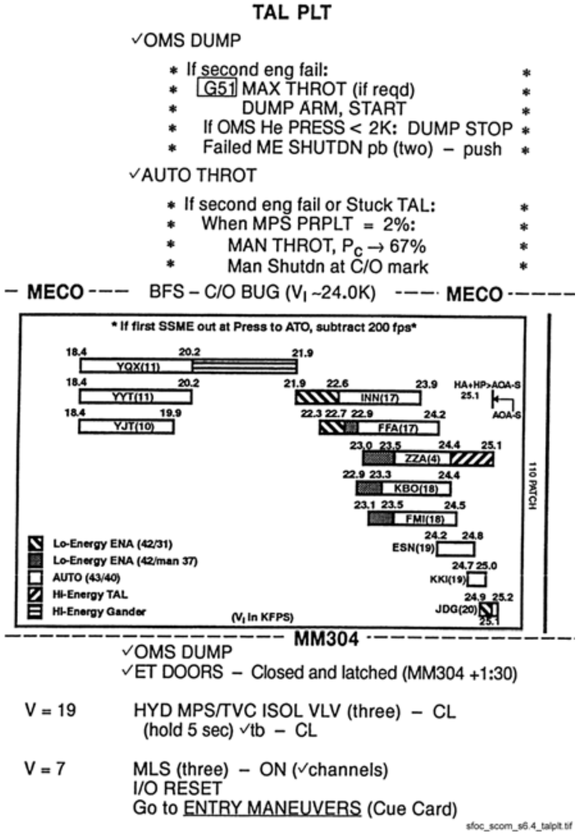
* Low energy: $\boxed{TRAJ}$ ITEM 3 (Lo Energy ENA) *
* If 42/man 37: Pitch – CSS at α = 37° *
* Pitch – AUTO at end of 2nd pullout *

V = 10 ✓SPDBK → 81%
V = 7 Go to ENTRY MANEUVERS (Cue Card)

WINDS	
50K	/
38	/
28	/
20	/
12	/
7	/
3	/
1	/
SURF	/
SPDBK @ 3000 FT	
ALT	
AIM PT	
SPDBK	

sfoc_scom_s6.4_talcdr.tif

TAL CDR Procedures



TAL PLT

✓OMS DUMP

* If second eng fail: *
* $\boxed{G51}$ MAX THROT (if reqd) *
* DUMP ARM, START *
* If OMS He PRESS < 2K: DUMP STOP *
* Failed ME SHUTDN pb (two) – push *

✓AUTO THROT

* If second eng fail or Stuck TAL: *
* When MPS PRPLT = 2%: *
* MAN THROT, P_c → 67% *
* Man Shutdn at C/O mark *

– MECO --- BFS – C/O BUG (V_I ~24.0K) --- MECO -----

* If first SSME out at Press to ATO, subtract 200 fps*

▧ Lo-Energy ENA (42/31)
▩ Lo-Energy ENA (42/man 37)
☐ AUTO (43/40)
▨ Hi-Energy TAL
▤ Hi-Energy Gander

(V_I in KFPS)

---------- MM304 ----------

✓OMS DUMP
✓ET DOORS – Closed and latched (MM304 +1:30)

V = 19 HYD MPS/TVC ISOL VLV (three) – CL
(hold 5 sec) ✓tb – CL

V = 7 MLS (three) – ON (✓channels)
I/O RESET
Go to ENTRY MANEUVERS (Cue Card)

sfoc_scom_s6.4_talplt.tif

TAL PLT Procedures

To lessen ET heating effects and to put the shuttle in the correct entry attitude at ET SEP, a roll to heads up is performed at an I-loaded reference velocity. If the shuttle is still in the heads down attitude when TAL is selected, roll to heads up will occur at the TAL I-loaded velocity. If the shuttle has already performed the nominal roll to heads up when TAL is selected, it will remain in the heads up attitude for the rest of powered flight. The roll is performed at 5° per second.

TAL MECO occurs about 2,800 n. mi. from the landing site. For inplane sites, very little banking for azimuth control is necessary if started as soon as possible after the first MM 304 pullout. Waiting to null out delta azimuth until late in the entry can severely reduce crossrange capability.

The MCC will recommend the best approach to the field. An overhead approach is preferred.

OPS Transition

TAL is a unique abort in that it requires transition to GNC OPS 3 after MECO and ET SEP, which is time-critical. The PASS computers obtain this software from upper memory.

WARNING

To prevent loss of control, engage BFS and type in OPS 301 PRO if the PASS does not mode into OPS 3 within 68 seconds.

The 68 seconds mentioned above are a holdover from when the OPS 3 software had to be loaded from the mass memory units. The maximum time it would take to try and load the software after attempting both SSMMs is 6-8 seconds.

About 3 minutes are available to complete the OPS transition between ET SEP and the start of dynamic pressure buildup depending on the altitude, flight path angle, and velocity at MECO. This period is critical. The shuttle is entering the atmosphere, and the TRANS DAP is not designed for atmospheric flight. All procedures must be completed quickly and accurately. Ignore all systems problems unless they are extremely critical until correct entry flight control is available.

Post-MECO Dumps

An MPS dump similar to the RTLS dump begins automatically at MM 304. The TAL LH2 MPS dump is unpressurized.

Once in MM 304, the OMS dump restarts to ensure separation with the ET. This dump adds about 100 fps ΔV to the shuttle's energy. (Several missions have used 200 fps ΔV.) For post-MECO TALs, the dump also ensures orbiter landing weight, c.g., and tank landing weight constraints are met.

The FRCS null jet dump typically starts at MM 304 to help control X c.g. location.

An aft RCS dump is commenced at V_{REL} = 9 k fps. This dump reduces aft propellant to meet weight and c.g. constraints. The dump time is an I-load, which is usually 88 seconds. Should the aft RCS quantity be low, the dump can be inhibited using SPEC 51. For missions with forward X c.g. concerns, this dump will not be performed.

Entry

MM 304 is very similar to a normal end-of-mission entry (discussed in detail in Section 7) with the exception of the 43° initial angle of attack flown during the TAL pullout phase which protects for high wing leading edge temperatures.

Post MECO Transoceanic Abort Landing

An intact abort capability is available between V_I ~21.5 to 23 k fps (mission specific) and AOA capability by using the TAL entry software. The abort is declared after MECO. For late systems problems after last pre-MECO TAL, the crew performs a manual MECO at the specified velocity using the *MAIN ENGINE SHUT DOWN* pushbuttons.

NOTE

For high inclination missions, a crew-initiated (MAN MECO) post-MECO TAL is not an option. This is because, for high inclination missions, the post-MECO TAL landing sites are emergency landing sites (ELSs), and the program has decided to try for an AOA rather than land at an ELS.

MECO velocity takes into account the ΔV due to SSME tailoff. This number is flight specific and depends upon inclination.

The boundaries chart shows approximate TAL site coverage for a range of early MECO conditions. Using the real time downrange abort evaluator (DAE), the MCC will determine the appropriate site and communicate data to the crew. Cue card boundaries are used for loss of communications.

High Energy TAL

MECO velocities between approximately 24.5 k and 25.2 k fps may be too low for AOA capability (especially if the OMS propellant has been dumped) and too high for auto guidance to make a TAL site. For inclinations <57°, a high-energy TAL procedure is available. This procedure uses high angles of attack, prebank, and OMS dumps to dissipate excess energy and to allow the orbiter to land at a TAL site from these MECO velocities. For inclinations >57° the only option in this situation is to abort to an ELS or to bail out.

Post MECO Dump

The high-energy TAL post-MECO OMS dump is similar to the TAL OMS dump. Interconnected dumps are performed automatically only in indicated regions.

Guidance

Upon entry into MM 304, guidance will roll the shuttle to heads up, if not there already.

The crew should verify that the proper runway is selected. For low energy cases, low energy logic is required until the shuttle is within the trajectory lines on the ENTRY TRAJ display.

After runway selection is verified, and guidance is converged, AUTO flight control may be reselected. The remaining high-energy TAL procedures are identical to the nominal TAL.

6.5 ABORT ONCE AROUND

CONTENTS

OMS-1 .... 6.5-1
OMS-2 .... 6.5-3
Entry 6.5-4

The abort once around (AOA) abort mode is used in cases where shuttle performance has been lost to such an extent that it is impossible to achieve a viable orbit, or not enough OMS propellant is available to accomplish the OMS-1, OMS-2, and deorbit burns. AOA may also be used when a major systems failure makes it necessary to land quickly.

In an AOA for a standard insertion, or a low performance direct insertion, one OMS burn is made to adjust the post MECO orbit such that a second burn will result in the orbiter deorbiting and landing at an AOA landing site. In an AOA for a systems failure during a nominal performance direct insertion, only the deorbit burn is required. Landing occurs about 1 hour and 45 minutes after lift-off.

There are two AOA trajectories with several different options for each one, depending upon the reason for performing an AOA: steep AOA and shallow AOA.

Entry trajectory for the steep AOA is very similar to a nominal entry and is the preferred trajectory due to thermal considerations. However, steep targets require more ΔV and therefore more propellant. Shallow AOA results in a flatter trajectory, which places the shuttle closer to the skipout boundary and thermal limits. This is less desirable, but requires less OMS propellant, which is important for severe underspeed cases or if both OMS helium tanks have failed with propellant quantities above max blowdown.

Execution of an AOA is determined by an MCC call and by checking the OMS-1 target solution against the OMS 1/2 TGTING cue card. If required, OMS-1 targets are loaded and burned. After OMS-1, the desired OMS-2 targets are selected on the MNVR EXEC display. Then the software is moded to OPS 3 and the appropriate OMS-2 (deorbit) targets are loaded and burned. After the deorbit burn, an entry is flown that is very similar to the nominal end of mission.

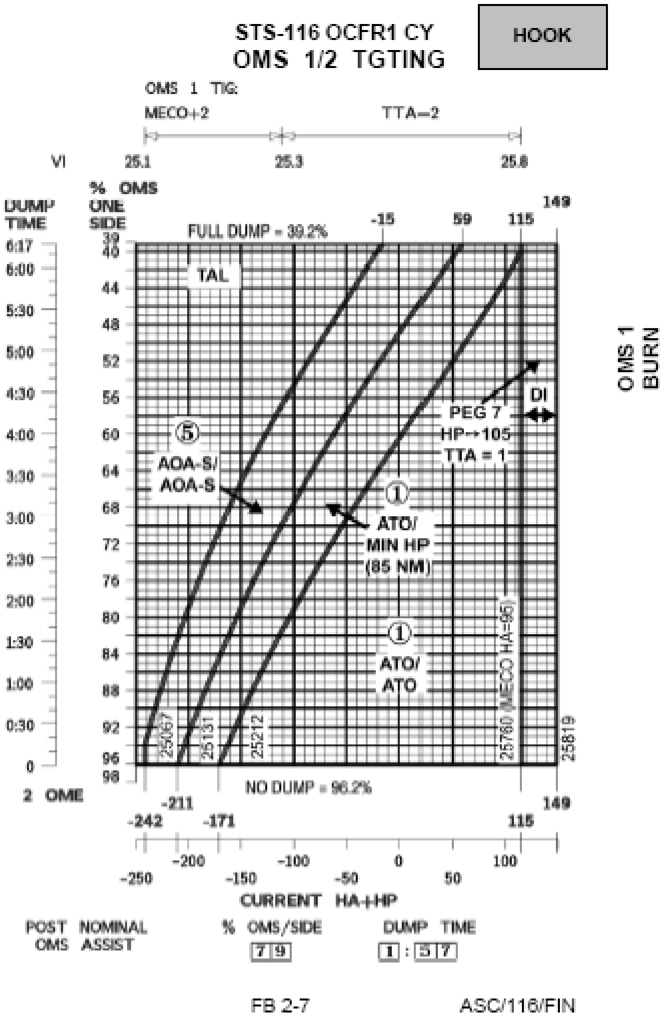
OMS-1

AOA can only be selected post MECO by crew selection of an AOA target set on the OMS MNVR display.

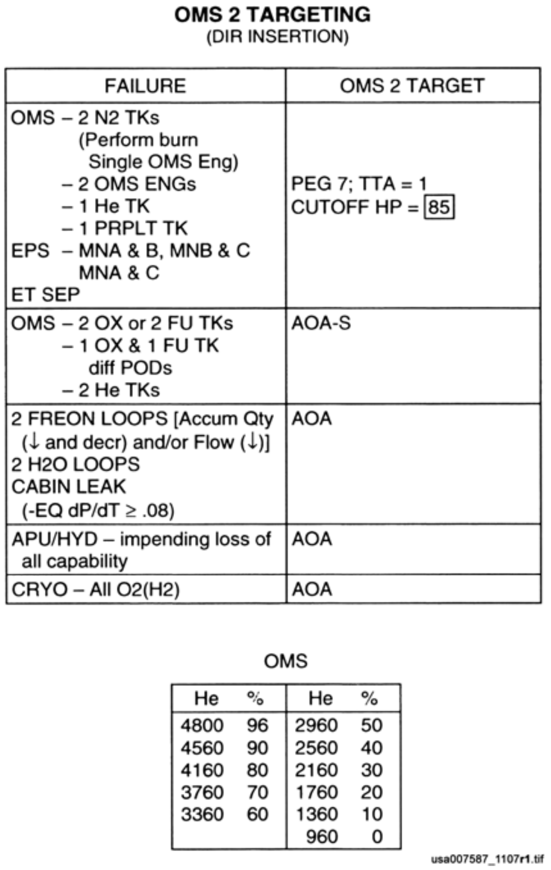
The OMS-1/2 targeting chart provides the crew with information describing the appropriate OMS-1/2 target sets as a function of MECO underspeed. This cue card assumes no system failures but does account for any ATO dump performed pre-MECO. The crew obtains the correct target set by calculating orbital energy (HA + HP) and noting the amount of OMS propellant remaining. Current HA + HP is obtained from the OMS-1 MNVR EXEC display after MM 104 transition.

The OMS 1/2 TGTING cue card should be used in conjunction with the OMS-2 TARGETING card, and worst case requirements will prevail. For combinations of failures, MCC help will be required. In any case, MCC is prime for all target selections as long as COMM exists.

For all flights there is an ATO OMS-1 target set that will allow either an ATO, AOA steep, AOA shallow, or minimum perigee (MIN Hp) OMS-2. This target set is referred to as the common targets. The common targets can be burned, and the decision to abort AOA may be delayed until after OMS-1 for most cases. If AOA is selected after OMS-1, the crew depresses the hydraulic systems instead of shutting down the APUs. This step avoids an APU shutdown and restart. Running the APUs in LOW PRESS instead of NORM PRESS will conserve APU fuel for entry.



OMS 1/2 TGTING Cue Card



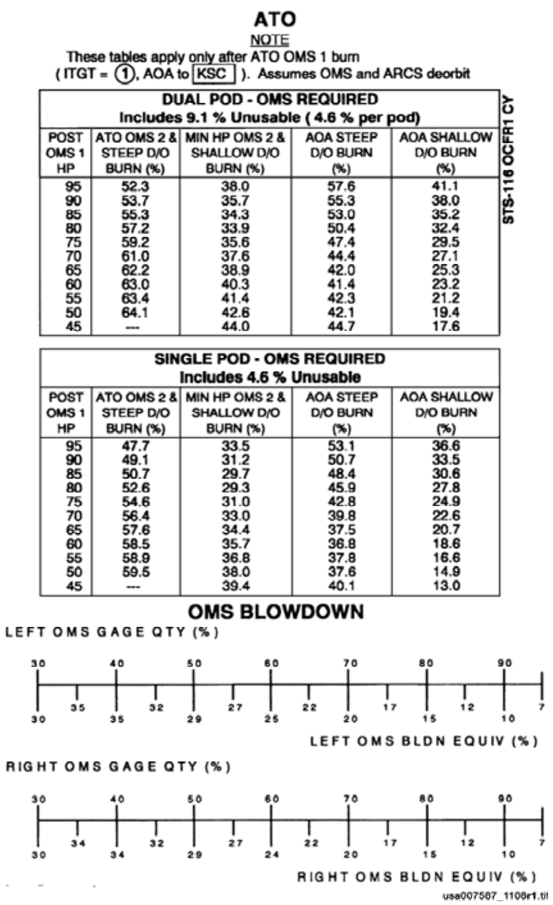
OMS 2 TARGETING
(DIR INSERTION)

FAILURE	OMS 2 TARGET
OMS – 2 N2 TKs (Perform burn Single OMS Eng) – 2 OMS ENGs – 1 He TK – 1 PRPLT TK EPS – MNA & B, MNB & C MNA & C ET SEP	PEG 7; TTA = 1 CUTOFF HP = 85
OMS – 2 OX or 2 FU TKs – 1 OX & 1 FU TK diff PODs – 2 He TKs	AOA-S
2 FREON LOOPS [Accum Qty (↓ and decr) and/or Flow (↓)] 2 H2O LOOPS CABIN LEAK (-EQ dP/dT ≥ .08)	AOA
APU/HYD – impending loss of all capability	AOA
CRYO – All O2(H2)	AOA

OMS

He	%	He	%
4800	96	2960	50
4560	90	2560	40
4160	80	2160	30
3760	70	1760	20
3360	60	1360	10
		960	0

usa007587_1107r1.tif



ATO

NOTE

These tables apply only after ATO OMS 1 burn
(ITGT = ①, AOA to KSC). Assumes OMS and ARCS deorbit

STS-116 OCFR1 CY

DUAL POD - OMS REQUIRED
Includes 9.1 % Unusable (4.6 % per pod)

POST OMS 1 HP	ATO OMS 2 & STEEP D/O BURN (%)	MIN HP OMS 2 & SHALLOW D/O BURN (%)	AOA STEEP D/O BURN (%)	AOA SHALLOW D/O BURN (%)
95	52.3	38.0	57.6	41.1
90	53.7	35.7	55.3	38.0
85	55.3	34.3	53.0	35.2
80	57.2	33.9	50.4	32.4
75	59.2	35.6	47.4	29.5
70	61.0	37.6	44.4	27.1
65	62.2	38.9	42.0	25.3
60	63.0	40.3	41.4	23.2
55	63.4	41.4	42.3	21.2
50	64.1	42.6	42.1	19.4
45	---	44.0	44.7	17.6

SINGLE POD - OMS REQUIRED
Includes 4.6 % Unusable

POST OMS 1 HP	ATO OMS 2 & STEEP D/O BURN (%)	MIN HP OMS 2 & SHALLOW D/O BURN (%)	AOA STEEP D/O BURN (%)	AOA SHALLOW D/O BURN (%)
95	47.7	33.5	53.1	36.6
90	49.1	31.2	50.7	33.5
85	50.7	29.7	48.4	30.6
80	52.6	29.3	45.9	27.8
75	54.6	31.0	42.8	24.9
70	56.4	33.0	39.8	22.6
65	57.6	34.4	37.5	20.7
60	58.5	35.7	36.8	18.6
55	58.9	36.8	37.8	16.6
50	59.5	38.0	37.6	14.9
45	---	39.4	40.1	13.0

OMS BLOWDOWN

usa007587_1108r1.tif

OMS 2 Targeting **OMS Required**

OMS-2 Targeting and OMS Required

OMS-2

After OMS-1 is burned, the OMS-2 TARGETING cue card is checked to determine the appropriate OMS-2 targets. Additionally, the OMS REQUIRED card is used to determine the appropriate abort mode in the event of an OMS propellant shortage or to confirm that sufficient OMS propellant is available for completion of the planned abort mode.

OMS targeting options are complex and vary greatly from flight to flight. For a complete explanation of targets, refer to the Ascent/ Aborts Flight Procedures Handbook.

For all AOA aborts, deorbit targets are called up in OPS 1 and carried across the transition to OPS 3. Targets are not loaded until after the OPS 3 transition because of different guidance targeting logic. Where the OMS-1 maneuver (if required) establishes a temporary orbital trajectory, OMS-2 is a deorbit burn.

AOA software computes the amount of excess OMS that may be burned out of plane during the deorbit maneuver. The crew can change this amount through keyboard entries on the OMS MNVR EXEC display.

Once the appropriate AOA OMS-2 targets are loaded, burn TIG may need to be adjusted to correct range from entry interface (REI). The FDF checklist provides the procedure for TIG adjust. The MCC may recommend a TIG that has already been adjusted.

If the key-in AOA targets are used, an AOA target set should still be called up in OPS 1 using Item 35 on the OMS MNVR display to establish the AOA Kalman filter covariance matrix. The key-in AOA targets can then be entered and ultimately loaded in OPS 3.

Entry

After the OMS-2 burn, the orbiter is maneuvered to an EI-5 attitude, which is similar to the nominal entry attitude. If AOA shallow targets were burned, a prebank will be required to ensure atmospheric capture.

The software transition from OPS 1 to OPS 3 will automatically load landing site data for an AOA. Included are data for the runways shown on the HORIZ SIT SPEC 50, an associated set of TACAN stations, and MLS data for the primary and secondary runways. Potential AOA landing sites are Edwards Air Force Base, California; Kennedy Space Center, Florida; and Northrup Strip, New Mexico. The crew should verify that the appropriate site and runway are selected.

The entry and landing phase of an AOA is similar to the normal entry and landing discussed in Section 7.

6.6 ABORT TO ORBIT

CONTENTS

Powered Flight 6.6-1
OMS-1 .... 6.6-1
OMS-2 .... 6.6-1

ATO aborts are designed to achieve a safe orbit that is lower than the nominal orbit. This requires less OMS propellant and allows time for problem evaluation to determine whether an early return is required or additional burns can be performed to raise the orbit and continue the mission. ATO may be selected for either a performance shortfall or certain systems failures.

Powered Flight

ATO is selected pre-MECO by using the *ABORT MODE* rotary switch or by item entry on SPEC 51. Primarily, pre-MECO ATO selection provides an OMS dump, switches to abort MECO targets (often the same as nominal), and may enable variable I-Y steering to freeze the inclination. The OMS dump adds performance by reducing weight and adding thrust. Freezing the inclination increases performance because in-plane is always the most fuel efficient route to orbit.

Three I-Loaded variables will determine dump size and inclination.

V_LIN - An ATO selected post V_LIN will result in less than a full dump. The amount dumped will, from there, ramp down to zero as a function of velocity.

V_ZERO - An ATO selected post V_ZERO will result in zero OMS propellant dumped.

V_MSSN_CNTN - An ATO selected post V_MSSN_CNTN will result in the nominal mission specific inclination. That is, the inclination will not be frozen as it has been determined that a safe orbit can be archived without an inclination adjustment.

As with nominal trajectories, the crew monitors ascent performance and keeps abreast of abort mode capability using the NO COMM MODE BOUNDARIES cue card, along with calls from the MCC.

ATO procedures during powered flight, with the exception of the pre-MECO OMS dump, are via the nominal ascent procedures in the ascent checklist, which is discussed in Section 7.

OMS-1

If possible, ATO abort is declared after MECO to ensure that other downmode options are available as long as possible. ATO OMS-1 targets are automatically called up if an ATO is declared either pre-MECO or pre-OMS 1. This may be a common target set from which either an AOA deorbit burn or an ATO circularization burn can be performed at OMS-2. The final decision can thus be delayed until after OMS-1 is completed.

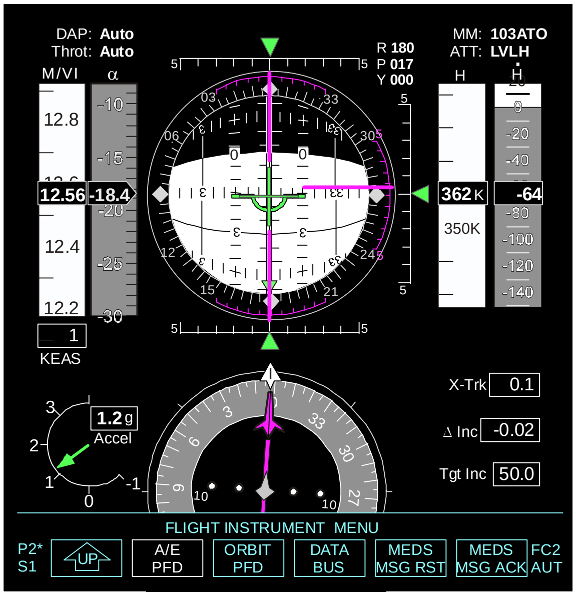
OMS-1 targeting is performed using the same procedures and cue cards as AOA. These are discussed in Section 6.5. To provide a fuel-efficient ATO or AOA burn, OMS-1 is initiated at time to apogee (TTA) equals 2 minutes, but no earlier than MECO + 2 minutes.

OMS-2

The ATO OMS-2 burn is performed using nominal Ascent Checklist and cue card procedures. Proper targets are selected and loaded, the shuttle is maneuvered to burn attitude, and the burn is executed.

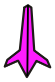
After completion of both ATO OMS burns, the orbiter should be in approximately a 105 n. mi. circular orbit. Once this safe orbit is attained, mission operations may be continued for at least 1 day. Additional burns may be used to raise the orbit or the mission may be ended early.

OMS-2 targeting for ATO is very similar to AOA, which is discussed in Section 6.5.



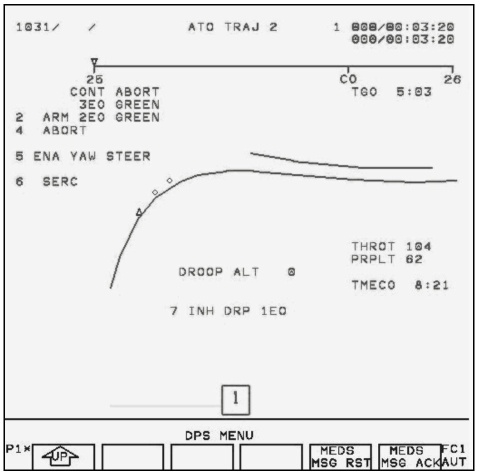
ATO Specific Notes

- **ATO** abort verified by letters "ATO" adjacent to MM field in upper-right corner *of PFD and in the TRAJ 2 title*.
- **Tgt Inc** displayed to give indication of variable IY steering for an ATO abort. ATO abort with an SSME failed prior to V_mission_continue I-load will freeze steering to the current inclination.



Course-arrow (magenta) points to the current target inclination, where 0° is defined as the initial target inclination.

- **ΔInc** and **X-Trk** digital readouts and **CDI** all display essentially zero if ATO abort & variable IY steering freeze to the current inclination.



```
1031/   /          ATO TRAJ 2       1 000/00:03:20
                                      000/00:03:20
        25                            CO          26
     CONT ABORT                       TGO   5:03
      3EO GREEN
2  ARM 2EO GREEN
4  ABORT

5 ENA YAW STEER

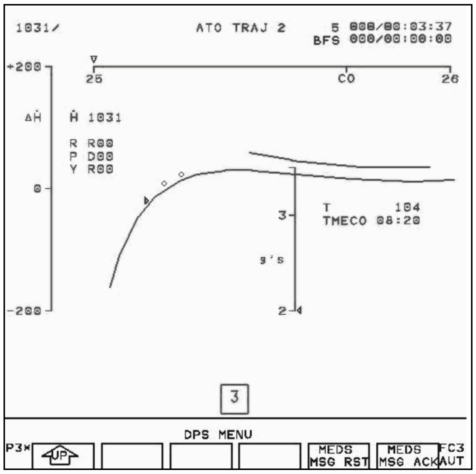
6  SERC

                                      THROT 104
                                      PRPLT 62
                DROOP ALT    0
                                      TMECO  8:21

               7 INH DRP 1EO

                          1
                      DPS MENU
P1*  UP                      MEDS     MEDS    FC1
                            MSG RST  MSG ACK  AUT
```

PASS ATO TRAJ 2 Display



```
1031/                      ATO TRAJ 2      5 000/00:03:37
                                         BFS 000/00:00:00
+200
        25                            CO          26

 ΔḢ    Ḣ 1031

       R R00
       P D00
       Y R00
  0
                                 3      T         104
                                        TMECO 08:20
                               g's

-200                             2

                          3
                      DPS MENU
P3*  UP                      MEDS     MEDS    FC3
                            MSG RST  MSG ACK  AUT
```

BFS ATO TRAJ 2 Display

6.7 CONTINGENCY ABORT

CONTENTS

Powered Flight 6.7-1
Three-Engine-Out Automation 6.7-2
ET Separation.. 6.7-2
Entry 6.7-3

During ascent, a contingency abort is performed when the orbiter's thrust-to-weight ratio is less than that needed to achieve a safe orbit or an intact abort, due to multiple engine failures. The purpose of a contingency abort is to guide the orbiter to a safe gliding flight condition, where bailout or a landing can be performed. Currently, two engine-out contingency aborts are automated for both powered flight and the entry pullout. Beginning with OI-25 three-engine-out contingency aborts were automated. The OI-25 software has the capability to be "no-opted"; reverting it back to manual contingency abort procedures for ET separation and maneuver to entry angle of attack until MM 602. However, this software is not expected to be no-opted. Contingency abort procedures are very dynamic flight modes that take the orbiter to the limits of its structural and flight control envelope. For certain cases, especially high altitude and low velocity, the resultant entry may not be survivable.

Contingency abort procedures are outlined on the Contingency Abort cue cards. These procedures are designed to protect the orbiter from exceeding certain limits:

- Q-bar - 800 psf
- N_Z - 3.9 g
- Elevon/body flap hinge moments

The procedures are separated into CONTINGENCY ABORT and RTLS CONTINGENCY cue cards. They are further subdivided into event timelines and color-coded for easier use. For detailed procedures, the Ascent/Aborts Flight Procedures Handbook or the Contingency Aborts 2102 Manual should be used. This section describes the basic information applicable to all contingency aborts, and is divided into three major phases: Powered Flight, ET Separation, and Entry.

The PASS is moded to OPS 6 (RTLS) during most contingency abort procedures. OPS 6 provides the entry guidance and flight control needed for contingency aborts. The BFS does not support contingency aborts because of several restrictions, including no single-engine roll control, no two- or three-engine-out automated software, and no CSS until post-ET separation.

Powered Flight

Should two SSMEs fail, the remaining thrust is used to reduce entry sink rate. Different procedures are used, depending on when the engine failure occurs. For early failures, when the orbiter has a large positive H-dot, the thrust vector is pointed toward the horizon to prevent further lofting. This increases downrange velocity and helps reduce severity of the entry pullout. At an inertial velocity between approximately 7,000 fps and 12,000 fps, a vertical thrust vector is used to counter gravity losses, which shallows the flight path angle and improves entry conditions. At inertial velocities greater than about 12,000 fps, the orbiter may have enough energy to continue to a downrange site.

If two engines fail prior to the SE OPS 3 boundary while the orbiter is within a predetermined velocity envelope, yaw steering of 45° can be performed for an east coast abort landing (ECAL) or Bermuda (BDA) landing. High inclination missions use ECAL procedures, while low and mid-inclination missions use BDA procedures. ECAL and BDA landing sites are available during certain portions of ascent, should a contingency abort be required. ECAL landing sites are strategically located along the east coast of the United States. These sites are available on missions with inclinations greater than 50°. On missions with inclinations less than 40° Bermuda is available. For due east missions, there is no capability to land at Bermuda unless the vehicle is already on a TAL abort that crosses the BDA window (which is out of plane and north). The yaw steering that occurs on these TALs provides the plane change required to reduce the entry cross range to Bermuda. The velocity for a BDA landing is mission dependent but generally ranges from 9 k fps to 12 k fps for BDA and 6 k fps to 12 k fps for ECAL. The powered flight yaw steering for these aborts is open loop. There is no range-velocity (R-V) target line being attempted, just a reduction in cross range to the site. Yaw steering generally increases entry pullout loads by approximately 0.1 g.

Powered flight is also used to dump OMS propellant. This reduces weight and moves the c.g. forward. Reducing weight decreases the peak q-bar during pullout, while more forward c.g.'s reduce elevon and body flap deflection required for pullout. This helps prevent aerosurface saturation and possible actuator stall.

The heads-up roll orients the bottom of the orbiter/ET into the velocity vector, which is generally the attitude desired for ET SEP and entry.

Three-Engine-Out Automation

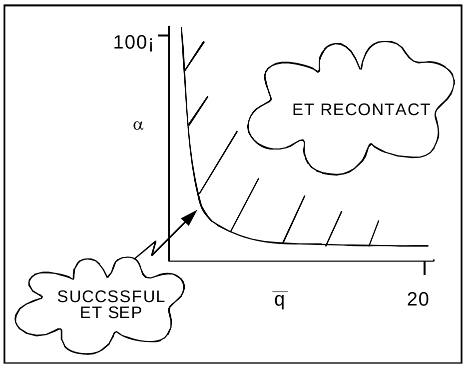
Three-engine-out guidance initiates automatically when MECO confirmed is set and color is displayed on the PFS Ascent/RTLS Traj; no item entries are required. If no color is displayed, contingency guidance has determined that either an OPS 3 entry or RTLS runway can be reached without contingency maneuvering. The primary goal is to maneuver to a safe ET separation position, separate from the tank, and subsequently maneuver to entry attitude via the shortest path. The following events occur automatically:

- RTLS abort declaration (if not previously selected)
- Maneuver to ET separation attitude (if required)
- ET separation
- Post-separation -Z translation
- Interconnected OMS dump (if required)
- Inhibit FRCS dump (if required)
- MM 602 transition

ET Separation

Safe ET SEP is a function of alpha and q-bar. As the shuttle descends, q-bar increases and ET SEP must be performed prior to 10 psf.

At pressures above 10 psf, the ET may recontact the orbiter. Between 2 and 10 psf, the shuttle must be at a small negative (about -2°) angle of attack to ensure successful separation. This is the same technique used for RTLS ET SEP. At less than 2 psf, larger angles of attack are acceptable, but the -Z translation is optimized to help prevent recontact.



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High sink rates during many contingency abort scenarios result in rapid entry into the atmosphere and, therefore, a rapid q-bar buildup. In most of these cases, there is not enough time for an RTLS-type PPD and a normal mated coast separation sequence. A fast SEP is performed instead, which takes about 5 seconds. This fast SEP can be performed in one of seven ways, depending on the vehicle attitude and q-bar at the time SEP is required. The first is the immediate, manually initiated fast SEP where no time is available to maneuver to a better attitude. The second is an alpha -2 fast SEP where there is time to achieve the attitude before q-bar exceeds 10 psf. The third is rate fast SEP where the separation is commanded while at a high angle of attack and a -4° per second pitch rate. This technique allows separation to be delayed as long as possible and extends the time available for powered flight. It is initiated when EAS is greater than 10 and increasing (q-bar of about 0.7 psf). The ET SEP occurs prior to the 2 psf limit for high alpha separations. Because the shuttle is near the alpha required for entry, the -4° per second pitch rate needs only to be slowed as the proper alpha is reached. Maneuvering the shuttle to a negative alpha for separation would require a second pitch maneuver to recover back to the entry alpha.

The pitch rate used for fast SEP is a compromise between a rapid pitchdown and the need to maintain control and slow/reverse the rate after SEP.

The fourth type of fast SEP is (SRB) PC < 50, that is used only in first stage when the entire stack (SRB and ET) is separated as a whole at SRB thrust tail-off. The fifth is an attitude-independent SEP where q-bar is low enough to allow the separation to occur in any attitude with zero rates. The sixth is the alpha 125 separation, used when high q-bar prevents a pitchdown maneuver to alpha -2. In this case, the vehicle is pitched up to an alpha of 125° for ET separation, then pitched back down to entry alpha. Last is the emergency separation, which is commanded at KEAS >77 any time the maneuver to ET separation attitude fails. This separation is commanded immediately when EAS exceeds 77 knots, regardless of attitude and rates.

The GPCs will automatically mode to MM 602 after structural separation, when close to entry attitude or >77 KEAS. After MM 602 transition, V_{REL} is displayed as Mach number on the AMI.

Entry

The powered flight, mated coast, and ET SEP portions of contingency aborts are designed to deliver the orbiter to acceptable entry conditions without loss of control. Entry phases include:

- Alpha recovery
- N_z hold/pullout
- Alpha-Mach
- ECAL/BDA landing or bailout

In general, reducing ET SEP altitude and H-dot will improve entry conditions. Any errors occurring in powered flight or ET SEP will result in a more stressful entry.

Alpha Recovery

Upon ET SEP completion, the orbiter is maneuvered to an alpha that maximizes lift and drag in a manner similar to GRTLS. The appropriate alpha is a function of Mach number and trim but lies in the range of 20° to 58°.

In some cases, alpha recovery is accomplished by stopping the -4° per second pitch rate at the appropriate alpha. Because the alpha tape on the AMI pegs at 60°, a maximum alpha of 58° is used.

The body flap and speed brake are set during the alpha recovery phase before the critical pullout begins. The speed brake and body flap affect hinge moment loads on the elevons. A body flap versus mach schedule is developed for each mission as a function of vehicle weight, c.g. and OMS load. The speed brake is left in auto unless the N_z hold is entered below mach three. If below mach three, the crew opens the speed brake to 65%.

N_Z Hold/Pullout

Orbiter H-dot will continue to decrease (more negative trend) throughout alpha recovery until sufficient q-bar and the resultant lift are developed for equilibrium flight. As lift increases, N_z will also increase. When $N_z = 1.0$, the orbiter is developing enough lift to support its own weight, and H-dot will begin to increase (more positive trend). The maximum negative H-dot is a good indicator of the severity of the entry. It is also used to calculate N_z required for pullout, using the equation:

$$N_z \text{ target} = -\text{H-dot}/1000 + 0.65 \text{ at } N_z = 1.0.$$

This N_z target is calculated by the GPCs and displayed on VERT SIT. The N_z hold/pullout is flown in AUTO, which significantly increases chances of survival. N_z target is a compromise between structural limits and q-bar limits. The structural load factor limit is actually a function of orbiter weight and wing root bending moment, but the software currently will not target more than 3.9 g. Simulator tests show that q-bar over 800 psf often leads to loss of control. However, this limit is scenario- and mission-dependent.

Load factor continues to increase until within approximately 0.4 g of N_z target. A pitchdown is then initiated to hold N_z target. The AMI acceleration tape is scaled in g's in MM 602, with 10 = 1 g, 20 = 2 g, and 30 = 3 g. As alpha is reduced while holding a constant g, q-bar will continue to increase until after the sink rate is stopped. When H-dot is positive, pullout is complete, and g load is reduced. The crew can then mode the body flap to AUTO and monitor the alpha/Mach schedule.

The N_z hold/pullout is the most critical phase of contingency aborts. Even if flown perfectly, some profiles will exceed structural, temperature, or flight control limits. Target N_z must be accurately flown.

Most regions of the contingency abort profile have adequate flight control margins. However, there are some regions where even flying the maximum structural load factor limit during N_z hold will not prevent q-bar from exceeding 800 psf, possibly stalling the elevons, and losing control.

Flight control gains were designed for a maximum q-bar of 375 psf. Loss of control results from a number of factors. In some cases, aerodynamic moments are so large that the orbiter rates cannot be controlled, even at maximum aerosurface deflection and with maximum jet firings. Additionally, in some cases the aerosurface loads are so large that the actuators cannot drive the surfaces. This is called actuator stall. Sometimes these control problems can be avoided by flying a higher g-level during pullout, but the best technique is to follow the contingency abort procedures explicitly and engage the AUTO system where it has the capability to execute critical maneuvers.

Alpha-Mach

The crew monitors the alpha-mach phase by making sure the vehicle is at the proper alpha for the Mach number. This information is in a table on the Contingency Abort Entry cue card.

Automated ECAL

Starting with OI-28, Item 1 (centered at the bottom of the MM 602 TRAJ) will enable/disable the automated ECAL logic. This item entry is initialized enabled (ENA) when the contingency abort flag is ON, and will require no action.

Entry ECAL energy and g's will be managed with AUTO FCS in OPS 602 and 603 with pitch and bank. For automated ECAL, the alpha range is 20° to 58°, while the bank range is 0° to 70°.

Bailout

An attitude hold mode in MM 603 allows the crew to stabilize the orbiter in gliding flight using the AUTO DAP functions. It is armed when Mach is less than 1.0, the *ABORT MODE* rotary switch is placed to *ATO*, and the *ABORT* pushbutton is pressed.

Guidance snapshots current airspeed and roll angle and attempts to hold both constant. The crew should stabilize the orbiter at 185 to 195 KEAS and zero roll angle, then abort MODE switch to ATO, press ABORT PBI, and select *PITCH* and *ROLL/YAW AUTO*. If a new airspeed or roll attitude is desired, select CSS, fly to the appropriate parameters, and reselect AUTO.

Once attitude hold is established, a middeck MS depressurizes the crew module using the emergency vent handle. When cabin pressure is equalized, the hatch is jettisoned, the escape pole is extended, and bailout is commenced.

6.8 SYSTEMS FAILURES

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Depending on flight phase, various Flight Data File documents are used to diagnose, correct, and reconfigure malfunctions of orbiter systems.

- Cue Cards
- Pocket Checklists
- Malfunction Book
- Payload Systems

Dynamic phases of flight, such as ascent and entry, do not allow leisurely identification and correction of malfunctions. The CDR and PLT flip books, along with the Ascent/Entry Systems book are designed to allow quick response to certain critical malfunctions in order to safe the affected system.

Procedures in the Ascent, Orbit, and Entry Pocket Checklists (PCL) are designed to safe critical systems where malfunctions require a response in less than 5 minutes. Three separate books are used, since actions vary significantly, depending upon the flight phase.

On orbit, with the exception of certain systems such as cabin pressurization, most malfunctions can be thoroughly investigated and isolated, and backup systems can be activated. The Malfunction Book provides step-by-step procedures that have been developed to allow a very structured, methodical approach to correcting systems failures.

Because each mission is unique, one or more Payload Systems procedures will be flown to allow the crew to troubleshoot various payload malfunctions.

None of these procedures relieves the crew from understanding how various orbiter and payload systems work and what failures may occur. This in-depth knowledge across a broad range of systems allows a well-trained crew to be confident that nearly all credible malfunctions can be handled without compromising safety or mission success.

The philosophy behind all orbiter emergency procedures separates into three categories:

- Detect and confirm the malfunction.
- Ensure a safe configuration.
- Attempt to correct the malfunction or reconfigure to optimize remaining systems.

Many orbiter malfunctions are accompanied by some type of caution and warning alarm. These are designed to help the crew identify the system involved and direct them to the correct procedure. Almost all emergency procedures titles reflect either a hardware caution and warning light or a software fault detection annunciation (FDA) message. It is extremely important to confirm the malfunction with whatever data is available. Sources of data may include dedicated displays, related system malfunctions, or an inventory of failed equipment. Mission Control is often able to provide confirmation, since a great deal more data is available on the ground, and highly trained and knowledgeable controllers are dedicated to each system.

Malfunction confirmation may be complicated by previous failures. Also, the caution and warning system cannot distinguish real failures from sensor failures. Thus, identification of the malfunction and selection of the correct procedure are sometimes difficult. Only through study, training, and practice in simulators can crewmembers develop the capability to quickly and accurately detect and confirm malfunctions in a vehicle as complex as the orbiter.

Once a malfunction has been identified and the proper procedure selected, the crew takes certain well-defined steps to put the orbiter into a safe configuration. An example is pressing the appropriate *MAIN ENGINE SHUT DOWN* pushbuttons after a second engine failure to establish single engine roll control. Due to the redundancy of most onboard systems, no immediate action should be required for most single and many dual failures. However, if multiple failures occur, there may be very little time to switch to alternative systems or take the necessary steps to prevent loss of control. In multiple failure cases, the crew must keep in mind the interaction of different systems and prioritize their responses.

Most malfunction procedures involve correcting a malfunction to recover lost capability or remaining systems. In general, switching to backup systems, interconnecting to components of other systems, or securing some remaining systems to reduce heat loads or power consumption are methods used by the crew.

On orbit, it may be possible to perform in-flight maintenance (IFM) to install replacement components or reconfigure systems. An IFM Checklist covers many of these pre-planned activities. A dedicated team of IFM specialists supports each mission and responds to MCC in the event an IFM procedure is contemplated. Mission Control also excels at developing new procedures in real time to deal with unexpected malfunctions. This capability is frequently exercised during simulations.

This section discusses malfunction signatures and confirming cues for some of the malfunctions that may be encountered during training and in flight. Brief summaries of actions required for safing and reconfiguration are also presented. For more detailed malfunction information, refer to Flight Data File books, Flight Procedures Handbooks, and System Workbooks.

APU/Hydraulics

The APU/HYD cue cards and PCL are used to provide response to APU and HYD malfunctions. During ascent, actions are taken to protect the main engines. Unless the APU or hydraulic failure could cause a catastrophe, the system will not be shut down until after MECO to avoid interrupting hydraulic power to the main engines. Loss of a hydraulic system in powered flight will result in an SSME hydraulic lockup. Loss of two hydraulic systems in powered flight will result in two SSME hydraulic lockups, one of which will have no thrust vector control (TVC). Both cases would then involve a pre-MECO SSME shutdown.

APU Failure

- Pressure decrease on both the SPEC page(s) and HYD/APU display (independent sensors)
- APU speed goes to zero
- APU SPD HI/LOW message
- *MASTER ALARM*
- *APU OVERSPEED/UNDERSPEED* light on F7
- Accumulator pressure decrease to ~2600 psia
- *HYD PRESS* light on F7

To safe the system, the crew performs the APU SHUTDOWN procedures to remove the start command, close fuel tank isolation valves, and remove power from the APU controller. The remaining APUs may be taken to high speed and auto shutdown inhibited, depending upon flight phase.

If APU shutdown was due to an underspeed, a restart may be attempted after completion of the APU COOLDOWN procedure. An APU that shut down due to a *confirmed* overspeed will <u>never</u> be restarted. *Only MCC can identify a false overspeed, which would be a candidate for possible restart.*

Hydraulic System Failure

- Pressure decrease on both the SPEC page(s) and HYD/APU display (independent sensors)
- APU speed good
- *MASTER ALARM*
- *HYD PRESS* light

- HYD PRESS message
- Accumulator pressure drops to ~2600 psia

Two of the three pressure sensors in each hydraulic system can be seen onboard. MCC receives data from all three sensors. If the hydraulic failure is confirmed, the APU will be shut down to prevent additional damage. The remaining APUs may be taken to high speed and auto shutdown inhibited, depending on flight phase.

Partial hydraulic failure due to a degraded pump or line blockage may produce pressure fluctuations. For ascent, the system is allowed to operate as long as sufficient pressure is available to keep a main engine from going into hydraulic lockup (~*1500* psi). During other flight phases, the hydraulic system is taken to low pressure in an attempt to restore stable operation and to ensure that the aerosurface switching valve has selected a "good" hydraulic system for aerosurface actuation. If the system is stable in low pressure, the APU is kept running until an appropriate shutdown time. If the system is required for critical functions such as landing, the system may be returned to normal pressure.

Hydraulic Leaks

- Unexpected drop in reservoir quantity
- *SM ALERT*
- SM2 HYD QTY message

During powered flight, the system is left in normal pressure to prevent SSME hydraulic lockup. At other times, the system is taken to low pressure to reduce leak rate. Normal pressure may be reselected if required. MCC determines leak rate and decides whether or not the system may be returned to normal pressure.

APU Fuel/Nitrogen Leaks

- Unexpected decrease in fuel quantity
- *SM ALERT*
- SM2 APU FUEL QTY message
- Difference in fuel quantity among APUs
- Decrease in fuel pressure

Since fuel and nitrogen leaks are indistinguishable until very low levels are reached, crew response is to assume a fuel leak (worst case). No action is required pre-MECO unless the APU shuts down. For other flight phases, the APU is shut down and the fuel tank isolation valves closed to attempt to isolate the leak. If isolated, the APU is only started for critical operations. If non-isolatable, the APU is restarted and run to fuel depletion. This prevents damage in the aft compartment from leaking hydrazine, which is very corrosive.

Water Quantity Low

- Abnormal decrease in water boiler quantity
- *SM ALERT*
- SM2 W/B QTY message

Water spray boiler nitrogen or water leaks, as well as excessive spraying by a faulty water spray boiler controller *or a faulty sensor (used in the PVT calculation)* can cause an abnormal decrease in water boiler quantity.

MCC can detect excessive spraying, but in any case, the crew should switch to the alternate controller. If switching controllers does not work, boiler power is cycled to reduce water usage. MCC will determine when and if APU shutdown is required, depending on mission phase.

For a water leak, switching controllers will not help, and APU cooling will be lost when the quantity reaches zero. The APU will then overheat within 4 minutes. Nitrogen leaks allow cooling for a short time even after water quantity reads zero. W/B QTY is a PVT calculation.

APU Shifts to High Speed

- APU rpm increases to 113%
- APU SPD HI Fault message
- SM ALERT

An APU shift to high speed can be caused by an APU controller electronic malfunction or an open failure of the Primary Control Valve. The crew will take APU control to high-speed to ensure proper controller logic for high-speed control. The APU will be shut down as soon as possible post MECO as long as two other APUs are working properly. APU auto shutdown must not be inhibited on an APU that has shifted to high-speed since auto shutdown via the fuel tank isolation valves is the only protection from APU overspeed if both control valves were to fail open.

Hydraulic Fluid/Lube Oil Overtemp

- High hydraulic fluid temp
- High lube oil temp
- *MASTER ALARM*
- *APU TEMP* light on F7
- *SM ALERT*
- APU TEMP message
- HYD RSVR T message

Excessive hydraulic fluid temperature (>230° F) or lube oil temperature (>290° F) are signatures of inadequate cooling. This may be caused by mechanical problems or a water spray boiler malfunction. The crew should switch boiler controllers first. If APU temperatures decrease, the problem was in the controller. If temperatures continue to rise, APU shutdown may be required.

Shutdown and restart may be possible if the APU is required for critical maneuvers. Although the system is not limited in run time for excessive hydraulic temperatures, the system may be taken to low pressure or shutdown in order to maintain the hydraulic fluid below limits that may cause system seal degradation if exceeded.

Priority Rate Limiting

- Possible differing hydraulic pressure on SPEC page(s) and HYD/APU display
- *SM ALERT*
- PRL DLMA message
- APU accumulator pressure
- APU speed

Pressure (or sensor) differences within a particular hydraulic system may cause the PRL software to be confused. MCC can see all three sensors in each hydraulic system and will assist the crew with proper actions. The first action is to use confirming cues to determine if the APU is running. Once APU status is known, the crew should verify all good systems are selected for PRL by executing appropriate item entries on the OVERRIDE (SPEC 51) display.

Switching Valve Failure

- MCC call
- Control problems

This failure can prevent the hydraulic systems from operating a control surface. The crew can cycle the affected system hydraulic pressure between *LOW* and *NORM* to attempt to reset the valve upon MCC direction. The other option is to deselect one or more hydraulic system in the PRL software and operate on reduced PRL rates. This will reduce the loads on the good APU(s). This procedure is also performed only at MCC direction.

Uncommanded Brake Pressure

- Brake pressure greater than zero in flight
- *SM ALERT*
- *SM0* BRAKE P message

Since brake pressure is measured downstream of the brake/skid control module, there is no way to determine which hydraulic system is responsible. Landing with pressure greater than 200 psi in the braking system can cause the wheels to be locked at touchdown. This will cause one or more tires to fail, resulting in directional control problems and possible loss of control. Nominally, none of the three brake isolation valves will be open prior to weight on wheels (WOW) or main gear touchdown. Therefore, there should be no concern for this problem. However, if the hydraulic system 2 brake isolation valve must be opened prior to WOW for nose gear deploy redundancy, there is potential to get uncommanded brake pressure. To correct this problem, the PLT must close brake isolation valve 2 as soon as possible after gear deploy and before WOW. This will allow for the pressure to bleed down.

The crew should close the appropriate isolation valves, then reopen them after nose gear touchdown. Since hydraulic system 1 supplies power for nosewheel steering, this procedure is modified for certain cases, and isolation valve 1 is reopened at main gear touchdown.

Communications

The orbiter communications system is extensive and complex. A great deal of redundancy exists, and the system has been very reliable. For normal operations, MCC commands system reconfigurations. Loss of communication can occur for reasons other than onboard equipment, such as ground station or satellite problems and antenna blockage. The crew should consider this possibility as well as their current communication mode, comm panel configuration, and position over the ground prior to executing lost communication procedures.

ICOM Lost

- Inability to communicate using ICOM

The procedure for ICOM lost will have the backup audio terminal unit (ATU) selected via the POSITIONS control switch. Positions with backup ATU include commander (CDR/left), pilot (PLT/right), mission specialist (MS), and airlock (AL). At other positions, or if alternate position doesn't regain ICOM, the alternate audio central control unit is selected via panel C3. If these actions do not regain ICOM, a different ATU, crew communications umbilical (CCU) connection, or headset/handheld mic may be required to regain ICOM.

Comm Lost

- ICOM operating properly
- S-band comm lost on multiple panels
- UHF comm status

The crew should first select ACCU alternate power. If this is unsuccessful, S-band PM panel C3 controls are verified and the crew switches the *S-BAND PM CONTROL* switch to *PANEL*, then back to *COMMAND*. This causes the S-band PM system to attempt to operate as specified by the panel A1L switches. If this corrects the problem, one of the originally selected S-band subsystems has malfunctioned.

CAUTION

Panel A1L switches must be set up for the current comm mode (including proper NSP configurations).

To troubleshoot antenna problems, manual antenna selection is attempted, using the SIGNAL STRENGTH meter and SM OPS 201 ANTENNA display. If comm is not restored, the *ANTENNA* rotary switch on panel C3 is returned to *GPC*.

Finally, the procedure provides steps to determine if MCC can uplink to a GNC GPC for state vector updates. If there is no uplink, the crew may have to deorbit without MCC direction to preserve IMU alignment entry limits. If there is uplink capability to the vehicle, an in-flight maintenance procedure is available to bypass a completely failed ACCU.

UHF Lost

- Unable to communicate on UHF

The crew first turns off the UHF squelch system to ensure good signal reception, then an alternate ACCU power source is selected.

Three frequencies are available (259.7, 296.8, and GUARD). All should be tried. GUARD is an international UHF frequency that is only used in emergencies.

Since the UHF antenna is located on the orbiter’s belly, a roll to heads up is performed to ensure optimum antenna gain.

Finally, the UHF power amplifier is turned off. If successful, a low power transmit mode will be available.

Cryo

The cryo O2 and H2 systems provide reactants to the fuel cells from tanks under the payload bay. The cryo O2 system also supplies oxygen to the crew module for metabolic use and for direct breathing while using the LES helmets.

Leaks

- *MASTER ALARM*
- *O2 (H2) PRESS* light (F7 matrix)
- *SM ALERT*
- CRYO O2 (H2) MANF message
- CRYO O2 (H2) PRES message
- Decreasing tank pressure
- Decreasing manifold pressure
- MCC call

If a cryo leak is detected, its location must first be determined, then steps must be taken to isolate the leak. If pressure decreases in only one tank, a tank leak is indicated. Check valves should prevent the other tanks from losing cryo through a leaking tank. Some cryo in the leaking tank may still be usable, depending on the leak rate. Mission duration may be affected.

A pressure decrease in all tanks requires closing the manifold isolation valves to isolate the leak. Once a potential leak area is isolated to a single manifold, additional troubleshooting may allow further isolation to either the PCS system or an individual fuel cell. Should the leak be in the manifold feeding a fuel cell or in the fuel cell itself, a shutdown and powerdown may be required. Mission duration may be affected, depending on leak location and the mission cryo quantity requirements.

Heater Problems

- *MASTER ALARM*
- *O2 (H2) PRESS* light (F7 matrix)
- *O2 HEATER TEMP* light (F7 matrix)
- CRYO O2 (H2) PRES message
- CRYO O2 HTR message
- High tank temperature
- High tank pressure
- High heater temperature

Cryo heaters can fail on or off. A heater can also have a short. If an O2 heater has a short, it should cause the O2 current sensor logic to trip and disable the heater.

A failed "on" heater may result in high tank temperature or pressure, requiring the affected heater to be turned off. A failed "off" heater can be a control problem or a failure of the heater itself. MCC normally alerts the crew to these conditions. Redundant heaters are used if there is a heater problem. For control problems, a manual heater control procedure can be used.

Failure of heaters in two tanks indicates a paired logic problem. For this case, each tank's heaters must be operated individually to determine the location of the failure.

Data Processing System

Hardware and software DPS problems are normally detected by monitoring software and annunciated by the C&W system. Failure signatures are shown in a table in this section. Once the failure is identified, the appropriate procedure is worked. The impact of a single DPS failure in other systems is normally a loss of redundancy rather than a loss of capability.

Key safing steps in each procedure are used to prevent commands to good systems from bad computers and prevent good computers from using data from bad components. To correct transient errors, an I/O RESET or power cycle is attempted. For port-dependent failures, the port mode procedure may allow communications to be resumed using alternate ports and a different data bus.

During ascent or entry, when certain DPS failures affect more than one flight-critical string, the MULTI DATA PATH cue card is used to identify failure effects and determine crew actions. For some multiple failures, when Flight Rules allow, the DPS can be reconfigured using the RESTRING cue card. This procedure allows good GPCs to take over flight-critical buses and components that are lost after one or more GPC failures.

FAILURE	CAUTION & WARNING		PROCEDURE	COMMENTS
	HARDWARE	SOFTWARE		
Fail to Sync	GPC light CAM lights	GPC Fail message Down arrow on SYS SUMM Failed GPC issues fail messages against the good GPCs GPC continues to drive its IDP	GPC Fail	GPC continues to run and send commands over the data buses Mode tb will be RUN and Output tb is grey
Fail to Halt	BP Output tb BP Mode tb CAM lights GPC light Big X Poll Fail	GPC Fail message Down arrow on SYS SUMM	GPC Fail	Dead GPC, no commands
Fail to Quit	GPC light CAM lights Big X Poll Fail	GPC Fail message Down arrow on SYS SUMM	GPC Fail	Like fail to halt, except Mode and Output tb's do not turn barberpole (BP)
PASS Total Set Split	All PASS GPCs stop talking to each other, each GPC issues fail messages against the others, diagonal CAM lights lit, BFS standalone		BFS Engage	Engage should be done with 10 sec for Ascent, 45 sec for Entry
Generic PASS Fatal Software Error	Fail to quit or halt on all four GPCs simultaneously/all PASS driven IDPs Big X and poll fail/BFS standalone		BFS Engage	Engage should be done within 10 sec for Ascent, 45 sec for Entry
Power Fail	Bp Output tb Bp Mode tb Big X Poll Fail	GPC Fail message Down arrow on SYS SUMM	GPC Fail	Like fail to halt, but no CAM lights or F7 GPC light
I/O Term B fails on	Bp Output tb	Down arrow on SYS SUMM for FF and FA FF and FA I/O Error messages	GPC Fail	GPC running, but commands inhibited on flight critical data buses
I/O Term A fails on		Down arrow on SYS SUMM for PL1 and PL2 PL1 and 2 I/O Error messages	BFS or SM GPC Fail	GPC running, but commands inhibited on payload and launch data buses
MDM I/O Error at MDM	Varies with MDM	I/O Error message (PASS & BFS) Down arrow on PASS SYS SUMM Down arrow on BFS SYS SUMM	MDM I/O Error	GPC good, MDM lost Port mode may recover
MDM I/O Error at GPC	Varies with MDM	PASS I/O Error message BFS BCE String PASS message Down arrow on PASS for failed MDM M's on BFS SYS SUMM for FF and FA	MDM I/O Error	Port mode will cause loss of other MDM on string (trade-off case)
Component omm. problems	Varies with component	BCE String x message M's on PASS and BFS SYS SUMM	BCE String X	Use Ref Data book to find parameters lost and verify signature
OI MDM/DSC Fail	Varies with MDM/DSC	M's on SYS SUMM for MDM L's on SYS SUMM for DSC I/O Error PCM annunciated by BFS for PCM port problem or MDM problem PASS SM machine will annunciate S62 BCE BYP OFX or OA message	I/O Error PCM	

DPS Failure Signatures

Set Splits

Since the GPCs run in a redundant set during ascent, entry, and some on-orbit operations, it is possible for one or more PASS GPCs to split apart from the rest of the set and continue running. Various combinations are possible, but in all cases it is imperative to determine if a good PASS set exists. A good set must include:

- 1 IMU
- 2 RGAs
- 2 AAs
- 2 FCS channels

Restring or BFS engage is required if a good set does not exist.

NOTE

See section 6.9 for GPC set splits during ascent.

BFS Engage

For unrecoverable PASS failures, the BFS is available to take over orbiter control. Monitoring of BFS and GNC systems status prior to engage is required to ensure the BFS is capable of control. For a successful BFS engage, the BFS must have a good nav state and be able to communicate with/command:

- 1 IMU
- 1 RGA
- 1 AA (for 1st stage)
- 2 FCS channels
- 1 ADTA

BFS Failures

For most transient software failures, the BFS will automatically attempt a software restart. If this is successful, operations will continue, and a GPC BITE message will be issued. A Halt transient results in the BFS restarting in OPS 0, and it must be moded to the appropriate OPS by the crew. For these transient failures, however, the BFS should be considered "suspect" for engage. This means that it should only be engaged for emergency situations for total PASS failures.

Total BFS GPC failures present a signature similar to a PASS GPC FAIL. The crew should see barberpole *OUTPUT* and *MODE* talkbacks, a big X on the BFS IDP, and a POLL FAIL message.

Actions for BFS failures are listed in the appropriate FDF procedures. Since the BFS also controls several systems during ascent and entry, the crew may be required to take manual control of communications or ECLSS equipment. The following table lists some commands issued by the BFS:

SYSTEM	COMMAND	MAJOR MODE
ECLSS	FES on	103
	NH3 on	603, 305
COMM	SPC to TDRS	104
	Antenna	Ops 1, 6, 3
	Other SPCs to ground stations for lost comm	Ops 1, 6, 3

BFS Commands Over Payload Buses

Environmental Control and Life Support System

Environmental control and life support system (ECLSS) malfunction procedures cover the four subsystems of pressurization, air revitalization, active thermal control, and supply/waste water. Since the ECLSS is highly redundant, the normal response to failures is to switch to the alternate system.

Cabin Pressure

- Klaxon
- *MASTER ALARM*
- Cabin pressure meter
- *dP/dt* meter
- SM SYS SUMM
- High O2 or N2 flow
- *CABIN ATM* light (F7 matrix)

Crew reaction to cabin leaks consists of four basic steps: assess magnitude of the leak, attempt leak isolation through system reconfiguration, power down, and prepare for deorbit.

The crew first closes cabin relief isolation valves and uses available data sources (DPS displays and meters) to verify the leak. If a leak is confirmed, the leak rate determines whether an ascent abort or an emergency deorbit is required. If enough time is available, additional leak isolation procedures are attempted.

An unexpected cabin pressure increase could be caused by either a PCS leak or a malfunction in the PCS control system. Flight Data File procedures are used to secure the PCS and isolate the failure. An early deorbit may be required for a non-isolatable leak to prevent O2 or N2 depletion. PCS leaks may be either internal or external to the crew module.

Pump/Fan Failures

- Rapid drop in flow rate
- Pressure differential in loop
- Rising temperatures
- *MASTER ALARM*
- Hardware caution and warning
- Fault messages

The normal response is to switch to an alternate pump/fan. However, during powered flight, only critical equipment will be swapped, typically during post MECO. The Freon pump and isolation valves are the most likely AC powered equipment to be swapped to prevent an abort. This avoids AC electrical transients, with possible loss of the engine controllers. Should avionics bay temperatures exceed limits, activation of the alternate water loop is permitted.

Water/Freon Leaks

- Decrease in flow rate
- Change in accumulator pressure
- Decrease in pump delta pressure
- *MASTER ALARM*
- Hardware caution and warning
- Fault messages

Depletion of fluid makes the loop unavailable for cooling. An early deorbit should be expected. On ascent, an abort may be required for the loss of two H2O loops or two Freon loops.

Fire

- Siren
- Master alarm
- *SMOKE DETECTION* lights on panel L1
- Fault messages
- Smoke concentration on DPS display

If a fire is confirmed by checking the smoke concentration on the DPS display, the crew must protect themselves with *quick-don masks (QDMs) if on orbit or by closing their visors and going on suit O2 if during ascent or entry*, then taking steps to extinguish the fire. Either a built-in or a portable Halon bottle is discharged to extinguish the fire.

Once the fire is under control, the WCS charcoal filter, ATCO, and LiOH canisters are used to clear the cabin atmosphere of combustion products. If the crew cannot purify the atmosphere to a safe level, then an early deorbit will be required, since the orbiter N2 supply is insufficient to maintain cabin PPO2 below flammability limits for more than 4 to 8 hours while the crew is wearing helmets and exhaling oxygen-rich air.

Cooling Loss

Loss of one or more heat rejection systems (radiators, FES, NH3 boiler) requires a reconfiguration to make up for lost cooling capability while troubleshooting. A powerdown may be required. For severe cooling loss, an early deorbit may be performed.

Electrical Power System

The orbiter EPS configuration during all flight phases is for all buses to be powered and operating independently. Payload and other considerations may mandate bus ties during orbit operations. EPS malfunctions that require an immediate response include reactant valves, fuel cells, major *DC* buses, *DC-AC* inverters, and

AC motors. Cryo-related problems are discussed in the Cryo section.

Shorts

- High amps
- Low volts
- Hardware caution and warning (F7 lights)
- *MASTER ALARM*
- Fault messages
- DPS displays
- F9 meter

For a confirmed short, power is removed from the affected bus. Circuit protection equipment built into the orbiter may also react to large shorts by tripping RPCs, blowing fuses, or popping circuit breakers.

Most bus shorts are characterized by high current and low voltage. Each bus failure has a particular signature that should be learned through practice in failure recognition in the Single System Trainer (SST). It is important to be able to react quickly and correctly to electrical shorts, particularly during critical flight phases.

> **CAUTION**
>
> Never tie a good bus to a shorted bus while executing malfunction procedures.

Bus Losses

- Bus loss ID in FDF
- Fault messages
- Hardware caution and warning

The following table is an abbreviated list of cues for certain bus losses. When the bus loss is confirmed, an attempt may be made to recover the bus, depending on flight phase, criticality, and the type of failure. If the bus cannot be regained, FDF bus loss actions must be completed to reconfigure and safe systems.

BUS	SIGNATURE
Main	*MAST ALARM* Hardware caution & warning *MAIN BUS UNDERVOLT* light and other lights on F7 matrix Fault messages MN volts = 0 IDP loss FC amps = 0
FPC	*MASTER ALARM* Hardware caution & warning *AC VOLTAGE* light, *FUEL CELL PUMP* light Fault messages AC volts = 0 AC amps = 0 MN volts good IDP loss Pump/motors
AC	*MASTER ALARM* Hardware caution & warning *AC VOLTAGE* light, other F7 lights Fault messages AC volts low AC amps low Pumps/motors
ESS	*MASTER ALARM* Hardware caution & warning Fault messages ESS volts low Bus loss ID FUEL CELL PUMP light on F7 matrix
CNTL	Control bus losses are difficult to diagnose. The signature could range from no indications to: SM Alert Fault messages, including SM CNTL/ESS V CNTL volts low Bus loss ID
Panel/ Sub bus	Equipment loss Bus loss ID

Abbreviated Bus Loss Signatures

Fuel Cell Reactant Valves

- *MASTER ALARM*
- *SM ALERT*
- *FUEL CELL REAC* light on panel F7
- FC REAC message
- FC COOL P message

If a reactant valve failure annunciates, the PLT should quickly attempt to reopen the valve and bus tie in order to prevent fuel cell loss and a subsequent main bus loss. For confirmed reactant valve failures, the affected fuel cell must be shutdown. If an O2 or H2 reactant valve fails closed, the fuel cell will fail from lack of fuel within *as little as 20 to 30* seconds, *depending on vehicle loading and cryo quantities*.

Fuel Cell Cooling Loss

- MASTER ALARM
- FUEL CELL PUMP light (F7 matrix)
- FC PUMP message
- FC coolant pump ΔP talkback barberpole

Fuel cell cooling can be lost for several reasons, including: coolant pump failure, AC bus loss, ECU failure, ESS bus loss, or a fuel cell coolant leak. The fuel cell temperature signatures vary with each failure, but in general, the fuel cell must be secured within 9 minutes to prevent stack overheating. To troubleshoot fuel cell cooling problems, use the following rules of thumb, although each is not applicable in all cases.

- If the coolant pump is not running, EXIT T should increase if the H2 pump is running.
- If the coolant pump and the H2 pump are not running, STACK T will decrease. EXIT T will increase slightly and stabilize. (Sensors are not reliable for the actual FC Temperature without any flow.)
- Combined coolant/H2 pump failures may be an indication of an ECU malfunction, or an AC problem affecting both motors.
- Steadily increasing STACK T and EXIT T are indications of a real fuel cell cooling problem.

Fuel Cell Internal Short

- Low fuel cell volts
- Low MN volts
- Reduced FC amps
- Increasing STACK T
- Increased reactant flow
- Fuel cell performance degraded

For this case, the MN BUS *UNDERVOLT* procedure is used. The fuel cell is shut down after dropping the affected bus. For a confirmed fuel cell short, the main bus may be regained using the BUS TIE procedure. (Long form, volts <20.)

Fuel Cell Crossover

- *SM ALERT*
- FC DELTA V message
- Increasing STACK T and EXIT T
- Decrease in FC volts

The FC DELTA V procedure is used to bus tie and safe the fuel cell.

Fuel Cell Shutdown

If a shutdown is required due to a failure or malfunction, the FC SHUTDOWN procedure is used. Upon completion, the appropriate LOSS OF 1 FC powerdown should be performed.

Should a second fuel cell shutdown be required, the 2ND FC SHUTDN procedure is used. In this case, some powerdown is required prior to fuel cell shutdown to prevent excessive loads on the single remaining fuel cell. During ascent, one FC cannot support the load of three main buses, so one main bus will have to be dropped. As before, a LOSS OF 2ND FC powerdown would be performed after the fuel cell is shut down.

Dual Gas Regulator

- *SM ALERT*
- FC COOL P message
- Reduction or increase in coolant loop pressure

Pressure that is either too high or too low will cause the fuel cell to operate incorrectly, and a shutdown will be required. The BUS TIE procedure is used to prevent loss of an MN bus. Time available before shutdown of the fuel cell varies depending upon the severity of the pressure problem.

Powerdowns

Powerdowns are performed to reduce electrical power consumption and reduce heat loads. The appropriate ascent, orbit, or entry FDF procedure is used. These procedures are designed specifically for each flight phase.

Guidance, Navigation, and Control

The most serious failures in GNC systems are those that affect flight control. It is imperative that the crew manage channels for the flight control system. Failures in the flight control systems can rapidly deteriorate into a loss of control.

FCS Channel

- *MASTER ALARM*
- *FCS CHANNEL* light on panel F7
- FCS CH message
- Down arrow on GNC SYS SUMM
- Down arrows on SPEC 53 CONTROLS display
- MCC call

Due to system redundancy, no action is required for the first failure. A second failure on the same effector requires the crew to place the remaining channels to *OVERRIDE*. This prevents a good channel from being bypassed in the event of a third failure.

Sensor Failures/Dilemmas

- SM ALERT or Master Alarm
- Fault message
- Down arrow, “?,” or M on GNC SYS SUMM
- Down arrow, “?,” or M on sensor displays

For single sensor failures or commfaults, redundancy should allow the good systems to continue to provide data without impacting control system performance. A second or third failure may confuse the selection filter, requiring crew intervention. MCC can generally resolve sensor dilemmas quickly, using the additional data available in the telemetry stream.

Mechanical

Malfunctions in orbiter mechanically actuated systems such as payload bay doors and latches can be electrical, mechanical, or DPS related. Since many of these systems are critical for entry, it is important to understand each system and troubleshoot correctly.

Motor Failure

All orbiter mechanical systems have two motors for redundancy, and all systems can drive with just one motor. Motor failures can occur due to power failures, control logic failures, software failures, or jams. Failure of a single motor doubles actuation time for the system. Failure of both motors precludes actuation. Workarounds, IFM, and, as a last resort, EVA procedures are available to restore capabilities on some systems.

Indicators

Microswitch failures can prevent automatic system operation or give false indications of a malfunction. Individual readouts of paired microswitches on most mechanical systems allow the crew or MCC to determine actual status of the system and its associated talkback indicators.

Main Propulsion System

MPS failures during ascent can cause degraded performance that may result in an abort. Most cue card procedures must be executed quickly to safe systems and protect against additional failures. Close crew coordination is required, especially where an ascent abort must be executed.

Engine Failure

- *MASTER ALARM*
- Red *MAIN ENGINE STATUS* light on panel F7
- SSME FAIL message
- Pc goes to zero
- Change in acceleration
- Reduced helium flow. (Helium flow increases during shutdown and then decreases to zero post shutdown)
- MCC call

The most important step following an engine failure is to ensure the GPCs know that an engine has failed. This is checked by verifying that an SSME FAIL message has annunciated. If the SSME FAIL message has not been annunciated, the crew must push the appropriate *MAIN ENGINE SHUT DOWN* pushbutton to mode guidance.

For any SSME failure, the PLT places the *AC BUS SENSOR* switches to the off position. This prevents the AC bus sensors from erroneously taking an AC bus offline, which would impact the engine controllers of the remaining engines.

Helium Leak

- SM ALERT
- MPS HE message
- HE *dP/dt* > 20
- Down arrow on BFS GNC SYS SUMM 1
- HE tank pressure lower than other engine tanks
- HE Reg A↑ or B↑ (may be present)

Early in ascent, a cue card isolation procedure is used to secure one helium leg at a time. If the leak is isolated, the bad valve is kept closed and MCC evaluates the remaining helium to determine if a safe shutdown will occur at MECO. It may be necessary to interconnect the pneumatic helium system. Failures later in ascent may require a shutdown using the shutdown pushbutton only if there is insufficient time for leak isolation. A pushbutton shutdown requires less helium than a pneumatic shutdown, since hydraulic pressure is used to actuate some SSME valves.

If a leak cannot be isolated, helium from a previously failed engine may be used as a source of additional helium to prevent a second engine failure. The engine will fail when helium is depleted. Limits must be enabled to ensure a safe shutdown. An early crew-initiated shutdown could also be required, depending on leak rate. MCC will analyze leak rate and recommend action if comm is available. Without comm, the crew uses the procedures on the MPS cue card.

Data Path Failure

- Engine Pc goes to zero
- *SM ALERT*
- SSME DATA message
- Amber *MAIN ENGINE STATUS* light on panel F7
- Acceleration cues
- Helium flow
- MCC call

The onboard software automatically inhibits limits for a data path failure. If the engine is still running, the crew re-enables limits and should assume a command path failure also exists (which requires a pre-MECO engine shutdown), unless told otherwise by MCC. If the engine has failed, the shutdown pushbutton must be pressed to mode guidance for the engine failure.

Stuck Throttle

- SM ALERT
- Amber *MAIN ENGINE STATUS* light on panel F7
- Static engine Pc
- MPS CMD (HYD, ELEC) message
- MCC call

Procedures for a stuck throttle are found on the MPS CMD/HYD/ELEC cue card. An SSME shutdown will be performed to protect for either SSME constraints for net positive suction pressure (NPSP) or to stay within the 3-g constraints. When this shutdown occurs varies for nominal ascent, TAL, and RTLS. However, it usually occurs about 30 seconds before MECO, to preserve the maximum amount of performance.

Engines with command path failures must always be shut down manually using the MPS controller *AC* power switches. After shutdown, the shutdown pushbutton is depressed to set discretes that allow the software to recognize an engine failure. This is called an AC/PB shutdown.

A single engine with a hydraulic or electric lockup will be shut down via the pushbutton only if three engines are running.

For multiple stuck throttles, the crew will address them in the following priority:

1. Command path failure
2. Hydraulic lockup
3. Electric lockup

ET SEP Inhibit

- *MAIN ENGINE STATUS* lights remain on panel F7
- *SM ALERT*
- SEP INH message

This malfunction can be caused by excessive rates or a feedline disconnect failure. If rates are the problem, the crew damps them manually and allows the automatic separation sequence to occur. Feedline disconnect failures require the crew to execute a manual separation 6 minutes after MECO. For performance problems or aborts, a separation may be performed sooner.

ET SEP Switch

- SM ALERT
- ET SEP MAN message
- ET SEP AUTO message (RTLS, TAL)

The software automatically defaults to a crew-initiated ET SEP if this switch fails to *MANUAL*, except for RTLS and TAL aborts, where the default is *AUTO*. The switch is overridden using an item number on SPEC 51.

MECO Confirm

- No auto ET SEP
- Glareshield DAP lights remain on
- Panel C3 *ORBITAL DAP* lights remain off
- No software mode transition

A failure of the software to confirm MECO prevents an auto ET SEP. The crew can set a MECO confirm flag in the software by simultaneously pushing all three engine shutdown pushbuttons, providing no other failures have occurred. The MECO confirm flag may also be set by manually moding the software via an OPS 104 PRO.

Orbital Maneuvering System/ Reaction Control System

Failures in the OMS/RCS are handled using procedures tailored for the current flight phase. For ascent, achieving a safe orbit while maintaining deorbit propellant margins is the primary concern. On orbit, maintaining at least two deorbit capabilities drive the procedures. During entry, vehicle control is paramount.

Leaks

- Helium pressure decrease
- Propellant quantity decrease
- MCC call
- *MASTER ALARM*
- *OMS* or *RCS* light on panel F7
- Leak message

Leaks must first be confirmed, using independent DPS display and meter indications, since sensor failures may cause false annunciation. Once confirmed, the crew attempts to isolate the leak by securing the affected system. Control requirements drive the procedure to be used.

Helium tank leaks are identified by a continual helium pressure decrease after the system has been secured. For this case, propellant is burned from the affected system to achieve blowdown capability. The point of “max blowdown” (39% OMS quantity, 22% RCS quantity) allows the optimum use of the system once all the helium is depleted.

A helium leg leak can be identified by the helium pressure stabilizing after the system has been secured. In this case, the helium isolation valves are manually operated to maintain pressure in the propellant tanks.

If propellant tank pressure continues to decrease when the system is secured, a tank leak is indicated. (RCS tank leaks in MM 304 are identified by propellant tank pressure diverging from good tank when the system is secured.) The system should be used as long as possible. Then a crossfeed is established to the other system prior to tank depletion. A burn may be performed to deplete the affected propellant tank, preventing leakage into the OMS/RCS pod where the corrosive propellants could damage other systems.

RCS manifold leaks and leg leaks are indicated by a pressure drop in the individual manifold or manifold pairs after leak isolation. In general, the leaking manifold/leg will be left secured and operations will be continued using the good systems.

Regulator Failed High

- Pressure increase in OMS/RCS system
- *MASTER ALARM*
- *OMS* or *RCS* light on panel F7
- OMS or RCS TK P message

Helium isolation valves are closed per the appropriate procedure and troubleshooting performed to isolate the bad regulator.

OMS Engine/Propellant Failure

- *MASTER ALARM*
- Drop in OMS Pc and/or increase in OMS injector temperature
- Reduced acceleration
- Down arrow on MNVR display
- OMS PC message
- *OMS* light on panel F7

Depending on flight phase, the appropriate OMS BURN MONITOR cue card is used. If the problem is real (i.e. not a sensor failure), the crew must use engine inlet pressures to determine whether the affect OMS propellant is still available for use through the remaining OMS engine and/or RCS jets (i.e. ENG FAIL) or has been lost along with the engine (*i.e.*, PRPLT FAIL).

RCS Jet Failures

- *MASTER ALARM*
- RCS light on panel F7
- RCS JET FAIL message
- GNC SYS SUMM indications
- SPEC 23 RCS display indications

Jets can fail off, on, or leak. False annunciations may also occur.

For a failed “on” jet, the RCS manifold must be quickly secured to prevent propellant depletion. If the failure was real, pressure will decrease in the affected manifold.

A single failed “off” jet usually has no major effect, since the RCS jets have a great deal of redundancy. The remaining jets take over per the software jet select priority. If the failure is false, the jet may be reselected so that the DAP will attempt to fire it again.

When a jet fail “leak” is annunciated, the crew and MCC examine available data to determine if the leak is real or an instrumentation problem. For actual leaks, the appropriate manifold is secured only if the leak is large enough to cause a quantity divergence.

Interconnect/Crossfeed

Crossfeed valves and lines allow crossfeeds between the left and right OMS and the left and right RCS. The crossfeed valves and lines also allow the OMS and RCS to be interconnected. During OPS 1 and 3, placing the OMS/RCS switches in *GPC* allows the software to automatically reconfigure these valves and establish OMS/RCS interconnects for abort dumps and RCS crossfeed for large RCS leaks.

For ascent abort dumps, the software will automatically configure the OMS/RCS valves to support interconnected flow, if required. The software will also automatically reconfigure the systems for DPS and electrical failures. With multiple failures, however, the software may inadvertently leave the OMS and RCS in a bad configuration once the abort dump is complete. In such cases, the crew will need to manually reconfigure the OMS and RCS to prevent inadvertent propellant depletion or loss of control.

When the systems are being operated in an interconnect or crossfeed mode, failure isolation becomes much more complex. If conditions permit, it is better to secure the OMS/RCS systems entirely prior to attempting trouble-shooting procedures.

OMS Gimbal

- *MASTER ALARM*
- *OMS TVC* light on panel F7
- OMS GMBL message
- Downmode to secondary gimbal

Either a gimbal failure or its data path caused this annunciation. For either case, operation on the secondary gimbal is initiated. A second gimbal failure may require shutting down the OMS engine if control problems exist. Should the OMS engine be pointed near the orbiter's c.g., then the RCS and the remaining OMS engine may be able to maintain control.

A gimbal failure that occurs prior to a burn will require the crew to use remaining gimbal system to park the affected engine through the c.g. Gimbal power is then removed via an item entry on the MNVR display. The procedure protects against the loss of the secondary gimbals which could render the OMS engine unusable.

6.9 MULTIPLE FAILURE SCENARIOS

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This section briefly describes multiple failures that may be encountered during training. Although the potential for these failures in flight is very low, they allow flight crews and MCC personnel to exercise their knowledge of orbiter systems. For each case, crew actions are noted after the multiple failure is discussed.

MPS He Leak with APC/ALC Failure

A failure of APC 4 (5,6) or ALC 1 (2,3) causes the "A" helium isolation valve on the C(L,R) main engine, *respectively*, to close. Should the crew then close the "B" helium isolation valve on the affected engine (e.g., in working the helium leak isolation steps), the engine would be starved of helium and possibly experience a catastrophic shutdown.

With an APC/ALC failure during powered flight, helium leak isolation must not be performed on the affected engine. A helpful cue that an APC/ALC has failed is the ullage pressure indication directly below the helium dP/dt readout on BFS GNC SYS SUMM 1. With an APC/ALC down, power is taken away from the signal conditioners for the LH2/LO2 ullage pressure sensors. Consequently, LH2 ullage pressure suddenly reads 12.0, and LO2 ullage pressure reads 0.0 for the affected engine.

Set Splits During Ascent

GPC set splits during ascent (2V1V1 or 2V2) can cause control problems, inhibit ET SEP, or cause MPS command and data path problems. Because of this, should a set split occur during ascent, BFS engage may be required to prevent a loss of control, to regain throttling, or ensure a safe ET SEP. Flight Rules permit reconfiguring the PASS GPCs after the set split if certain very specific conditions are met. However, because of time criticality during powered ascent, there may not be enough time to reconfigure the set to ensure vehicle safety. In these cases, a BFS engage should be performed.

Stuck Throttle in the Bucket

For cases when an SSME throttle is stuck while still in the bucket (due to a MPS CMD, HYD, ELEC), it may be possible to continue into orbit, depending on throttle level and actual performance. (More than likely, a pre-MECO OMS dump would be required.) If uphill capability is lost, MCC may call for a TAL (or even an RTLS). This is a real-time call that can be made only by the MCC using the abort region determinator (ARD). A restring may also be performed in some cases if it will recover the stuck throttle.

Second Hydraulic Failure and 1 SSME Failed

Loss of two APUs or hydraulic systems during ascent causes a loss of TVC on one SSME. If another engine fails, the non-gimbaling engine may have to be shut down also to prevent loss of control. Simulations have demonstrated a high probability of control problems with two engines running and one non-gimbaling.

Two APUs/Hydraulic Systems

Loss of two hydraulic systems during powered flight will result in two SSMEs experiencing MPS hydraulic lockups, one of which has also lost ATVC capability. Steps will be taken to protect flight control against the next failure, and a pre-MECO engine shutdown will be required to protect 3-g constraints.

Loss of two hydraulic systems will also affect flight control for glided flight, since aerosurface rates are reduced. Abrupt maneuvers should be avoided to prevent control system saturation.

APU 1 and Multiple Prox Box Failures

Either hydraulic system 1 or one of the *two* landing gear proximity boxes is required to deploy the landing gear. APU 1 provides power for hydraulic system 1, which performs hydraulic gear deploy. Pyrotechnic backup is provided by either prox box. One of these three systems is required for a successful gear deploy.

If two of these systems are failed, attempts will be made to recover at least one of them by repowering failed buses, resetting RPCs/circuit breakers, *or* restarting APU 1. Failure of both prox boxes results in all landing gear talkbacks remaining barberpoled. Gear deployment verification may not be possible via physical cues.

NOTE

Bailout is preferred over a gear-up landing attempt.

Two Freon/Water Loops

Loss of cooling capability requires an emergency deorbit. Procedures are contained in the FDF CONTINGENCY DEORBIT PREP or the SYSTEMS AOA books for losses during ascent. It is extremely important to understand the related powerdown procedures for these cases and perform them expeditiously. Successful entry and landing depend on proper execution of the powerdowns.

Total Loss of FES

Complete loss of the FES during ascent requires an emergency payload bay door opening to obtain adequate cooling. Either the BFS or an SM GPC is used, depending on urgency and what other malfunctions are present.

If the FES has failed on orbit, the payload bay doors will be closed as late as safely possible prior to entry. The ammonia boiler will be activated as soon as possible for cooling during entry. Minimum acceleration of 0.05 g is required for ammonia boiler operation (around 400 k). Due to entry heating and lack of cooling with a FES failure, orbiter temperatures will rise to high levels between payload bay door closing and ammonia boiler activation.

Total Loss of FES with BFS Failure

In order to accomplish emergency payload bay door opening with BFS failed, it will be necessary to either IPL a new BFS machine using the BFS GPC IPL procedure in the Ascent Pocket Checklist or transition a PASS GPC to SM OPS 2 using nominal post insertion procedures. MCC and the crew will work together to pick the best course of action depending on the time available, progress through post insertion when failures occur, and other system failures.

Two Fuel Cells

On orbit, all three main buses may be tied upon completion of the LOSS OF 2 FC POWERDOWN. During ascent or entry, the cue card or Pocket Checklist powerdown is performed, but one main bus will remain unpowered to prevent overloading the remaining fuel cell.

Both OMS Engines

Assuming OMS propellant is still *usable* via OMS/RCS interconnect, the RCS jets are used to perform the remaining ascent and deorbit burns. A staged deorbit burn using aerobraking to provide some of the deorbit deceleration may be performed, so as to not overburn the jets.

OMS/RCS Leak with DPS/EPS Failures

Electrical failures affect the capability to operate the motor-driven OMS/RCS valves, and DPS failures take away crew insight and affect software commands to the valves. If time permits, the OMS/RCS sliderule is used to determine which valves are operational for various failures. Some workarounds are available. These are coordinated through MCC.

For some control bus failures, it is possible to actuate OMS/RCS valves using GPC commands. The master crossfeed, automatic crossfeed, or a software read/write procedure is used to command the valve.

MDM failures can cause the GPCs to lose RCS status information. This may result in good jets being declared failed or unavailable by the RM software. Using item entries on SPEC 23, it may be possible to override the software to the correct status and regain RCS jets or prevent firing a failed jet or jets on a failed manifold.

Cryo Leak with Failed Manifold Valve

A bus tie and fuel cell shutdown may be required to isolate the leak. The PCS systems may also be secured individually to assist in leak isolation. The manifold valve may be closed if the failed bus can be temporarily powered or an IFM performed. If the valve cannot be closed or the leak isolated, then two fuel cells will be lost when the cryo H2 or O2 is depleted. Emergency deorbit or ascent abort may be required, depending on leak rate.

BFS Self Engage

This scenario can occur as a result of multiple BFS GPC and Backup Flight Controller failures, or with only one failure and crew action. Certain failure modes of the Backup Flight Controller and the BFS GPC can put the BFS one failure away from self engage. Should this occur, the crew must be aware that moving the BFS *OUTPUT* switch out of *BACKUP* could result in a self engage. This is a condition where the BFS engages but the PASS does not shut down.

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6.10 SWITCH AND PANEL CAUTIONS

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Because the design of some orbiter controls is very similar, when they are placed in close proximity, inadvertent actuation can occur. Training, along with close attention during high workload tasks, will minimize these problems. This section discusses several potential areas where crewmembers should exercise caution to avoid pitfalls. By being aware that these situations exist, crewmembers can execute time-critical procedures confidently.

MPS Switches

The six *ENGINE POWER* switches and the six *He ISOLATION* switches are located in adjacent rows on panel R2. The switches are very similar, except for a yellow band around the six power switches. Caution should be exercised during MPS helium leak isolation or SSME shutdown procedures.

Fuel Cell Reactant Valves

Because of panel design, which represents a schematic of the PRSD and FC systems, the *FUEL CELL REAC* valve switches are arranged in a 1-3-2 order (1 on top, 3 in the middle, 2 on the bottom) on panel R1. Closing the incorrect reactant valve results in the loss of a second fuel cell and possibly two main buses.

IDP/CRT Power Switch

The *IDP/CRT POWER* switches on panel C2 are adjacent to the *MAJOR FUNC* switch. This makes it relatively easy to power off an IDP when intending to switch major functions. If this occurs, simply power the IDP back ON, inform MCC of the incorrect switch throw, and continue.

GPC/MDM

During dynamic ascent and entry, the GPC and MDM switches on panel O6 are very difficult to reach. They are also hard for the CDR to see when wearing a launch/entry suit helmet. When executing DPS malfunction procedures, it is important to ensure the correct switch is actuated. One technique is to have the MS2 verify that the CDR has selected the correct switch prior to actuation. Powering off the wrong MDM or moding the incorrect GPC can leave you critical to a single failure.

PLB Mech Power/Enable

These switches are located adjacent to each other on panel R13L and perform entirely different functions. Because of their similar nomenclature and same appearance, they are easily confused. The *PL BAY DOOR SYS ENABLE* switches are used during PLBD opening/closing. The *PL BAY MECH PWR SYS* switches are used for other mechanical systems in the PLB (such as radiators, PRLAs, RMS, etc). A careful procedure crosscheck will avoid problems.

HYD Press and APU Controller Power Switches

The *HYD MAIN PUMP* and APU *CNTLR PWR* switches look similar and are in adjacent rows on panel R2. It is easy to confuse these two switches during the APU shutdown procedure or when taking a hydraulic system to LOW PRESS.

OMS Kit

OMS KIT switches are on the left side of panel O8. It is easy to confuse the *OMS KIT* switches with the *LEFT OMS* switches. The OMS KIT switches are inoperative.

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6.11 SYSTEMS FAILURE SUMMARY

This section summarizes actual, in-flight failures that have occurred in the shuttle program. It includes major systems and selected repeat failures important to the crew. The purpose is to give crewmembers a feel for the type and severity of equipment failures and their potential impact on operations. Complete lists of anomalies and failures for both flight and ground operations are available from the Orbiter Project Office.

SYSTEM	FAILURE	CAUSE
APU/HYD	• APU lube oil temp high • Two APUs underspeed shutdown • APU shifted to high speed • Hydraulic leak on entry • APU underspeed - FCS checkout	• WSB ice • Hydrazine leak and fire • Failed control valve • Leak in pump hose • Valve contamination
COMM	• Loss of KU antenna gimbal and stow control • TAGS jam	• Loose screw and circuit burnout • Paper jam
CRYO	• O2 leak	• PCS O2 restrictor installed backwards
DPS	• GPC 2 quit • RS split • BFS failed pre-launch • GPC 1 and 2 failed • GPC 5 failed • GPC 4 failed on orbit • MDM OF3 failed pre-launch • MDM port failure • MDM failure pre-launch • MDM card problems	• CPU timing • Chip problem • Failed string tracking • Contamination • Engage term errors • Failed to sync; changed on orbit • Component contamination • Power supply fail • I/O errors • Card fail
ECLSS	• FES shutdown • *FES failure to come out of standby* • *Freon flow degrade* • *Airlock equalization valve would not depress (for EVA)*	• Ice, temp transducer, or thermal transient • *Controller failure* • *Debris* • *Debris*
EPS	• Hum Sep signal conditioner B circuit breaker popped • TAGS cable arcing • Fuel cell 1 failed • Fuel cells produced excessive hydrogen • High drift rates • *Fuel cell coolant pump single phase AC short*	• Wire bundles short • Cable short • H2 pump fail due to blockage • H2 entrainment in new filter screen • IMU failed • *Wire damage*
GNC	• IMU cage • IMU failed • Spurious IMU accelerometer output • 3 deg/sec vehicle yaw rate during crew sleep • Radar altimeter loss of lock/intermittent lock/fail • TACAN no lock, up or biases	• • Power supply failed (9) • Accelerometer component shift • Bad state vector uplink • Transmission system malfunction • Low receiver sensitivity
Mechanical Systems	• Air data problems • PLBD would not close • Brake damage on landing • Thermal blanket and PLBD seal dislodged	 • Thermal warping • Inadequate brake capability • Unknown; venting suspected
MPS	• Pad abort after SSME start • Launch scrub • 14,000 lb of LO2 drained from ET pre-launch. Launch held due to strange LO2 temp indications in engine • Orbiter ET/SRB structural breakup • SSME failed (auto shutdown) ATO	• Engine valve slow to open • Various component failure, including H2 leakage • Operator error • Right SRB lower field joint burnthrough • Failed sensor
OMS/RCS	• OMS cracks discovered post flight • Left OMS pod burnthrough • Loss of verniers • RCS jet failed off • RCS jet failed leak • RCS Reg leak	• Launch stresses • APU detonation and fire • F5L and F5R leak • OX valve failed/clogged Pc tube/ main poppet stuck/He ingestion • Leaks • Helium leaks

Systems Failure Summary Chart

7. TRAJECTORY MANAGEMENT AND FLIGHT CHARACTERISTICS

CONTENTS

7.1 ASCENT 7.1-1
7.2 ORBIT... 7.2-1
7.3 ENTRY 7.3-1
7.4 TERMINAL AREA ENERGY MANAGEMENT AND APPROACH, LANDING, AND ROLLOUT (OPS 305) 7.4-1

This section presents space shuttle flight characteristics and trajectory management during powered flight, on orbit, reentry into the atmosphere, approach, landing, and rollout. Some guidance and navigation information is included so the crewmember will be acquainted with the parameters that are important in influencing flight control. Much of the information was supplied by crewmembers who have flown the space shuttle. Additional information was derived from simulator runs in the Shuttle Mission Simulator, Shuttle Engineering Simulator, and Vertical Motion Simulator.

For each flight phase (ascent, orbit, entry), manual control techniques are presented, along with information on vehicle handling qualities, performance monitoring, and takeover criteria.

For detailed information on these subjects, consult the appropriate Flight Procedures Handbooks, Flight Data Files, or Flight Rules.

Each subsection discusses the primary controls and displays used during each flight phase. When used, external devices, such as runway lighting, ball-bar, and aimpoints, are integrated with the flight crew techniques in order to present a coordinated picture to the crewmember.

Where the backup flight system (BFS) differs from the primary avionics system software (PASS), (also called primary flight system (PFS)), BFS characteristics are discussed separately. This generally applies to ascent and entry flight phases, because the BFS has limited capability on orbit.

Each subsection concludes with rules of thumb.

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7.1 ASCENT

CONTENTS

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Insertion OMS Burns 7.1-8
Backup Flight System 7.1-9
Sensory Cues.. 7.1-10
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Powered Flight

During powered flight, the crew monitors orbiter performance and system status using dedicated displays, DPS displays, and cue cards. This section describes the displays used, the monitoring task, takeover criteria, and manual control.

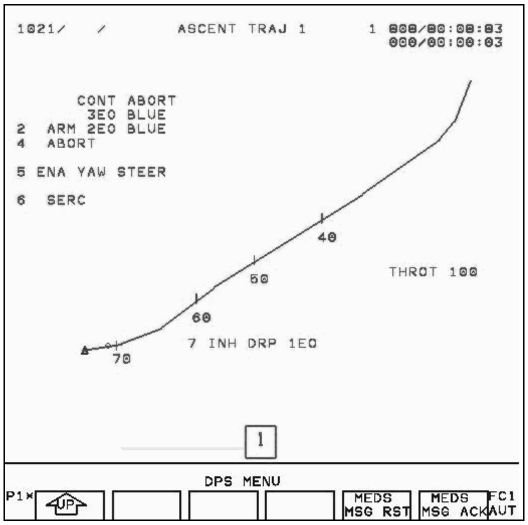
DPS Displays

Several types of DPS displays are used to monitor vehicle performance during powered flight. For a more detailed description of the displays presented here, refer to the Flight Procedures Handbook and DPS Dictionary.

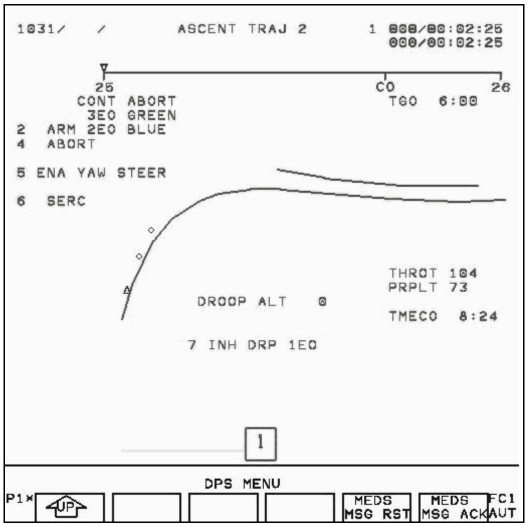
GNC TRAJ Displays

In first stage, *the PASS and* BFS ASCENT TRAJ 1 displays *depict* a nominal trajectory plot with altitude on the y-axis and relative velocity (V_{REL}) on the X-axis. Altitude scale is from 0 to 170,000 ft and velocity from 0 to 5,000 fps. Tick marks on the profile show attitude director indicator (ADI) pitch attitudes at appropriate reference points. Orbiter state (from NAV) is displayed by a moving triangle with a 20 sec predictor circle. An airspeed scale is marked with speeds, and the current knots equivalent airspeed (KEAS) is shown by a triangle. A staging (STG) tick mark denotes maximum q-bar for SRB SEP.

The *PASS and* BFS ASCENT TRAJ 1 display, along with the ascent cue cards, *are* used to monitor first-stage trajectory.

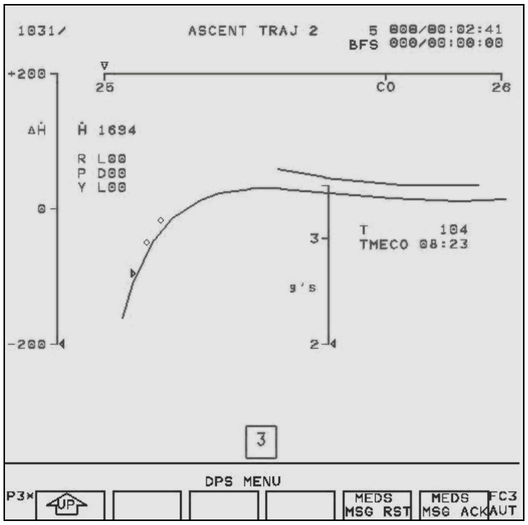


PASS **Ascent TRAJ 1**



PASS **Ascent TRAJ** *2*

PASS and BFS ASCENT TRAJ 2 *displays are* automatically displayed at *the* transition to major mode (MM) 103. The profile represents a nominal second stage ascent with altitude vs inertial velocity (V_I) as the axes. Altitude scale ranges from 140,000 to 525,000 ft and velocity from 5,000 to 26,000 fps. *Current altitude and velocity data from NAV is indicated by a moving triangle. Predicted states at 30- and 60-second intervals are represented with moving circles.* The short line roughly parallel to the last part of the profile represents a TAL TRAJ for an engine failure at the earliest TAL opportunity. *An* expanded V_I scale from 25,000 to 26,000 fps with a cutoff (CO) tick at the MECO velocity *is* *available at the top of the TRAJ displays.* Current V_I is indicated by a moving triangle driven by NAV. *The BFS ASCENT TRAJ 2 shows* total load factor (g) *on a vertical scale, which* ranges from 2.0 to 3.5 g with current value indicated by a triangle.



BFS Ascent TRAJ 2

The orbiter symbol and predictors should track the appropriate profile through MECO. Other monitoring items are:

- V_I: used to monitor proper MECO velocity
- g: used to monitor throttling.

NOTE

TRAJ DISPLAY titles change to include the abort mode when an ascent abort is executed.

GNC SYS SUMM Displays

GNC SYS SUMM displays are the principal means of monitoring flight-critical systems. They should be scanned frequently during ascent to verify system status and aid in determining causes for alarms. The BFS also supports a THERMAL display and two SM SYS SUMM displays. These are accessed by placing the BFS IDP *MAJ FUNC* switch to *SM*. These displays should also be scanned frequently to detect impending system problems and are also used to deal with orbiter systems problems during ascent. DPS displays are presented in Appendix B.

OVERRIDE Display

The OVERRIDE display (SPEC 51) allows the crew to deselect/reselect certain line replaceable units (LRUs) to solve a redundancy management (RM) dilemma or to force RM to consider a previously deselected LRU. The OVERRIDE display also contains various software switches that may be used to override dedicated switch failures, controls for OMS and reaction control system (RCS) dumps, and several other additional functions.

Dedicated Displays

Dedicated displays are also used during ascent to monitor shuttle performance.

The attitude director indicator (ADI) displays attitude, rates, and error information and is used in combination with the DPS displays and cue cards. ADI attitude depends upon the position of the *ADI ATTITUDE* switch on panel F6 or F8. Switch positions are:

- *REF*: reference frame based on nominal launch azimuth at lift-off (can be redefined)
- *LVLH*: Earth-referenced pitch/roll (local vertical local horizontal)
- *INRTL*: referenced to Mean of 1950 (M50) inertial frame (see Section 2.13 for reference frame definitions)

ADI rates are body rates driven by the rate gyro assemblies (RGAs). Scaling depends on the position of the *ADI RATE* switch. Switch positions *during powered flight* are:

- *HIGH*: 10° per second
- *MED*: 5° per second
- *LOW*: 1° per second

ADI errors are the difference between actual and commanded body attitude. Scaling is controlled by the *ADI ERROR* switch. *Switch positions during powered flight are:*

- *HIGH*: 10°
- *MED*: 5°
- *LOW*: 1°

The available scaling of ADI errors and rates is used to tailor vehicle displays for the sensitivity appropriate in each flight phase. If guidance is unconverged, the error needles will be stowed. An OFF flag is displayed for invalid or missing data.

Attitude Director Indicator

The horizontal situation indicator (HSI) is used to monitor AUTO guidance and provide information needed by the crew to fly manually. HSIs provide a geometric view of orbiter location with respect to various NAV points. During powered flight, the HSI displays data relative to the target insertion orbit.

North on the compass card is the desired insertion plane. Heading of the body +X axis with respect to desired insertion plane is read at the lubber line. The difference between current heading and north is vehicle yaw. A course pointer indicates heading of V_{REL}, while the course deviation indicator shows estimated sideslip (the angle between body X-axis and V_{REL}). The primary bearing pointer indicates heading to the selected runway for TAL and RTLS aborts only. It is not driven in first stage. Heading of V_I with respect to target insertion plane is indicated by the secondary bearing pointer.

Notes

Inertial Velocity bearing pointer is displayed throughout a nominal ascent.

Earth-Relative Velocity bearing pointer and **Beta** digital readout are displayed until 2+30 MET or 200K altitude, whichever comes first(β-limiting constraints released).

Course-arrow (magenta) is pinned to 0° on the compass card to mark the targeted inclination.

- **X-Trk** digital readout and **CDI** both display lateral offset from the targeted plane in n. mi.
- **ΔInc** digital readout is the angular difference between the current and targeted inclinations.
- The **HSI compass card** displays 0° through 360° counterclockwise while heads-down (as shown), then **inverts** clockwise after the roll to heads up (RTHU).

The alpha/mach indicator (AMI) is driven by NAV during powered flight. ALPHA displays angle of attack, and ACCEL displays acceleration (computed thrust/weight) in second stage. The ALPHA tape is not driven in first stage.

M/VEL displays magnitude of V_{REL} in first stage, then V_I in second stage, while equivalent airspeed (EAS) shows equivalent airspeed throughout powered flight. EAS is an indirect indication of q-bar.

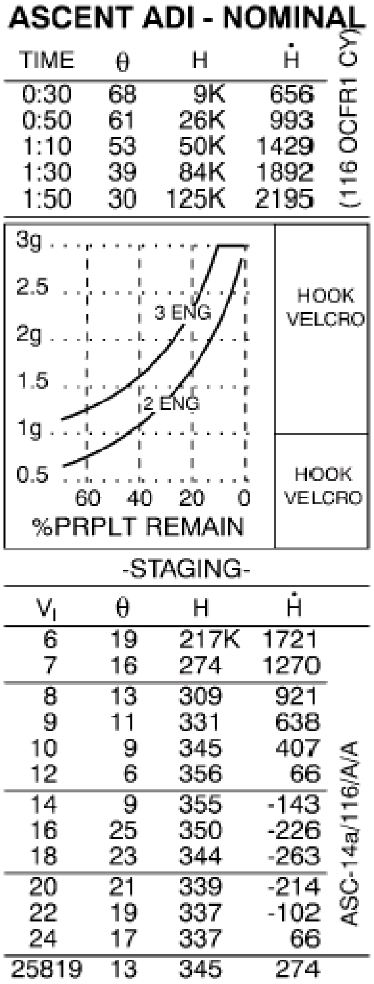
The altitude/vertical velocity indicator (AVVI) is driven by NAV during powered flight. ALT is displayed with respect to the selected runway. ALT RATE (H-dot) is the radial component of V_I.

Pushbutton indicators on the glare shield on panels F2 and F4 indicate status of *PITCH, ROLL/YAW*, and *SPD BK/THROT*. Lights within the pushbuttons correspond to control modes. The *BODY FLAP* pushbutton light also indicates the status of the main propulsion system (MPS) dump sequence post-MECO. The light comes on when the MPS dump is started and goes out when the dump is complete. All other pushbuttons extinguish at space shuttle main engine (SSME) zero thrust (MECO confirmed +3.75 sec). The *BFC* light illuminates when the BFS is engaged and flashes when the BFS is standalone.

Powered Flight Monitoring

Sequential SSME start is monitored on the chamber pressure (Pc) gauges on *the OMS/MPS MEDS display*. After solid rocket booster (SRB) ignition (about 7 seconds after SSME start) the orbiter should perform a vertical rise for about 8 seconds, followed by a combination roll, pitch, and yaw maneuver onto the launch azimuth. Roll attitude on the ADI should be 180° upon completion. Switch *ADI ATT* from *REF* to *LVLH* after the roll is complete to obtain proper pitch/roll attitude information. *REF* is used for lift-offs to avoid large ADI movements at the LVLH 90° pitch singularity.

Throughout first stage, the crew monitors the parameters listed on the ASCENT ADI cue card (especially attitude) and also vehicle rates. Some deviation of the error needles during first stage can be expected due to load relief, but the error needles may not recenter precisely and veto differences in the load relief flight software and error needle display software logic. Guidance will turn the vehicle into unexpected winds to reduce aerodynamic loading during the load relief phase. The crew will be briefed on expected dynamic response prior to launch.



ASCENT ADI - NOMINAL

TIME	θ	H	$\dot{H}$
0:30	68	9K	656
0:50	61	26K	993
1:10	53	50K	1429
1:30	39	84K	1892
1:50	30	125K	2195

(116 OCFR1 CY)

-STAGING-

V_I	θ	H	$\dot{H}$
6	19	217K	1721
7	16	274	1270
8	13	309	921
9	11	331	638
10	9	345	407
12	6	356	66
14	9	355	-143
16	25	350	-226
18	23	344	-263
20	21	339	-214
22	19	337	-102
24	17	337	66
25819	13	345	274

ASC-14a/116/A/A

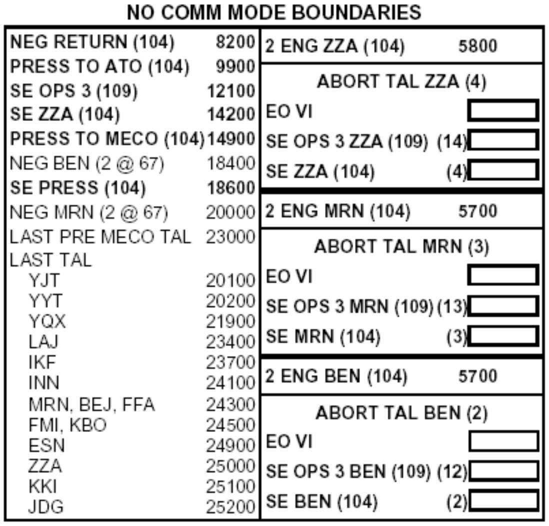
ASCENT ADI
Cue Card

SSME throttle-down at 20 to 30 seconds and throttle-up at about 60 seconds is monitored on the Pc gauges. Throttle command (T) is displayed digitally on the ASCENT TRAJ.

Second stage follows SRB SEP. DPS displays should change to MM 103, and AMI/AVVI tapes display inertial velocity. Monitor closed loop guidance convergence by noting that the time of main engine cutoff (TMECO) on the *PASS* and BFS *ASCENT TRAJ* displays is within a few seconds of the expected MECO time.

The *PASS and* BFS ASCENT TRAJ 2 and the dedicated displays *are used to* monitor *the* trajectory during second stage. Continue to compare displayed data with the ASCENT ADI cue card.

The crew must be continuously aware of the orbiter's abort mode status. Boundaries are monitored by Mission Control Center (MCC) based on tracking data and projected vehicle performance capability as computed by the abort region determinator (ARD) program. Boundaries are transmitted to the crew by the capsule communicator (CAPCOM), but the crew should use the NO COMM MODE BOUNDARY cue card to maintain onboard status if communications with MCC are lost. Boundaries listed on the CONTINGENCY ABORT cue cards should also be monitored.



NO COMM MODE BOUNDARIES

NEG RETURN (104)	8200
PRESS TO ATO (104)	9900
SE OPS 3 (109)	12100
SE ZZA (104)	14200
PRESS TO MECO (104)	14900
NEG BEN (2 @ 67)	18400
SE PRESS (104)	18600
NEG MRN (2 @ 67)	20000
LAST PRE MECO TAL	23000
LAST TAL	
YJT	20100
YYT	20200
YQX	21900
LAJ	23400
IKF	23700
INN	24100
MRN, BEJ, FFA	24300
FMI, KBO	24500
ESN	24900
ZZA	25000
KKI	25100
JDG	25200

2 ENG ZZA (104)	5800	
ABORT TAL ZZA (4)		
EO VI		☐
SE OPS 3 ZZA (109)	(14)	☐
SE ZZA (104)	(4)	☐
2 ENG MRN (104)	5700	
ABORT TAL MRN (3)		
EO VI		☐
SE OPS 3 MRN (109)	(13)	☐
SE MRN (104)	(3)	☐
2 ENG BEN (104)	5700	
ABORT TAL BEN (2)		
EO VI		☐
SE OPS 3 BEN (109)	(12)	☐
SE BEN (104)	(2)	☐

NO COMM MODE BOUNDARY Cue Card

About 60 seconds before MECO, 3 g throttling commences and is monitored on the Pc gauges and DPS displays. MECO should be observed at guidance predicted TMECO and near the design MECO velocity on the AMI. All three red MAIN ENGINE STATUS lights on panel F7 will come on for a nominal MECO, and the ORBITAL DAP pushbutton lights on panel C3 will illuminate *after* MECO confirmed is set in the GPC software.

AUTO ET SEP should occur at MECO +*20* seconds and is indicated by the red *MAIN ENGINE STATUS* lights going out. A SEP INH message indicates vehicle rate in any axis exceeds 0.7° per second or failure of a feedline disconnect valve to close. For *a* rate exceedance, wait for rates to damp, and separation (SEP) will occur automatically. Feedline disconnect failure is handled using cue card and checklist procedures to perform a delayed ET sep.

After external tank separation (ET SEP), an automatic -Z translation occurs to obtain -4 ft/sec ĐV and move the orbiter away from the external tank. Upon completion, the crew should observe software transition to MM 104 by the appearance of the MNVR displays on the DPS displays.

Takeover Criteria

During powered flight, the crew should be prepared to take whatever action is necessary in off-nominal situations to preserve safety and mission success. The Flight Rules define potential takeover criteria. These rules are built into the Flight Data File cue cards and checklists.

The most serious situations involve control problems. In many cases, these are time-critical and an FCS downmode (control stick steering (CSS) or BFS engage) must be rapidly performed. Downmode is an onboard decision that may be made for:

- Impending loss of control
- Failure of an expected maneuver to occur
- Unexplained attitude/rate excursions or undamped oscillatory motions

If the roll maneuver is not initiated as scheduled, auto guidance is considered no-go, and a BFS engage should be performed.

Throughout first-stage flight, rate excursions are a parameter requiring crew action. Prior to 90 seconds, if pitch or yaw rates exceed 5° per second, the crew should engage BFS. After 90 seconds, the crew should select CSS, followed, if necessary, by BFS engage.

CAUTION

With manual throttle control selected, an automatic guided MECO will not occur. To obtain the correct MECO velocity, the main engines must be shut down manually. In low performance cases, a low-level shutdown may occur prior to the planned MECO velocity.

After staging, if TMECO has not converged within 10 seconds, MCC should be consulted. In a NO COMM situation, CSS and manual throttle should be selected.

To avoid violation of range safety limits, CSS takeover may be required. MCC will provide yaw steering commands to allow the crew to fly away from limit lines. Trajectory deviations of such magnitude to require takeover are extremely unlikely. Potential causes are:

- Faulty onboard NAV
- Erroneous guidance
- Launch day winds
- SRB dispersions

Range safety agreements for first-stage deviations allow for limit exceedance as long as control is maintained.

As the orbiter approaches 3-g acceleration, throttling commands and SSME throttle-down should be observed. If this does not occur, manual throttling must be performed using the pilot's speed brake/thrust controller (SBTC) to ensure vehicle loads do not exceed design limit constraints.

Any time the AUTO guidance is unacceptable for vehicle attitude control, it should not be allowed to control the main engines. Manual throttle should be selected whenever CSS takeover is initiated. Automatic guided MECO is inhibited with manual throttles selected.

If MCC predicted TMECO is 2 seconds different than onboard predicted TMECO, a manual SSME shutdown will be initiated on the ground-computed value.

The MCC abort region determinator (ARD) program is the prime tool for determining abort capabilities. The onboard NO COMM MODE BOUNDARIES cue card lists inertial velocity values that define flight design mode boundaries computed prior to flight using predicted ascent performance and including ground rule flight performance reserves. The ARD is a real-time computational system designed to handle:

- One or more SSME failures at any time
- Performance dispersions visible in the vehicle state
- Performance dispersions not visible in the vehicle state
- SSME mixture ratio changes

Multiple or single-engine abort capabilities are determined throughout ascent for any combination of these failures using ground radar tracking or telemetry of current vehicle state. A discussion of performance boundaries is presented in Section 6.

Should the translational hand controller (THC) be moved out of detent post-MECO and prior to the completion of the -Z ET SEP maneuver, the maneuver will be inhibited (terminated if in progress) with no moding to MM 104. If for any reason the -Z maneuver is not completed either automatically or manually, the crew can manually mode to MM 104 by keying in OPS 104 PRO.

Manual Control

Select manual control during powered flight by depressing the *PITCH* or the *ROLL/YAW CSS* pushbutton indicator on the commander (CDR) or pilot (PLT) eyebrow panel (F2 or F4). Selecting any CSS pushbutton indicator gives CSS in all axes to both the CDR and the PLT. To reselect auto control, depress the *PITCH* or the *ROLL/YAW AUTO* pushbutton indicator on the CDR or PLT eyebrow panel (F2 or F4).

If CSS is selected, manual throttles will also be selected on panel C3. The PLT can select manual throttle by depressing the red button on the C3 SBTC and moving the lever to match the current commanded throttle setting within 4 percent. As the throttle level is matched, the *AUTO SPD BK/THROT* lights extinguishes on the eyebrow panels, and the *MAN SPD BK/THROT* light on the PLT side eyebrow panel illuminates. SSME throttling is then controlled by the PLT's SBTC. The CDR manual throttle light does not illuminate because manual throttling cannot be accomplished from that side. Pushing the *SPD BK/THROT* pushbutton on the C2 or C4 eyebrow panel returns throttle control to the digital auto pilot (DAP).

The control system in powered flight is rate control, attitude hold, with a maximum rate of about 12° per second in pitch and roll, and about 6° per second in yaw. If both RHCs are out of detent, the rates are summed.

To fly a nominal ascent to MECO in CSS, the trajectory displays and the ASCENT ADI cue card are the prime and secondary tools, respectively. Displayed data are only as good as the NAV state, so the crew must confirm NAV state with MCC at takeover.

The ADI is primary for roll and is used to maintain roll at 180° before the roll to heads up (RTHU) cue and then 0° after the RTHU cue. The ADI is secondary for pitch.

The E (Earth-Relative Velocity) bearing pointer is primary for yaw in first stage. Placing it on the lubber line (nose) creates the best conditions for attach point loading and SRB SEP.

The I (Inertial Velocity) bearing pointer is primary for yaw after SRB accelerations have dissipated in second stage (MET 2:30). Placing it on the lubber line (nose) creates the most efficient yaw profile because it points to the most in-plane heading.

The ASCENT TRAJ display is primary for pitch. Steer to keep the current state bug (triangle) and the two predictor bugs (circles) on the TRAJ line while making small (less than 5°) attitude changes. Observe the results prior to making each subsequent correction.

If BFS guidance is good, BFS roll pitch and yaw digital information can also be used to fly the ascent profile.

Because H-dot at MECO is extremely critical, concentrate on controlling H-dot rather than altitude within 90 seconds of MECO. Attempt to achieve the nominal MECO H-dot shown on the ASCENT ADI cue card. This will result in a nominal gamma or flight path angle at MECO. Errors of ±100 fps are usually acceptable, while a positive H-dot (and gamma) is always required.

Use the ASCENT ADI cue card to confirm MECO velocity and H-dot.

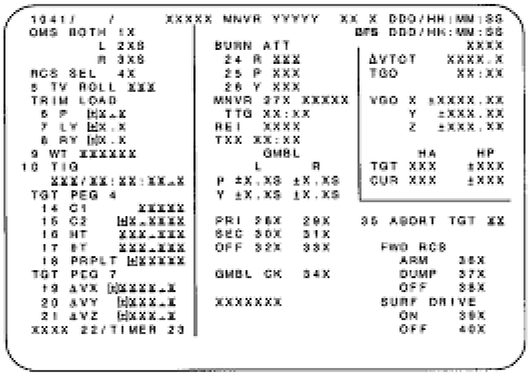
CRM: As the CDR is flying CSS; the PLT manages manual throttle control. MS2 coordinates the CDR and PLT actions. Manual throttle requires a manual MECO. Trajectory monitoring is everyone's first duty. Roll to the ADI, pitch to the TRAJ, and yaw to the HSI. CSS requires manual throttle. Perform manual shutdown by depressing all three shutdown pushbuttons on panel C3 when the cutoff bug meets the cutoff mark. Time of manual MECO can be anticipated as the cutoff bug approaches the cutoff mark. Push the SSME pb's ahead of (lead) the MECO C/O cue by about 150 fps (about a bug width) to allow for SSME tail off. This procedure will result in the best possible V_I at MECO.

Insertion OMS Burns

Monitoring and Targeting

To monitor insertion OMS burns (OMS 1 and/or OMS 2), the MNVR EXEC display and BFS GNC SYS SUMM 2 are used in addition to the ADI. These displays are available in both PASS and BFS in similar formats. The MNVR EXEC display provides digital data to target and monitor orbital maneuvering system (OMS) burns. MNVR EXEC is an interactive display requiring keyboard inputs from the crew, as well as monitoring prior to and during burns. Current HA and HP are used in conjunction with the OMS 1/2 TGTING cue card to determine which OMS targets should be used. Each mission has a flight-specific card, which the crew must understand thoroughly. The MNVR display is described in detail in Section 2.18.

After the crew loads the appropriate targets, the GPC software will compute a burn solution. The target set and burn solution can be checked by comparing data on the DPS display with the expected solution listed in the OMS targeting section of the ascent check list or OMS maneuver pads.



```
 1041/     /     XXXXX MNVR YYYYY   XX X DDD/HH:MM:SS
OMS BOTH 1X                          BFS DDD/HH:MM:SS
        L 2XS     BURN ATT                       XXXX
        R 3XS      24 R XXX          ΔVTOT     XXXX.X
RCS SEL   4X       25 P XXX          TGO        XX:XX
5 TV ROLL XXX      26 Y XXX
TRIM LOAD         MNVR 27X XXXXX     VGO X ±XXXX.XX
  6 P  ±XX.X       TTG XX:XX              Y  ±XXX.XX
  7 LY ±X.X       REI  XXXX               Z  ±XXX.XX
  8 RY ±X.X       TXX XX:XX
 9 WT XXXXXX           GMBL                  HA     HP
10 TIG               L      R        TGT XXX    ±XXX
   XXX/XX:XX:XX.X  P ±X.XS ±X.XS     CUR XXX    ±XXX
TGT PEG 4          Y ±X.XS ±X.XS
  14 C1      XXXXX
  15 C2   ±X.XXXX  PRI 28X  29X    35 ABORT TGT XX
  16 HT   XXX.XXX  SEC 30X  31X
  17 θT   XXX.XXX  OFF 32X  33X       FWD RCS
  18 PRPLT ±XXXXX                       ARM   36X
TGT PEG 7          GMBL CK  34X         DUMP  37X
  19 ΔVX ±XXXX.X                        OFF   38X
  20 ΔVY  ±XXX.X   XXXXXXX            SURF DRIVE
  21 ΔVZ  ±XXX.X                        ON    39X
XXXX 22/TIMER 23                        OFF   40X
```

MNVR Display

For a quick check, scan ÐVTOT, TGO, apogee altitude (HA) and perigee altitude (HP), burn attitude, and time of ignition (TIG) to make sure they are reasonable. Before executing a burn, automatic maneuvers to the inertial burn attitude may be performed using ITEM 27. Prior to executing the burn, crosscheck the attitude with the ADI and compare PFS and BFS solutions.

NOTE

> Burn attitudes on the MNVR display are inertial, and the *ADI MODE* switch must be in *INRTL* for a proper crosscheck of orbiter burn attitude.

The ADI is used for OMS burns in a similar fashion to its use during powered flight. BFS GNC SYS SUMM 2 is used to monitor the OMS system during insertion OMS burns.

Once the targets are loaded, and a solution is available, the crew follows ASCENT CHECKLIST/OMS Burn cue card procedures to prepare for and execute the burn. When in the correct burn attitude, error needles should be centered, and the ADI inertial attitude and commanded attitude on the MNVR display should match.

CAUTION

If OMS 1 is required, maneuvering to burn attitude should be delayed if the DAP has failed to maintain the orbiter within 10° of the ET SEP attitude during the -Z translation. This will avoid recontact with the ET.

Provided perigee is high enough to remain in orbit for a few revolutions, cutoff conditions of an ascent OMS burn are relatively unconstrained compared to a deorbit burn. Achieving the planned orbit is a mission success issue. Reaching an orbit above minimum HP is a safety issue. For failures during insertion OMS burns, the crew will downmode from 2 OMS to 1 OMS to + X RCS to forward RCS as necessary to reach at least minimum HP. Downmode procedures are listed on the INSERTION OMS BURN cue cards.

Manual Control

Takeover criteria and manual flight characteristics during insertion OMS burns are similar to those encountered during deorbit burns. Refer to Section 7.3 for a more detailed discussion of OMS burn takeover criteria and flight characteristics.

Insertion OMS burns for ascent aborts are discussed in Section 6.2. Some special situations encountered during insertion OMS burns are discussed here.

Backup Flight System

The BFS is unique software contained in a single GPC that supports nominal ascent and most shuttle aborts. The BFS can be engaged at any time after lift-off. Once engaged, it is irreversible until the orbiter is in orbit or back on the ground.

BFS state vector degrades very rapidly during powered flight if the BFS is standalone, since it is propagated using the last known accelerations from the inertial measurement units (IMUs). Therefore, if the PASS were to fail, BFS engage must be performed within 10 seconds to ensure the vehicle will remain under control.

BFS engage criteria are listed in the Flight Rules and summarized on the DPS cue cards. They include:

- Loss of redundant set
- Loss of PASS capability to control the vehicle due to general purpose computer (GPC)/multiplexer/demultiplexer (MDM)/ LRU failures
- Loss of control due to divergent trajectory
- Roll maneuver not initiated as scheduled

There are a number of functional differences between the PASS and the BFS:

- No manual control during powered flight.
- No manual throttling.

- BFS does not support contingency aborts.
- No single-engine roll control.
- BFS runs pre-engage in parallel with PASS although not in control of the orbiter.
- BFS has only one memory load. Unique ascent and entry requirements are merged into one common set of guidance requirements.
- When BFS is engaged, it takes command of all flight-critical buses.
- When BFS is engaged, two IDPs are driven unless additional IDPs are assigned with keyboard inputs.
- The BFS can drive all four IDPs simultaneously while the PASS is limited to three.
- BFS performs limited SM functions while PASS GNC does not.
- Post ET SEP, only AUTO -Z translation is available. In the TRANS DAP, attitude maneuvers are manual only.
- OMS burn attitude must be controlled manually.

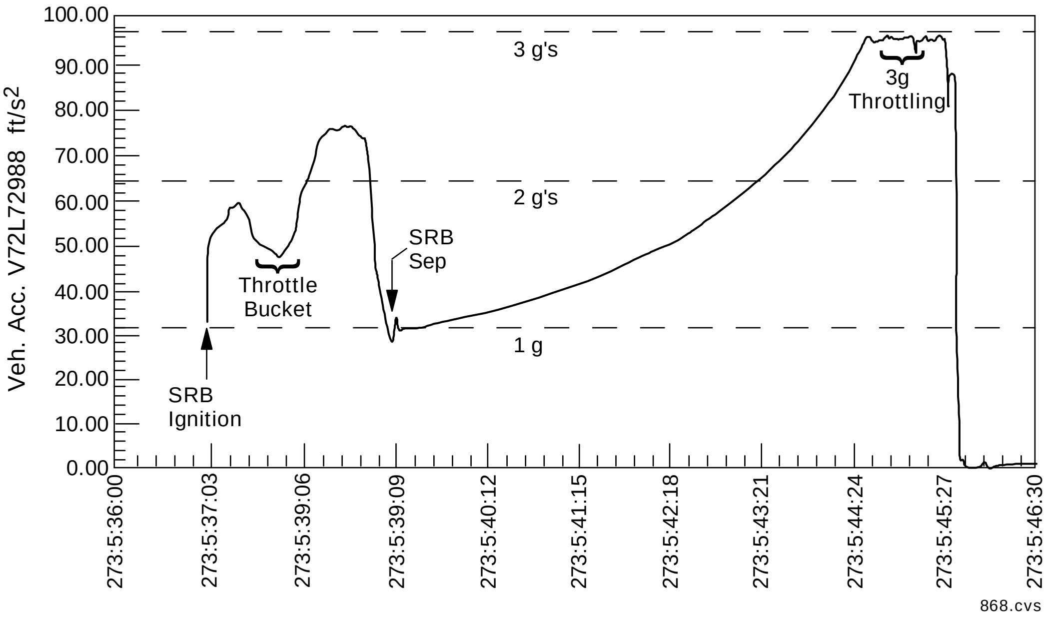
Sensory Cues

Prelaunch, SSME gimbal checks can be felt through the shuttle structure.

First stage is characterized by a rapid g buildup to slightly over 2 g, accompanied by a great deal of noise and vibration. Instruments and DPS displays can be monitored, but precise tasks are difficult.

SRB SEP results in a large amount of flame across the windows from the SRB separation motors. When the flame disappears, forward windows appear to be coated with residue, making them nearly opaque at certain Sun angles.

At SRB SEP, g-load undergoes a nearly instantaneous reduction from 2.3 g to 1.0 g, coupled with a significant reduction in noise and vibration. Since the orbiter is above most of the atmosphere, many crewmembers have remarked that it seems to stop accelerating.



Vehicle Acceleration During Ascent

During second stage, g-load builds very gradually until 3 g's are reached and the SSMEs throttle to maintain 3 g.

A good fit of the pressure suit and harness is very important to avoid discomfort during ascent, particularly at high g loads. Centrifuge runs with actual flight equipment should be performed to ensure proper adjustment.

Some crewmembers report that the eye position in an actual orbiter differs from that encountered in the SMS. Checking seat position in an actual orbiter prior to flight is recommended for first time flight deck crewmembers.

MECO results in g-load decreasing rapidly to zero. Indication of MECO is limited to observing the red SSME status lights, Pc meter readings dropping to 0, and g-reduction.

Some crews have reported an audible thump at ET SEP which could be caused by the explosive severing of the forward attach fitting. Other crews noted that ET SEP had occurred by extinguishment of the SSME status lights.

When the forward RCS jets fire to perform the -Z translation, their ignition is accompanied by a loud boom (just like "cannons" according to some crewmembers). Aft jets produce a noticeable structural vibration, but no sound. The OMS engines do not produce sounds, but the thrust can be noted by unrestrained objects translating aft in the cabin.

Night launches are a special case. The SRB and SSME plumes appear to reflect off the air molecules and produce a "pulsing" light that is most pronounced through the overhead windows, but can be seen through the front windows also.

Ascent Rules of Thumb

- At L/O, check Auto FCS.

- Monitor roll program on the ADI and BFS ASCENT TRAJ display.

- Before L/O +90 seconds, BFS engage is the crew’s only option for loss of guidance and/or control. After 90 seconds, the crew can try CSS.

- Monitor the trajectory on the ASCENT ADI cue card and the PASS and BFS TRAJ displays. The shuttle bug and predictors should follow the nominal trajectory line. Also monitor the HSI for the inertial velocity to be in the desired orbit insertion plane.

- Monitor guidance convergence by observing PASS and BFS TMECOs converging to expected time.

- If the crew takes CSS, they should take manual throttles. If the crew takes manual throttles, manual shutdown is required unless a low level shutdown occurs due to low performance. The cue for MECO is the MECO cutoff bug *on the PASS or BFS ASCENT TRAJ 2 display,* or planned MECO V_I minus 150 fps.

- Use OMS 1 TGTING cue card for system problems and OMS 1/2 TGTING cue card for performance problems to determine proper OMS 1 and 2 targets.

- CSS means manual throttle and manual throttle means manual MECO.

7.2 ORBIT

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Attitude Control

Orbiter attitude is primarily controlled automatically using either inertial attitude hold or track mode. The universal pointing (UNIV PTG) display, combined with the digital autopilot (DAP) display and control panel C3 are used for automatic attitude control. For manual attitude control, the RHC is also used.

Orbit flight control software includes the RCS DAP, OMS TVC DAP, an attitude processor to calculate vehicle attitude, and logic to govern which DAP is selected. Attitudes calculated by the attitude processor are displayed on the ADI and UNIV PTG. Vehicle attitude is used by the DAP to determine attitude and rate errors.

As part of mission planning, an attitude timeline (ATL) is generated. While the Flight Plan is being developed, the ATL is also developed using information about payloads, experiments, and other constraints. An ATL is produced for both the Basic and Final versions of the Flight Plan. When complete, the ATL is incorporated into the Flight Plan, although it is not usually flown. Missions with large numbers of time-critical maneuvers may carry the ATL onboard and use it to perform maneuvers.

Common Attitudes

While each shuttle mission is unique, some attitudes are used frequently and are described briefly in this section.

Top/Bottom Sun

These are inertial attitudes that point either the +Z or -Z body axis at the Sun. They are normally used for thermal control of payloads. Obviously, a rotation angle about the pointing axis must be defined to constrain the attitude. This is usually flight-specific and is driven by look angles, communications coverage, or other constraints.

Tail Sun

Another inertial attitude, but with the -X axis pointed toward the Sun. This is one of the coldest attitudes.

Nose Sun

Opposite to tail Sun. A semi-cold attitude used to cool the aft section of the orbiter or to warm the nose area, particularly the nose wheelwell.

Deorbit Prep Tail Sun

A special case of the tail Sun attitude designed to "cold soak" the radiators prior to entry. This is a track attitude using body vector of pitch = 184°, yaw = 0°, and OMICRON either 90° or 270°.

Tail Sun Rotation

The coldest attitude for the payload bay. This is an inertial attitude that keeps the -X axis pointed at the Sun while phasing rotation to keep the payload bay pointed away from the Earth. It is used for thermal bending tests or to meet specific payload requirements.

Passive Thermal Control (PTC)

This is another inertial attitude rotation about the + or -X axis, but it maintains the Sun in the Y-Z plane. The result is even warming of the orbiter. PTC is sometimes called the "barbecue" mode. It is used to meet various payload thermal constraints.

Gravity Gradient

A stable attitude controlled by balancing differential gravitational and aerodynamic forces. The RCS is not used. Combined forces are very small, and only a few stable attitudes exist. These are difficult to establish and vary according to altitude, inclination, time of year, and many other variables. Gravity gradient is used to conserve propellant or to inhibit RCS firings during certain payload tests and experiments.

Local Vertical Local Horizontal (LVLH)

This attitude maintains a constant orbiter orientation to the earth. Typically, the –Z axis is pointed at the center of the earth with the

-X axis pointed in the direction of the velocity vector. This attitude (payload bay to the earth, tail into the wind) provides excellent extended earth viewing for the crew and PLB experiments.

Displays

Attitude data for the attitude processor are provided by the inertial measurement units (IMUs). Rate data are derived from the IMUs by dividing attitude delta by the time interval between attitude measurements.

ADIs provide an analog attitude display relative to three selectable reference frames. These are selectable via the *ADI ATTITUDE* switch. Inertial (*INRTL*) and reference (*REF*) positions represent inertial reference frames. Local vertical/local horizontal (*LVLH*) represents the orbiter in a fixed position relative to a rotating reference frame.

In addition to the forward ADIs, which always operate in the +X sense, the aft ADI may operate in either a -X or -Z sense. Selection is made using the *ADI SENSE* switch. This allows proper orientation, depending on whether the crewmember is viewing through the payload bay (-X) windows (W 9/10) or the overhead (-Z) windows (W 7/8).

The ADIs also display attitude errors that are calculated from the difference between current attitude and required attitude. The error needles are mechanized to indicate a “fly-to” sense (i.e. the direction in which to maneuver to null the errors). Rate needles are also fly-to (i.e. the direction in which to maneuver to null the sensed rates).

Control

Attitude control on-orbit is provided by the RCS. The RCS is designed to control the orbiter independently in each of three axes. Minimum on/off cycle time for the jets is 80 milliseconds. Vernier jets (25 lb thrust) are normally used on orbit for attitude control since the primary jets (870 lb thrust) use more propellant for fine attitude control. Primary jets are used for translation and higher rate attitude maneuvers. ALT PRCS DAP uses the primary jets but limits the number, duration, and spacing of jet firings to achieve attitude control and RMS loading similar to vernier jets.

OI-23 added notch filter capability. Simply stated, notch filtering allows the crew to select different frequencies to attenuate. This new capability was driven by the previous need for extensive preflight stability analysis in regard to the acceptable RMS/payload position envelope. Without notch filtering, the DAP may tend to excite rather than damp attitude oscillations caused by an unstable RMS/payload position.

For OMS burns, the OMS TVC DAP controls OMS engine gimballing, allowing OMS engine thrust vectors to be independently pointed several degrees in any direction relative to the orbiter c.g. This allows complete attitude control with the OMS engines alone during normal two-engine burns. For single-engine OMS burns, the RCS is used for roll control. The OMS TVC DAP also contains an RCS “wraparound” capability. If the attitude error exceeds 10° in pitch or yaw, or 5° in roll during an OMS burn, RCS jets are fired to correct the attitude.

DAP Configuration

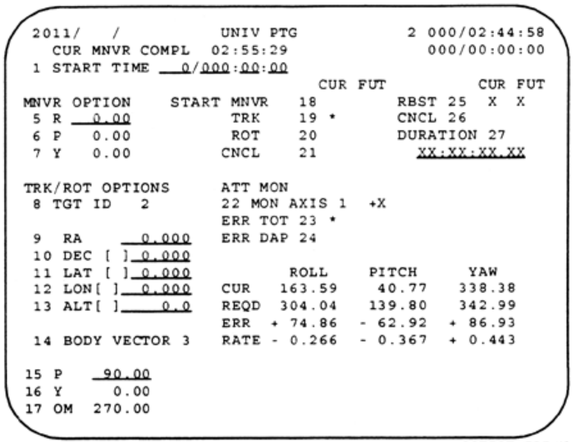
The DAP uses current attitude to determine attitude and rate errors.

Rotation rates and deadbands are functions of DAP configuration. Values may be changed on orbit using SPEC 20 DAP CONFIG. For convenience, each planned DAP configuration is assigned a number. The crew uses these numbers, which are called out in flight data file procedures, to select the proper DAP mode for maneuvers. Typically, DAP A has lower rates and larger deadbands than DAP B, making it more propellant conservative. However, the various DAPs are configured in any number of ways to meet mission objectives.

Attitude Control

Rotation and pointing maneuvers are required to achieve correct attitudes for deployments, on-orbit burns, star tracker operations, thermal control, flyarounds during proximity operations, and pointing.

The RCS controls rotation independently in three axes. Jets are appropriately located and oriented to provide this control. Two independent sets of jets, primary (PRI) and vernier (VERN) are capable of attitude control. Most on-orbit rotation maneuvers are performed with the VERN jets.



```
 2011/   /            UNIV PTG           2 000/02:44:58
   CUR MNVR COMPL  02:55:29                000/00:00:00
  1 START TIME ___0/000:00:00
                                CUR FUT           CUR FUT
MNVR OPTION     START MNVR   18          RBST 25   X  X
 5 R ___0.00          TRK    19 *        CNCL 26
 6 P    0.00          ROT    20          DURATION 27
 7 Y    0.00        CNCL     21             XX:XX:XX.XX

TRK/ROT OPTIONS     ATT MON
 8 TGT ID   2       22 MON AXIS 1   +X
                    ERR TOT 23 *
 9  RA     ___0.000 ERR DAP 24
 10 DEC [ ]_0.000
 11 LAT [ ]_0.000            ROLL     PITCH      YAW
 12 LON[ ]__0.000   CUR    163.59     40.77    338.38
 13 ALT[ ]____0.0   REQD   304.04    139.80    342.99
                    ERR  + 74.86   - 62.92   + 86.93
 14 BODY VECTOR 3   RATE - 0.266   - 0.367   + 0.443

15 P   __90.00
16 Y      0.00
17 OM  270.00
```

usa007587_525.tif

UNIV PTG Display

The UNIV PTG display is used to control automatic attitude maneuvers input by the crew. By entering data on the UNIV PTG display, the crew can command automatic maneuvers to point a specific body axis at a specified target, maneuver to a predetermined attitude, rotate about a specified body axis, or maintain attitude hold. The UNIV PTG display also shows attitude information, errors, and completion time for current maneuvers. Types of automatic attitude maneuvers are presented in the following summaries.

To perform an automatic maneuver, the crew first enters the required data on the UNIV PTG display for the desired maneuver. To start the maneuver at a set time, that time is also entered on the UNIV PTG display. After checking the data, the crew enters an Item 18, 19, or 20, as appropriate, to start the maneuver. With AUTO DAP selected, an auto maneuver will begin at the set time or as soon as Item 18, 19, or 20 is entered if the maneuver start time is in the past. Item 21 is used to cancel a maneuver.

Maneuver

The maneuver (MNVR) option is used to maneuver the orbiter from current attitude to a new inertial attitude specified on UNIV PTG. AUTO maneuvers are three-axis at the rate specified on SPEC 20. Maximum acceptable error in any axis is the SPEC 20 attitude deadband (ATT DB). Total error, displayed on UNIV PTG, is the difference between required and current attitude. Allowable rate error in any axis is specified by the rate deadband (RATE DB) on SPEC 20. When the flight control software determines the orbiter is at the required attitude, attitude hold is initiated.

NOTE

> Manually maneuvering away from a commanded attitude is possible. However, the DAP will return the orbiter to the commanded attitude when AUTO is reselected.

Track

The track (TRK) option is by far the most complex in universal pointing software. There are six subcases: orbital object tracking, center of Earth, Earth-relative target, center of Sun, celestial target (e.g., planet, Moon), and navigation star target. Each subcase is selected by a target ID (TGT ID) on UNIV PTG. The TGT ID is the line of sight or target vector from the orbiter c.g. to one of the defined targets.

The track option is used in conjunction with a body pointing vector, which is centered at the orbiter c.g. and is defined by a pitch and yaw combination. These angles are referenced to the orbiter +X axis.

Track software allows the crew to point a specified body vector at one of the defined targets. Attitude is not completely constrained until body orientation about the body pointing vector has been specified. Rotation about the body pointing vector is called OMICRON. By selecting a pitch, yaw, and OMICRON, a body pointing vector and the orbiter's orientation with respect to that vector are specified.

When a TRK option is initiated, TRK software performs a three-axis maneuver at the rate specified by the current DAP, then begins active track of the target. TRK subcases perform the following functions:

Orbital object tracking (TGT ID = 1)

State vectors of the orbiter and another orbiting target are used to determine a relative target vector. The target state vector is maintained by the REL NAV software. This mode is used post-deploy to track a payload. It is also used extensively during rendezvous operations.

NOTE

> It is important to have REL NAV (RNDZ NAV) enabled (SPEC 33, ITEM 1) prior to tracking another orbiting body. It is also important to disable a TGT ID = 1 prior to an OPS transition. Although UNIV PTG remains active in OPS 8, REL NAV does not. Excessive fuel usage could occur due to universal pointing chasing a stale state vector.

Center of Earth (TGT ID = 2)

Selected body vector is pointed at the Earth, with orientation specified by OMICRON, and maintained. This is, in effect, an LVLH attitude hold, requiring the orbiter to establish a small rotation rate that matches orbital rate. Center of Earth tracking is frequently used on orbit for normal operations that do not require specific attitudes.

Earth-relative target (TGT ID = 3)

Latitude, longitude, and altitude of an Earth target are entered on UNIV PTG. This determines target line of sight from the orbiter. TRK maintains this attitude. Latitude and longitude are entered in degrees. Altitude is entered in nautical miles. Typically, primary jets will be required to maintain this track as the orbiter flies over the target.

Center of Sun (TGT ID = 4)

Present values of right ascension (RA) and declination (DEC) are used to determine line of sight to the center of the Sun. TRK then maintains the proper attitude. RA and DEC on the UNIV PTG display are updated with each new recall of TGT ID=4 as the Sun RA and DEC change. This mode is used primarily for thermal control.

Celestial target (TGT ID = 5)

RA and DEC of a desired celestial object are entered. TRK will then point the defined body vector at this target and commence tracking it. An astronomical target can be tracked in this mode to point specific instruments. It may also be used during payload deployment to provide illumination or shading.

Navigation star target (TGT ID = 11-110)

TRK software contains the RA and DEC of 100 navigation stars that are defined by a number (11-110). Selecting a particular star and defining a body vector allows TRK to point the body vector at the star and track it. Obviously, this mode can be used for star sightings. It may also be used to point instruments.

Rotation

The rotation (ROT) option takes the body vector defined by pitch and yaw and initiates a rate (specified on DAP CONFIG, SPEC 20) about it, while holding that axis in an inertial attitude.

NOTE

> Transitioning to OPS 8 with an active rotation continues the rotation. Ensure correct DISC RATE is selected prior to transition, since neither UNIV PTG nor DAP CONFIG (SPEC 20) is available.

Cancel

Executing the cancel (CNCL) item on UNIV PTG snapshots and maintains current inertial attitude. All other current and future options (MNVR, TRK, ROT) are terminated. CNCL is selected automatically when entering OPS 2 from any OPS except OPS 8. Otherwise, the crew must select CNCL via an ITEM entry.

Manual Attitude Control

The RHC controls roll, pitch, and yaw movements on orbit with the OMS and RCS. Flight characteristics depend totally on DAP configuration. Various DAP configurations have been optimized for certain tasks, using off-line simulation. With the DAP mode in *INRTL,* and *DISC RATE* selected on panel C3 or A6U, deflecting the RHC out of detent fires appropriate RCS jets until an angular rate is achieved in that axis equal to the rate specified in the DAP CONFIG display (SPEC 20). Different rates may be specified for DAP A and B, and for PRI or VERN jets. When the rate is achieved, the jets are turned off until the RHC is returned to detent or deflected in another axis. Jets also fire to maintain attitude or rates within selected DAP CONFIG deadbands. Returning the RHC to detent snapshots the attitude, and jets are fired to stop rates and hold the snapshot attitude.

Deflecting the RHC beyond the soft stop causes jets to fire continuously, producing a constant angular acceleration. When the RHC is repositioned inside the soft stop, jets are turned off, but rates continue until the RHC is returned to detent.

With *PULSE* selected, RHC deflection fires jets to achieve the angular rate change specified by rotational pulse (ROT PLS) on SPEC 20. *PULSE* is also a free drift mode.

High Rate Attitude Maneuvers

To quickly maneuver to attitude in an emergency, a high maneuver rate may be required. With the appropriate DAP ROTATION in DISC, bump the RHC past the soft stop and back within the soft stop several times until the desired rate is achieved, being careful not to let the RHC return to detent. Stop the maneuver by returning the RHC to the detent. It will be necessary to lead the desired attitude by an amount proportional to the rotation rate.

Flying Techniques for COAS /HUD Calibrations and HUD IMU Alignments

To perform a HUD (or COAS) calibration or IMU alignment using the HUD, the orbiter must be maneuvered manually to align the HUD test pattern (or COAS reticle) with a preselected star. The largest portion of the maneuver will be performed using a coarse control DAP with rates and deadbands selected to minimize maneuver time without exceeding propellant allotments.

Once the star is near the proper location in the HUD test pattern, the crew must switch to a DAP optimized for fine attitude control. A vernier DAP will provide the finest attitude control with minimum fuel consumption.

Patience is very important when attempting to properly locate the star in the HUD test pattern. After making an RHC input, wait until movement is noticed, and the star is near the desired position before releasing the RHC. This will minimize jet firings and fuel consumption. The coarse control DAP will usually allow higher maneuver rates than the fine control DAP. The higher rates require more time to start and stop so pilots will notice a requirement to lead RHC inputs when using the coarse control DAP (i.e., return the RHC to the center detent slightly before the star reaches the desired position in the HUD).

Translation

Orbit translation maneuvers can be conducted using the OMS engines or RCS jets. The OMS engines are usually used for larger maneuvers. Burn targets for preplanned orbit OMS or RCS burns are normally transmitted to the crew from Mission Control. The crew will then load those (or verify auto-loaded) targets and execute the burn at the appropriate time. OMS/RCS burn monitoring and control for orbit burns is similar to that discussed in Section 7.3.

RCS Translation

The RCS is used to control translation when small velocity changes are required. For example, the RCS might be used for the initial maneuvers used to separate from a payload after deploy. In these situations, the CDR/PLT uses the THC and DAP panel to transmit control commands to the GPCs and ultimately to the RCS jets.

Translation flight characteristics depend on DAP panel configuration and the DAP parameters listed on the DAP CONFIG display. DAP parameters are optimized for planned tasks preflight, using off-line simulation.

THC deflection with *PULSE* selected on the *ORBITAL DAP* panel fires jets to cause a velocity change as specified on SPEC 20. Selecting *NORM* allows continuous acceleration as long as the THC is deflected. *HIGH Z* is a submode available for +Z translations only. Selection of this submode fires all nine upfiring jets and should be used only in an emergency.

LOW Z is a submode that allows +Z translations by firing +X and -X jets simultaneously to minimize payload/Space Station pluming. *LOW Z* translations also affect pitch and roll, since upfiring jets are inhibited. There are significant translational cross-coupling effects in this mode.

Rendezvous/Proximity Operations

Rendezvous and proximity operations require coordinated attitude and translation maneuvers to join with or maintain a position relative to another orbiting object. This section covers some of the tasks and problem areas encountered during rendezvous and proximity operations along with some suggested techniques. The normal rendezvous sequence is presented in the orbit mission events summary in Section 5. For a more detailed discussion of Rendezvous/Proximity Operations, refer to the Rendezcous Concepts CBT Lesson.

Plume Impingement

For translations near targets, there is a concern about contamination and also the induced body rates and torques caused by an RCS jet plume striking the target. Certain types of payloads may be sensitive to propellant contamination. For example, a payload with delicate optical equipment could be damaged by the plume from an RCS jet at a short distance. Selecting which jets to fire, as well as distance and orientation of the orbiter with respect to the target, may be adjusted to reduce contamination.

Nearly all payloads are sensitive to the force and resultant body rates/torques caused by an RCS jet firing at close range. Usually, a sphere of influence is identified, and no upfiring jet firings at the target are allowed within it; typically, 200 ft to grapple range for small payloads and 1000 ft. for large payloads and stations.

Braking Techniques

Braking is used to reduce relative velocity between the orbiter and a target. Three techniques will be discussed: Norm Z, Low Z, and orbital mechanics effects.

Norm Z braking uses upfiring jets to generate braking in a +Z direction. Since the jets pointing toward the target provide the braking force, plume impingement is a concern.

Low Z reduces plume impingement by using the cant of the +X jets and scarfing (design of the nozzle) of the -X jets to produce a resultant force in the +Z direction. Low Z braking can use up to 12 times the amount of propellant as Norm Z. This mode should only be used where plume impingement must be minimized. When in Low Z, Y-axis jet firings induce higher closing rates, requiring expensive braking maneuvers.

CAUTION

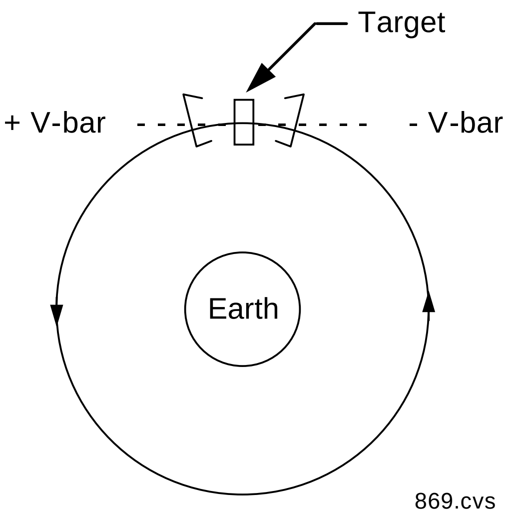
Due to cross-coupling effects, minimize Y-axis translations when flying in low Z mode (increases closure).

Orbital mechanics may provide small separation forces for various approaches. This may be used effectively for plume-sensitive targets and to help minimize propellant usage. The best illustration of this concept is the +R-bar approach, where “natural” braking (slowing of the orbiter) lessens the requirement for +Z thrusting.

Stationkeeping

Stationkeeping is the technique used to maintain the orbiter at a desired relative position, attitude, and attitude rate with respect to a target vehicle. When stable in a stationkeeping position, the crew has time to obtain navigation information and determine and set up approach maneuvers. Stationkeeping most commonly is performed on the target’s velocity vector (V-bar) or the radius vector of the target to the center of the Earth (R-bar).

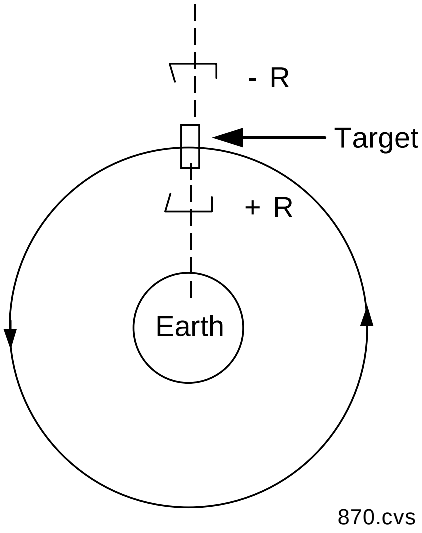
V-bar stationkeeping can be accomplished either ahead of (+V-bar) or behind (-V bar) the target. For a given range V-bar stationkeeping uses less prop than R-bar stationkeeping since both the orbiter and the target are nearly in the same orbit.



V-Bar Stationkeeping

This results in the most efficient type of stationkeeping because minimal propellant is required to maintain the orbiter at the same altitude and coplanar with the target. At about 600 ft on the V-bar, position can be maintained for about 100 pounds of propellant per orbit, using optimum techniques.

Similarly, R-bar stationkeeping can occur either below (+R-bar) or above (-R-bar) the target.



R-Bar Stationkeeping

This is an unstable configuration, since orbital mechanics effects will result in the orbiter and target changing their relative positions over an extended period. R-bar stationkeeping is more complex and requires higher propellant usage. About 0.5 lb/ft range per rev, above and beyond V-bar usage, is required (600 ft. = 400 lb/orbit).

Stationkeeping position is maintained using the COAS, rendezvous radar, lasers, and CCTV triangulation. The crew must judge when attitude and translation corrections are necessary and make corrections manually. Typically, attitude is controlled by UNIV PTG so the crew has only translation corrections to maintain position.

For convenience, stationkeeping operations are classified by range (close in, short, medium, and long). There are significant differences between techniques used at different ranges.

RANGE	DISTANCE
Close in	35 - 200 ft
Short	200 - 1000 ft
Medium	8 miles
Long	40 miles

Stationkeeping Ranges

Close In

Close in techniques are required after the orbiter has achieved a stable position near the target. Alignment with the desired target axis may or may not have been completed. Orbital mechanics effects are minimal, and flying is done using a combination of out-the-window and CCTV cues. Most payloads will use Low Z operations in this area.

NOTE

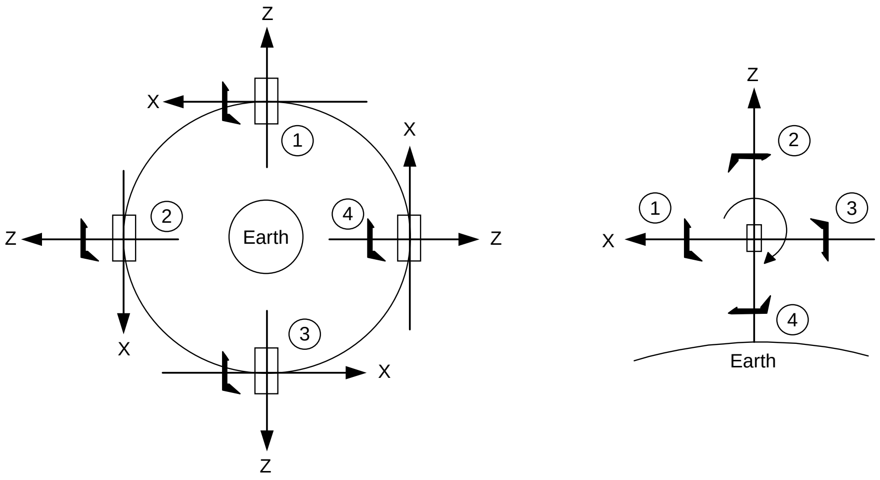
> Low Z requirements are defined for each rendezvous mission so may vary from these generalized descriptions. Close in stationkeeping requires constant attention by the crew. A flyaround or matching the target's rates may be required to affect a capture.

Short Range

Short range techniques are used after the orbiter is positioned on the desired target axis or immediately after target deploy. Orbital mechanics effects cannot be ignored, and plume impingement must be considered for larger payloads (HST, Station). The primary tasks are matching attitude rates and translating to maintain correct relative position on the desired target axis.

These require visual translation guidance techniques that can be described by three types of targets: inertially stabilized, fixed in LVLH frame, and arbitrary rate.

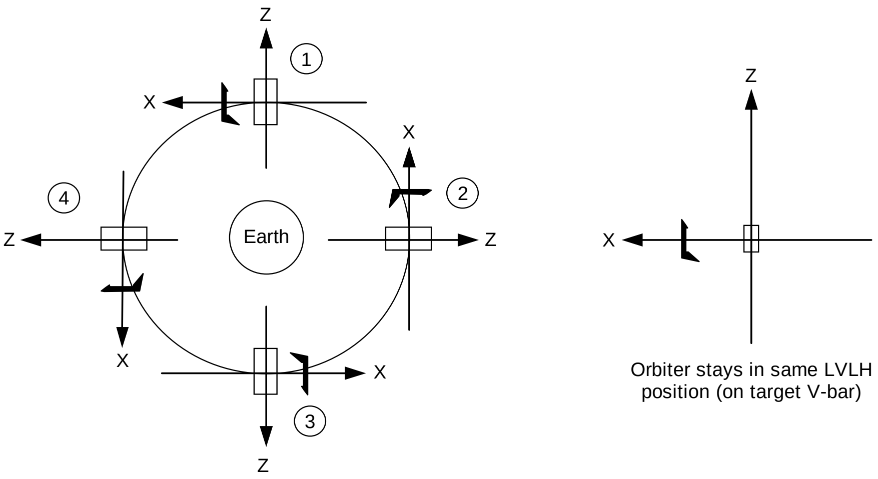
Inertially stabilized targets usually have some type of control system or are spin-stabilized. To keep the same relative geometry, the orbiter must also maintain inertial hold. This requires a constant translation to stay in the desired orientation to the target and maintain the desired range. Procedurally, UNIV PTG and the DAP: INRTL are used to automatically maintain inertial hold, while the crew uses the THC to maintain the –Z orbiter axis pointed at the target at the desired range.



Stationkeeping WRT inertially stabilized target

872.cvs

Inertial Stationkeeping



Orbiter stays in same LVLH position (on target V-bar)

Stationkeeping WRT target rotating in inertial frame at orbital rate (i.e., target attitude fixed relative to LVLH frame)

873.cvs

LVLH Stationkeeping

Some targets may be maintaining a constant attitude relative to the LVLH reference frame and therefore rotating in the inertial frame at orbit rate. The target may have an active or passive (gravity gradient) control system.

The orbiter maintains a fixed position and attitude with respect to the target's LVLH reference frame. Procedurally, UNIV PTG or LVLH is used to automatically control attitude, and translation is controlled manually. Since LVLH stationkeeping is much more stable than inertial, fewer translation inputs are required to maintain position.

Should the target lose its control system, causing it to rotate at an arbitrary rate about a principal axis of inertia, stationkeeping becomes more difficult. Either an inertial or LVLH mode may be used, depending on the situation.

Medium Range

Medium range stationkeeping may be required during long-term payload checkout/ troubleshooting or recovery from an orbiter malfunction. Burns are targeted by MCC or onboard using NAV state data. Attitude maneuvers are performed using the AUTO DAP. The radar should provide relative position information. One technique, called a "football," attempts to keep the orbiter within some predefined boundary centered at some range on the V-bar. When the orbiter approaches a boundary, a maneuver is performed to drive it back to the center. This is repeated as required. Orbital mechanics effects can be used to maintain the "football" with minimal maneuvering required.

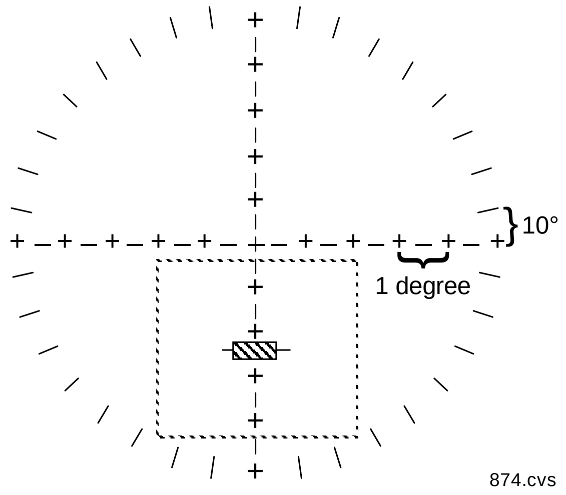
Long Range

Long range stationkeeping is typically done at 40 n. mi. (or greater). This is usually done to support a possible rendezvous at some later time in the mission (similar to HST deploy). This stationkeeping is usually maintained by ground targeted coelliptic (NSR burns) and is done on the V-bar.

Prox Ops Techniques

Whenever possible, use the DAP and UNIV PTG to automatically maintain attitude. Select vernier jets for attitude control to conserve fuel.

Aim for an "ideal" target position in the -Z COAS reticle. Typically this is in the lower half of the COAS to keep the CGs close.



COAS Sight Picture

Translate using the THC to maintain this position. Small inputs and patience are essential. When rates are low, use the smallest translational pulse size available. Use vernier jets for attitude control. Maintain the payload in an imaginary box, sized to reflect attitude deadbands, about the "ideal" position and translate only when the target moves out of a self-imposed box which is about two times that attitude deadbands.

NOTE

> It is more important to null the rates in the COAS (keep it stationary) than to "drive" it to the "ideal" position.

This will reduce fuel consumption and take maximum advantage of orbital mechanics effects.

Use radar and REL NAV (SPEC 33) to maintain distance and range rate.

NOTE

> The tendency is to focus on keeping target position fixed in the COAS. A good scan and crew coordination are necessary to control range rate and maintain distance.

Transition

Transitions are maneuvers that maintain the orbiter at a constant distance from the target while it moves from one position to another. The orbiter will continue pointing a specified body vector (usually -Z) at the target. In contrast to a flyaround, which requires the orbiter to actually fly around the target in an inertial sense, a transition involves moving the orbiter around the target in a target-centered, rotating LVLH reference frame without regard to the target's inertial attitude. Transitions can be completed by placing the orbiter in inertial attitude hold with the -Z axis pointed toward the target (inertial stationkeeping), or by pitching the orbiter (tail up or tail down).

Flying a transition from the +V-bar to the -R-bar (90° of the orbit) using a pitch maneuver is similar to inertial stationkeeping for ¼ of an orbit. Which transition is selected depends on propellant or time/lighting concerns.

Separation

Translating away from another object requires establishing an opening rate between the bodies. Usually, relative state vectors are well known, and a planned sequence can be followed to minimize propellant usage. However, payload sensitivity to plume impingement and payload control system characteristics tend to complicate separation maneuvers. Long- and short-term recontact must be considered; therefore, some separation sequences require multiple separation maneuvers. Separation is usually performed in two stages. A small separation burn (< 1 fps) is performed to start opening, then a larger burn is performed when the orbiter is further away.

Cross-Coupling Effects

Because the thrust of the RCS jets is not through the orbiter c.g., commanded translation/ rotation maneuvers in one axis tend to induce motion in other axes, which is called "cross-coupling;" it can have a significant impact during rendezvous manual phase and proximity operations.

With the orbiter on the target V-bar, tail-to-Earth, and payload bay toward target, the crew should be aware of cross-coupling effects, as follows:

- NORM ROLL: Affects every degree of freedom. Much worse in LOW Z than NORM Z .
- NORM ±X: Induces braking (+Z) translations, and pitch cross-coupling. When flying Prox Ops, use the 1 to 5 Rule: 1 +Z input for every 5 ±X inputs.
- NORM -Z: Significant +X translation.
- LOW Z +Z: negative pitch cross coupling, translation pulse may loose half its force due to counteraction of attitude firings when in attitude hold.
- LOW Z ± Y: In attitude hold, major closing (-Z) rates induced, more than half the size of commanded Y-axis translation.
- ROLL/PITCH deadbanding: using Primary jets, induces a small opening (+Z) rate. In LOW Z, causes a major closing (-Z rate). Minus pitch also produces a significant +X translation when in LOW Z.
- TAIL ONLY: A control mode used to conserve forward RCS propellant. Pitch maneuvers induce a powerful Z translation and a significant +X translation. Yaw induces a powerful Y translation and noticeable X and Z translations. All other control mode effects are identical to normal control (NOSE and TAIL).
- NOSE ONLY: For pitch, translational effects are mirror image of TAIL ONLY, except no X effects. Yaw is also opposite to TAIL ONLY, but significantly reduced. (NOSE-ONLY is rarely used.)

These effects point out the requirements for patience after performing translation pulses. Crewmembers should learn how to separate translational motion from deadbanding (keep ADI needles and UNIV PTG in your scan) Cross coupling must be understood. Techniques are developed through practice in simulation facilities.

Vernier jets, when used for attitude control, induce their own cross-coupling effects. Even though verniers produce much smaller forces than primary jets, their geometry is even more awkward. All vernier firings induce translational cross-coupling in the -Z direction. This can induce significant downtrack errors in orbiter position that are important during rendezvous over long periods. This “vern-effect” can cause unwanted closure during prox ops.

NOTE

The crew must closely monitor R-dot using all ranging devices (CCTV, radar, laser, COAS) to avoid undesirable closing rates.

Orbit Rules of Thumb

- In propellant-limited situations, use the following guidelines:
  - Use Verns for attitude hold and ALT DAP for attitude maneuvers.
  - To conserve forward RCS, use TAIL ONLY control mode.
  - Prox Ops
    - Null rates (all axis)
    - Null out of plane velocity at the node
    - Do not confuse deadbanding with translation
    - Anticipate (do not fight) orbital mechanics effects
    - Range rate is the most important parameter

7.3 ENTRY

CONTENTS

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Overview of Entry Flying Tasks

The entry phase of flight covers the transition from Earth orbit to the end of landing rollout. Guidance phases for portions of the entry phase are deorbit burn guidance, entry guidance, TAEM guidance, and approach/land guidance.

Monitoring

Crew monitoring of performance is required throughout entry. This subsection presents the information necessary to monitor and control the vehicle during the deorbit burn and entry phases of guidance. This task consists of monitoring vehicle displays to determine if guidance, navigation, and flight control are performing correctly and taking action, if required, to ensure a safe landing. An in-depth knowledge of how these systems work, along with an understanding of the reference trajectory and orbiter flight control system (FCS) will enable crewmembers to recognize off-nominal situations and correct them before serious performance or control problems develop.

Takeover

Takeover rules and criteria are described in the Flight Rules. Interpretation of onboard information will aid the crew in their assessment of when to manually intervene. From the available information, the crew assesses the performance of the automatic guidance system and remains prepared to take over with manual guidance for off-nominal situations. Some of the conditions requiring crew takeover are:

- Navigation errors
- L/D dispersions
- Atmosphere variations
- Winds
- Deorbit execution errors
- GNC failures
- Degraded performance

Any of these conditions, if left uncorrected, could lead to unrecoverable range problems or loss of vehicle control.

Guidance and flight control perform well. It is highly unlikely manual takeover will be required. MCC is also available to help with a ground controlled approach (GCA).

Manual Control

In some instances, the crew will be required to take manual control and fly the orbiter. The Deorbit Burn and Entry sections contain the basic principles for CSS flying, although these portions of the flight profile are normally flown in AUTO. Manual flight control is the normal mode of operation from .96 Mach until the completion of rollout. (This portion of the flight profile is discussed in detail in Section 7.4.) Self-generated guidance based on navigation information will be discussed, but if guidance is good, flying the error needles in CSS will result in the most consistent tracking of the planned entry trajectory.

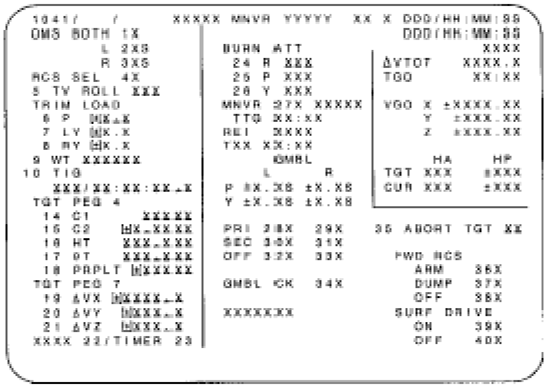
Deorbit Burn

Monitoring

Normally, the deorbit burn will be flown in AUTO using both OMS engines. The OMS engines are gimballed to control orbiter attitude in all three axes. Capability exists to downmode from both OMS engines to one OMS engine, to the aft +X RCS jets, or to the forward -X RCS jets. The burn time of ignition (TIG) is selected to protect for one OMS engine failure at TIG or at any time during the burn. A single OMS engine can control pitch and yaw, but roll must be controlled by the RCS. If flight control does not recognize the OMS engine failure, control will be sloppy but acceptable. Deorbit burns using the RCS only must be flown manually.

The DEORBIT BURN, DEORBIT BURN MONITOR, and the DEORBIT BURN FLIGHT RULES cue cards are used to determine the required actions for malfunctions affecting the burn. The philosophy embodied in these cards is to either safely complete the burn or stop the burn above a safe altitude.

The ADI error needles are used to monitor guidance and control during deorbit burns. The body axis burn velocity components (VGO_X, VGO_Y, and VGO_Z), along with TGO and ΔVTOT, should also be cross checked.



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 1041/   /      XXXXX MNVR YYYYY  XX X DDD/HH:MM:SS
 OMS BOTH 1X                           DDD/HH:MM:SS
        L 2XS      BURN ATT                    XXXX
        R 3XS       24 R XXX         ΔVTOT   XXXX.X
 RCS SEL  4X        25 P XXX         TGO      XX:XX
 5 TV ROLL XXX      26 Y XXX
 TRIM LOAD         MNVR 27X XXXXX    VGO X ±XXXX.XX
  6 P  ±X.X         TTG XX:XX            Y  ±XXX.XX
  7 LY ±X.X        REI   XXXX            Z  ±XXX.XX
  8 RY ±X.X        TXX XX:XX
 9 WT XXXXXX             GMBL              HA     HP
10 TIG                L       R      TGT XXX    ±XXX
    XXX/XX:XX:XX.X  P ±X.XS ±X.XS    CUR XXX    ±XXX
 TGT PEG 4          Y ±X.XS ±X.XS
  14 C1       XXXXX
  15 C2   ±X.XXXX   PRI 28X  29X    35 ABORT TGT XX
  16 HT   XXX.XXX   SEC 30X  31X
  17 θT   XXX.XXX   OFF 32X  33X      FWD RCS
  18 PRPLT ±XXXXX                       ARM    36X
 TGT PEG 7          GMBL CK  34X        DUMP   37X
  19 ΔVX ±XXXX.X                        OFF    38X
  20 ΔVY  ±XXX.X    XXXXXXX           SURF DRIVE
  21 ΔVZ  ±XXX.X                        ON     39X
 XXXX 22/TIMER 23                       OFF    40X
```

DEORB MNVR Display

Monitoring the VGOs in addition to the error needles provides insight into the status of guidance during the burn. The TTG field will blank when the orbiter is in burn attitude. The VGOx prior to TIG will be 80% of ΔVtot when the vehicle is in burn attitude. To monitor burn progress, the crew can watch VGOs, HA, and HP during the burn. The VGOs display how much ΔV is left to go in orbiter body axis coordinates. For any OMS or ±RCS burn, most of the burn should be in the appropriate X direction. HP will gradually increase or decrease, depending on whether the OMS burn is posigrade or retrograde. For deorbit burns, HP should always decrease.

WARNING

Since the flight controller power is ON, the RHC is "hot" during an OMS burn. The DAP will mode to manual (INRTL) if the RHC is bumped. The message "DAP DNMODE RHC" will be annunciated.

An SM alert and "DAP DNMODE RHC" message will annunciate with OI-28 and subs software.

NOTE

> Propellant-wasting, out-of-plane deorbit burns will have a PEG 7 delta V_Y (LVLH) component. If no propellant is wasted then the PEG 7 delta V_Y is typically zero.

OMS burn thrust vector control (TVC) is calculated independently from the ADI error needles.

- OMS TVC gimbals the OMS engines to null vehicle rates and point sensed thrust in the desired ΔVTOT direction.

- ADI error needles display vehicle attitude error from the attitude that would point the net thrust through the c.g., as defined by the trim angles, and in the desired ΔVTOT direction. If trim angles are incorrect or flight control does not recognize an engine failure, the ADI error needles will not display correct error information.

For a +X RCS burn, the ADI error needles are correct, as long as flight control recognizes that it is an RCS burn. Error needles are never correct for a -X RCS burn.

Approaching cutoff, the crew should monitor current HP approaching targeted HP, TGO approaching zero, and ΔVTOT approaching zero. If TGO goes to zero, and the OMS engines do not cut off (chamber pressure zero and engine valves closed), the OMS engine switches should be turned *OFF* to prevent an overburn.

NOTE

> OMS guidance will cut off, based on VGOX. If out of attitude, there will be large residuals in VGOY or VGOZ after the burn is complete. VGOZ residuals should be trimmed by the CDR using the THC, per the Deorbit Burn cue card procedure.

If an early cutoff occurs, the appropriate procedure from the Deorbit Burn cue card should be executed to achieve deorbit targets. OMS propellant, aft RCS, forward RCS, and prebank may be used to recover the underburn. If the underburn magnitude exceeds RCS and prebank capability, landing site redesignation may be required. For more detailed information on OMS burn downmoding, consult the appropriate Flight Procedures Handbook.

Takeover

Deorbit burns are normally flown in AUTO flight control and are started and stopped by GPC commands. Duration of the burn, as well as maintaining proper attitude during the burn, are the two most important criteria.

If while perigee is still above SAFE HP a failure occurs that severely impacts OMS capability, the crew will stop the burn. SAFE HP guarantees at least 24 hours of orbit time, which MCC can use to properly retarget the deorbit burn and assess the impacts of the failure.

On the other hand, if the failure occurs below SAFE HP, the crew must do what they can to complete the deorbit burn, which includes using the aft and forward RCS and possibly a recovery prebank.

Given a normal doerbit burn, EI targets will be met within allowable tolerances if the post burn residual ΔV is within 2 fps. Specifically, a 2 fps underburn equates to a 30 nautical mile (n. mi.) energy error at EI, which is well within guidance capability.

A 3° attitude deadband is used in the TRANS DAP. Attitude error or deviation greater than 3° prior to the burn indicates a flight control malfunction. The crew should check ITEM 27 on the MNVR display or downmode to MAN DAP and maneuver back to ignition attitude. The deorbit burn attitude is entered in a controlled, timely manner, and the burn can be postponed for an unacceptable attitude error.

Deadband in the TVC DAP is very small. If ignition has occurred, a manual takeover should be performed for unexplained deviations greater than 5°.

NOTE

> Engine out transients may cause a momentary attitude deviation greater than 10°. These transients are an excellent confirmation of an engine out. Manual takeover should not be required.

Manual Control

Fly the error needles or the ADI REF ball if available. Cross-check the VGO components. During OMS TVC DAP attitude maneuvers, keep rates reasonable (less than 2 deg/sec). Approximate VGO component fractions of DVTOT depend on the type of burn. If only one OMS engine is used, yaw the vehicle about 10° into the good engine. Normally, manual flight control during an OMS burn requires very few RHC inputs once the guidance needles are centered, and the TVC DAP begins attitude hold.

For an RCS-only burn, the attitude deadband is 3°, and the burn is flown manually using the RHC for attitude control and the THC for the burn with four +X aft RCS jets.

One technique for +X RCS burns is called the Patterson Maneuver. Here, the crew first maneuvers the vehicle to the proper burn attitude, as displayed on the MNVR EXEC display. Then they pitch the nose up 3° high. So, when they start the burn with the THC, the vehicle will pitch down to the correct attitude, since aft RCS jets are above the c.g., and the 3° deadband will hold it there. A variation on the technique is to start the burn in attitude, allow the vehicle to pitch down toward the 3° deadband limit, then pitch up 6° to the other side of the deadband. The vehicle will slowly pitch back down and hold the desired attitude.

It is also acceptable to just keep the needles centered using small RHC inputs. This technique requires constant inputs in pitch and will use more propellant to hold attitude, but is easier to remember than the Patterson maneuver. For short RCS burns, the extra propellant usage is minimal.

The VGO ratio table below lists appropriate ratios of $VGO_{X,Y,Z}$ to VTOT for different burn maneuvers.

	BOTH OMS	L (R) OMS	+X RCS	-X RCS
VGO_x	1	1	1	-1
VGO_y	0	1/5 (-1/5)	0	0
VGO_z	1/4	1/4	1/6	1/3

VGO Ratios

NOTE

A BFS OMS burn is targeted in the same manner as PASS, but must be flown manually.

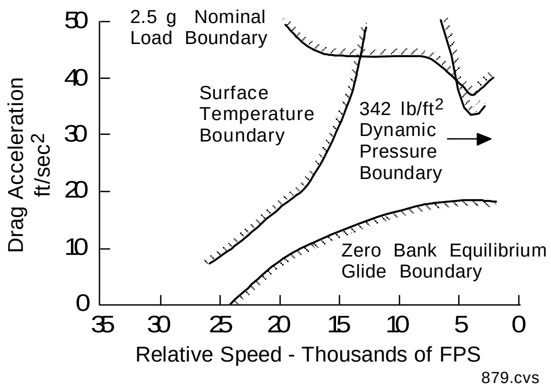
Entry

Monitoring

During the entry phase, guidance provides steering commands for trajectory control from initial penetration of the atmosphere (about 400,000 ft) at a range of about 4100 n. mi. from the landing site, until TAEM (2500 fps, about 60 n. mi. from landing site at an altitude of about 80,000 ft). The primary objectives of entry guidance are:

- Guide the orbiter along a path that prevents exceeding structural, thermal, and stability design limits.
- Deliver the orbiter to a satisfactory energy state and vehicle attitude at initiation of TAEM guidance.

Entry guidance is based on drag control. The correct drag level is calculated, based on Mach (velocity) and range. Bank is then used to control lift until the desired drag is established. Entry trajectory constraints are shown in the following chart.



Entry Trajectory Constraints

Entry navigation (NAV) computes the orbiter's position, velocity, and distance/direction to the landing site. NAV also computes Mach, q-bar, and alpha. There are numerous interfaces between NAV and flight control. The crew optimizes NAV performance by accepting or inhibiting five types of sensed data: drag-H, TACAN, air data, MLS, and GPS. Bad NAV information can cause flight control problems, since NAV information is used to tailor flight control for the varying flight regimes encountered. Mission Control monitors navigation performance during entry using tracking data. TACAN and air data should not be accepted to NAV, or air data accepted to G&C without a go from Mission Control, unless communication capability is lost.

WARNING

Large NAV errors can cause loss of vehicle control, because NAV data are used to select control effectors and set control gains.

Dedicated instruments, DPS displays, and cue cards are available to assist the crew in monitoring entry performance. The ADI, alpha/Mach indicator (AMI), and the altitude/vertical velocity indicator (AVVI) are the primary dedicated instruments for monitoring entry performance. Five ENTRY TRAJ displays are available for monitoring entry guidance. ENTRY cue cards are used as references to compare actual and predicted performance.

After the deorbit burn, the crew transitions to MM 303 and maneuvers to the EI-5 attitude that was uplinked with the deorbit targets and voiced up in the DEL PAD.

During the early part of entry, the RCS command lights are a good indication of DAP activity. If the crew transitions to MM 304 at EI-5, the vehicle will be very close to attitude, and only occasional jet firings will occur as attitude drifts back and forth between DAP deadbands. If the crew is late transitioning to MM 304, or if an attitude error has been allowed to develop while working system problems, a large number of jet firings can occur. Up to 250 lb of RCS propellant can be wasted. Crews should closely check that the orbiter is in the proper attitude prior to MM 304.

From q-bar = 0 to q-bar = 0.5, the RCS only is used for attitude control. From q-bar = 0.5 (12 KEAS) to q-bar = 8.0 (48 KEAS), the elevons will trim in response to pitch jet firings. At q-bar = 2.0 (24 KEAS), the elevons are used for control. At q-bar = 40 (109 KEAS), the pitch jets are turned off.

At q-bar = 10 (54 KEAS), the roll jets are deactivated. Yaw jets continue to fire for bank control until Mach is less than 1.0. Yaw jets should fire from both pods at a similar rate (symmetric firings).

At q-bar = 50 (122 KEAS), the RCS *PITCH* and *ROLL* activity lights are reconfigured. Illumination of the *PITCH* light indicates elevon or aileron rate saturation. Three or more yaw jet commands turn on the *ROLL* light. The yaw jets are terminated at Mach 1. The *PITCH* jet light will continue to indicate elevon and aileron rate saturation.

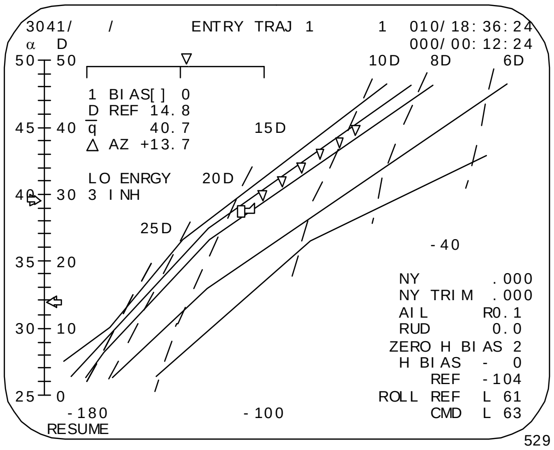
Orbiter performance during bank maneuvers is the pilot's cue to dynamic stability characteristics. The two most important factors the crew must monitor are *YAW* jet activity lights and roll rate. The first roll command is at 3 deg/sec; subsequent roll reversals are commanded at 5 deg/sec. The rate of roll maneuvers is important to minimize H-dot and drag excursions. Prompt execution of roll commands will minimize the bank angle required to establish the desired drag profile.

Using the ADI, AMI, and AVVI, in conjunction with the ENTRY ALPHA cue card, allows the crew to monitor vehicle performance relative to pre-mission planned trajectory. Comparing alpha, range, altitude, H-dot, and roll reference to actual values is a good crosscheck on guidance. The data on this card is flight (and planned entry) specific, but most of the data is useful on any entry. The only data that changes significantly is the direction of Rref (reference roll angle). The magnitude of Rref does not change much.

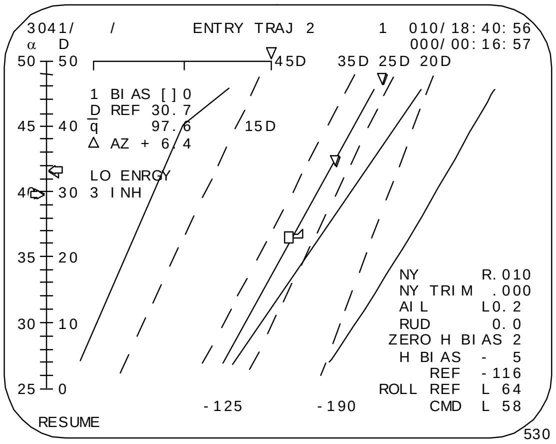
ENTRY ALPHA Cue Card

Five DPS displays are the primary displays for entry monitoring or manually flying entry. ENTRY TRAJ 1 appears at MM 304 (OPS 304 PRO). TRAJ 2 through 5 appear at predetermined velocity breakpoints. Each display is a continuation of the previous one.

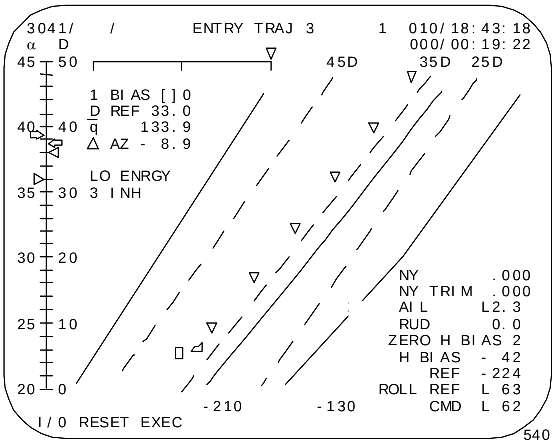
In the center of the ENTRY TRAJ display there is a dynamic plot of velocity (Y-axis) vs. range (X-axis). An orbiter "bug" is placed on this display as a function of range and velocity. The dashed drag lines are used to determine the desired drag for the current range and velocity. Interpolation is required. For example, the orbiter bug on TRAJ 1 shows desired drag of 14 fpss.



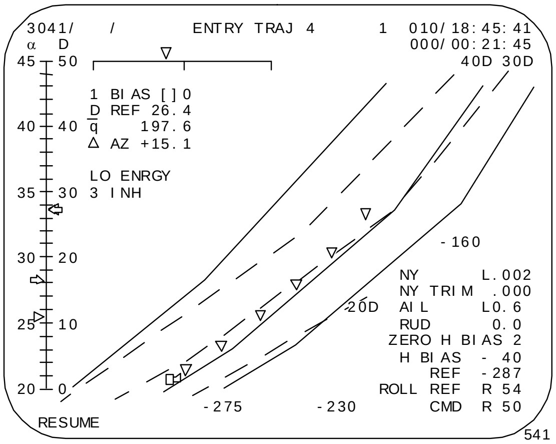
ENTRY TRAJ 1 Display (Mach 25-Mach 17)



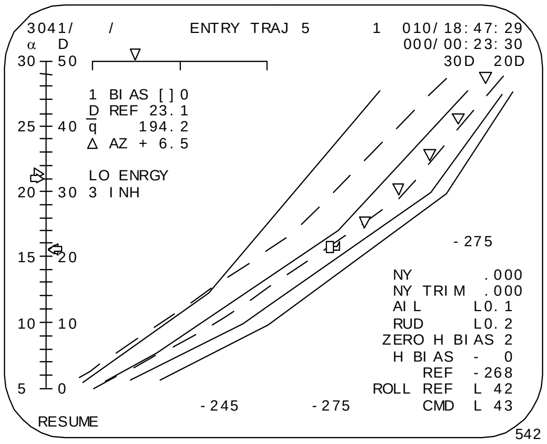
ENTRY TRAJ 2 Display (Mach 17-Mach 14)



ENTRY TRAJ 3 Display (Mach 14-Mach 10)



ENTRY TRAJ 4 Display (Mach 10-Mach 5)



ENTRY TRAJ 5 Display (Mach 5-Mach 2.5)

NOTE

On TRAJ 4 and 5, the orbiter bug is placed by energy (E/W) vs. range. This difference does not change the operational use of the displays.

NOTE

Desired, reference, and commanded drag are interchangeable terms; they mean the same thing.

The entry guidance algorithm is also running real time to calculate desired drag. The output of this algorithm is indicated by the arrow on the drag scale (left side of the ENTRY TRAJ display). Remember, the arrow points to where you want to be.

The current drag, as sensed by the IMUs, is displayed as a triangle on the TRAJ display.

Guidance commands a roll angle that will dump lift as required to achieve the desired drag. H-dot control is an essential part of this operation. Guidance will bank until it sees an acceptable H-dot, then bank to an H-double-dot that equals zero to maintain this H-dot.

The desired H-dot is a function of reference H-dot and drag error. Reference H-dot is the H-dot required to maintain desired drag. If current drag is less than reference drag, guidance will fly to a higher H-dot (more negative).

Guidance displays reference H-dot on the lower right corner of the TRAJ display. The crew can also look directly below the orbiter bug and read a rough estimate of reference H-dot at the bottom of the TRAJ display.

Entry guidance will also modulate alpha to remove drag errors. By changing alpha ±3°, guidance can instantly change the drag by about 10 percent (3 degree modulation is the limit). Alpha modulation is much faster than roll control. If guidance is using alpha modulation to remove drag errors, it will roll to achieve an H-dot that will eventually put the orbiter in the correct air density. In a few minutes, the drag error will be removed without using alpha modulation.

As the orbiter bug proceeds down the trajectory lines, it leaves triangular trailers every 15 guidance cycles (28.8 sec) that are used for trend analysis. For ENTRY TRAJ 3, 4, and 5, the trailers are displayed every 8 guidance cycles (15.36 sec). Only six trailers can be displayed at one time.

A guidance box appears upon initiation of closed loop guidance and moves relative to the shuttle symbol to reflect drag errors ($D-D_{REF}$). The guidance box leaves trailer dots. Ideally, the nose of the shuttle symbol will be inside the box, and a dot will be located in every triangle. The first roll command will be visible on the TRAJ display shortly after the initiation of closed loop guidance. Timely execution of the first roll command will minimize the bank angle required to establish desired drag.

If the guidance box is to the left of the shuttle symbol, drag is too small (you will land long) and the guidance trend is toward high energy. The opposite condition indicates drag is too high.

Alpha is monitored on the Ascent/Entry Flight Displays (AFD) and on the ENTRY TRAJ displays. These parameters should be compared with the values on the ENTRY ALPHA cue card. ENTRY TRAJ displays reference alpha (computed by guidance) via an arrow and nav-derived (actual) alpha by a triangle. Normally, these overlay each other. However, guidance will add small biases to alpha to remove drag errors. If the ADI pitch error needle is centered and the alpha triangle is offset from the arrow, it is an indication of alpha modulation. Alpha modulation is expected during and after a roll reversal.

Heading error is defined as delta azimuth (DEL AZ or ΔAZ on the ENTRY TRAJ displays) and is the angle between the velocity vector and the great circle direction to the runway. DEL AZ is displayed on the HSI as the difference between the "H" pointer and the lubber line. There is also a digital value of DEL AZ right next to the HSI and on the ENTRY TRAJ displays. Bank angle controls drag, and therefore energy, during entry. Because the bank angle causes the orbiter to continually turn, a crossrange capability of approximately 750 n. mi. can be obtained. This gives the orbiter the advantage of using landing sites that are not directly under the orbital groundtrack. Roll reversals are performed to keep DEL AZ within limits. The velocities at which the reversals occur are a function of crossrange.

Several onboard indicators alert the crew that a roll reversal is needed: on the ENTRY TRAJ, the orbiter bug and phugoid damper start flashing; on the HSI, the box surrounding the digital DEL AZ value turns red and flashes; on the ADI, the roll error needle indications a full scale deflection. The first roll reversal will occur at a DEL AZ of 10.5°. Subsequent roll reversals occur at a DEL AZ of 17.5° until Mach = 4 when DEL AZ limit ramps to 10.0 by Mach 2.8.

The ENTRY MANEUVERS cue card itemizes important events that the crew must monitor during entry. Off-nominal activities are indicated by asterisks (*). Crew action items are keyed to velocity. Items to be verified only are marked with a check (√)..

See section 5.4 for more detail on this card.

NOTE

> V in Kft/sec is equal to Mach; e.g., V=10K=Mach 10.

Automatic program test inputs (PTIs) may be included as part of entry trajectories to obtain aero data postflight. These data are used to further define the aerodynamic characteristics of the shuttle, help expand the operational envelope, and reduce aero data base uncertainties. PTIs are executed automatically by the entry DAP and are input into the flight controls downstream of gains and filters so that a known control deflection or jet firing can be made. The crew enables PTIs on SPEC 50, and flight control must be in AUTO. Execution of PTIs is monitored on the SPI and GNC SYS SUMM 1 for control deflections, by the RCS activity lights for jet firings, and by data on the PTI Monitor Cue Card. Normal vehicle performance parameters also must be continuously monitored to ensure there is no trajectory degradation introduced by the PTIs.

Takeover

The entry trajectory is normally flown in AUTO until subsonic, when the crew modes to CSS. Upon moding the GPCs to MM 304, dedicated displays and ENTRY TRAJ displays become available. DAP controls for the AEROJET DAP are located on each eyebrow panel. Manual takeover can be executed using the pushbuttons or by moving the RHC more than 7° out of detent.

NOTE

> During entry, moding to CSS is separate for the pitch axis and roll/yaw axes. It is possible to be in CSS pitch control and AUTO roll/yaw or vice versa.

Low Energy

A ROLL REF “down” arrow on the ENTRY TRAJ display indicates a low energy condition. In addition to the down arrow, a fault message will be generated. If DEL AZ is allowed to go out to 10.5, the small roll angles required to fly low energy may not be able to bring DEL AZ back in. The crew should select R/Y CSS and initiate the first roll reversal when DEL AZ = 5°. AUTO flight control may be reengaged after completion of the first roll reversal.

Delta State Update

If the NAV state of the orbiter goes bad on entry, data from the GPS unit will be forced to update the orbiter state vector. MCC can uplink a good state vector (position and velocity). This is normally done by using the command uplink. If both GPS and the command uplink are not available, the delta state will be read up on the voice uplink, and the crew will have to enter the values on SPEC 50.

The crew must also take manual control (CSS) before a velocity uplink is incorporated into the GPCs. MCC will remind the crew when to take CSS.

Undesirable Transients

Prior to any event capable of introducing an unwanted transient into the flight control system, such as a delta state update that includes a velocity component, the crew should select CSS to prevent undesirable transients. Automatic flight control may be reengaged upon completion of the event and reconvergence of the guidance needles.

Entry Control Cue Card

The ENTRY CONTROL cue card contains three procedures that cover possible DAP problems during entry.

ARCS QTY (L + R) <10%

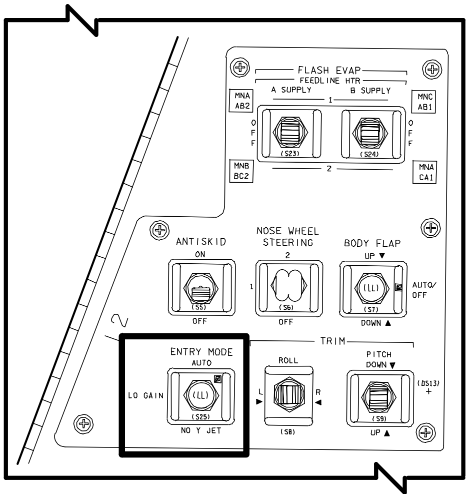
The procedure applies when the total ARCS quantity drops below 10 percent during entry. With available propellant so low, steps are taken to conserve what propellant is left for those times when RCS jets are really needed to maintain attitude control.

The crew takes no action until q-bar is more than 20 psf or if RCS jets start failing due to propellant depletion, whichever occurs first. At that time, the crew moves the ENTRY MODE switch on panel L2 to NO Y JET (No Yaw Jet) and select the FIXED elevon schedule on their displays. NO Y JET (which becomes certified at q-bar = 20 psf) forces the Entry DAP to use the aerosurfaces rather than the yaw jets to perform banking maneuvers. With the FIXED elevon schedule, the elevons tend to deflect further into the airstream, becoming more effective.

WARNING

Selecting NO Y JET will automatically downmode flight control to CSS in the R/Y axis. Crew must manually fly the vehicle, using the ADI error needles and other indicators.

If at any point the crew experiences control problems, and as long as propellant remains, they can move the ENTRY MODE switch back to AUTO and use the RCS jets to try to regain control. Once control is re-established, the crew goes back to NO Y JET to again conserve propellant.



ENTRY MODE Switch on Panel L2

Below Mach 6, the aerosurfaces should have enough authority to adequately control the vehicle the rest of the way down. The crew can at this point take both the ENTRY MODE switch and the R/Y axis back to AUTO.

Below Mach 5, the crew trims the ailerons to ≤1°. This forces the rudder to pick up the trim load, freeing the elevons to better maneuver the vehicle.

WARNING

Never trim the ailerons back until the rudder is active at Mach 5. Otherwise, RCS propellant is needlessly wasted in trying to trim the vehicle rates.

AIL TRIM ≥3°

This procedure applies when the crew notes that the aileron trim starts exceeding 3° during entry. The trim function of the Entry DAP is dangerously close to becoming saturated, which could then lead to control issues with the vehicle.

The software limit for aileron trim is 3° for the Baseline DAP (default for TAL) and 5° for Wrap DAP (default EOM). So, the first thing the crew does is to ensure that Wrap DAP is enabled.

If aileron trim goes on to saturate at 5°, the crew next raises the body flap. This causes the elevons to move down further into the airstream, becoming more effective. Then below Mach 13 (where changing dynamics on the vehicle will more than likely lead to control issues), the crew will manually fly alpha to as close to 30° as allowed by thermal constraints. Engineering studies show that alpha 30° is the most optimum angle of attack for controllability. If the crew is already in CSS due to having the ENTRY MODE switch in NO Y JET, they will need to limit their maneuvering rates, as the elevons are already having difficulty maintaining control

Below Mach 5, the crew trims the ailerons to ≤1°. This forces the rudder to pick up the trim load, freeing the elevons to better maneuver the vehicle.

Below Mach 2, the crew returns the body flap to AUTO for the transonic region and approach and land transition.

High Freq OSC or Surf/Jet Cycle

High frequency oscillations can be due to any number of reasons: bent airframe, incorrect bending filters, improper gains, etc. The crew may observe these oscillations on the SPI or the ADI rate needles. A yaw jet limit cycle may also occur.

The procedure first ensures that the correct body bending filter is in use. The DAP includes bending filters in all axes that protect the DAP from coupling with the orbiter structure in a resonant oscillation. If the bending filter constants were wrong, oscillations can occur.

If the condition persists, then the problem may be with AUTO. The crew takes CSS and manually flies the vehicle.

If the condition still persists, then perhaps the DAP is overcontrolling the vehicle. The crew moves the ENTRY MODE switch to LO GAIN, which cuts the Entry DAP gains in half.

If at any time the oscillations stop, the crew can return everything back to AUTO. If, on the other hand, the oscillations continue, the crew must continue as best they can in CSS.

Manual Control

WARNING

If possible, do not downmode to CSS without consulting MCC. Deviations from the desired entry drag profile can cause violation of thermal limits or failure to reach the planned landing site.

After closed loop guidance, the first bank command should be in the direction of the landing site ("H" pointer on the HSI). This maneuver is usually done in AUTO. It should occur at an H-dot of -240 fps.

If CSS is required, move the RHC to about half deflection, watch the roll rate needle on the ADI, and bank at about 3 deg/sec. Prompt execution of the first roll command will minimize the bank angle required to establish the entry profile.

To fly the most fuel-efficient entry, closely monitor the guidance needles, and always center the pitch needle first. Keep rates small and try not to start and stop the rate more often than necessary. Minimize the number of discrete RHC movements to reduce unnecessary RCS jet firings. Overly aggressive control during entry can cause depletion of available RCS propellant. The *MED* position of the *ADI ERROR* switch is recommended for entry.

Use 6 deg/sec roll rate (full RHC deflection to the hard stop) to perform a roll reversal. A good cue to stop the roll reversal maneuver is H-double dot passing through zero. Returning the RHC to detent at this point will result in a smooth reduction in bank rate with final bank angle very close to roll command. A 6 deg/sec roll rate will minimize H-dot and drag excursions during the reversal. A gentle roll reversal at less than 6 deg/sec roll rate can require the use of large bank angles to recapture the desired drag profile.

WARNING

Monitor DEL AZ carefully when flying R/Y CSS, especially at lower velocity. Azimuth errors can quickly make it impossible to reach the desired landing area.

A good instrument crosscheck of actual drag (D_{ACT}), reference drag (D_{REF}), bank angle, H-dot, and H-double dot is required when flying a CSS entry.

The following is a summary of tasks required during a CSS entry:

- Fly scheduled alpha per the cue card or ENTRY TRAJ.
- Bank as required to maintain H-dot ≈ H-dot REF +20 (D_{ACT} - D_{REF})
- Perform roll reversals based on DEL AZ (10.5° for first reversal, 17.5° for subsequent reversals) to Mach = 4. The DEL AZ limit then ramps down to 10° at Mach 2.8.

No Yaw Jet/RCS Critical Entry

The hypersonic handling characteristics of the orbiter are very different when in NO Y JET. The primary difference is the time required to start and stop roll rates. This difference is so great that the flight control system automatically downmodes to R/Y CSS when NO Y JET is select, requiring the crew to fly manually

When in NO Y JET, the flight control system uses adverse yaw to start and stop a bank. The crew will see this by an initial roll opposite the commanded direction. This adverse yaw decreases with Mach. By Mach 5, the rudder becomes active and the orbiter flies much better. When performing roll reversals, it is important to use the recommended 6 deg/sec roll rate to minimize altitude descent rate and drag fluctuations. A gentle roll rate of less than 6 deg/sec may feel more comfortable, but the trajectory dispersions it will cause will make the ride uncomfortable later.

To initiate a roll reversal in NO Y JET, the RHC should be moved smoothly to establish a roll rate of 6 deg/sec. To stop a roll reversal, a large lead is required to prevent overshooting the desired bank angle. This lead varies with Mach. The following is a list of typical lead angles required to capture the desired bank from a 6 deg/sec roll. The roll is stopped by centering the RHC.

Mach	Lead Angle (deg)
>22	55
22-7	35
<7	15

After the roll reversal, the roll needle should be kept centered. Control will be sloppy, so the needle cannot be kept perfectly centered. It takes a lot of work. It helps to try and lead the roll needle by monitoring H-dot and predicting what guidance is going to do next. For example, if guidance is commanding to a large negative H-dot, you can expect that guidance will command a roll out of bank in the near future. Developing good skills in flying manual entries helps in predicting what guidance will do next.

NOTE

Do not compensate for the sloppy control by lagging behind the needles. Adding lag to the system will cause large, low-frequency oscillations in H-dot and drag.

The most critical region of a NO Y JET entry is between Mach 12 and Mach 8, where control margins are smallest. This is empirically derived from 6 degree-of-freedom simulations. With the aero uncertainties present today, a control problem is not expected in the NO Y JET mode. If control problems are encountered at any velocity, and RCS control is still an option, reenable the yaw jets by returning the ENTRY MODE switch to AUTO. Once control is restored, and the orbiter is in a stable attitude, return to the NO Y JET mode.

Off Nominal Trajectory Control

Should the orbiter be outside the DPS-displayed nominal energy envelope, for whatever reason, corrections are necessary to recover. Both the high and low energy cases are discussed from a manual control point of view.

High Energy Recovery

If the orbiter is very high energy on entry, guidance will calculate a drag that is larger than the orbiter can withstand. This can be seen when the orbiter bug is to the left of the high energy line on the ENTRY TRAJ display. The high energy line is the solid line furthest to the left on the TRAJ display. In this case, the crew must take CSS and manually fly to the maximum drag that the orbiter can withstand.

The details of this procedure are beyond the scope of the SCOM, and are taught in the Entry Guidance Workbook, CBT, and classes.

WARNING

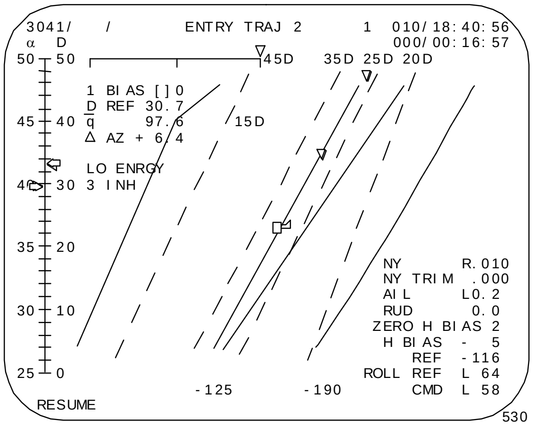
It is very easy to overshoot maximum drag while flying high energy entries. It is better to be high energy at TAEM interface than to be at TAEM interface without wings.

Low Energy Recovery

If the orbiter bug is to the right of the low energy line, guidance is calculating a drag that is smaller than the orbiter can sustain. In this case, the orbiter must fly into air that is so thin that there is not enough lift. The low energy line is the farthest right line on the ENTRY TRAJ display.

If on a TAL abort, the crew should enable LOW ENERGY logic on the TRAJ display. Low energy logic automatically flies a bank angle of approximately 2.2 times delta azimuth. It also varies alpha between 42° and 25°, which optimizes range/crossrange capability while protecting orbiter thermal limitations. Although this software will function on an end of mission (EOM) return, it is not certified.

If low energy on an EOM, the crew should take CSS. In pitch, fly alpha low (3° below the alpha arrow on the ENTRY TRAJ display), in roll fly 2.2 times DEL AZ.



ENTRY TRAJ 2 Display

Backup Flight System

The backup flight system (BFS) is capable of performing nearly all of the primary flight system functions (controlled by PASS software) during deorbit, entry, approach, and landing. This section presents the major differences, from the flight crew viewpoint, between the two systems. Differences in handling qualities between the PASS and the BFS are very small in the training simulators, and no large differences are expected if BFS is engaged onboard the orbiter. A moderate control transient should be expected when BFS is engaged.

Deorbit

Automatic maneuvers are not available in BFS. The crew must manually fly to deorbit burn attitude using the error needles, MNVR EXEC display, and ADI attitude. The TRANS DAP supports both *DISC RATE* and *PULSE* modes, but all three axes are switched when *DISC RATE* or *PULSE* is selected.

During the burn, attitude must be maintained manually using the ADI error needles and REF ball. Upon completion of the burn, the maneuver to EI-5 attitude is a manual maneuver.

Entry

BFS does not support PTIs. Upon entering MM 304, flight control mode is CSS through landing/rollout.

The BFS maintains only one state vector during entry. Redundancy management is performed on most systems, but in a simpler manner than PASS. BFS is also set up to accept air data to G&C immediately upon engage. If air data has not been previously accepted in PASS, the crew should inhibit air data to G&C upon BFS engage.

There is no digital DEL AZ output in BFS. However, the crew still has the HSI with its digital output and the "H" pointer with respect to the lubber line.

Sensory Cues

During the night portion of an entry, the glowing plasma sheath around the vehicle can be observed through the orbiter windows. The pulsing light has not interfered with tasks inside the vehicle. The plasma glow is less visible during daylight portions of entry and may not be noticeable.

Returning from orbit, some crewmembers have reported increased sensitivity to g as it builds during entry. One crewmember observed that "when you hit a quarter g on entry, it seems like two g's in the T-38." Crewmembers should be aware that their ability to perform entry tasks may be degraded from that experienced in the SMS during training. Keep in mind that Gs stay around 1.3 until Mach 2.5.

Roll reversals on entry will feel different than pure roll maneuvers in a conventional aircraft due to the orbiter's entry angle of attack. Pilots will probably notice the yaw rate required during the bank change as much as the roll rate.

Some mission specialists have stated that they could barely feel the roll reversals.

At high Mach numbers, a slight vehicle buffet may be noticed as well as some light structural vibration as dynamic pressure increases during entry.

Ground Controlled Approach

Although GCA techniques are available, they are emergency alternatives only. Control should be quickly returned to auto when conditions permit.

During entry, trajectory is monitored via the Tracking and Data Relay Satellite (TDRS) and ground radars. Should the trajectory diverge and approach energy limits, a GCA will be performed.

MCC, via the CAPCOM, will provide the crew with bank attitude, heading, airspeed, and speed brake information.

WARNING

On a high energy GCA, the crew should help monitor Gs. If the crew thinks that the current bank angle is leading to an over-g, the crew should call MCC and roll out of bank to not exceed Nz limit (2.0 to 2.5 g's, depending on orbiter weight.

Important—H-dot leads an over g. An H-dot of about -300 fps will maintain about 2.0 g's. If H-dot is bigger (more negative) than about -300 fps, and Gs are headed up to the limit (~2.0 - 2.5 g's), roll angle should be decreased. MCC should be notified before roll angle is decreased.

GCAs are divided into three phases, based on energy: high velocity (Mach 10 - Mach 3), TAEM (Mach 3 - Mach 0.9), and final approach.

Criteria for electing to perform a GCA depend upon guidance's capability to achieve a nominal trajectory by Mach 5.

In the high velocity phase, MCC provides bank magnitude information to control drag and bank direction to control crossrange. To keep workload under control, fly roll/yaw CSS and pitch, speed brake, and body flap AUTO.

During TAEM, a more conventional technique of heading to control ground track and airspeed to control energy is used. Fly both pitch and roll/yaw in CSS. Perform turns using 30° bank angle unless MCC requests a steeper bank. Control airspeed by modulating alpha and bank angle.

Final approach GCAs are similar to traditional airplane GCAs. Heading information controls alignment with the runway centerline, and position information references glide slope. Speed brake is used to control airspeed.

Off-nominal energy situations could be caused by incorporating erroneous navigation data into guidance or selecting an incorrect landing site. If this is the case, the GCA will be used to control the entry profile until NAV can be updated via a ground uplink or a manual state vector update. Once the NAV state is correct, MCC will terminate the GCA and call for a return to AUTO flight control.

Entry Rules of Thumb

- 2 OMS: TGO ≈ΔVTOT/2.
- 1 OMS: TGO ≈ΔVTOT.
- RCS: TGO ≈1.7 x ΔVTOT.
- Adjust H-dot reference 20 ft/sec for every 1 fps^2 of drag error. [H-dot ~ H-dot_{REF} + 20 (D_{ACT} - D_{REF})]
- As an approximation, 1° of bank change produces 0.7 ft/sec^2 H-double-dot change. However, there is no lag in the H-double-dot tape. You can roll until the H-double-dot tape reads the desired value.
- A 3° change in alpha produces a 10 percent drag change.
- First bank (H-dot capture) should occur at an H-dot approximately -240 ft/sec.
- Monitor the trajectory on the ENTRY ALPHA cue card, and the PASS and BFS TRAJ displays:
  - The shuttle bug superimposed on guidance box superimposed on nominal trajectory line
  - Actual drag equal to reference drag
  - Appropriate bank angle, H-dot, range and altitude
- Attempt to contact MCC before taking CSS.
- If you must take CSS:
  - Control range by controlling drag.
  - Control drag by controlling H-dot.
  - Control H-dot by controlling H-double-dot.
  - Control H-double-dot by controlling roll angle.
  - Control everything slowly by small corrections.

7.4 TERMINAL AREA ENERGY MANAGEMENT AND APPROACH, LANDING, AND ROLLOUT (OPS 305)

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Terminal Area Energy Management
and Approach, Landing, and
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Definition and Overview

This section presents information required to pilot the orbiter from an Earth-relative velocity (Vrel) of 2500 fps (Mach 3.2 for RTLS), where terminal area energy management (TAEM) begins, all the way through approach, landing, and rollout on the runway. TAEM guidance provides information to the pilot and guides the orbiter until the transition to approach/landing guidance at an altitude of 5000 to 10,000 feet. Derotation and rollout logic take over after the orbiter touches down on the runway. Procedural information for the TAEM and approach/landing guidance phases are contained in the Entry Checklist and cue cards. Pilots sometimes refer to the flight phase from .95 Mach to touchdown as the approach and landing phase of flight. This is the phase of flight in which the crew normally controls the vehicle manually (CSS) and in which the Shuttle Training Aircraft operates. By this definition, the approach and landing portion of the trajectory includes both subsonic TAEM guidance and the approach/landing guidance regions.

TAEM and approach/landing guidance trajectories allow the orbiter to handle a large variety of dispersions. Certain specified ground rules and constraints such as weight, c.g., aerodynamic limits, distance past runway threshold, velocity, altitude rates, lateral rates, and energy margin must be observed to ensure guidance is capable of directing the orbiter to a safe landing. Mission Control monitors these limits closely. Carefully following guidance commands (error needles) will generally provide the crew the best chance for coping with environmental dispersions.

TAEM is divided into four phases: S-turn, acquisition, heading alignment, and prefinal. Approach and landing trajectories are divided into five segments: trajectory capture, outer glideslope (OGS), preflare and inner glideslope (IGS), final flare, and touchdown. TAEM and approach and landing regions are jointly designed to allow the orbiter to land safely. This section presents information for monitoring and takeover during the early portions of TAEM and then details the manual flying tasks during each segment of the trajectory.

General information on handling qualities, flight control surfaces, priority rate limiting (PRL), winds, limits, BFS, sensory cues, and autoland is presented at the end of this section.

Terminal Area Energy Management

Monitoring

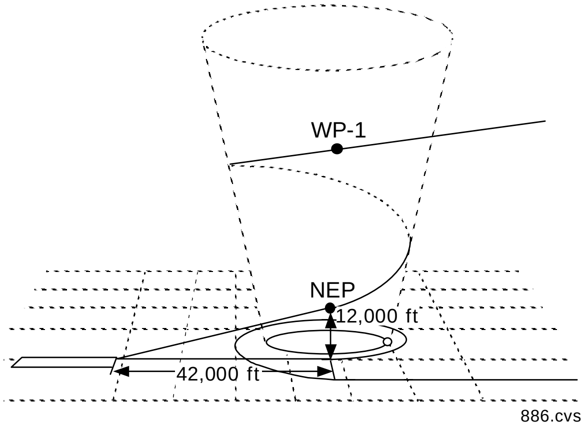
TAEM guidance is initiated automatically as the orbiter decelerates through Vrel = 2500 fps (≈Mach 2.5, Mach 3.2 for RTLS). This normally occurs at about 82,000 ft altitude and about 60 n. mi. from the runway. The crew should note transition to MM 305 (MM 603 for RTLS) and appearance of the VERT SIT displays. Head-up display (HUD) symbology also appears at TAEM interface. TAEM guidance controls the orbiter by flying an altitude vs. range profile (glideslope). TAEM also has energy and airspeed limiting features (and angle of attack for RTLS).

The outputs of TAEM guidance are functions of errors from these profiles. The validity of the output commands depends upon the accuracy of

NAV and air data. Guidance is only as good as the NAV state.

TAEM Guidance

TAEM guidance operates by phases. S-turn, if required, dissipates energy by turning away from the HAC until energy conditions allow a nominal approach. Acquisition turns the orbiter until its ground track is pointed at the HAC.



Heading Alignment Cone (HAC) Profile

Heading alignment turns around the HAC until the orbiter is near the runway centerline. Prefinal transitions from the HAC to the runway centerline.

Outputs of TAEM guidance are:

- Pitch command (N_z)
- Roll command
- Speed brake command

At TAEM interface, if vehicle energy is too high and the HAC turn angle is <200° (for OPS 3 entries), an S-turn will be commanded. During the S-turn, the orbiter will fly a constant bank angle of 30° for end-of-mission (45° for RTLS) until the total energy/weight decreases to nominal +10,000 ft. Acquisition phase is then resumed, and the orbiter turns back toward the HAC tangency point.

Between Mach 0.95 and 14,000 ft, the speed brake is controlling energy. Below 9000 ft, it is controlling airspeed to 300 KEAS. The logic is blended between 14,000 and 9000 ft.

NOTE

Energy can be dissipated very rapidly. Ensure a high energy condition exists (MCC or visual) if an S-turn is triggered.

Tracking the HAC

Guidance uses an algorithm for roll command that is a function of error with respect to HAC radius (ΔR) and the rate of change of distance to the center of the HAC (ΔR-dot). The horizontal situation indicator (HSI) bearing pointers marked "H" and "C" are referenced to the HAC tangency point and HAC center, respectively, as computed by Area Nav. Wind magnitude affects HAC tracking. Roll angle is larger when flying with a tailwind and smaller with a headwind. On average, the HAC roll angle is 45°.

Prefinal

When the orbiter is approximately 6.8 miles away from the runway, or below an altitude of 7000 feet, guidance transitions to prefinal. At prefinal, the roll error needle may become very sensitive. The crew should either aggressively fly the roll needle or manually fly to the runway. Lagging the needles will only add to the oscillation of the roll error needles.

If the orbiter is flying into a headwind when prefinal starts, the roll needle may command a roll to wings level. This is more likely in the STA, which is not usually flying as fast as the orbiter does at this point. This rollout is due to a small Y-dot, where Y-dot is the closure rate to the runway center line.

At prefinal, the flight director marker changes from a square to a circle. It also points to the orbiter's velocity vector at this time.

Overshooting the runway centerline may cause the course deviation indicator (CDI) and the glideslope indicator (GSI) on the HSI to disappear momentarily. Area Nav thinks the orbiter wants to go around another HAC. This will clear itself momentarily. Although not required, the crew can ensure having a GSI by placing the *HSI SELECT MODE* switch on panel

F6 or F8 to *APPROACH*. This will force the GSI to display deviation from final approach glide path.

Pitch Commands

The output of the TAEM pitch channel is a delta N_Z command which is sent to flight control. If the orbiter is down to two AAs, it is fail critical (i.e., one more failure will cause bad N_Z feedback). In this case, the crew will fly pitch CSS and closely monitor the pitch error needles by cross-checking the other data.

The crew has a great deal of data to monitor to make sure the pitch channel of TAEM is working correctly. There are five different sources of glideslope (altitude) information.

Glideslope data source	Type of glideslope	Type of HAC	Scaling
GSI on HSI	Reference	Spiral	±5000 ft till about Prefinal, then ±1000 ft
Orbiter bug on VERT SIT	Nominal	Spiral	Scale: 30K to 100K
GSI on HUD	Reference	Spiral	±5000 ft till 10,000 ft then a linear ramp down of scaling to ±500 ft at 5000 ft altitude
Vertical scale on PASS SPEC 50 HORIZ SIT	Reference	Spiral	±5000 ft until Prefinal, then ±1000 ft
ADI pitch rate pointer	Reference	Spiral	±5000 ft until Prefinal, then ±1000 ft

Glideslope Parameters

In addition to glideslope information, the crew must monitor energy and airspeed. Both energy and airspeed are used in the pitch channel. In addition to the onboard displays, MCC is calling "energy" based on radar tracking data. This data must be incorporated by the crew. Before HAC intercept, MCC measures energy and calls energy. On the HAC, MCC measures glideslope (altitude) and will make calls based on the following:

- < ±1000 ft altitude error – ON
- 1000 to 2000 ft altitude error – slightly high or low
- >2000 ft altitude error – high or low

NOTES

It is essential not to confuse glideslope and energy. TAEM guidance does certain things based on energy (mainly move the speed brake) and certain things based on glideslope. There are also glideslope displays and energy displays. People often use these terms interchangeably.

TAEM limits the supersonic roll limit to 30° to protect the ground from a large sonic boom. The HAC cannot be flown at 30°. If supersonic on the HAC, crew intervention is required to go over 30°.

Large HAC Turn Angles (300°)

Several unusual things happen with a large HAC turn angle. A large HAC turn angle is typically >~325°.

First, TAEM guidance will command an energy dump, a pull-up maneuver, and a pull-up recovery maneuver. The crew has very little insight into what is happening inside of guidance. In general, the vehicle will pitch down for the energy dump, pitch up to get subsonic, and then pitch down to recover. The crew must faithfully fly the pitch error needles until 270° on the HAC. At this time, a normal instrument scan may be used.

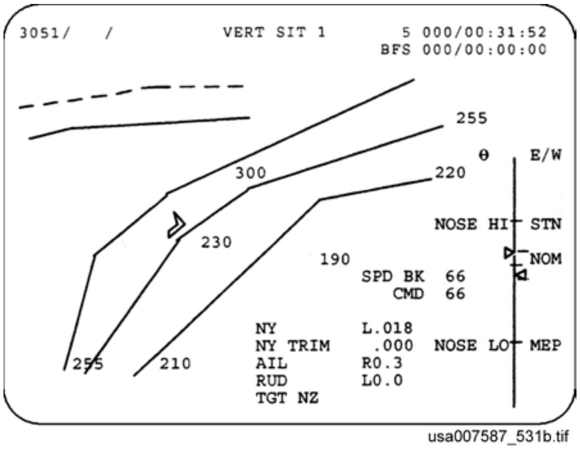
> **WARNING**
>
> The pull-up maneuver is performed in TAEM by lowering maximum airspeed to about 200 KEAS. If TAEM does not have air data, it will command an uncontrollable pitch up at about Mach 1.3.

Second, the crew will have very little time flying before HAC intercept on an entry with a large HAC turn angle.

Displays

The primary glideslope/energy displays for TAEM are the vertical situation displays (VERT SIT 1 and VERT SIT 2). The VERT SIT plot is scaled with altitude on the Y-axis and guidance determined range (range to fly) to the runway on the X-axis. Three trajectory guidelines represent maximum airspeed, nominal, and maximum lift-to-drag (L/D) ratio. Numerical values along the lines are EASs that should be flown to maintain that reference. An orbiter symbol shows current altitude versus range (glideslope). Pitch attitude of the orbiter (bug) symbol indicates H-dot. Use of theta limits is discussed later in this section.

The HSI is driven by Area Nav, which does calculations independent of shuttle guidance and navigation. This gives the crew a source of navigation processed differently from the onboard state vector and based only on data taken from GPS, TACAN or MLS (microwave landing system). The HSI and Area Nav are driven according to the *HSI SELECT SOURCE* switches on panels F6 and F8. There are three options available: *NAV* (NAV state vector to Area Nav), *TACAN* (raw (TACAN data to Area Nav), and *MLS* (raw MLS data to Area Nav). For 3-string GPS vehicles, the TACAN option above is replaced with GPS (i.e raw GPS data to Area Nav). An additional switch allows selection of the individual TACAN or MLS LRU (1, 2, or 3).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BFS 000/00:00:00
SPD BK 66
CMD 66
NY L.018
NY TRIM .000
AIL R0.3
RUD L0.0
TGT NZ

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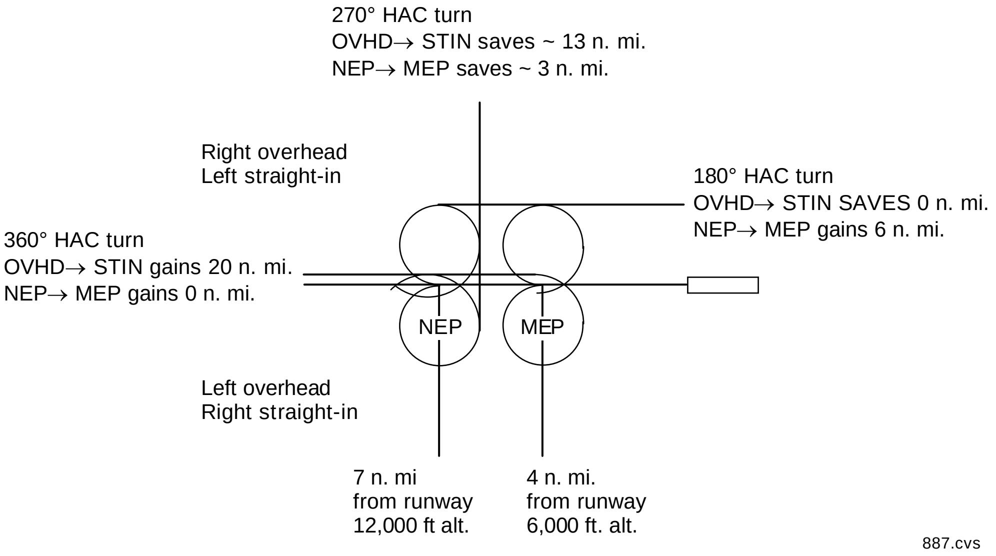
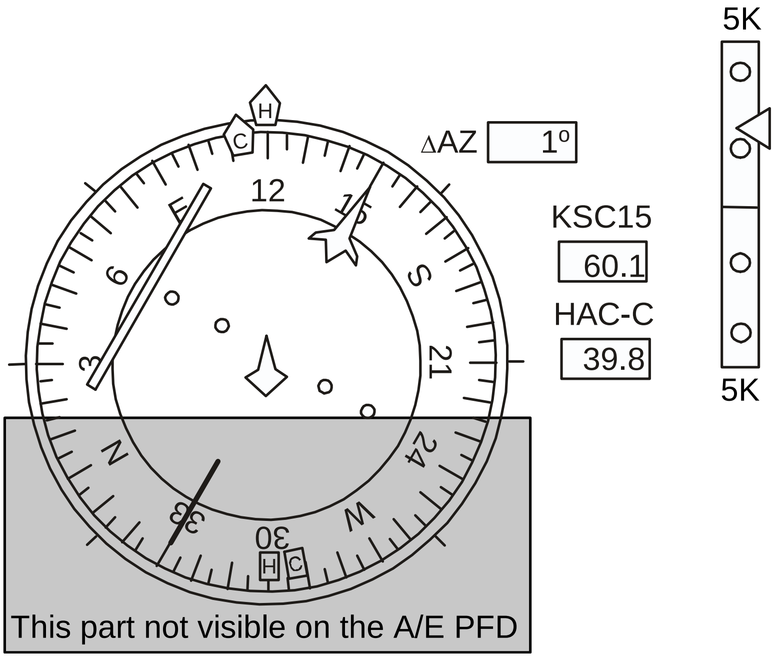
VERT SIT 1 Display (PFS/BFS)

During TAEM, the HSI ″H″ bearing pointer indicates the bearing toward the HAC tangency point called way point 1 (WP1), and the ″C″ bearing pointer indicates bearing to the center of the HAC. Range displayed on the HSI corresponds to range to the runway via the HAC (e.g., KSC15) and range to the HAC center (HAC-C). Range to the runway can be varied by changing the HAC using ITEM 6 and 7 on SPEC 50. Both the SPEC 50 and HSI HACs are imaginary inverted cones tangent to the runway centerline at 12,000 ft altitude and nominally centered approximately 7 n. mi. from the runway threshold. For low energy situations, the crew can shift the HAC to a point approximately 4 n. mi. from the threshold by executing ITEM 7. The point where the HAC is tangent to the runway centerline is called the entry point. For a nominal HAC configuration, the entry point is called the nominal entry point (NEP). Executing ITEM 7 repositions the HAC to a minimum entry point (MEP), which is tangent to the runway centerline at 6000 ft.

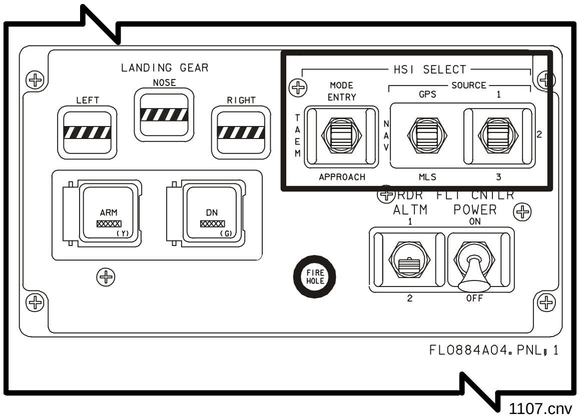
ITEM 6 allows selection of an overhead (OVHD) approach or a straight-in (STRT) approach. This allows the crew to position the HAC on either side of the runway centerline. OVHD/STRT and NEP/MEP can be combined to define four HACs that are available to the crew for energy management purposes. Guidance is always initialized to the OVHD NEP HAC.



HAC Turns



Horizontal Situation Indicator in TAEM



HSI SELECT Switches on Panels F6 and F8

NOTE

> Within 35 n. mi. of the runway, switching between OVHD/STRT is not recommended. The heading error generated by a downmode could nullify any energy gains.

The GSI on the HSI displays calculated altitude error computed by Area Navigation. Note that this is not a guidance computation. The scale is 2500 ft per dot until Area Nav transitions to Approach (usually within 2.5° of Course Deviation), then it becomes 500 ft per dot. Crewmembers can force this scale change by selecting *APPROACH* on the *HSI SELECT MODE* switch on panel F6 or F8. With the *HSI MODE* switch in *ENTRY*, HSI mode, auto switching from TAEM to Approach will occur under the following conditions:

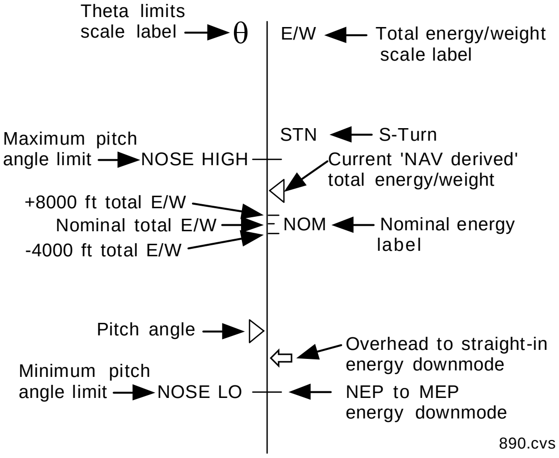
- Orbiter altitude is less than 18,018 ft for NEP (12,000 ft for MEP), and the absolute value of the CDI is less than 2.5°.
- Orbiter altitude is less than 12,018 ft for NEP (6000 ft for MEP) irrespective of CDI value).

Data presented by the glideslope indicator are calculated assuming the orbiter will fly from its present position, over the proper ground track trajectory, to touchdown.

The GSI shows altitude error only, not energy error. Similarly, on the VERT SIT displays, the vertical scale is altitude, not energy.

The E/W scale (E/W = units in feet) on VERT SIT 1 and 2 is displayed above 20,000 ft AGL. A triangle shows the calculated energy of the vehicle relative to the design trajectory. Overbright lines above and below the center NOM indication show 8000 ft high and 4000 ft low on total specific energy. If the pointer is between the +8000 and -4000 ft marks, TAEM is controlling glideslope. If out of this band, TAEM is controlling energy.

These are energy status lines, not altitude. As with the glideslope indicator, E/W assumes a proper ground track will be flown. A high E/W bug means high energy. A high HSI glideslope pointer indicates low altitude on the glideslope.



E/W Scale on VERT SIT 1

Above the nominal energy marks is a mark labeled STN (S-turn). When vehicle energy, represented by the triangle, is above the STN mark, guidance may command an S-turn to dissipate energy. Near the bottom of the scale is another mark labeled MEP. Energy below this mark triggers an "SW TO MEP" message. An arrow on the bottom half of the scale marks the straight-in (STRT) energy level. Below this mark, an "OTT ST IN" message is triggered. The arrow disappears at 45 n. mi. range, signifying that a downmode to STRT will probably produce a longer range-to-go.

For low energy situations, it is best to try the STRT downmode first. This avoids a short OGS prior to preflare. If energy is still below the MEP mark, try the MEP downmode. The best downmoding option is a function of the HAC turn angle. For example, downmoding from an OVHD to STRT-IN within 180° has little effect.

Unfortunately, the energy pointer is not very useful in deciding if the orbiter can make the runway. The orbiter bug combined with airspeed must be used. If the orbiter bug is on the low line on the VERT SIT and the orbiter is currently flying maximum L/D, then the runway will barely be reached on a no-wind day. If the orbiter bug is on the high line on the VERT SIT and the orbiter is currently flying maximum airspeed, then the runway will barely be reached on a no-wind day.

Both the high and low lines assume that no downmode is made. An S-turn, selecting straight-in, selecting MEP, or selecting a different runway will all have large changes to the range flown to the runway.

NOTE

> Take CSS before evaluating different downmodes so that the displays can be assessed without committing a turn in the new direction. If the downmode is accepted, AUTO flight control can be resumed.

In summary, crew concerns during TAEM are:

- Remaining within critical flight control and structural limits (q-bar, N_Z, beta, roll angle, angle of attack)
- Ensuring timely and accurate data are input to the NAV state
- Maintaining E/W within limits required to achieve A/L interface
- Monitoring critical systems
- Keeping pace with increasing workload

Takeover

In addition to the takeover conditions discussed in the Entry section, the crew must downmode to pitch CSS if air data has not been taken to guidance and control (G&C) prior to Mach 2.5 (ITEM 28 on SPEC 50 HORIZ SIT). Since TAEM guidance tries to set up an altitude/range profile, a transient is possible if NAV altitude is incorrect prior to air data being incorporated. A step change in FCS gains is also possible due to Mach, alpha, and q-bar errors. If air data is not incorporated into G&C by Mach 2, the crew must go CSS and fly theta limits. Flying theta limits is discussed later in this section.

Manual Control

The easiest way to fly TAEM manually is to precisely fly the guidance needles on the ADI. Each tick mark in pitch is the equivalent to a 0.25g error, and each roll tick mark is a 5° roll error. Maintaining even a one tick mark error over an extended period of time can cause large errors in the trajectory.

During the supersonic portion of TAEM, the pilot’s main goal is to guide the orbiter to the edge of the HAC on the glideslope with the correct amount of energy. As with the rest of entry, closely following guidance provides the best chance for coping with environmental dispersions—if guidance is working correctly. If NAV is bad (guidance is also bad), TACAN/GPS data can be taken directly to the HSI and the Area Nav HAC can be flown (mentioned earlier in this section).

With good NAV, put the “H” pointer on the HSI on the lubber line (the predictors will point at the HAC on SPEC 50).

The most precise pitch control indicator is the orbiter bug on the VERT SIT. Pitch up and down until an H-dot that drives the orbiter bug back to the nominal line is achieved. Make sure not to fly slower than max L/D or faster than maximum airspeed. Max L/D is best flown by using max L/D alpha. L/D alpha is not a function of weight and roll angle and responds much faster than airspeed.

The maximum airspeed of the orbiter is now 333 KEAS. TAEM and the displays still have the old limit of 305 KEAS supersonic built in. Because of worst case air data errors, it is recommended not to go over 321 KEAS (actual indicated airspeed).

If very low, fly maximum range alpha (max L/D) and change the HAC or runway selection if required. Back up navigation with real world visual cues if weather permits.

In extreme cases where guidance and navigation are bad, a GCA, along with the view out the windows, can be used to arrive overhead the field for landing. GCA procedures are discussed in Section 7.3.

Manual control during the subsonic portion of TAEM is discussed later in this section.

Heading Alignment Cone

The HAC is intercepted at various altitudes, depending on HAC turn angle. The altitude varies between about 50,000 ft for a 360° HAC to 20,000 ft for a 90° HAC (straight in). The SPEC 50 HORIZ SIT horizontal scale and the ADI roll rate pointer provide a HAC turn prediction or countdown.

A proper lead is the easiest way to keep the roll guidance needle centered. Leading the HAC turn correctly will quickly establish the orbiter on the HAC without calling for more than 45° bank nominally or up to a maximum of 60° with a strong tailwind. As long as NAV and guidance are good, closely following guidance on the HAC will optimize the chances of staying within vehicle g limitations and countering wind effects.

HSI glideslope data (GSI) can also be used to maintain situational awareness while flying the HAC in order to anticipate guidance commands and minimize deviations from the reference altitude profile.

The circle displayed on SPEC 50 is based on the instantaneous radius of the HAC at the orbiter's current position. For large HAC turn angles, the extended runway centerline initially will be projected inside, rather than tangent to, the SPEC 50 circle. As the orbiter continues around the HAC, the circle will become tangent to the runway extended centerline. Since the displayed circle is based on the instantaneous HAC radius, there will be a very slight trajectory error if the predictor dots are overlaid on the circle. For most situations, these errors are small and do not affect the usefulness of the SPEC 50 display. To fly precisely on the HAC requires that the guidance predictor dots be maintained slightly inside the SPEC 50 circle.

NOTE

> Any delay in following the guidance commanded roll on the HAC can result in going below glideslope, even if the guidance needles are flown perfectly after the delay.

The SPEC 50 HORIZ SIT and ADI rate pointer scales for crosstrack error and glideslope error may also be used to fly the HAC. Keeping the reference triangle or pointer centered on the scales ensures flying the reference trajectory.

HAC Options

Profile options are included in the guidance and navigation system to improve low energy situations. The options include:

- Straight-in approach
- HAC shrink (spiral adjust)
- MEP

Selecting the straight-in approach option on SPEC 50 will reduce the HAC turn angle to 180° or less. When guidance computes the orbiter to be well below glideslope, a HAC shrink is invoked automatically by TAEM guidance. The HAC radius shrinks, allowing the orbiter to fly a shorter approach profile. The final HAC radius is normally 14,000 feet but the HAC can shrink to a final radius of 5,000 feet if necessary.

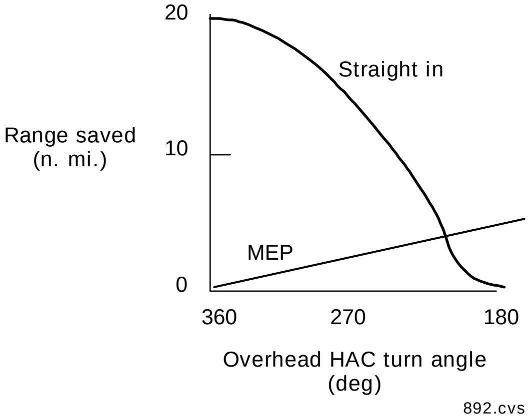
NOTE

> A HAC shrink will occur only if the remaining HAC turn angle is greater than 90° and the orbiter is on the HAC.

The MEP option moves the HAC center point 3 n. mi. closer to the runway. MEP is selected by ITEM 7 on SPEC 50.

Range savings using these options vary as a function of HAC turn angle.

None of the options are nominal procedures. They are used only when the orbiter is in a low energy situation.



Range Saved vs. HAC Turn Angle

Default Air Data and Theta Limits

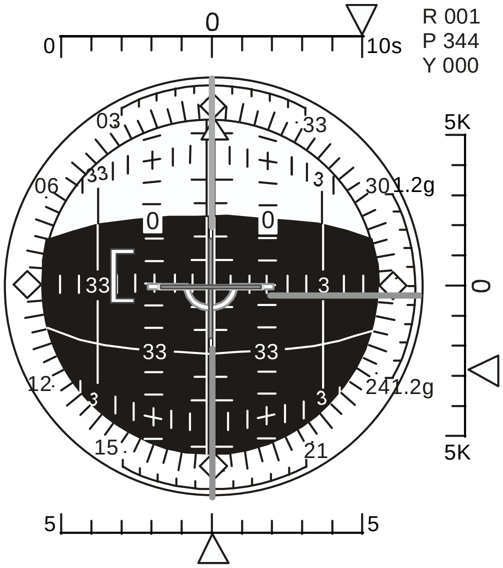
If air data has not been incorporated to G&C by Mach 1.5, default air data values will be used to set DAP parameters. Default air data should ensure adequate flight control for a safe landing, although flying qualities might be degraded.

Although default air data ensures that the flight control gains are set correctly, it essentially removes the airspeed limiting features on TAEM. Default air data will never tell TAEM it is flying too slow or too fast.

Theta limits are a set of pitch attitude limits that keep the orbiter between minimum and maximum airspeeds. Vehicle pitch attitude, as well as the NOSE HI and NOSE LO limits, is displayed on the VERT SIT display. Also, a theta limits bracket (green) appears on the ADI if ADTA is not taken to G&C or if ADTA is in dilemma, and Mach <2.0. The ADI theta limits bracket is dynamic and contracts/expands according to bank angle. A 50° bank angle limit is imposed when flying theta limits. With no air data to G&C, theta limits apply from 1500 fps (2000 fps operational constraint) until rolling out on final.

NOTE

Operationally, do not exceed 50° angle of bank during theta limits. Bank angles greater than 57° will exceed maximum and/or minimum theta limits.



ADI in TAEM with Theta Limits Bracket

WARNING

No warning is provided when pitch up alpha limits are exceeded. Crewmembers should closely monitor theta limits and air speed to prevent loss of control. The pitch error needle will command past this limit if in a low energy situation or approaching a HAC greater than 300°. Mach 1.5 to 1.0 is the most critical phase.

NOTE

Theta limits and a tailwind combination can rapidly cause a low energy situation, requiring aggressive corrections. This is one of the situations where the crew will take the last ADTA data, if available, rather than fly theta limits.

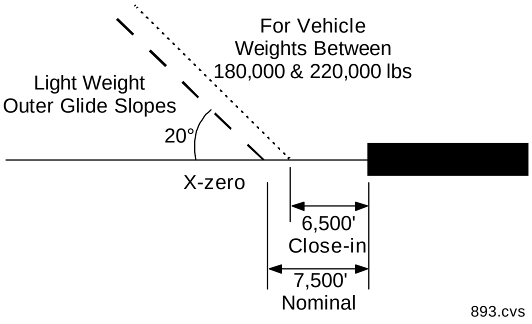
Outer Glideslope

The OGS is an equilibrium glide path that provides sufficient energy at preflare for a safe landing. Sufficient energy includes:

- Having enough energy to compensate for deceleration between preflare and touchdown

- Allowing a minimum of 5 seconds of stable flight time on the IGS for the pilot to make final corrections

To provide sufficient energy at preflare, the OGS design must handle both high and low energy dispersions over the entire weight span of the orbiter. The OGS is a sloped-line segment that intercepts the ground at the aim point.



OGS Profile

Time to correct trajectory dispersions is provided by the altitude at which the OGS is acquired. Nominally, this occurs at 12,000 ft. Transition from TAEM to A/L guidance normally occurs at 10,000 ft, but if the transition criteria have not been satisfied by 5000 ft, A/L transition is forced. The criteria for transition from TAEM to A/L get tighter as altitude decreases. This allows A/L equations to cycle through initial transients and time for the rate terms to reach their damping values.

TAEM TO APPROACH/LAND TRANSITION CRITERIA				
10,000 FT			5000 FT	
< 4	DEG	FLIGHT PATH ANGLE ERROR	< 0.5	DEG
< 1000	FT	CROSSRANGE ERROR	< 100	FT
< 1000	FT	ALTITUDE ERROR	< 50	FT
< 24	PSF	DYNAMIC PRESSURE ERROR	< 24	PSF
(288-312 KEAS)			(288-312 KEAS)	

TAEM to A/L Transition Criteria

Reference velocity on the OGS is 300 KEAS for all vehicle weights. This velocity is required to compensate for the expected deceleration on the IGS. The design goal is to fly as fast as possible while remaining within maximum airspeed limits (333 KEAS)/q-bar (375 psf).

A 20° OGS is used for lightweight vehicles and an 18° OGS for heavyweight vehicles. The design goal was to fly as shallow as possible while maintaining sufficient speed brake reserve to cope with winds and trajectory dispersions. Since both high and low energy dispersions are possible, GSs were selected that resulted in a speed brake setting of 65 percent for midrange weights. One of the reasons for not forcing A/L guidance until 5000 ft is that TAEM has direct q-bar control limits that will keep the orbiter on the front side of the L/D curve.

Guidance and Control

Guidance attempts to maintain the reference-altitude-range profile by computing a normal acceleration command to guide the orbiter along the selected OGS trajectory. The N_Z command is converted to a pitch command and displayed on the ADI and HUD. If the pitch command results in a velocity that is different than 300 KEAS, the speed brake responds to correct the velocity error.

Leaving the speed brake in AUTO allows guidance to reposition it, as required, to maintain the reference 300 KEAS velocity.

The body flap, if in AUTO, is commanded to retract to the trail position (34% on SPI) on the first A/L guidance pass.

Navigation

Upon receiving good data from the ground-based MLS, preland navigation is begun. Unlike entry NAV, preland NAV maintains only one state vector, but executes twice as fast (every 1.92 sec vs. 3.84 sec).

The MLS provides extremely accurate azimuth, range, and elevation, which correct the onboard NAV state. Typical errors are about 5 ft altitude, 21 ft downtrack, and 17 ft crosstrack when processing MLS data.

NOTE

> Both range and azimuth data "good" flags are required to process MLS data. Without an elevation data "good" flag, azimuth and range are still processed, but if either the azimuth or the range data "good" indicator is lost, all MLS processing ceases.

If MLS data are lost for any reason (above 1500 ft) after processing has begun, TACAN and ADTA information will again become available to NAV until 1500 ft and 500 ft respectively. If MLS data are lost below 1500 ft, ADTA altitude processing is not possible.

NOTE

With TACAN data in FORCE mode, MLS data cannot be processed.

Smart Speed Brake Logic

To control orbiter touchdown energy, the speed brake is retracted at 3000 ft to a value calculated by onboard guidance that will target the remaining velocity profile to a fixed touchdown energy. The calculated speed brake position is a function of:

- Wind speed
- Vehicle weight
- Velocity error
- Density altitude
- Aim point (if applicable)
- Short field speed brake option (if applicable)

This position is maintained until 500 ft where the A/L guidance calculates an adjustment to the retract angle. This adjustment is based on any changes in winds and predicted density altitude since the 3000 ft calculation. No more adjustments are made until touchdown. The 500 ft adjustment altitude was selected because the time to fly from 3000 to 500 ft is approximately the same time it takes to fly from 500 ft to touchdown. This allows time for the adjustment to have an effect on the vehicle energy state.

When the close-in aim point is selected, 1000 ft are directly added to the downrange total. The idea is to keep the same touchdown energy target even though the geometry has been shifted in by 1000 ft. This lets the vehicle respond to atmospheric conditions that required the close-in aim point.

Selecting the short field option on SPEC 50 forces Autoland guidance to dissipate an additional 1000 ft of touchdown energy. The energy dissipation is achieved by carrying an additional 12° to 13° of speed brake from 3000 ft altitude to touchdown. When this option is used, the pilot lands the orbiter 10 KEAS slower than the planned touchdown velocity and maintains the same nominal 2500 ft touchdown range. From an energy point of view, the additional 1000 ft of dissipated downrange can be converted to a velocity 10 KEAS slower than nominal touchdown velocity.

The short field speed brake retract option may also be used on all missions if the touchdown ground speed is predicted to be greater than the flight rule limit (214 knots). Using the short field option for this reason will be decided by the flight director and will require an item 39 entry by the crew. The goal is to provide additional margin from the 225 KGS certified tire speed limit. It is for this safety concern and for common training procedures that when the short field option is used, the crew should land 10 knots slower rather than 1000 ft shorter.

The short field option may be selected for TAL/ECAL runways to ensure an adequate rollout margin. In the case of heavyweight abort landings at runways with useable length of less than 11,000 ft, the CDR will target touchdown for 205 KEAS at 1500 ft down the runway.

An additional speed brake option, selected with an ITEM 39 on SPEC 50, is the emergency landing site (ELS) speed brake. ELS speed brake will be selected for heavyweight landings on runways with a usable length of less than 8500 ft. ELS speed brake dissipates an additional 1500 ft of energy over the short field option. For landings with ELS speed brake selected, the CDR targets 195 KEAS at 1000 ft.

The maximum allowable nominal speed brake command at 500 ft is 50 percent, because of degradation of orbiter handling qualities near touchdown. This maximum limit is 80 percent when the short field, or ELS option, is selected.

After the speed brake setting is adjusted at 500 ft, the guidance command remains constant until the weight-on-wheels signal is sent to the GPCs. When this signal is latched, the speed brake is commanded to full open.

Visual Aids

Aim Points

The OGS aim point location was determined by energy requirements for landing and geometry constraints for transition between the two glideslopes. Distance from preflare to touchdown is proportional to orbiter deceleration time. This distance is directly related to aim point location.

The nominal aim point is located 7500 ft from the runway threshold. A close-in aim point is located 6500 ft from the runway threshold. Use of the close-in aim point provides an immediate energy increase by moving the OGS intercept point 1000 ft closer to the runway.

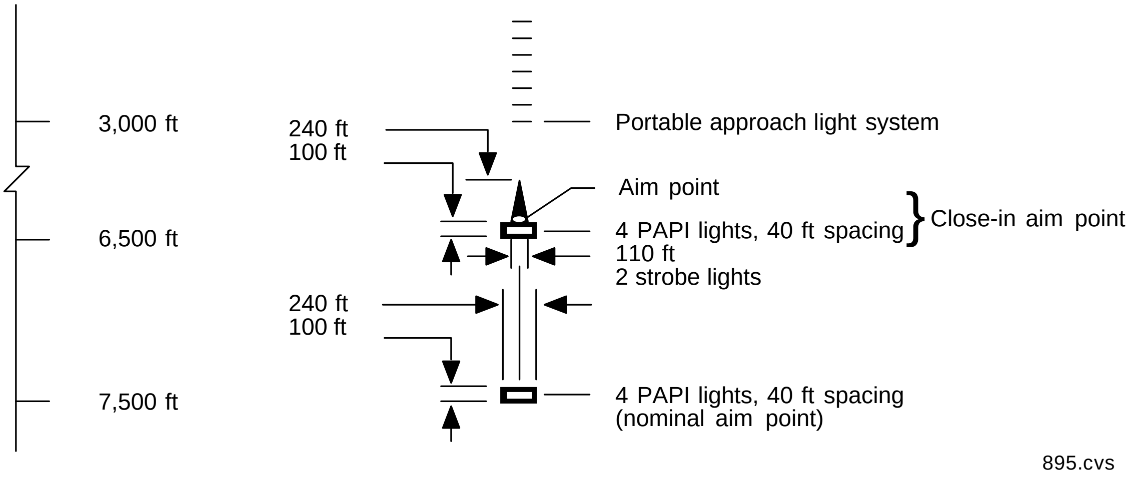
The nominal aim point is a rectangle, whereas the close-in aim point is a triangle. Colors are chosen to contrast with the local terrain. Aim points on lakebeds and light-color terrain are usually black. For tree- or vegetation-covered terrain, aim points are usually white. A dark background is preferred for the precision approach path indicator (PAPI) lights, which are placed on each aim point.

PAPI Lights

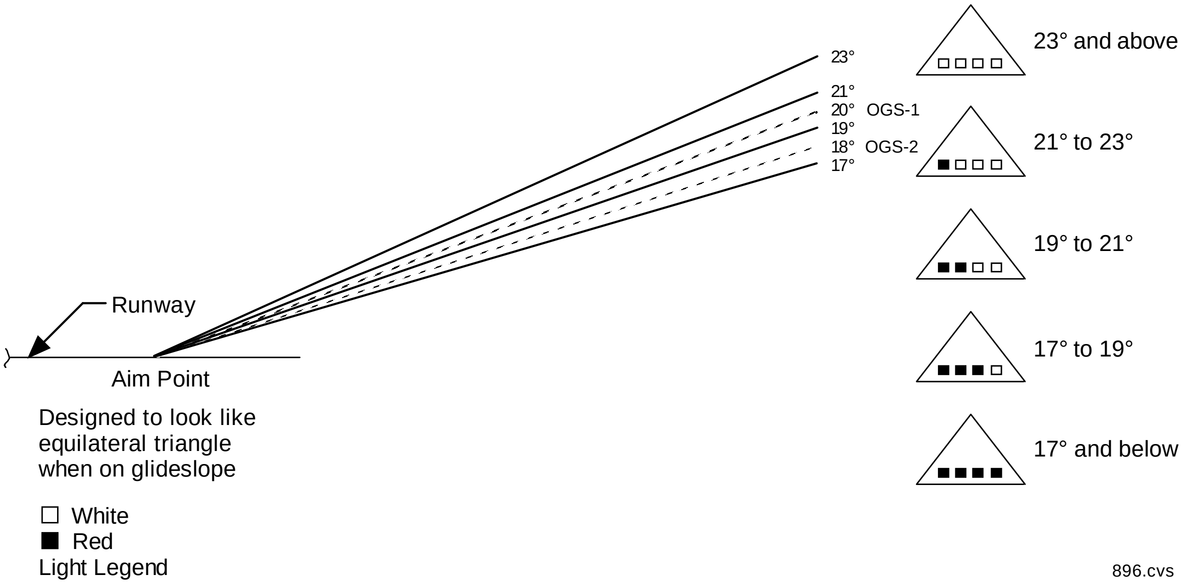
The PAPI lights define the OGS. On a nominal approach, the crew should see two red and two white lights (20° GS). For heavyweight landings, an 18° GS is flown (three red and one white PAPI.

Three intensity settings are available for the PAPI lights: day, dusk, and night.

At fixed installations such as Kennedy Space Center and some Edwards and Northrup runways, intensity is controllable from the tower. Portable PAPIs must be adjusted at the aim point.



Aim Points



PAPI Light Diagram

Techniques

When established on the OGS, the HUD runway should overlay the actual runway. Differences indicate the amount of NAV error. If the overlay is good, then NAV and guidance should be good, and declutter level one or two may be selected and the guidance symbol followed. If excessive NAV error exists, declutter but do not follow guidance. The HUD gamma reference marks should lie next to the aim point if the vehicle is on the proper trajectory.

Without a HUD, use the ADI error needles as long as the NAV state is good. With MLS data, the NAV state will generally be very good. Use of TACAN only will produce errors requiring the pilot to fly the OGS primarily using the HUD and external references.

Since the PAPI lights only show an instantaneous GS status, they must be continuously monitored for trends. If the onboard NAV state is reasonably good, and the crew tracked guidance around the HAC, energy should be close to nominal, and the HUD velocity vector should be positioned near the aim point after rolling wings level on final. If the PAPI lights are not operational, use the rectangle on the ground at the nominal aim point (or the triangle at the close aim point), and align the gamma reference marks on the HUD with the appropriate aim point on the ground.

Night approaches should be considered instrument approaches. Due to lack of outside references, bank control is more difficult. Sink rate is not apparent until after preflare.

The speed brake is left in AUTO mode for the approach. This allows automatic guidance to command the speed brake to control airspeed on the OGS to 300 KEAS. There are failure modes that may fail the speed brake in any position from full open to full closed.

With speed brake stuck closed, lowering the landing gear early results in equivalent drag of 60 percent speed brake.

Stuck open speed brake can be compensated for by flying a steeper OGS with an adjusted aim point closer to the runway.

If a higher than nominal altitude condition exists at rollout (GSI full deflection), the CDR must make an immediate and aggressive pushover to reacquire the proper flightpath to ensure the transition to A/L occurs as early as possible.

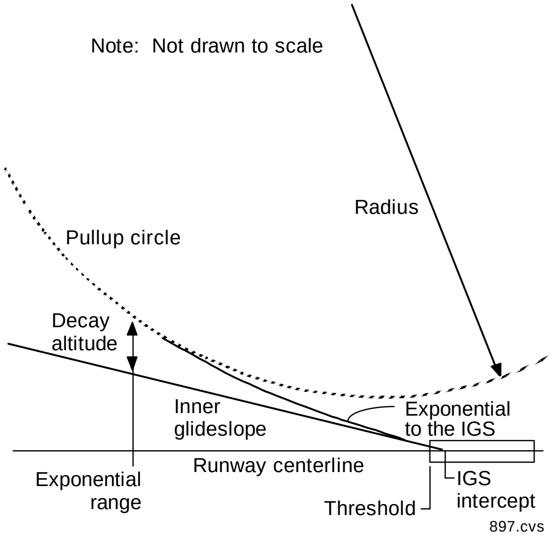
If the BFS is engaged, it is even more imperative that the CDR make an early attempt to correct to the proper glidepath, since the BFS has no A/L guidance mode.

CAUTION

When rolling onto the OGS with excess altitude, TAEM prefinal guidance gains may not be aggressive enough to command the orbiter back into the A/L envelope. If guidance is followed, the resulting flight-path will parallel the reference OGS with the aim point displaced down the runway. When A/L is forced (not later than 5000 ft AGL), guidance will give aggressive pitch commands to try to reacquire the OGS. If followed, these commands could result in an excessive dive angle requiring as much as a 2.0 g pullout for the preflare maneuver. This can be avoided if the CDR closely monitors the HSI GSI while flying the HAC and bearing in mind that the ADI pitch steering needle provides a much more noticeable indication of N_Z command than the HUD.

Preflare

The preflare maneuver is used to transition from the OGS to the IGS. Flight path geometry is a sector of a circle tangent to the OGS and an exponential to the IGS. H-dot of about 190 fps must be reduced to less than 3 fps at touchdown. Preflare reduces H-dot to about 12 fps, with the remainder taken out in final flare. Pullup is about 1.35 g.



Preflare Geometry

Since the speed brake is retracted at 3000 ft and preflare nominally occurs at 2000 ft, the orbiter’s velocity will increase about 10 KEAS. As flight path angle nears the minimum steady state value (-12°), velocity will begin to decrease.

Techniques

There is a strong tendency, especially with inexperienced pilots, to be too aggressive in the preflare or to anticipate the maneuver, ending up high and slow. This tendency is aggravated at night, when closure rate and depth perception cues are reduced.

CAUTION

The preflare is a gentle maneuver. Early and/or aggressive preflare may result in a high and slow inner glideslope from which a hard landing can occur.

Utilizing the HUD flare markers will generally result in good preflare maneuvers. Approaching 1000 ft to 800 ft, use the ball bar to intercept the IGS at about 300 ft. Without a HUD, the ball bar is the best reference during preflare.

For some low energy cases, delaying preflare to as late as 1000 ft may help to correct the situation. Perform a flare maneuver that results in a landing with a very minimal amount of IGS. Stuck open speed brake (greater than 60 percent) will require a more aggressive preflare with very little time on the IGS.

CAUTION

Failure to anticipate the rapid airspeed decay during preflare with stuck open speed brake (more than 60 percent) may result in high sink rate landings.

Use crab angle to control drift due to crosswind during the preflare. A significant change in crab angle during preflare should be expected due to the large change in airspeed and altitude during the maneuver.

Inner Glideslope

Transition to the IGS begins at 300 ft. Once the landing gear is deployed, and the orbiter is on the IGS, deceleration is fairly constant at 4 KEAS per sec. Each additional second the orbiter remains airborne results in a 4 knot slower touchdown velocity. The 1.5° IGS was designed to give the pilot at least 5 sec of stable flight before final flare.

Once stabilized on the inner glideslope, since the orbiter is decelerating, some pitch attitude changes will be required to maintain the desired trajectory.

Landing Gear

The landing gear creates a great deal of aero dynamic drag, which can significantly alter touchdown energy. The landing gear is deployed on an altitude cue by the pilot who is not flying the approach. Current flight procedures are to arm the gear at preflare (2000 ft) and lower the gear at 300 ± 100 ft. The design requirement is to have the gear down and locked at least 5 sec before touchdown. Gear deploy should not be delayed below 200 ft. A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy. A nominal 300 ft deploy is assumed in landing energy predictions.

Final Flare

The final flare maneuver reduces H-dot on the IGS to an acceptable value at touchdown. Final flare should be a smooth increase in pitch attitude started at an altitude high enough to result in a timely decrease in H-dot before touchdown. Strive to touch down 2000-3000 feet down the runway at a safe rate of descent. Shoot for an airspeed within +5 to -10 knots of the target airspeed.

Maximum H-dot at touchdown was designed to protect the main gear struts from unacceptable loadings. Each strut can withstand up to 207,000 lb, although the actual H-dot limit varies from 6 to 9 fps as a function of vehicle weight and crosswind.

A very important factor in reducing H-dot is the powerful aerodynamic ground effect of the orbiter. This effect grows as altitude decreases, increasing L/D by about 25 percent. Minimize RHC inputs prior to touchdown, and expect ground effect to cushion sink rate.

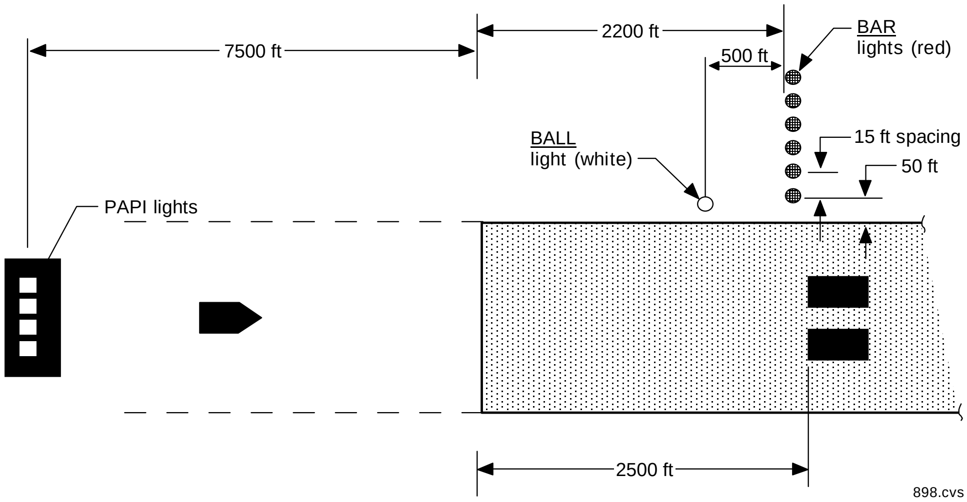
The 1.5° IGS used by guidance is a compromise. It does not require a large maneuver to land, yet maintains a reasonable ground clearance when coming out of preflare.

Techniques

A negative handling quality of the orbiter is that initial vehicle response to pitch control inputs is backwards from the desired performance. This is due to relative locations of the c.g., aerodynamic center, control surfaces, and the pilot's seat. For example, a pitchup command from the RHC causes an upward elevon deflection. The up elevon initially causes a decrease in lift (approximately 2000 lb per degree), and the wheels actually move closer to the ground at a faster rate. The expected positive lift increment will not occur until the orbiter has rotated to a higher angle of attack.

CAUTION

Attempting to reduce H-dot may actually increase the rate, and, if timed incorrectly, can result in an early touchdown.



Ball Bar Geometry

Pilot eye height just prior to landing is nearly constant. Therefore, out-the-window cues are poor indicators of actual H or H-dot after control inputs.

The HUD should be used to monitor pitch attitude and make precise adjustments both on the IGS and for final flare. For no-HUD approaches, use the far end of the runway or the horizon, since pitch attitude changes are very difficult to see due to a lack of references.

A “bang-bang” technique of pitch attitude corrections on the IGS has proven to be effective for some pilots. Small pitch inputs are made, and the RHC is quickly returned to detent. After each input (or series of inputs for larger corrections), wait until the effect is apparent before making another correction. This technique is less effective as landing weight increases and c.g. moves forward.

Ball Bar

The ball bar defines a 1.5° GS. Overlaying the center of the ball across the center of the bar results in a threshold crossing height of 26 ft. Normal guidance profile changes due to winds will result in some difference in threshold crossing heights. Try to shoot for 20-30 feet threshold crossing height during training.

Touchdown rectangles on the runway surface may also be used. The leading edges of the marks are 2500 ft from the threshold, and the marks are 200 ft long and 40 ft wide. Aiming the orbiter straight toward the marks from ball bar intercept until final flare results in good IGS control and safe threshold crossing heights. This technique is especially helpful for no-HUD approaches.

For the final flare, matching digital altitude and digital airspeed on the HUD (40, 240 . . . 30, 230 . . . 20, 220) will result in a smooth maneuver from the IGS to touchdown.

Touchdown

A/L trajectory was designed to result in touchdowns about 2500 ft past the runway threshold at a safe speed and sink rate.

The same touchdown speeds are usually targeted by the pilot when flying CSS to provide a more consistent energy reserve and orbiter pitch attitude at touchdown. Energy reserve is the time (in sec) that the orbiter could have flown until pitch attitude reached tailscrape angle (15°). Energy reserve varies with weight, since heavier vehicles must fly faster than lighter vehicles in order to produce aerodynamic lift equal to weight. Consistent energy reserve and consistent pitch attitude are very important factors that help pilots land with sink rates within vehicle limits. With nominal speed brake selected target touchdown speed is 195 KEAS for weights less than or equal to 222,000 lb and 205 KEAS for weights greater than 222,000 lb.

Speed brake selection	T/D Point (ft)	T/D velocity by vehicle weight (KEAS)			
		< 200 K	200 K - 222 K	> 222 K	> 245 K
Nominal	2500	195*	195	205	205
Short field - for tire speed margin	2500	185	185	195	205 @ 1500 ft
Short field - for runway length	1500	195	195	205	205
ELS	1000	n/a	n/a	195	195

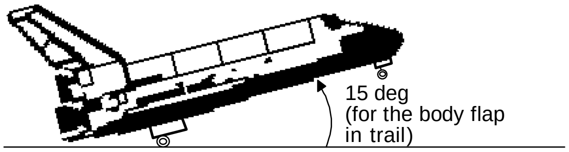
* 185 KEAS is acceptable for certain touchdown energy cases.

Touchdown Targets

Energy Reserve/Tailscrape

Starting with STS-50, the speed brake (in AUTO) targets 2500 ft at 195 KEAS touchdown energy for lightweight vehicles and 205 KEAS for heavyweight vehicles. A rough rule of thumb is 90 ft of touchdown distance corresponds to 1 knot of airspeed.

$$\text{ENERGY RESERVE} = \frac{V_{\text{Tailscrape}} - V_{\text{Touchdown}}}{\text{Deceleration}_{\text{Avg}}}$$



TAILSCRAPE — The maximum pitch attitude (deg) the vehicle can land at and not scrape the tail (body flap).

ENERGY RESERVE — The time (sec) the vehicle could have continued flying after touchdown until the tailscrape condition.

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The most significant factors influencing touchdown energy are:

- Winds
- Density altitude
- Vehicle weight
- Velocity error at 3000 ft

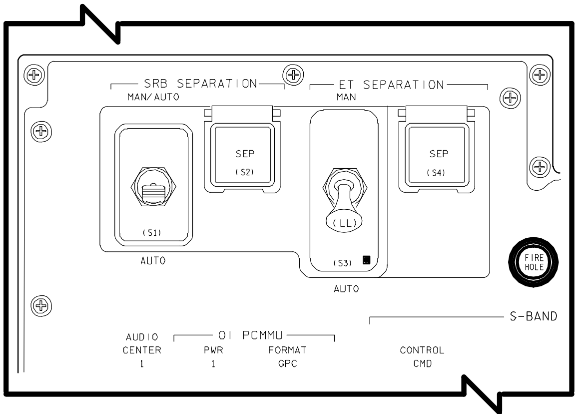
Off-nominal factors such as landing gear deploy altitude, GNC air data errors, tile damage, stuck speed brake, and NAV errors may also be significant.

Variations in touchdown energy of ±500 feet due to the factors listed above are not unusual. Pilots should strive to touch down 2000-3000 feet down the runway at a safe rate of descent within +5/-10 knots of the target airspeed, allowing touchdown airspeed to vary slightly with touchdown energy dispersions. Minimal RHC activity prior to touchdown is desired to preclude pilot induced oscillations.

For crosswind landings, use crab angle to control drift. Maintain the required crab angle all the way to touchdown.

Weight on Wheels Discretes and Flight Control Moding

At touchdown, the weight on wheels (WOW) discrete must be set to properly mode flight control for derotation and rollout. WOW is automatically set by the combination of wheel speed sensors and squat switches (weight on wheels sensors) in the main landing gear struts. Weight on nose gear (WONG) discretes are set by the squat switches in the nose gear. The crew can set the WOW/WONG discretes manually by selecting the *SRB* or *ET SEPARATION MAN* mode and depressing the appropriate pushbutton. Procedurally the SRB Sep switch is favored over the ET Sep switch because the SRB Sep switch is a single toggle switch and the ET Sep switch is an over-center lever lock switch. This makes the SRB Sep switch easier and quicker to operate.



SRB SEPARATION and ET SEPARATION Switches and Pushbuttons on Panel C3

CAUTION

Failure to set the WOW/WONG discrete allows the DAP to remain in A/L mode. Flight control gains are not optimized for derotation and rollout and may cause control problems. Braking and nose wheel steering will not be available.

Crews are trained to routinely set WOW/WONG manually at nose gear touchdown to protect for a WOW and/or WONG discrete failure.

WARNING

Do not attempt to set WOW/WONG manually prior to nose gear touchdown. If set in the air and pitch attitude is less than 0°, as on the OGS, the WOW/WONG flags are set true, including elevon load relief. Elevon load relief drives the elevons to the 10° down position, causing an abrupt pitch down maneuver. Additionally the pitch axis modes to AUTO and the RHC pitch CSS downmode angle opens to 21.7°. This requires full aft RHC to mode back to CSS and recover from the pitch down. If a manual *SEP* pushbutton is depressed at main gear touchdown, the rollout discrete will be set when pitch attitude decreases below 0°. Elevon load relief would cause excessive rates on the nose gear strut at slapdown.

Once the WOW discrete is set, the speed brake opens to 100 percent to help slow down the vehicle. The WOW discrete also sets flat turn and HUD discretes, which cause mode changes in the aerojet DAP. In the roll/yaw channel, when WOW is set, rudder trim and aileron trim freeze, and auto load balancing becomes active. Auto load balancing uses aileron commands generated through the roll channel to balance loads on the main tires. These commands are computed as a function of true airspeed, lateral acceleration, and vehicle yaw rate. Also at main gear touchdown, lateral acceleration feedback and rudder trim loops are opened. In CSS, pitch axis information drives only the ADI error needles. Brake isolation valves are opened allowing the main wheel brakes to operate. Operationally, braking is delayed until after WONG, past midfield, and less than 140 KGS.

Derotation

There are two phases of the derotation portion of orbiter landings, attitude hold and the derotation maneuver itself. Both are important and are discussed separately for clarity.

Attitude Hold

This phase is designed to reduce maximum loads on the main landing gear. Pitch attitude is held constant until EAS decreases to 185 KEAS, when beep trim is used to perform the derotation. This speed was selected as a compromise between maximum load on the main gear, maximum load on the nose gear, time between touchdown and start of derotation, and the need to have the nose gear on the runway surface in time to start braking.

Derotation Maneuver

Derotation is accomplished by the CDR pushing the RHC trim switch (the beep trim switch) forward at 185 KEAS. The beep trim switch ramps up to a commanded 1.5 deg/sec rate and gives a smooth derotation. The manual backup derotation maneuver will be used if beep trim is inoperable or inhibited. The recommended pitch rate in CSS is 1 to 2 deg/sec. Input the derotation command smoothly over a period of 1 to 2 seconds.

Derotation must be commenced at the proper speed and the pitch rate maintained throughout the maneuver. Attempts to significantly slow or stop the pitchdown rate can cause dangerous pilot-induced oscillation (PIO).

Executing a manual derotation requires good crew coordination and must be practiced in the simulator. The pilot not flying the approach and landing should call out airspeeds, with a "derotate" statement at 185 KEAS. A positive nosedown command must be input and held with the RHC to generate the desired 1 to 2 deg/sec pitch rate. When pitch rate is established, callouts of "down at 1, down at 1-1/2, . . ." are very helpful in maintaining a constant rate until nose gear touchdown. The pitch rate needle on the ADI is the best source of this information. The onset rate of the derotation rate command is critical for minimizing main gear loading during and after derotation. Too quick an onset can result in main gear oscillations and load spikes that go over the max limit. Too slow an onset can result in high nose gear loads. Heavy gross weight landings on lakebeds (high rolling friction coefficient) are the most difficult to control.

CAUTION

Derotation is a critical maneuver. Do not delay derotation, especially on lakebeds at heavy gross weight. Loss of elevon effectiveness can cause hard nose gear slapdowns and possible structural damage. Derotation must also be initiated at the proper rate. If the derotation command is input too quickly, main gear loads may be exceeded at high landing weights due to strut oscillations. If the derotation is input too slowly or at the wrong rate, nose gear limit loads may be exceeded.

Rollout

Two phases of rollout are coast and braking. Rollout margin and brake energy limits are defined to ensure the orbiter can stop prior to the end of the runway. Generally, high-energy rollout margin is considered to be 2000 ft and is measured either from the end of the runway or the end of the usable overrun. Brake energy is limited to 42 M ft-lb for end of mission landings. If predicted brake energy exceeds these values, runway redesignation will be considered.

Note that crosswinds directly increase resulting brake energy when differential braking is used for lateral control during rollout.

Short field speed brake may be selected on SPEC 50 to achieve required rollout margin or brake energy limits. This software logic adjusts the speed brake retract function to target a touchdown velocity 10 KEAS slower at 2500 ft past the threshold for all weights.

Coast

Coast phase begins when the weight on nose gear (WONG) signal is set. Elevons are moved automatically from the position required to control derotation to 10° down in order to reduce loads on the main landing gear. The crew should monitor auto load relief on the SPI. If it does not occur, WOW/WONG should be set manually with the SRB Sep switch and pushbutton. WONG also sets the RHC to half the original gains.

WARNING

Failure to perform load relief can cause unacceptably high loads on the main gear, resulting in potential tire failures and loss of control.

Deceleration on the runway during coast is about the same 4 KEAS per sec as on the IGS.

Nose Wheel Steering

HUD rollout discrete and groundspeed enable are nominally set at nose gear touchdown. Nose wheel steering (NWS) is available once ground speed enable is set. Steering may be accomplished with differential braking, rudder inputs (above 100 KGS), or NWS. Two modes of NWS are available:

1. NWS 1(2): Rudder pedal deflections incorporated as biases to N_Y feedback.

2. OFF: No steering commands; nose wheels caster.

Braking

The start of braking is normally determined by groundspeed, although distance remaining on the runway is also considered. Braking begins when groundspeed is less than 140 KGS and the orbiter has passed the midfield point, or if distance remaining is less than 5000 ft. Deceleration rate of 8 to 10 fps^2 should be maintained until below 40 KGS where the rate is decreased to about 6 fps^2. Maximum braking is applied if distance remaining is less than 5000 ft at more than 140 KGS.

Barrier

The barrier net system has been removed from all runways.

Techniques

NWS should be used for directional control and brakes used for stopping unless differential braking is required. NWS operations in *NWS 1(2)* are crisp and responsive with no tendency to overshoot or overcontrol.

The *NOSE WHEEL STEERING* switch on panel L2 has an extension device mounted on the shaft to make it easier to locate.

If NWS 1 fails during rollout, NWS 2 may be selected, however it is susceptible to the same failure and become inoperative.

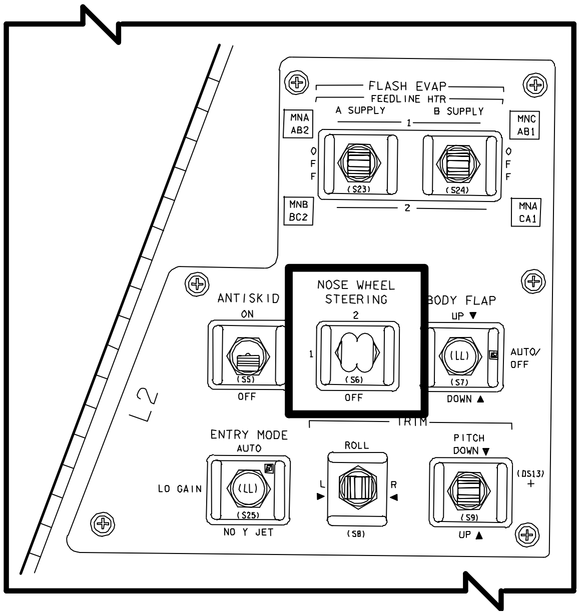
With NWS in *NWS 1 (2)* , the orbiter will tend to turn into a crosswind during rollout. With NWS in caster (*OFF*), the orbiter will tend to turn away from a crosswind.

If a tire failure occurs during rollout, the orbiter will turn toward the failed tire. When the turning moments due to crosswind and tire failure are in the same direction, large control inputs will be required to maintain runway centerline. When the turning moments are in opposite directions, smaller control inputs will be required, and pilots must be careful not to overcontrol.

Rollout performance is best demonstrated in the vertical motion simulator (VMS) at NASA Ames Research Center. NWS and tire failures are realistically modeled, allowing crewmembers to experience actual orbiter dynamics while making corrections. Crew coordination and skills are practiced in the Shuttle Mission Simulator (SMS). Crewmembers should ensure that different rolling friction coefficients and wind conditions are seen, as well as appropriate system failures that disable or downgrade the NWS system.

Handling Qualities

The space shuttle DAP is a rate command system. When the RHC is moved from detent, aerosurfaces are deflected to command a bank or pitch rate. Due to control requirements during high speed flight, the aerosurfaces are very large and can generate large rates, even with a heavyweight vehicle. Smooth control inputs will minimize transients and the initial tendency to overcontrol.



NOSE WHEEL STEERING
Switch on Panel L2

Control harmony is excellent in all axes, with crisp response and essentially deadband damping. Returning the RHC to detent reduces vehicle rates to zero (plus or minus rate deadbands). Control surfaces remain active and will attempt to maintain attitude.

The shuttle training aircraft (STA) is an extremely accurate simulator of orbiter flying qualities below 35,000 ft altitude. Training for high and low energy cases in the STA will prepare crewmembers to handle the actual vehicle from about the 180° point on the HAC. The STA also has the capability to demonstrate navigation state errors up to 6500 ft short, 2000 ft long, and 1,200 ft laterally from the desired touchdown point.

Elevons

During subsonic flight, all four elevons are commanded up and down simultaneously for pitch control. For roll control, the elevons are commanded differentially, similar to ailerons on a conventional aircraft.

Body Flap

The body flap is used to trim the elevons during entry and TAEM. When guidance transitions to the A/L phase, the body flap is commanded to trail. Normally, the body flap is operated in AUTO. If the body flap is not in AUTO, the crew should return to AUTO or manually position the body flap to trail at A/L transition.

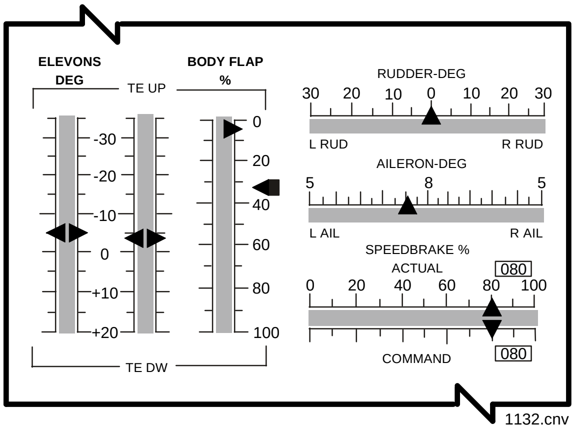
CAUTION

The body flap is a large control surface and exerts a powerful pitching moment on the vehicle. Proper positioning is required to ensure adequate control margins.

Speed Brake

Although energy is controlled primarily by bank angle and the resulting drag in hypersonic and supersonic flight, the speed brake is the primary energy control device in subsonic flight. A/L guidance modulates the speed brake to control airspeed, when operated in AUTO. Speed brake position is constrained to a lower limit of 15° to prevent physical binding of mechanical linkages when the rudder is deflected.

Manual control of the speed brake may be taken if guidance or NAV is questionable. For example, erroneous air data could cause flight control to generate erroneous position commands, resulting in high or low energy or a flight control transient at a critical moment. At 3000 ft AGL, the speed brake is retracted automatically to a computed value based on wind, weight, density altitude, velocity error, aim point, and short field option. At 500 ft AGL, guidance can command a final adjustment of the speed brake position based on density altitude and wind velocity.



Surface Position Indicator

The speed brake is normally operated in AUTO throughout approach and landing. Speed brake position and command are displayed on the SPI and the HUD.

WARNING

The speed brake is a very powerful drag device. Overlooking a stuck speed brake or neglecting to retract the speed brake when operating in MAN can result in dangerously low energy.

Rudder

Corrected body roll rate is used in the DAP yaw channel as a yawing rate error to generate rudder commands. This essentially provides turn coordination. Rudder pedal deflection serves only to bias the N_Y feedback. Since rudder deflection is largely a function of the automatic stability loops, crewmember rudder pedal input should not be required prior to touchdown.

Trim

Automatic trim loops in the shuttle flight control system work very well, and although manual capability is available, it is not usually required in the approach and landing flight phase. One exception is after a BFS engage. In this case, the trim values initialize at zero, and the pilot can help the flight control system return to a trimmed condition more quickly by trimming manually.

Priority Rate Limiting

All aerosurfaces (except the body flap) are rate command limited by priority rate limiting (PRL) software. This allows full advantage of available hydraulic system power while not overloading the hydraulic systems. Rate command limits vary as a function of the number of hydraulic systems available. Simulations have shown that vehicle control is adequate with reduced rate limits, but pilots should be aware that control could be degraded in aggressive maneuvers. Beep trim derotation will be used to prevent elevon saturation and high nose gear slapdown loads.

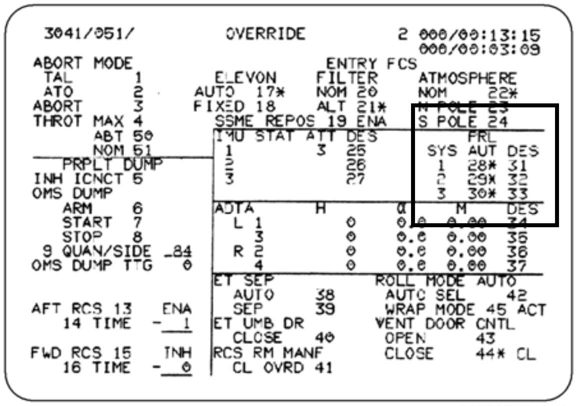
HYD SYS	ELEVONS	AILERONS	SPEED BRAKE	RUDDER
1	13.9	13.9	5.47 (OP), 6.06 (CL)	7.0
2	20.0	20.0	6.1 (OP), 10.86 (CL)	12.0
3	20.0	20.0	6.1 (OP), 10.86 (CL)	14.0

PRL Rate Limits in Degrees per Second

Automatic PRL normally requires little crew interaction. Hydraulic pressure from all three sensors in each system is sent to the GPCs via flight aft (FA) multiplexer/demultiplexers (MDMs). A hydraulic subsystem operating program (HYD SOP) provides redundancy management (RM) for fault detection and isolation of failed transducers. A selection filter generates one pressure from each system.

HYD SOP declares a hydraulic system failed if the selected system pressure drops below 1760 psi. Fail flags are provided to PRL software, which then rate-limits aerosurface commands based on number of good systems. PRL status and management are on SPEC 51.

Using item numbers, the crew can place PRL in automatic systems management, deselect a system, or invoke manual systems management. A failed system is indicated by a down arrow in the system status column. Failed systems are not used by PRL. Loss of hydraulic pressure information can cause a PRL dilemma and a question mark (?) is displayed next to the affected system. When a dilemma is declared, PRL leaves the system status as it was prior to the dilemma. The crew can then either manually deselect or reselect the system after determining its real status using other cues.



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 3041/051/          OVERRIDE          2 000/00:13:15
                                        000/00:03:09
ABORT MODE                    ENTRY FCS
 TAL        1       ELEVON     FILTER    ATMOSPHERE
 ATO        2     AUTO  17*    NOM 20    NOM      22*
ABORT       3     FIXED 18     ALT 21*   N POLE 23
THROT MAX 4         SSME REPOS 19 ENA    S POLE 24
     ABT 50       IMU STAT ATT DES            PRL
     NOM 51       1          3  25        SYS AUT DES
   PRPLT DUMP     2             26         1  28* 31
INH ICNCT 5       3             27         2  29* 32
OMS DUMP                                   3  30* 33
   ARM     6      ADTA     H         α       M     DES
   START   7        L 1          0   0.0   0.00    34
   STOP    8          3          0   0.0   0.00    35
 9 QUAN/SIDE .84    R 2          0   0.0   0.00    36
OMS DUMP TTG   0      4          0   0.0   0.00    37
                  ET SEP                ROLL MODE AUTO
                    AUTO     38          AUTO SEL     42
AFT RCS 13    ENA   SEP      39          WRAP MODE 45 ACT
   14 TIME  -  1  ET UMB DR             VENT DOOR CNTL
                    CLOSE    40          OPEN         43
FWD RCS 15    INH RCS RM MANF            CLOSE        44* CL
   16 TIME  -  0    CL OVRD 41
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**PRL STAT/MGMT ON OVERRIDE
SPEC 51 Display**

Wind Effects on Trajectory

Winds affect the orbiter's capability to fly the desired HAC trajectory and can result in high or low energy situations if not handled correctly. Since the onboard navigation and guidance systems cannot predict winds, the crew must be prepared to anticipate high wind conditions and compensate for them. Information on wind speed and direction is passed to the crew prior to the deorbit burn. This information is updated as required during entry. Data are provided for the following altitudes:

ALTITUDE	HAC POSITION
50K	
38K	270
28K	180
20K	90
12K	FINAL
7K	
3K	
1K	
SURF	

Wind Data Table

The current speed brake energy-control logic in TAEM guidance compensates for wind conditions prior to and on the HAC to maintain a nominal energy profile. Manual flying techniques should not be required to counter wind conditions. Normal piloting techniques, flying the guidance needles, should be sufficient.

Wind data is obtained by the Flight Dynamics Officer (FDO) in the MCC from the NASA meteorologists. Wind data is forecast based on balloon data and later compared to winds observed by the STA weather aircraft. Since the wind conditions that can cause low energy have much more serious consequences, they are discussed in more detail here.

Constant Headwind

For a given reference airspeed, any headwind greater than zero will result in less kinetic energy (less ground speed) than the no wind or tailwind case.

Sudden Headwind Increase

For a given initial energy state, a headwind shear will cause more drag and greater energy loss, until the pilot compensates for the immediate drag increase.

Tailwind Below 50 Feet

Tailwinds, or reduction in headwinds, are normally favorable in a glider because of the reduction of drag. However, at less than about 50 ft, the beneficial effects of drag reduction, integrated over such a short period of time, are outweighed by the sudden loss of available energy caused by the instantaneous decrease in KEAS. Large sink rates and hard landings may result.

Crosswinds

Use crab angle to control lateral drift due to crosswind from outer glideslope intercept until touchdown. Expect a noticeable change in crab angle during preflare and on the inner glideslope due to the large changes in velocity and the change in wind speed as altitude decreases.

Post touchdown, align the fuselage with the runway to reduce nose gear side loads at nose gear touchdown. During rollout, the orbiter will tend to turn into a crosswind with NWS in *NWS 1(2)*. With NWS inactive, the orbiter will tend to turn away from a crosswind.

Limits

Headwind, tailwind, and crosswind limits are listed in the Flight Rules and summarized in the Limits section of this manual. These limits are conservative and are based on simulator, wind tunnel, and actual flight data. End of mission runways are selected so that all parameters are within limits.

Backup Flight System

The BFS is capable of performing nearly all of the primary flight system functions during TAEM, approach, and landing. This section presents the major differences, from the flight crew viewpoint, between the two systems. Differences in handling qualities between the PASS and the BFS are very small in the training simulators, and no large differences are expected if BFS is engaged onboard the orbiter. A moderate control transient should be expected when BFS is engaged.

The BFS does not support PTIs. Flight control mode is CSS from engage through landing rollout.

The BFS maintains only one state vector during entry. Redundancy management is performed on most systems, but in a simpler manner than PASS. BFS is also set up to accept air data to G&C immediately upon engage. If air data has not been previously accepted in PFS, the crew should inhibit air data to G&C after BFS engage.

MLS is not supported. Guidance terminates in BFS at 2000 ft, ADI error needles are stowed, and the speed brake is commanded closed at 2000 ft. On a BFS approach to landing, the crew must manually set the speed brake to the DEL PAD setting at 3000 ft and then open the speed brake to 100% at main gear touchdown.

Off-Nominal Approaches

This section briefly summarizes the procedures used to correct problems typically encountered during training. More detailed information is available in the Approach and Landing Flight Procedures Handbook.

Navigation Errors

A bad navigation state can put the orbiter in a high or low energy condition. If the error is detected early in entry or TAEM, Mission Control will declare a GCA and provide guidance to the landing site until the navigation state can be corrected with GPS, a state vector uplink, or manual state vector update. If errors are observed after the field is in sight, pilots can use visual cues in addition to MCC calls to fly to the runway.

Known Tire Fail / Leak

Landing with a known flat or leaking main gear tire requires special landing techniques to try to save the remaining tire on the strut. Landing on a concrete runway (KSC or EDW) is preferred over lakebed runways due to better vehicle handling qualities on the concrete in the event of both tires failing on the same strut. Approach to the runway should be made with the crosswind, if any, coming from the same side as the failed tire. At touchdown this reduces the load on the remaining good tire due to the vehicle tendency to roll away from the crosswind.

At main gear touchdown the crew should mode the pitch axis to AUTO. This will allow an automatic derotation to begin at 180 KEAS. The drag chute should be deployed at 185 KEAS to coordinate the timing of chute disreef and max gear load during derotation.

At nose gear touchdown the CDR should command a maximum roll, with the RHC, away from the failed tire. This causes the elevons on the wing with the failed tire to move down as much as possible, further relieving the load on the remaining good tire on that strut.

During rollout, the crew should be prepared to use NWS and differential braking, on the good wheels, for directional control.

FAILED TIRE TECHNIQUE

Post-MGTD	P - AUTO
185 KEAS	Deploy drag chute
180 KEAS	√Auto derotation
NGTD	Max RHC roll away from failed tire

Single APU Landing

Fly a nominal approach. At 3000 ft manually set the speed brake to the DELPAD setting. Do not adjust the speed brake at 500 ft. Do not open the speed brake at main gear touchdown. This prevents the speed brake from taking hydaulic flow from the elevons during high hydraulic flow demand flight activites - gear deploy, touchdown, derotation.

Stuck Speed Brake

Procedures for stuck speed brake approaches vary with speed brake setting and are summarized in the following table. These procedures depend on detection of the stuck speed brake prior to the HAC, where energy can be adjusted more easily without using the speed brake. *The Stuck Speed Brake procedure is not a published crew procedure and, as such, is not found in the Flight Data File (FDF). This is an on-console procedure for the Guidance Procedures Officer (GPO) in the event it is needed.*

SB Setting (stuck)	TAEM	A/L	Selected Aimpoint
≥70[1]	*M <0.95 → 1 dot Hi on GSI (use pitch)* *Nominal gear deploy* *(If EDW, select MEP)*	*Fly needles* *Keep EAS <321* *(by pitch)*	3000 ft
51 - 69	AUTO P, R/Y *Nominal gear deploy*		
40 - 50	*AUTO P, R/Y* @ 300 ↑EAS, deploy gear		Close-in
<40[2]	AUTO P, R/Y @ M=0.95, deploy gear		

[1] *For high headwinds at HAC I/C → delay MEP until M=1.5 (EDW); CSS at M=1.5 and fly max. L/D until M<0.95; use pitch to fly 1 dot hi; fly 4000 ft inside HAC.*

[2] *If speed brake stuck closed, consider nominal aimpoint if landing at KSC.*

Stuck Speed Brake Procedures

Early Gear Deploy

If the gear is deployed early (on the HAC), 3000-ft altitude, manually close the speed brake. In general, if the auto speed brake retract command is less then 30 percent, expect to land short/slow. If the auto retract command is greater than 40 percent, expect to land long. At main gear touchdown, open the speed brake to 100%.

Sensory Cues

Most crewmembers report a fairly smooth ride throughout TAEM to landing, with the exception of some buffet during the transonic region. On final, the orbiter responds very little to turbulence in comparison to the STA due to the orbiter's higher wing loading.

When returning from orbit, crewmembers should be aware of the potential for some change in vestibular sensations. Head movements will tend to make these changes more noticeable. Flight crewmembers should avoid exaggerated head movements during landing to reduce the possibility of disorientation.

Sun glare and residue on the windows from the SRB separation motors can reduce visibility during landing, especially at low Sun angles.

Gear deploy causes very little structural vibration and may be difficult to detect.

The orbiter landing gear absorbs touchdown loads very well, and for low sink rate landings, it may be difficult to feel touchdown. The first cue to the middeck crewmembers that the orbiter has landed may be the beginning of derotation followed by nose gear touchdown. For some flights, depending on runway surface, vehicle weight, and center of gravity, derotation and nose gear touchdown could be quite dramatic.

After returning from orbit, crewmembers need to be aware that some degree of decreased balance and coordination, as well as dizziness, may be experienced when getting out of their seats. Studies are in progress to quantify these effects and improve current countermeasures. At present, crewmembers should exercise caution when leaving their seats and preparing for egress.

Autoland

Although the orbiter has been certified for hands-off automatic landings, this capability has not been verified. Simulations indicate that performance is acceptable under reasonable wind conditions for most weight and c.g. combinations.

Although the orbiter may be flown in AUTO for the entire approach and landing, CSS control until MLS acquisition is recommended. This is due to possible transients as the NAV state is updated by MLS data. A runway equipped with MLS is required for autoland.

Based on SMS and STA data, the autoland system tightly controls azimuth and elevation tracking during the approach. Corrections may be abrupt if not close to the nominal trajectory when AUTO is selected.

As with any automatic control system, the crew's task is to monitor the approach and take over manually if performance is not acceptable or to recover from system failures. Since there is no onboard independent monitor, the crew's visual perception of the approach determines takeover criteria. This may differ somewhat among crewmembers and requires a significant number of automatic approaches in the SMS and STA to achieve a reasonable level of proficiency. Both the HUD and ADI should be monitored during the approach. Splitting crewmember duties between the pilots has proven to be an effective method of monitoring autoland performance.

CAUTION

Pilots must use extreme care when executing a manual takeover from automatic flight control after commencement of pre-flare. Very little time exists before touchdown to damp vehicle attitude transients which may be induced by the takeover.

Techniques

After OGS intercept, MLS acquisition, and A/L transition, engage *AUTO PITCH* and *ROLL/YAW*. Attempt to have ADI error needles centered or tracking toward the center position prior to engagement. Should a takeover be required, the *CSS PITCH* and *ROLL/YAW* pushbuttons should be used to downmode. This avoids undesirable transients caused by a "hot-stick" downmode. Takeover should be performed only during stable flight conditions, if possible. A manual takeover on the OGS or IGS is much less demanding than during a dynamic phase of the approach such as preflare.

With good autoland performance, the crew should only be required to lower the gear at 300 ft and apply brakes after nose wheel touchdown. Rollout guidance is provided by the MLS and lateral control by the NWS.

		PAPI 7500 FT	PAPI 6500 FT	MARKING 7500 FT	AIM PT. 6500 FT	BALL	TACAN	TACAN	
RWY	MLS	(NOMINAL)	(CLOSE-IN)	▬	♦	BAR	(PRIMARY)	(BACKUP)	REMARKS
EDW 17L	√ JR CH 6	√	√	√	√	√	EDW 111 (SS)	PMD 92 (SS)	
EDW 23L	—	*	*	√	√	*			Threshold & TD MK
EDW 35R	—	*	*	√	√	*			Threshold & TD MK
EDW 05R	—	—	—	—	√	*			Threshold & TD MK
EDW 15	√ JR CH 6	√	√	√	√	√			Threshold & TD MK XENON
EDW 33	—	*	√	√	√	√			Threshold & TD MK
EDW 22	√ SR CH 8	√	√	√	√	√			XENON **
EDW 04	—	√	√	√	√	√			Underrun unusable/ displaced threshold XENON **
EDW 18L	—	*	*	√	√	*			Threshold & TD MK XENON **
KSC 15	√ SR CH 8	√	√	—	—	√	TTS 59Y (DS)	COF 97 (DS)	XENON
KSC 33	√ SR CH 6	√	√	—	—	√	SNG 121Y (SS)	HMN 92 (SS)	XENON
NOR 17	√ JR CH 6	√	√	√	√	√			XENON
NOR 23	—	√	√	√	√	√			
NOR 35	—	√	—	√	√	√			
NOR 05	—	—	—	√	√	—			
BEN 36	√ SR CH 6	√	√	√	√	√	BEN 118 (DS)	CBA 116 (DME)	XENON
BEN 18	—	√	√	√	√	√			
MRN 20	√ SR CH 6	√	√	—		√	MRN 100 (SS)	AOG 23 (DS)	XENON **
ZZA 30	√ SR CH 6	√	√	—		√	ZZA 64 (DS)	MLA 58 (DME)	XENON **
BYD 32	√ 2JRS CH 6	√	√	—		√	BYD 121Y (DS)	BJ 76 (DME)	XENON **
HNL 08R	√ JR CH 6	—	—	—		√	HNL 95	CKH 86	XENON **
GUA 06L	√ JR CH6	—	√	—		√	UAM 54	UNZ 100	XENON **

NOTE

THIS CHART REFLECTS CAPABILITIES AND CONFIGURATIONS WHICH ARE DEPENDENT ON MISSION CHARACTERISTICS; i.e., INCLINATION, AND DAY VS NIGHT RTLS, TAL, AOA CASES. * SURVEYED POINTS WHERE PAPI LIGHTS/BALL BAR CAN BE INSTALLED. ** XENON lights can be installed at these locations for mission requirements. AIM POINT MARKING @ 6500 FT IS A TRIANGLE, 7500 FT MARKING IS A RECTANGLE. (2) SINGLE GENERATOR ONLY. (DS) REFERS TO DUAL STRING TACAN TRANSPONDERS, (SS) IS A SINGLE STRING UNIT.

Navaids/Landing Aids Hi/Low Inclination

Terminal Area Energy Management and Approach, Landing, and Rollout Rules of Thumb

- A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy. Gear deploy should not be delayed past 200 feet altitude.

- 90 ft of touchdown distance corresponds to 1 knot of airspeed.

- TAEM guidance uses pitch to control glideslope, bank angle to control ground track, and speed brake to control energy above about 14,000 ft and airspeed below this altitude.

- Overhead HAC with NEP allows the most downmode options for energy.

- Fly theta limits at Mach 2 (NLT Mach 1.5) if air data is not incorporated to G&C. Maximum bank angle is 50°.

- OGS is 20° lightweight (<222,000 lb) and 18° heavyweight (>222,000 lb). Aim point is 7500 ft nominal and 6500 close in. Touchdown speed is 205 knots heavyweight and 195 knots lightweight. When short field speed brake is selected, touch down 10 knots slower than nominal.

- Deploy the drag chute at 195 KEAS (after main gear touchdown). Start the derotation at 185 KEAS using beep trim. At nose gear touchdown, manually back up WOW/WONG by taking the SRB SEP switch to MAN and pushing the pushbutton.

- During training, pilots should strive for a threshold crossing height of 20 - 30 feet on nominal approaches. Touchdown goals are airspeed within +5/-10 knots of the target value, sink rate within structural limits, negligible lateral drift, and minimal RHC activity. A good target value for sink rate is 3 fps or less, ensuring ample margin before violating limits.

- With NWS in *NWS 1(2)*, the orbiter will tend to turn into a crosswind. With NWS *OFF*, the orbiter will tend to turn away from a crosswind.

- If the orbiter is landing with a known failed tire special landing techniques were developed to try to save the second tire on that axle.

- If both main gear tires fail on one side, the orbiter will tend to turn toward that side. The turning moment due to crosswind can either reinforce or reduce this effect, as will the drag chute due to weathervane effects.

- If the turning moments due to tire failure and crosswind are in the same directions, large control inputs will probably be required.

- If the turning moments due to tire failure and crosswind are in opposite directions, the control inputs required to counteract tire failure will be reduced. In this situation, pilots must be careful not to overcontrol. A good rule of thumb is to be more cautious with the rudder pedal, matching the crosswind turning tendency.

- Flight Rules call for landing with an existing crosswind on the same side as a known or expected bad tire.

8. INTEGRATED OPERATIONS

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8.2 WORKING WITH MISSION CONTROL................ 8.2-1
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The most successful teams are those that have learned to work together and know each other's responsibilities, strengths, and weaknesses. In a system as complex as the space shuttle, the Mission Control Center (MCC), the Launch Control Center (LCC), and the flight crew must work as an integrated team with each part supporting and contributing to the performance of the other.

Each team member must be completely aware of his or her responsibilities and realize that safety and mission success depend on proper coordination among team members. The duties and coordination functions discussed in this section are typical of the responsibilities assigned by the CDR and the Flight and Launch Directors. Specific assignments will vary from mission to mission.

Preplanned decisions that have been approved by the Space Shuttle Program are published in the Flight Rules and Launch Commit Criteria. These are designed to minimize the amount of real-time discussions when off-nominal situations occur. The Flight Rules also serve as the basis for real-time decisions. Rules are developed using system performance capabilities documented in the Shuttle Operational Data Book (SODB), along with program certified capability. Where circumstances do not allow staying within the operating base (SODB + certified capability), the Mission Management Team (MMT) may choose to take any necessary action to ensure the safety of the crew and shuttle.

During prelaunch and flight operations, the MMT chairman is responsible for near-real-time policy decision. The launch team and the flight teams consult with the MMT chairman as soon as possible whenever operations outside the shuttle operating base are required.

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8.1 FLIGHT CREW DUTIES AND COORDINATION

CONTENTS

Dynamic Flight Phases........................ 8.1-1
Orbit Phase.. 8.1-1
Intercom Protocol................................. 8.1-2

Dynamic Flight Phases

For a shuttle flight crew to work well together, each crewmember needs to have his or her job clearly defined. This definition includes the tasks assigned and when they are to be performed. Individual responsibilities will be assigned by the mission commander based on mission requirements. One way in which duties might be divided for dynamic flight phases is summarized in the following table.

POSITION	PRIMARY	SECONDARY
CDR	Trajectory/Nav Abort Boundaries * DPS ECLSS Nominal Timeline Navaids ** Mission Success Mission Safety Voice Transmissions to MCC	Communications Flight Control Channels OMS RCS Contingency Abort Boundaries *
PLT	MPS EPS APU/HYD OMS RCS Flight Control Channels	Trajectory/Nav Navaids ** Mission Success Mission Safety Voice Transmissions to MCC
MS2	Overhead Panels Overhead Gauges Communications	Abort Boundaries * Navaids ** Nominal Timeline Reference Data
MS1	Contingency Abort Boundaries ** Photography Reference Data	Nominal Timeline Overhead Panels Overhead Gauges
MS3	Stowage Middeck Panels/Actions	Photography

* Ascent only
** Entry only

Flight Crew Duties for Dynamic Flight Phases

It is critical for the crew to lay out responsibilities early during training and follow their plan. As malfunctions occur, the division of responsibilities may change. For example, the PLT may have to concentrate on the trajectory while the CDR deals with an ECLSS malfunction. To ensure the trajectory is being monitored, especially during the early portion of crew training, the CDR could verbally ask the pilot to watch the gauges. As training progresses, crews gain an understanding of when another crewmember requires assistance and usually provide backup without being asked.

Another way crews work together is to monitor keyboard entries and switch throws. By allowing someone else to check a keyboard entry before it is fed to the GPCs or check that the correct switch is being actuated before it is moved, crewmembers can greatly reduce the chance of errors. For crewmembers to provide a good crosscheck for each others' activities, they must remain together as they work nominal and malfunction procedures. Calling out page numbers, procedural titles, and step numbers will help everyone follow through the procedures.

During dynamic flight phases, or any time when dealing with several malfunctions, it may be best to divide into groups or detail individuals to separate tasks to successfully deal with all problems in a timely manner. The CDR usually takes the lead in assigning tasks. As the proficiency of crews increases, crewmembers often assume responsibility without being formally assigned by the CDR. Whenever groups/ individuals begin working separate problems, they should attempt to periodically update the other members of the crew on their progress. This is especially critical when the problems being worked are interrelated. The CDR and PLT must exercise care to ensure that at least one member of the crew monitors the vehicle trajectory and maintains awareness of the nominal timeline when their attention is drawn to different problems.

Orbit Phase

On orbit tasks are usually less time critical and responsibilities are redistributed as necessary. It is important that more than one crewmember is trained for each flight task to protect for the occasion when the prime crewmember might be ill or busy with another task. Mission specialists usually assume the prime responsibility for major payload activities. For Spacehab flights, the senior mission specialist will be assigned as the Payload Commander and charged with successful payload operations. The following table lists a sample division of duties for the orbit phase.

POSITION	CDR	PLT	MS1	PS2	MS2	MS3	PS2
EVA					X		
EVA 2						X	
IVA		X					
MEDIC	2				1		
IFM		1			2		
EARTH OBS		2			1		
PHOTO/TV		2			1		
Prime Payload	2	1					
Secondary Payloads			X	X			
DTO XXX	1					2	
DSO XXX						1	2

1 Prime
2 Backup

On-Orbit Division of Responsibilities

Intercom Protocol

During ascent or entry most crews have a standard protocol of voice callouts to help them keep track of mission events. Typical callouts and associated displays for ascent and entry are listed in the following tables.

MET	EVENT	CALLOUT
00:00	SRB Ignition	DCR: Lift-off/102
00:30	Throttle Bucket	PLT: Throttle down
01:00	Throttle Up	PLT: Three at 104
02:12	SRB Sep	DCR: Pc < 50, Sep, 103, TMECOs converged
03:00		MS2: EVAP OUT t coming down
08:00	MECO -30 sec	DCR: Coming up on MECO
08:32	MECO	DCR: MECO, MECO confirm, ET sep, 104, check targets
10:32	MECO +2:00	PLT Dump/start

Ascent Displays and Callouts

EVENT	CREWMEMBER	CALL
MLS to state vector	MS	MLS
A/L	MS	Approach & land, BF trail
~5 K ft	PLT	Radar altimeter, 1 & 2 check good
4K ft	PLT	4,000
3K ft	PLT MS	3000 Boards ___%
2K ft	PLT CDR PLT	2,000, Preflare next Preflare, arm the gear Gear is armed with a light
1K ft	PLT	1,000 ft ___kts(PLT call max EAS in preflare)
500 ft	PLT	500
400 ft	PLT	400
300 ft	CDR PLT MS	Gear down Gear coming Boards ___%, gear is down
300 200 100 70 50 --ft 40 30 20 10 5	PLT	___ft, ___ knots (steady rhythm)
TD	PLT CDR	Touchdown Drag chute (if abort landing or high energy.)
195 KEAS	CDR	Drag chute
185 KEAS	PLT	185 Derotate
Derotation	PLT	Pitch rate ___(Report at a regular cadence during derotation. Target 1°-2° per sec).
Nosegear TD	PLT MS	WOW set (Manual by depressing SRB SEP PB) Load relief (or no load relief) NWS Fail - (if NWS light is on)
Midfield	PLT	Midfield
5K ft remaining	PLT	5,000 ft remaining
140 130 120 110 100 --KGS 90 80 70 60 50	PLT	___ft, ___ (Decel reading) (Target 6-8 ft/sec^2)
60 kts (±20)	CDR	Chute (drag chute jettison)
40 kts	PLT	40 kts, ease off
Wheels Stopped	CDR	Wheels Stopped

Landing Comm Protocol

8.2 WORKING WITH MISSION CONTROL

CONTENTS

MCC Resources 8.2-1
Operations Monitoring and Control 8.2-1
Air-to-Ground Voice Communications 8.2-2
Telemetry Uplink 8.2-3

To work well together, the flight crew and MCC must be aware of each other's capabilities. Integrated simulations, where members practice their roles on an actual mission, are one way in which the team members learn about each other. Another way is for members of the flight crew to observe in MCC during integrated simulations and for Flight Controllers to ride along and observe flight crews operating in the Shuttle Mission Simulator (SMS).

MCC Resources

While visiting MCC, crewmembers will notice that an immense amount of downlist data is available for Flight Controllers to analyze the performance of orbiter systems and follow mission activities. The downlist data is formatted on various displays with orbiter DPS keyboard entries, fault messages, and switch discretes available, as well as numerical parameters. Many of the parameters in the downlist data stream are not displayed onboard the orbiter. The flight control team also has access to inputs from the customer, direction from NASA management, weather observations and forecasts, engineering test data and analysis, systems performance histories, and radar tracking data.

To properly utilize this data, personnel are divided into groups concentrating on specific vehicle systems or operational functions, with each group led by a Flight Controller. The Flight Controllers pass information and recommendations over the intercom voice loops to the Flight Director. The Flight Director uses the information to make decisions on the proper conduct of the mission, and manages the flow of information to the crew via the CAPCOM or uplink commands.

Operations Monitoring and Control

Optimum MCC performance depends on successful receipt of telemetry and tracking data. Orbiter DPS or instrumentation failures, as well as communications failures, can quickly degrade the amount of assistance available from the ground. If possible, the CAPCOM will inform the crew whenever downlist data is lost or regained.

To track the crew's progress through the nominal timeline, Flight Controllers observe individual crew keyboard entries and switch throws via MCC displays. It is usually possible for the ground to follow the crew's progress without voice calls, but an occasional status call can be helpful. The crew can also help the ground by closely following the nominal timeline and by loading maneuvers with future start times well before they are required.

MCC will try to anticipate points in the timeline where an MCC GO is required for the crew to proceed, and call before the crew reaches that point. If the crew reaches a point where an MCC GO is required before MCC calls, they should ask for a GO.

When malfunctions occur, the controllers in MCC will usually see a trend develop in their data before the crew hears an onboard alarm. Whenever possible, and especially on orbit, MCC will attempt to warn the crew and advise a course of action before a fault message occurs. For failures that occur more rapidly, the crew will see a fault message first and the ground will see the problem a few seconds later in the telemetry data stream. After a few seconds to diagnose the problem, the responsible Flight Controller will advise the Flight Director on the proper course of action. On direction from the Flight Director, the CAPCOM will then relay the necessary information to the crew. Usually this transmission will include instructions to follow a procedure in the FDF, specific switch actions, or information on why a false alarm occurred. CAPCOMs will strive to use the precise FDF procedural titles and the same switch nomenclature listed on orbiter panels to minimize confusion. If the situation permits, the CAPCOM will also try to pass to the crew the rationale for the decisions that have been made, especially those involving resources not available to the crew.

Air-to-Ground Voice Communications

Flight crews should be aware that the monitoring of crew voice calls is given very high priority in MCC. Whenever the crew calls on air-to-ground, all discussions cease on the Flight Director's loop in order to concentrate on the crew's transmission. Crew calls to inform MCC of fault messages or advise the ground on progress through normal procedures can interrupt information flow in MCC. Advisory calls on progress through nominal procedures should be reserved for periods of reduced communications activity or for when the ground is having problems with downlist data. For confirmation of noncritical system problems, one plan that works well is to wait 15 to 20 seconds after the appearance of a noncritical fault message before calling the ground. This allows the ground time to digest the problem and call the crew, without interruption. Waiting for MCC to make the first call when noncritical fault messages occur should result in the quickest possible problem confirmation.

Of course, flight crew calls can be extremely helpful when MCC is experiencing data problems or when failures occur which require immediate attention. A crew call in these instances will focus MCC's attention on the problem brought up by the crew. Following are some appropriate calls to MCC that are not specifically required by procedure:

Acknowledging MCC transmissions.

- Reporting deviations from the timeline or from a procedure.
- Beginning/Ending postinsertion, deorbit prep, or major payload activities.
- Beginning/Ending malfunction procedures. (This call is generally not made for critical malfunctions or during periods of high workload.)
- Beginning major DPS reconfigurations or cockpit switch configurations.
- Shutting down a main engine, APU, or fuel cell, or taking electrical buses off line unless previously directed by MCC.
- Reporting engine failure, fire, DPS set splits, or flight control problems. (These problems may not be immediately apparent in downlist data.)
- Reporting any problem the crew desires MCC to give immediate attention.
- Calling MCC prior to MDM port mode/power cycle.
- Changing telemetry formats.
- Switching to alternate ACCU or PCMMU.
- Reporting headset, CCU, or ATU problems.

If practical, flight crews should obtain MCC confirmation of a malfunction before working a malfunction procedure. By the same token, crews should call MCC whenever beginning a malfunction procedure for deviating from the nominal timeline without MCC direction, if the pace of activities and communication status permits. During periods of high activity, MCC will assume that the flight crew is prioritizing problems and automatically working the necessary malfunction procedures as problems arise. In these cases, MCC will save voice confirmation and direction to work malfunction procedures for the most critical problems.

To minimize verbiage and confusion, standard phraseology is frequently used in calls between the orbiter and MCC. Some of these calls are summarized in the table on the next page. Standard abort mode boundary calls are presented in Section 6, Emergency Procedures.

Unplanned downmodes to manual flight control should be discussed with MCC if time and flight control performance permit.

Aborts or redesignation of landing site/runway should only be performed at the direction of MCC if air-to-ground communication is available. If air-to-ground communication is not available, or if mission safety is in question, the CDR assumes ultimate authority for mission decisions. In this case, the crew will use onboard procedures and flight rule summaries to take whatever action is required to safely conclude the mission.

CALL	MEANING
Roger	Your transmission has been received.
Wilco	Will comply with received instructions.
Say again/repeat	Repeat your last transmission.
Read back	Repeat the list of information just transmitted.
Good read-back	The information just repeated was correct.
Stand by	Wait, we will have an answer or be ready to listen shortly.
Stand by on the xx procedure	Wait, we will have a plan of procedure/action soon, do not execute the xx procedure.
Hold…	Stop executing the mentioned procedure at the current step.
You are go for…	You have permission to execute…
The xx system is go	The xx system is working adequately.
Expect ratty comm due to…	Expect degraded communication due to…
…in the blind	We can't hear you, but we're transmitting, hoping that you can hear us.
Lost data	MCC has lost vehicle downlink data, expect reduced MCC troubleshooting assistance.
Regained data	MCC has regained downlist data.
…UHF only	MCC or orbiter transmitting or receiving on UHF only. May also mean loss of orbiter downlink data.
Comm check	Voice communication check, acknowledge and describe quality of transmission.
LOS	Loss of signal/without comm. Sometimes used to mean star/object no longer in view.
AOS	Acquisition of signal/good comm. Sometimes used to mean star/object in view.
Abort…	Execute the…abort mode. MCC will also uplink an abort light.
Take TACAN	Accept TACAN for use by NAV software.
Take Air Data	Accept Air Data information for use by NAV and GNC software.
Go…CSS	Take pitch and/or roll/yaw CSS as called.
Go…Auto	Return to Auto Pitch and/or Roll/Yaw flight control. For Orbit Ops, select Auto DAP.
Check DAP…	Ensure the DAP mode matches the mode mentioned in call.

Standard Air-to-Ground Voice Calls

Telemetry Uplink

In addition to voice communication, MCC has the capability to electronically uplink information to the orbiter. This capability is frequently used to reduce crew workload, uplink large amounts of information, or to uplink information where accuracy is critical. Crews may request that MCC uplink information rather than using a voice transmission if they feel it would be beneficial and if there is sufficient time for the ground to prepare the uplink. In extreme cases, the MCC also has the capability to uplink keyboard entries to the orbiter GPCs in the form of DEU equivalent uplinks. Common uplink information is shown below:

- Communication system configuration commands.
- State vector updates.
- Table maintenance block updates (TMBU) to alter software caution and warning limits.
- IMU compensation.
- OMS burn targets.
- Alternate landing site information.
- TIPS messages for daily execute packages. Contains flight plan and procedural changes, amplifying information, news from home, systems, and consumables status.
- Unscheduled TIPS messages containing information not conveniently passed using voice transmission.

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8.3 PRELAUNCH

CONTENTS

Flight Crew 8.3-1
Mission Control Center 8.3-1
Launch Control Center 8.3-1

Prelaunch activities begin at KSC with the start of the launch countdown. Relative to the responsibilities of the flight crew as they relate to the LCC and MCC teams, prelaunch is considered to start at flight crew arrival at KSC.

Flight Crew

Crew activities at KSC are outlined in a letter promulgated by the Director of Flight Crew Operations Directorate (FCOD). All activities are coordinated by the FCOD Vehicle Integration Test Office. Each mission has different timelines, and activities vary among pilots, mission specialists, and payload specialists.

The flight crew is subject to Health Stabilization Plan restrictions. These limit direct contact to a small group of individuals who are especially badged as Primary Contacts. Thus, exposure of the crew to communicable diseases with short incubation periods is minimized.

Typical activities for the flight crew at KSC include:

- Shuttle systems briefing
- Countdown status briefing
- STA flights
- Weather briefing
- FDF review
- Preflight physical exam
- Equipment checks
- T-38 flights

Unless mission requirements dictate a different timeline, the crew will arrive at KSC 3 days prior to launch. Circadian shifts are performed during this period, except for flights requiring large shifts and 24-hour operations. Those crews start their circadian shift prior to departing Houston.

Crew activities are conducted per a relaxed timeline until the actual launch day, when the schedule is tightly controlled. Basically, crew members are responsible for their scheduled events.

Mission Control Center

The MCC is in a monitor mode for most of the launch countdown. Active participation is required for communication checks, weather coordination, and inputs to the Mission Management Team (MMT) on shuttle systems anomalies.

Flight controllers and MCC support personnel are responsible for their own readiness for flight. This includes console and computer systems configuration and checks. All necessary materials required to support flight operations are positioned. The MCC shift teams usually begin their circadian shift during the countdown.

Launch Control Center

LCC personnel man consoles around the clock once the launch countdown commences. Each shuttle and ground system is monitored by one or more members of the launch team. The countdown is managed by an Orbiter Test Conductor (OTC) who has responsibility for accomplishment of all steps listed in the countdown Operations and Maintenance Instructions (OMI). Prelaunch OMIs implement checkout requirements designed to demonstrate operation of all testable subsystems within prescribed limits. The launch countdown OMI is performed under strict quality control. Any deviation is documented and must be accounted for, either by repair, replacement, or a waiver from the MMT. In certain areas, launch may be permitted with equipment losses, provided they are well understood to be isolated occurrences and not symptomatic of a generic problem.

LCC responsibilities include the conduct of the countdown OMI under the OTC's direction, systems monitoring, test and checkout, recording any deviations, making recommendations on system problems, and ensuring any violations of the Launch Commit Criteria are brought to the attention of the Launch Director.

The launch team is stationed in one of the firing rooms of the Launch Control Center building at KSC.

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8.4 LAUNCH

CONTENTS

Flight Crew 8.4-1
Mission Control Center 8.4-2
Launch Control Center 8.4-2

Shuttle launches are complex interactive tasks, where each member of the LCC, MCC, and flight crew performs an integral part. For purposes of discussing responsibilities of each element, launch activities are considered to start at flight crew ingress into the shuttle.

Flight Crew

The flight crew enters the orbiter about 2 hours 45 minutes before launch. Prior to ingress, final weather and systems briefings are conducted and the crew dons their advanced crew escape system (ACES) suits.

Ingress is accomplished with the assistance of a suit technician and an astronaut support person (ASP). These individuals are part of the closeout crew who perform final shuttle checks on the launch pad.

Upon completion of ingress, activities are governed by the FDF Ascent Checklist, which summarizes crew tasks from the countdown OMI. These activities are presented in Section 5.

Crew responsibilities include responding to LCC and MCC requests per the checklist. Emergency procedures are discussed in Section 6.

As the launch countdown progresses, crewmembers will be asked to configure certain systems and make various keyboard entries. This direction will come from the OTC via air-to-ground loops. The NASA Test Director (NTD) may also communicate with the crew via air-to-ground loops, especially if an off-nominal situation occurs. MCC inputs are voiced to the crew by the CAPCOM, who also utilizes the air-to-ground loops. The crew normally uses air to ground to respond to LCC or MCC calls during the launch count.

The LCC has the capability to transmit to the crew using A/G 1, A/G 2, or A/A loops. Normally, only one loop is used at a time. The MCC transmits simultaneously on all three loops. Occasionally, this causes an echo because of different time delays. The crew should report this phenomenon to MCC because the delays can be adjusted in real time to remove the echo. Normally the LCC OIS 212 loop, which is used for the direction of launch activities, will be patched into the A/G loop for the crew to monitor.

The LCC also has the capability to talk and listen on ICOM 1 and ICOM 2. Transmission on these loops is restricted to a small number of consoles in the Firing Room. If the LCC enables a patch, the entire launch team can receive ICOM conversation. This patch is normally disabled. ICOM is used only as an emergency backup to the A/G and A/A loops. The ICOM loops are routed through the T-0 umbilical. A/G and A/A loops are RF transmissions through the MILA ground station.

Weather aircraft observations may be patched directly into one of the RF loops if necessary. This will allow the shuttle crew to communicate directly with the weather aircraft crew.

Certain other consoles in the LCC have the capability to transmit directly to the crew. These include the Launch Director, Landing Recovery Director, and Shuttle Operations Director.

All voice loops are recorded continuously. This includes both ICOM loops, all three RF loops, and all LCC/MCC channels.

The maximum time the crew will remain in the shuttle in the event of a launch scrub is 5 hours 15 minutes, excluding safing and egress time. This allows 2-1/2 hours of hold time after the earliest planned launch time.

Prior to actuation of any shuttle switches or controls other than those called out in the checklist, the crew should inform the OTC. This will prevent the LCC team from recording an unplanned configuration change that could cause a launch hold. This is particularly important in the final minutes of the countdown.

Mission Control Center

The MCC Flight Director is responsible for calling a launch "hold" for all problems that jeopardize the ability to safely monitor and recover the shuttle and crew after launch. This includes problems in:

- MCC
- Spacecraft tracking and data network
- Landing area facilities
- Abort landing area weather

In addition, the Flight Director is responsible for overall control of the MCC command uplink capability.

Individual flight controllers are responsible for monitoring their systems and interfacing in real time with their counterparts in the LCC.

Launch Control Center

The LCC Launch Director is responsible for giving the launch team the final go for launch. A formal poll of all elements is taken by the chairman of the MMT during a planned countdown hold at T-9 minutes. If all elements are go, the Launch Director is given permission to proceed with the launch countdown.

The Launch Director is also responsible for making a decision on weather acceptability at the launch pad for ascent trajectory.

When the countdown clock is restarted at T-9 minutes, all operations are under control of a computer system called the ground launch sequencer (GLS). Shuttle systems are automatically configured and monitored by the GLS.

Preplanned hold points for troubleshooting are available in the final 9 minutes of the countdown. These hold points, called GLS milestones, allow the countdown clock to be restarted without recycling back to some previous time. GLS milestones are shown in the following table.

TIME TO LAUNCH	EVENT
9 min	GLS sequence start
7 min 30 sec	Access arm retract
5 min	APU start
4 min	Purge sequence 4
2 min 55 sec	LOX pressurization
1 min 57 sec	LH2 terminals replenish
31 sec	Go for RSLS auto sequence

If a hold command is issued between T-9 minutes and T-31 seconds, the countdown clock will be restarted upon successful resolution of the problem without a "GO" survey made of all elements. After T-31 seconds, only a cutoff is available. Cutoff will result in a recycle to T-20 minutes. Depending on launch window, another launch attempt may be possible.

At T-31 seconds, the GLS issues a command to the onboard GPC Redundant Set Launch Sequencer (RSLS) software. This command, GO FOR AUTO SEQUENCE START, enables the RSLS to reconfigure certain onboard systems such as the vent doors, start the main engines, and issue the SRB ignition commands. Throughout this period, the GLS continuously monitors various system parameters and will issue an automatic cutoff should the Launch Commit Criteria be violated.

If a cutoff command is issued, the RSLS will automatically shift control back to the GLS. A program is then automatically started, which safes the shuttle systems. If this GLS safing program does not run automatically, then LCC controllers safe the systems manually by issuing appropriate commands.

Throughout the countdown, individual LCC controllers are responsible for monitoring their systems and executing commands per the countdown OMI. Any deviations or anomalies are reported to the OTC.

8.5 ASCENT

CONTENTS

Flight Crew 8.5-1
Mission Control Center 8.5-1

The ascent flight phase starts at SRB ignition and continues through OMS-2 cutoff. This is one of the most dynamic phases of a shuttle flight.

Flight Crew

The flight crew is responsible for monitoring vehicle performance and systems and executing procedures on the nominal timeline. Flight crew and MCC coordination is most critical in this phase of flight because of the time-critical nature of most activities. General crew and MCC coordination is discussed in Sections 8.1 and 8.2.

Mission Control Center

The Flight Director is responsible for overall direction of shuttle flights from SRB ignition until crew egress after landing. The Flight Director, after analysis of the flight condition, may choose to take any necessary real-time action required to ensure the safety of the crew and shuttle.

MCC has the prime responsibility for abort mode determination, since the abort region determinator (ARD) program can assess shuttle abort capabilities in real time. Data from independent ground radar tracking, along with telemetry of the current onboard state, is used in the ARD.

Each flight controller on the MCC team has specific responsibilities, based on discipline. For example, the Booster Officer monitors SRB, SSME, and MPS performance and informs the Flight Director of malfunctions and recommended actions.

Many voice loops are used within the MCC. All controllers have a responsibility to monitor the Flight Director loop and air-to-ground loops, in addition to their own internal and external communication loops. Because the workload can be quite high during off-nominal situations, the crew can help by minimizing air-to-ground calls when possible. Also, allowing time for the MCC to formulate an action, coordinate it among several disciplines, and transmit it back to the crew prior to making additional transmission will aid in MCC/crew teamwork.

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8.6 ORBIT

CONTENTS

Flight Crew 8.6-1
Mission Control Center 8.6-1

The orbit flight phase starts at OMS-2 cutoff and continues through deorbit burn ignition. Nearly all mission objectives are accomplished during the orbit phase.

Flight Crew

The crew is responsible for monitoring vehicle systems and executing the nominal timeline. Operating primary and secondary payloads is the major user of available time. This is the most benign portion of a shuttle mission in that time is usually available to perform in-depth troubleshooting of any malfunctions. Crews and MCC will take advantage of the available time to thoroughly troubleshoot malfunctions. General crew and MCC coordination is discussed in Sections 8.1 and 8.2.

Execution of on-orbit tasks, as called out in the Flight Plan and other FDF documents, is the responsibility of the crew. Some tasks must be accomplished on a very strict timeline. Deployment of a payload or experiment operations fall into this category. Other activities are not time critical. For example, crew exercise can be accomplished on a not-to-interfere basis.

Based on preflight assignments and training, each crewmember will have certain responsibilities. Most crews designate backup crewmembers for critical activities. These backup crewmembers receive nearly all of the training that the prime crewmember receives. This policy provides the necessary redundancy that might be required in the event of unforeseen circumstances, such as an injured crewmember or an unplanned contingency. A typical list of duty assignments is shown in Section 8.1.

Mission Control Center

The MCC is responsible for onboard navigation maintenance. Adequate navigation and maneuver definition will be maintained onboard to provide runway landing capability after loss of communication. The Flight Rules specify navigation state requirements.

Individual flight controllers monitor onboard systems and make recommendations to the Flight Director for any changes or reconfiguration. In some cases, uplink commands may be used to perform certain tasks such as antenna management or limit changes (to prevent nuisance alarms).

The Flight Activities Officer and the Payloads Officer are responsible for tracking the Flight Plan and payload activities, respectively. When there is a remote Payload Operations Control Center (POCC), responsibility for the major payload activity (such as Spacehab) resides with the POCC Director. Other payloads, such as middeck experiments, are still controlled by the MCC Payloads Officer. Changes to the Flight Plan, updates to the orbiter attitude and pointing, and replanning are the responsibility of the Flight Activities Officer.

The Integrated Communications Officer (INCO) in the MCC is responsible for operation of the MCC and shuttle command system. Status of the communications link and the command system is included in this responsibility. The INCO is the designated control point and representative of the Flight Director for approval of all types of commands, including those sent to payloads. With the exception of routine communications systems commands and nonhazardous commands, most command uplinks directly affect the systems being used by the flight crew for control of the orbiter or payload. To ensure that the flight crew has current shuttle and payload system status, if communication is lost, MCC has a responsibility to inform the flight crew when command uplinks are transmitted. Typically, several hundred commands are sent during each mission. The majority of these are transparent to the crew and do not require coordination.

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8.7 ENTRY

CONTENTS

Flight Crew 8.7-1
Mission Control Center 8.7-1

The second dynamic phase of a shuttle mission is entry. For purposes of discussing team responsibilities, entry activities are considered to start at deorbit burn ignition and continue through rollout.

Flight Crew

The crew is responsible for monitoring vehicle trajectory and systems and execution of the nominal timeline. The pace of activities during entry is generally not as severe as that experienced during ascent until the beginning of TAEM. Depending on inclination and altitude, communication with MCC may not be available for the deorbit burn and part of entry. Crews should be mentally prepared to carry out mission activities without MCC assistance during the deorbit burn and early portion of entry.

Crew duty assignments during entry are similar to those for ascent. General crew coordination and working with MCC are discussed in Sections 8.1 and 8.2.

Mission Control Center

MCC has the prime responsibility for deorbit burn targets. Factors in the selection include shuttle systems status, consumables, c.g. control, weather, and other landing site information. Although the crew has onboard capability to generate deorbit targets in an emergency, the MCC team, with their extensive capability, will normally calculate and uplink planned targets.

Upon completion of the deorbit burn, MCC is responsible for monitoring the entry trajectory and status of the onboard systems. Should a malfunction occur and be confirmed by the MCC, the crew is expected to work the appropriate cue card or pocket checklist procedure with no further direction. Activities outside the published procedures will be requested by the MCC.

If the trajectory diverges and approaches energy limits, the Flight Dynamics Officer will perform a ground controlled approach (GCA). Procedures are discussed in Section 7.3.

The communication workload during entry is similar to ascent with numerous loops in use. The crew can help to simplify the process by minimizing air-to-ground calls and allowing time for the MCC to develop a coordinated decision.

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8.8 POSTLANDING

CONTENTS

Flight Crew 8.8-1
Mission Control Center 8.8-1
Launch Control Center 8.8-1

Postlanding activities start at completion of rollout and continue through crew egress. The LCC and convoy commander have certain responsibilities during this phase.

Flight Crew

After wheels stop, crew activities are controlled by the FDF Entry Checklist which summarizes crew procedures from the postlanding OMI. Normal activities include shuttle safing and systems reconfiguration for extended power up. These are described in Section 5, Normal Procedures.

The crew responds to MCC requests for activities outside the normal procedures. For example, certain reconfiguration procedures might be modified because of previous systems failures.

Communication with the convoy commander is established shortly after wheels stop. The convoy commander controls postlanding activities in the vicinity of the shuttle and can pass information about hazardous situations to the flight crew.

Mission Control Center

The MCC retains responsibility for orbiter systems until crew egress or ground support equipment (GSE) cooling activation, whichever occurs later. At this time the Flight Director hands over control to the responsible NASA Kennedy Space Center (KSC) ground operations representative. For KSC landings, this representative will be the Landing Recovery Director (LRD); at DFRC/Edwards AFB it will be the NASA Convoy Commander (NCC); and at the White Sands Space Harbor (WSSH) or any TAL site, it will be the Ground Operations Manager (GOM). Should MCC voice and telemetry be lost, or if an emergency crew egress is required, handover to the LRD/NCC/GOM (as appropriate) will be accomplished ASAP.

While the MCC is controlling ground operations, flight controllers are responsible for monitoring their systems and interfacing in real time with their counterparts in the LCC.

Launch Control Center

Until handover, the LCC monitors the progress of shuttle safing and reconfiguration. LCC data monitoring is available to the LRD/NCC (KSC and DFRC only) if loss of MCC system insight and communications capability occurs. In this case, handover will occur ASAP so that normal postlanding operations can continue. Should LCC monitoring capability be lost, the MCC will continue to support until LCC capability is regained or the shuttle is powered down.

Once handover is complete, the LRD (if KSC) or NCC (if DFRC) or GOM (if WSSH or TAL) have responsibility for all shuttle activities. The OTC coordinates completion of postlanding procedures and preparation for turnaround operations.

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9. PERFORMANCE

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9.1 ASCENT 9.1-1
9.2 ORBIT... 9.2-1
9.3 ENTRY (OPS 304) 9.3-1

This section contains information regarding the performance capability of the space shuttle during ascent, orbit, and entry (EI to wheels stop). Some performance related material is also included. The information presented is accurate but is usually derived from representative 28.5° and 57° missions. It is not intended for mission planning. The information is presented only for the purpose of broadening the crew's fundamental understanding of the vehicle's performance capabilities during each flight phase under the stated conditions. Mission-specific questions or requests for more detailed explanations should be referred to the appropriate Flight Design and Dynamics Division (DM) personnel.

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9.1 ASCENT

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Altitude, Velocity, and Dynamic
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MECO Targets 9.1-8
ET Impact 9.1-8
Abort Mode Boundaries...................... 9.1-9
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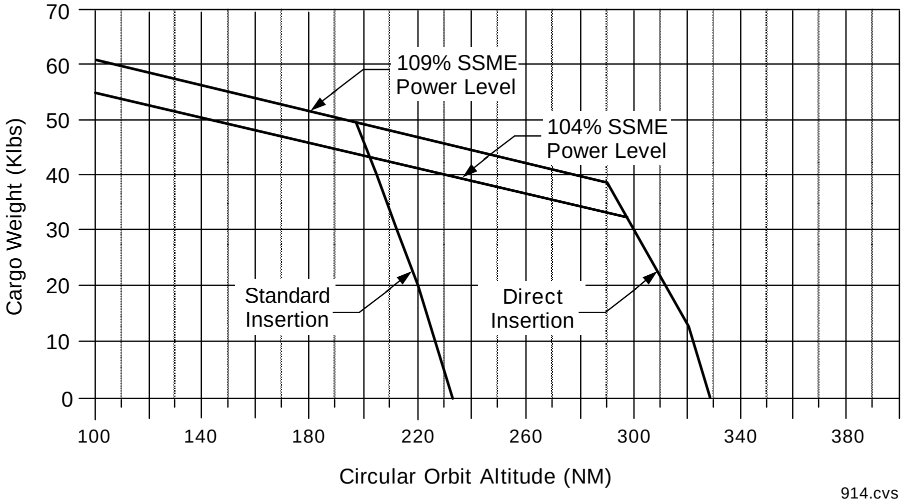
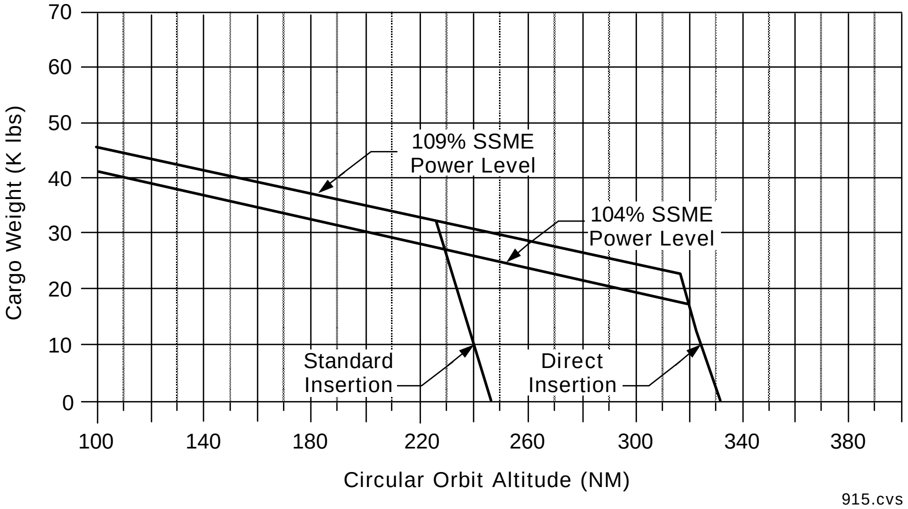
Payload

The graphs below indicate the maximum weight payload that can be launched to a particular circular orbit with a 28.5° or 57° inclination. Also shown is the higher altitude capability of a direct insertion versus standard insertion mission profile, as well as the performance increase available using 109 percent versus 104 percent main engine power.



Cargo Weight vs. Circular Orbital Altitude 28.5° Inclination



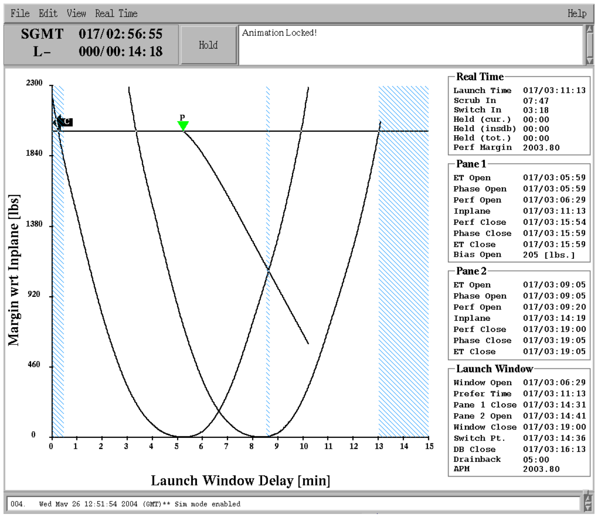
Cargo Weight vs. Circular Orbital Altitude 57° Inclination

Launch Window

The launch window for a ground-up rendezvous mission must satisfy several constraints. A major factor determining the window is ensuring that the orbiter has sufficient performance capability (plus reserves) to achieve a coplanar orbit. The chart at the right (for a 51.6° mission) indicates the additional performance required if the launch occurs other than at the "in-plane" time. Also shown is available propellant that allows a 10-minute window.

The launch window developed for each shuttle mission delineates the period in which the orbiter can be launched without violating shuttle and/or payload constraints. Whenever possible, launch windows will protect daylight (sunset + 15 min) for abort and end-of-mission (EOM) landings. The following chart depict the launch windows for a shuttle to ISS mission. The launch windows for STS-121 is constrained by many factors as shown.

This Rendezvous Mission Performance chart for STS-114 shows approximately 2000 pounds fuel in flight performance reserve (FPR) when launching mid-window, or in-plane. Launching other than in-plane creates the need to steer to the rendezvous plane, which uses additional fuel. To be exact, 2003.80 pounds of additional fuel is required to launch at the open or close of the window. The "P" indicates the performance degrade for launch holds inside of MPS drain-back. Also shown is the STS-114 mission that has two panes inside of their window on this day. A very close look at the chart will show launch time is January 17 (the 017th day of the year) at 03:11:13 GMT at the in-plane point Pane 1. Further, a move from Pane 1 to Pane 2 is planned after 3 minutes and 18 seconds if in a launch hold. Pane 2 will close 7 minutes and 47 seconds after the Pane 1 in-plane point. Pane 2 closes (which would equate to a launch scrub for that day) at 017/03:19:00.



SGMT 017/02:56:55
L- 000/00:14:18

Animation Locked!

Real Time

Launch Time	017/03:11:13
Scrub In	07:47
Switch In	03:18
Held (cur.)	00:00
Held (insdb)	00:00
Held (tot.)	00:00
Perf Margin	2003.80

Pane 1

ET Open	017/03:05:59
Phase Open	017/03:05:59
Perf Open	017/03:06:29
Inplane	017/03:11:13
Perf Close	017/03:15:54
Phase Close	017/03:15:59
ET Close	017/03:15:59
Bias Open	205 [lbs.]

Pane 2

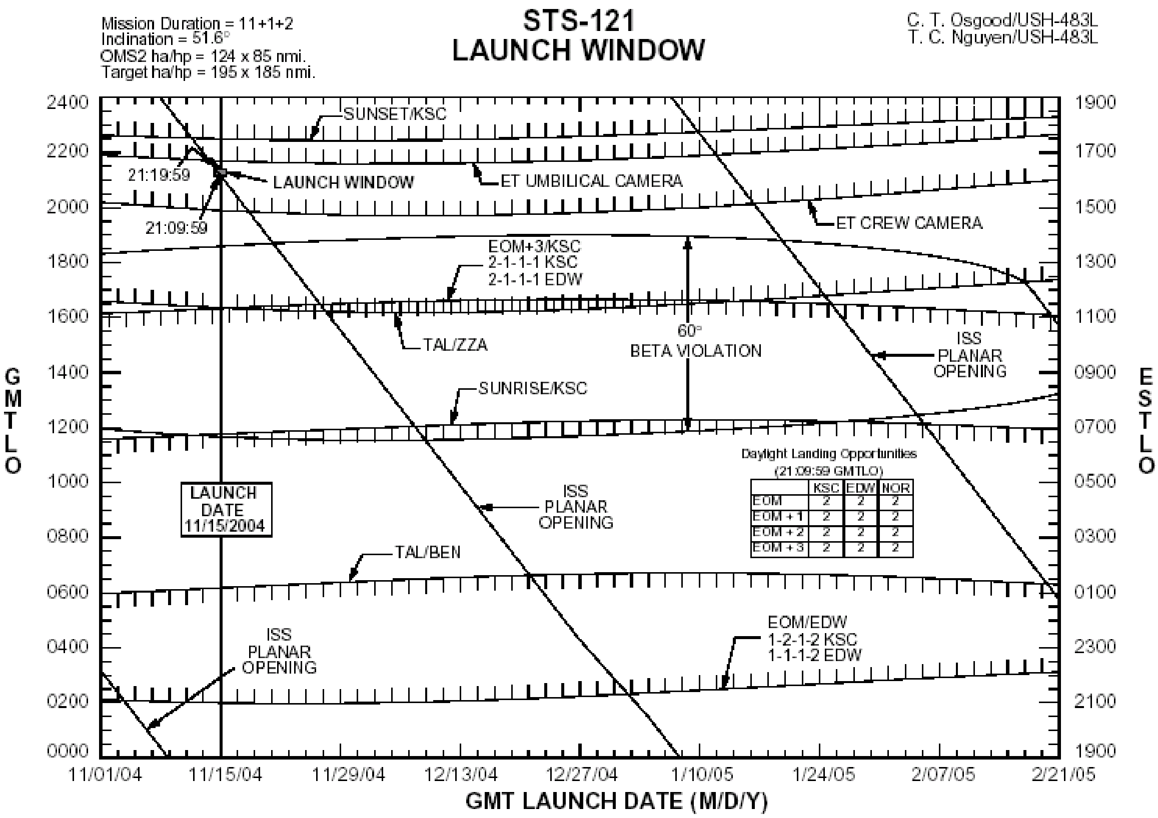
ET Open	017/03:09:05
Phase Open	017/03:09:05
Perf Open	017/03:09:20
Inplane	017/03:14:19
Perf Close	017/03:19:00
Phase Close	017/03:19:05
ET Close	017/03:19:05

Launch Window

Window Open	017/03:06:29
Prefer Time	017/03:11:13
Pane 1 Close	017/03:14:31
Pane 2 Open	017/03:14:41
Window Close	017/03:19:00
Switch Pt.	017/03:14:36
DB Close	017/03:16:13
Drainback	05:00
APM	2003.80

```
004.   Wed Mav 26 12:51:54 2004 (GMT)** Sim mode enabled
```

Rendezvous Mission Performance, STS-114



Daylight Landing Opportunities
(21:09:59 GMTLO)

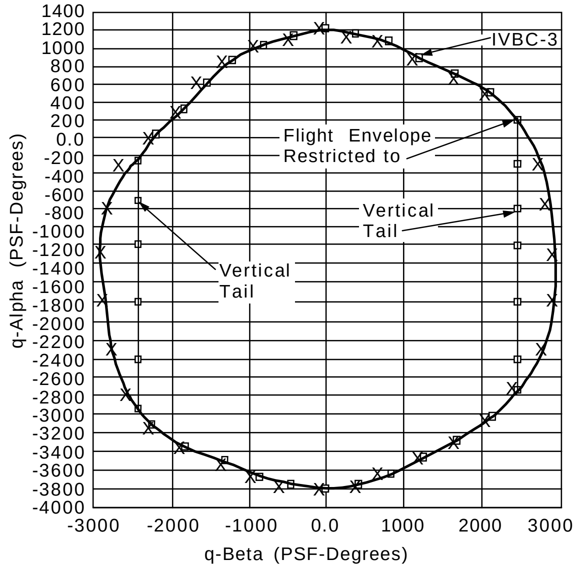
	KSC	EDW	NOR
EOM	2	2	2
EOM + 1	2	2	2
EOM + 2	2	2	2
EOM + 3	2	2	2

Note: EOM lighting lines, based on an OMS2 phase angle of 295 deg, are representative only.
The ISS beta angle requirement for mated operations is $|\beta| < 60°$ beginning ~1/19:42 MET (FD3 Rendezvous) and ending ~9/18:11 MET.

Launch Windows for STS-121

Squatcheloids

Squatcheloids are curves that define the q-alpha (product of dynamic pressure (q)) and angle of attack (alpha) and q-beta (product of dynamic pressure) and sideslip angle (beta) limits of the orbiter first stage ascent. These q-alpha and q-beta limits are determined by the design limits of various orbiter structural components. The graphs show three representative squatcheloids for Mach 0.6, 1.25, and 2.20.



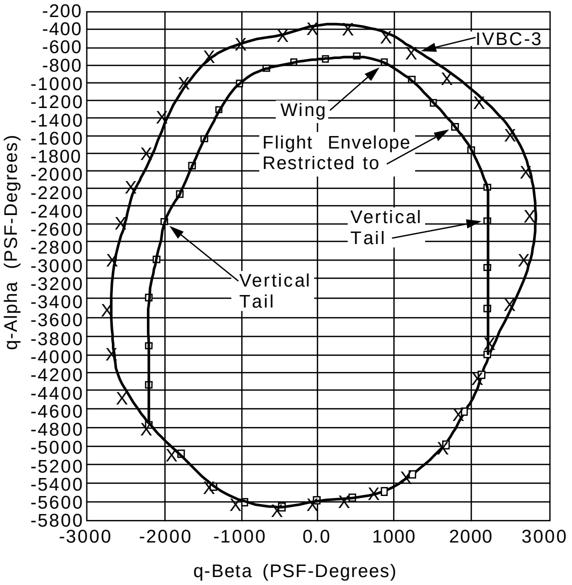
X Integrated vehicle baseline configuration -3 (IVBC -3) Loads analysis

☐ Composite allowable flight contstraints (Greenlines), Nov 1989

Constraint Envelope Limitations
0 Ascent Only
0 Estimated, based on V6.0 margins
0 Aero surfaces only
0 For IVBC-3 ground rules, constraints: Other nominal trajectory criteria may alter constraint envelope
0 Vertical tail loads ensure 1.4 safety factor

920.cvs

Mach = 0.60 Restricted Squatcheloid and IVBC-3 Loads Squatcheloid



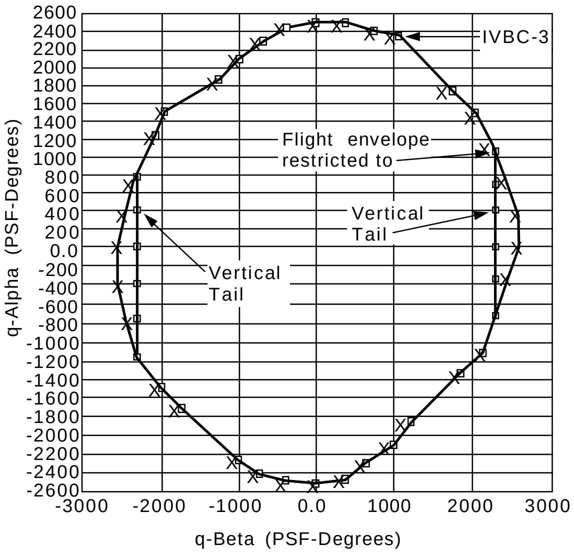
X Integrated vehicle baseline configuration -3 (IVBC -3) loads analysis

☐ Composite allowable flight contraints (Greenlines), Nov 1989

Constraint Envelope Limitations
0 Ascent only
0 Estimated, based on V6.0 margins
0 Aero surfaces only
0 For IVBC-3 ground rules, constraints: Other nominal trajectory criteria may alter constraint envelope
0 Vertical tail loads ensure 1.4 safety factor

921.cvs

Mach = 1.25 Restricted Squatcheloid and IVBC-3 Loads Squatcheloid



X Integrated vehicle baseline configuration -3 (IVBC -3) loads analysis

☐ Composite allowable flight contraints (Greenlines), Nov 1989

Constraint Envelope Limitations
0 Ascent only
0 Estimated, based on V6.0 margins
0 Aero surfaces only
0 For IVBC-3 ground rules, constraints: other nominal trajectory criteria may alter constraint envelope
0 Vertical tail loads ensure 1.4 safety factor

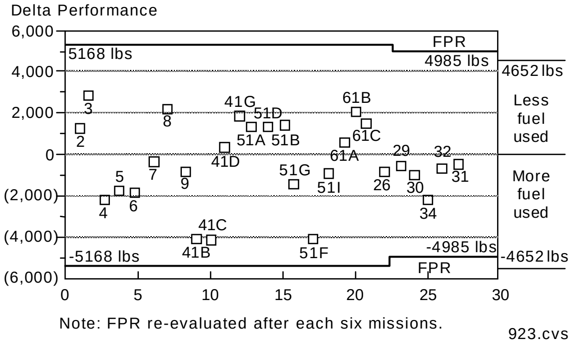
922.cvs

Mach = 2.20 Restricted Squatcheloid and IVBC Loads Squatcheloid

Main Engines

Prior to each mission, after day-of-launch winds and propellant loadings are known, the main engine propellant at MECO is calculated (including dispersions). The Space Shuttle Program Flight Performance Reserve (FPR) is the difference between propellant loaded and propellant required for the ascent profile. The FPR normally used for mission planning is 4652 lb. The FPR must be positive when recalculated on launch day using measured wind data.

The chart below shows the difference between planned and actual MPS propellant usage for several shuttle missions.



Note: FPR re-evaluated after each six missions.

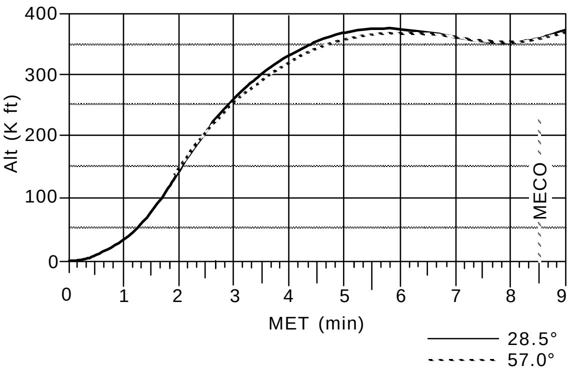
923.cvs

Main Engine Actual vs. Predicted Performance

One percent MPS propellant is approximately equal to 15,310 lb of LO2/LH2.

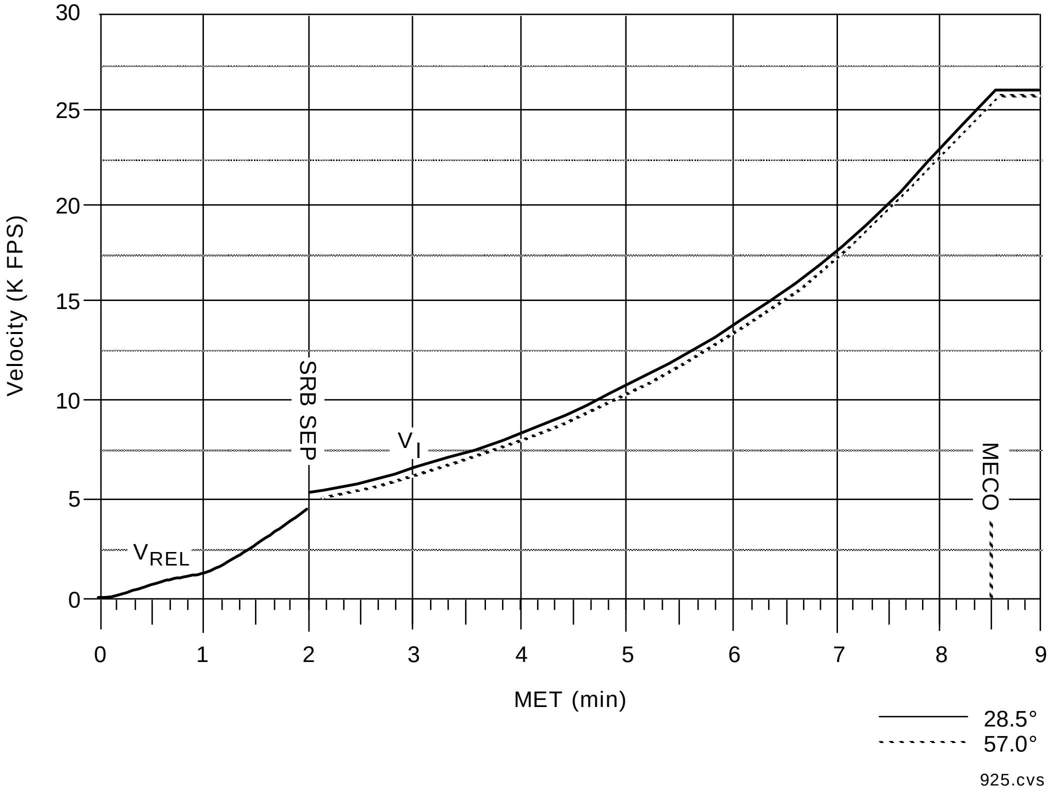
Altitude, Velocity, and Dynamic Pressure

The following three charts depict ascent altitude, velocity, and dynamic pressure as a function of MET for actual 28.5° and 57° missions.

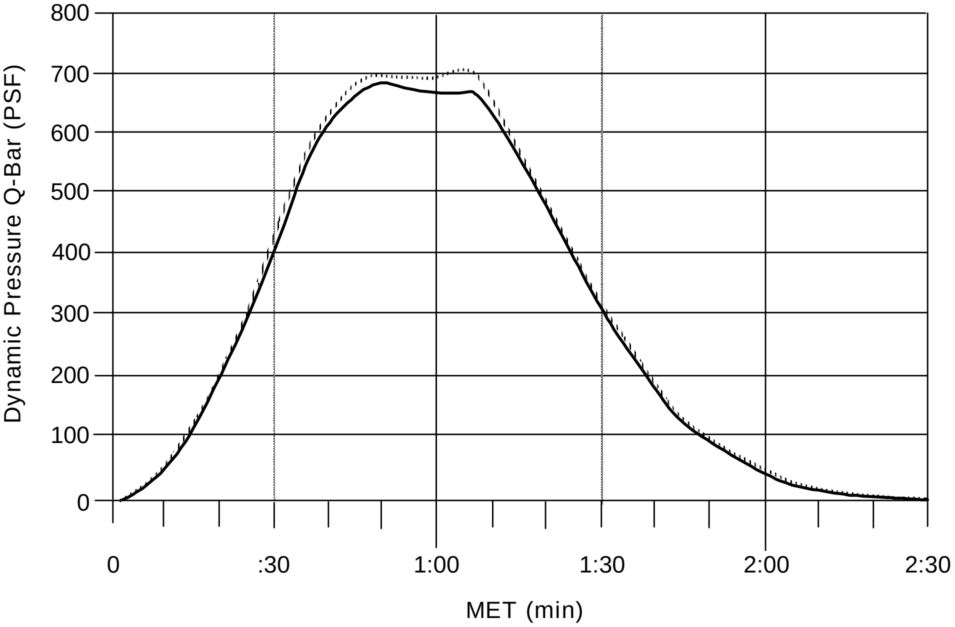


924.cvs

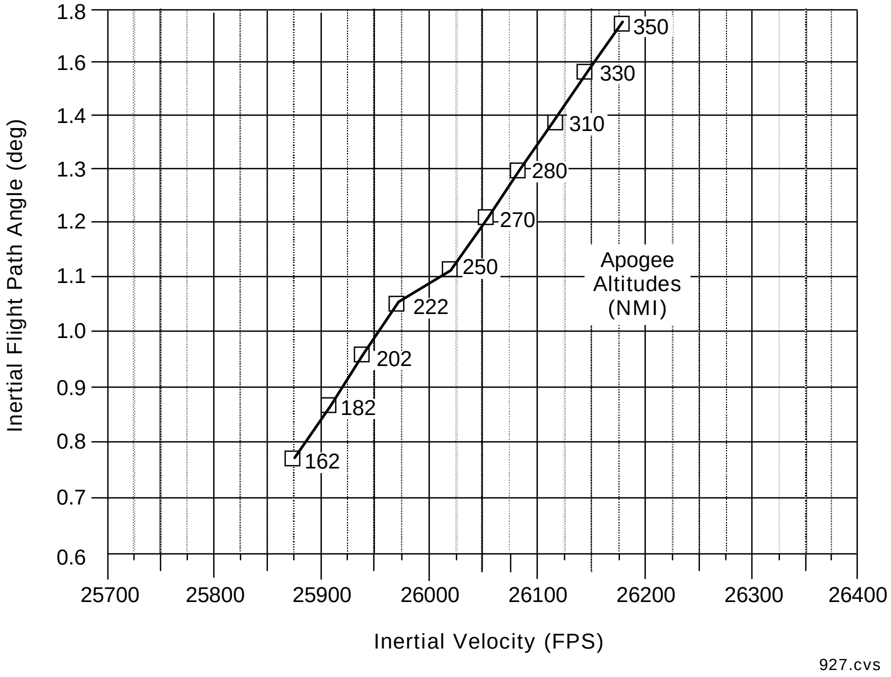
Ascent Altitude vs. MET



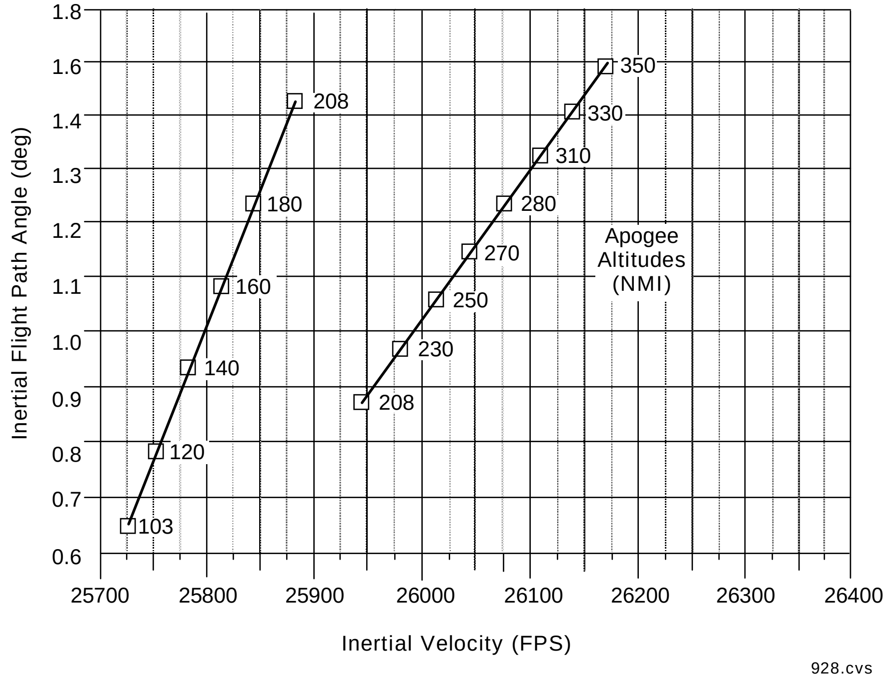
Ascent Velocity vs. MET



Ascent Dynamic Pressure vs. MET



Direct Insertion MECO Target Line 28.5



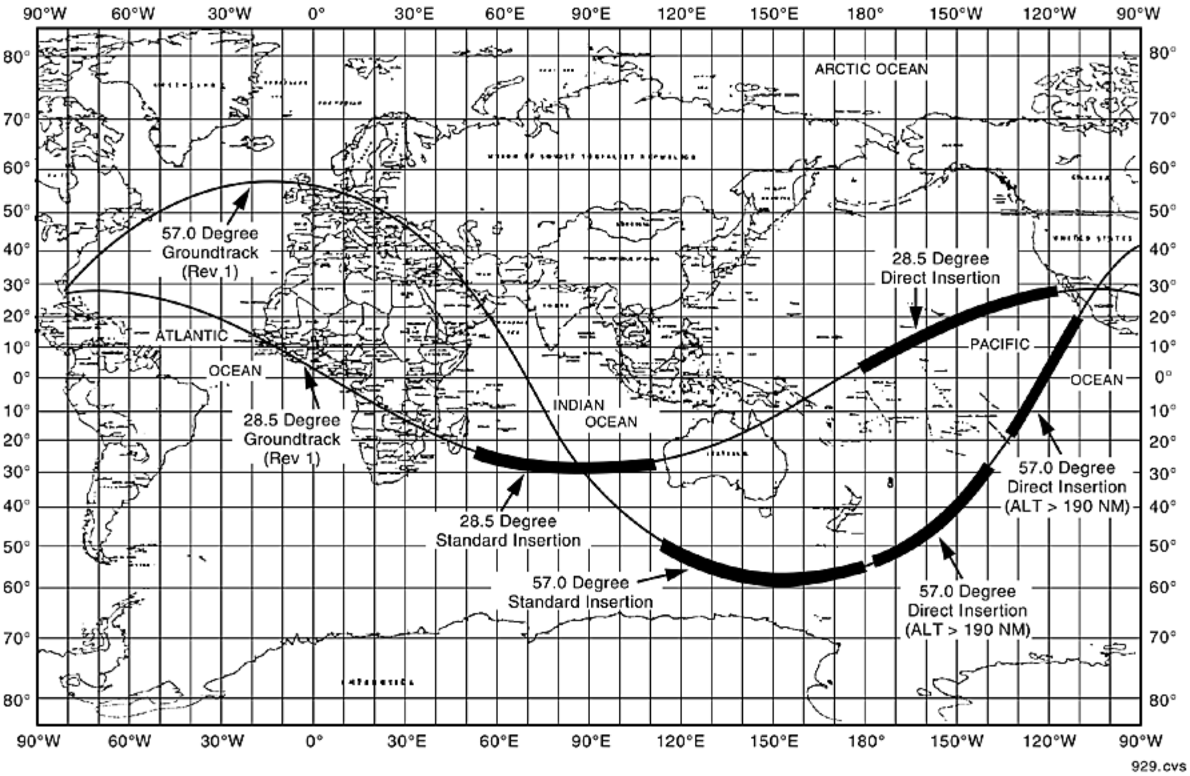
Direct Insertion MECO Target Line 57°

MECO Targets

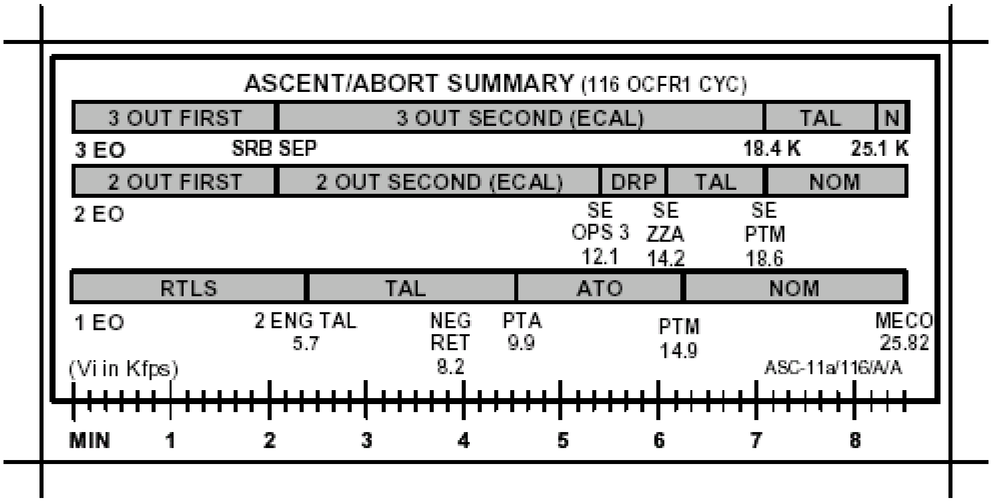
The direct insertion MECO target line charts depict the inertial velocity and inertial flight path angle required for various apogee altitudes for 28.5° and 57° missions.

ET Impact

The following map shows the projected ET impact areas for 28.5° and 57° (<190 and >190 n. mi.) standard and direct insertion missions given nominal performance and a nominal ET separation.



ET Impact Areas



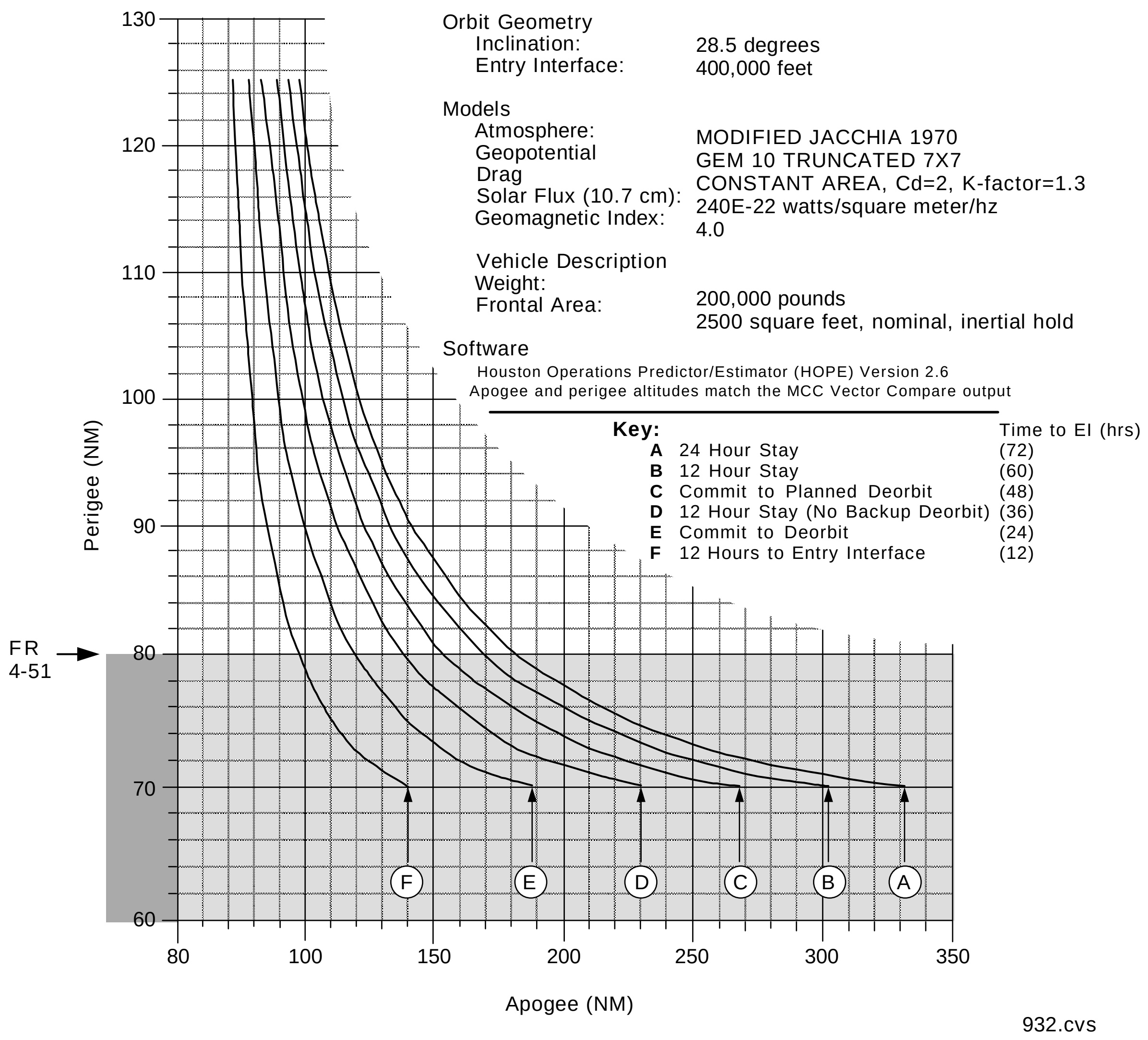
Ascent/Abort Summary Cue Card

Abort Mode Boundaries

Abort mode boundaries can be discovered via the Ascent/Abort Summary Cue Card. An Ascent/Abort Summary Cue Card is created for each mission. It is part of the Ascent Checklist on pages 2-42 and CC 10-26 (unflown versions). It can be found in its flown version on the eyebrow panel (F-2 and F-4) just below the HUD. It depicts the abort options available from lift-off until MECO. This cue card will direct the crew to the proper procedure after one, two, or three main engine failures (simultaneously) at any time during the nominal profile. Locating inertial velocity or MET of engine failure(s) along the bottom scale will correspond to the appropriate abort mode for that Vi/MET.

Minimum Safe Orbit

If the orbiter is inserted into an off-nominal orbit, Mission Control will ensure that the vehicle has sufficient orbital lifetime. The lowest perigee that will guarantee the minimum orbital lifetime is a function of apogee and the delta time to the next prime deorbit opportunity. Reference Flight Rule 4-51 for more details. The following chart shows approximate time on orbit versus apogee and perigee for low inclination insertion.



Minimum Safe HP vs. HA

9.2 ORBIT

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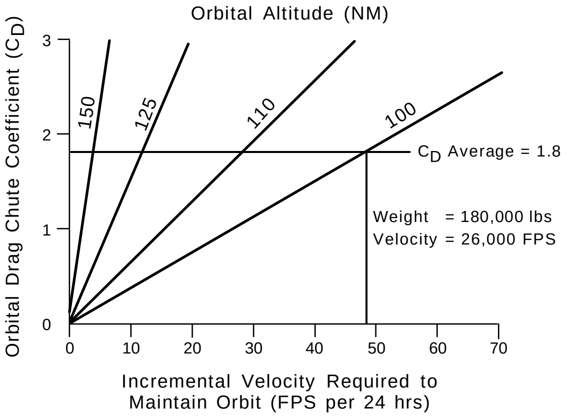
OMS/RCS 9.2-2

Drag

Aerodynamic drag is a factor that must be considered when planning on-orbit performance capabilities. This is taken into account by Mission Control in evaluating orbital lifetime. The following chart indicates the incremental velocities required to maintain a specified orbit during a 24 hr period. Notice that the velocity requirement is approaching 0 at 160 n. mi. (nominal orbital altitude).

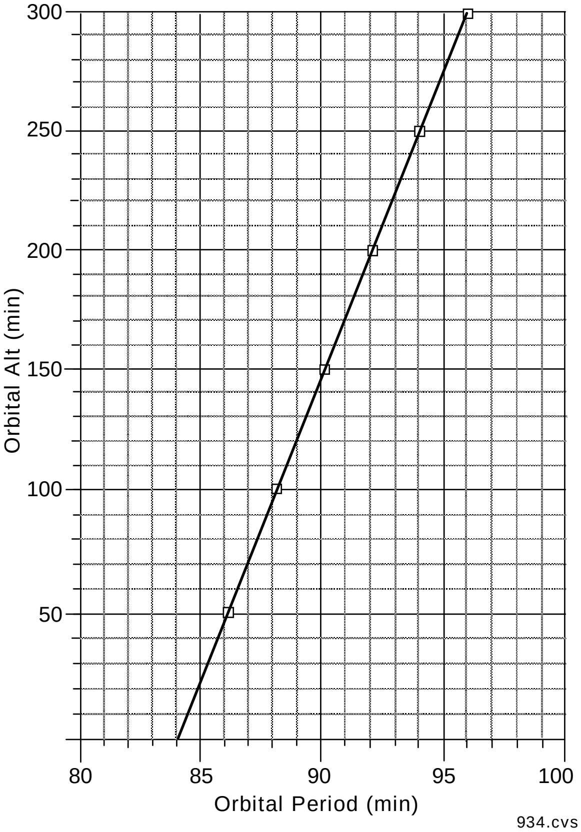


933.cvs

Aerodynamic Drag Effect On Orbital Velocity Chart

Period

As orbital altitude increases, the time it takes the shuttle to complete a full orbit also increases, independent of inclination. The following chart plots these approximate times (orbital periods) for various orbital altitudes.



934.cvs

Orbital Period vs. Altitude

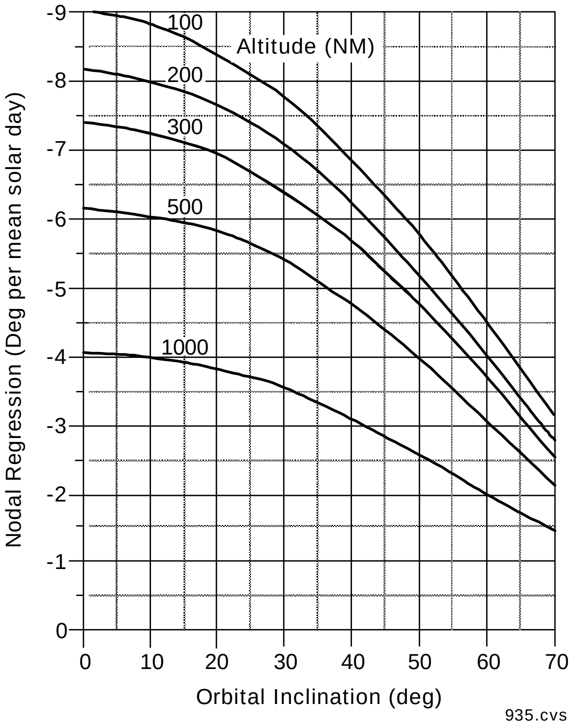
Perturbations

While each orbital period takes approximately 87 - 96 minutes, the Earth has completed a fraction of its full 360° rotation per day. That fractional portion will cause subsequent groundtracks to be displaced westward an equivalent amount, based on this simple formula:

$$\frac{360\text{ deg}}{24\text{ hr}} \times \frac{1\text{ hr}}{60\text{ min}} \times \frac{\text{period min}}{1\text{ orbit}} = \frac{\begin{array}{c}\text{Westward}\\ \text{Displacement}\\ \text{deg}\end{array}}{1\text{ orbit}}$$

Given an 87- to 96-minute range of periods, each successive orbit will be displaced 21.75° to 24° west with about 22.5° nominal (160 n. mi. orbit).

If the orbiter's track were influenced only by the period of the orbit, at the end of the 16th orbit (90-minute period), the track would be expected to go directly over the launch site. This does not occur due to another force influencing the orbit. Nodal regression will shift the track approximately 7.5° west (for a 28.5° X 160 n. mi. orbit) each 24 hr. This force on the vehicle is caused by the gravitational impact of the equatorial bulge. The chart below depicts the nodal regression for various low-Earth orbits. It can be seen that higher orbital altitudes and inclinations diminish the amount of the perturbation.



Nodal Regression

OMS/RCS

On orbit, the vehicle's performance capability is dictated by the amount of usable OMS/RCS propellant minus the amount required for deorbit, entry, and reserve. This performance capability can be maximized by using the most efficient burns possible for mission accomplishment and attitude/altitude control. The charts on the next page provide a convenient "quick look" method for determining the performance penalty for OMS/RCS use.

1% OMS = 130 lbs propellant

1% RCS = 22 lbs propellant

ORBITER WEIGHT (1000 LB)	AVERAGE ORBITER ACCELERATION (FT/SEC²)										
	RCS									OMS	
	+ X		- X	± Y	+ Z			- Z			
	HIGH 1	NORM 2	NORM 1, 2	NORM 1, 2	HIGH 2	NORM 1, 2	LOW 2	HIGH 3	NORM 1, 2	TWO ENG	ONE ENG
180	0.61	0.31	0.32	0.22	1.29	0.43	0.05	0.98	0.61	2.14	1.07
200	0.55	0.28	0.29	0.20	1.16	0.39	0.05	0.88	0.55	1.93	0.97
220	0.50	0.25	0.26	0.18	1.06	0.35	0.04	0.80	0.50	1.75	0.88
240	0.46	0.23	0.24	0.17	0.99	0.33	0.04	0.72	0.46	1.60	0.80
260	0.42	0.21	0.22	0.16	0.94	0.32	0.04	0.65	0.42	1.48	0.74

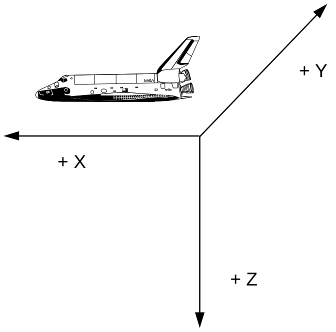
DAP CODE 1 = TRANSITION 2 = ON ORBIT 3 = ET SEP ONLY

JETS	ROTATION RATE (DEG/SEC)	PROPELLANT USAGE TO START, MAINTAIN, AND STOP A 115 DEGREE ROTATION MANEUVER (LB)							
		ROLL		PITCH		YAW		3-AXIS	
		FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT
VRCS	0.2	1.4	5.7	2.0	6.5	1.6	8.3	2.0	9.6
PRCS	0.2	10.3	23.9	13.1	28.3	9.0	20.3	8.8	20.2
PRCS	0.5	8.2	20.7	10.0	19.4	10.2	21.0	10.6	18.2
PRCS	1.0	6.8	23.7	12.9	22.4	13.2	24.1	16.5	26.9
PRCS	2.0	6.4	34.2	22.0	32.7	21.0	36.6	30.2	45.5

AVERAGE ORBITER ACCELERATION (DEG/SEC²)				
ROTATION MANEUVER	NORM PRCS	LOW PRCS		YRCS
		FWD	AFT	
± Roll	0.923	☒	☒	0.021
+ Pitch	1.230	0.696	0.534	0.019
- Pitch	0.851	0.478	0.373	0.008
± Yaw	0.703	0.449	0.242	0.014

ORBITER C.G. SHIFT FOR OMS/RCS USAGE		
	INCHES/100 LB	
	$X_{c.g.}$	$Y_{c.g.}$
FRCS	-0.36	0
ARCS	+0.11	0.04
OMS	+0.13	0.04

ORBITER WEIGHT (1000 LB)	PROPELLANT USAGE FOR TRANSLATION MANEUVERS (LB/FPS)												
	RCS												OMS
	+ X		- X		± Y		+ Z		+ Z (LOW)		- Z		
	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	
0.2	0.5	20.8	19.6	4.1	8.6	25.2	7.5	12.5	140.0	117.0	10.5	18.9	17.9
0.2	0.5	23.1	21.8	5.1	9.3	27.4	8.1	14.1	159.0	132.0	11.3	21.2	19.8
0.5	0.5	25.4	24.0	6.1	10.0	29.6	8.7	15.7	178.0	147.0	12.1	23.5	21.8
1.0	0.5	27.7	26.2	7.1	10.7	31.8	9.3	17.3	197.0	162.0	12.9	25.8	23.8
2.0	0.5	30.0	28.4	8.1	11.4	34.0	9.9	18.9	216.0	177.0	13.7	28.1	25.8



ORBITER ORIENTATION	PRIMARY RCS THRUSTERS PROPELLANT USAGE (LB/HOUR) (ATTITUDE DEADBANDS = 3.5 DEG/AXIS)									
	100 NM		120 NM		150 NM		200 NM		300 NM	
	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT
X-pop inertial	10.5	20.2	10.2	19.8	9.8	19.3	9.3	18.6	8.8	18.0
Y-pop inertial	11.0	24.0	10.2	19.9	9.4	17.7	8.4	15.7	7.6	14.6
Z-pop inertial	8.6	21.0	8.6	20.2	8.6	19.3	8.6	18.5	8.6	18.0
X-pop -Z-LV	9.8	21.2	9.3	20.8	8.4	20.4	7.3	19.8	6.0	19.0
Y-pop -Z-LV	10.3	18.0	10.1	17.8	9.8	17.5	9.5	17.1	9.1	16.5
-X sol inertial	10.4	20.8	10.4	20.4	10.4	19.9	10.4	19.4	10.4	19.0
-Z sol inertial	10.0	19.9	10.0	19.9	10.0	19.9	10.0	19.9	10.0	19.9
X-PSL PTC	9.3	19.0	9.3	19.0	9.3	19.0	9.3	19.0	9.3	19.0

ORBITER ORIENTATION	VERNIER RCS THRUSTERS PROPELLANT USAGE (LB/HOUR) (ATTITUDE DEADBANDS = 1.0 DEG/AXIS)									
	100 NM		120 NM		150 NM		200 NM		300 NM	
	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT
X-pop inertial	3.0	11.6	1.5	5.7	0.9	3.8	0.7	3.0	0.6	2.8
Y-pop inertial	1.9	6.3	1.6	4.7	1.5	4.5	1.4	4.3	1.3	3.9
Z-pop inertial	2.9	11.5	2.0	8.1	1.6	6.8	1.5	6.5	1.4	5.9
X-pop -Z-LV	4.1	13.3	1.6	5.1	0.7	1.3	0.4	0.6	0.4	0.4
Y-pop -Z-LV	0.5	1.0	0.5	0.8	0.5	0.7	0.5	0.6	0.5	0.5
-X sol inertial	2.9	10.6	2.2	7.7	1.8	6.7	1.8	6.5	1.8	6.1
-Z sol inertial	3.6	8.8	2.6	5.5	2.3	4.8	2.2	4.7	2.2	4.5
X-PSL PTC	5.6	10.9	4.8	7.2	4.2	4.9	3.8	3.4	4.3	3.6

ENGINE	SPECIFIC IMPULSE (SEC)	THRUST PER ENGINE (LB)	PROP FLOW RATE (LB/SEC)	PROP MIXTURE RATIO (OX/FU)
OMS	313.2	6000	19.16	1.65
PRCS	280.0	870	3.11	1.60
VRCS	265.0	24	0.09	1.60

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OMS/RCS Estimated Performance

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9.3 ENTRY (OPS 304)

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Downrange/Crossrange

TAL, emergency deorbit, or a waveoff to the secondary landing site can result in mission-critical assessments of the orbiter's downrange and crossrange capabilities. Once the orbiter has committed to its descent, only a carefully flown profile can put it on the runway safely.

The orbiter begins entry at EI (400,000 ft) on average 4,176 n. mi. from the landing site. Given a crossrange situation of about 500 n. mi. (414 n. mi. being the average), the vehicle has the ability to stretch the descent approximately 800 n. mi. downrange by flying a lower drag profile. TPS thermal constraints prevent the use of lower angles of attack. The orbiter remains in the equilibrium glide phase longer, likely bypassing the constant drag phase altogether. If the crossrange requirement is reduced below this arbitrary (but realistic) number, the downrange can be increased slightly.

The downrange can be reduced by approximately 1,100 n. mi. (again given a 500 n. mi. crossrange) by flying higher drag profile. This results in higher temperatures on the TPS as the vehicle descends more quickly into the atmosphere. TPS thermal constraints are the initial limiting factor in this profile. During the descent, as the vehicle's mach and alpha decrease, maximum drag is limited by "g" (~ Mach 16) and eventually q-bar (~ Mach 5), thereby limiting downrange reduction.

In the event of an emergency deorbit, the orbiter's crossrange capability becomes a significant factor. The following charts list the dispersed and undispersed crossrange limits for 28.5° and 57° missions at the stated entry weights. The dispersed crossrange limits protect for 3-sigma entry dispersions. However, for an emergency deorbit, the crew could deorbit to a landing site that is within the undispersed crossrange limit if there were no site within the dispersed limit.

APPROACH DIRECTION	RANGE N. MI.
Ascending, left	753
Descending, left	753

Dispersed crossrange limits 28.5°, 160 n. mi. orbit, 197 k lb

APPROACH DIRECTION	RANGE N. MI.
Ascending, left	815
Descending, left	815

Dispersed crossrange limits 28.5°, 160 n. mi. orbit, 197 k lb

APPROACH DIRECTION	RANGE N. MI.
Ascending, left	774
Ascending, right	828
Descending, left	781
Descending, right	818

Dispersed crossrange limits 57°, 160 n. mi. orbit, 217 k lb

APPROACH DIRECTION	RANGE N. MI.
Ascending, left	850
Ascending, right	904
Descending, left	857
Descending, right	894

Undispersed crossrange limits 57°, 160 n. mi. orbit, 217 k lb

Trajectory

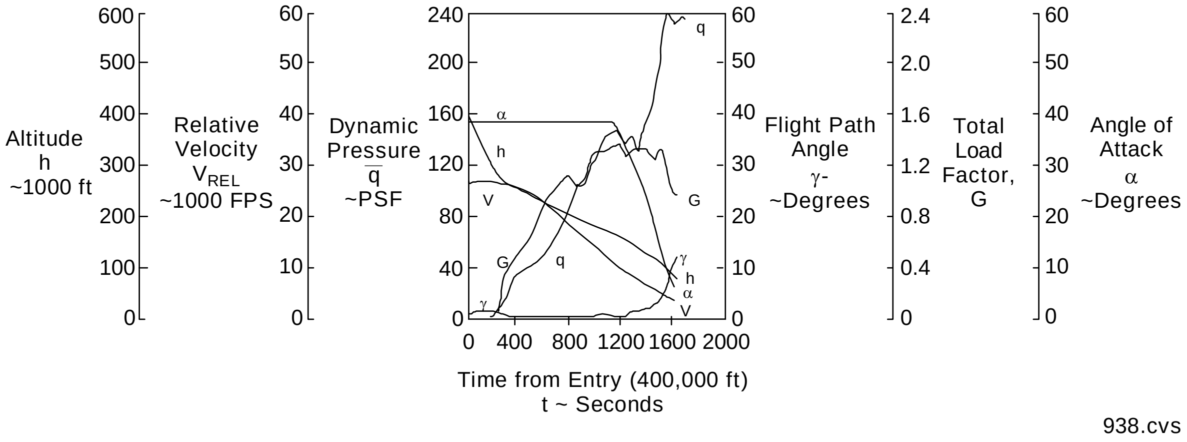
The following chart plots nominal performance in terms of altitude, VREL, q-bar, flight path angle, g, and alpha against time from EI.

Entry History

The following table lists flight history performance and performance related data for the first 74 space shuttle missions.

Entry RCS Use Data

Typically, the orbiter deorbits with approximately 50 percent aft RCS (ARCS) propellant in each pod (~1100 lb). Prior to OI-26 and wraparound DAP, RCS propellant use during entry averaged about 13 percent (600 lb) of full ARCS tanks. Since the implementation of wrap DAP, aft RCS usage has averaged 16 percent (350 lb) total aft usage. Certain missions are selected to conduct Program Test Inputs (PTIs), which are modifications to flight control software to collect entry performance data. In addition to nominal RCS use, other jet firings are used to collect RCS PTI data or to correct for aerosurface PTIs. Missions conducting PTIs will typically use in excess of 23 percent (1000 lb) of full ARCS tanks during entry. Analysis of actual versus predicted use is ongoing.



Orbiter Entry Trajectory

ENTRY AERODYNAMICS

Miss Seq. No.	STS- No.	Orb. OV-	Notes	Entry Interface			Cross Range, nmi.	Max. Load Factor, g	Max. Dyn. Press., psf	First Roll Rev. Vel., fps	Term. Area Energy Mgmt				Approach and Landing			
				Velocity, fps	Flt. Pth. Angle, deg	Range, nmi.					I/F Range, nmi.	Load Factor, g	Max. Dyn. Press., psf	I/F Alt ft.	Glide Slope, deg	Velocity, Keas		
																Max.	Over thld	At MGTD
1	1	102		25,731.	-1.19	4372	228	1.6	217	18,310.	58.9	1.7	286	10,000	20	315	250	183
2	2	102		25,726.	-1.17	4474	63	1.61	215	20,297.	59.7	1.93	280	5,000	19	276	206	197
3	3	102		25,659.	-1.13	4136	276	1.62	220	17,784.	59.1	1.54	295	10,000	19	302	232	220
4	4	102		25,797.	-1.28	3817	581	1.77	241	11,461.	59.4	1.46	278	10,000	19	295	215	204
5	5	102		25,758.	-1.24	4036	580	1.59	219	11,397.	59.8	1.59	280	10,000	19	298	216	198
6	6	99		25,755.	-1.24	4045	378	1.53	207	15,808.	59.9	1.41	257	10,000	19	293	213	190
7	7	99		25,771.	-1.25	4040	738	1.59	220	7,143.	59.6	1.65	305	9,834	19	295	232	202
8	8	99		25,649.	-1.12	4037	519	1.54	223	12,900.	58.9	1.56	281	5,000	19	309	226	195
9	9	102		25,696.	-1.18	4349	69	1.6	232	21,581.	59.9	1.52	280	10,000	17	295	203	185
10	41B	99		25,752.	-1.2	4137	524	1.57	220	12,957.	59.4	1.59	289	10,000	19	292	218	196
11	41C	99		25,998.	-1.52	4089	381	1.54	216	16,208.	59.4	1.43	293	10,000	19	313	234	213
12	41D	103		25,776.	-1.26	4112	474	1.54	206	14,072.	60	1.42	265	10,000	19	299	227	200
13	41G	99		25,684.	-1.12	4308	614	1.54	241	11,927.	60.2	1.4	285	10,000	19	296	216	208
14	51A	103		25,869.	-1.35	4141	486	1.56	225	14,063.	60.5	1.46	285	10,000	19	299	217	186
15	51C	103		25,855.	-1.32	4144	380	1.54	211.8	16,118.	60.1	1.5	281	10,000	19	293	223	185
16	51D	103		25,955.	-1.45	4064	518	1.59	211.1	13,573.	60.9	1.4	294	10,000	19	301	215	200
17	51B	99		25,857.	-1.26	4264	274	1.57	241.6	18,500.	59.1	1.5	282	10,000	19	300	219	204
18	51G	103		25,850.	-1.34	4050	694	1.58	217.7	8,680.	59.3	1.6	218	5,000	19	301	0	198
19	51F	99		25,813.	-1.19	4221	603	1.58	235.6	11,537.	59.7	1.54	290	10,000	19	306	244	199
20	51I	103		25,829.	-1.31	4004	692	1.58	215.3	8,626.	59.7	1.56	274	10,000	19	307	204	191
21	51J	104	a															
22	61A	99		25,830.	-1.19	4345	69	1.55	241	22,257.	59.8	1.3	319	10,000	19	303	231	203
23	61B	104		25,882.	-1.35	4106	533	1.54	232	13,172.	59.1	1.4	286	10,000	19	293	224	189
24	61C	102		25,815.	-1.31	4154	661	1.56	224	9,480.	59.2	1.42	292	10,000	19	311	233	217
25	51L	99	a												0			
26	26	103		25,790.	-1.25	4117	383	1.56	203	15,774.	60	1.3	288	10,000	19	297	219	187
27	27	104		25,121.	-1.5	4220	520	1.61	206	14,564.6	60.2	1.4	294	10,000	19	297	211	194
28	29	103		25,787.	-1.23	4163	384	1.54	207	15,852.	60.1	1.6	287	10,000	19	307	218	205
29	30	104		25,788.	-1.22	4155	350	1.56	207	16,452.	60.08	1.5	287	9,957	19	295	206	196
30	28	102		25,803.	-1.11	4332	186	1.54	213	19,494.	58.8	1.6	295	10,000	19	299	224	155
31	34	104		25,784.	-1.19	4156	496	1.54	219	13,653.	60.1	1.7	286	10,000	19	305	220	195
32	33	103		25,998.	-1.48	4068	226	1.52	215	16,988.	60.2	1.5	301	10,000	19	300	211	199
33	32	102		25,823.	-1.25	4317	372	1.62	253	16,293.	58.8	1.7	295	10,000	17	300	230	207
34	36	104		25,713.	-1.18	4338	255	1.57	204	18,520.	59.5	1.9	325	5,000	19	298	218	199
35	31	103		26,120.	-1.61	4121	420	1.6	205	15,905.	60.2	1.54	279	10,000	19	299	194	177
36	41	103		25,762.	-1.2	4147	492	0	212.7	13,639.	60	1.67	291	9,777	19	306	224	192
37	38	104		25,729.	-1.16	4146	3	1.57	207	20,816.	60.3	1.42	273	9,819	19	301	218	199

a - Data not Available - DOD Mission
b - Report containing data not as yet published

Source: JSC/DM5 Flight Design and Dynamics Division,
Descent Post-flight summaries

Orbit Entry Trajectory

ENTRY AERODYNAMICS

Miss Seq. No.	STS- No.	Orb. OV-	Notes	Entry Interface			Cross Range, nmi.	Max. Load Factor, g	Max. Dyn. Press., psf	First Roll Rev. Vel., fps	Term. Area Energy Mgmt				Approach and Landing			
				Velocity, fps	Flt. Pth. Angle, deg	Range, nmi.					I/F Range, nmi.	Load Factor, g	Max. Dyn. Press., psf	I/F Alt ft.	Glide Slope, deg	Velocity, Keas		
																Max.	Over thld	At MGTD
38	35	102		25,858.	-1.32	4266	426	1.58	245.8	15,406.	59.15	1.59	279	8,052	17	300	217	201
39	37	104		24,612.	-1.4	4175	375	1.57	205	16,455.	59	1.66	276	5,048	19	288	161	168
40	39	103		25,765.	-1.06	4502	616	1.57	246.5	11,543.	60.2	1.5	295	9,862	19	302	222.1	218
41	40	102		25,772.	-1.23	4339	211	1.56	245.4	18,904.	58.9	1.7	298	10,014	17	311	218.6	203
42	43	104		25,794.	-1.16	4312	180	1.57	294	19,141.	60.3	1.4	223	10,000	19	295	221	197
43	48	103		26,077.	-1.58	4194	690	1.56	286	11,167.	59.9	1.5	217.5	10,000	19	297	219	203
44	44	104		25,868.	-1.28	4195	379	1.6	285	16,190.	60.5	1.74	222.5	9,833	19	295	222	189
45	42	103		25,785.	-1.12	4358	536	1.61	232	14,053.	59.6	1.4	308	10,000	19	310	229	196
46	45	104		25,785.	-1.13	4231	679	1.56	241.23	10,840.6	60.4	1.82	328	7,451	19	309	212	192
47	49	105		25,841.	-1.28	4162	410.8	1.56	215	15,850.	59.2	1.57	293	9,931	19	299	217	194
48	50	102		25,786.	-1.18	4347	389	1.51	248.4	15,984.3	59.7	1.51	313	9,885	17	311	229	203
49	46	104		25,698.	-0.99	4397	499	1.57	225	13,624.	59.7	1.45	299	9,869	19	303	216	195
50	47	105		25,803.	-1.11	4341	669	1.57	240.1	11,228.4	60.6	1.39	307	9,917	17	305	233	202
51	52	102		25,666.	-0.94	4454	223	1.58	247	18,350.	60.1	1.51	297	9,820	19	302	224	211
52	53	103		25,813.	-1.28	4237	791	1.56	210	7,202.	60	1.96	287	9,431	19	301	226	212
53	54	105		25,780.	-1.2	4213	320	1.56	211	17,043.	60.5	1.8	295	9,873	19	302	232	212
54	56	103		25,797.	-1.23	4375	6	1.63	227	21,354.	60.1	1.69	291	9,844	19	304	219	206
55	55	102		25,779.	-1.16	4299	640	1.56	260	10,463.	58.8	1.5	309	9,848	17	319	238	217
56	57	105		25,988.	-1.43	4210	587	1.58	252	12,389.	58.9	1.38	320	9,907	17	313	233	207
57	51	103		25,794.	-1.22	4250	89	1.56	221	20,253.	59.9	1.43	281	9,840	19	302	222	194
58	58	102		25,755.	-1.21	4378	144	1.58	250	19,625.	59.2	1.51	323	9,888	18	315	237	198
59	61	105		26,096.	-1.56	4220	3	1.54	231	21,281.	60.8	1.68	312	9,787	20	312	236	201
60	60	103		25,858.	-1.35	4349	376	1.57	230	16,900.	59.9	1.72	308	9,866	20	315	235	205
61	62	102		25,708.	-1.13	4391	116	1.59	250	19,802.	59.5	1.49	309	9,964	18	306	236	207
62	59	105		25,660.	-1.02	4468	721	1.57	252	9,331.	59.2	1.62	318	9,937	18	315	231	215
63	65	102		25,720.	-1.1	4381	180	1.59	265	19,114.	59	1.45	315	9,966	18	305	233	199
64	64	103		25,727.	-0.98	4433	110	1.54	228	20,344.	59.7	1.77	305	9,892	20	311	229	198
65	68	105		25,658.	-1.02	4479.5	746	1.57	258	8,686.	58.4	1.75	314	9,841	18	305	234	193
66	66	104		25,798.	-1.09	4387	310	1.58	251	17,796.	59.7	1.5	309	9,914	20	314	232	193
67	63	103		25,903.	-1.36	4329	469	1.56	243	15,176.	59.7	1.81	316	9,897	20	319	229	212
68	67	105		25,852.	-1.26	4216	628	1.56	242	10,780.	59.9	1.5	309	9,843	20	317	227	209
69	71	104		25,913.	-1.19	4320	645	1.6	245	11,299.	60	1.5	308	9,972	-20	311	221	201
70	70	103		25,789.	-1.14	4265	430	1.56	202	15,057.	60.1	1.35	297	9,805	-20	310	225	198
71	69	105		25,839.	-1.23	4332	202	1.59	255	18,979.	59.6	1.55	309	9,839	-18	309	233	201
72	73	102		25,744.	-1.1	4519	231	1.58	250	18,580.	59.6	1.56	319	9,939	-18	313	246	214
73	74	104		25,840.	-1.29	4346	612	1.58	237	12,026.	59.4	1.45	313	9,802	-20	321	233	196
74	72	105		25,799.	-1.17	4340	220	1.56	239	18,619.	60.2	1.7	309	9,891	-20	306	231	193

a - Data not Available - DOD Mission

b - Report containing data not as yet published

Source: JSC/DM5 Flight Design and Dynamics Division,
Descent Post-flight summaries

Orbit Entry Trajectory (continued)

ENTRY AERODYNAMICS

Miss Seq. No.	STS- No.	Orb. OV-	Notes	Entry Interface			Cross Range, nmi.	Max. Load Factor, g	Max. Dyn. Press., psf	First Roll Rev. Vel., fps	Term. Area Energy Mgmt				Approach and Landing			
				Velocity, fps	Flt. Pth. Angle, deg	Range, nmi.					I/F Range, nmi.	Load Factor, g	Max. Dyn. Press., psf	I/F Alt ft.	Glide Slope, deg	Velocity, Keas		
																Max.	Over thld	At MGTD
75	75	102		25,816.	-1.21	4375	234	1.58	256	18,518.	59.5	1.47	301	9,885	-18	321	243	211
76	76	104		25,898.	-1.4	4243	763	1.59	245	8,918.	59.3	1.57	303	9,908	-20	313	223	198
77	77	105		25,763.	-1.16	4378	314	1.6	240	17,534.	60.5	1.55	304	9,776	-18	309	234	216
78	78	102		25,749.	-1.11	4466	91	1.59	251	20,165.	59.9	1.48	308	9,920	-18	309	233	208
79	79	104		25,872.	-1.34	4276	777	1.56	251	8,360.	59.4	1.7	315	9,882	-20	309	232	217
80	80	102		25,877.	-1.29	4346	72	1.54	258	21,647.	60.2	1.66	316	9,932	-18	307	243	203
81	81	104		25,891.	-1.33	4428	34	1.57	245	21,700.	60.2	1.44	301	9,824	-20	307	236	195
82	82	103		26,120.	-1.57	4238	484	1.59	235	14,908.	60.4	1.46	313	9,791	-20	311	224	191
83	83	102		25,791.	-1.17	4402	56	1.55	280	21,390.	59.1	1.58	314	9,897	-18	319	238	197
84	84	104		25,906.	-1.31	4397	31	1.57	244	21,620.	60.5	1.48	305	9,886	-20	306	232	208
85	94	102		25,792.	-1.17	4396	82	1.56	249	20,441.	59.8	1.54	305	9,826	-18	306	236	202
86	85	103		25,755.	-0.98	4492	346	1.59	238	17,272.	60.2	1.42	298	9,829	-18	304	224	192
87	86	104		25,898.	-1.18	4380	376	1.56	258	16,778.	60	1.54	304	9,922	-20	309	228	194
88	87	102		25,670.	-1.11	4424	66	1.55	254	21,497.	60.4	1.57	304	9,820	-18	313	231	196
89	89	105		25,900.	-1.17	4341	600	1.56	257	11,999.	60.6	1.34	312	9,884	-20	308	231	198
90	90	102		25,758.	-1.15	4422	246	1.56	251	18,456.	60.7	1.54	316	9,828	-18	308	234	218
91	91	103		25,889.	-1.15	4418	317	1.56	238	17,719.	60.4	1.45	311	9,797	-18	308	225	207
92	95	103		26,063.	-1.52	4290	174	1.58	245	19,699.	60.4	1.67	312	9,852	-18	314	241	196
93	88	105		25,889.	-1.2	4343	153	1.57	224	19,934.	61.8	1.41	302	9,787	-21.5	312	234	197
94	96	103		25,915.	-1.2	4358	712	1.56	257	9,239.	60.1	1.43	298	9,944	-18	306	233	210
95	93	105		25,762.	-1.12	4332	82	1.56	222	20,293.	61	1.47	295	9,916	-20	302	226	196
96	103	103		26,114.	-1.59	4237	155.3	1.55	239	19,930.	60.8	1.62	310	9,810	-20	304	223	186
97	99	105		25,714.	-1.07	4624	244	1.56	260	18,641.	59.2	1.55	303	9,791	-18	312	238	207

a - Data not Available - DOD Mission
b - Report containing data not as yet published

Source: JSC/DM5 Flight Design and Dynamics Division,
Descent Post-flight summaries

Orbit Entry Trajectory (concluded)

Rollout/Braking

The design rollout figure depicts a nominal touchdown to wheels stop profile for a 15 K ft runway.

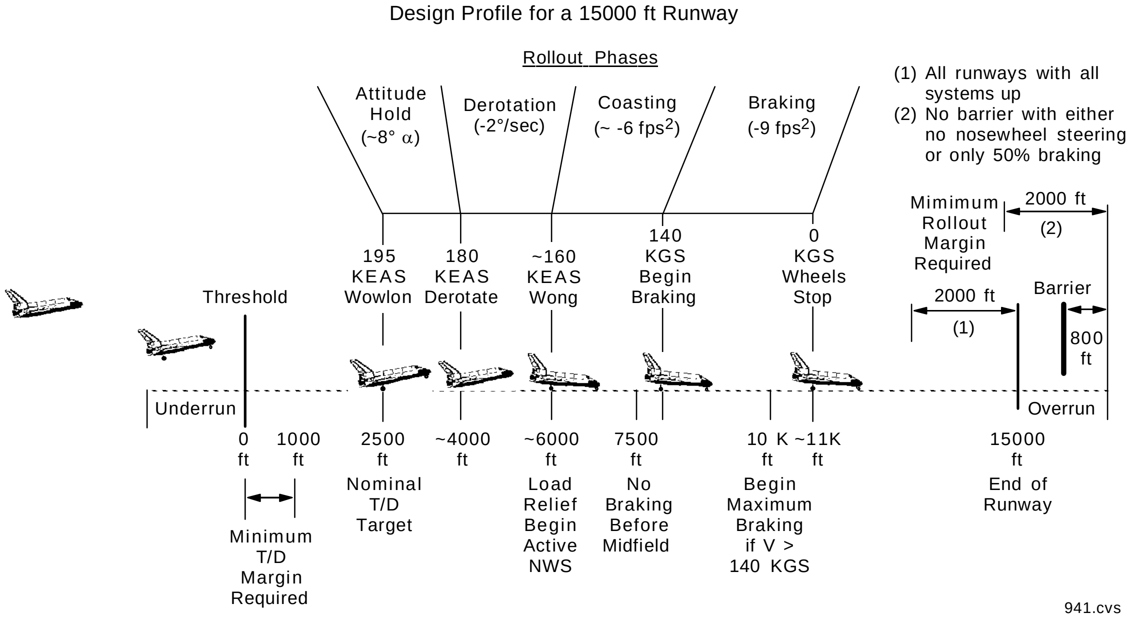
Loss of Braking

Some general comments can be made about the impact of the drag chute. The 40 ft partially reefed chute deployed 75 ft behind the lower trailing edge of the vertical tail can reduce the orbiter's stopping distance 2.5K to 3.5K ft. It provides increased directional control with two blown tires (NWS engaged) and in the absence of NWS will greatly reduce the speed at which the vehicle departs the runway. It also will significantly reduce the speed at which a heavy weight orbiter engages the barrier at a TAL site.

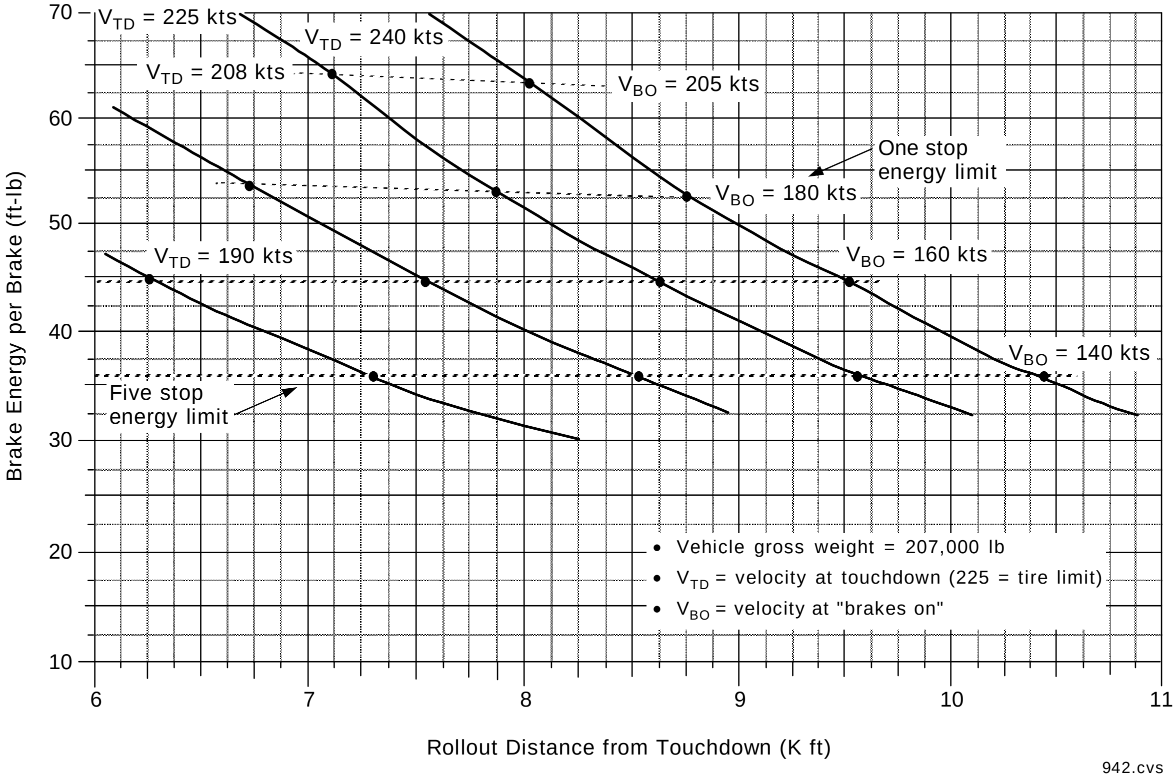
The structural carbon brakes, while not dramatically reducing the braking distance (300 to 500 ft), substantially improve the energy absorption capability over the old beryllium/carbon brakes. Vibration induced brake damage and heat damage (including heat induced blown tires) has been virtually eliminated. All orbiters are equipped with structural carbon brakes.

Rollout History

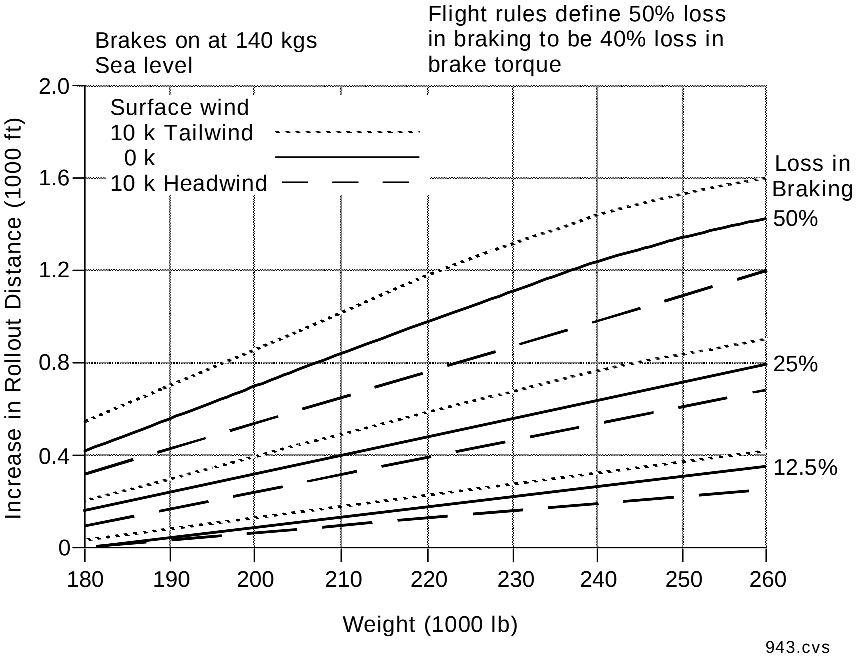
The Landing Rollout Flight History Table reflects the landing environment and the orbiters' performance from main gear touchdown to wheels stop for the first 97 shuttle missions.



Design Rollout Phases



Rollout Distance/Brake Energy



Loss of Braking

LANDING DECELERATION

Miss Seq. No.	STS- No.	Orb. OV-	Notes		Velocities and Rates				Distance from Threshold, ft a				Total Rollout, ft	Rollout time, sec	Runway Data
				MGTD kgs b	Sink rates, ft/sec	NGTD, kgs a	Pitch rate, deg/sec	Brake init., kgs b	MGTD	NGTD	Brake init.	Stop			
1	1	102		190.3	0.8	152.9	4.8	104.7	6,053	9,152	12,025	15,046	8,993.00	60	Edwards 23 Lakebed
2	2	102		185.9	1.0	135	4.4	109.5	780	4,429	5,780	8,491	7,711.00	53	Edwards 23 Lakebed
3	3	102		232.5	5.7	177.4	7.2	149	1,092	6,261	8,159	14,824	13,732.00	83	White Sands 17 Lakebed
4	4	102		195.7	2.0	161.2	3.2	133.2	948	4,988	7,839	10,826	9,878.00	73	Edwards 22 Concrete
5	5	102		201	1.0	175.9	4	167	1,637	4,675	5,286	11,190	9,553.00	63	Edwards 22 Concrete
6	6	099		180	2.0	147	3.4	136	2,026	4,970	5,072	9,270	7,244.00	49	Edwards 22 Concrete
7	7	099		200	2.5	154.4	4.4	124.5	2,726	6,843	7,040	13,176	10,450.00	75	Edwards 15 Lakebed
8	8	099		196	1.6	174.6	3.7	154.3	2,793	5,515	7,403	12,164	9,371.00	50	Edwards 22 Concrete
9	9	102		204	2.5	144.6	8.5	126	1,649	5,897	6,749	10,105	8,456.00	53	Edwards 17L Lakebed
10	41B	099		198.2	<2.0	159.5	2.4	135.9	1,930	5,789	7,448	12,737	10,807.00	67	KSC 15 Concrete
11	41C	099		220	2.0	138	4	110	1,912	7,167	8,538	10,628	8,716.00	49	Edwards 17L Lakebed
12	41D	103		216.3	<2.0	166	4.8	106.5	2,510	6,713	10,018	12,785	10,275.00	60	Edwards 17L Lakebed
13	41G	099	c	209.4	1.8c	161	2.6	113	962	5,505	8,986	11,527	10,565.00	54	KSC 33 Concrete
14	51A	103	c	193.7	2.0c	157.8	4	141.6	2,724	6,380	7,550	12,178	9,454.00	58	KSC 15 Concrete
15	51C	103	c	179.1	0.7c	142.7	3.4	116.7	2,753	5,752	7,677	10,105	7,352.00	50	KSC 15 Concrete
16	51D	103	c	209	2.8c	180	5.1	156	1,639	4,303	6,667	11,937	10,298.00	63	KSC 33 Concrete
17	51B	099		206.5	<1.0	153	6.1	106	1,576	5,528	7,589	9,893	8,317.00	59	Edwards 17L Lakebed
18	51G	103		202.3	5.0	159.6	6.9	154.2	1,117	4,990	5,248	8,550	7,433.00	42	Edwards 23 Lakebed
19	51F	099		204.3	4.0	171.8	6.1	126.2	3,713	6,412	9,059	12,282	8,569.00	55	Edwards 23 Lakebed
20	51I	103		175	<2.0	142	4.8	114	2,101	4,384	5,571	8,201	6,100.00	47	Edwards 23 Lakebed
21	51J	104		187	3.0	154.8	4.8	117.2	2,476	4,873	7,421	10,532	8,056.00	65	Edwards 23 Lakebed
22	61A	099		209.9	1.0	173.8	6.7	110.9	1,829	4,767	7,923	10,133	8,304.00	45	Edwards 17L Lakebed
23	61B	104		201.3	1.0	165.7	3.1	126.4	2,386	5,909	9,321	13,145	10,759.00	78	Edwards 22 Concrete
24	61C	102		217	2.0	162.9	2.7	138.4	1,530	6,300	7,831	10,197	10,202.00	59	Edwards 22 Concrete
25	51L	099	d												
26	26	103		195	1.0	154	4	134	2,569	5,671	6,750	10,020	7,451.00	46	Edwards 17L Lakebed
27	27	104		204	1.0	168	3.8	134	1,469	4,423	5,908	8,592	7,123.00	43	Edwards 17L Lakebed
28	29	103		204	2.9	163	1.7	130	1,195	5,027	7,550	10,534	9,339.00	52.7	Edwards 22 Concrete
29	30	104		204	2.4	164	2	138	1,314	5,088	6,028	11,609	10,295.00	64.3	Edwards 22 Concrete
30	28	102		158	1.0	128	7.6	82	5,311	7,393	9,776	11,326	6,015.00	46.5	Edwards 17L Lakebed
31	34	104		204.7	1.0	157.9	3.4	77.6	1,871	5,355	10,063	11,548	9,677.00	60.4	Edwards 23L Lakebed

a. Based on runway measurements except for brake initiation (onboard service)
b. kgs = knots, ground speed
c. Sink rate based on LaRC analysis of KSC spin-up measureme
d. Data not available

Source: JSC/ES6, Mechanical Design and Analysis Branch
In-house Mission Reports

Landing Rollout Flight History Table

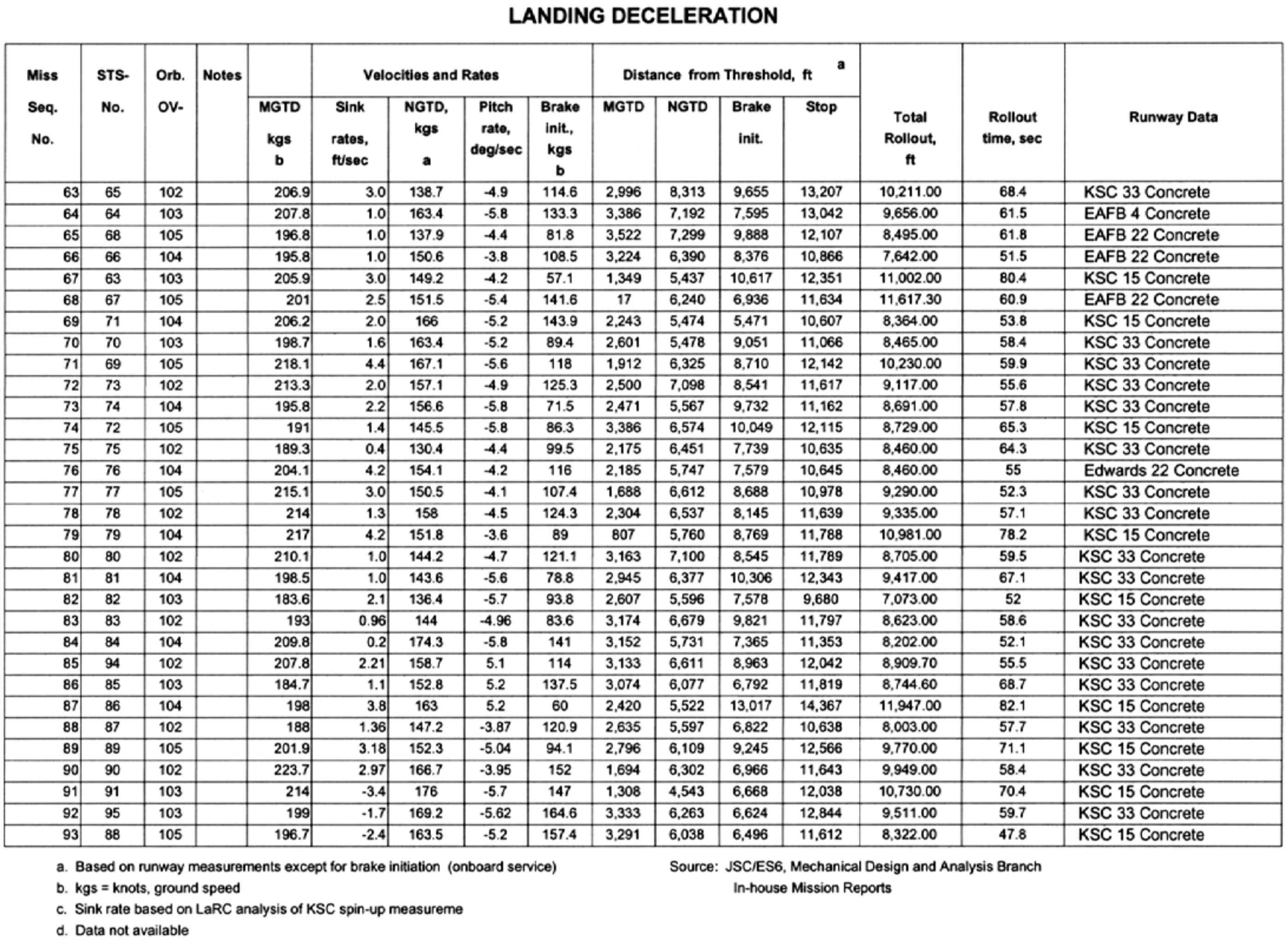
LANDING DECELERATION

Miss	STS-	Orb.	Notes		Velocities and Rates				Distance from Threshold, ft a						
Seq. No.	No.	OV-		MGTD kgs b	Sink rates, ft/sec	NGTD, kgs a	Pitch rate, deg/sec	Brake init., kgs b	MGTD	NGTD	Brake init.	Stop	Total Rollout, ft	Rollout time, sec	Runway Data
32	33	103		191.6	3.0	159.4	2.9	148	740	3,982	4,856	8,504	7,764.00	46.1	Edwards 04 Concrete
33	32	102		209.3	1.0	161.5	2.2	141.3	2,399	6,606	8,096	12,495	10,096.00	62.2	Edwards 22 Concrete
34	36	104		187.8	1.0	143.2	3.8	97	1,622	4,862	6,405	9,522	7,900.00	52.9	Edwards 23L Lakebed
35	31	103		180.1	3.0	144.4	2.9	118.6	1,176	4,560	6,718	10,065	8,889.00	60.7	Edwards 22 Concrete
36	41	103		194.6	1.0	155.5	2.3	135.7	2,295	6,359	7,713	10,827	8,532.00	49.2	Edwards 22 Concrete
37	38	104		196.5	1.0	162.9	2.6	130.5	1,414	4,600	6,966	10,417	9,003.00	56.3	KSC 33 Concrete
38	35	102		207.9	1.0	169.5	3.4	134.5	1,535	5,559	8,465	12,101	10,566.00	57.7	Edwards 22 Concrete
39	37	104		156.6	2.3	131.8	7.3	93.6	623	1,200	3,197	5,741	6,364.00	53.9	Edwards 33 Lakebed
40	39	103		210.4	2.0	159.8	2.5	136.5	168	4,700	6,316	9,403	9,235.00	55.5	KSC 15 Concrete
41	40	102		199.8	2.0	153.3	3.5	135.2	1,485	5,914	7,323	10,923	9,438.00	54.6	Edwards 22 Concrete
42	43	104		203.4	2.0	166.6	2.4	132.5	1,986	5,517	8,243	11,876	9,890.00	58.9	KSC 15 Concrete
43	48	103		215.7	1.0	172	2.5	145.4	1,235	4,882	6,851	10,619	9,384.00	49.6	Edwards 22 Concrete
44	44	104		183.4	1.0	150	4.5	15.2	2,607	5,077	13,570	13,798	11,191.00	106.6	Edwards 05R Lakebed
45	42	103		199.5	2.0	169	3.7	134.8	2,835	5,901	8,769	12,676	9,841.00	58.3	Edwards 22 Concrete
46	45	104		187.7	1.0	162.6	3.6	135.3	1,765	4,393	6,721	10,992	9,227.00	59.6	KSC 33 Concrete
47	49	105		211	1.0	175.1	3	96.3	2,156	5,770	9,923	11,646	9,490.00	57.7	Edwards 22 Concrete
48	50	102		209.4	2.0	151.2	4.4	112.9	2,321	7,832	10,573	12,995	10,674.00	58.6	KSC 33 Concrete
49	46	104		203.8	2.0	156	3.7	132.2	1,865	6,521	8,510	12,725	10,860.00	65.6	KSC 33 Concrete
50	47	105		210.6	1.0	137	1.9	115.6	2,458	7,651	8,591	11,025	8,567.00	50.9	KSC 33 Concrete
51	52	102		219.6	1.0	151.4	3	101.1	1,080	6,949	9,321	11,788	10,708.00	63.1	KSC 33 Concrete
52	53	103		208.8	3.0	144.9	1.9	106.2	1,108	6,329	7,927	11,273	10,165.00	72.8	Edwards 22 Concrete
53	54	105		205	2.0	150.2	2.7	106.8	1,536	6,249	8,233	10,260	8,724.00	49.2	KSC 33 Concrete
54	56	103		196.1	3.0	143.8	2.9	128	1,075	5,587	6,295	10,605	9,530.00	63.1	KSC 33 Concrete
55	55	102		210.3	3.5	149	3.9	85	1,819	7,283	10,030	11,944	10,125.00	60.9	Edwards 22 Concrete
56	57	105		203	1.5	135	2.9	99.7	2,297	7,498	9,371	12,251	9,954.00	65.3	KSC 33 Concrete
57	51	103		198.4	1.5	144.1	3.3	113.4	2,099	6,539	7,977	10,370	8,271.00	50.1	KSC 15 Concrete
58	58	102		204.9	2.0	167.6	3.2	137.2	3,380	6,948	8,772	13,020	9,640.00	60.9	Edwards 22 Concrete
59	61	105		192.1	1.5	148.7	3	118	2,903	6,635	8,029	10,825	7,922.00	53.4	KSC 33 Concrete
60	60	103		191.9	2.0	118.2	3.52	97.5	2,463	7,455	8,295	10,234	7,771.00	49.8	KSC 15 Concrete
61	62	102		210.5	3.0	148.2	3.2	122.4	3,004	8,746	10,044	13,155	10,151.00	54.5	KSC 33 Concrete
62	59	105		228.3	3.5	171.4	3.8	117.9	1,664	7,067	9,819	12,355	10,691.00	53.7	EAFB 22 Concrete

a. Based on runway measurements except for brake initiation (onboard service)
b. kgs = knots, ground speed
c. Sink rate based on LaRC analysis of KSC spin-up measureme
d. Data not available

Source: JSC/ES6, Mechanical Design and Analysis Branch
In-house Mission Reports

Landing Rollout Flight History Table (continued)



LANDING DECELERATION

Miss Seq. No.	STS- No.	Orb. OV-	Notes	Velocities and Rates					Distance from Threshold, ft a				Total Rollout, ft	Rollout time, sec	Runway Data
				MGTD kgs b	Sink rates, ft/sec	NGTD, kgs a	Pitch rate, deg/sec	Brake init., kgs b	MGTD	NGTD	Brake init.	Stop			
63	65	102		206.9	3.0	138.7	-4.9	114.6	2,996	8,313	9,655	13,207	10,211.00	68.4	KSC 33 Concrete
64	64	103		207.8	1.0	163.4	-5.8	133.3	3,386	7,192	7,595	13,042	9,656.00	61.5	EAFB 4 Concrete
65	68	105		196.8	1.0	137.9	-4.4	81.8	3,522	7,299	9,888	12,107	8,495.00	61.8	EAFB 22 Concrete
66	66	104		195.8	1.0	150.6	-3.8	108.5	3,224	6,390	8,376	10,866	7,642.00	51.5	EAFB 22 Concrete
67	63	103		205.9	3.0	149.2	-4.2	57.1	1,349	5,437	10,617	12,351	11,002.00	80.4	KSC 15 Concrete
68	67	105		201	2.5	151.5	-5.4	141.6	17	6,240	6,936	11,634	11,617.30	60.9	EAFB 22 Concrete
69	71	104		206.2	2.0	166	-5.2	143.9	2,243	5,474	5,471	10,607	8,364.00	53.8	KSC 15 Concrete
70	70	103		198.7	1.6	163.4	-5.2	89.4	2,601	5,478	9,051	11,066	8,465.00	58.4	KSC 33 Concrete
71	69	105		218.1	4.4	167.1	-5.6	118	1,912	6,325	8,710	12,142	10,230.00	59.9	KSC 33 Concrete
72	73	102		213.3	2.0	157.1	-4.9	125.3	2,500	7,098	8,541	11,617	9,117.00	55.6	KSC 33 Concrete
73	74	104		195.8	2.2	156.6	-5.8	71.5	2,471	5,567	9,732	11,162	8,691.00	57.8	KSC 33 Concrete
74	72	105		191	1.4	145.5	-5.8	86.3	3,386	6,574	10,049	12,115	8,729.00	65.3	KSC 15 Concrete
75	75	102		189.3	0.4	130.4	-4.4	99.5	2,175	6,451	7,739	10,635	8,460.00	64.3	KSC 33 Concrete
76	76	104		204.1	4.2	154.1	-4.2	116	2,185	5,747	7,579	10,645	8,460.00	55	Edwards 22 Concrete
77	77	105		215.1	3.0	150.5	-4.1	107.4	1,688	6,612	8,688	10,978	9,290.00	52.3	KSC 33 Concrete
78	78	102		214	1.3	158	-4.5	124.3	2,304	6,537	8,145	11,639	9,335.00	57.1	KSC 33 Concrete
79	79	104		217	4.2	151.8	-3.6	89	807	5,760	8,769	11,788	10,981.00	78.2	KSC 15 Concrete
80	80	102		210.1	1.0	144.2	-4.7	121.1	3,163	7,100	8,545	11,789	8,705.00	59.5	KSC 33 Concrete
81	81	104		198.5	1.0	143.6	-5.6	78.8	2,945	6,377	10,306	12,343	9,417.00	67.1	KSC 33 Concrete
82	82	103		183.6	2.1	136.4	-5.7	93.8	2,607	5,596	7,578	9,680	7,073.00	52	KSC 15 Concrete
83	83	102		193	0.96	144	-4.96	83.6	3,174	6,679	9,821	11,797	8,623.00	58.6	KSC 33 Concrete
84	84	104		209.8	0.2	174.3	-5.8	141	3,152	5,731	7,365	11,353	8,202.00	52.1	KSC 33 Concrete
85	94	102		207.8	2.21	158.7	5.1	114	3,133	6,611	8,963	12,042	8,909.70	55.5	KSC 33 Concrete
86	85	103		184.7	1.1	152.8	5.2	137.5	3,074	6,077	6,792	11,819	8,744.60	68.7	KSC 33 Concrete
87	86	104		198	3.8	163	5.2	60	2,420	5,522	13,017	14,367	11,947.00	82.1	KSC 15 Concrete
88	87	102		188	1.36	147.2	-3.87	120.9	2,635	5,597	6,822	10,638	8,003.00	57.7	KSC 33 Concrete
89	89	105		201.9	3.18	152.3	-5.04	94.1	2,796	6,109	9,245	12,566	9,770.00	71.1	KSC 15 Concrete
90	90	102		223.7	2.97	166.7	-3.95	152	1,694	6,302	6,966	11,643	9,949.00	58.4	KSC 33 Concrete
91	91	103		214	-3.4	176	-5.7	147	1,308	4,543	6,668	12,038	10,730.00	70.4	KSC 15 Concrete
92	95	103		199	-1.7	169.2	-5.62	164.6	3,333	6,263	6,624	12,844	9,511.00	59.7	KSC 33 Concrete
93	88	105		196.7	-2.4	163.5	-5.2	157.4	3,291	6,038	6,496	11,612	8,322.00	47.8	KSC 15 Concrete

a. Based on runway measurements except for brake initiation (onboard service)
b. kgs = knots, ground speed
c. Sink rate based on LaRC analysis of KSC spin-up measureme
d. Data not available

Source: JSC/ES6, Mechanical Design and Analysis Branch
In-house Mission Reports

Landing Rollout Flight History Table (continued)

LANDING DECELERATION

Miss	STS-	Orb.	Notes		Velocities and Rates				Distance from Threshold, ft a						
Seq. No.	No.	OV-		MGTD kgs b	Sink rates, ft/sec	NGTD, kgs a	Pitch rate, deg/sec	Brake init., kgs b	MGTD	NGTD	Brake init.	Stop	Total Rollout, ft	Rollout time, sec	Runway Data
94	96	103		210	-1.0	156	-5	112	1,963	6,504	8,510	10,829	8,866.00	50	KSC 15 Concrete
95	93	102		201	-1.0	159	-3.6	122	2,533	5,470	7,167	9,384	6,851.00	44	KSC 33 Concrete
96	103	103		186.5	-1.74	140.5	-4.59	110.1	2,926	5,998	7,480	9,901	7,075.20	48.15	KSC 33 Concrete
97	99	105		206.1	-1.31	169	-5.55	167.8	2,967	6,535	6,615	12,921	9,963.90	58.2	KSC 33 Concrete

a. Based on runway measurements except for brake initiation (onboard service)
b. kgs = knots, ground speed
c. Sink rate based on LaRC analysis of KSC spin-up measureme
d. Data not available

Source: JSC/ES6, Mechanical Design and Analysis Branch
In-house Mission Reports

Landing Rollout Flight History Table (concluded)

Performance Rules of Thumb

ASCENT

Ascent Performance Margin
Management Reserve Req. (lbs)
Pre Flight Design Requirements
Document = 3500
Flight Design Requirements
Document = 2500
Cargo Integration Review = 1500
Flight Planning Stowage
Review = 1500
FPR = 4652

ORBIT

1 hr launch delay = change in
orbital noon by 4 minutes

Ascending node
28.5 deg - 1st ascending node
is @ Long = 173.38 East
57 deg = 121.55 West

MISCELLANEOUS

Orbiters
OV103 - Discovery
OV104 - Atlantis
OV105 - Endeavor

Min planned flt duration = 96 hours

Max/Min Beta Angle
Max = 23.5 + orbital inclination
Min = 23.5 - orbital inclination

Time
CDT = GMT - 5 hr
CST = GMT - 6 hr
Daylight savings time from
1st Sunday in April to
last Sunday in October

DESCENT

Xcg Limits
FWD = 1076.7 in (RTLS = 1079.0 in)
AFT = 1109.0 in
CONT AFT = 1119.0 in

D/O Delta V's
Descending approach is worst case ΔV
90 deg prebank will decrease ΔV ~ 10 ft/s
(function of altitude)

If Xcg > 1091.5: 1 in Xcg = 2.2 miles
If Xcg < 1091.5: 1 in Xcg = 1.1 miles
As Xcg increases (more aft), XR decreases
1 nm XR = 5780 lbs EI weight
1 nm XR = 4.38 nm D/O altitude
As altitude and weight increase, XR increases
As inclination increases, XR increases (non-linear)
As temp increases, XR increases (non-linear)

Touchdown speeds
195 kts if TD weight < 222 k lbs
205 kts if TD weight > 222 k lbs

10 kts slower if short field speedbrake
guidance mode is used if 200 k lb < TD weight
≤ 245 k lbs

Derotation 185 KGS with beep trim (Prime)
or with RHC (manual) derotation (Backup)

Mass Moment
MM = TD Weight * (1172.3 - Xcg)/12
for medium lakebed runways
If MM > 1.47 M ft-lbs Concrete desire
If MM > 1.54 M ft-lbs Concrete required
Note: If TD Xcg not known, use
Xcg @ M = 3.5 + 1.5 in

Landing Weight Limits
EOM 233 k lbs
RTLS 242 - 248 k lbs *
TAL 241 - 248 k lbs *
AOA 233 - 240 k lbs *
(Abort limits a function of Inclination)

Noctilucent Clouds
If Inc > 50, do not enter on descending opportunity
June through August.

RENDEZVOUS

1 deg of phasing/hour = 10 nm of Δ height
1 deg of phasing = 60 nm
17.5 ft/s burn changes other side of orbit 10 nm
440 ft/s burn will change plane by 1 deg of wedge
1 deg of ΔRAAN occurs for each relative lap

PROPELLANT

1 deg of plane change = 440 ft/s

OMS philosophy
1 ft/s = 21.8 lbs OMS @ 220 k lbs ~1/6%
1.78 ft/s = 1 nm

Maximum OMS load
OV103/4 = 25064 lbs
Min = 10800 lbs
Max OMS ballast = 4000 lbs
1% OMS = 130 lbs/side

Hard Ballast
OV103/104 - Bay 13

RCS philosophy
1 ft/s = 25 lbs (+ X) or 35 - 40 lbs
(multi axis) @ 220 k lbs
Max burn = 250 sec = 55 fps
Full FRCS = 2446 lbs
ET blowdown offload = 2225 lbs
Min FRCS - 1862 lbs
Full ARCS = 4970 lbs (over 100%)
1% ARCS = 22 lbs/side

IINTERCONNECT logic
If OMS < 14,000 lbs, I/C off
If OMS > 17,000 lbs, I/C on
If 14 k < OMS < 17 k, analysis req.

ECS - N2

OV103/4
5.28 lbs/day for 4 person crew @ 14.7 psi
add .114 lbs/day for additional crewmember
3.66 lbs/day for 4 person crew @ 10.2 psi
add .079 lbs/day for additional crewmember

	Dry wt	Fully loaded wt
N2	83 lbm	143 lbm

EPS

.09 lbm Hydrogen = 1 kwh
.7 lbm Oxygen = 1 kwh
.07 lbm Oxygen/hour = cabin leak rate

	Dry wt	Fully loaded wt
H2	227 lbm	319 lbm
O2	215 lbm	996 lbm

* Orbiter Engineering Memo VE3-90-096.

usa007587_945**r1**.cvx

APPENDIX A PANEL DIAGRAMS

CONTENTS

Forward

F1 ... A-2
F2 ... A-2
F3 ... A-2
F4 ... A-2
F5 ... A-3
F6 ... A-4
F7 ... A-5
F8 ... A-6
F9 ... A-7

Overhead

O1 ... A-8
O2 ... A-9
O3 ... A-10
O5 ... A-11
O6 ... A-12
O7 ... A-13
O8 ... A-14
O9 ... A-15
O13 ... A-16
O14 ... A-17
O15 ... A-18
O16 ... A-19
O17 ... A-20
O19 ... A-20

Left

L1 ... A-21
L2 ... A-22
L4 ... A-23
L5 ... A-24
L9 ... A-24
L11 ... A-25
L12U ... A-26
L12L ... A-27
L15 ... A-28

Center Console

C2 ... A-29
C3 ... A-30
C5 ... A-31
C6 ... A-31
C7 ... A-31

Right

R1 ... A-32
R2 ... A-33
R4 ... A-34
R6 ... A-34
R7 ... A-35
R11U ... A-36
R11L ... A-36
R10 ... A-37
R12U ... A-37
R12L ... A-37
R13U ... A-38
R13L ... A-39
R14 ... A-40

Aft

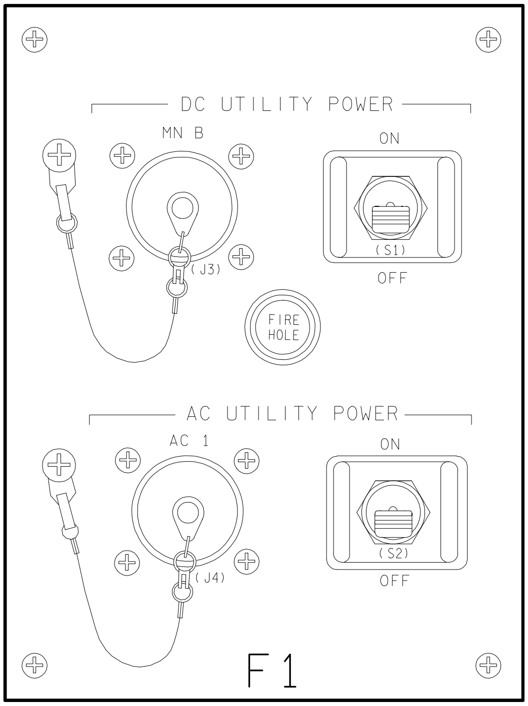
A1U ... A-41
A1L ... A-42
A1R ... A-43
A2 ... A-44
A3 ... A-44
A4 ... A-45
A6U ... A-45
A6L ... A-46
A7U ... A-46
A7L ... A-47
A8U ... A-48
A8L ... A-49
A11 ... A-49, 50
A12 ... A-51
A13 ... A-51
A14 ... A-52
A15 ... A-53*, 54*

Middeck

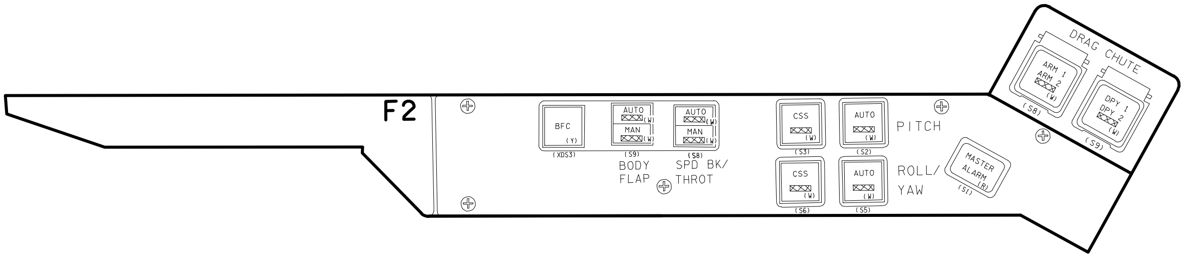
MA73C ... A-5*5*
MD24K ... A-5*6*
MD44F ... A-5*6*
ML18F ... A-5*6*
ML26C ... A-5*6*
ML31C ... A-5*7*
ML85E ... A-5*7*
ML86B ... A-5*8*
MO10W ... A-5*9*
MO13Q ... A-*60*
MO29J ... A-6*1*
MO30F ... A-6*1*
MO32M ... A-6*1*
MO39M ... A-6*1*
MO42F ... A-6*2*
MO51F ... A-6*2*
MO52J ... A-6*3*
MO58F ... A-6*3*
MO62M ... A-6*4*
MO69M ... A-6*4*
MO63P ... A-64
WCS ... A-6*5*
Thermal Impulse Printer ... A-6*6*

Airlock

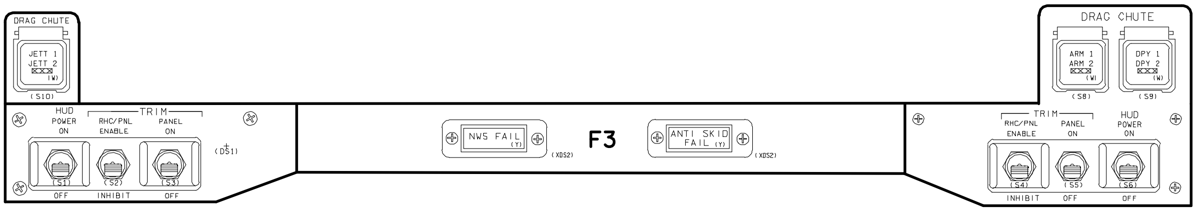
AW18A ... A-6*7*
AW18D ... A-6*7*
AW18H ... A-6*8*
AW82A ... A-6*9*
AW82B ... A-6*9*
AW82D ... A-6*9*
AW82H ... A-*70*



Panel F1



Panel F2



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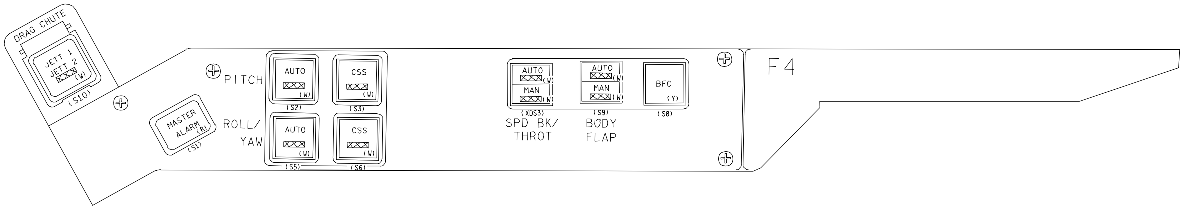

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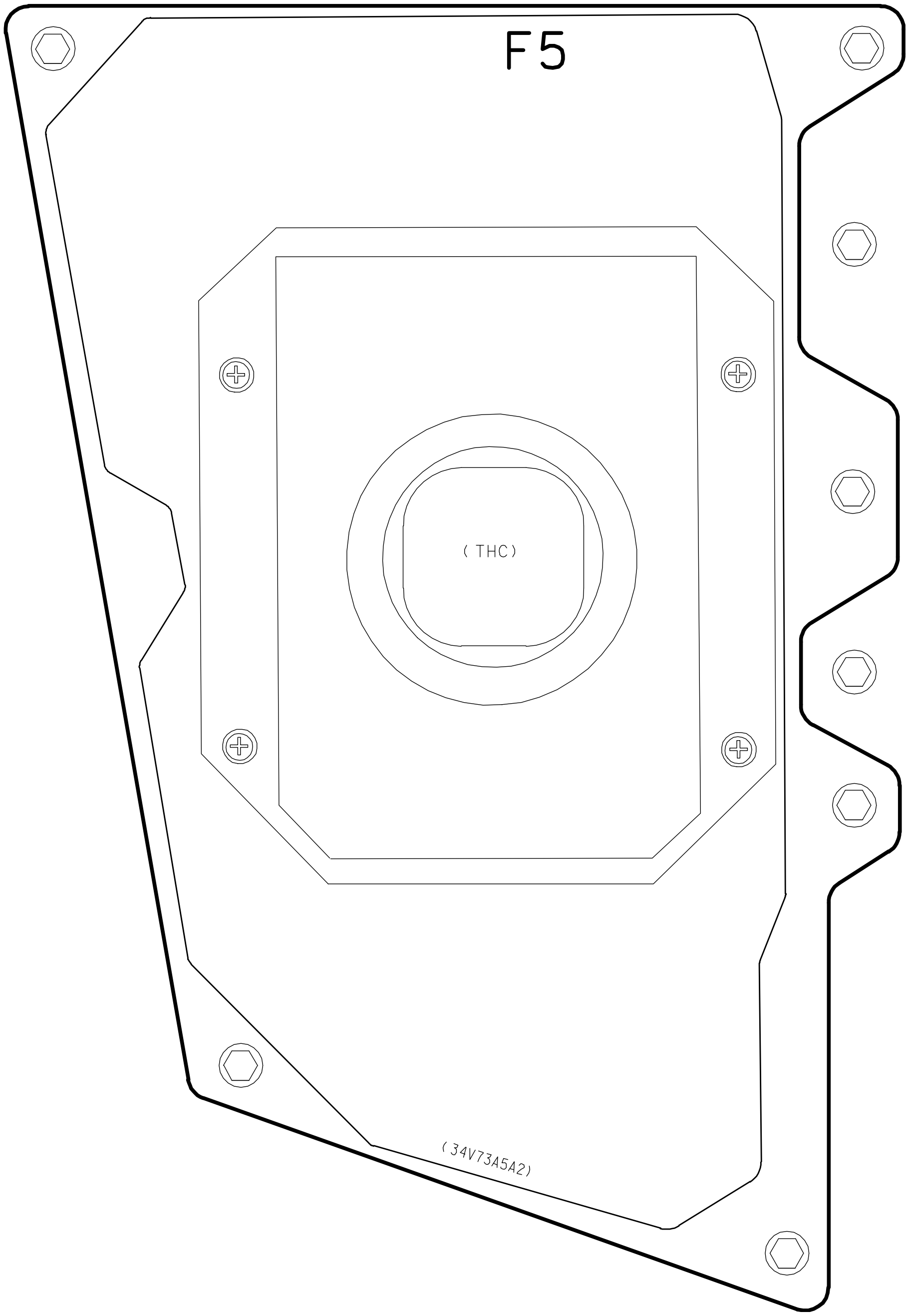

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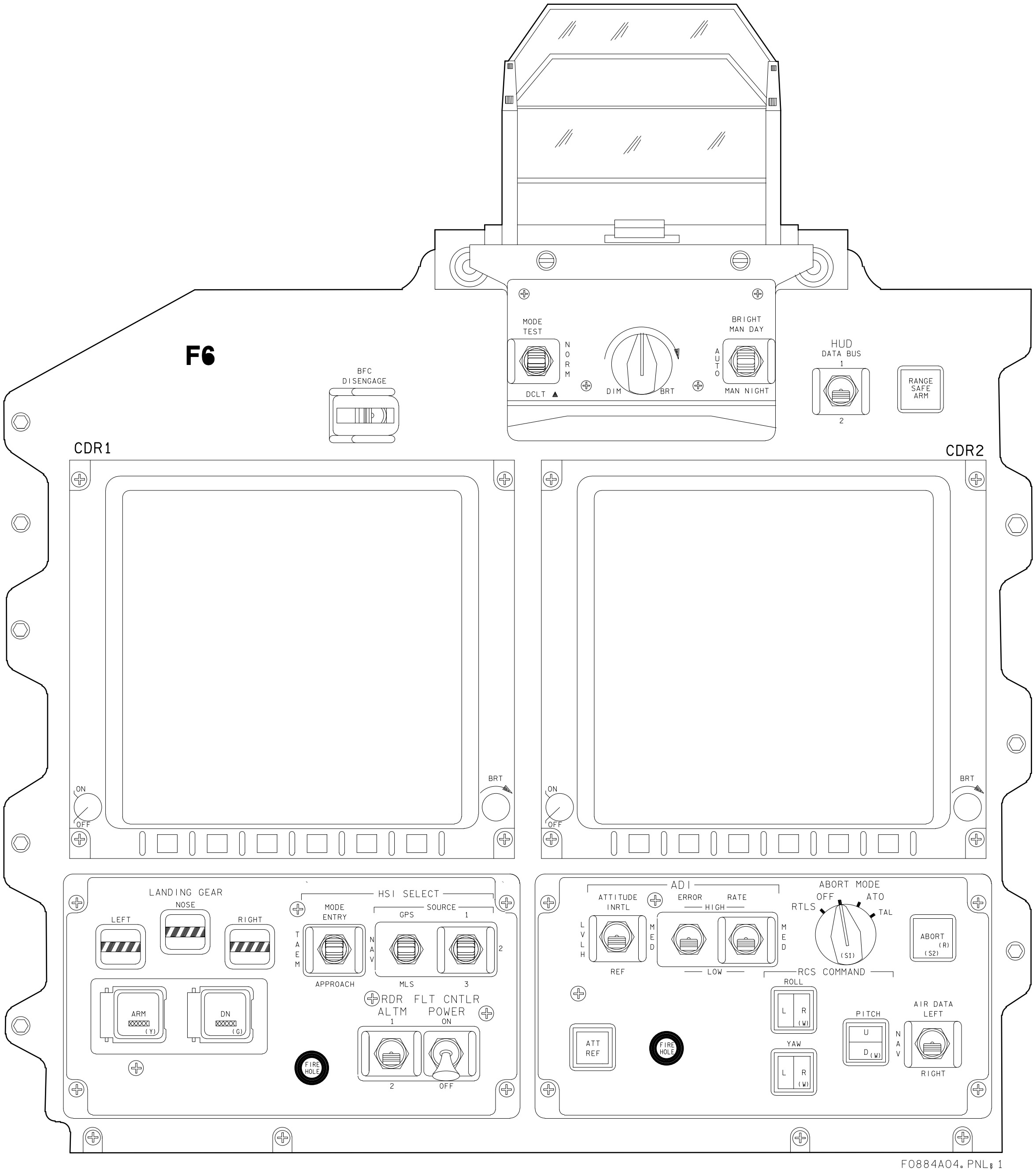
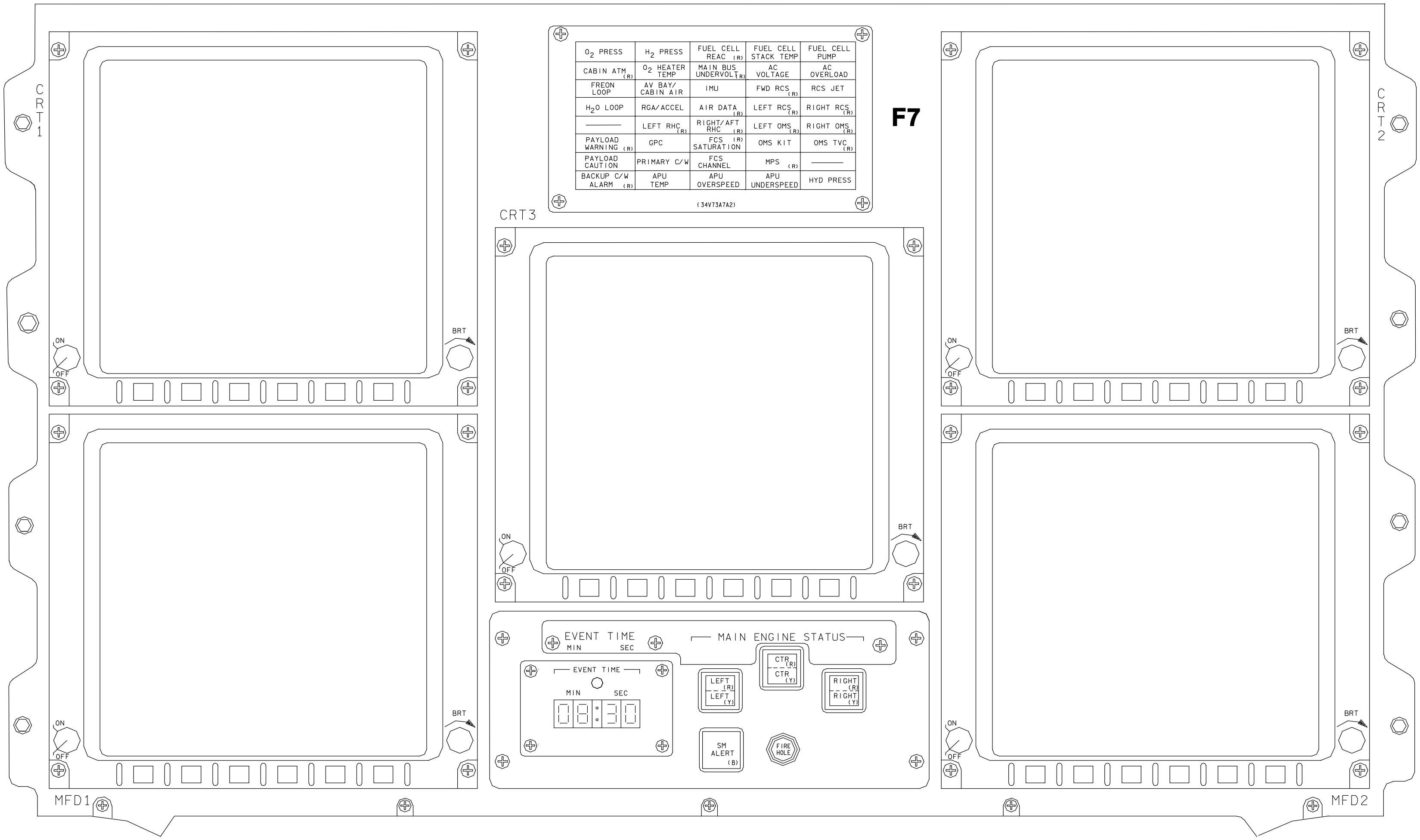

F6
BFC
DISENGAGE
MODE
TEST
NORM
DCLT ▲
DIM
BRT
BRIGHT
MAN DAY
AUTO
MAN NIGHT
HUD
DATA BUS
1
2
RANGE
SAFE
ARM
CDR1
CDR2
ON
OFF
BRT
LANDING GEAR
NOSE
LEFT
RIGHT
ARM
(Y)
DN
(G)
HSI SELECT
MODE
ENTRY
TAEM
APPROACH
SOURCE
GPS
1
NAV
MLS
2
3
RDR ALTM
FLT CNTLR POWER
ON
OFF
FIRE HOLE
ADI
ATTITUDE
INRTL
LVLH
REF
ERROR
RATE
HIGH
MED
LOW
ABORT MODE
OFF
ATO
RTLS
TAL
(S1)
ABORT
(R)
(S2)
RCS COMMAND
ROLL
L
R
(W)
YAW
PITCH
U
D
AIR DATA
LEFT
RIGHT
ATT
REF
F0884A04.PNL;1

Panel F6



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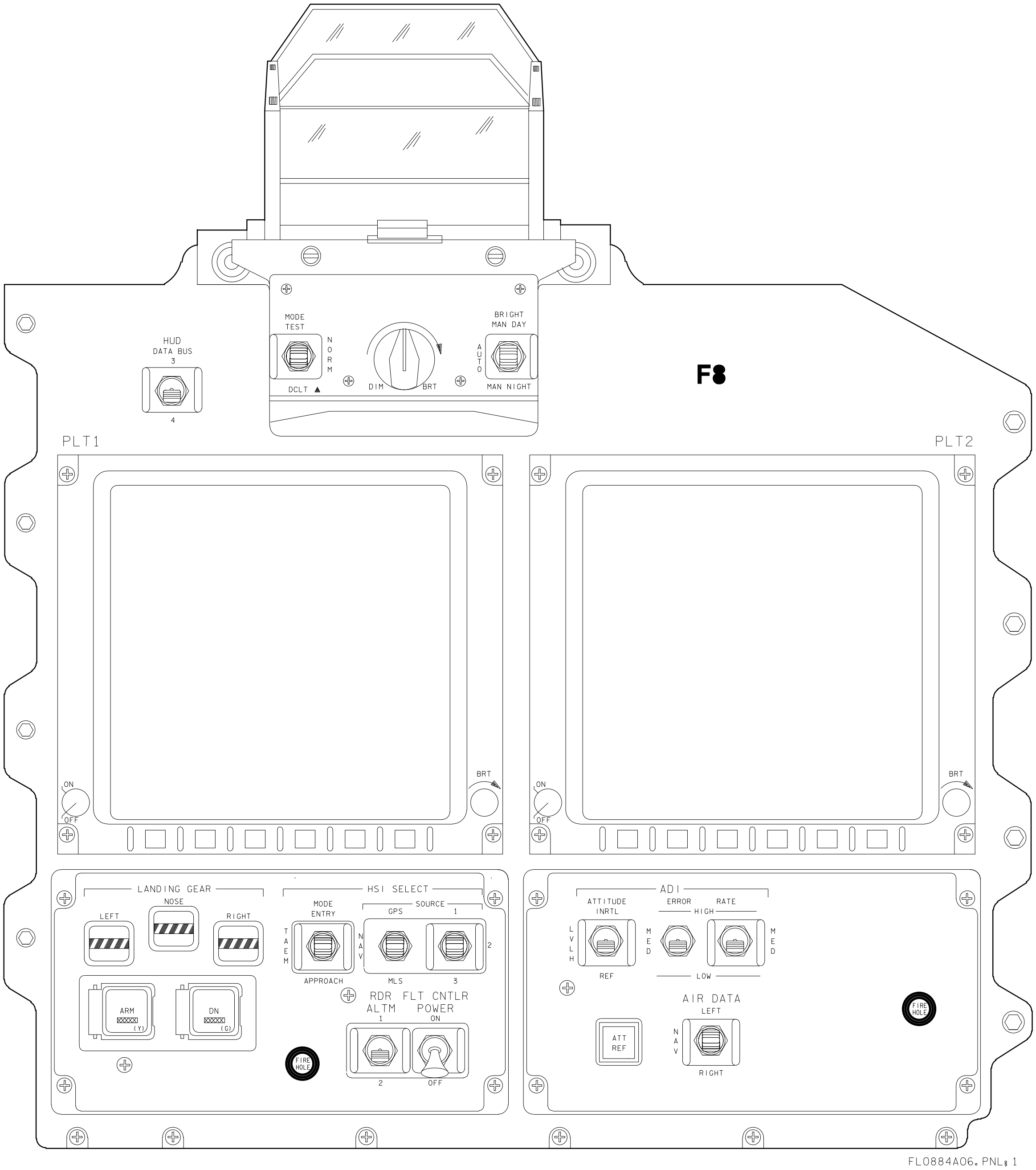
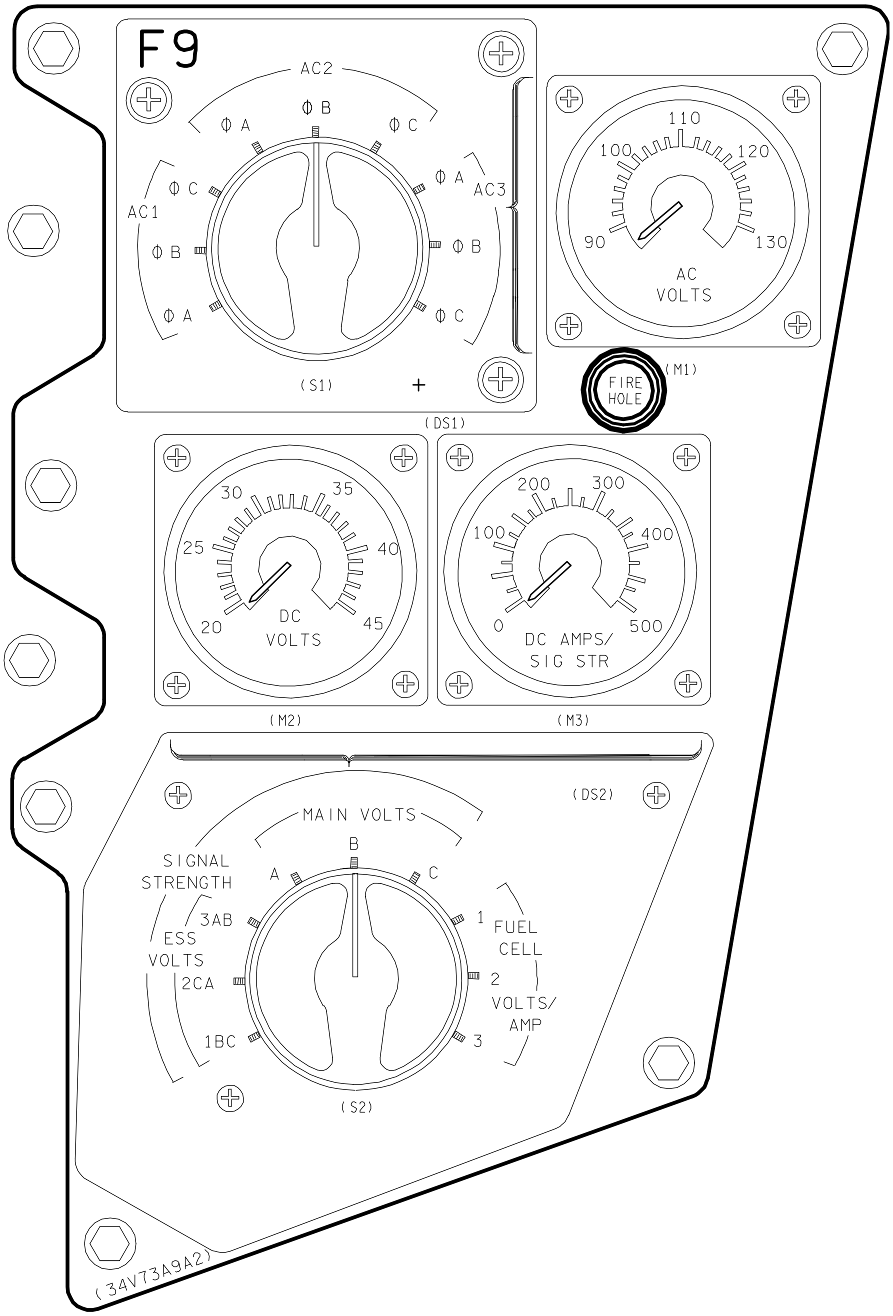
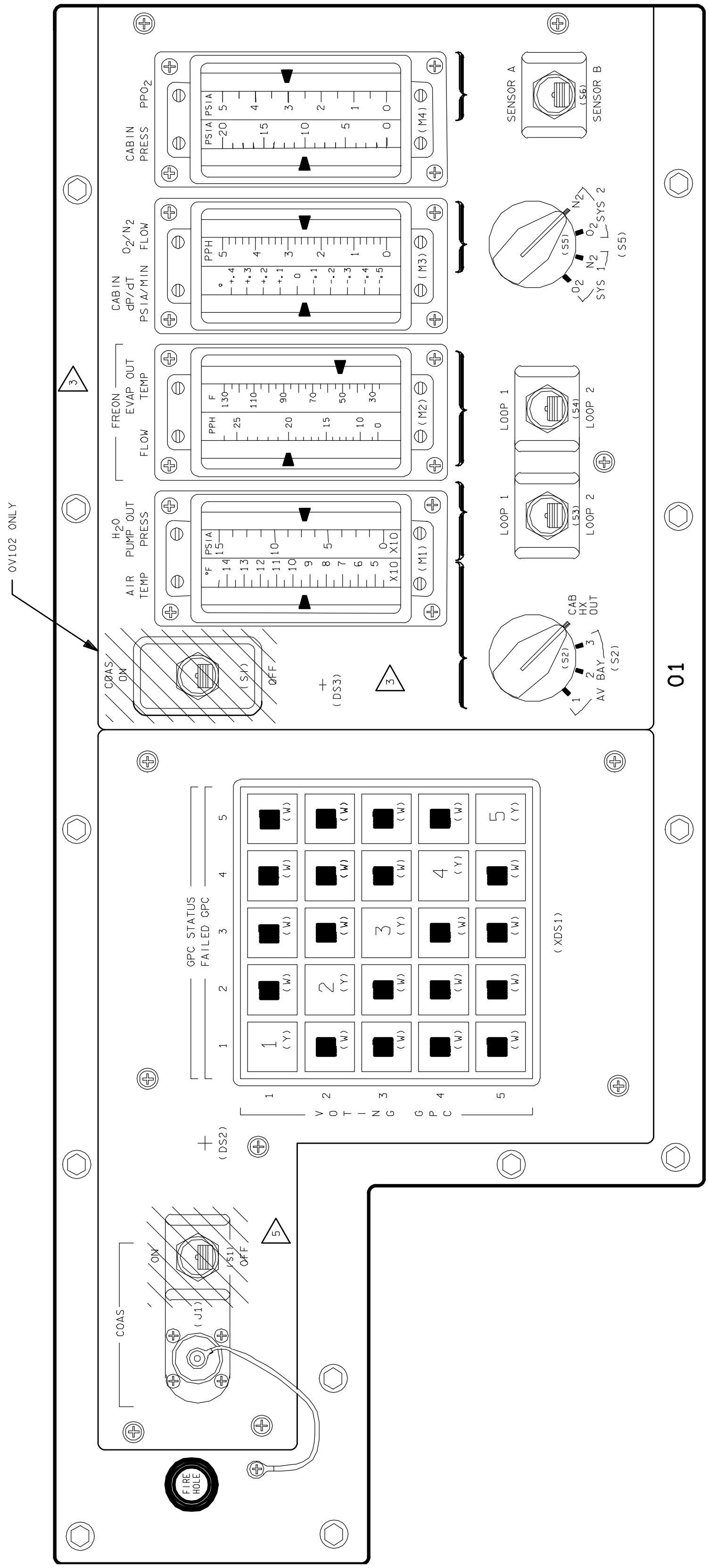
Panel F7


HUD
DATA BUS
3
4
MODE
TEST
NORM
DCLT ▲
DIM
BRT
BRIGHT
MAN DAY
AUTO
MAN NIGHT
F8
PLT1
PLT2
ON
OFF
BRT
ON
OFF
BRT
LANDING GEAR
LEFT
NOSE
RIGHT
ARM
(Y)
DN
(G)
FIRE HOLE
HSI SELECT
MODE
ENTRY
TAEM
APPROACH
SOURCE
GPS
1
NAV
2
MLS
3
RDR ALTM
1
2
FLT CNTLR POWER
ON
OFF
ADI
ATTITUDE
INRTL
LVLH
REF
ERROR
RATE
HIGH
MED
MED
LOW
AIR DATA
LEFT
NAV
RIGHT
ATT REF
FIRE HOLE
FL0884A06.PNL;1

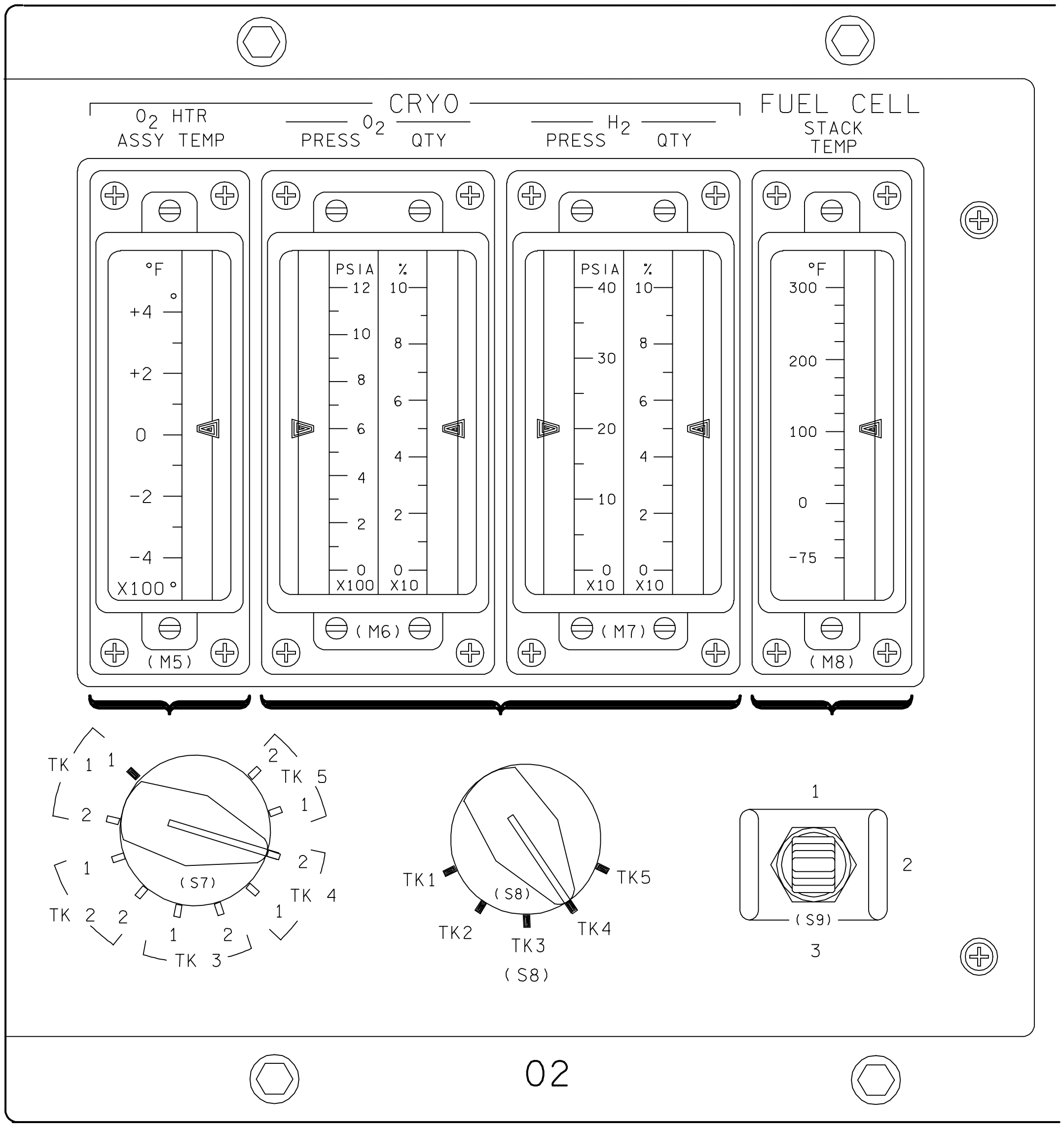
Panel F8


F9
AC2
Φ A
Φ B
Φ C
AC1
Φ C
Φ B
Φ A
AC3
Φ A
Φ B
Φ C
(S1)
+
(DS1)
110
100
120
90
130
AC
VOLTS
FIRE
HOLE
(M1)
30
35
25
40
20
45
DC
VOLTS
200
300
100
400
0
500
DC AMPS/
SIG STR
(M2)
(M3)
(DS2)
MAIN VOLTS
A
B
C
SIGNAL
STRENGTH
3AB
ESS
VOLTS
2CA
1BC
1
FUEL
CELL
2
VOLTS/
AMP
3
(S2)
(34V73A9A2)

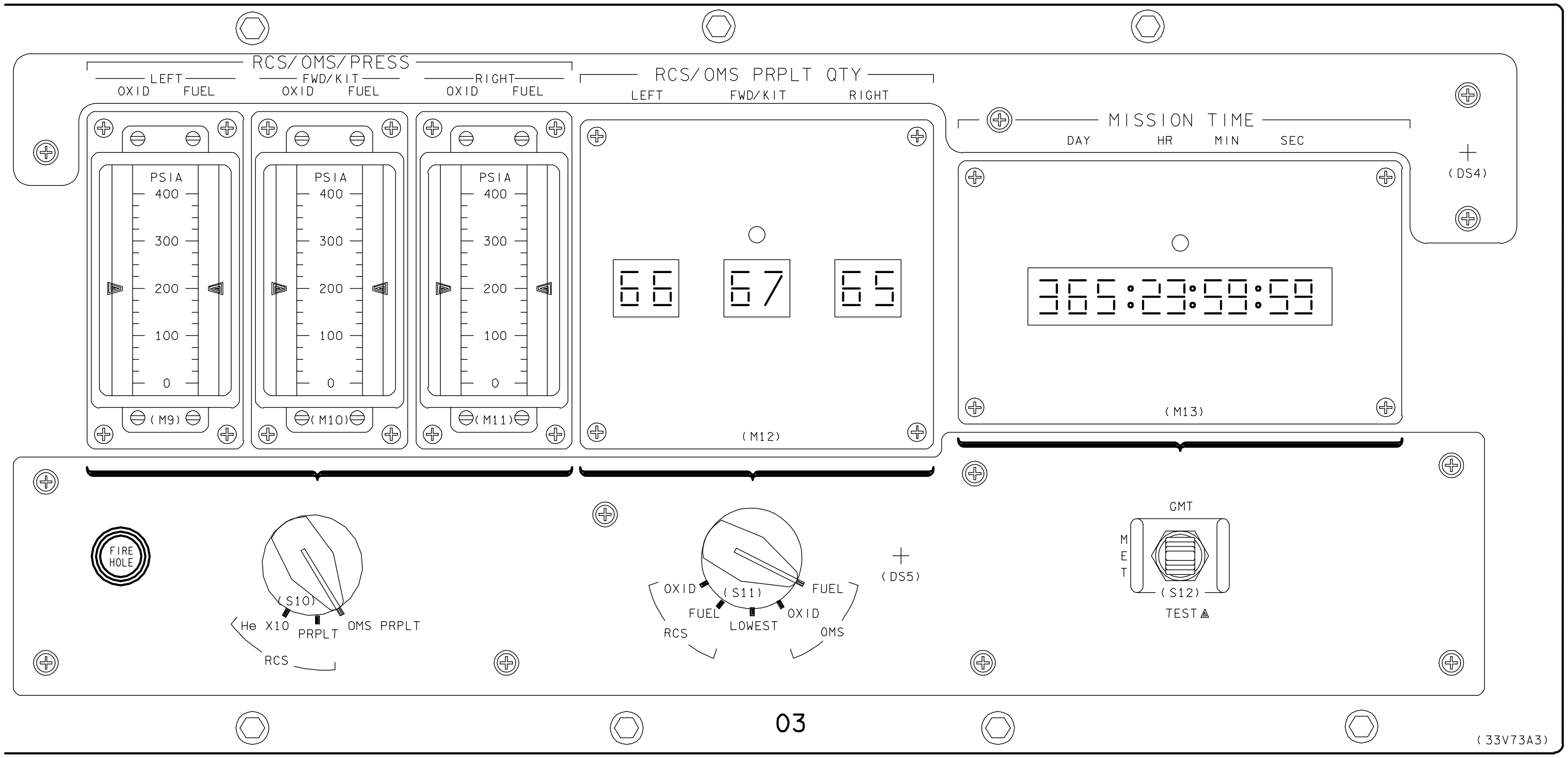
Panel F9


CABIN PRESS
PPO2
PSIA
(M4)
SENSOR A
(S6)
SENSOR B
CABIN dP/dT PSIA/MIN
O2/N2 FLOW
PPH
(M3)
O2 N2 SYS 1
O2 N2 SYS 2
(S5)
FREON
FLOW
EVAP OUT TEMP
(M2)
LOOP 1
(S4)
LOOP 2
LOOP 1
(S3)
LOOP 2
AIR TEMP
H2O PUMP OUT PRESS
(M1)
CAB HX OUT
1 2 3
AV BAY
(S2)
O1
COAS
ON
OFF
(DS3)
3
OV102 ONLY
GPC STATUS
FAILED GPC
1 2 3 4 5
(W)
(Y)
(XDS1)
VOTING GPC
(DS2)
COAS
ON
(S1)
OFF
5
(J1)
FIRE HOLE

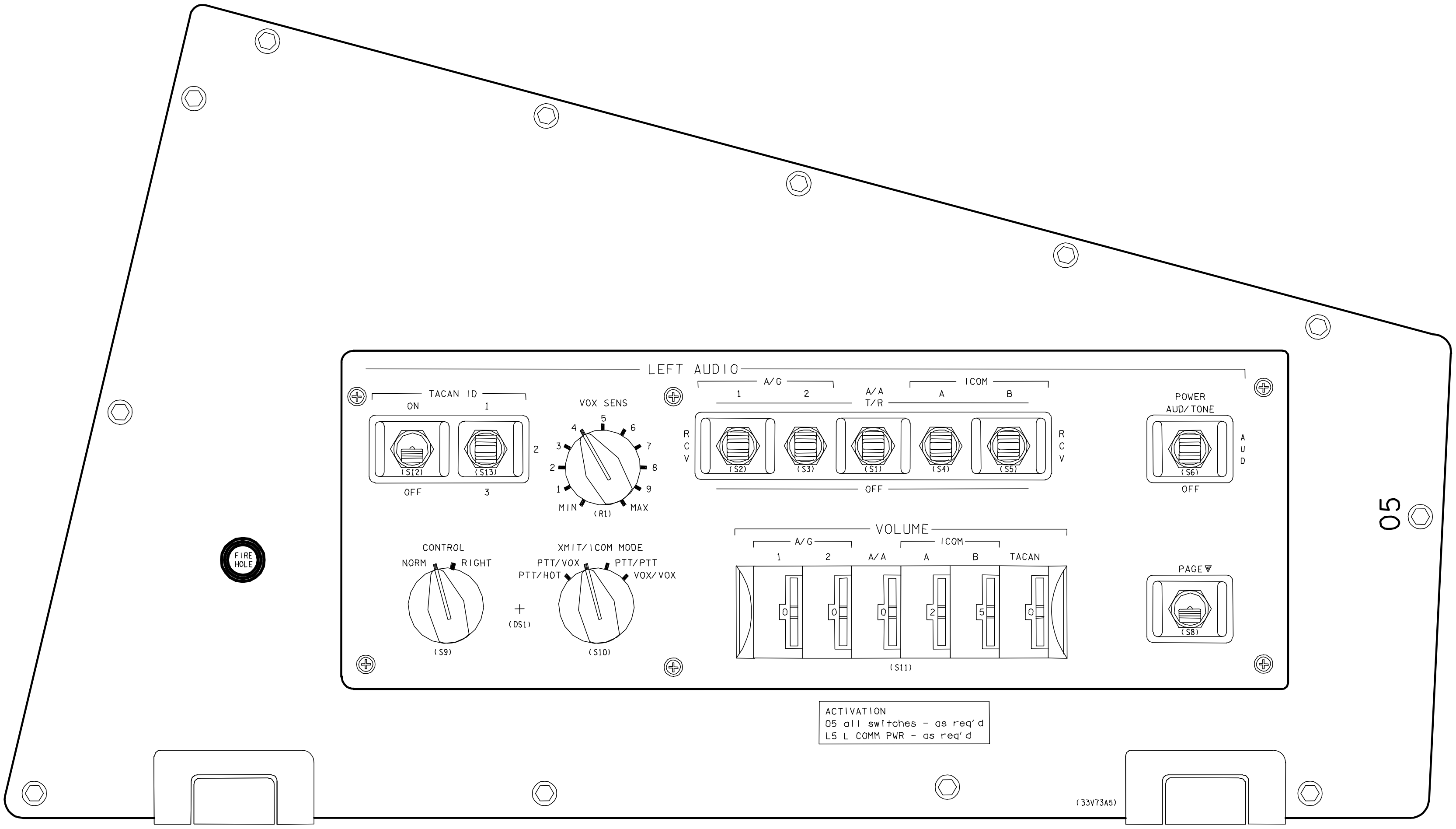
Panel O1


CRYO
FUEL CELL
O2 HTR ASSY TEMP
O2
PRESS
QTY
H2
PRESS
QTY
STACK TEMP
°F
X100°
(M5)
PSIA
%
X100
X10
(M6)
PSIA
%
X10
X10
(M7)
°F
(M8)
TK 1
TK 2
TK 3
TK 4
TK 5
(S7)
TK1
TK2
TK3
TK4
TK5
(S8)
1
2
3
(S9)
02

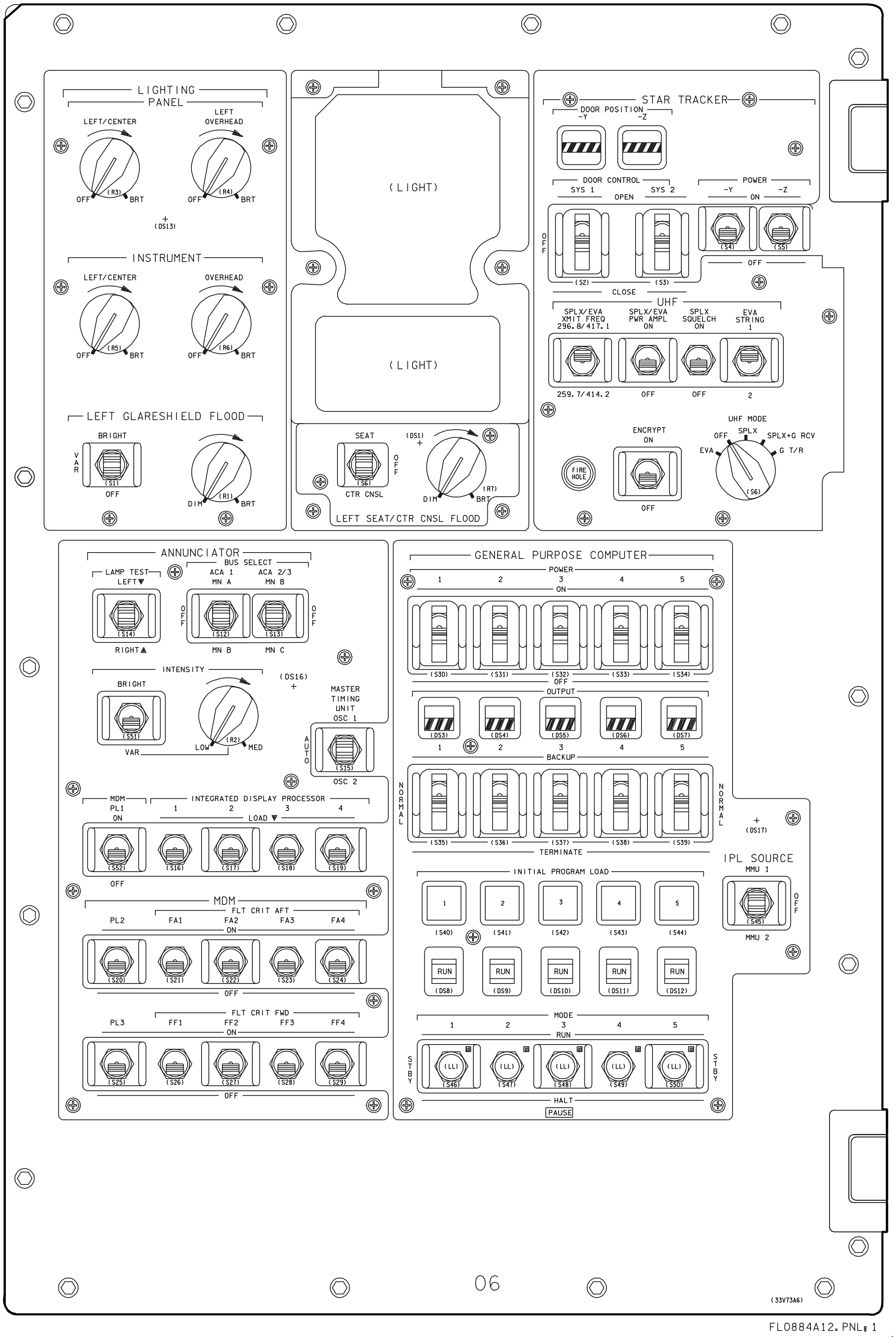
Panel O2


RCS/OMS/PRESS
LEFT
OXID
FUEL
FWD/KIT
OXID
FUEL
RIGHT
OXID
FUEL
PSIA
400
300
200
100
0
(M9)
(M10)
(M11)
RCS/OMS PRPLT QTY
LEFT
FWD/KIT
RIGHT
66
67
65
(M12)
MISSION TIME
DAY
HR
MIN
SEC
365:23:59:59
(M13)
(DS4)
FIRE HOLE
(S10)
He X10
PRPLT
OMS PRPLT
RCS
(S11)
OXID
FUEL
LOWEST
OXID
FUEL
RCS
OMS
(DS5)
GMT
MET
(S12)
TEST
O3
(33V73A3)

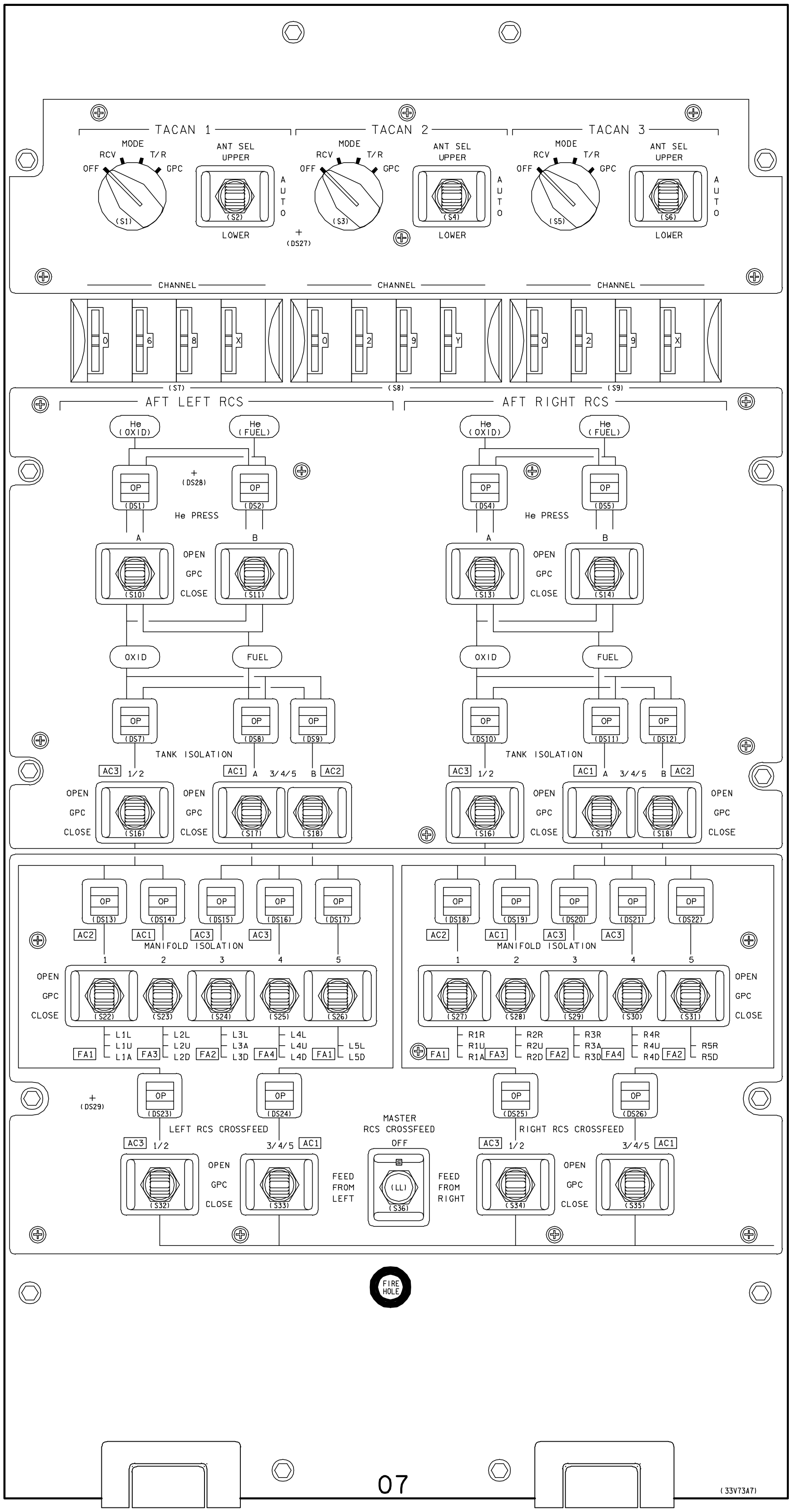
Panel O3


O5
LEFT AUDIO
TACAN ID
ON
1
2
3
OFF
(S12)
(S13)
VOX SENS
1
2
3
4
5
6
7
8
9
MIN
MAX
(R1)
A/G
1
2
A/A
T/R
ICOM
A
B
RCV
(S2)
(S3)
(S1)
(S4)
(S5)
OFF
POWER
AUD/TONE
AUD
(S6)
OFF
CONTROL
NORM
RIGHT
(S9)
(DS1)
XMIT/ICOM MODE
PTT/VOX
PTT/HOT
PTT/PTT
VOX/VOX
(S10)
VOLUME
A/G
1
2
A/A
ICOM
A
B
TACAN
0
0
0
2
5
0
(S11)
PAGE
(S8)
FIRE HOLE
ACTIVATION
O5 all switches - as req'd
L5 L COMM PWR - as req'd
(33V73A5)

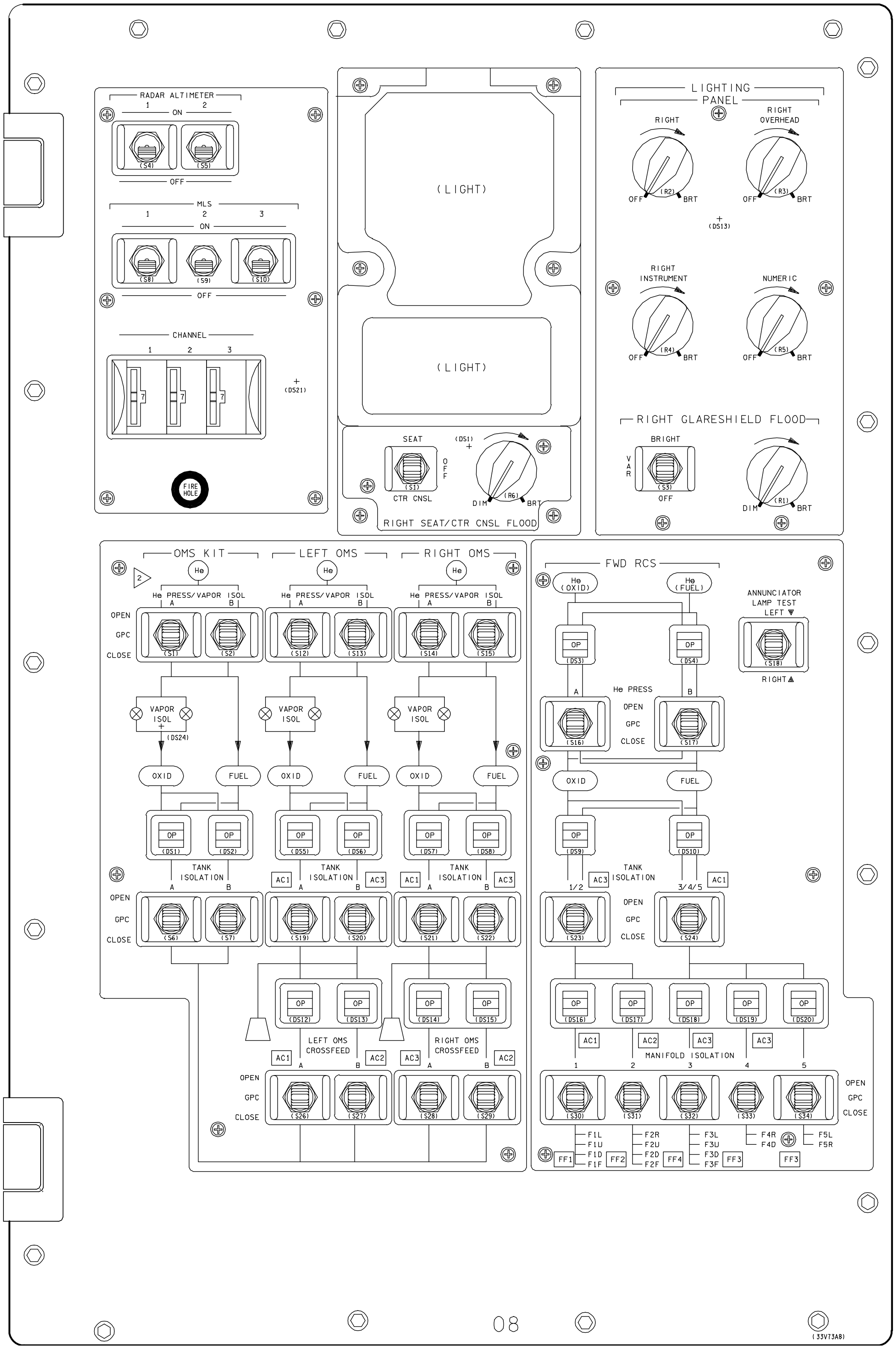
Panel O5


LIGHTING
PANEL
LEFT/CENTER
LEFT OVERHEAD
OFF
(R3)
BRT
OFF
(R4)
BRT
(DS13)
INSTRUMENT
LEFT/CENTER
OVERHEAD
OFF
(R5)
BRT
OFF
(R6)
BRT
LEFT GLARESHIELD FLOOD
BRIGHT
VAR
(S1)
OFF
DIM
(R1)
BRT
(LIGHT)
(LIGHT)
SEAT
(S6)
OFF
CTR CNSL
(DS1)
DIM
(R7)
BRT
LEFT SEAT/CTR CNSL FLOOD
STAR TRACKER
DOOR POSITION
-Y
-Z
DOOR CONTROL
SYS 1
OPEN
SYS 2
POWER
-Y
ON
-Z
OFF
(S2)
(S3)
CLOSE
(S4)
(S5)
OFF
UHF
SPLX/EVA XMIT FREQ 296.8/417.1
SPLX/EVA PWR AMPL ON
SPLX SQUELCH ON
EVA STRING 1
259.7/414.2
OFF
OFF
2
ENCRYPT ON
OFF
FIRE HOLE
UHF MODE
OFF
SPLX
SPLX+G RCV
EVA
G T/R
(S6)
ANNUNCIATOR
LAMP TEST
LEFT▼
(S14)
RIGHT▲
BUS SELECT
ACA 1 MN A
ACA 2/3 MN B
OFF
(S12)
(S13)
OFF
MN B
MN C
INTENSITY
BRIGHT
(S51)
VAR
LOW
(R2)
MED
(DS16)
MASTER TIMING UNIT
OSC 1
AUTO
(S15)
OSC 2
MDM PL1 ON
INTEGRATED DISPLAY PROCESSOR
1
2
3
4
LOAD ▼
(S52)
(S16)
(S17)
(S18)
(S19)
OFF
MDM
FLT CRIT AFT
PL2
FA1
FA2
FA3
FA4
ON
(S20)
(S21)
(S22)
(S23)
(S24)
OFF
FLT CRIT FWD
PL3
FF1
FF2
FF3
FF4
ON
(S25)
(S26)
(S27)
(S28)
(S29)
OFF
GENERAL PURPOSE COMPUTER
POWER
1
2
3
4
5
ON
(S30)
(S31)
(S32)
(S33)
(S34)
OFF
OUTPUT
(DS3)
(DS4)
(DS5)
(DS6)
(DS7)
1
2
3
4
5
BACKUP
NORMAL
(S35)
(S36)
(S37)
(S38)
(S39)
TERMINATE
NORMAL
(DS17)
IPL SOURCE
MMU 1
(S45)
OFF
MMU 2
INITIAL PROGRAM LOAD
1
2
3
4
5
(S40)
(S41)
(S42)
(S43)
(S44)
RUN
(DS8)
RUN
(DS9)
RUN
(DS10)
RUN
(DS11)
RUN
(DS12)
MODE
1
2
3
4
5
RUN
STBY
(LL)
(S46)
(LL)
(S47)
(LL)
(S48)
(LL)
(S49)
(LL)
(S50)
STBY
HALT
PAUSE
O6
(33V73A6)
FL0884A12.PNL;1

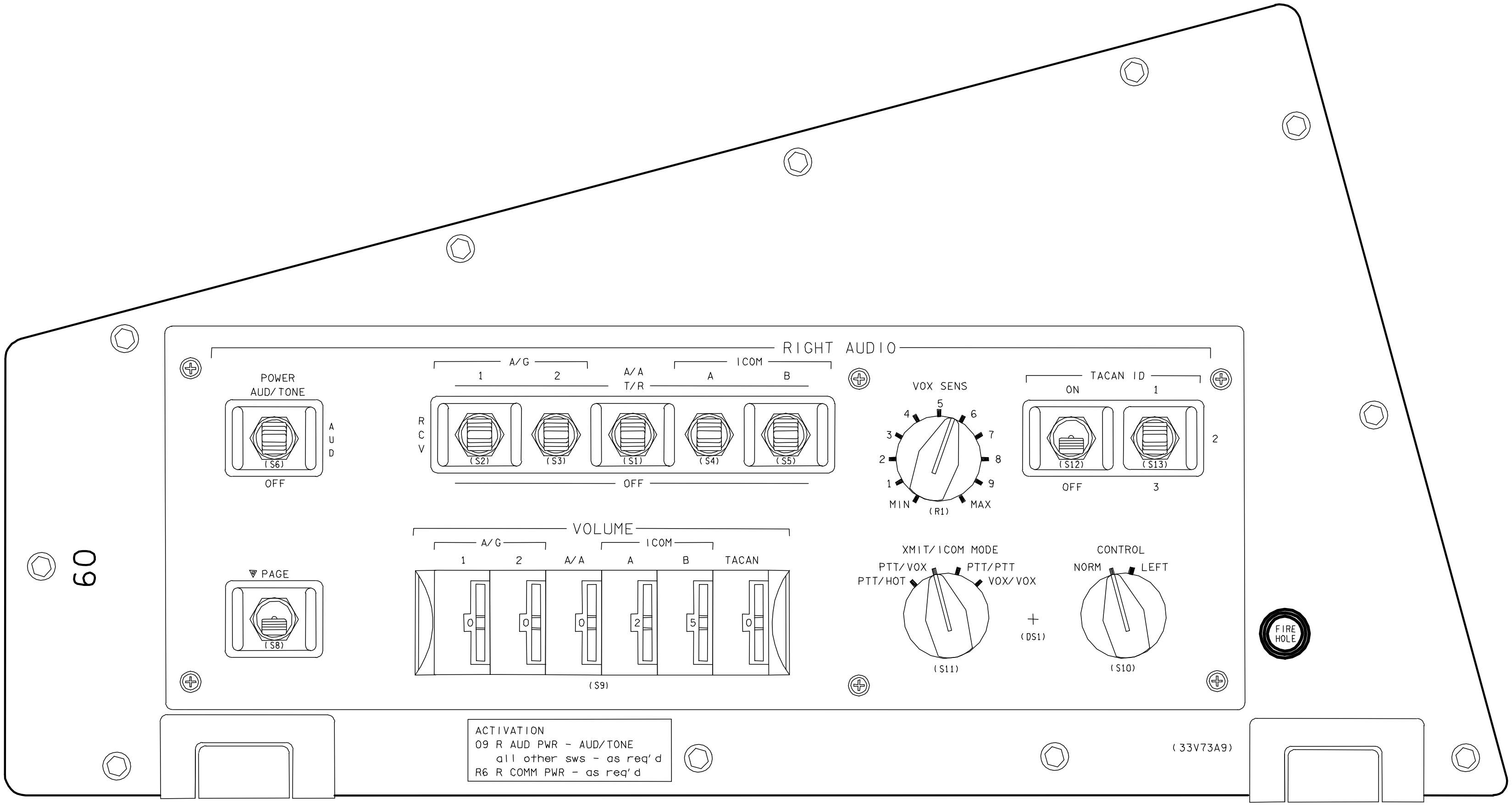
Panel O6


TACAN 1
MODE
RCV
T/R
OFF
GPC
(S1)
ANT SEL
UPPER
AUTO
(S2)
LOWER
+
(DS27)
TACAN 2
(S3)
(S4)
TACAN 3
(S5)
(S6)
CHANNEL
0 6 8 X
0 2 9 Y
0 2 9 X
(S7)
(S8)
(S9)
AFT LEFT RCS
AFT RIGHT RCS
He (OXID)
He (FUEL)
OP
(DS1)
(DS2)
(DS28)
He PRESS
(DS4)
(DS5)
A
B
OPEN
GPC
CLOSE
(S10)
(S11)
(S13)
(S14)
OXID
FUEL
(DS7)
(DS8)
(DS9)
(DS10)
(DS11)
(DS12)
TANK ISOLATION
AC3
1/2
AC1
A
3/4/5
B
AC2
(S16)
(S17)
(S18)
(DS13)
(DS14)
(DS15)
(DS16)
(DS17)
(DS18)
(DS19)
(DS20)
(DS21)
(DS22)
MANIFOLD ISOLATION
1
2
3
4
5
(S22)
(S23)
(S24)
(S25)
(S26)
(S27)
(S28)
(S29)
(S30)
(S31)
L1L L1U L1A
L2L L2U L2D
L3L L3A L3D
L4L L4U L4D
L5L L5D
R1R R1U R1A
R2R R2U R2D
R3R R3A R3D
R4R R4U R4D
R5R R5D
FA1
FA3
FA2
FA4
(DS29)
(DS23)
(DS24)
LEFT RCS CROSSFEED
MASTER
RCS CROSSFEED
OFF
FEED FROM LEFT
FEED FROM RIGHT
(LL)
(S36)
(DS25)
(DS26)
RIGHT RCS CROSSFEED
(S32)
(S33)
(S34)
(S35)
FIRE HOLE
O7
(33V73A7)

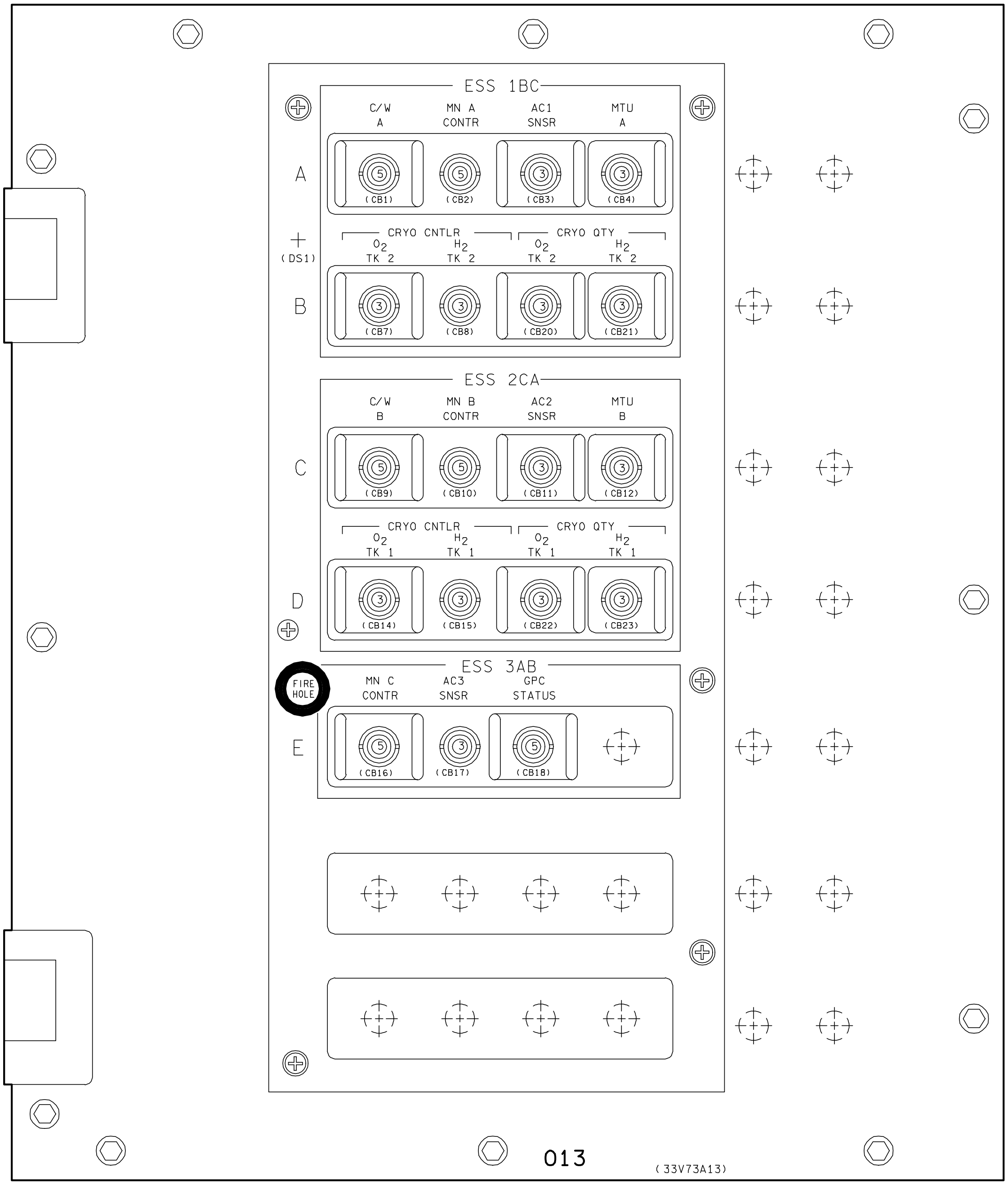
Panel O7


RADAR ALTIMETER
1
2
ON
(S4)
(S5)
OFF
MLS
1
2
3
ON
(S8)
(S9)
(S10)
OFF
CHANNEL
1
2
3
(DS21)
FIRE HOLE
(LIGHT)
(LIGHT)
SEAT
OFF
(S1)
CTR CNSL
(DS1)
DIM
(R6)
BRT
RIGHT SEAT/CTR CNSL FLOOD
LIGHTING PANEL
RIGHT
RIGHT OVERHEAD
OFF
(R2)
BRT
OFF
(R3)
BRT
(DS13)
RIGHT INSTRUMENT
NUMERIC
OFF
(R4)
BRT
OFF
(R5)
BRT
RIGHT GLARESHIELD FLOOD
BRIGHT
VAR
(S3)
OFF
DIM
(R1)
BRT
OMS KIT
LEFT OMS
RIGHT OMS
He
He PRESS/VAPOR ISOL
A
B
OPEN
GPC
CLOSE
(S1)
(S2)
(S12)
(S13)
(S14)
(S15)
VAPOR ISOL
(DS24)
OXID
FUEL
OP
(DS1)
(DS2)
(DS5)
(DS6)
(DS7)
(DS8)
TANK ISOLATION
AC1
AC3
(S6)
(S7)
(S19)
(S20)
(S21)
(S22)
(DS12)
(DS13)
(DS14)
(DS15)
LEFT OMS CROSSFEED
RIGHT OMS CROSSFEED
AC1
AC2
AC3
AC2
(S26)
(S27)
(S28)
(S29)
FWD RCS
He (OXID)
He (FUEL)
ANNUNCIATOR LAMP TEST
LEFT ▼
(S18)
RIGHT ▲
(DS3)
(DS4)
He PRESS
A
B
OPEN
GPC
CLOSE
(S16)
(S17)
OXID
FUEL
(DS9)
(DS10)
TANK ISOLATION
AC3
AC1
1/2
3/4/5
(S23)
(S24)
(DS16)
(DS17)
(DS18)
(DS19)
(DS20)
AC1
AC2
AC3
AC3
MANIFOLD ISOLATION
1
2
3
4
5
(S30)
(S31)
(S32)
(S33)
(S34)
F1L
F1U
F1D
F1F
F2R
F2U
F2D
F2F
F3L
F3U
F3D
F3F
F4R
F4D
F5L
F5R
FF1
FF2
FF4
FF3
FF3
O8
(33V73A8)

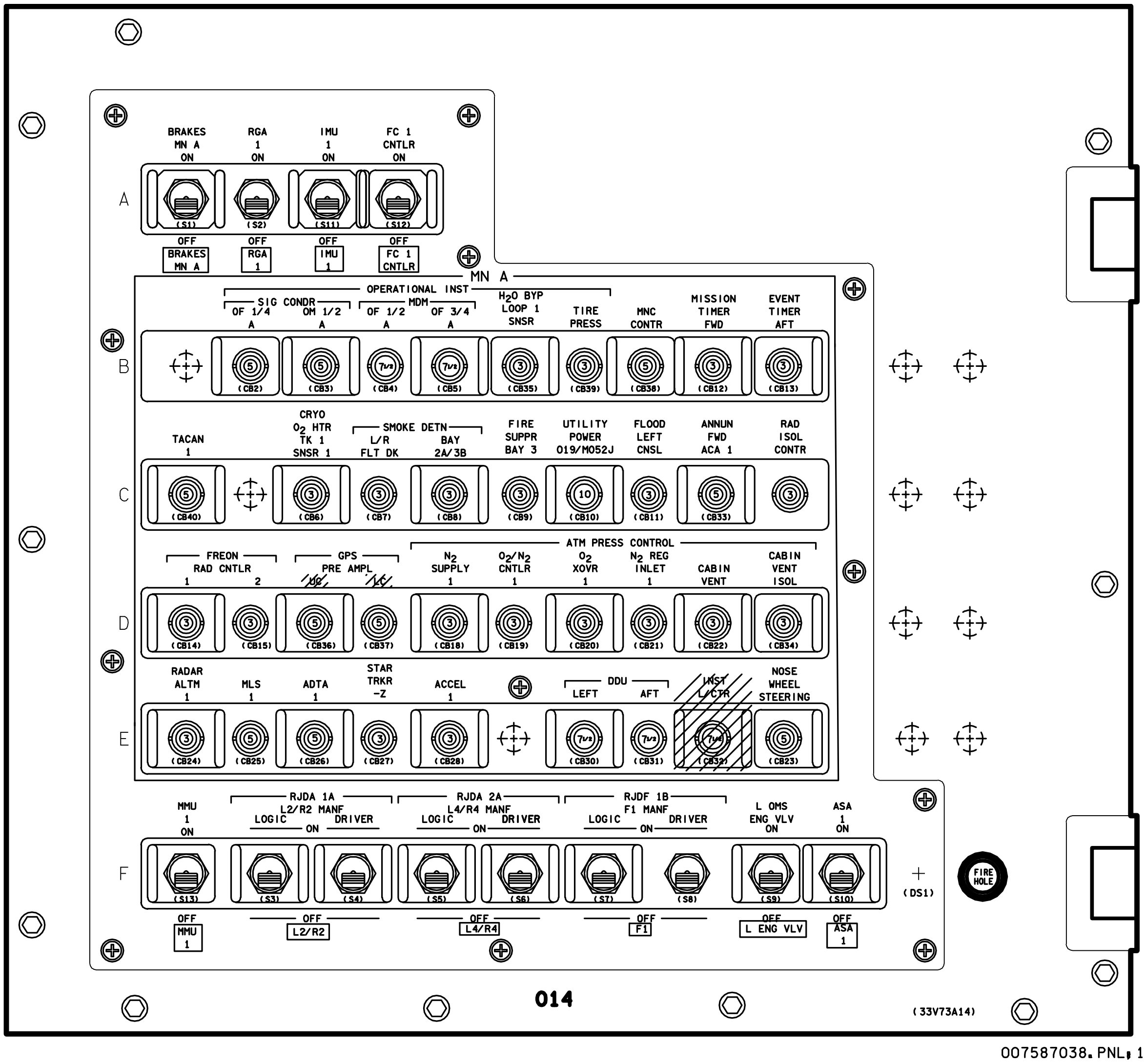
Panel O8


RIGHT AUDIO
POWER
AUD/TONE
AUD
OFF
(S6)
A/G
1
2
A/A
T/R
ICOM
A
B
RCV
(S2)
(S3)
(S1)
(S4)
(S5)
OFF
VOX SENS
1
2
3
4
5
6
7
8
9
MIN
MAX
(R1)
TACAN ID
ON
1
2
3
OFF
(S12)
(S13)
PAGE
(S8)
VOLUME
A/G
1
2
A/A
ICOM
A
B
TACAN
0
0
0
2
5
0
(S9)
XMIT/ICOM MODE
PTT/HOT
PTT/VOX
PTT/PTT
VOX/VOX
(S11)
(DS1)
CONTROL
NORM
LEFT
(S10)
FIRE HOLE
09
ACTIVATION
O9 R AUD PWR - AUD/TONE
all other sws - as req'd
R6 R COMM PWR - as req'd
(33V73A9)

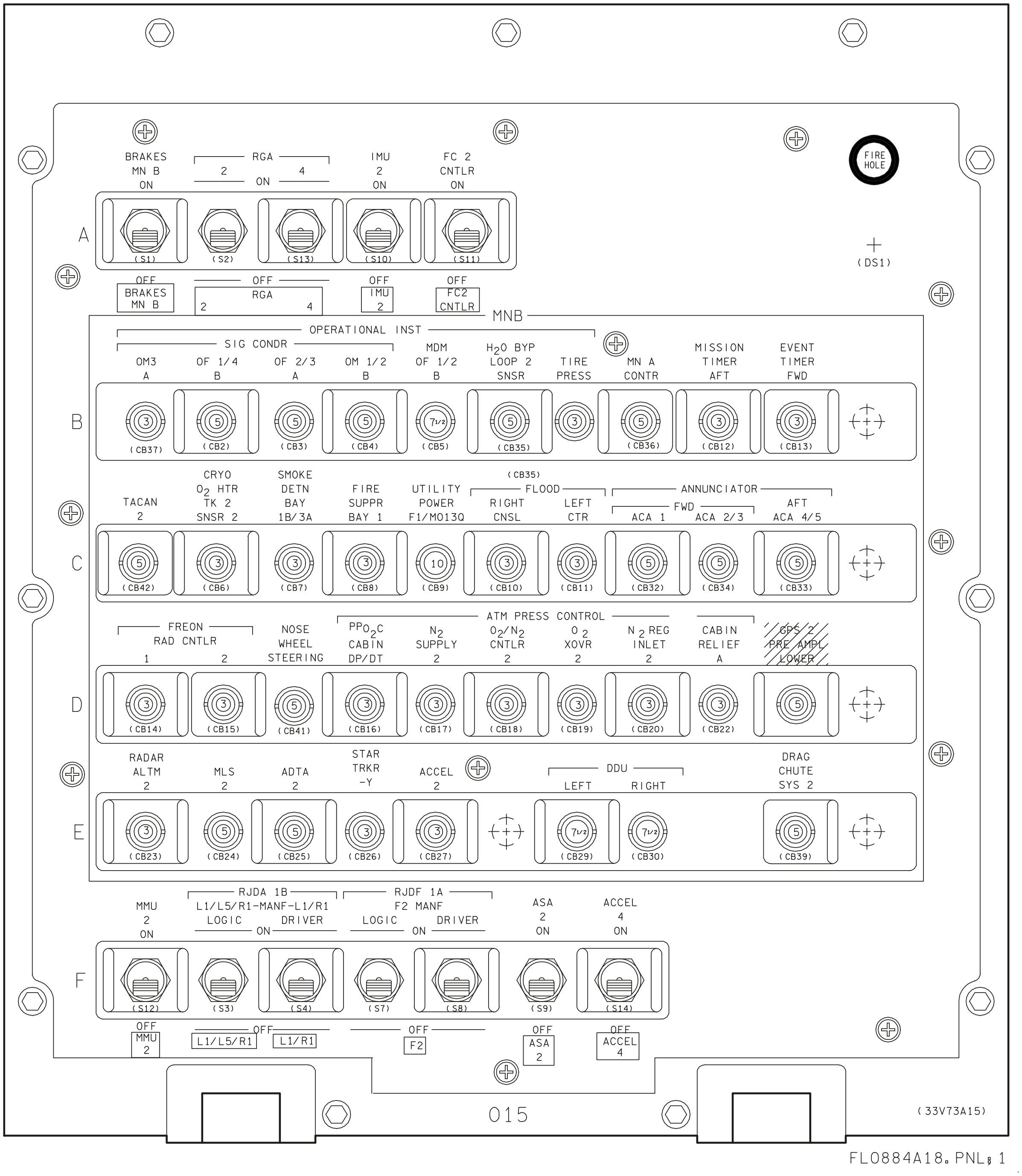
Panel O9


ESS 1BC
C/W A
MN A CONTR
AC1 SNSR
MTU A
A
(CB1)
(CB2)
(CB3)
(CB4)
(DS1)
CRYO CNTLR
CRYO QTY
O2 TK 2
H2 TK 2
O2 TK 2
H2 TK 2
B
(CB7)
(CB8)
(CB20)
(CB21)
ESS 2CA
C/W B
MN B CONTR
AC2 SNSR
MTU B
C
(CB9)
(CB10)
(CB11)
(CB12)
CRYO CNTLR
CRYO QTY
O2 TK 1
H2 TK 1
O2 TK 1
H2 TK 1
D
(CB14)
(CB15)
(CB22)
(CB23)
ESS 3AB
FIRE HOLE
MN C CONTR
AC3 SNSR
GPC STATUS
E
(CB16)
(CB17)
(CB18)
O13
(33V73A13)

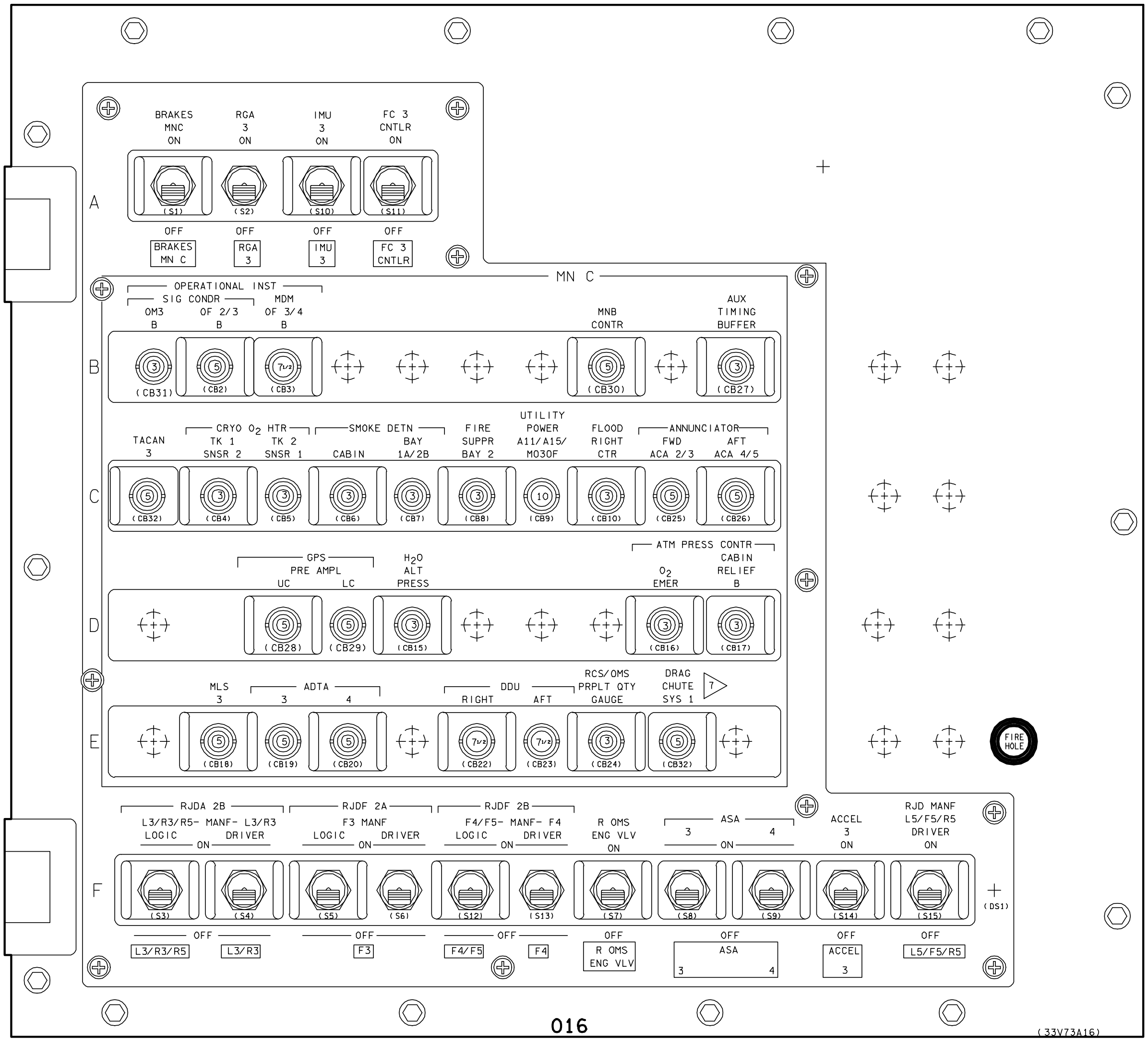
Panel O13


BRAKES MN A ON
RGA 1 ON
IMU 1 ON
FC 1 CNTLR ON
A
(S1)
(S2)
(S11)
(S12)
OFF BRAKES MN A
OFF RGA 1
OFF IMU 1
OFF FC 1 CNTLR
MN A
OPERATIONAL INST
SIG CONDR
OF 1/4 A
OM 1/2 A
MDM
OF 1/2 A
OF 3/4 A
H2O BYP LOOP 1 SNSR
TIRE PRESS
MNC CONTR
MISSION TIMER FWD
EVENT TIMER AFT
B
(CB2)
(CB3)
(CB4)
(CB5)
(CB35)
(CB39)
(CB38)
(CB12)
(CB13)
TACAN 1
CRYO O2 HTR TK 1 SNSR 1
SMOKE DETN
L/R FLT DK
BAY 2A/3B
FIRE SUPPR BAY 3
UTILITY POWER O19/MO52J
FLOOD LEFT CNSL
ANNUN FWD ACA 1
RAD ISOL CONTR
C
(CB40)
(CB6)
(CB7)
(CB8)
(CB9)
(CB10)
(CB11)
(CB33)
FREON RAD CNTLR
1
2
GPS PRE AMPL
UC
LC
ATM PRESS CONTROL
N2 SUPPLY 1
O2/N2 CNTLR 1
O2 XOVR 1
N2 REG INLET 1
CABIN VENT
CABIN VENT ISOL
D
(CB14)
(CB15)
(CB36)
(CB37)
(CB18)
(CB19)
(CB20)
(CB21)
(CB22)
(CB34)
RADAR ALTM 1
MLS 1
ADTA 1
STAR TRKR -Z
ACCEL 1
DDU
LEFT
AFT
INST L/CTR
NOSE WHEEL STEERING
E
(CB24)
(CB25)
(CB26)
(CB27)
(CB28)
(CB30)
(CB31)
(CB32)
(CB23)
MMU 1 ON
RJDA 1A L2/R2 MANF
LOGIC
ON
DRIVER
RJDA 2A L4/R4 MANF
LOGIC
ON
DRIVER
RJDF 1B F1 MANF
LOGIC
ON
DRIVER
L OMS ENG VLV ON
ASA 1 ON
F
(S13)
(S3)
(S4)
(S5)
(S6)
(S7)
(S8)
(S9)
(S10)
(DS1)
FIRE HOLE
OFF MMU 1
OFF L2/R2
OFF L4/R4
OFF F1
OFF L ENG VLV
OFF ASA 1
O14
(33V73A14)
007587038.PNL; 1

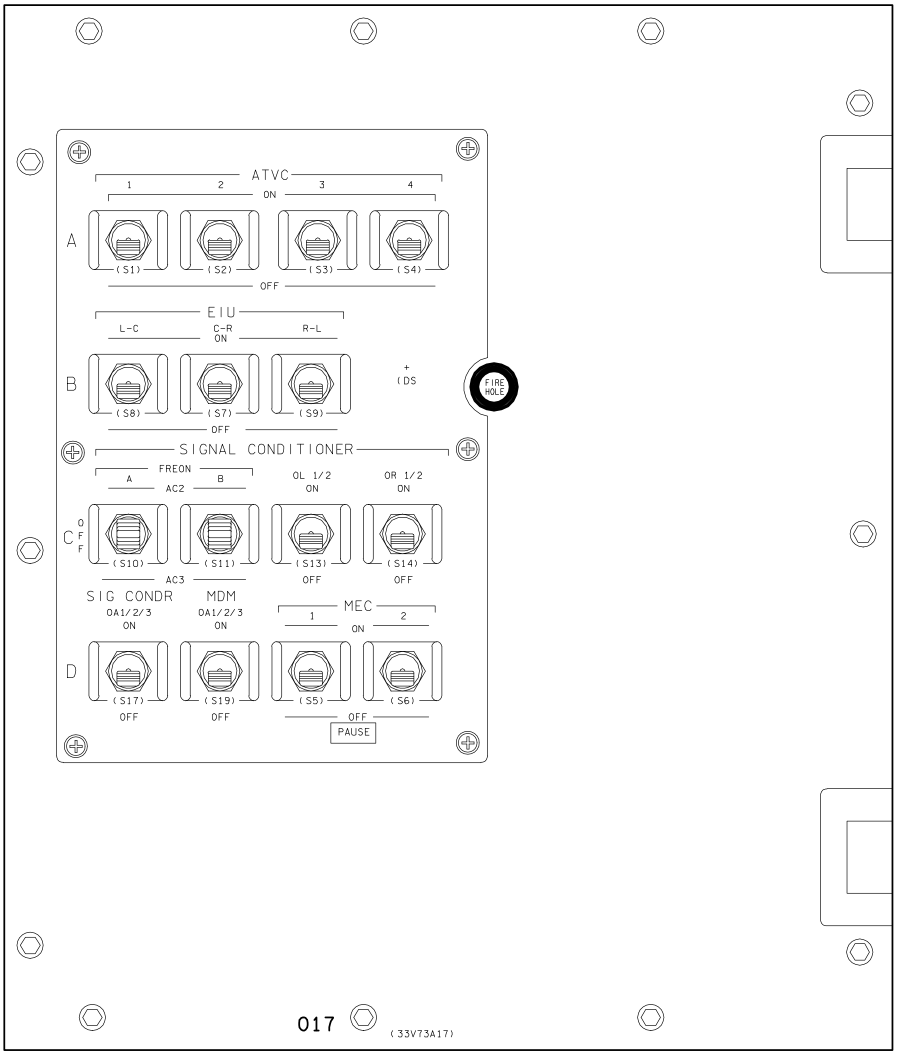
Panel O14


BRAKES MN B ON
RGA 2 ON 4
IMU 2 ON
FC 2 CNTLR ON
FIRE HOLE
A
(S1)
(S2)
(S13)
(S10)
(S11)
(DS1)
OFF BRAKES MN B
OFF RGA 2 4
OFF IMU 2
OFF FC2 CNTLR
MNB
OPERATIONAL INST
SIG CONDR
OM3 A
OF 1/4 B
OF 2/3 A
OM 1/2 B
MDM OF 1/2 B
H2O BYP LOOP 2 SNSR
TIRE PRESS
MN A CONTR
MISSION TIMER AFT
EVENT TIMER FWD
B
(CB37)
(CB2)
(CB3)
(CB4)
(CB5)
(CB35)
(CB36)
(CB12)
(CB13)
TACAN 2
CRYO O2 HTR TK 2 SNSR 2
SMOKE DETN BAY 1B/3A
FIRE SUPPR BAY 1
UTILITY POWER F1/MO13Q
(CB35)
FLOOD
RIGHT CNSL
LEFT CTR
ANNUNCIATOR
FWD
ACA 1
ACA 2/3
AFT ACA 4/5
C
(CB42)
(CB6)
(CB7)
(CB8)
(CB9)
(CB10)
(CB11)
(CB32)
(CB34)
(CB33)
FREON RAD CNTLR 1 2
NOSE WHEEL STEERING
ATM PRESS CONTROL
PPO2C CABIN DP/DT
N2 SUPPLY 2
O2/N2 CNTLR 2
O2 XOVR 2
N2 REG INLET 2
CABIN RELIEF A
GPS 2 PRE AMPL LOWER
D
(CB14)
(CB15)
(CB41)
(CB16)
(CB17)
(CB18)
(CB19)
(CB20)
(CB22)
RADAR ALTM 2
MLS 2
ADTA 2
STAR TRKR -Y
ACCEL 2
DDU
LEFT
RIGHT
DRAG CHUTE SYS 2
E
(CB23)
(CB24)
(CB25)
(CB26)
(CB27)
(CB29)
(CB30)
(CB39)
MMU 2 ON
RJDA 1B
L1/L5/R1-MANF-L1/R1
LOGIC ON DRIVER
RJDF 1A
F2 MANF
LOGIC ON DRIVER
ASA 2 ON
ACCEL 4 ON
F
(S12)
(S3)
(S4)
(S7)
(S8)
(S9)
(S14)
OFF MMU 2
OFF L1/L5/R1 L1/R1
OFF F2
OFF ASA 2
OFF ACCEL 4
O15
(33V73A15)
FL0884A18.PNL;1

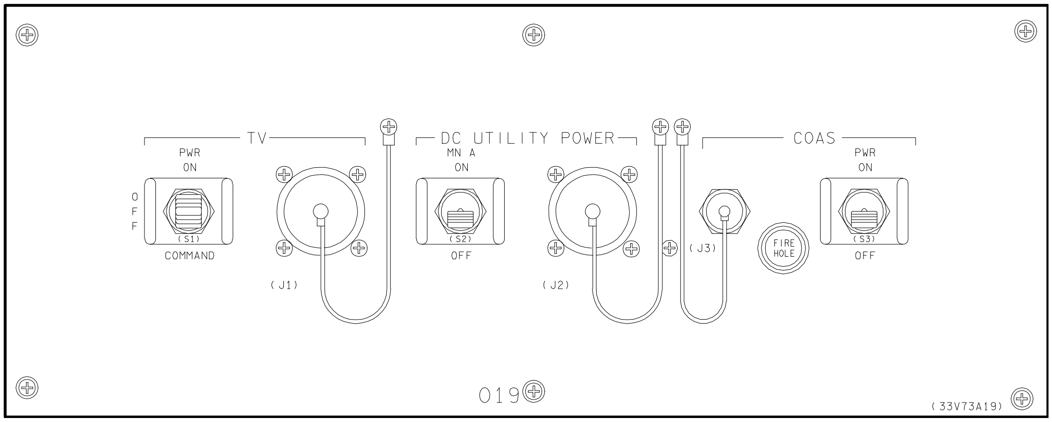
Panel O15


BRAKES MNC ON
RGA 3 ON
IMU 3 ON
FC 3 CNTLR ON
A
(S1)
(S2)
(S10)
(S11)
OFF
BRAKES MN C
RGA 3
IMU 3
FC 3 CNTLR
MN C
OPERATIONAL INST
SIG CONDR
OM3 B
OF 2/3 B
MDM OF 3/4 B
MNB CONTR
AUX TIMING BUFFER
B
(CB31)
(CB2)
(CB3)
(CB30)
(CB27)
TACAN 3
CRYO O2 HTR
TK 1 SNSR 2
TK 2 SNSR 1
SMOKE DETN
CABIN
BAY 1A/2B
FIRE SUPPR BAY 2
UTILITY POWER A11/A15/ MO30F
FLOOD RIGHT CTR
ANNUNCIATOR
FWD ACA 2/3
AFT ACA 4/5
C
(CB32)
(CB4)
(CB5)
(CB6)
(CB7)
(CB8)
(CB9)
(CB10)
(CB25)
(CB26)
GPS PRE AMPL
UC
LC
H2O ALT PRESS
ATM PRESS CONTR
O2 EMER
CABIN RELIEF B
D
(CB28)
(CB29)
(CB15)
(CB16)
(CB17)
MLS 3
ADTA
3
4
DDU
RIGHT
AFT
RCS/OMS PRPLT QTY GAUGE
DRAG CHUTE SYS 1
7
E
(CB18)
(CB19)
(CB20)
(CB22)
(CB23)
(CB24)
(CB32)
FIRE HOLE
RJDA 2B
L3/R3/R5- MANF- L3/R3
LOGIC
DRIVER
ON
RJDF 2A
F3 MANF
LOGIC
DRIVER
ON
RJDF 2B
F4/F5- MANF- F4
LOGIC
DRIVER
ON
R OMS ENG VLV ON
ASA
3
4
ON
ACCEL 3 ON
RJD MANF L5/F5/R5 DRIVER ON
F
(S3)
(S4)
(S5)
(S6)
(S12)
(S13)
(S7)
(S8)
(S9)
(S14)
(S15)
(DS1)
OFF
L3/R3/R5
L3/R3
F3
F4/F5
F4
R OMS ENG VLV
ASA
3
4
ACCEL 3
L5/F5/R5
O16
(33V73A16)

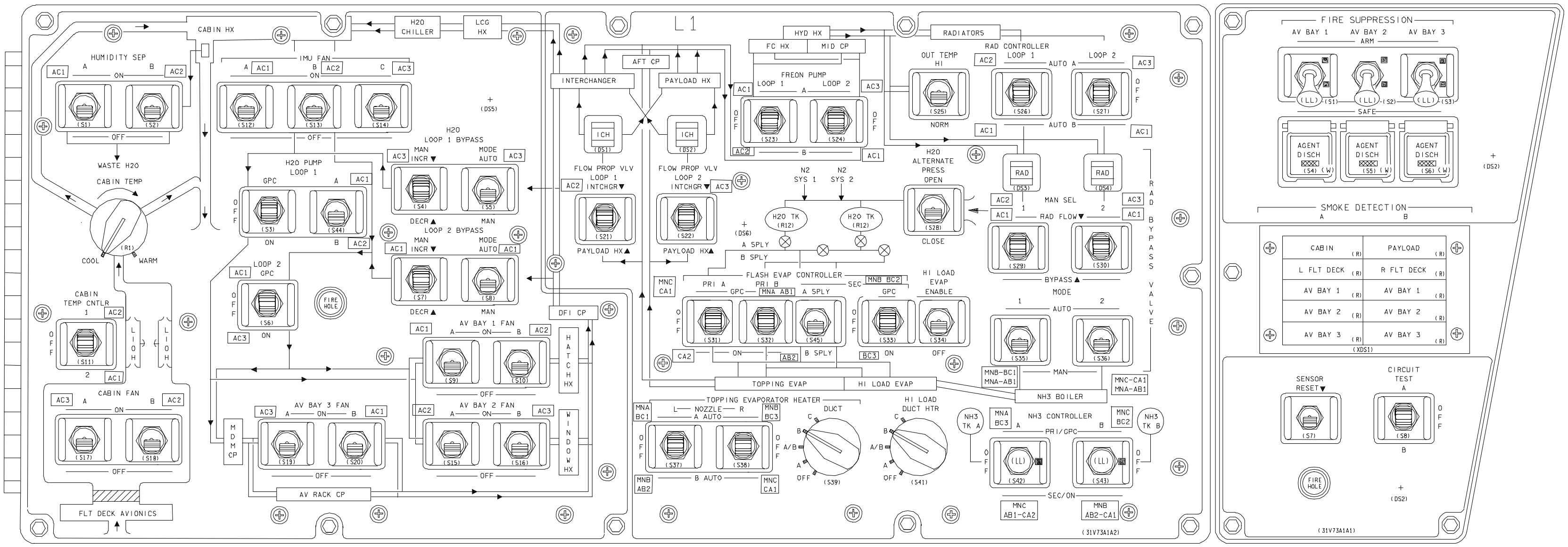
Panel O16



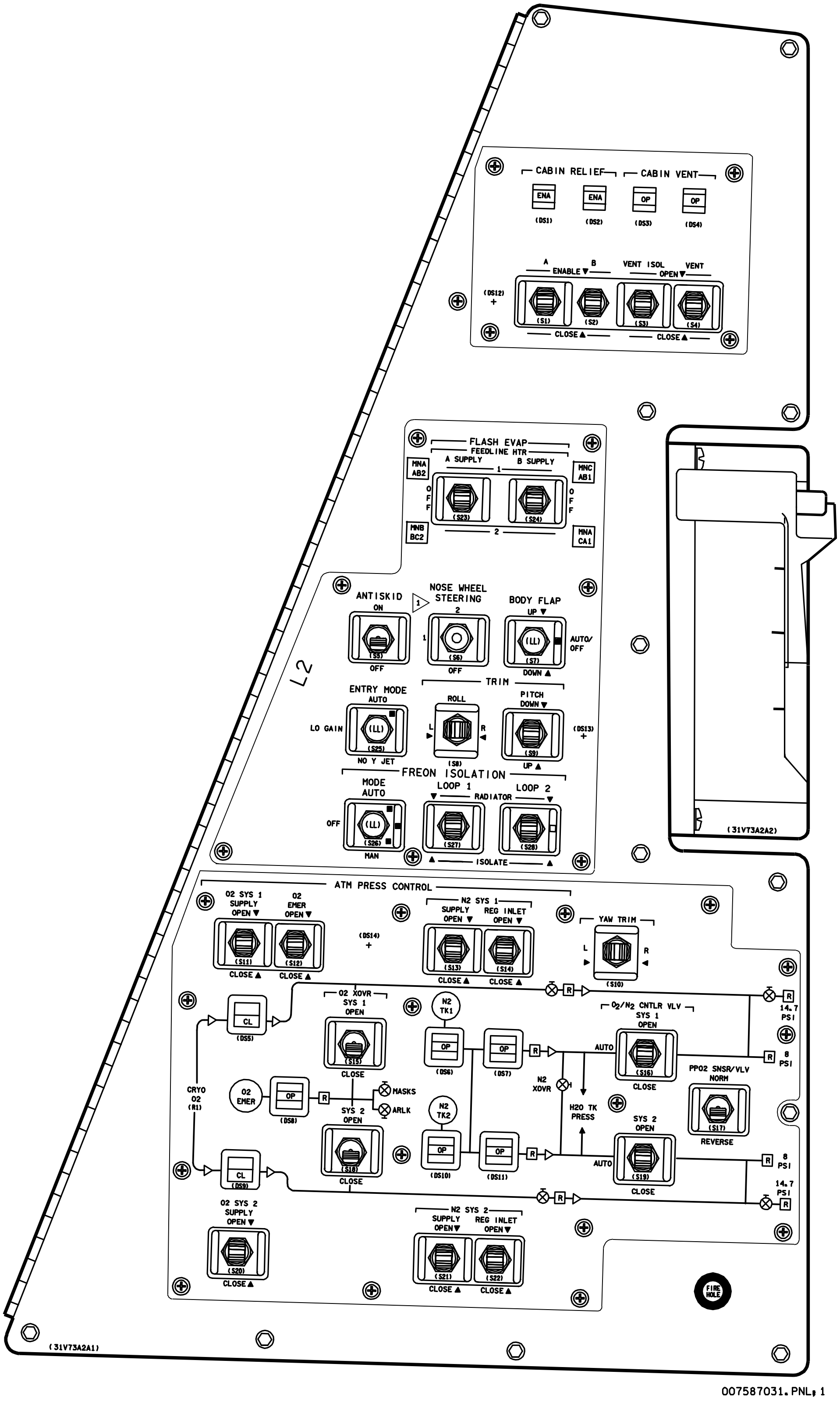
Panel O17



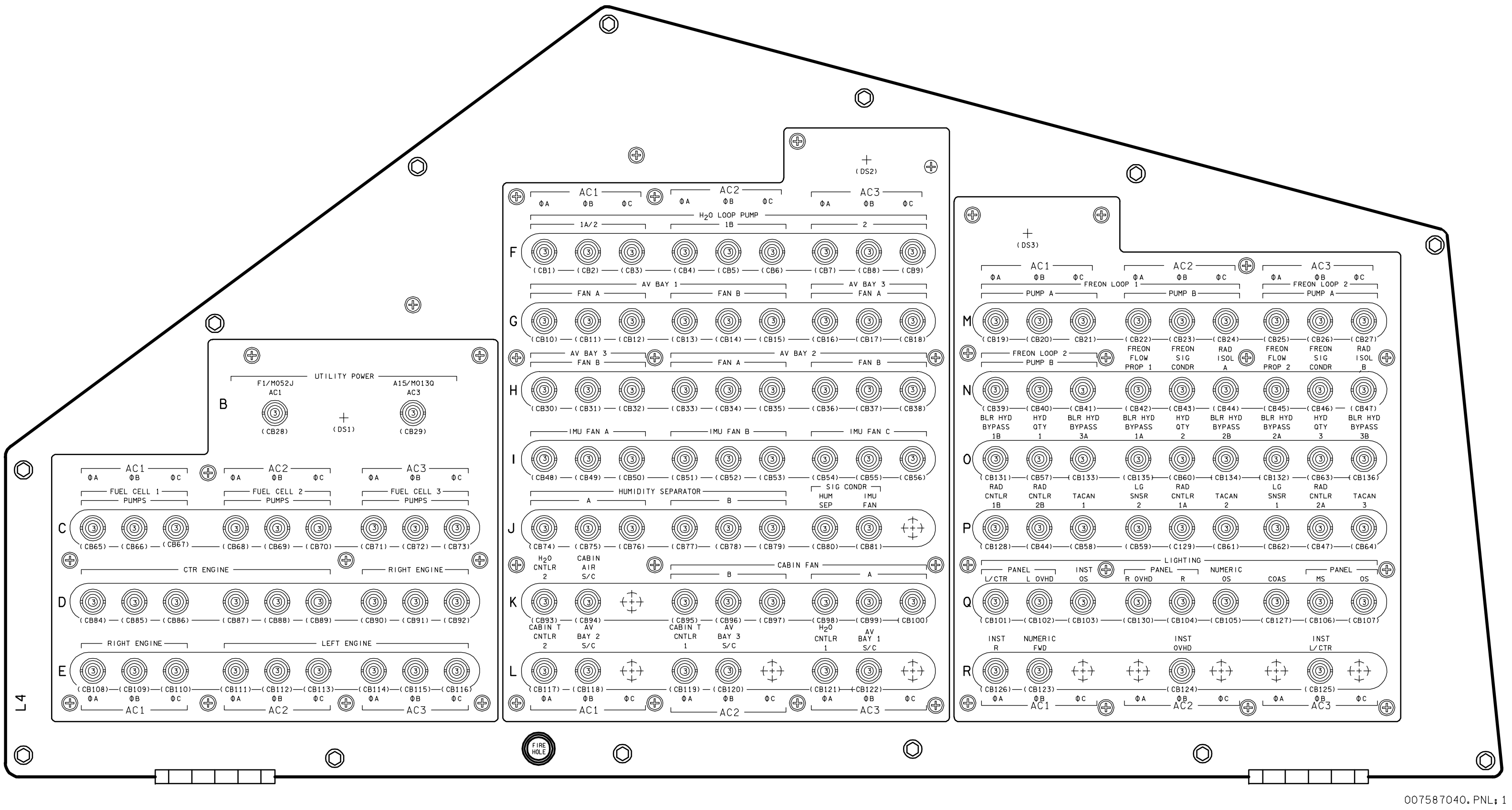
Panel O19


L1
FIRE SUPPRESSION
AV BAY 1
AV BAY 2
AV BAY 3
ARM
SAFE
(LL) (S1)
(LL) (S2)
(LL) (S3)
AGENT DISCH (S4) (W)
AGENT DISCH (S5) (W)
AGENT DISCH (S6) (W)
(DS2)
SMOKE DETECTION
A
B
CABIN (R)
PAYLOAD (R)
L FLT DECK (R)
R FLT DECK (R)
AV BAY 1 (R)
AV BAY 1 (R)
AV BAY 2 (R)
AV BAY 2 (R)
AV BAY 3 (R)
AV BAY 3 (R)
(XDS1)
SENSOR RESET▼
(S7)
CIRCUIT TEST
A
OFF
B
(S8)
FIRE HOLE
(DS2)
(31V73A1A1)
CABIN HX
H2O CHILLER
LCG HX
HUMIDITY SEP
AC1
A
ON
B
AC2
(S1)
(S2)
OFF
WASTE H2O
CABIN TEMP
COOL
(R1)
WARM
CABIN TEMP CNTLR
1
AC2
OFF
(S11)
2
AC1
LIOH
LIOH
CABIN FAN
AC3
A
ON
B
AC2
(S17)
(S18)
OFF
FLT DECK AVIONICS
IMU FAN
A
AC1
B
AC2
C
AC3
ON
(S12)
(S13)
(S14)
OFF
(DS5)
H2O LOOP 1 BYPASS
AC3
MAN INCR▼
MODE AUTO
AC3
(S4)
(S5)
DECR▲
MAN
LOOP 2 BYPASS
AC1
MAN INCR▼
MODE AUTO
AC1
(S7)
(S8)
DECR▲
MAN
H2O PUMP LOOP 1
GPC
A
AC1
OFF
(S3)
(S44)
ON
B
AC2
LOOP 2 GPC
AC1
OFF
(S6)
ON
AC3
FIRE HOLE
AV BAY 1 FAN
AC1
A
ON
B
AC2
(S9)
(S10)
OFF
HATCH HX
AV BAY 2 FAN
AC2
A
ON
B
AC3
(S15)
(S16)
OFF
WINDOW HX
AV BAY 3 FAN
AC3
A
ON
B
AC1
(S19)
(S20)
OFF
MDM CP
AV RACK CP
DFI CP
INTERCHANGER
AFT CP
PAYLOAD HX
ICH (DS1)
ICH (DS2)
FLOW PROP VLV LOOP 1 INTCHGR▼
AC2
(S21)
PAYLOAD HX▲
FLOW PROP VLV LOOP 2 INTCHGR▼
AC3
(S22)
PAYLOAD HX▲
HYD HX
FC HX
MID CP
FREON PUMP
AC1
LOOP 1
A
LOOP 2
AC3
OFF
(S23)
(S24)
OFF
AC2
B
AC1
RADIATORS
OUT TEMP HI
(S25)
NORM
RAD CONTROLLER
AC2
LOOP 1
AUTO A
LOOP 2
AC3
(S26)
(S27)
OFF
AC1
AUTO B
AC1
H2O ALTERNATE PRESS
OPEN
(S28)
CLOSE
N2 SYS 1
N2 SYS 2
H2O TK (R12)
H2O TK (R12)
(DS6)
A SPLY
B SPLY
RAD (DS3)
RAD (DS4)
AC2
MAN SEL
AC3
AC1
1
RAD FLOW▼
2
AC1
RAD BYPASS VALVE
(S29)
(S30)
BYPASS▲
MODE
1
AUTO
2
(S35)
(S36)
MAN
MNB-BC1
MNA-AB1
MNC-CA1
MNA-AB1
NH3 BOILER
FLASH EVAP CONTROLLER
MNC CA1
PRI A
GPC
PRI B
MNA AB1
A SPLY
SEC
MNB BC2
OFF
(S31)
(S32)
(S45)
OFF
GPC
(S33)
HI LOAD EVAP ENABLE
(S34)
CA2
ON
AB2
B SPLY
BC3
ON
OFF
TOPPING EVAP
HI LOAD EVAP
TOPPING EVAPORATOR HEATER
MNA BC1
L
NOZZLE
R
MNB BC3
A AUTO
OFF
(S37)
(S38)
OFF
MNB AB2
B AUTO
MNC CA1
DUCT
C
B
A/B
A
OFF
(S39)
HI LOAD DUCT HTR
C
B
A/B
A
OFF
(S41)
NH3 TK A
MNA BC3
NH3 CONTROLLER
MNC BC2
NH3 TK B
A
PRI/GPC
B
OFF
(LL) (S42)
(LL) (S43)
OFF
SEC/ON
MNC AB1-CA2
MNB AB2-CA1
(31V73A1A2)

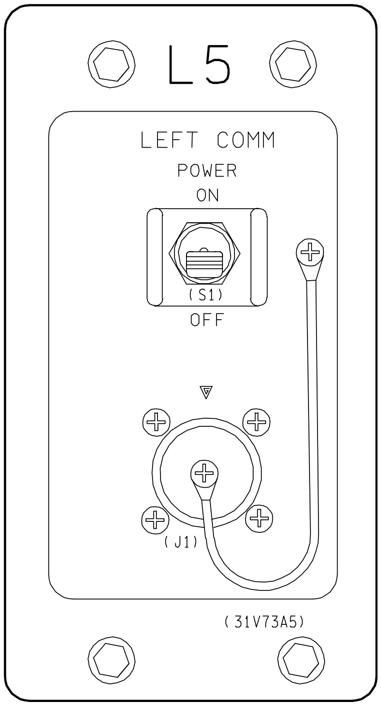
Panel L1


CABIN RELIEF
CABIN VENT
ENA
ENA
OP
OP
(DS1)
(DS2)
(DS3)
(DS4)
A
B
ENABLE ▼
VENT ISOL
VENT
OPEN ▼
(DS12)
+
(S1)
(S2)
(S3)
(S4)
CLOSE ▲
CLOSE ▲
FLASH EVAP
FEEDLINE HTR
A SUPPLY
B SUPPLY
1
MNA AB2
MNC AB1
OFF
(S23)
(S24)
OFF
MNB BC2
MNA CA1
2
L2
ANTISKID
ON
1
NOSE WHEEL STEERING
2
BODY FLAP
UP ▼
(S5)
1
(S6)
(S7)
AUTO/OFF
OFF
OFF
DOWN ▲
TRIM
ENTRY MODE
AUTO
ROLL
PITCH
DOWN ▼
LO GAIN
(S25)
L
R
(DS13)
+
(S9)
NO Y JET
(S8)
UP ▲
FREON ISOLATION
MODE
AUTO
LOOP 1
RADIATOR
LOOP 2
OFF
(S26)
(S27)
(S28)
MAN
ISOLATE
(31V73A2A2)
ATM PRESS CONTROL
O2 SYS 1
SUPPLY
OPEN ▼
O2
EMER
OPEN ▼
(DS14)
+
N2 SYS 1
SUPPLY
OPEN ▼
REG INLET
OPEN ▼
YAW TRIM
L
R
(S11)
(S12)
(S13)
(S14)
(S10)
CLOSE ▲
CLOSE ▲
CLOSE ▲
CLOSE ▲
R
R
14.7 PSI
CL
(DS5)
O2 XOVR
SYS 1
OPEN
N2 TK1
O2/N2 CNTLR VLV
SYS 1
OPEN
OP
OP
R
AUTO
(S15)
(DS6)
(DS7)
(S16)
R
8 PSI
CLOSE
N2 XOVR
CLOSE
PPO2 SNSR/VLV
NORM
CRYO
O2
(R1)
O2 EMER
OP
R
MASKS
ARLK
(DS8)
SYS 2
OPEN
N2 TK2
H2O TK PRESS
SYS 2
OPEN
(S17)
REVERSE
OP
OP
R
AUTO
(S18)
(DS10)
(DS11)
(S19)
R
8 PSI
CL
(DS9)
CLOSE
CLOSE
R
14.7 PSI
R
O2 SYS 2
SUPPLY
OPEN ▼
N2 SYS 2
SUPPLY
OPEN ▼
REG INLET
OPEN ▼
(S20)
(S21)
(S22)
CLOSE ▲
CLOSE ▲
CLOSE ▲
FIRE HOLE
(31V73A2A1)
007587031.PNL, 1

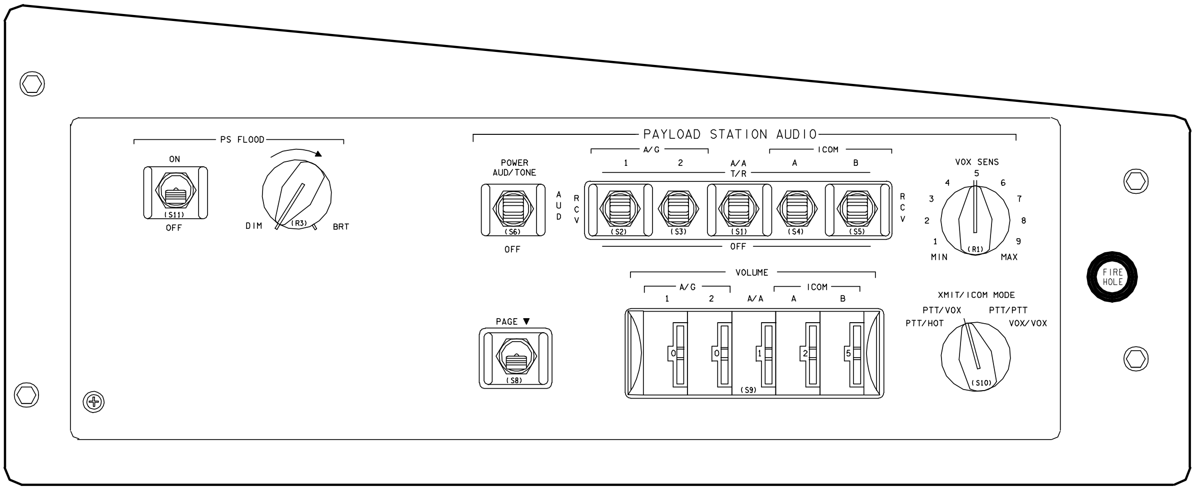
Panel L2


L4
B
UTILITY POWER
F1/M052J AC1 (CB28)
(DS1)
A15/M013Q AC3 (CB29)
AC1 ΦA ΦB ΦC
AC2 ΦA ΦB ΦC
AC3 ΦA ΦB ΦC
FUEL CELL 1 PUMPS
FUEL CELL 2 PUMPS
FUEL CELL 3 PUMPS
C (CB65) (CB66) (CB67) (CB68) (CB69) (CB70) (CB71) (CB72) (CB73)
CTR ENGINE
RIGHT ENGINE
D (CB84) (CB85) (CB86) (CB87) (CB88) (CB89) (CB90) (CB91) (CB92)
RIGHT ENGINE
LEFT ENGINE
E (CB108) (CB109) (CB110) (CB111) (CB112) (CB113) (CB114) (CB115) (CB116)
ΦA ΦB ΦC AC1
ΦA ΦB ΦC AC2
ΦA ΦB ΦC AC3
(DS2)
AC1 ΦA ΦB ΦC
AC2 ΦA ΦB ΦC
AC3 ΦA ΦB ΦC
H2O LOOP PUMP
1A/2
1B
2
F (CB1) (CB2) (CB3) (CB4) (CB5) (CB6) (CB7) (CB8) (CB9)
AV BAY 1
FAN A
FAN B
AV BAY 3
FAN A
G (CB10) (CB11) (CB12) (CB13) (CB14) (CB15) (CB16) (CB17) (CB18)
AV BAY 3
FAN B
AV BAY 2
FAN A
FAN B
H (CB30) (CB31) (CB32) (CB33) (CB34) (CB35) (CB36) (CB37) (CB38)
IMU FAN A
IMU FAN B
IMU FAN C
I (CB48) (CB49) (CB50) (CB51) (CB52) (CB53) (CB54) (CB55) (CB56)
HUMIDITY SEPARATOR
A
B
SIG CONDR
HUM SEP
IMU FAN
J (CB74) (CB75) (CB76) (CB77) (CB78) (CB79) (CB80) (CB81)
H2O CNTLR 2
CABIN AIR S/C
CABIN FAN
B
A
K (CB93) (CB94) (CB95) (CB96) (CB97) (CB98) (CB99) (CB100)
CABIN T CNTLR 2
AV BAY 2 S/C
CABIN T CNTLR 1
AV BAY 3 S/C
H2O CNTLR 1
AV BAY 1 S/C
L (CB117) (CB118) (CB119) (CB120) (CB121) (CB122)
ΦA ΦB ΦC AC1
ΦA ΦB ΦC AC2
ΦA ΦB ΦC AC3
FIRE HOLE
(DS3)
AC1 ΦA ΦB ΦC
AC2 ΦA ΦB ΦC
AC3 ΦA ΦB ΦC
FREON LOOP 1
PUMP A
PUMP B
FREON LOOP 2
PUMP A
M (CB19) (CB20) CB21) (CB22) (CB23) (CB24) (CB25) (CB26) (CB27)
FREON LOOP 2
PUMP B
FREON FLOW PROP 1
FREON SIG CONDR
RAD ISOL A
FREON FLOW PROP 2
FREON SIG CONDR
RAD ISOL B
N (CB39) (CB40) (CB41) (CB42) (CB43) (CB44) (CB45) (CB46) (CB47)
BLR HYD BYPASS 1B
HYD QTY 1
BLR HYD BYPASS 3A
BLR HYD BYPASS 1A
HYD QTY 2
BLR HYD BYPASS 2B
BLR HYD BYPASS 2A
HYD QTY 3
BLR HYD BYPASS 3B
O (CB131) (CB57) (CB133) (CB135) (CB60) (CB134) (CB132) (CB63) (CB136)
RAD CNTLR 1B
RAD CNTLR 2B
TACAN 1
LG SNSR 2
RAD CNTLR 1A
TACAN 2
LG SNSR 1
RAD CNTLR 2A
TACAN 3
P (CB128) (CB44) (CB58) (CB59) (C129) (CB61) (CB62) (CB47) (CB64)
LIGHTING
PANEL
L/CTR
L OVHD
INST OS
PANEL
R OVHD
R
NUMERIC OS
COAS
PANEL
MS
OS
Q (CB101) (CB102) (CB103) (CB130) (CB104) (CB105) (CB127) (CB106) (CB107)
INST R
NUMERIC FWD
INST OVHD
INST L/CTR
R (CB126) (CB123) (CB124) (CB125)
ΦA ΦB ΦC AC1
ΦA ΦB ΦC AC2
ΦA ΦB ΦC AC3
007587040.PNL;1

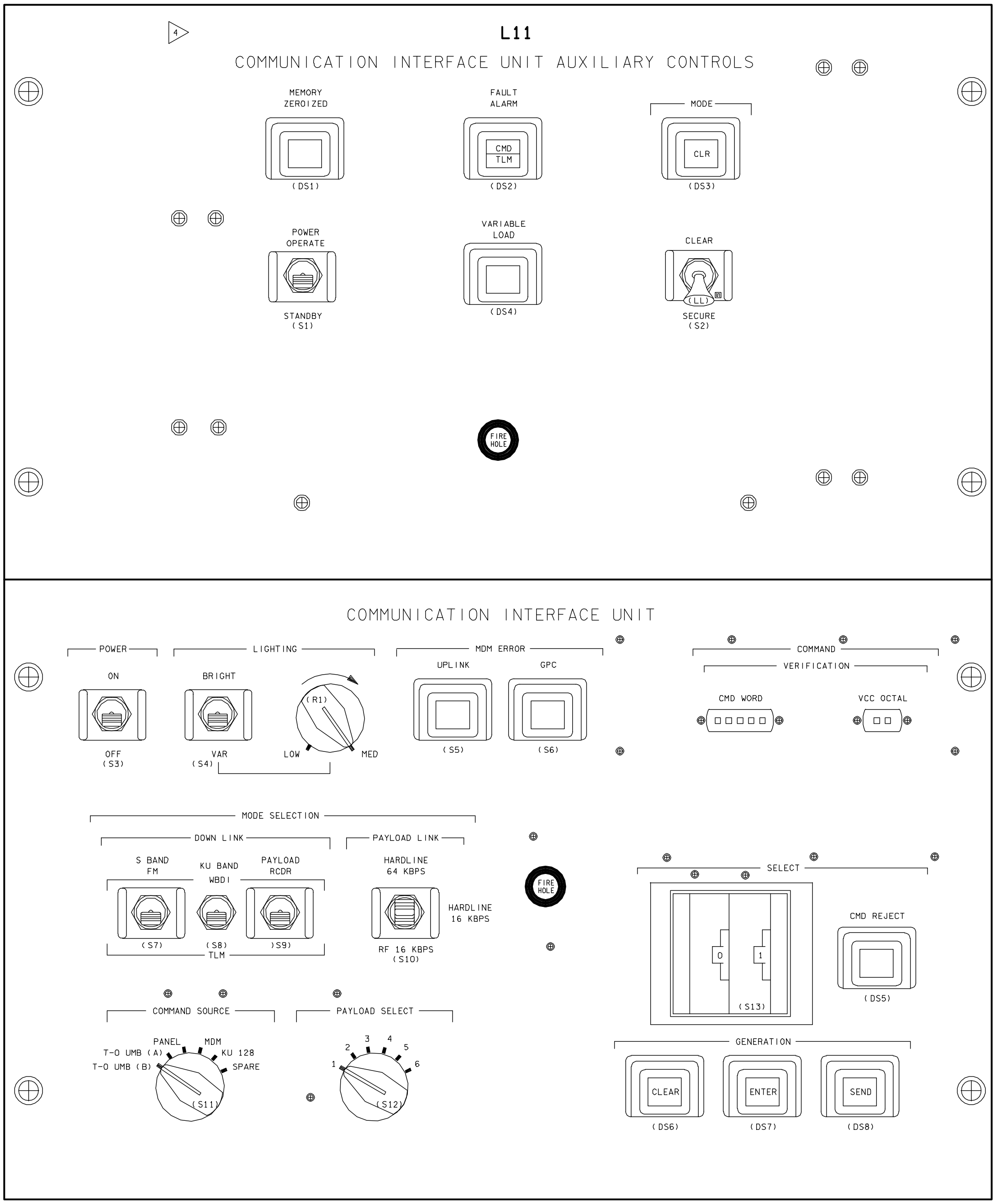
Panel L4



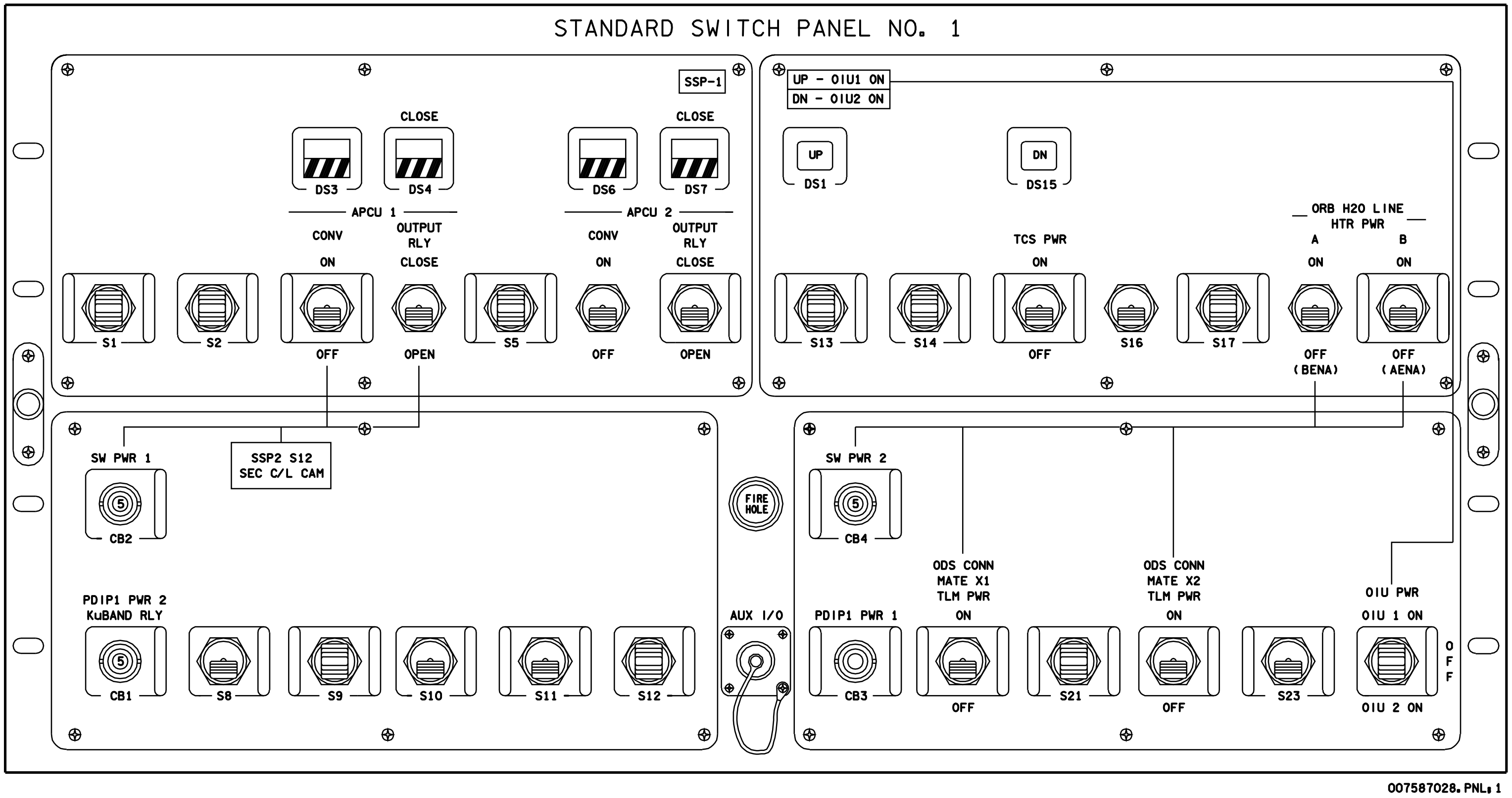
Panel L5



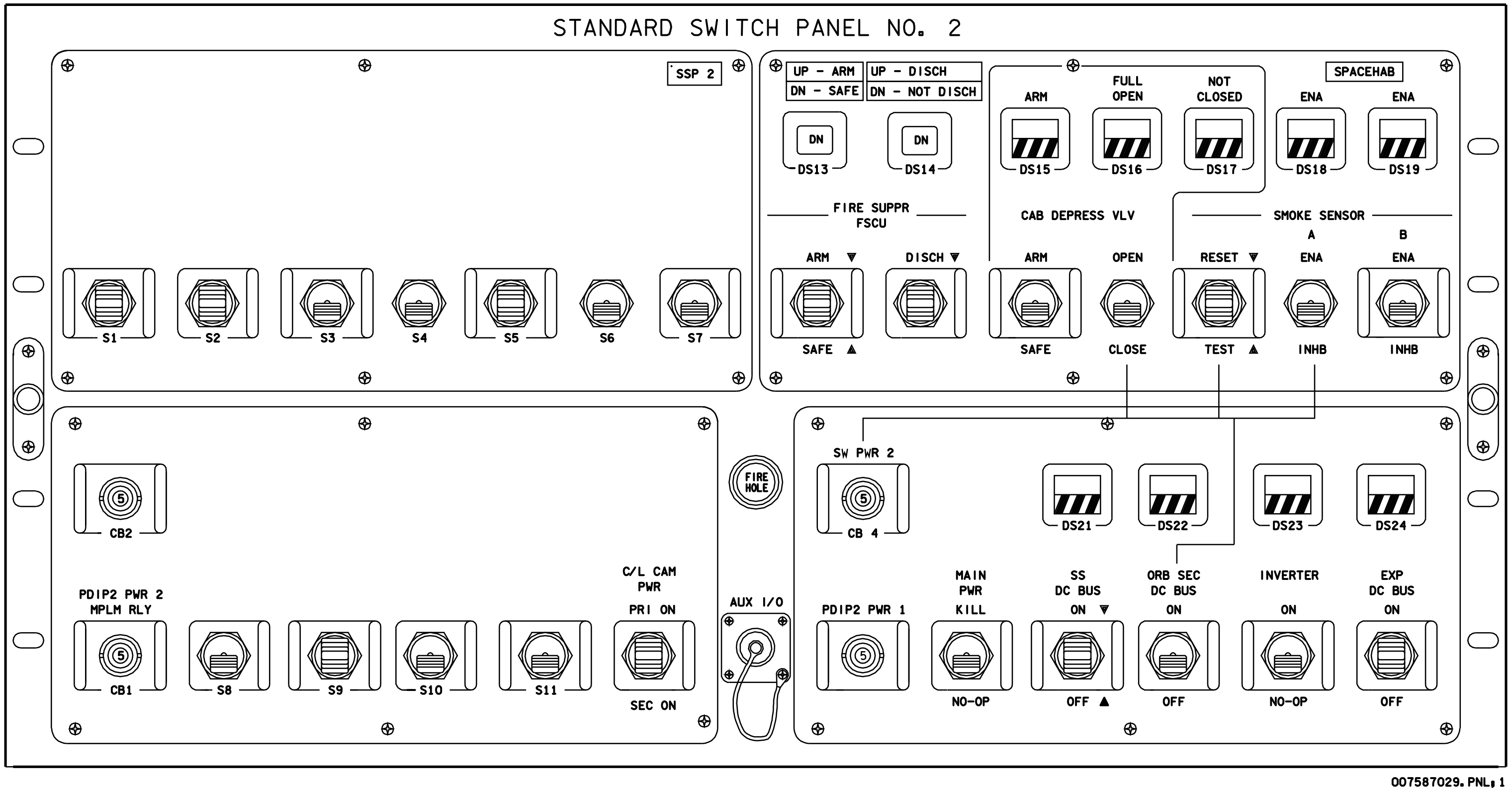
Panel L9


4
L11
COMMUNICATION INTERFACE UNIT AUXILIARY CONTROLS
MEMORY ZEROIZED
(DS1)
FAULT ALARM
CMD
TLM
(DS2)
MODE
CLR
(DS3)
POWER OPERATE
STANDBY
(S1)
VARIABLE LOAD
(DS4)
CLEAR
LL
SECURE
(S2)
FIRE HOLE
COMMUNICATION INTERFACE UNIT
POWER
ON
OFF
(S3)
LIGHTING
BRIGHT
VAR
(S4)
(R1)
LOW
MED
MDM ERROR
UPLINK
(S5)
GPC
(S6)
COMMAND
VERIFICATION
CMD WORD
VCC OCTAL
MODE SELECTION
DOWN LINK
S BAND FM
(S7)
KU BAND WBDI
(S8)
PAYLOAD RCDR
(S9)
TLM
PAYLOAD LINK
HARDLINE 64 KBPS
HARDLINE 16 KBPS
RF 16 KBPS
(S10)
FIRE HOLE
SELECT
0
1
(S13)
CMD REJECT
(DS5)
COMMAND SOURCE
PANEL
MDM
T-O UMB (A)
KU 128
T-O UMB (B)
SPARE
(S11)
PAYLOAD SELECT
1
2
3
4
5
6
(S12)
GENERATION
CLEAR
(DS6)
ENTER
(DS7)
SEND
(DS8)

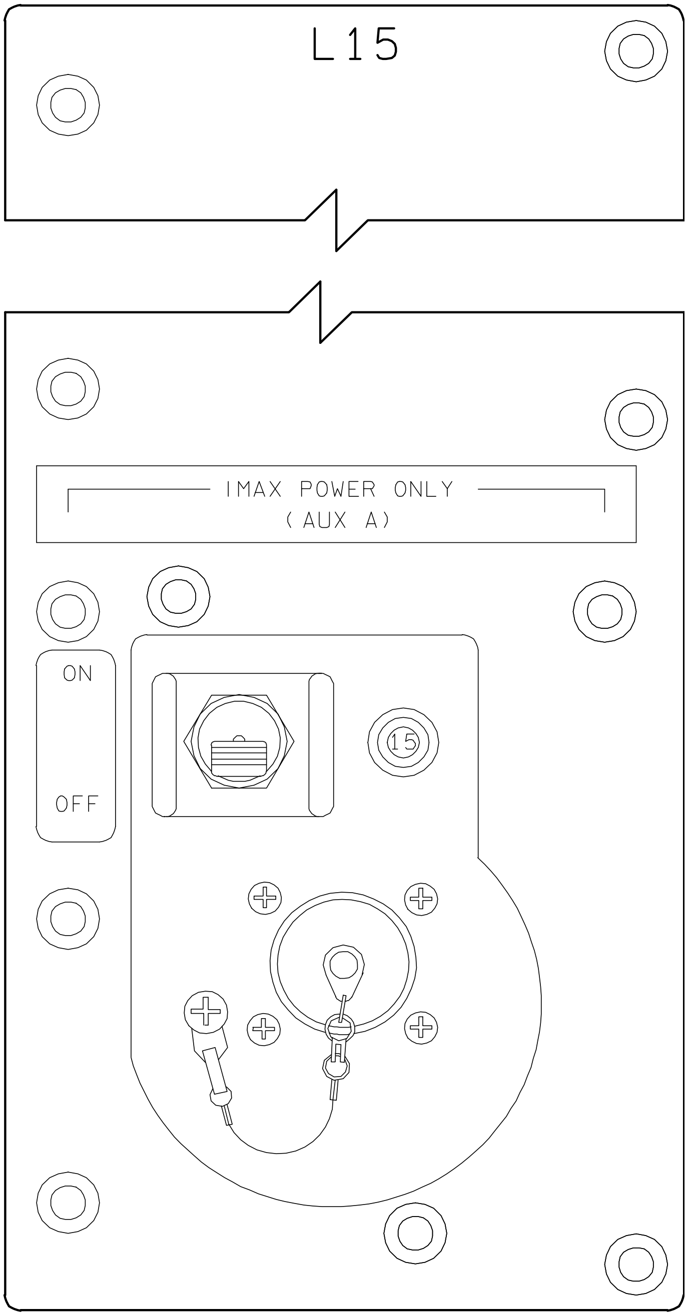
Panel L11



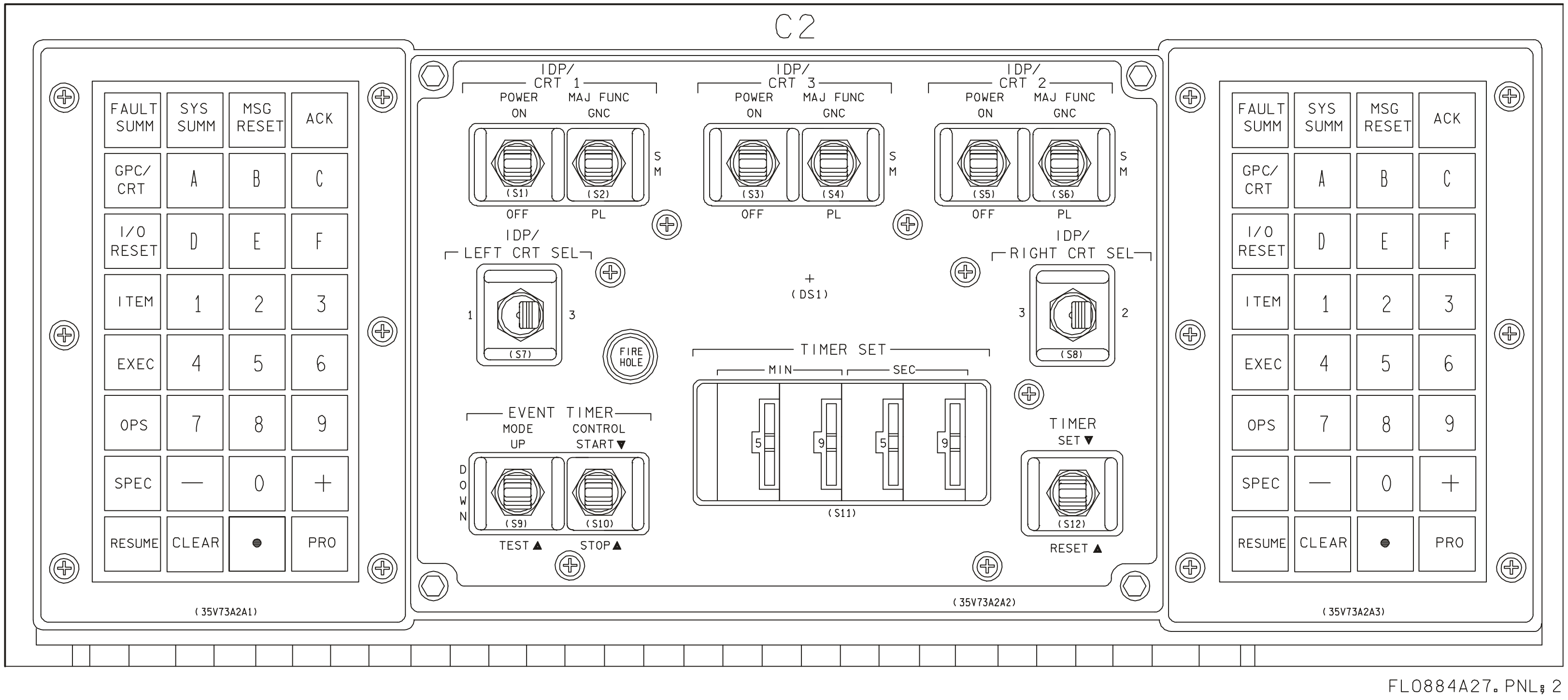
Panel L12U (Mission Dependent)



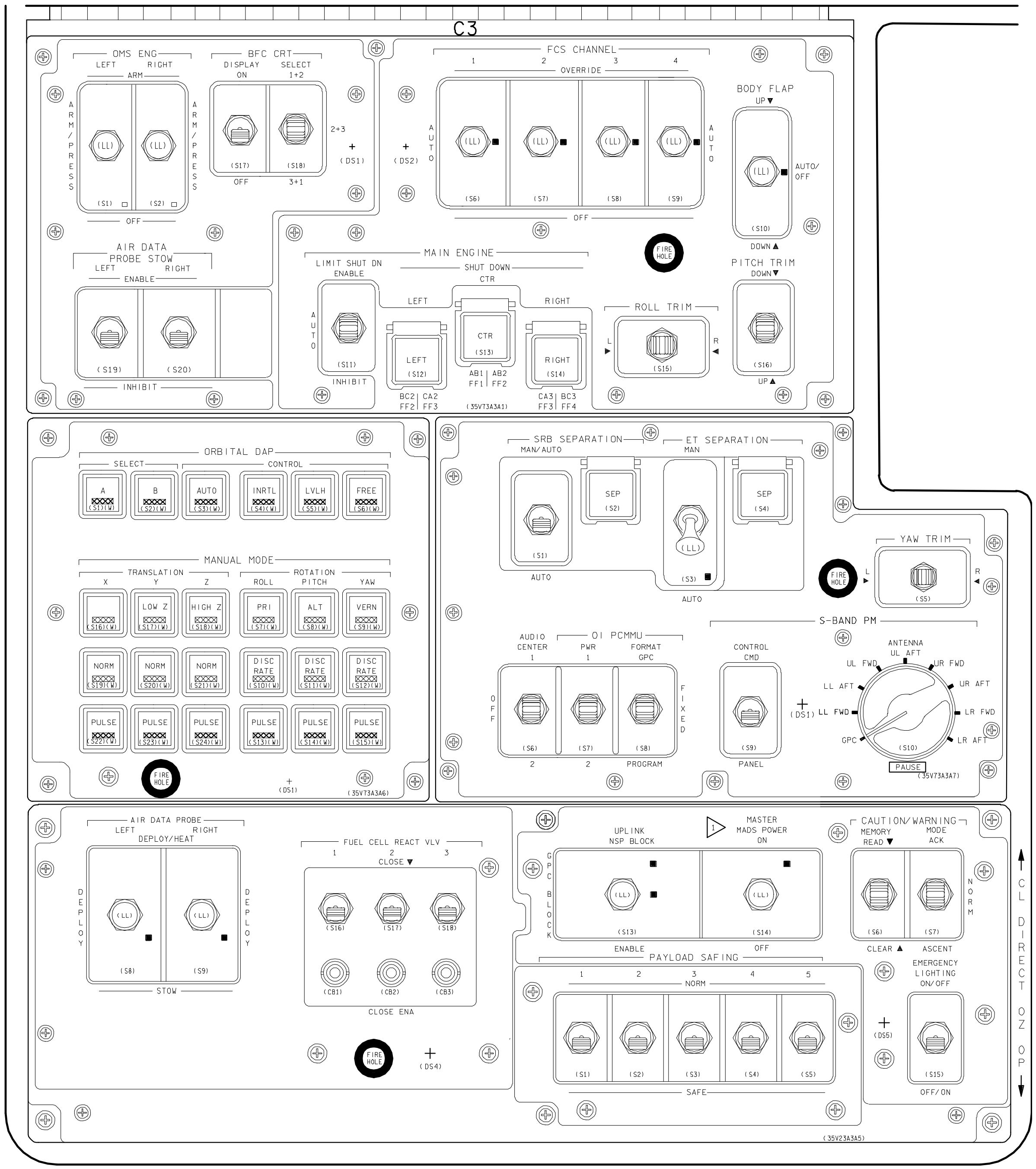
Panel L12L (Mission Dependent)



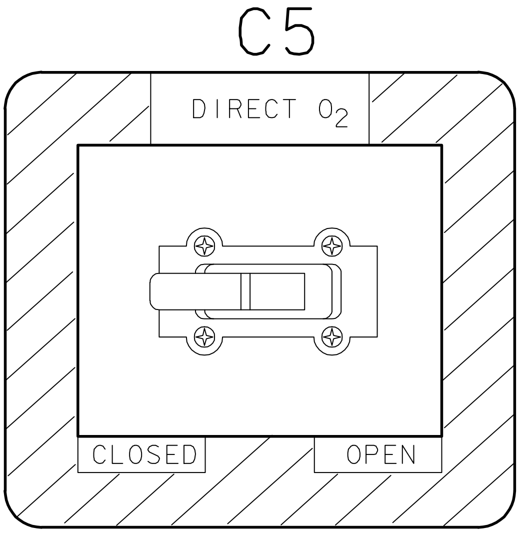
Panel L15


C2
FAULT SUMM
SYS SUMM
MSG RESET
ACK
GPC/ CRT
A
B
C
I/O RESET
D
E
F
ITEM
1
2
3
EXEC
4
5
6
OPS
7
8
9
SPEC
—
0
+
RESUME
CLEAR
●
PRO
(35V73A2A1)
IDP/ CRT 1
IDP/ CRT 3
IDP/ CRT 2
POWER
ON
OFF
MAJ FUNC
GNC
PL
S M
(S1)
(S2)
(S3)
(S4)
(S5)
(S6)
IDP/ LEFT CRT SEL
1
3
(S7)
IDP/ RIGHT CRT SEL
3
2
(S8)
FIRE HOLE
+ (DS1)
TIMER SET
MIN
SEC
5
9
5
9
(S11)
EVENT TIMER
MODE
UP
DOWN
TEST ▲
(S9)
CONTROL
START ▼
STOP ▲
(S10)
TIMER
SET ▼
RESET ▲
(S12)
(35V73A2A2)
(35V73A2A3)
FLO884A27.PNL;2

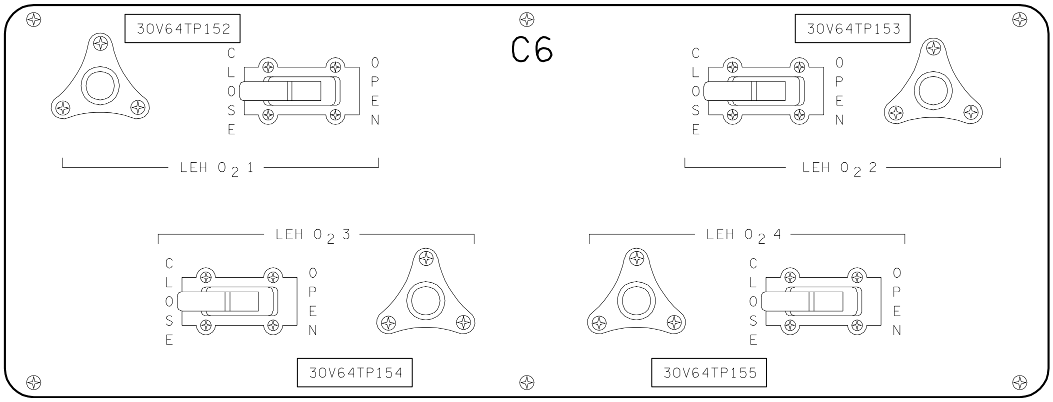
Panel C2


C3
OMS ENG
LEFT
RIGHT
ARM
ARM/PRESS
(LL)
(S1)
(S2)
OFF
BFC CRT
DISPLAY
ON
SELECT
1+2
2+3
3+1
(S17)
(S18)
(DS1)
(DS2)
AIR DATA PROBE STOW
ENABLE
INHIBIT
(S19)
(S20)
FCS CHANNEL
1
2
3
4
OVERRIDE
AUTO
(S6)
(S7)
(S8)
(S9)
BODY FLAP
UP
AUTO/OFF
(S10)
DOWN
FIRE HOLE
MAIN ENGINE
LIMIT SHUT DN
SHUT DOWN
CTR
(S11)
LEFT
(S12)
(S13)
RIGHT
(S14)
AB1 FF1
AB2 FF2
BC2 FF2
CA2 FF3
CA3 FF3
BC3 FF4
(35V73A3A1)
ROLL TRIM
L
R
(S15)
PITCH TRIM
(S16)
ORBITAL DAP
SELECT
CONTROL
A
B
AUTO
INRTL
LVLH
FREE
(S1)(W)
(S2)(W)
(S3)(W)
(S4)(W)
(S5)(W)
(S6)(W)
MANUAL MODE
TRANSLATION
X
Y
Z
ROTATION
ROLL
PITCH
YAW
LOW Z
HIGH Z
PRI
ALT
VERN
NORM
DISC RATE
PULSE
(35V73A3A6)
SRB SEPARATION
MAN/AUTO
ET SEPARATION
MAN
SEP
YAW TRIM
S-BAND PM
OI PCMMU
AUDIO CENTER
PWR
FORMAT GPC
FIXED
PROGRAM
CONTROL CMD
PANEL
ANTENNA
UL AFT
UL FWD
UR FWD
UR AFT
LL AFT
LL FWD
LR FWD
LR AFT
GPC
PAUSE
(35V73A3A7)
AIR DATA PROBE
DEPLOY/HEAT
DEPLOY
STOW
FUEL CELL REACT VLV
CLOSE
CLOSE ENA
(CB1)
(CB2)
(CB3)
(DS4)
UPLINK NSP BLOCK
GPC BLOCK
ENABLE
MASTER MADS POWER
ON
CAUTION/WARNING
MEMORY READ
MODE ACK
CLEAR
ASCENT
NORM
PAYLOAD SAFING
SAFE
EMERGENCY LIGHTING ON/OFF
(DS5)
OFF/ON
CL DIRECT OZ OP
(35V23A3A5)

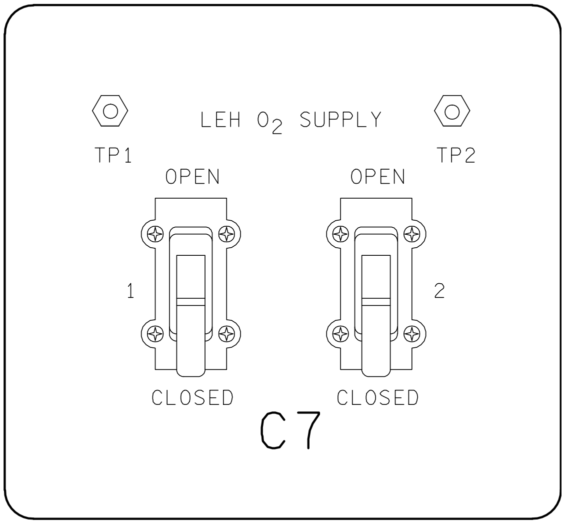
Panel C3



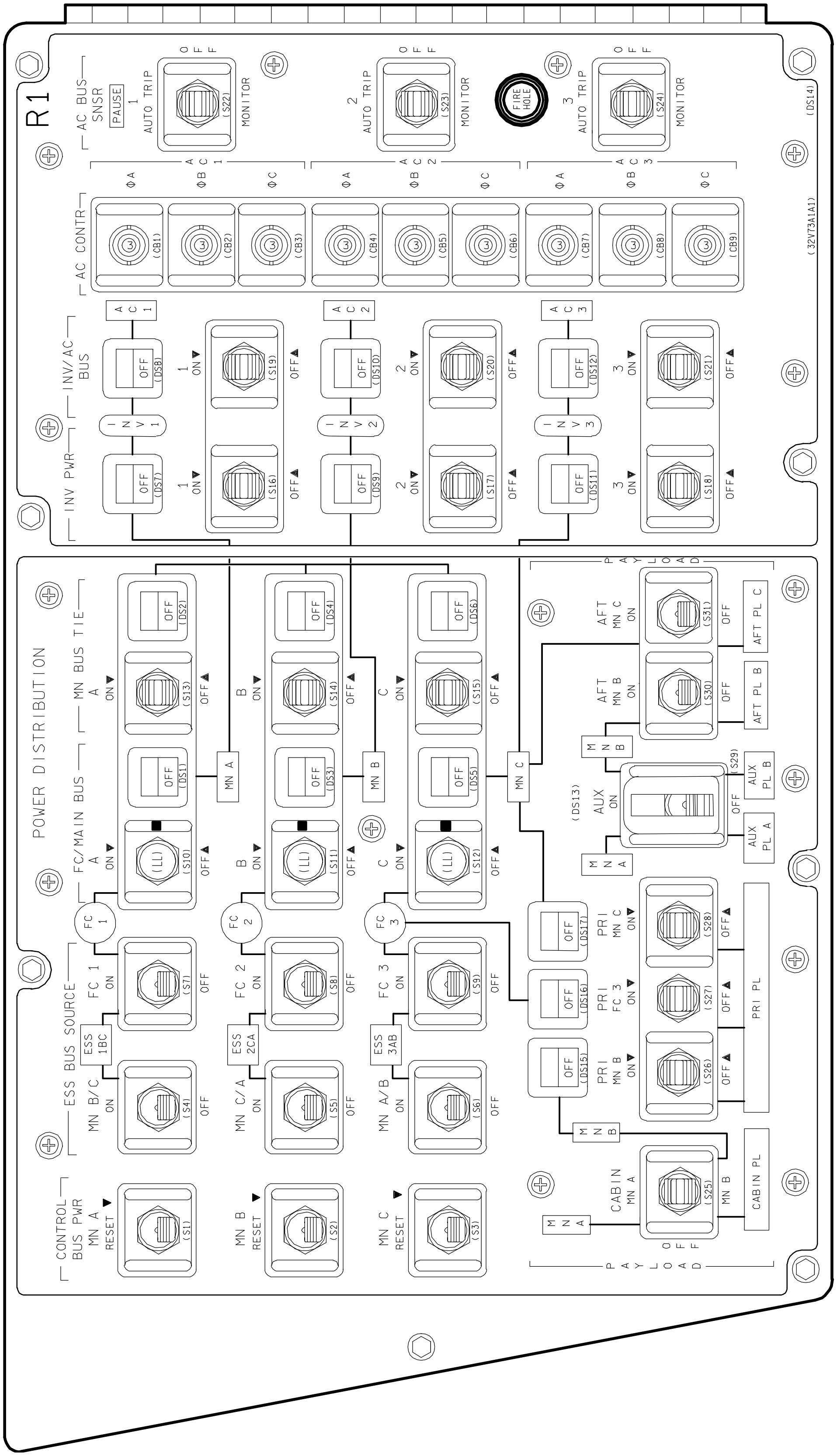
Panel C5



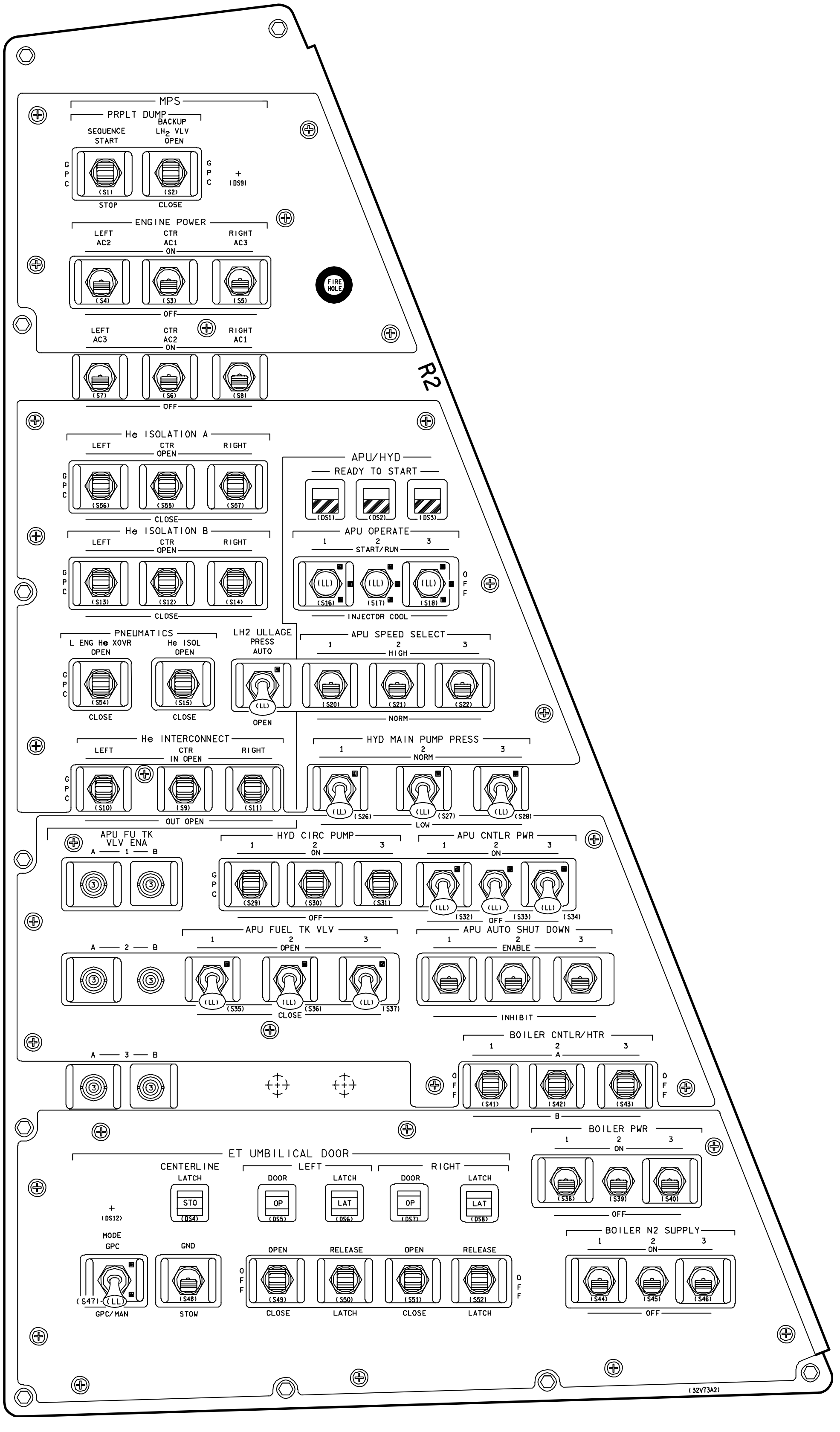
Panel C6



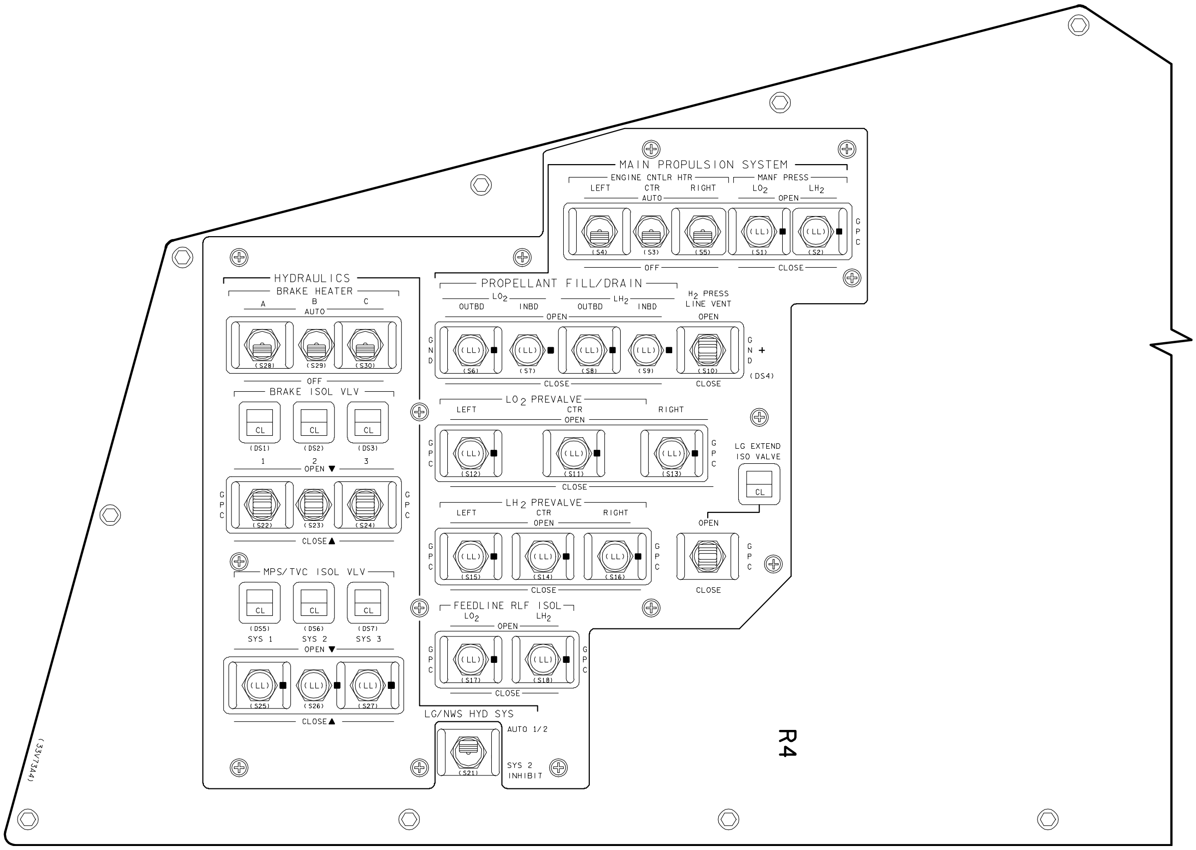
Panel C7


R1
AC BUS SNSR
PAUSE
1 AUTO TRIP
2 AUTO TRIP
3 AUTO TRIP
OFF
MONITOR
(S22)
(S23)
(S24)
FIRE HOLE
(DS14)
AC 1
AC 2
AC 3
ΦA
ΦB
ΦC
AC CONTR
(CB1)
(CB2)
(CB3)
(CB4)
(CB5)
(CB6)
(CB7)
(CB8)
(CB9)
(32V73A1A1)
INV/AC BUS
INV 1
INV 2
INV 3
INV PWR
ON
OFF
(DS7)
(DS8)
(DS9)
(DS10)
(DS11)
(DS12)
(S16)
(S17)
(S18)
(S19)
(S20)
(S21)
POWER DISTRIBUTION
MN BUS TIE
FC/MAIN BUS
A
B
C
(DS1)
(DS2)
(DS3)
(DS4)
(DS5)
(DS6)
(S10)
(S11)
(S12)
(S13)
(S14)
(S15)
(LL)
MN A
MN B
MN C
FC 1
FC 2
FC 3
ESS BUS SOURCE
ESS 1BC
ESS 2CA
ESS 3AB
MN B/C
MN C/A
MN A/B
(S4)
(S5)
(S6)
(S7)
(S8)
(S9)
CONTROL BUS PWR
RESET
(S1)
(S2)
(S3)
PAYLOAD
AFT MN C
AFT MN B
AFT PL C
AFT PL B
(S30)
(S31)
AUX
AUX PL A
AUX PL B
(DS13)
(S29)
PRI MN C
PRI FC 3
PRI MN B
PRI PL
(DS15)
(DS16)
(DS17)
(S26)
(S27)
(S28)
CABIN MN A
CABIN PL
(S25)
PAYLOAD

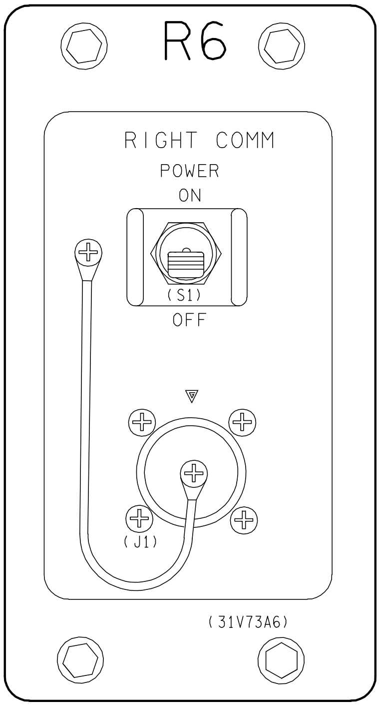
Panel R1


MPS
PRPLT DUMP
SEQUENCE START
BACKUP LH2 VLV OPEN
GPC
(S1)
(S2)
STOP
CLOSE
GPC
+ (DS9)
ENGINE POWER
LEFT AC2
CTR AC1
RIGHT AC3
ON
(S4)
(S3)
(S5)
OFF
FIRE HOLE
LEFT AC3
CTR AC2
RIGHT AC1
ON
(S7)
(S6)
(S8)
OFF
R2
He ISOLATION A
LEFT
CTR
RIGHT
OPEN
GPC
(S56)
(S55)
(S57)
CLOSE
He ISOLATION B
LEFT
CTR
RIGHT
OPEN
GPC
(S13)
(S12)
(S14)
CLOSE
APU/HYD
READY TO START
(DS1)
(DS2)
(DS3)
APU OPERATE
1
2
3
START/RUN
(LL)
(S16)
(S17)
(S18)
OFF
INJECTOR COOL
PNEUMATICS
L ENG He XOVR OPEN
He ISOL OPEN
GPC
(S54)
(S15)
CLOSE
CLOSE
LH2 ULLAGE PRESS AUTO
(LL)
OPEN
APU SPEED SELECT
1
2
3
HIGH
(S20)
(S21)
(S22)
NORM
He INTERCONNECT
LEFT
CTR
RIGHT
IN OPEN
GPC
(S10)
(S9)
(S11)
OUT OPEN
HYD MAIN PUMP PRESS
1
2
3
NORM
(LL)
(S26)
(S27)
(S28)
LOW
APU FU TK VLV ENA
A
1
B
HYD CIRC PUMP
1
2
3
ON
GPC
(S29)
(S30)
(S31)
OFF
APU CNTLR PWR
1
2
3
ON
(LL)
(S32)
OFF
(S33)
(S34)
A
2
B
APU FUEL TK VLV
1
2
3
OPEN
(LL)
(S35)
(S36)
(S37)
CLOSE
APU AUTO SHUT DOWN
1
2
3
ENABLE
INHIBIT
A
3
B
BOILER CNTLR/HTR
1
2
3
A
OFF
(S41)
(S42)
(S43)
OFF
B
ET UMBILICAL DOOR
CENTERLINE
LATCH
STO
(DS4)
LEFT
DOOR
OP
(DS5)
LATCH
LAT
(DS6)
RIGHT
DOOR
OP
(DS7)
LATCH
LAT
(DS8)
+ (DS12)
MODE
GPC
(S47)
(LL)
GPC/MAN
GND
(S48)
STOW
OPEN
RELEASE
OPEN
RELEASE
OFF
(S49)
(S50)
(S51)
(S52)
OFF
CLOSE
LATCH
CLOSE
LATCH
BOILER PWR
1
2
3
ON
(S38)
(S39)
(S40)
OFF
BOILER N2 SUPPLY
1
2
3
ON
(S44)
(S45)
(S46)
OFF
(32VT3A2)

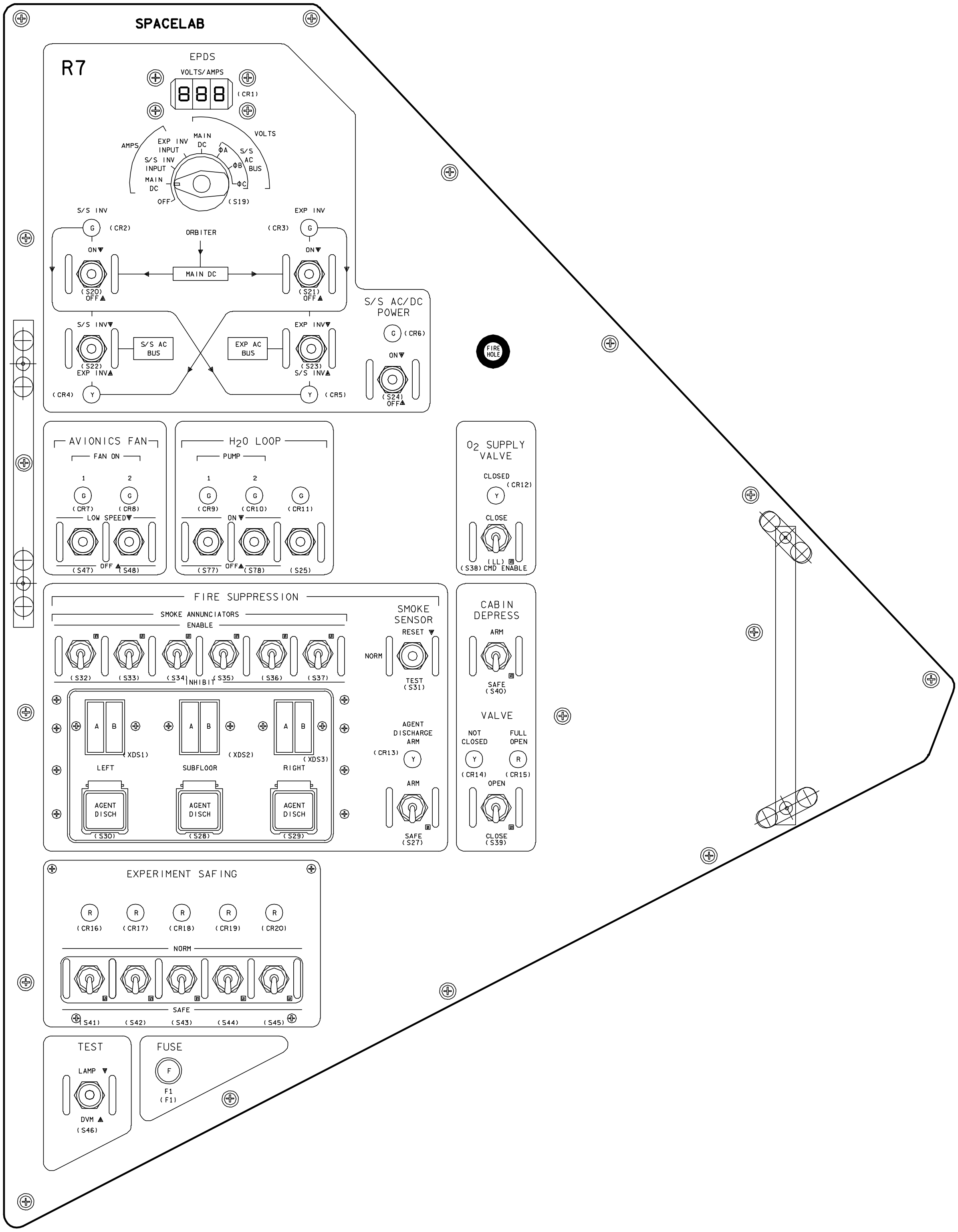
Panel R2



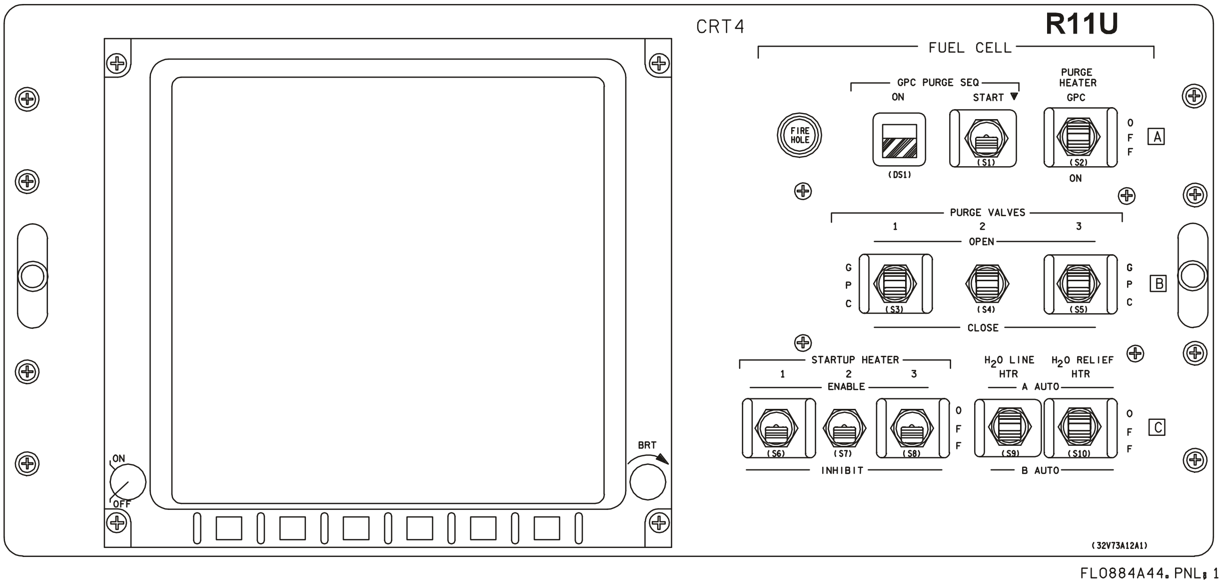
Panel R4



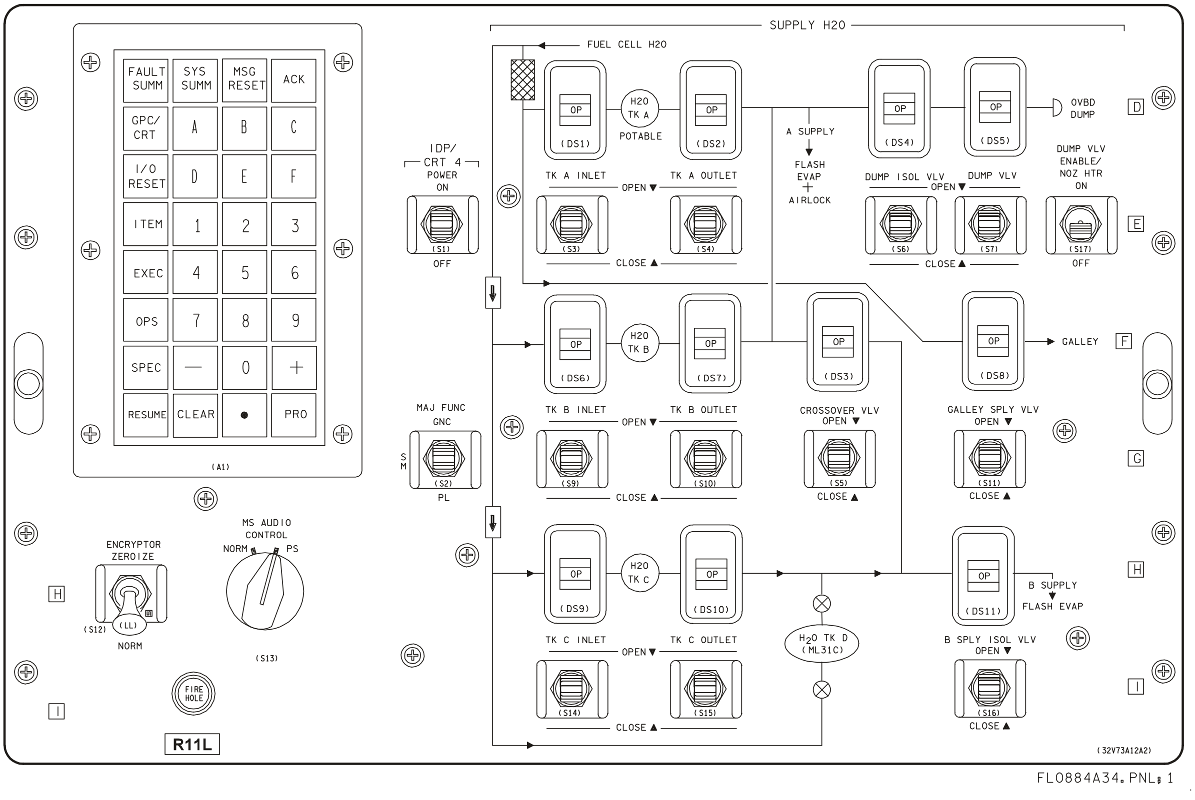
Panel R6


SPACELAB
R7
EPDS
VOLTS/AMPS
888
(CR1)
AMPS
EXP INV INPUT
MAIN DC
VOLTS
S/S INV INPUT
ΦA
S/S AC BUS
ΦB
ΦC
MAIN DC
OFF
(S19)
S/S INV
(CR2)
ORBITER
(CR3)
EXP INV
ON▼
MAIN DC
(S20)
OFF▲
(S21)
OFF▲
S/S AC/DC POWER
G
(CR6)
S/S INV▼
S/S AC BUS
EXP AC BUS
EXP INV▼
(S22)
EXP INV▲
(S23)
S/S INV▲
(CR4)
Y
(CR5)
(S24)
OFF▲
FIRE HOLE
AVIONICS FAN
FAN ON
1
2
(CR7)
(CR8)
LOW SPEED▼
OFF▲
(S47)
(S48)
H2O LOOP
PUMP
1
2
(CR9)
(CR10)
(CR11)
ON▼
OFF▲
(S77)
(S78)
(S25)
O2 SUPPLY VALVE
CLOSED
(CR12)
CLOSE
(LL)
(S38) CMD ENABLE
FIRE SUPPRESSION
SMOKE ANNUNCIATORS
ENABLE
(S32)
(S33)
(S34)
(S35)
(S36)
(S37)
INHIBIT
SMOKE SENSOR
RESET ▼
NORM
TEST
(S31)
A
B
(XDS1)
(XDS2)
(XDS3)
LEFT
SUBFLOOR
RIGHT
AGENT DISCH
(S30)
(S28)
(S29)
AGENT DISCHARGE ARM
(CR13)
ARM
SAFE
(S27)
CABIN DEPRESS
ARM
SAFE
(S40)
VALVE
NOT CLOSED
FULL OPEN
(CR14)
(CR15)
OPEN
CLOSE
(S39)
EXPERIMENT SAFING
R
(CR16)
(CR17)
(CR18)
(CR19)
(CR20)
NORM
SAFE
(S41)
(S42)
(S43)
(S44)
(S45)
TEST
LAMP ▼
DVM ▲
(S46)
FUSE
F
F1
(F1)

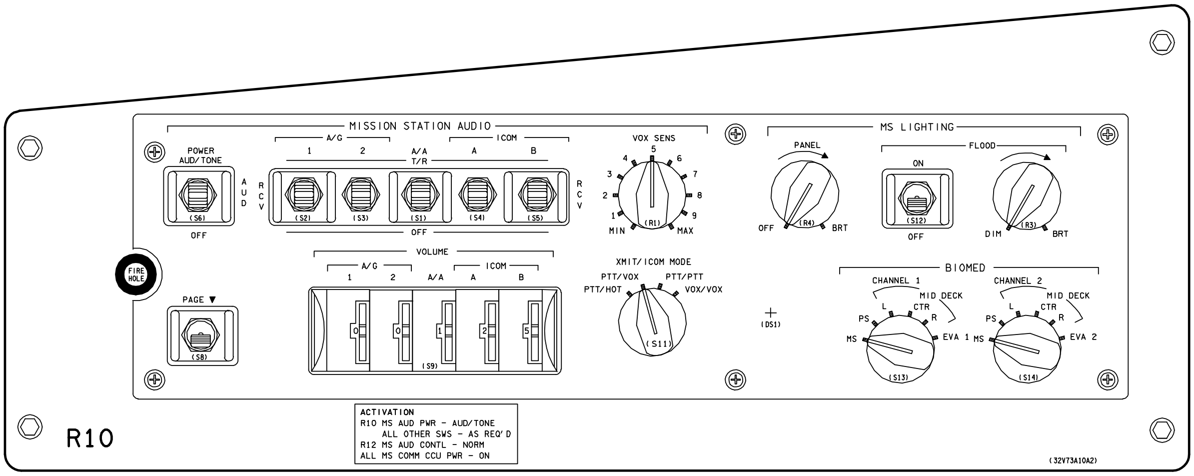
Panel R7



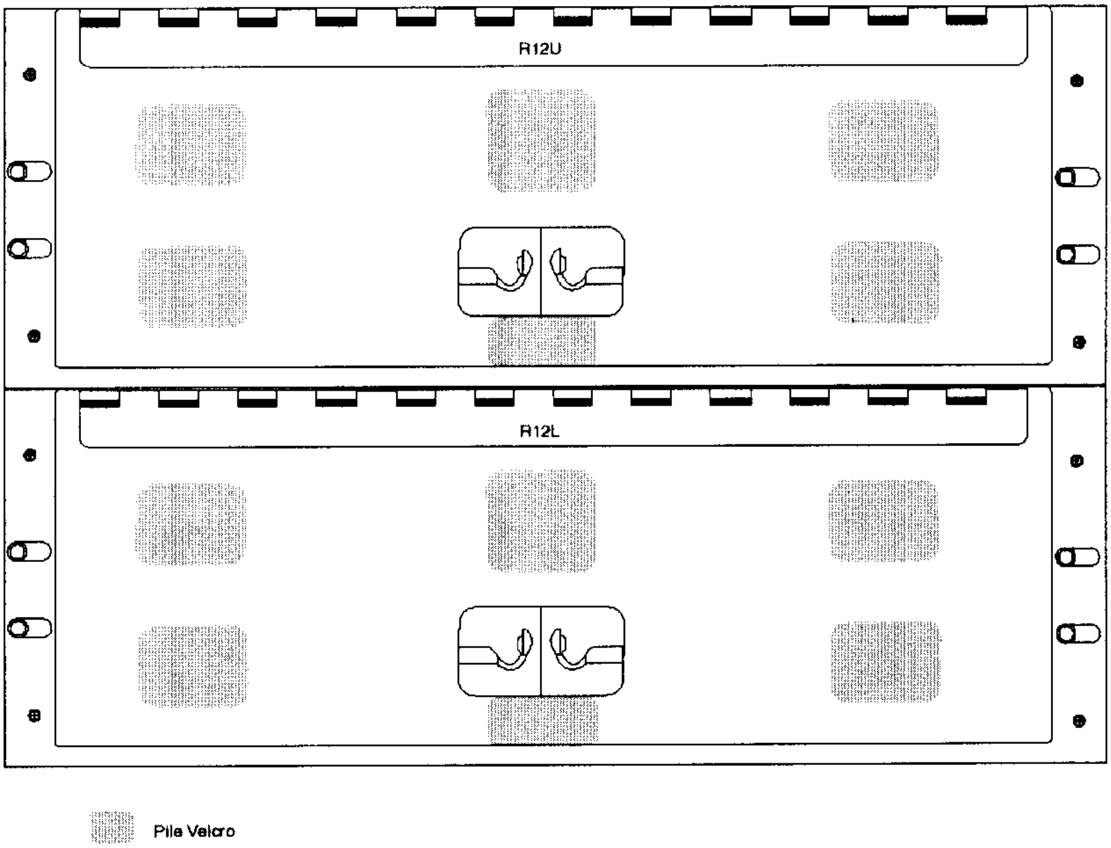
Panel R11U



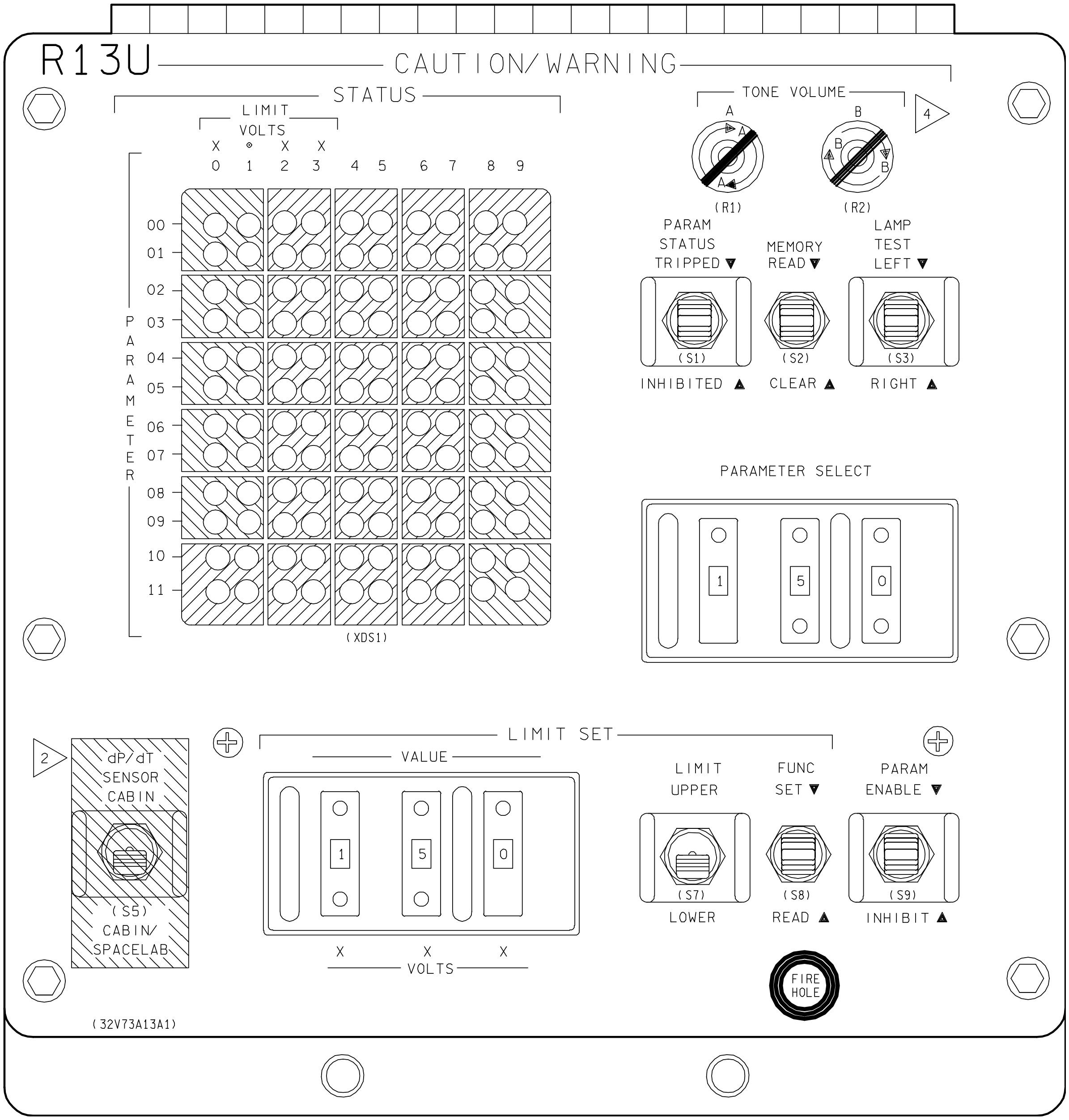
Panel R11L



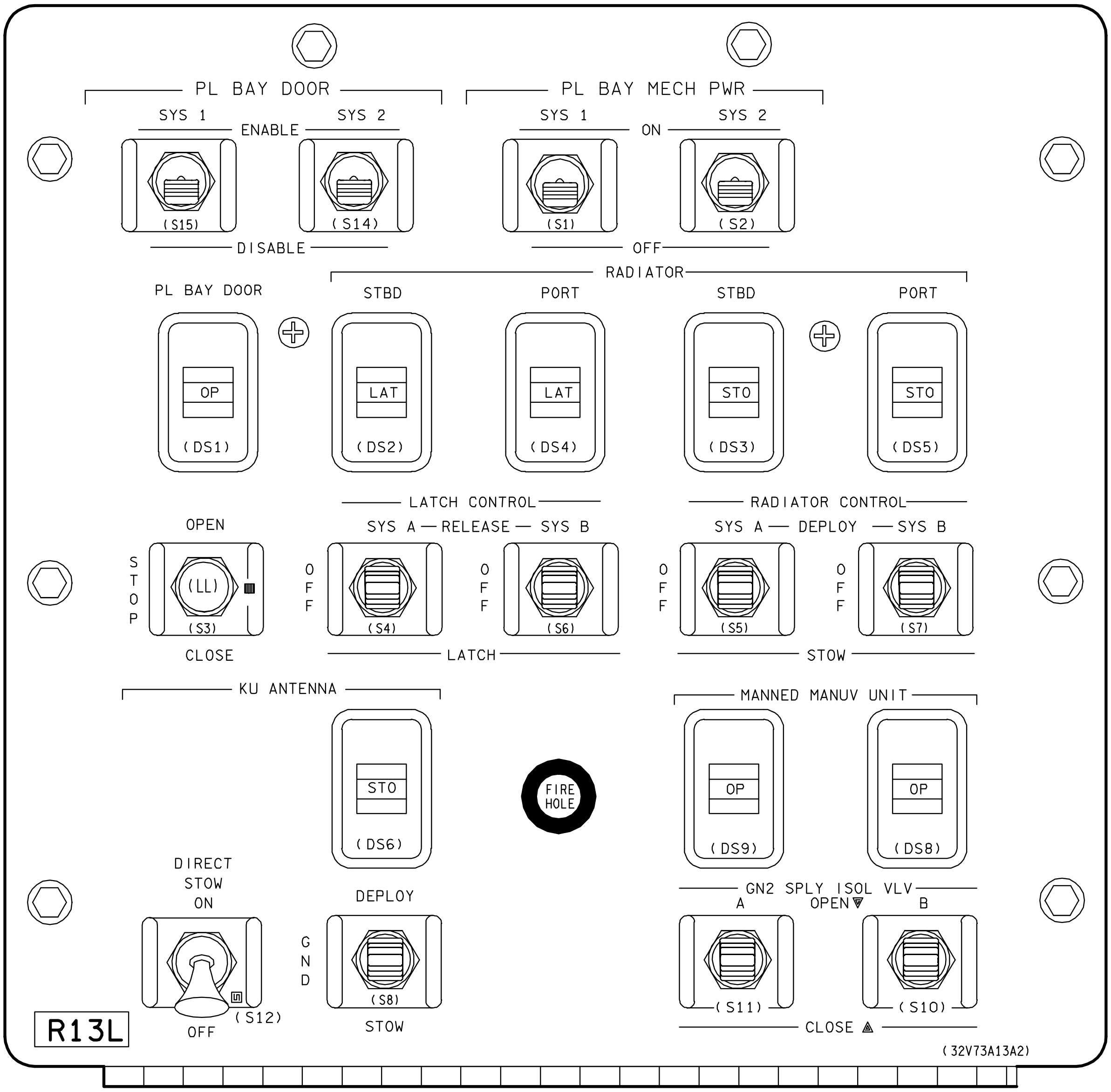
Panel R10



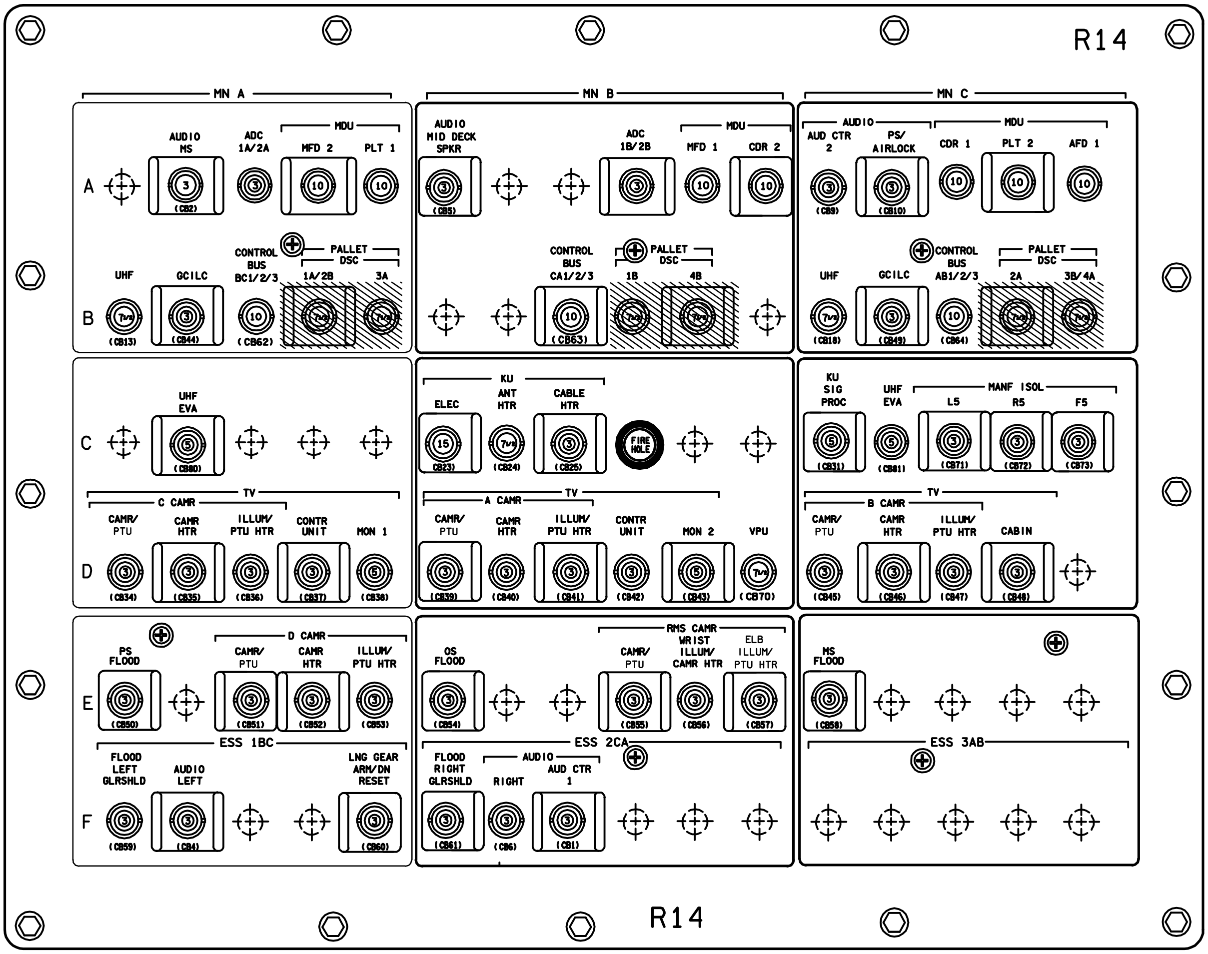
Panels R12U and R12L (Mission Dependent)


R13U
CAUTION/WARNING
STATUS
LIMIT
VOLTS
X ⚬ X X
0 1 2 3 4 5 6 7 8 9
PARAMETER
00
01
02
03
04
05
06
07
08
09
10
11
(XDS1)
TONE VOLUME
A
B
(R1)
(R2)
4
PARAM STATUS TRIPPED ▼
MEMORY READ ▼
LAMP TEST LEFT ▼
(S1)
(S2)
(S3)
INHIBITED ▲
CLEAR ▲
RIGHT ▲
PARAMETER SELECT
1
5
0
2
dP/dT SENSOR CABIN
(S5)
CABIN/ SPACELAB
LIMIT SET
VALUE
X X X
VOLTS
LIMIT UPPER
FUNC SET ▼
PARAM ENABLE ▼
(S7)
(S8)
(S9)
LOWER
READ ▲
INHIBIT ▲
FIRE HOLE
(32V73A13A1)

Panel R13U

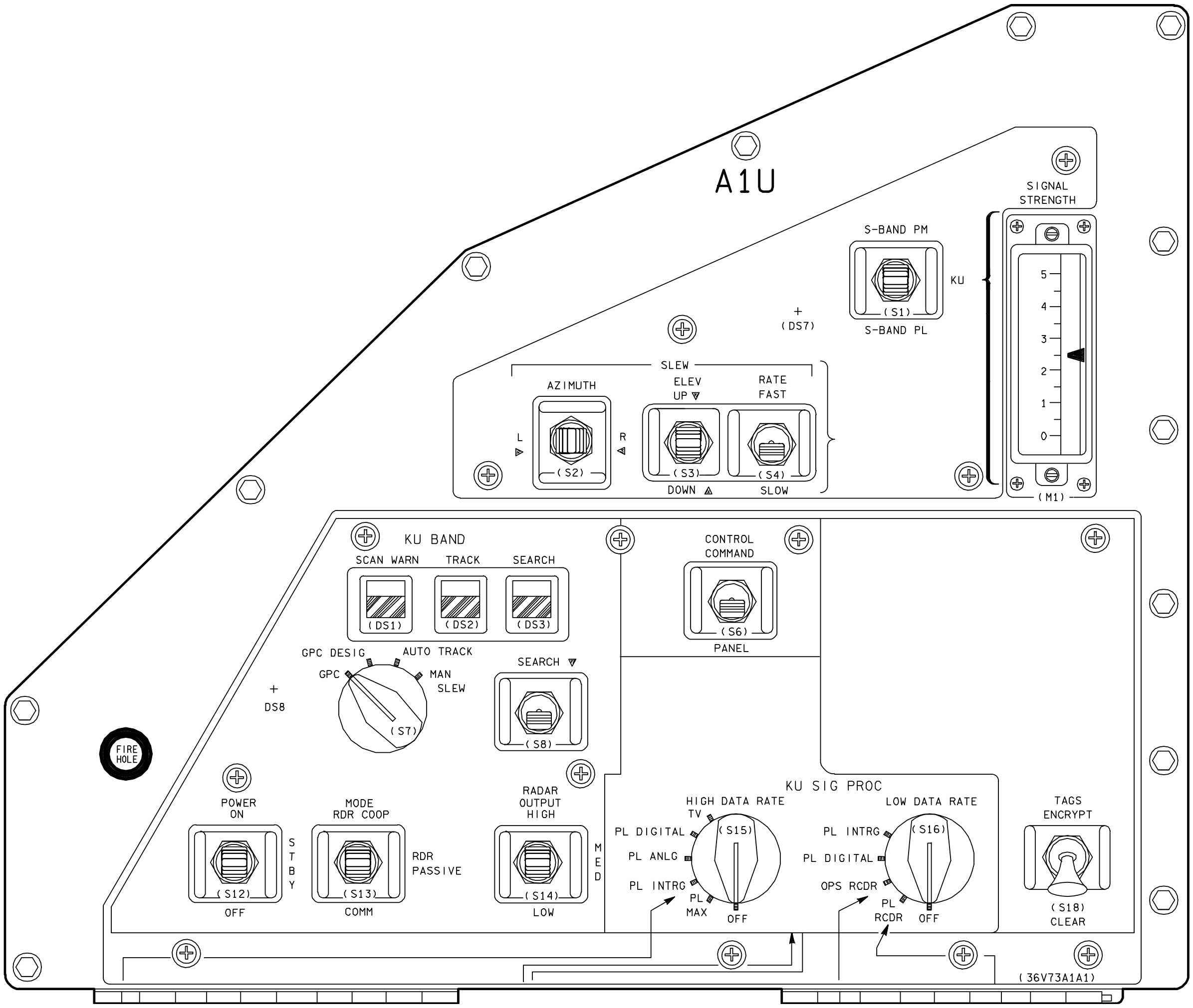

PL BAY DOOR
SYS 1
ENABLE
SYS 2
(S15)
(S14)
DISABLE
PL BAY MECH PWR
SYS 1
ON
SYS 2
(S1)
(S2)
OFF
RADIATOR
PL BAY DOOR
STBD
PORT
STBD
PORT
OP
LAT
LAT
STO
STO
(DS1)
(DS2)
(DS4)
(DS3)
(DS5)
LATCH CONTROL
SYS A — RELEASE — SYS B
RADIATOR CONTROL
SYS A — DEPLOY — SYS B
OPEN
STOP
(LL)
(S3)
CLOSE
OFF
(S4)
(S6)
(S5)
(S7)
LATCH
STOW
KU ANTENNA
STO
(DS6)
FIRE HOLE
MANNED MANUV UNIT
OP
OP
(DS9)
(DS8)
DIRECT STOW ON
(S12)
OFF
DEPLOY
GND
(S8)
STOW
GN2 SPLY ISOL VLV
A
OPEN
B
(S11)
(S10)
CLOSE
R13L
(32V73A13A2)

Panel R13L

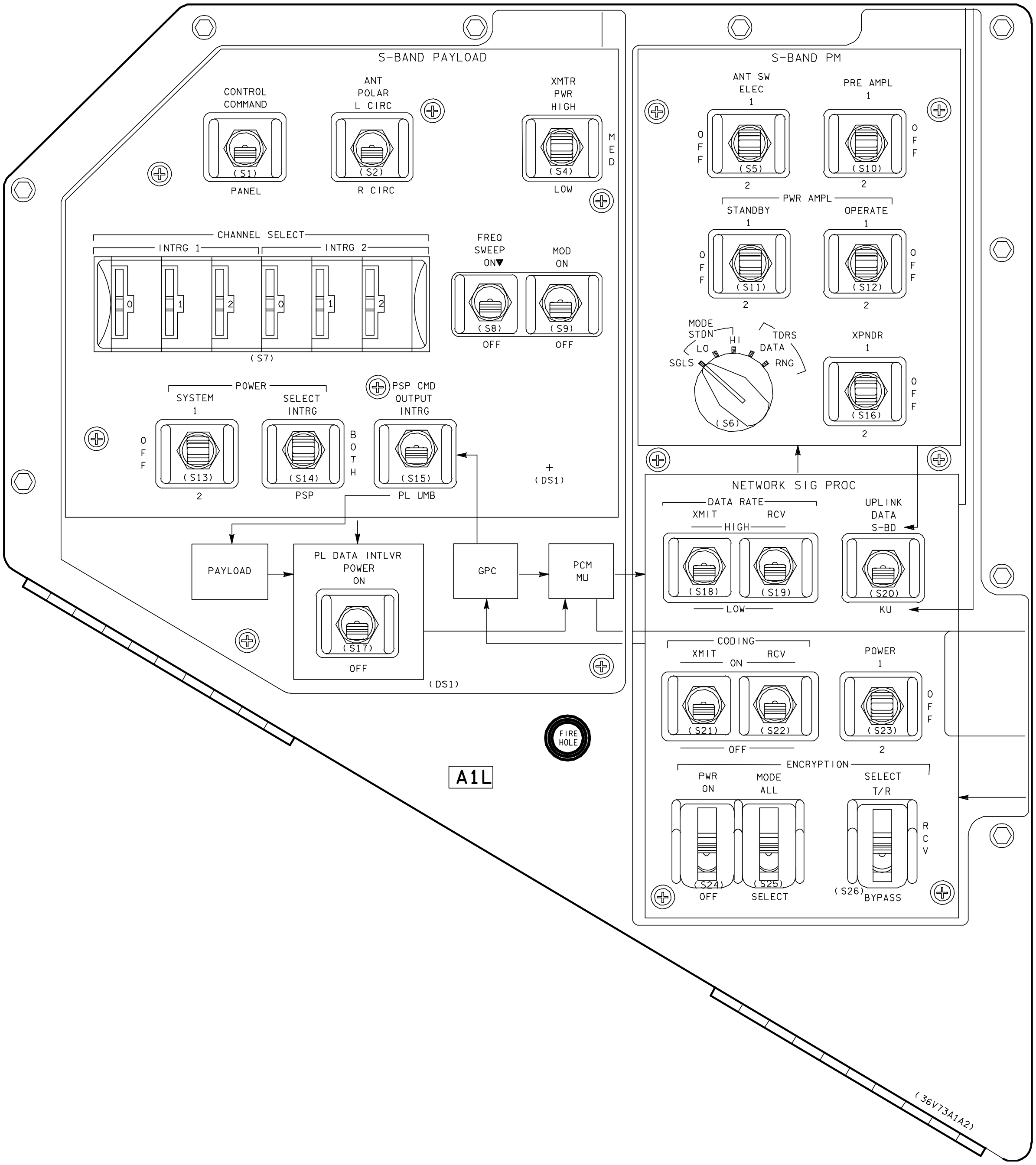


007587003.PNL;2

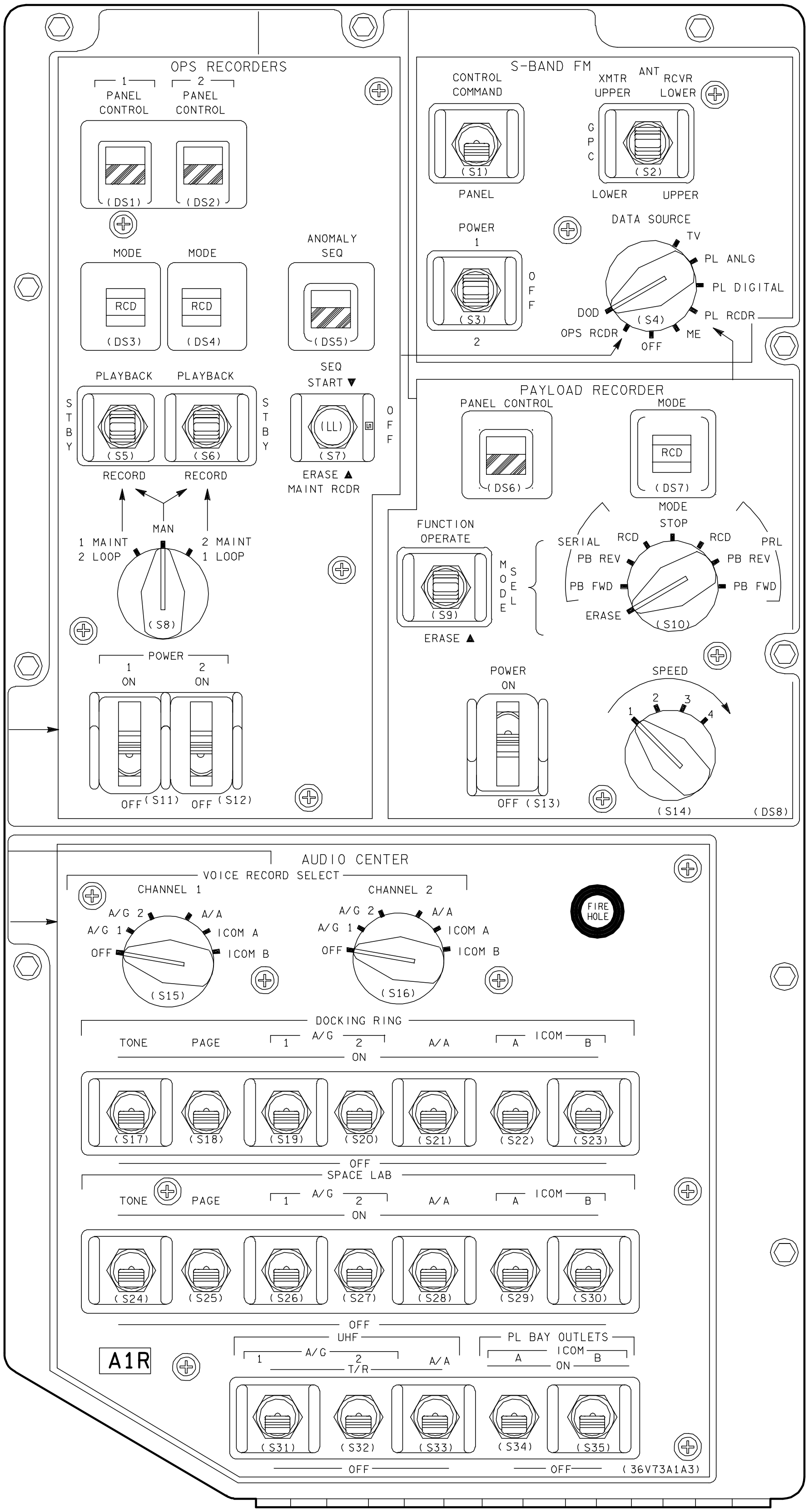
Panel R14


A1U
SIGNAL STRENGTH
S-BAND PM
(S1)
S-BAND PL
KU
(DS7)
5
4
3
2
1
0
(M1)
SLEW
AZIMUTH
L
R
(S2)
ELEV
UP
(S3)
DOWN
RATE
FAST
(S4)
SLOW
KU BAND
SCAN WARN
TRACK
SEARCH
(DS1)
(DS2)
(DS3)
CONTROL
COMMAND
(S6)
PANEL
GPC DESIG
AUTO TRACK
GPC
MAN
SLEW
(S7)
DS8
SEARCH
(S8)
FIRE HOLE
POWER
ON
(S12)
STBY
OFF
MODE
RDR COOP
(S13)
RDR PASSIVE
COMM
RADAR OUTPUT
HIGH
(S14)
MED
LOW
KU SIG PROC
HIGH DATA RATE
TV
PL DIGITAL
PL ANLG
PL INTRG
PL MAX
(S15)
OFF
LOW DATA RATE
PL INTRG
PL DIGITAL
OPS RCDR
PL RCDR
(S16)
OFF
TAGS
ENCRYPT
(S18)
CLEAR
(36V73A1A1)

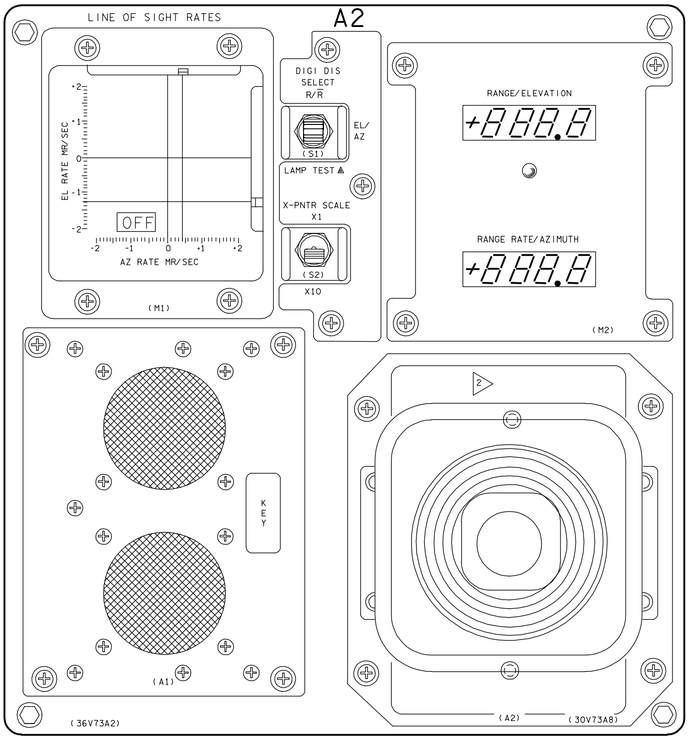
Panel A1U


S-BAND PAYLOAD
CONTROL
COMMAND
(S1)
PANEL
ANT
POLAR
L CIRC
(S2)
R CIRC
XMTR
PWR
HIGH
MED
(S4)
LOW
CHANNEL SELECT
INTRG 1
INTRG 2
0
1
2
0
1
2
(S7)
FREQ
SWEEP
ON▼
(S8)
OFF
MOD
ON
(S9)
OFF
POWER
SYSTEM
1
OFF
(S13)
2
SELECT
INTRG
BOTH
(S14)
PSP
PSP CMD
OUTPUT
INTRG
(S15)
PL UMB
+
(DS1)
PAYLOAD
PL DATA INTLVR
POWER
ON
(S17)
OFF
(DS1)
GPC
PCM
MU
S-BAND PM
ANT SW
ELEC
1
OFF
(S5)
2
PRE AMPL
1
OFF
(S10)
2
PWR AMPL
STANDBY
1
OFF
(S11)
2
OPERATE
1
OFF
(S12)
2
MODE
STDN
LO
HI
TDRS
DATA
SGLS
RNG
(S6)
XPNDR
1
OFF
(S16)
2
NETWORK SIG PROC
DATA RATE
XMIT
RCV
HIGH
(S18)
(S19)
LOW
UPLINK
DATA
S-BD
(S20)
KU
CODING
XMIT
RCV
ON
(S21)
(S22)
OFF
POWER
1
OFF
(S23)
2
ENCRYPTION
PWR
ON
(S24)
OFF
MODE
ALL
(S25)
SELECT
SELECT
T/R
RCV
(S26)
BYPASS
FIRE
HOLE
A1L
(36V73A1A2)

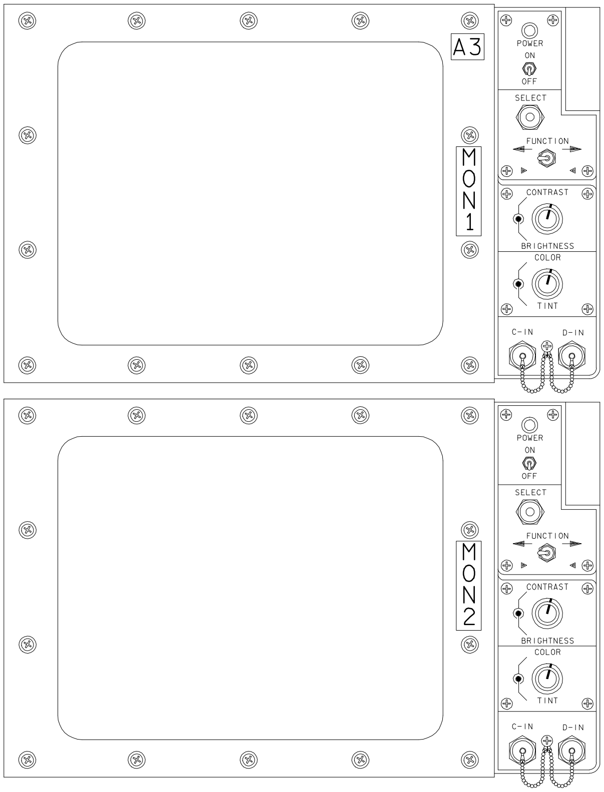
Panel A1L


OPS RECORDERS
1
PANEL CONTROL
2
PANEL CONTROL
(DS1)
(DS2)
MODE
MODE
RCD
RCD
(DS3)
(DS4)
ANOMALY SEQ
(DS5)
PLAYBACK
PLAYBACK
STBY
STBY
(S5)
(S6)
RECORD
RECORD
SEQ START ▼
(LL)
(S7)
OFF
ERASE ▲
MAINT RCDR
MAN
1 MAINT
2 LOOP
2 MAINT
1 LOOP
(S8)
POWER
1 ON
2 ON
OFF (S11)
OFF (S12)
S-BAND FM
CONTROL COMMAND
(S1)
PANEL
XMTR UPPER
ANT
RCVR LOWER
GPC
(S2)
LOWER
UPPER
POWER
1
OFF
(S3)
2
DATA SOURCE
TV
PL ANLG
PL DIGITAL
PL RCDR
ME
OFF
OPS RCDR
DOD
(S4)
PAYLOAD RECORDER
PANEL CONTROL
(DS6)
MODE
RCD
(DS7)
FUNCTION OPERATE
(S9)
ERASE ▲
MODE SEL
MODE
STOP
SERIAL
RCD
RCD
PRL
PB REV
PB REV
PB FWD
PB FWD
ERASE
(S10)
POWER ON
OFF (S13)
SPEED
1
2
3
4
(S14)
(DS8)
AUDIO CENTER
VOICE RECORD SELECT
CHANNEL 1
A/G 2
A/A
A/G 1
ICOM A
OFF
ICOM B
(S15)
CHANNEL 2
A/G 2
A/A
A/G 1
ICOM A
OFF
ICOM B
(S16)
FIRE HOLE
DOCKING RING
TONE
PAGE
A/G
1
2
A/A
ICOM
A
B
ON
(S17)
(S18)
(S19)
(S20)
(S21)
(S22)
(S23)
OFF
SPACE LAB
TONE
PAGE
A/G
1
2
A/A
ICOM
A
B
ON
(S24)
(S25)
(S26)
(S27)
(S28)
(S29)
(S30)
OFF
UHF
A/G
1
2
T/R
A/A
PL BAY OUTLETS
ICOM
A
B
ON
A1R
(S31)
(S32)
(S33)
(S34)
(S35)
OFF
OFF
(36V73A1A3)

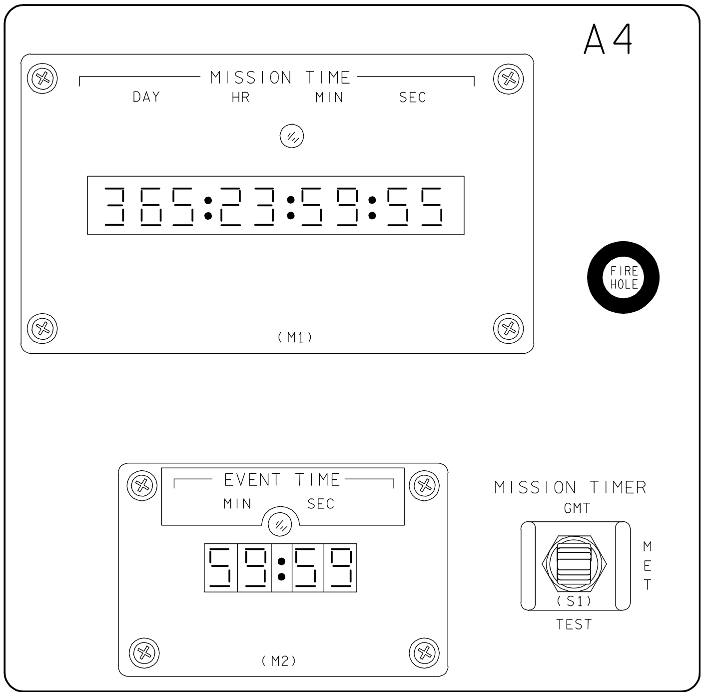
Panel A1R



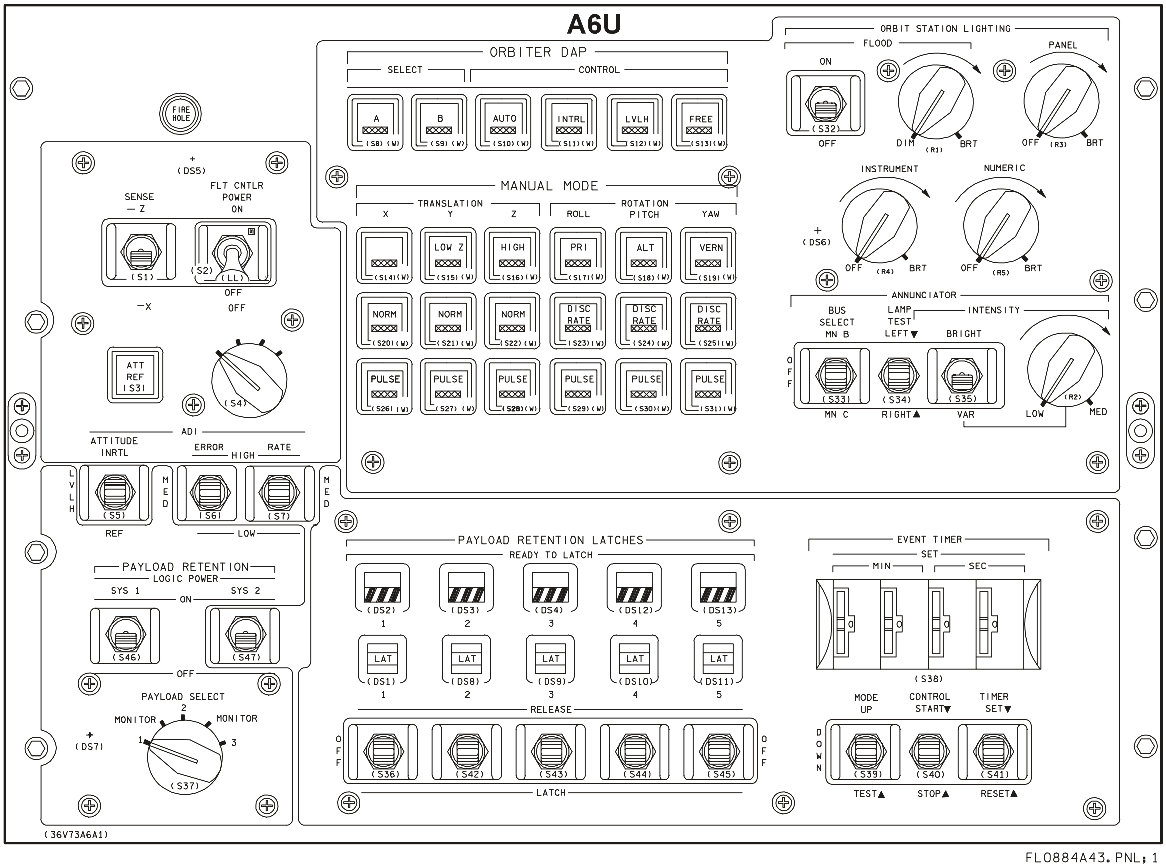
Panel A2



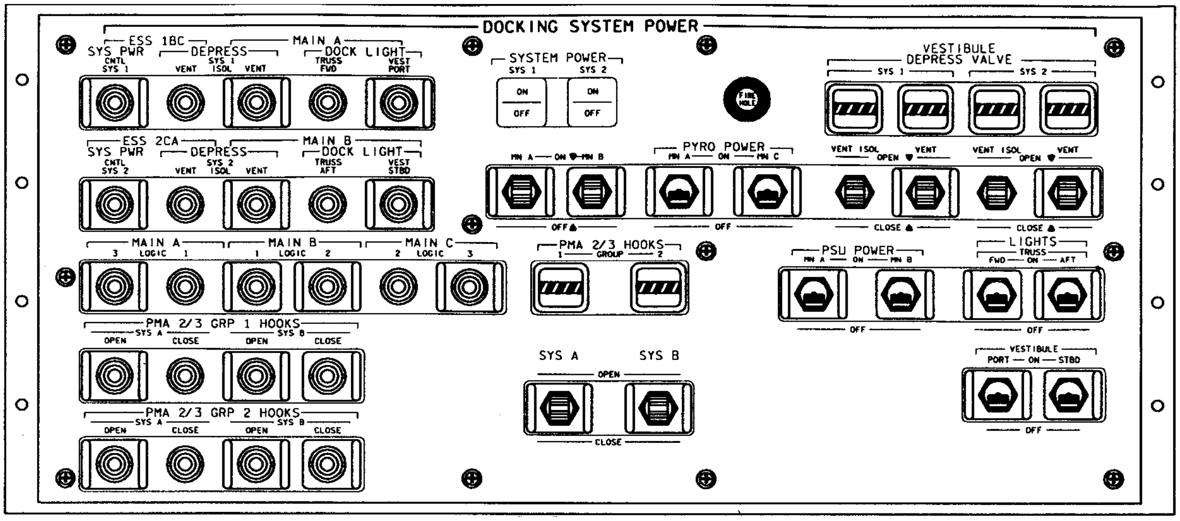
Panel A3



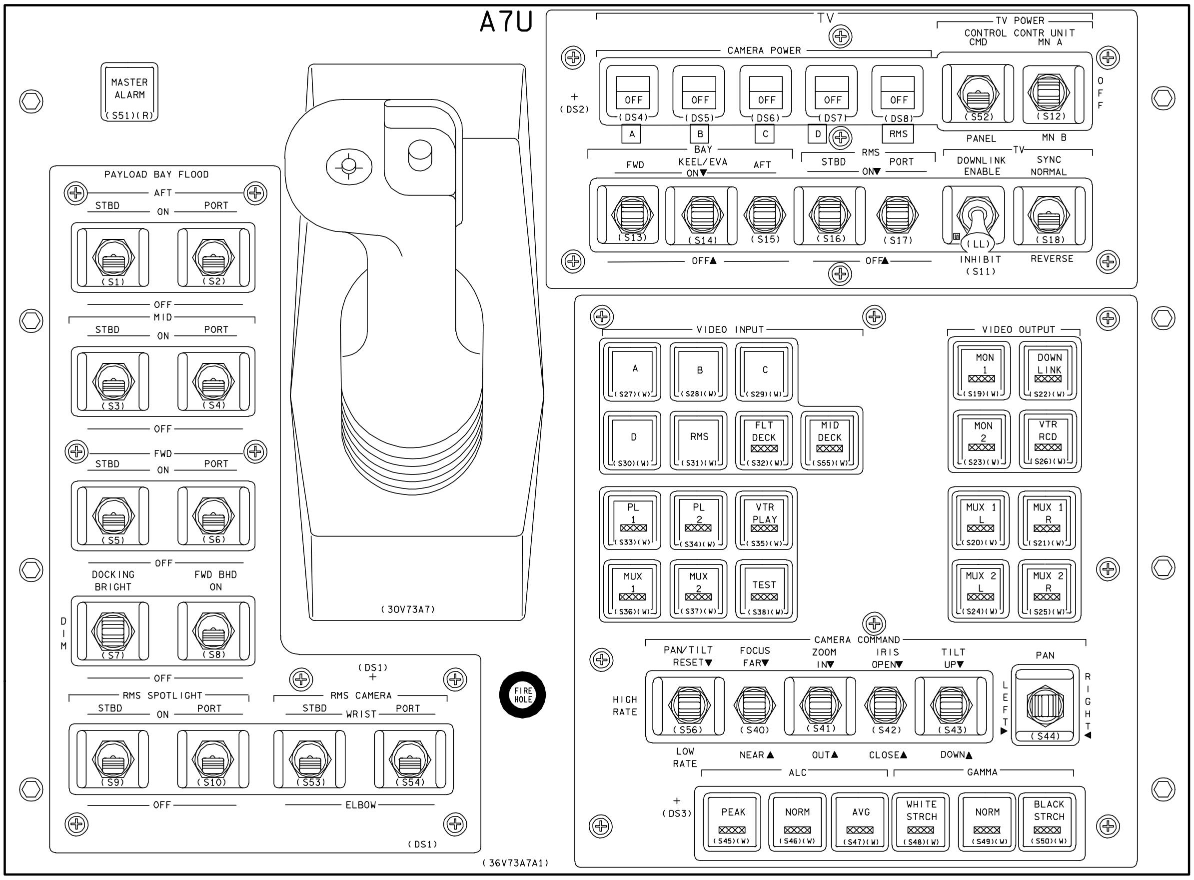
Panel A4



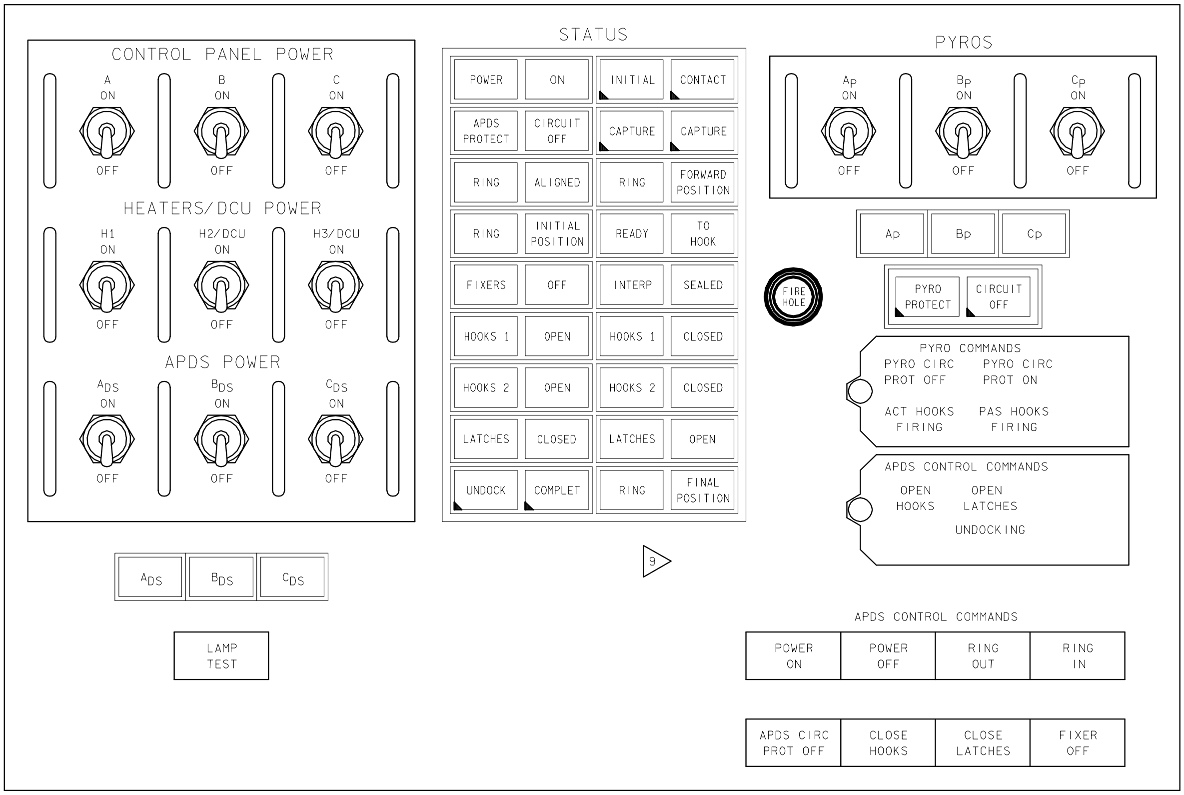
Panel A6U



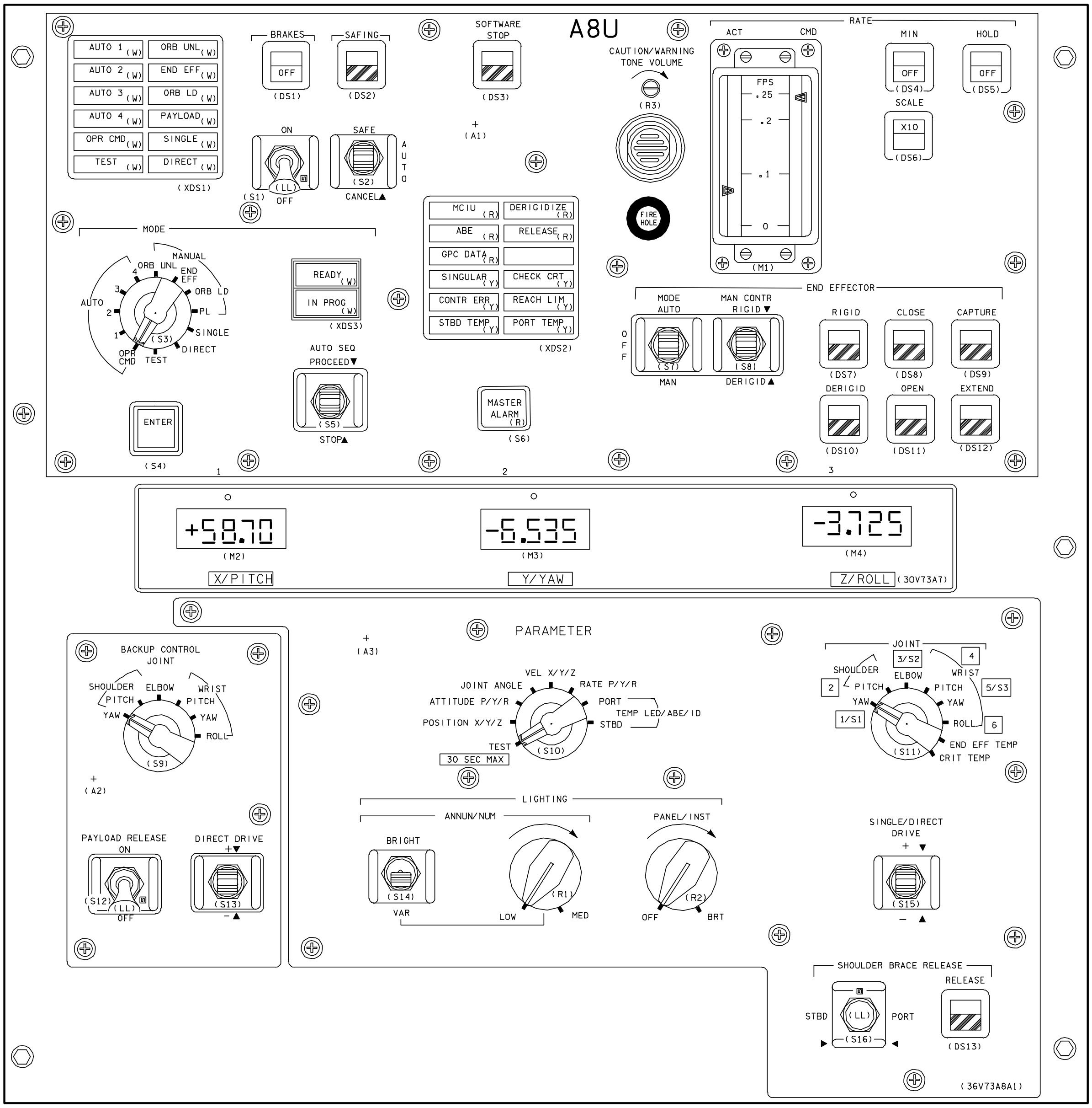
Panel A6L



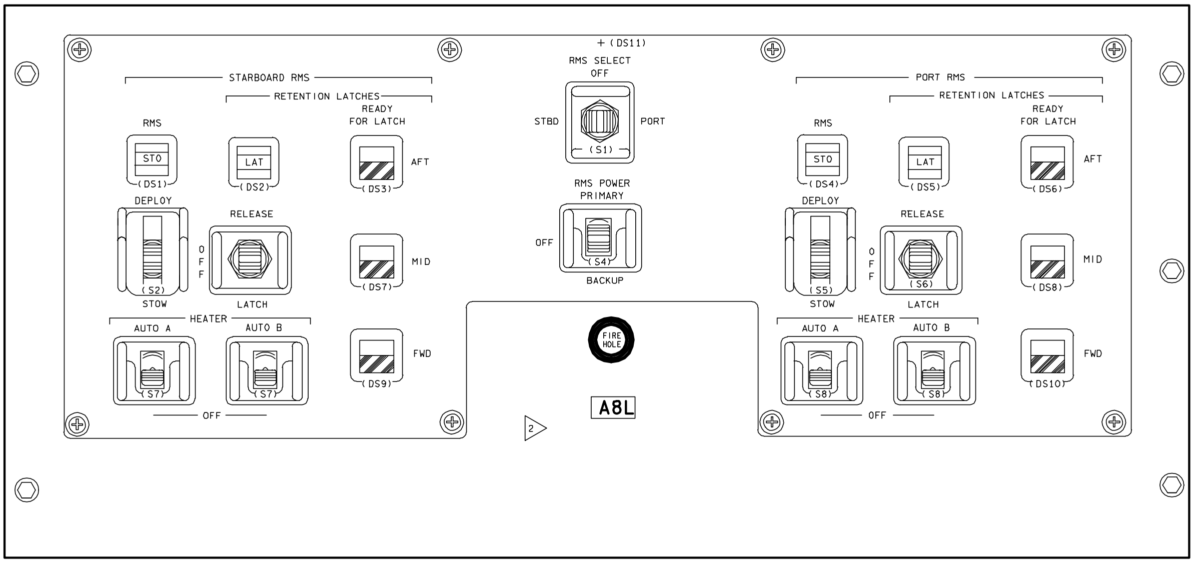
Panel A7U



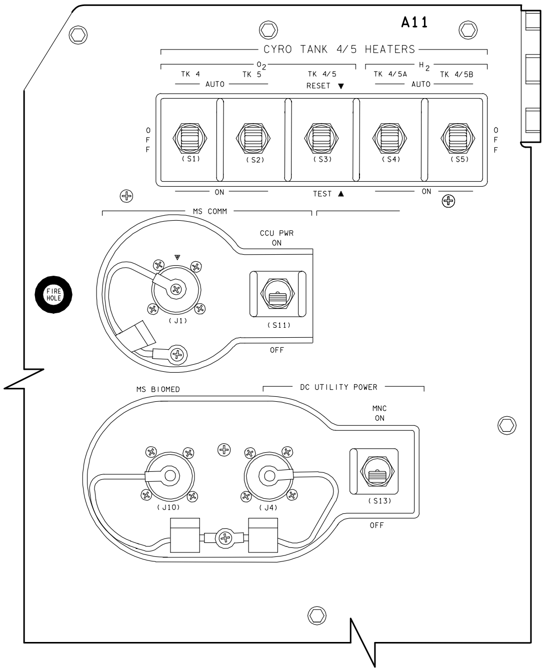
Panel A7L, APDS Control Panel


A8U
AUTO 1 (W)
ORB UNL (W)
AUTO 2 (W)
END EFF (W)
AUTO 3 (W)
ORB LD (W)
AUTO 4 (W)
PAYLOAD (W)
OPR CMD (W)
SINGLE (W)
TEST (W)
DIRECT (W)
(XDS1)
BRAKES
OFF
(DS1)
SAFING
(DS2)
ON
(S1)
OFF
SAFE
AUTO
(S2)
CANCEL▲
SOFTWARE STOP
(DS3)
(A1)
CAUTION/WARNING TONE VOLUME
(R3)
FIRE HOLE
RATE
ACT
CMD
FPS
.25
.2
.1
0
(M1)
MIN
OFF
(DS4)
HOLD
OFF
(DS5)
SCALE
X10
(DS6)
MODE
MANUAL
ORB UNL
END EFF
ORB LD
PL
SINGLE
DIRECT
TEST
OPR CMD
AUTO
1
2
3
4
(S3)
READY (W)
IN PROG (W)
(XDS3)
MCIU (R)
DERIGIDIZE (R)
ABE (R)
RELEASE (R)
GPC DATA (R)
SINGULAR (Y)
CHECK CRT (Y)
CONTR ERR (Y)
REACH LIM (Y)
STBD TEMP (Y)
PORT TEMP (Y)
(XDS2)
END EFFECTOR
MODE AUTO
OFF
(S7)
MAN
MAN CONTR RIGID▼
(S8)
DERIGID▲
RIGID
(DS7)
CLOSE
(DS8)
CAPTURE
(DS9)
DERIGID
(DS10)
OPEN
(DS11)
EXTEND
(DS12)
AUTO SEQ PROCEED▼
(S5)
STOP▲
MASTER ALARM (R)
(S6)
ENTER
(S4)
1
2
3
+58.70
(M2)
X/PITCH
-6.535
(M3)
Y/YAW
-3.725
(M4)
Z/ROLL
(30V73A7)
BACKUP CONTROL JOINT
SHOULDER
ELBOW
WRIST
PITCH
YAW
PITCH
YAW
ROLL
(S9)
(A2)
(A3)
PARAMETER
VEL X/Y/Z
JOINT ANGLE
RATE P/Y/R
ATTITUDE P/Y/R
PORT
TEMP LED/ABE/ID
POSITION X/Y/Z
STBD
TEST
(S10)
30 SEC MAX
JOINT
3/S2
4
SHOULDER
2
PITCH
ELBOW
WRIST
PITCH
5/S3
YAW
YAW
1/S1
6
ROLL
END EFF TEMP
CRIT TEMP
(S11)
PAYLOAD RELEASE
ON
(S12)
OFF
DIRECT DRIVE
+▼
(S13)
−▲
LIGHTING
ANNUN/NUM
BRIGHT
(S14)
VAR
LOW
(R1)
MED
PANEL/INST
OFF
(R2)
BRT
SINGLE/DIRECT DRIVE
+ ▼
(S15)
− ▲
SHOULDER BRACE RELEASE
RELEASE
STBD
(S16)
PORT
(DS13)
(36V73A8A1)

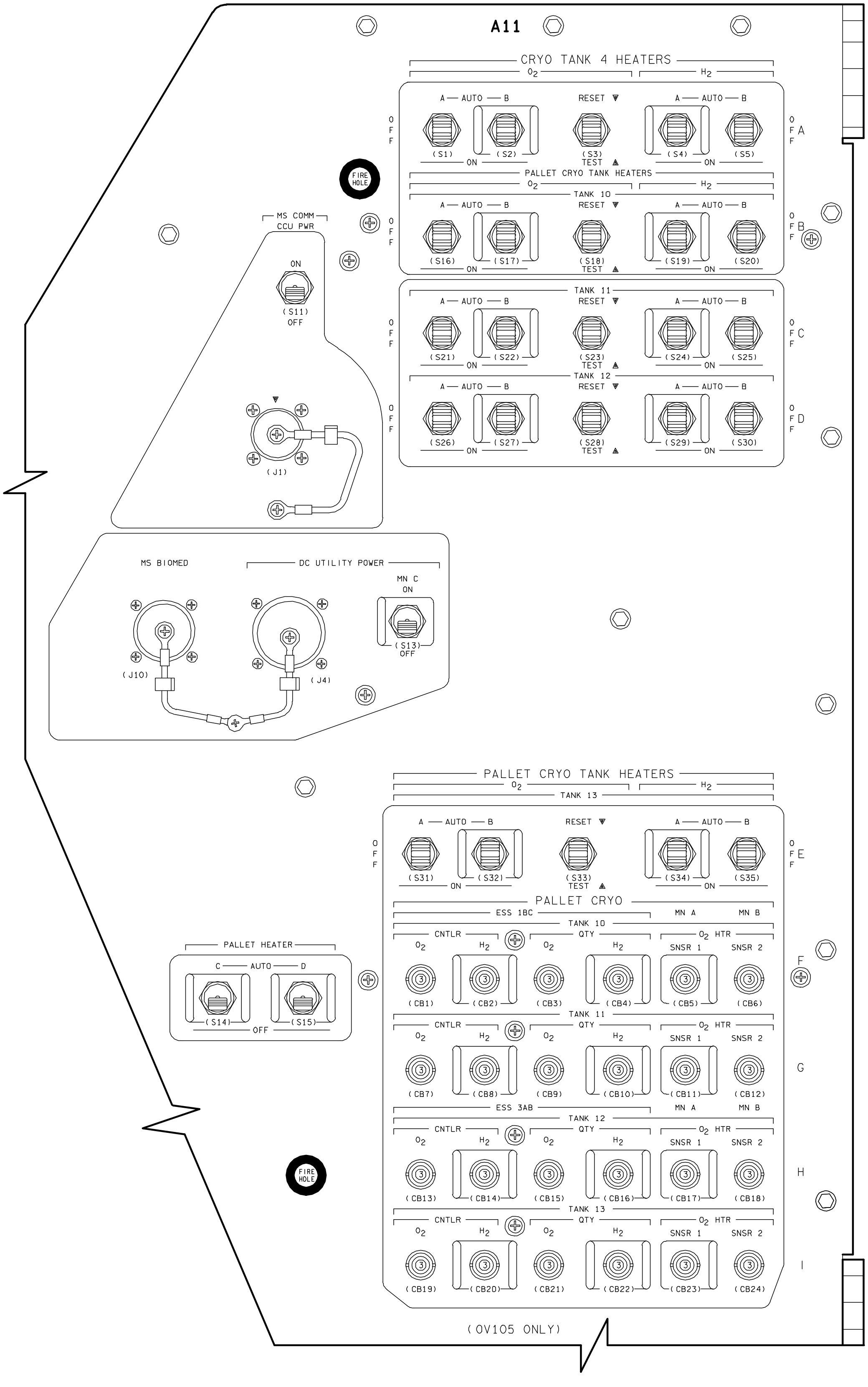
Panel A8U



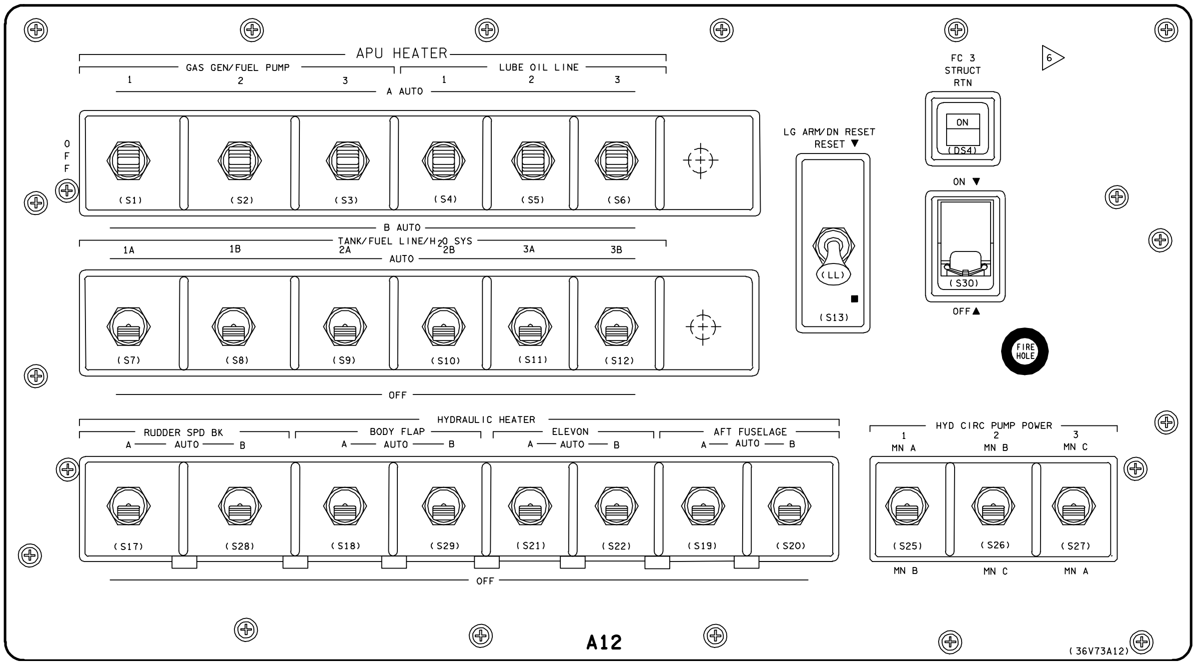
Panel A8L



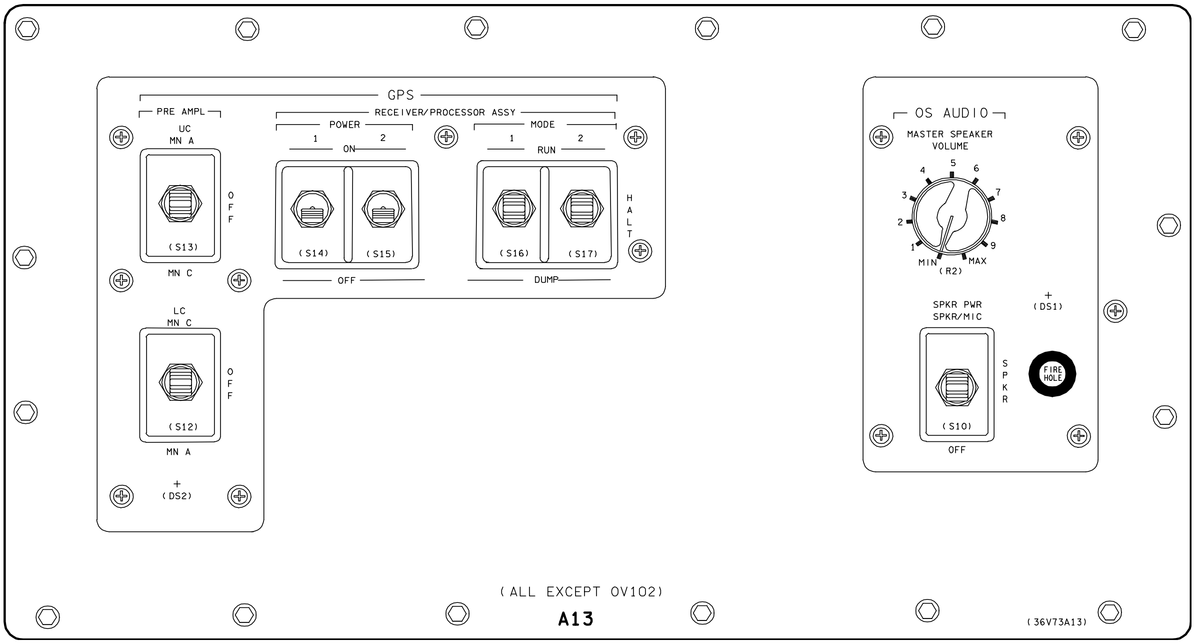
Panel A11 (OV-103 and OV-104 only)



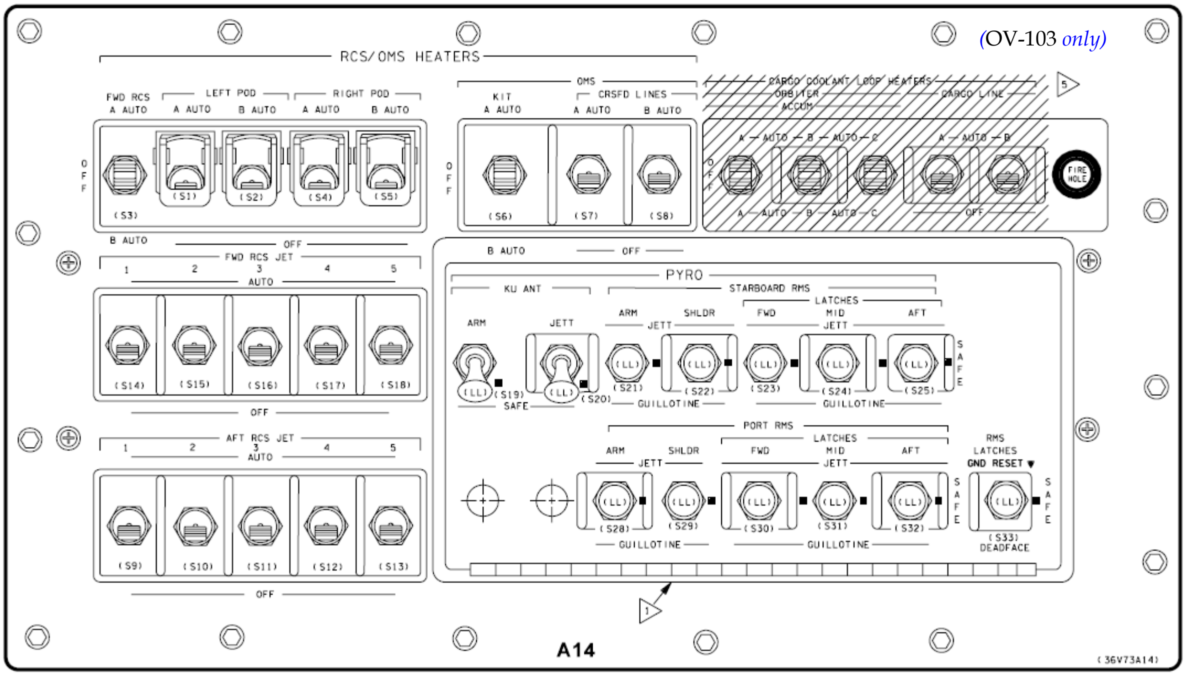
Panel A11
(OV-105 only)



Panel A12

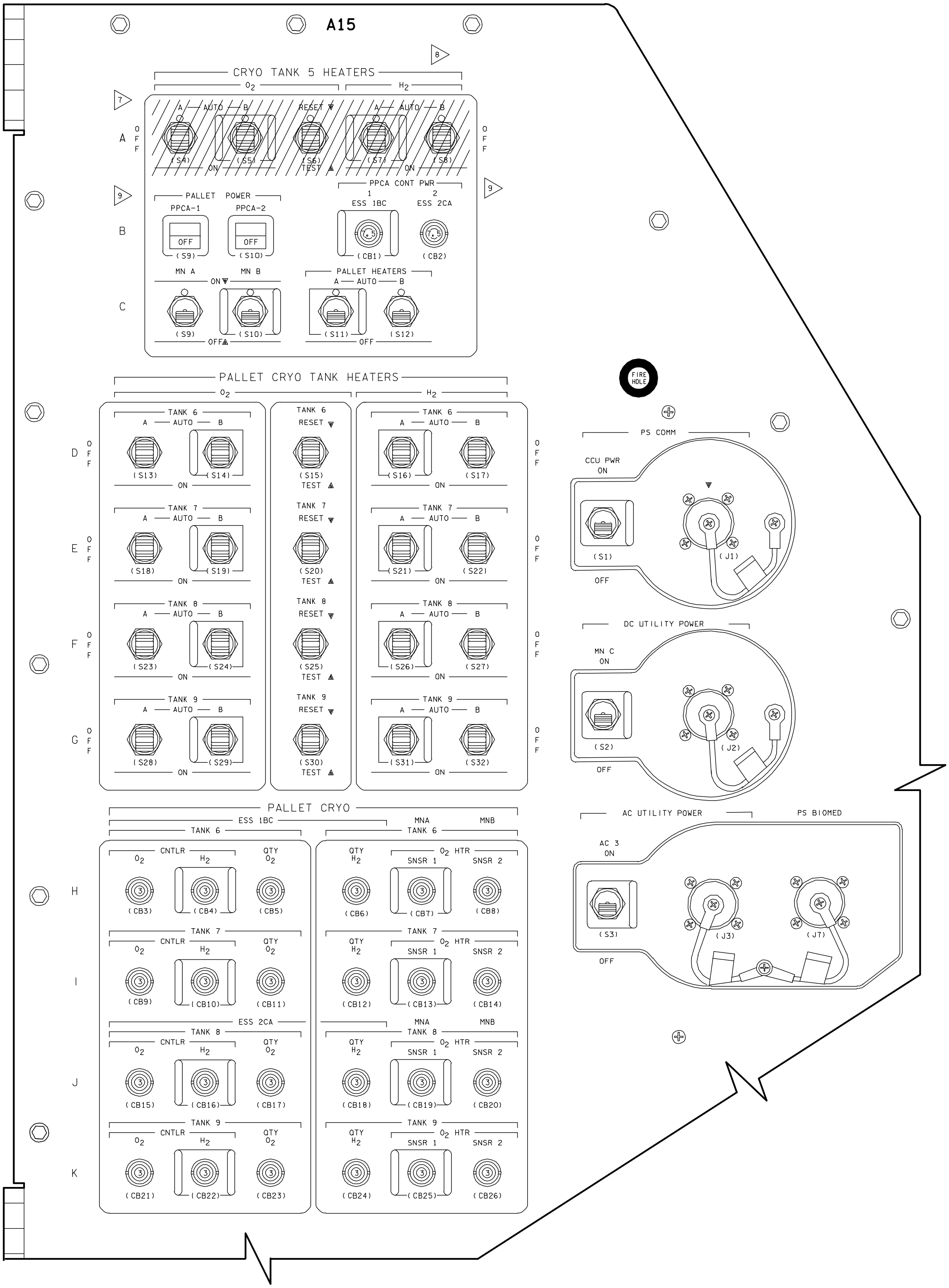


Panel A13

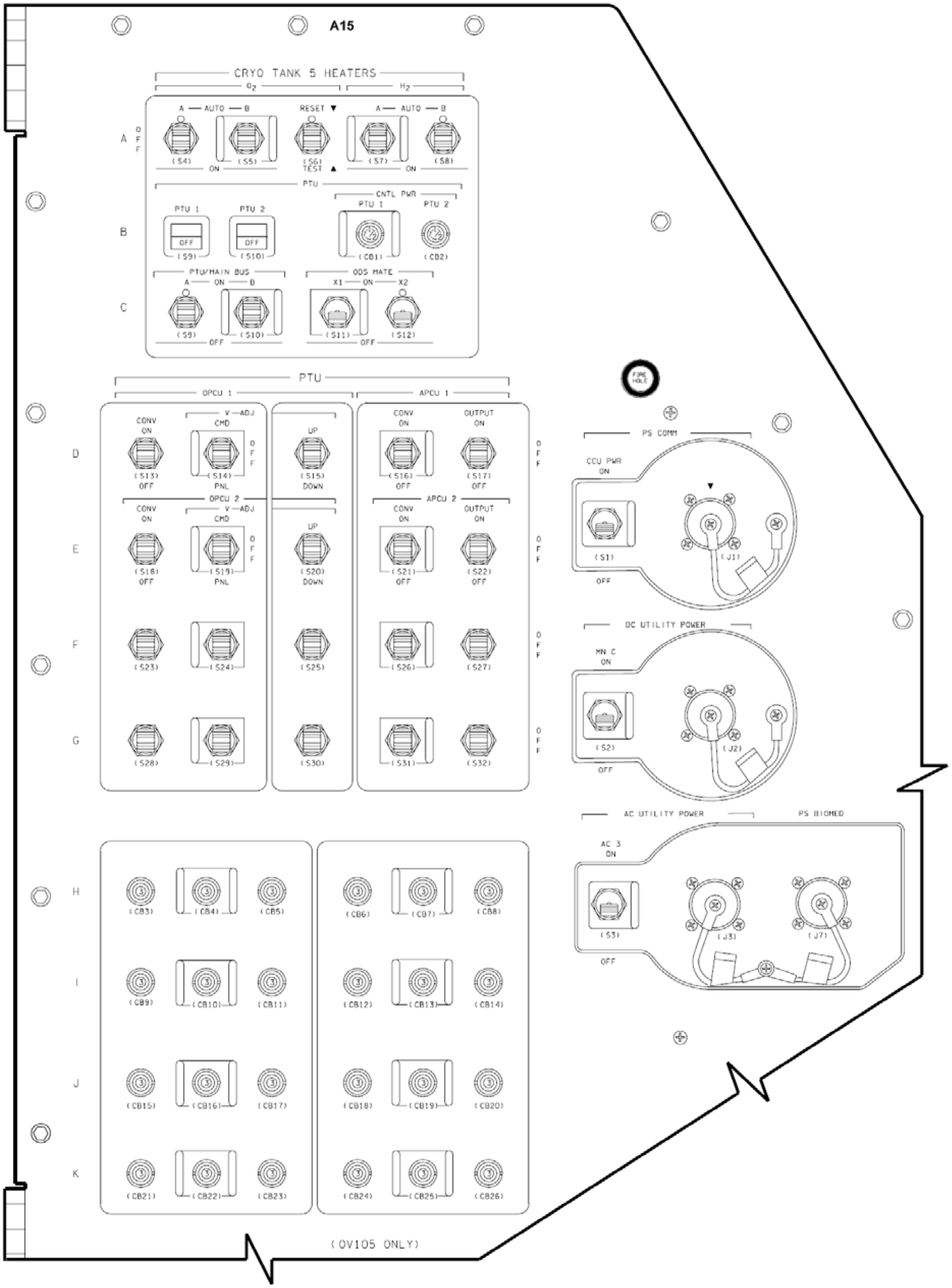


(OV-103 *only*)

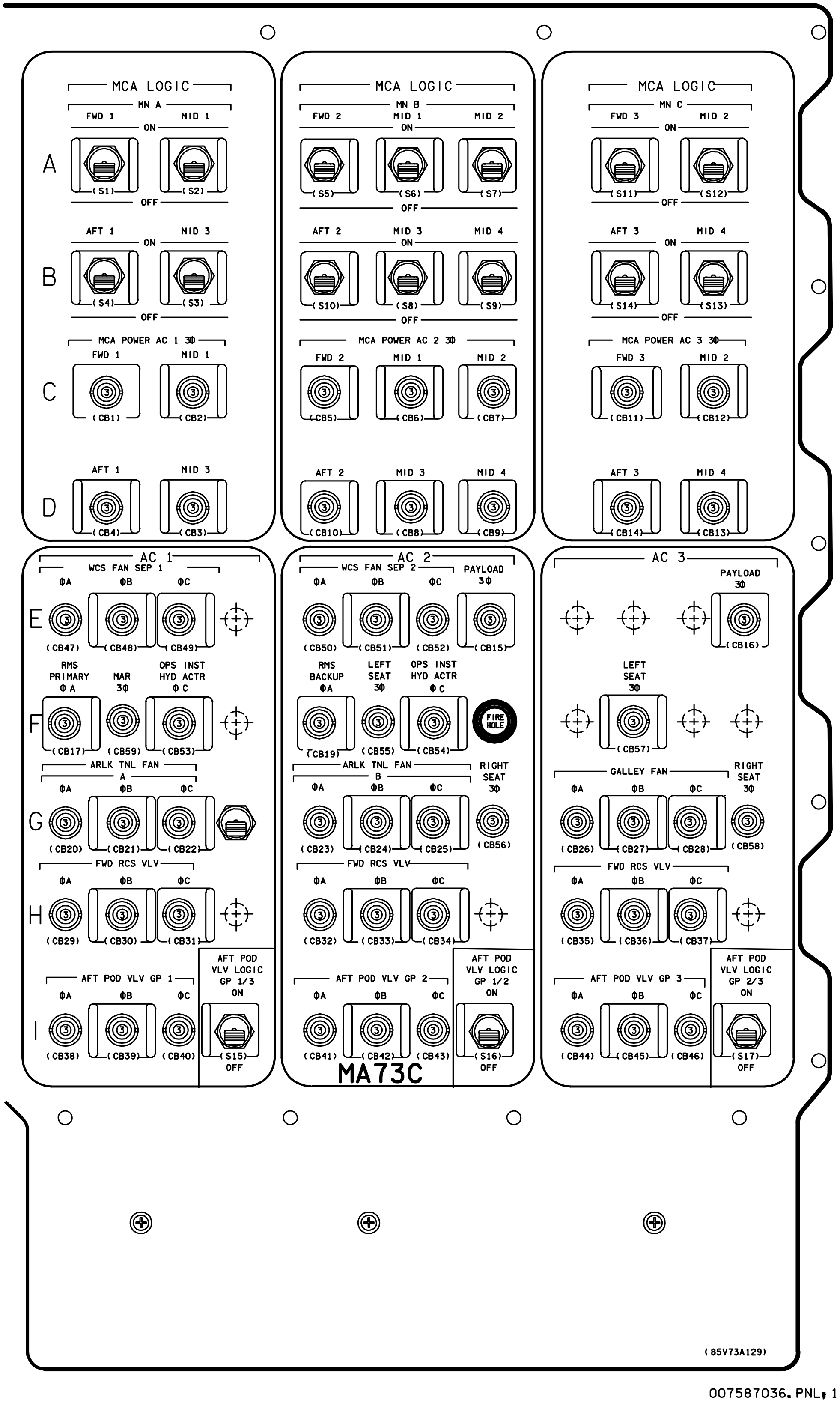
Panel A14



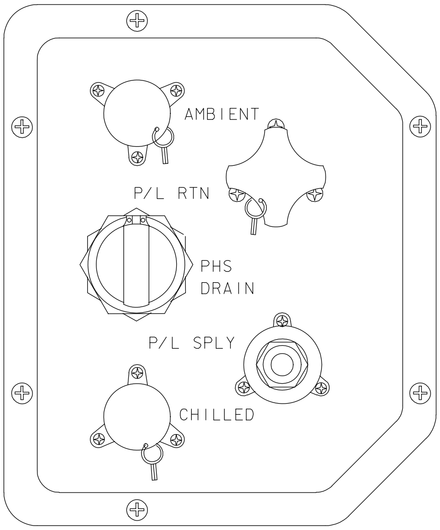
Panel A15 *(OV-104 only)*



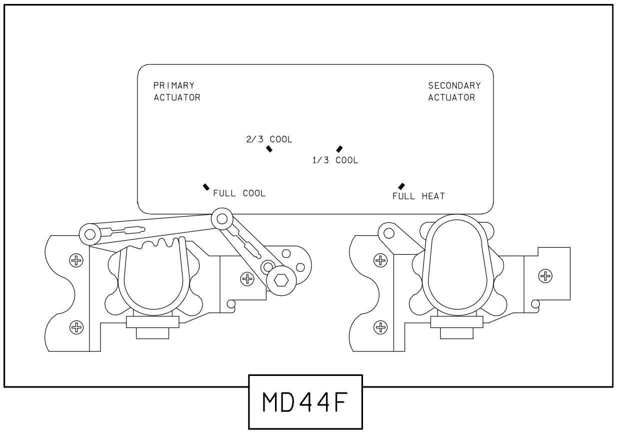
Panel A15 (OV-103, 105 only)


MCA LOGIC
MN A
FWD 1
MID 1
ON
A
(S1)
(S2)
OFF
AFT 1
MID 3
ON
B
(S4)
(S3)
OFF
MCA POWER AC 1 3Φ
FWD 1
MID 1
C
(CB1)
(CB2)
AFT 1
MID 3
D
(CB4)
(CB3)
MCA LOGIC
MN B
FWD 2
MID 1
MID 2
ON
(S5)
(S6)
(S7)
OFF
AFT 2
MID 3
MID 4
ON
(S10)
(S8)
(S9)
OFF
MCA POWER AC 2 3Φ
FWD 2
MID 1
MID 2
(CB5)
(CB6)
(CB7)
AFT 2
MID 3
MID 4
(CB10)
(CB8)
(CB9)
MCA LOGIC
MN C
FWD 3
MID 2
ON
(S11)
(S12)
OFF
AFT 3
MID 4
ON
(S14)
(S13)
OFF
MCA POWER AC 3 3Φ
FWD 3
MID 2
(CB11)
(CB12)
AFT 3
MID 4
(CB14)
(CB13)
AC 1
WCS FAN SEP 1
ΦA
ΦB
ΦC
E
(CB47)
(CB48)
(CB49)
RMS PRIMARY Φ A
MAR 3Φ
OPS INST HYD ACTR Φ C
F
(CB17)
(CB59)
(CB53)
ARLK TNL FAN
A
ΦA
ΦB
ΦC
G
(CB20)
(CB21)
(CB22)
FWD RCS VLV
ΦA
ΦB
ΦC
H
(CB29)
(CB30)
(CB31)
AFT POD VLV GP 1
ΦA
ΦB
ΦC
I
(CB38)
(CB39)
(CB40)
AFT POD VLV LOGIC GP 1/3
ON
(S15)
OFF
AC 2
WCS FAN SEP 2
ΦA
ΦB
ΦC
PAYLOAD 3Φ
(CB50)
(CB51)
(CB52)
(CB15)
RMS BACKUP ΦA
LEFT SEAT 3Φ
OPS INST HYD ACTR Φ C
FIRE HOLE
(CB19)
(CB55)
(CB54)
ARLK TNL FAN
B
ΦA
ΦB
ΦC
RIGHT SEAT 3Φ
(CB23)
(CB24)
(CB25)
(CB56)
FWD RCS VLV
ΦA
ΦB
ΦC
(CB32)
(CB33)
(CB34)
AFT POD VLV GP 2
ΦA
ΦB
ΦC
(CB41)
(CB42)
(CB43)
AFT POD VLV LOGIC GP 1/2
ON
(S16)
OFF
MA73C
AC 3
PAYLOAD 3Φ
(CB16)
LEFT SEAT 3Φ
(CB57)
GALLEY FAN
RIGHT SEAT 3Φ
ΦA
ΦB
ΦC
(CB26)
(CB27)
(CB28)
(CB58)
FWD RCS VLV
ΦA
ΦB
ΦC
(CB35)
(CB36)
(CB37)
AFT POD VLV GP 3
ΦA
ΦB
ΦC
(CB44)
(CB45)
(CB46)
AFT POD VLV LOGIC GP 2/3
ON
(S17)
OFF
(85V73A129)
007587036.PNL, 1

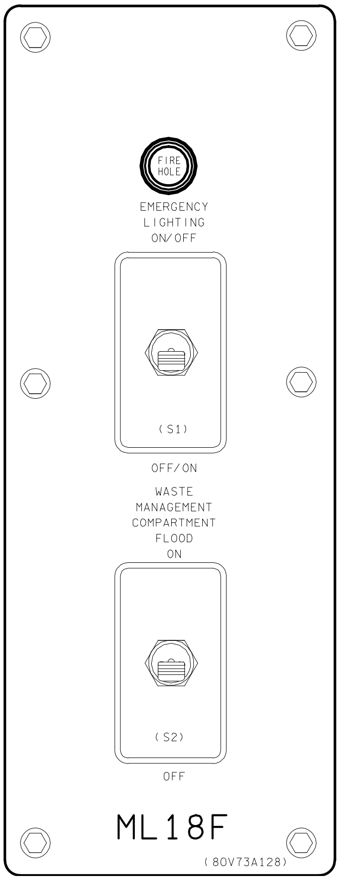
Panel MA73C



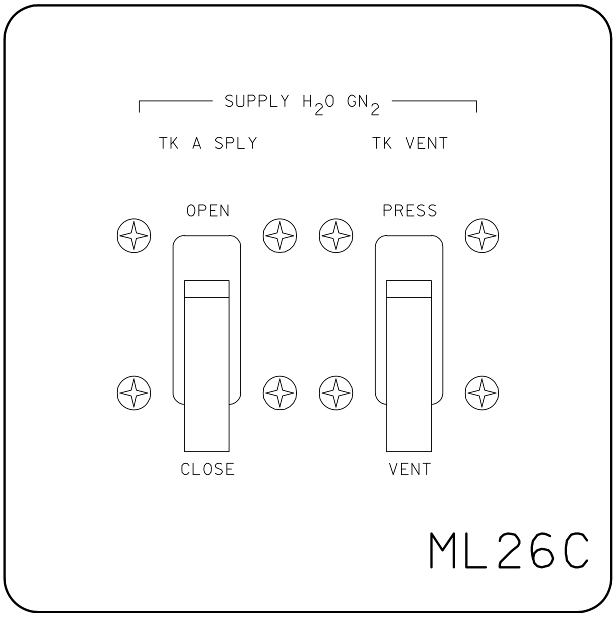
MD24K



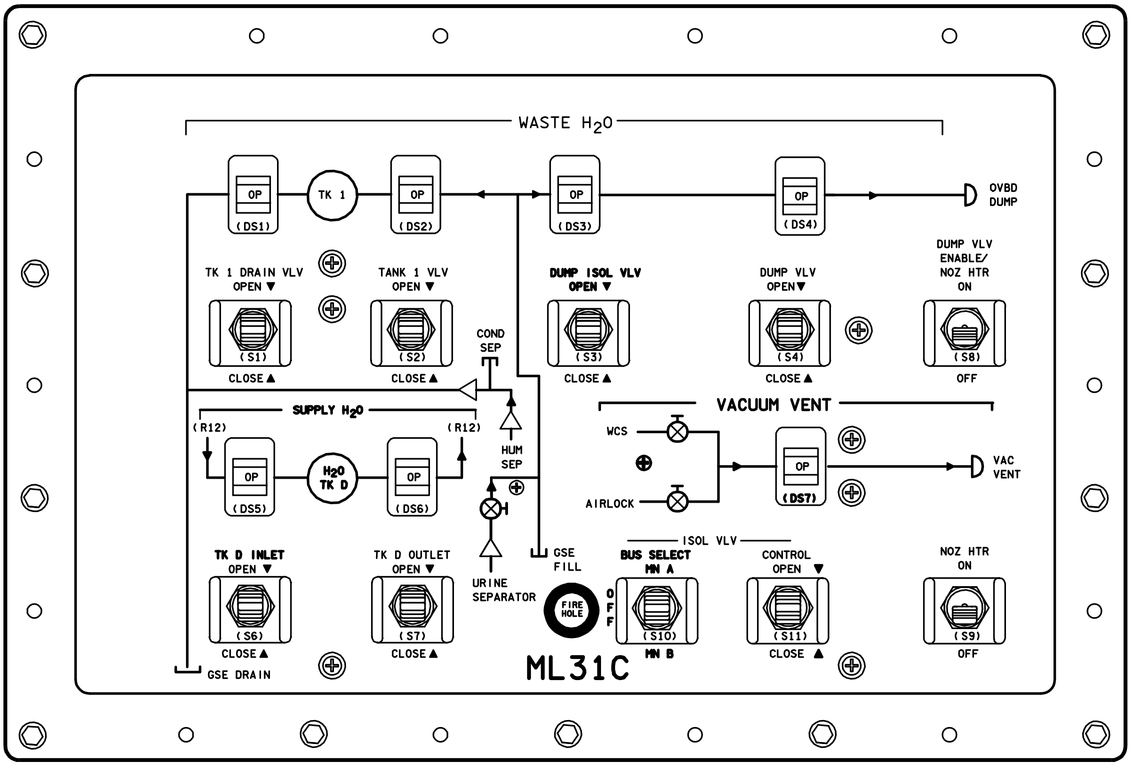
Panel MD44F



Panel ML18F

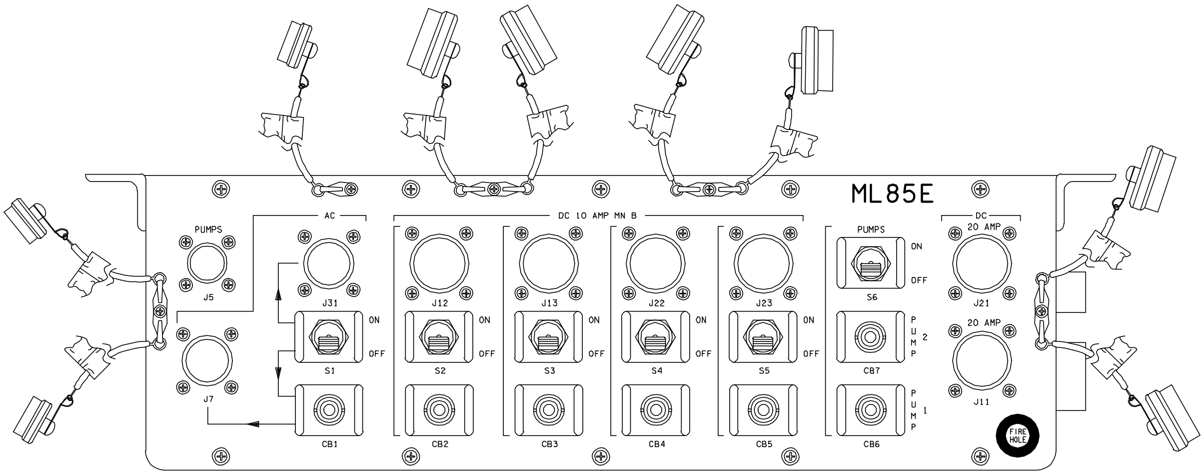


Panel ML26C

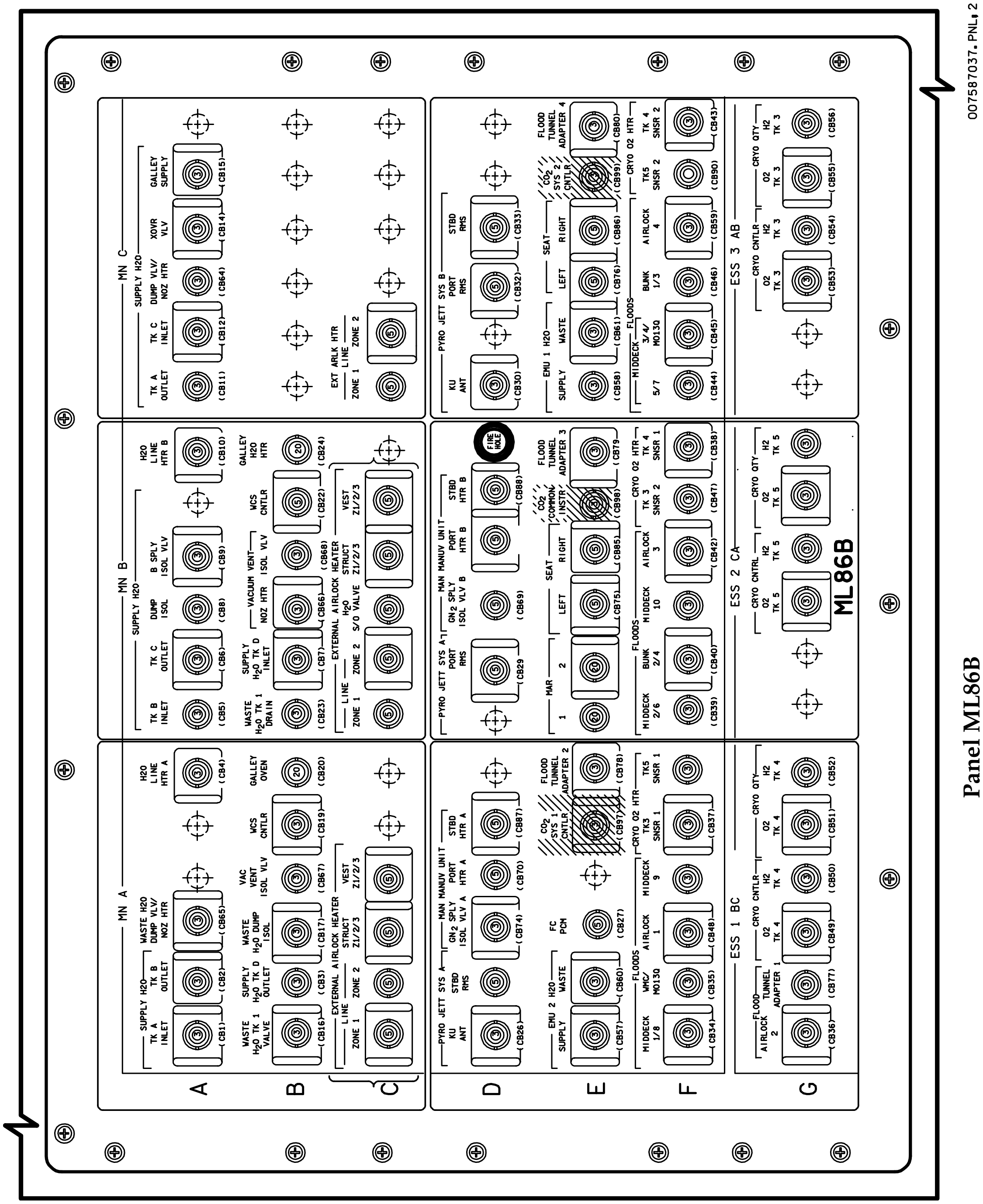


007587039.PNL;1

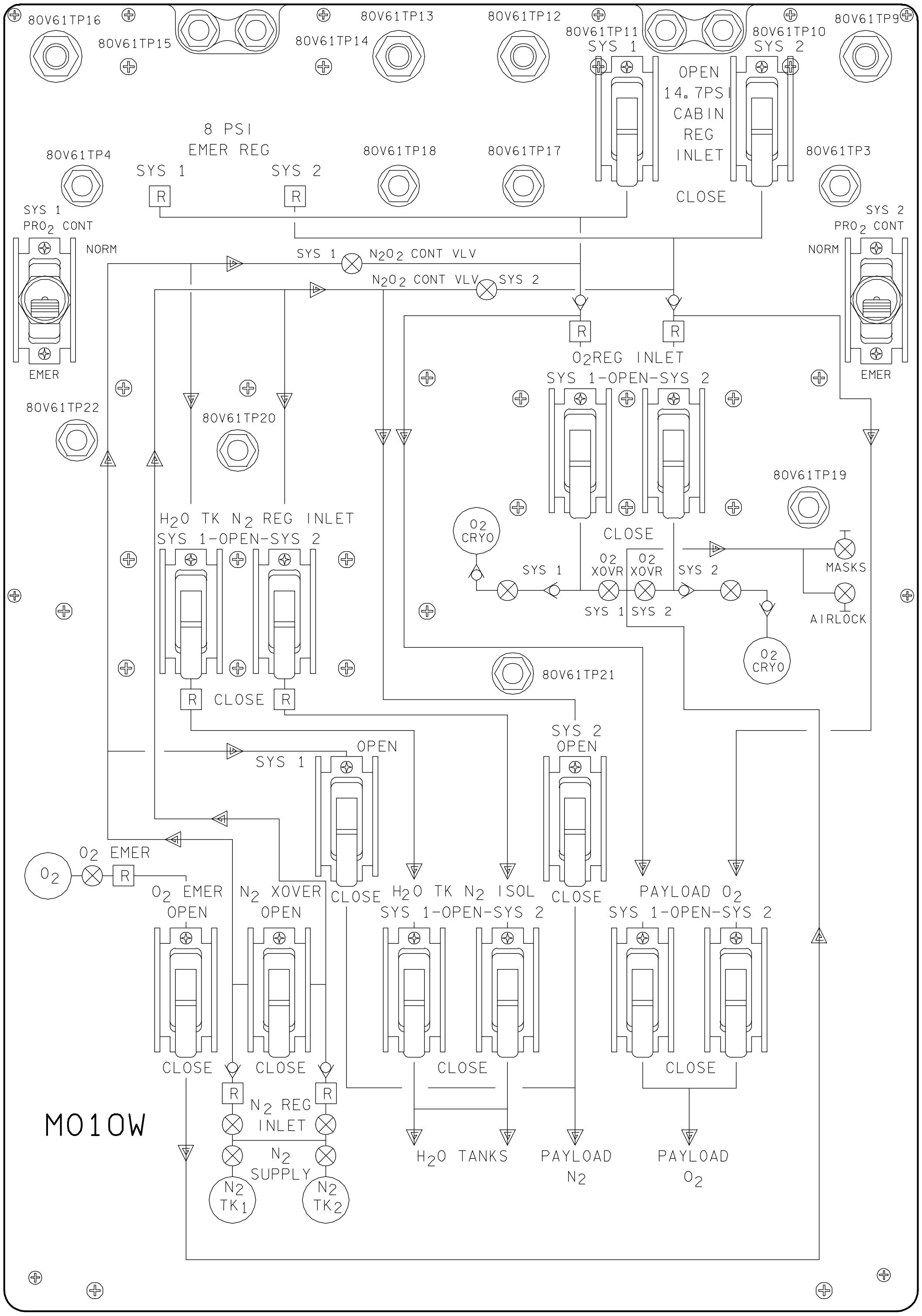
Panel ML31C



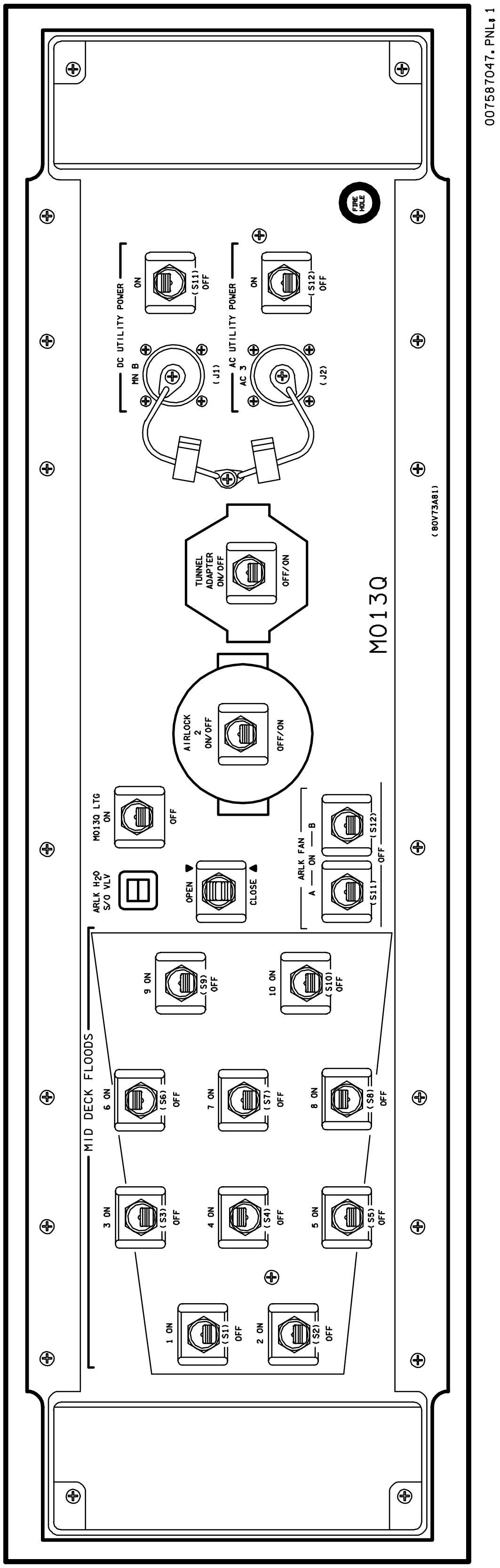
Panel ML85E


007587037.PNL;2
ML86B
MN A
MN B
MN C
ESS 1 BC
ESS 2 CA
ESS 3 AB
A
B
C
D
E
F
G
FIRE HOLE

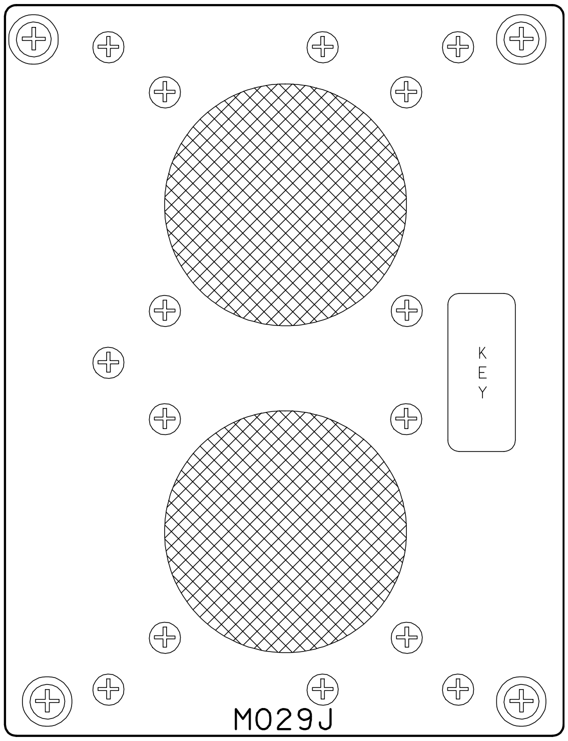
Panel ML86B


80V61TP16
80V61TP15
80V61TP14
80V61TP13
80V61TP12
80V61TP11
SYS 1
80V61TP10
SYS 2
80V61TP9
OPEN
14.7PSI
CABIN
REG
INLET
CLOSE
8 PSI
EMER REG
SYS 1
SYS 2
R
R
80V61TP4
80V61TP18
80V61TP17
80V61TP3
SYS 1
PRO2 CONT
NORM
EMER
SYS 2
PRO2 CONT
NORM
EMER
SYS 1
N2O2 CONT VLV
N2O2 CONT VLV
SYS 2
R
R
O2REG INLET
SYS 1-OPEN-SYS 2
CLOSE
80V61TP22
80V61TP20
80V61TP19
H2O TK N2 REG INLET
SYS 1-OPEN-SYS 2
CLOSE
R
R
O2 CRYO
SYS 1
O2 XOVR
O2 XOVR
SYS 2
SYS 1
SYS 2
MASKS
AIRLOCK
O2 CRYO
80V61TP21
OPEN
SYS 1
SYS 2
OPEN
CLOSE
CLOSE
O2
O2 EMER
R
O2 EMER
OPEN
N2 XOVER
OPEN
H2O TK N2 ISOL
SYS 1-OPEN-SYS 2
PAYLOAD O2
SYS 1-OPEN-SYS 2
CLOSE
CLOSE
CLOSE
CLOSE
R
R
N2 REG
INLET
N2
SUPPLY
N2 TK1
N2 TK2
H2O TANKS
PAYLOAD
N2
PAYLOAD
O2
MO10W

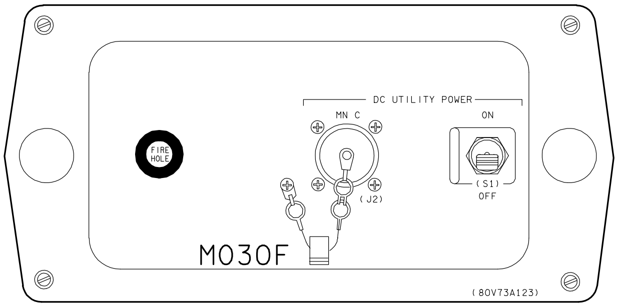
Panel MO10W


007587047.PNL;1
FIRE HOLE
DC UTILITY POWER
MN B
ON
(S11) OFF
(J1)
AC UTILITY POWER
AC 3
ON
(S12) OFF
(J2)
TUNNEL ADAPTER ON/OFF
OFF/ON
AIRLOCK 2 ON/OFF
OFF/ON
MO13Q
(80V73A81)
MO13Q LTG ON
OFF
ARLK H2O S/O VLV
OPEN
CLOSE
ARLK FAN
A
ON
B
(S11)
(S12)
OFF
MID DECK FLOODS
9 ON
(S9) OFF
10 ON
(S10) OFF
6 ON
(S6) OFF
7 ON
(S7) OFF
8 ON
(S8) OFF
3 ON
(S3) OFF
4 ON
(S4) OFF
5 ON
(S5) OFF
1 ON
(S1) OFF
2 ON
(S2) OFF

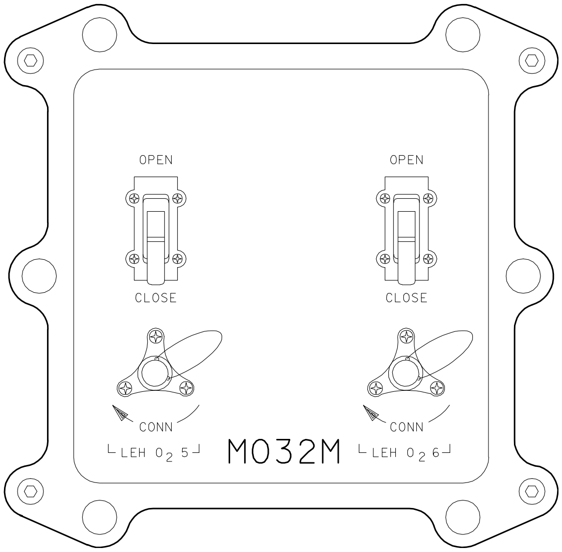
Panel MO13Q



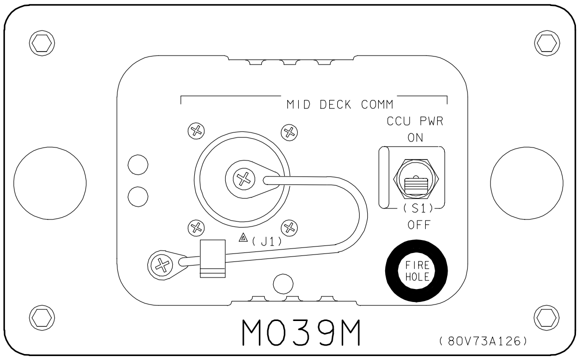
Panel MO29J



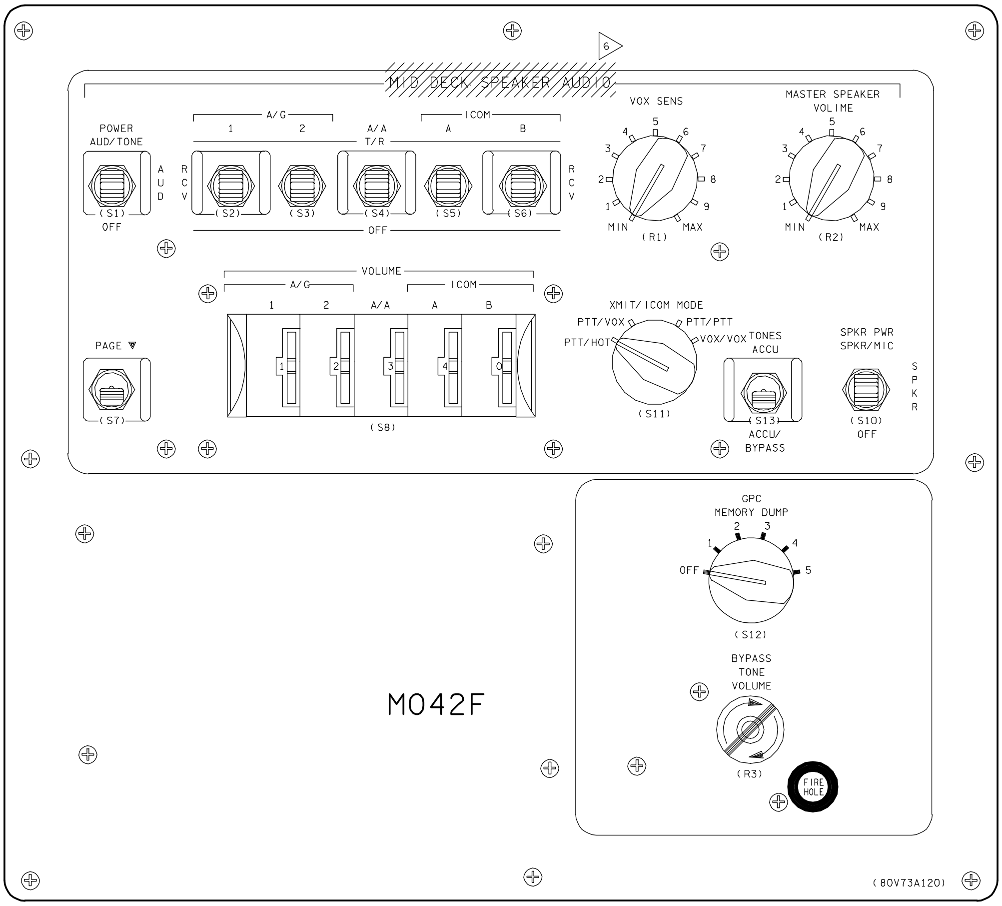
Panel MO30F



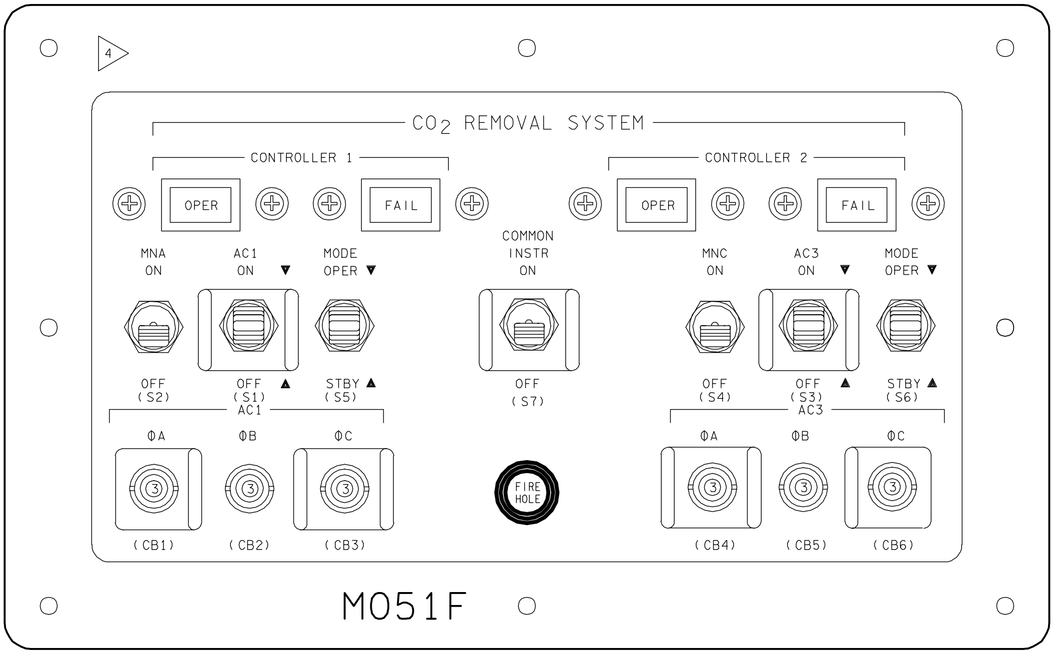
Panel MO32M



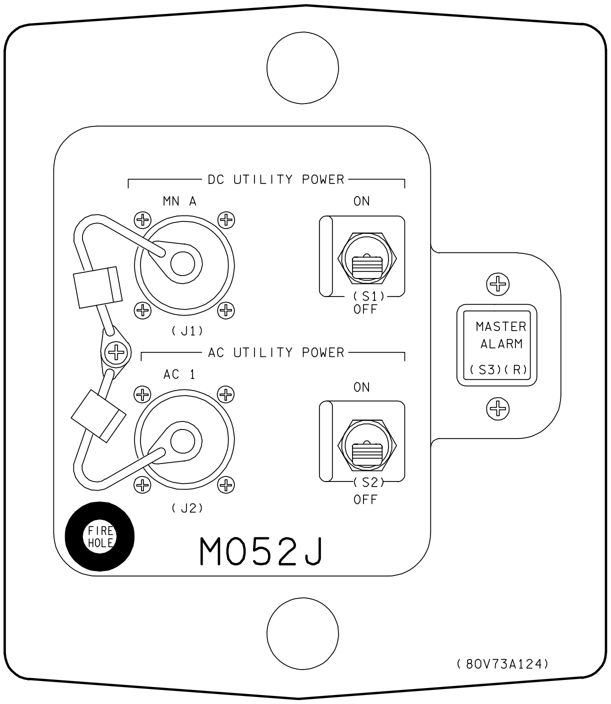
Panel MO39M



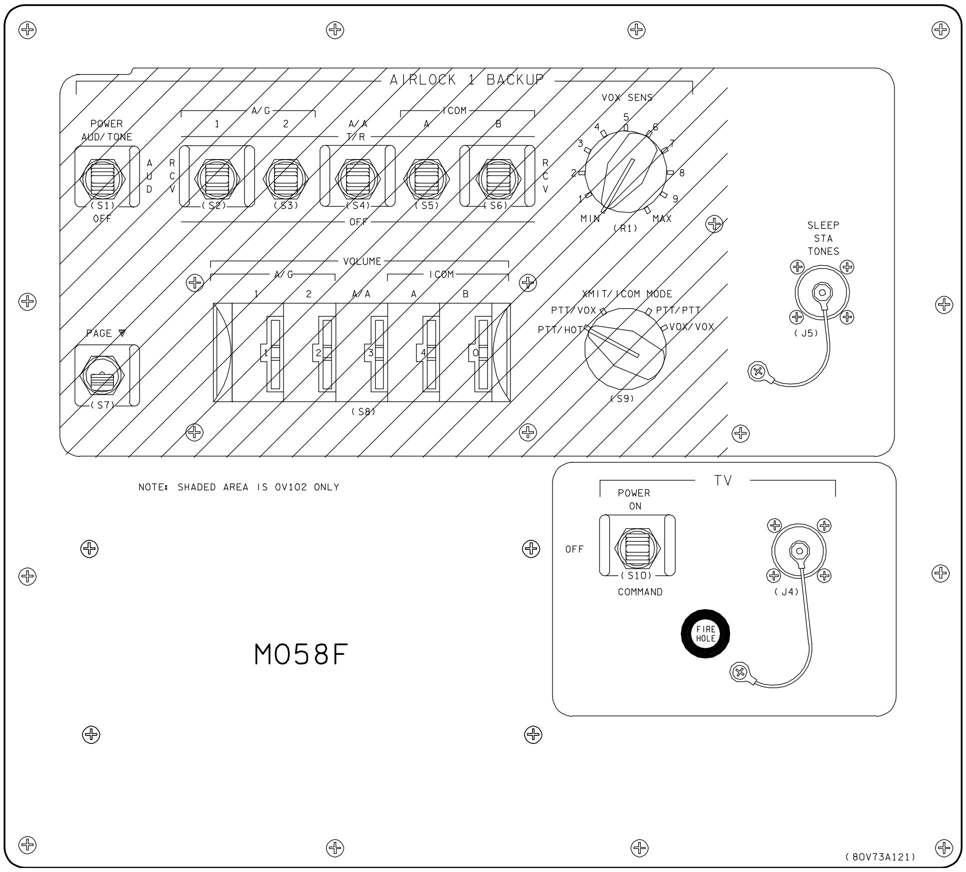
Panel MO42F



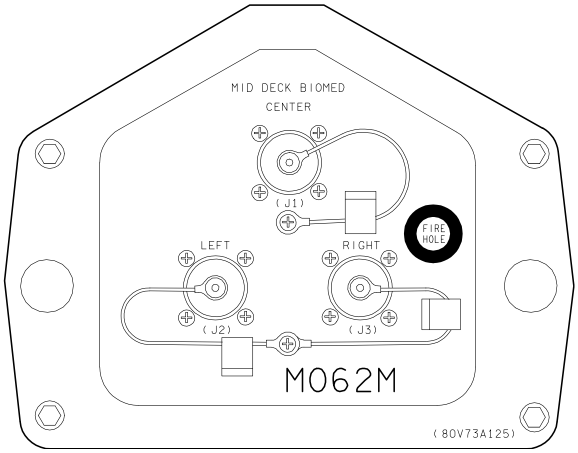
Panel MO51F *(OV-104, 105 only)*



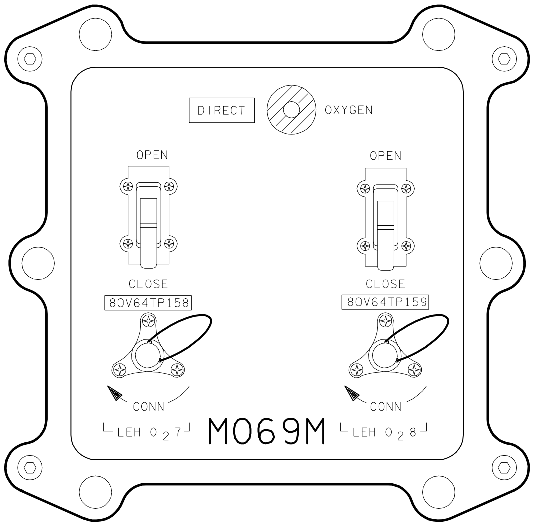
Panel MO52J



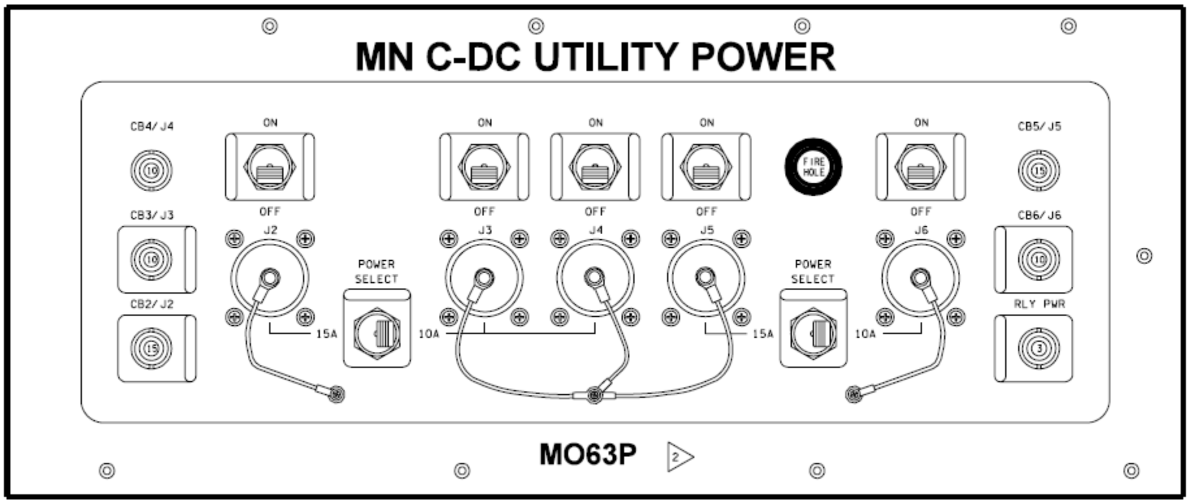
Panel MO58F



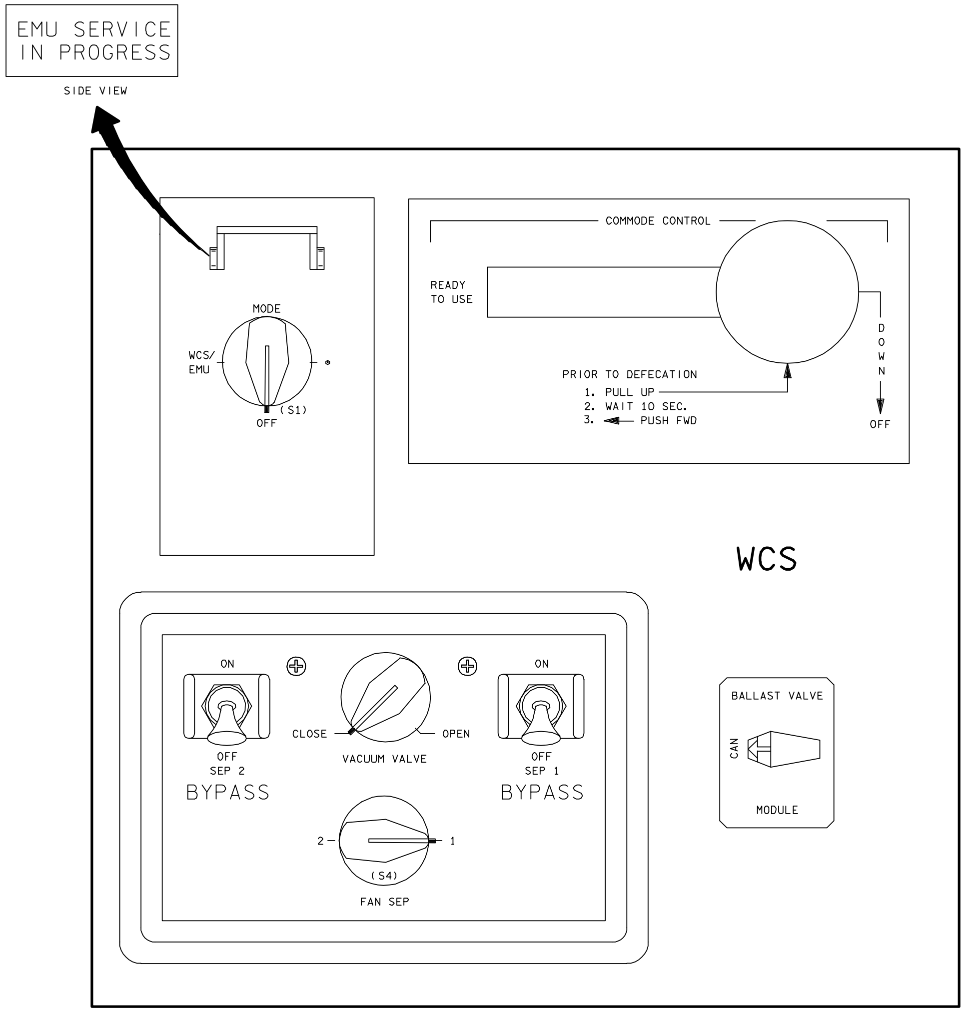
Panel MO62M



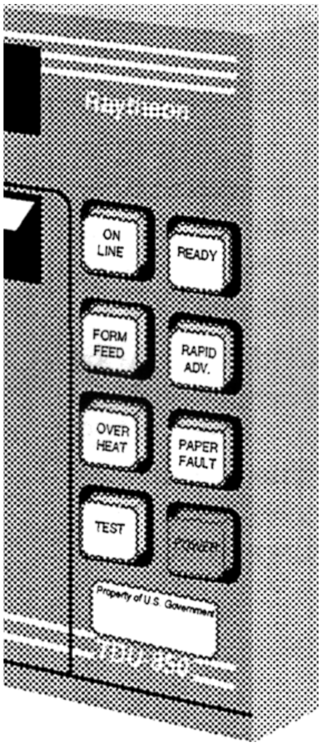
Panel MO69M



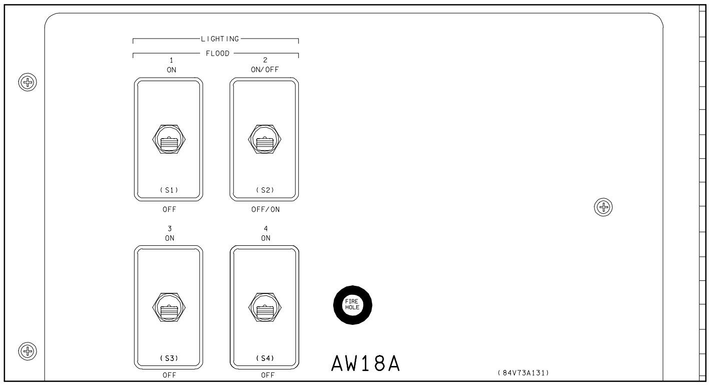
Panel MO63P (OV-103, 104 only)


EMU SERVICE IN PROGRESS
SIDE VIEW
MODE
WCS/ EMU
OFF
(S1)
COMMODE CONTROL
READY TO USE
DOWN
OFF
PRIOR TO DEFECATION
1. PULL UP
2. WAIT 10 SEC.
3. PUSH FWD
WCS
ON
OFF
SEP 2
BYPASS
CLOSE
OPEN
VACUUM VALVE
ON
OFF
SEP 1
BYPASS
2
1
(S4)
FAN SEP
BALLAST VALVE
CAN
MODULE

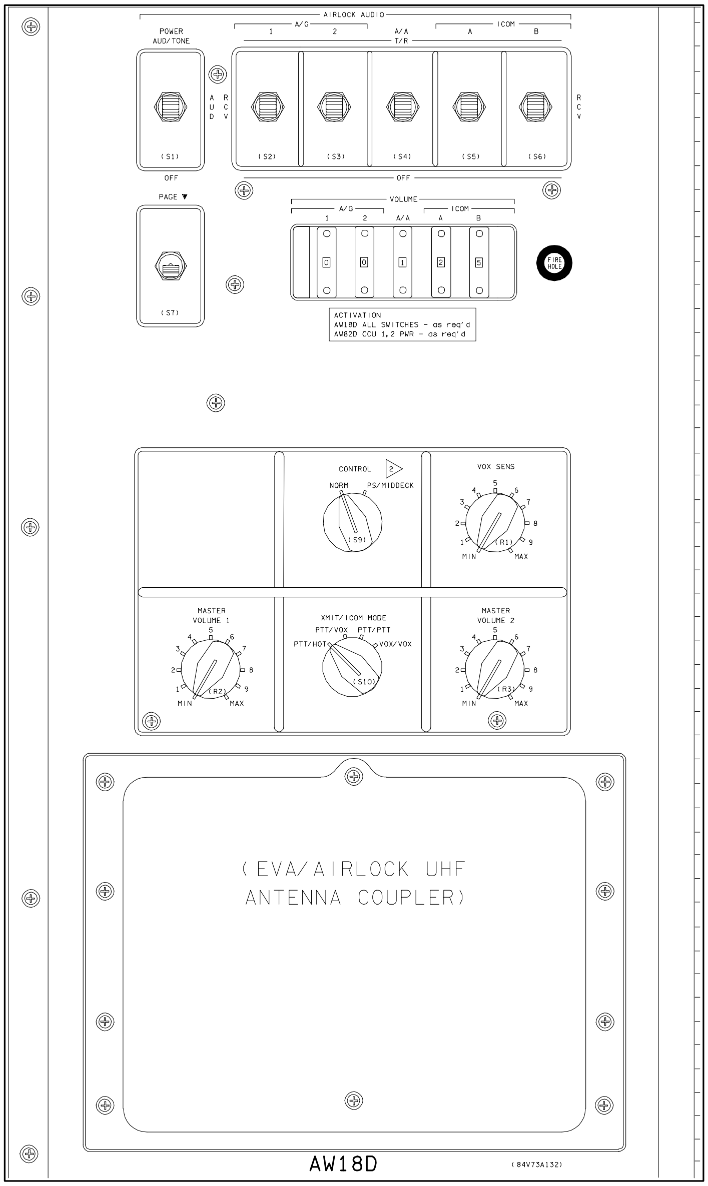
WCS



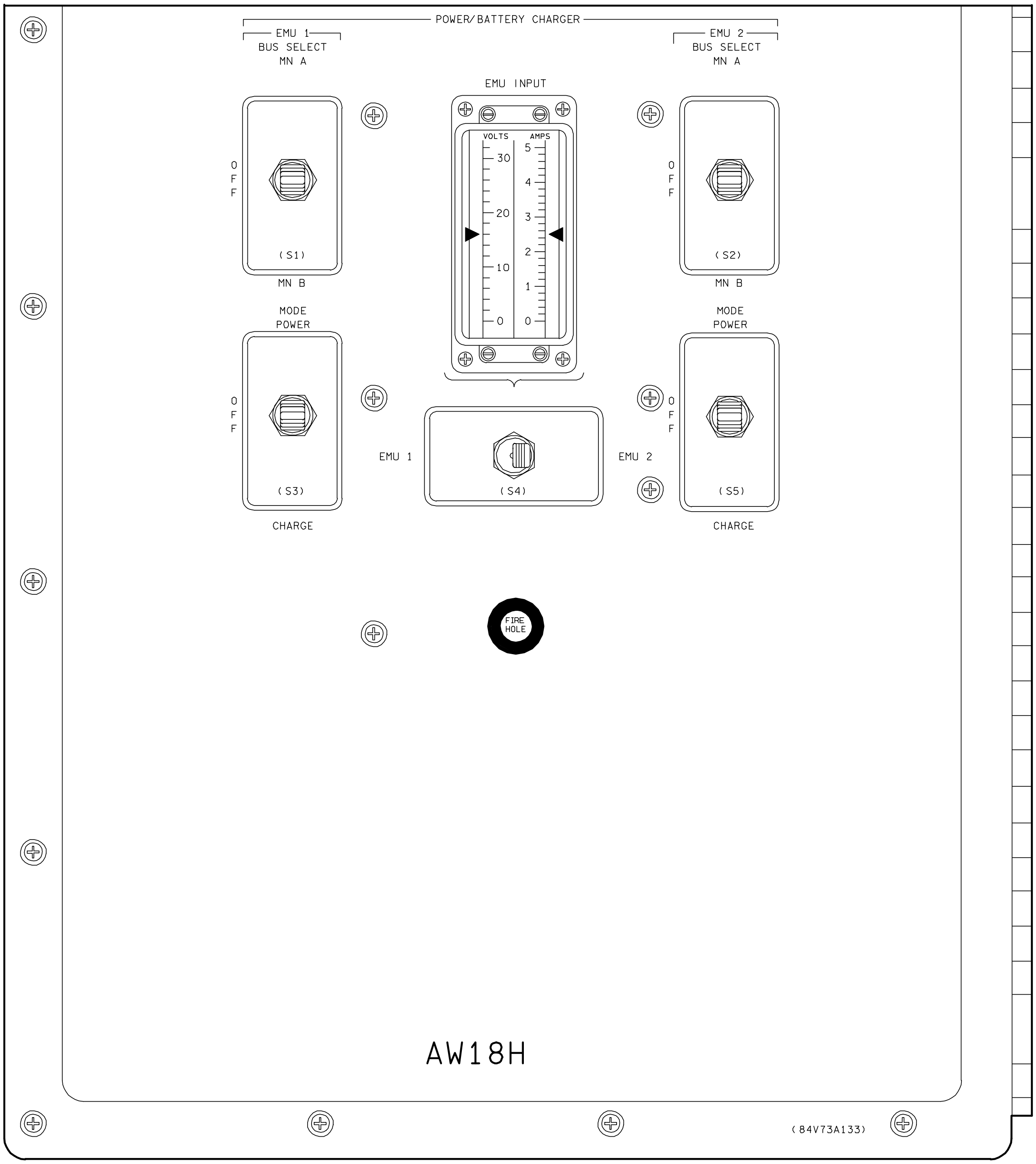
Thermal Impulse Printer



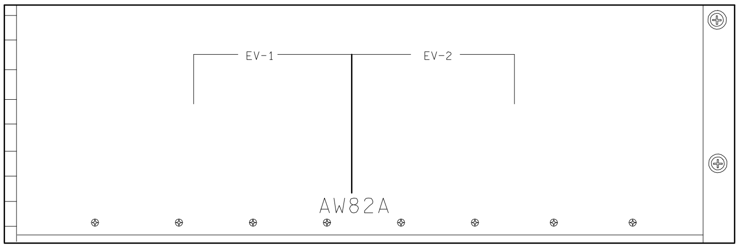
Panel AW18A



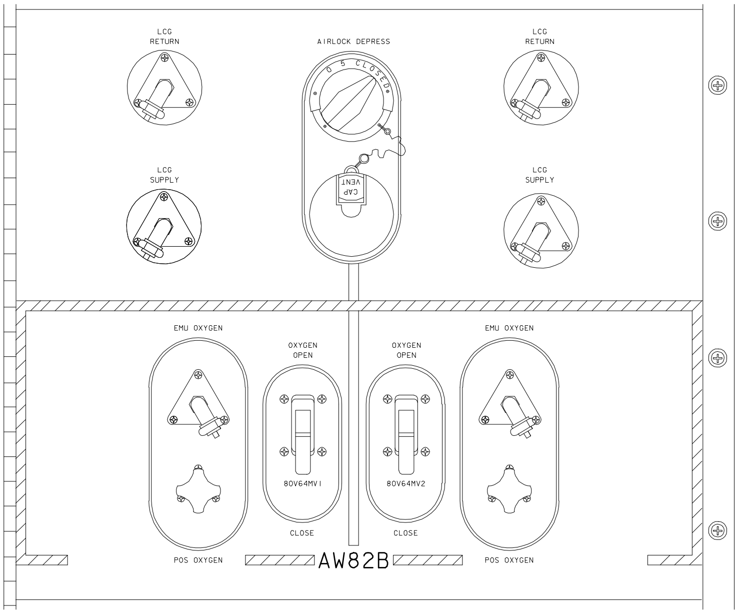
Panel AW18D


POWER/BATTERY CHARGER
EMU 1
BUS SELECT
MN A
OFF
(S1)
MN B
EMU 2
BUS SELECT
MN A
OFF
(S2)
MN B
EMU INPUT
VOLTS
AMPS
30
20
10
0
5
4
3
2
1
0
MODE
POWER
OFF
(S3)
CHARGE
EMU 1
(S4)
EMU 2
MODE
POWER
OFF
(S5)
CHARGE
FIRE HOLE
AW18H
(84V73A133)

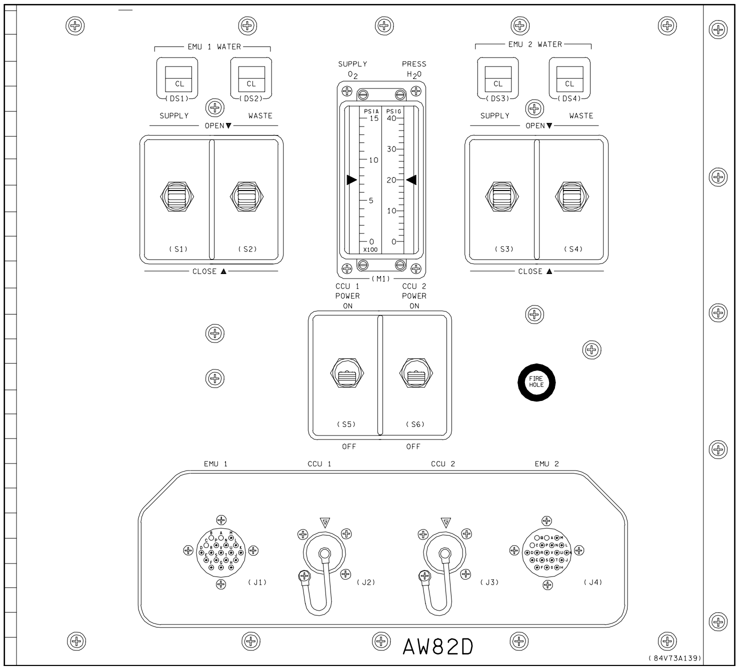
Panel AW18H



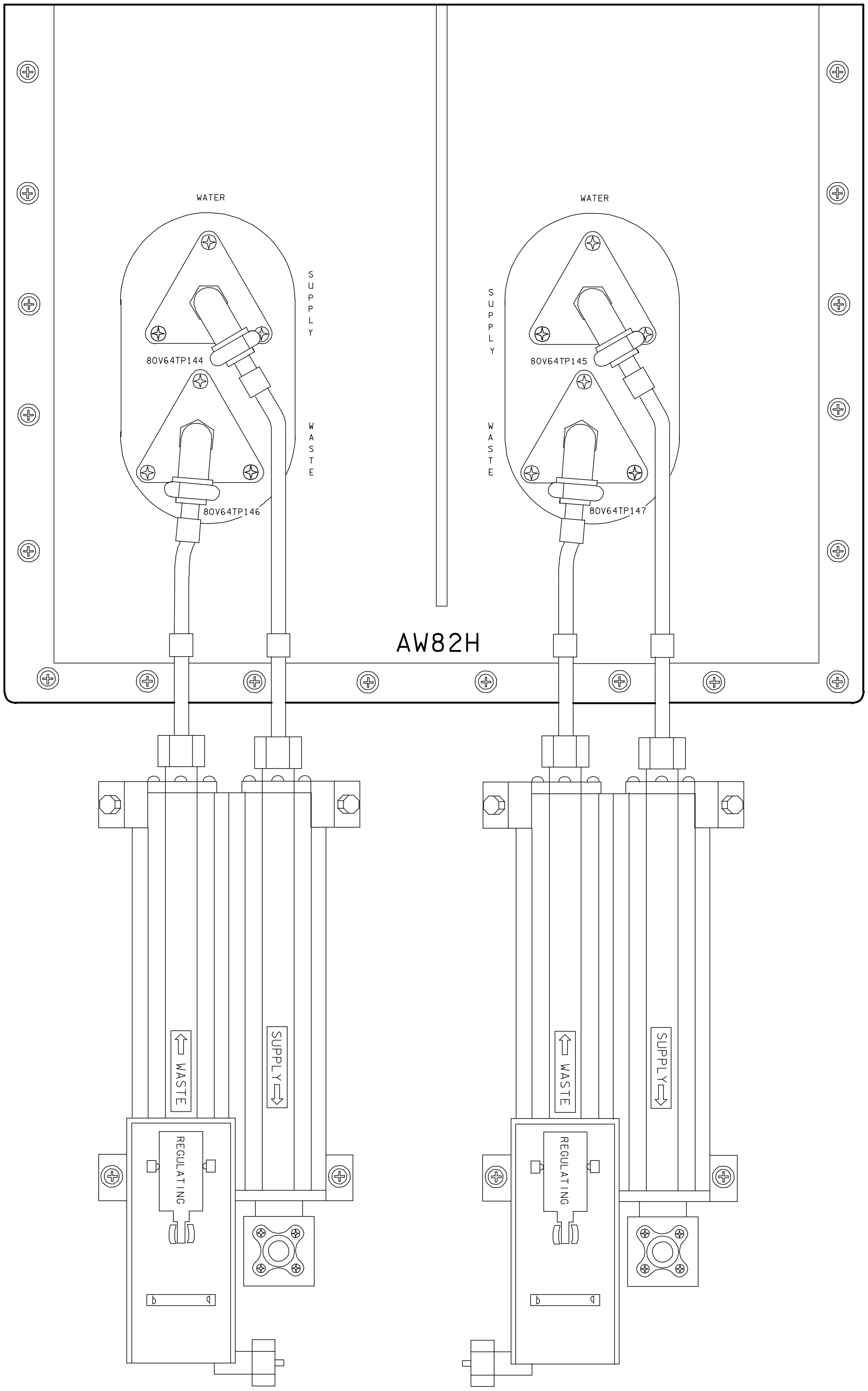
Panel AW82A



Panel AW82B



Panel AW82D


WATER
SUPPLY
80V64TP144
WASTE
80V64TP146
WATER
SUPPLY
80V64TP145
WASTE
80V64TP147
AW82H
WASTE
SUPPLY
REGULATING
WASTE
SUPPLY
REGULATING

Panel AW82H

APPENDIX B DISPLAYS AND CONTROLS

Orbiter Displays Reference Guide

Space Shuttle Orbiter Displays and Controls (CRT & HUD)

OI-32

July 2007

BOEING

General Information

This Orbiter Displays Reference Guide is for information only as it pertains to CRT and HUD displays. The guide was developed as a quick-reference tool for personnel supporting tests involving Orbiter displays. It provides the CRT displays documented in the November 8, 2005 Level C Functional Subsystem Software Requirements (FSSR) Display and Controls Specification, STS 83-0020-32, with an effectivity of OI-32 and subs. This guide also provides System Management (SM) mission reconfigurable displays documented in the baseline version of JSC-19590 Level C Flight Software Requirements document. Please note the SM displays are mission reconfigurable and there could be changes to the displays subsequent to STS-120.

This reference guide reflects the incorporation of approved Software Change Requests (SCR's) listed in SCR 98085D - Flight Software Release Baseline Specification: OI-32. For more detailed information, refer to the above-mentioned documents. For information regarding the publication and distribution of this guide, contact Jose Rosa (321-861-4658) or Pete Wilson (321-861-4656).

How To Use This Guide

The CRT and HUD displays are listed in alphabetical order by title. The CRT displays are shown with their OPS availability and type. The tables on the next four pages will provide assistance in locating a specific CRT and HUD display quickly, including CRT displays related to Initial Program Load (IPL). There are also tables provided in descending order according to hierarchy of OPS, SPEC and DISP for the CRT displays.

Contents A - Alphabetical

Primary Avionics Software System (PASS) Display	GNC							SM			PL	
	0	1	2	3	6	8	9	0	2	4	9	Page
Actuator Control							X					1A
Antenna									X	X		1B
APU/Environ Therm*									X			1C
APU/HYD*									X			1D
Communications*									X			2B
Controllers						X						2C
Controls		X		X	X							2D
CRYO Pallet/Cargo*									X			3B
CRYO System*									X			3C
DAP Config			X									3D
Docking Status*									X			4A
DPS Utility	X	X	X	X	X	X	X		X	X	X	4B
Electric*									X			4C
Entry TRAJ 1				X								5A
Entry TRAJ 2				X								5C
Entry TRAJ 3				X								6A
Entry TRAJ 4				X								6C
Entry TRAJ 5				X								7A
Environment*									X			7B
External Airlock*									X			7C
Fault	X	X	X	X	X	X	X	X	X	X	X	8A
FCS/DED Displays C/O						X						8B
Fuel Cells*									X			8C
GNC Sys SUMM 1		X	X	X	X	X						9A
GNC Sys SUMM 2			X			X						9B
GND IMU CNTL/MON							X					9C
GPC Memory	X	X	X	X	X	X	X	X	X	X	X	9D
GPC/BTU I/F							X					10A
GPC/Bus Status	X	X	X	X	X	X	X		X	X	X	10B
GPCF PL C&W									X	X		10C
GPCF PL Commanding									X	X		10D
GPCF PL Status									X	X		11A
GPS Status		X	X	X	X	X	X					11D
GTS Display							X				X	12A
Horiz Sit (in-left/3 TAC)		X		X	X							12D
Horiz Sit (in-right/3 TAC)		X		X	X							13A
Horiz Sit (out-left/3 TAC)		X		X	X							13B
Horiz Sit (out-right/3 TAC)		X		X	X							13C
Horiz Sit (right/3 GPS)		X		X	X							13D
HYD Thermal*									X			15A
IMU Align			X	X								15B
Manual Controls							X					15C
Mass Memory R/W									X	X	X	15D
NWS Check						X						16A
Orbit TGT			X									16B
Override		X		X	X							16D
PCMMU/PL COMM							X		X	X		17A
PDRS Control									X	X		17B
PDRS Faults*									X			17C
PDRS Override									X	X		17D
PDRS Status*									X			18A
PL Bay Doors									X	X		18B
PL Retention*									X			18C
Power Transfer									X			18D
PRPLT Thermal*									X			19A
RCS		X	X	X	X	X						19B
RCS/RGA/ADTA Test							X					19C
Rel Nav			X									19D
RGA/ADTA/RCS (On-Orbit)						X						20A
RM Orbit			X									20B
RTLS TRAJ 2					X							20D
S TRK/COAS CNTL			X	X								21A
Sensor Self-Test (3 GPS)							X					21B
Sensor Self-Test (3 TACAN)							X					21C
Sensor Test (3 GPS)						X						21D
Sensor Test (3 TACAN)						X						22A
SL Memory Dump											X	22B
SM Ground Checkout									X	X		22C
SM OIU*									X			22D
SM Sys SUMM 1*									X			23B
SM Sys SUMM 2*									X			23D
SM Table Maint									X	X		24A
Switches						X						24B
Switch/Surf						X						24C
TCS Control							X					24D
Time	X		X			X	X		X	X	X	25B
Universal PTG			X									25C
Vert Sit 1				X	X							25D
Vert Sit 2				X	X							26B
Vert Sit 1 GRTLS					X							26A
Vert Sit 2 GRTLS					X							26C
XXXXX MNVR YYYYY		X	X	X								27A
XXXXXX TRAJ 1		X										27C
XXXXXX TRAJ 2		X										28A

* - Mission Reconfigurable

Backup Flight System (BFS) Displays

Display	GNC				SM	
	0	1	3	6		Page
BFS Memory	X	X	X	X	X	2A
CRYO Pallet/Cargo*					X	3A
Entry TRAJ 1			X			4D
Entry TRAJ 2			X			5B
Entry TRAJ 3			X			5D
Entry TRAJ 4			X			6B
Entry TRAJ 5			X			6D
Fault	X	X	X	X	X	7D
GNC Sys SUMM 1		X	X	X		8D
GNC Sys SUMM 2		X	X	X		9B
GPS Status		X	X	X		11C
Horiz Sit (single string or no GPS)		X	X	X		12B
Horiz Sit (3 string GPS)		X	X	X		12C
Override		X	X	X		16C
PL Bay Doors					X	18B
RTLS TRAJ 2				X		20C
SM Sys SUMM 1					X	23A
SM Sys SUMM 2					X	23C
Thermal					X	25A
Vert Sit 1			X	X		25D
Vert Sit 2			X	X		26B
XXXXX MNVR YYYYY		X	X			27A
XXXXXX TRAJ 1		X				27B
XXXXXX TRAJ 2		X				27D

* - Mission Reconfigurable

Initial Program Load (IPL) Displays

Display	Page
XXXXIPL Menu (1)	26D
GPCIPL Menu (2)	11B

Head Up Displays

Display	Page
HUD Display Format 1 After-WOW	14A
HUD Display Format 1 Pre-WOW	14B
HUD VU OPS 8 Low	14C
HUD VU OPS 9 Low	14D

OPS Displays

OPS	Display	PASS	BFS	GNC	SM	PL	Page
0001	GPC Memory	X		X			9D
0001	BFS Memory		X	X			2A
0001	Thermal		X		X		25A
1011	XXXXXXX Traj 1	X		X			27C
1011	XXXXXXX Traj 1		X	X			27B
1021	XXXXXXX Traj 1	X		X			27C
1021	XXXXXXX Traj 1		X	X			27B
1031	XXXXXXX Traj 2	X		X			28A
1031	XXXXXXX Traj 2		X	X			27D
1041	XXXXXX MNVR YYYYY	X	X	X			27A
1051	XXXXXX MNVR YYYYY	X	X	X			27A
1061	XXXXXX MNVR YYYYY	X	X	X			27A
2011	Antenna	X			X		1B
2011	Univ PTG	X		X			25B
2021	PL Bay Doors	X			X		18B
2021	XXXXXX MNVR YYYYY	X		X			27A
3011	XXXXXX MNVR YYYYY	X	X	X			27A
3021	XXXXXX MNVR YYYYY	X	X	X			27A
3031	XXXXXX MNVR YYYYY	X	X	X			27A
3041	Entry Traj 1	X		X			5A
3041	Entry Traj 1		X	X			4D
3041	Entry Traj 2	X		X			5C
3041	Entry Traj 2		X	X			5B
3041	Entry Traj 3	X		X			6A
3041	Entry Traj 3		X	X			5D
3041	Entry Traj 4	X		X			6C
3041	Entry Traj 4		X	X			6B
3041	Entry Traj 5	X		X			7A
3041	Entry Traj 5		X	X			6D
3051	Vert Sit 1	X	X	X			25D
3051	Vert Sit 2	X	X	X			26B
4011	Antenna	X			X		1B
4021	PL Bay Doors	X			X		18B
6011	RTLS Traj 2	X		X			20D
6011	RTLS Traj 2		X	X			20C
6021	Vert Sit 1	X	X	X			25D
6021	Vert Sit 1 GRTLS	X		X			26A
6031	Vert Sit 1	X	X	X			25D
6031	Vert Sit 2	X	X	X			26B
6031	Vert Sit 2 GRTLS	X		X			26C
8011	FCS/DED Displays C/O	X		X			8B
9011	Mass Memory R/W	X				X	15D
9011	GPC Memory	X		X			9D

* - Mission Reconfigurable

Vehicle Utility (VU) Displays

	GNC							SM			PL	
Display	0	1	2	3	6	8	9	0	2	4	9	Page
Actuator Control							X					1A
Controllers						X						2C
FCS/DED Display C/O						X						8B
GND IMU CNTL/MON							X					9C
GPC/BTU I/F							X					10A
GTS Display							X				X	12A
Manual Controls							X					15C
Mass Memory R/W									X	X	X	15D
NWS Check						X						16A
RCS/RGA/ADTA Test							X					19C
RGA/ADTA/RCS (On-Orbit)						X						20A
Sensor Self-Test (3 GPS)									X			21B
Sensor Self-Test (3 TACAN)									X			21C
Sensor Test (3 GPS)						X						21D
Sensor Test (3 TACAN)						X						22A
SL Memory Dump											X	22B
Switches						X						24B
Switch/Surf						X						24C
TCS Control							X					24D

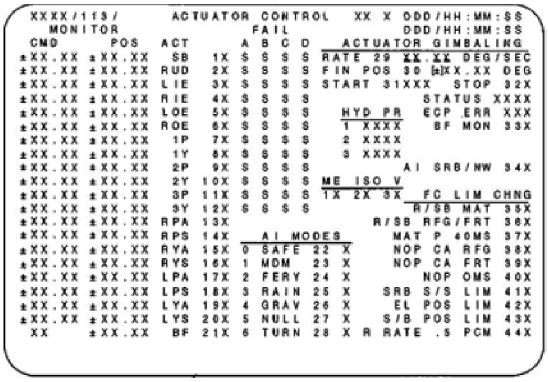
System Level Displays

	GNC							SM			PL	
Display	0	1	2	3	6	8	9	0	2	4	9	Page
DPS Utility	X	X	X	X	X	X	X		X	X	X	4B
Fault	X	X	X	X	X	X	X	X	X	X	X	8A
GPC Memory	X	X	X	X	X	X	X	X	X	X	X	9D
GPC/Bus Status	X	X	X	X	X	X	X		X	X	X	10B
Time	X		X			X	X		X	X	X	25B

SPEC and DISP Displays

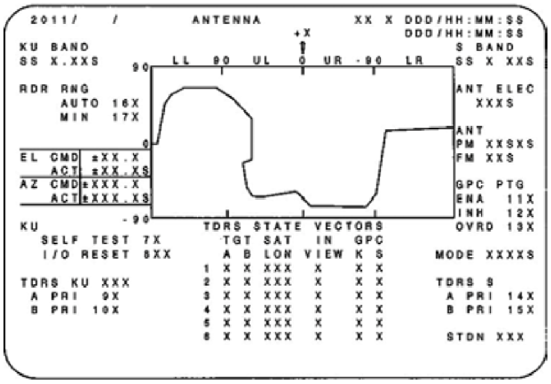
SPEC	Display	PFS	BFS	GNC	SM	PL	Page
001	DPS Utility	X		X	X	X	4B
002	Time	X		X	X	X	25A
006	GPC/Bus Status	X		X	X	X	10B
018	GNC Sys Summ 1	X		X			9A
018	GNC Sys Summ 1		X	X			8D
019	GNC Sys Summ 2	X	X	X			9B
020	DAP Config	X		X			3D
021	IMU Align	X		X			15B
022	S TRK/COAS CNTL	X		X			21A
023	RCS	X		X			19B
025	RM Orbit	X		X			20B
033	Rel Nav	X		X			19D
034	Orbit TGT	X		X			16B
040	Sensor Test (3 GPS)	X		X			21D
040	Sensor Test (3 TACAN)	X		X			22A
041	RGA/ADTA/RCS (On-Orbit)	X		X			20A
042	Switch/Surf	X		X			24C
043	Controllers	X		X			2C
044	Switches	X		X			24B
045	NWS Check	X		X			16A
050	Horiz Sit (in-left/3 TAC)	X		X			12D
050	Horiz Sit (in-right/3 TAC)	X		X			13A
050	Horiz Sit (out-left/3 TAC)	X		X			13B
050	Horiz Sit (out-right/3 TAC)	X		X			13C
050	Horiz Sit (right/3 GPS)	X		X			13D
050	Horiz Sit (1 string/no GPS)		X	X			12B
050	Horiz Sit (3 string GPS)		X	X			12C
051	Override	X		X			16D
051	Override		X	X			16C
053	Controls	X		X			2D
055	GPS Status	X		X			11C
055	GPS Status		X	X			11D
060	SM Table Maint	X			X		24A
062	PCMMU/PL COMM	X		X	X		17A
063	PL Bay Doors	X	X		X		18B
064	SM Ground Checkout	X			X		22C
066	Environment*	X			X		7B
067	Electric*	X			X		4C
068	Cryo System*	X			X		3C
069	Fuel Cells*	X			X		8C
071	GPCF PL Status	X			X		11A
072	GPCF PL Commanding	X			X		10D
073	GPCF PL C&W	X			X		10C
076	Communications*	X			X		2B
078	SM Sys Summ 1*	X			X		23B
078	SM Sys Summ 1*		X		X		23A
079	SM Sys Summ 2*	X			X		23D
079	SM Sys Summ 2*		X		X		23C
085	Mass Memory R/W	X			X	X	15D
086	APU/HYD*	X			X		1D
087	HYD Thermal*	X			X		15A
088	APU/Environ Thermal*	X			X		1C
089	PRPLT Thermal*	X			X		19A
094	PDRS Control	X			X		17B
095	PDRS Override*	X			X		17D
096	PDRS Faults	X			X		17C
097	PL Retention*	X			X		18C
099	Fault	X		X	X	X	8A
099	Fault		X	X	X	X	7D
100	GTS Display	X		X		X	12A
101	Sensor Self-Test (3 GPS)	X		X			21B
101	Sensor Self-Test (3 TACAN)	X		X			21C
102	RCS/RGA/ADTA Test	X		X			19C
104	GND IMU CNTL/MON	X		X			9C
105	TCS Control	X		X			24D
106	Manual Controls	X		X			15C
111	SL Memory Dump	X				X	22B
112	GPC/BTU I/F	X		X			10A
113	Actuator Control	X		X			1A
167	Docking Status*	X			X		4A
168	Cryo Pallet/Cargo*	X			X		3A
168	Cryo Pallet/Cargo*		X		X		3B
169	PDRS Status*	X			X		18A
177	External Airlock*	X			X		7C
178	SM OIU*	X			X		22D
179	Power Transfer*	X			X		18D

* - Mission Reconfigurable



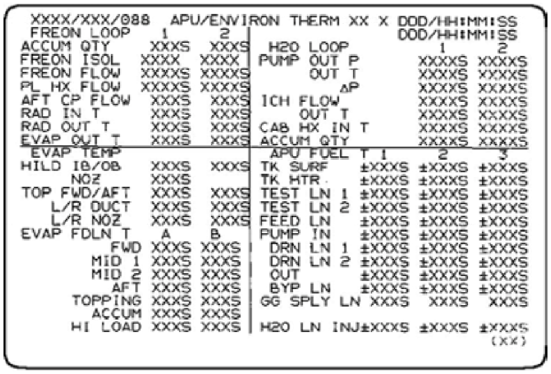
```
XXXX/115/       ACTUATOR CONTROL   XX X DDD/HH:MM:SS
  MONITOR              FAIL             DDD/HH:MM:SS
 CMD       POS    ACT        A B C D   ACTUATOR GIMBALING
±XX.XX ±XX.XX     SB   1X  S S S S RATE 29 XX.XX DEG/SEC
±XX.XX ±XX.XX    RUD   2X  S S S S FIN POS 30 [±]XX.XX DEG
±XX.XX ±XX.XX    LIE   3X  S S S S START 31XXX   STOP 32X
±XX.XX ±XX.XX    RIE   4X  S S S S             STATUS XXXX
±XX.XX ±XX.XX    LOE   5X  S S S S   HYD PR   ECP ERR XXX
±XX.XX ±XX.XX    ROE   6X  S S S S   1 XXXX     BF MON 33X
±XX.XX ±XX.XX     1P   7X  S S S S   2 XXXX
±XX.XX ±XX.XX     1Y   8X  S S S S   3 XXXX
±XX.XX ±XX.XX     2P   9X  S S S S            AI SRB/NW 34X
±XX.XX ±XX.XX     2Y  10X  S S S S ME ISO V
±XX.XX ±XX.XX     3P  11X  S S S S 1X 2X 3X   FC LIM CHNG
±XX.XX ±XX.XX     3Y  12X  S S S S              R/SB MAT 35X
±XX.XX ±XX.XX    RPA  13X                 R/SB RFG/FRT 36X
±XX.XX ±XX.XX    RPS  14X     AI MODES          MAT P 40MS 37X
±XX.XX ±XX.XX    RYA  15X  0 SAFE  22 X     NOP CA RFG 38X
±XX.XX ±XX.XX    RYS  16X  1 MDM   23 X     NOP CA FRT 39X
±XX.XX ±XX.XX    LPA  17X  2 FERY  24 X        NOP OMS 40X
±XX.XX ±XX.XX    LPS  18X  3 RAIN  25 X    SRB S/S LIM 41X
±XX.XX ±XX.XX    LYA  19X  4 GRAV  26 X     EL POS LIM 42X
±XX.XX ±XX.XX    LYS  20X  5 NULL  27 X    S/B POS LIM 43X
 XX    ±XX.XX     BF  21X  6 TURN  28 X R RATE .5 PCM 44X
```

(A) ACTUATOR CONTROL



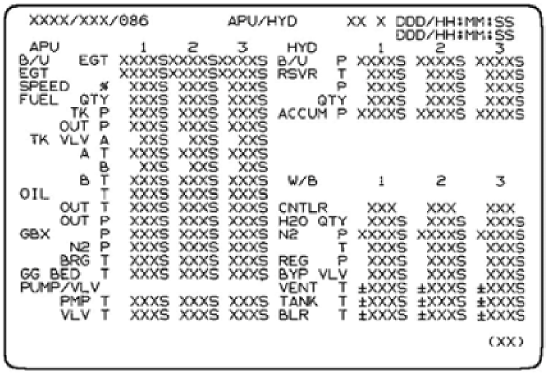
```
2011/    /       ANTENNA            XX X DDD/HH:MM:SS
                           +X            DDD/HH:MM:SS
KU BAND                                   S BAND
SS X.XXS      LL  90  UL   0  UR -90  LR  SS X XXS
           90
RDR RNG                                   ANT ELEC
    AUTO 16X                                XXXS
    MIN  17X
                                          ANT
           0                              PM XXSXS
EL CMD  ±XX.X                             FM XXS
   ACT  ±XX.XS
AZ CMD ±XXX.X                             GPC PTG
   ACT ±XXX.XS                            ENA  11X
                                          INH  12X
         -90                              OVRD 13X
KU                 TDRS STATE VECTORS
  SELF TEST 7X       TGT SAT  IN  GPC
  I/O RESET 8XX      A B LON VIEW K S     MODE XXXXS
                   1 X X XXX  X   X X
TDRS KU XXX        2 X X XXX  X   X X     TDRS S
 A PRI  9X         3 X X XXX  X   X X      A PRI 14X
 B PRI 10X         4 X X XXX  X   X X      B PRI 15X
                   5 X X XXX  X   X X
                   6 X X XXX  X   X X      STDN XXX
```

(B) ANTENNA



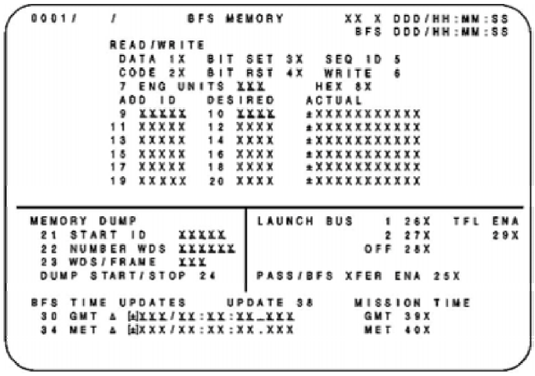
```
XXXX/XXX/088  APU/ENVIRON THERM XX X DDD/HH:MM:SS
 FREON LOOP     1      2              DDD/HH:MM:SS
ACCUM QTY     XXXS   XXXS  H2O LOOP          1     2
FREON ISOL   XXXX   XXXX  PUMP OUT P     XXXXS XXXXS
FREON FLOW   XXXXS  XXXXS      OUT T     XXXXS XXXXS
PL HX FLOW   XXXXS  XXXXS         ΔP     XXXXS XXXXS
AFT CP FLOW   XXXS   XXXS ICH FLOW       XXXXS XXXXS
RAD IN T      XXXS   XXXS     OUT T      XXXXS XXXXS
RAD OUT T     XXXS   XXXS CAB HX IN T    XXXXS XXXXS
EVAP OUT T    XXXS   XXXS ACCUM QTY      XXXXS XXXXS
 EVAP TEMP                 APU FUEL T 1      2      3
HILD IB/OB    XXXS   XXXS TK SURF  ±XXXS ±XXXS ±XXXS
    NOZ       XXXS        TK HTR   ±XXXS ±XXXS ±XXXS
TOP FWD/AFT   XXXS   XXXS TEST LN 1 ±XXXS ±XXXS ±XXXS
   L/R DUCT   XXXS   XXXS TEST LN 2 ±XXXS ±XXXS ±XXXS
   L/R NOZ    XXXS   XXXS FEED LN  ±XXXS ±XXXS ±XXXS
EVAP FDLN T    A      B   PUMP IN  ±XXXS ±XXXS ±XXXS
          FWD XXXS XXXS    DRN LN 1 ±XXXS ±XXXS ±XXXS
        MID 1 XXXS XXXS    DRN LN 2 ±XXXS ±XXXS ±XXXS
        MID 2 XXXS XXXS    OUT     ±XXXS ±XXXS ±XXXS
          AFT XXXS XXXS    BYP LN  ±XXXS ±XXXS ±XXXS
      TOPPING XXXS XXXS   GG SPLY LN XXXS  XXXS  XXXS
        ACCUM XXXS XXXS
      HI LOAD XXXS XXXS   H2O LN INJ±XXXS ±XXXS ±XXXS
                                                  (XX)
```

(C) APU/ENVIRON THERM



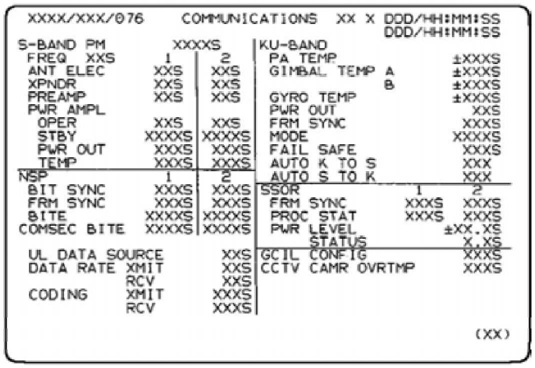
```
XXXX/XXX/086         APU/HYD      XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS
 APU           1    2    3    HYD        1     2     3
B/U   EGT   XXXXSXXXXSXXXXS B/U    P  XXXXS XXXXS XXXXS
EGT         XXXXSXXXXSXXXXS RSVR   T   XXXS  XXXS  XXXS
SPEED    %   XXXS XXXS XXXS        P   XXXS  XXXS  XXXS
FUEL   QTY   XXXS XXXS XXXS      QTY   XXXS  XXXS  XXXS
        TK P XXXS XXXS XXXS ACCUM  P  XXXXS XXXXS XXXXS
       OUT P XXXS XXXS XXXS
  TK  VLV A   XXS  XXS  XXS
        A T  XXXS XXXS XXXS
          B   XXS  XXS  XXS
        B T  XXXS XXXS XXXS   W/B        1     2     3
OIL       T  XXXS XXXS XXXS
      OUT T  XXXS XXXS XXXS CNTLR       XXX   XXX   XXX
      OUT P  XXXS XXXS XXXS H2O QTY     XXXS  XXXS  XXXS
GBX       P  XXXS XXXS XXXS N2     P  XXXXS XXXXS XXXXS
       N2 P  XXXS XXXS XXXS        T   XXXS  XXXS  XXXS
      BRG T  XXXS XXXS XXXS REG    P   XXXS  XXXS  XXXS
GG BED    T  XXXS XXXS XXXS BYP VLV    XXXS  XXXS  XXXS
PUMP/VLV                    VENT   T ±XXXS ±XXXS ±XXXS
      PMP T  XXXS XXXS XXXS TANK   T ±XXXS ±XXXS ±XXXS
      VLV T  XXXS XXXS XXXS BLR    T ±XXXS ±XXXS ±XXXS

                                                  (XX)
```

(D) APU/HYD



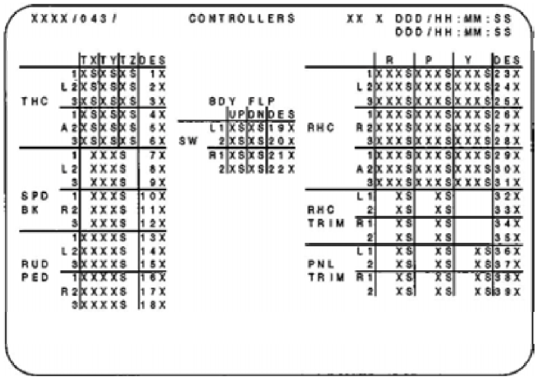
```
0001/    /        BFS MEMORY        XX X DDD/HH:MM:SS
                                      BFS DDD/HH:MM:SS
         READ/WRITE
          DATA 1X   BIT SET 3X   SEQ ID 5
          CODE 2X   BIT RST 4X   WRITE  6
          7 ENG UNITS XXX        HEX 8X
          ADD ID    DESIRED     ACTUAL
           9 XXXXX  10 XXXX    ±XXXXXXXXXXX
          11 XXXXX  12 XXXX    ±XXXXXXXXXXX
          13 XXXXX  14 XXXX    ±XXXXXXXXXXX
          15 XXXXX  16 XXXX    ±XXXXXXXXXXX
          17 XXXXX  18 XXXX    ±XXXXXXXXXXX
          19 XXXXX  20 XXXX    ±XXXXXXXXXXX

MEMORY DUMP                | LAUNCH BUS   1 26X   TFL ENA
 21 START ID    XXXXX      |              2 27X       29X
 22 NUMBER WDS  XXXXXX     |            OFF 28X
 23 WDS/FRAME   XXX        |
 DUMP START/STOP 24        | PASS/BFS XFER ENA 25X

BFS TIME UPDATES     UPDATE 38     MISSION TIME
 30 GMT Δ [±]XXX/XX:XX:XX.XXX        GMT 39X
 34 MET Δ [±]XXX/XX:XX:XX.XXX        MET 40X
```

(A) BFS MEMORY



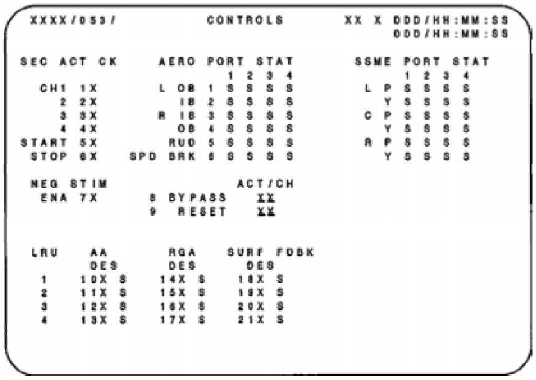
```
XXXX/XXX/076    COMMUNICATIONS  XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
S-BAND PM          XXXXS  |KU-BAND
 FREQ  XXS        1  |  2 | PA TEMP             ±XXXS
 ANT ELEC       XXS  | XXS| GIMBAL TEMP A        ±XXXS
 XPNDR          XXS  | XXS|             B        ±XXXS
 PREAMP         XXS  | XXS| GYRO TEMP            ±XXXS
 PWR AMPL            |    | PWR OUT                XXS
  OPER          XXS  | XXS| FRM SYNC              XXXS
  STBY        XXXXS |XXXXS| MODE                 XXXXS
  PWR OUT      XXXS | XXXS| FAIL SAFE             XXXS
  TEMP         XXXS | XXXS| AUTO K TO S            XXX
NSP               1  |  2 | AUTO S TO K            XXX
 BIT SYNC      XXXS | XXXS|SSOR            1      2
 FRM SYNC      XXXS | XXXS| FRM SYNC      XXXS   XXXS
 BITE         XXXXS |XXXXS| PROC STAT     XXXS   XXXS
COMSEC BITE   XXXXS |XXXXS| PWR LEVEL           ±XX.XS
                          |     STATUS            X.XS
 UL DATA SOURCE       XXS |GCIL CONFIG            XXXS
 DATA RATE XMIT       XXS |CCTV CAMR OVRTMP       XXXS
           RCV        XXS |
 CODING    XMIT      XXXS |
           RCV       XXXS |
                                                  (XX)
```

(B) COMMUNICATIONS



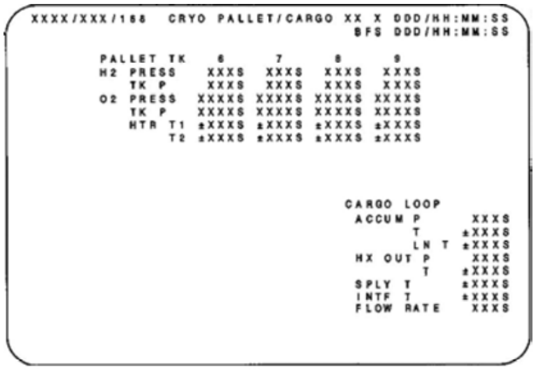
```
XXXX/043/         CONTROLLERS       XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS

        |TX|TY|TZ|DES                      | R  | P  | Y  |DES
       1|XS|XS|XS| 1X                     1|XXXS|XXXS|XXXS|23X
     L 2|XS|XS|XS| 2X                   L 2|XXXS|XXXS|XXXS|24X
THC    3|XS|XS|XS| 3X  BDY FLP           3|XXXS|XXXS|XXXS|25X
       1|XS|XS|XS| 4X     |UP|DN|DES      1|XXXS|XXXS|XXXS|26X
     A 2|XS|XS|XS| 5X    L1|XS|XS|19X RHC R 2|XXXS|XXXS|XXXS|27X
       3|XS|XS|XS| 6X SW  2|XS|XS|20X     3|XXXS|XXXS|XXXS|28X
       1|  XXXS  | 7X    R1|XS|XS|21X     1|XXXS|XXXS|XXXS|29X
     L 2|  XXXS  | 8X     2|XS|XS|22X   A 2|XXXS|XXXS|XXXS|30X
       3|  XXXS  | 9X                     3|XXXS|XXXS|XXXS|31X
SPD    1|  XXXS  |10X                    L1|  XS|  XS|    |32X
BK   R 2|  XXXS  |11X              RHC    2|  XS|  XS|    |33X
       3|  XXXS  |12X              TRIM  R1|  XS|  XS|    |34X
       1| XXXXS  |13X                     2|  XS|  XS|    |35X
     L 2| XXXXS  |14X                    L1|  XS|  XS|  XS|36X
RUD    3| XXXXS  |15X              PNL    2|  XS|  XS|  XS|37X
PED    1| XXXXS  |16X              TRIM  R1|  XS|  XS|  XS|38X
     R 2| XXXXS  |17X                     2|  XS|  XS|  XS|39X
       3| XXXXS  |18X
```

(C) CONTROLLERS



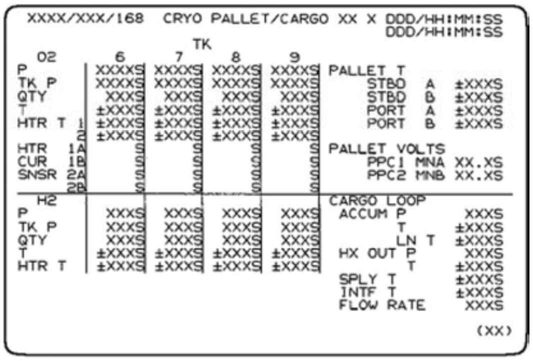
```
XXXX/053/          CONTROLS         XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS

SEC ACT CK    AERO PORT STAT          SSME PORT STAT
                      1 2 3 4               1 2 3 4
 CH1 1X          L OB 1 S S S S         L P S S S S
   2 2X            IB 2 S S S S           Y S S S S
   3 3X          R IB 3 S S S S         C P S S S S
   4 4X            OB 4 S S S S           Y S S S S
START 5X          RUD 5 S S S S         R P S S S S
 STOP 6X      SPD BRK 6 S S S S           Y S S S S

 NEG STIM               ACT/CH
  ENA 7X      8 BYPASS   XX
              9  RESET   XX


 LRU    AA      RGA    SURF FDBK
        DES     DES      DES
  1   10X S   14X S    18X S
  2   11X S   15X S    19X S
  3   12X S   16X S    20X S
  4   13X S   17X S    21X S
```

(D) Controls



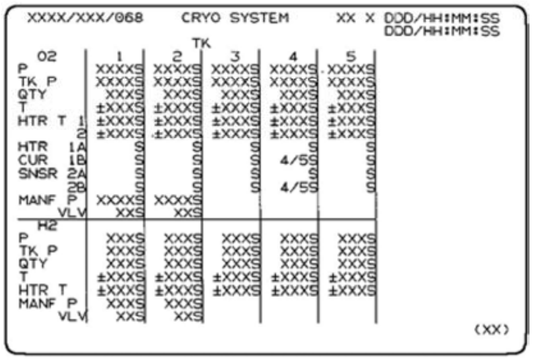
```
XXXX/XXX/168   CRYO PALLET/CARGO XX X DDD/HH:MM:SS
                                  BFS DDD/HH:MM:SS

        PALLET TK     6      7      8      9
        H2 PRESS    XXXS   XXXS   XXXS   XXXS
           TK P     XXXS   XXXS   XXXS   XXXS
        O2 PRESS   XXXXS  XXXXS  XXXXS  XXXXS
           TK P    XXXXS  XXXXS  XXXXS  XXXXS
           HTR T1  ±XXXS  ±XXXS  ±XXXS  ±XXXS
               T2  ±XXXS  ±XXXS  ±XXXS  ±XXXS




                                   CARGO LOOP
                                    ACCUM P       XXXS
                                          T      ±XXXS
                                          LN T   ±XXXS
                                    HX OUT P      XXXS
                                           T     ±XXXS
                                    SPLY T       ±XXXS
                                    INTF T       ±XXXS
                                    FLOW RATE     XXXS
```

(A) CRYO PALLET/CARGO (BFS)



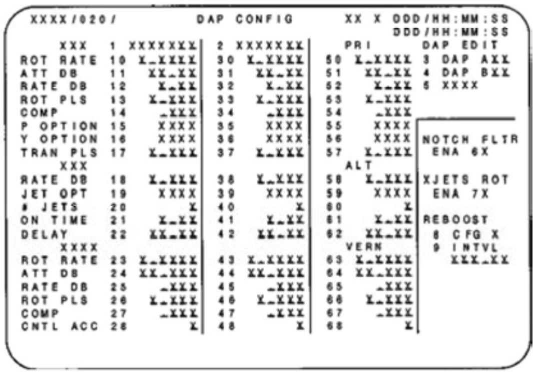
```
XXXX/XXX/168   CRYO PALLET/CARGO XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
                  TK
  O2        6      7      8      9
P      |XXXXS| XXXXS| XXXXS| XXXXS| PALLET T
TK P   |XXXXS| XXXXS| XXXXS| XXXXS|    STBD  A  ±XXXS
QTY    | XXXS|  XXXS|  XXXS|  XXXS|    STBD  B  ±XXXS
T      |±XXXS| ±XXXS| ±XXXS| ±XXXS|    PORT  A  ±XXXS
HTR T 1|±XXXS| ±XXXS| ±XXXS| ±XXXS|    PORT  B  ±XXXS
      2|±XXXS| ±XXXS| ±XXXS| ±XXXS|
HTR  1A|    S|     S|     S|     S| PALLET VOLTS
CUR  1B|    S|     S|     S|     S|    PPC1 MNA XX.XS
SNSR 2A|    S|     S|     S|     S|    PPC2 MNB XX.XS
     2B|    S|     S|     S|     S|
-----------------------------------------------------
  H2   |     |      |      |      | CARGO LOOP
P      | XXXS|  XXXS|  XXXS|  XXXS|  ACCUM P      XXXS
TK P   | XXXS|  XXXS|  XXXS|  XXXS|        T    ±XXXS
QTY    | XXXS|  XXXS|  XXXS|  XXXS|        LN T ±XXXS
T      |±XXXS| ±XXXS| ±XXXS| ±XXXS|  HX OUT P     XXXS
HTR T  |±XXXS| ±XXXS| ±XXXS| ±XXXS|         T   ±XXXS
                                     SPLY T      ±XXXS
                                     INTF T      ±XXXS
                                     FLOW RATE    XXXS

                                                  (XX)
```

(B) CRYO PALLET/CARGO (PASS)



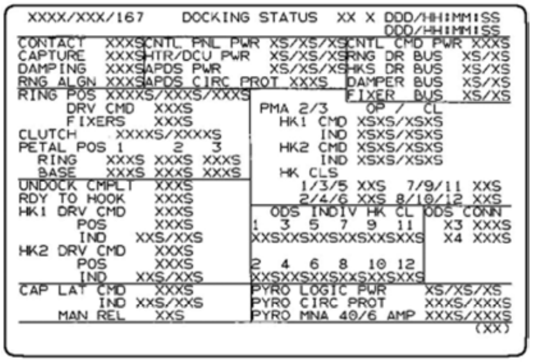
```
XXXX/XXX/068     CRYO SYSTEM      XX X DDD/HH:MM:SS
                                      DDD/HH:MM:SS
                  TK
  O2   |   1  |   2  |   3  |   4  |   5  |
P      |XXXXS| XXXXS| XXXXS| XXXXS. XXXXS|
TK P   |XXXXS| XXXXS| XXXXS| XXXXS| XXXXS|
QTY    | XXXS|  XXXS|  XXXS|  XXXS|  XXXS|
T      |±XXXS| ±XXXS| ±XXXS| ±XXXS| ±XXXS|
HTR T 1|±XXXS| ±XXXS| ±XXXS| ±XXXS| ±XXXS|
      2|±XXXS| ±XXXS| ±XXXS| ±XXXS| ±XXXS|
HTR  1A|    S|     S|     S|     S|     S|
CUR  1B|    S|     S|     S|  4/5S|     S|
SNSR 2A|    S|     S|     S|     S|     S|
     2B|    S|     S|     S|  4/5S|     S|
MANF  P|XXXXS| XXXXS|      |      |      |
    VLV|  XXS|   XXS|      |      |      |
-------------------------------------------
  H2   |     |      |      |      |      |
P      | XXXS|  XXXS|  XXXS|  XXXS|  XXXS|
TK P   | XXXS|  XXXS|  XXXS|  XXXS|  XXXS|
QTY    | XXXS|  XXXS|  XXXS|  XXXS|  XXXS|
T      |±XXXS| ±XXXS| ±XXXS| ±XXXS| ±XXXS|
HTR T  |±XXXS| ±XXXS| ±XXXS| ±XXXS| ±XXXS|
MANF  P| XXXS|  XXXS|      |      |      |
    VLV|  XXS|   XXS|      |      |      |
                                                  (XX)
```

(C) CRYO SYSTEM



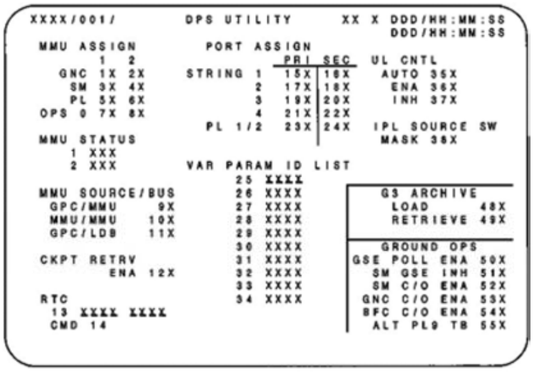
```
XXXX/020/           DAP CONFIG        XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
    XXX      1 XXXXXXX | 2 XXXXXXX |    PRI      DAP EDIT
ROT RATE 10 X.XXXX     | 30 X.XXXX | 50 X.XXXX  3 DAP AXX
ATT DB   11   XX.XX    | 31  XX.XX | 51  XX.XX  4 DAP BXX
RATE DB  12    X.XX    | 32   X.XX | 52   X.XX  5 XXXX
ROT PLS  13   X.XXX    | 33  X.XXX | 53  X.XXX
COMP     14    .XXX    | 34   .XXX | 54   .XXX  ___________
P OPTION 15    XXXX    | 35   XXXX | 55   XXXX |
Y OPTION 16    XXXX    | 36   XXXX | 56   XXXX |NOTCH FLTR
TRAN PLS 17   X.XXX    | 37  X.XXX | 57  X.XXX | ENA 6X
    XXX                |           |    ALT    |
RATE DB  18   X.XXX    | 38  X.XXX | 58  X.XXX |XJETS ROT
JET OPT  19    XXXX    | 39   XXXX | 59   XXXX | ENA 7X
# JETS   20       X    | 40      X | 60      X |
ON TIME  21    X.XX    | 41   X.XX | 61   X.XX |REBOOST
DELAY    22   XX.XX    | 42  XX.XX | 62  XX.XX | 8 CFG X
    XXXX               |           |    VERN   | 9 INTVL
ROT RATE 23 X.XXXX     | 43 X.XXXX | 63 X.XXXX |   XXX.XX
ATT DB   24 XX.XXX     | 44 XX.XXX | 64 XX.XXX |
RATE DB  25    .XXX    | 45   .XXX | 65   .XXX |
ROT PLS  26   X.XXX    | 46  X.XXX | 66  X.XXX |
COMP     27    .XXX    | 47   .XXX | 67   .XXX |
CNTL ACC 28       X    | 48      X | 68      X |
```

(D) DAP CONFIG



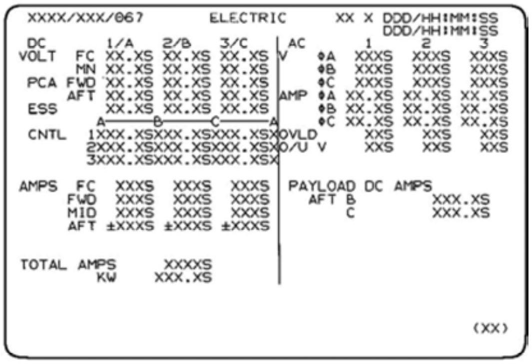
```
XXXX/XXX/167     DOCKING STATUS   XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS
CONTACT   XXXS|CNTL PNL PWR  XS/XS/XS|CNTL CMD PWR XXXS
CAPTURE   XXXS|HTR/DCU PWR   XS/XS/XS|RNG DR BUS   XS/XS
DAMPING   XXXS|APDS PWR      XS/XS/XS|HKS DR BUS   XS/XS
RNG ALGN  XXXS|APDS CIRC PROT XXXS   |DAMPER BUS   XS/XS
RING POS  XXXXS/XXXS/XXXS            |FIXER  BUS   XS/XS
     DRV CMD    XXXS      | PMA 2/3      OP / CL
     FIXERS     XXXS      |    HK1 CMD XSXS/XSXS
CLUTCH      XXXXS/XXXXS   |        IND XSXS/XSXS
PETAL POS 1      2    3   |    HK2 CMD XSXS/XSXS
  RING    XXXS XXXS XXXS  |        IND XSXS/XSXS
  BASE    XXXS XXXS XXXS  |    HK CLS
UNDOCK CMPLT    XXXS      |      1/3/5 XXS  7/9/11 XXS
RDY TO HOOK     XXXS      |      2/4/6 XXS 8/10/12 XXS
HK1 DRV CMD     XXXS      |  ODS INDIV HK CL |ODS CONN
        POS     XXXS      |1  3  5  7  9  11 |  X3 XXXS
        IND  XXS/XXS      |XXSXXSXXSXXSXXSXXS|  X4 XXXS
HK2 DRV CMD     XXXS      |                  |
        POS     XXXS      |2  4  6  8  10 12 |
        IND  XXS/XXS      |XXSXXSXXSXXSXXSXXS|
CAP LAT CMD     XXXS      |PYRO LOGIC PWR      XS/XS/XS
        IND  XXS/XXS      |PYRO CIRC PROT     XXXS/XXXS
    MAN REL     XXS       |PYRO MNA 40/6 AMP  XXXS/XXXS
                                                  (XX)
```

(A) DOCKING STATUS



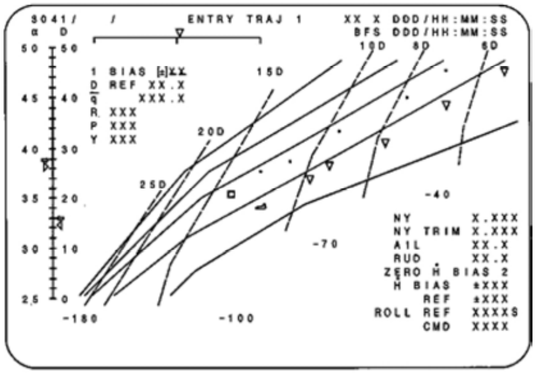
```
XXXX/001/         DPS UTILITY        XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS
  MMU ASSIGN         PORT ASSIGN
         1  2                  PRI SEC   UL CNTL
     GNC 1X 2X      STRING 1   15X|16X    AUTO 35X
      SM 3X 4X             2   17X|18X     ENA 36X
      PL 5X 6X             3   19X|20X     INH 37X
  OPS 0  7X 8X             4   21X|22X
                       PL 1/2  23X|24X   IPL SOURCE SW
  MMU STATUS                      |       MASK 38X
     1 XXX
     2 XXX          VAR PARAM ID LIST
                          25 XXXX
  MMU SOURCE/BUS          26 XXXX     |   G3 ARCHIVE
   GPC/MMU     9X         27 XXXX     |    LOAD     48X
   MMU/MMU    10X         28 XXXX     |    RETRIEVE 49X
   GPC/LDB    11X         29 XXXX     |______________
                          30 XXXX     |   GROUND OPS
  CKPT RETRV              31 XXXX     |GSE POLL ENA 50X
         ENA 12X          32 XXXX     |  SM GSE INH 51X
                          33 XXXX     |  SM C/O ENA 52X
  RTC                     34 XXXX     | GNC C/O ENA 53X
   13 XXXX XXXX                       | BFC C/O ENA 54X
   CMD 14                             |  ALT PL9 TB 55X
```

(B) DPS UTILITY



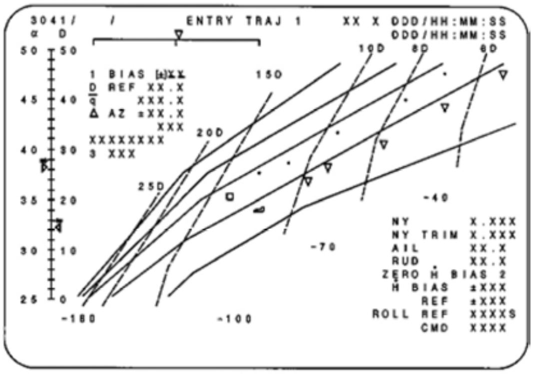
```
XXXX/XXX/067       ELECTRIC      XX X DDD/HH:MM:SS
                                      DDD/HH:MM:SS
 DC         1/A    2/B    3/C  |AC        1      2      3
VOLT  FC  XX.XS  XX.XS  XX.XS  V    ΦA  XXXS   XXXS   XXXS
      MN  XX.XS  XX.XS  XX.XS  |    ΦB  XXXS   XXXS   XXXS
 PCA FWD  XX.XS  XX.XS  XX.XS  |    ΦC  XXXS   XXXS   XXXS
     AFT  XX.XS  XX.XS  XX.XS  AMP  ΦA XX.XS  XX.XS  XX.XS
 ESS      XX.XS  XX.XS  XX.XS  |    ΦB XX.XS  XX.XS  XX.XS
        A------B------C------A |    ΦC XX.XS  XX.XS  XX.XS
 CNTL   1XXX.XSXXX.XSXXX.XSXOVLD       XXS    XXS    XXS
        2XXX.XSXXX.XSXXX.XSXO/U V      XXS    XXS    XXS
        3XXX.XSXXX.XSXXX.XSX
                               |
AMPS  FC   XXXS   XXXS   XXXS  | PAYLOAD DC AMPS
     FWD   XXXS   XXXS   XXXS  |   AFT B          XXX.XS
     MID   XXXS   XXXS   XXXS  |       C          XXX.XS
     AFT  ±XXXS  ±XXXS  ±XXXS  |
                               |
 TOTAL AMPS      XXXXS         |
         KW     XXX.XS         |

                                                  (XX)
```

(C) ELECTRIC

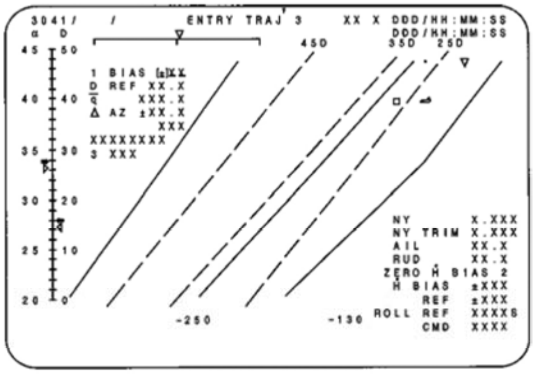


```
3041/    /        ENTRY TRAJ 1     XX X DDD/HH:MM:SS
                                  BFS DDD/HH:MM:SS
     1 BIAS [±]XX
     D REF XX.X
     q̄       XXX.X
     R XXX
     P XXX
     Y XXX

                                  NY         X.XXX
                                  NY TRIM    X.XXX
                                  AIL         XX.X
                                  RUD         XX.X
                                 ZERO Ḣ BIAS 2
                                  Ḣ BIAS     ±XXX
                                      REF    ±XXX
                                 ROLL REF    XXXXS
                                      CMD    XXXX
```

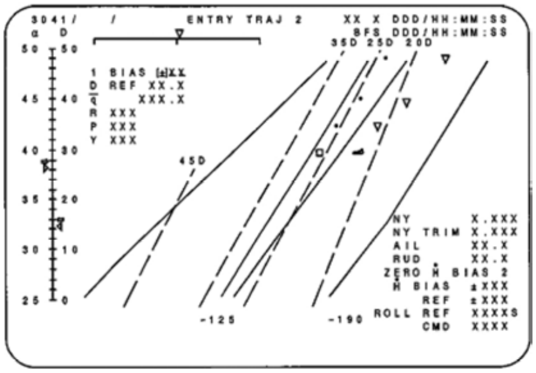
(D) ENTRY TRAJ 1 (BFS)



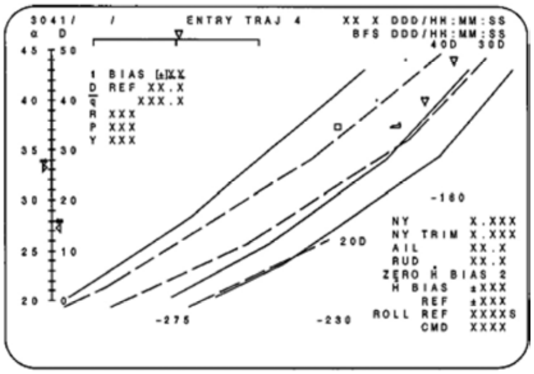
(A) ENTRY TRAJ 1 (PASS)



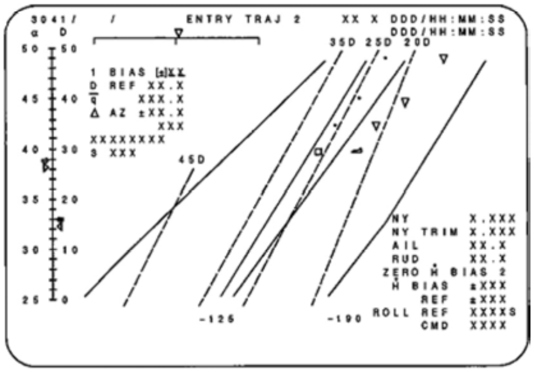
(A) ENTRY TRAJ 3 (PASS)



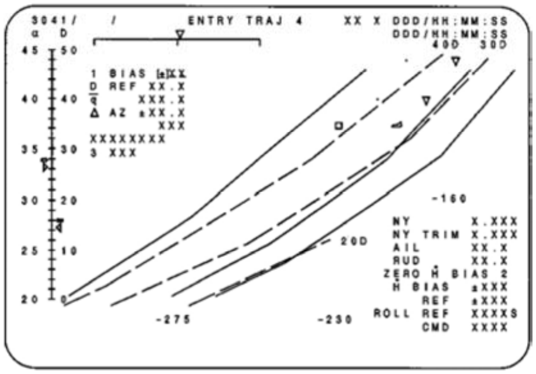
(B) ENTRY TRAJ 2 (BFS)



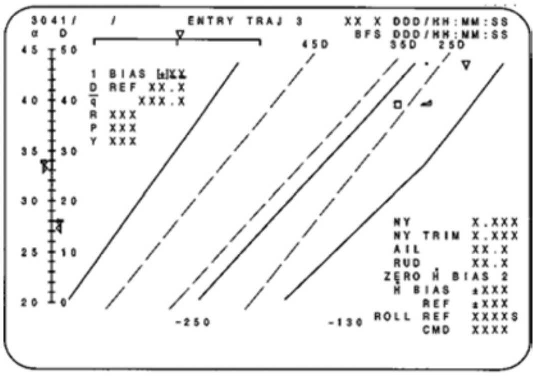
(B) ENTRY TRAJ 4 (BFS)



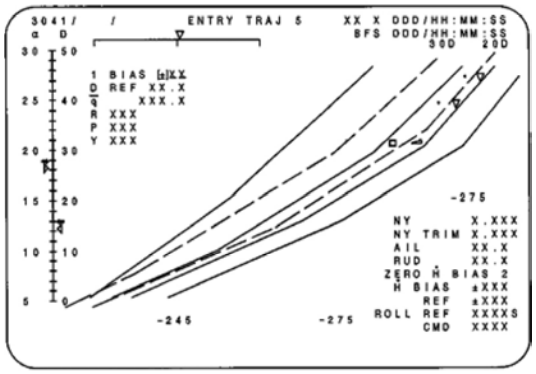
(C) ENTRY TRAJ 2 (PASS)



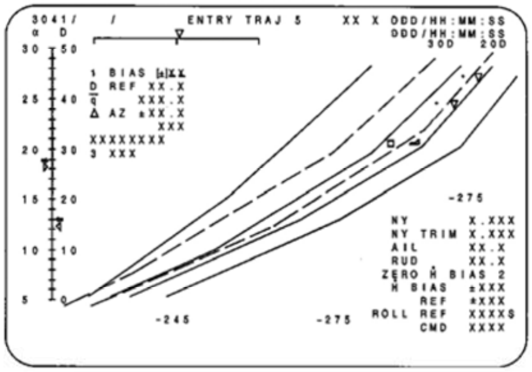
(C) ENTRY TRAJ 4 (PASS)



(D) ENTRY TRAJ 3 (BFS)

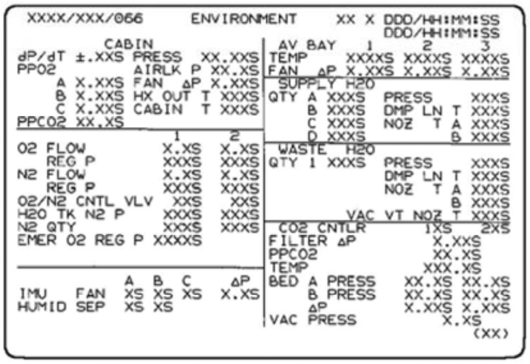


(D) ENTRY TRAJ 5 (BFS)



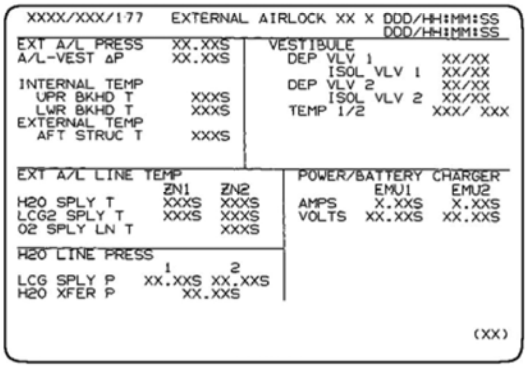
```
3041/     /          ENTRY TRAJ 5      XX X DDD/HH:MM:SS
α   D                                       DDD/HH:MM:SS
                                               30D   20D
30 50
      1 BIAS ±XX
      D REF XX.X
25 40 q      XXX.X
      Δ AZ  ±XX.X
               XXX
      XXXXXXXX
20 30 3 XXX

15 20                                      -275
                                    NY          X.XXX
                                    NY TRIM     X.XXX
10 10                               AIL          XX.X
                                    RUD          XX.X
                                    ZERO Ḣ BIAS 2
                                    Ḣ BIAS      ±XXX
                                         REF    ±XXX
5                                   ROLL REF    XXXXS
         -245           -275             CMD    XXXX
```

(A) ENTRY TRAJ 5 (PASS)



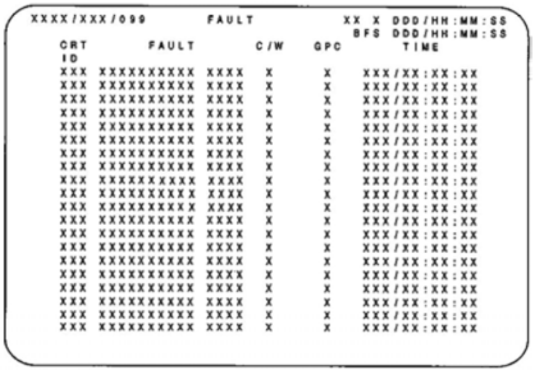
```
XXXX/XXX/066      ENVIRONMENT      XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
          CABIN                | AV BAY    1      2      3
dP/dT ±.XXS PRESS    XX.XXS    |TEMP     XXXXS  XXXXS  XXXXS
PPO2         AIRLK P  XX.XS    |FAN  ΔP  X.XXS  X.XXS  X.XXS
     A X.XXS FAN  ΔP X.XXS     | SUPPLY H2O
     B X.XXS HX OUT T XXXS     |QTY A XXXS  PRESS       XXXS
     C X.XXS CABIN  T XXXS     |    B XXXS  DMP LN T    XXXS
PPCO2 XX.XS                    |    C XXXS  NOZ    T A  XXXS
                  1       2    |    D XXXS           B  XXXS
O2 FLOW         X.XS    X.XS   | WASTE  H2O
   REG P        XXXS    XXXS   |QTY 1 XXXS  PRESS       XXXS
N2 FLOW         X.XS    X.XS   |            DMP LN T    XXXS
   REG P        XXXS    XXXS   |            NOZ    T A  XXXS
O2/N2 CNTL VLV   XXS     XXS   |                     B  XXXS
H2O TK N2 P     XXXS    XXXS   |        VAC VT NOZ   T  XXXS
N2 QTY          XXXS    XXXS   | CO2 CNTLR        1XS     2XS
EMER O2 REG P XXXXS            |FILTER ΔP          X.XXS
                               |PPCO2              XX.XS
                               |TEMP              XXX.XS
            A   B   C     ΔP   |BED A PRESS     XX.XS  XX.XS
IMU   FAN   XS  XS  XS  X.XS   |    B PRESS     XX.XS  XX.XS
HUMID SEP   XS  XS             |      ΔP        X.XXS  X.XXS
                               |VAC PRESS            X.XS
                                                     (XX)
```

(B) ENVIRONMENT



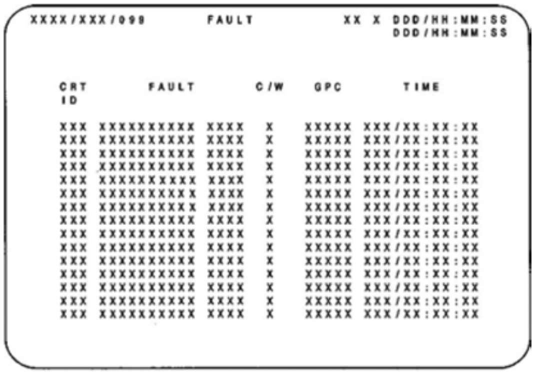
```
XXXX/XXX/177   EXTERNAL AIRLOCK XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
EXT A/L PRESS      XX.XXS | VESTIBULE
A/L-VEST ΔP        XX.XXS |   DEP VLV 1          XX/XX
                          |      ISOL VLV 1      XX/XX
INTERNAL TEMP             |   DEP VLV 2          XX/XX
  UPR BKHD T         XXXS |      ISOL VLV 2      XX/XX
  LWR BKHD T         XXXS |   TEMP 1/2         XXX/ XXX
EXTERNAL TEMP             |
  AFT STRUC T        XXXS |
EXT A/L LINE TEMP          | POWER/BATTERY CHARGER
                ZN1   ZN2  |           EMU1     EMU2
H2O SPLY T     XXXS  XXXS  | AMPS     X.XXS    X.XXS
LCG2 SPLY T    XXXS  XXXS  | VOLTS   XX.XXS   XX.XXS
O2 SPLY LN T         XXXS  |
H2O LINE PRESS             |
                  1       2|
LCG SPLY P  XX.XXS XX.XXS  |
H2O XFER P       XX.XXS    |
                                                 (XX)
```

(C) EXTERNAL AIRLOCK



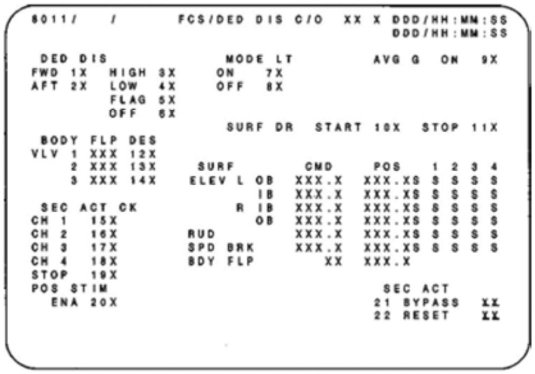
```
XXXX/XXX/099          FAULT            XX X DDD/HH:MM:SS
                                      BFS DDD/HH:MM:SS
    CRT        FAULT        C/W    GPC        TIME
    ID
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X      X     XXX/XX:XX:XX
```

(D) FAULT (BFS)



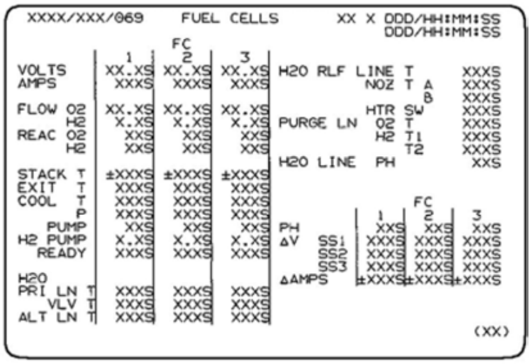
```
XXXX/XXX/099        FAULT          XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS

    CRT        FAULT        C/W    GPC        TIME
    ID

    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
    XXX XXXXXXXXXX XXXX      X    XXXXX XXX/XX:XX:XX
```

(A) FAULT (PASS)



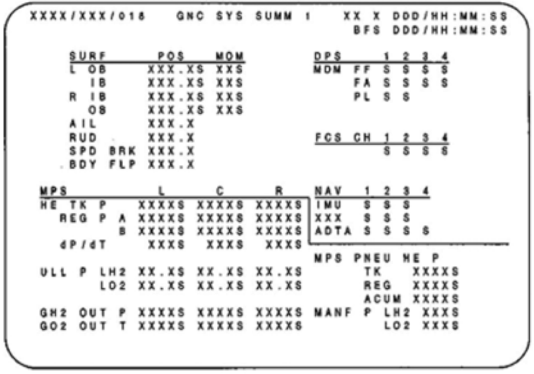
```
8011/    /       FCS/DED DIS C/O  XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS

 DED DIS              MODE LT          AVG G   ON   9X
FWD 1X  HIGH 3X      ON    7X
AFT 2X  LOW  4X      OFF   8X
        FLAG 5X
        OFF  6X
                      SURF DR  START 10X  STOP 11X
 BODY FLP DES
VLV 1 XXX 12X
    2 XXX 13X      SURF         CMD     POS    1 2 3 4
    3 XXX 14X    ELEV L OB     XXX.X  XXX.XS  S S S S
                          IB   XXX.X  XXX.XS  S S S S
 SEC ACT CK             R IB   XXX.X  XXX.XS  S S S S
CH 1   15X                OB   XXX.X  XXX.XS  S S S S
CH 2   16X       RUD           XXX.X  XXX.XS  S S S S
CH 3   17X       SPD BRK       XXX.X  XXX.XS  S S S S
CH 4   18X       BDY FLP          XX  XXX.X
STOP   19X
POS STIM                              SEC ACT
  ENA 20X                           21 BYPASS   XX
                                    22 RESET    XX
```

(B) FCS/DED DIS C/O



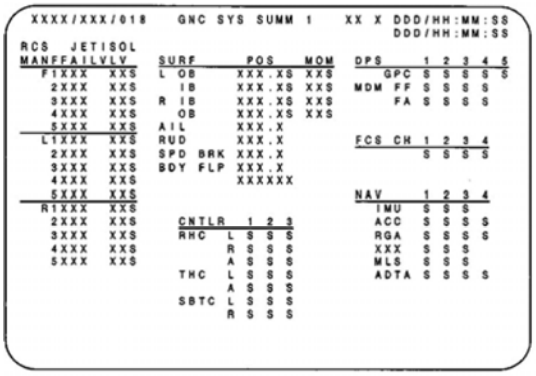
```
XXXX/XXX/069     FUEL CELLS       XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS
                   FC
           |  1  |  2  |  3  |
VOLTS      |XX.XS|XX.XS|XX.XS| H2O RLF LINE T       XXXS
AMPS       | XXXS| XXXS| XXXS|          NOZ T A     XXXS
           |     |     |     |                B     XXXS
FLOW O2    |XX.XS|XX.XS|XX.XS|          HTR SW      XXXS
     H2    | X.XS| X.XS| X.XS| PURGE LN  O2 T       XXXS
REAC O2    |  XXS|  XXS|  XXS|           H2 T1      XXXS
     H2    |  XXS|  XXS|  XXS|              T2      XXXS
           |     |     |     | H2O LINE  PH          XXS
STACK T    |±XXXS|±XXXS|±XXXS|
EXIT  T    | XXXS| XXXS| XXXS|
COOL  T    | XXXS| XXXS| XXXS|                 FC
      P    | XXXS| XXXS| XXXS|            |  1  |  2  |  3
   PUMP    |  XXS|  XXS|  XXS| PH         |  XXS|  XXS|  XXS
H2 PUMP    | X.XS| X.XS| X.XS| ΔV   SS1   | XXXS| XXXS| XXXS
   READY   | XXXS| XXXS| XXXS|      SS2   | XXXS| XXXS| XXXS
           |     |     |     |      SS3   | XXXS| XXXS| XXXS
H2O        |     |     |     | ΔAMPS      |±XXXS|±XXXS|±XXXS
PRI LN T   | XXXS| XXXS| XXXS|
   VLV T   | XXXS| XXXS| XXXS|
ALT LN T   | XXXS| XXXS| XXXS|
                                                    (XX)
```

(C) FUEL CELLS



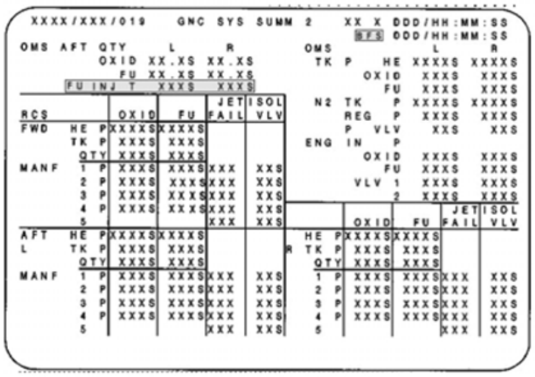
```
XXXX/XXX/018    GNC SYS SUMM 1    XX X DDD/HH:MM:SS
                                 BFS DDD/HH:MM:SS

     SURF       POS    MOM          DPS     1 2 3 4
     L OB     XXX.XS  XXS           MDM FF  S S S S
       IB     XXX.XS  XXS               FA  S S S S
     R IB     XXX.XS  XXS               PL  S S
       OB     XXX.XS  XXS
     AIL      XXX.X
     RUD      XXX.X                 FCS CH  1 2 3 4
     SPD BRK  XXX.X                         S S S S
     BDY FLP  XXX.X

MPS              L      C      R   | NAV   1 2 3 4
HE TK P      XXXXS  XXXXS  XXXXS   | IMU   S S S
   REG P A   XXXXS  XXXXS  XXXXS   | XXX   S S S
         B   XXXXS  XXXXS  XXXXS   | ADTA  S S S S
   dP/dT      XXXS   XXXS   XXXS   |
                                    MPS PNEU HE P
ULL P LH2    XX.XS  XX.XS  XX.XS        TK    XXXXS
      LO2    XX.XS  XX.XS  XX.XS        REG   XXXXS
                                        ACUM  XXXXS
GH2 OUT P    XXXXS  XXXXS  XXXXS    MANF P LH2  XXXS
GO2 OUT T    XXXXS  XXXXS  XXXXS           LO2  XXXS
```

(D) GNC SYS SUMM 1 (BFS)



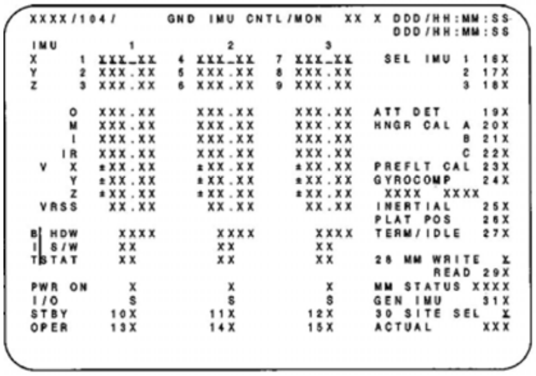
```
XXXX/XXX/018    GNC SYS SUMM 1     XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
RCS   JETISOL
MANFFAILVLV    SURF       POS    MOM   DPS      1 2 3 4 5
   F1XXX  XXS  L OB     XXX.XS  XXS       GPC  S S S S S
    2XXX  XXS     IB    XXX.XS  XXS    MDM  FF  S S S S
    3XXX  XXS  R IB     XXX.XS  XXS         FA  S S S S
    4XXX  XXS     OB    XXX.XS  XXS
    5XXX  XXS  AIL      XXX.X
   L1XXX  XXS  RUD      XXX.X          FCS CH   1 2 3 4
    2XXX  XXS  SPD BRK  XXX.X                   S S S S
    3XXX  XXS  BDY FLP  XXX.X
    4XXX  XXS           XXXXXX
    5XXX  XXS                          NAV      1 2 3 4
   R1XXX  XXS                            IMU    S S S
    2XXX  XXS    CNTLR   1 2 3           ACC    S S S S
    3XXX  XXS    RHC   L S S S           RGA    S S S S
    4XXX  XXS          R S S S           XXX    S S S
    5XXX  XXS          A S S S           MLS    S S S
                 THC   L S S S           ADTA   S S S S
                       A S S S
                 SBTC  L S S S
                       R S S S
```

(A) GNC SYS SUMM 1 (PASS)



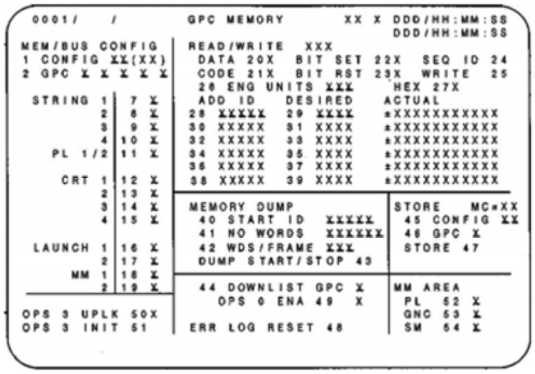
```
XXXX/XXX/019    GNC SYS SUMM 2     XX X DDD/HH:MM:SS
                                   BFS  DDD/HH:MM:SS
OMS AFT QTY      L      R          OMS           L      R
         OXID XX.XS  XX.XS          TK P    HE  XXXXS  XXXXS
           FU XX.XS  XX.XS                OXID   XXXS   XXXS
     FU INJ T   XXXS   XXXS                  FU   XXXS   XXXS
                            JET|ISOL   N2  TK   P  XXXXS  XXXXS
RCS          OXID |  FU |FAIL| VLV         REG  P   XXXS   XXXS
FWD   HE  P XXXXS|XXXXS|    |              P VLV     XXS    XXS
      TK  P  XXXS| XXXS|    |          ENG  IN  P
         QTY XXXS| XXXS|    |                 OXID   XXXS   XXXS
MANF   1  P  XXXS| XXXS|XXX | XXS               FU   XXXS   XXXS
       2  P  XXXS| XXXS|XXX | XXS            VLV 1   XXXS   XXXS
       3  P  XXXS| XXXS|XXX | XXS                2   XXXS   XXXS
       4  P  XXXS| XXXS|XXX | XXS                              JET|ISOL
       5         |     |XXX | XXS              OXID |  FU |FAIL| VLV
AFT   HE  P XXXXS|XXXXS|    |         HE  P XXXXS|XXXXS|    |
L     TK  P  XXXS| XXXS|    |      R  TK  P  XXXS| XXXS|    |
         QTY XXXS| XXXS|    |            QTY XXXS| XXXS|    |
MANF   1  P  XXXS| XXXS|XXX | XXS     1  P  XXXS| XXXS|XXX | XXS
       2  P  XXXS| XXXS|XXX | XXS     2  P  XXXS| XXXS|XXX | XXS
       3  P  XXXS| XXXS|XXX | XXS     3  P  XXXS| XXXS|XXX | XXS
       4  P  XXXS| XXXS|XXX | XXS     4  P  XXXS| XXXS|XXX | XXS
       5         |     |XXX | XXS     5         |     |XXX | XXS
```

(B) GNC SYS SUMM 2 (PASS/BFS)



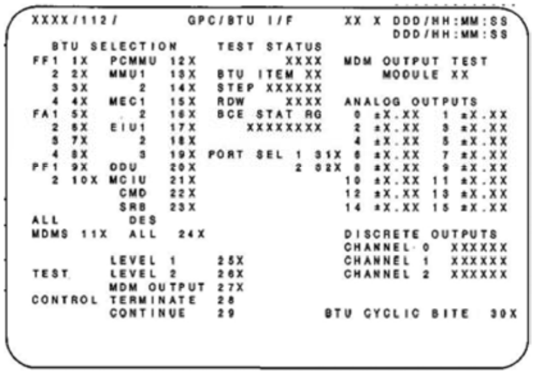
```
XXXX/104/      GND IMU CNTL/MON   XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS
IMU          1           2           3
X      1 XXX.XX    4 XXX.XX    7 XXX.XX    SEL IMU 1 16X
Y      2 XXX.XX    5 XXX.XX    8 XXX.XX            2 17X
Z      3 XXX.XX    6 XXX.XX    9 XXX.XX            3 18X

     O   XXX.XX      XXX.XX      XXX.XX   ATT DET      19X
     M   XXX.XX      XXX.XX      XXX.XX   HNGR CAL A   20X
     I   XXX.XX      XXX.XX      XXX.XX            B   21X
    IR   XXX.XX      XXX.XX      XXX.XX            C   22X
  V  X   ±XX.XX      ±XX.XX      ±XX.XX   PREFLT CAL   23X
     Y   ±XX.XX      ±XX.XX      ±XX.XX   GYROCOMP     24X
     Z   ±XX.XX      ±XX.XX      ±XX.XX    XXXX  XXXX
  VRSS    XX.XX       XX.XX       XX.XX   INERTIAL     25X
                                          PLAT POS     26X
B| HDW     XXXX        XXXX        XXXX   TERM/IDLE    27X
I| S/W     XX          XX          XX
T|STAT     XX          XX          XX     28 MM WRITE    X
                                                  READ 29X
PWR ON     X           X           X      MM STATUS XXXX
I/O        S           S           S      GEN IMU      31X
STBY      10X         11X         12X     30 SITE SEL    X
OPER      13X         14X         15X     ACTUAL       XXX
```

(C) GND IMU CNTL/MON



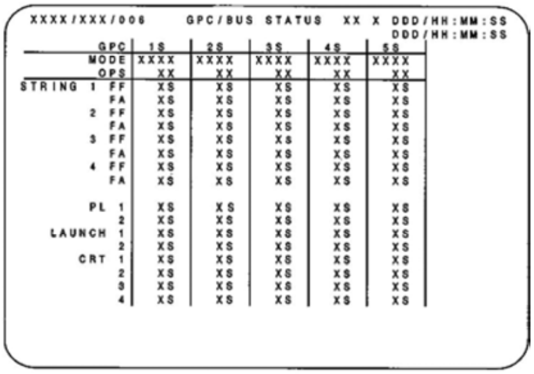
```
0001/   /          GPC MEMORY        XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
MEM/BUS CONFIG    | READ/WRITE  XXX
1 CONFIG XX(XX)   |  DATA 20X  BIT SET 22X  SEQ ID 24
2 GPC X X X X X   |  CODE 21X  BIT RST 23X  WRITE  25
                  |  26 ENG UNITS XXX     HEX 27X
  STRING 1|  7 X  |  ADD ID    DESIRED    ACTUAL
         2|  8 X  | 28 XXXXX  29 XXXX    ±XXXXXXXXXXX
         3|  9 X  | 30 XXXXX  31 XXXX    ±XXXXXXXXXXX
         4| 10 X  | 32 XXXXX  33 XXXX    ±XXXXXXXXXXX
    PL 1/2| 11 X  | 34 XXXXX  35 XXXX    ±XXXXXXXXXXX
          |       | 36 XXXXX  37 XXXX    ±XXXXXXXXXXX
     CRT 1| 12 X  | 38 XXXXX  39 XXXX    ±XXXXXXXXXXX
         2| 13 X  |------------------------------------
         3| 14 X  | MEMORY DUMP              | STORE   MC=XX
         4| 15 X  |  40 START ID   XXXXX     |  45 CONFIG XX
          |       |  41 NO WORDS   XXXXXX    |  46 GPC X
  LAUNCH 1| 16 X  |  42 WDS/FRAME XXX        |  STORE 47
         2| 17 X  |  DUMP START/STOP 43      |
      MM 1| 18 X  |------------------------------------
         2| 19 X  |  44 DOWNLIST GPC X       | MM AREA
------------------|    OPS 0 ENA 49   X      |  PL  52 X
OPS 3 UPLK 50X    |                          |  GNC 53 X
OPS 3 INIT 51     | ERR LOG RESET 48         |  SM  54 X
```

(D) GPC MEMORY



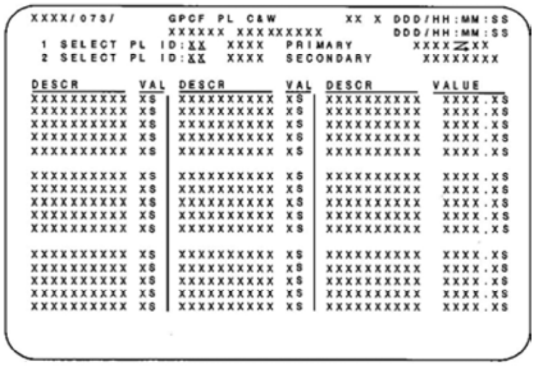
```
XXXX/112/         GPC/BTU I/F       XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS
  BTU SELECTION      TEST STATUS
FF1  1X  PCMMU 12X          XXXX   MDM OUTPUT TEST
  2  2X  MMU1  13X   BTU ITEM XX       MODULE XX
  3  3X     2  14X   STEP XXXXXX
  4  4X  MEC1  15X   RDW    XXXX   ANALOG OUTPUTS
FA1  5X     2  16X   BCE STAT RG     0 ±X.XX   1 ±X.XX
  2  6X  EIU1  17X      XXXXXXXX     2 ±X.XX   3 ±X.XX
  3  7X     2  18X                   4 ±X.XX   5 ±X.XX
  4  8X     3  19X  PORT SEL 1 31X   6 ±X.XX   7 ±X.XX
PF1  9X  DDU   20X           2 32X   8 ±X.XX   9 ±X.XX
  2 10X  MCIU  21X                  10 ±X.XX  11 ±X.XX
          CMD  22X                  12 ±X.XX  13 ±X.XX
          SRB  23X                  14 ±X.XX  15 ±X.XX
ALL        DES
MDMS 11X   ALL   24X               DISCRETE OUTPUTS
                                   CHANNEL 0   XXXXXX
         LEVEL 1      25X          CHANNEL 1   XXXXXX
TEST     LEVEL 2      26X          CHANNEL 2   XXXXXX
         MDM OUTPUT   27X
CONTROL  TERMINATE    28
         CONTINUE     29             BTU CYCLIC BITE  30X
```

(A) GPC/BTU I/F



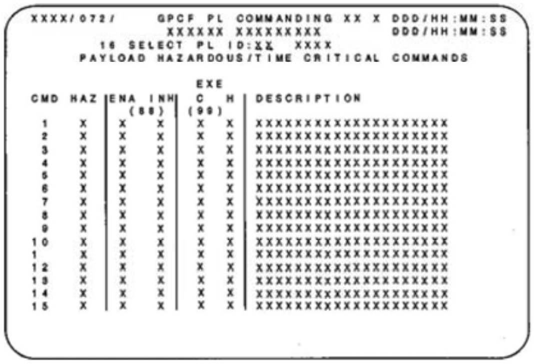
```
XXXX/XXX/006      GPC/BUS STATUS  XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS
            GPC|  1S  |  2S  |  3S  |  4S  |  5S  |
           MODE| XXXX | XXXX | XXXX | XXXX | XXXX |
            OPS|   XX |   XX |   XX |   XX |   XX |
STRING  1   FF |   XS |   XS |   XS |   XS |   XS |
            FA |   XS |   XS |   XS |   XS |   XS |
        2   FF |   XS |   XS |   XS |   XS |   XS |
            FA |   XS |   XS |   XS |   XS |   XS |
        3   FF |   XS |   XS |   XS |   XS |   XS |
            FA |   XS |   XS |   XS |   XS |   XS |
        4   FF |   XS |   XS |   XS |   XS |   XS |
            FA |   XS |   XS |   XS |   XS |   XS |
               |      |      |      |      |      |
          PL  1|   XS |   XS |   XS |   XS |   XS |
              2|   XS |   XS |   XS |   XS |   XS |
      LAUNCH  1|   XS |   XS |   XS |   XS |   XS |
              2|   XS |   XS |   XS |   XS |   XS |
         CRT  1|   XS |   XS |   XS |   XS |   XS |
              2|   XS |   XS |   XS |   XS |   XS |
              3|   XS |   XS |   XS |   XS |   XS |
              4|   XS |   XS |   XS |   XS |   XS |
```

(B) GPC/BUS STATUS



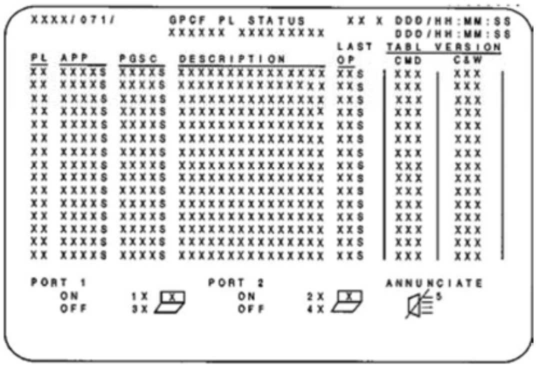
```
XXXX/073/        GPCF PL C&W          XX X DDD/HH:MM:SS
                 XXXXXX XXXXXXXXX          DDD/HH:MM:SS
 1 SELECT PL ID:XX  XXXX  PRIMARY           XXXX≥XX
 2 SELECT PL ID:XX  XXXX  SECONDARY        XXXXXXXX

DESCR       VAL  DESCR       VAL  DESCR         VALUE
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
               |                |
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
               |                |
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
XXXXXXXXXX  XS | XXXXXXXXXX  XS | XXXXXXXXXX   XXXX.XS
```

(C) GPCF PL C&W



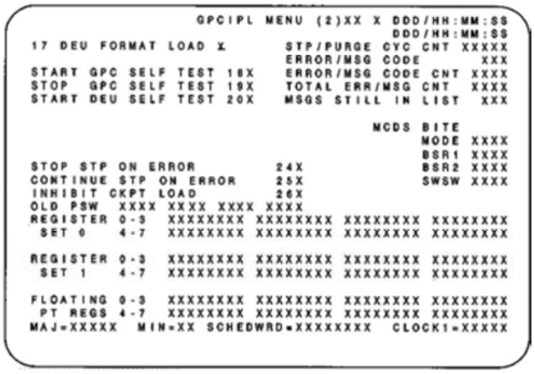
```
XXXX/072/      GPCF PL COMMANDING XX X DDD/HH:MM:SS
                XXXXXX XXXXXXXXX       DDD/HH:MM:SS
        16 SELECT PL ID:XX  XXXX
     PAYLOAD HAZARDOUS/TIME CRITICAL COMMANDS

                         EXE
CMD  HAZ |ENA  INH|  C    H | DESCRIPTION
         |  (88)  | (99)    |
  1   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  2   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  3   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  4   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  5   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  6   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  7   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  8   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
  9   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
 10   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
 1    X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
 12   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
 13   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
 14   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
 15   X  | X    X |  X    X | XXXXXXXXXXXXXXXXXXXX
```

(D) GPCF PL COMMANDING



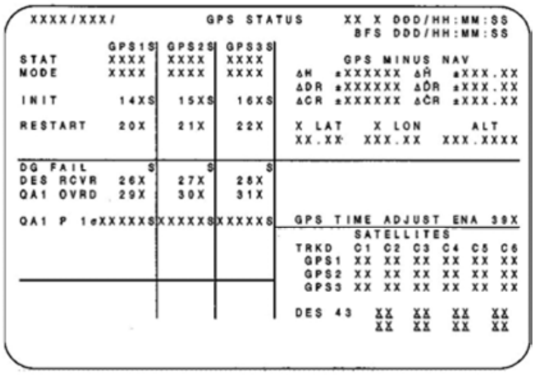
```
XXXX/071/       GPCF PL STATUS     XX X DDD/HH:MM:SS
                XXXXXX XXXXXXXXX        DDD/HH:MM:SS
                                   LAST TABL VERSION
PL APP    PGSC  DESCRIPTION        OP    CMD    C&W
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |
XX XXXXS  XXXXS XXXXXXXXXXXXXXXXX  XXS  | XXX |  XXX |

PORT 1                  PORT 2                 ANNUNCIATE
   ON      1X X            ON      2X X             5
   OFF     3X              OFF     4X
```

(A) GPCF PL STATUS



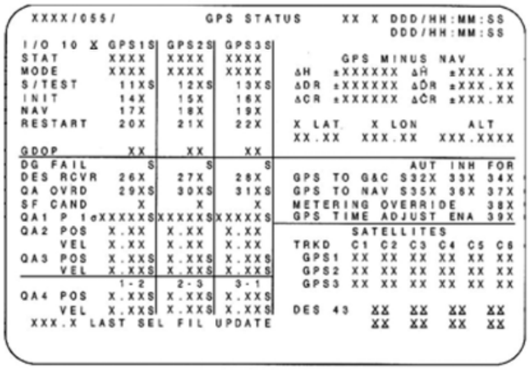
```
                        GPCIPL MENU (2)XX X DDD/HH:MM:SS
                                            DDD/HH:MM:SS
17 DEU FORMAT LOAD X         STP/PURGE CYC CNT  XXXXX
                             ERROR/MSG CODE       XXX
START GPC SELF TEST 18X      ERROR/MSG CODE CNT  XXXX
STOP  GPC SELF TEST 19X      TOTAL ERR/MSG CNT   XXXX
START DEU SELF TEST 20X      MSGS STILL IN LIST   XXX

                                       MCDS BITE
                                            MODE XXXX
                                            BSR1 XXXX
STOP STP ON ERROR          24X              BSR2 XXXX
CONTINUE STP ON ERROR      25X              SWSW XXXX
INHIBIT CKPT LOAD          26X
OLD PSW   XXXX XXXX XXXX XXXX
REGISTER 0-3  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
 SET 0   4-7  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

REGISTER 0-3  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
 SET 1   4-7  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

FLOATING 0-3  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
 PT REGS 4-7  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
MAJ=XXXXX  MIN=XX SCHEDWRD=XXXXXXXX  CLOCK1=XXXXX
```

(B) GPCIPL MENU (2) (PASS/BFS)



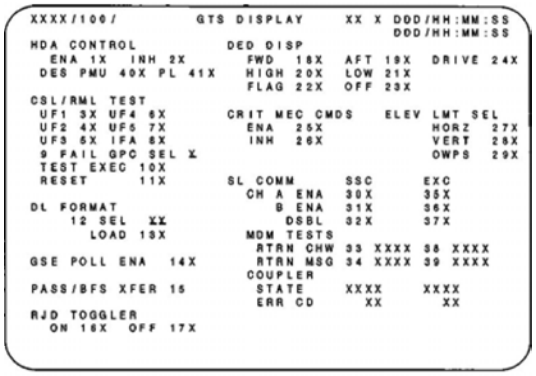
```
XXXX/XXX/              GPS STATUS     XX X DDD/HH:MM:SS
                                          BFS DDD/HH:MM:SS
            GPS1S| GPS2S| GPS3S|
STAT        XXXX | XXXX | XXXX |        GPS MINUS NAV
MODE        XXXX | XXXX | XXXX |  ΔH  ±XXXXXX ΔḢ  ±XXX.XX
                 |      |      |  ΔDR ±XXXXXX ΔḊR ±XXX.XX
INIT         14XS|  15XS|  16XS|  ΔCR ±XXXXXX ΔĊR ±XXX.XX
                 |      |      |
RESTART      20X |  21X |  22X |  X LAT    X LON     ALT
                 |      |      |  XX.XX  XXX.XX  XXX.XXXX
---------------------------------------------------------
DG FAIL         S|     S|     S|
DES RCVR     26X |  27X |  28X |
QA1 OVRD     29X |  30X |  31X |

QA1 P 1σXXXXXS|XXXXXS|XXXXXS|  GPS TIME ADJUST ENA 39X
                 |      |      |-------------------------
                 |      |      |        SATELLITES
                 |      |      |  TRKD  C1 C2 C3 C4 C5 C6
                 |      |      |   GPS1 XX XX XX XX XX XX
                 |      |      |   GPS2 XX XX XX XX XX XX
-------------------------------|   GPS3 XX XX XX XX XX XX
                 |      |      |
                 |      |      |  DES 43  XX  XX  XX  XX
                                          XX  XX  XX  XX
```

(C) GPS STATUS (BFS)



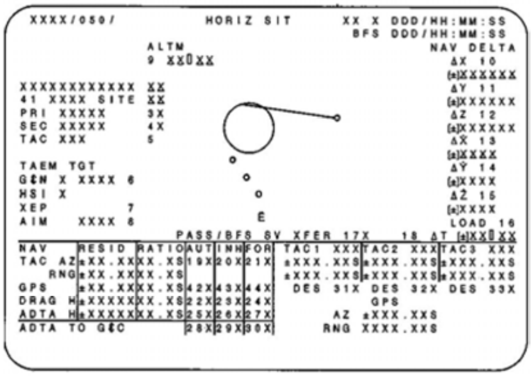
```
XXXX/055/              GPS STATUS     XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS
I/O 10 X GPS1S| GPS2S| GPS3S|
STAT        XXXX | XXXX | XXXX |        GPS MINUS NAV
MODE        XXXX | XXXX | XXXX |  ΔH  ±XXXXXX ΔḢ  ±XXX.XX
S/TEST       11XS|  12XS|  13XS|  ΔDR ±XXXXXX ΔḊR ±XXX.XX
INIT         14X |  15X |  16X |  ΔCR ±XXXXXX ΔĊR ±XXX.XX
NAV          17X |  18X |  19X |
RESTART      20X |  21X |  22X |  X LAT    X LON     ALT
                 |      |      |  XX.XX  XXX.XX  XXX.XXXX
GDOP          XX |   XX |   XX |
---------------------------------------------------------
DG FAIL         S|     S|     S|             AUT  INH  FOR
DES RCVR     26X |  27X |  28X |  GPS TO G&C S32X 33X 34X
QA OVRD      29XS|  30XS|  31XS|  GPS TO NAV S35X 36X 37X
SF CAND        X |     X|     X|  METERING OVERRIDE    38X
QA1 P 1σXXXXXS|XXXXXS|XXXXXS|  GPS TIME ADJUST ENA  39X
QA2 POS    X.XX  | X.XX | X.XX |-------------------------
    VEL    X.XX  | X.XX | X.XX |        SATELLITES
QA3 POS    X.XXS |X.XXS |X.XXS |  TRKD  C1 C2 C3 C4 C5 C6
    VEL    X.XXS |X.XXS |X.XXS |   GPS1 XX XX XX XX XX XX
-------------------------------|   GPS2 XX XX XX XX XX XX
             1-2 |  2-3 |  3-1 |   GPS3 XX XX XX XX XX XX
QA4 POS    X.XXS |X.XXS |X.XXS |
    VEL    X.XXS |X.XXS |X.XXS |  DES 43  XX  XX  XX  XX
 XXX.X LAST SEL FIL UPDATE                XX  XX  XX  XX
```

(D) GPS STATUS (PASS)



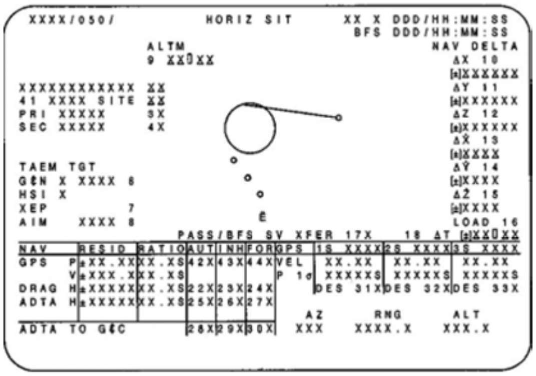
```
XXXX/100/          GTS DISPLAY      XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS
HDA CONTROL             DED DISP
  ENA 1X   INH 2X         FWD  18X  AFT 19X  DRIVE 24X
 DES PMU 40X PL 41X       HIGH 20X  LOW 21X
                          FLAG 22X  OFF 23X
CSL/RML TEST
 UF1 3X UF4 6X          CRIT MEC CMDS   ELEV LMT SEL
 UF2 4X UF5 7X            ENA  25X          HORZ  27X
 UF3 5X IFA 8X            INH  26X          VERT  28X
 9 FAIL GPC SEL X                           OWPS  29X
 TEST EXEC 10X
 RESET      11X         SL COMM       SSC      EXC
                          CH A ENA    30X      35X
DL FORMAT                    B ENA    31X      36X
    12 SEL  XX                DSBL    32X      37X
      LOAD 13X            MDM TESTS
                           RTRN CHW   33 XXXX  38 XXXX
GSE POLL ENA  14X          RTRN MSG   34 XXXX  39 XXXX
                          COUPLER
PASS/BFS XFER 15           STATE      XXXX     XXXX
                           ERR CD       XX       XX
RJD TOGGLER
  ON 16X  OFF 17X
```

(A) GTS DISPLAY



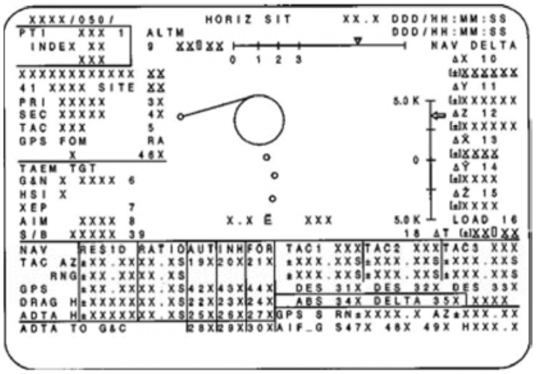
```
XXXX/050/           HORIZ SIT      XX X DDD/HH:MM:SS
                                    BFS DDD/HH:MM:SS
                ALTM                       NAV DELTA
                9 XX0XX                      ΔX 10
                                         (±)XXXXXX
XXXXXXXXXXXX XX                              ΔY 11
41 XXXX SITE XX                          (±)XXXXXX
PRI XXXXX    3X                              ΔZ 12
SEC XXXXX    4X                          (±)XXXXXX
TAC XXX      5                               ΔẊ 13
                                         (±)XXXX
TAEM TGT                                     ΔẎ 14
G¢N X XXXX 6                             (±)XXXX
HSI X                                        ΔŻ 15
XEP        7                             (±)XXXX
AIM   XXXX 8                 E              LOAD 16
                 PASS/BFS SV XFER 17X    18 ΔT (±)XX0XX
NAV    |RESID |RATIO|AUT|INH|FOR| TAC1 XXX|TAC2 XXX|TAC3 XXX
TAC AZ|±XX.XX|XX.XS|19X|20X|21X|±XXX.XXS|±XXX.XXS|±XXX.XXS
   RNG|±XX.XX|XX.XS|   |   |   |±XXX.XXS|±XXX.XXS|±XXX.XXS
GPS   |±XX.XX|XX.XS|42X|43X|44X| DES 31X  DES 32X  DES 33X
DRAG H|±XXXXX|XX.XS|22X|23X|24X|          GPS
ADTA H|±XXXXX|XX.XS|25X|26X|27X|      AZ ±XXX.XXS
ADTA TO G¢C        |28X|29X|30X|     RNG XXXX.XXS
```

(B) HORIZ SIT (BFS, SINGLE OR NO GPS)



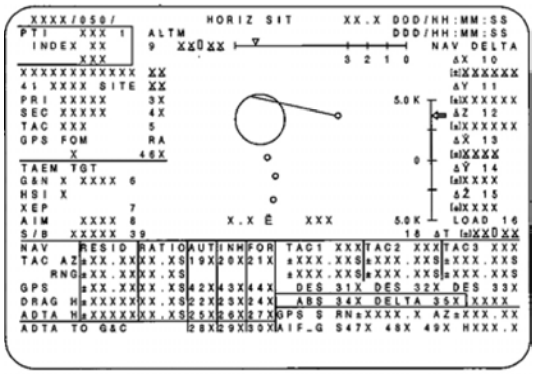
```
XXXX/050/           HORIZ SIT      XX X DDD/HH:MM:SS
                                    BFS DDD/HH:MM:SS
                ALTM                       NAV DELTA
                9 XX0XX                      ΔX 10
                                         (±)XXXXXX
XXXXXXXXXXXX XX                              ΔY 11
41 XXXX SITE XX                          (±)XXXXXX
PRI XXXXX    3X                              ΔZ 12
SEC XXXXX    4X                          (±)XXXXXX
                                             ΔẊ 13
                                         (±)XXXX
TAEM TGT                                     ΔẎ 14
G¢N X XXXX 6                             (±)XXXX
HSI X                                        ΔŻ 15
XEP        7                             (±)XXXX
AIM   XXXX 8                 E              LOAD 16
                 PASS/BFS SV XFER 17X    18 ΔT (±)XX0XX
NAV    |RESID |RATIO|AUT|INH|FOR|GPS |1S XXXX|2S XXXX|3S XXXX
GPS   P|±XX.XX|XX.XS|42X|43X|44X|VEL |  XX.XX|  XX.XX|  XX.XX
      V|±XXX.X|XX.XS|   |   |   |P 1σ| XXXXXS| XXXXXS| XXXXXS
DRAG  H|±XXXXX|XX.XS|22X|23X|24X|    |DES 31X|DES 32X|DES 33X
ADTA  H|±XXXXX|XX.XS|25X|26X|27X|
                                     AZ      RNG      ALT
ADTA TO G¢C         |28X|29X|30X|  XXX    XXXX.X    XXX.X
```

(C) HORIZ SIT (BFS, 3 GPS)

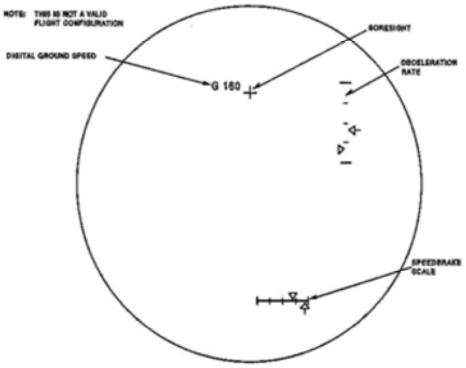


```
XXXX/050/           HORIZ SIT      XX.X DDD/HH:MM:SS
PTI    XXX 1   ALTM                     DDD/HH:MM:SS
 INDEX XX      9 XX0XX                     NAV DELTA
       XXX            0 1 2 3                ΔX 10
XXXXXXXXXXXX XX                          (±)XXXXXX
41 XXXX SITE XX                              ΔY 11
PRI XXXXX    3X                   5.0K   (±)XXXXXX
SEC XXXXX    4X                              ΔZ 12
TAC XXX      5                           (±)XXXXXX
GPS FOM      RA                              ΔẊ 13
      X     46X                      0   (±)XXXX
TAEM TGT                                     ΔẎ 14
G&N X XXXX 6                             (±)XXXX
HSI X                                        ΔŻ 15
XEP        7                             (±)XXXX
AIM   XXXX 8        X.X E    XXX  5.0K      LOAD 16
S/B  XXXXX 39                            18 ΔT (±)XX0XX
NAV    |RESID |RATIO|AUT|INH|FOR| TAC1 XXX|TAC2 XXX|TAC3 XXX
TAC AZ|±XX.XX|XX.XS|19X|20X|21X|±XXX.XXS|±XXX.XXS|±XXX.XXS
   RNG|±XX.XX|XX.XS|   |   |   |±XXX.XXS|±XXX.XXS|±XXX.XXS
GPS   |±XX.XX|XX.XS|42X|43X|44X| DES 31X  DES 32X  DES 33X
DRAG H|±XXXXX|XX.XS|22X|23X|24X| ABS 34X DELTA 35X| XXXX
ADTA H|±XXXXX|XX.XS|25X|26X|27X|GPS S RN±XXXX.X AZ±XXX.XX
ADTA TO G&C         |28X|29X|30X|AIF_G S47X 48X 49X HXXX.X
```

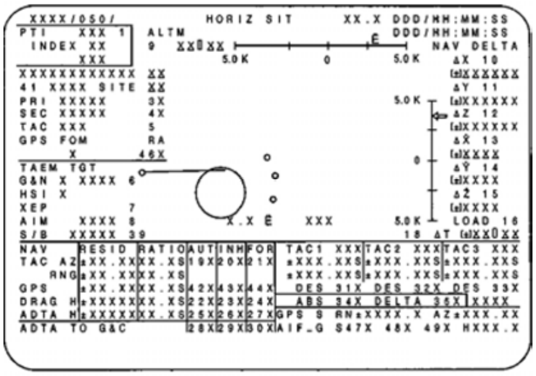
(D) HORIZ SIT (IN-LEFT HAC, 3 TACANS)



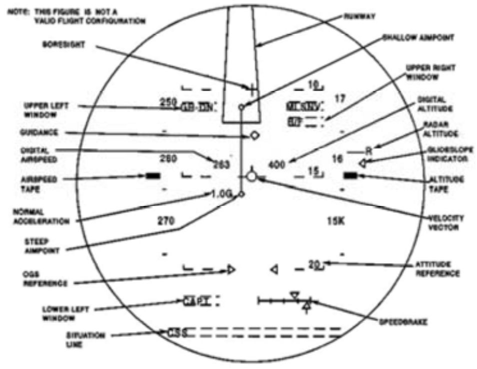
(A) HORIZ SIT (IN-RIGHT HAC, 3 TACANS)



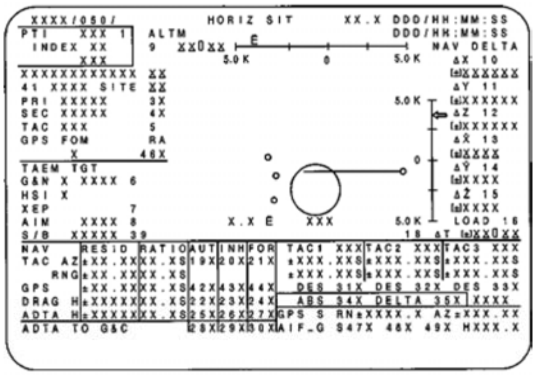
(A) HUD DISPLAY FORMAT 1 AFTER-WOW



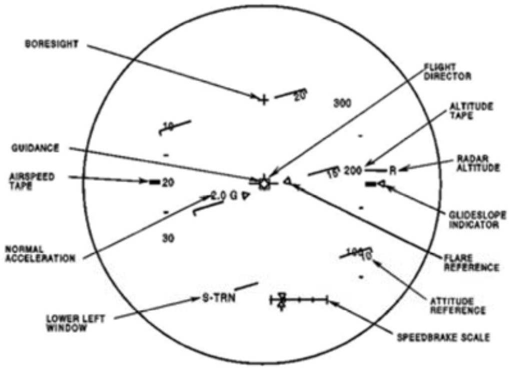
(B) HORIZ SIT (OUT-LEFT HAC, 3 TACANS)



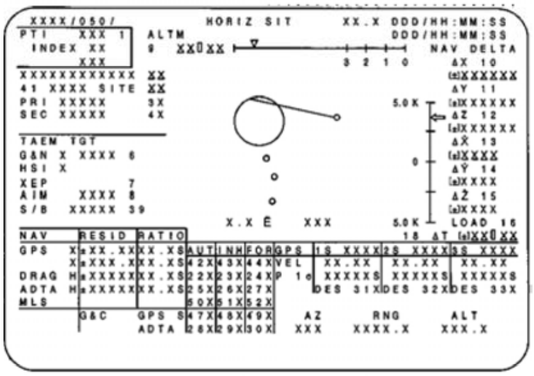
(B) HUD DISPLAY FORMAT 1 PRE-WOW



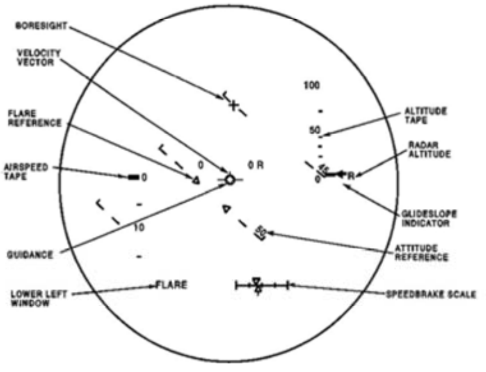
(C) HORIZ SIT (OUT-RIGHT HAC, 3 TACANS)



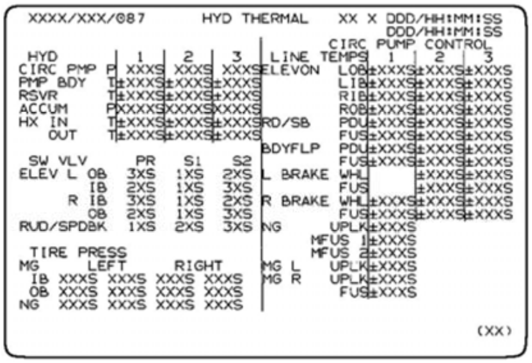
(C) HUD VU OPS 8 LOW



(D) HORIZ SIT (RIGHT HAC, 3 GPS)

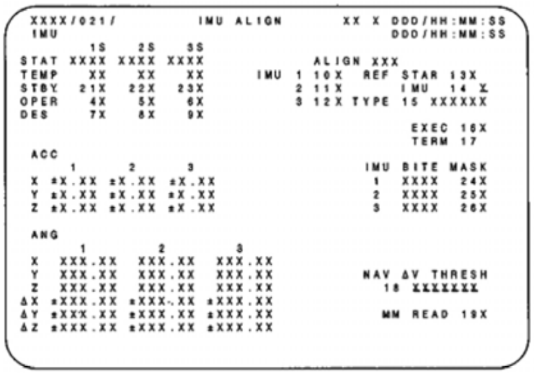


(D) HUD VU OPS 9 LOW



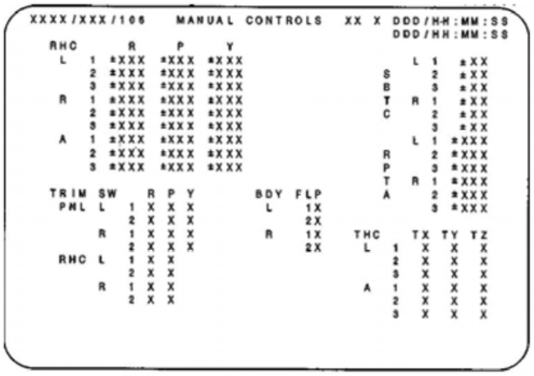
```
 XXXX/XXX/087        HYD THERMAL     XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
                                  CIRC PUMP CONTROL
 HYD          |  1  |  2  |  3  | LINE TEMPS|  1  |  2  |  3
CIRC PMP P| XXXS| XXXS| XXXSELEVON   LOB±XXXS±XXXS±XXXS
PMP BDY  T±XXXS±XXXS±XXXS            LIB±XXXS±XXXS±XXXS
RSVR     T±XXXS±XXXS±XXXS            RIB±XXXS±XXXS±XXXS
ACCUM    PXXXXSXXXXSXXXXS            ROB±XXXS±XXXS±XXXS
HX  IN   T±XXXS±XXXS±XXXSRD/SB       PDU±XXXS±XXXS±XXXS
    OUT  T±XXXS±XXXS±XXXS            FUS±XXXS±XXXS±XXXS
                         BDYFLP      PDU±XXXS±XXXS±XXXS
 SW VLV      PR    S1    S2          FUS±XXXS±XXXS±XXXS
ELEV L OB   3XS   1XS   2XS L BRAKE  WHL     ±XXXS±XXXS
       IB   2XS   1XS   3XS          FUS     ±XXXS±XXXS
     R IB   3XS   1XS   2XS R BRAKE  WHL±XXXS±XXXS±XXXS
       OB   2XS   1XS   3XS          FUS±XXXS±XXXS±XXXS
RUD/SPDBK   1XS   2XS   3XS NG      UPLK±XXXS
                                  MFUS 1±XXXS
 TIRE PRESS                       MFUS 2±XXXS
MG      LEFT      RIGHT     MG L    UPLK±XXXS
 IB XXXS XXXS XXXS XXXS     MG R    UPLK±XXXS
 OB XXXS XXXS XXXS XXXS              FUS±XXXS
NG  XXXS XXXS XXXS XXXS

                                                      (XX)
```

(A) HYD THERMAL



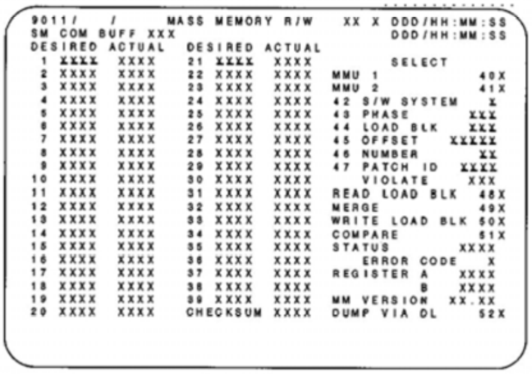
```
 XXXX/021/          IMU ALIGN        XX X DDD/HH:MM:SS
 IMU                                      DDD/HH:MM:SS
       1S    2S    3S
STAT XXXX  XXXX  XXXX              ALIGN XXX
TEMP   XX    XX    XX        IMU 1 10X  REF STAR 13X
STBY  21X   22X   23X            2 11X       IMU  14 X
OPER   4X    5X    6X            3 12X TYPE 15 XXXXXX
DES    7X    8X    9X
                                           EXEC 16X
                                           TERM 17
 ACC
     1       2       3                IMU BITE MASK
 X ±X.XX  ±X.XX  ±X.XX                 1   XXXX   24X
 Y ±X.XX  ±X.XX  ±X.XX                 2   XXXX   25X
 Z ±X.XX  ±X.XX  ±X.XX                 3   XXXX   26X

 ANG
       1         2         3
 X   XXX.XX    XXX.XX    XXX.XX
 Y   XXX.XX    XXX.XX    XXX.XX          NAV ΔV THRESH
 Z   XXX.XX    XXX.XX    XXX.XX            18 XXXXXXX
ΔX ±XXX.XX   ±XXX.XX   ±XXX.XX
ΔY ±XXX.XX   ±XXX.XX   ±XXX.XX             MM READ 19X
ΔZ ±XXX.XX   ±XXX.XX   ±XXX.XX
```

(B) IMU ALIGN



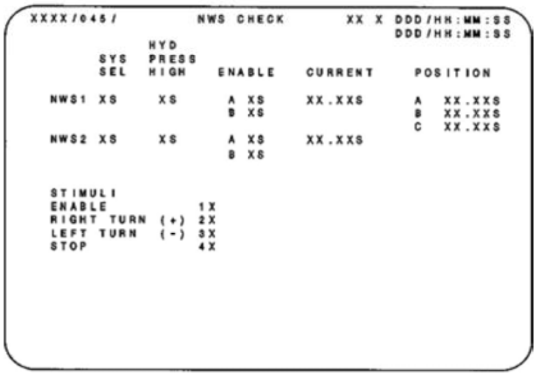
```
 XXXX/XXX/106    MANUAL CONTROLS   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
   RHC       R      P      Y
   L   1  ±XXX   ±XXX   ±XXX                  L 1    ±XX
       2  ±XXX   ±XXX   ±XXX             S       2    ±XX
       3  ±XXX   ±XXX   ±XXX             B       3    ±XX
   R   1  ±XXX   ±XXX   ±XXX             T    R 1    ±XX
       2  ±XXX   ±XXX   ±XXX             C       2    ±XX
       3  ±XXX   ±XXX   ±XXX                     3    ±XX
   A   1  ±XXX   ±XXX   ±XXX                  L 1   ±XXX
       2  ±XXX   ±XXX   ±XXX             R       2   ±XXX
       3  ±XXX   ±XXX   ±XXX             P       3   ±XXX
                                         T    R 1   ±XXX
   TRIM SW     R  P  Y        BDY FLP    A       2   ±XXX
    PNL L   1  X  X  X         L    1X           3   ±XXX
            2  X  X  X              2X
        R   1  X  X  X         R    1X    THC     TX  TY  TZ
            2  X  X  X              2X     L   1   X   X   X
    RHC L   1  X  X                            2   X   X   X
            2  X  X                            3   X   X   X
        R   1  X  X                        A   1   X   X   X
            2  X  X                            2   X   X   X
                                               3   X   X   X
```

(C) MANUAL CONTROLS



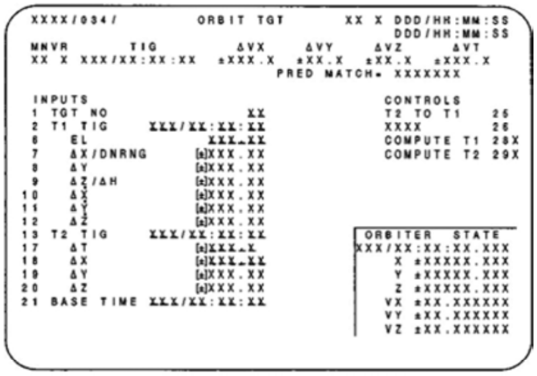
```
9011/    /      MASS MEMORY R/W    XX X DDD/HH:MM:SS
SM COM BUFF XXX                         DDD/HH:MM:SS
DESIRED ACTUAL  DESIRED ACTUAL
  1 XXXX   XXXX    21 XXXX   XXXX         SELECT
  2 XXXX   XXXX    22 XXXX   XXXX   MMU 1              40X
  3 XXXX   XXXX    23 XXXX   XXXX   MMU 2              41X
  4 XXXX   XXXX    24 XXXX   XXXX   42 S/W SYSTEM      X
  5 XXXX   XXXX    25 XXXX   XXXX   43 PHASE          XXX
  6 XXXX   XXXX    26 XXXX   XXXX   44 LOAD BLK       XXX
  7 XXXX   XXXX    27 XXXX   XXXX   45 OFFSET       XXXXX
  8 XXXX   XXXX    28 XXXX   XXXX   46 NUMBER          XX
  9 XXXX   XXXX    29 XXXX   XXXX   47 PATCH ID      XXXX
 10 XXXX   XXXX    30 XXXX   XXXX      VIOLATE        XXX
 11 XXXX   XXXX    31 XXXX   XXXX   READ LOAD BLK     48X
 12 XXXX   XXXX    32 XXXX   XXXX   MERGE              49X
 13 XXXX   XXXX    33 XXXX   XXXX   WRITE LOAD BLK    50X
 14 XXXX   XXXX    34 XXXX   XXXX   COMPARE            51X
 15 XXXX   XXXX    35 XXXX   XXXX   STATUS           XXXX
 16 XXXX   XXXX    36 XXXX   XXXX      ERROR CODE       X
 17 XXXX   XXXX    37 XXXX   XXXX   REGISTER A       XXXX
 18 XXXX   XXXX    38 XXXX   XXXX            B       XXXX
 19 XXXX   XXXX    39 XXXX   XXXX   MM VERSION      XX.XX
 20 XXXX   XXXX   CHECKSUM   XXXX   DUMP VIA DL        52X
```

(D) MASS MEMORY R/W



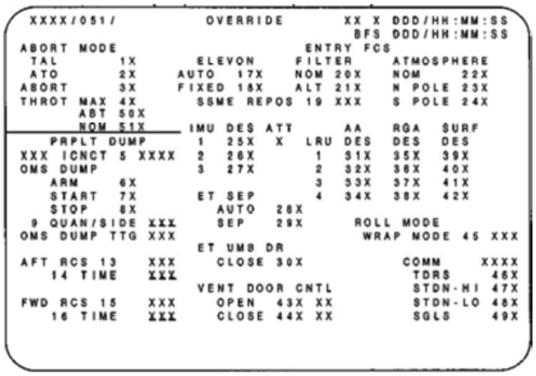
```
 XXXX/045/          NWS CHECK        XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
             HYD
       SYS   PRESS
       SEL   HIGH    ENABLE    CURRENT     POSITION

  NWS1 XS     XS      A XS     XX.XXS      A   XX.XXS
                      B XS                 B   XX.XXS
                                           C   XX.XXS
  NWS2 XS     XS      A XS     XX.XXS
                      B XS


  STIMULI
  ENABLE              1X
  RIGHT TURN  (+)     2X
  LEFT TURN   (-)     3X
  STOP                4X
```

(A) NWS CHECK



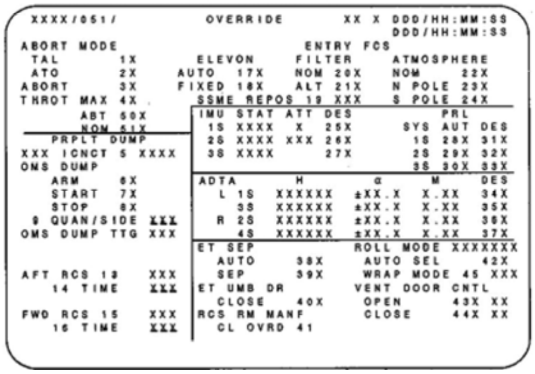
```
 XXXX/034/          ORBIT TGT        XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
 MNVR        TIG          ΔVX      ΔVY      ΔVZ      ΔVT
 XX X  XXX/XX:XX:XX    ±XXX.X    ±XX.X    ±XX.X   ±XXX.X
                              PRED MATCH= XXXXXXX

  INPUTS                                   CONTROLS
  1 TGT NO                     XX          T2 TO T1    25
  2 T1 TIG          XXX/XX:XX:XX           XXXX        26
  6    EL                   XXX.XX         COMPUTE T1 28X
  7    ΔX/DNRNG          [±]XXX.XX         COMPUTE T2 29X
  8    ΔY                [±]XXX.XX
  9    ΔZ/ΔH             [±]XXX.XX
 10    ΔẊ                [±]XXX.XX
 11    ΔẎ                [±]XXX.XX
 12    ΔŻ                [±]XXX.XX
 13 T2 TIG          XXX/XX:XX:XX         | ORBITER  STATE
 17    ΔT                [±]XXX.X        XXX/XX:XX:XX.XXX
 18    ΔX                [±]XXX.XX       |     X ±XXXXX.XXX
 19    ΔY                [±]XXX.XX       |     Y ±XXXXX.XXX
 20    ΔZ                [±]XXX.XX       |     Z ±XXXXX.XXX
 21 BASE TIME       XXX/XX:XX:XX         |    VX ±XX.XXXXXX
                                         |    VY ±XX.XXXXXX
                                         |    VZ ±XX.XXXXXX
```

(B) ORBIT TGT



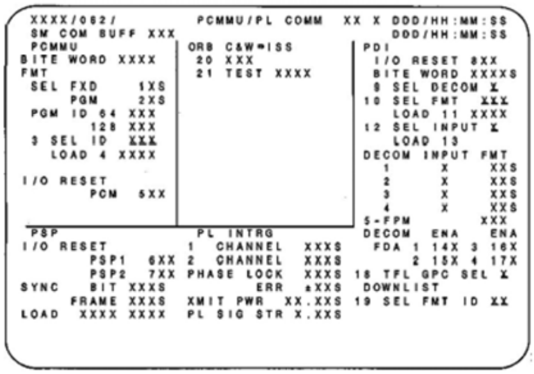
```
 XXXX/051/           OVERRIDE        XX X DDD/HH:MM:SS
                                      BFS DDD/HH:MM:SS
ABORT MODE                        ENTRY FCS
 TAL         1X      ELEVON     FILTER     ATMOSPHERE
 ATO         2X    AUTO  17X    NOM 20X    NOM      22X
ABORT        3X    FIXED 18X    ALT 21X    N POLE   23X
THROT MAX    4X      SSME REPOS 19 XXX     S POLE   24X
      ABT   50X
      NOM   51X     IMU DES ATT        AA    RGA   SURF
   PRPLT DUMP       1   25X  X    LRU  DES   DES   DES
XXX ICNCT 5 XXXX    2   26X        1   31X   35X   39X
OMS DUMP            3   27X        2   32X   36X   40X
   ARM      6X                     3   33X   37X   41X
   START    7X      ET SEP         4   34X   38X   42X
   STOP     8X        AUTO   28X
 9 QUAN/SIDE XXX      SEP    29X       ROLL MODE
OMS DUMP TTG XXX                        WRAP MODE 45 XXX
                    ET UMB DR
AFT RCS 13   XXX      CLOSE 30X             COMM    XXXX
   14 TIME   XXX                             TDRS     46X
                    VENT DOOR CNTL           STDN-HI  47X
FWD RCS 15   XXX      OPEN  43X XX           STDN-LO  48X
   16 TIME   XXX      CLOSE 44X XX           SGLS     49X
```

(C) OVERRIDE (BFS)



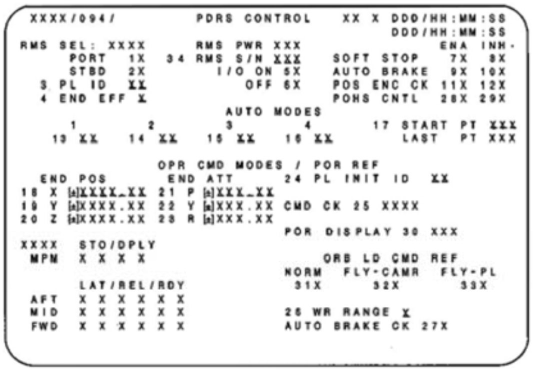
```
 XXXX/051/           OVERRIDE        XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
ABORT MODE                        ENTRY FCS
 TAL         1X      ELEVON     FILTER     ATMOSPHERE
 ATO         2X    AUTO  17X    NOM 20X    NOM      22X
ABORT        3X    FIXED 18X    ALT 21X    N POLE   23X
THROT MAX    4X      SSME REPOS 19 XXX     S POLE   24X
      ABT   50X   |IMU STAT ATT DES             PRL
      NOM   51X   | 1S XXXX  X   25X       SYS AUT DES
   PRPLT DUMP     | 2S XXXX XXX  26X        1S 28X 31X
XXX ICNCT 5 XXXX  | 3S XXXX      27X        2S 29X 32X
OMS DUMP          |                         3S 30X 33X
   ARM      6X    |ADTA     H       α      M      DES
   START    7X    |  L 1S XXXXXX  ±XX.X  X.XX     34X
   STOP     8X    |    3S XXXXXX  ±XX.X  X.XX     35X
 9 QUAN/SIDE XXX  |  R 2S XXXXXX  ±XX.X  X.XX     36X
OMS DUMP TTG XXX  |    4S XXXXXX  ±XX.X  X.XX     37X
                  |ET SEP              ROLL MODE XXXXXXX
                  |  AUTO      38X      AUTO SEL      42X
AFT RCS 13   XXX  |  SEP       39X      WRAP MODE 45 XXX
   14 TIME   XXX  |ET UMB DR           VENT DOOR CNTL
                  |  CLOSE     40X      OPEN      43X XX
FWD RCS 15   XXX  |RCS RM MANF          CLOSE     44X XX
   16 TIME   XXX  |  CL OVRD 41
```

(D) OVERRIDE (PASS)



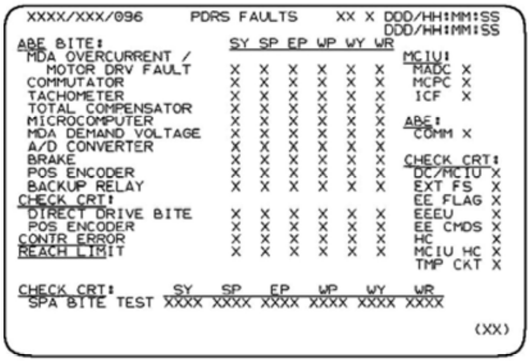
```
 XXXX/062/            PCMMU/PL COMM    XX X DDD/HH:MM:SS
 SM COM BUFF XXX                            DDD/HH:MM:SS
 PCMMU              | ORB C&W=ISS         | PDI
BITE WORD XXXX      |  20 XXX             |  I/O RESET 8XX
FMT                 |  21 TEST XXXX       |  BITE WORD XXXXS
 SEL FXD     1XS    |                     |  9 SEL DECOM X
     PGM     2XS    |                     | 10 SEL FMT   XXX
 PGM ID 64 XXX      |                     |    LOAD 11 XXXX
       128 XXX      |                     | 12 SEL INPUT X
 3 SEL ID  XXX      |                     |    LOAD 13
   LOAD 4 XXXX      |                     | DECOM  INPUT  FMT
                    |                     |   1      X      XXS
I/O RESET           |                     |   2      X      XXS
       PCM   5XX    |                     |   3      X      XXS
                    |                     |   4      X      XXS
                    |                     | 5-FPM          XXX
 PSP                   PL INTRG             DECOM   ENA    ENA
I/O RESET              1  CHANNEL   XXXS     FDA 1 14X 3 16X
       PSP1  6XX    2  CHANNEL   XXXS          2 15X 4 17X
       PSP2  7XX    PHASE LOCK   XXXS   18 TFL GPC SEL X
SYNC   BIT XXXS              ERR  ±XXS   DOWNLIST
     FRAME XXXS     XMIT PWR  XX.XXS   19 SEL FMT ID XX
LOAD  XXXX XXXX     PL SIG STR X.XXS
```

(A) PCMMU/PL COMM



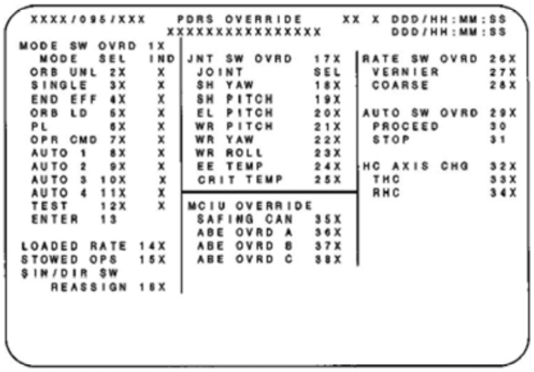
```
 XXXX/094/            PDRS CONTROL    XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS
RMS SEL: XXXX         RMS PWR XXX                 ENA INH·
     PORT  1X   34 RMS S/N XXX    SOFT STOP    7X  8X
     STBD  2X       I/O ON 5X     AUTO BRAKE   9X 10X
  3 PL ID  XX          OFF 6X     POS ENC CK  11X 12X
  4 END EFF X                     POHS CNTL   28X 29X
                         AUTO MODES
     1         2         3         4        17 START PT XXX
   13 XX    14 XX    15 XX    16 XX              LAST PT XXX

                  OPR CMD MODES / POR REF
  END POS         END ATT        24 PL INIT ID  XX
18 X [±]XXXX.XX 21 P [±]XXX.XX
19 Y [±]XXXX.XX 22 Y [±]XXX.XX CMD CK 25 XXXX
20 Z [±]XXXX.XX 23 R [±]XXX.XX
                               POR DISPLAY 30 XXX
XXXX   STO/DPLY
 MPM   X X X X                      ORB LD CMD REF
                               NORM    FLY-CAMR   FLY-PL
       LAT/REL/RDY              31X       32X        33X
 AFT   X X X X X X
 MID   X X X X X X             26 WR RANGE X
 FWD   X X X X X X             AUTO BRAKE CK 27X
```

(B) PDRS CONTROL



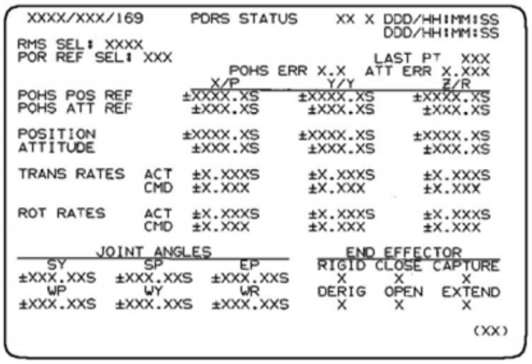
```
 XXXX/XXX/096      PDRS FAULTS      XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS
ABE BITE:                   SY SP EP WP WY WR
 MDA OVERCURRENT /                             MCIU:
   MOTOR DRV FAULT          X  X  X  X  X  X    MADC X
 COMMUTATOR                 X  X  X  X  X  X    MCPC X
 TACHOMETER                 X  X  X  X  X  X    ICF  X
 TOTAL COMPENSATOR          X  X  X  X  X  X
 MICROCOMPUTER              X  X  X  X  X  X   ABE:
 MDA DEMAND VOLTAGE         X  X  X  X  X  X    COMM X
 A/D CONVERTER              X  X  X  X  X  X
 BRAKE                      X  X  X  X  X  X   CHECK CRT:
 POS ENCODER                X  X  X  X  X  X    DC/MCIU  X
 BACKUP RELAY               X  X  X  X  X  X    EXT FS   X
CHECK CRT:                                      EE FLAG  X
 DIRECT DRIVE BITE          X  X  X  X  X  X    EEEU     X
 POS ENCODER                X  X  X  X  X  X    EE CMDS  X
CONTR ERROR                 X  X  X  X  X  X    HC       X
REACH LIMIT                 X  X  X  X  X  X    MCIU HC  X
                                                TMP CKT  X

CHECK CRT:          SY   SP   EP   WP   WY   WR
 SPA BITE TEST    XXXX XXXX XXXX XXXX XXXX XXXX

                                                    (XX)
```

(C) PDRS FAULTS



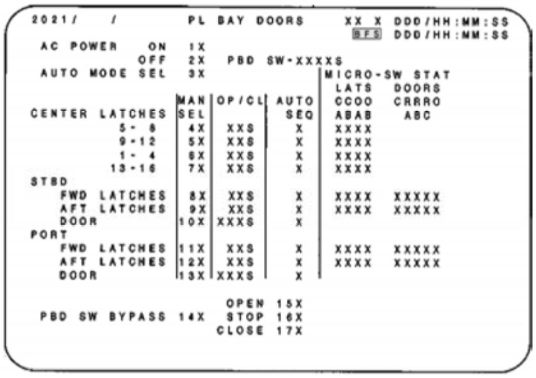
```
 XXXX/095/XXX     PDRS OVERRIDE       XX X DDD/HH:MM:SS
               XXXXXXXXXXXXXXXXX           DDD/HH:MM:SS
MODE SW OVRD 1X |
  MODE   SEL  IND| JNT SW OVRD    17X | RATE SW OVRD 26X
 ORB UNL 2X    X |  JOINT         SEL |  VERNIER     27X
 SINGLE  3X    X |  SH YAW        18X |  COARSE      28X
 END EFF 4X    X |  SH PITCH      19X |
 ORB LD  5X    X |  EL PITCH      20X | AUTO SW OVRD 29X
 PL      6X    X |  WR PITCH      21X |  PROCEED     30
 OPR CMD 7X    X |  WR YAW        22X |  STOP        31
 AUTO 1  8X    X |  WR ROLL       23X |
 AUTO 2  9X    X |  EE TEMP       24X | HC AXIS CHG  32X
 AUTO 3 10X    X |  CRIT TEMP     25X |  THC         33X
 AUTO 4 11X    X |--------------------|  RHC         34X
 TEST   12X    X | MCIU OVERRIDE      |
 ENTER  13       |  SAFING CAN    35X |
                 |  ABE OVRD A    36X |
LOADED RATE 14X  |  ABE OVRD B    37X |
STOWED OPS  15X  |  ABE OVRD C    38X |
SIN/DIR SW       |
   REASSIGN 16X  |
```

(D) PDRS OVERRIDE



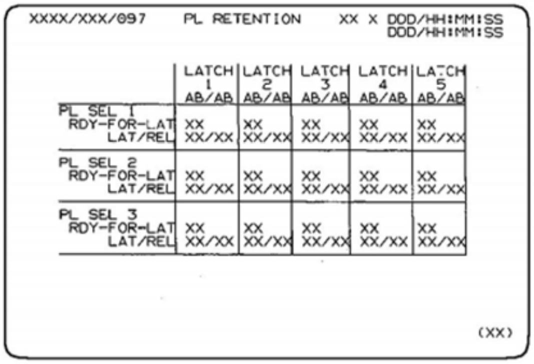
```
 XXXX/XXX/169       PDRS STATUS      XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
RMS SEL: XXXX
POR REF SEL: XXX                           LAST PT   XXX
                      POHS ERR X.X  ATT ERR X.XXX
                       X/P           Y/Y           Z/R
POHS POS REF        ±XXXX.XS      ±XXXX.XS      ±XXXX.XS
POHS ATT REF         ±XXX.XS       ±XXX.XS       ±XXX.XS

POSITION            ±XXXX.XS      ±XXXX.XS      ±XXXX.XS
ATTITUDE             ±XXX.XS       ±XXX.XS       ±XXX.XS

TRANS RATES   ACT   ±X.XXXS       ±X.XXXS       ±X.XXXS
              CMD   ±X.XXX        ±X.XXX        ±X.XXX

ROT RATES     ACT   ±X.XXXS       ±X.XXXS       ±X.XXXS
              CMD   ±X.XXX        ±X.XXX        ±X.XXX

        JOINT ANGLES                    END EFFECTOR
    SY          SP          EP       RIGID CLOSE CAPTURE
±XXX.XXS    ±XXX.XXS    ±XXX.XXS       X     X      X
    WP          WY          WR       DERIG  OPEN  EXTEND
±XXX.XXS    ±XXX.XXS    ±XXX.XXS       X     X      X

                                                    (XX)
```

(A) PDRS STATUS



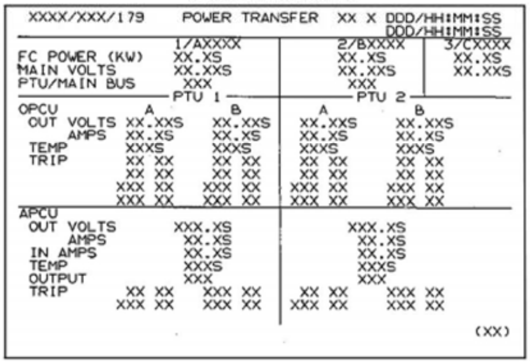
```
 2021/   /          PL BAY DOORS      XX X DDD/HH:MM:SS
                                       BFS DDD/HH:MM:SS
  AC POWER     ON   1X
              OFF   2X   PBD SW-XXXXS
  AUTO MODE SEL     3X               |MICRO-SW STAT
                                     | LATS   DOORS
                   |MAN|OP/CL| AUTO  | CCOO   CRRRO
 CENTER LATCHES    |SEL|     |  SEQ  | ABAB    ABC
            5- 8   | 4X| XXS |   X   | XXXX
            9-12   | 5X| XXS |   X   | XXXX
            1- 4   | 6X| XXS |   X   | XXXX
           13-16   | 7X| XXS |   X   | XXXX
 STBD              |   |     |       |
    FWD LATCHES    | 8X| XXS |   X   | XXXX   XXXXX
    AFT LATCHES    | 9X| XXS |   X   | XXXX   XXXXX
    DOOR           |10X|XXXS |   X   |
 PORT              |   |     |       |
    FWD LATCHES    |11X| XXS |   X   | XXXX   XXXXX
    AFT LATCHES    |12X| XXS |   X   | XXXX   XXXXX
    DOOR           |13X|XXXS |   X   |

                          OPEN 15X
  PBD SW BYPASS 14X       STOP 16X
                         CLOSE 17X
```

(B) PL BAY DOORS (PASS/BFS)



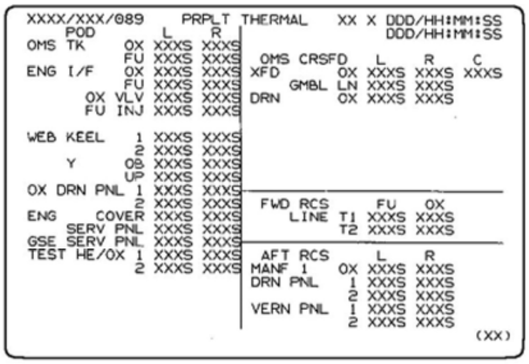
```
 XXXX/XXX/097      PL RETENTION      XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS

                  |LATCH|LATCH|LATCH|LATCH|LATCH
                  |  1  |  2  |  3  |  4  |  5
                  |AB/AB|AB/AB|AB/AB|AB/AB|AB/AB
     PL SEL 1     |-----|-----|-----|-----|-----
      RDY-FOR-LAT | XX  | XX  | XX  | XX  | XX
          LAT/REL |XX/XX|XX/XX|XX/XX|XX/XX|XX/XX
     -------------|-----|-----|-----|-----|-----
     PL SEL 2     |     |     |     |     |
      RDY-FOR-LAT | XX  | XX  | XX  | XX  | XX
          LAT/REL |XX/XX|XX/XX|XX/XX|XX/XX|XX/XX
     -------------|-----|-----|-----|-----|-----
     PL SEL 3     |     |     |     |     |
      RDY-FOR-LAT | XX  | XX  | XX  | XX  | XX
          LAT/REL |XX/XX|XX/XX|XX/XX|XX/XX|XX/XX
     -------------------------------------------

                                                    (XX)
```

(C) PL RETENTION



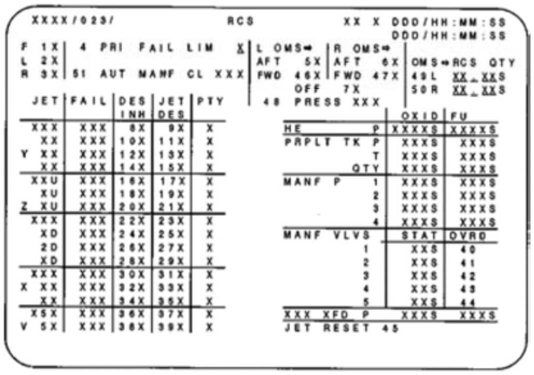
```
 XXXX/XXX/179      POWER TRANSFER  XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
---------------------------------------------------------
                 1/AXXXX        |      2/BXXXX  | 3/CXXXX
FC POWER (KW)    XX.XS          |      XX.XS    |  XX.XS
MAIN VOLTS       XX.XXS         |      XX.XXS   |  XX.XXS
PTU/MAIN BUS      XXX           |       XXX     |
----------------- PTU 1 ------------------ PTU 2 --------
OPCU            A          B    |   A           B
 OUT VOLTS  XX.XXS    XX.XXS    | XX.XXS     XX.XXS
      AMPS  XX.XS     XX.XS     | XX.XS      XX.XS
  TEMP      XXXS      XXXS      | XXXS       XXXS
  TRIP      XX XX     XX XX     | XX XX      XX XX
            XX XX     XX XX     | XX XX      XX XX
           XXX XX    XXX XX     |XXX XX     XXX XX
           XXX XX    XXX XX     |XXX XX     XXX XX
---------------------------------------------------------
APCU                            |
 OUT VOLTS       XXX.XS         |      XXX.XS
      AMPS        XX.XS         |       XX.XS
  IN AMPS         XX.XS         |       XX.XS
  TEMP            XXXS          |       XXXS
  OUTPUT          XXX           |       XXX
  TRIP      XX XX    XXX XX     | XX XX     XXX XX
           XXX XX    XXX XX     |XXX XX     XXX XX
                                                    (XX)
```

(D) POWER TRANSFER



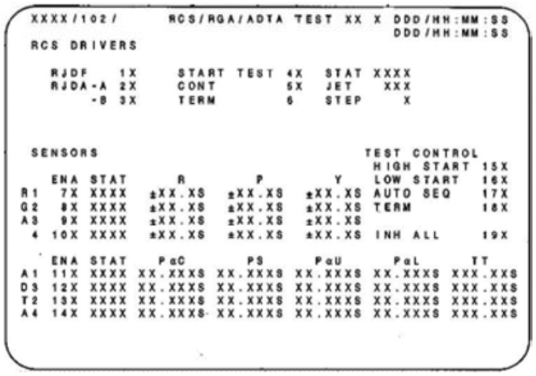
```
XXXX/XXX/089     PRPLT THERMAL    XX X DDD/HH:MM:SS
       POD           L    R  |                 DDD/HH:MM:SS
OMS TK          OX XXXS XXXS |
                FU XXXS XXXS |  OMS CRSFD   L    R    C
ENG I/F         OX XXXS XXXS | XFD       OX XXXS XXXS XXXS
                FU XXXS XXXS |      GMBL LN XXXS XXXS
          OX VLV   XXXS XXXS | DRN       OX XXXS XXXS
          FU INJ   XXXS XXXS |
                             |
WEB KEEL         1 XXXS XXXS |
                 2 XXXS XXXS |
     Y          OB XXXS XXXS |
                UP XXXS XXXS |
OX DRN PNL       1 XXXS XXXS |-------------------------------
                 2 XXXS XXXS |  FWD RCS        FU   OX
ENG       COVER    XXXS XXXS |      LINE T1 XXXS XXXS
     SERV PNL      XXXS XXXS |           T2 XXXS XXXS
GSE  SERV PNL      XXXS XXXS |-------------------------------
TEST HE/OX       1 XXXS XXXS |  AFT RCS        L    R
                 2 XXXS XXXS | MANF 1    OX XXXS XXXS
                             | DRN PNL    1 XXXS XXXS
                             |            2 XXXS XXXS
                             | VERN PNL   1 XXXS XXXS
                             |            2 XXXS XXXS
                                                      (XX)
```

(A) PRPLT THERMAL



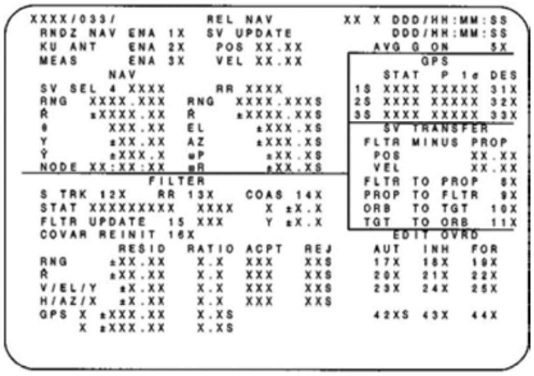
```
XXXX/023/                RCS             XX X DDD/HH:MM:SS
                                              DDD/HH:MM:SS
F 1X| 4 PRI FAIL LIM   X|L OMS→ |R OMS→ |
L 2X|                   |AFT  5X|AFT  6X|OMS→RCS QTY
R 3X|51 AUT MANF CL XXX |FWD 46X|FWD 47X|49L  XX.XXS
                        |    OFF   7X   |50R  XX.XXS
 JET|FAIL|DES|JET|PTY   | 48 PRESS XXX  |
    |    |INH|DES|                     |OXID |FU
 XXX| XXX| 8X| 9X| X      HE          P|XXXXS|XXXXS
  XX| XXX|10X|11X| X      PRPLT TK    P| XXXS| XXXS
Y XX| XXX|12X|13X| X                  T| XXXS| XXXS
  XX| XXX|14X|15X| X                QTY| XXXS| XXXS
 XXU| XXX|16X|17X| X      MANF P      1| XXXS| XXXS
  XU| XXX|18X|19X| X                  2| XXXS| XXXS
Z XU| XXX|20X|21X| X                  3| XXXS| XXXS
 XXX| XXX|22X|23X| X                  4| XXXS| XXXS
  XD| XXX|24X|25X| X      MANF VLVS    | STAT|OVRD
  2D| XXX|26X|27X| X                  1|  XXS| 40
  XD| XXX|28X|29X| X                  2|  XXS| 41
 XXX| XXX|30X|31X| X                  3|  XXS| 42
X XX| XXX|32X|33X| X                  4|  XXS| 43
  XX| XXX|34X|35X| X                  5|  XXS| 44
 X5X| XXX|36X|37X| X      XXX XFD P     XXXS   XXXS
V 5X| XXX|38X|39X| X      JET RESET 45
```

(B) RCS



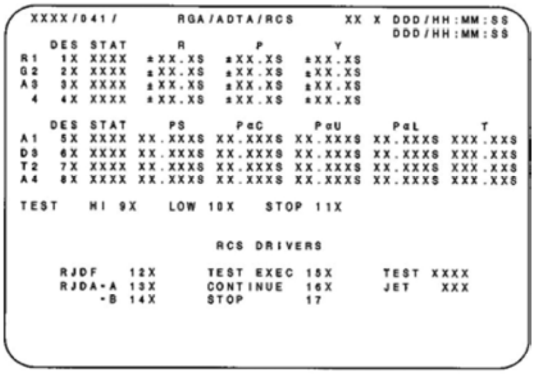
```
XXXX/102/      RCS/RGA/ADTA TEST XX X DDD/HH:MM:SS
                                      DDD/HH:MM:SS
RCS DRIVERS

  RJDF    1X    START TEST 4X   STAT XXXX
  RJDA-A  2X    CONT       5X   JET   XXX
      -B  3X    TERM       6    STEP    X


SENSORS                                 TEST CONTROL
                                         HIGH START  15X
    ENA STAT    R        P        Y      LOW START   16X
R1   7X XXXX  ±XX.XS   ±XX.XS   ±XX.XS  AUTO SEQ     17X
G2   8X XXXX  ±XX.XS   ±XX.XS   ±XX.XS  TERM         18X
A3   9X XXXX  ±XX.XS   ±XX.XS   ±XX.XS
 4  10X XXXX  ±XX.XS   ±XX.XS   ±XX.XS  INH ALL      19X

    ENA STAT   PαC      PS       PαU      PαL      TT
A1  11X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
D3  12X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
T2  13X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
A4  14X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
```

(C) RCS/RGA/ADTA TEST



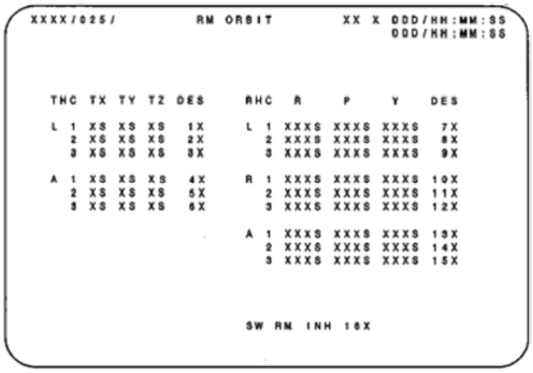
```
XXXX/033/             REL NAV          XX X DDD/HH:MM:SS
 RNDZ NAV ENA 1X    SV UPDATE               DDD/HH:MM:SS
 KU ANT   ENA 2X     POS XX.XX           AVG G ON     5X
 MEAS     ENA 3X     VEL XX.XX         |      GPS
        NAV                            |   STAT  P 1σ DES
 SV SEL 4 XXXX        RR XXXX          |1S XXXX XXXXX 31X
 RNG   XXXX.XXX   RNG   XXXX.XXXS      |2S XXXX XXXXX 32X
 Ṙ     ±XXXX.XX   Ṙ    ±XXXX.XXS       |3S XXXX XXXXX 33X
 θ       XXX.XX   EL      ±XXX.XS      |   SV TRANSFER
 Y       ±XX.XX   AZ      ±XXX.XS      | FLTR MINUS PROP
 Ẏ       ±XXX.X   ωP       ±XX.XS      |  POS        XX.XX
 NODE XX:XX:XX    ωR       ±XX.XS      |  VEL        XX.XX
              FILTER                   | FLTR TO PROP   8X
 S TRK 12X    RR 13X     COAS 14X      | PROP TO FLTR   9X
 STAT XXXXXXXXX   XXXX     X ±X.X      | ORB  TO TGT   10X
 FLTR UPDATE  15 XXX       Y ±X.X      | TGT  TO ORB   11X
 COVAR REINIT 16X                          EDIT OVRD
          RESID   RATIO ACPT   REJ      AUT   INH   FOR
 RNG     ±XX.XX    X.X  XXX    XXS      17X   18X   19X
 Ṙ       ±XX.XX    X.X  XXX    XXS      20X   21X   22X
 V/EL/Y   ±X.XX    X.X  XXX    XXS      23X   24X   25X
 H/AZ/X   ±X.XX    X.X  XXX    XXS
 GPS X ±XXX.XX     X.XS                 42XS  43X   44X
     X ±XXX.XX     X.XS
```

(D) REL NAV



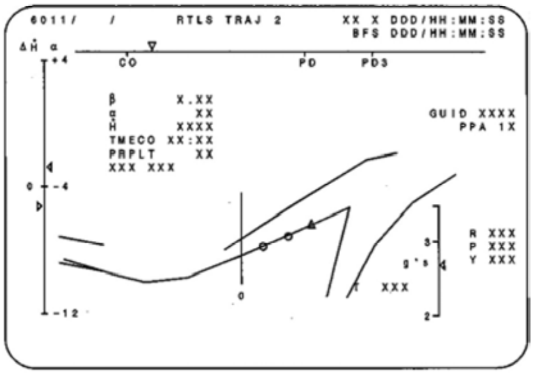
```
XXXX/041/        RGA/ADTA/RCS      XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
   DES STAT     R        P        Y
R1  1X XXXX  ±XX.XS   ±XX.XS   ±XX.XS
G2  2X XXXX  ±XX.XS   ±XX.XS   ±XX.XS
A3  3X XXXX  ±XX.XS   ±XX.XS   ±XX.XS
 4  4X XXXX  ±XX.XS   ±XX.XS   ±XX.XS

   DES STAT   PS       PαC      PαU      PαL      T
A1  5X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
D3  6X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
T2  7X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
A4  8X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS

TEST    HI 9X    LOW 10X    STOP 11X


                   RCS DRIVERS

   RJDF    12X      TEST EXEC 15X     TEST XXXX
   RJDA-A  13X      CONTINUE  16X     JET   XXX
       -B  14X      STOP      17
```

(A) RGA/ADTA/RCS (ON-ORBIT)



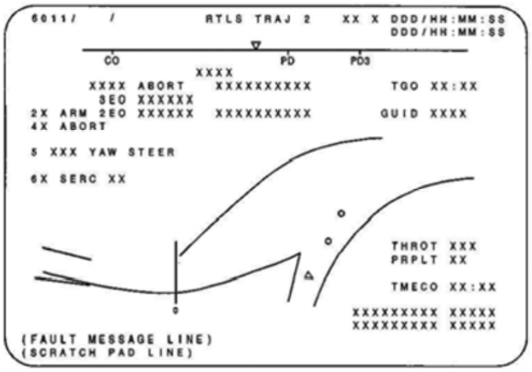
```
XXXX/025/          RM ORBIT        XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS



  THC TX TY TZ DES     RHC  R    P    Y   DES

  L 1 XS XS XS  1X     L 1 XXXS XXXS XXXS  7X
    2 XS XS XS  2X       2 XXXS XXXS XXXS  8X
    3 XS XS XS  3X       3 XXXS XXXS XXXS  9X

  A 1 XS XS XS  4X     R 1 XXXS XXXS XXXS 10X
    2 XS XS XS  5X       2 XXXS XXXS XXXS 11X
    3 XS XS XS  6X       3 XXXS XXXS XXXS 12X

                       A 1 XXXS XXXS XXXS 13X
                         2 XXXS XXXS XXXS 14X
                         3 XXXS XXXS XXXS 15X



                       SW RM INH 16X
```

(B) RM ORBIT



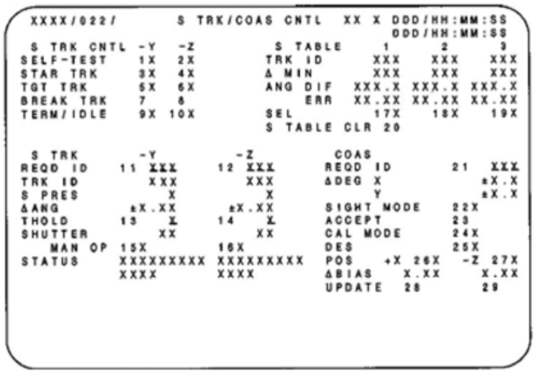
```
6011/    /        RTLS TRAJ 2      XX X DDD/HH:MM:SS
                                    BFS DDD/HH:MM:SS
ΔḢ α
     +4   CO                   PD     PD3

          β         X.XX
          α           XX                      GUID XXXX
          Ḣ         XXXX                          PPA 1X
          TMECO    XX:XX
          PRPLT       XX
          XXX XXX
0   -4



                                                   R XXX
                                              3    P XXX
                                            g's    Y XXX
                        0                T   XXX
    -12
                                              2
```

(C) RTLS TRAJ 2 (BFS)



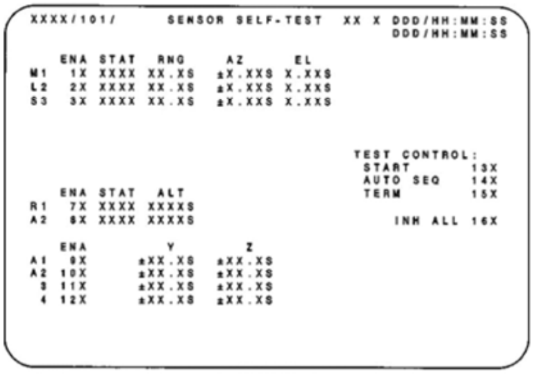
```
6011/    /            RTLS TRAJ 2   XX X DDD/HH:MM:SS
                                         DDD/HH:MM:SS

       CO                PD      PD3
                 XXXX
       XXXX ABORT    XXXXXXXXXX          TGO XX:XX
            3EO XXXXXX
2X ARM 2EO XXXXXX    XXXXXXXXXX         GUID XXXX
4X ABORT

5 XXX YAW STEER

6X SERC XX



                                       THROT XXX
                                       PRPLT XX

                                       TMECO XX:XX
                  0
                                   XXXXXXXXX XXXXX
                                   XXXXXXXXX XXXXX
(FAULT MESSAGE LINE)
(SCRATCH PAD LINE)
```

(D) RTLS TRAJ 2 (PASS)



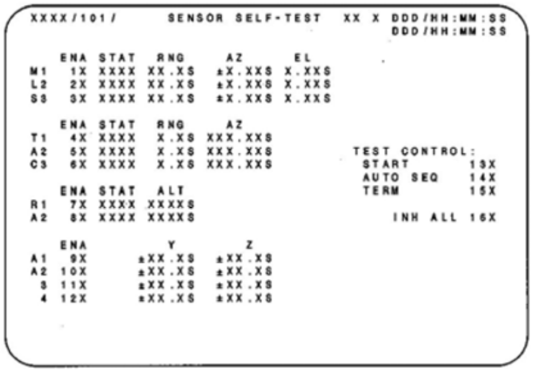
```
XXXX/022/        S TRK/COAS CNTL   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
 S TRK CNTL -Y   -Z         S TABLE     1      2      3
SELF-TEST    1X   2X        TRK ID     XXX    XXX    XXX
STAR TRK     3X   4X        Δ MIN      XXX    XXX    XXX
TGT TRK      5X   6X        ANG DIF  XXX.X  XXX.X  XXX.X
BREAK TRK    7    8             ERR  XX.XX  XX.XX  XX.XX
TERM/IDLE    9X  10X        SEL        17X    18X    19X
                            S TABLE CLR 20

 S TRK          -Y         -Z         COAS
REQD ID     11 XXX     12 XXX      REQD ID      21  XXX
TRK ID         XXX        XXX      ΔDEG X           ±X.X
S PRES           X          X           Y           ±X.X
ΔANG         ±X.XX      ±X.XX      SIGHT MODE   22X
THOLD       13   X     14   X      ACCEPT       23
SHUTTER         XX         XX      CAL MODE     24X
   MAN OP   15X        16X         DES          25X
STATUS      XXXXXXXXX XXXXXXXXX    POS    +X 26X   -Z 27X
            XXXX      XXXX         ΔBIAS   X.XX      X.XX
                                   UPDATE  28        29
```

(A) S TRK/COAS CNTL



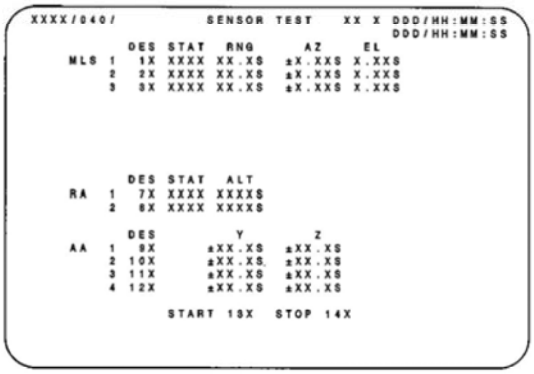
```
XXXX/101/       SENSOR SELF-TEST  XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS

    ENA STAT  RNG     AZ      EL
M1   1X XXXX XX.XS  ±X.XXS X.XXS
L2   2X XXXX XX.XS  ±X.XXS X.XXS
S3   3X XXXX XX.XS  ±X.XXS X.XXS



                                  TEST CONTROL:
                                   START        13X
                                   AUTO SEQ     14X
    ENA STAT  ALT                  TERM         15X
R1   7X XXXX XXXXS
A2   8X XXXX XXXXS                      INH ALL 16X

    ENA         Y       Z
A1   9X      ±XX.XS  ±XX.XS
A2  10X      ±XX.XS  ±XX.XS
 3  11X      ±XX.XS  ±XX.XS
 4  12X      ±XX.XS  ±XX.XS
```

(B) SENSOR SELF-TEST (3 GPS)



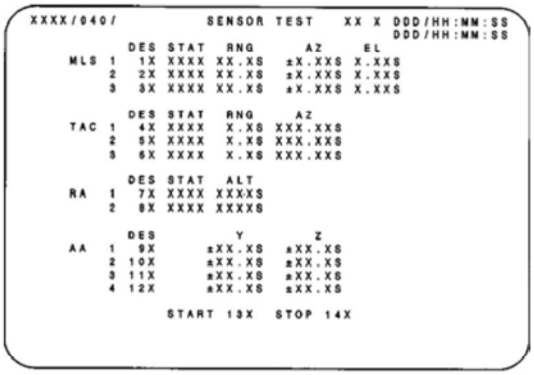
```
XXXX/101/       SENSOR SELF-TEST  XX X DDD/HH:MM:SS
                                       DDD/HH:MM:SS

    ENA STAT  RNG     AZ      EL
M1   1X XXXX XX.XS  ±X.XXS X.XXS
L2   2X XXXX XX.XS  ±X.XXS X.XXS
S3   3X XXXX XX.XS  ±X.XXS X.XXS

    ENA STAT  RNG    AZ
T1   4X XXXX  X.XS XXX.XXS
A2   5X XXXX  X.XS XXX.XXS         TEST CONTROL:
C3   6X XXXX  X.XS XXX.XXS          START        13X
                                    AUTO SEQ     14X
    ENA STAT  ALT                   TERM         15X
R1   7X XXXX XXXXS
A2   8X XXXX XXXXS                       INH ALL 16X

    ENA         Y       Z
A1   9X      ±XX.XS  ±XX.XS
A2  10X      ±XX.XS  ±XX.XS
 3  11X      ±XX.XS  ±XX.XS
 4  12X      ±XX.XS  ±XX.XS
```

(C) SENSOR SELF-TEST (3 TACANS)



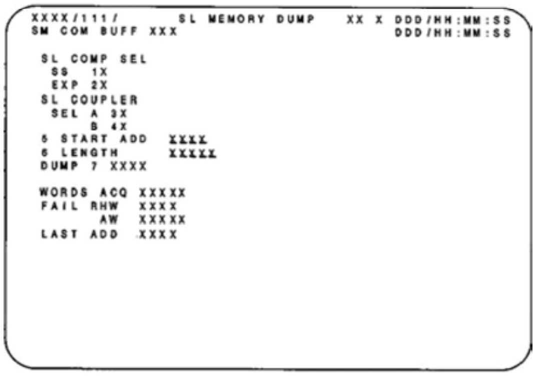
```
XXXX/040/            SENSOR TEST   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
           DES STAT  RNG      AZ     EL
    MLS 1   1X XXXX XX.XS  ±X.XXS X.XXS
        2   2X XXXX XX.XS  ±X.XXS X.XXS
        3   3X XXXX XX.XS  ±X.XXS X.XXS




           DES STAT  ALT
    RA  1   7X XXXX XXXXS
        2   8X XXXX XXXXS

           DES           Y        Z
    AA  1   9X        ±XX.XS   ±XX.XS
        2  10X        ±XX.XS   ±XX.XS
        3  11X        ±XX.XS   ±XX.XS
        4  12X        ±XX.XS   ±XX.XS
                START 13X  STOP 14X
```

(D) SENSOR TEST (ON-ORBIT, 3 GPS)



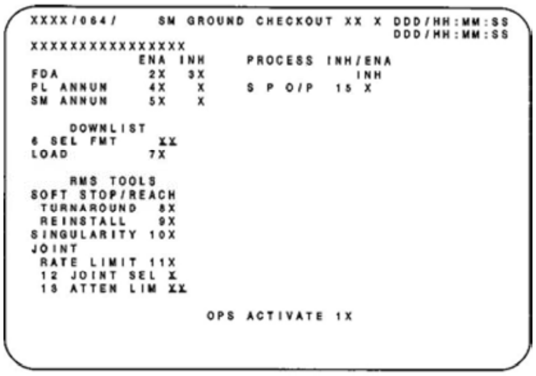
```
XXXX/040/            SENSOR TEST   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
           DES STAT  RNG      AZ     EL
    MLS 1   1X XXXX XX.XS  ±X.XXS X.XXS
        2   2X XXXX XX.XS  ±X.XXS X.XXS
        3   3X XXXX XX.XS  ±X.XXS X.XXS

           DES STAT  RNG     AZ
    TAC 1   4X XXXX  X.XS XXX.XXS
        2   5X XXXX  X.XS XXX.XXS
        3   6X XXXX  X.XS XXX.XXS

           DES STAT  ALT
    RA  1   7X XXXX XXXXS
        2   8X XXXX XXXXS

           DES           Y        Z
    AA  1   9X        ±XX.XS   ±XX.XS
        2  10X        ±XX.XS   ±XX.XS
        3  11X        ±XX.XS   ±XX.XS
        4  12X        ±XX.XS   ±XX.XS

               START 13X  STOP 14X
```

(A) SENSOR TEST (ON-ORBIT, 3 TACAN)



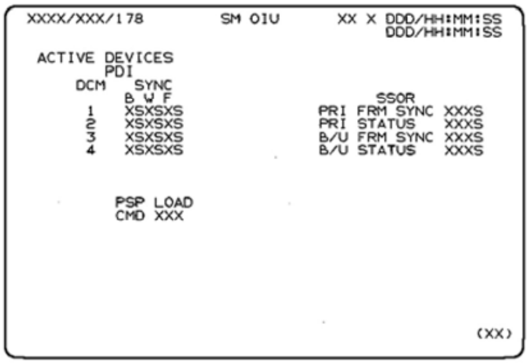
```
XXXX/111/        SL MEMORY DUMP    XX X DDD/HH:MM:SS
SM COM BUFF XXX                         DDD/HH:MM:SS

 SL COMP SEL
  SS  1X
  EXP 2X
 SL COUPLER
  SEL A 3X
      B 4X
 5 START ADD   XXXX
 6 LENGTH      XXXXX
 DUMP 7 XXXX

 WORDS ACQ XXXXX
 FAIL RHW  XXXX
       AW  XXXXX
 LAST ADD  XXXX
```

(B) SL MEMORY DUMP



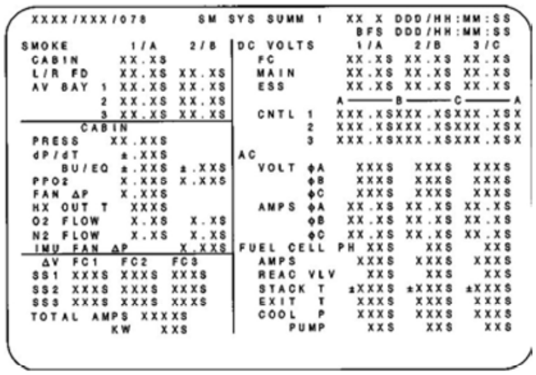
```
XXXX/064/     SM GROUND CHECKOUT XX X DDD/HH:MM:SS
                                      DDD/HH:MM:SS
XXXXXXXXXXXXXXXX
              ENA INH     PROCESS INH/ENA
FDA            2X  3X                INH
PL ANNUN       4X   X     S P O/P  15 X
SM ANNUN       5X   X

    DOWNLIST
6 SEL FMT      XX
LOAD           7X

    RMS TOOLS
SOFT STOP/REACH
 TURNAROUND   8X
 REINSTALL    9X
SINGULARITY 10X
JOINT
 RATE LIMIT 11X
 12 JOINT SEL X
 13 ATTEN LIM XX

                 OPS ACTIVATE 1X
```

(C) SM GROUND CHECKOUT



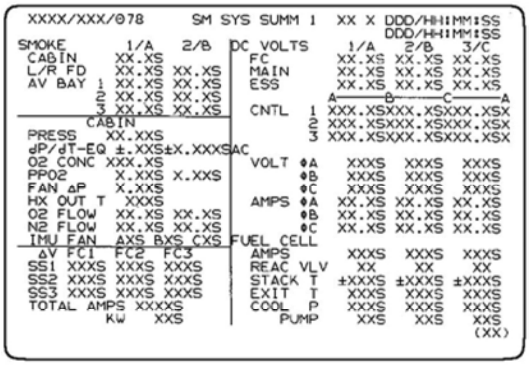
```
XXXX/XXX/178         SM OIU        XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS

 ACTIVE DEVICES
        PDI
   DCM   SYNC
         B W F                        SSOR
    1    XSXSXS              PRI FRM SYNC  XXXS
    2    XSXSXS              PRI STATUS    XXXS
    3    XSXSXS              B/U FRM SYNC  XXXS
    4    XSXSXS              B/U STATUS    XXXS


         PSP LOAD
         CMD XXX





                                              (XX)
```

(D) SM OIU



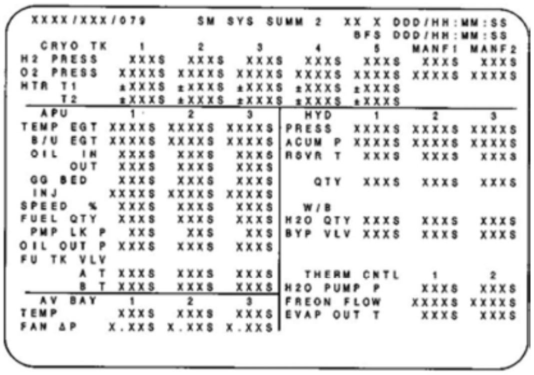
```
XXXX/XXX/078        SM SYS SUMM 1   XX X DDD/HH:MM:SS
                                     BFS DDD/HH:MM:SS
SMOKE        1/A    2/B  |DC VOLTS      1/A    2/B    3/C
 CABIN      XX.XS        |  FC         XX.XS  XX.XS  XX.XS
 L/R FD     XX.XS  XX.XS |  MAIN       XX.XS  XX.XS  XX.XS
 AV BAY  1  XX.XS  XX.XS |  ESS        XX.XS  XX.XS  XX.XS
         2  XX.XS  XX.XS |            A------B------C------A
         3  XX.XS  XX.XS |  CNTL   1  XXX.XSXXX.XSXXX.XSX
        CABIN            |         2  XXX.XSXXX.XSXXX.XSX
 PRESS    XX.XXS         |         3  XXX.XSXXX.XSXXX.XSX
 dP/dT      ±.XXS        |AC
    BU/EQ   ±.XXS  ±.XXS |  VOLT  ϕA    XXXS   XXXS   XXXS
 PPO2       X.XXS  X.XXS |        ϕB    XXXS   XXXS   XXXS
 FAN ΔP     X.XXS        |        ϕC    XXXS   XXXS   XXXS
 HX OUT T    XXXS        |  AMPS  ϕA   XX.XS  XX.XS  XX.XS
 O2 FLOW     X.XS   X.XS |        ϕB   XX.XS  XX.XS  XX.XS
 N2 FLOW     X.XS   X.XS |        ϕC   XX.XS  XX.XS  XX.XS
 IMU FAN ΔP         X.XXS|FUEL CELL PH XXS     XXS    XXS
  ΔV  FC1  FC2  FC3      |  AMPS        XXXS   XXXS   XXXS
 SS1  XXXS XXXS XXXS     |  REAC VLV     XXS    XXS    XXS
 SS2  XXXS XXXS XXXS     |  STACK T    ±XXXS  ±XXXS  ±XXXS
 SS3  XXXS XXXS XXXS     |  EXIT  T     XXXS   XXXS   XXXS
 TOTAL AMPS XXXXS        |  COOL  P     XXXS   XXXS   XXXS
           KW   XXS      |     PUMP      XXS    XXS    XXS
```

(A) SM SYS SUMM 1 (BFS)



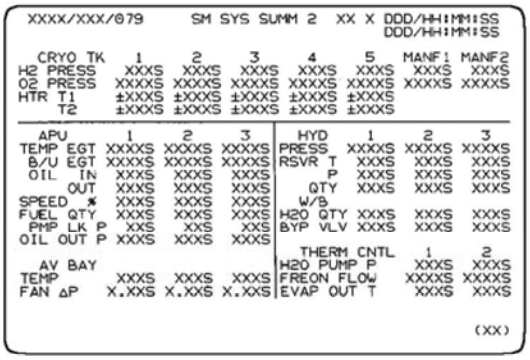
```
XXXX/XXX/078       SM SYS SUMM 1  XX X DDD/HH:MM:SS
                                      DDD/HH:MM:SS
SMOKE       1/A    2/B  |DC VOLTS     1/A    2/B    3/C
 CABIN     XX.XS        |  FC        XX.XS  XX.XS  XX.XS
 L/R FD    XX.XS  XX.XS |  MAIN      XX.XS  XX.XS  XX.XS
 AV BAY  1 XX.XS  XX.XS |  ESS       XX.XS  XX.XS  XX.XS
         2 XX.XS  XX.XS |          A------B------C------A
         3 XX.XS  XX.XS |  CNTL   1 XXX.XSXXX.XSXXX.XSX
        CABIN           |         2 XXX.XSXXX.XSXXX.XSX
 PRESS    XX.XXS        |         3 XXX.XSXXX.XSXXX.XSX
 dP/dT-EQ ±.XXS±X.XXXS  AC
 O2 CONC  XXX.XS        |  VOLT ϕA    XXXS   XXXS   XXXS
 PPO2      X.XXS  X.XXS |       ϕB    XXXS   XXXS   XXXS
 FAN ΔP    X.XXS        |       ϕC    XXXS   XXXS   XXXS
 HX OUT T   XXXS        |  AMPS ϕA   XX.XS  XX.XS  XX.XS
 O2 FLOW   XX.XS  XX.XS |       ϕB   XX.XS  XX.XS  XX.XS
 N2 FLOW   XX.XS  XX.XS |       ϕC   XX.XS  XX.XS  XX.XS
 IMU FAN   AXS BXS CXS  FUEL CELL
  ΔV  FC1  FC2  FC3     |  AMPS       XXXS   XXXS   XXXS
 SS1 XXXS XXXS XXXS     |  REAC VLV    XX     XX     XX
 SS2 XXXS XXXS XXXS     |  STACK T   ±XXXS  ±XXXS  ±XXXS
 SS3 XXXS XXXS XXXS     |  EXIT  T    XXXS   XXXS   XXXS
 TOTAL AMPS XXXXS       |  COOL  P    XXXS   XXXS   XXXS
          KW   XXS      |     PUMP     XXS    XXS    XXS
                                                  (XX)
```

(B) SM SYS SUMM 1 (PASS)



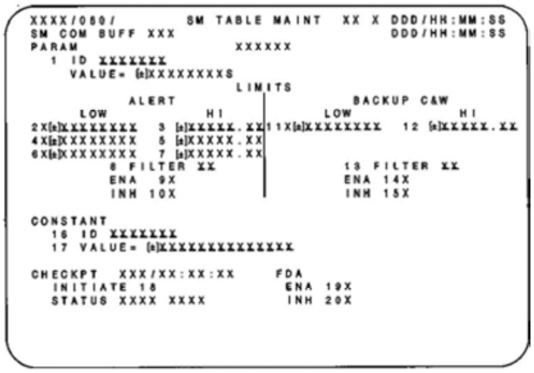
```
XXXX/XXX/079        SM SYS SUMM 2   XX X DDD/HH:MM:SS
                                     BFS DDD/HH:MM:SS
  CRYO TK      1      2      3      4      5    MANF1  MANF2
H2 PRESS     XXXS   XXXS   XXXS   XXXS   XXXS   XXXS   XXXS
O2 PRESS    XXXXS  XXXXS  XXXXS  XXXXS  XXXXS  XXXXS  XXXXS
HTR T1      ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS
    T2      ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS
  APU          1      2      3  |  HYD      1      2      3
TEMP EGT   XXXXS  XXXXS  XXXXS  |PRESS   XXXXS  XXXXS  XXXXS
 B/U EGT   XXXXS  XXXXS  XXXXS  |ACUM P  XXXXS  XXXXS  XXXXS
 OIL  IN    XXXS   XXXS   XXXS  |RSVR T   XXXS   XXXS   XXXS
     OUT    XXXS   XXXS   XXXS  |
 GG BED     XXXS   XXXS   XXXS  |    QTY  XXXS   XXXS   XXXS
 INJ       XXXXS  XXXXS  XXXXS  |
SPEED  %    XXXS   XXXS   XXXS  |  W/B
FUEL QTY    XXXS   XXXS   XXXS  |H2O QTY  XXXS   XXXS   XXXS
 PMP LK P    XXS    XXS    XXS  |BYP VLV  XXXS   XXXS   XXXS
OIL OUT P   XXXS   XXXS   XXXS  |
FU TK VLV                       |
       A T  XXXS   XXXS   XXXS  |  THERM CNTL     1      2
       B T  XXXS   XXXS   XXXS  |H2O PUMP P     XXXS   XXXS
  AV BAY     1      2      3    |FREON FLOW    XXXXS  XXXXS
TEMP        XXXS   XXXS   XXXS  |EVAP OUT T     XXXS   XXXS
FAN ΔP     X.XXS  X.XXS  X.XXS  |
```

(C) SM SYS SUMM 2 (BFS)



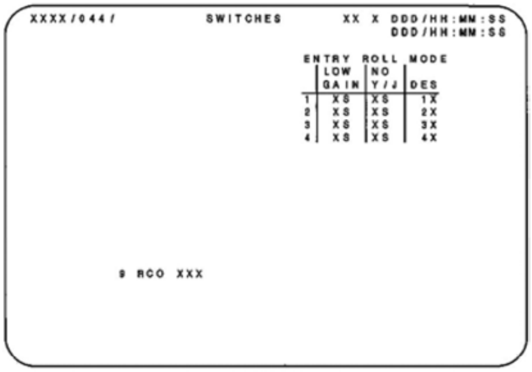
```
XXXX/XXX/079       SM SYS SUMM 2  XX X DDD/HH:MM:SS
                                      DDD/HH:MM:SS

  CRYO TK     1     2     3     4     5   MANF1 MANF2
H2 PRESS    XXXS  XXXS  XXXS  XXXS  XXXS  XXXS  XXXS
O2 PRESS   XXXXS XXXXS XXXXS XXXXS XXXXS XXXXS XXXXS
HTR T1     ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
    T2     ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS

  APU         1     2     3  |  HYD      1     2     3
TEMP EGT  XXXXS XXXXS XXXXS  |PRESS   XXXXS XXXXS XXXXS
 B/U EGT  XXXXS XXXXS XXXXS  |RSVR T   XXXS  XXXS  XXXS
 OIL  IN   XXXS  XXXS  XXXS  |       P XXXS  XXXS  XXXS
     OUT   XXXS  XXXS  XXXS  |     QTY XXXS  XXXS  XXXS
SPEED  %   XXXS  XXXS  XXXS  |  W/B
FUEL QTY   XXXS  XXXS  XXXS  |H2O QTY  XXXS  XXXS  XXXS
 PMP LK P   XXS   XXS   XXS  |BYP VLV  XXXS  XXXS  XXXS
OIL OUT P  XXXS  XXXS  XXXS  |
                             |  THERM CNTL    1     2
  AV BAY                     |H2O PUMP P    XXXS  XXXS
TEMP       XXXS  XXXS  XXXS  |FREON FLOW   XXXXS XXXXS
FAN ΔP    X.XXS X.XXS X.XXS  |EVAP OUT T    XXXS  XXXS

                                                 (XX)
```

(D) SM SYS SUMM 2 (PASS)



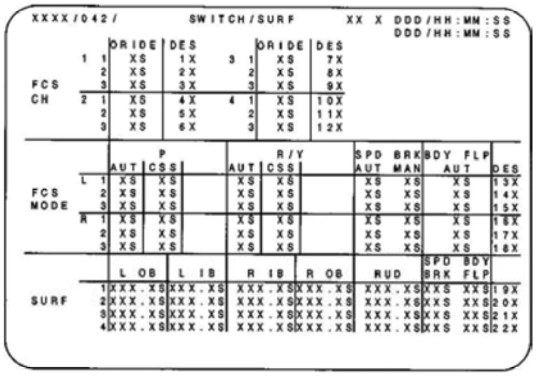
```
XXXX/060/          SM TABLE MAINT   XX X DDD/HH:MM:SS
SM COM BUFF XXX                          DDD/HH:MM:SS
PARAM                        XXXXXX
  1 ID XXXXXXX
    VALUE= [±]XXXXXXXXS
                             LIMITS
             ALERT                |           BACKUP C&W
     LOW                HI        |       LOW               HI
2X[±]XXXXXXXX   3 [±]XXXXX.XX|11X[±]XXXXXXXX   12 [±]XXXXX.XX
4X[±]XXXXXXXX   5 [±]XXXXX.XX|
6X[±]XXXXXXXX   7 [±]XXXXX.XX|
          8 FILTER XX        |           13 FILTER XX
          ENA  9X            |           ENA 14X
          INH 10X            |           INH 15X

CONSTANT
  16 ID XXXXXXX
  17 VALUE= [±]XXXXXXXXXXXXXX

CHECKPT  XXX/XX:XX:XX      FDA
  INITIATE 18               ENA 19X
  STATUS XXXX XXXX          INH 20X
```

(A) SM TABLE MAINT



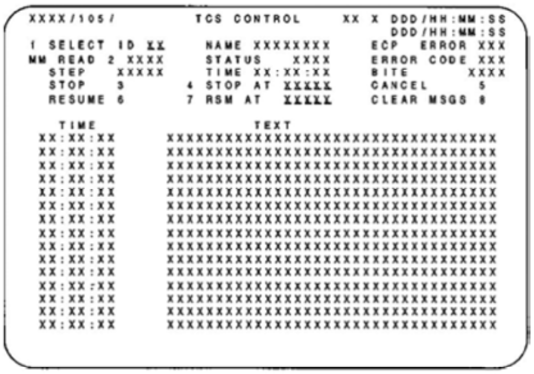
```
XXXX/044/             SWITCHES          XX X DDD/HH:MM:SS
                                             DDD/HH:MM:SS

                                  ENTRY ROLL MODE
                                   |LOW  |NO  |
                                   |GAIN |Y/J |DES
                                  1|  XS |XS  |  1X
                                  2|  XS |XS  |  2X
                                  3|  XS |XS  |  3X
                                  4|  XS |XS  |  4X





         9 RCO XXX
```

(B) SWITCHES



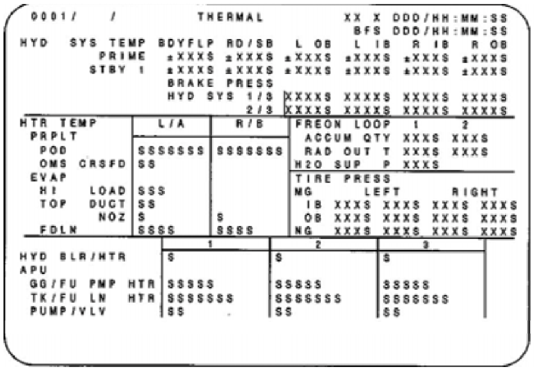
```
XXXX/042/             SWITCH/SURF        XX X DDD/HH:MM:SS
                                              DDD/HH:MM:SS
           |ORIDE|DES          |ORIDE|DES
       1  1|  XS |  1X    3   1|  XS |  7X
          2|  XS |  2X        2|  XS |  8X
FCS       3|  XS |  3X        3|  XS |  9X
CH     2  1|  XS |  4X    4   1|  XS | 10X
          2|  XS |  5X        2|  XS | 11X
          3|  XS |  6X        3|  XS | 12X
           |       P        |      R/Y      |SPD BRK|BDY FLP|
           |AUT|CSS|        |AUT|CSS|       |AUT MAN|  AUT  |DES
       L  1| XS| XS|        | XS| XS|       | XS  XS|   XS  |13X
FCS       2| XS| XS|        | XS| XS|       | XS  XS|   XS  |14X
MODE      3| XS| XS|        | XS| XS|       | XS  XS|   XS  |15X
       R  1| XS| XS|        | XS| XS|       | XS  XS|   XS  |16X
          2| XS| XS|        | XS| XS|       | XS  XS|   XS  |17X
          3| XS| XS|        | XS| XS|       | XS  XS|   XS  |18X
                                                    |SPD BDY|
           | L OB   | L IB   | R IB   | R OB   | RUD    |BRK FLP|
SURF      1|XXX.XS|XXX.XS| XXX.XS|XXX.XS| XXX.XS|XXS  XXS|19X
          2|XXX.XS|XXX.XS| XXX.XS|XXX.XS| XXX.XS|XXS  XXS|20X
          3|XXX.XS|XXX.XS| XXX.XS|XXX.XS| XXX.XS|XXS  XXS|21X
          4|XXX.XS|XXX.XS| XXX.XS|XXX.XS| XXX.XS|XXS  XXS|22X
```

(C) SWITCH/SURF



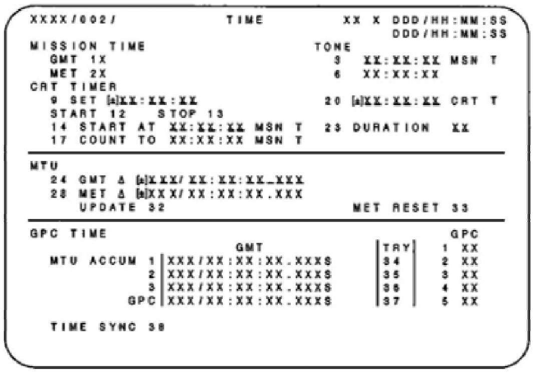
```
XXXX/105/           TCS CONTROL        XX X DDD/HH:MM:SS
                                            DDD/HH:MM:SS
1 SELECT ID XX       NAME XXXXXXXX      ECP  ERROR XXX
MM READ 2 XXXX       STATUS    XXXX     ERROR CODE XXX
  STEP   XXXXX       TIME XX:XX:XX      BITE      XXXX
  STOP   3         4 STOP AT XXXXX      CANCEL       5
  RESUME 6         7 RSM AT  XXXXX      CLEAR MSGS   8

   TIME                      TEXT
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 XX:XX:XX      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

(D) TCS CONTROL



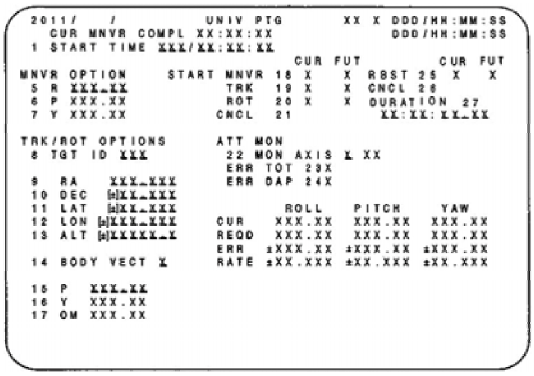
```
0001/     /            THERMAL           XX X DDD/HH:MM:SS
                                              BFS DDD/HH:MM:SS
HYD   SYS TEMP BDYFLP RD/SB  L OB   L IB   R IB   R OB
           PRIME  ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS
          STBY 1  ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS
                  BRAKE PRESS
                  HYD SYS 1/3 XXXXS  XXXXS  XXXXS  XXXXS
                          2/3 XXXXS  XXXXS  XXXXS  XXXXS
HTR TEMP     |   L/A   |   R/B   |FREON LOOP   1     2
 PRPLT       |         |         | ACCUM QTY XXXS  XXXS
  POD        |SSSSSSS  |SSSSSSS  | RAD OUT T XXXS  XXXS
  OMS CRSFD  |SS       |         |H2O SUP  P XXXS
 EVAP        |         |         |TIRE PRESS
  HI    LOAD |SSS      |         |MG      LEFT       RIGHT
  TOP   DUCT |SS       |         | IB  XXXS XXXS XXXS XXXS
         NOZ |S        |S        | OB  XXXS XXXS XXXS XXXS
  FDLN       |SSSS     |SSSS     |NG   XXXS XXXS XXXS XXXS
                        |     1     |     2     |     3     |
HYD BLR/HTR             |S          |S          |S          |
APU                     |           |           |           |
 GG/FU PMP HTR          |SSSSS      |SSSSS      |SSSSS      |
 TK/FU LN  HTR          |SSSSSSS    |SSSSSSS    |SSSSSSS    |
 PUMP/VLV               |SS         |SS         |SS         |
```

(A) THERMAL



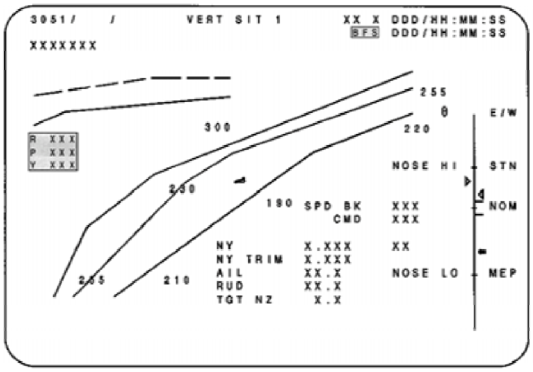
```
XXXX/002/              TIME            XX X DDD/HH:MM:SS
                                            DDD/HH:MM:SS
MISSION TIME                          TONE
  GMT 1X                                 3  XX:XX:XX MSN T
  MET 2X                                 6  XX:XX:XX
CRT TIMER
  9 SET [±]XX:XX:XX                   20 [±]XX:XX:XX CRT T
  START 12    STOP 13
  14 START AT XX:XX:XX MSN T   23 DURATION   XX
  17 COUNT TO XX:XX:XX MSN T
-----------------------------------------------------------
MTU
  24 GMT Δ [±]XXX/XX:XX:XX.XXX
  28 MET Δ [±]XXX/XX:XX:XX.XXX
     UPDATE 32                          MET RESET 33
-----------------------------------------------------------
GPC TIME                                           GPC
                        GMT                  |TRY|  1 XX
  MTU ACCUM 1|XXX/XX:XX:XX.XXXS              |34 |  2 XX
            2|XXX/XX:XX:XX.XXXS              |35 |  3 XX
            3|XXX/XX:XX:XX.XXXS              |36 |  4 XX
          GPC|XXX/XX:XX:XX.XXXS              |37 |  5 XX

  TIME SYNC 38
```

(B) TIME



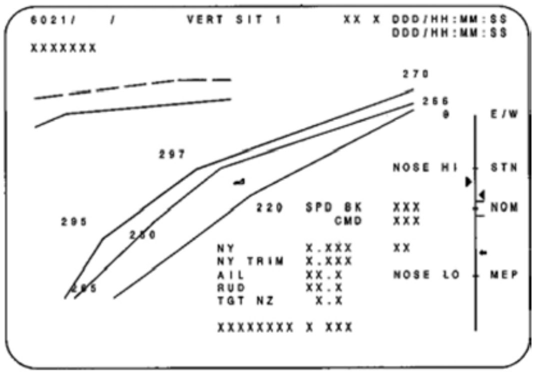
```
2011/     /          UNIV PTG         XX X DDD/HH:MM:SS
  CUR MNVR COMPL XX:XX:XX                  DDD/HH:MM:SS
 1 START TIME XXX/XX:XX:XX
                                 CUR FUT        CUR FUT
MNVR OPTION     START MNVR 18 X    X  RBST 25 X    X
 5 R XXX.XX           TRK  19 X    X  CNCL 26
 6 P XXX.XX           ROT  20 X    X  DURATION 27
 7 Y XXX.XX          CNCL  21              XX:XX:XX.XX

TRK/ROT OPTIONS      ATT MON
 8 TGT ID XXX         22 MON AXIS X XX
                      ERR TOT 23X
 9  RA    XXX.XXX     ERR DAP 24X
 10 DEC  [±]XX.XXX
 11 LAT  [±]XX.XXX               ROLL    PITCH     YAW
 12 LON [±]XXX.XXX   CUR     XXX.XX   XXX.XX   XXX.XX
 13 ALT [±]XXXXX.X   REQD    XXX.XX   XXX.XX   XXX.XX
                     ERR    ±XXX.XX  ±XXX.XX  ±XXX.XX
 14 BODY VECT X      RATE  ±XX.XXX  ±XX.XXX  ±XX.XXX

 15 P  XXX.XX
 16 Y  XXX.XX
 17 OM XXX.XX
```

(C) UNIV PTG



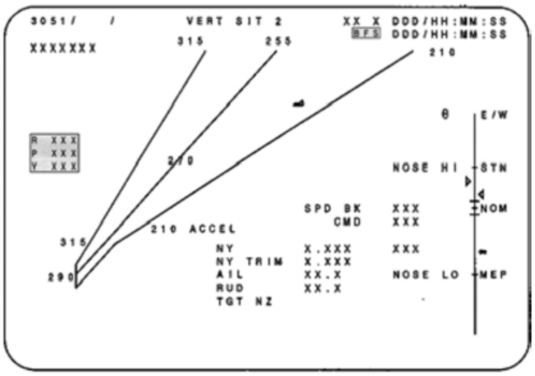
```
3051/     /        VERT SIT 1         XX X DDD/HH:MM:SS
                                       BFS DDD/HH:MM:SS
XXXXXXX

R XXX
P XXX
Y XXX
                            SPD BK    XXX
                               CMD    XXX

                   NY         X.XXX    XX
                   NY TRIM    X.XXX
                   AIL        XX.X
                   RUD        XX.X
                   TGT NZ      X.X
```

(D) VERT SIT 1 (PASS/BFS)



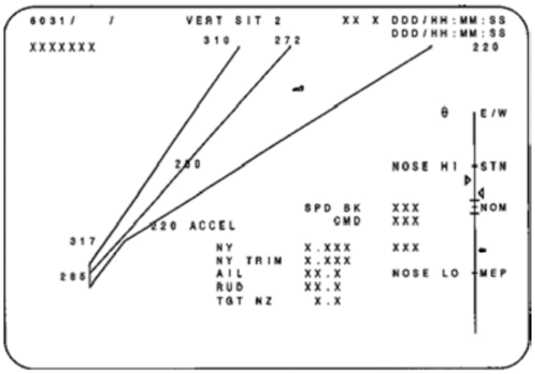
```
6021/     /        VERT SIT 1         XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS
XXXXXXX

                            SPD BK    XXX
                               CMD    XXX

                   NY         X.XXX    XX
                   NY TRIM    X.XXX
                   AIL        XX.X
                   RUD        XX.X
                   TGT NZ      X.X

                   XXXXXXXX X XXX
```

(A) VERT SIT 1 GRTLS



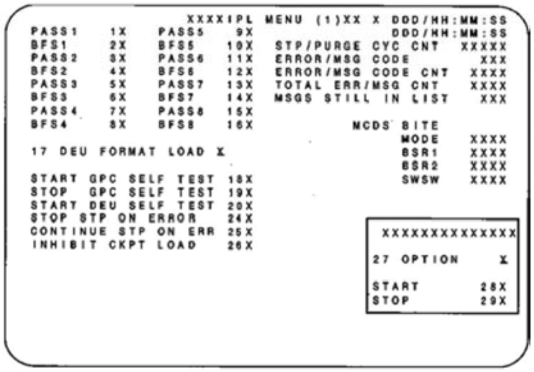
```
3051/     /        VERT SIT 2         XX X DDD/HH:MM:SS
                                       BFS DDD/HH:MM:SS
XXXXXXX

R XXX
P XXX
Y XXX
                            SPD BK    XXX
                               CMD    XXX

                   NY         X.XXX    XXX
                   NY TRIM    X.XXX
                   AIL        XX.X
                   RUD        XX.X
                   TGT NZ
```

(B) VERT SIT 2 (PASS/BFS)



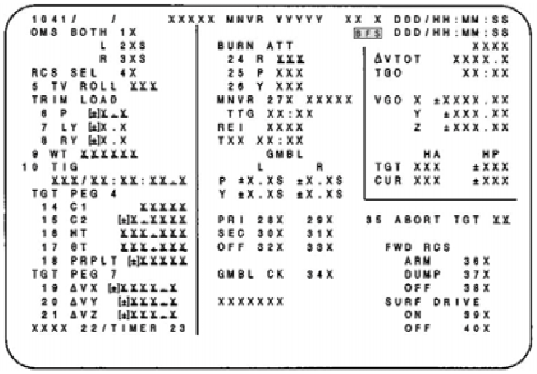
```
6031/     /        VERT SIT 2         XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS
XXXXXXX

                            SPD BK    XXX
                               CMD    XXX

                   NY         X.XXX    XXX
                   NY TRIM    X.XXX
                   AIL        XX.X
                   RUD        XX.X
                   TGT NZ      X.X
```

(C) VERT SIT 2 GRTLS



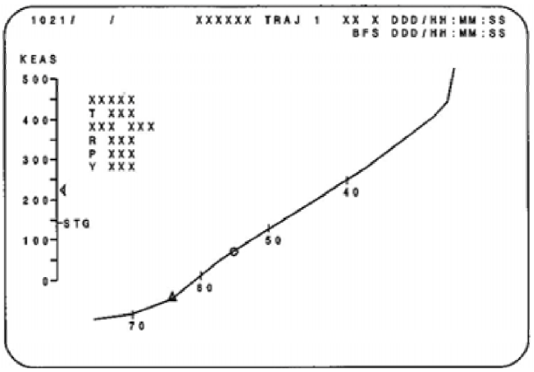
```
                   XXXXIPL MENU (1)XX X DDD/HH:MM:SS
PASS1   1X   PASS5    9X                DDD/HH:MM:SS
BFS1    2X   BFS5    10X  STP/PURGE CYC CNT  XXXXX
PASS2   3X   PASS6   11X  ERROR/MSG CODE       XXX
BFS2    4X   BFS6    12X  ERROR/MSG CODE CNT  XXXX
PASS3   5X   PASS7   13X  TOTAL ERR/MSG CNT   XXXX
BFS3    6X   BFS7    14X  MSGS STILL IN LIST   XXX
PASS4   7X   PASS8   15X
BFS4    8X   BFS8    16X           MCDS BITE
                                        MODE  XXXX
17 DEU FORMAT LOAD X                    BSR1  XXXX
                                        BSR2  XXXX
START GPC SELF TEST  18X                SWSW  XXXX
STOP  GPC SELF TEST  19X
START DEU SELF TEST  20X
STOP STP ON ERROR    24X           +---------------+
CONTINUE STP ON ERR  25X           | XXXXXXXXXXXXXX|
INHIBIT CKPT LOAD    26X           |27 OPTION     X|
                                   |               |
                                   |START       28X|
                                   |STOP        29X|
                                   +---------------+
```

(D) XXXX IPL MENU (1)



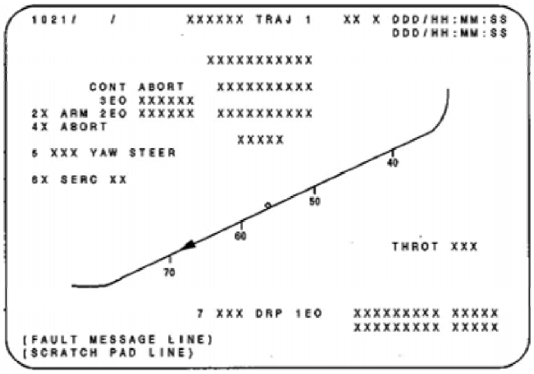
```
1041/     /       XXXXX MNVR YYYYY  XX X DDD/HH:MM:SS
OMS BOTH 1X                         BFS DDD/HH:MM:SS
        L 2XS      BURN ATT                  XXXX
        R 3XS       24 R XXX      ΔVTOT    XXXX.X
RCS SEL   4X        25 P XXX      TGO       XX:XX
5 TV ROLL XXX       26 Y XXX
TRIM LOAD          MNVR 27X XXXXX VGO X ±XXXX.XX
 6 P  [±]X.X        TTG XX:XX         Y  ±XXX.XX
 7 LY [±]X.X       REI   XXXX         Z  ±XXX.XX
 8 RY [±]X.X       TXX XX:XX
9 WT XXXXXX             GMBL           HA      HP
10 TIG                 L        R  TGT XXX    ±XXX
  XXX/XX:XX:XX.X   P ±X.XS ±X.XS   CUR XXX    ±XXX
TGT PEG 4          Y ±X.XS ±X.XS
 14 C1      XXXXX
 15 C2  [±]X.XXXX  PRI  28X  29X   35 ABORT TGT XX
 16 HT   XXX.XXX   SEC  30X  31X
 17 θT   XXX.XXX   OFF  32X  33X     FWD RCS
 18 PRPLT [±]XXXXX                      ARM    36X
TGT PEG 7          GMBL CK  34X         DUMP   37X
 19 ΔVX [±]XXXX.X                       OFF    38X
 20 ΔVY  [±]XXX.X  XXXXXXX             SURF DRIVE
 21 ΔVZ  [±]XXX.X                       ON     39X
XXXX 22/TIMER 23                        OFF    40X
```

(A) XXXXX MNVR YYYYY (PASS/BFS)



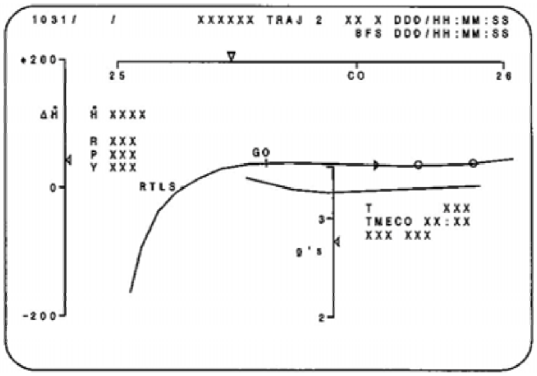
```
1021/     /            XXXXXX TRAJ 1  XX X DDD/HH:MM:SS
                                      BFS DDD/HH:MM:SS
KEAS
500
        XXXXX
400     T XXX
        XXX XXX
300     R XXX
        P XXX
        Y XXX
200
100  STG
0
```

(B) XXXXXX TRAJ 1 (BFS)



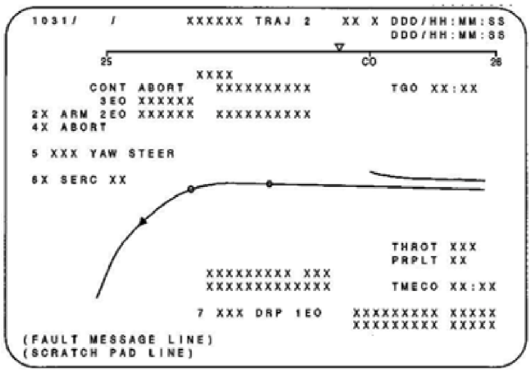
```
1021/     /          XXXXXX TRAJ 1   XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
                        XXXXXXXXXXX

        CONT ABORT       XXXXXXXXXX
           3EO XXXXXX
2X ARM 2EO XXXXXX        XXXXXXXXXX
4X ABORT
                            XXXXX
5 XXX YAW STEER

6X SERC XX

                                       THROT XXX

                     7 XXX DRP 1EO    XXXXXXXXX XXXXX
                                      XXXXXXXXX XXXXX
(FAULT MESSAGE LINE)
(SCRATCH PAD LINE)
```

(C) XXXXXX TRAJ 1 (PASS)



```
1031/     /            XXXXXX TRAJ 2  XX X DDD/HH:MM:SS
                                      BFS DDD/HH:MM:SS
+200
        25                   CO                 26
 ΔḢ   Ḣ XXXX

      R XXX
      P XXX
      Y XXX
                                   T          XXX
                                   TMECO XX:XX
                                   XXX XXX
-200
```

(D) XXXXXX TRAJ 2 (BFS)



```
1031/     /        XXXXXX TRAJ 2   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
           25                       CO            26
                     XXXX
        CONT ABORT    XXXXXXXXXX            TGO XX:XX
           3EO XXXXXX
2X ARM 2EO XXXXXX     XXXXXXXXXX
4X ABORT

5 XXX YAW STEER

6X SERC XX

                                            THROT XXX
                                            PRPLT XX
                    XXXXXXXXX XXX
                    XXXXXXXXXXXXXX          TMECO XX:XX

                   7 XXX DRP 1EO       XXXXXXXXX XXXXX
                                       XXXXXXXXX XXXXX
(FAULT MESSAGE LINE)
(SCRATCH PAD LINE)
```

(A) XXXXXX TRAJ 2 (PASS)

Notes

Notes

Notes

APPENDIX C STUDY NOTES

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This appendix contains a set of study notes originally developed by Ron Grabe in September 1989. They have been extensively modified and updated over the years and reviewed for technical content by the Training Division.

The purpose of these notes is to provide crewmembers with a set of critical “need-to-know” items that can be reviewed in their entirety at one sitting. The notes are directed at the PLT crew position, but should be useful for other crewmembers as well.

The Study Notes are organized alphabetically by major system. Under each system heading, notes on critical subsystems and malfunctions are presented. The text is written in Flight Data File shorthand using switch nomenclature and DPS display terminology, which results in a somewhat cryptic format. Although directed primarily toward Generic and Flight-Specific training, they should be readily understood by crewmembers who have progressed through at least part of Pilot Pool training.

Preparation for Shuttle Mission Simulator (SMS) training sessions is difficult due to the complexity of the Space Shuttle and the many flight phases that crewmembers are required to understand. A quick review of these Study Notes prior to SMS sessions should help make training more productive.

APU/HYD

General

- Ascent: all APUs will be kept running through MECO if possible.
  - Loss of one APU means hydraulic lock on one engine.
  - Loss of two APUs means two SSMEs in hydraulic lock plus loss of TVC for one SSME.
- Entry
  - Pre-TAEM, a sick APU (high oil temperature, high hydraulic temperature, pump leak P, H_2O leak) may be manually shut down, cooled down, and restarted near Mach 1 to support landing.
  - Post-TAEM, APUs generally will be kept running except for high oil temperature. An APU will be shut down for high oil temperature if Mach >1. A gearbox failure for high oil temperature is not catastrophic.

Auto Shutdown

- Controller will issue an auto shutdown command, if auto shutdown is enabled, for RPM less than 80% or above 129% (auto shutdown is inhibited for the first 10.5 seconds after start to allow turbine spinup).
- Auto shutdown closes secondary fuel control valve and fuel tank valves.
- An APU with an underspeed shutdown is a candidate for cooldown and restart.
- APUs with confirmed overspeed shutdown will not be restarted.
- If auto shutdown inhibited and APU speed is confirmed above 129%, manual shutdown is required as soon as possible.

Single APU Loss

- Single APU loss will not affect nosewheel steering (hydraulic system 1 is prime and system 2 is backup).
- Single APU loss will not affect braking (loss of APU 3 plus either 1 or 2 means half brakes).
- Hyd system 1 is prime for main and nose gear deploy. If APU 1 is lost, the landing gear will be deployed with pyros. There is no *hydraulic* backup to *main* landing gear deploy*, Hyd system 2 gives a hydraulic backup to nose gear deploy only*.

Switching Valves

- Supply either primary or one of two back-up hydraulic systems to the aerosurface actuators.
- Valve status only visible on SPEC 86 (SM OPS 2).
- During FCS checkout, check active hydraulic system selected.

Fuel Tank

- Supply supports about 110 minutes of operations, enough for an AOA if the APUs are taken to low pressure post-MECO.
- Nitrogen pre-charge required for start-up.
- Different Hyd Pressure sensors are displayed on the MEDS meter and SM SYS SUM 2.
- Quantity (DPS display and MEDS meter) is a PVT calculation.
- Isolation valves must be closed (de-powered) when APU is not running. No fuel cooling of solenoid valves.
  - Post APU shutdown, if fuel tank valve temperature high, pull circuit breakers.
  - Solenoid short may overtemp valves while APU is still running. Pull circuit breaker for second valve in parallel. Will keep APU running.

Fuel Pump

- Gear driven pump delivers fuel under pressure post start.
- “APU PUMP LK P” shows build-up of leaking oil or fuel in catch bottle. Bottle relieves overboard.

Cooling

- GG bed *injectors* cooled by separate H_2O injection system for re-start. H_2O system not used during normal ops.
- Cooling required for 3.5 minutes in *INJECTOR COOL* prior to start. If no cooling of GG injector apparent, do not perform restart.
- If APU not started immediately following cool-down, injector temperature will rise again rapidly.
- Common tank for all APUs. Total cooling capacity is 21 minutes.
- Fuel pump and fuel control valves are cooled passively by heat sinks and radiation shields.
- Water spray boiler cools hydraulic and lube oil.
  - Bypass valve isolates hydraulic cooling feature when not required.
  - Two controllers (A and B) use common water lines but have different spray logic.
  - Water quantity should not decrease during ascent. Pre-charge in H_2O boiler immerses oil lines. No spraying until MET about 8:00.
  - PGME (an antifreeze) is present in the cooling water *to* prevent the WSBs from freezing.

Hydraulic Accumulator

- Maintains pressure of about 2600 psi when APU not running (hydraulic pressure still about 65 psi).
- Prevents hydraulic pump cavitation.

- Low accumulator pressure on orbit indicates nitrogen leak or internal priority valve or unloader valve failure.

Circulation Pump

- Two-stage pump. First stage low pressure, high volume. Second stage high pressure, low volume. High pressure fluid can be diverted to repress accumulator. Otherwise, high pressure fluid mixes with low pressure fluid.

- On orbit, automatically turns on (when pressure < 1960 psi) to maintain accumulator pressure.

- Circ pumps keep hydraulic fluid moving for thermal conditioning on orbit. Automatically turn on for low hydraulic line temperatures.

- Only one circ pump operates at a time in GPC control for electrical loads considerations. The system with low accumulator pressure has higher priority than the system with low hydraulic line temperatures. For thermal reasons, two circ pumps at a time are OK if needed to recharge two accumulators.

Priority Rate Limiting

- Software routine used to prevent over-demanding the available hydraulic systems in the event one or more systems fail. It ensures that the more important aerosurfaces (e.g., elevons, rudder) are given hydraulic pressure demand priority over the less important aerosurfaces (e.g., speed brake and body flap).

- Gets 3 hydraulic pressure inputs from each system.

- Crew can see 2 of the inputs on BFS SYS SUMM and MEDS meter. MCC has access to all three inputs.

- Crew can also see hydraulic accumulator pressure that PRL does not see.

    - Use hydraulic accumulator pressure and RPM to resolve dilemma.

    - Accumulator pressure = 3000 means hydraulic system OK.

- PRL will show down arrow if declaring system down.

- SPEC 51 data:

    - AUT* means auto logic is active.

    - DES* means manual deselection (toggle to reselect).

- For PRL "?" and system good, leave auto logic selected.

    - Subsequent transducer fail may require deselect of auto logic and a manual deselect or reselect.

- For PRL down arrow and system good, deselect auto logic to reinstate hydraulic system into PRL.

Manual Shutdown

- Used to back up auto shutdown.

- Controller power off protects against uncommanded hot re-start.

- Must identify over or underspeed shutdown prior to controller power off (caution and warning light extinguished).

Ready-To-Start Talkback Gray

- Low press selected.

- H_2O spray boiler ready.

- APU fuel isolation valves open.

- GG bed temperature >190 degrees.

- APU speed below 80%.

- Underspeed immediately after start is probably caused by 10.5-second timer failure. Auto shutdown is normally disabled during first 10.5 seconds of start. *AUTO SHUTDOWN* to *INHIBIT* may allow start.

Comm-Voice Data

General

- *PANEL/CMD* on panel C3 switch passes S-band control to system selected on aft panel. One step total reconfiguration to alternate system.
- Normally, INCO manages system on LRU by LRU basis. All LRUs are system 1/system 2 redundant.
  - Crew can manually reconfigure the comm system via switches on panel A1L and/or by item entries on BFS G51.

ACCU

- Routes all audio to ATUs.
- No voice (ICOM and A/G), switch ACCUs.
- CDR and PLT can talk to each other on same ATU without an ACCU.

Antenna Electronics Unit

- Switches antenna per GPC or RTC command.
- BFS commands for ascent and entry.
- SM GPC command on orbit.
- Commands routed to antenna electronics 1/2 over PL MDM 1/2, respectively. No cross-strapping capability.
- Manual selection available with loss of auto select.

Ascent/Entry Configuration

- S-band system 2 active in STDN mode.
  - STDN sites prime for comm.
  - On orbit, 1 to 2 hour call up.
- A/G 1 and A/G 2 selected simo.
- UHF T/R on A/A loop.
- TDRS available on ascent and TAL.
  - On ascent, a stored program command will mode to TDRS at L/O + 7:30.

Encryptor, Transponder, and Power Amp

- Power amp and preamp are not used if configured for STDN low mode.
- Encryption is normally on uplink only.
  - Encryptor dedicated to one NSP. Not selectable separately.
  - Bypass selected for encryption failure.

NSP

- Processes uplink and downlink (voice, commands, and data), except UHF that bypasses NSP.
- Failure means no S-band voice, commands or data to/from ground.
  - "BCE STRG X NSP" where X = active FF MDM (1 or 3). Could be just command failed. Check data/voice with MCC.

Cryo

General

- Separate transducers for DPS display and overhead meters.
- DPS display data goes off scale low for big leaks.

Heaters

- Each tank has A and B heaters.
- Separate controls/logic for O_2 and H_2 heaters.
- O_2 heaters have two elements with two current sensors per heater.
- Crew insight into sensor status in OPS2 only.
- If any current sensor trips (short), that heater is disabled.
- Heater logic (applies separately to O_2 and H_2).

  - Both tanks in a ganged pair must have low P before heaters in either tank are turned on.
  - Only one high P is needed to turn both heaters off.
  - During leak isolation, pressure in good tank may prevent heaters in leaking tank from coming on with both tanks' heaters enabled.
  - Control points for heaters:

    H_2 tank 1 and 2 pressure = 203 to 223

    O_2 tank 1 and 2 pressure = 811 to 846

  - Tank 3, 4, and 5 set points slightly higher so tank 3, 4, and 5 will preferentially feed on orbit with all tanks in *AUTO*.

Leaks

- First step in ascent and entry cryo leak procedure is to determine number of tanks with pressure decreasing.
  - Only one tank leaking, leave configuration as is (manifold isolation valves open). Leak is a tank leak. Isolating tank will starve its fuel cell.
  - If all tanks decreasing, close manifold valves to isolate leak. Must react quickly for large multi-tank leaks.
  - If leak internal to fuel cell 3, need to reopen manifold valves ASAP. Manifold 3 does not have a relief valve.

DPS

General

- It is important to be able to identify GPC failures, for MCC often has little insight. Crew information affects MCC analysis and planning for subsequent failures (both DPS and non DPS).

- When using the *GPC MODE* switch, remove your hand between positions. On past missions, there have been problems with the switch being in two positions at the same time. This problem can occur on other orbiter switches also. It is good practice to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.

- Always clear the fault message line as soon as messages have been seen. This will avoid missing annunciations of subsequent failures.

- Resume SPECs and DISPs from IDPs when not in use or prior to switching to another major function on that IDP.

- Hard assign IDPs (both PASS and BFS) via PASS IDP keyboard (BFS will DK listen). Dual DPS display commanders can be caused by trying to assign an IDP to BFS that a PASS GPC is still driving.

- When moding PASS GPCs into the common set (i.e., STBY to RUN), always pause 10 seconds before making further switch throws or item entries to avoid possible fail-to-sync and ensure proper common set initialization.

BFS Engage

- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both *MODE* and *OUTPUT* talkbacks are barberpole). If not, take the offending GPC to *HALT* (or power it off) immediately to avoid I/O problems on the flight-critical strings.

Restringing

- Deassign IDPs to avoid inadvertent entries.

- Before OPS transitions and restrings, verify the NBAT. Check proper *MAJOR FUNCTION* and GPC switch configuration.

- Ensure the correct memory configuration is displayed prior to making NBAT changes.

- Dynamic flight.
  - Use the Restring cue card.
  - Take the failed GPC to *HALT (or STBY, HALT)* prior to OPS MODE RECALL.

  - Deselect surface feedbacks prior to OPS MODE RECALL. Reselect following OPS MODE RECALL.
  - Follow OPS MODE RECALL with BFS I/O RESET (or PRO to OPS 3 if TAL).
  - Avoid assignment of all three IDPs to the same GPC, especially on orbit.
  - Keep hands off of everything during OPS transitions, especially switches and IDP keyboards.

- Rules.
  - Always restring to regain critical capability.
  - Powered flight. In general, you can recover stuck throttle if necessary for uphill performance.
  - Post MECO, pre ET SEP. Recover jets required for SEP.
  - Pre OMS-1. Recover single OMS ignition capability (delay burn). Regain critical system insight (if engagable BFS still available). Maintain single fault tolerance.
  - Entry. Regain vent door commands. Regain nose wheel steering for abort landing site or known directional control problems during rollout. Maintain ASA command and body flap command.
  - In general, port moding is preferred over restring to regain lost capability.
  - Prior to EI-5, restring for any failed GPC.

Set Split

- 2 on 2 or 2 on 1 on 1 split during ascent
  - Engage BFS.
  - If desired, the PASS set can be reconfigured pre-MECO if BFS is tracking and no additional complicating failures are present, rather than engaging the BFS.
  - Treat simplex machines or undesired set as failed GPCs. Work the GPC fail procedure twice sequentially.
  - BFS engage required on ascent for MPS commands if simplex machines or undesired set cannot be taken to HALT pre-MECO.
  - Restring may be performed with MCC coordination, in accordance with Flight Rules.
  - Be prepared for BFS engage if sets begin force fight or total set split.

- BFS engage decisions for set splits.
  - On seeing multiple GPC fault and CAM lights, call "SET SPLIT".
  - Check BFS and PASS GNC SYS SUMM.
  - If BFS tracking 2 PASS GPCs, check them for 1 IMU, 2 FCS channels, 1 RGA, and 1 AA. (Minimum for good PASS set.)
  - If BFS standalone, check PASS if time permits. Time available is based on NAV state without IMU data:

    Powered flight - ≈10 seconds
    Entry - ≈45 seconds
    Orbit - plenty of time

- Distribute IDPs among different GPCs. On orbit, ensure all IDPs are not assigned to the SM GPC or a single GNC OPS GPC. Loss of the GPC with all IDPs loses PASS DPS display interface.

ECLSS

General

- During ascent, only Freon pumps will be swapped if lost*, and then only to avoid RTLS or TAL*. All other fans and pumps are cooling equipment that can wait until post-MECO.
- All ECLSS data seen on the overhead meters (panel O1) come from the same sensors as seen on the DPS displays.

- NH_3 Boiler A(B) control based on temperature in Freon loop 1(2).
  - If no flow in Freon loop, must use NH_3 boiler corresponding to good loop.
  - If degraded flow in Freon loop, select NH_3 boiler for loop with degraded flow.
  - *Control to the good loop but not the dead loop.*

Cabin Pressure

- First reaction to cabin leak is to close cabin relief isolation valves one at a time.
- Double check leak indications with MCC. May be due to cabin expansion or thermal effects such as seen during First Stage.
- N_2/O_2 leak into cabin will cause rise in cabin pressure and for O_2 leak, PPO_2 will also rise (O_2 concentration available on orbit).
- *dP/dt* on meter and DPS display come from *dP/dt* sensor.
- EQ *dP/dt* is calculated from cabin pressure *and dP/dt* sensors by BFS and standardized to a 14.7 *psi* cabin. EQ *dP/dt* is used when available to make ascent abort decisions for cabin leak. Backup *dP/dt* is also calculated from cabin pressure, but not standardized for a 14.7 cabin.

EPS

General

- Do not reset popped circuit protection device (RPC or circuit breaker) without consulting MCC.
- For critical actions, MCC may call for momentary reset of failed control or essential bus while crew holds switch for affected system in desired position ("three finger trick").

AC Bus

- Surge on AC bus can cause main engine controller to trip off line. Avoid actuation or switching of AC powered equipment during powered flight unless called for in malfunction procedures *or by MCC*.
  - Loads that can be switched in powered flight:

    Avionics bay fans (only for 3-phase motor stop)
    Freon pumps *(only to help determine if RTLS or TAL is required)*
    H_2O loops (only for Evap Out T Low)
- AC bus sensors *OFF* on ascent to protect SSMEs for:
  - Loss of first engine.
  - Loss of SSME controller redundancy on any engine.
  - Loss of a single AC phase (takes down an SSME controller on two engines).
  - When AC bus sensors are *OFF*, no hardware caution and warning lights will illuminate (no AC VOLTS or AC OVERLOAD light).
- AC voltage high
  - Ride until MECO unless volts exceed 130, or affected main engine controllers are lost *(MCC call)*.
  - Trip bus off line with *AUTO TRIP* selection on bus sensor.
- AC phase shift (three-phase motors stop)
  - Verified by normal volts and multi-phase amps possibly slightly high.
  - Multiple three-phase motors fall off line: fuel cell pump, Freon pump, H_2O pump, AC bay fans, etc.
  - Take individual phases off line separately to find bad phase.
- If AC bus sensor in *AUTO TRIP*, AC phase will be automatically disconnected for either an AC overload or high AC volts.

- If AC bus sensor in *MONITOR*, will get hardware caution and warning, but will not get AUTO TRIP feature.

- AC bus sensor uses different transducer than one feeding F9 meter or DPS display.

- AC bus sensor needs to see rapid rise or delta amps to issue an AC OVERLOAD indication.

Bus Tie Actions

- If re-establishing power to a main bus (main bus volts < 20), always unpower the AC inverters before tying to a good bus (prevents surges). Use long form bus tie procedure on cue card.

- If a tie results in a short, immediately untie.

- Never tie 3 main buses during powered flight. OK post-MECO, on orbit, and entry.

- Never tie into a short.

- Payload primary bus can be used to tie Main B to Main C (back door bus tie), or connect FC3 to Main C.

- *Do not bus tie in first stage for the first fuel cell problem.*

Fuel Cell

- Coolant pump and H_2 pump both driven by same AC bus and both pumps controlled by fuel cell ECU and *START/STOP* switch.

- Coolant pump draws 0.5 amps, H_2 pump draws 0.3 amps.

- Coolant pump delta P indication.

  - Ground can see immediately if loss of fuel cell coolant pump is real (stop/start to check run current not required).

  - No comm, can stop fuel cell and check for 0.8 amp drop. This indicates both pumps were running (bad sensor). Restart gives full recovery (should see 0.8 amp increase).

- *START* switch sends pump start commands.

  - Pressure should be sensed in 3 seconds. *Delta P* talkback goes gray.

  - *READY FOR LOAD* talkback requires 30 second timer and good heaters.

  - Delta P relay failure may prevent fuel cell ECU from latching on fuel cell start command. *DELTA P* talkback won't stay gray. OK to hold *START* switch in *START*. After 30 seconds, second relay should latch command on (can release *START* switch).

- Coolant pump failure stagnates coolant loop.

  - Stack T measured *downstream of the stack outlet*. *Will slowly* decrease after coolant pump failure.

  - Exit T measured in H_2/H_2O loop.

  - If H_2 pump running, exit T will progressively increase after coolant pump failure.

  - Nine minutes of run time available after first coolant pump failure, assuming normal fuel loading.

- O_2 is entirely consumed. H_2 is circulated continuously through power section and condenser.

  - H_2O is drawn out of stack by mixing with H_2.

  - H_2O is separated at the H_2/H_2O pump.

  - Dual gas regulator maintains proper pressure of reactants (about 60 psia). O_2 pressure feeds coolant loop accumulator.

  - Dual gas regulator problem indicated by COOL P HIGH/LOW. Tie buses and monitor fuel cell for degradation.

  - If O_2 reactant valve closes, coolant pressure will drop.

- Failure of the H_2/H_2O pump will lead to fuel cell flooding since water is not removed.

  - Ascent and entry: pH status fail followed by slow degrade and exit temperature decreasing may be first signatures of flooding.

  - Indicated on orbit by H_2 pump status fail.
- Crossover (uncontrolled O_2 and H_2 mixing).
  - Highly unlikely to happen rapidly without warning signs.
  - Fuel cell delta volts increasing is a warning.
  - PH high may occur, but not necessarily.
  - Fuel cell degradation will eventually occur.
- Separate pH sensor for each fuel cell and common sensor in H_2O manifold.
  - pHfail may indicate pending breakdown of Fuel Cell matrix (fuel cell crossover). Potential explosive mixing of H_2 and O_2.
  - High fuel cell delta volts provides confirming cue.
  - Assume matrix failure for pH fail and bus tie as soon as possible. Problem may be an H_2/H_2O pump failure.
  - Common pHsensor can confirm individual fuel cell sensor. Will annunciate about 10 minutes after individual fuel cell pH (common pH only seen by crew on orbit).
- In normal configuration, redundantly powered loads are load shared (also known as dioded loads).
  - Hot running fuel cell (real STACK T high) will grab more than its share of the load. Indication is high amps.
  - Flooding (real EXIT T low) will cause fuel cell to shed load.
- Water output of all fuel cells feeds common manifold.
  - Water expulsion for fuel cell is preferentially: Tank A (primary), Tank B (alternate), Dumped overboard (relief).
  - *FC H_20 LINE HTR* controls heaters on each fuel cell primary and alternate path.
  - *FC RELIEF LINE HTR* controls heaters on each fuel cell relief line.
  - Each fuel cell relief line merges into one common manifold that vents H_2O overboard.
- Purge process pumps extra O_2 and H_2 through fuel cell.
  - Removes contaminants.
  - Excess O_2 and H_2 dumped overboard. All three fuel cell purge lines merge into one O_2 and one H_2 manifold.
  - Purge only one fuel cell at a time.
- Nominal load is 7 kw per fuel cell. For powerdown operations, 13 kw OK on one fuel cell for 4 hours, 12 kW OK continuously.

Main Bus Short

- Fuel cell will overheat in time. Amps high, fuel cell and main volts low.
  - Short before the fuel cell main bus switch will have high amps and will not drop when fuel cell is isolated from main bus. Fuel cell and main volts will remain low. Should be treated like a fuel cell short.
  - Fuel cell internal short. Amps low, fuel cell and main volts low.
  - Fuel cell inadvertent disconnect. Amps low (should be zero), fuel cell volts greater than 32, main volts near zero. OK to attempt reconnect.

Ascent/Entry FCS

FCS Channels

- Each FCS channel includes:
  - One GPC
  - One FA MDM
  - Two black boxes (ASA and ATVC)
  - Sixteen servovalves
  - One solenoid set for body flap

- Always maintain at least two good FCS channels and one good position feedback for each aerosurface.

- "Port bypass" means a servovalve's isolation valve (which is spring-loaded closed) is commanded open. This allows hydraulic fluid to flow freely past the servovalve, making it ineffective.

- FCS Channel Switches:

  Assumes ASA switches (panels O14, O15, O16) and ATVC switches (panel O17) are ON.

  OVERRIDE:

  – Supplies internal power to ASA and ATVC.

  – Resets all ports on affected channel (unless manually bypassed - aerosurface ports only).

  – Inhibits port bypass due to high SEC ΔP on affected channel. (Can still bypass due to internal power fail or from manual bypass.)

  AUTO:

  – Supplies internal power to ASA and ATVC.

  – Allows ports to bypass due to high SEC ΔP.

  OFF:

  – Interrupts internal power to ASA and ATVC.

  – Bypasses all ports on channel (due to loss of internal power fail).

  – For ASAs, causes zero voltage feedback to go to FDIR/selection filter.

- Pause 2 seconds between all FCS channel switch position changes.

  – Switches are break-before-make.

  – Switch actuation can result in momentary loss of channel.

- ASA/ATVC Internal Power Fail:

  – Results in all affected ports being bypassed.

  – For ASAs, results in zero voltage feedback being sent to GPCs. (Feedback needs to be deselected, either manually or by FDIR.)

- No action required for single port bypass with no other failures.

- For two failures on the same actuator, take remaining good channels to *OVERRIDE*. Prevents a good channel from bypassing (thus leaving only a bad channel) in the event of a subsequent 1-on-1 force fight.

- MCC may call to manually bypass a port (via SPEC 53) if the port does not bypass on its own or to prevent the port from resetting if the affected FCS channel is subsequently taken to *OVERRIDE*.

Position Feedbacks

- Each aerosurface position feedback is measured by four transducers (one per FCS channel). SRB/SSME position feedback does not use transducers, but rather is built into the servovalve hardware.

- Aerosurface feedbacks go to FDIR and selection filter to determine aerosurface position for GPC computations.

- FDIR:

  – Each aerosurface has its own FDIR.

  – FDIR compares feedbacks against I-load tolerances. If a feedback exceeds tolerances, FDIR will declare that feedback invalid.

  – FDIR quits after first "failure" (i.e., manual or auto deselection, commfault).

  – FDIR will return if all failures removed (i.e., feedbacks are reselected or if commfaults are cleared).

- Selection Filter (excluding body flap):
    - Selection filter schemes:

3 valid inputs	MVS
2 valid inputs	Average
1 valid input	Pass Thru
0 valid inputs	Last Value

    - Initially uses inputs across FCS channels 1, 2, and 3. Channel 4 is held in reserve.
    - If an input is declared invalid (either by FDIR or by being manually deselected), input from channel 4 is used in its place.
    - Selection filter will downmode if a feedback is either deselected or commfaulted.
    - Selection filter will upmode if a feedback is reselected or if the commfault is removed.
- BFS RM Differences:
    - BFS has no FDIR. Crew must manually deselect bad feedbacks.
    - BFS selection filter uses an IMVS scheme (i.e., uses feedbacks on all four channels).
    - BFS selection filter downmodes/upmodes due to crew input only.
- The ASAs combine position feedbacks and GPC position commands to create position error commands, which go toward moving the servovalves.
- A bad feedback can cause the affected servovalve to force fight the others. If SEC ΔP exceeds limits, the affected port will bypass. At the same time, if the feedback itself exceeds tolerances, it will be declared invalid by FDIR.
- Feedback deselection on SPEC 53 deselects all feedbacks on channel and terminates FDIR on all aerosurfaces.
- Any *OFF* channel should have feedbacks deselected. If channel is recovered, reselect feedback after channel is taken to *AUTO*.

Body Flap Differences

- Body flap commanding goes across FCS channels 1, 2, and 3 only.
- Body flap feedback goes across all four FCS channels.
- The APUs are hard assigned to the body flap channels. An APU failure also means a lost body flap channel.
- Body flap channels use solenoids instead of servovalves, so there are no ports to bypass.
- Body flap feedback goes through a QMVS selection filter.

GPC/MDM Impacts to FCS Channels

- GPC/MDM failures commfault port statuses. Take affected FCS channel to *OFF*. This causes all affected ports to bypass and avoids possible force fights.
- GPC/MDM failures commfault position feedbacks. Deselect affected feedback. This prevents GPCs from using a potentially bad feedback if I/O is later restored.
- After a restring, and one GPC has control over two FCS channels, one channel is taken to *OFF*, so that the GPC's control authority is equal to that of the other GPCs.
- BCE STRG X "D" failure will commfault feedback on affected FCS channel, but commanding across the affected FCS channel remains good.

GNC Sensors and Controllers

AAs and RGAs

- AAs and RGAs go through an FDIR and selection filter to determine values used for GPC computations.
- FDIR:
  - FDIR compares AA and RGA values against I-load tolerances. If a value exceeds tolerances, FDIR will declare that AA or RGA invalid.
  - FDIR quits after first failure (i.e., manual or auto deselection, commfault).
  - FDIR will return if all failures removed (i.e., AA or RGA is reselected or if the commfault is cleared).
  - RGAs have an additional SMRD (spin motor run detector) FDIR, which protects against RGA power failures. SMRD quits after the third deselection.
- Selection Filter:
  - Selection filter schemes:

4 valid inputs	IMVS
3 valid inputs	MVS
2 valid inputs	Average
1 valid input	Pass Thru
0 valid inputs	Last Value

  - Selection filter will downmode if an AA or RGA is either deselected or commfaulted.
  - Selection filter will upmode if the AA or RGA is reselected or if the commfault is removed.
- BFS RM Differences:
  - BFS has no FDIR. Crew must manually deselect failed AAs and RGAs.
  - BFS selection filter also uses an IMVS scheme.
  - BFS selection filter downmodes/upmodes due to crew input only.

IMU

- SPEC 21 shows IMU status.
  - OFF, BITE, blank in status field.
  - Mode designated by *: STBY (caged) or OPER (operate)
- GPC send operate command through FF MDMs.
  - IMU returns status (operate discrete) over FF MDM card A.
  - IMU returns digital data over FF MDM serial I/O card
  - STBY and power off conditions available on SPEC 21 after "BCE STRG X IMU", but not after FF MDM lost.
- GPC or FF MDM port failure.
  - IMU will maintain operate command. Commands and output of MDMs are latched at last value.
  - IMU will operate without pulse torquing compensation. Should maintain reasonable align for several hours.
- FF power cycle.
  - IMUs can maintain OPER CMD LATCH for approximately 8 seconds.
- FF power fail.
  - IMU loses operate command and goes to STBY (upon recovery of I/O).
  - In STBY, IMU spins down and cages.
  - FF 1,2,3 power failure signature (following "I/O ERROR FF X") is loss of SSME Pc tape (ascent). Deselect IMU PASS and BFS after FF power fail (IMU will come back caged when I/O regained). PASS will automatically deselect a commfaulted IMU in OPS 3.

- BCE STRG IMU.
    - Could be result of IMU losing power. SPEC 21 (orbit and entry only) shows IMU status OFF, mode STBY. An IMU BITE/T message annunciated at the same time is also a confirming cue for the IMU power fail.
    - Could be loss of IMU data to the FF MDM (serial I/O card down). Status and data blank on SPEC 21. Mode will still show operate, received over card A.
- Standby mode.
    - If IMU has moded to STBY, it will begin startup sequencing once the operate discrete is restored.
    - Transient power fail, causes startup sequence which cages IMU (approximately 90 seconds).
    - When IMU completes startup sequence (caged), it will mode to operate and be available to selection filter upon an I/O reset. Hence, any caged IMU should be deselected (PASS and BFS), if not already.
- PASS selection filter.
    - Any IMU not commfaulted (M) or deselected is a candidate.
    - An IMU in STBY is not a candidate.
    - Attitude selection is MVS at 3 level.
    - Downmode or upmode to 2 level. Maintain previously selected if available. Otherwise lowest numbered IMU.
    - Velocity is MVS at 3 level (component basis). Averaged at 2 level.
- PASS RM.
    - Either attitude or velocity fail removes IMU from selection filter.
    - PASS will not RM fail an IMU for a BITE (H/W or S/W) at 3 level.
    - IMU with BITE will fail RM if dilemma at 2 level.
    - If IMU miscompare at 2 level and PASS sees no BITE, IMU dilemma declared. Manual deselection required to break dilemma. Use MCC or deselect IMU. BFS is prime selecting to break tie.
- BFS RM and selection.
    - Only commfaults, power loss, hardware BITE, and manual deselect will remove an IMU from candidacy.
    - Selection is MVS at 3 level.
    - Once downmoded to 2 level, BFS will only upmode to 3 level if taken through OPS 0 and up to OPS 3.
    - Selection on downmode to 2 level is lowest numbered IMU.
    - At 2 level, BFS can be taken off lowest numbered IMU with deselect followed by reselect.
    - BFS uses first deselected, last reselected logic after MVS broken.
    - IMU deselected for H/W BITE will not be upmoded if other IMUs lost.
- IMU dilemma.
    - If MCC comm available, ask MCC which IMU to deselect (PASS and BFS).
    - No comm, deselect lowest numbered IMU in PASS. BFS will use lowest numbered.
    - Let NAV run to determine which IMU is better.

Navaids

- For TACAN and ADTA management, talk to MCC before incorporating. Without communication, use the NO COMM TACAN MGMT and ADTA MGMT cue card.

RHC/THC/SBTC/RPTA

- Availability
  - RHC
    - L, R RHC: All OPS
    - A RHC: OPS 2, 8
  - THC
    - L THC: OPS 1 (post MECO)
OPS 2, 8
OPS 3 (MM 301-303)
    - A THC: OPS 2, 8
  - SBTC
    - L SBTC: OPS 3 (MM 304-305)
OPS 6 (MM 602-603)
    - R SBTC: OPS 1 (MM 102-103)
OPS 3 (MM304-305)
OPS 6
  - L,R RPTA: OPS 3 (MM304-305)
- FF MDM Channelization
  - RHC
    - L RHC: FFs 1, 2, 3
    - R RHC: FFs 2, 3, 4
    - A RHC: FFs 1, 2, 3 (pitch, yaw)
FFs 1, 4, 3 (roll)
  - THC
    - L THC: FFs 1, 2, 3
    - A THC: FFs 1, 2, 3
  - SBTC
    - L SBTC: FFs 1, 2, 3
    - R SBTC: FFs 2, 3, 4
  - RPTA
    - L RPTA: FFs 1, 2, 3
    - R RPTA: FFs 2, 3, 4
- FDIR
  - FDIR compares channel inputs against I-loaded tolerances. If an input exceeds tolerances, FDIR will declare that channel invalid.

    For THC, FDIR performs 2/3 voting.

    For RHC, a failure in a single axis (pitch, yaw, roll) is enough for FDIR to declare the channel invalid.

    For THC, each direction (+X, -X, +Y, -Y, +Z, -Z) has its own FDIR. A failure in one direction has no impact on the others.
  - After second failure (excluding comm-faults), FDIR will declare a dilemma. Controller is no-opted.

    For THC, dilemma affects only the one direction. THC still works in other directions.

    For a dilemma, the affected FLT CNTLR PWR is turned OFF to protect against the next failure from clearing the dilemma but resulting in a bad input being processed.
- Selection Filter
  - Selection filter schemes:

3 valid inputs	MVS (THC: 2/3 vote)
2 valid inputs	Ave (THC: 2/2 vote)
1 valid input	Pass Thru
0 valid inputs	Last Value

  - Selection filter will downmode if a channel is manually deselected (via OPS 2,8), declared invalid by FDIR, or commfaulted.
  - Selection filter will upmode if a channel is either reselected (via OPS 2,8), the channel is no longer invalid, or the commfault is removed.
- BFS RM Differences
  - Controllers not available during powered flight with BFS engaged.

    BFS does not process R RPTA, but right rudder pedals are mechanically linked to left rudder pedals.
  - BFS has no FDIR.
  - BFS Selection Filter is always MVS and cannot downmode.

    No manual deselection, and BFS does not recognize commfaults.

- Taking manual throttles (PLT only):
  - Mash and hold the takeover button.

    SPD BK/THROT light extinguishes for both CDR and PLT.
  - Match the current throttle setting to within 4%.

    MAN SPD BK/THROT light illuminates for PLT only.

    "Throt" field on Ascent/Entry Flight Display shows "Man" and is surrounded by a yellow box.
  - Release the takeover button.

- Taking manual speedbrake:
  - Depress the takeover button. (No need to match current setting.)
  - SPD BK/THROT light:

    MAN light illuminates for SBTC in control.

    Light extinguished for SBTC not in control.
  - "SB" field on Ascent/Entry Flight Display shows "Man" and is surrounded by a yellow box.

- Manual attitude control:
  - Powered: All axes simo

    Both P and R/Y CSS lights illuminates for CDR and PLT.

    "DAP" field on Ascent Entry Flight Display shows "CSS" and is surrounded by a yellow box.
  - Orbit: All axes simo

    INRTL light illuminates on ORB DAP panel.

    "DAP" field on Ascent/Entry Flight Display shows "Inrtl," and is surrounded by a yellow box (if not BFS engaged).
  - Glided: All axes simo, or Pitch only, or Roll/Yaw only

    Appropriate CSS lights (P or R/Y) for both CDR and PLT illuminates.

    On Ascent/Entry Flight Display, "CSS" shows by the appropriate field ("Pitch" or "R/Y"). Field is surrounded by a yellow box if M>1 and not BFS engaged.

- "Hot Stick" Downmode
  - Not available during powered flight.
  - Occurs when RHC is deflected by more than 6°.
  - Triggers "DAP DNMODE RHC" fault message.

- Aft Sense Switch (Panel A6)
  - Affects aft RHC and aft THC only.
  - Specifies whether RHC/THC commands are oriented to either the -X or -Z orbiter body axis.
  - Visual control reference based on line of site.

Instrumentation

General

- OI MDM loss results in parameters showing Ms.

- OI Dedicated Signal Conditioner (DSC) loss shows data on respective parameters as L.

- Loss of OI MDM does not affect data to meters, but some digital data may be lost. DSC loss will affect most meters.

- OI DSC loss section of REF DATA is accurate only for DSC parameters, not MDMs.

Data

- Runs through signal conditioners and/or MDMs
  - OI MDM data is sent to the PCMMU where the BFS and/or SM GPC can retrieve it.

  - PCMMU swap reads alternate ports on OI MDMs.
  - GNC GPCs receive OI data from sensors and OI DSCs through flight-critical MDMs.

Mechanical Systems

General

- ET doors and latches, vent doors, star tracker doors, air data probes, payload bay doors and latches, RMS latching gear, and payload retention latches are powered by dual AC motors linked through a differential.
  - One motor fail results in double actuation time. Actuation times are listed in the FDF.
  - Most actuators have dual microswitch pairs for open and close indications.
- Failed mid-motor controllers or popped circuit breakers on MA73C are a frequent cause of payload bay door, ET door, or vent door single motor ops.

Payload Bay Doors

- *PL BAY DOOR SYS ENABLE* switches only enable payload bay doors. Other systems in payload bay use *PAYLOAD BAY MECH POWER* switches to allow operation.
- "PBD CONFIG" message means a microswitch is indicating differently than required by software for auto operations. Can occur any time during auto open/close sequence. May require manual door operation.
- "PBD SEQ FAIL" message caused by failure of proper microswitch indications within single motor actuation time. Can occur during auto sequence.
- A Dilemma ("?") results from the software seeing conflicting microswitch indications. Can occur during Auto or Manual sequence.
- When operating the doors in Manual mode, stay in Manual (do not go back to Auto) unless MCC or the procedures direct otherwise.

ET Doors

- Close manually for uphill or AOA, automatically for RTLS (MM602) or TAL (MM304).
- Always double check doors closed before AOA OPS 3 transition, or TAL flag set before late TAL OPS3 transition: software command on SPEC 51 is only available in MM104, 105, and 106.

MPS

General

- The amount of propellant (PRPLT) in the ET is displayed, in percent, on the PASS ASCENT TRAJ *2 display*. This value is calculated by PASS, not measured from the ET.
- The SSMEs at 104% throttles will consume about 4% propellant per engine per minute (i.e., 1% every 5 seconds with three engines running).
- Actual throttle setting in bucket will vary with SRB performance.
  - "Cold" SRBs = shallow bucket
  - "Hot" SRBs = two-stage bucket
- Take manual throttles whenever CSS is taken. Manual throttles means manual MECO
(3 pb simo at BFS cutoff cue).
- At fine count, engines are throttled back to protect for a low level cut: 67% (for three engines), 91% (for two or one engine).

Engine Failure

- Indications of a failed engine:
  - Master alarm
  - Loss of acceleration

- Fault messages:
  "SSME FAIL C(L,R)"
  "MPS H2 OUT P C(L,R)" -- BFS only
  "MPS O2 OUT T C(L,R)" -- BFS only
- Helium *dP/dt* = 0
- Pc meter = 0
- Red status light (no red light if data path failure exists)

- Ensure that the GPCs recognize failed engine (i.e., check for "SSME FAIL C(L,R)" fault message). If no message, use pushbutton to mode guidance and flight control, and to safe the SSME.

- Work SSME FAIL/SHUTDN procedure:

  - AC Bus Sensors - OFF. (Prevents the AC bus sensors from erroneously taking an AC bus offline, which would impact the engine controllers of the remaining engines.)

  - Check with MCC about reenabling SSME limits. (Limits on the remaining engines were automatically inhibited.)

  - If second SSME fail, the MPS 2% steps apply, unless MCC says otherwise:

  - At 2% prop remaining, manual throttle to 67%, then manual MECO at BFS cutoff cue.

Command Path Failure

- Command path failure created when the main engine controller does not receive two out of three valid inputs from the GPCs.

- GPC and electrical failures can impact SSME commanding. Use MPS 2 cue card to evaluate.

- Command path failure may not annunciate until as late as 3-g throttling (when next command from GPCs is issued).

- Command path failures always require manual shutdown pre-MECO via AC/pb.

Data Path Failure

- Data path failure created when GPCs lose both primary and secondary SSME data coming from the main engine controller.

- Must determine whether engine is still running.

  If SSME has failed:

  - Use the pushbutton to mode guidance and flight control, and to safe the SSME.

  - Work SSME FAIL/SHUTDN procedure.

  If SSME is still running:

  - Check with MCC about reenabling SSME limits. (Limits on the other two engines were automatically inhibited.)

  - Assume that the data path failure is also a command path failure, unless MCC explicitly says otherwise.

- Pc meter will be set to zero for engine with a data path failure. Also, red status light will not illuminate after engine shutdown.

Hydraulic/Electric Lockup

- Hydraulic lockup caused when main engine controller sees that one of the five hydraulic valves in the SSME is not in the commanded position.

- Electric lockup caused when main engine controller loses either Pc or fuel flow rate data from the engine.

- Loss of an APU will eventually cause a hydraulic lockup. This may also cause a "MPS CMD C(L,R)" fault message post-MECO, during MPS dump.

- When having to choose between shutting down a hydraulic lockup and an electric lockup, preference is given to the hydraulic lockup (the "sicker" engine).

- With two hydraulic systems failures, two engines are in hydraulic lockup. In addition, one of those two is also non-gimbaling.

Helium Leaks

- Non-isolatable leak requires interconnect at TK P < 1150 psi to extend run time.
  - Use pneumatic helium tank (i.e., leaking ENG He ICNCT - IN OP).
  - Use helium from any failed SSME (i.e., failed ENG He ICNCT - OUT OP).
  - MCC may call for interconnect at a TK P other than 1150 psi.
  - Return all helium interconnect switches to GPC post ET SEP to support automatic MPS dumping and inerting.
- Crew assumes that non-isolatable leak will not support zero-g shutdown at MECO.
  - Manual shutdown via pushbutton required pre-MECO. (Requires less helium than a zero-g shutdown.)
  - MCC may say shutdown not required, depending on leak size.
- APC4(5,6) or ALC1(2,3) Failures:
  - For ALC failure, BFS GNC SYS SUMM 1 shows the following:

```
ULL P LH2   12.0↓
      LO2    0.0
```

  - For APC failure, along with the same ULL P indications for an ALC failure, there is also an "SM2 APU SPD LO 1(2,3)" fault message.
  - C(L,R) He ISOL A has failed closed. Do not attempt leak isolation steps.
  - Treat helium leaks on affected engine as non-isolatable.
- Pneumatic accumulator leak requires steps to repress accumulator at 30 seconds before MECO.

Manual Shutdown

- Manual shutdown cues of VI=23K (3-ENG), 24.5K (2-ENG), and 22.5K (TAL) correspond roughly to 30 seconds before MECO.
- Manual shutdown typically done via pushbuttons.
- If pushbutton does not work, shutdown via AC/pb. (Creates a data path failure on that engine.)
- Shutdown with AC switches no-ops the MPS LO2 dump for affected SSME. Manual LO2 inerting may be required.

SSME Pushbuttons

- Pushing the SSME pushbutton generates two commands in the GPCs:
  - SHUTDN command - Initiates SSME shutdown
  - SAFING command - In the presence of a Data Path Failure, will set in motion three things:
    1. Modes Guidance
    2. Modes Flight Control
    3. Closes the prevalves
- Each pushbutton has two contacts.
  - Each contact powered by a CNTL bus.
  - Status of each contact carried to the GPCs via an FF MDM.
  - CNTL bus/FF MDM assignments are printed on panel C3 below each pushbutton.
- Pushbutton Conditions:

  Fully Operational - There are no failures:
  - Pushbutton will generate both SHUTDN command and SAFING command.

  Commfaulted - One (not both) of the contacts has an associated FF MDM that is commfaulted:
  - Pushbutton will only generate SAFING command.
  - Pushbutton will NOT generate SHUTDN command. Manual shutdown must be done via AC/pb.

  - For BFS, a commfaulted pushbutton will NOT generate either command. (BFS does not recognize commfaults.)

  Broken - Either contact has an associated CNTL bus that is failed, or either contact is failed OP (i.e., some type of contamination):

  - Pushbutton will NOT generate either a SHUTDN command nor a SAFING command.
  - Pushbutton in dilemma when one contact reads OP and the other contact reads CL; "ME SHDN SW C(L, R)" fault message generated.

- Broken pushbutton can be used to generate SAFING command, given the following:
  - Affected contact is either fixed (CNTL bus is recovered or contamination clears).
  - Affected contact is commfaulted by power cycling the associated FF MDM. (Does not apply to BFS, because BFS does not recognize commfaults.)

MECO CONFIRMED Flag

- The MECO CONFIRMED flag can be set by any of the following:
  - 3 Pc's < 30%
  - 2 Pc's < 30% and a data path failure
  - 3 SAFING commands (i.e., pressing all three SSME pushbuttons)
  - OPS 104 PRO (OPS 602 PRO will not set MECO CONFIRMED)
  - Fast ET sep
- Crew sees that MECO CONFIRMED is set when they see Orbit DAP lights turn on. (Orbit DAP lights not driven on RTLS.)

Status Lights / Pc Meters

- Status Lights:
  - Amber = Stuck throttle (command path failure, hydraulic lockup, electric lockup) or data path failure
  - Red = Engine has shut down, or is violating redlines (if limits are inhibited)
- MDMs assigned to status lights and Pc meters:
  - Center: FF1
  - Left: FF2
  - Right: FF3
- Impacts from MDM failure:
  - MDM port failure: Latches current indication.
  - MDM power failure: Pc meter reads zero; status light goes off (or stays off).

Entry

- MPS Helium Regulator Failure
  - Failure indications:

    SM Alert

    "MPS He P C(L,R)" message or "MPS PNEU REG" message

    MPS C&W light on F7 matrix (for Reg A failure only)
  - Use BFS GNC SYS SUMM 1 or OMS/MPS MEDS display to identify failed reg, and close appropriate helium isol valve.
  - A helium regulator failed open before M=2.4 (i.e., before the vent doors are commanded open) could be catastrophic, due to an overpressurized aft compartment.
- During RTLS, due to additional helium usage, MPS C&W light and fault messages might occur also for low He TK Ps and for low He REG Ps.

OMS

General

- Nominally used for orbital transfers:
  - OMS 2 burn
  - Rendezvous burns
  - Deorbit burn
- Supplemental uses:
  - OMS assist (flight specific)
  - Propellant source for aft RCS jets (via interconnect)
- Off-nominal uses:
  - OMS 1 burn (in the event of severe ascent performance problems)
  - Ascent abort dumps

OMS Subsystems

- Helium Tank
  - Provides pressurization to maintain propellant flow to the OMS engines.
  - For helium tank leaks, procedures set up an OMS burn to “max blowdown” in the propellant tanks (Qty ~ 39%)
- Propellant Tanks
  - Stores the propellants:
    OX = nitrogen tetroxide
    FU = monomethyl hydrazine
  - At one time, engineers considered providing for an OMS Kit (a supplemental set of propellant tanks), but this effort was later abandoned.
  - For propellant tank leaks, procedures set up an OMS burn to depletion, rather than let propellant accumulate in aft compartment.
- Nitrogen Tank
  - Nitrogen used to open ball valves for the burn. Post burn, nitrogen used to purge fuel lines.
  - GN2 accumulator designed to preserve enough nitrogen for at least one OMS burn.
  - If the GN2 tank has failed but the GN2 accumulator is still adequately pressurized, the affected OMS engine is reserved for the deorbit burn.
  - With an GN2 accumulator leak, the ball valves cannot open once all the nitrogen has leaked out, resulting in an OMS ENG FAIL.
- Engine (OME)
  - Each engine provides about 6000 lb of thrust.
  - OX flows straight into injector plate; FU first flows through cooling jacket before flowing into injector plate.
  - Hypergolic reaction between OX and FU in combustion chamber produces thrust.
- Gimbal Actuator
  - Two actuators per engine (pitch and yaw).
  - Two motors per actuator (PRI and SEC), powered through the APC subbuses.
  - FF MDMs carry the ENA commands. FA MDMs carry the position commands and position feedbacks.
  - Gimbals move to TRIM LOAD positions at TIG-15 sec (but only if the delta is greater than 0.4°).
  - During OMS burns, TVC DAP gimbals engines to keep the thrust vector pointed through the c.g. (i.e., nulls IMU-sensed rates).
  - Operationally, crew selects between PRI and SEC gimbals twice (to ensure ZAP command).
- OMS/RCS interfaces
  - OMS and RCS use the same OX and FU.
  - OMS propellant can be used in one of three ways:
    Straight feed [i.e., L(R)OMS propellant through L(R)OMS engine]

Crossfeed [i.e., L OMS propellant through R OMS engine, or vice versa]

Interconnect [i.e., L(R) OMS propellant through Aft RCS jets]

- Cannot interconnect RCS propellant to OMS engine. (Could damage the RCS tanks.)
- Cannot interconnect OMS to Fwd RCS.

  At one time, engineers considered providing for a Fwd RCS interconnect, but this effort was later abandoned.

- Heaters
  - Collection of pod heaters, panel heaters, and line heaters, designed to prevent the propellants from freezing.
  - Two circuits: "A" (typically used during first half of mission) and "B" (typically used during second half).
  - Caution: Simultaneously running both "A" and "B" OMS pods heaters will result in burnout of the heaters.

OMS Quantity Gauging

- OMS quantity determined via an electrical probe that runs along the central axis of the propellant tank.
- Gauging only updates when at least one OMS engine is burning. Otherwise, quantity readings are static.
- Totalizer integrator:
  - Functions during first 15 sec of OMS burn while propellant settles, after which quantities are taken from probe.
  - Functions for an accumulated 108 sec when propellant level is between 45% and 30% (the ungaugeable region), after which quantities are taken from the aft probe.
  - Assumes single engine flow rates.

Rules of Thumb

- 2 ft/sec ~ 1 n. mi.
- % to ΔV conversions:
  - 1% of OMS ~ 5-6 ft/sec
  - 1% of RCS ~ 1 ft/sec
- Accelerations:
  - 2 OMS: ~ 2 ft/sec^2
  - 1 OMS: ~ 1 ft/sec^2
  - ARCS: ~ 0.6 ft/sec^2
- Flow rates:
  - 20 lbs/sec/OME
  - 10 lbs/sec/4+X ARCS
- % to lb conversions:
  - 1% of OMS ~ 130 lb of propellant
  - 1% of RCS ~ 22 lb of propellant
- VGO fraction of ΔVTOT:

	2 OMS	1 OMS	ARCS	FRCS
VGO X	+1	+1	+1	-1
VGO Y	0	±1/5	0	0
VGO Z	+1/4	+1/4	+1/6	+1/3

ENG FAIL / PRPLT FAIL

- "L(R) OMS PC" = OX Blockage
  (√aff OX IN P)

  "L(R) OMS TEMP" = FU Blockage
  (√aff FU IN P)

- For OMS ENG FAIL:
  - OX(FU) IN P is now higher than steady-state inlet pressures.
  - Engine lost, but propellant still available through crossfeed or interconnect.
- For OMS PRPLT FAIL:
  - OX(FU) IN P is now lower than steady-state inlet pressures.
  - Both engine and propellant lost (i.e., neither crossfeed nor interconnect are available).

Performing 2-ENG OMS Burns

- When burn starts:
  - Time the burn (in the event a manual shutdown is required).

    OMS Assist and ATO dumps should also be timed. Backs up OMS quantity gauging. (Needed for OMS 1/2 Targeting.)
  - Check OMS Pc > 80%.
  - Check ball valves > 70%.
  - Note decreasing ΔVTOT.
  - Monitor engine inlet pressures. Note steady-state values.
- For first OMS FAIL (ENG or PRPLT):
  - If ENG FAIL, crossfeed at ½ ΔVTOT remaining.

    Perform "hot crossfeed" (momentarily tie tanks) to maintain good propellant flow to remaining OMS engine.
  - If PRPLT FAIL during OMS 2 or orbit burns, stop the burn (provided HP > MIN HP).
  - If PRPLT FAIL during the deorbit burn, will attempt a crossfeed only after good propellant has run out. (Possibility of blockage being downstream of crossfeed "T".)
- For second OMS FAIL (ENG or PRPLT):
  - Interconnect good OMS propellant to RCS.

    Perform "hot intereconnect" to maintain good propellant flow to RCS jets.
  - Determine RCS burn time using OMS% vs. RCS ΔV chart.

    OMS quantity gauging not active without an OMS engine burning.

    Double burn time if only 2 +X jets (due to RCS failures, FA1/FA2 failures, etc.).
  - If no good OMS propellant remains, complete burn using RCS propellant (but preserve enough for use during deorbit/entry).

OMS RM

- Three events must happen before guidance will downmode:
  - L(R) OMS Pc FAIL (Pc < 80%)
  - Loss of acceleration
  - L(R) OMS ENG - OFF
- OMS↓ on MNVR EXEC display triggered by OMS Pc FAIL <u>and</u> loss of acceleration. (For BFS, OMS↓ triggered by OMS Pc FAIL only.)
- If OMS Pc failed high <u>prior to burn</u>, OMS RM will set the affected OMS Pc FAIL flag at TIG - 15 sec. (Guidance can still downmode.)
- Auto Downmode
  - Occurs when a certain CNTL bus fails (specifically at Pnl C3), and subsequently there is an OMS FAIL (ENG or PRPLT).

    For L OMS: CNTL AB1 or AB2
    For R OMS: CNTL CA1 or CA2
  - OMS RM into thinks L(R) OMS ENG switch is in the OFF position.

    Failure of CNTL AB1 or AB2 (CA1 or CA2) puts the L(R) OMS ENG switch in dilemma.

    The OMS ENG default position when in dilemma is OFF.
  - Crew assumes OMS↓ is a PRPLT FAIL.

    Failure signature looks like ENG FAIL (ENG VLV 1 & 2 < 70%).

    Guidance immediately downmodes once it sees OMS Pc FAIL and loss of acceleration. (OMS ENG - OFF already set in software, regardless of actual switch position.)

    Ball valves closed before crew can diagnose ENG FAIL vs. PRPLT FAIL.
  - No GN2 purge post burn on affected engine.

    Software thinks OMS ENG switch is in OFF, as opposed to ARM/PRESS.

- No Guidance Downmode
  - Two scenarios will prevent Guidance from downmoding, even after the failed OMS engine switch is taken to OFF.

    OMS Pc failed high <u>during burn</u> -- GPCs will never see Pc < 80%, thus never setting the OMS Pc FAIL flag. (Crew can see OMS Pc off-scale high indications on MEDS meter.)

    MDM FA3(4) failures - Commfaults L(R) OMS Pc, so GPCs will never see OMS Pc < 80%, thus never setting the OMS Pc FAIL flag. (Crew can still see OMS Pc on MEDS meter.)
  - After first OMS FAIL:

    TVC DAP will gimbal remaining engine to keep thrust vector through c.g.

    ADI error needles will be incorrect, since they will still be based on a two-engine attitude.

    Guidance commands cut off too soon. (Still thinks it has two OMS engines.) Results in about a 6 ft/sec underburn.
  - After second OMS FAIL:

    Stuck in TVC DAP (i.e., no downmode to RCS). Causes sluggish control (i.e., “sloppy DAP”) because TVC DAP has broader rate deadbands than RCS DAP.

    TVC DAP will downmode to RCS DAP when either:

      TGO = 0,

      Major mode change, or

      Crew maneuvers vehicle 90° out of attitude.

RCS

General

- Nominal uses:
  - Rotational and translational control of the orbiter.
  - Small orbital transfers (ΔV < 6 fps).

    Aft RCS burns:
      OPS 1/3: 4 +X jets
      OPS 2: 2 +X jets
    Fwd RCS burns: 2 -X jets
  - Forward window protection during SRB SEP.
- Off-nominal uses:
  - Abort dumps
  - Single engine roll control (SERC)
  - OMS burn completion
  - RCS wraparound
  - RCS deorbit burn

RCS Subsystems

- Two identical, independent systems for OX and FU. (OX and FU sides are overlaid on FDF schematic.)
- Helium Tanks
  - One helium tank for OX; one helium tank for FU.
  - Helium provides pressurization to maintain propellant flow to the RCS jets.
  - Helium tank leaks.

    Ascent: Crossfeed from non-leaking side to protect for ET SEP.

    Orbit: Set up an RCS burn to “max blowdown” in the propellant tanks (~ 23%).

    Entry: When helium has all leaked out, crossfeed from non-leaking side to maintain entry attitude control.

- Propellant Tanks
  - Store the propellants:

    OX = nitrogen tetroxide
    FU = monomethyl hydrazine
  - Fwd RCS tanks designed to operate in zero g only.
  - Propellant tank leaks:

    Ascent: Crossfeed from non-leaking side to protect for ET SEP.

    Orbit: Set up an RCS burn to depletion (rather than let propellant accumulate in aft compartment).

    Entry: When propellant has all leaked out, crossfeed from non-leaking side to maintain entry attitude control.
- Jets
  - Two kind of jets: Primary and Vernier
  - Primary jets:

    Total of 38 jets:

    14 Fwd; 12 aft left; 12 aft right

    Used for coarse attitude control and orbital translations.

    Each jet produces 870 lb thrust.
  - Vernier jets:

    Total of 6 jets:

    2 Fwd; 2 aft left; 2 aft right

    Used for fine attitude control during OPS 2/8 only.

    Each jet produces 24 lb thrust.
  - Jet Nomenclature:

    X Y Z

    X = Pod: F (fwd) L (left), R (right)

    Y = Manifold: 1, 2, 3, 4, 5

    Z = Plume Direction: U (up), D (dwn), L (left), R (right), F (fwd), A (aft)
  - Primary jets are on manifolds 1 through 4; vernier jets are on manifold 5.
  - All jets are non-gimbaling.
- OMS/RCS interfaces
  - RCS and OMS use the same OX and FU.
  - RCS jets can be used in one of three configurations:

    Straight feed [i.e., L(R) RCS propellant feeding L(R) RCS jets]

    Crossfeed [i.e., L(R) RCS propellant feeding all aft RCS jets]

    Interconnect [i.e., OMS propellant feeding all aft RCS jets]
  - Cannot interconnect RCS propellant to OMS engine. (Could damage the RCS tanks.)
  - Fwd RCS cannot crossfeed with Aft RCS, nor can it interconnect to OMS.

    At one time, engineers considered providing for a Fwd RCS interconnect, but this effort was later abandoned.
- Heaters
  - Collection of pod heaters, panel heaters and line heaters, designed to prevent the propellants from freezing.

    Two circuits: "A" (typically used during first half of mission) and "B" (typically used during second half).

    Caution: Simultaneously running both "A" and "B" OMS pods heaters will result in burnout of the heaters.
  - Collection of jet heaters (for each manifold) to keep jet injectors at operating temperatures.

RCS Quantity Gauging

- Quantity is calculated based on pressure, volume, and temperature (PVT) relationships.
- A helium leak causes erroneous quantity calculations.

  PVT calculations assume that helium moves only from the helium tank into the propellant tank.

- Long RCS burns can temporarily corrupt quantity calculations.

  Long RCS burns cause rapid temperature drops in the helium tank, which impact the PVT calculations.

- A difference of 9.5% between OX and FU quantities will trigger "F(L,R) RCS LEAK" fault message. Message will reannunciate every 9.5% increment.

PASS Jet RM

- Jet Failures
  - *FAIL OFF* - Jet commanded to fire, but no rise in chamber pressure.
  - *FAIL ON* - Jet fires, but with no fire command issued.
  - *FAIL LK* - Jet injector temperatures fall below operating levels (possibly caused by leaking propellant that is freezing on the injectors).
- Jet Fail Limit
  - Initialized at two per pod. Can be modified via PASS SPEC 23.
  - Applies only to PRI jets.
  - Applies only to jets that FAIL OFF or FAIL LK.
- Situations when a jet is no longer available:
  - Manually deselected (PASS SPEC 23).
  - Auto deselected, due to either FAIL OFF or FAIL LK (if still below jet fail limit).

    FAIL ON is <u>not</u> auto deselected.
  - Manifold status is "CL", resulting from:
    1. Taking MANF ISOL to CL.
    2. Overriding MANF STAT to CL on PASS SPEC 23.
    3. Commfaulted manifold status.
    4. RCS manifold dilemma.
    5. JET FAIL ON, with AUTO MANF CL enabled (OPS 2,8 only).
- Resetting RM (via PASS SPEC 23):
  - ITEM 45 (JET RESET) resets RM (i.e., clears FAIL OFF, ON, or LK) for all jets that are not deselected.
  - DES INH once:

    Places affected jet in last priority.

    Prevents FAIL OFF or FAIL LK from auto deselecting affect jet.

    Does not reselect jet.
  - DES INH twice (i.e., toggle RM) resets RM and leaves affected jet in last priority.
- Impacts from BCE STRG X
  - "BCE STRG X B" impacts Fwd RCS; "BCE STRG X D" affects Aft RCS.
  - Manifold status changes to "CLM". (Jets are not available.)
  - GPCs can no longer annunciate FAIL OFF, FAIL ON, or FAIL LK.
  - If jets needed for attitude control, crew can override manifold status to "OPM" to regain affected jets.

    BCE STRG X only takes away feedback to the GPCs. Jets can still be commanded to fire.

BFS Jet RM Differences

- No SPEC 23.

- BFS annunciates FAIL OFF and FAIL ON only when engaged. BFS does not annuniciate FAIL LK.

- BFS does not show manifold status unless engaged.

- BFS will annunciate and auto deselect only the first FAIL OFF, and only if it is not previously FAIL ON.

  BFS will simply annunciate subsequent FAIL OFF jets.

Reconfiguring RCS

- Rules of Thumb
  1. Do not starve a jet.
  2. Do not feed a leak.
  3. Do not tie tanks.
- When securing RCS, work from bottom up.
  1. Close manifolds.
  2. Close crossfeed valves (if applicable).
  3. Close tank isolations.
  4. Close helium isolation.
- When reopening RCS, work from top down.
  1. Open helium isolation.
  2. Open tank isolations.
  3. Open crossfeed valves (if applicable).
  4. Open manifolds.

Auto Crossfeed

Assumes AFT L,R RCS TK ISOL and XFEED are in GPC position

- Auto crossfeed sequence
  - Active in PASS OPS 1, 3, and 6.
  - If OX(FU) TK P < 220 psi, crossfeed from other pod automatically established.

    Triggers "L(R) RCS XFEED" fault message.
  - Protects against He REG FAIL LOW.
- Master crossfeed sequence
  - Available in PASS OPS 1, 3, and 6.
  - Reduces crossfeed from L(R) RCS to a single switch throw.
  - Used especially for leaks during dynamic flight.
  - Limits the number of jets that fire simultaneously.

    The flow rate from a large number of jet firings could damage the propellant tank.

    Throwing the MSTR XFEED switch will limit simultaneous jet firings, even if crossfeed was configured manually.

Interconnected Abort Dumps

Assumes the GPC position for the AFT L,R RCS TK ISOL and XFEED, as well as the L,R OMS XFEED.

- For interconnected abort dumps, Smart Interconnect will automatically reconfigure OMS and RCS valves when dump is initiated.
  - Interconnected dumps normally burn 2 OMS engines with all 24 aft RCS jets (i.e., 2+24 dump).
  - If OMS or RCS valves do not configure properly (due to DPS or EPS failures, etc.), the dump will burn either:

    2 OMS engines with 10 aft RCS jets (i.e., 2+10 dump), or

    2 OMS engines only, depending on which valves are misconfigured.
- Smart Interconnect will automatically reconfigure OMS and RCS valves back to straight feed when dump is complete.
  - Certain DPS and EPS failures can result in the OMS and RCS being left with tied tanks post-dump.
  - MCC may call the crew to manually reconfigure OMS and RCS post-dump.

APPENDIX D RULES OF THUMB

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This appendix is a compilation of the rules of thumb from the body of this manual. Topics are organized alphabetically keyed on commonly used acronyms and abbreviations.

APU/HYD

- APU fuel usage rates vary with loading, but average 1% per minute (3 to 3.5 lb/minute). Usage rates are reduced by about *two thirds* if the hydraulic main pump is taken to low pressure (*HYD MAIN PUMP PRESS* switch on panel R2 set to *LOW*), as is done during the abort once around deorbit coast period.

- The APU injector cooling tank shared by all three APUs contains enough water for 21 minutes of continuous flow. This is enough for six complete 3.5-minute injector cooling cycles.

- If all water spray boiler cooling is lost to the lube oil after an APU reaches full operating temperatures, only 4 to 5 minutes of operating time are available before *non-catastrophic* bearing seizure occurs. The APU should be able to support from Mach 1 to the ground. Expect overtemp alarms, and MCC should call for immediate shutdown after wheels stopped.

Ascent

- Monitor roll program on the ADI and BFS ASCENT TRAJ display.

- Before L/O +90 seconds, BFS engage is the crew's only option for loss of guidance and/or control. After 90 seconds, the crew can try CSS.

- Monitor the trajectory on the ASCENT ADI cue card and the PASS and BFS *ASCENT* TRAJ displays. The Shuttle bug and predictors should follow the nominal trajectory line. Also monitor the HSI for the inertial velocity to be in the desired orbit insertion plane.

- Monitor guidance convergence by observing PASS and BFS TMECOs converging to expected time.

- If the crew takes CSS, they should take manual throttles. If the crew takes manual throttles, manual shutdown is required unless a low level shutdown occurs due to low performance. The cue for MECO is the BFS MECO cutoff bug or planned MECO V_I minus 150 fps.

- Use OMS 1 TGTING cue card for system problems and OMS 1/2 TGTING cue card for performance problems to determine proper OMS 1 and 2 targets.

CCTV System

- When the VCU is powered on, the crew must wait 10 seconds before any CCTV commands can be accepted. This time is used to initialize the VCU.

- Always wait at least 10 seconds after powering off a camera before powering it back on. This gives the iris enough time to fully close.

- Always wait at least 10 seconds after switching from the RMS wrist camera to the RMS elbow camera before switching back to wrist, and vice versa. This gives the iris enough time to fully close.
- Never leave a payload bay camera in a manual mode (either semi- or full) while in direct sunlight or any bright light. Damage to the camera will result.
- If neither you nor Mission Control is using a camera for extended periods, power it off to conserve energy and to keep it cool.

Communications System

- When the TDRS has an elevation of greater than +70 degrees or less than –60 degrees relative to the orbiter (as shown on OPS 201), there is a risk of degraded communications as the orbiter nose or tail blocks line of sight between the orbiter antenna and the TDRS.
- SM OPS 201 Antenna display shows an S-band PM signal strength of 2.50 for the true received signal strength of 0 indicated on the F9 and A1U meters.

C/W System

- The *SENSOR RESET* switch on panel L1 should be pressed when smoke concentration goes below 1.8. This prevents masking of alarms.
- When panel R13U is not in use, the *PARAMETER SELECT* thumbwheels should be set to a value greater than 119.
- Crewmembers should reset fault messages as quickly as possible after review to avoid covering other messages.
- The fault summary should be reviewed regularly to avoid missed fault messages.

DPS

- Always deassign IDPs from fail to sync GPCs and reassign to good GPCs to avoid inadvertent entries (NBATs/restrings, burn targets, etc.).
- Before OPS transitions and restrings, always verify the appropriate NBAT is what you want it to be; never assume that it is correct! Also check the proper major function and GPC switch configuration. Post OPS transitions and restrings, check good configuration with SPEC 6.
- Make sure you have the correct memory configuration called up before you start making NBAT changes.
- During OPS transitions, keep "hands off" everything, including all switches and item entries.
- Always clear the Fault Message line as soon as you have seen the message; otherwise, you may miss subsequent annunciations from other failures.
- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both *MODE* and *OUTPUT* talkbacks are barberpole). If not, take the offending GPC to *HALT* (or if this does not work, power it *OFF*) immediately to avoid I/O problems on the flight critical strings.
- It is a very good idea to resume SPECs and DISPs from IDPs when not using them or before going to another major function on that IDP.
- When moding PASS GPCs into the common set (i.e., STBY-RUN), always pause 10 seconds before making further switch throws or item entries to avoid a possible fail-to-sync and to ensure proper common set initialization.
- It is important to be able to identify GPC failures, for Mission Control often has little insight. The information you provide will affect Mission Control analysis and its ability to plan for subsequent failures (both DPS and non DPS).
- Always hard assign IDPs (both PASS and BFS) via PASS IDPs (BFS will DK listen). You can cause dual commanders if you try to assign BFS to an IDP that a PASS GPC is still driving via a BFS IDP keyboard.
- Always distribute your IDPs among different GPCs. On orbit, always be sure SM is not on all IDPs at the same time; if you lose SM, you

also lose PASS DPS display interface. The same applies for single GPC GNC OPS configuration.

- When using the *GPC MODE* switch, always take your hand off between positions. On past missions, there have been problems with the switch being in two positions at the same time. This problem can occur on other orbiter switches too. It is a good idea to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.
- The *IDP/CRT SEL* switch should always be checked before making a keyboard entry, and data should always be checked on the DPS display scratch line before it is entered.
- When moving GPC mode switches from RUN to STBY or STBY to RUN, refrain from moving any other GPC monitored switches or making keyboard entries for 10 seconds.

ECLSS

NOTE

Numbers presented here are for typical orbit power and heat loads and may vary significantly depending on attitude and power loading.

- Supply water tanks fill at about 6.7 percent per hour *(if filling into a single tank),* depending on fuel cell load (.77 lb/kW hr ÷ 1.6 lb over 1%; 14 kW typical orbit power load).
- Water tanks empty at about 100 percent per hour for a water dump, about 50 percent per hour when using the FES high load evaporator for cooling with payload bay doors closed, and about 16 percent per hour when using the FES topping evaporator for supply water dumps on orbit with the doors open.
- On-orbit cold soak is good for 20 to 30 minutes of cooling. Prelaunch Freon conditioning is good for *about 5* minutes of cooling.
- NH_3 boiler supply is good for 35 minutes of ground cooling *for the first tank and 25 minutes for the second tank*.
- A single cryo O_2 tank is good for about 2 to 3 days of orbit usage depending on crew size and power level. H_2 tanks are sized to match O_2 usage.
- A single LiOH canister is usable for about 48 man-hours.
- Choose the NH3 controller such that it is controlling to the slow Freon loop but not a dead loop.

Entry

- 2 OMS: TGO $\approx \Delta VTOT/2$.
- 1 OMS: TGO $\approx \Delta VTOT$.
- RCS: TGO $\approx 1.7 \times \Delta VTOT$.
- Prior to the first bank, monitor vehicle attitude at 0 degrees bank and 40 degrees alpha.
- First bank (flight path angle capture) should occur at a drag acceleration of approximately 3 fps^2 and/or q-bar of approximately 8 psf.
- Monitor the trajectory on the ENTRY ALPHA cue card, and the PASS and BFS TRAJ displays:
- The Shuttle bug superimposed on guidance box superimposed on nominal trajectory line.
  - Actual drag equal to reference drag.
  - Appropriate bank angle, H-dot, range and altitude.
- For an off-nominal trajectory, check that guidance is working to put the guidance box back on the Shuttle bug (zero range error) within the trajectory envelope.
- Attempt to contact MCC before taking CSS.

- If you must take CSS:
  - Control range by controlling drag.
  - Control drag by controlling H-dot.

Hdot Desired =
(Dcurrent - Dref) x 20 + Hdot Ref

  - Control H-dot by controlling H-double dot.
  - Control H-double dot by controlling bank angle.
  - Control everything slowly by small corrections.

EPS

- *Never* close a circuit breaker or reset an RPC found out of configuration without MCC coordination.
- Loss of cooling to a fuel cell requires crew action within 9 minutes to prevent a catastrophic loss of crew/vehicle due to possible fuel cell fire and explosion.
- Any interruption of continuous AC power during ascent *will* result in the loss of main engine controller redundancy. Reconfiguration of AC powered equipment prior to MECO should be avoided.
- *Never* connect or reconnect power to a known shorted or failed component; this includes switch throws, circuit protection device resets, or bus ties.
- Fuel cell run limit prior to shutdown for loss of cooling is 9 minutes at a 7 kW nominal load. Run time varies inversely with fuel cell load.
- Three oxygen and hydrogen tanks are good for up to 8 days on orbit; five oxygen and hydrogen tanks are good for up to 12 days on orbit. Duration varies with crew complement and power load. *SSPTS will extend on-orbit duration by lowering fuel cell loads.*
- A fuel cell hydrogen pump uses 0.3 amps/AC phase; a coolant pump uses 0.5 amps/AC phase.

EVA

- Always use "make before break" tether protocol.
- Do not use the glove as a hammer.
- EVA crewmember must remain tethered at all times.
- Slow and deliberate motion provides much greater stability than quick, jerky motions.
- Body positioning is 90 percent of the task.
- Each EVA crewmember should check out his or her own EMU.

GNC

- The PASS FDIR for the RGAs, AAs, and aerosurfaces terminates after the first failure. After the first failure, crew management of the selection filter is required. For the BFS selection filter, crew management is always required. Proper selection filter management is required for proper control.
- For FCS channel management:
  - Never have more active channels on one GPC than another.
  - If there are two failures on the same actuator, take the remaining FCS channels to *OVERRIDE.*
  - Always maintain two good commands and one good feedback on each aerosurface.
  - Delay 2 seconds between switch throws when moving *FCS CHANNEL* switches.
  - Port bypass, or port pop, is a mechanical means to avoid force fights; feedback deselection is a software means to avoid a bad input into the selection filter.
- For ascent, only the pilot's SBTC is active. To get manual throttles, the pilot must depress the *TAKEOVER* button and then match the

commanded throttle setting. Manual rotational control is available only in PASS and must be both pitch and roll/yaw.

- For entry, both SBTCs are active. To get manual speed brake, the CDR or pilot must depress the *TAKEOVER* button. Manual rotational control is available in either pitch or bank in PASS, and required in both axes in BFS.

- For TACAN and ADTA management, talk to MCC before incorporating.

- Without communication, the crew will use the NO-COMM TACAN MGMT and ADTA MGMT cue card.

Landing/Deceleration System

- Landing gear should not be deployed at equivalent airspeeds greater than 297 knots.

- ± 1 knot of touchdown speed corresponds to ± 100 feet of distance.

Lighting System

- Power consumption of cockpit lighting can be as much as 1 to 2 kW with all lights on.

- When payload bay floodlights are turned off, they should remain unpowered for 10 to 16 minutes prior to repowering.

- *When payload bay floodlights are turned on, they should remain powered for 10 minutes prior to unpowering.*

Mechanical Systems

- Always use a timer when operating mechanical systems, noting either dual or single motor time. Do not continue driving if greater than the single motor time has elapsed without the mechanism reaching the desired state. If motion stops prematurely, take the mechanism switch(es) to Stop.

MPS

- Direct insertion MECO is usually close to 8 minutes 30 seconds.

- For three engines at 104 percent, fuel consumption is about 1 percent propellant/ 5 seconds. For three engines at 65 percent, fuel consumption is about 1 percent/8 seconds.

- An SSME will consume approximately 4 percent propellant per engine per minute at 104 percent. Propellant remaining is displayed on the PASS ASCENT TRAJ 2 display and is a guidance-calculated number.

- Selecting max throttles greatly increases the risk of a catastrophic failure occurring. As such, max throttles are only used in cases of severely degraded ascent performance.

- Five ways to set MECO confirmed are:
  - 3 Pc's < 30%
  - 2 Pc's < 30% and a data path failure
  - 3 SAFING commands (i.e., pressing all three SSME pushbuttons)
  - OPS 104 PRO (OPS 602 PRO will not set MECO CONFIRMED)
  - Fast ET sep

- *MAIN ENGINE SHUT DOWN* Pushbuttons:

  - With two good contacts, the pushbutton will generate both the SHUTDN command and the SAFING command.

  - With one commfaulted contact, the pushbutton will only generate the SAFING command.

  - With a broken contact (due to CNTL bus or a contact failed OP), the pushbutton is in dilemma and will not generate the SHUTDN command nor the SAFING command.

  - A broken contact can be masked by a commfault (via FF MDM power cycle) so that the pushbutton can once again generate the SAFING command.

  - A SAFING command, in the presence of a Data Path Failure will set into motion three things: 1) mode guidance, 2) mode flight control, and 3) close the prevalves.

  - Because BFS does not recognize commfaults, a commfaulted contact is the same as a broken contact.

- Do NOT use the *MAIN ENGINE SHUT DOWN* pushbutton for these cases:
  - Data Path Failure + Commfaulted button
  - Data Path Failure + Command Path Failure

  SHUTDN command either not generated (commfault) or is ignored by the controller (command path failure).

  SAFING command is generated. Coupled with a Data Path Failure, this closes the prevalves on a running engine, resulting in catastrophic shutdown.

- On panel R2, the *MPS ENGINE POWER* switches (or "AC switches") look very similar to the *He ISOLATION* switches. Also, both sets of switches are located close together. ***Use caution***.

- A Command Path Failure must always be shut down manually pre-MECO via AC/pb.

- Throwing the AC switches to OFF creates a Data Path Failure.

- An "SSME FAIL C(L,R)" message indicates that the GNC software has recognized an engine shut down.

- An engine with a Data Path Failure will never display a red *MAIN ENGINE STATUS* light, even after shutdown.

- Limits must be enabled on an engine when the helium regulator pressure begins to decay due to a helium leak. An SSME will almost certainly fail catastrophically if there is insufficient helium, and limit shutdown is inhibited.

- With three SSMEs running, an hydraulic lockup or electric lockup will be shut down pre-MECO to protect NPSP in the event of a low-level cutoff.

- Actual throttle levels on the first stage throttle bucket can vary due to SRB thrust level dispersions. This is an artifact of "first stage adaptive guidance."

- Loss of an APU means the affected engine is in hydraulic lockup. Can also trigger "MPS CMD C(L,R)" messages post-MECO during MPS dump.

- Manual shutdown cues of VI=23K (3-ENG), 24.5K (2-ENG), and 22.5K (TAL) correspond roughly to 30 seconds before MECO.

- APC4(5,6) or ALC1(2,3) Failures:
  - For ALC failure, BFS GNC SYS SUMM 1 shows the following:

```
ULL P LH2   12.0↓
      LO2    0.0
```

  - For APC failure, along with the same ULL P indications for an ALC failure, there is also an "SM2 APU SPD LO 1(2,3)" fault message.
  - C(L,R) He ISOL A has failed closed. Do not attempt leak isolation steps.
  - Treat helium leaks on affected engine as non-isolatable.

OMS

- 1 percent of OMS propellant

  = 6 fps ΔV

  = 3 n.m. ΔHp

  = 130 lbs (80 lbs oxidizer, 50 lbs fuel)
  uses 40 psi of helium for long burns.

- One OMS engine causes approximately 1 fps^2 acceleration.

- For OMS ignition, there must be power and command to at least one coil on both control valves.

- OMS TVC requires an enable discrete from the FF MDM, and commands from the FA MDM.

- FUEL INJECTOR TEMP message may be a signature of a bad temperature transducer or a fuel blockage.

- CHAMBER PRESSURE message may be a signature of a bad pressure transducer or an oxidizer blockage.

- There are several failures that inop OMS FDI (FA3(4) MDM commfault or Pc transducer failed high).

- Always check redundant sources to confirm any malfunction.

- An OMS engine failure post-MECO should be signified by a down arrow on the MNVR display.

- Max blowdown on the OMS is approximately 39 percent.

- 1,000 lb of OMS (approximately 8 percent) moves the X c.g. 1.5 inches aft and the Y c.g. 0.5 inches left or right.

- Max OMS quantity for landing = 21 percent.

Orbit

- In propellant-limited situations, use the following guidelines:

  - Stay in VERN as much as possible.

  - To conserve forward RCS, use TAIL ONLY control mode.

  - During prox ops, when controlling out-of-plane errors, start as early as possible, wait for the node to make inputs to null rates, watch the deadbands, and do not fight orbital mechanics effects.

- TRAJECTORY:

  - NC: Sets up 1-rev transfer to Ti

  - NCC: 1st onboard targeted burn targets the Ti point

  - Ti: Burn (usually posigrade) that sends the orbiter into proximity with the target, uses RADAR data

  - MC1-4: Midcourse correction burns

  - Out-of-Plane Null (OOPN): Usually between MC1 and MC2, places target and orbiter co-planar (Y = 0)

  - Ti Delay: Places orbiter in a football-shaped holding pattern, posigrade (Ti DVX +3 fps)

  SOURCE OF ERRORS: Trajectory

  Attitude maneuvers and jet cross coupling

  Burn trims

  Orbiter vents (APU, FES, etc.)

  Drag uncertainties

- STAR TRACKER PASS:

  - Deselect an IMU during ST pass to reach 2-level (RM will prime select an IMU for attitude)

  - Monitor RESIDS < 0.05 (BREAK TRACK if locked onto star or debris)

  - Assumes on PROP vector, FDF provides criteria to select FLTR vector

  SOURCE OF ERRORS: Star Tracker Pass

  Prime selected IMU attitude problem

  Either IMU accelerometer problems

  Star tracker bias

  Maneuvers and length of time since last state vector update

  Marking on a star instead of the target

- RADAR PASS:

  - Use radar if range <135 k (range eclipsing at greater ranges)

  - Radar data verifies data from ST pass

  - Procedure handles either FLTR or PROP vector selected

  - Procedure provides criteria to select FLTR vector or to do FLTR to PROP vector transfer
  - INH angles data and mode radar to ATRK during maneuvers to burn attitude

  SOURCE OF ERRORS: RADAR Pass

    Range eclipsing

    EL/AZ greater than 30 deg

    Ku biases (range).

- TARGETING:
  - Onboard targeting done on SPEC 34
  - Load BASE TIME (Ti TIG) to TGT SET #1
  - Load and verify TGT SETs with ITEM 1 +
  - Compute burn solutions with ITEM 28
  - MC2 TIG based on elevation angle constraint (rather than a particular time), so MC2 TIG can change

    -3 and +7 minute TIG slip limits

    MC2 TIG becomes the new BASE TIME

- NAV MANAGEMENT:
  - Always have a FLTR vector
  - Upon RNDZ NAV enable, PROP vector is created and TGT vector begins propagating
  - Perform FLTR to PROP vector transfer after new sensor acquisition
  - If commfault or suspect bad data, then troubleshoot and ask questions
- BURNS:
  - ΔV <4 fps - Multi-axis RCS burn (DAP:LVLH)
  - ΔV >4 fps - +X RCS burn (maneuver to attitude, then DAP:INTL)
  - ΔV >6 fps - OMS burn (maneuver to attitude, DAP:AUTO)
  - Posigrade burns: Thrust Vector Roll (TVR) = 0
  - Retrograde burns: TVR = 180
  - For RCS burns, DAP TRANS: NORM until VGO <1 fps then PULSE
  - If VGO Z is positive: burn X, Y, Z
  - If VGO Z is negative: burn Z, X, Y
- PTG/DAP MANAGEMENT:
  - -Z target track until reaching the R-bar, then +ZLV
  - A7/VERN – Used for attitude hold (1 deg attitude deadband, 0.016 deg/sec rotation rate)
  - B7/PRI – Used for maneuvers (2 deg attitude deadband, 0.5 deg/sec rotation rate)
  - TRANS pulse size = 0.1 fps during RNDZ, .05 fps during prox ops
- SYSTEMS CONCERNS (single point):
  - GNC GPC FAIL:

    2 GNC GPCs are required for Ti and PROX OPS

    RNDZ NAV is disabled when go through OPS 0 (such as during redundant set expansion or contraction). Only the FLTR vector is saved when RNDZ NAV is disabled. Restrings do not affect RNDZ NAV

CNCL pointing option (TGT ID = 1) before RNDZ NAV disabled

  - MDM FF3:

    Loss of VERN jets

    Loss of RADAR data to NAV (display on Panel A2 is unaffected

    Loss of -Y star tracker

  - MDM FA1 or FA2:

    Loss of VERN jets

  - MDM FF1:

    Loss of -Z star tracker

  - PL 1:

    Loss of automatic Ku pointing (Ku modes: GPC and GDSG lost)

  - IMU 2 - Restring 1221 for IMU redundancy

- MISCELLANEOUS:

  - 1 fps posigrade or retrograde =:

    16 kft downtrack/rev

    3.5 kft radial/0.5 rev

    0.5 nm altitude change (HA or HP)

  - 1 fps radial =:

    3.5 kft downtrack/0.5 rev

    900 ft radial/0.25 and 0.75 rev (decoupled from the other axis)

  - 1 fps Out of Plane = 900 ft/0.5 rev (decoupled from the other axis)

  - LVLH rate = 0.06 deg/sec; 4 deg/min; 360 deg/90 min

  - Expending about 35-40 lb of RCS propellant to maintain attitude results in a cross-coupling of 1 fps in –Z direction

  - In propellant-limited situations, use the following guidelines:

    Stay in VERN as much as possible

    To conserve forward RCS, use TAIL ONLY control mode

    During prox ops, when controlling out-of-plane errors, start as early as possible, wait for the node to make inputs to null rates, watch the deadbands, and do not fight orbital mechanics effects

PDRS

- Whenever there are both talkbacks and DPS displays that reflect microswitch status, they should ALWAYS both be checked during any operation affecting them.

- Whenever troubleshooting RMS malfunctions in the long-form MAL book, always READ AHEAD. The MALs sometimes may require an operator response after the execution of the block, which is listed in the next block, depending on the path that is taken.

- The hand controllers are rate-proportional and are extremely sensitive. They should be held in such a way that you can control the full range of inputs without ever stopping to rearrange your hand. Care must be taken to not overcontrol the inputs. A good practice is to slowly and steadily input a desired command, wait patiently until you see the reactions of that command on the arm, and as the desired motion is achieved, slowly back off the input. Ideally, you should reach the axis detent at the same time the arm achieves the desired position and attitude.

- MPM motion may cease during deployment or stowage before the expected microswitches are made. This is due to the fact that the last part of travel in either direction is when the overcenter lock is locking. Therefore, don’t turn off the *PORT RMS* switch when visible motion stops. Wait for the microswitches.

- Practice safety habits, the most important of which are brakes on, then power off (if required) for abnormal joint response and use EE CC for abnormal EE ops during the specified conditions.

- During arm cradling, periodically check all joint angles to make sure that joints that you have already aligned to zero have not moved.
- CCTV cameras have a tendency to malfunction at the most inconvenient times. Expect this and know how to perform all operations without cameras.
- Develop a scan pattern that encompasses window, CCTV, and panel status.
- Always remember what the DAP should be for the operations you are performing. In addition, keep in mind the down mode option for the DAP in case the arm enters an unexpected singularity or reach limit.
- Never rotate the *MODE* switch through *DIRECT* while the brakes are on. This actually puts the arm in mode, and sets you up for a possible runaway if a *SINGLE/DIRECT DRIVE* switch failure occurs or is present.
- Verify the *RATE* switch setting by feel <u>and</u> talkback status. This should be done EVERY TIME prior to moving the arm, regardless of mode.
- Make sure you know the proper definitions of “cradling,” “stowing,” “berthing,” “mating,” and “installing.”
- Rates for berthing/unberthing: Usually maintain rates at about 0.01 to 0.02 ft/sec between Z = 414 and -438. For Z < -438 (away from the bay), rates can be increased somewhat.
- For berthing or unberthing of payloads with keel trunnions: the keel pin enters/exits the AKA when the longeron trunnions are at the top of the built-in 8-inch PRLA guides.

RCS

- 1% RCS prop = 1 fps ΔV.
- 1% RCS prop = 22 lb.
- 1,000 lbs of ARCS prop moves X c.g. 1.2 in, X c.g. ± 0.4 in.
- 1,000 lbs of FRCS prop moves X c.g. –3.5 in.
- ARCS max blowdown qty 24%.
- FRCS max blowdown qty 22%.
- Loss of a single downfiring vernier jet is loss of vernier mode.
- If fuel tank pressure is 20 psi higher than the oxidizer tank pressure, then verniers are NO-GO.
- Always secure the RCS from the manifolds to the helium tanks.
- Always open the RCS from the helium tanks to the manifolds.

TAEM and A/L

- A 100-ft-difference in gear deploy altitude equals about 250 ft of touchdown energy. Gear deploy should not be delayed past 200 feet altitude.

- 90 ft of touchdown distance corresponds to 1 knot of airspeed.

- TAEM guidance uses pitch to control range, bank angle to control ground track, and speed brake to control q-bar.

- Overhead HAC with NEP allows the most downmode options for energy.

- Fly theta limits at Mach < 2 (NLT Mach 1.5) if air data is not incorporated to G&C. Maximum bank angle is 50 degrees.

- OGS is 20 degrees lightweight (< 222,000 lb) and 18 degrees heavyweight (> 222,000 lb). Aimpoint is 7,500 ft nominal and 6,500 close-in. Touchdown speed is 205 knots heavyweight and 195 knots lightweight.

- Chute deploy at 195 knots.

- Start derotation with beep trim at 185 KEAS at approx. 2 deg/sec. At nose gear touchdown, manually back up WOW/WONG.

- During training, pilots should strive for a threshold crossing height of 25 to 30 feet on nominal approaches. Touchdown goals are airspeed within 5 knots of the target value, sink rate within structural limits, negligible lateral drift, and minimal RHC activity. A good target value for sink rate is 3 fps or less, insuring ample margin before violating limits.

- With NWS in 1 or 2, the orbiter tends to turn into a crosswind. With NWS *OFF*, the orbiter will tend to turn away from a crosswind.

- If the orbiter is landing with a known failed tire, special landing techniques are used to try to save the second tire on that axle.

- If both main gear tires fail on one side, the orbiter will tend to turn toward that side. The turning moment due to crosswind can either reinforce or reduce this effect, as will the drag chute due to weathervane effects. The orbiter will turn into the crosswind and the drag chute will also cause the orbiter to turn into the wind.

- If the flat tire is on the upwind side, rudder pedal input opposite the blown tire will be required. If the flat tire is on the downwind side, the effects are balanced and minimal rudder input is required.

- Flight Rules call for landing with an existing crosswind on the same side as a known or expected bad tire.

Performance Rules of Thumb

ASCENT

Ascent Performance Margin Management Reserve Req. (lbs)
Pre Flight Design Requirements Document = 3500
Flight Design Requirements Document = 2500
Cargo Integration Review = 1500
Flight Planning Stowage Review = 1500
FPR = 4652

ORBIT

1 hr launch delay = change in orbital noon by 4 minutes

Ascending node
28.5 deg - 1st ascending node is @ Long = 173.38 East
57 deg = 121.55 West

MISCELLANEOUS

Orbiters
OV103 - Discovery
OV104 - Atlantis
OV105 - Endeavor

Min planned flt duration = 96 hours

Max/Min Beta Angle
Max = 23.5 + orbital inclination
Min = 23.5 - orbital inclination

Time
CDT = GMT - 5 hr
CST = GMT - 6 hr
Daylight savings time from 1st Sunday in April to last Sunday in October

DESCENT

Xcg Limits
FWD = 1076.7 in (RTLS = 1079.0 in)
AFT = 1109.0 in
CONT AFT = 1119.0 in

D/O Delta V's
Descending approach is worst case ΔV
90 deg prebank will decrease ΔV ~ 10 ft/s (function of altitude)

If Xcg > 1091.5: 1 in Xcg = 2.2 miles
If Xcg < 1091.5: 1 in Xcg = 1.1 miles
As Xcg increases (more aft), XR decreases
1 nm XR = 5780 lbs EI weight
1 nm XR = 4.38 nm D/O altitude
As altitude and weight increase, XR increases
As inclination increases, XR increases (non-linear)
As temp increases, XR increases (non-linear)

Touchdown speeds
195 kts if TD weight < 222 k lbs
205 kts if TD weight > 222 k lbs

10 kts slower if short field speedbrake guidance mode is used if 200 k lb < TD weight ≤ 245 k lbs

Derotation 185 KGS with beep trim (Prime) or with RHC (manual) derotation (Backup)

Mass Moment
MM = TD Weight * (1172.3 - Xcg)/12
for medium lakebed runways
If MM > 1.47 M ft-lbs Concrete desire
If MM > 1.54 M ft-lbs Concrete required
Note: If TD Xcg not known, use Xcg @ M = 3.5 + 1.5 in

Landing Weight Limits
EOM 233 k lbs
RTLS 242 - 248 k lbs *
TAL 241 - 248 k lbs *
AOA 233 - 240 k lbs *
(Abort limits a function of Inclination)

Noctilucent Clouds
If Inc > 50, do not enter on descending opportunity June through August.

RENDEZVOUS

1 deg of phasing/hour = 10 nm of Δ height
1 deg of phasing = 60 nm
17.5 ft/s burn changes other side of orbit 10 nm
440 ft/s burn will change plane by 1 deg of wedge
1 deg of ΔRAAN occurs for each relative lap

PROPELLANT

1 deg of plane change = 440 ft/s

OMS philosophy
1 ft/s = 21.8 lbs OMS @ 220 k lbs ~1/6%
1.78 ft/s = 1 nm

Maximum OMS load
OV103/4 = 25064 lbs
Min = 10800 lbs
Max OMS ballast = 4000 lbs
1% OMS = 130 lbs/side

Hard Ballast
OV103/104 - Bay 13

RCS philosophy
1 ft/s = 25 lbs (+ X) or 35 - 40 lbs (multi axis) @ 220 k lbs
Max burn = 250 sec = 55 fps
Full FRCS = 2446 lbs
ET blowdown offload = 2225 lbs
Min FRCS - 1862 lbs
Full ARCS = 4970 lbs (over 100%)
1% ARCS = 22 lbs/side

IINTERCONNECT logic
If OMS < 14,000 lbs, I/C off
If OMS > 17,000 lbs, I/C on
If 14 k < OMS < 17 k, analysis req.

ECS - N2

OV103/4
5.28 lbs/day for 4 person crew @ 14.7 psi
add .114 lbs/day for additional crewmember
3.66 lbs/day for 4 person crew @ 10.2 psi
add .079 lbs/day for additional crewmember

	Dry wt	Fully loaded wt
N2	83 lbm	143 lbm

EPS

.09 lbm Hydrogen = 1 kwh
.7 lbm Oxygen = 1 kwh
.07 lbm Oxygen/hour = cabin leak rate

	Dry wt	Fully loaded wt
H2	227 lbm	319 lbm
O2	215 lbm	996 lbm

* Orbiter Engineering Memo VE3-90-096.

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APPENDIX E OI UPDATES

CONTENTS

OI-33 SUMMARY E-1
Change Requests E-1

OI-33 SUMMARY

OI-33 FSW, like the OI-32 FSW, adds numerous capabilities as well as corrections to existing capabilities. Most of the OI-33 CRs changed details of flight software code but did not change how the vehicle systems are monitored or operated by the crew. Summarized below are the most operationally significant/apparent functional changes of this OI. The significant operational changes affect PASS enhancements, OMS gimbal selection, ADI rate pointer travel, GRTLS Alpha recovery, three-engine-out SERC, ET SEP improvement, and adds SPEC 54 Bearing displays.

Change Requests

CR 93073: PASS Non-Universal Enhancement (PASS)

Changes I/O ERROR and BCE STRG messages to Class 2 Caution and Warning (Master Alarm) from Class 3 (SM Alert) when not detected by the entire GPC redundant set.

CR 93074A - MM102 Three Out SERC (PASS)

Automatically enables Single Engine Roll Control (SERC) when three SSMEs are recognized as failed in first stage.

- *Eliminates the need to manually initiate SERC in "3 OUT First" block on the Contingency Abort Cue Card*
- *Simplifies the Contingency Abort Cue Card by combining the "3 OUT FIRST" and "3 OUT SECOND" blocks into one procedural block, now titled "3 OUT COLOR"*

CR 93075D- Correct OMS ZAP Command Timing (PASS and BFS)

Modifies the relationship between issuance of the Zap command and OMS TVC gimbal selection.

- *No longer a need to perform OMS gimbal selection twice on the Mnvr Exec Display as a result of a gimbal failure or GPC/MDM loss*

CR 93084: SPEC 60 Checkpoint Capability Enhancement (PASS)

Adds SM Mass Memory assignment and checkpoint retrieval item entries to SPEC 60 "SM TABLE MAINT" Display.

CR 93098A - Reverse Direction of ADI Rate Pointer Travel (PASS and BFS)

ADI rate pointer direction of travel is reversed for all flight phases, except when functioning as HAC predictors during TAEM.

- *Rate pointers now move in the direction of vehicle rotation, which means they are no longer fly-to to null rates, instead they are fly-to to establish rates.*

CR 93160: Year End Roll Over (YERO) Reset (PASS)

Allows in-flight reset to January 1 without an IPL and complicated procedures while maintaining a good state vector.

CR 93174A - Improved GRTLS TAEM "Alpha Trap" (PASS & BFS)

The alpha transition logic controlling the GRTLS Alpha Recovery to Nz Hold flight phase is separated into two I-loads, forming a transition hysteresis for moding to Nz Hold.

- *The logic is armed when alpha increases above 45° and fired when it subsequently decreases below 35°.*
- *The existing Nz trigger for the Nz Hold phase is not changed with this CR.*

This prevents premature moding to Nz Hold by reducing the likelihood of a CSS or 3-engine-out contingency that is induced early into Nz Hold due to difficulty controlling alpha when flying Alpha Recovery post ET separation.

CR 93087E - RTLS ET Separation Improvements (PASS and BFS)

Intact RTLS mated coast and ET separation guidance and flight control are changed to increase the success rate of RTLS ET separation. With a GPC failure taking a manifold of jets in each pod, the success rate improves to something greater than 84 percent with one sigma environment and systems dispersions present.

- *Alpha target for RTLS MECO is 0° (vs. -2° previously).*
- *After 11.3 sec of mated coast, DAP commands a -0.8 deg/sec pitch rate that will result in an alpha of approximately -2.8° for ET separation.*
- *Speedbrake is commanded to 80 percent immediately after MECO in MM601 (not visible on the SPI until MM602, but can be monitored on GNC SYS SUMM 1).*
- *ET SEP INH message due to an out-of-limit alpha is eliminated because the delay is changed from 6 seconds to 2.2 seconds.*
- *Remaining changes are internal to the DAP (updated flight control laws to improve pitch and roll control authority).*
- *Intact and POWERED CSS RTLS procedures are updated to reflect the new MECO alpha target and subsequent mated coast maneuvering.*
- *The MPS CMD/HYD/ELEC Cue Card was updated to target engine shutdown when applicable on an RTLS, at an alpha of +2° (a = +2) (vs. -1° previously).*

CR 93090E - Bearing Displays - SPEC 54 (PASS)

Adds SPEC 54 to PASS GNC during ascent and entry, a new phase tailored "BEARING" display that provides a geographical representation of the current and targeted trajectory in the horizontal plane relative to multiple landing sites. Additionally, a new item entry is added on the ENTRY TRAJ display to allow range monitoring of trajectory progress to two alternate sites, in addition to the currently selected site.

- *This display works in conjunction with the ASCENT and ENTRY TRAJ displays to provide trajectory situational awareness in both the vertical and horizontal planes.*
- *Improves real-time onboard assessment of ascent, abort, and entry performance.*
- *SPEC 54 has different formats for ascent and for entry.*
- *ASCENT BEARING*
  - *Available in OPS 1 and MM601 (SPEC 54 display will resume to TRAJ on transition from OPS 1 to OPS 3 or 6).*
  - *Plots against two contiguous longitude vs. geodetic latitude maps, including an inset window extending the map further downrange (latitude of larger map and smaller inset map is contiguous). RTLS, ELS, and TAL abort landing sites are depicted on all the maps.*
  - *The desired target insertion plane is depicted by a yellow line. If a TAL abort is declared, a yellow crossrange-circle is also shown centered on the selected TAL site on the appropriate map.*
  - *Dashed lines, representing the launch azimuth groundtrack at the open and close of the launch window, are also displayed, extending out from KSC.*
  - *Current position of a yaw-oriented shuttle is depicted with attached velocity vector along with 30- and 60-second predictors.*
  - *Also displays an overbright "+" depicting an instantaneous impact point (IIP) should all three main engines fail at the current time. Based on ballistic entry biased with rudimentary approximation of entry lift/drag effects for ECAL aborts.*
  - *ITEM 41 entry in the upper-left corner is equivalent to the currently selected site on SPEC 50; either SPEC 50 or 54 can be used to alter the ITEM 41 selected site.*
  - *ITEMs 1 and 2 are alternate sites. They are I-loaded to reflect two sites most closely associated with the current selected site*

(ITEM 41), but can be altered manually by the crew as desired.

- *Delta Az to the selected and alternate sites is digitally displayed alongside the identifier.*
- *The following four figures depict typical SPEC 54 ASCENT BEARING displays for abort profiles.*

```
1031/054/         ASCENT BEARING    2 000/00:05:48
 SITE ID      ΔAZ                     000/00:05:48
41  1 KSC33   180
 1  5 MYR36    89
 2  6 ILM06    65

VI 12716
```

Ascent ATO Trajectory – Map 1

```
1031/054/         ASCENT BEARING    2 000/00:08:18
 SITE ID      ΔAZ                     000/00:08:18
41  1 KSC33  -179
 1  5 MYR36   159
 2  6 ILM06   157

VI 19545
```

Ascent ATO Trajectory – Map 2

```
1031/054/         ASCENT BEARING    2 000/00:04:46
 SITE ID      ΔAZ                     000/00:04:46
41  3 MRN20 - 17
 1  4 ZZA30 - 11
 2 29 FMI33 -  7

VI  7499
```

TAL Abort to MRN – Map 1

```
1031/054/         ASCENT BEARING    2 000/00:09:54
 SITE ID      ΔAZ                     000/00:09:54
41  3 MRN20 - 12
 1  4 ZZA30 -  5
 2 29 FMI33 -  2

VI 18409
```

TAL Abort to MRN – Map 2

- *ENTRY BEARING*
  - *Available in OPS 3 and MM602, 603 (if SPEC 54 ASCENT BEARING is selected in MM601, it will automatically transition to ENTRY BEARING upon transition to MM602).*
  - *ITEM 41 as well as alternate sites for ITEMs 1 and 2 carry over from the ASCENT BEARING.*
  - *A bank-oriented shuttle is parked central to the display.*
  - *An overbright "+" is also displayed off the nose of the orbiter representing the IIP, similar to the Ascent display. It is based on ballistic entry biased with rudimentary approximation of entry lift/drag effects for ECAL aborts.*
  - *The selected and alternate sites are plotted "polar" to the shuttle's position using the guidance-calculated range and current delta azimuth. A yellow line connects the shuttle to the selected site. Site-centric range rings give an approximate indication of range to the selected site.*

NOTE

If the Delta Az is sufficiently large, that site would not show in the field of view.

WARNING

The guidance-calculated range to a site with large Delta Az (> ~20°) is inaccurate while the shuttle is wings-level, which may make it look like some sites are farther away than straight geographic range would imply. This could result in a range difference between that displayed on SPEC 54 and that displayed to the selected site on the Ascent/Entry Primary Flight Display (AEPFD).

  - *Delta Az is also shown digitally beneath site identifiers for all three sites.*
  - *During MM602 (post Nz Hold) and MM603, the energy-over-weight (E/W) is displayed to the selected and alternate sites in the same manner that it is displayed on the VERT SIT.*
  - *During OPS 3, the E/W scales are not displayed at all. Energy assessment in that case is available in MM304 only, using the ENTRY TRAJ to depict range to the alternate sites via ITEM 4.*
  - *During MM304, roll-reversal lines are also shown on either side of the orbiter.*

The next three figures show typical ENTRY BEARING displays for ECAL and TAL trajectories. The fourth figure shows an example of a low energy TAL MM304 ENTRY TRAJ with ITEM 4 enabled for alternate sites.

ECAL Entry to Cherry Point (NKT) with high ΔAz - MM602 pre Nz Hold

ECAL Entry to Cherry Point (NKT) with High ΔAz - MM602 Post Nz Hold

TAL Entry to Moron (MRN) - MM304

ENTRY TRAJ on Low Energy TAL with Alternate Sites

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NASA-JSC

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DA712	J. Wall
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DA723	T. Hagin
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