

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 CRT (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 with 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 sequence for closing the doors 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 (although the BFS SM SPEC 63 display can be used).

#### *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 the auto sequence is initiated by taking the *PL BAY DOOR* switch to *CLOSE*. The status of the sequence is displayed on the CRT. One manual step is taken during the Auto procedures; i.e., after the port door has been closed and latched, 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. 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*

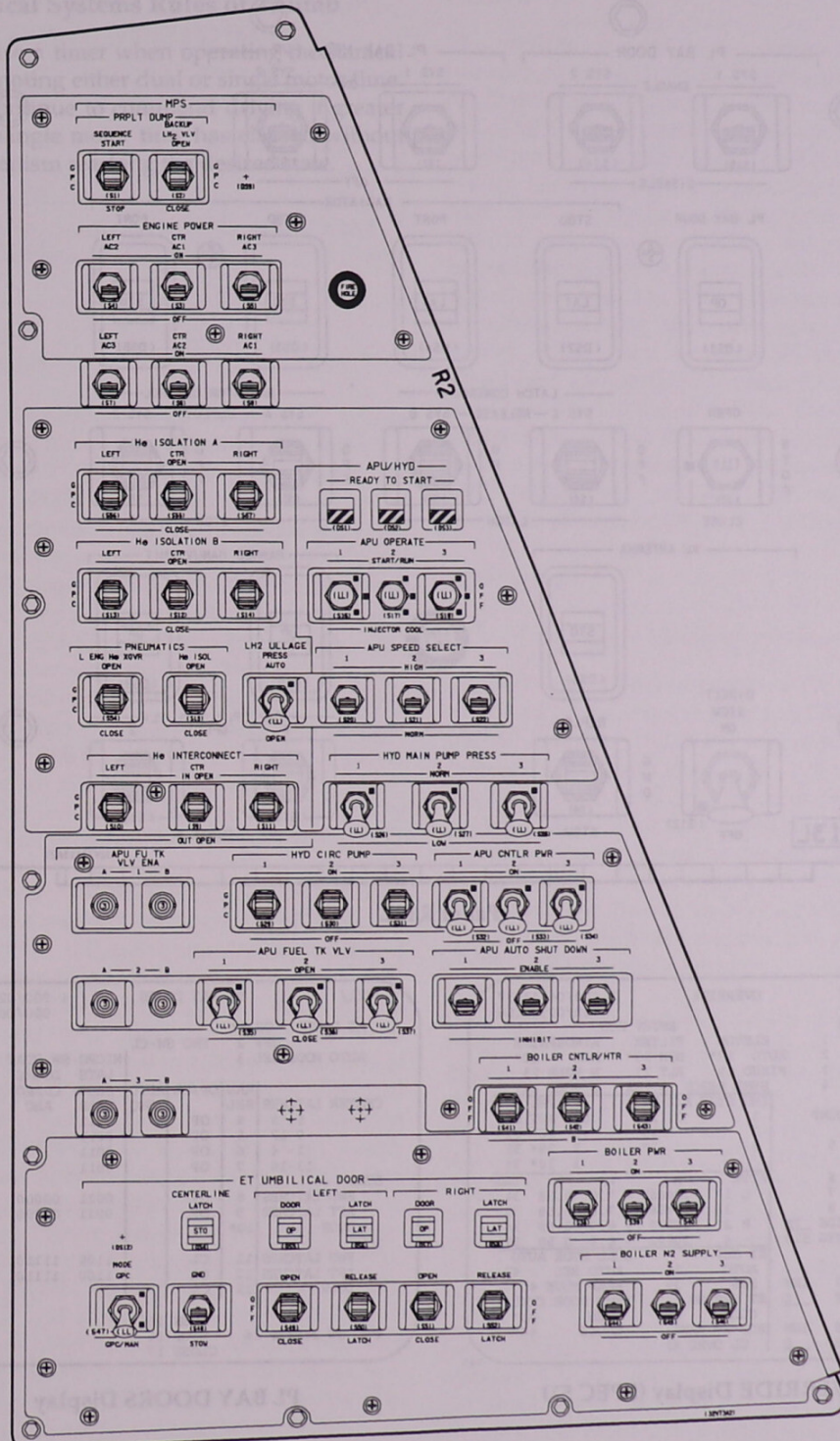
To close the doors using the Manual mode, the crew first configures the ac and dc power sources. The manual sequence is initiated by selecting the individual mechanism item(s) and driving them taking the *PL BAY DOOR* switch to *CLOSE*, then deselecting the items, and proceeding to the next active group.

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.

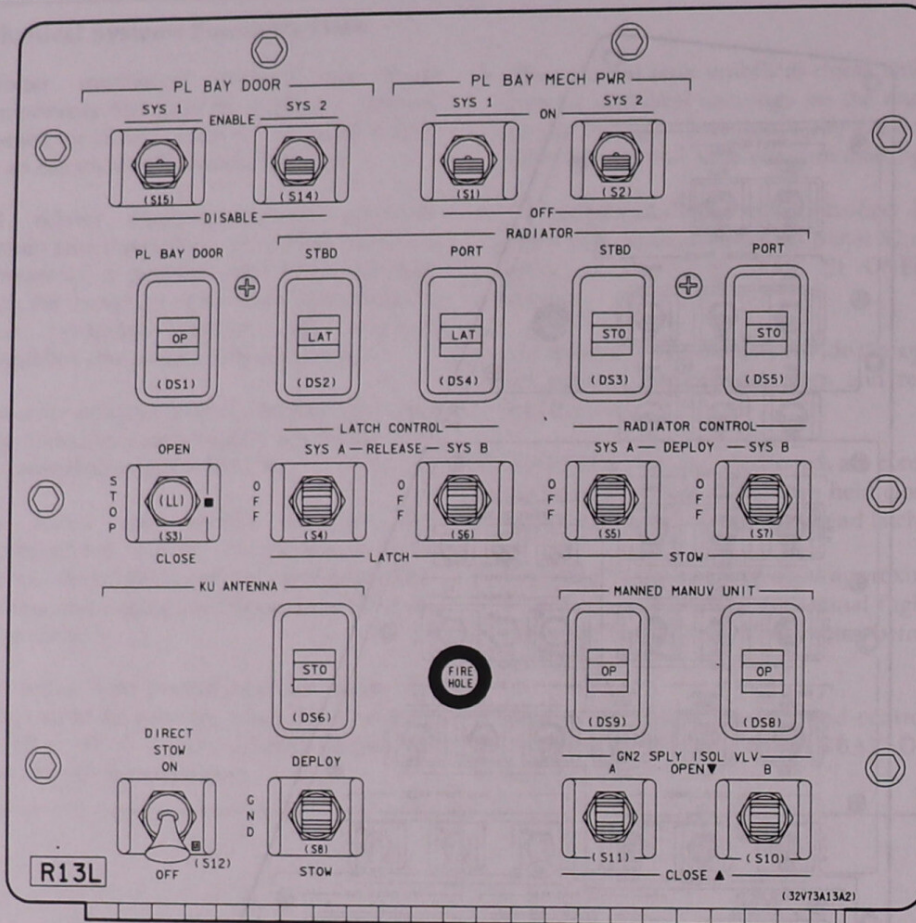
When the last of the latches is closed, the *PL BAY DOOR* switch is set to *STOP* and the ac and dc power sources are removed.

### 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 vent doors and 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.



Panel R2



Panel R13L

3051/051/      OVERRIDE      2 008/04:13:37  
000/00:29:56

ABORT MODE	TAL 1	ELEVON	FILTER	ATMOSPHERE	
ATO 2	AUTO 17*	NOM 20*	NOM 22*		
ABORT 3	FIXED 18	ALT 21	N POLE 23		
MAX THROT 4	SSME REPOS 19	ENA	S POLE 24		
PRPLT DUMP	IMU STAT	ATT	DES	PRL	
INH ICNCT 5	1	3	25	SYS AUT DES	
OMS DUMP	2	26	1	28* 31	
ARM 6	3	27	2	29* 32	
START 7			3	30* 33	
STOP 8	ADTA	H	α	M	DES
9 QUAN/SIDE 78	L 1	20466	+ 7.0	0.58	34
OMS DUMP TTG 520	3	20466	+ 7.0	0.58	35
	R 2	20892	+ 6.9	0.58	36
	4	20892	+ 6.9	0.58	37
AFT RCS 13	ET SEP	AUTO	38	ROLL MODE	AUTO
14 TIME 0	SEP	39		AUTO SEL	42
FWD RCS 15	ET UMB DR	40		WRAP MODE	45
16 TIME 0	CLOSE	40		VENT DOOR CNTL	
	RCS RM MANF	OPEN	43*		
	CL OVRD 41	CLOSE	44		

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		
CENTER LATCHES	MAN SEL	OP/CL	AUTO SEQ
	5- 8	4	OP
	9-12	5	OP
	1- 4	6	OP
	13-16	7	OP
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	
PBD SW BYPASS	14		
	OPEN 15		
	STOP 16		
	CLOSE 17		

PL BAY DOORS Display

## 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.

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### Description

The multifunction electronic display system (MEDS) will modernize the orbiter by having a "glass cockpit" integrated display system. In general, MEDS will replace the current electromechanical flight instruments, the servodriven tape meters, and the cathode ray tube (CRT) display units. MEDS is modernizing the cockpit and is also providing a solution to a problem. Existing meters, instruments, and CRTs are becoming obsolete. The lack of space for these components leads to raids on other orbiters for the necessary digital display units. MEDS will also reduce orbiter weight, power consumption, and logistics costs by minimizing the number of component types. MEDS will allow for future display enhancements.

The MEDS hardware components consist of 4 integrated display processors (IDPs), 11 multifunction display units (MDUs), and 4 analog-to-digital converters (ADCs). The existing display components that MEDS replaces are four display electronics units (DEUs), four display units (DUs), three display driver units (DDUs), three attitude direction indicators (ADIs), two horizontal situation indicators (HSIs), two alpha/Mach indicators (AMIs), two altitude/vertical velocity indicators (AVVIs), a surface position indicator (SPI), nine meters that display data on the main propulsion system (MPS), the auxiliary power unit (APU), and the orbital maneuvering system (OMS). The DDU's will be retained as a power source only for the hand controllers. All data that had been available via the eliminated hardware will be available on various displays that can be selected on the MDUs via edgekeys.

### Design

The MEDS system was designed to be transparent to the GPCs and flight software, and no flight software changes were made for the initial MEDS incorporation. This initial requirement can be seen throughout the MEDS design. As the MEDS system matures, changes in the flight software are being made to provide more data to upgrade the various displays. This is being done to provide better and more intuitive data to the crew. The MEDS hardware units are distributed among the three main buses for power. The nine forward MDUs are also distributed among IDP1 through IDP3. IDP1 is only connected to the aft MDUs. The MEDS low-replaceable units (LRUs) were also distributed so that no two failures will eliminate all of the CRT MDUs and no two IDP failures will eliminate all of the CDP or FLT MDUs.

### Hardware

#### Integrated Display Processor

The IDP is an 80386 processor (16 MHz) that functionally replaces the DEU and DDU. It is the core of MEDS. The IDP serves as 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 manages its own status and the status of other MEDS units. 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 display/keyboard (DK) bus, in addition to the panel switches and the keyboard. Each IDP is a functional replacement for a single DEU/CRT (e.g., IDP1 replaces CRT1, etc.). In general, it can display flight instrument and subsystem data to more than one crew station (left, right, etc.). On the MEDS side, each IDP controls a 1553B data bus, which will allow the IDP to interface with the MDUs and a pair of the ADCs.

Each IDP has 2.5 Mb of volatile random access memory (RAM) and 1.0 Mb of nonvolatile electrically erasable programmable read-only memory (EEPROM). The RAM is a temporary storage for critical display formats and

## 2.18 MULTIFUNCTION ELECTRONIC DISPLAY SYSTEM (MEDS)

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### Description

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The MEDS system was designed to be transparent to the GPCs and flight software, and no flight software changes were made for the initial MEDS incorporation. This initial requirement can be seen throughout the MEDS design. As the MEDS system matures, changes to the flight software are being made to provide more data to upgrade the various displays. This is being done to provide better and more intuitive data to the crew. The MEDS hardware units are distributed among the three main buses for power. The nine forward MDUs are also distributed among IDP1 through IDP3. IDP4 is only connected to the aft MDUs. The MEDS line replaceable units (LRUs) were also distributed so that no two failures will eliminate all of the CRT MDUs and no two IDP failures will eliminate all of the CDR or PLT MDUs.

### Hardware

#### Integrated Display Processor

The IDP is an 80386DX processor (16 MHz) that functionally replaces the DEU and DDU; it is the brains of MEDS. The IDP serves as 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 display/keyboard (DK) bus, in addition to the panel switches and the keyboards. Each IDP is a functional replacement for a single DEU/CRT (e.g., IDP1 replaces CRT1, etc.). 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, which will allow the IDP to interface with the MDUs and a pair of the ADCs.

Each IDP has 2.5 Mb of volatile random access memory (RAM) and 1.0 Mb of nonvolatile electrically erasable programmable read-only memory (EEPROM). The RAM is a temporary storage for critical display formats and

executable software. The IDP software will execute from RAM. The EEPROM is a storage location for critical display formats, self-test results, failure information, and the IDP's executable programs. Both the RAM and EEPROM are protected by error detection and correction (EDAC). Each IDP also contains a mass storage unit (MSU) disk drive for storing copies of the MDU and IDP software and files for error logs. The MSU is a 300-Mb magnetic hard disk. Ground support equipment (GSE) can access the disk for software updates and retrieval through a connector on the IDP.

#### Power

IDPs require 28 V dc and 42.6 W, which 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 where the CRT power switches were located, panels C2 and R12. However, the power switch is now a two-position switch versus a three-position switch. These switches also power their respective CRT MDUs.

#### Cooling

The IDPs are forced-air cooled with new ducting being installed.

#### Location

The IDPs are located where the DEUs were located. An IFM capability is available.

#### Lifetime

The IDP has a mean time between failures (MTBF) estimate of 16,000 hours.

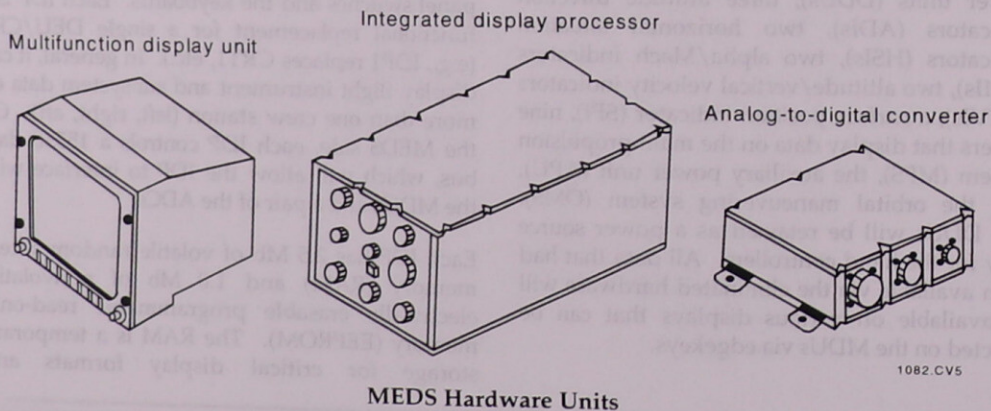
### Multifunction Display Unit

The MDU is an R3081 processor (a derivative of the RISC 3000/3010) with a full color, flat panel, 6.7-inch-square, active matrix liquid crystal display (AMLCD). Its graphics coprocessor is a TMS34020 32-bit processor. The MDU's primary function is to drive the variety of MEDS color displays that are readable in the sunlight. As a future enhancement, the MDU could be equipped to display NTSC/RS-170 video from the CCTV video system.

Similar to the IDP, the MDU has built-in tests (BITs) 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 located on the bezel on either side of the edgekeys. The edgekeys are not used to interact with the DPS system (i.e., clearing DPS fault messages, item entries, etc.). Even though the edgekeys are located on the MDU, the edgekey commands are handled by the IDP, unless the MDU is in autonomous mode.

In general, each MDU has two ports (primary, secondary) that are connected to two IDPs via a 1553B data bus. Only one IDP will command an MDU at a given time, but both IDPs will monitor the status of the MDU. The exception is the CRT MDUs, which will be using only their primary port. Their secondary port will not be connected to any data bus. Thus, they will be connected only to a single IDP and indirectly to only one display/keyboard data bus. Operationally, the CRT MDUs will be dedicated to the DPS display. This configuration will



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maintain the current keyboard/CRT associations. While in the autonomous mode, the MDU continues to run and monitors its two ports for an operating IDP.

#### *Power*

The MDUs are powered via 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 switch. The MDUs will use 28 V dc and 72.2 W. 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.

#### *Cooling*

New ducting has been installed to allow forced-air cooling of the MDUs.

#### *Location*

The MDUs located 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. AFD1 will protrude into the cabin slightly more than the old aft ADI box.

An MDU in-flight maintenance (IFM) capability is available. It is easier than the previous

multifunction CRT display system (MCDS) changeout because no access from the orbiter middeck is necessary.

#### *Lifetime*

The MDU has an MTBF estimate of 50,000 hours.

#### **Analog-to-Digital Converter**

The ADC converts 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 will convert the analog signals from the MPS, OMS, and SPI meters. ADCs 2A and 2B will convert the signals from the APU and HYD meters.

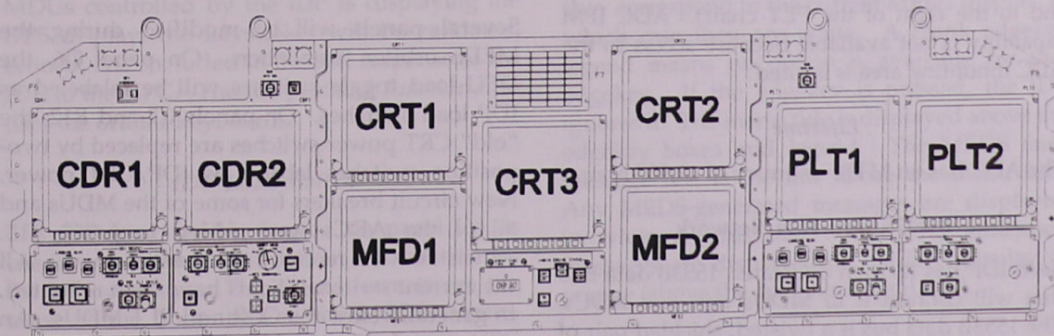
The ADC has the capability to sample 32 input channels at a rate of 25 Hz. It will convert the data into 12-bit digital data and transmit the data to the associated IDP when requested. Each ADC will maintain communication with two IDPs simultaneously. The ADC software will perform a continuous self-test.

#### *Power*

ADCs are powered by 28 V dc and 4.5 W. 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.

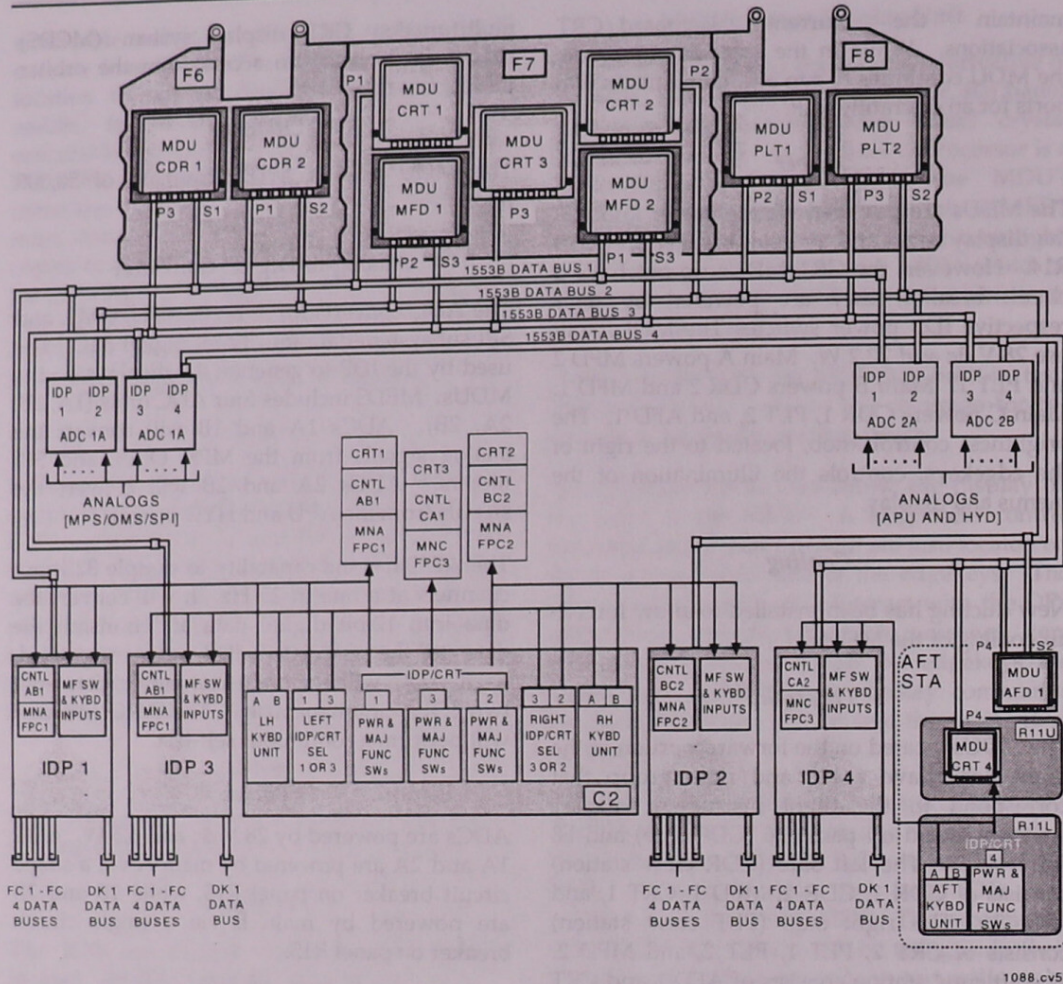
#### *Cooling*

The ADCs are cooled passively and do not require forced air or a cold plate.



**Forward Flight Deck Configuration**





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**MEDS Data Bus Network**

**Location**

The ADCs are located where the electronic boxes for the AMI and AVVI were located (behind the panel to the left of the CDR chair and to the right of the PLT chair). ADC IFM capability is not available because access to the ADC mounting area is limited.

**Lifetime**

The ADC has an MTBF estimate of 48,000 hours.

**MEDS Data Bus Network**

Each IDP has its own dedicated 1553B data bus that will connect it to MDUs and two ADCs. The 1553B data bus is a twisted, shielded pair of copper wires that carries a signal on both buses.

However, MEDS will use only one of the two parallel buses. This data bus is based upon a 16-bit word size.

**Orbiter Panel Reconfiguration**

Several panels will be modified during the MEDS orbiter installation. On panel O6, the DEU load toggle switches will be relabeled as IDP load switches. On panels C2 and R12, the "old" CRT power switches are replaced by two-position switches labeled as IDP/CRT power. New circuit breakers for some of the MDUs and all of the ADCs were added to panel R15. Panels F6 - F8 received the most changes. All the current switches/lights have been relocated, in general, below the CDR and PLT MDUs. An exception is the data bus select rotary switch

that controlled which flight-critical data bus would be used by the DDU for the tapes/instruments and the head up display (HUD). With MEDS, the user will now be able to select the flight-critical data bus via the edgekey menu system. For the HUD, panels F6 and F8 each will contain a two-position HUD data bus switch that will allow the CDR (PLT) to switch between flight-critical 1 and 2 (3 and 4). The data bus select switch for the aft station and the flight instrument circuit breakers on panel O14 and O15 will remain but will be unlabeled and serve no function.

## Software

### IDP Software

The IDP software manages the edgekey menu system, generates the graphical displays, and emulates the 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. The file patching function also uses the orbiter keyboards.

### 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 are the same as the ones used in the MCDS system. 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 "DEU Load" information and stores only the critical format information in the EEPROM. Nominally, the only time the IDP needs to be loaded with critical formats is after an OI flight software change has occurred in the GPCs.

Inadvertent IDP loads via a PASS GNC GPC disable the DPS display for a given IDP with the message VM LOAD IN PROGRESS. Power cycling the IDP or completing a valid IDP LOAD (via PASS SM or BFS) recovers the DPS display. Critical formats are not lost after a BFS IDP LOAD because the BFS does not overwrite the current critical formats in the IDP.

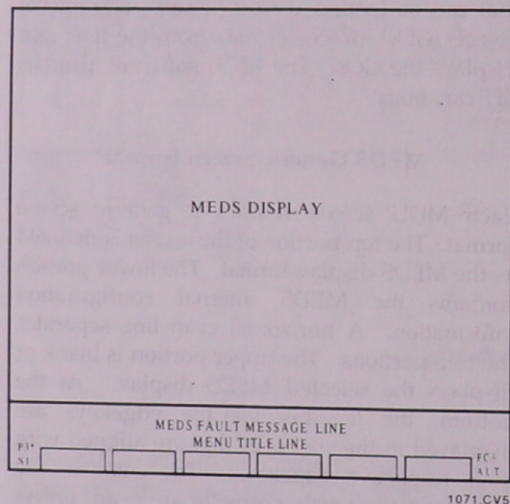
### MDU Software

The MDU function (MDUF) software drives the hardware engine for the graphical display capabilities. It provides a graphical database that can be loaded with a library of graphical objects (GOs), processes data from the IDP, and displays the GOs. The MDU software also has BIT capability.

### 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.



**MEDS Generic Screen Format**

### MEDS Displays

The user may view all flight instrument and subsystem status information via the various MEDS displays.

#### *Flight Instruments*

The ascent and entry flight instruments have been divided into three separate displays: ADI/AMI, HSI/AVVI, and COMP ADI/HSI. The composite ADI/HSI consists of the ADI,

AMI, AVVI, and the upper portion of the HSI. For orbit, only the ADI is used; therefore, there is a display that consists of only the ADI. The ADI on the ascent/entry flight instrument displays will work on orbit. The ADI, HSI, AMI, and AVVI work as described in Section 2.7, Dedicated Display Systems, with the following exceptions.

Digital readouts are given for all the tapes and the ADI. The digital readout is in nautical miles (n. mi.) for altitudes from 400,000 feet to 165 n. mi. An "M" is displayed next to the digital readout box. For altitudes in the range of 10,000 to 400,000 feet, the digital readout value is in thousands of feet with a "K" next to the box. Altitudes below 10,000 feet are in feet. When the altitude is less than or equal to 5,000 feet, the radar altitude is displayed in the digital readout box with an "R" next to the box and also as a moving pointer along the altitude tape. The scale on the altitude tape below 5,000 feet was modified to allow smooth movement of the tape.

The alpha tape on both the HSI/AMI and the Composite ADI/HSI displays has been modified. A green bar has been added to indicate the maximum and minimum angle of attack. The max. and min. alpha are the same as the numbers found on the Entry Alpha Cue Card. This green bar will appear anytime the vehicle is at a velocity less than Mach 2.5, and will shrink and expand based on Mach number. A magenta and black diamond has also been added to indicate maximum lift over drag (L/D) alpha. This max L/D diamond will appear anytime the vehicle is less than Mach 3. Note that the alpha bar and max L/D diamond appear during both ascent and entry, however, they have meaning only during the entry phase.

The units on the Accel tape are labeled G's.

On the composite ADI/HSI display, the Mach and equivalent air speed locations change at Mach 0.9 during entry (Major Mode 305 and 603). If above Mach 0.9 during entry, Mach is displayed as a digital readout and a tape, while air speed is just a digital readout. If below Mach 0.9, the air speed is a tape and digital readout and Mach is only a digital readout. During ascent, Mach is always a tape and digital, while air speed is a digital only.

The HSI now displays a digital value for the delta azimuth.

In Major Mode 104, the Mach number, altitude, and altitude rate parameters at MECO are preserved. All other tapes are displayed as red-outlined empty boxes (invalid data indications). These parameters were chosen to be preserved to aid in determining the MECO state for OMS targeting. In Major Mode 105, the Mach number, altitude, and altitude rate will go invalid as well.

### *Subsystem Status Displays*

The three subsystem status displays show the OMS, MPS, APU, and HYD meters and the SPI in a digital and tape format. OMS and MPS data are displayed together, while APU and HYD data are together. The SPI is the third display. The SPI display is essentially the same as before, but now has color and digital readouts for the actual and commanded speed brake.

The OMS, MPS, HYD, and APU meters allow all data to be displayed at the same time. Therefore, it is no longer necessary to move switches to see different tanks or quantities. The displays consist of a digital readout and colored bar meters that indicate nominal (green/white) or off nominal (yellow/red) conditions. Tick marks indicate certain limits.

### *DPS Display*

The MEDS DPS display is the equivalent of the "old" MCDS CRT image. The IDP emulates the DPS display 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. (Keyboard operations are discussed in detail in Section 2.6, Data Processing System.)

The DPS display basically has the same format as it did before. Colors have been added for various purposes. The BIG "X," "POLL FAIL," and DPS fault messages are now orange. Overbright characters are now yellow.

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. Colored keyboard bars were also added to indicate which keyboards are currently active for an IDP. These keyboard bars appear and disappear, depending on the positions of the Left and Right IDP/CRT Select switches. For example, if the Left IDP/CRT Select 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 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 (or "CRT" image) is being displayed. IDP 4's DPS display has the green box and number, but it does not have any keyboard bars displayed because only the aft keyboard can talk to it.

### *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 of 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.

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 BIT summary in hex. If one or more bits in the BIT summary are off nominal, the entire BIT summary shows 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. If a CST has not been performed, the CST results display NO-CST in white.

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 last row indicates which flight-critical data buses currently are being supported. The buses are displayed in reverse video.

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 BIT summary in hex. If one or more bits in the BIT summary are off nominal, the entire BIT 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 to the GPC fault summary (SPEC 99). The display lists the past 15 MEDS fault messages and the time of annunciation by the current IDP.

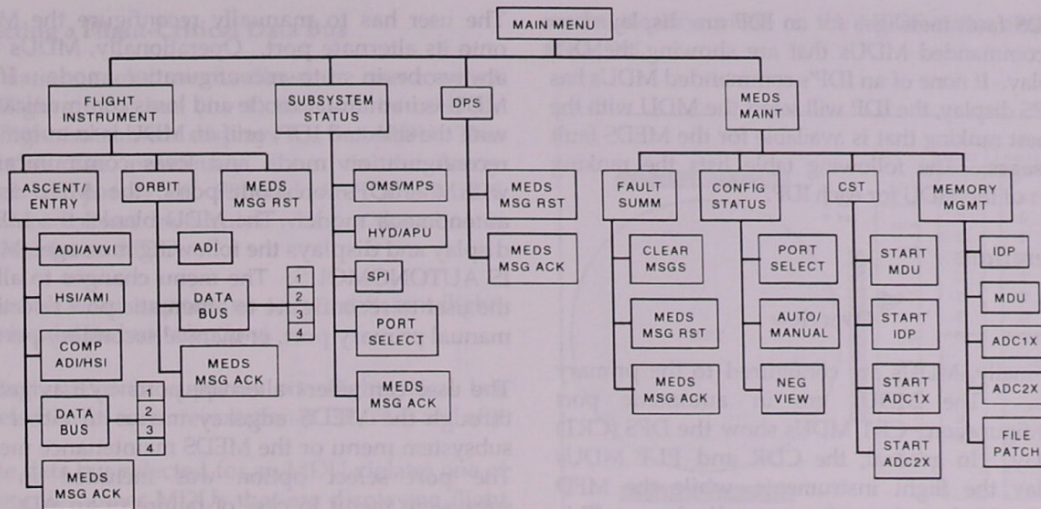
### **Edgekey Menu System**

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.

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, in addition to clearing the MEDS fault message line. Under the ascent/entry submenu, you can select the ADI/AVVI display, the HSI/AMI display, the COMP ADI/HSI display, the data bus select menu, or scroll through the MEDS fault messages using the MEDS MSG ACK. Under the orbit menu, the only selections are the ADI, data bus select menu, and the MEDS MSG ACK. 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.



1085.cv5

### MEDS Edgekey Menu Hierarchy

After selecting the DPS menu, the DPS display is displayed automatically. The available 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. 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 allows the user to 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.

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 announce. 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 error entry, and/or inform the crew by a 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. The following table lists the ranking order of the MDU for each IDP.

## Operations

### Overview

Nominally, MDUs are configured to the primary ports. The MDUs are in automatic port reconfiguration. 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 current non-MEDS flight-critical data bus 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.)

MDU Fault Message Ranking for Each IDP

IDP 1		IDP 2		IDP 3		IDP 4	
Rank	MDU	Rank	MDU	Rank	MDU	Rank	MDU
1	CRT1	1	CRT2	1	CRT3	1	CRT4
2	CDR1	2	PLT2	2	PLT2	2	AFD1
3	CDR2	3	PLT1	3	MFD2		
4	MFD2	4	MFD1	4	MFD1		
5	PLT1	5	CDR2	5	CDR1		
		6	AFD1				

### Selecting a Flight-Critical Data Bus

The data bus select menu allows the user to select the flight-critical bus (1 - 4) that will be used for the flight instrument displays for that MDU. This selection was previously done via the rotary switch on panels F6, F8, and A6. The MEDS software follows two rules when a data bus is selected for an MDU.

- Each IDP can support up to two different flight-critical data bus selections.
- Each IDP only supports one flight-critical bus selection for each crew station (CDR, PLT, and aft).

If the 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 flight-critical data bus selection.

To select a different flight-critical data bus, the user must go to either the ascent/entry flight instrument submenu or the orbit flight instrument submenu. The user can select the DATA BUS option via the edgekeys. The MDU will retain the current MEDS display, but a new submenu appears and allows the user to select flight-critical 1, 2, 3, or 4 via the edgekey.

Note: Although all displays indicate a flight-critical bus, it is only meaningful on the flight instrument displays.

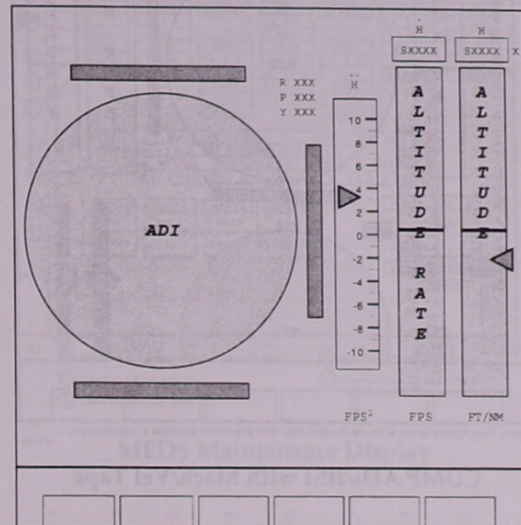
### Recovering from a Disabled Edgekey

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

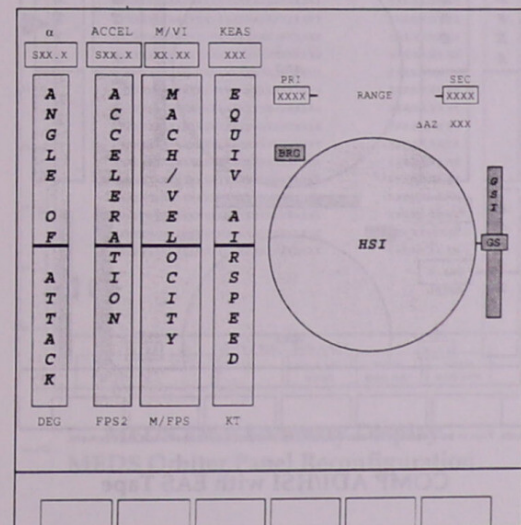
The configuration status submenu allows the viewer to change the viewing mode. The viewing mode can be changed only for the Hosiden MDUs. The negative viewing mode enhances the readability of the aft MDUs. When negative viewing is selected, "NEG VIEW" is displayed above the flight-critical bus selection and

reconfiguration mode on the MEDS status area of the MDU.



\*Note: Text in bold italics is for clarification only and does not constitute a requirement. 1072.cvi

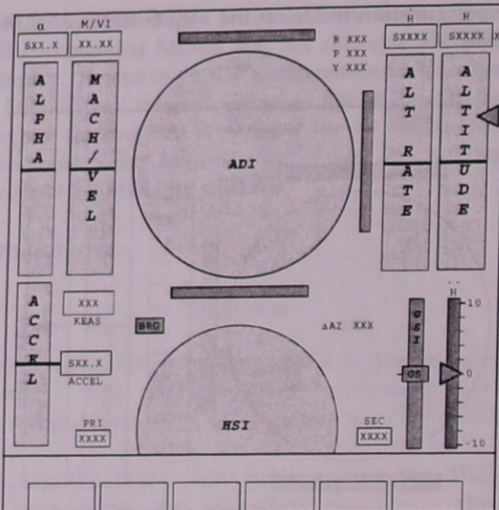
ADI/AVVI Display



\*Note: Text in bold italics is for clarification only and does not constitute a requirement. 1073.cvi

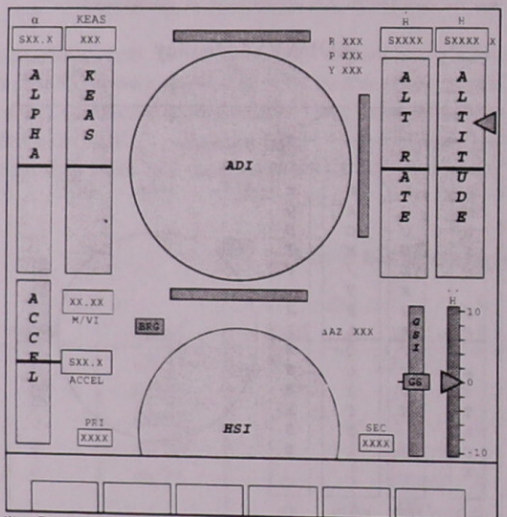
HSI/AMI Display





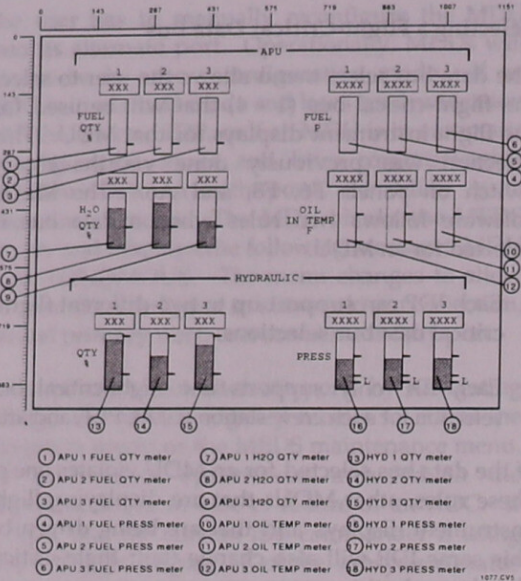
\*Note: Text in bold italics is for clarification only and does not constitute a requirement. 1074 rev

COMP ADI/HSI with Mach/Vel Tape

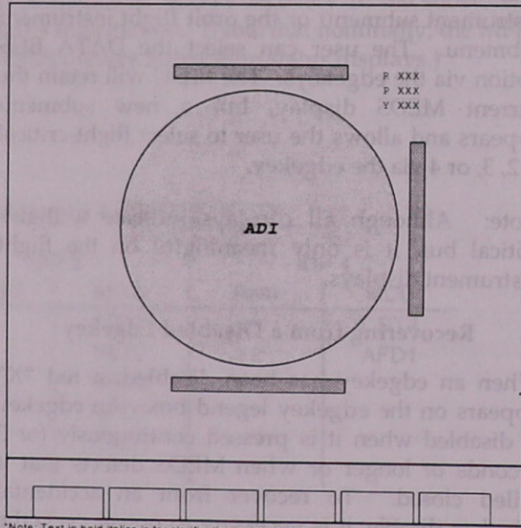


\*Note: Text in bold italics is for clarification only and does not constitute a requirement. 1073 rev

COMP ADI/HSI with EAS Tape

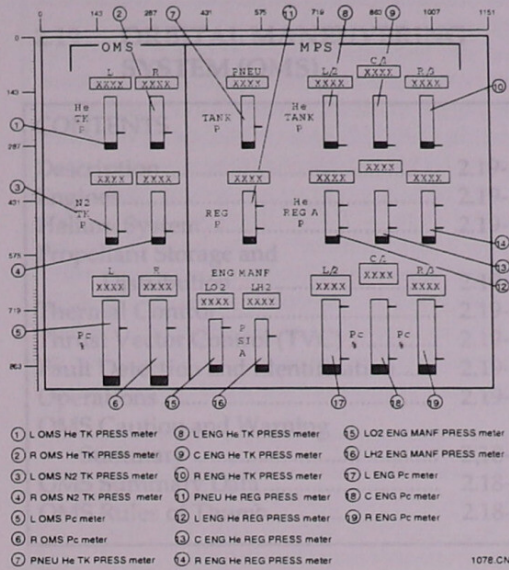


HYD/APU Display

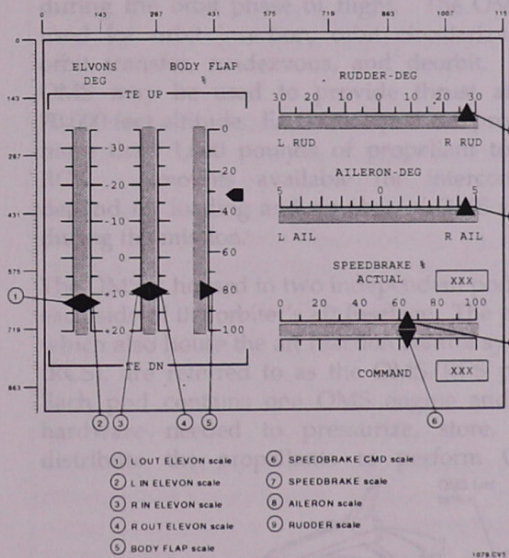


\*Note: Text in bold italics is for clarification only and does not constitute a requirement. 1076 rev

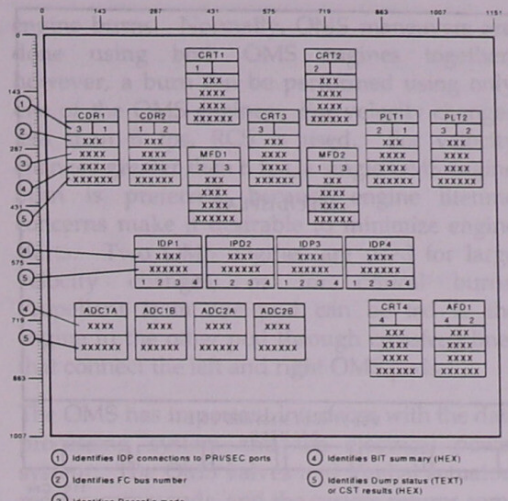
ADI Display



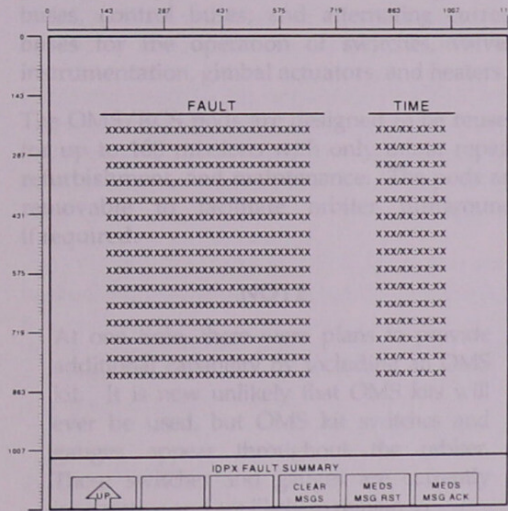
OMS/MPS Display



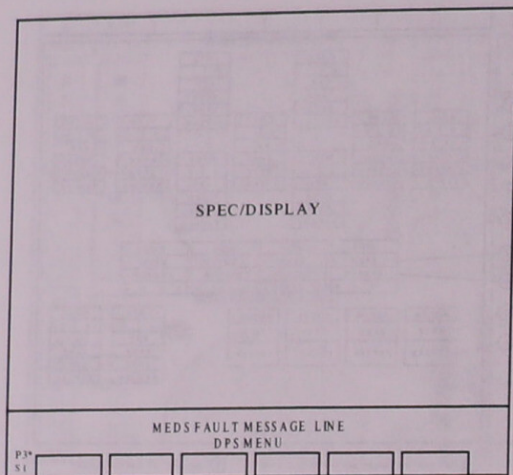
SPI Display



MEDS Maintenance Display



MEDS Fault Summary Display  
MEDS Orbiter Panel Reconfiguration



1101.Cnv

DPS Display

## 2.19 ORBITAL MANEUVERING SYSTEM (OMS)

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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. The OMS may be used to 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

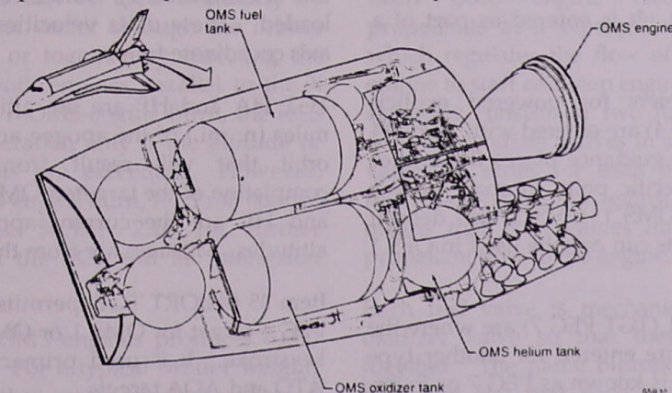
engine burns. Normally, OMS maneuvers are done using both OMS engines together; however, a burn can be performed using only one of the OMS engines. For velocity changes less than 6 fps, RCS is used. For velocity changes greater than 6 fps, a single OMS engine burn is preferred, because engine lifetime 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 general purpose computers through multiplexer/demultiplexer units. Electrical power is supplied to the OMS through main buses, control buses, and alternating current buses for the operation of 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. These switches and gauges are currently inoperative and are likely to remain so.



Orbital Maneuvering System

## Maneuver Display

```

1041/ OMS 1 MNVR EXEC 1 000/00:40:23
OMS BOTH 1* L 2 000/00:15:37
R 3
RCS SEL 4 BURN ATT
S TV ROLL 180 24 R 083 AVTOT 0
TRIM LOAD 25 P 195 TGO 0:00
6 P [-] 0.1 MNVR 27* VGO X +
7 LY [-] 15.7 REI 4366 Y +
8 RY [-] 15.7 TFF 24:40 Z +
9 WT 217047 L R HA HP
10 TIG P +0.4 +0.4 TGT 130 +129
TGT PEG 4 : : : CUR 130 + 9
14 C1 PRI 28* 29* 35 ABORT TGT
15 C2 [-] SEC 30 31 FWD RCS
16 HT OFF 32 33 ARM 36
17 OT GMBL CK 34 DUMP 37
18 PRPLT [-] SURF DRIVE
TGT PEG 7 ON 39
19 AVX [-] OFF 40*
20 AVY [+]
```

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°, which corresponds to a heads-down attitude. A different number can be entered in MM 202 only, but it 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.

The target parameters for powered explicit guidance (TGT PEG 4) are entered with items 14 through 18. PEG 4 guidance places 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 can only be used in OPS 1 and 3.

Items 19 through 21 (TGT PEG 7) are where the target parameters are entered for another type of guidance, which is known as PEG 7 or External  $\Delta V$  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, which 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 GMBL L, R items on the display are the actual gimballed position angles. Items 28 through 33 (PRI, SEC, OFF) permit selection of primary or secondary gimballed motors or turn off both gimballed motors.

Executing item 34 (GMBL CK) starts an automatic gimballed check sequence.

The EXEC item flashes on the screen 15 seconds before TIG and remains there until the EXEC key is depressed, which enables OMS burn ignition.

$\Delta V$  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  $\Delta V$  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 (MM). 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 phase
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. See Section 2.20 for further information about the RCS and its interaction with the OMS.

Each of the two OMS engines produces 6,000 pounds of thrust. For a typical orbiter weight, both engines together create an acceleration of approximately 2 ft/sec<sup>2</sup> 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.

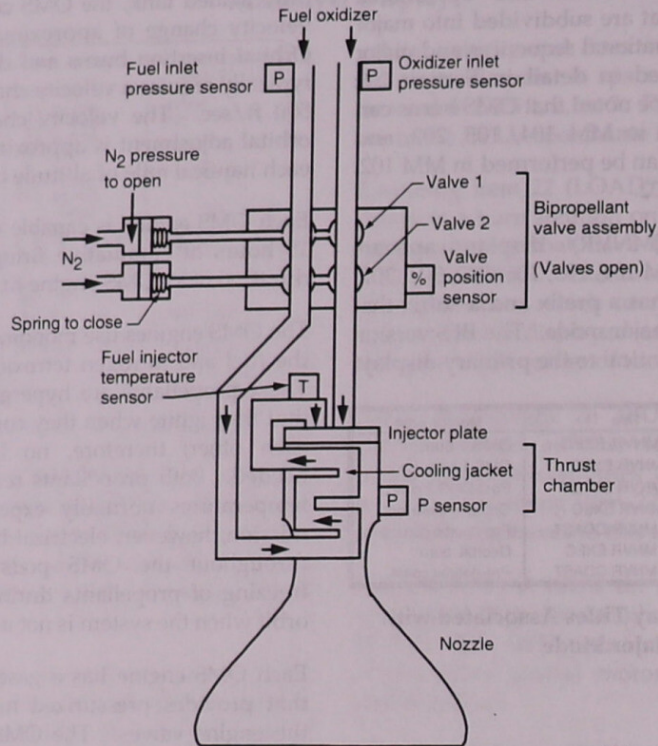
Each OMS engine has a gaseous nitrogen tank that provides pressurized nitrogen to operate the engine valves. The OMS engine does not have propellant pumps; propellant flow to the engines is maintained by pressurizing the propellant tanks with helium.

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 comes from the fact that each linked set of valves controls the flow of both propellants.



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### 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 APT 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
RCS		OXID	FU	JET ESOL			
FWD HE P		1464	1264	N2 TK P		2220	2220
TK P		248	244	REG P		319	319
QTY		0	0	P VLV		CL	CL
MANF		1 P	248 242	ENG IN		P	
		2 P	248 244	OXID		257	258
		3 P	250 246	FU		258	258
		4 P	244 244	VLV		1 - 2 - 2	
		5				2	0 0
AFT HE P		2800	2672	JET ESOL			
L TK P		244	249	OXID		FU	FAIL VLV
QTY		63	63	HE P		2744	2616
MANF		1 P	244 246	R TK P		247	247
		2 P	246 250	QTY		62	61
		3 P	248 250	1 P		242	246
		4 P	246 250	2 P		250	246
		5		3 P		246	250
				4 P		246	242
				5			

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OMS Parameters on BFS GNC SYS SUMM 2 Display

2011/ /089 PRPLT THERMAL				4 000/02:37:12			
000/00:00:00							
POD		L	R	OMS CRSFD		L	R
OMS TK		OX	80 80	XFD		OX	68 68 67
		FU	80 80	GMBL LN		68	68 67
ENG I/F		OX	70 70	DRN		OX	65 65 64
		FU	70 70				
		OX VLV	71 71				
		FU INJ	81 81				
WEB KEEL		1	70 70				
		2	70 70	BLD APT FUS		FU	OX
Y		OB	74 74	PL BAY		65	66
		UP	74 74	OX QD		65	67
OX DRN PNL		1	67 67				
		2	67 67	FWD RCS		FU	OX
ENG COVER		71	73	LINE T1		67	66
SERV PNL		70	70	T2		67	66
GSE SERV PNL		74	73				
TEST HE/OX		1	70 70	AFT RCS		L	R
		2	70 70	MANF 1		OX	69 68
				DRN PNL		1	68 66
						2	68 66
				VERN PNL		1	67 67
						2	67 67

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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

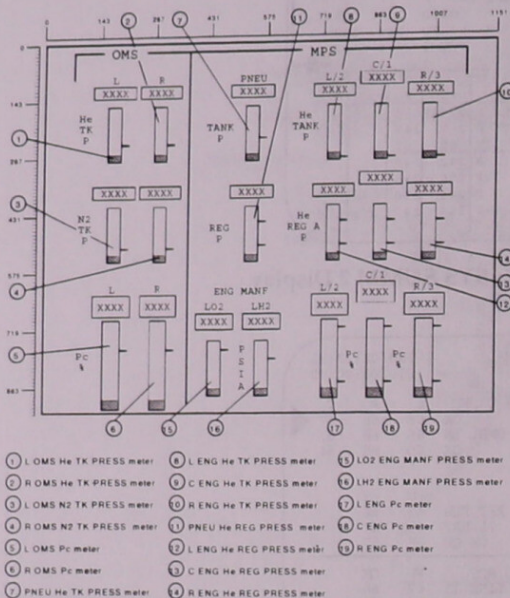
chamber walls, providing regenerative cooling to the combustion chamber walls, and then to the injector of the engine. The oxidizer is routed directly to the injector.

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. 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 P<sub>c</sub> N<sub>2</sub> 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.

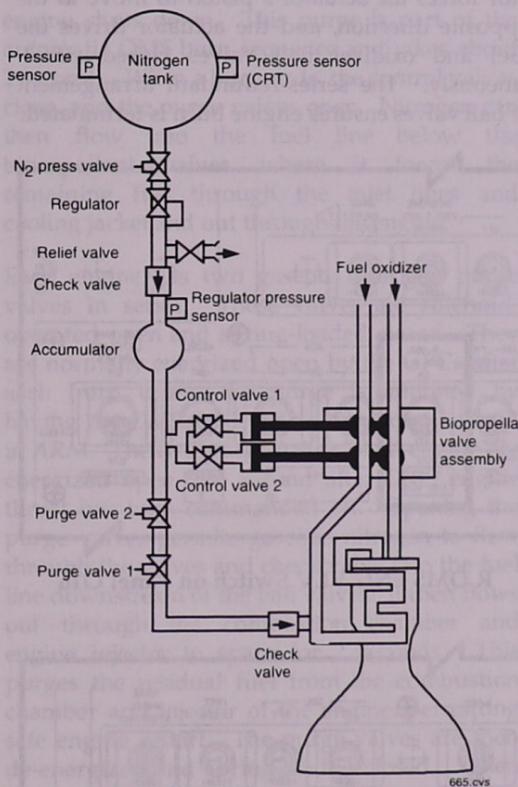
Two sensors monitor each tank's pressure. One sensor displays the tank pressure on the MEDS MPS/OMS display. The other sensor displays the tank pressure on the GNC SYS SUMM 2 display. Both pressures are downlisted by telemetry.

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

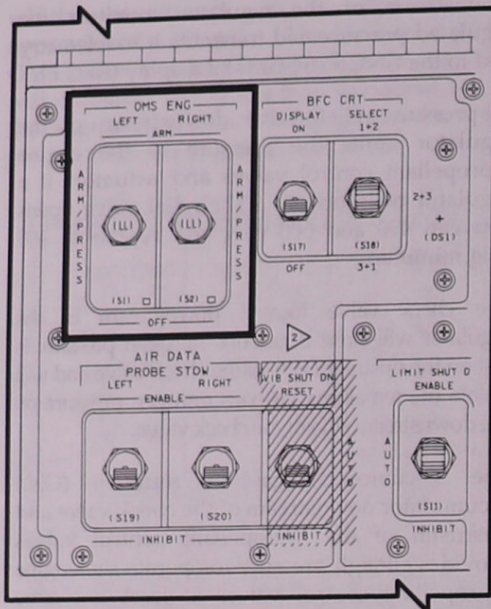
downstream of the regulator monitors the regulated pressure and transmits it to telemetry and to the GNC SYS SUMM 2 display (REG P).

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 ( $\text{GN}_2$ ) 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<sub>2</sub> 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<sub>2</sub> 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.

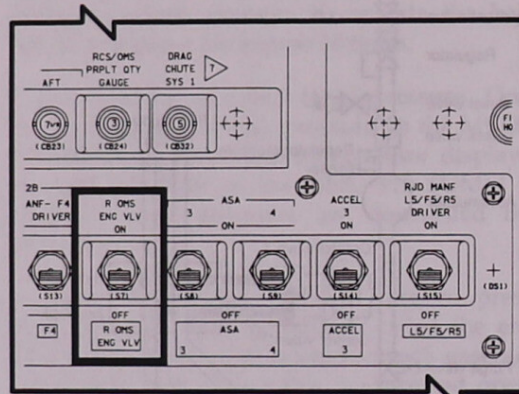
Check valves are installed in the vent port outlet of each GN<sub>2</sub> solenoid control valve on the spring pressure side of each actuator to protect the seal of these components from atmospheric contamination.

**Ball Valve Actuation**

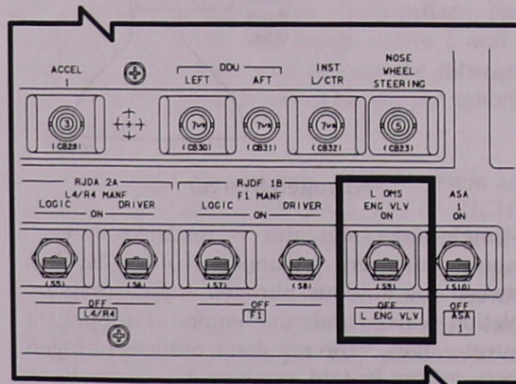
When the GN<sub>2</sub> solenoid control valves are energized open, pressure is directed into the two actuators in each engine. The nitrogen acts against the piston in each actuator, overcoming the spring force on the opposite side of the actuators. Each actuator has a rack-and-pinion gear; the linear 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<sub>2</sub> pressure from the actuators. The GN<sub>2</sub> 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 sublime. 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.

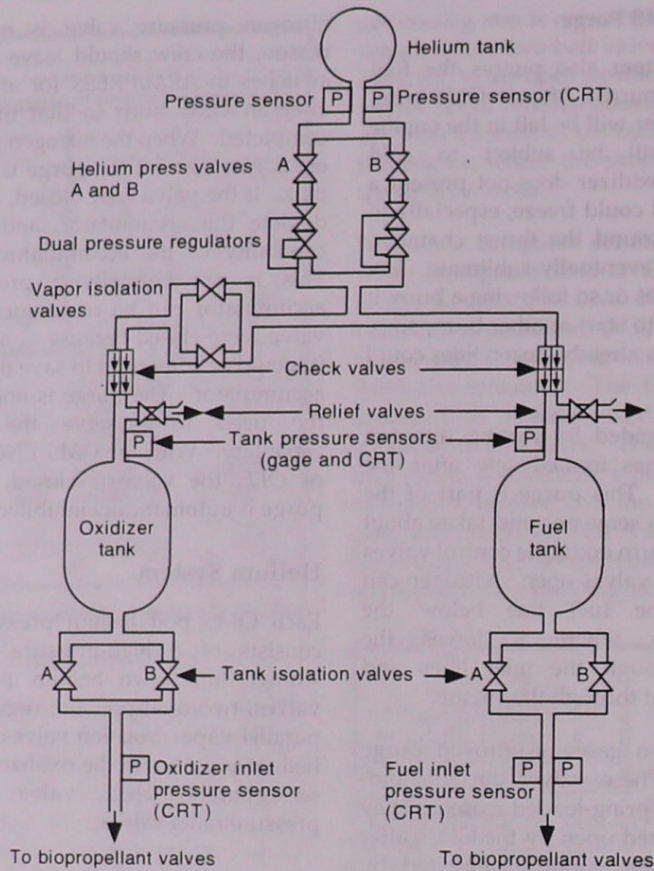
### Helium System

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).



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### 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.

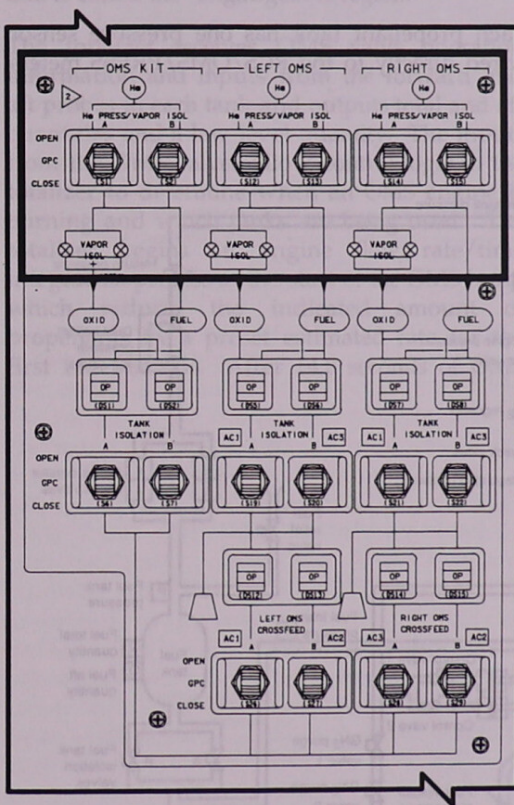
#### NOTE

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 reseal 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 reseals at 280 psig.

## Propellant Storage and Distribution

The OMS propellant storage and distribution system consists of one fuel tank and one

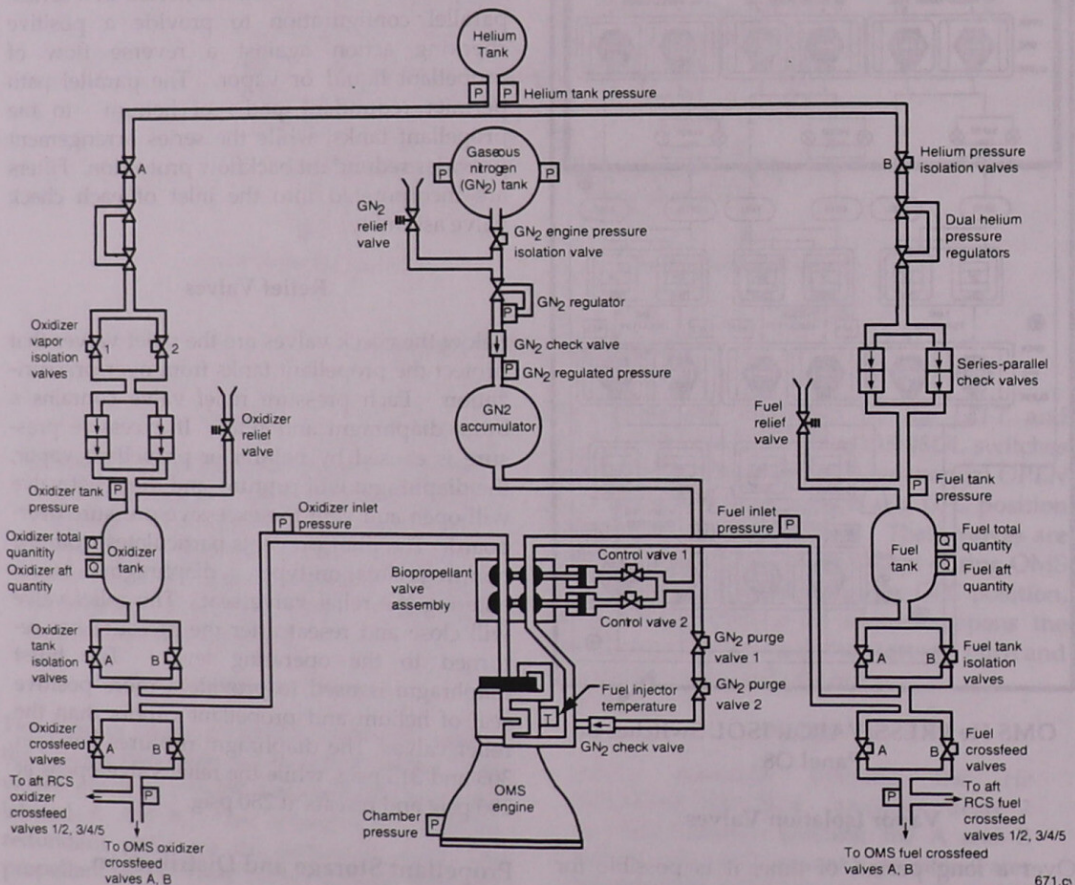
oxidizer tank in each pod. It also contains propellant feed lines, crossfeed lines, isolation valves, and crossfeed valves. The OMS propellant in both pods enables the orbiter to perform a 1,000-foot-per-second velocity change with a 65,000-pound payload in the payload bay. The OMS pod crossfeed lines 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.

Each propellant tank has one pressure sensor wired directly to the RCS/OMS/PRESS meters



Orbital Maneuvering System Pressurization and Propellant Feed System for One Engine (other Engine Identical)

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

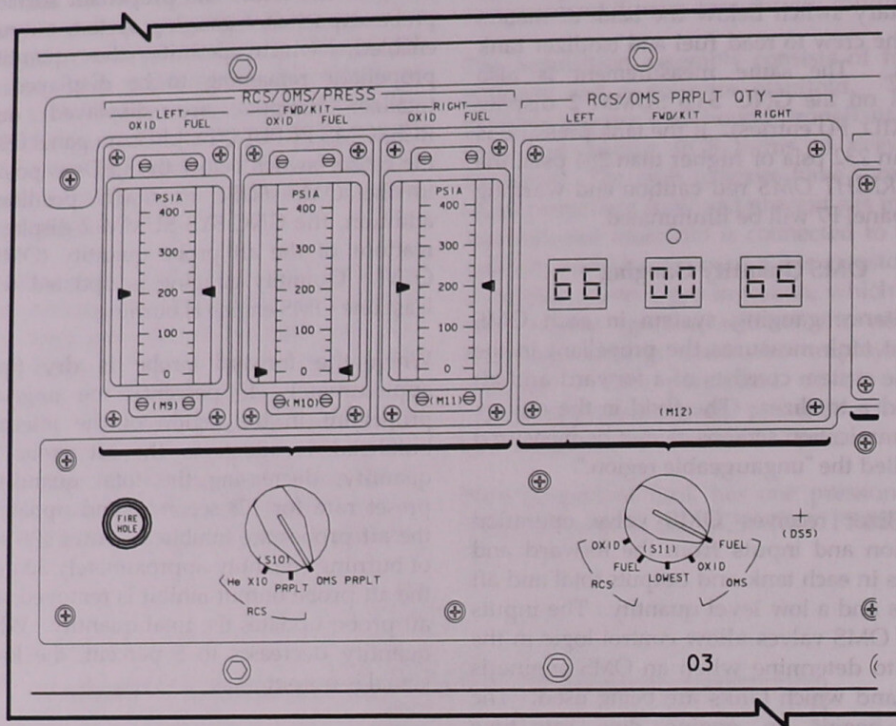
burn, which settles the propellant surface, the probe capacitance gauging system outputs are enabled, which permits the quantity of propellant remaining to be displayed. The totalizer outputs are displayed on the RCS/OMS PRPLT QTY LEDs on panel O3 when the rotary switch below the LEDs is positioned to 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 ungaugable 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.

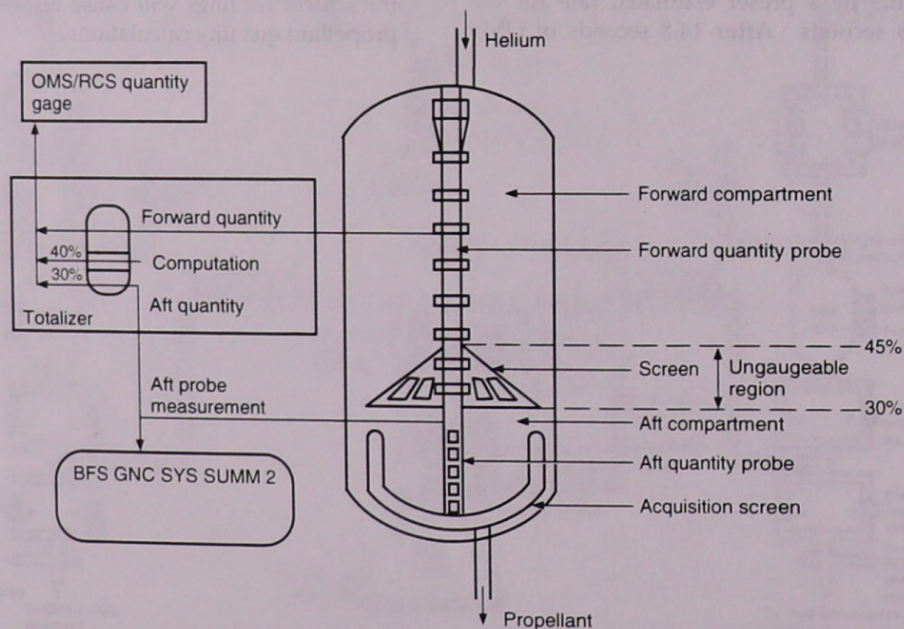
### NOTE

Erroneous temperature and/or pressure transducer readings will cause erroneous propellant quantity calculations.





RCS/OMS/PRESS Meters and PRPLT QTY LEDs on Panel 03



Orbital Maneuvering System Quantity Gauging

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### 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.

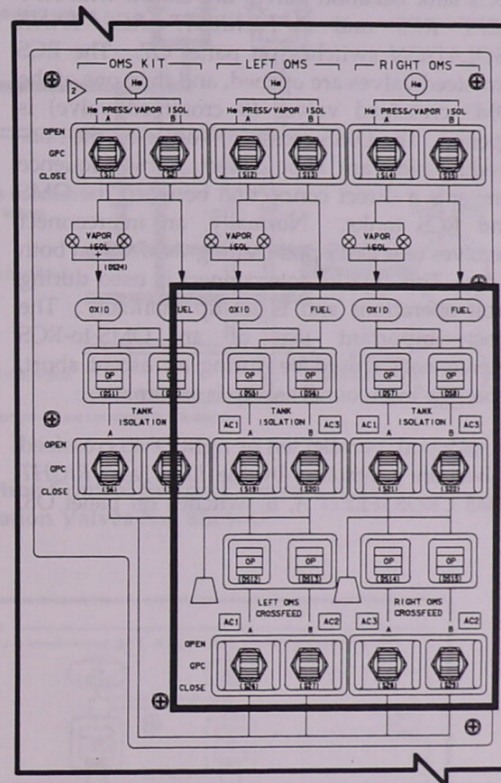
The *LEFT* and *RIGHT* OMS TANK ISOLATION A switches on panel O8 control the A fuel and A oxidizer valve in that pod, and the B switches control the B fuel and B oxidizer valve in that pod. The switches have manual *OPEN* and *CLOSE* positions and a *GPC* position that enables automatic control of the 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

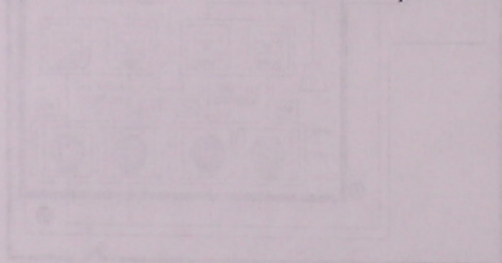
When a crossfeed is set up, the tank isolation valves on the receiving side are closed. (The OMS propellant tanks on each side should not be directly connected in most cases.) The OMS crossfeed valves are then opened for the feeding and receiving side to establish a flow path from the OMS propellant 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.

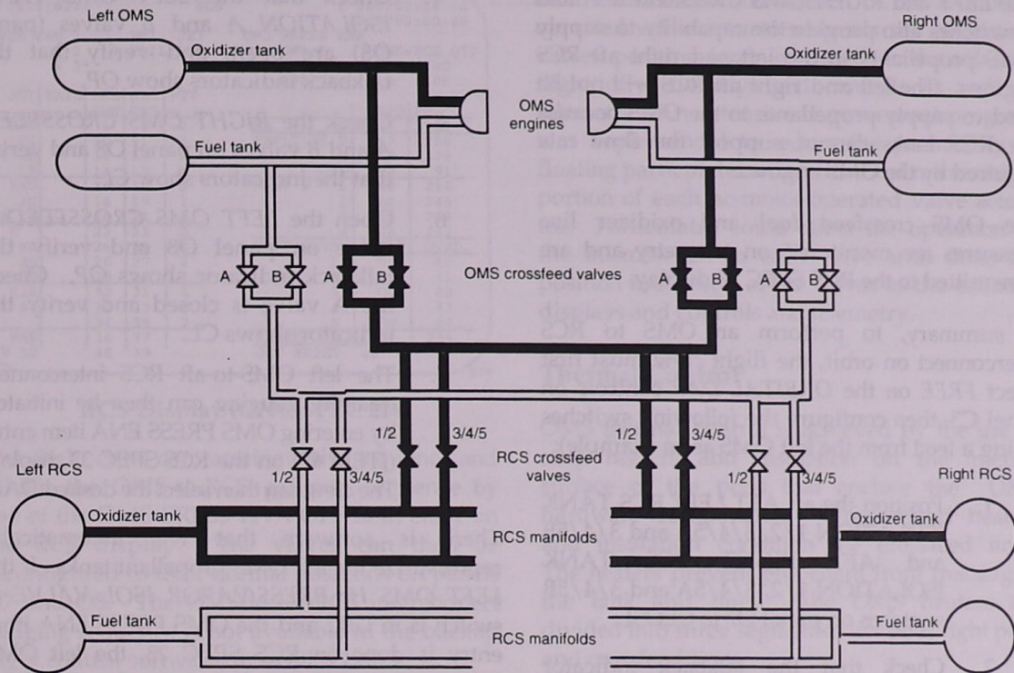
In each pod, parallel left or right OMS crossfeed valves are controlled by the *LEFT* and *RIGHT OMS CROSSFEED A, B* switches on panel O8.



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.

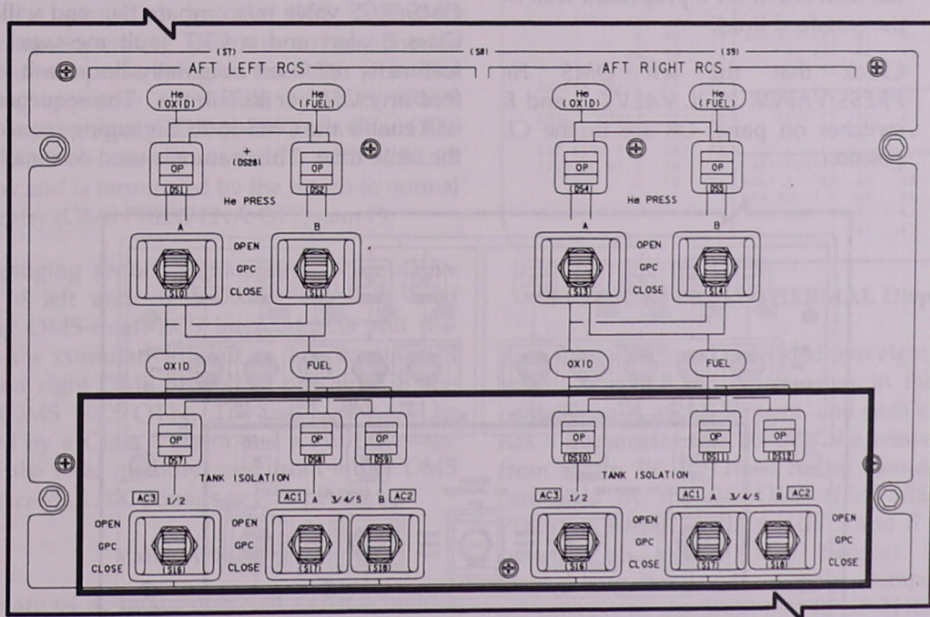
For example, when the *A* or *B* pair of crossfeed valves in the left pod is opened, fuel and oxidizer from the left pod are routed to the OMS crossfeed valves of the right pod; thus, a pair of *A* or *B* crossfeed valves in the right pod must be opened to permit the left pod fuel and oxidizer to be 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.



675.cvs

**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.

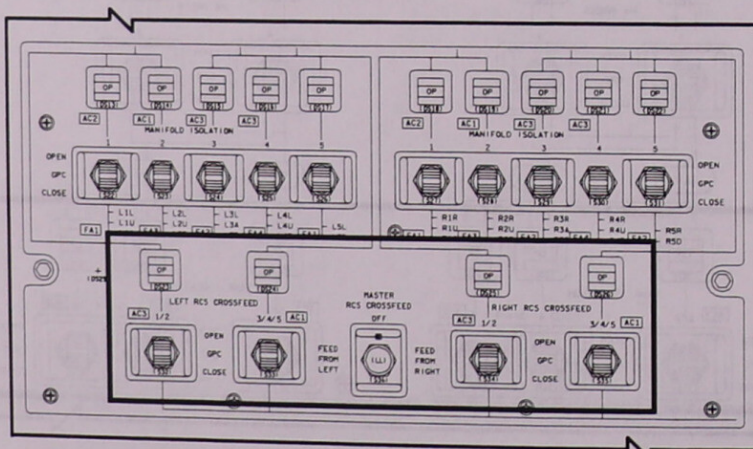
The OMS crossfeed fuel and oxidizer line pressures are monitored on telemetry and are transmitted to the RCS SPEC 23 display.

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 LEFT RCS CROSSFEED 1/2, 3/4/5* and *AFT RIGHT RCS 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 will automatically repressurize 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 is done on RCS SPEC 23, the left OMS helium pressure vapor isolation valve *A* will be commanded open when the left OMS tank (ullage) pressure drops to 236 psig, and the open commands will be terminated 30 seconds later. If the left OMS tank (ullage) pressure remains below 236 psia, the sequence will set an *OMS/RCS valve miscompare* flag and will set a *Class 3 alert* and a *CRT fault message*. This feature is not used nominally because it would feed any OMS or RCS leaks. The sequence also will enable the *OMS-to-RCS gauging* sequence at the same time. This feature is used nominally.



RCS CROSSFEED Switches and Talkbacks on Panel O7

2011/023/		RCS		1 000/03:14:16	
RCS FWD 1		PRI JET		000/00:00:00	
L 2		4 FAIL LIM 2		L OMS 5	
R 3*				R OMS 6	
				OFF 7*	
				OMS=RCS QTY	
				L 0.00	
				R 0.00	
JET	FAIL	DES	JET	PTY	
		INH	DES		
R4R		8	9	2	
2R		10	11	1	
Y 3R		12	13	2	
1R		14	15	1	
R4U		16	17	2	
2U		18	19	1	
Z 1U		20	21	3	
R		22	23	2	
4D		24	25	1	
2D		26	27	2	
3D		28	29	1	
R1A		30	31	1	
X 3A		32	33	3	
		34	35	2	
R5R		36	37		
V 5D		38	39		

HE	P	OXID	FU
PRPLT TK	P	3376	3360
	T	247	250
	T	77	79
	T	90	91
MANF P	1	242	246
	2	250	246
	3	248	248
	4	246	242
MANF VLV	STAT	OVERD	
	1	OP	40
	2	OP	41
	3	OP	42
	4	OP	43
	5	OP	44
XFEED	P	254	254
JET RESET		45	

678

### RCS Display (GNC SPEC 23)

The flight crew can terminate the sequence and inhibit the OMS-to-RCS gauging sequence by use of the OMS PRESS ENA-OFF item entry 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 OMS PRESS ENA 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 (OMS PRESS ENA-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 will be alerted by a Class 3 alarm and a fault message when the total quantity used from either OMS pod exceeds 1,000 pounds or 7.72 percent.

### 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

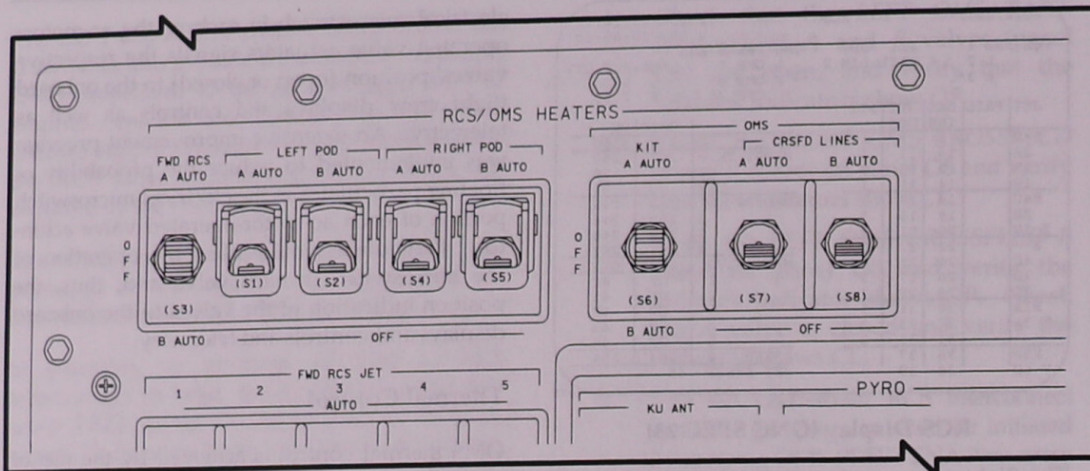
OMS thermal control is achieved by the use of strip heaters and insulation on the interior surface of the pods that enclose the OMS hardware components. Wraparound heaters and insulation condition the crossfeed lines. The heaters prevent propellant from freezing in the tank and lines. The OMS heaters are divided into three segments: left pod, right pod, and crossfeed lines.

2011/ /089		PRPLT THERMAL		4 000/02:37:12	
				000/00:00:00	
POD	L	R			
OMS TK	OX	80	80	OMS CRSD	L P C
	FU	80	80	XFD	OX 68 68 67
ENG I/F	OX	70	70		GBL LN 68 68 67
	FU	70	70	DRN	OX 65 65 64
OX VLV	71	71			
FU INJ	81	81			
WEB KEEL	1	70	70		FU OX
	2	70	70	BLD AFT FUS	65 66
Y	OB	74	74	PL BAY	65 67
	UP	74	74	OX OD	66 67
OX DRN PNL	1	67	67		
	2	67	67	FWD RCS	FU OX
ENG COVER	71	73		LINE T1	67 66
SERV PNL	70	70		T2	67 66
GSE SERV PNL	74	73			
TEST HE/OX	1	70	70	AFT RCS	L R
	2	70	70	MANF 1	OX 69 68
				DRN PNL	1 68 66
				VERN PNL	1 67 67
					2 67 67

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### 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 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.



RCS/OMS HEATERS Switches on Panel A14

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 and bleed 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 gimballed mounts that allow the engines to pivot up and down and from side to side. The OMS TVC system consists of a gimballed ring assembly, two gimballed actuator assemblies, and two gimballed actuator controllers. The engine gimballed ring assembly and gimballed actuator assemblies provide OMS TVC by gimballed 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 gimballed ring assembly contains two mounting pads to attach the engine to the gimballed ring

and two pads to attach the gimballed ring to the orbiter. The ring transmits engine thrust to the pod and orbiter.

The pitch and yaw gimballed actuator assembly for each OMS engine provides the force to gimballed 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  $\pm 6^\circ$  in pitch, and  $\pm 7^\circ$  in yaw with clearance provided for an additional  $1^\circ$  for snubbing and tolerances.

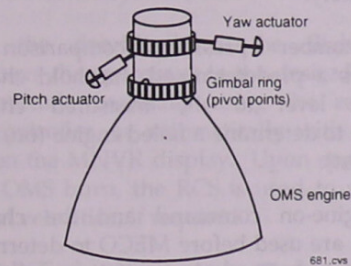
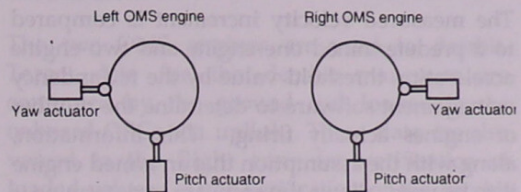
The thrust vector control command subsystem operating program (SOP) processes and outputs pitch and yaw OMS engine actuator commands and the actuator power selection discretetes. The OMS TVC command SOP is active during the following operational sequences: orbit insertion (OMS-1 and OMS-2), orbit coast, 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  $7^\circ$  yaw and  $6^\circ$  pitch, then to minus  $7^\circ$  yaw and  $6^\circ$  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 discretetes 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.

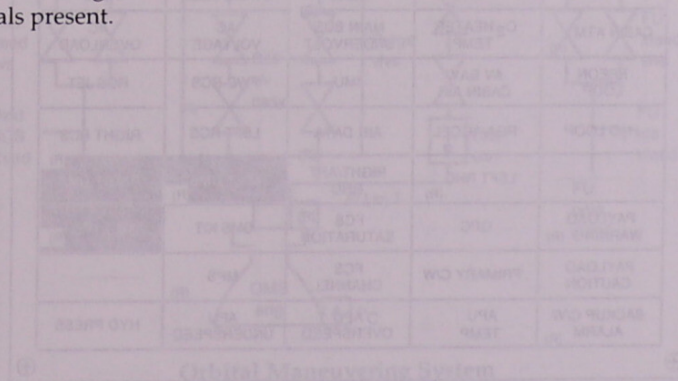
The ascent profile for a mission uses a single OMS burn, and is referred to as direct insertion. In a direct-insertion ascent profile, the OMS-1 burn after main engine cutoff is normally not required unless there is an underspeed. The OMS-2 burn is then used to achieve orbit circularization. The direct-insertion 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 CRT 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.

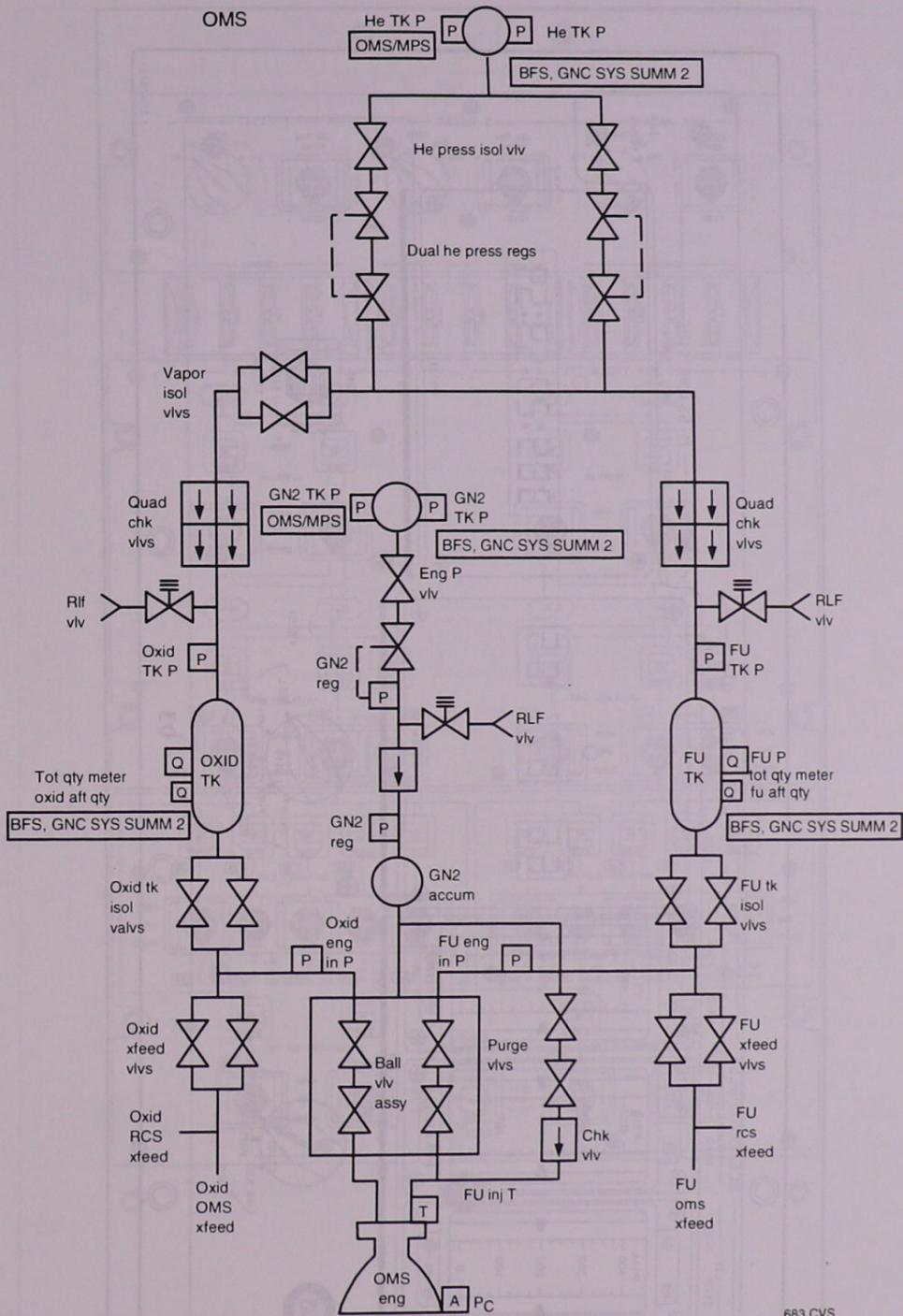


### OMS Caution and Warning Summary

- 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  $P_c$  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  $2^\circ$  difference between command and feedback position for an OMS gimbal actuator.
- An L (R) OMS PC fault message will be displayed when OMS engine  $P_c$  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  $N_2$  tank pressure is below 1,200 psi; or OMS  $N_2$  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  $260^\circ$  F.
- A G23 OMS RCS QTY fault message will be displayed when more than 7.72 percent (1,000 lb) of left or right OMS propellant is used during an orbit interconnect.

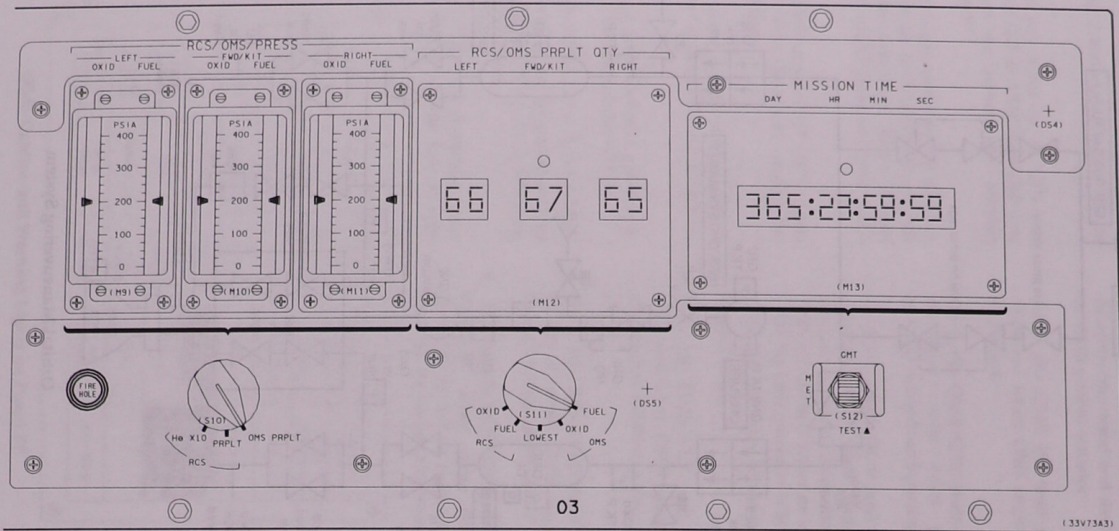
O <sub>2</sub> PRESS	H <sub>2</sub> PRESS	FUEL CELL REAC	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O <sub>2</sub> HEATER TEMP	MAIN BUS UNDERVOLT (R)	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H <sub>2</sub> O LOOP	RGA/ACCEL	AIR DATA	LEFT RCS (R)	RIGHT RCS (R)
	LEFT RHC (R)	RIGHT/AFT RHC (R)	LEFT OMS (R)	RIGHT OMS (R)
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

OMS Caution and Warning Lights on Panel F7

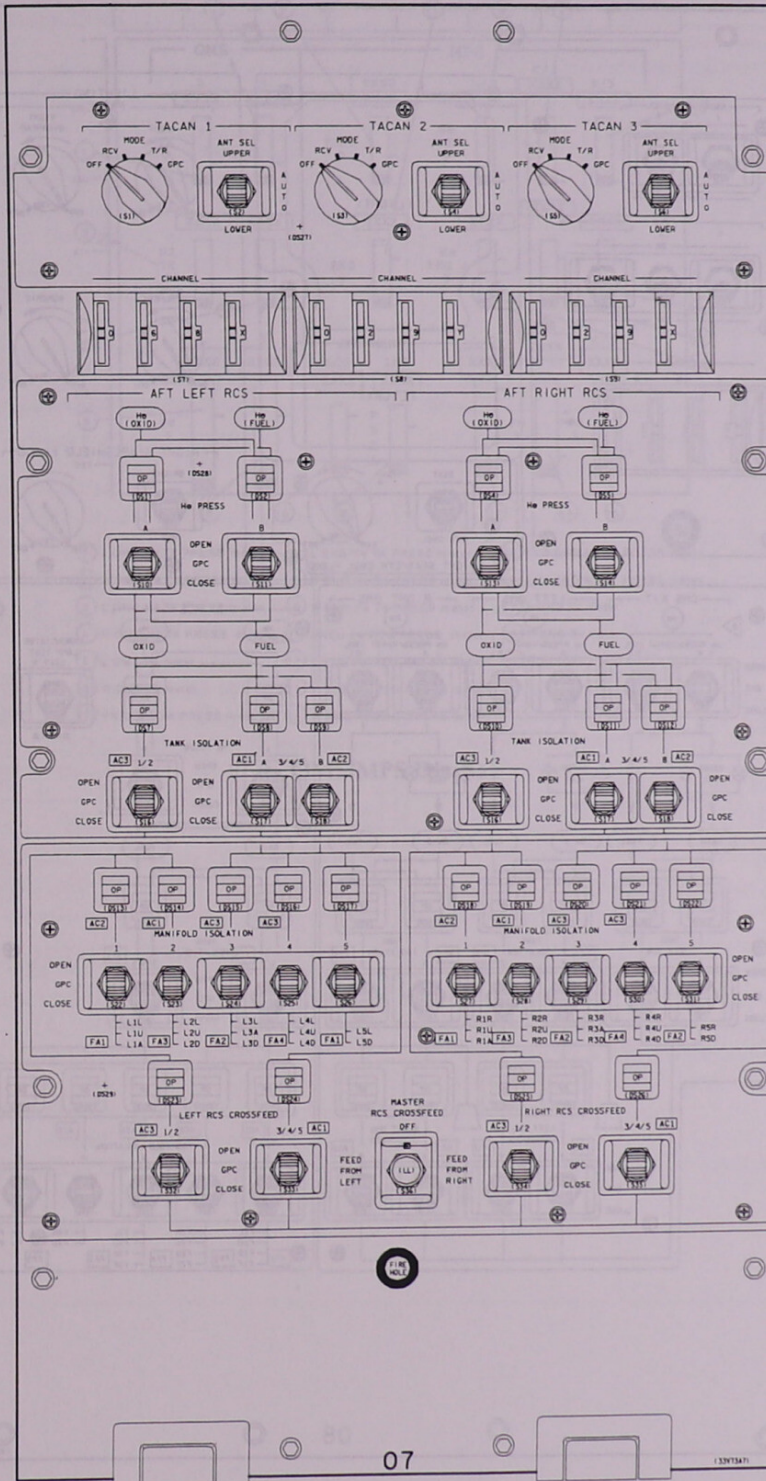


Orbital Maneuvering System

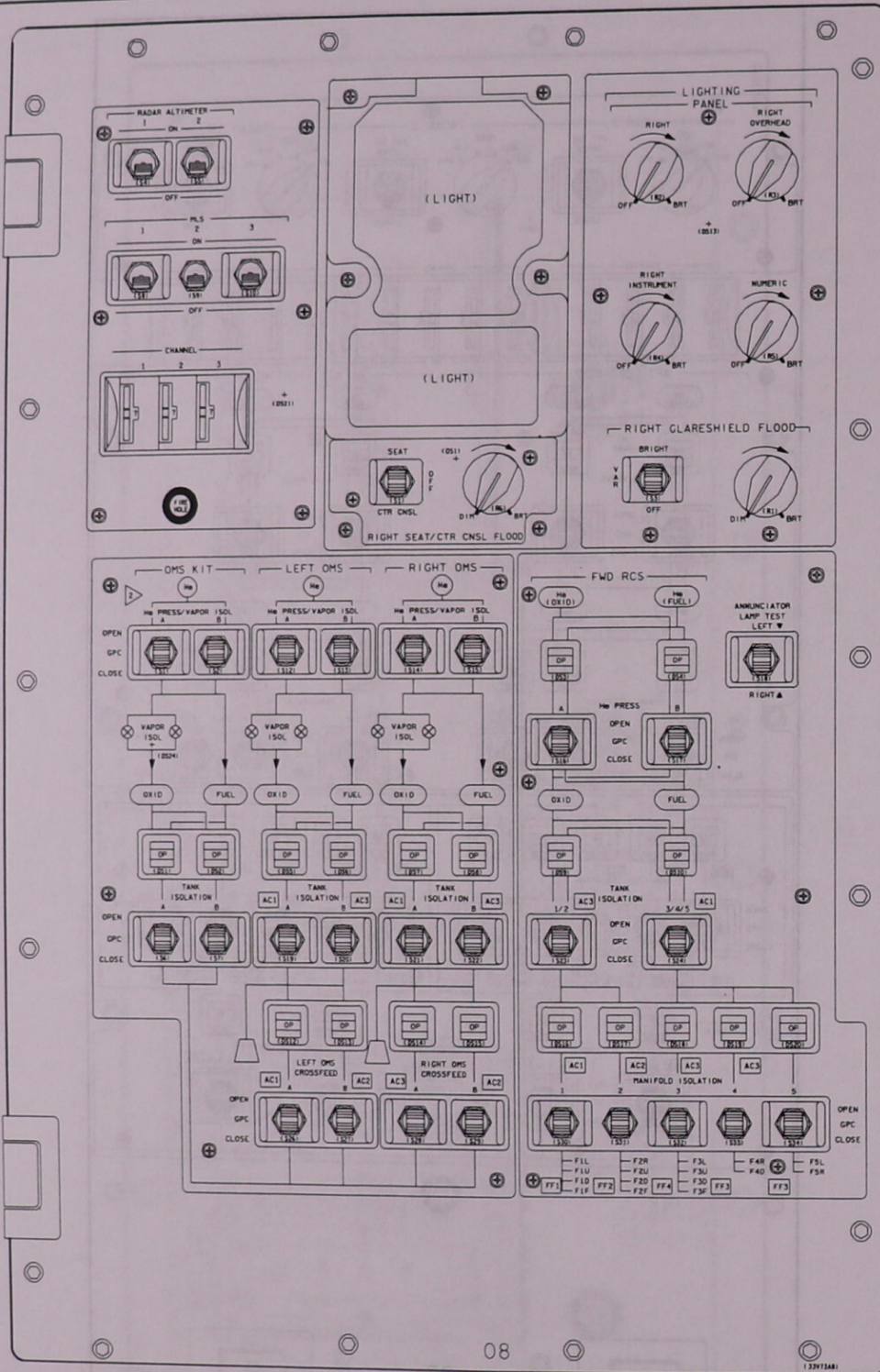
683.CVS



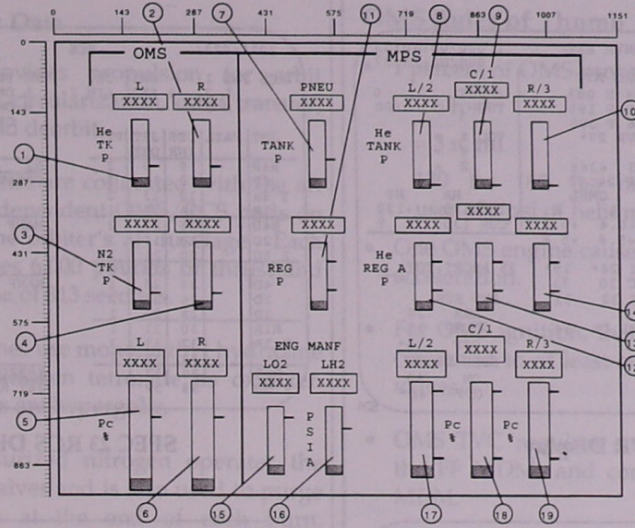
Panel O3



Panel O7



Panel O8



- |                           |                            |                            |
|---------------------------|----------------------------|----------------------------|
| ① L OMS He TK PRESS meter | ⑧ L ENG He TK PRESS meter  | ⑮ LO2 ENG MANF PRESS meter |
| ② R OMS He TK PRESS meter | ⑨ C ENG He TK PRESS meter  | ⑯ LH2 ENG MANF PRESS meter |
| ③ L OMS N2 TK PRESS meter | ⑩ R ENG He TK PRESS meter  | ⑰ L ENG Pc meter           |
| ④ R OMS N2 TK PRESS meter | ⑪ PNEU He REG PRESS meter  | ⑱ C ENG Pc meter           |
| ⑤ L OMS Pc meter          | ⑫ L ENG He REG PRESS meter | ⑲ R ENG Pc meter           |
| ⑥ R OMS Pc meter          | ⑬ C ENG He REG PRESS meter |                            |
| ⑦ PNEU He TK PRESS meter  | ⑭ R ENG He REG PRESS meter |                            |

**OMS/MPS Display**



1041/ OMS BOTH 1*	OMS 1 MNVR EXEC	1 000/00:40:23 000/00:15:37
L 2	BURN ATT	AVTOT 0
R 3	24 R 083	TGO 0:00
RCS SEL 4	25 P 195	
S TV ROLL 180	26 Y 300	VGO X +
TRIM LOAD	MNVR 27*	Y +
6 P [-10.1]		Z +
7 LY [-15.7]	REI 4366	
8 RY [-15.7]	TFP 24:40	HA HP
9 WT 217047	GMBL	TGT 130 +129
10 TIG	L R	CUR 130 + 9
TGT PEG 4	P +0.4 +0.4	
14 C1	Y +5.8 +5.8	
15 C2 [-]		35 ABORT TGT
16 HT	PRI 28* 29*	FWD RCS
17 0T	SEC 30 31	ARM 36
18 PRPLT [-]	OFF 32 33	DUMP 37
TGT PEG 7	GMBL CK 34	OFF 38*
19 AVX [-]		SURF DRIVE
20 AVY [+]		ON 39
21 AVZ [-]		OFF 40*
LOAD 22/TIMER 23		

MNVR Display

526

2011/023/	RCS	1 000/03:14:16 000/00:00:00
RCS FWD 1	PRI JET	OMS PRESS ENA
L 2 4 FAIL LIM 2	L 2	L OMS 5
R 3*	R 3*	R OMS 6
		OFF 7*
		OMS=RCS QTY
		L 0.00
		R 0.00

JET	FAIL	DES	JET	PTY
		INH	DES	
R4R		8	9	2
2R		10	11	1
Y 3R		12	13	2
1R		14	15	1
R4U		16	17	2
2U		18	19	1
Z 1U		20	21	3
R		22	23	2
4D		24	25	1
2D		26	27	2
3D		28	29	1
R1A		30	31	1
X 3A		32	33	3
		34	35	2
R5R		36	37	
V 5D		38	39	

HE	P	OXID	FU
PRPLT TK P		3376	3360
T		77	79
QTY		90	91
MANF P	1	242	246
	2	250	246
	3	248	248
	4	246	242
MANF VLVs		STAT	OVRD
	1	OP	40
	2	OP	41
	3	OP	42
	4	OP	43
	5	OP	44
XFEED P		254	254
JET RESET		45	

SPEC 23 RCS Display

678

3011/ /019	GNC SYS SUMM 2	5 015/20:25:34 BFS 000/00:26:24
OMS APT QTY L R	OMS L R	HE 2610 2680
OXID 28.6 28.6	TK P	OXID 260 258
FU 28.3 28.3		FU 267 258
FU INJ T 79 79		FU 70 70
		OX VLV 71 71
		FU INJ 81 81
RCS	OXID	FU
FWD HE P 464 1264		
TK P 248 244		
QTY 0 0		
MANF 1 P 248 242		
2 P 248 244		
3 P 250 246		
4 P 244 244		
5		
AFT HE P 800 2672		
L TK P 244 249		
QTY 63 63		
MANF 1 P 244 246		
2 P 246 250		
3 P 248 250		
4 P 246 250		
5		

GNC SYS SUMM 2 Display

242

2011/ /089	PRPLT THERMAL	4 000/02:37:12 000/00:00:00
POD	L R	
OMS TK	OX 80 80	
	FU 80 80	
ENG I/F	OX 70 70	
	FU 70 70	
	OX VLV 71 71	
	FU INJ 81 81	
WEB KEEL	1 70 70	
	2 70 70	
Y	OB 74 74	
	UP 74 74	
OX DRN PNL	1 67 67	
	2 67 67	
ENG COVER	71 73	
SERV PNL	70 70	
GSE SERV PNL	74 73	
TEST HE/OX	1 70 70	
	2 70 70	

OMS CRSFD	L	R	C
XFD	OX 68 68 67		
GMBL LN	68 68 67		
DRN	OX 65 65 64		
		FU	OX
BLD AFT FUS	65 66		
PL BAY	65 67		
OX QD	66 67		
FWD RCS	FU	OX	
LINE T1	67 66		
T2	67 66		
AFT RCS	L	R	
MANF 1	OX 69 68		
DRN PNL	1 68 66		
	2 68 66		
VERN PNL	1 67 67		
	2 67 67		

SM SPEC 89 PRPLT THERMAL Display

663

### 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 6,000 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 gimballed mounts that allow the engines to pivot up and down and from side to side ( $\pm 6^\circ$  pitch,  $\pm 7^\circ$  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 lbs (80 lbs oxidizer, 50 lbs fuel) uses 400 psi of helium for long burns.
- One OMS engine causes approximately 1 fps<sup>2</sup> 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.

**2.20 ORBITER DOCKING SYSTEM**

**Description**

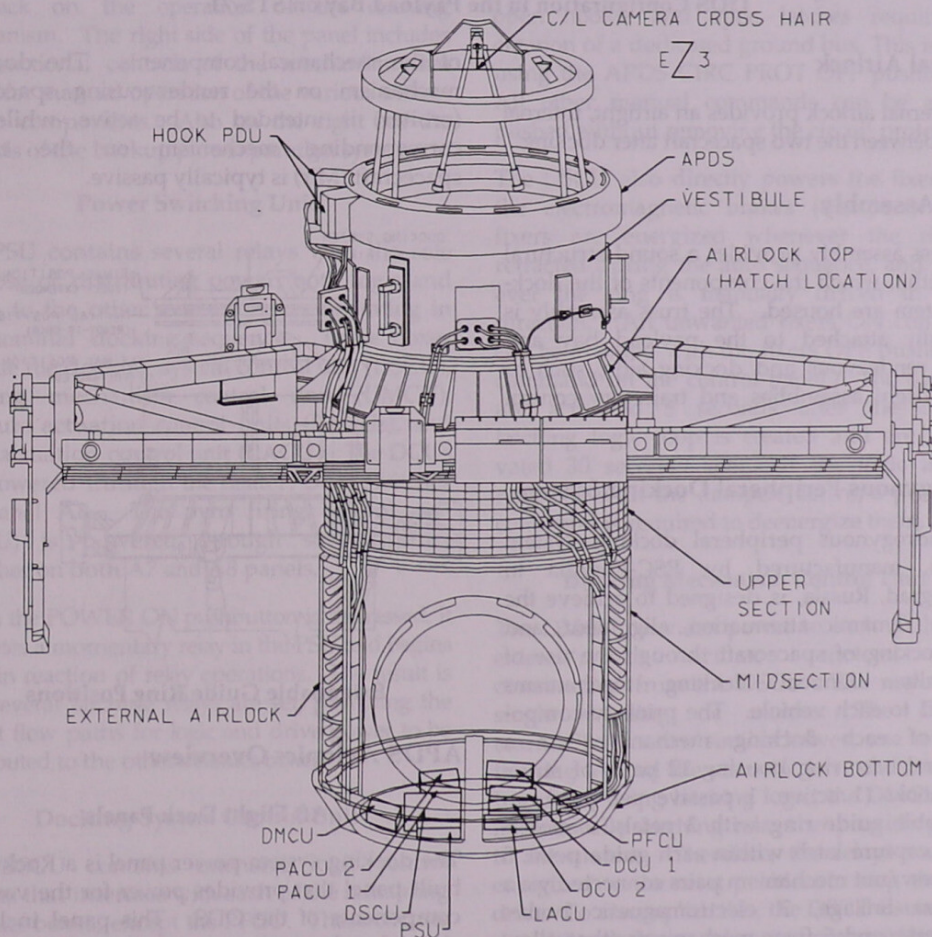
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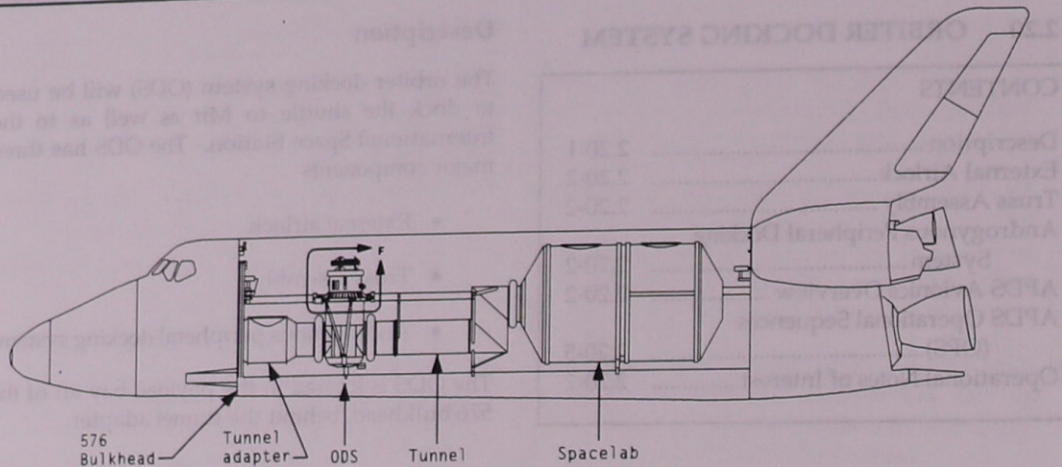
The orbiter docking system (ODS) will be used to dock the shuttle to Mir as well as to the International Space Station. The ODS has three major components

- 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-71

### External Airlock

The external airlock provides an airtight, internal tunnel between the two spacecraft after docking.

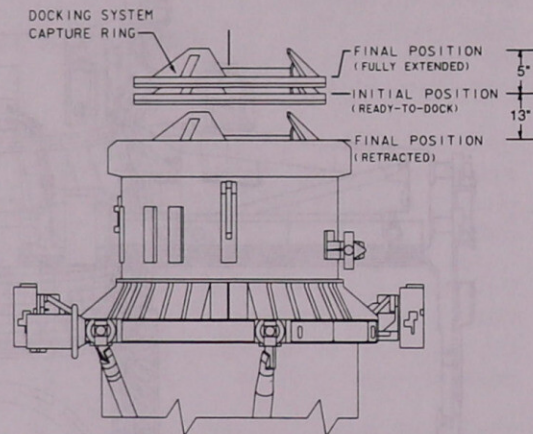
### Truss Assembly

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 through the use of 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 ring with 3 petals, a motor-driven capture latch within each guide petal, 3 ball screw/nut mechanism pairs connected via a common linkage, 3 electromagnetic brakes (dampers), and 5 fixer mechanisms (that allow for only z-axis movement of the guide 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 (Mir) is typically passive.



Extendable Guide Ring Positions

### APDS Avionics Overview

#### Aft Flight Deck Panels

The docking system power panel is a Rockwell-built panel that provides power for the various components of the ODS. This panel includes circuit breaker 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 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 switches supply logic bus power to the control panel functions. The heater/data collection units (DCUs) switches provide power to heaters located around the docking ring. The H2/DCU and H3/DCU switches 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 switches also illuminates indicator lights below each switch. 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.

#### **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 A8. The pyro firing control unit (PFCU) is powered through several other switches on both A7 and A8 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.

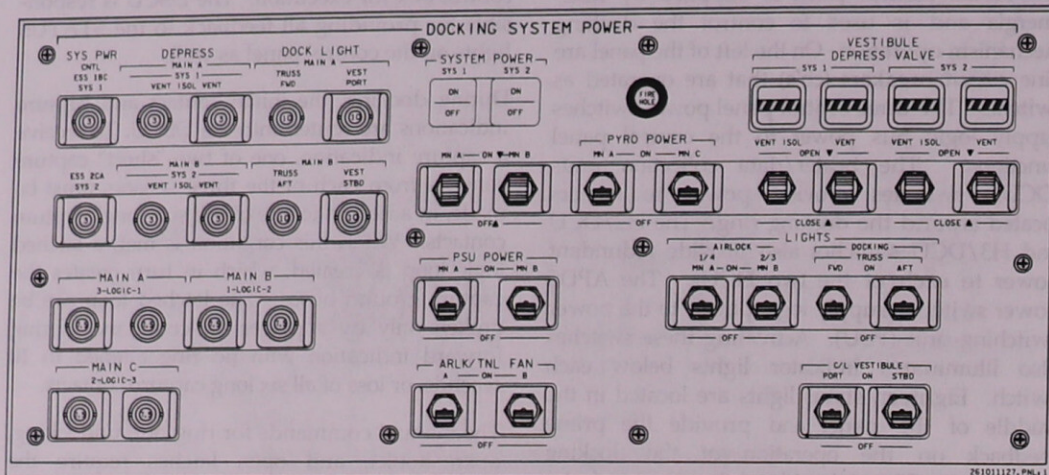
During docking, the initial contact and capture indications are routed into the DSCU. To receive a capture indication, one of two "short" capture contacts from each of the three sensors must be made, in addition to one of the six "long" capture contacts. When this condition is met, a latched logic loop is created, which in turn creates the capture ground buses. The latched loop can be broken only by a power off command, a ring forward indication with no ring aligned in 10 seconds, 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.

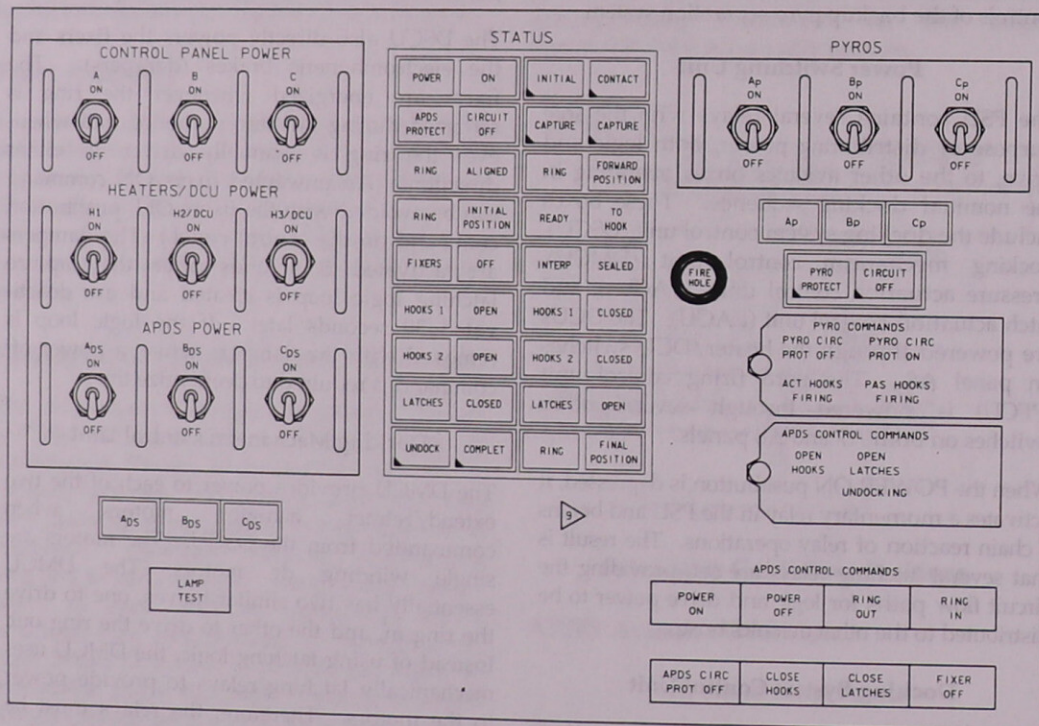
The DSCU also directly powers the fixers and the electromagnetic brakes (dampers). The fixers are energized whenever the ring is retracted during the auto sequence, and whenever the ring is manually driven in either direction. (An unwanted fixers ON command can be avoided with the fixers OFF pushbutton command on the control panel.) The dampers are activated 5 seconds after the capture latching logic loop is created and are deactivated 30 seconds later. If the logic loop is removed with the dampers active, a power off command is required to deenergize them.

#### **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 A7A3



APDS Control Panel, Panel A8A3

### Pressure Actuation Control Units

PACUs 1 and 2 control the operation of 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 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 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 the docking system panel, and the pyro A, B, C switches on the APDS control panel 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 A7 panel provides three logic power buses to the Russian A8 panel. These switches also provide MN A/B power to the A7 panel for the docking lights, depress valves, etc. Then the three HEATER/DCU POWER cb switches on A8 are turned on to activate heaters on elements of the docking mechanism. The H2 and H3 switches also power the two DCU avionics boxes that provide telemetry data. These steps may be accomplished earlier in flight than the powerup, since there are no constraints to having these continuously powered.

### Docking Mechanism Powerup

First, the PSU power switches on panel A7 are turned on to feed MNA and MNB bus power to the PSU avionics box. Now, on A8, 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 switches provide logic power from the control panel to the PSU 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 A8 panel. The control panel also has a lamp test pushbutton that is used to test all 36 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 will not send commands.

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 (13 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 rigidized while it drives. One second after the ring reaches its initial position, the ring motors and the fixers are 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 initial contact, the initial contact light on A8 will illuminate and the ring aligned light will 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.

Once capture is achieved, the capture light will illuminate and the initial contact light will extinguish. At this time, the automatic docking sequence is initiated, and the crew will start a timer to follow the auto sequence through its steps. There is also a Manual Docking Sequence cue card that allows the crew to complete the docking sequence manually, if required, as long as the active damping is complete.

### 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 verify function and realign it, and either retracting it to the initial position or fully retracting it and then reextending it to the initial position. If the mechanism appears good, 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 Mir does not get the signal (i.e., the orbiter does not get active damping or the Mir 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 is to open the capture latches and back away.

### Automatic Docking Sequence

After a 5-second time delay postcapture, three electromagnetic brakes (high-energy dampers) are energized for 30 seconds to damp relative motion. There are also three low-energy dampers that are always active on the docking ring and serve to dampen lateral and rotational motion. Sixty seconds after capture, the ring will start to drive out. The crew will then stop the ring drive by depressing the POWER ON pushbutton. This stops the ring and turns off the fixers, but does not deactivate the auto sequence (this just pauses it). The crew will wait up to 8 minutes to allow relative motion to damp, as indicated by a continuously illuminated ring aligned light. If the ring aligns within that time, the automatic sequence can be picked up again with a RING IN command (there is no need to fully extend the ring). Similarly, if the ring is not aligned after 8 minutes, a RING OUT command will restart the auto sequence and drive the ring out to the forward position. If it does not align within 10 seconds, the auto sequence will be terminated and the manual sequence will be necessary to complete the operation.



After  $\approx 3$  min of ring retraction, the ring will 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 either set of hooks is closed, the ring is extended slightly (10-second drive) to relieve loads on the capture latches. The capture latches are opened, and the ring is retracted to its final position. The docking is then complete, and the system can be powered down.

### Manual Docking Sequence

The entire docking sequence, with the exception of the active damping, 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. A Manual Docking Sequence cue card was developed to provide for a manual docking from the completion of active damping through the final retraction of the ring. The sequence can also be picked up in midstream just by entering the cue card at the appropriate step.

### Undocking Timeline

Prior to undocking, the external airlock, internal airlock, and Spacelab hatches must be closed and the Mir verified ready for undock, including the release of any Mir hooks used for structural margin. Again, the docking lights and cameras will be turned on. The vestibule will be depressed using the switches on A7L, 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, and open latches pushbuttons are enabled. The undocking sequence nominally requires just the undocking pushbutton 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 Mir/orbiter. The sep burns are then accomplished, 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 Mir side, the pyro system for the passive hooks can be used from the orbiter to effect undocking. The pyro power switches on A7 provide four buses to the pyro firing control unit avionics box. The pyro switches on A8 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 release the hooks, a third method of separation has been developed. It involves the crew going EVA and removing the 98 bolts that attach the vestibule to the external airlock.

### 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 because of heatup 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.

## 2.21 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.

### Spacelab

With Spacelab module missions, PGSCs are used to interface with the Spacelab computer systems and experiments performed in the Spacelab module.

### Spacehab

Similar to Spacelab, PGSCs in the Spacehab provide an interface to Spacehab systems data and to experiments in Spacehab.

### Rendezvous

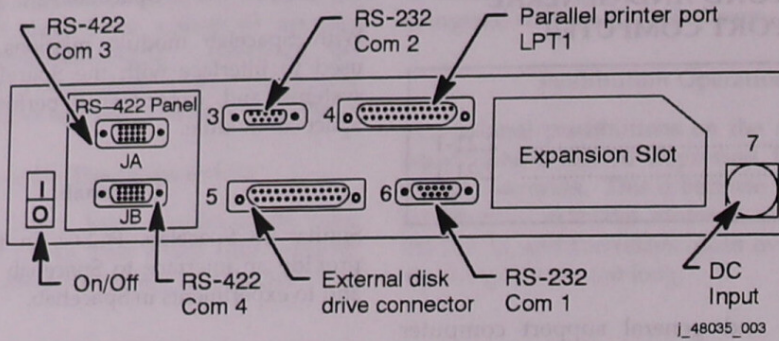
During missions that deploy or rendezvous with a payload or dock with Space Station, PGSCs are used as a tool to facilitate the orbiter's approach to its targets. Other tools used in conjunction with the PGSCs include:

- Handheld laser (HHL)
- Pulse code modulation master unit (PCCMU) data (PCDECOM)
- Rendezvous proximity operations program (RPOP)
- Trajectory control sensor (TCS)
- Tools for rendezvous and docking (TRAD)

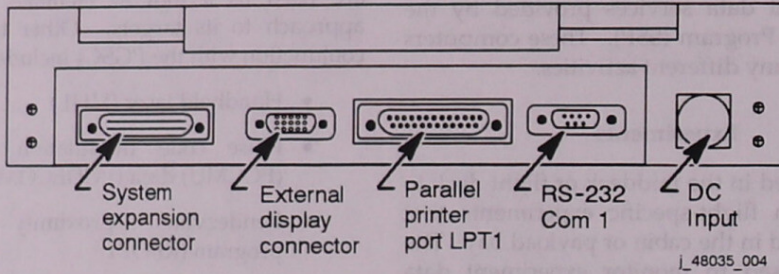
### Equipment

Equipment flown to support PGSC activities includes:

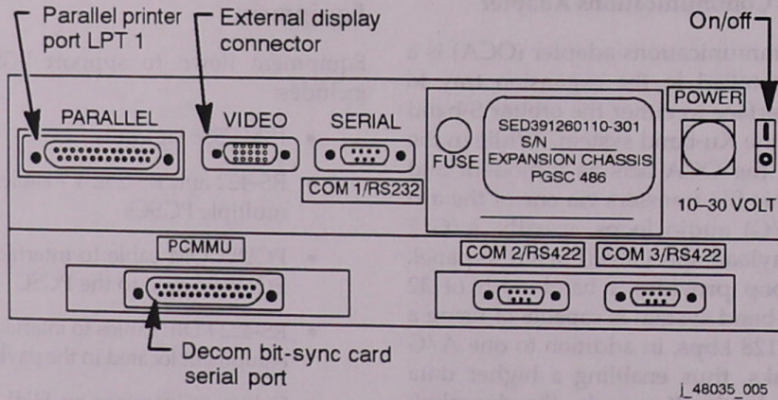
- IBM 755c laptop
- RS-422 and RS-232 Y - cables to interface multiple PGSCs
- PCDECOM cable to interface the orbiter PCMMU data to the PGSC
- RS-422 PDIP cables to interface PGSC with equipment located in the payload bay
- Cables to interface an HHL or TCS to a PGSC
- Expansion tray to provide additional 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



PGSC (386) - 715; GRID



PGSC (486) - Thinkpad



PGSC (486) - Thinkpad Expansion Chassis

Back of PGSC and Expansion Chassis

## 2.22 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

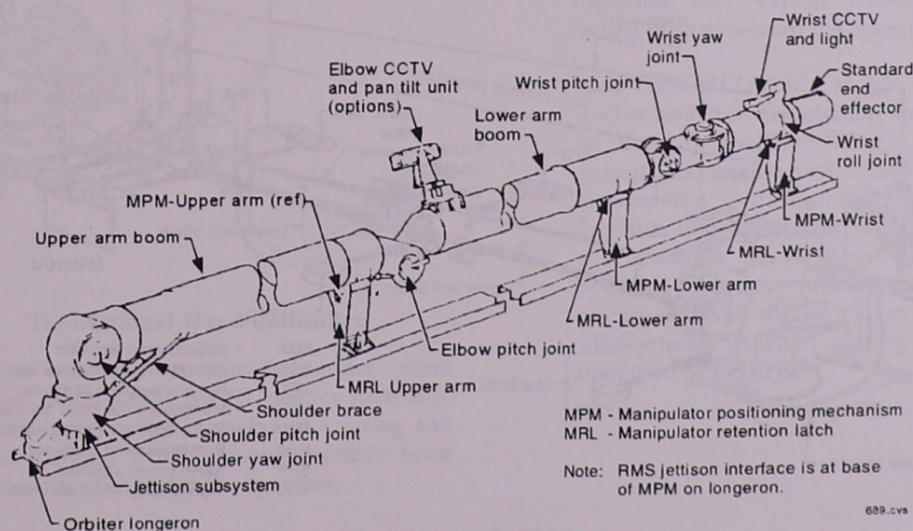
The RMS is the mechanical arm portion of the PDRS. The arm can perform several tasks, such as deploying and retrieving a payload, providing a stable platform for EVA crew-member foot restraints or work stations, mating space station components, and taking payload bay surveys. The RMS is capable of maneuvering 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.

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, 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.

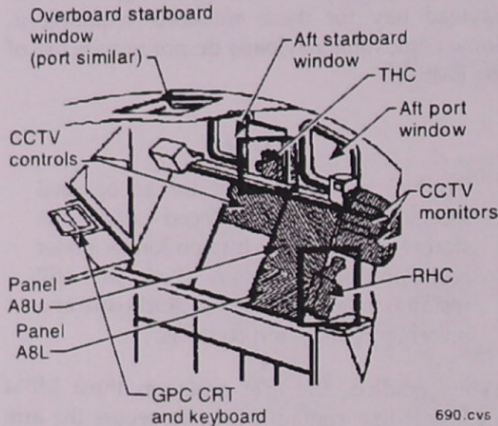


RMS-Stowed Position and General Arrangement

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.

controls CRT 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 CRT and are available for downlink through orbiter telemetry.

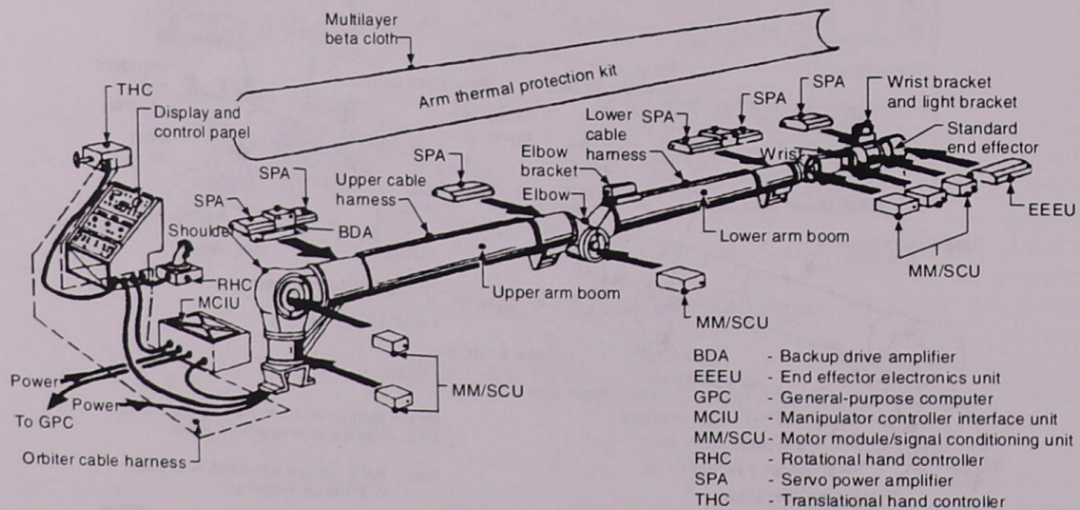


All the major systems of the ABE are monitored. The MCIU checks the integrity of the communications link between itself and the ABE, D&C, and the orbiter SM GPC. The MCIU also monitors end effector functions, thermistor circuit operation, and its own internal integrity. The computer checks include an 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.

### RMS Displays and Controls, Aft Station

The RMS can be operated only in a weightless environment because the arm dc 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.

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



### RMS Components

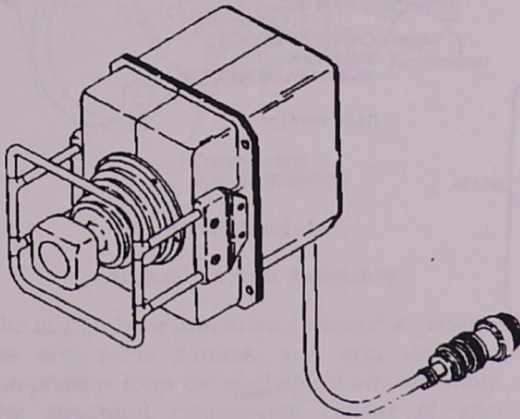
### Manipulator Controller Interface Unit (MCIU)

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 (THC)

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 (RHC)

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.

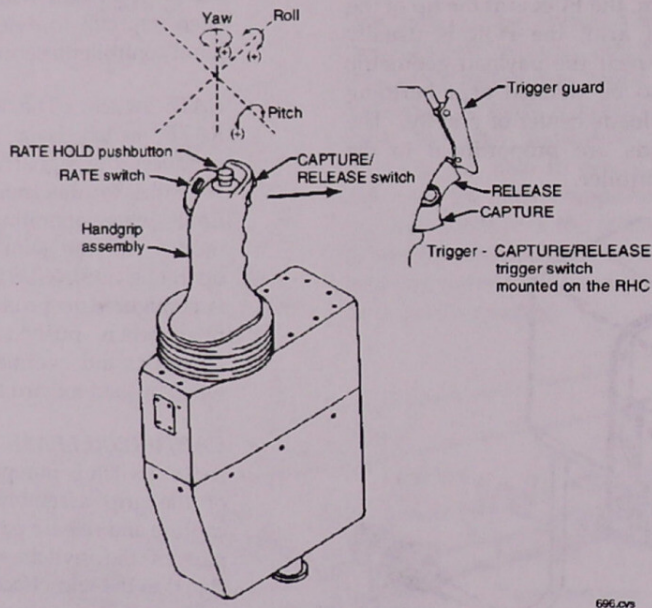
### Manipulator Arm Drive System

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.

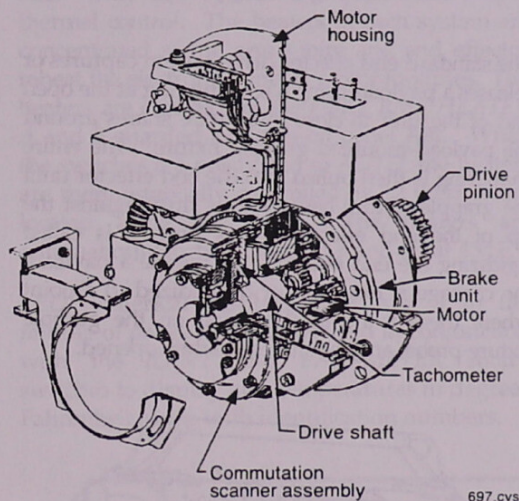


Rotational Hand Controller



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**

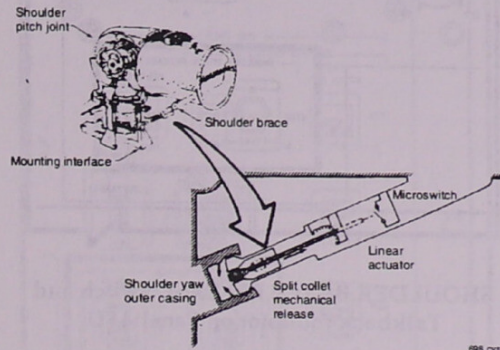
**Mechanical Arm Assembly**

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.

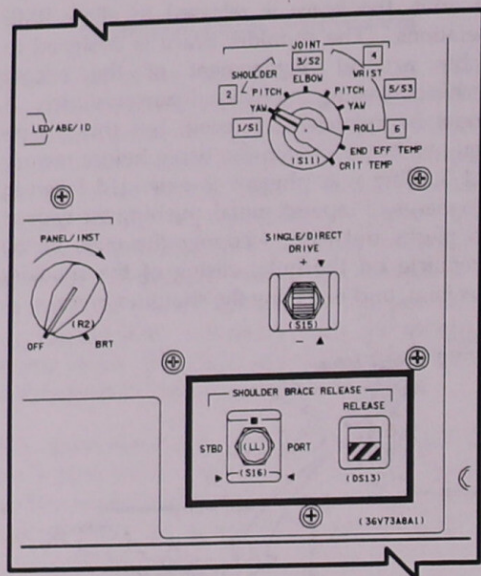
On orbit, the brace is released to allow RMS operations. The shoulder brace is designed to enable ground engagement of the release mechanism using an external power source. It cannot be relatched on orbit, but there is no requirement to relatch the brace before reentry and landing. A plunger is extended 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.



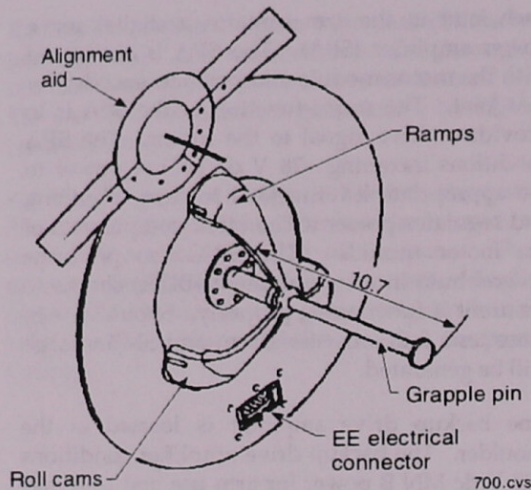
**SHOULDER BRACE RELEASE Switch and Talkback Indicator on Panel A8U**

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 light-weight 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.

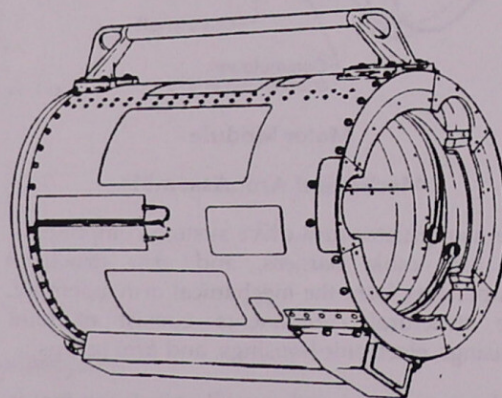
**End Effectors**

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**

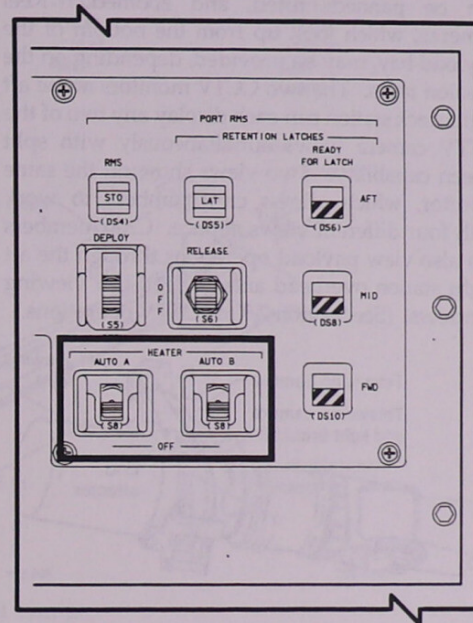
### Thermal Protection

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.

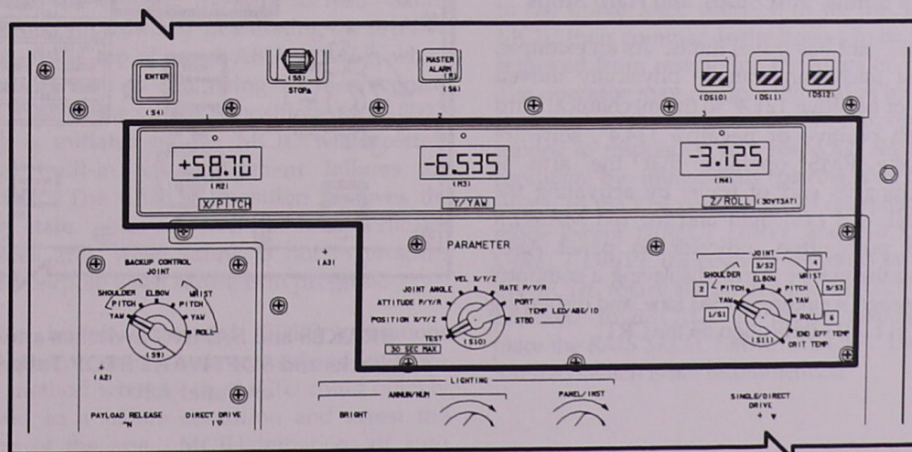
To maintain the arm's temperature within predetermined operating limits, an active system of 26 heaters on the arm supplies 520 watts of power at 28 V dc. There are two redundant heater systems, one powered from the orbiter's MN A dc bus and the other from the MN B dc bus. Only one system is required 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 heaters are automatically turned on at 14° F and off at 43° 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 of the thermistor to be in the end effector.



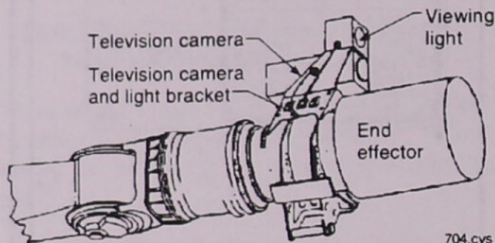
PORT TMS HEATER Switches on Panel A8L



LEDs and Rotary Switches on Panel A8U

### CCTV

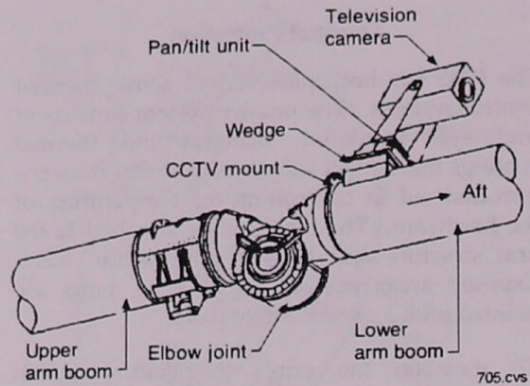
The orbiter's CCTV aids the flight crew in monitoring PDRS operations. Mounted on the end effector is a spotlight and a fixed CCTV camera that can be zoomed. A CCTV with pan and tilt capability is located below the elbow. In addition, four CCTV cameras in the payload bay can be panned, tilted, and zoomed. Keel cameras, which look up from the bottom of the payload bay, may be provided, depending on the mission tasks. 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

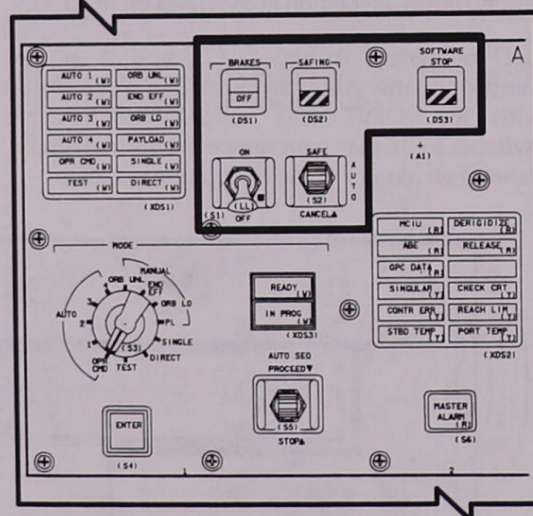
### Reach Limits, Soft Stops, and Hard Stops

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 CRT.



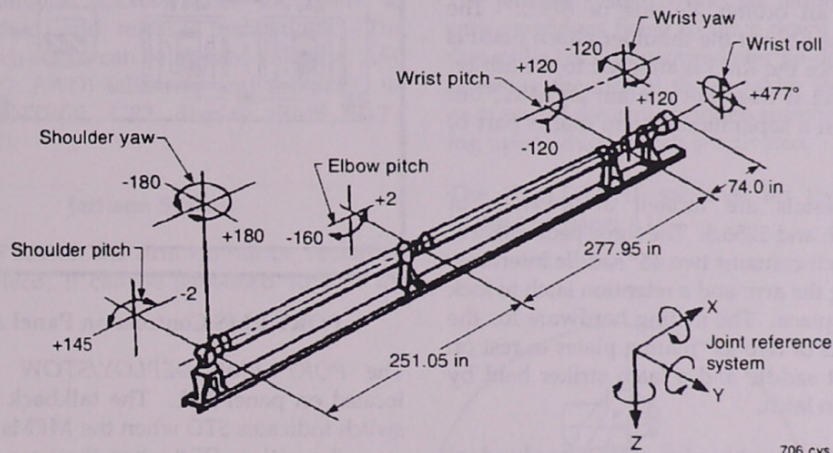
Elbow CCTV System

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.



BRKES 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°



706.cvs

### 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. 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 manipulator retention latches (MRLs), and the jettison system.

### MPM Pedestals

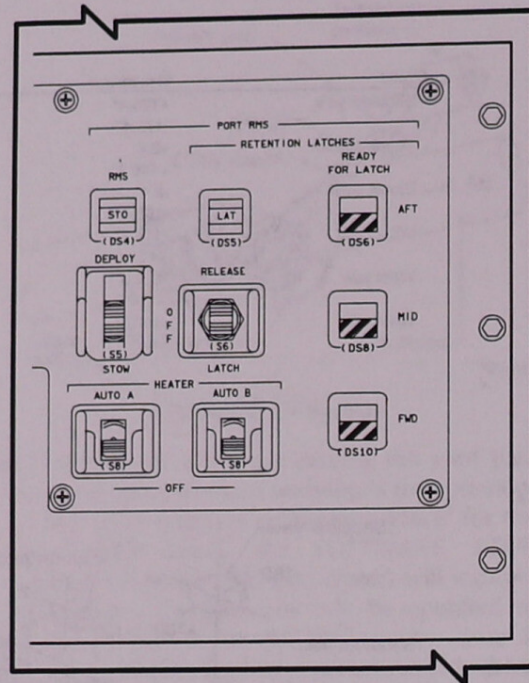
The pedestals house the separation system and are the cradling units upon which the arm rests in the cradled position. There are four support assemblies. One is a shoulder attach point located at an orbiter X-value of 679.5. The support assembly at the shoulder attach point is unique. Since the RMS is 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.

Three 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.

### 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.



PORT RMS Controls on Panel A8L

The *PORT RMS DEPLOY/STOW* switch is located on panel A8L. The talkback above the switch indicates *STO* when the MPMs are in the stowed position, *DEP* when they are deployed, and barberpole in transit. The status of the shoulder MPM can be monitored on the SPEC 94 PDRS CONTROL display (RMS STO/DPLY SHLD).

2011/094/	PDRS CONTROL	4 000/02:32:45
		000/00:00:00
RMS SEL:	RMS PWR OFF	ENA INH
PORT 1*		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
13	14	15
		16
		17
		18
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PDR CONTROL Display (SPEC 94)

### Manipulator Retention Latches

The arm is latched in three locations (aft, mid, and forward) along the orbiter 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 CRT display (RMS LAT/REL/RDY).

### Jettison System

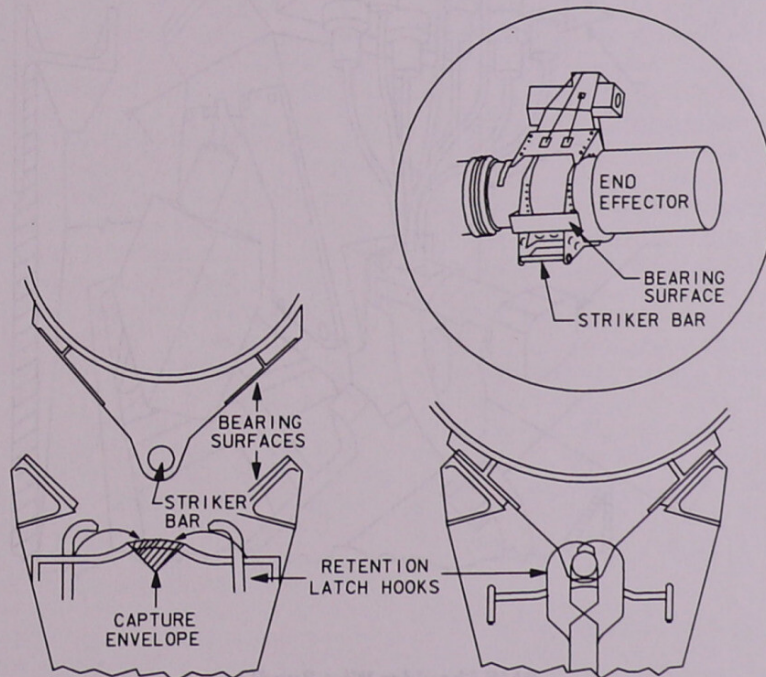
If for any reason the arm cannot be recradled and restowed, it can be jettisoned so that the

payload bay doors can be closed. There are four separation points, one at the shoulder and one 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.

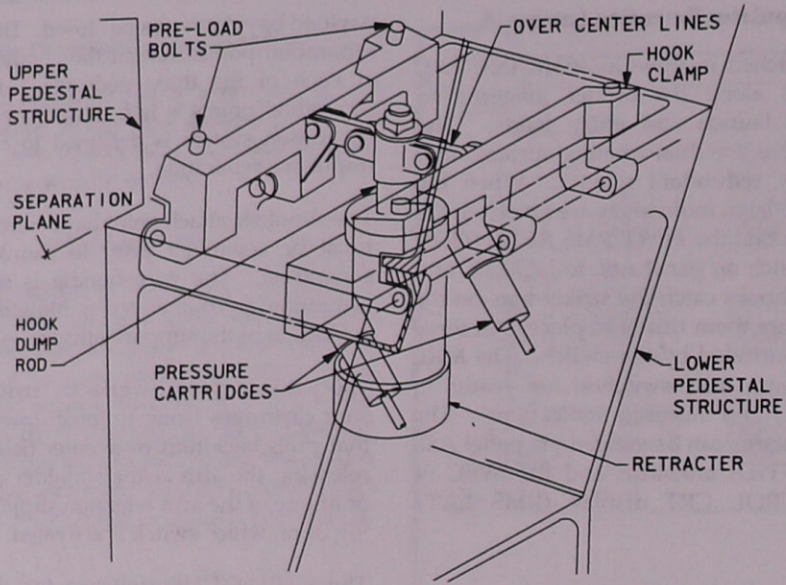
The shoulder attach point has a wire bundle that must be separated prior to shoulder support separation. The wire bundle is severed by a redundant pyro-operated guillotine prior to the activation of the support jettison system.

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 at the shoulder joint support or at one of the arm retention supports, depending upon which switch is activated.

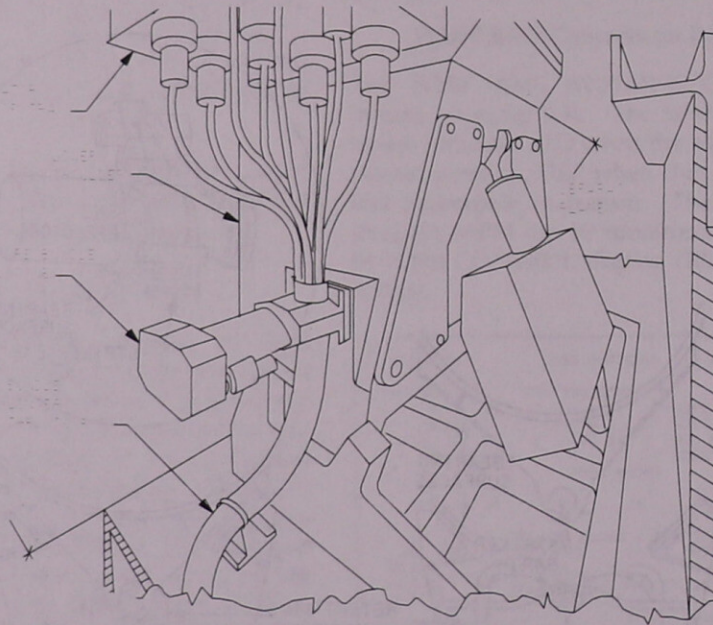
The *GUILLOTINE* switches for the RMS are located on panel A14.



RMS Retention Mechanism

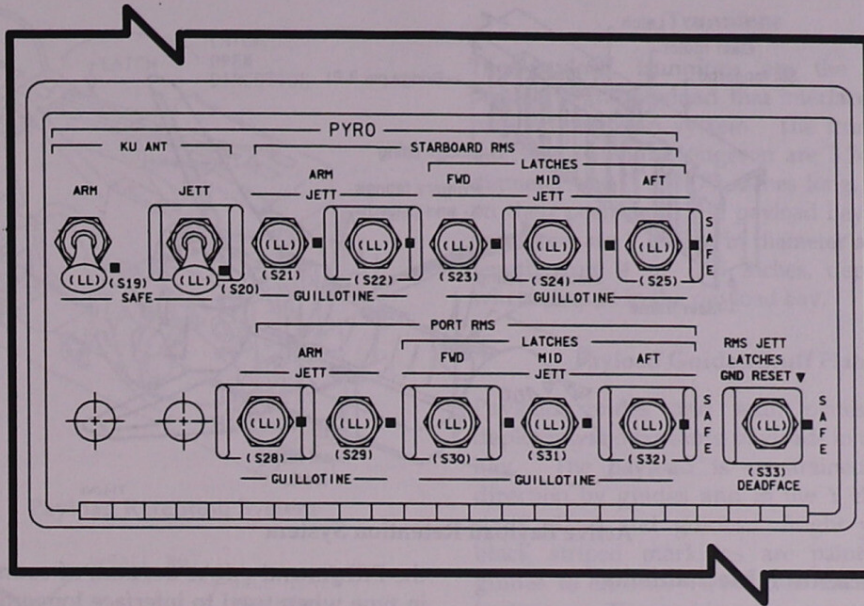


Jettison System

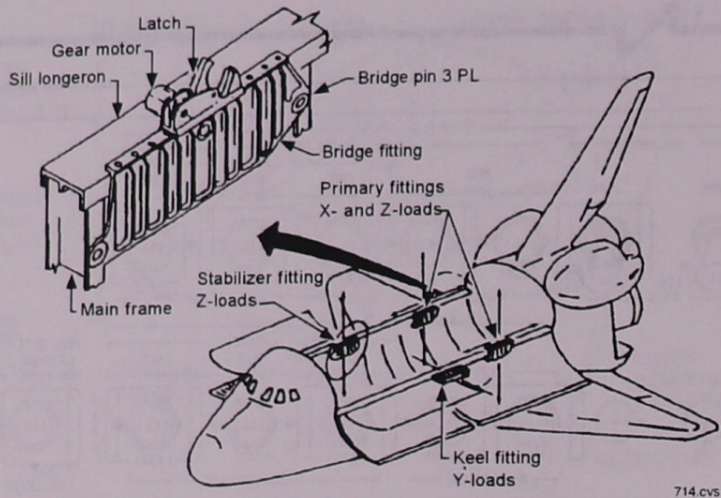


RMS Shoulder Wire Bundle





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

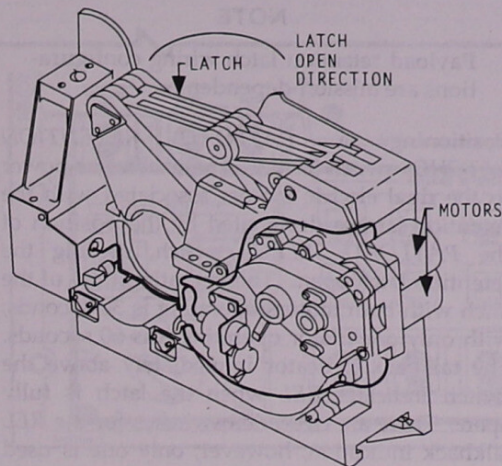
the PRLAs and AKAs do, and, of course, differ in type when used to interface longeron versus keel latches.

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.

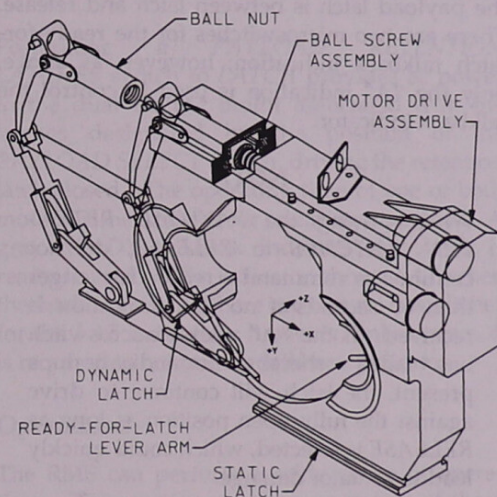
The standard and lightweight bridge fittings differ in both cross-sectional thickness and material. The standard fittings are made of titanium and are thicker than their lightweight aluminum counterparts. Bridge fittings, whether standard or lightweight, longeron or keel type, are compatible with the 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 yaw 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.

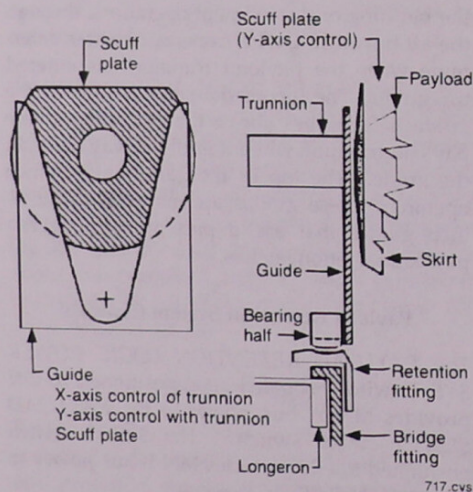
**Payload Retention System Controls**

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 (both labeled "M"). These positions allow the crewmember to monitor all the 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.



Orbiter Payload Guide, Active Retention Fitting

**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 is used to control the talkback indicator.

**NOTE**

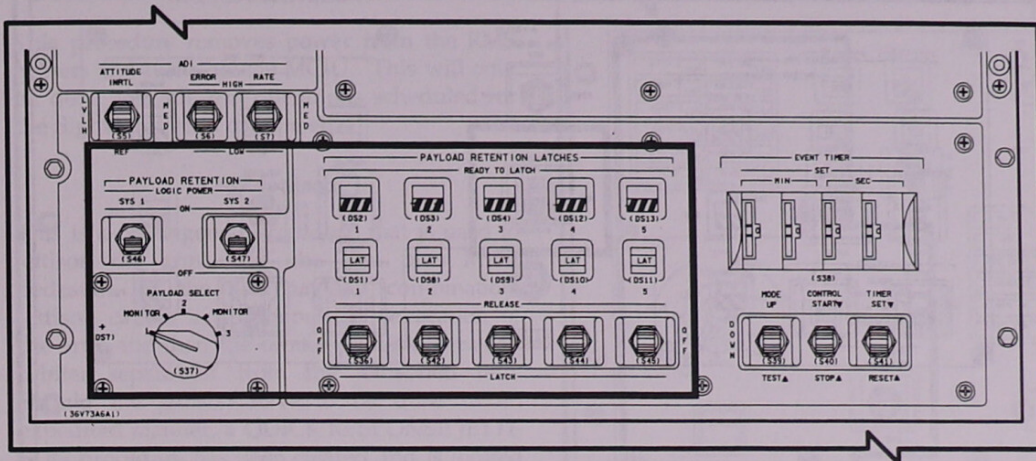
When driving the PAYLOAD RETENTION LATCHES to RELEASE, do not continue to command a release for longer than 60 seconds if no REL indication is received. If the "A" release microswitch has failed whereby no indication is present, the latch will continue to drive against the fully open position as long 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 1	LATCH 2	LATCH 3	LATCH 4	LATCH 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 LAT/REL	00 00/00	00 00/00	00 00/00	00 00/00	00 00/00

718

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, and checks the status of some of the panel lights, talkbacks, and switches. 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 hours MET.

### RMS Powerup

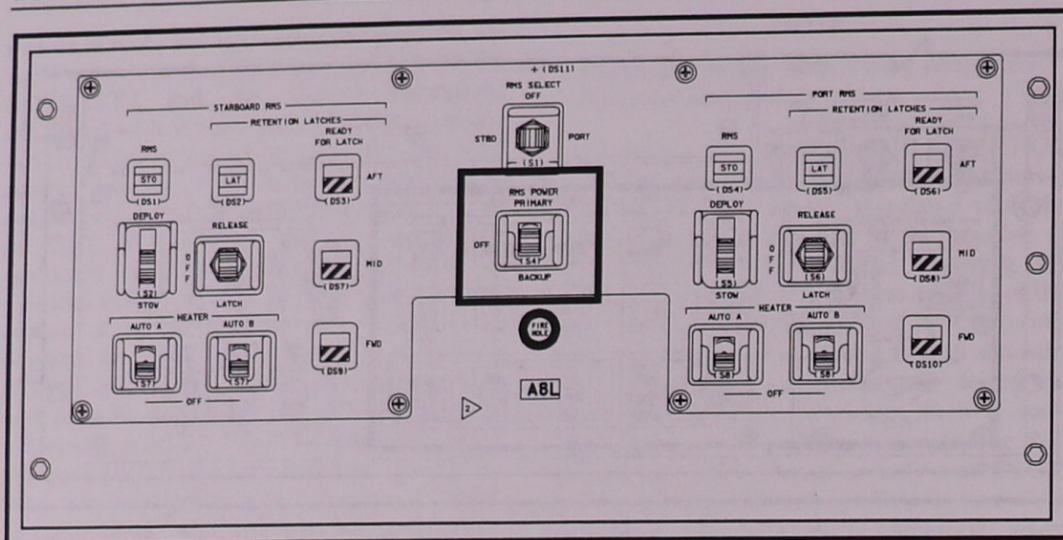
This procedure releases the MRLs and gets the arm out of the cradle to a "pre-cradle" configuration. This procedure is usually performed several times during a flight, as the arm is always powered down when not in use. The *RMS POWER* switch is on panel A8L.

#### 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 at about 3 or 4 hours MET on flight day 1 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 six 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.

### RMS Powerdown

This procedure returns the arm to the cradled configuration and relatches the MRLs. This is done any time arm operations are not required. 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.

### Operating Modes

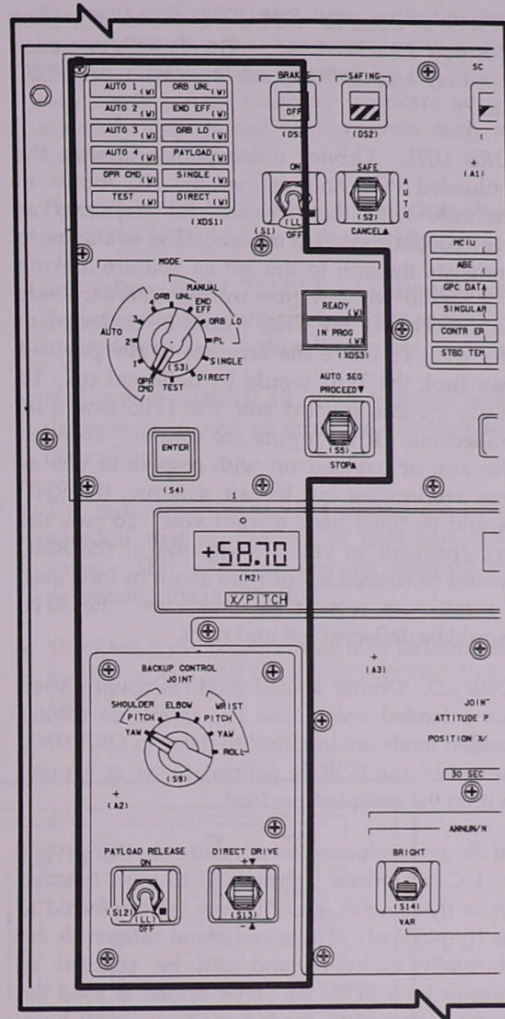
The RMS can be operated in a variety of modes. These modes are detailed below.

#### 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. Uncrading and cradling must be done via a single joint mode, since the arm is in the soft stop region for several joints. The single joint modes, selected by two rotary switches on panel A8U, 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.

*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-from 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.

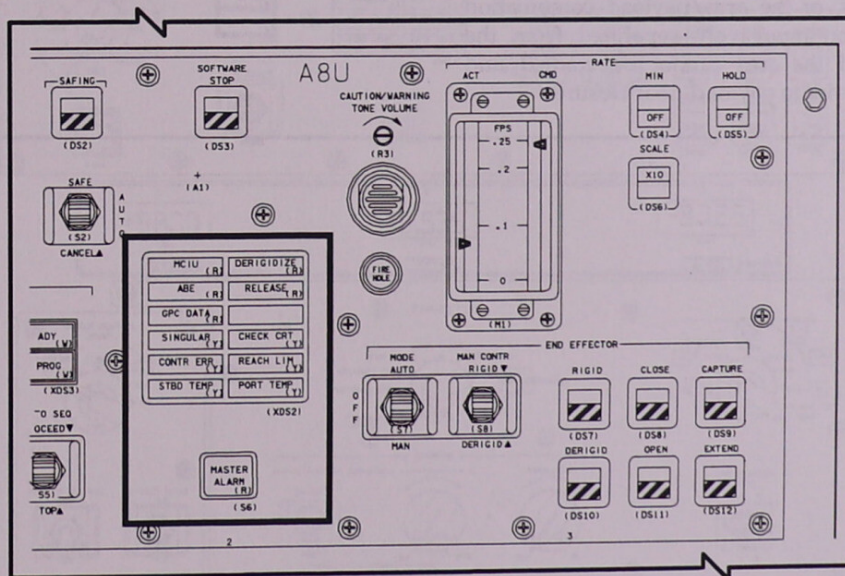
Auto-Commanded Auto Sequences. These sequences consist of up to 200 pre-defined points that can be grouped in up to 20 sets, or sequences. To use an auto-commanded auto sequence, the operator enters the desired sequence number on the PDRS CONTROL SPEC for one of AUTO 1, 2, 3, or 4 slots, then selects *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.

Operator-Commanded Auto Sequences. 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

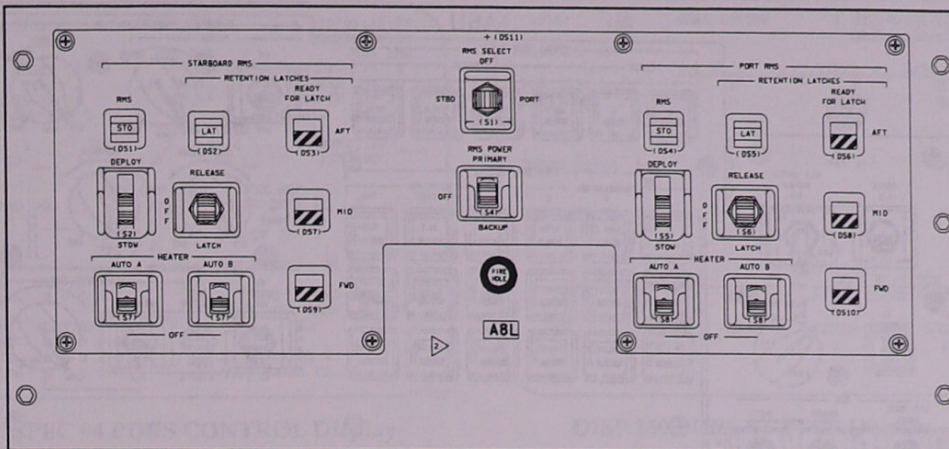
- The RMS has a separate C/W matrix on panel A8U. This system is not associated with the orbiter's C/W system.
- The red *MCIU* light indicates that the MCIU has failed a self-test.
- The red *DERIGIDIZE* light indicates that the end effector has derigidized without command.
- The red *ABE* light indicates 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 CRT.
- 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.



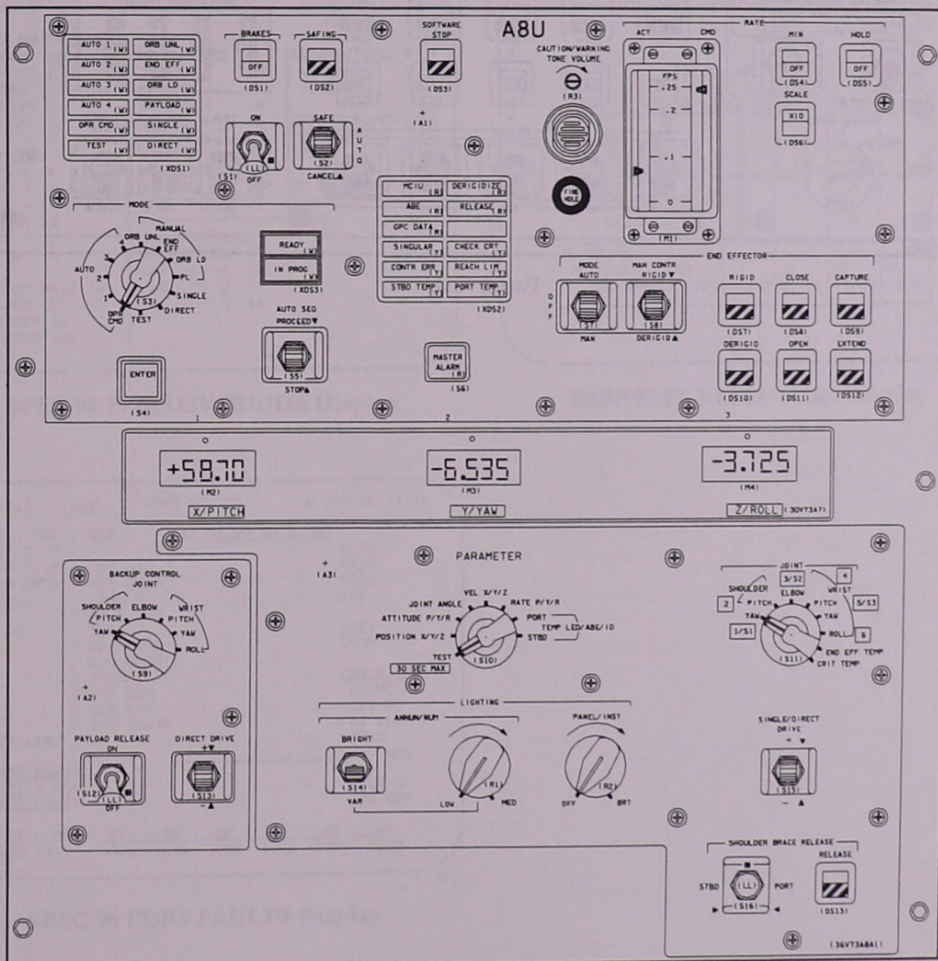
RMS Caution and Warning Lights on Panel A8U

**PDRS Summary Data**

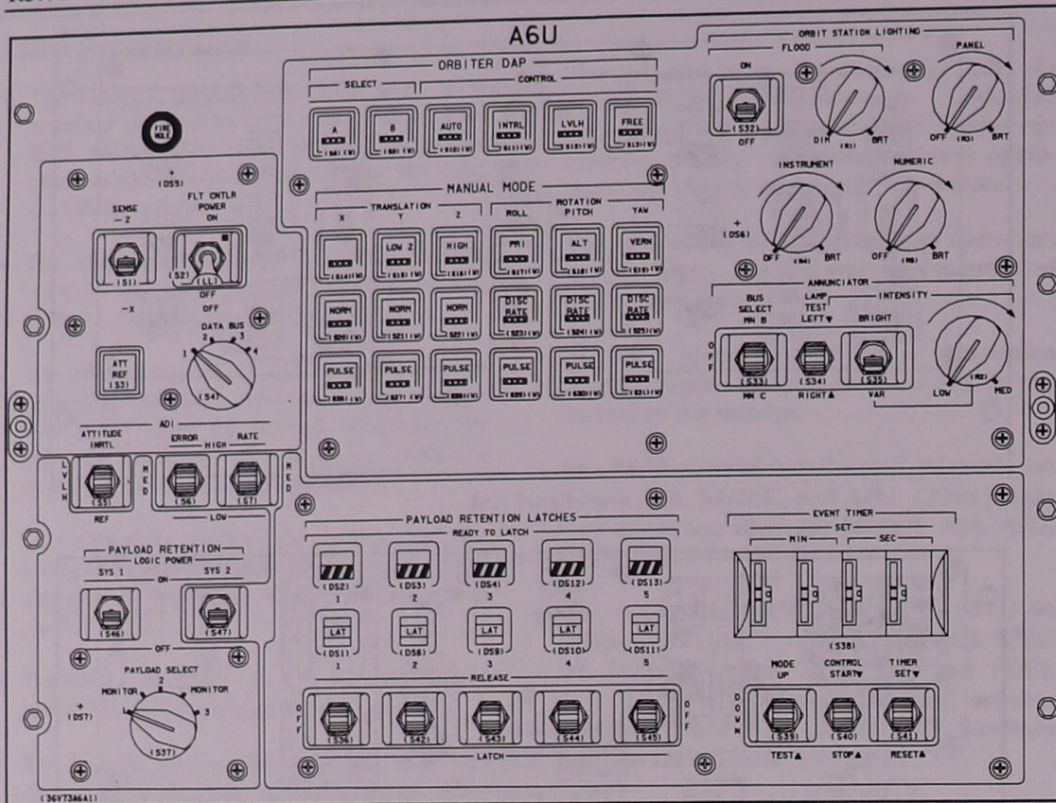
- The PDRS is used to maneuver itself or an attached payload in orbit. It consists of the RMS, MPM, AND MRLS, and interfaces with other orbiter systems such as the SM GPC, the EPDS, and the CCTV.
- The RMS consists of the arm itself and the controls and interfaces needed to maneuver it. It is located on the port longeron.
- The MPM consists of the torque tube, the pedestals, the MRLs, and the jettison system. The MPM must be stowed whenever the payload bay doors are closed and must be deployed for any loaded operations.
- The pedestals contain the MRLs and the jettison electronics and mechanics and are the supports on which the RMS rests while it is cradled.
- The MRLs latch the arm to the MPM and restrain it during periods of RMS inactivity.
- The jettison allows the arm, the arm and pedestals, or the arm/payload combination 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 six categories: contingency-only unloaded operations, unloaded operations, loaded operations, deploy operations, retrieve operations, and deploy and retrieve 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 A8L, MA73C, and A8U. Other panels that affect the RMS are ML86B, A14, A7U, A6, and R13.
- The major PDRS CRT 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 A8L



Panel A8U



Panel A6U

```

2011/094/      PDRS CONTROL      4 000/02:32:45
                000/00:00:00
RMS SEL:      RMS PWR OFF      EMA INH
PORT 1*      SOFT STOP 7* 8
STBD 2      I/O CN 5      AUTO BRAKE 9* 10
3 PL ID 0      OFF 6*      POS ENG CK 11* 12
4 END EFF 1      PCHS NTL 28* 29

                AUTO MODES
                1      2      3      4      17 START PT
                13    14    15    16    LAST PT

END POS      OPR CMD MODES / POR REP
18 X []      21 P []      24 PL INIT ID _0
19 Y []      22 Y []      CMD CK 25
20 Z []      23 R []

RMS          STO/DPLY
SHLD 0 0 0 0      ORB LD CMD REF
                NORM FLY-CAMR FLY-PL
RMS          LAT/REL/RDY      31 32 33
AFT 0 0 0 0 0 0
MID 0 0 0 0 0 0
FWD 0 0 0 0 0 0      26 WR RANGE 4
                AUTO BRAKE CK 27
    
```

SPEC 94 PDRS CONTROL Display

```

2011/ /169     PDRS STATUS      4 000/02:39:10
                000/00:00:00
RMS SEL: OFF
POSITION      X/P      Y/Y      Z/R
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
    
```

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     MCIU OVERRIDE      RHC 34
TEST 12
ENTER 13      SAFING CAN 35
                ABE OVRD A 36
                ABE OVRD B 37
                ABE OVRD C 38
LOADED RATE 14
STOWED OPS 15
SIN/DIR SW
REASSIGN 16
    
```

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
LAT/REL 00/00 00/00 00/00 00/00 00/00
    
```

DISP 97 PL RETENTION Display

```

2011/ /096     PDRS FAULTS      4 000/02:37:34
                000/00:00:00
ABE: - OLD / NEW      SY SP EP WP WY WR
JPC BITE /
MDA BITE / MDA O/C
SPA CMTR / SPA CMTR
TACH / TACH PLL
                / TACH TCO
                / CPU
                / MDA DMND
                / A/D CONV
                / BRAKE
                / POS ENG
                / DIR DRV
                / B/U RELAY
                SPA +28V /
                CONTR ERROR
                CKCRT - POS
                REACK LIMIT
                MCIU:
                MADC
                MCPC
                ICF
                ABE:
                COMM
                CHECK CRT:
                DC/MCIU
                EXT FS
                EE FLAG
                EEEU
                EE CMDS
                HC
                MCIU HC
                TMP CKT
                CKCRT - SPA: SY SP EP WP WY WR
                BITE TEST LOSS LOSS LOSS LOSS LOSS LOSS
    
```

SPEC 96 PDRS FAULTS Display

### PDRS Rules of Thumb

- Whenever there are both talkbacks and CRT 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 have a knack for having page breaks in extremely bad locations, and if you don't know what you're supposed to look for before you turn the page, you could be in trouble.
- 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 because the last part of travel in either direction is when the affected overcenter lock is locking. Therefore, don't 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 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 0 have not moved. During soft stop, position hold does not work; therefore, external forces can move joints out of desired alignment.
- 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.
- 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 and 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," and "berthing."
- Rates for berthing/unberthing: Usually maintain rates at about 0.4 to 0.5 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.

## 2.23 REACTION CONTROL SYSTEM (RCS)

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### Description

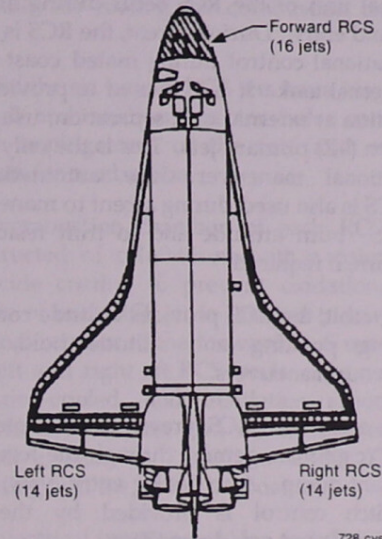
The orbiter's RCS consists of forward and aft control jets, propellant storage tanks, and distribution networks located in three vehicle modules: forward, left, and right. The forward module is contained in the nose area, forward of the cockpit windows. The left and right (aft) modules are collocated 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:

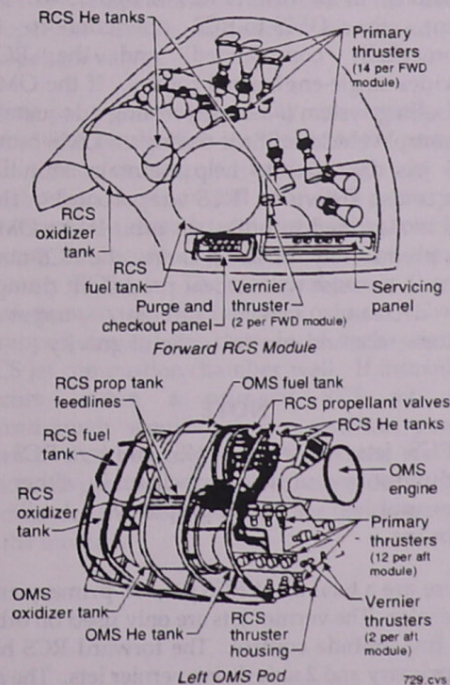
- Attitude control
- Rotational maneuvers (pitch, yaw, roll)
- Small velocity changes along the orbiter axes (translational maneuvers)

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



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.

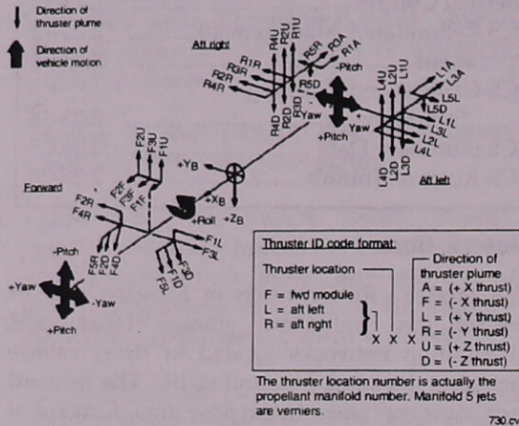
The RCS is also used during off-nominal situations. In the case of loss of two SSMEs on ascent, the OMS-to-RCS interconnect is automatically commanded, and the RCS provides single-engine roll control. If the OMS gimbaling system is not performing adequately to control vehicle attitude during an OMS burn, 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.



**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<sub>2</sub>O<sub>4</sub>) 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

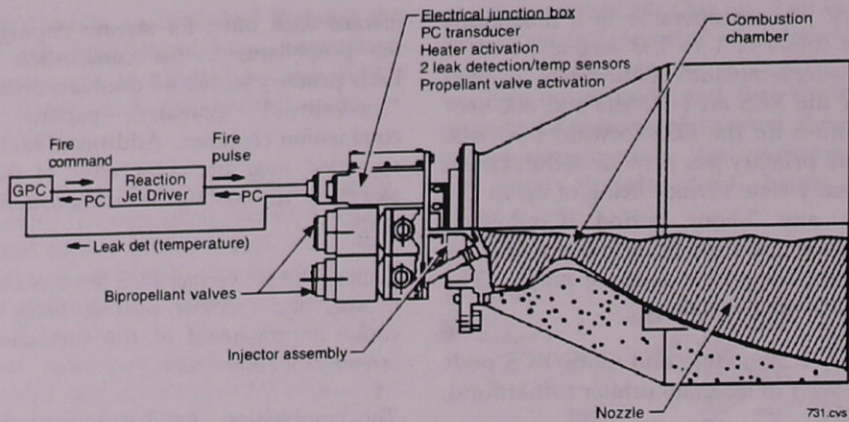
toward each other for stream impingement of the propellants in the combustion chamber. Each primary jet has 84 doublets arranged in a "showerhead" circular pattern in the combustion chamber. Additional fuel holes are provided near the outer edge of the injector assembly for cooling the combustion chamber 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.

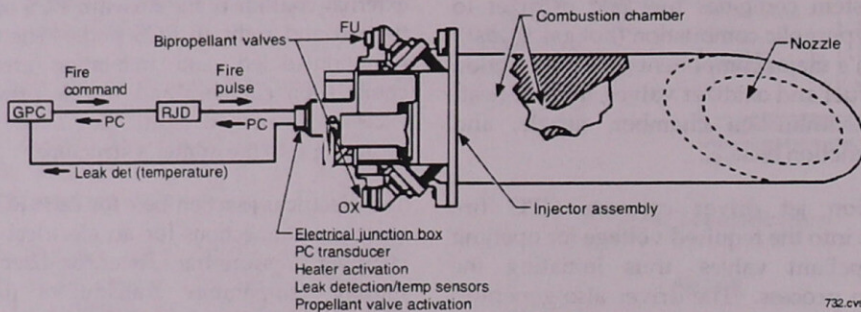
The combustion chamber of each RCS jet is constructed of columbium with a columbium disilicide coating to prevent oxidation. The nozzle of each RCS jet is tailored to match the external contour of the forward RCS module or the left and right aft RCS pods. The nozzle is radiation-cooled, and insulation 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.

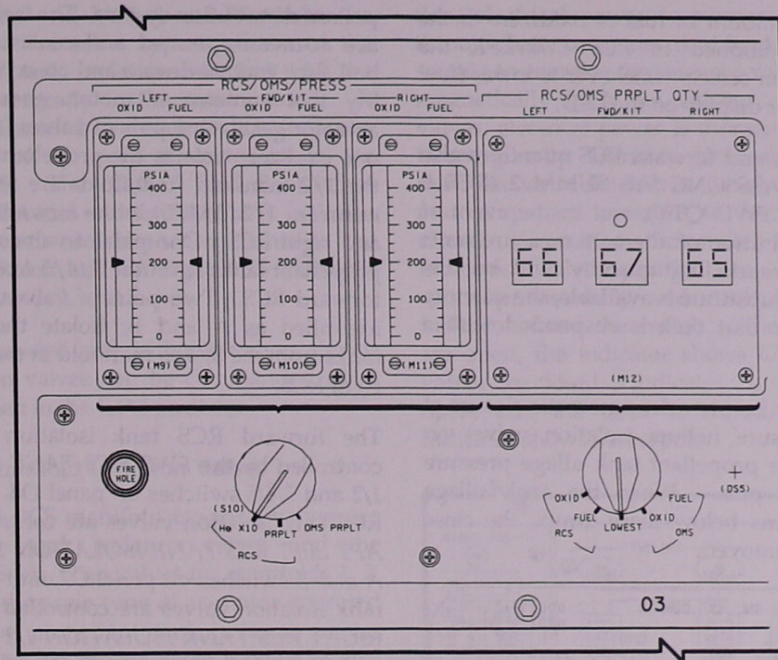
### Propellant Tanks

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/OXS/PRESS Meters and Rotary Switch and  
RCS/OXS/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/OXS/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/OXS/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.

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		
					N2 TK	F	2260	2260		
					REG P		324	324		
					P VLV		CL	CL		
					ENG IN	P				
					OXID		258	258		
					FU		260	260		
					VLV 1		3	0		
					2		0	2		
RCS	OXID	FU	JETISOL							
FWD	HE F3048	2968								
	TK F 247	248								
	QTY	67	67							
	1 P	248	242		OP					
	2 P	248	246		OP					
	3 P	250	246		OP					
	4 P	246	246		OP					
	5				OP					
AFT	HE F3200	3144								
L	TK F 245	249								
	QTY	82	83							
	1 H	246	246		OP					
	2 P	246	250		OP					
	3 P	250	250		OP					
	4 P	246	250		OP					
	5				OP					

**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 CRT. 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 pro-

pellant 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.

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.

Unlike the forward tank isolation valves, the aft tank isolation valves can be commanded open or closed when in the GPC position.

### Manifold Isolation Valves

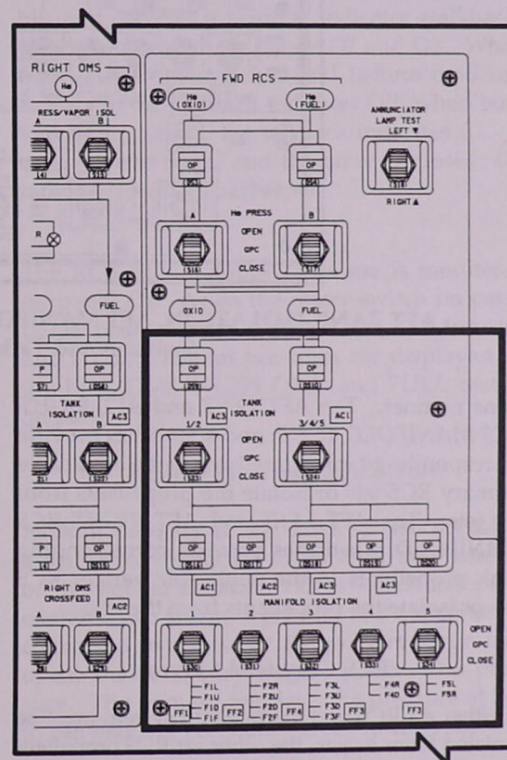
The forward RCS manifold isolation valves are between the tank isolation valves and the forward RCS jets. The valves for manifolds 1, 2, 3, and 4 are the same type of ac-motor-operated valves as the propellant tank isolation valves and are controlled by the same type of motor-switching logic. The forward 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 of the corresponding oxidizer and fuel valves. The *GPC* position is not supported.

#### 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.

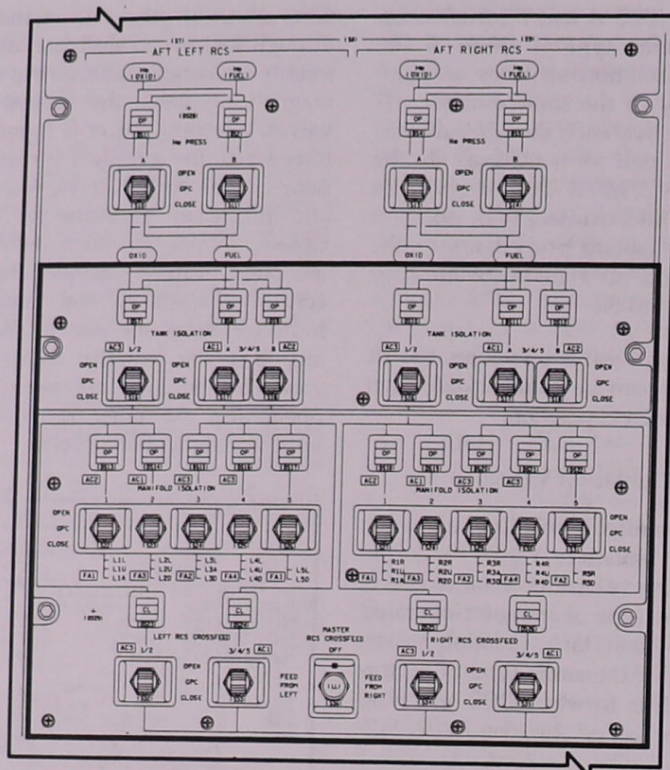
The *FWD RCS MANIFOLD ISOLATION 5* switch on panel O8 controls the manifold 5 fuel and oxidizer valves, which control propellants for the forward vernier RCS jets only. The switch is spring-loaded in the *GPC* position. When the switch is moved to the *OPEN* posi-

tion, 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 valves 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**

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



**AFT TANK ISOLATION, AFT MANIFOLD ISOLATION, and RCS CROSSFEED Switches and Talkbacks on Panel O7**

same manner. 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.

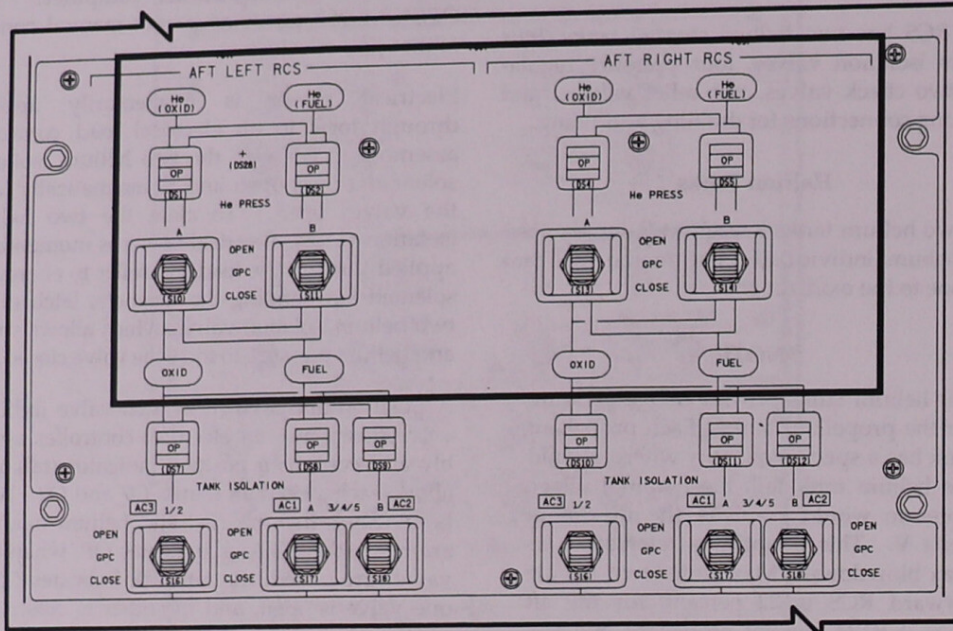
Electrical power is momentarily applied through logic in an electrical load controller assembly to energize the two helium isolation solenoid valves open and to magnetically latch the valves open. To close the two helium isolation valves, electrical power is momentarily applied through the load controller 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.

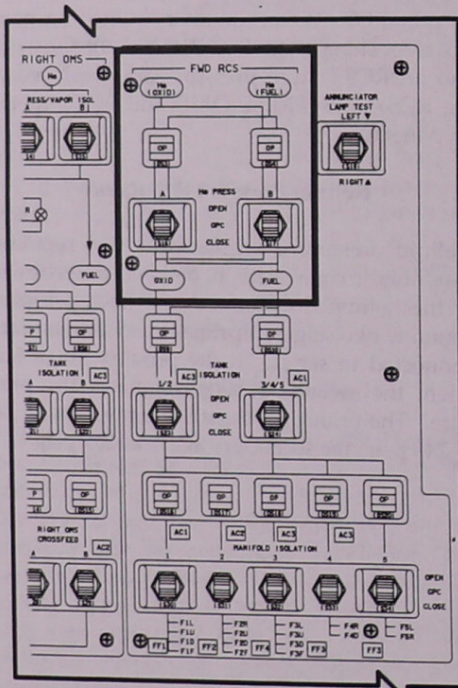
The RCS helium supply pressure is monitored on panel O3. When the rotary switch on panel O3 is positioned to *RCS He X10*, the forward and aft RCS helium pressures are displayed on the *RCS/OMS/PRESS OXID* and *FUEL* meters on panel O3.

### Helium Pressure Regulators

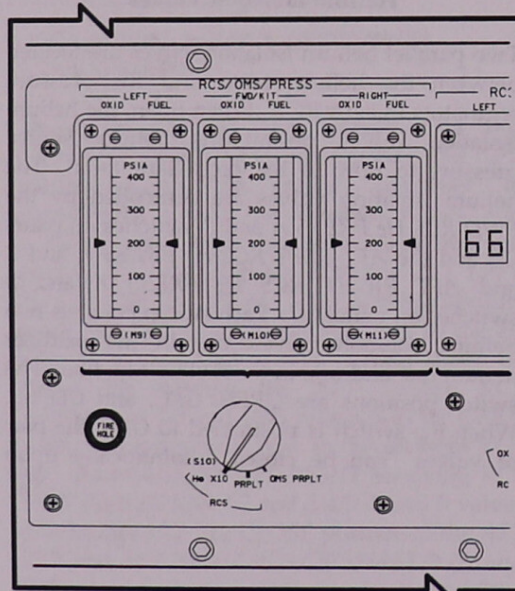
Helium pressure is regulated by two regulator assemblies, connected in parallel, downstream of the helium isolation valves. Each assembly contains two stages, a primary and a secondary, connected in series. If the primary stage fails open, the secondary stage regulates the pressure. The primary regulates 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.

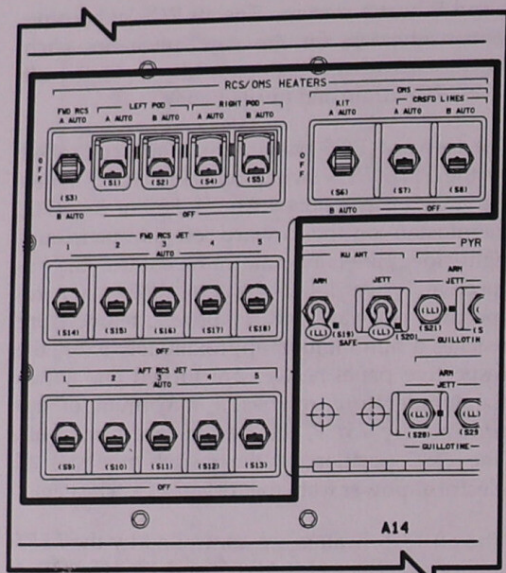
The forward RCS has six heaters mounted on radiation panels in six locations. Each OMS/RCS pod is divided into nine heater zones. Each zone is controlled in parallel by an

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 1 000/03:14:16  
000/00:00:00

RCS FWD 1 PRI JET OMS PRESS ENA  
L 2 4 FAIL LIM 2 L OMS 5 OMS=RCS QTY  
R 3\* R OMS 6 L 0.00  
OFF 7\* R 0.00

JET	FAIL	DES INH	JET DES	PTY	OXID	FU
R4R		8	9	2	3376	3360
2R		10	11	1	247	250
Y 3R		12	13	2	T 77	79
1R		14	15	1	QTY 90	91
R4U		16	17	2	MANF P 1	242 246
2U		18	19	1	2	250 246
Z 1U		20	21	3	3	248 248
R		22	23	2	4	246 242
4D		24	25	1	MANF VLVS	STAT OVRD
2D		26	27	2	1	OP 40
3D		28	29	1	2	OP 41
R1A		30	31	1	3	OP 42
X 3A		32	33	3	4	OP 43
		34	35	2	5	OP 44
RSR		36	37		XFEED P	254 254
V 5D		38	39		JET RESET	45

678

SPEC 23 RCS Display

3011/051/ OVERRIDE 5 006/09:38:04  
BFS 000/00:17:56

ABORT MODE ENTRY FCS

TAL 1	ELEVON 17*	FILTER 20*	ATMOSPHERE 22*
ATO 2	FIXED 18	ALT 21	N POLE 23
ABORT 3	SSME REPOS 19	ENA 24	S POLE 24
MAX THROT 4	IMU DES ATT	AA	RG A SURF
PROPLT DUMP	1 25 2	LRU DES	DES DES
INH IONCT 5	2 26	1 31	35 39
OMS DUMP	3 27	2 32	36 40
ARM 6		3 33	37 41
START 7		4 34	38 42
STOP 8			
9 QUAN/SIDE 041			
OMS DUMP TTG 227			

ET SEP AUTO 28 ROLL MODE  
14 TIME 000 SEP 29 WRAP MODE 45

FWD RCS 15 INH ET UMB DR VENT DOOR CNTL  
16 TIME 000 CLOSE 30 OPEN 43  
CLOSE 44

741b

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.

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:

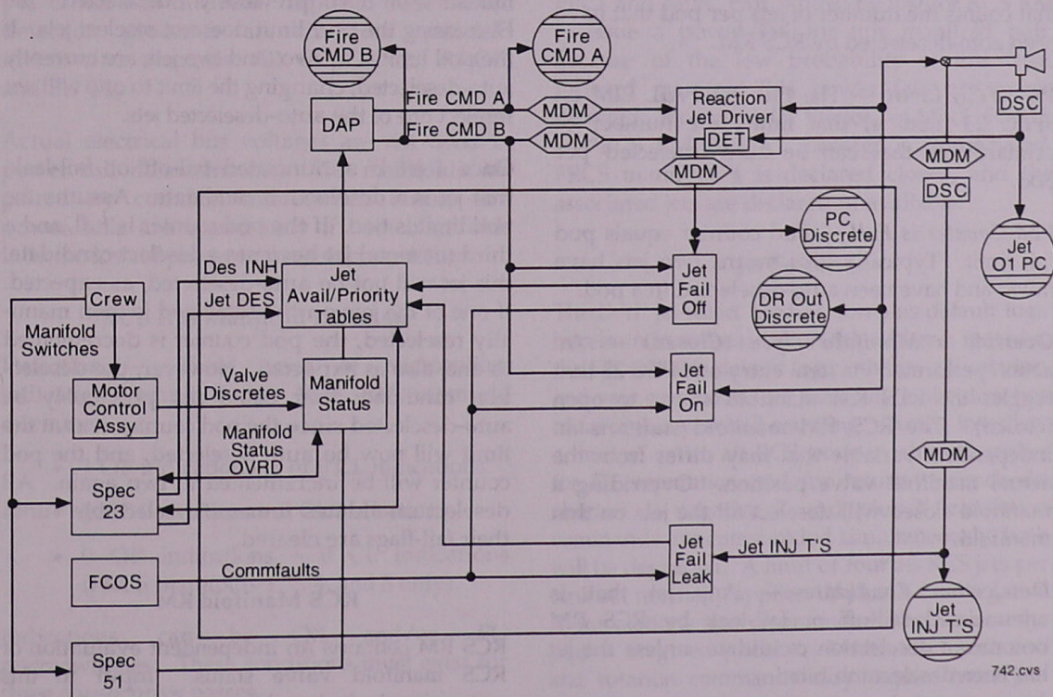
- Fail-leak flag is set.
- Message is annunciated.
- Jet is deselected unless the pod limit has been reached.

### Jet Fail-Leak

Detection:

- Either oxidizer or fuel injector temperature is below the RCS RM injector

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 disretes: 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 disretes 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.

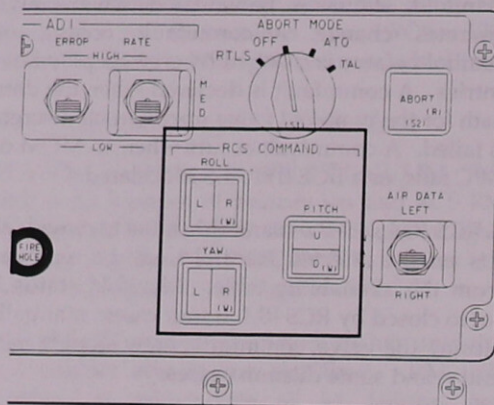
The DAP jet-select module determines which aft RCS jets (right, left, or both) must be turned on in response to the pitch, roll, and yaw jet commands from the entry flight control system. The forward RCS jets are not used during entry. After entry interface, only the four Y-axis and six Z-axis RCS jets 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.



### 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 CRT 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.

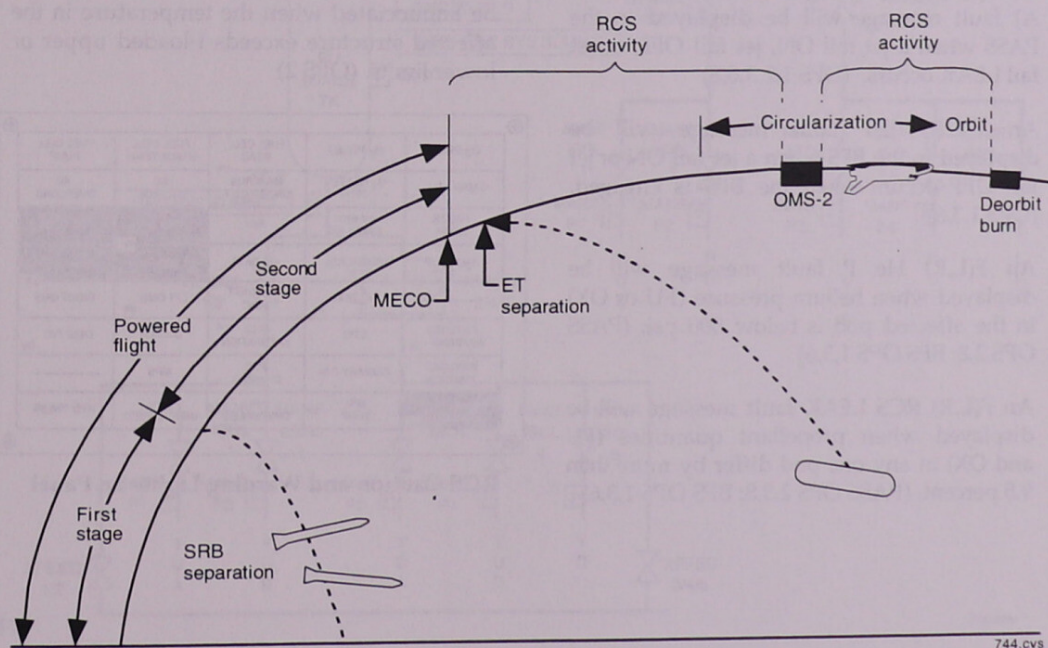
On orbit, the vernier jets are used for fine attitude control, and the primary jets are used for coarse attitude control and minor translations.

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).



Nominal Ascent Profiles

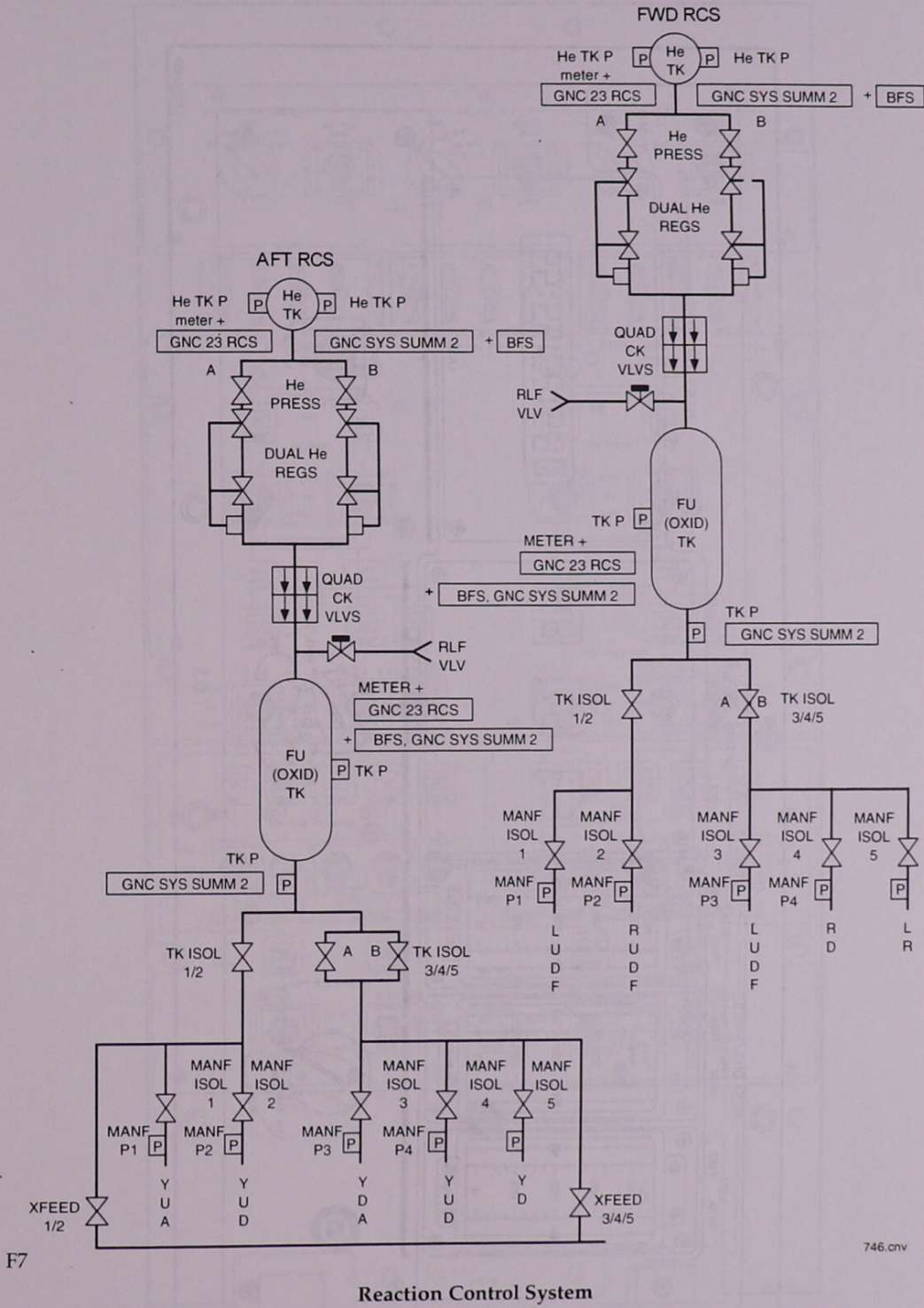
### RCS Caution and Warning Summary

- 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 CRT.
- RCS jet failure illuminates the yellow *RCS JET* and red *BACKUP C/W ALARM* lights and sends a fault message to the CRT.
- 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)

O <sub>2</sub> PRESS	H <sub>2</sub> PRESS	FUEL CELL REAC <sup>(R)</sup>	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM <sup>(R)</sup>	O <sub>2</sub> HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS <sup>(R)</sup>	RCS JET
H <sub>2</sub> O LOOP	RGA/ACCEL	AIR DATA	LEFT RCS <sup>(R)</sup>	RIGHT RCS
	LEFT RHC <sup>(R)</sup>	RIGHT/AFT RHC <sup>(R)</sup>	LEFT OMS <sup>(R)</sup>	RIGHT OMS
PAYLOAD WARNING <sup>(R)</sup>	GPC	FCS SATURATION <sup>(R)</sup>	OMS KIT	OMS TVC <sup>(R)</sup>
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS <sup>(R)</sup>	
BACKUP C/W ALARM <sup>(R)</sup>	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

RCS Caution and Warning Lights on Panel

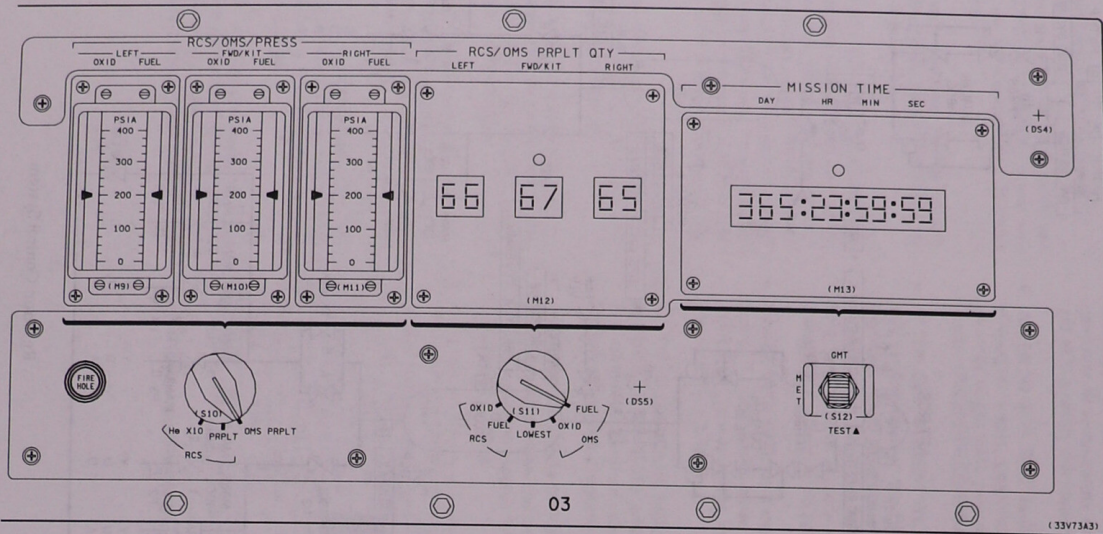




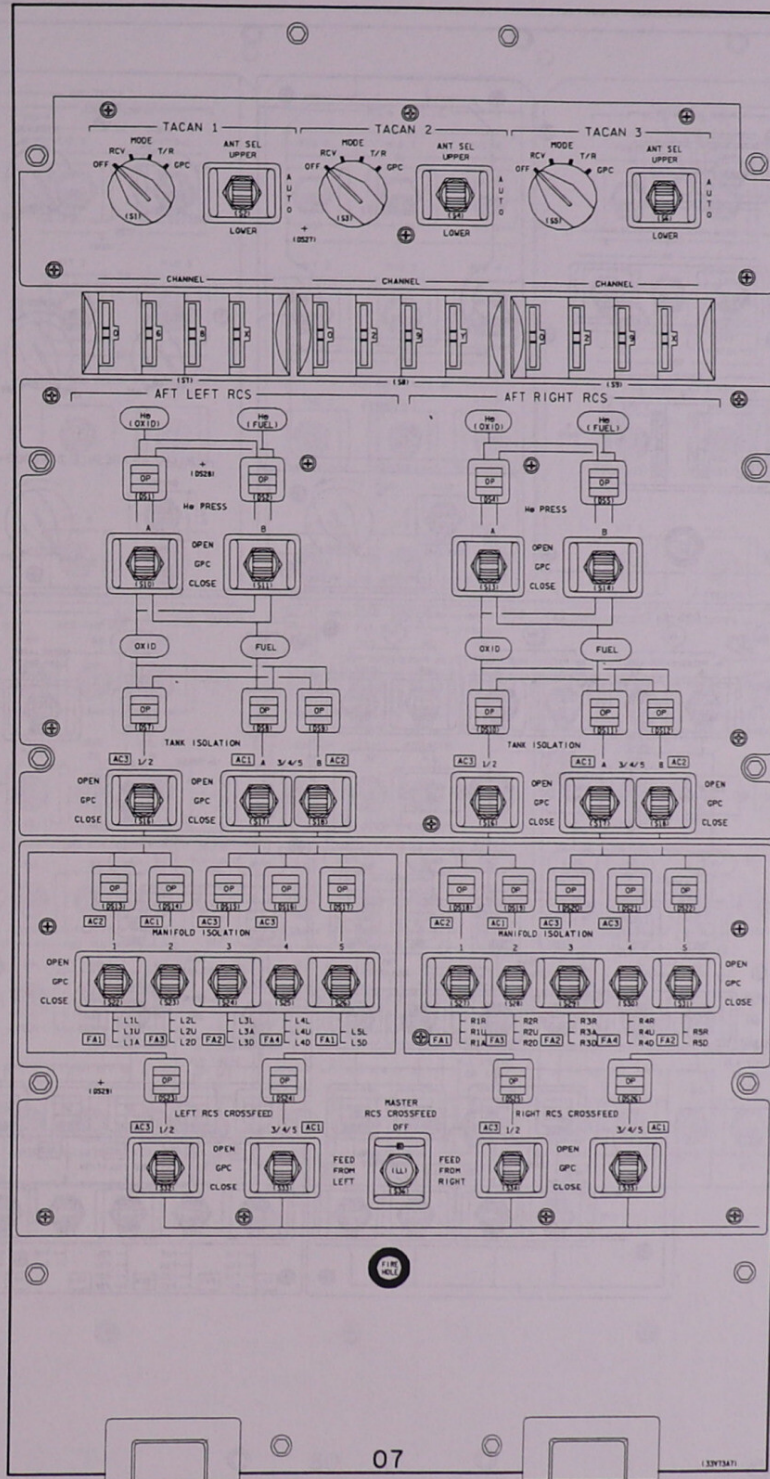
F7

746.crv

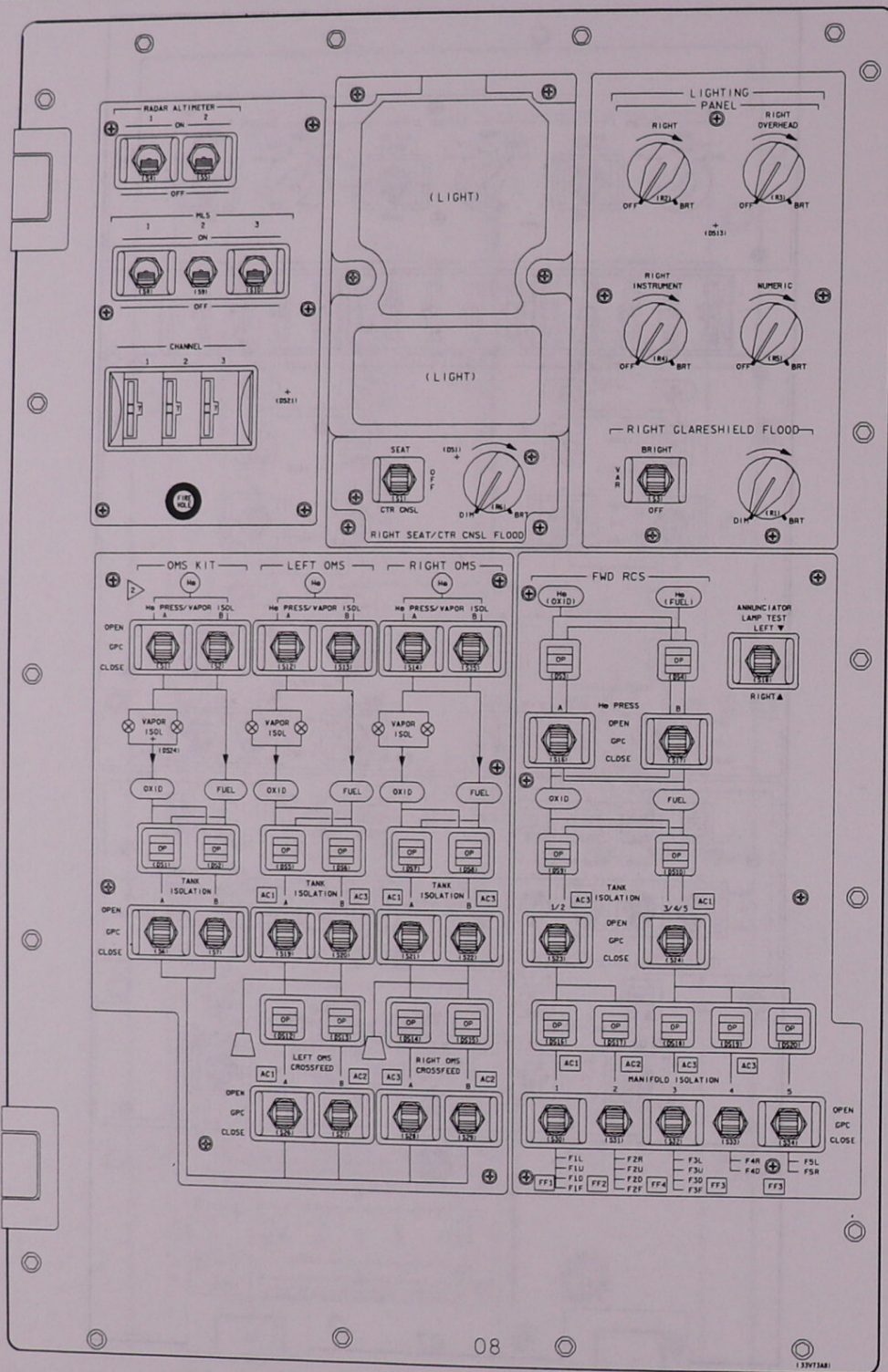
Reaction Control System



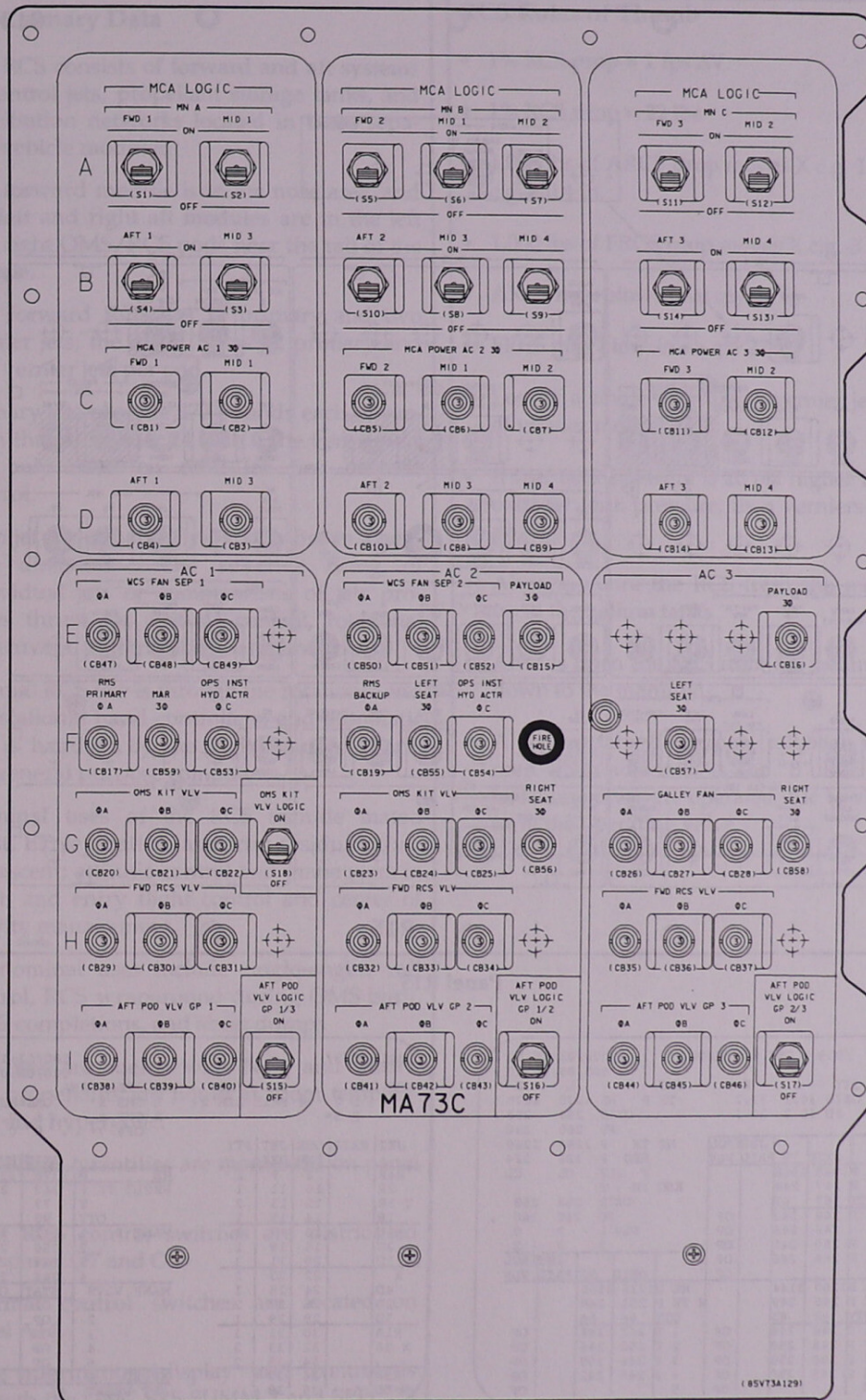
Panel O3



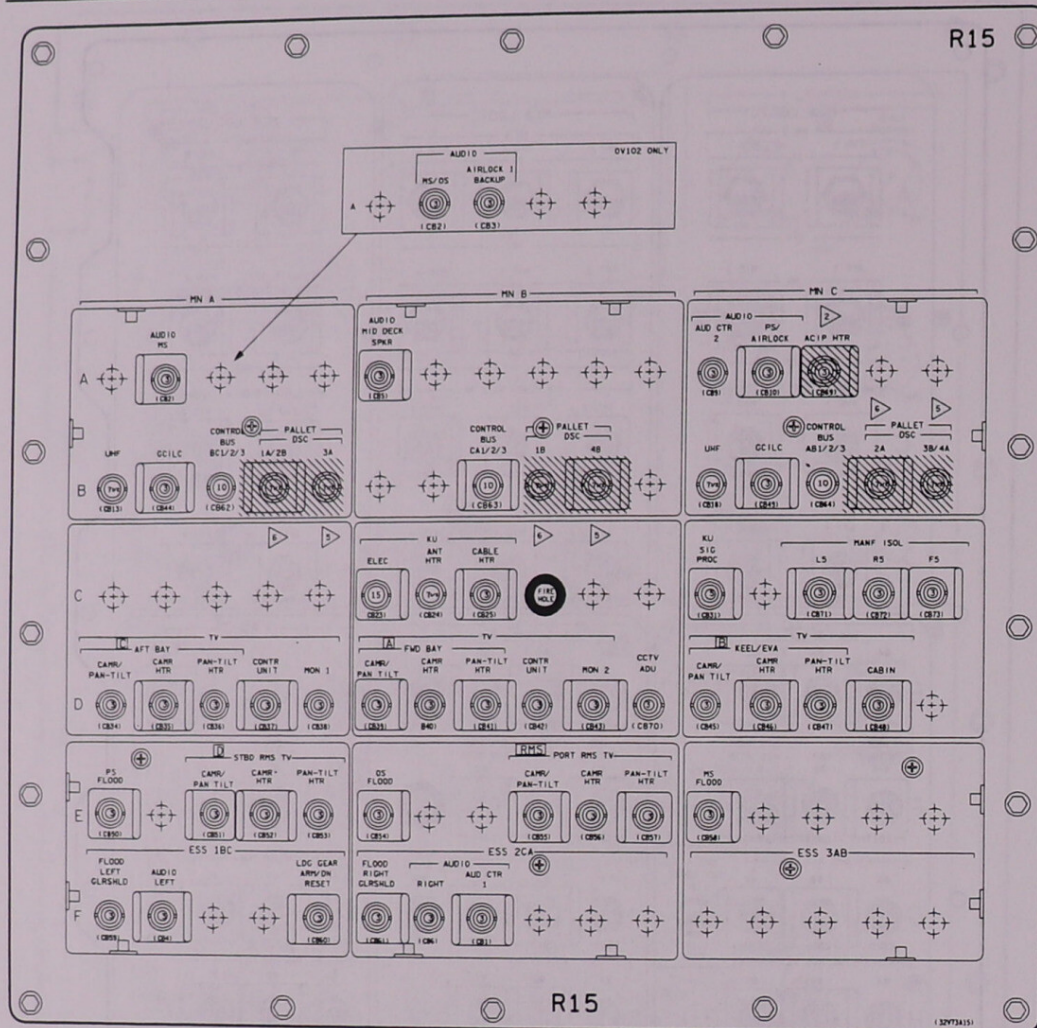
Panel O7



Panel O8



Panel MA73C



Panel R15

2011/ /019 GNC SYS SUMM 2 2 000/03:15:52  
000/00:00:00

OMS APT	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
					REG P 324	324
					P VLV	CL CL
					ENG IN	P
					OXID 258	258
					FU 260	260
					VLV 1 - 3	0
					2	0 - 2

RCS	HE	PR	QTY	JET	SOL
FWD	HE P	048	2968		
TK P		247	248		
QTY		67	67		
MANF	1 P	248	242	OP	
	2 P	248	246	OP	
	3 P	250	246	OP	
	4 P	246	246	OP	
	5			OP	
AFT	HE P	200	3144		
L TK P		245	249		
QTY		82	83		
MANF	1 P	246	246	OP	
	2 P	246	250	OP	
	3 P	250	250	OP	
	4 P	246	250	OP	
	5			OP	

PASS GNC SYS SUMM 2 Display

2011/023/ RCS 1 000/03:14:16  
000/00:00:00

RCS FWD	1	PRI	JET	DES	PTY	OMS PRESS	ENA
L	2	4	FAIL	LIM	2	L	OMS 5
R	3*					R	OMS 6
							OFF 7*
							R 0.00

JET	FAIL	DES	JET	PTY
R4R	8	9	2	
2R	10	11	1	
Y 3R	12	13	2	
1R	14	15	1	
R4U	16	17	2	
2U	18	19	1	
Z 1U	20	21	1	
R	22	23	2	
4D	24	25	1	
2D	26	27	2	
3D	28	29	1	
R1A	30	31	1	
X 3A	32	33	3	
	34	35	2	
R5R	36	37		
V 5D	38	39		

HE	P	OXID	FU
PRPLT	TK P	3376	3360
	T	247	250
		77	79
	QTY	90	91
MANF	P	1	242
		2	250
		3	248
		4	246
MANF	VLVS	STAT	OVRD
		1	OP
		2	OP
		3	OP
		4	OP
		5	OP
XFEED	P	254	254
JET RESET		45	

SPEC 23 RCS Display

### 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  $\Delta V$ .
- 1% RCS prop = 22 lbs.
- 1,000 lbs of ARCS prop moves X c.g. 1.2. in, Y c.g.  $\pm 0.4$  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.

2.24 SPACEHAB

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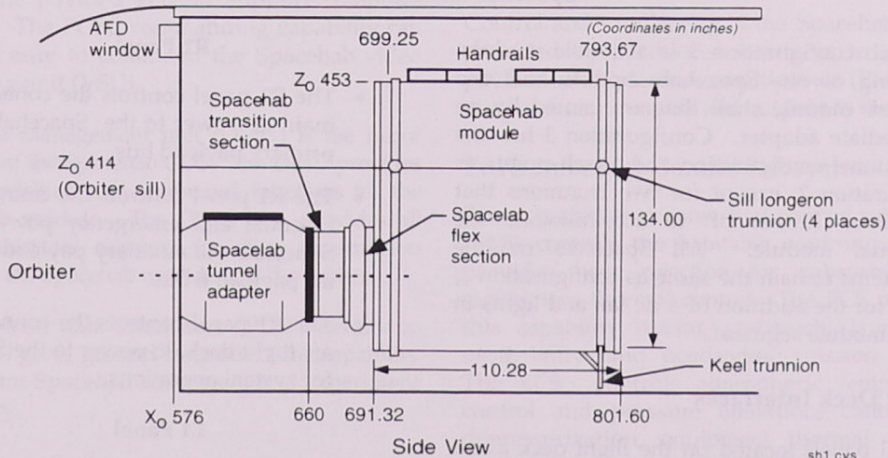
Description

The Spacehab module is a pressurized experiment carrier designed to augment space shuttle middeck experiment accommodations. 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 three module configurations to accommodate mission-specific requirements.

Configurations

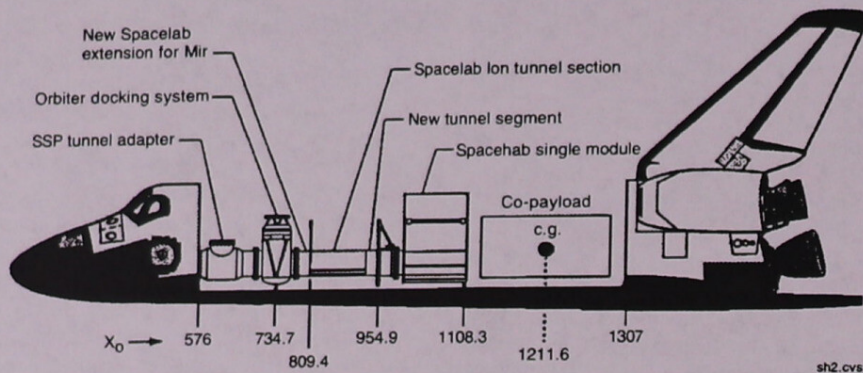
Spacehab configuration 1 is connected to the orbiter using a modified Spacelab tunnel adapter and standard orbiter payload support resources from the cabin and payload bay. The Spacehab single module to orbiter tunnel adapter connection is accomplished using the Spacehab tunnel adapter, the Spacehab transition section, and the Spacelab flex section. The Spacehab module provides crewmembers with a place to carry out their 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).

Spacehab configuration 2 allows the Spacehab single module to be mounted in a new trunnion location to accommodate the orbiter docking system (ODS). The module is connected to the ODS using a Spacelab flex section, the new Spacelab extension for Mir, the Spacehab long tunnel segment, the Spacelab tunnel segment, and another flex section. All Spacehab module subsystems remain the same as configuration 1, except for a lower air exchange rate with the orbiter and the addition of two negative pressure relief valves (NPRVs).

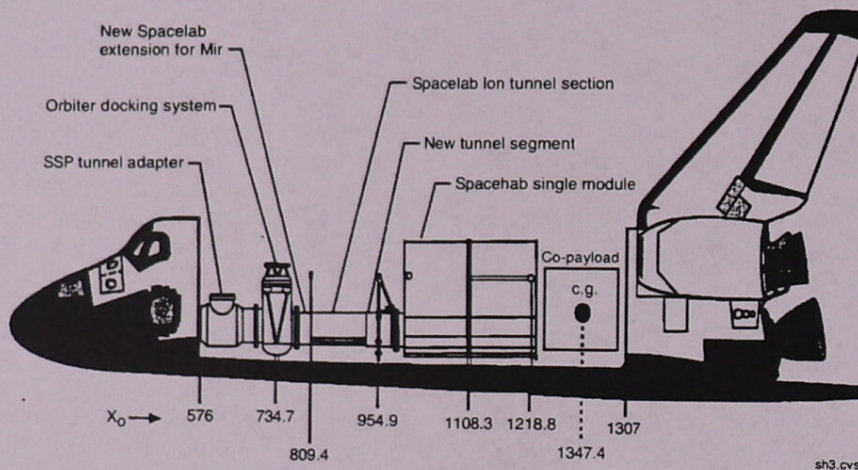


Spacehab Configuration 1





Spacehab Configuration 2



Spacehab Configuration 3

Spacehab configuration 3 is a double module, consisting of one Spacehab module and one Spacehab module shell that are joined by an intermediate adapter. Configuration 3 has the same tunnel configuration and attach points as configuration 2, except for two trunnions that are moved further aft to accommodate the additional module. All Spacehab module subsystems remain the same as configuration 2, except for the addition of a dc fan and lights in the aft module segment.

### 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 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<sub>2</sub>O line heaters.

### CRT

- The orbiter CRT allows the crew to monitor and control Spacehab subsystems via the Spacehab displays and SPECs (BFS display 206 SH Launch/Entry, SM SPEC 210 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. The CDS can receive commands for Spacehab subsystem and experiment activation and deactivation from either ground uplink or the orbiter CRT 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

## 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) provides the Spacehab crew with an audio communication link to the orbiter and to the flight controllers in the Mission Control Center (MCC). The ACS panel, located in the Spacehab module, interfaces with the orbiter's audio central control network (ACCN) to facilitate on-orbit operation. The ACS provides the crew with two independent communication stations located on the ACS panel.

Each communication station 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 CRT. 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.

## 2.25 SPACELAB

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### Description

Spacelab is a mission-specific, non-deployable payload that is carried in the orbiter's payload bay. Spacelab was developed to be modular, and it can be varied to meet specific mission requirements. Its four principal components are the man-rated module, one or more open pallets that expose materials and equipment to space, a tunnel to gain access to the module, and an instrument pointing system.

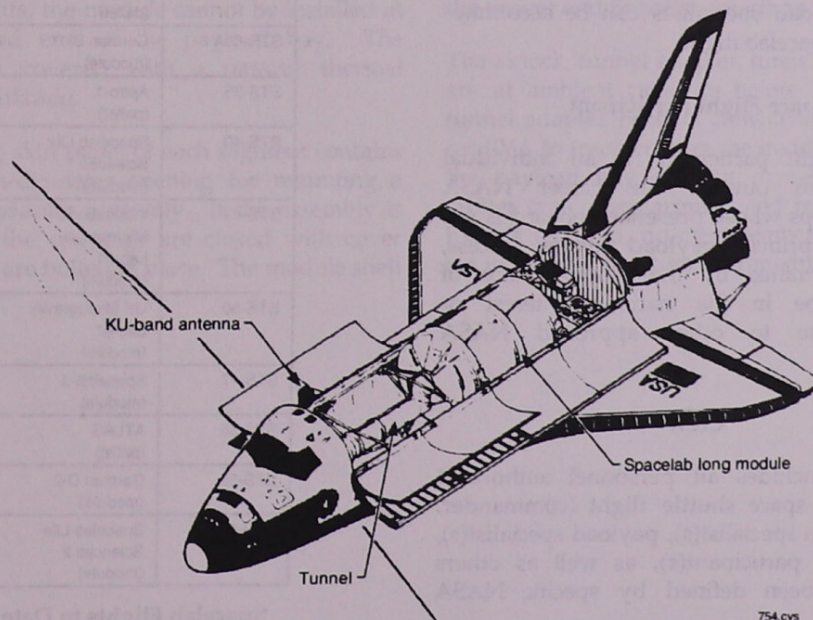
Several terms that delineate crew roles and responsibilities on Spacelab flights are described below.

### Payload Commander

A payload commander is an experienced mission specialist who has been designated to represent FCOD and the Astronaut Office on a Spacelab or complex payload flight. This individual will have full authority to work with the payload mission managers to identify and resolve issues associated with payload assignment and integration, training, crewmember qualification, and operational constraints.

### Mission Specialist

A mission specialist is a career NASA astronaut trained and skilled in the operation of space shuttle systems related to payload operations and thoroughly familiar with the operational requirements and objectives of the payloads with which the mission specialist will fly. The mission specialist, when designated for a flight, will participate in the planning of the mission and will be responsible for the coordination of the overall payload/space shuttle interaction. The mission specialist will direct the allocation



Spacelab On Orbit

of space shuttle and crew resources to the accomplishment of the combined payload objectives during the payload operations phase of the flight in accordance with the approved flight plan. The mission specialist will have prime responsibility for experiments for which no payload specialist is assigned and will assist the payload specialist when appropriate.

#### Science Mission Specialist

A science mission specialist is a career NASA astronaut assigned as an additional crewmember on a science-intensive mission.

#### Payload Specialist

A payload specialist is an individual(s) other than NASA astronauts (commanders, pilots, and mission specialists) whose presence is required onboard the space shuttle to perform specialized functions with respect to operation of one or more payloads or other essential mission activities. Payload specialists are nominated by the scientists sponsoring the experiments aboard Spacelab. They are accepted, trained, and certified for flight by NASA. Their training includes familiarization with experiments and payloads as well as information and procedures to fly aboard the orbiter. From one to three payload specialists can be accommodated for a Spacelab flight.

#### Space Flight Participant

A space flight participant is an individual selected from outside the career NASA astronaut corps whose presence onboard is not required for primary payload mission success, but is determined by the Administrator of NASA to be in the national interest or to contribute to other approved NASA objectives.

#### Crew

The crew includes all personnel authorized to fly on a space shuttle flight (commander, pilot, mission specialist(s), payload specialist(s), space flight participant(s), as well as others who have been defined by specific NASA agreements).

#### Flight Crew

The flight crew normally consists of the commander, pilot, and mission specialist(s). The responsibility for on-orbit management of orbiter systems and attached payload support systems and for extravehicular activity and payload manipulation with the remote manipulator system will rest with the flight crew since extensive training is required for safe and efficient operation of these systems. In general, the flight crew will operate orbiter systems and standard payload support systems, such as Spacelab and Inertial Upper Stage systems.

#### Payload Crew

The payload crew consists of payload specialists and mission specialist(s) primarily assigned to operate experiments.

#### Spacelab Mission Summary

The Spacelab missions flown to date are summarized in the table below.

FLIGHT	PAYLOAD
STS-9	Spacelab 1 (module)
STS-51B	Spacelab 3 (module)
STS-51F	Spacelab 2 (pallet)
STS-61A	German D-1 (module)
STS-35	Astro-1 (pallet)
STS-40	Spacelab Life Sciences 1 (module)
STS-42	International Microgravity Lab-01 (module)
STS-50	US Microgravity Lab-01 (module)
STS-47	Spacelab-J (module)
STS-56	ATLAS (pallet)
STS-55	German D-2 (module)
STS-58	Spacelab Life Sciences 2 (module)

#### Spacelab Flights to Date

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**NOTE**

Spacelab is a complex system, and several workbooks address the details of using and operating the Spacelab systems. This subsection provides only overview information.

**Module**

The module, or laboratory, is available in two segments. One, called the core segment, contains supporting systems, such as data processing equipment and utilities for the module and pallets (if pallets are used in conjunction with the module). The laboratory has floor-mounted racks and a workbench. The second, called the experiment segment, provides more working laboratory space and contains only floor-mounted racks. When only one segment is needed, the core segment is used. Each segment is a pressurized cylinder 13.5 feet in outside diameter and 9 feet long. When both segments are assembled with end cones, their maximum outside length is 23 feet.

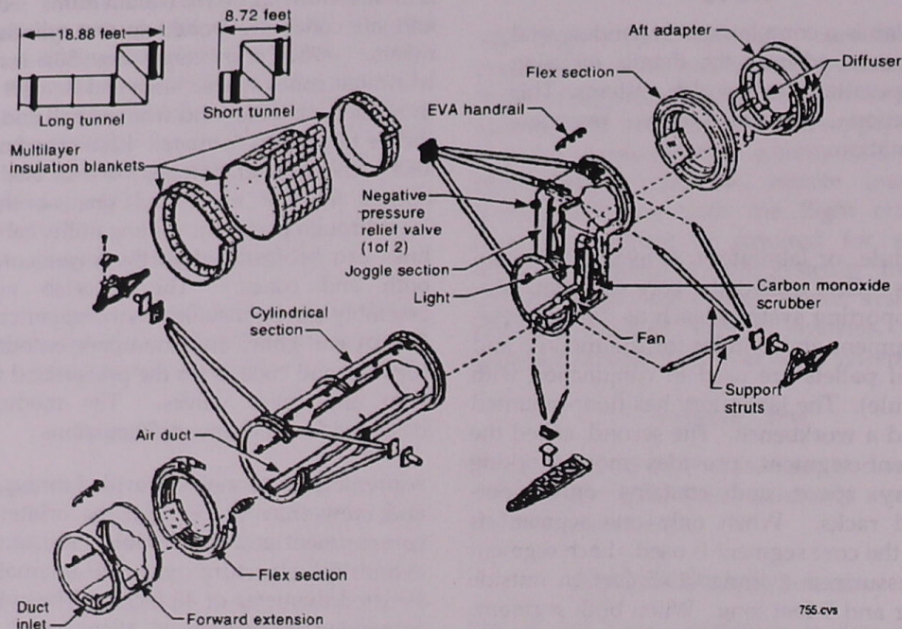
The module is structurally attached to the orbiter payload bay by four attach fittings consisting of three longeron fitting sets (two primary and one stabilizing) and one keel fitting. Because of the orbiter's center-of-gravity requirements, the module cannot be installed at the forward end of the payload bay. The module is covered with a passive thermal control insulation.

The ceiling skin panel of each segment contains a 51.2-inch-diameter opening for mounting a viewport adapter assembly. If the assembly is not used, the openings are closed with cover plates that are bolted in place. The module shell

is made from 2219-T851 aluminum. Forward and aft cones are bolted to the cylinder segments. The end cones are 30.8-inch-long truncated cones whose large end is 161.9 inches in outside diameter and whose small end is 51.2 inches in outside diameter. Each cone has three 16.4-inch-diameter cutouts: two located at the bottom of the cone and one at the top. Feedthrough plates for routing utility cables and lines can be installed in the lower cutouts of both end cones. The Spacelab viewport assembly can be installed in the upper cutout of the aft end cone, and the upper cutout of the forward end cone is for the pressurized module vent and relief valves. The modules are designed for a lifetime of 50 missions.

A pressurized tunnel is provided for equipment and crew transfer between the orbiter's crew compartment and the module. The tunnel is a cylindrical structure with an internal unobstructed diameter of 40 inches. The cylinder is assembled in sections to allow length adjustment for different module configurations. Two tunnel lengths can be used: a long tunnel of 18.88 feet and a short tunnel of 8.72 feet. A "joggle" section of the tunnel compensates for the 42.1-inch vertical offset of the middeck airlock to the module's centerline. There are flexible sections on each end of the tunnel near the orbiter and Spacelab interfaces.

The airlock, tunnel adapter, tunnel, and module are at ambient pressure before launch. The tunnel adapter permits crewmembers outfitted for EVA to transfer from the middeck airlock to the payload bay without depressurizing the orbiter crew compartment and module. If an EVA is required, no crewmembers are permitted in the Spacelab tunnel or module.



Spacelab Transfer Tunnel

## Pallet

Each pallet is more than a platform for mounting instrumentation; with an igloo attached, it can also cool equipment, provide electrical power, and furnish connections for commanding and acquiring data from experiments. When only pallets are used, the Spacelab pallet portions of essential systems required for supporting experiments (power, experiment control, data handling, communications, etc.) are protected in a pressurized, temperature-controlled igloo housing.

The pallets are designed for large instruments, experiments requiring direct exposure to space, or systems needing unobstructed or broad fields of view, such as telescopes, antennas, and sensors (e.g., radiometers and radars). The U-shaped pallets are covered with aluminum honeycomb panels. A series of hard points attached to the main pallet structure is provided for mounting heavy payload equipment. Up to five segments can be flown on a single mission. Each pallet train is held in place in the payload bay by a set of five attach fittings, four longeron sill fittings, and one keel fitting. Pallet-to-pallet

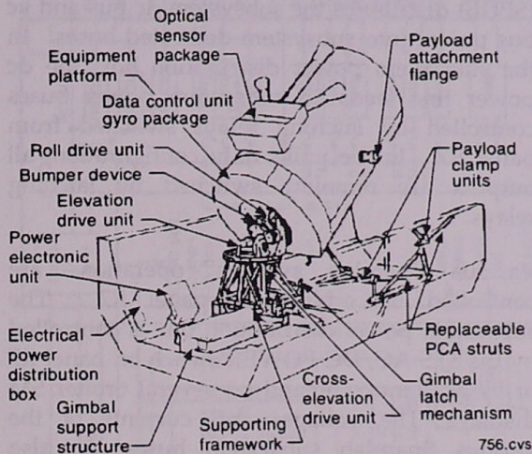
joints are used to connect the pallets to form a single rigid structure called a pallet train. Twelve joints are used to connect two pallets.

Cable ducts and cable support trays can be bolted to the forward and aft frame of each pallet to support and route electrical cables to and from the experiments and subsystem equipment mounted on the pallet. All ducts mounted on the starboard side of the pallet are used to route subsystem cables, and all ducts on the port side carry experiment utility cables. The ducts and cable trays are made of aluminum alloy sheet metal. In addition to basic utilities, some special accommodations are available for pallet-mounted experiments.

The igloo is attached vertically to the forward end frame of the first forward pallet. Its outer dimensions are approximately 7.9 feet in height and 3.6 feet in diameter. The igloo is a closed cylindrical shell made of aluminum alloy. A removable cover allows full access to the interior. The igloo houses subsystems and equipment in a pressurized, nitrogen environment at 14.7 psia. The igloo is covered with multilayer insulation.

## Instrument Pointing Subsystem (IPS)

Some Spacelab mission research requires that instruments be pointed with very high accuracy and stability at stars, the Sun, the Earth, or other targets of observation. The IPS provides precision pointing for instruments of diverse sizes and weights (up to 15,432 pounds) and can point them to within 2 arc seconds and hold them on target to within 1.2 arc seconds.



### Instrument Pointing System

The IPS consists of a three-axis gimbal system mounted on a gimbal support structure, and a control system. The control system is based on the inertial reference of a three-axis gyro package and operated by a gimbal-mounted minicomputer.

The basic structural hardware is the gimbal system, which includes three bearing/drive units, a payload/gimbal separation mechanism, a replaceable extension column, an emergency jettisoning device, a support structure and rails, and a thermal control system. The gimbal structure itself is minimal, consisting only of a yoke, an inner gimbal, and an outer gimbal to which the payload is attached by the payload-mounted integration ring.

The three identical drive units are arranged so that their axes intersect at one point. From pallet to payload, the order of the axes is elevation, cross-elevation, and roll. Each drive assembly includes three wet-lubricated ball bearings, two brushless dc-torquers, and two single-speed/multispeed resolvers.

The gimbal/payload separation mechanism is located between the outer gimbal and the payload integration ring. This device prevents the payload and the pointing mechanism from exerting excessive loads on each other during launch and landing. For orbital operations, the outer gimbal and integration ring are pulled together and locked.

The operating modes of the different scientific investigations vary considerably. Some require manual control capability, others long periods of pointing at a single object, others slow scan mapping, still others high angular rates and accelerations. Performance in all these modes requires flexibility, which is achieved by computer software. The IPS is controlled through the Spacelab subsystem computer and a data display system (DDS). Beginning with STS 50 the data display unit (DDU) and keyboard have been replaced on Spacelab missions with the Payload and General Purpose Computer (PGSC) and an interface box. The IPS can be operated by the crew from either the Spacelab module or the aft flight deck. It can also be operated by ground commands from the Payload Operations Control Center (POCC). Any manual pointing operations of the IPS must be performed by the crew using the Manual Pointing Controller (MPC). The POCC cannot manually point the IPS but can enable the MPC.

An optical sensor package (OSP) consists of one boresighted fixed-head star tracker (FHST) and two skewed FHSTs. Each FHST operates as an independent unit during IPS pointing operations and is used to null IPS inertial platform attitude and rate errors resulting from gyro drifts and scale factors. For solar observations, the boresight tracker is equipped with a four quadrant sunlight beam-splitter which produces a negative star image that is tracked. For earth observations, a stellar or solar observation is required to establish the gyro drift computation.

### Flight Deck Interfaces

There are several Spacelab interfaces located in the mission station (MS), or starboard side of the aft flight deck, and the payload station (PS), or the port side of the aft flight deck.

For a module configuration, a data display system (DDS) will be in the L11 position, a standard switch panel will be in L12, and a



power control panel will be in L14. In the avionics bay behind these panels is a subsystem remote acquisition unit (RAU) and the systems management tone generator (SMTG). The SMTG generates message tones which are annunciated through the Spacelab aural annunciator (SAA), located behind panel L14.

For a pallet configuration, in addition to the above, a second DDS will be in R12 and a video tape recorder (VTR) will be in R11.

For both module and pallet configurations, the integrated module control panel (IMCP), located in R7, provide control of many Spacelab subsystems.

### Electrical Power

The Spacelab electrical power distribution system (EPDS) provides primary dc power, emergency dc power, and three phase ac power to Spacelab subsystem equipment and to Spacelab experiments. The Spacelab main bus is normally powered via the orbiter primary payload bus MN C feed. The primary payload bus may also be powered by the MN B bus or by fuel cell 3 by direct feed. Spacelab main power is available during all flight phases, with some limited power constraints.

The primary dc power received by Spacelab from the orbiter primary payload bus is nominally 30 V. The four redundant power feeders from the orbiter supply the Spacelab power control box through a 200 and 125 amp fuse in each feeder. Spacelab main bus voltage and current reading are available on the S/L LAUNCH/ENTRY, A/L SS DC POWER, S/L AC POWER, AND S/L EXP POWER displays. The Spacelab power control box is installed in the subfloor of the Spacelab module core segment and in the igloo of the pallet-only configuration.

The main bus dc voltage and amperage are available through the EPDS VOLTS/AMPS digital meter and rotary switch on panel R7 and on Spacelab monitoring and control panel (MCP) at location R2D. The voltage reading is obtained by setting the VOLTS segment of the

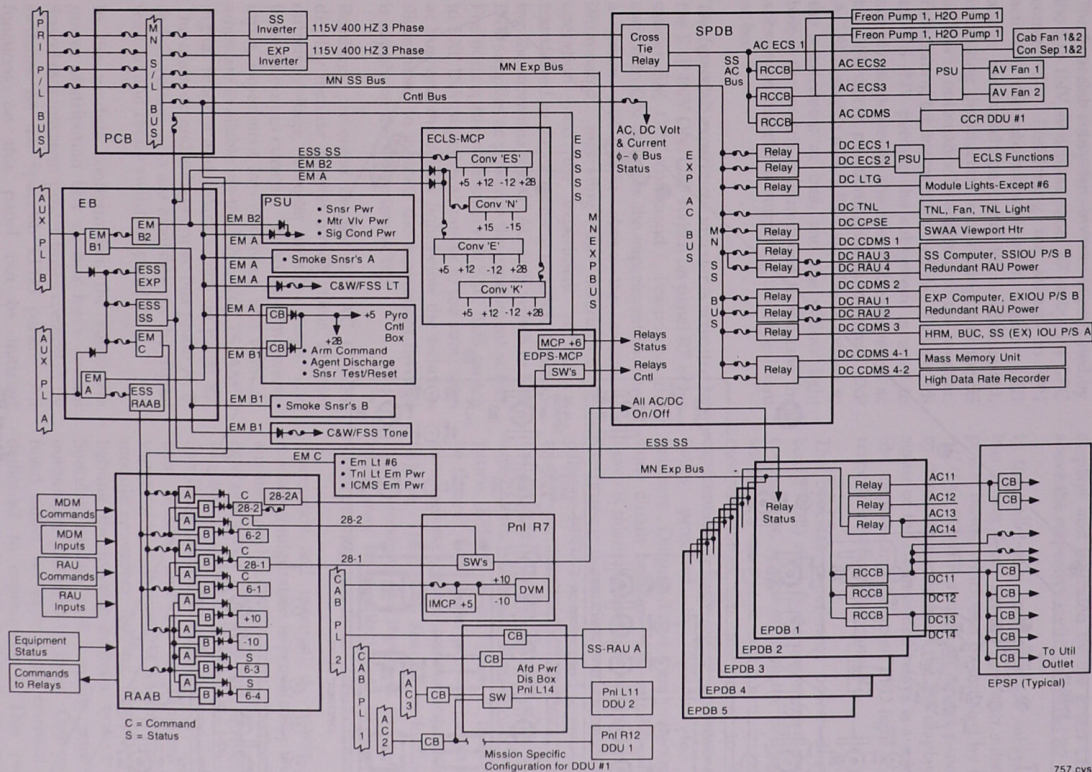
rotary switch to the MAIN DC position, and the amperage reading is obtained by setting the AMPS segment to the MAIN DC position. The R2D meter has only colored zones to indicate nominal (green) or off-nominal (red) readings. The AMP readout for main dc power has an additional color field (yellow) to indicate a peak power loading condition. The orbiter R7 LED display is not colored.

The Spacelab subsystem power distribution box (SPDB) distributes the subsystem dc bus and ac bus power into subsystem-dedicated buses. In the subsystem power distribution box, the dc power line feeds 15 subsystem power buses controlled by latching relays switched from panel R7. In the pallet-only configuration, all outputs are remotely switched by latching relays.

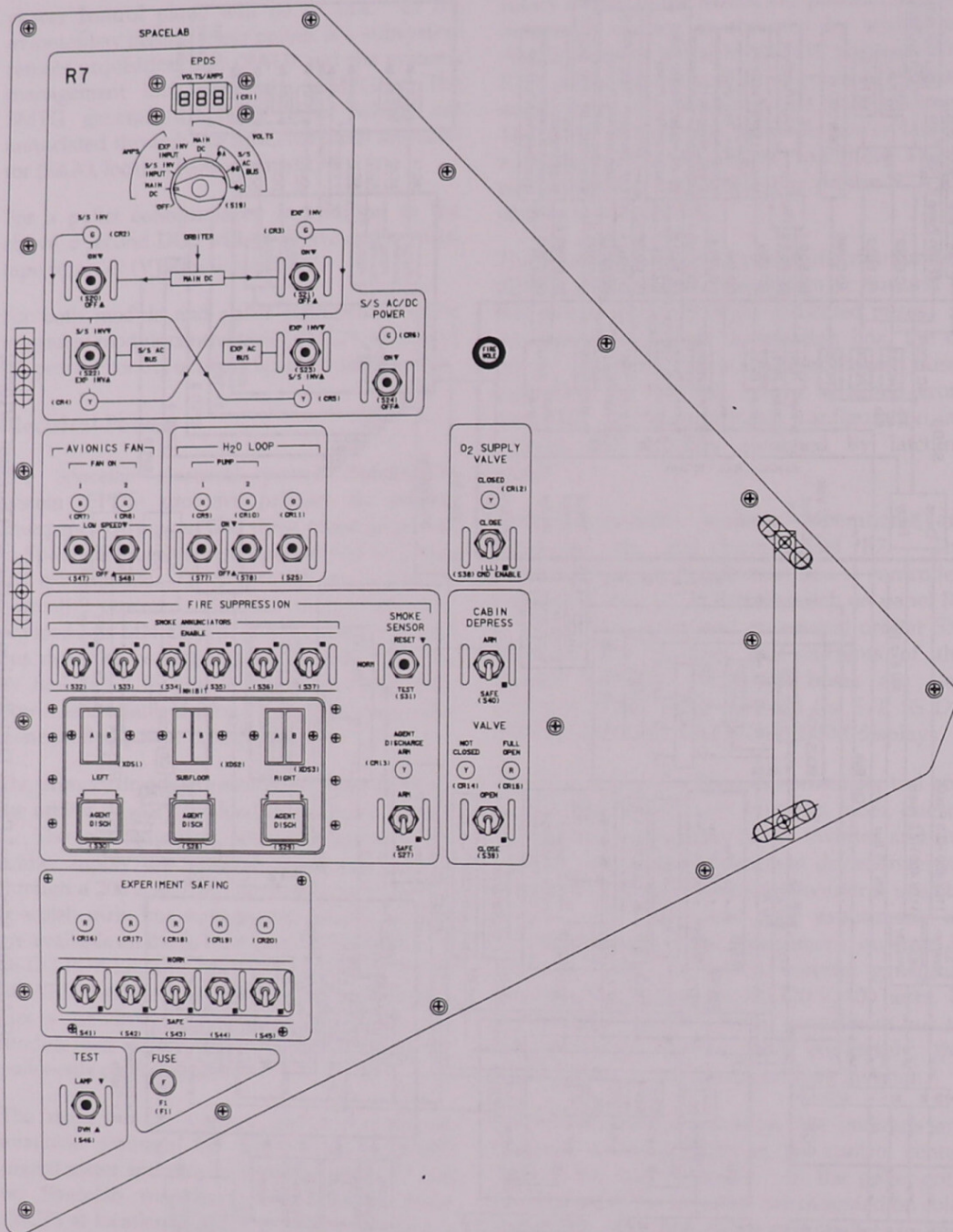
Various Spacelab systems' operations are controlled on orbit from panel R7. The subsystem power distribution box is controlled by the S/S AC/DC POWER switch on panel R7 or by an item command on several orbiter SM displays. The voltages and currents of the various Spacelab subsystem buses are also available to the flight crew on the S/L SS DC POWER and S/L SS AC POWER SM displays.

The dc power in the Spacelab power control box is directed through two 150-amp fuses, one to the Spacelab subsystem dc/ac inverter and the other to a Spacelab experiment dc/ac inverter. Normally, only the subsystem inverter is used to power both subsystem and experiment ac requirements, and the experiment inverter is used as a backup. Each inverter generates three-phase ac power at 112/120 V, 400 hertz. It is possible to connect the ac experiment bus to the subsystem inverter and, conversely, the subsystem ac bus to the experiment inverter.

In the module configuration, the inverters are mounted on cold plates in the control center rack of the core segment. In the pallet-only configuration, the inverters are mounted on cold plates on the first (forward) pallet in the payload bay.



S/L Module Electrical Power Distribution Functional Diagram (1/10/91)



Panel R7

The Spacelab subsystem inverter is activated by the S/S INV switch on panel R7 or by SM GPC command. Positioning the switch to ON activates the subsystem inverter, a green LED above the switch on panel R7 is illuminated, indicating the inverter is operating, and the SS ac bus is automatically attached to the inverter. Positioning the momentary S/S AC BUS switch to S/S INV permits the subsystem inverter to supply ac power to the Spacelab subsystem ac bus. Similarly, positioning the momentary EXP AC BUS switch to S/S INV supplies ac power to the experiment ac bus, and the yellow light below the switch is illuminated to indicate the subsystem inverter is supplying the experiment ac bus.

The Spacelab experiment inverter is activated by the EXP INV ON/OFF switch on panel R7 or by orbiter SM GPC command. Positioning the switch to ON activates the experiment inverter, a green LED light above the switch is illuminated, indicating the inverter is in operation, and the experiment ac bus is transferred to the experiment inverter. Positioning the momentary EXP AC BUS switch to EXP INV supplies ac power to the experiment ac bus. Positioning the momentary S/SAC BUS switch to EXP INV supplies ac power to the subsystem ac bus, and the yellow light below the switch is illuminated to indicate the experiment inverter is supplying the subsystem ac bus.

Readings presented on the S/L AC POWER display include inverter on/off status, inverter output voltage, inverter input voltage, and inverter output current. The subsystem inverter input, experiment inverter input, and main dc amps are available via the EPDS VOLTS/AMPS digital readout and rotary switch on panel R7. The main dc and subsystem ac bus phase A, B, and C voltage also are available via the digital readout and rotary switch on panel R7.

In the module configuration, the subsystem power distribution box ac bus feeds several Spacelab subsystem power buses controlled by switches on the Spacelab EPDS panel. All functions on this panel can be initiated simultaneously by the S/S AC/DC POWER switch on panel R7 or by item commands from orbiter SM displays. The status of the commanded relays is available via orbiter SM

displays and indicated by the green LED light above the respective switch on panel R7

In the pallet-only configuration, subsystem ac bus power feeds several Spacelab subsystems' power buses, which can be initiated by the S/S AC/DC POWER switch on orbiter panel R7 or by item commands from the SM displays. The status of the commanded relays is available via SM displays and the green LED light above the respective switches on panel R7.

The Spacelab experiment power distribution box (EPDB) receives dc power from the power control box, ac power from the SPDB, via the subsystem inverter or experiment inverter, and then distributes the bus power to Spacelab experiments. Each EPDB provides four dc buses protected by 60-amp-rated circuit breakers. Outputs 3 and 4 are protected by the same circuit breaker. The number of EPDBs flown is mission dependent, with a maximum of five (three in the module and one on each of two pallets). EPDB 3 may be used to provide power to an experiment support structure, exterior to the module. EPDB dc power is routed to experiments via experiment power switching panels (EPSPs). A maximum of 10 EPSPs may be flown. EPSPs also provide power to rack-mounted experiment remote acquisition units (RAUs). The EPDBs also power four ac buses. In the module, the inputs of these EPDB ac buses may be distributed to EPSPs, each of which provides two three-phase ac buses.

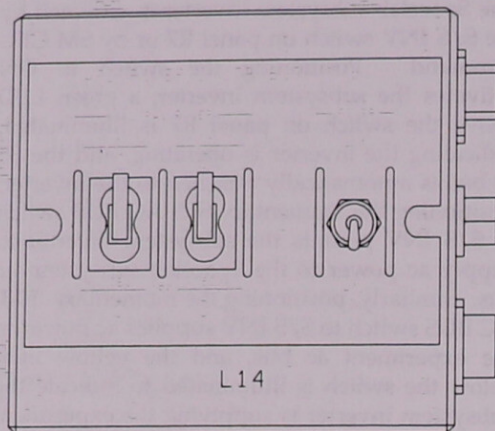
Emergency and essential dc power for the module configuration is provided by the orbiter auxiliary payload buses A and B to the Spacelab emergency box. The Spacelab emergency box supplies emergency and essential power for Spacelab critical environmental control subsystem sensors and valves, fire and smoke suppression equipment, ECS water line heaters, module emergency lighting, tunnel emergency lighting, the Spacelab intercom system, and the Spacelab caution and warning panel. The outputs are protected by fuses. One separately fused outlet, an experiment essential bus, is dedicated to experiments. This power is available during all flight phases and when degraded power is delivered to Spacelab. The Spacelab emergency box is located in the subfloor of the core segment.

Emergency and essential dc power for the pallet-only configuration is also provided by orbiter auxiliary payload buses A and B, which send dc power to the Spacelab emergency box located in the igloo. The Spacelab emergency box provides emergency or essential power to Spacelab subsystem equipment. The outputs are protected by fuses. One separately fused outlet, an experiment essential bus, is dedicated to experiments. This power is available during all flight phases and when degraded power is delivered to Spacelab.

In the module configuration, experiment power distribution boxes provide distribution, control, and monitoring facilities for the experiment electrical power distribution system. The experiment electrical power distribution system consists of a nominal redundant 28-volt experiment main dc supply and a 115-volt, 400-hertz ac experiment supply. One distribution box (EPDB 1) is located under the core segment floor on a support structure; for the long module configuration, two additional units (EPDBs 2 and 3) are installed. In the pallet-only configuration, the experiment power distribution box is mounted on a cold plate that is fitted to a support structure and attached to the pallet.

The orbiter SM displays present emergency and essential bus current, voltages for auxiliary buses A and B, output voltages for Spacelab subsystem emergency buses, output voltage for the Spacelab subsystem essential bus, and output voltage for the RAAB essential bus. The on-orbit SM display for activation/deactivation, subsystem dc power, and system summary indicates an undervoltage condition for auxiliary buses A and B. Nominal auxiliary bus amperage from the orbiter can be monitored on the EPDS VOLTS/AMPS meter (colored zone only) on Spacelab panel R2D.

In the pallet-only configuration, the orbiter SM displays include emergency and essential bus current, voltages for auxiliary buses A and B, output voltages for Spacelab subsystem emergency buses, output voltage for the Spacelab subsystem essential bus, and output voltage for the RAAB essential bus. The orbiter SM displays will indicate an undervoltage condition for auxiliary buses A and B.



**Panel L14**

The aft flight deck (AFD) power distribution box (L14) distributes dc power to the Spacelab subsystem remote acquisition unit (RAU) located in the avionics bay behind panel L14. This dc power comes from orbiter fuel cell 1 main bus A through cabin payload bus 1 and 2 or from orbiter fuel cell 2 main bus B. This power is not affected by the KILL switch of the primary payload bus. The AFD power distribution panel L14 S/S RAU POWER 1 ON/OFF and S/S RAU POWER 2 ON/OFF circuit breakers are used to feed power to the RAU from either bus.

### Command and Data Management System

The Spacelab command and data management system (CDMS) provides a variety of services to Spacelab experiments and subsystems. Most of the CDMS commands are carried out through the use of the computerized system aboard Spacelab, called the data processing assembly (DPA). The DPA formats telemetry data and transfers the information to the orbiter for transmission, receives command data from the orbiter and distributes them to Spacelab subsystems, transfers data from the orbiter to experiments, and distributes timing signals from the orbiter to experiments.

The CDMS includes three identical IBM AP 101-SL computers and assorted peripherals. One computer is dedicated to Spacelab experiments,

one supports Spacelab subsystems, and the third is a backup that can function in place of either. The flight crew monitors and operates Spacelab subsystems and payload experiments through data display and keyboard units. The computers have a main memory capacity of 512k 16-bit words. The experiment computer activates, controls, and monitors payload operations and provides experiment data acquisition and handling. The subsystem computer provides control and data management for basic Spacelab experiment support services, such as electrical power distribution and equipment cooling.

An input/output unit buffers all communications between the computer and the rest of the subsystem. The experiment computer also has at least one RAU (and as many as 20, depending on the payload) for interfacing between experiments and the subsystem. The subsystem computer may have as many as nine RAUs, depending on the Spacelab configuration.

The experiment and subsystem computers and their associated input/output units (SS10 and EX10 respectively), as well as the backup computer, are located in the workbench rack (opposite the control center rack) of the module core segment. In the pallet-only configuration, they are located in the igloo.

#### Mass Memory Unit (MMU)

The MMU is a tape recorder that contains all of the operating system and applications software for the subsystem and experiment computers. The memory unit provides the initial program load for the Spacelab subsystem, experiment, and backup computers; it can also be used to completely reload computer memory if required. The MMU stores various files, time lines, and displays. Writing onto the unit during flight is possible. Approximately half of the unit's storage capability is available for software and data supporting Spacelab experiments.

#### Data Display Systems

The data display systems (DDSs) are the primary onboard interface between the CDMS

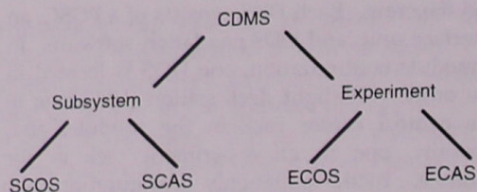
and the crew. Each DDS consists of a PGSC, an interface unit, and DDS emulation software. In a module configuration, one DDS is located in the orbiter aft flight deck station (L11), one in the control center rack in the module, and, possibly, one in an experiment rack in the module. In the pallet-only configuration, two DDSs can be located in the crew compartment aft flight deck station (L11 and R11).

STS 50 was the first Spacelab mission utilizing the PGSC as a replacement for the data display unit (DDU). PGSC is a Gridcase 1530, 386-based laptop personal computer with an electroluminescent monochrome display. The PGSC communicates with the CDMS through the interface unit, which performs protocol translation between the PGSC and CDMS. The DDS emulation software performs function key mapping and display formatting.

The PGSCs via DDSs are connected to the experiment and subsystem input/output units. Each can display information from both computers simultaneously, for monitoring purposes, although each DDS can communicate with only one computer at a time. Crewmembers can use the PGSC to call various displays onto the screen for subsystem and experiment monitoring and control.

CDMS software consists of experiment software and subsystem software, each of which includes operating systems and applications. Within the experiment computer, both the operating system and the application software are wholly dedicated to the direct support of Spacelab payload experiments. CDMS software consist of the software that resides in the subsystem and experiment computers. The software within the Subsystem Computer (SSC) and the Experiment Computer (EXC) contains both the operating system and user defined application software.

The subsystem computer functions mainly to monitor and control Spacelab subsystems and equipment such as the electrical power distribution subsystem and the environmental control subsystem. These functions are performed by the subsystem computer operating software (SCOS).



Subsystem computer application software (SCAS) is available for use by any Spacelab application but to date the only user has been the Instrument Pointing System (IPS). SCAS is used for Spacelab thermal control, system monitoring, IPS activation/deactivation, and IPS attitude control associated with stellar, solar and earth pointing operations.

The experiment computer operating system (ECOS) provides general services for experiments such as activation/deactivation and experiment system monitoring. Experiment computer application software (ECAS) is dedicated to the direct support of Spacelab payload experiments and provides experiment control, data handling, and experiment data downlink.

Orbiter payload multiplexers/demultiplexers (MDMs) PF1 and PF2 are used for data communications between the orbiter GPCs and the Spacelab CDMS computers. The payload MDMs are under orbiter GPC control. The orbiter pulse code modulation master units (PCMMUs) can access Spacelab data for performance monitoring and limit sensing. The PCMMUs contain a fetch command sequence and a random-access memory for storing fetched data. Spacelab and other payload telemetry data from the PCMMU random access memory are combined with orbiter pulse code modulation data and sent to the orbiter network signal processors for transmission on the downlink through S-band or Ku-band.

The Spacelab experiment computer interfaces with two telemetry systems. The orbiter PCMMU allows the orbiter to acquire data for onboard monitoring of systems and provides Mission Control with system performance data for real-time display and recording through the orbiter network signal processor and S-band or Ku-band. The other telemetry system, the Spacelab high-rate multiplexer, is a high-rate link to the Ku-band signal processors that sends scientific data to the Payload Operations

Control Center for real-time display and to the Goddard Space Flight Center for recording.

Spacelab high-rate data acquisition is provided by a high-rate multiplexer (HRM) and a high-data-rate recorder (HDRR). The HRM multiplexes up to 16 experiment channels, each with a maximum of 16 Mbps, two direct-access channels with data rates up to 50 Mbps, data from the Spacelab subsystem computer, from the Spacelab experiment computer, and up to three analog voice channels from the Spacelab intercom master station in the module configuration. The three digitized channels are pre-multiplexed onto a single 128-kbps channel for interleaving in the format along with Greenwich Mean Time (GMT) signals from the orbiter master timing unit. This composite output data stream is routed to the Ku-band signal processor for transmission on Ku-band or is sent to the HDRR or orbiter payload recorder. The HRM is located on the control center rack in the pressurized module and in the igloo for the pallet-only configuration.

In the module, the HDRR is located next to the DDS; in the pallet-only configuration, it is pallet mounted. It records real-time, multiplexed data, or data from two direct-access channels, and stores the information at rates from 1 to 32 Mbps during mission periods with no downlink capability or degraded downlink capability for playback when the capability is available. The HDRR is dumped in the reverse direction at 2, 4, 8, 12, 16, 24, or 32 Mbps. At a rate of 32 Mbps, a tape runs for 20 minutes. During normal HDRR operations, data is recorded and subsequently dumped to the ground via recorder playback. Tape changeout would only be required for a damaged or broken tape. A spare HDRR can be flown to substitute for a failed recorder via an LRU.

The orbiter payload recorder serves as a backup for the Spacelab HDRR for data rates from 0.125 to 1 Mbps and can record only real-time, multiplexed data. The orbiter payload timing buffer provides mission elapsed time and GMT. The master timing unit provides 100-hertz, 1-kHz, 1,024-kHz, and 4,608-kHz timing signals to the Spacelab data processing assembly. Activation of the Spacelab DPA is controlled and monitored from orbiter SM displays.

### Closed-Circuit Television (CCTV)

The module has its own CCTV that interfaces with the orbiter CCTV and the Ku-band signal processor. The orbiter CCTV system can accept three video inputs from the Spacelab system. A sync signal is provided by the orbiter, and Spacelab cameras can be commanded and controlled through the orbiter CCTV system. The orbiter also has one video output to the Spacelab CCTV system. The Spacelab accommodates a video switching unit and the video analog switches (VAS) that provides routing and control functions. The Spacelab analog/video output is directed to the orbiter Ku-band signal processor channel 3, payload analog input. Also included as part of the Spacelab CCTV system are different types of video/analog recorders. Data downlinked on Ku-band channel 3 are time-shared by the orbiter's CCTV system, the Spacelab TV/analog output, and the Spacelab high-rate multiplexer data.

### Module Intercom

The Spacelab intercom master station interfaces with the orbiter audio central control unit (ACCU) for communications through orbiter duplex (simultaneous talk and listen) audio channels. ACCU loops that can be routed to Spacelab include air-to-ground (A/G) 1 and 2, air-to-air (A/A), intercom (ICOM) A and B, C&W tones, and page. Another selection is an internal voice loop which provides an intercom for Spacelab only.

Each orbiter loop, with the exception of page, may be selected on any of three Spacelab channels using rotary switches on the Spacelab intercom master station. One Spacelab channel may in turn be monitored at each intercom remote station. With the addition of audio channel interface units (ACIU) and Spacelab audio ground isolators (SAGI), channels from two intercom remote stations can be monitored simultaneously and individual channels selectively keyed from a single headset. During normal Spacelab operations, the orbiter A/G 1 loop is used for air-to-ground communications with the Payload Operations Control Center (POCC), A/G 2 is used for orbiter to Mission Control communications and either ICOM A or ICOM B is used for orbiter to module communications. The page channel can be used for

general address and calling purposes, but voice does not go to the ground. Page signals can originate in the orbiter, the Spacelab, or both.

The Spacelab talk and listen lines are also routed to voice digitizers in the HRM to provide a redundant downlink only path for the three Spacelab channels.

### Module Environmental Control and Life Support (ECLS)

The ECLS consists of the atmosphere storage and control subsystem (ASCS), the atmosphere revitalization system (ARS), and the active thermal control system (ATCS).

The ASCS receives gaseous oxygen from the orbiter power reactant storage and distribution system and gaseous nitrogen from a tank located on the module's exterior. The system regulates the gaseous oxygen and nitrogen pressure and flow rates to provide a shirt-sleeve environment for the module compatible with the orbiter cabin atmosphere.

Gaseous oxygen enters the module through the lower feedthrough plate in the Spacelab forward end cone at 100 psi and a maximum flow rate of 7 pounds per hour (nominal 0.5 lbs/hr). A motor-controlled valve in the module controls the flow of gaseous oxygen. This valve, operated by Spacelab RAU commands, opens when the O<sub>2</sub> SUPPLY VALVE switch on panel R7 is in the CMD ENABLE position, and an item 13 is executed on SPEC 223. It closes when the switch is in the CLOSE position or when an item 14 is executed on SM SPEC 223. A yellow LED above the switch on panel R7 is illuminated to indicate that the valve is closed. The oxygen supply valve receives 28 V from the Spacelab emergency buses (EMA + EMB2 redundantly).

The gaseous nitrogen is stored in a tank outside the module on the forward end cone. The capacity of the nitrogen tank is sufficient to support a nominal 7-day mission. The GN<sub>2</sub> tank is pressurized to approximately 2300 psi. The GN<sub>2</sub> enters the module via the forward end cone feedthrough via a flow restrictor that restricts the flow to a maximum of 90 pounds per hour. Pressure regulators then regulate the pressure down to 215 psi. Pressure regulators on the



Spacelab O<sub>2</sub>/N<sub>2</sub> control panel regulate the air pressure in the cabin to 14.7 psi. This system also utilizes PPO<sub>2</sub> measurements to maintain the proper balance of O<sub>2</sub> and N<sub>2</sub> in the cabin.

The Spacelab cabin depressurization assembly is primarily for contingency venting-to-vacuum of Spacelab cabin atmosphere in case of fire that cannot be handled by the Spacelab fire suppression system. The depressurization assembly consists of a vent with two filters, a manual shutoff valve, and a motor-driven shutoff valve. The motor-driven shutoff valve is powered by the Spacelab emergency buses and controlled by the *CABIN DEPRESS VALVE OPEN/CLOSE* switch and a *CABIN DEPRESS ARM/SAFE* switch. The *CABIN DEPRESS ARM* switch arms the Spacelab cabin depressurization motor-driven valve; and when the *CABIN DEPRESS VALVE* switch is positioned to *OPEN*, the Spacelab cabin depressurization assembly in the Spacelab forward end cone opens, depressurizing the module at 0.38 pound per second. The yellow LED above the switch on panel R7 is illuminated to indicate that the motor-operated depressurization valve is fully open. The red LED above the switch on panel R7 is illuminated to indicate that the Spacelab cabin depressurization valve is not closed. If this indication is received without a full *OPEN* indication, the valve has not completed its full travel.

The ARS is composed of these three air loops: cabin, tunnel, and avionics. The cabin air loop contains breathing air in the module. This loop is responsible for removing heat, humidity, odors, and carbon dioxide from the air before it is returned to the module. Once the hatch between Spacelab and the orbiter is opened, air is allowed to interchange between the two via the tunnel air loop. This loop removes any carbon monoxide from the module air. The avionics air loop is used to remove heat from subsystem and experiment equipment located in the module racks.

Air in the Spacelab avionics air loop is circulated by one of two dual-redundant fans, with check valves to prevent recirculation through the inactive fan and a filter upstream to protect both fans.

The fans are designed to operate in low speed and high speed modes. Airflow and power consumption in low speed is 639 pounds per hour and 110 watts. In high speed these values climb to 1,923 pounds per hour and 643 watts. The two fans, powered by separate 115-volt ac buses, are activated and deactivated by the AVIONICS FAN switches on panel R7. Each switch has a green LED that is illuminated above the respective switch to indicate that the respective fan is activated. The fans' status is also available on orbiter displays and the PGSC avionics power/cooling display.

The Spacelab avionics fans can also be activated in the low-speed mode by commands from the orbiter CRT keyboard. The fans are activated in the high-speed mode by commands from the orbiter CRT keyboards. The orbiter MDM deactivation command deactivates both fans simultaneously, and the Spacelab RAU deactivation command turns off each fan separately. The high-speed status of the Spacelab avionics fans is available on an orbiter SM display and a DDU display.

#### Cabin/Tunnel Air Loop

When the middeck airlock hatch and the Spacelab hatch are open, the orbiter air revitalization system provides air at 48 cubic feet per minute through a duct that branches off the orbiter cabin air loop downstream of the orbiter cabin heat exchanger and enters the tunnel adapter. In the tunnel adapter, the duct can be controlled by a manual shutoff valve before it passes into the transfer tunnel itself. For the transfer tunnel to be entered, the Spacelab hatch must be opened. The tunnel air duct passes through the structure below the Spacelab hatch. The fan located in the transfer tunnel draws additional air into the duct through an air inlet located just on the tunnel side of the Spacelab hatch.

The fan draws in additional air from the tunnel at a rate of 77 cubic feet per minute for a total nominal duct flow of 125 cubic feet per minute. This flow rate is delivered to the Spacelab cabin. The return air passes through the transfer tunnel itself, initially at 125 cubic feet per minute. However, 77 cubic feet per minute of air is

sucked into the duct inlet at the Spacelab side of the Spacelab hatch, and 48 cubic feet per minute of air enters the orbiter cabin through the middeck airlock hatch. A scrubber in the tunnel duct removes carbon monoxide. The scrubber produces an air flow of 1.5 to 4 cubic feet per minute.

The switch for the fan located in the transfer tunnel cannot be accessed until the Spacelab hatch is opened, and the flight crew initially transfers to the Spacelab from the orbiter.

The tunnel fan receives dc power from the Spacelab electrical power distribution subsystem. A delta pressure sensor located in the tunnel provides telemetry data for calculating air flow.

### Active Thermal Control System

The Spacelab active thermal control subsystem consists of a water loop and the mission dependent equipment (MDE) fluid loop (FL) to remove heat from the Spacelab module and a Freon loop to remove heat from equipment on any pallets that may be flown with the module. The water loop is normally active only during on-orbit flight phases. The need to cool experiments during ascent and descent requires operation of the water loop in a reduced performance mode during these phases. The MDE FL may be used to remove heat from specific rack-mounted experiments, based on mission requirements.

The Spacelab water loop is circulated by a water pump package consisting of dual-redundant pumps (primary and backup) with inlet filters, manually (ground) adjustable bypass valves, check valves to prevent recirculation through the inactive pump, and an accumulator assembly to compensate for thermal expansion within the loop and maintain a positive pump inlet pressure.

The pump package is contained in a housing and mounted on the outside of the module's forward end cone. The nominal flow rate is 500 pounds per hour.

The Spacelab water pumps are powered by separate 115-volt buses. The pumps are activated and deactivated by the *H<sub>2</sub>O LOOP PUMP* switches on panel R7 or by commands

from orbiter SM SPEC 224. The green LED above each switch on panel R7 is illuminated to indicate that the pump is in operation. The on/off status of the Spacelab water pumps is also shown on the orbiter SM displays.

The MDE FL consists of the fluid loop monitoring and control panel (FLMCP), a fluid loop pump (FLP) package, a Spacelab experiment heat exchanger (HX), and the coolant distribution system. The FLP package resides in experiment rack R3 and contains the two centrifugal pumps, the accumulator and an electronic controller/signal conditioner. The pump circulates coolant through the required experiment racks where experiment heat loads are collected, transported, and rejected via the experiment HX to the SL water loop.

The FL pumps are powered by a 115-volt, 400-Hz, 3-phase ac bus. The FL pumps are activated and deactivated by switches on the FLMCP or from commands issued from orbiter SM SPEC 224. Talkbacks, located on the FLMCP, indicate the status of the system. The crew may also monitor values from the analog and discrete parameters on SM SPEC 224.

The Spacelab Freon coolant loop removes heat from any pallets that may be flown with the module and transfers the heat of the interloop heat exchanger to the Spacelab water loop system. The flow rate is approximately 3,010 pounds per hour. From the Spacelab water loop system, the water passes through the orbiter payload heat exchanger, which transfers all the heat it has collected to the orbiter Freon coolant loops.

### Caution and Warning

The orbiter receives caution and warning inputs from Spacelab through the orbiter payload MDMs. Four channels in the Spacelab systems are dedicated to sending payload warning signals to the orbiter, and four channels in the Spacelab systems send payload caution signals to the orbiter. These channels cause illumination of the PAYLOAD CAUTION, PAYLOAD WARNING, and BACKUP C/W ALARM lights on panel F7. The two PAYLOAD lights can be inhibited via panel R13U. Fifteen remaining caution and warning input channels to the

O <sub>2</sub> PRESS	H <sub>2</sub> PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O <sub>2</sub> HEATER TEMP	MAIN BUS UNDERVOLT (R)	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/CABIN AIR	IMU	FWD RCS (R)	RCS JET
H <sub>2</sub> O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS (R)	RIGHT RCS (R)
_____	LEFT RHC (R)	RIGHT/AFT RHC (R)	LEFT OMS (R)	RIGHT OMS (R)
[REDACTED]	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
	PRIMARY C/W	FCS CHANNEL	MPS (R)	_____
_____	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

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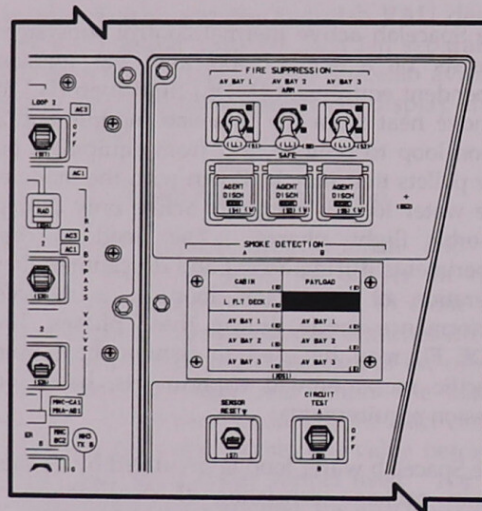
**Payload Caution and Warning Lights on Panel F7**

orbiter payload MDMs are available for Spacelab experiment limit sensing in the orbiter GPCs. These can feed up to four channels in the caution and warning electronics unit on panel R13U. The orbiter provides a maximum of 36 safing commands for use in response to Spacelab caution and warning conditions with 22 reserved for experiment safing commands. All safing commands are initiated at the orbiter CRT and keyboard.

The orbiter GPC can obtain data from the Spacelab CDMS through the orbiter PCMMU as an alternative source for caution and warning.

**Emergency Conditions**

There are two categories of Spacelab emergency conditions: fire/smoke in the module and rapid module depressurization. The orbiter and Spacelab annunciate these conditions and can issue safing commands if they occur. These signals are available during all flight phases.



**Payload Fire/Smoke Detection Light on Panel L1**

Redundant Spacelab fire/smoke inputs are generated by two ionization chamber smoke sensors at three locations in the Spacelab. The six fire/smoke discrete signals are hard-wired to six annunciator indicators located on panel R7. These indicators are divided into three pairs labeled *LEFT A* and *B*, *SUBFLOOR A* and *B*, and *RIGHT A* and *B*. The six *SMOKE ANNUNCIATORS* switches on panel R7 can be used to inhibit each fire/smoke sensor's output individually. The *SMOKE SENSOR* switch on panel R7 is used to reset or test all six sensors simultaneously.

Three signals, each from a different sensor location, are run through an OR gate and connected to orbiter panel L1, which has a *PAYLOAD* fire/smoke detection light. The three remaining signals are treated in the same manner.

When a Spacelab fire/smoke signal is detected, an emergency tone (siren) generated by the orbiter caution and warning circuitry is transmitted by the orbiter audio central control unit and announced in the Spacelab module by the loudspeaker, and the Spacelab *MASTER ALARM* light is illuminated. The six fire/smoke signals are also connected to six orbiter MDM inputs for display as emergency alert parameters on the orbiter CRT and for telemetry.

Two methods are provided for extinguishing a fire in the Spacelab module: discharging a fire suppressant into the affected area or dumping the Spacelab cabin atmosphere, when appropriate. The fire suppressant system (FSS) consists of 15 orbiter-common fire suppression bottles, each filled with the Halon 1301 suppressant agent.

The *AGENT DISCHARGE ARM/SAFE* switch on panel R7 or the Spacelab C/W/FSS panel in the spacelab control center rack is used to arm or safe the FSS. Each panel has a yellow indicator light that is illuminated when the FSS is armed. Arming the FSS also shuts off the module cabin fans to avoid diluting the suppressant's concentration.

The agent can be discharged from either orbiter panel R7 or the C&W/FSS panel by three identical sets of *AGENT DISCH* buttons, one each for the left, subfloor, and right areas. The buttons on the C&W/FSS panel are protected by individual guards. Depressing one of these buttons completely discharges the contents of all suppressant bottles in the indicated area of the Spacelab module.

In addition, the module *O<sub>2</sub> SUPPLY VALVE CLOSE/CMD ENABLE* switch on panel R7 can be used to close off the oxygen supply from the orbiter oxygen system to deprive the fire of oxygen. Module atmosphere dumping is controlled by the *CABIN DEPRESS ARM/SAFE* and *VALVE OPEN/CLOSE* switches on orbiter

panel R7. The Spacelab motor-controlled cabin dump valve's status is indicated by the yellow *NOT CLOSED* and the red *FULL OPEN* indicators on panel R7, as well as by the SM SPEC 223 display. In addition, the manual cabin depressurization valve on panel F6D must be opened to allow cabin depressurization. The motorized and manual cabin depressurization valves are in series; both must be opened.

### Pallet-Only Environmental Control Subsystem

The environmental control subsystem provides thermal control of Spacelab experiments and subsystems. The Spacelab Freon coolant loop services the pallet systems and collects heat dissipated by the subsystem and experiment equipment. The coolant loop collects heat from the pallet-mounted subsystems and experiments through cold plates, some of which have thermal capacitors to store peak heat loads. The cold plates in the Freon loop are bolted to an intermediate support structure that is attached to the pallet. A maximum of eight cold plates can be used on the pallets for a particular mission.

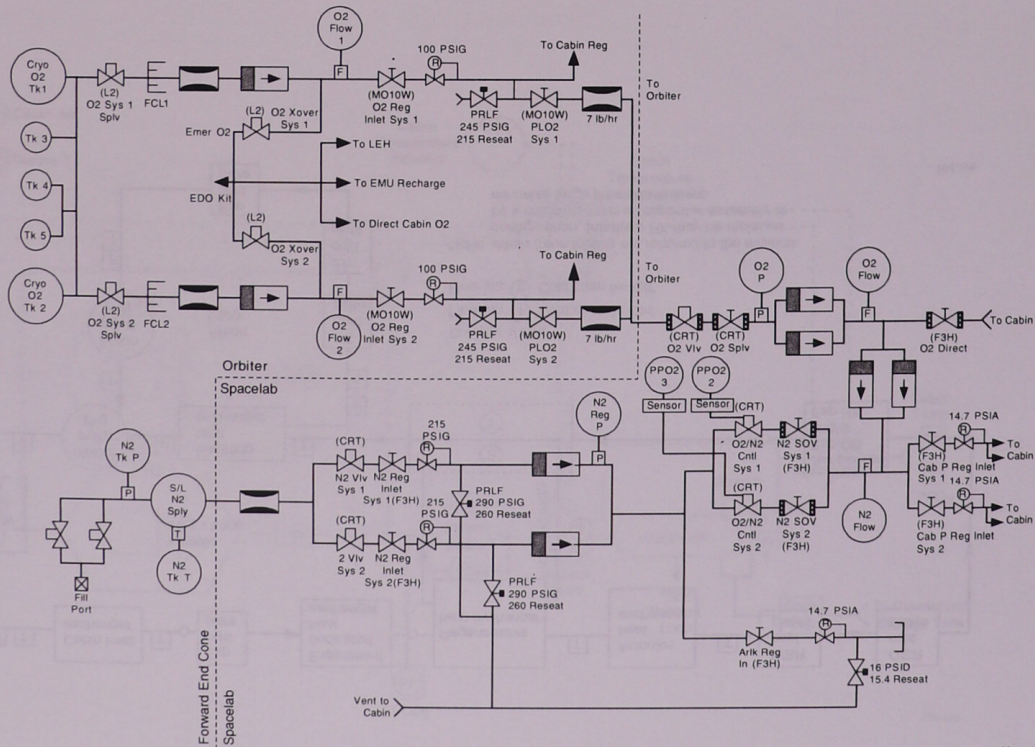
The subsystem equipment mounted in the igloo is also serviced by the Freon loop, which interfaces directly with the orbiter's payload heat exchanger. The Freon pump package is mounted on the front frame of the first pallet (forward) in the orbiter payload bay. Thermal coatings are applied to minimize heat leakage and the effects of solar radiation. A special paint is used to reduce the hot-case temperature of the pallet structure itself. An insulated shield installed between the pallet-mounted cold plates and the pallet structure reduces radiation exchange between them. Multilayer insulation thermal tents also protect pallet-mounted subsystems.

### Spacelab Summary Data

- Spacelab is a mission-specific, non-deployed payload carried in the payload bay.
- The four principal components of Spacelab are: module, pallets, a tunnel, and an instrument pointing system. Electrical power, command and data management, caution and warning, and environmental control and life support systems support the Spacelab.
- The module is available in a core and experiment segment. A pressurized tunnel is provided for equipment and crew transfer between the orbiter's crew compartment and the module.
- The pallets are platforms designed for large instruments, experiments requiring direct exposure to space, or systems needing unobstructed or broad fields of view.
- The instrument pointing system provides precision pointing for a wide range of payloads, including large single instruments, clusters of instruments, or single small-rocket-class instruments.
- The Spacelab electrical power distribution subsystem controls and distributes main, essential, and emergency dc and ac power to Spacelab subsystems and experiment equipment.
- The Spacelab command and data management system which consists of three identical computers and assorted peripherals provides a variety of services to Spacelab experiments and subsystems.
- Spacelab has a separate environmental and thermal control system.
- The majority of Spacelab subsystem controls are on panel R7, flown only when Spacelab is flown.
- Spacelab-specific CRT displays include: S/L LAUNCH/ENTRY, S/L COOLING LOOPS, S/L AIR LOOPS, S/L ATMOSPHERE, SL SS DC POWER, SL AC POWER, S/L DPA, S/L DPA PERIPHERAL, S/L LINK MGMT, S/L EXP RAUS, S/L COMM, and S/L EXP POWER.

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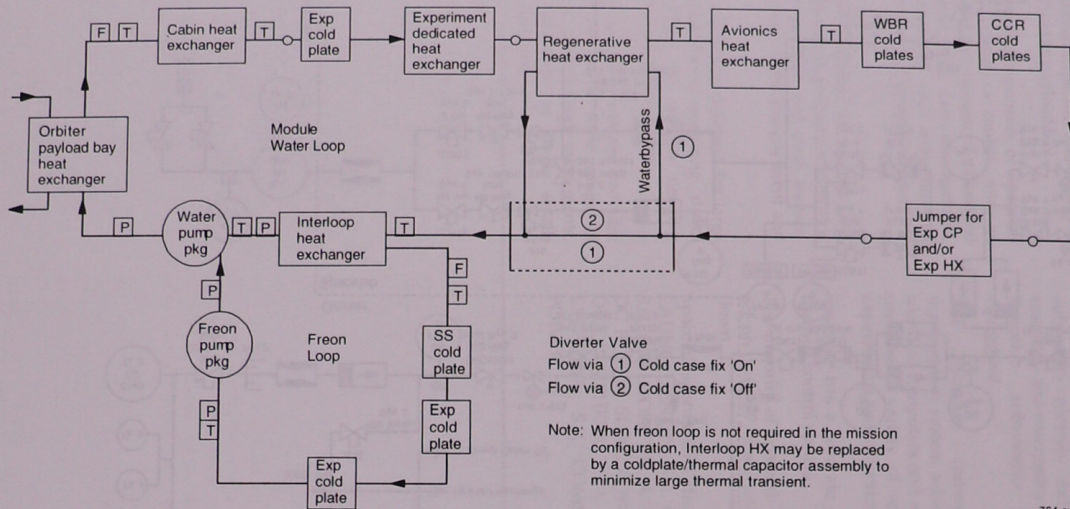
2. SYSTEMS  
2.25 Spacelab



ECLS Spacelab/Orbiter Interface

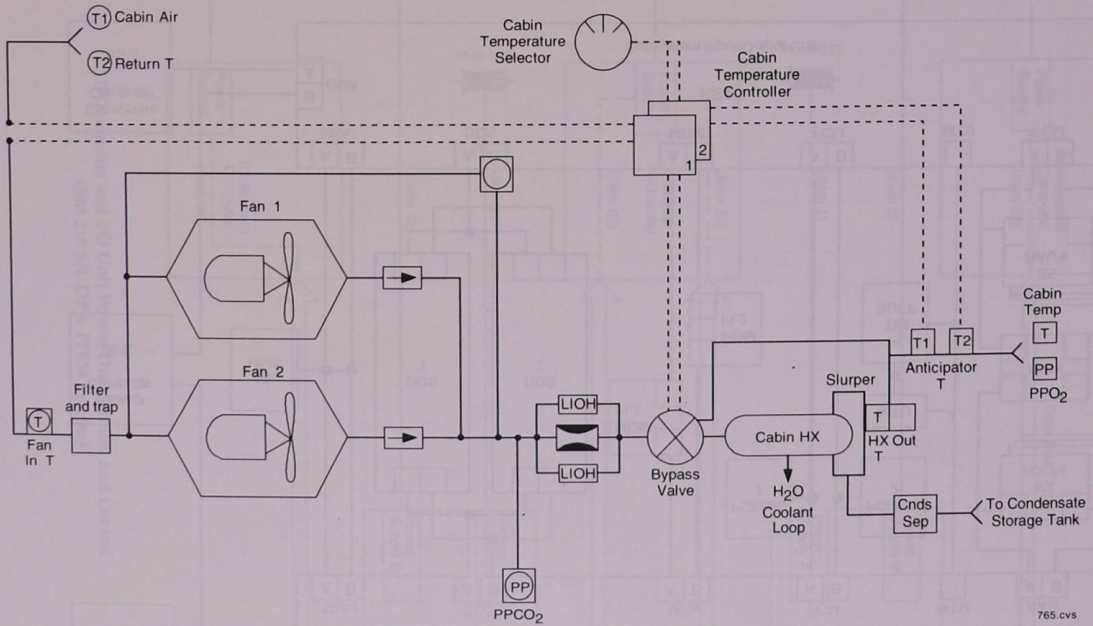
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Spacelab Coolant Loops

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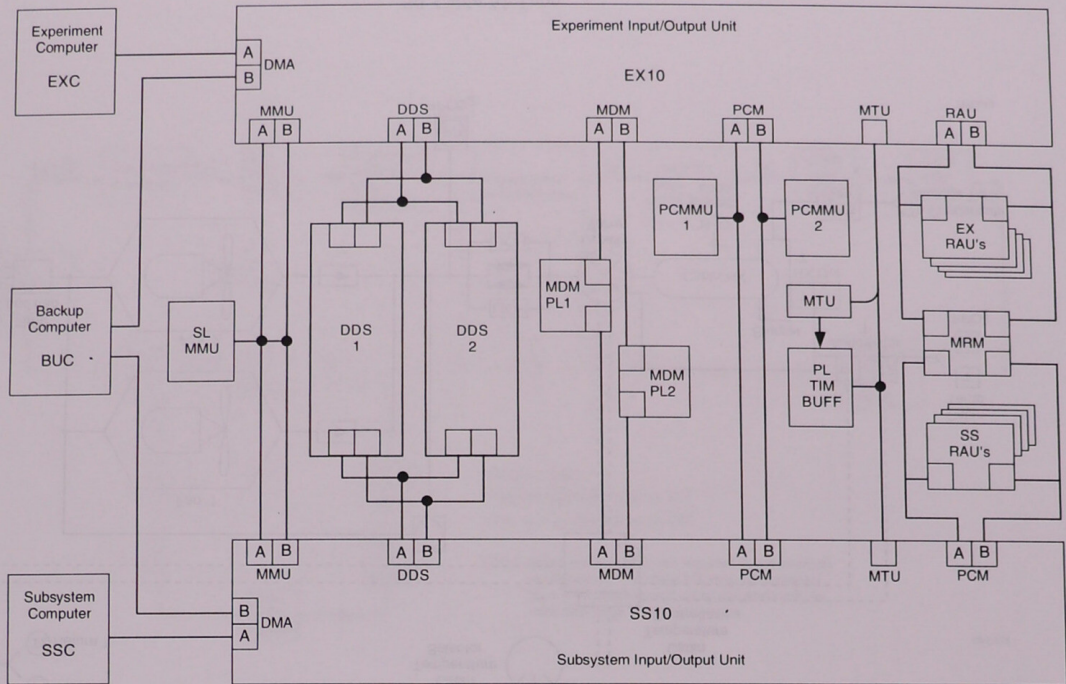
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2. SYSTEMS  
2.25 Spacelab

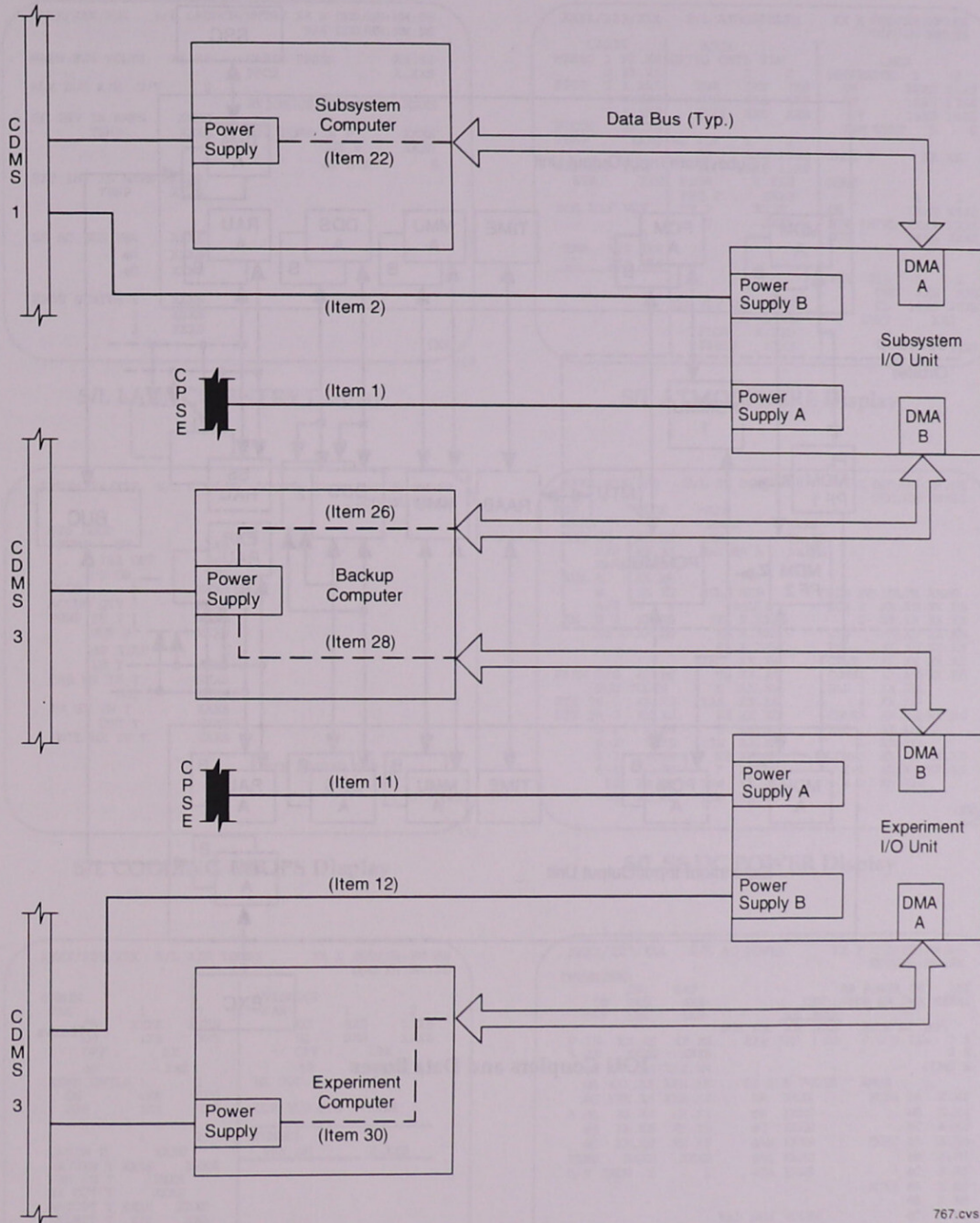
S/L Cabin Air Loop

SFOC-FI.0884  
Rev. B



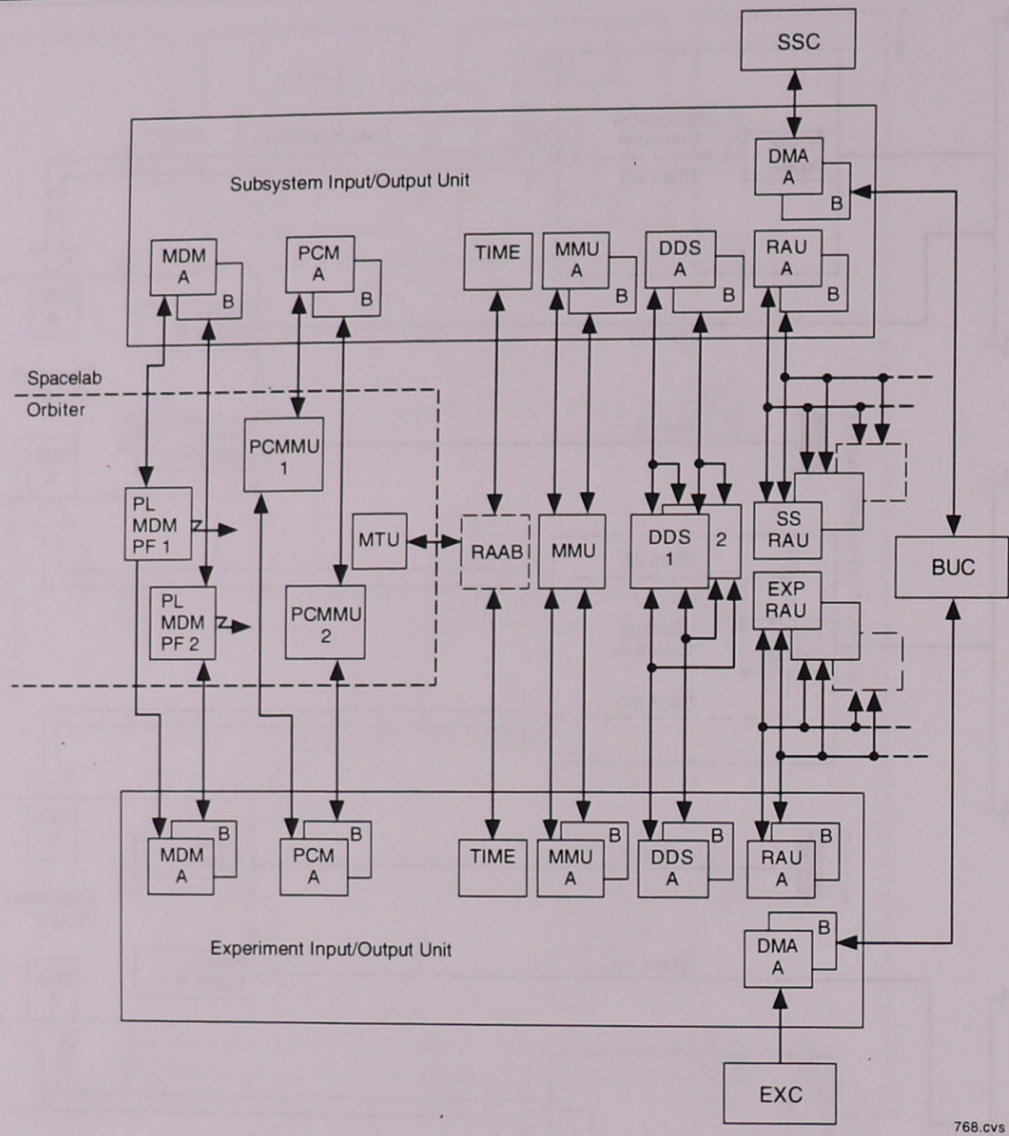


CDMS Redundancy



767.cvs

SL Computer and I/O Unit Power Distribution and Control  
(SM 210 S/L DPA ITEM Entries)



768.cvs

IOU Couplers and Data Buses

XXXX/XXX/206 S/L LAUNCH/ENTRY XX X DDD/HH:MM:SS		BFS DDD/HH:MM:SS	
MAIN BUS VOLTS	XX.XS	CABIN PRESS	XX.XS
AUX BUS A/B U/V	S	PPO2	X.XXS
SS INV IN AMPS	XXXXS	AVIONICS FAN ΔP	.XXXS
TEMP	XXXXS	H2O PUMP IN P	XXXXS
		OUT P	XXXXS
		ΔP STAT	S
EXP INV IN AMPS	XXXXS		
TEMP	XXXXS		
SS AC BUS V <sub>φA</sub>	XXXXS		
φB	XXXXS		
φC	XXXXS		
EPDB STATUS	1 XXXXS		
	2 XXXXS		
	3 XXXXS		

(XX) 769

S/L LAUNCH/ENTRY Display

XXXX/223/XXX S/L ATMOSPHERE		XX X DDD/HH:MM:SS	
		DDD/HH:MM:SS	
CABIN PRESS	1 XX.XS	ASCS O2/N2 CNTL VLV	1 2
	2 XX.XS		
PPO2	1 X.XXS	ENA	5XS 7XS
	2 X.XXS	INH	6XS 8XS
	3 X.XXS	STAT	XXS XXS
PPO2 TEMP	XX.XS		
	XXXXS		
DEPRESS VLV		N2 VLV	1 2
STAT	XXS	OP	9XS 11XS
		CL	10XS 12XS
POS RLF VLV		FLOW	X.XXS
		REG P	XXXXS
		TK P	XXXXS
		T	XXXXS
ENA	1XS 3KS		
CL	2XS 4XS		
		O2 VLV OP	13XS
		CL	14XS
		FLOW	X.XXS
		PRESS	XXXXS
		SEPARATOR	1 2
		CB	XXXXS XXXS
		ON	15XS 17XS
		OFF	16XS 18XS
		RPM STAT	S S
		TANK P	XX.XS
		DUMP	
		CB	1 2
		HTR	XXXXS XXXS
		NOZ T	XXXXS XXXS
		VLV COIL	1 2
		CMD	XXS XXS
		CL	19XS 20XS
		STAT	XXS

(XX) 772

S/L ATMOSPHERE Display

XXXX/224/XXX S/L COOLING LOOPS		XX X DDD/HH:MM:SS	
		DDD/HH:MM:SS	
H2O LOOP			
PUMP 1 ON	1XS		
1&2 OFF	2X		
2 ON	3XS		
FLOW	XXXXS		
ACCUM QTY	XXXXS		
PUMP IN P	XXXXS		
OUT P	XXXXS		
ΔP STAT	S		
IN T	XXXXS		
CAB HX IN T	XXXXS		
OUT T	XXXXS		
AV HX IN T	XXXXS		
OUT T	XXXXS		
INTL HX IN T	XXXXS		

(XX) 770

S/L COOLING LOOPS Display

XXXX/XXX/208 S/L SS DC POWER		XX X DDD/HH:MM:SS	
		DDD/HH:MM:SS	
BUS MAIN	VOLTS	MAIN AMPS	XXXXS
ESS	SS XX.XS	KW	XX.XS
EXP	XX.XS	ESS:EM A	XX.XS
RAAB	XX.XS		
AUX A	XX.XS		
B	XX.XS	ECLS MCP	SPDB DC VOLTS AMPS
A/B UV	S	VOLTS	ECS 1 XX.XS XX.XS
EM B	2 XX.XS	5K X.XXS	2 XX.XS XX.XS
SS C	XX.XS	ES X.XXS	LTG XX.XS XX.XS
		E X.XXS	TNL XX.XS XX.XS
		28K XX.XS	CPSE XX.XS XX.XS
RAAM P/S	AS BS	ES XX.XS	CDMS1 XX.XS-XX.XS
BUS VOLTS	E XX.XS	E XX.XS	RAU 3 XX.XS
STX 28-1	XX.XS	12K XX.XS	4 XX.XS
STX 28-2	XX.XS	ES XX.XS	CDMS3 XX.XS-XX.XS
6-1	X.XS	E XX.XS	RAU 1 XX.XS
6-2	X.XS	-12K XX.XS	2 XX.XS
6-3	X.XS	ES XX.XS	CDMS3 XX.XS XX.XS
6-4	X.XS	E XX.XS	4-1 XX.XS-XX.XS
10	XX.XS	15N XX.XS	4-2 XX.XS
-10	XX.XS	-15N XX.XS	

(XX) 773

S/L SS DC POWER Display

XXXX/225/XXX S/L AIR LOOPS		XX X DDD/HH:MM:SS	
		DDD/HH:MM:SS	
CABIN FAN	1 2	AVIONICS FAN	1 2
CB	XXXXS XXXS	LO	8XS 11XS
ON	1XS 3XS	HI	9XS 12XS
OFF	2X	OFF	10X
ΔP	.XXXS	ΔP	.XXXS
TEMP CNTLR	1 2	HX OUT T	XXXXS
ON	4XS 6XS	CCR VLV POS	XXXXS
OFF	5XS 7XS		
CABIN T	1 XXXS	TUNNEL	
RETURN T	XXXXS XXXS	FAN ΔP	X.XXS
FAN IN T	XXXXS		
HX OUT T	XXXXS		
ANTCPT T	XXXXS XXXS		
SELECT T	XXS XXS		
BYP VLV ACT	1 2		
POS	XXXXS XXXS		

(XX) 771

S/L AIR LOOPS Display

XXXX/222/XXX S/L AC POWER		XX X DDD/HH:MM:SS	
		DDD/HH:MM:SS	
INVERTERS			
ON	SS 2XS	EXP 4XS	SS POWER ON 1XS
OFF	3XS	5XS	SPDB SW PWR XXXXS
V IN	XX.XS	XX.XS	SS EXP
A IN	XXXXS	XXXXS	SS EXP
V φA	XX.XS	XX.XS	BUS SS XS 6XS
φB	XX.XS	XX.XS	EXP 7XS XS
φC	XX.XS	XX.XS	SS BUS VOLTS
A φA	XX.XS	XX.XS	φA XXXS
φB	XX.XS	XX.XS	φB XXXS
φC	XX.XS	XX.XS	φC XXXS
TEMP	XXXXS	XXXXS	φAB XXXS
O/V SHDN	S	S	φC XXXS
			φCA XXXS
			EXP BUS VOLTS
			φAB XXXS
			φC XXXS
			φCA XXXS
			CDMS φA X.XS
			φB X.XS
			φC X.XS
			φA X.XS
			φB X.XS
			φC X.XS

(XX) 774

S/L AC POWER Display

XXXX/210/XXX		S/L DPA		XX X DDD/HH:MM:SS	
I/O UNIT SS EXP		33 CDM5 MSTR OFF X		DDD/HH:MM:SS	
PWR ON A	1XS	11XS			
B	2XS	12XS			
OFF	3XS	13XS			
AMPS	XX.XS	COMPUTER	SSC	BUC	EXC
TEMP	XXXS	RESTART ENA	21XS	25XS	
5V	X.XS	PWR ON-DMA A	22XS		30XS
O/A	S	TEST FAIL	23XS	27XS	31XS
U/V	S	MMU LOAD	24	29	32
COUPLER	S	LOAD EXEC	XS	XS	XS
ALL A ON	4				
PMU B ON	5XS				
RAU B ON	6XS				
MDM B ON	7XS				
MMU B ON	8XS				
DDU B ON	9XS				
TIME OFF	10XS				
DMA	S	PROGRAM LOAD	SS	EXP	
RAU	S	MMU BITE	XS	XS	
MDM	S	LOAD COUNTER	XXXS	XXXS	
MMU	S	PIOL COUNTER	XXXS	XXXS	
DDU	S	TIME SOURCE	XXXS	XXXS	
TIME	S	SYS STOP ERR	XXXXS	XXXXS	
		IT LEVEL	XXS	XXS	

S/L DPA Display

XXXX/213/XXX		S/L EXP RAUS		XX X DDD/HH:MM:SS	
ALL EXP RAUS ON 1				XX X DDD/HH:MM:SS	
RAU ON	OFF	P/S	OP	NOP	SEQ STATUS
		OK			FAIL
10	2	3	XS	4XS 5XS	S XXS
11	6	7	XS	8XS 9XS	S XXS
13	10	11	XS	12XS 13XS	S XXS
15	14	15	XS	16XS 17XS	S XXS

S/L EXP RAUS Display

XXXX/211/XXX		S/L DPA PERIPHERAL		XX X DDD/HH:MM:SS	
SS RAU ALL ON 1 OFF 2				DDD/HH:MM:SS	
ON	OP	NOP	P/S	SEQ STATUS	MMU STATUS
			OK	FAIL	PWR ON 42XS
A	3XS	12XS	21XS	XS	OFF 43XS
B	4XS	13XS	22XS	XS	SV X.XS
C	5XS	14XS	23XS	XS	TEMP XXXXS
D	6XS	15XS	24XS	XS	SSC EXC
E	7XS	16XS	25XS	XS	OP 44XS 46XS
F	8XS	17XS	26XS	XS	NOP 45XS 47XS
G	9XS	13XS	27XS	XS	ERRORS
					REGA XXXXS XXXXS
					REGB XXXXS XXXXS
DDS	1	2			
DDU A	X.XS	X.XS			
KB	X.XS	X.XS			
TEMP	XXXS	XXXS			
SSC OP	30XS	34XS			
NOP	31XS	35XS			
EXC OP	32XS	36XS			
NOP	33XS	37XS			

S/L DPS PERIPHERAL Display

XXXX/214/XXX		S/L COMM		XX X DDD/HH:MM:SS	
				XX X DDD/HH:MM:SS	
VOICE DIGIT	ENA	INH		HDRR	
CHAN 1	1XS	4XS		PWR ON	19XS
2	2XS	5XS		OFF	20XS
3	3XS	6XS		STAT EU	XS
HRM				TU	XS
PWR ON	7XS	INP OVFL		MTR A	X.XS
OFF	8XS	1XS 12XS		TEMP	+XXXX
STAT	XS	2XS 13XS		RATE MHZ	2 21XS
TEMP	+XXXX	3XS 14XS			4 22XS
PSO	9XS	4XS 15XS			8 23XS
PS1	10XS	5XS 16XS			16 24XS
PS2	11XS	6XS 16XS			32 25XS
OP SSC	12XS	7XS PRXS		MODE STOP	26XS
NOP SSC	13XS	8XS HRXS		RCD	27XS
OP EXC	14XS	9XS SXS		FB	28XS
NOP EXC	15XS	10XS EXXS		FFWD	29XS
SLF TEST	16XS	11XS		RWD	30XS
STATUS	XXXXS			MOTION	XXXXS
CUR FMT	XXS			TAPE	XXX.XS
17 LOAD FMT	XXS			EOT	XS
EXEC 18				SELF TEST	31XS
				STATUS	XXXXS (XX)

S/L COMM Display

XXXX/212/XXX		S/L LINE MGMT		XX X DDD/HH:MM:SS	
				DDD/HH:MM:SS	
MDM SEL	SSC	EXC		GPC/SL LINK	ERROR
CHANNEL	A B A B			SSC	EXC
ENA	1X 2X 4X 5X			NOP IND	X X
DSBL	3X 6X			CDMM	X X
MDM TEST	SSC	EXC		LINK INTRPT	X X
RTRN CHW	7XXXX 8XXXX			NO SL RESP	X X
MSG	9XXXX10XXXX			GPC NO MATCH	X X
SV SEL	SSC	EXC		SL LENGTH	X X
ENA GTOD	11X 12X			AR NO MATCH	X X
M50	13X 14X			SR NO MATCH	X X
MSG REJECT	SSC	EXC		R/W ERROR STATUS	
ITEM	X X			RMT RI	XXX XXX
GNC	X X			GPC RCVD RI	XXX XXX
U/L	X X			SL RCVD RI	XXX XXX
PCS	X X			LENGTH	XXX XXX
TEC	X X			LINK BUSY	X X
				DSBL	X X
				ERROR RESET	15

S/L LINK MGMT Display

XXXX/220/XXX		S/L EXP POWER		XX X DDD/HH:MM:SS	
				DDD/HH:MM:SS	
EPDB	DC	AC	SOVS	MN	VDC XX.XS
	ON OFF	ON OFF	P/C		KW XX.XS
11	1XS 2XS 3XS 4XS		L3/4XS		EXP BUS VOLTS
12	5XS 6XS 7XS 8XS		R3/4XS		φAB φBC φCA
13/4	9XS 10XS 11XS 12XS		L5XS		XXXXS XXXS XXXS
			R5XS		
21	13XS 14XS 15XS 16XS		R6/7XS		SMOKE
22	17XS 18XS 19XS 19XS		R8/9XS		L A XX.XS EPDB
23/4	21XS 22XS 23XS 24XS		R10XS		B XX.XS DC AMPS
31	25XS 26XS 27XS 28XS		L6/7XS		SF A XX.XS 1 XXXS
32	29XS 30XS 31XS 32XS		L8/9XS		B XX.XS 2 XXXS
33/4	33XS 34XS 35XS 35XS		L10XS		R A XX.XS 3 XXXS
					B XX.XS
					EPDB AC AMPS
					1 φA φB φCA
					2 XX.XS XX.XS XX.XS
					3 XX.XS XX.XS XX.XS
EPDB	1 2 3				
ON	61XS 63XS 65XS				
OFF	62XS 64XS 66XS				

S/L EXP POWER Display

## 2.26 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:

- Flight data file (FDF) containers
- Modular lockers
- Floor compartments
- Volume B return trash containers.

The flexible containers are as follows:

- Flight deck storage bags
- Helmet storage bag
- Specialist seat FDF containers
- Soft storage containers
- Trash containers
- Temporary storage bag
- Jettison storage bags
- In-flight storage bags
- Middeck retention net
- Airlock storage bags
- Airlock retention net.

Stowage areas in the orbiter crew compartment are located on the flight deck, the middeck, and in the airlock.

### Rigid Containers

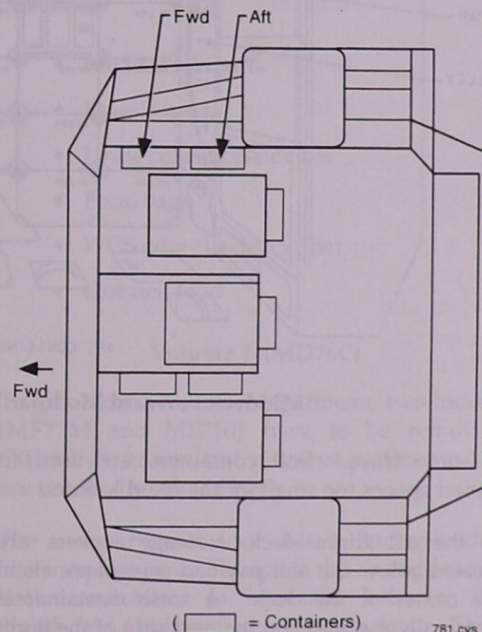
#### FDF Containers

Four permanently mounted lockers, two located to the right side of the CDR seat (C4), and two located to the right side of the PLT seat (R3) provide partial stowage of FDF on the flight deck. Remaining FDF items are stowed in specialist seat FDF containers and in middeck

modular stowage lockers. To gain access to the CDR/PLT container contents, the crewmember needs only to lift the latch handle to unlock the lid of the container.

### 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.



Flight Deck DFD Containers

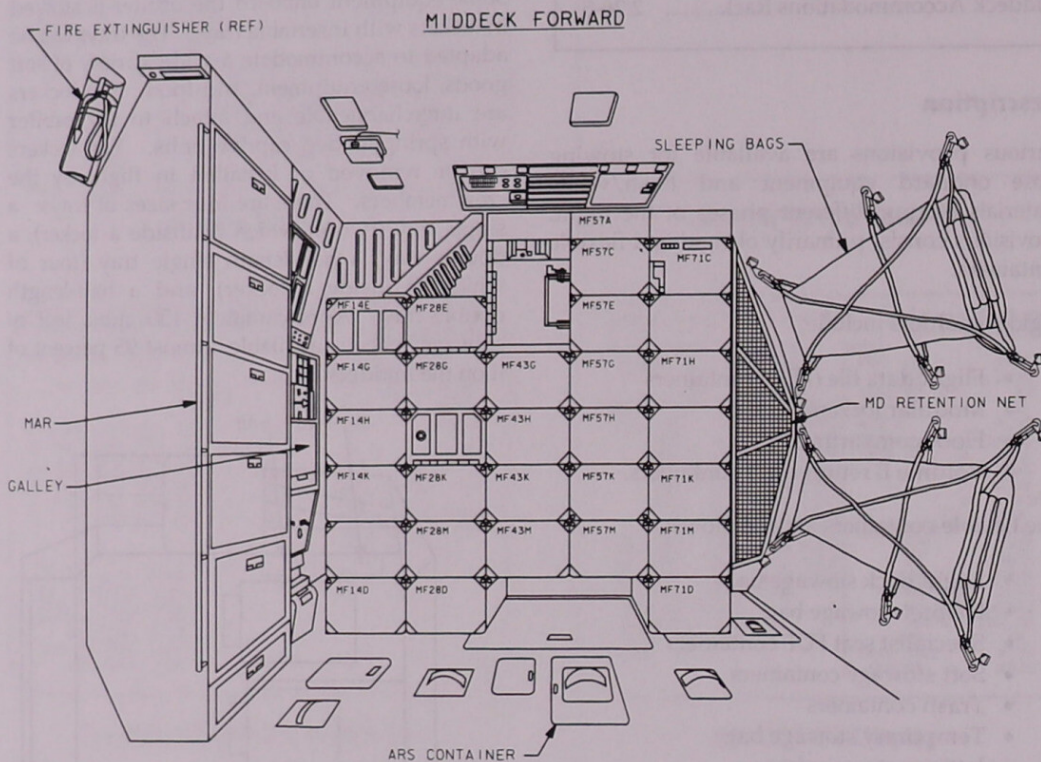
The lockers are made of either epoxy- or polyimide-coated Kevlar honeycomb material joined at the corners with aluminum channels. Inside dimensions are approximately 11 by 18 by 21 inches. The honeycomb material is approximately 0.25-inch-thick, and was chosen for its strength and light weight. The lockers

contain about 2 cubic feet of space and can hold up to 66 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

of the airlock module where nine containers 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



### Middeck Forward Modular Lockers and Floor Compartment

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 side of the flight deck, near the interdeck access opening. A temporary stowage bag is nominally located on the starboard side in approximately the same location. These side containers are interchangeable.

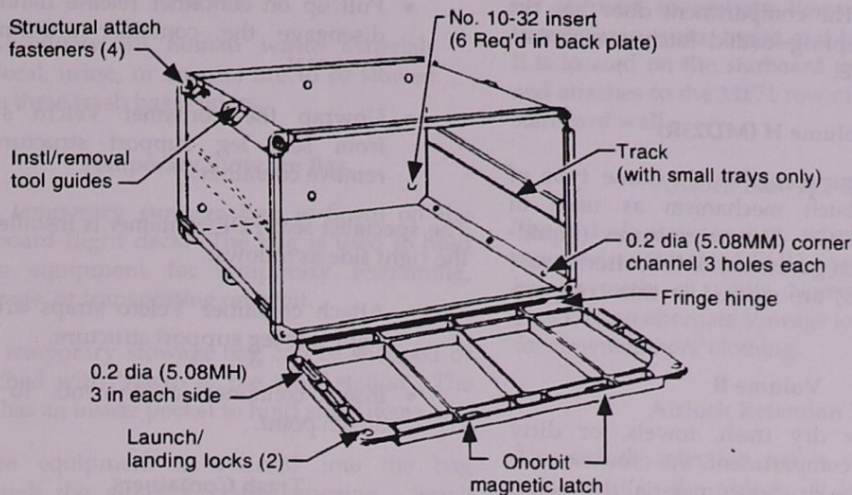
In the middeck, container modules can be attached to the forward avionics bay. Provisions for 33 containers are available in this area. In addition, there is an area to the starboard side

locker door. For on-orbit operations, the door is held closed by double magnetic latches.

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.



**CAUTION**  
Two captive wingnut locks must be secured for entry/landing.

783.cvs

### Schematic of Modular Lockers

#### Floor Compartments

Six floor compartments are available. Volume F (MD76M), the wet trash compartment, provides 8 ft<sup>3</sup> of stowage under the middeck floor. The CO<sub>2</sub> 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. The remaining floor compartment, volume E (MD76C), is used primarily to store official flight kits and personal preference kits.

#### 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. Wet trash 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
- Emesis bags
- Urine collection devices
- Fecal bags
- WCS odor/bacteria filter
- Uneaten food

#### Volume E (MD76C)

To gain access to this compartment, two lockers (MF71M and MF710) have to be removed. Official flight kits and personal preference kits are nominally stowed here.

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 G (MD80R)

To gain access to this compartment, locker MA16N has to be removed. Contingency hygiene equipment (urine collection devices, diapers, Apollo fecal bags, wet wipes, etc.) is



stowed here. The compartment door has the same type of spring-loaded latch mechanism used in volume E.

### 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.

### Volume B

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.

## 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.

### Helmet Stowage Bag

A polybenzine imidazole-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 and is utilized for stowing the launch/entry suit 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.

### Specialist Seat FDF Containers

A soft fabric container is available for each specialist seat to store FDF or other small loose items.

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.

## Trash Containers

Three 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 located on AV bay 3B. The third container is located on the port 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 a jettison stowage bag. A new liner is inserted through the trash bag top opening and secured by the Velcro strips on the liner to the trash bag mating surfaces.

Particular types of trash should be stowed only in these containers. They are as follows:

- Waste food/containers
- Wet wipes used for nonwaste collection system purposes
- Wet/dry towels and washcloths
- Clothing
- Vacuum cleaner residue/bag

**NOTE**

Absolutely *no* human waste materials (fecal, urine, or emesis) are to be stowed in these trash bags/liners.

**Temporary Stowage Bag**

One temporary stowage bag is flown on the starboard flight deck. The bag is used to hold loose equipment for temporary restraining, stowage, or transporting on orbit.

The temporary stowage bag can be snapped or attached with Velcro to the crew station. The bag has an inside pocket to hold small items.

Loose equipment is inserted into the bag through the alligator clamp opening. Small items are stowed in the bag inside pocket.

**NOTE**

No wet/odor-producing waste materials are to be stowed in this bag.

**Jettison Stowage Bags**

Teflon-coated Nomex cloth bags are provided to stow waste/trash 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**

Polybenzine imidazole brown-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 launch/entry suits, boots, and harness. Each bag has a drawstring for sealing the opening of the bag.

**Middeck Retention Net**

The middeck retention net, a polybenzine imidazole brown-colored mesh net with caribiners, is manifested on nonsleepstation 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.

**Airlock Stowage Bag**

The airlock stowage bag, when manifested, is mounted to the third EMU adapter plate. This bag is made of white Nomex material and provides an alternate stowage location primarily for crewmembers' clothing.

**Airlock Retention Net**

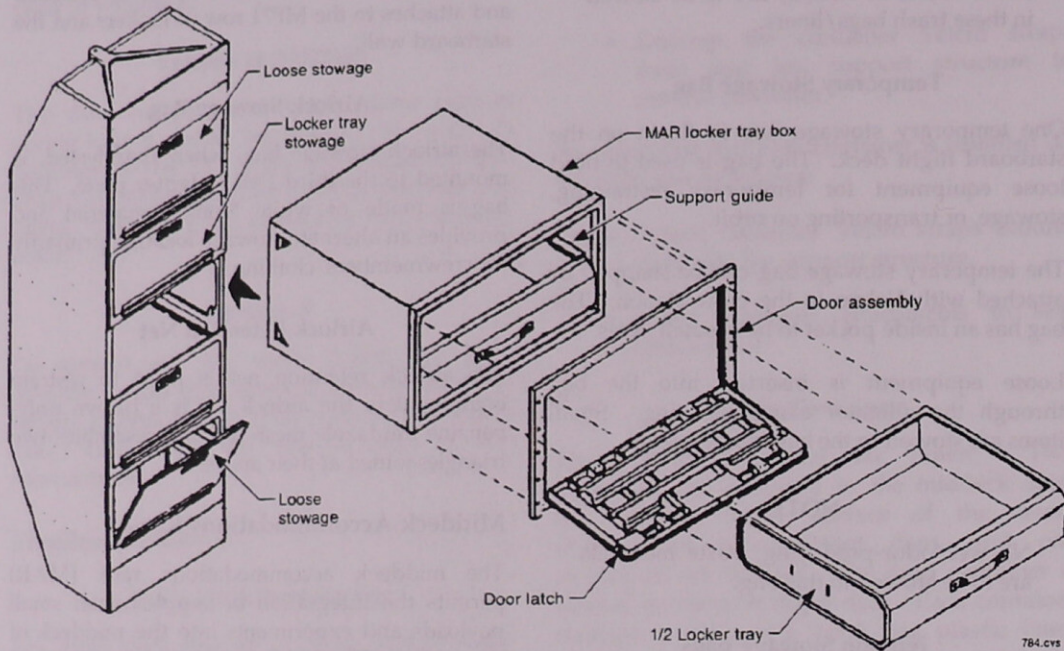
The airlock retention net is used to restrain equipment in the airlock. It is a brown polybenzine imidazole mesh net that resembles two triangles joined at their apexes.

**Middeck Accommodations Rack**

The middeck accommodations rack (MAR) permits the integration of supplemental small payloads and experiments into the middeck of the orbiter. The MAR is installed just forward of the side hatch in the area previously occupied by the galley. The blue anodized structure provides approximately 15 cubic feet of internal volume with a maximum payload weight of about 340 lb. The MAR can be used for stowage or as an experiment rack with electrical power and thermal control.

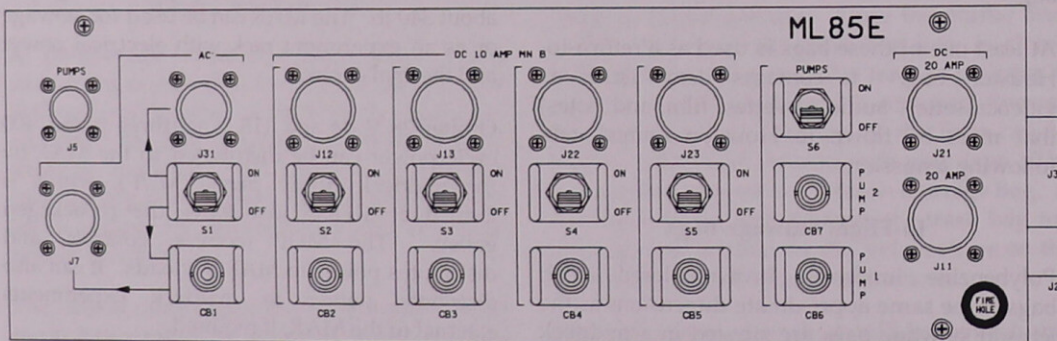
Orbiter 28 V dc and 115 V ac (three phase, 400 cycle power can be distributed to the MAR by the middeck utility panel (MUP), which is located at ML85E just above the repackaged galley. The MUP receives, controls, and distributes power to MAR payloads. It can also distribute power to middeck experiments external to the MAR, if required.

Thermal control for payloads in the MAR may be provided by either a water-to-air heat exchanger or water circulation through cold-plates. These NASA provided designs can dissipate heat loads of up to 1000 watts. An approved payload-unique system, located in the MAR, that connects to the orbiter heat exchange loop may also be used.



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Middeck Accommodations Rack (MAR) Locker Tray Assembly



NOTES:

1. J31 AND J7 BOTH OPERATE OFF SWITCH S1.
2. CB1 ONLY CUTS OFF J7. J31 USES THE ML86B PANEL BREAKER.
3. ALL DC POWER FROM MAIN B.
4. FRONT PANEL DESIGNED TO ACCEPT OVERLAYS.

ML85E Middeck Utility Panel (MUP)

## 2.27 WASTE MANAGEMENT SYSTEM (WMS)

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### Description

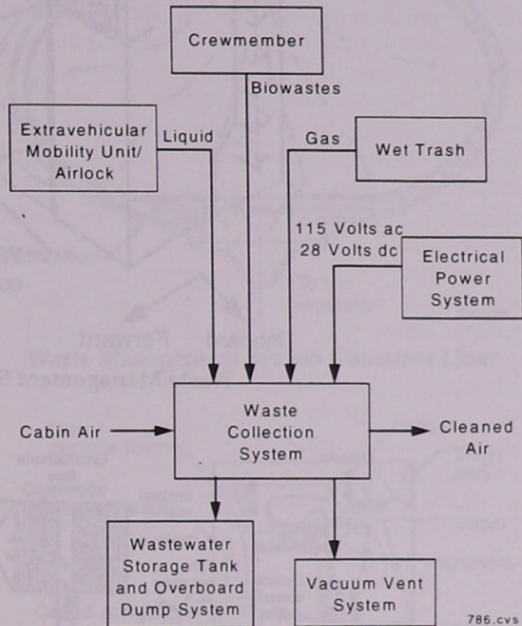
The waste management system is an integrated, multifunctional system used primarily to collect and process crew biological wastes. The WMS is located in the middeck of the orbiter crew compartment in a 29-inch-wide area immediately aft of the crew ingress and egress side hatch.

The system collects, stores, and dries fecal wastes and associated paper tissues. 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 door and interfaces with the galley, 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 and 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

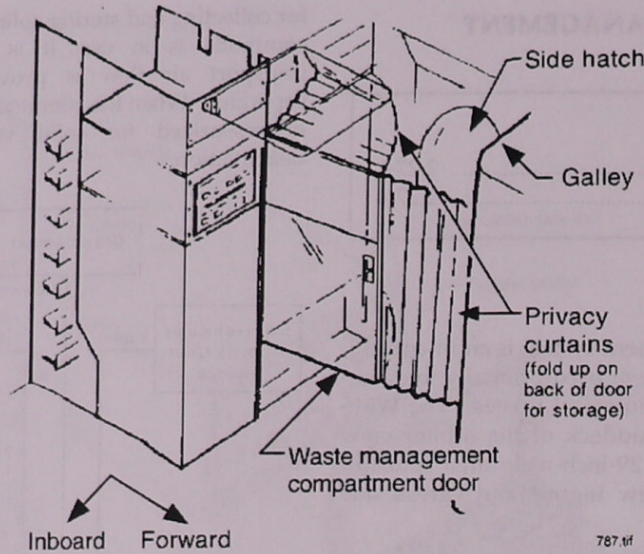
for collecting and storing solid waste. When the commode is in use, it is pressurized, and transport air flow is provided by the fan separator. When the commode is not in use, it is depressurized for solid waste drying and deactivation.



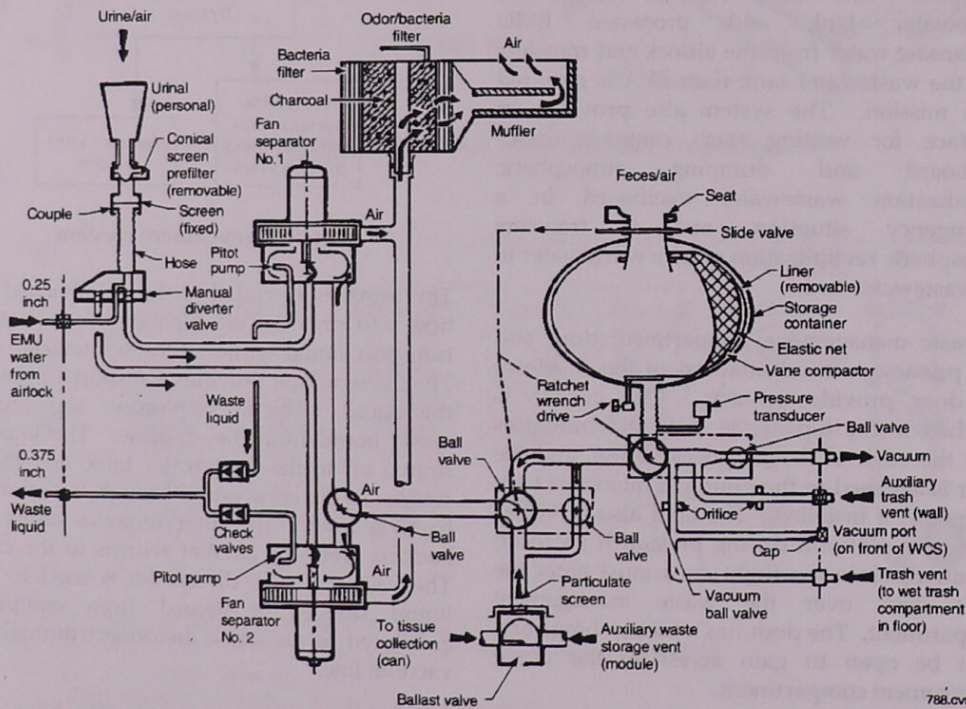
**Waste Management System**

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 and bacteria filter. The filter removes odors and bacteria from the air that returns to the cabin. The vacuum quick disconnect is used to vent liquid 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, or it can be attached to the commode by a pivoting mounting bracket for use in a sitting position.



Waste Management System Privacy Curtains

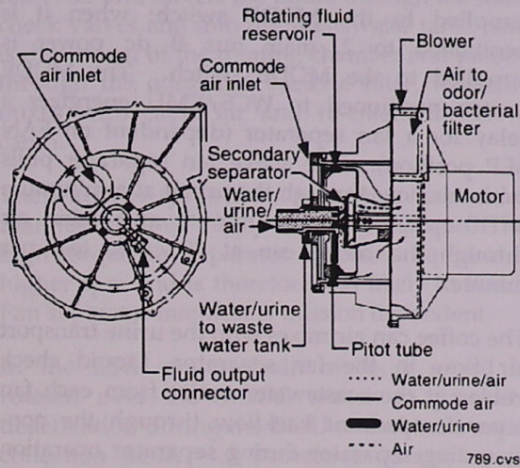


Waste Management System

All waste management system gases are ducted from the fan separator into the odor and 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.



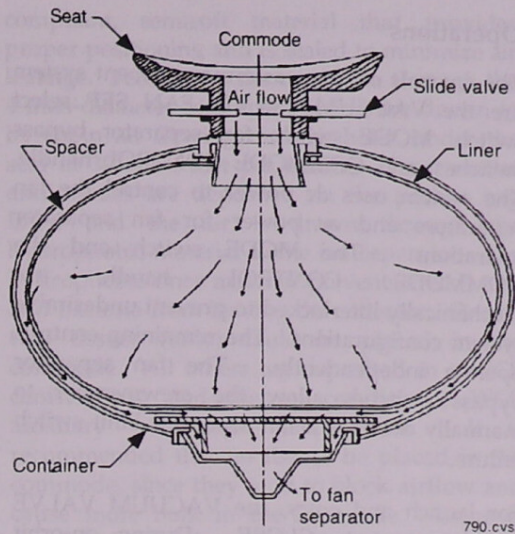
### Waste Management System Fan Separator

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.

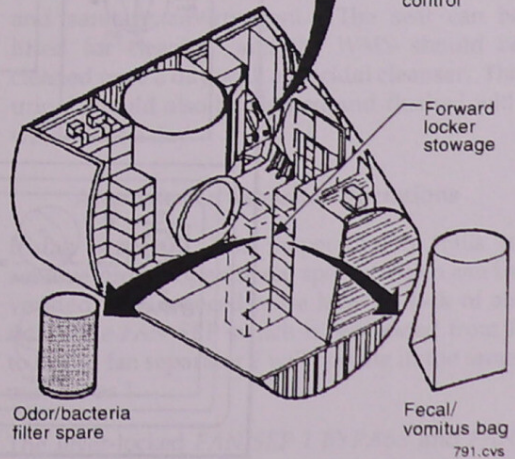
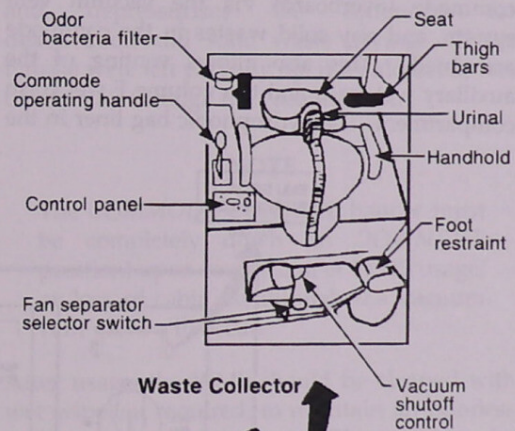
One body restraint is provided for use when crewmembers are seated on the commode. This restraint is a thigh bar that the crewmember lifts up out of the detent position, rotates over the thigh, and releases. The thigh bar exerts a preloaded force of approximately 10 pounds on each thigh.

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.

Stowage space in the WMS compartment is stocked with dry wipes, tissues, and wet washes. Rubber grommets in the compartment allow crewmembers to restrain their towels and washcloths.



### Waste Management System Container Liner



### Waste Management System - Middeck

## Operations

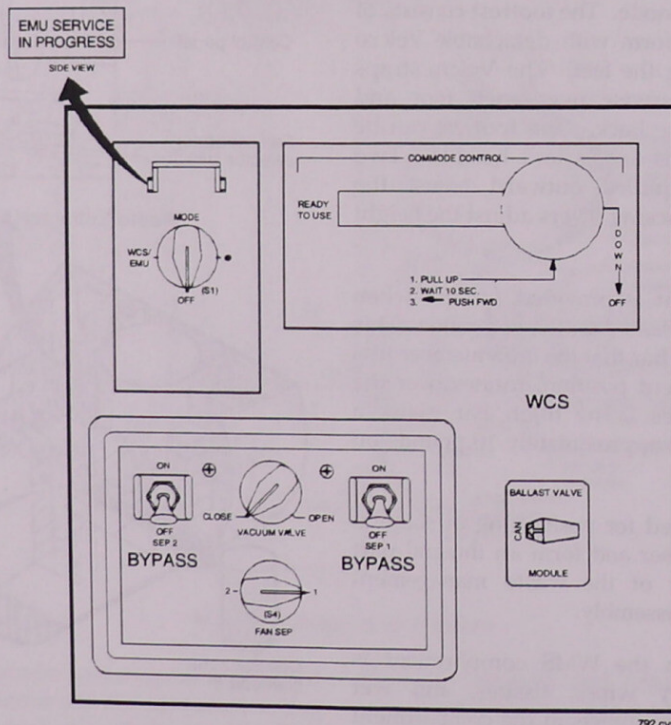
The controls on the waste management system are the VACUUM VALVE, FAN SEP select switch, MODE switch, fan separator bypass switches, and COMMODE CONTROL handle. The system uses dc power to control the fan separators and ac power for fan separator operations. The MODE switch and the COMMODE CONTROL handle 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 WMS 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 the MODE switch; when it is positioned to 2, main bus B dc power is supplied to the MODE switch. The MODE switch positioned to WCS/EMU energizes a relay for a fan separator (dependent on FAN SEP position). 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.

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



Waste Management System Controls

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 and bacteria filter, where it mixes with cabin air and re-enters the crew cabin.

There are two types of fan separators that can be manifested: low torque and high torque. The high torque fan separator processes liquid at a higher rpm and is therefore less likely to flood. Fan separator manifest is mission dependent.

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. A protective screen cap is installed on the urinal because it cannot be used during the EMU dump because of possible separator flooding. The WCS commode is still available for use during this mode. 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 *COMMODOE CONTROL* handle is pulled up, and the commode is pressurized with cabin air through the debris screen and flow restrictor in approximately 20 seconds. (Note that if the *MODE* switch is positioned to OFF, the handle cannot be pulled up because of a mechanical interlock.) The *COMMODOE CONTROL* handle is positioned to *PUSH FWD* after 20 seconds (it cannot be pushed forward until after 20 seconds because of the delta pressure across the sliding gate valve, and it cannot be pushed forward unless the *MODE* switch is positioned all the way to the *WCS/EMU* position). When the *COMMODOE CONTROL* handle is pushed forward, the sliding gate valve on the commode is opened.

The WMS is used like a normal toilet. The commode seat is made of a contoured,

compliant, semisoft 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 and tissues are deposited on 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. One or two tissues (only) could be placed in the commode. All others are 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 *DOWN/OFF* position of the *COMMODOE CONTROL* handle closes the sliding gate 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 *COMMODOE CONTROL* handle must be completely down (in *DOWN/OFF* position) upon completion of WMS usage, or loss of cabin air through the vacuum vent valve will occur.

After usage, the WMS should be cleaned with wet wipes, if required, to maintain an odorless and sanitary environment. The seat can be lifted for cleaning, and the WMS should be cleaned once a day with a biocidal cleanser. The urinal should also be cleaned and flushed with water once a day.

#### 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 fan separator 2 will operate in the same manner as 1.

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 should be positioned in the corresponding fan separator position to preset the fan separator inlet valve, and the *MODE* switch should be positioned to *WCS/EMU* to preset the urine collection valve.

### Vacuum Vent System

The vacuum vent system provides a pathway for removal of hydrogen (off-gassed by the fuel cells), for nominal depressurization of the internal airlock for EVAs, 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 WCS is off, the commode 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<sub>2</sub>O 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<sub>2</sub>O 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 *OFF* 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.

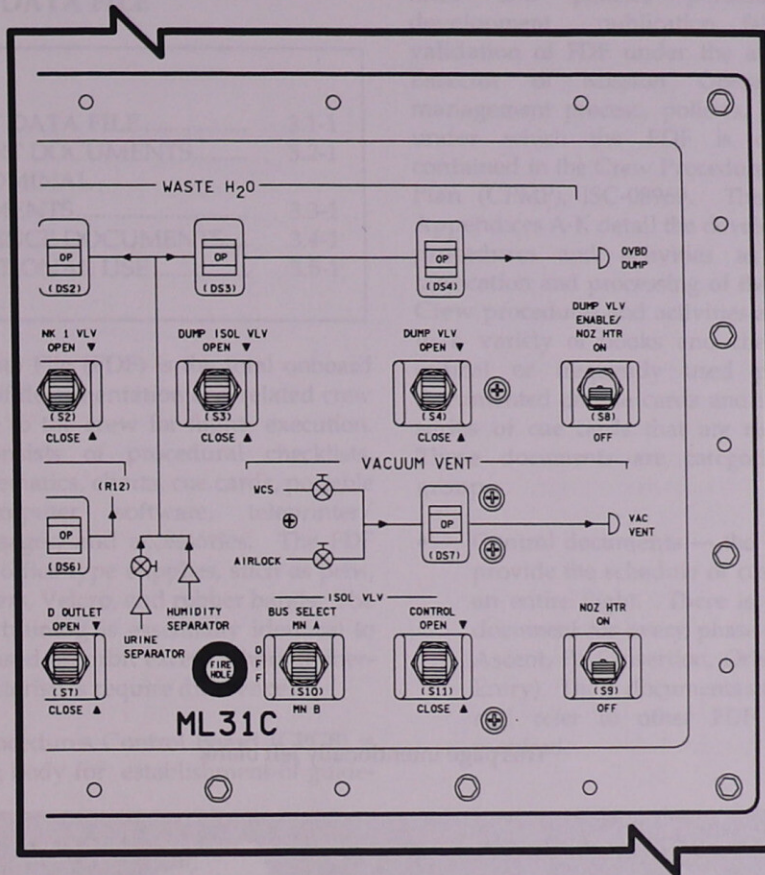
### Heaters

Thermostatically controlled heaters are installed on the vacuum vent line. Electrical power for the A and B heaters is supplied on the *H<sub>2</sub>O 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.)

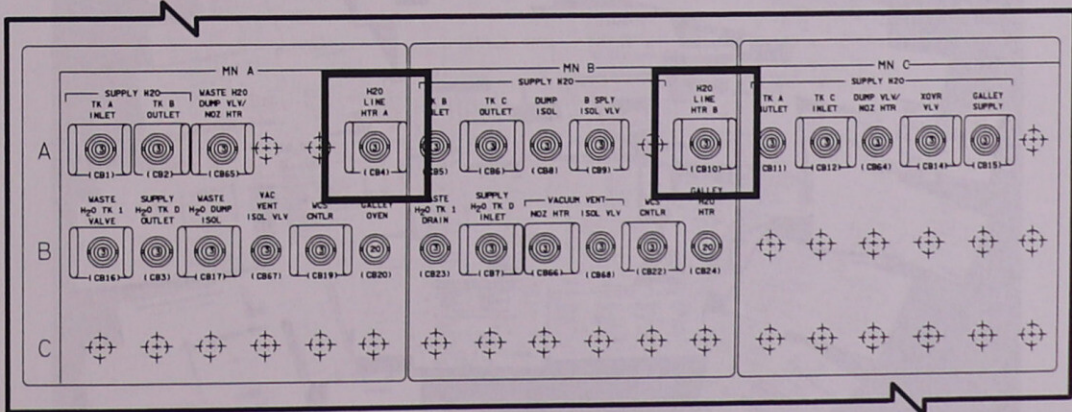
Heaters are also installed on the vacuum vent nozzle and are controlled by the *WASTE H<sub>2</sub>O VACUUM VENT NOZ HTR* switch on panel ML31C. Electrical power is supplied to the vacuum vent nozzle heaters when the switch is positioned to *ON*. The *OFF* position removes electrical power from the vacuum 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 the maximum absorption garment (MAG). The MAG is a modified version of an adult diaper.



VACUUM VENT Switches and Talkback on Panel ML31C



H<sub>2</sub>O LINE HTR A and B Circuit Breakers on Panel ML86B

### 3. FLIGHT DATA FILE

#### CONTENTS

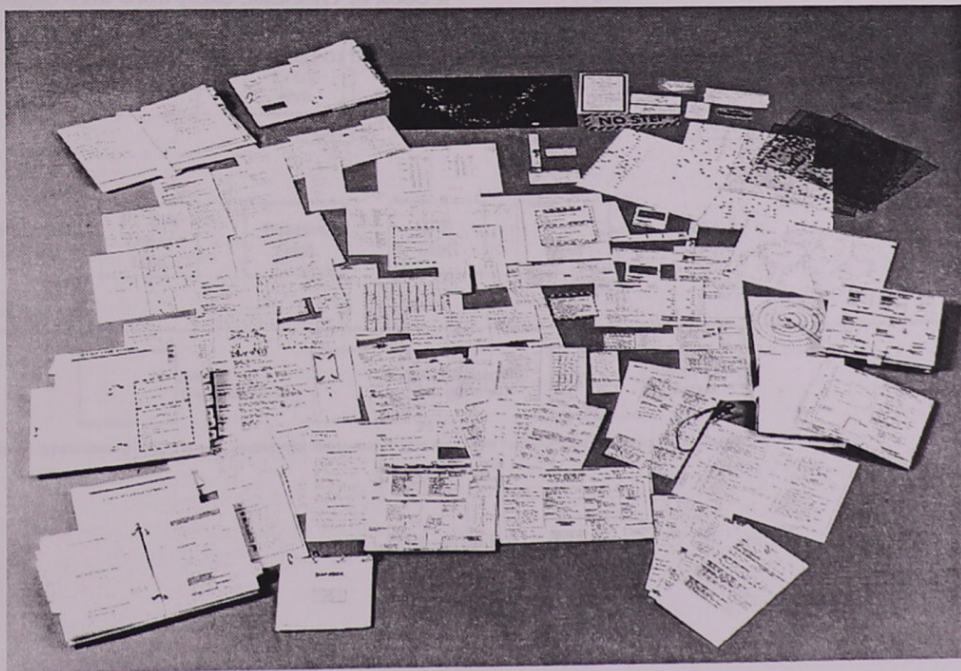
3.1	FLIGHT DATA FILE .....	3.1-1
3.2	SUPPORT DOCUMENTS.....	3.2-1
3.3	OFF-NOMINAL DOCUMENTS.....	3.3-1
3.4	REFERENCE DOCUMENTS....	3.4-1
3.5	OPERATIONAL USE.....	3.5-1

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 establishment of guide-

lines 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), JSC-08969. This plan and its Appendices A-K 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 CRT displays, caution and warning (C/W) parameters, landing site charts, and stowage locations for crew use items.

When a Spacelab module or pallet is flown, separate Control, Support, Off-Nominal, and Reference documents for Spacelab are flown.

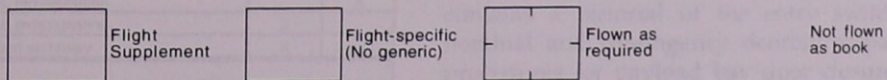
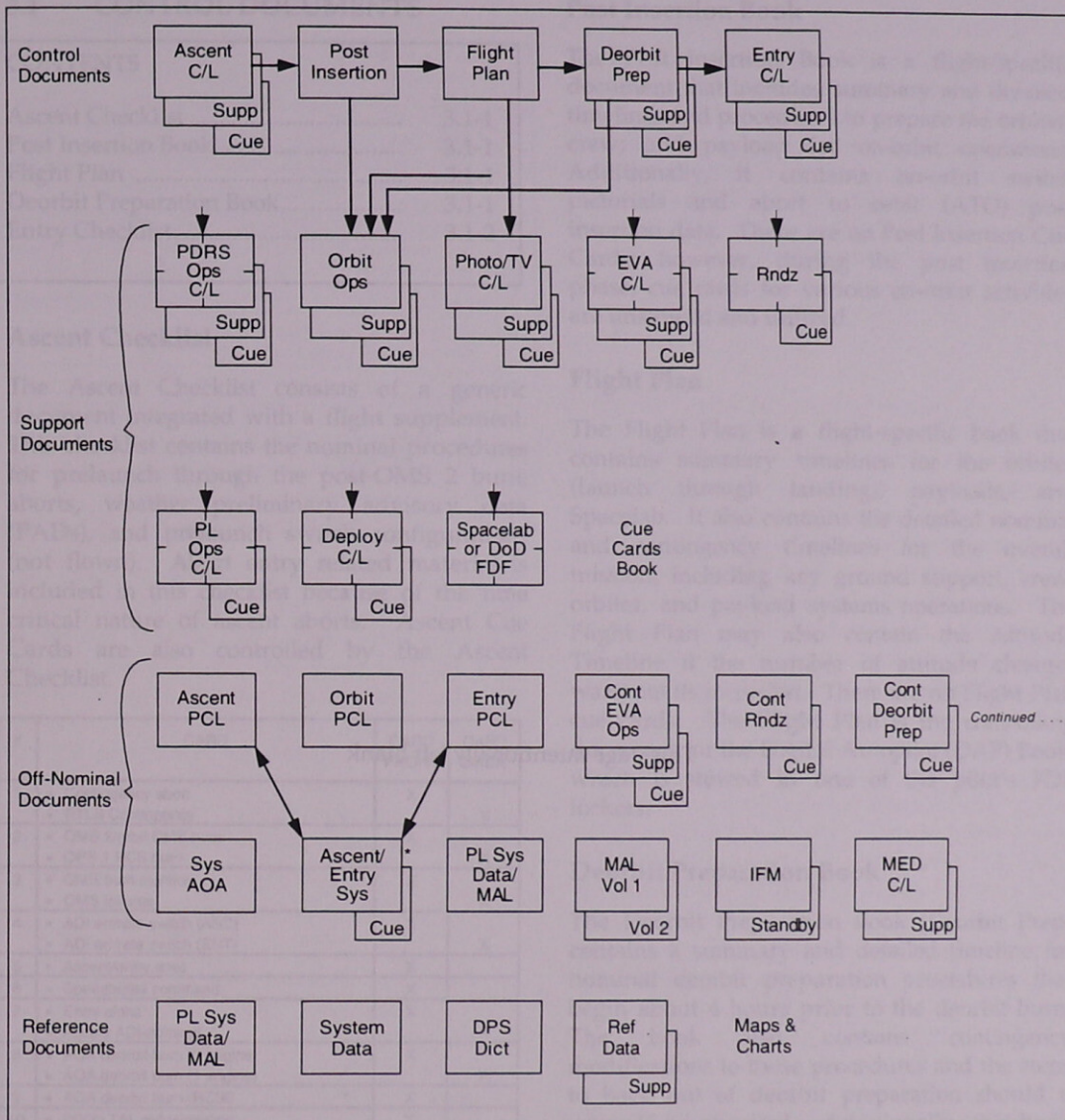
Each FDF book within the four main groups can also be categorized into one of three subgroups:

- **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 are not 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.



\* Not flown - for training and MCC use only. Appropriate pages are placed in the front of the MS Pocket Checklists for use in-flight.

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### STS FDF Structure

### 3.1 CONTROL DOCUMENTS

CONTENTS	
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 consists of a generic document integrated with a flight supplement. 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	<ul style="list-style-type: none"> <li>Contingency abort</li> <li>RTLS Contingency</li> </ul>	X	X
2	<ul style="list-style-type: none"> <li>OMS 2/orbit OMS burn</li> <li>OPS 1 RCS burn</li> </ul>	X	X
3	<ul style="list-style-type: none"> <li>OMS burn monitor</li> <li>OMS failures</li> </ul>	X	X
4	<ul style="list-style-type: none"> <li>ADI err/rate switch (ASC)</li> <li>ADI err/rate switch (ENT)</li> </ul>	X	X
5	Ascent/entry spec	X	
6	Speedbrake command	X	
7	<ul style="list-style-type: none"> <li>Entry alpha</li> <li>Ascent ADI-nominal</li> </ul>	X	X
8	<ul style="list-style-type: none"> <li>AOA deorbit burn (2 engine)</li> <li>AOA deorbit burn (1 engine)</li> </ul>	X	X
9	AOA deorbit burn (RCS0)	X	
10	<ul style="list-style-type: none"> <li>(XXX) TAL redesignation</li> <li>(XXX) TAL redesignation</li> </ul>	X	X
11	(XXX) TAL redesignation	X	
12	Ascent/abort summary	X	

\* Hinged Card

#### Ascent Cue Card

There are five Ascent and Entry Flip Books which 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), payloads, and Spacelab. 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)	X	X
5	• Unbalanced propellant deorbit burn	X	
6	• Entry maneuvers (EI-5 - V=10K) • Entry maneuvers (V=7K - STOP)/ Orbiter Xwind limits	X	X
7	• Entry no/go checklist • ADTA mgmt; no comm TACAN mgmt; nav delta pad; bailout mode 8; postlanding mode 5	X	X
8	• Mach/alpha	X	
9	• RCS critical entry • Speedbrake scheduler; trim/OSC	X	X
10	• STS-XX PTI monitor	X	

\* Hinged Card

### Entry Cue Cards

#	CARD	CARD FRONT	CARD BACK
1	• Deorbit burn flight rules	X	X
2	• Deorbit burn monitor	X	X
3	• Deorbit burn (RCS)	X	
4	• Deorbit burn (2 engine)	X	X
5	• Deorbit burn (1 engine)	X	X
6	• Unbalanced propellant deorbit burn	X	
7	• Entry maneuvers (EI-5 - V=10K)	X	X
8	• Entry maneuvers (V=7K - STOP)/ Orbiter Xwind limits	X	X
9	• Entry no/go checklist	X	X
10	• Mach/alpha	X	
11	• RCS critical entry	X	X
12	• Speedbrake scheduler; trim/OSC	X	X
13	• STS-XX PTI monitor	X	

## 3.2 SUPPORT DOCUMENTS

### CONTENTS

Orbit Operations Checklist.....	3.2-1
Photo/TV Checklist .....	3.2-1
Payload Deployment and Retrieval System Operations Checklist....	3.2-1
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. Three cue cards are controlled by the Orbit Ops Checklist, which provide procedures for saving data in the mass 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 (excluding CCTV cameras). Four Photo/TV Cue Cards detail nominal procedures for the use of the CCTV system, video tape recorder (VTR), and airborne digitizing unit (ADU), and provide data for Earth observation 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 three 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 of 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. Manned maneuvering unit (MMU) procedures reside in the EVA Flight Supplement for missions manifesting the MMU. Three cue cards are controlled through the EVA Checklist. They contain procedures for orbiter and Spacelab 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. The Rendezvous Checklist also controls seven cue cards: RCS burn, RNDZ propellant PAD, Proximity Operations Procedures, Ku Radar Rendezvous Operations, Nominal Radar Angles & Camera Angles Ranging Chart, Spacehab 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, 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.

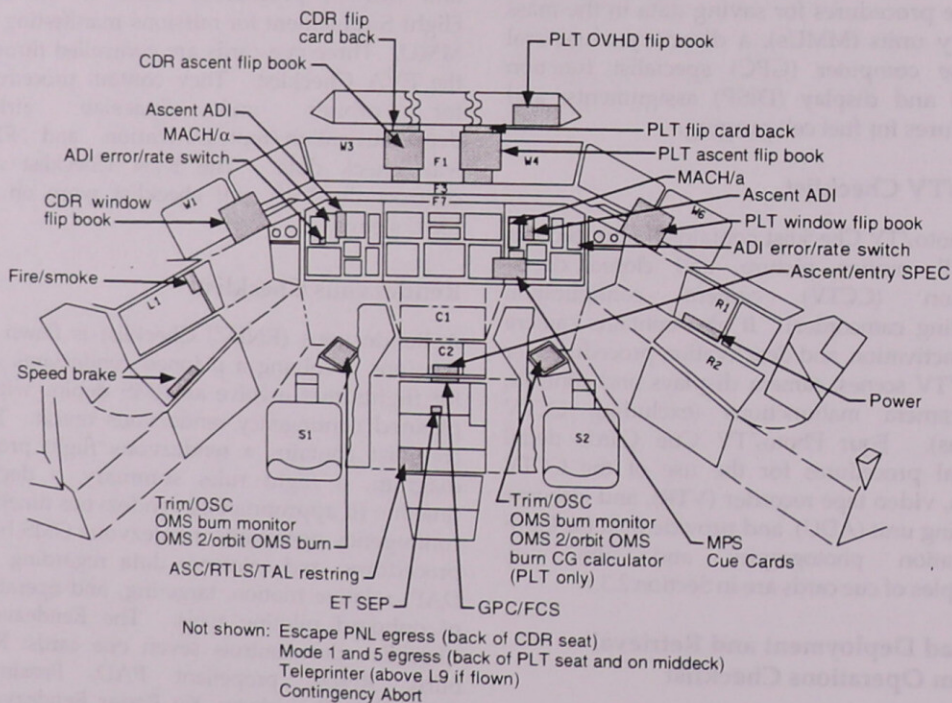
**Deploy Checklist**

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 for Department of Defense (DOD) missions. The additional DOD books are only required for classified activity. The termination of dedicated classified DOD missions has eliminated the need for these publications. 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.



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 EVA Operations 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. Orbit PCL procedures are duplicated in the MAL book with further troubleshooting steps added. 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.

#### 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 CRT 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 and Flight Supplement contain emergency medical procedures, medical technique illustrations, equipment/medicine stowage, and medical detailed supplemental objectives (DSO) data. There are three cue cards controlled by the MED Checklist. They provide data for electrocardiogram electrode placement and logging of radiation dosimeter readings.

### Contingency EVA Operations Checklist

Included in the Off-Nominal documents are books containing information and procedures for contingency EVA, rendezvous, and deorbit preparation. The Contingency EVA Operations (CONT EVA OPS) Generic Checklist contains the payload bay door contingency EVA summary and detailed timelines and the

intravehicular activity (IVA) procedures. The book also contains deorbit prep data (so that deorbit can be accomplished quickly post EVA) and EVA reference data. The Flight Supplement to this document is flown for flight-specific payloads and incorporates timelines and procedures.

### 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 CRT 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.

### 3.5 OPERATIONAL USE

#### CONTENTS

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. Appendix G 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

The development of the FDF for a mission normally starts about 1 year prior to the launch date. The preliminary work for payloads and Spacelab 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
Δ	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—CRT callout
□	box—read "block n" which refers to corresponding block of procedures

#### FDF Symbols

##### Basic

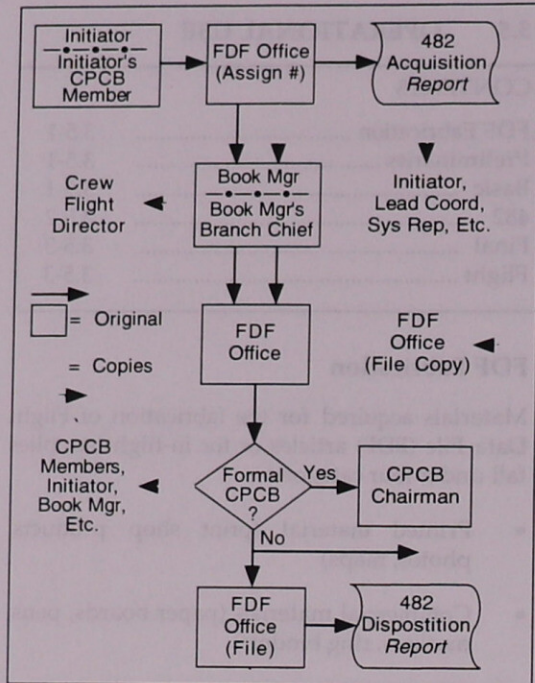
Approximately 4 months prior to the launch date, the Basic editions of all flight-specific/supplement FDF are published. The documents are now under the configuration control of the CPCB and all changes must be requested through formal channels that include approval by cognizant personnel. Generic documents 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**

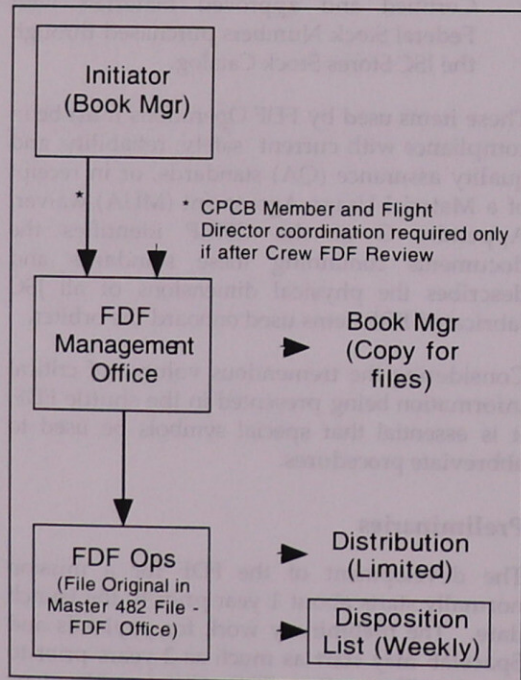
Subsequent to the FOR, changes to FDF must be made via a Crew Procedures Change Request, JSC Form 482-B. The 482 process is detailed in CPMP Appendix D. As before, anyone may submit a 482 requesting a change to a particular FDF document. The 482 will be reviewed by cognizant personnel and approved or disapproved. Disapproval by anyone in the review process causes the 482 to be dispositioned by the CPCB. There is an appellate process for 482's 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.

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.



482 Flow

799.cvs



EZ 482 Flow

800.cvs

## 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, D. C. The backup copies are reused if feasible, or destroyed. The crew may request portions of the backup material as mementos.

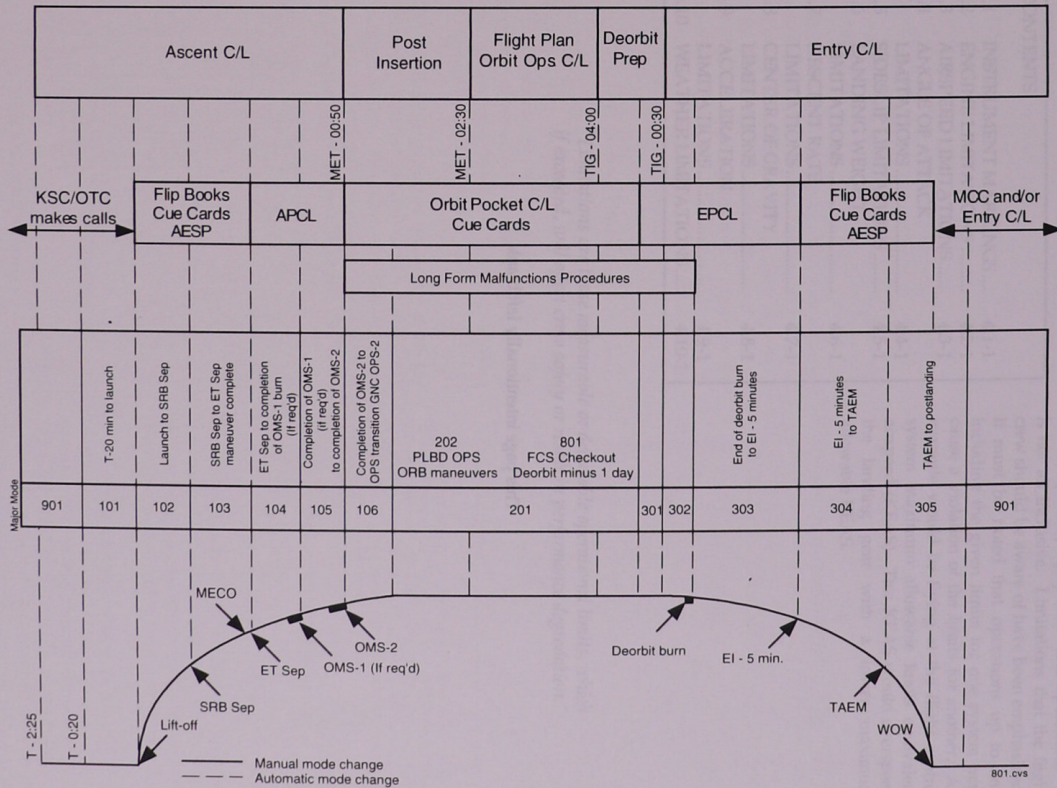
FLIGHT PHASE	EVENT	SOFTWARE			FLIGHT DATA FILE	
		MEMORY CONFIG	MAJOR MODE **		FLIGHT PROCEDURE	TROUBLESHOOTING PROCEDURES*
			GNC	SYSTEMS MGMT		
A S C E N T	Precount	9	901	--	Ascent Checklist	
	Terminal Count	1	101	--		
	First Stage	1	102	--	Ascent Flip Book Cue Cards	CDR Flip Book Pilot Flip Book Pilot 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 2 <sup>nd</sup> 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	--			
O R B I T	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		
E N T R Y	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	
	Preentry Monitor	3	303	--	Cue Cards	
	Early Entry	3	304	--		
	TAEM/Landing	3	305	--		
	Post-Landing	9	901	--	Entry Checklist	

\* 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

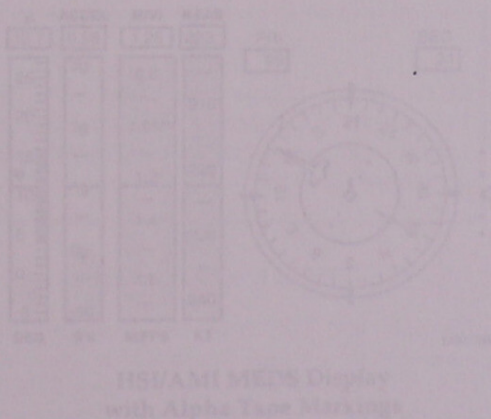
4. OPERATING LIMITATIONS

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4.1	INSTRUMENT MARKINGS.....	4.1-1
4.2	ENGINE LIMITATIONS .....	4.2-1
4.3	AIRSPPEED LIMITATIONS.....	4.3-1
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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."*



HSU/AMI MEPS Display with Alpha Tape Markings

OAS MEPS MEPS Display

OAS PRESS IN Meter

The left and right Pitot probe chamber pressure is measured by a sensor that is routed through a dedicated right conditioner (CSC) before being displayed on the Pz Meter and also to the OAS.

OAS PRESS N2/O2 Tank Meter

Separate N2 and O2 pressure sensors (left and right) are wired through a TPC to the meter and OTCs. Redundant pressure sensors provide the pressure readings for N2 and O2 on the OAS OAS/STANB Display.

## 4.1 INSTRUMENT MARKINGS

### CONTENTS

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

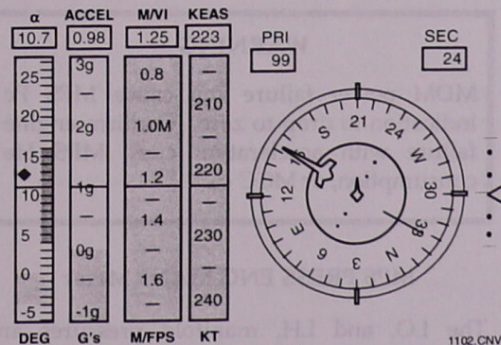
### Description

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.

### Alpha/Mach Indicator

The MEDS alpha tape displays a maximum lift-to-drag (L/D) black diamond. The maximum L/D is displayed when Mach  $\leq 3.0$ . The diamond position is a linear interpolation of table values from Mach 3.0 to 0.95. For Mach  $\leq 0.95$ , the diamond is fixed at 10.5°.

The MEDS alpha tape also displays a green bar indicating maximum and minimum alpha limits when Mach  $\leq 2.5$ . The maximum and minimum positions are a linear interpolation of a table of values based on the current flight rule limits.



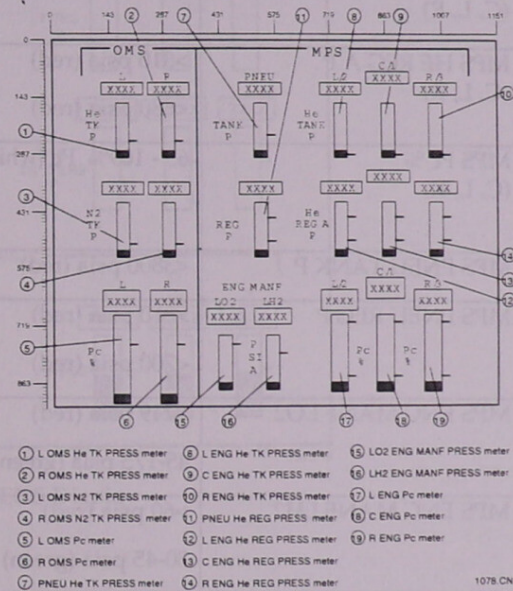
HSI/AMI MEDS Display with Alpha Tape Markings

### 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



### 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 Pc Meter 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 meter 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) <80% Pc (red)	Normal operating range Low limit (Class 2 C/W) 72% Pc allowed during ullage blowdown
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) <680 psia (red)	High limit (Class 2 C/W) 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) <700 psia (red)	High limit (Class 3 C/W) Low limit (Class 3 C/W)
MPS ENG MANF LO2	>249 psia (red) 45-175 psia (green)	High limit (Class 2 C/W) Normal operating range for LO2
MPS ENG MANF LH2	>60 psia (red) 30-45 psia (green)	High limit (Class 2 C/W) 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 multiplexer/demultiplexer (MDM) 2, 1, or 3 respectively, to the Pc meter. Power failure of an MDM or a data path failure will cause the affected Pc meter to drop to zero. GPC failure and some flight forward 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.

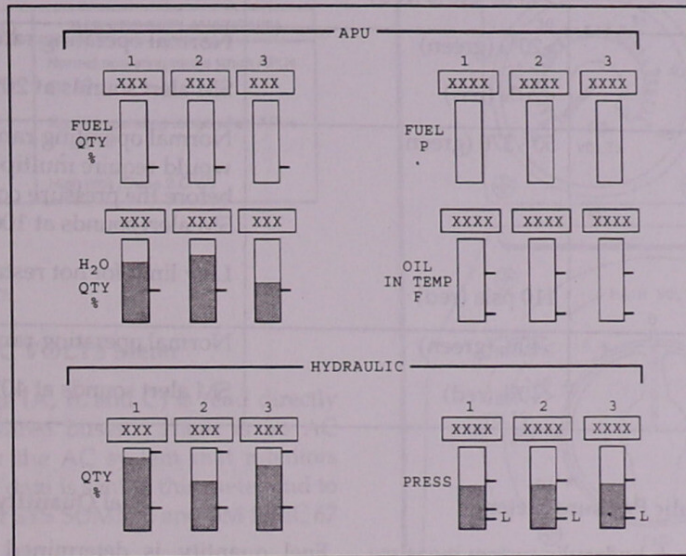
**MPS PRESS ENG MANF Meter**

The LO<sub>2</sub> and LH<sub>2</sub> manifold pressures are measured by a single transducer in each LO<sub>2</sub> and LH<sub>2</sub> line between the ET and SSMEs. The data are sent directly to the meter and through an MDM to CRT display BFS GNC SYS SUMM 1.

### 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 meter and through an MDM to the GPCs. The data are available on this meter (TANK selected) by reading the upper (non-boxed) numbers x 100 and on CRT display 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 meter and through an MDM to the GPCs. The data are available on this meter (REG selected) by reading the boxed numbers x 100 and on CRT display BFS GNC SYS SUMM 1.



HYD/APU MEDS Display

Meter	Meter Marking(s)	Marking Explanation(s)
Hydraulic Pressure	2900 - 3200 psia (green)	Normal operating range
	2400 psia (red)	Low limit (Class 2 C/W)
	500 - 1000 psia (green)	Normal "low pressure" operating range
Hydraulic Quantity	40 - 80% (green)	Normal operating range
	>95 or <40% (red)	SM alert sounds
Fuel Quantity	>20% (green)	Normal operating range
	<20% (red)	SM alert sounds at 20%
Fuel Pressure	50 - 370 (green)	Normal operating range; however, it would require multiple failures before the pressure could reach 50. SM alert sounds at 100 and 350 psia
	110 psia (red)	Low limit for hot restart
Water Quantity	>40% (green)	Normal operating range
	<40% (red)	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 CRT displays SM SYS SUMM 2, SPEC 87 APU/HYD, and SPEC 87 HYD THERMAL. 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 CRT display OVERRIDE (SPEC 51).

#### Hydraulic Quantity Meter

A sensor located in each of the three hydraulic reservoirs provides the information displayed on the HYDRAULIC QUANTITY meter (HYD/APU MEDS display) and on CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD. 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 CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD.

#### Fuel Pressure

There are two sensors: one on the N<sub>2</sub> side and one on the fuel side. Both go to the CRT display, SPEC 86 APU/HYD, but only the N<sub>2</sub> side sensor goes to the meter (HYD/APU MEDS display) via a DSC.

#### WSB H<sub>2</sub>O Quantity

The H<sub>2</sub>O quantity is determined by a PVT calculation based on H<sub>2</sub>O tank pressure and temperature transducer readings as well as GN<sub>2</sub> tank pressure and temperature transducer readings. The calculated quantity is output to the HYD/APU display and to CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD.

### Oil Temperature

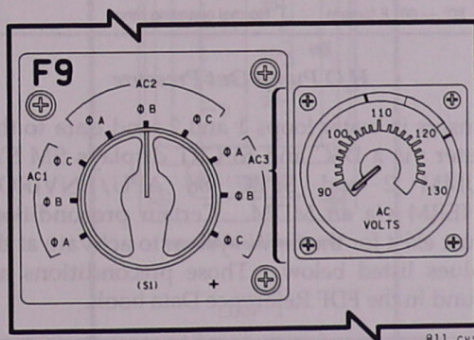
Oil temperature in the three APUs is measured by sensors located upstream and downstream of the water spray boilers. Data from the downstream sensor (OIL IN T) is routed to the OIL IN TEMP meter (HYD/APU MEDS display) via a DSC. CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD show data from both sensors (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 CRT displays SM SYS SUMM 1 and SM SPEC 67 ELECTRIC.



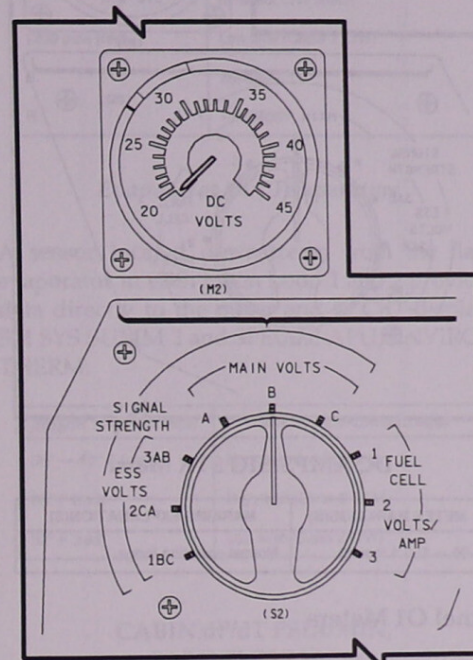
811.cvs

#### 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 are routed to the meter and to CRT displays SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS.



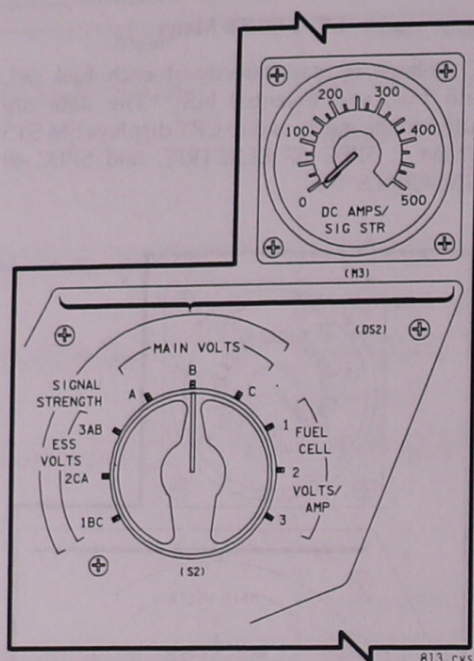
812.cvs

#### 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 CRT displays SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS.



DC AMPS/SIG STR Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
90 — 350 A (green)	Normal operating range

## Panel O1 Meters

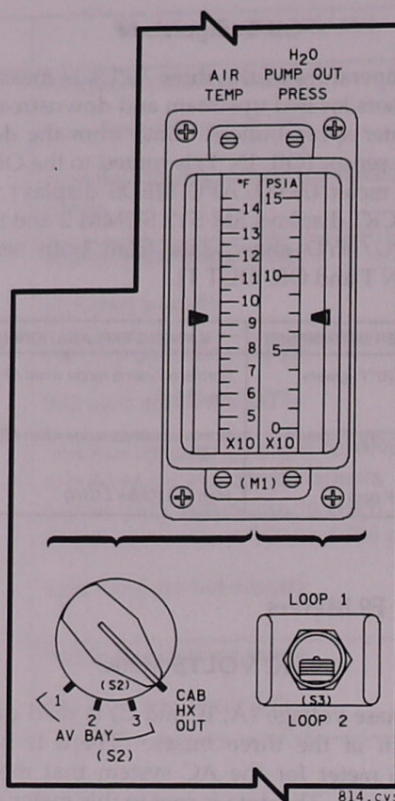
AIR TEMP, H<sub>2</sub>O PUMP OUT PRESS Meter*Cabin Heat Exchanger Air Temperature*

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 CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.

*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 CRT displays SM SYS SUMM2 and SPEC 66 ENVIRONMENT.

METER MARKINGS(S)	MARKING EXPLANATION(S)
75° — 110° F (green)	Normal operating range
130° F (red)	High limit for avionics bay air temp (Class 2 C/W)

AIR TEMP, H<sub>2</sub>O PUMP OUT PRESS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
50° — 60° F (green)	Normal operating range

*H<sub>2</sub>O Pump Out Pressure*

Sensors in water loops 1 and 2 send data to this meter via a DSC and to CRT displays SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM 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)
<u>Loop 1</u>	
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)
<u>Loop 2</u>	
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)



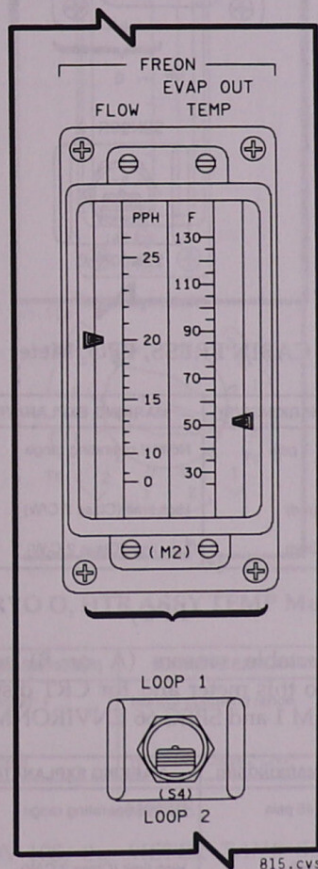
**NOTE**

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 H<sub>2</sub>O/Freon Interchanger in Freon Loops 1 and 2 provides a readout of Freon interchanger flow directly to the meter and to CRT displays SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM.



**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 CRT displays SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM.

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,  
O<sub>2</sub>/N<sub>2</sub> FLOW Meter**

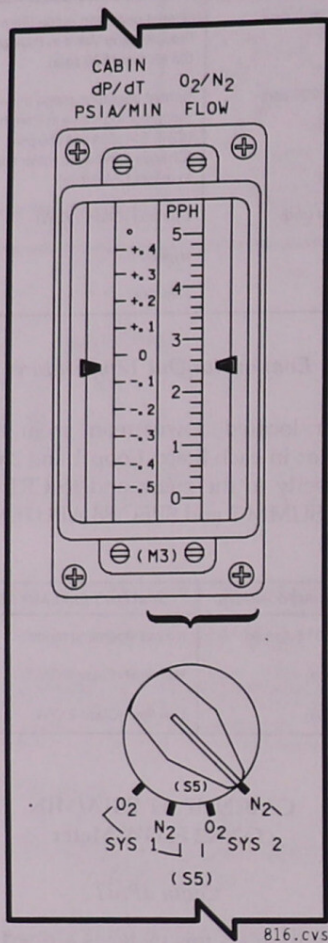
*Cabin dP/dT*

The indication on this meter is a direct readout of the dP/dT sensor. The data are also transmitted to CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT. The CRT displays also contain an additional backup dP/dT supplied by computations.

*O<sub>2</sub>/N<sub>2</sub> Flow*

An O<sub>2</sub> and N<sub>2</sub> flow sensor in each of the two pressure control systems (four total) send data directly to the O<sub>2</sub>/N<sub>2</sub> FLOW Meter. The readings are also available on CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.

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)



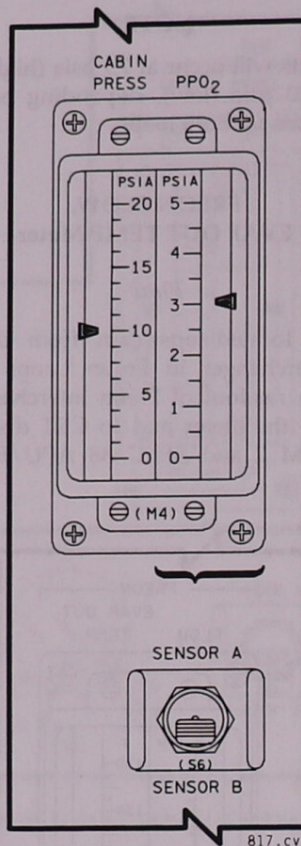
**CABIN dP/dT PSIA/MIN,  
O2/N2 FLOW Meter**

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 Meter**

*Cabin Pressure*

A cabin pressure sensor provides a direct indication for this meter and for CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT. (The airlock pressure on the CRT ENVIRONMENT display can be used as a backup.)



**CABIN PRESS, PPO<sub>2</sub> 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<sub>2</sub>*

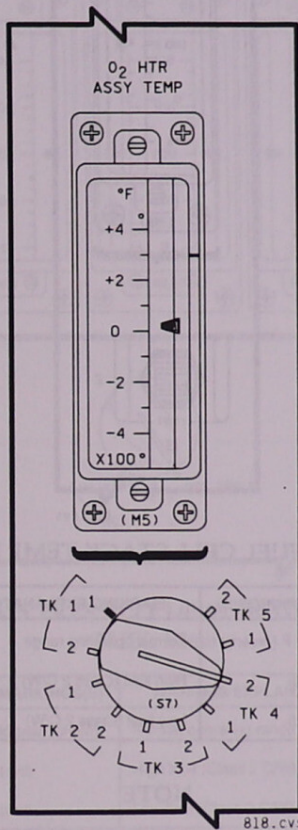
Dual selectable sensors (A or B) send data directly to this meter and for CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.

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 O<sub>2</sub> Meters

CRYO O<sub>2</sub> HTR ASSY TEMP Meter

A temperature sensor in each of the eight O<sub>2</sub> tank heater assemblies monitors the temperature of warmed O<sub>2</sub> and sends the data via a DSC to this meter and CRT displays SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM.



CRYO O<sub>2</sub> HTR ASSY TEMP Meter

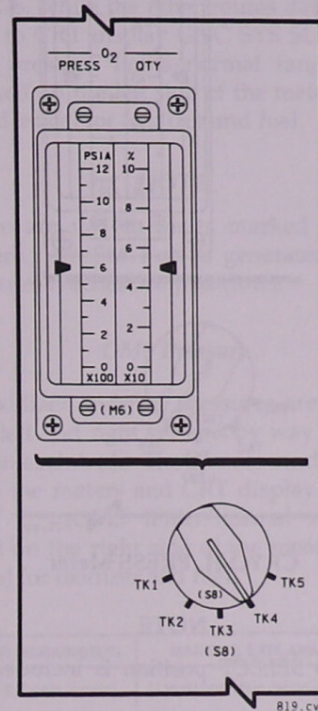
METER MARKINGS(S)	MARKING EXPLANATION(S)
-300° — +200° F (green)	Normal operating range
+349° F (red)	High limit (Class 2 C/W)

NOTE

For OV-105, the *METER TANK SELECT* switch will show HTRS 1 and 2 for tank 5 as well.

CRYO O<sub>2</sub> PRESS Meter

One sensor for each of the O<sub>2</sub> tanks provides pressure data via a DSC to the meter and SM program while another sensor (heater controller) sends data to CRT displays SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM.



CRYO O<sub>2</sub> PRESS Meter

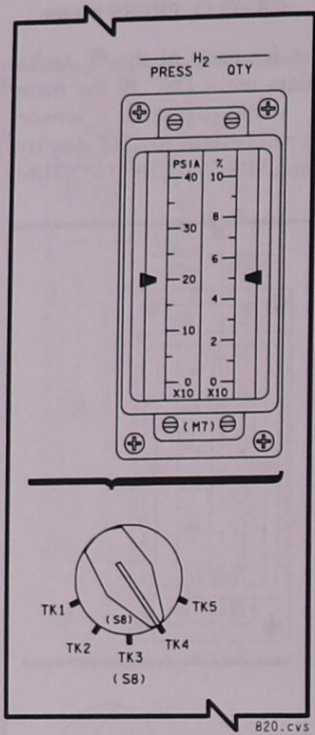
METER MARKINGS(S)	MARKING EXPLANATION(S)
802 — 930 psia (green)	Normal operating range
985 psia (red)	High limit (Class 2 C/W)
540 psia (red)	Low limit (Class 2 C/W)

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<sub>2</sub> PRESS Meter

One sensor for each of the H<sub>2</sub> tanks provides pressure data to the meter via a DSC and SM software, while another sensor (heater controller) sends data to CRT displays SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM.



CRYO H<sub>2</sub> PRESS Meter

**NOTE**

Tank 5 *SELECT* position is included on OV-105.

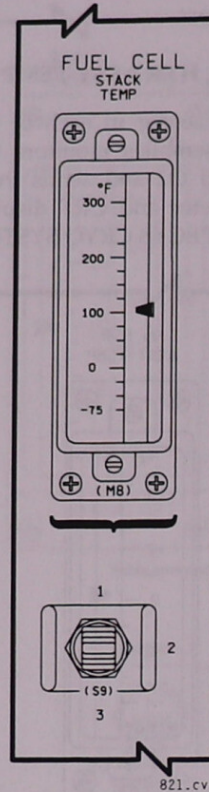
METER MARKINGS(S)	MARKING EXPLANATION(S)
200 — 250 psia (green)	Normal operating range
293.8 psia (red)	High limit (Class 2 C/W)
153 psia (red)	Low limit (Class 2 C/W)

**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 CRT displays SM SYS SUMM 1 and SPEC 69 FUEL CELLS.



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)

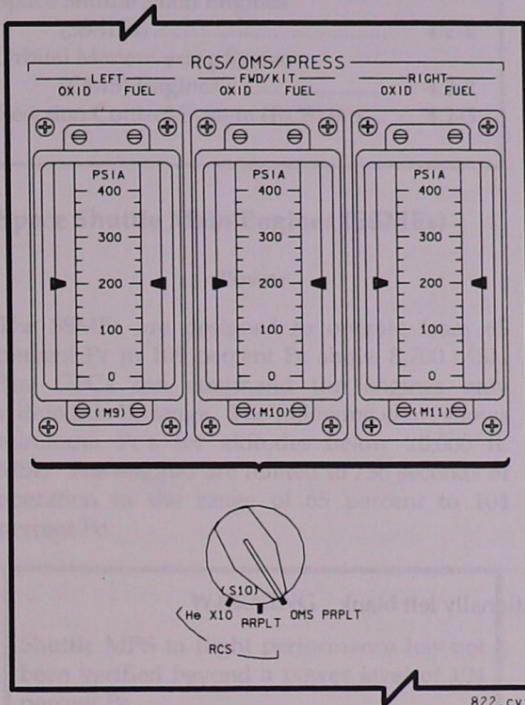
**NOTE**

SM alerts occur at:

<u>High</u>	<u>Low</u>	<u>If FC Output is:</u>
(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



822.cvs

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 CRT display SPEC 23 RCS, while the other routes data via a DSC to CRT display GNC SYS SUMM 2. 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 CRT display GNC SYS SUMM 2. 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)

## 4.2 ENGINE LIMITATIONS

### CONTENTS

Space Shuttle Main Engines (SSMEs) .....	4.2-1
Orbital Maneuvering System (OMS) Engines .....	4.2-2
Reaction Control System (RCS) Jets ...	4.2-3

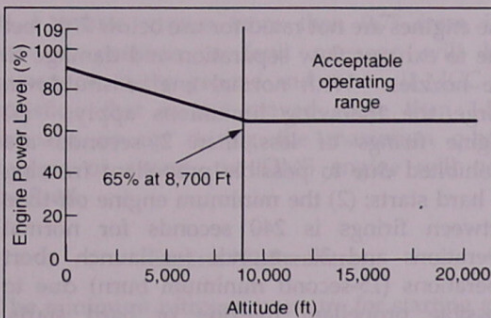
### Space Shuttle Main Engines (SSMEs)

#### 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 can be 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 out. An SM alert is annunciated when this value drops below 125°.

### Propellant Pressure

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. MCC personnel monitor additional data not available on crew CRTs such as HPFT coolant liner pressure-high, HPOT intermediate seal purge pressure-low, HPOT secondary seal pressure-high, 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. The crew has insight into the GH2 OUT P (outlet pressure), which can be 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 out. 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 and 3). 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 (root mean square) for longer than 500 msec. Should this happen, channel switchover (A to B) or engine shutdown will occur. An electric lockup can 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 Hydraulics

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.



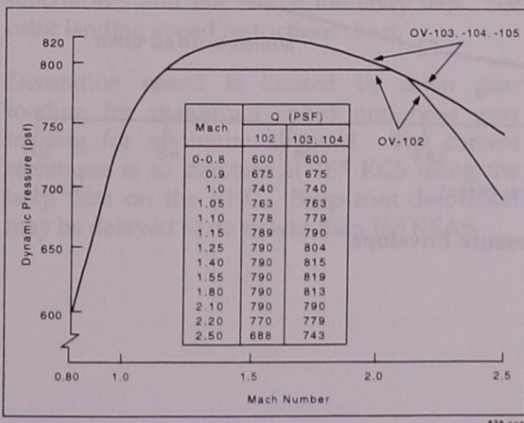
### 4.3 AIRSPEED LIMITATIONS

CONTENTS	
Ascent.....	4.3-1
Entry .....	4.3-1
Landing.....	4.3-2

#### Ascent

The maximum airspeed (based on the q-bar limit of 819 psf) for OV-103, -104, and -105 is 492 knots equivalent airspeed (KEAS) where KEAS =  $\sqrt{q - \text{bar}} \times 17.18$ . The OV-102 limit is 483 KEAS. 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. There is, however, a minimum orbit (dictated by flight rule) that designates 80 n. mi. as the minimum acceptable perigee altitude. This altitude (given a minimum apogee of 155 n. mi.) ensures at least 48 hours before orbital decay to 400,000 ft. (A 105 n. mi. x 85 n. mi. orbit can be tolerated for a few hours before the orbiter must deorbit or raise the perigee.) The minimum circular orbit allowed by flight rule is 105 n. mi.



Source: NSTS 08934, SODB, Vol. VII

Mach Number  $V_1$  Dynamic Pressure

#### Entry

The maximum certified speed 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) 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.

**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**

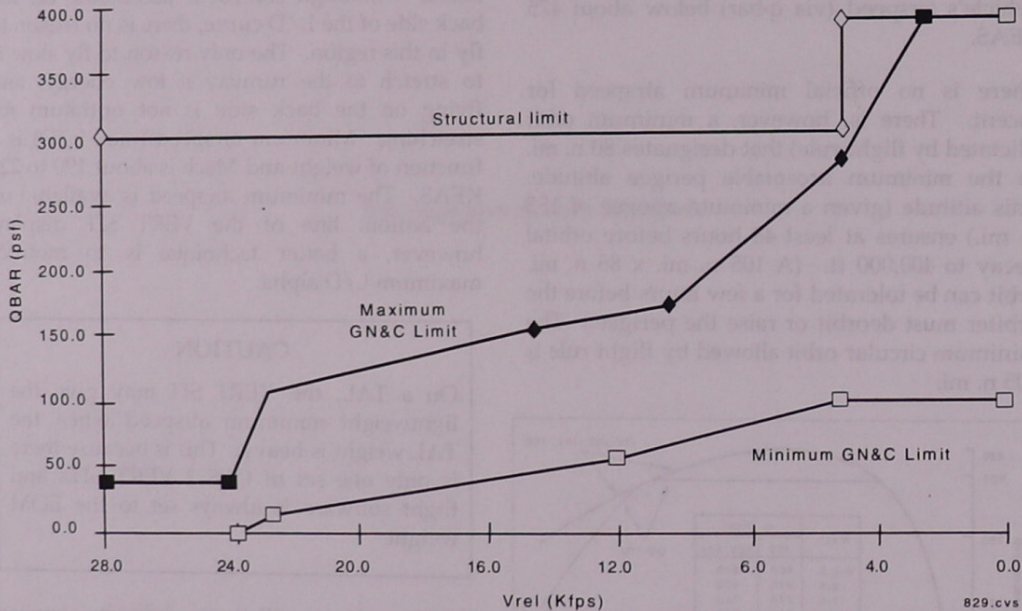
TAEM guidance must have air data to perform airspeed limiting. If air data is not incorporated to TAEM (G&C on SPEC 50), the crew must fly pitch attitude limits (theta limits) to avoid violating airspeed limits. See section 7.4 for more details.

**Landing**

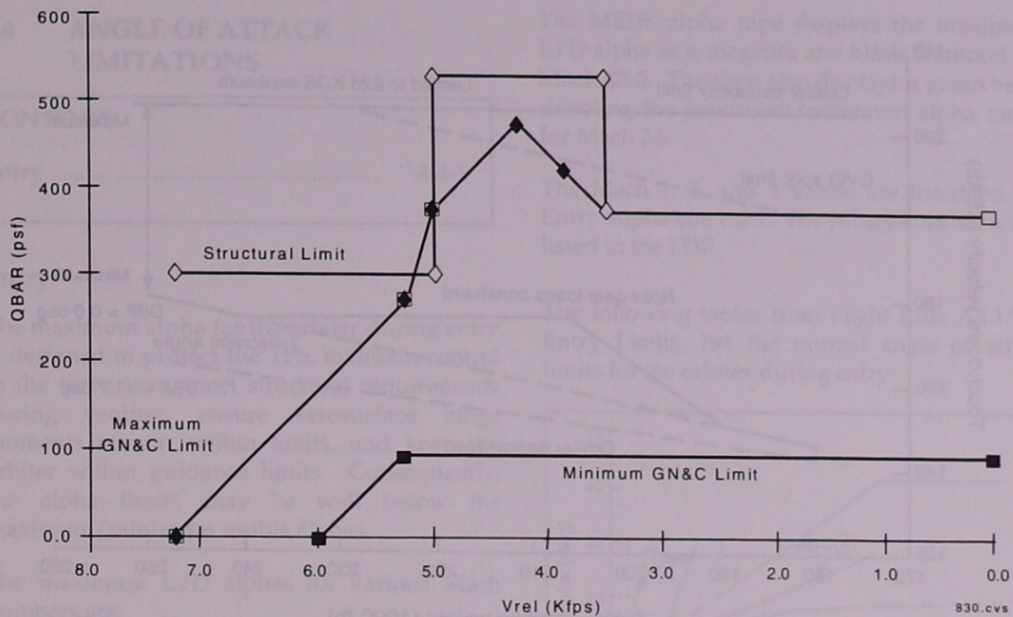
Maximum airspeed for lowering the gear is 312 KEAS, based on landing gear structural limits.

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. The 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.

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.



**Entry Dynamic Pressure Envelope**



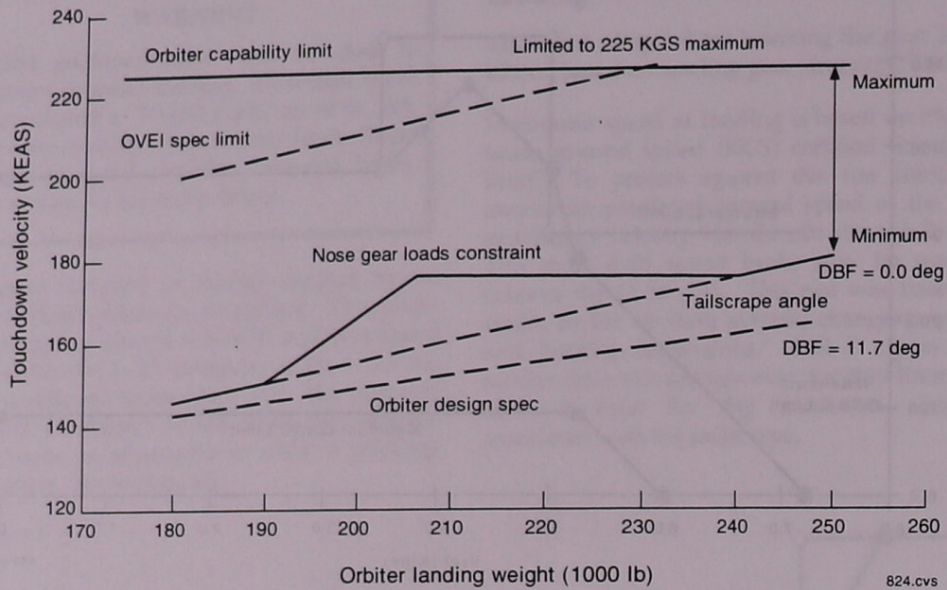
RTLS Dynamic Pressure Envelope

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 deployment is 230 KEAS. Above this velocity, the drag chute shear pin will fail. This protects the orbiter from an inadvertent deploy on final. Minimum deployment 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.

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### 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.

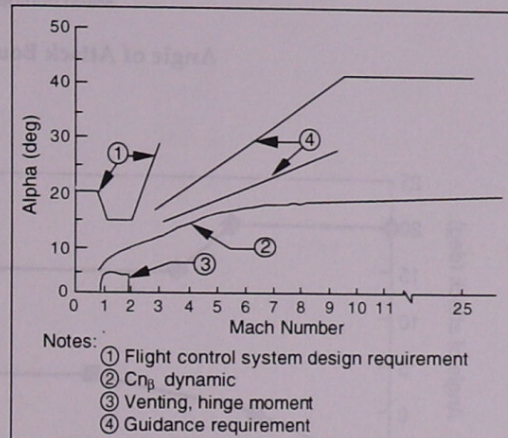
The maximum L/D alphas for various Mach numbers are:

Mach	Max L/D $\alpha$
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  $\leq 3.0$ . The tape also displays a green band denoting the maximum/minimum alpha range for Mach 2.5.

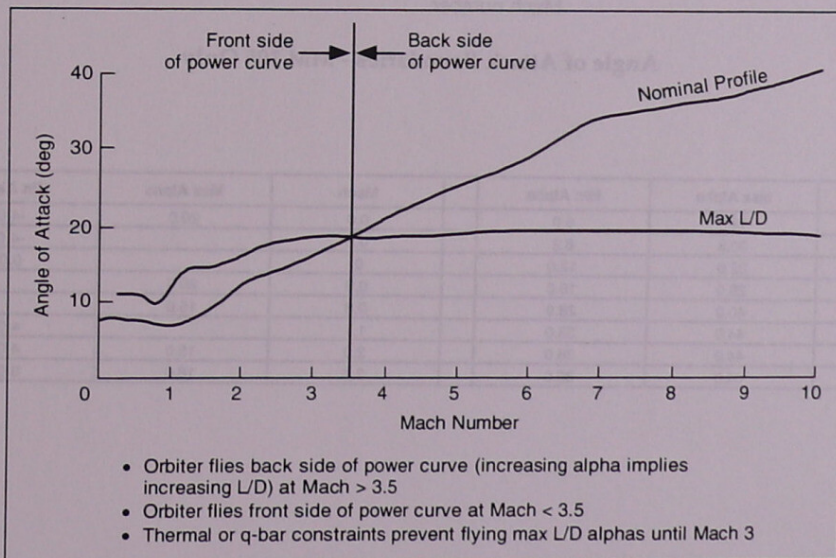
The Mach 1, 2, and 3 values are listed on the Entry Alpha cue card. The subsonic value is not listed in the FDF.

The following tables from Flight Rule A4.1.5-7, Entry Limits, list the normal angle of attack limits for the orbiter during entry.



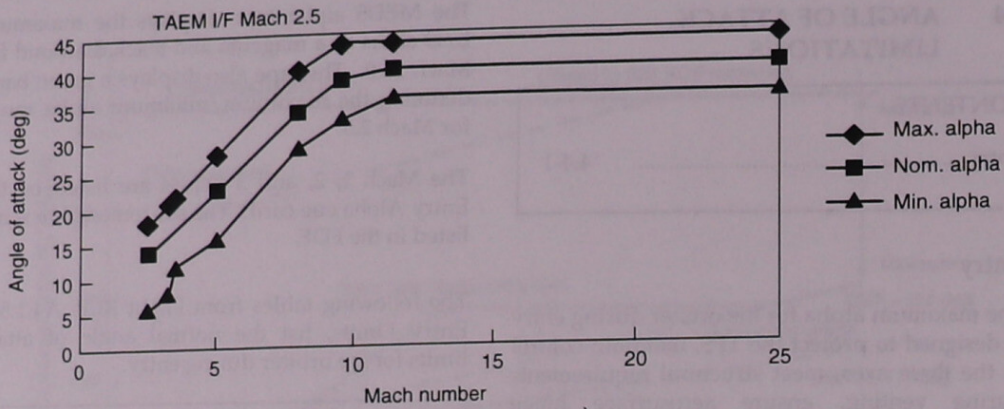
825.cvs

Orbiter Design Angle of Attack Limits

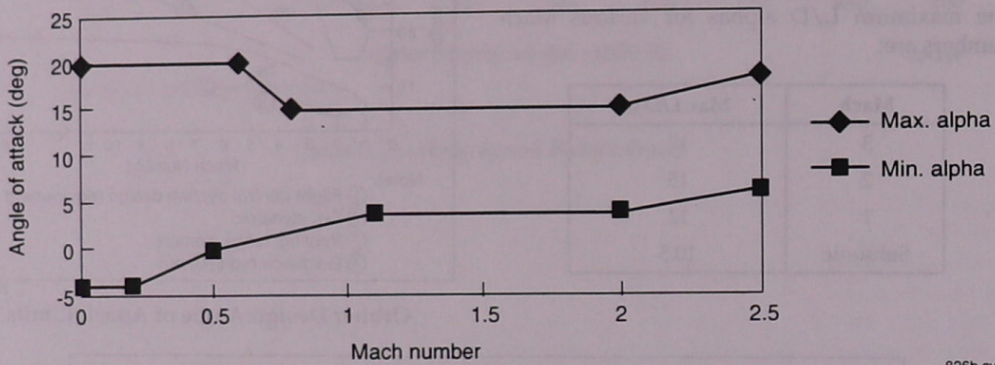


826.cvs

Orbiter Nominal Angle of Attack Profile



Angle of Attack Boundaries - MM 304 Only



826b.cvs

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,  $\beta$ , 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  $\beta$  allowable ranges from  $\pm 3^\circ$  to  $\pm 6^\circ$ .

During entry, the maximum sideslip angle is  $\pm 5^\circ$ . Also during entry ( $2 < \text{Mach} < 12$ ), the crew, by using the Roll Trim switch, will manually trim to reduce RCS jet firings if steady state sideslip exceeds  $2^\circ$ , one or more yaw jets fire continuously, or if scaled  $A_y$  (sensed lateral acceleration) exceeds the two-jet capability.

The following table lists orbiter maximum landing weights for ascent aborts and ELOM.

Landing weight limits are reduced for higher inclination flights because of orbiter thermal

Flight Phase	Inclination			
	$28.5^\circ$	$39.0^\circ$	$51.6^\circ$	$57.0^\circ$
RTLS	240k lb	239k lb	245k lb	242k lb
TAL	241k lb	239k lb	244k lb	241k lb
AOA/ATO	240k lb	248k lb	242k lb	236k lb
ECM	238k lb	232k lb	237k lb	233k lb

Source: 1875-07-00, Vol. 1, Rev. 1

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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.

Flight Phase	Inclination			
	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



## 4.7 DESCENT RATE LIMITATIONS

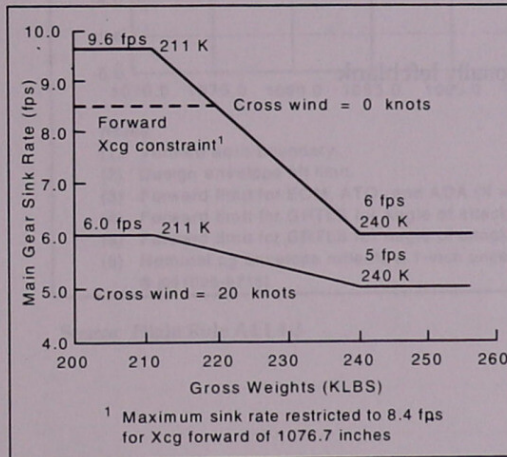
### CONTENTS

Main Gear Touchdown.....	4.7-1
Nose Gear Touchdown.....	4.7-1

### Main Gear Touchdown

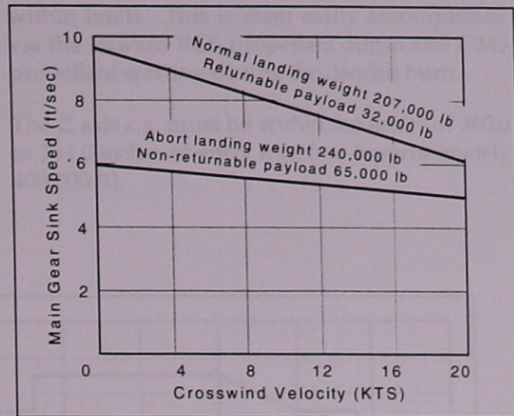
The orbiter was designed to withstand the loads developed from landing at the maximum sink rates shown in the following figure. The maximum allowable sink rate is a function of orbiter gross landing weight and crosswind. Crosswinds reduce the allowable sink rate.

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.



Source: NSTS 08934, SODB, Vol. V

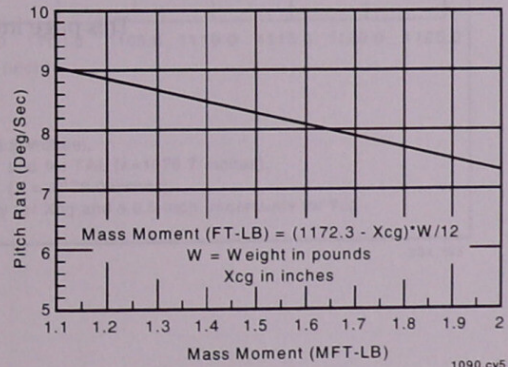
Main Gear Sink Rate



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.)



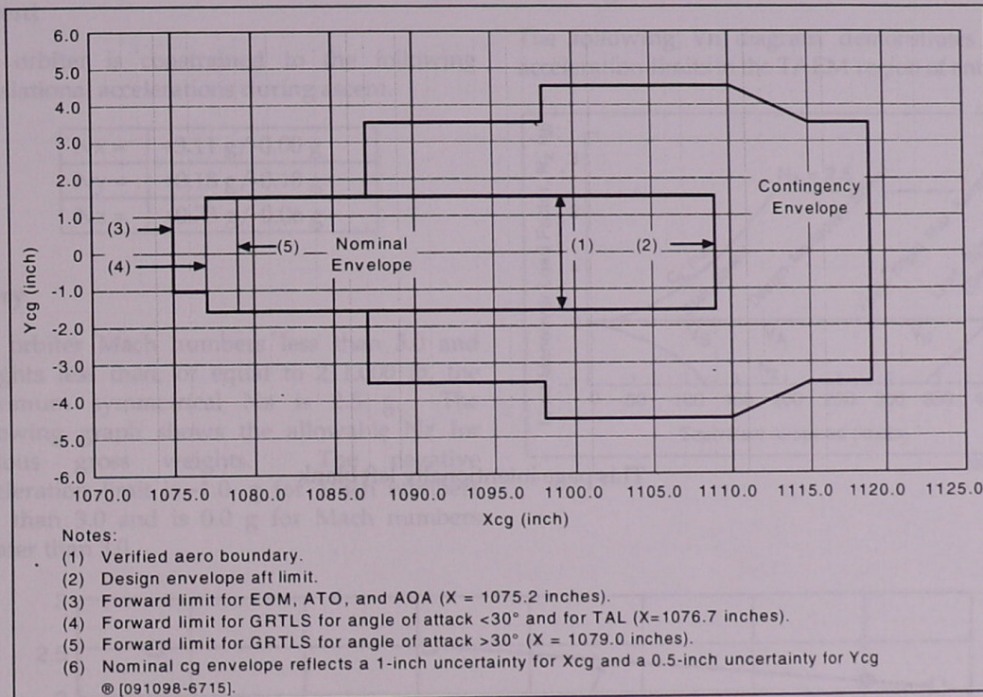
Nose Gear Slapdown Pitch Rate Limit

#### 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).



834.cv5

Source: Flight Rule A4.1.4-3

## 4.9 ACCELERATION LIMITATIONS

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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

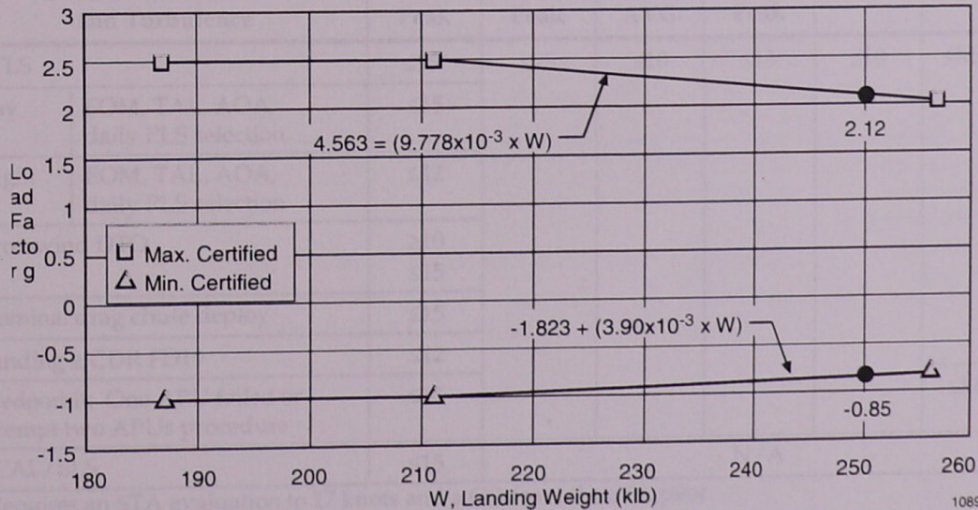
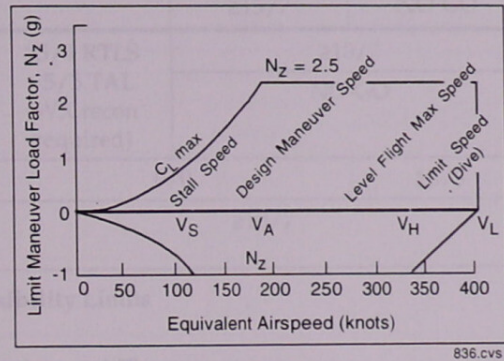
### Entry

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.



Orbiter Operational Maneuver Limits

#### 4.10 WEATHER LIMITATIONS

Weather limitations for launch, abort landing, and end of mission landing are presented below.

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					
ECAL/ELS		≤15	N/A				≤LGT

\*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**

5. NORMAL PROCEDURES SUMMARY

CONTENTS

5.1. PRELAUNCH

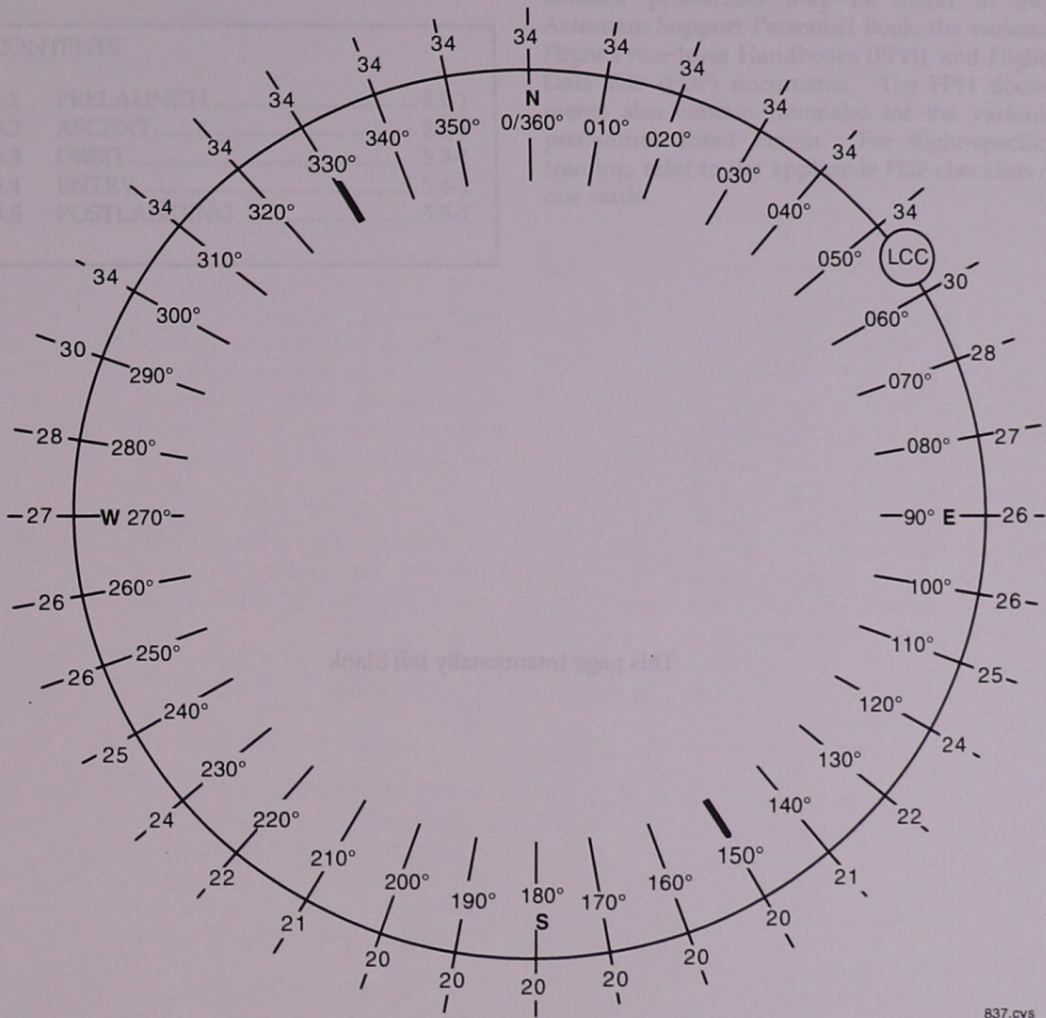
5.2. ASCENT

5.3. ORBIT

5.4. INTAKE

5.5. POSTFLIGHT

### Shuttle Launch Wind Limits



Launch Commit Constraint (60-ft winds at the pad)

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**5. NORMAL PROCEDURES SUMMARY**

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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.

head over the C/W case. UHF Guard is checked, and headset interface units (HIU) are checked for proper operation, along with intercom (ICOM) loops A and B. If the ICOM module has been manifested, it is installed and tested.

L-18:30 ASP ensures crew module has been vacuumated and performs ascent switch list configuration.

L-19:30 The backup ASP conducts a check of the middeck and flight deck and installs certain cue cards, flipbooks, and checklists.

L-21:45 The backup ASP adjusts CDR and FLT seats to the full down and all position and then configures all seats for launch. Intentional hand controllers (IHCs) are adjusted, and SBTCs are set full forward.

L-24:15 Pad is cleared for tanking.

L-25:35 ASP reports panel ABORT light status when initiated by the Flight Director.

L-25:30 ASP Checklist is initiated. Checklist includes communications check, potable/supply water quantity adjustment, LCH cart installation, air sample, pregress switch reconfiguration, RC/SS Press control loop "physical" heat exchanger flow restriction, navigation aids activation, and C/W memory clearing.

L-26:15 Crew departs for the Pad.

L-26:45 Crew arrives at the White Room; ASP verifies CDR and FLT launch/entry and LRS/light equipment is properly configured, brings seat ingress assist with egress and installation of ascent FDF, verifies CDR/FLT communication, air-ground checks, assists with post-ingress switch reconfigurations, and coordinates the C/W and intercom volume adjustments to the MSB system. The ASP verifies the LRS/light equipment configuration and assists ingress and communication hook-up and checks.

L-28:45 ASP verifies all non-flight equipment is removed from the crew compartments, handles communications transfer with the Launch Control Center (LCC), and ingresses.

L-1:30 After the hatch is closed, a cabin lock check is performed.

L-1:00 CRTs will already have the following displays:

- (1) GNC CPC MEMORY
- (2) GNC IMU GNC IMU CNTL WCN
- (3) GNC CPC MEMORY, IMU preflight alignment lights at the time

L-1:35 CDR initiates the crew seat redundancy checks at LCC direction.

5.1 PRELAUNCH

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-4:55	Crew wakeup.
L-18:30	ASP ensures crew module has been vacuumed and performs ascent switch list configuration.	L-4:25	Crew breakfast and photo opportunity.
L-16:30	The backup ASP conducts a check of the middeck and flight deck and installs certain cue cards, flipbooks, and checklists.	L-3:55	CDR, PLT, MS2 get weather briefing. MS1/3 (PSs) don flight clothing and equipment.
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-3:45	CDR, PLT, MS2 don flight clothing and equipment.
L- 8:15	Pad is cleared for tanking.	L-3:15	Crew departs for the Pad.
L-5:35	ASP reports panel ABORT light status when initiated by the Flight Director.	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-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-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-1:30	After the hatch is closed, a cabin leak check is performed.
		L-1:20	CRTs will already have the following displays:  (1) GNC GPC MEMORY  (2) GNC 104 GND IMU CNTL/ MON  (3) GNC GPC MEMORY; IMU preflight alignment begins at this time
		L-1:05	CDR initiates the cabin vent redundancy checks at LCC direction.



L-1:00	CDR opens the cabin vent isolation valve.	L-25:00	The OMS/RCS crossfeed valves are configured for launch by the Launch Processing System.
Min:Sec (approx)		L-19:00	Planned 10 min hold, which synchronizes L and T time.
L-52:00	CDR prepares for the primary avionics software system (PASS)/ backup flight system (BFS) transfer. GNC BFS MEMORY display is assigned to CRT display 3.	L-11:00	PLT clears the F7 C/W lights with the C/W MEM switch on C3.
L-50:00	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.	T-9:00	GO for launch given, and event timers started.
L-45:00	All crewmembers conduct an A/G voice check with MCC and receive updates to ascent/abort data.	T-8:00	PLT connects essential buses to the fuel cells.
L-42:00	CDR initiates PASS/BFS transfer, reports the cabin press (CRT, O1) to MCC, and closes the cabin vent isolation valve (if not already directed to do so by LCC).	T-7:30	Access arm retracts, and the crew makes final checks on seat positions, suit closures, and restraints.
L-30:00	Planned 10 min hold; OPS 1 Load is initiated and GNC FAULT is displayed on CRT 1 while C/W is cleared. A ground-controlled fuel cell purge takes place about this time.	T-6:15	PLT performs APU prestart and verifies three gray "READY TO START" talkbacks. CRT 1-3 displays are GNC LAUNCH TRAJ, GNC SYS SUMM 1, AND BFS, SM SYS SUMM 2.
L-29:00	CDR initiates BFS to OPS 1 with BFS, puts GNC FAULTS display on CRT 3, and clears C/W.	T-5:00	Pilot starts APUs and verifies normal pressure. CDR turns off flash evaporator feedline heaters.
L-27:00	PLT conducts horizontal situation configuration for TAL sites and RTLS to KSC with CRTs 2/3 displaying GNC 50 HORIZ SIT/BFS GNC 50 HORIZ SIT. When this activity is complete, the PLT configures for OMS interconnect with PASS and BFS. Displays for CRTs 1-3 are GNC LAUNCH TRAJ, GNC SYS SUMM 1, BFS, GNC SYS SUMM 2.	T-3:25	Main engine nozzles are gimballed during the next 30 sec. The crew may feel the motion/vibration.
L-26:00	PLT performs the MPS He reconfiguration by opening He and pneumatic isolation valves	T-2:30	PLT clears the C/W with GNC 99 FAULT and BFS GNC 99 FAULT display on CRTs 2 and 3 and the F7 C/W lights with the C/W MEM switch on C3. Displays are then changed to GNC SYS SUMM 1 and BFS GNC LAUNCH TRAJ.
		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 CRT 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 CRT displays for ascent are CRT 1 ASCENT TRAJ, CRT 2 GNC SYS SUMM 1, and CRT 3 BFS ASCENT TRAJ. CRT 3 is also used for both BFS GNC and SM SYS SUMM 1/2 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  $\geq 127$  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). 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 An OMS assist burn during transition + 10 seconds 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 (DTG). The crew should verify the OMS assist by monitoring the OMS PRESS Pc gauges and OMS quantity. When the OMS assist completes, DTG 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, DTG will reflect any amount of OMS assist completed. In other words, if the OMS assist completed, DTG would only reflect the ATO dump because the dump time during the OMS assist has already been decremented.

MET

Min:Sec (approx)

3:00 Crew verifies the flash evaporator is working properly ( $T < 60^{\circ}$  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)

57.0° inclination RTHU at  
VI = 13.0 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.

8:30

Main engine cutoff (MECO) occurs. Crew cues are that the main engine MPS PRESS Pc meters drop to zero, the MAIN ENGINE STATUS lights illuminate red, and the cutoff bug on the BFS ASCENT TRAJ 2 indicates MECO velocity. MECO time may vary, depending on flight profile, but should match simulation time.

Post MECO

MECO velocity should be approximately 25,650 fps (standard insertion (SI) due east) or 25,850 fps (DI due east). Crew verifies *ORBITAL DAP* lights illuminated, indicating MECO confirmed for ET separation. Crew verifies external tank (ET) separation (*MAIN ENGINE STATUS* lights extinguish). If ET separation is inhibited, the crew must null rate(s) (if  $> 0.7^{\circ}/\text{sec}$ ) or react to feedline disconnect failure. -Z translation occurs and GNC transitions to MM 104 at completion of -Z translation. Once in MM 104, the crew refers to the Ascent Pocket Checklist for malfunction procedures. 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 nominal MECO, no OMS 1 is required.

**OMS Burns**

SI OMS 1 targets appear on GNC OMS 1 MNVR EXEC displays (CRTs 1 and 2). 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 cross-checked 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.

CRT 1 in GNC OMS 1 MNVR EXEC, CRT 2 in SYS SUMM 1, and CRT 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 the end of the 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 listed 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 will extinguish at the end of a timer). During that time, the MPS dump should have completed (~2:00 duration). 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 (MONITOR during ascent to prevent SSME loss due to bus trip).

CDR/PLT modes GPCs to MM 105 for the OMS 2 burn.

CRT displays are as follows:

- (1) GNC OMS 2 MNVR EXEC
- (2) GNC OMS 2 MNVR EXEC
- (3) BFS, GNC OMS 2 MNVR EXEC

CDR/PLT load 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 are verified (PASS and BFS).

PLT secures MPS engine power and performs GH2 inerting.

PLT closes the ET umbilical doors.

#### WARNING

ET centerline latches must be stowed prior to door closure to prevent door drive mechanism damage.

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*. CRT 3 display is changed to BFS, GNC SYS SUMM 2.

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  $\Delta V$  and attitude error; however, an attitude error  $\geq 90^\circ$  guarantees ignition cutoff.)

TIG

MET

Hr:Min (approx)

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. CRT displays for 1 and 3 are PASS and BFS GNC OMS 2 MNVR COAST, CRT 2 is GNC SYS SUMM 1. 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 five 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) Align IMU via star trackers (usually not completed until a night pass after post insertion phase is complete).
- (5) Doff and stow LES, reconfigure cockpit for orbit operations.

MET

Day/Hr:Min (approx)

0/0:53 CDR/PLT reconfigure the GPCs. On-orbit software (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 independ-

ent source of data) while GPC 5 retains BFS software but is placed in HALT. With SM software loaded, uplink for S-band and TDRSS is enabled with a DPS utility. Because only 3 CRTs can be assigned to the PASS, CRT 3 is de-assigned, and CRT 4 (powered up during MS aft flight deck configuration) is assigned to GPCs 2 and 4 (GNC and SM OPS). 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 CRTs to the same GPC; e.g., do not use all three CRTs for SM.

Mission/payload specialists egress seats during this period. MSs perform the following functions on the middeck:

- Install UV filter on hatch window (except OV 102).
- Repressurize water supply tank A.
- 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 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 (OV-102 aft ATU is set up), S-band communication is configured for TDRSS at the high rate, R15 cb's are closed as required, CRT 4 is powered up, 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.

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.

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

PLT or MS2 initiates automatic PLBD opening with CRT 4 display SM PL BAY DOORS and switch throws 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 CRT 4 when other displays are not required. The MCC will uplink table maintenance block updates (TMBU) as required.

MET

Day/Hr:Min (approx)

0/1:00 MSs unstow and activate the payload general support computers (PGSCs).

0/1:08 PLT verifies the payload electrical bus configuration (payload dependent).

0/1:10 CDR, PLT don their headsets and configure their personal communications equipment, normally selecting push to talk (PTT) for air-to-ground and voice activation (VOX) for intercom.

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/PRI are selected.

0/1:35

CDR activates star trackers.

0/1:36

If there are no indications of problems with the major orbiter systems at this point, the MCC will issue a GO for orbit operations.

0/1:37

CDR, PLT egress seats, and all crew doff and stow launch/entry suits. During this time, the MCC will uplink the orbiter state vector and RCS quantity compensations.

0/1:52

CDR selects CRT display SM 88 APU/ENVIRON THERM on CRT 1, and if Freon loops are operating nominally (Freon loop radiator out temp <60° F), takes the NH3 controller and high load

	evaporator off and takes H2O Loop 2 Bypass Mode Controller to AUTO (mission dependent). Radiators may be deployed at this point if required. CRT 1 is returned to GNC UNIV PTG display.		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.
0/1:56	Both star tracker doors are opened (8 to 12 sec.). CDR selects GNC 22 S TRK/COAS CNTL display on CRT 1, and activates the star trackers. CRT 1 is returned to GNC UNIV PTG display.	0/2:21	PLT performs the hydraulic thermal conditioning enable steps, which allows the GPCs to operate hydraulic circulation pumps when pressures or temperatures are below set limits.
0/1:57	MS activates the galley and waste collection system (WCS), closes appropriate circuit breakers, and stows the escape pole. PLT opens the supply H2O dump isolation valve to ensure redundant dump capability and configures the supply water system for the mission.		Note: Payload electrical constraints may alter power source selection for the hydraulic circulation pumps and will be called out in this block.
		0/2:24	MS resets C/W system from ascent to on-orbit operations. Limits for some systems are changed while others are inhibited.
0/2:00	PLT activates the APU steam vent heaters to remove any possible ice formation on the water spray boiler (WSB) vent openings.	0/2:25	CDR performs automatic maneuver to the IMU alignment attitude. This is a time-critical action. (The time depends on the flight profile.)
MET			
Day/Hr:Min (approx)		0/2:29	Fuel cell performance is plotted using the Fuel Cell VI Performance Plot procedure in the Orbit Operations Checklist.
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 configure controls for on-orbit operations by using panel diagrams in the Post Insertion Checklist that depict switch positions.		
0/2:20	If the remote manipulator system (RMS) is flown, initial activation procedures begin at about this time. RMS AC cb's are closed,		



## 5.3 ORBIT

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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, combustion products analyzer (CPA) 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.	0/3:20	Ku-band antenna is deployed (~23 sec). Antenna data is monitored on display SM ANTENNA.
0/2:45	IMU alignment (S TRK) is accomplished during orbiter night pass. CRT display GNC 21 IMU ALIGN and GNC 22 S TRK/COAS CNTL are used for this activity.	0/3:30	Ku-band antenna activation (comm mode only normally). Signal strength is available on panel F9 DC AMPS/SIG STR meter (Ku selected) as well as SM ANTENNA display.
0/3:10	Aft controller checkout initiated in each axis with the output verified on CRT 4 display GNC 25 RM ORBIT.	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 (CRT display SM 68 CRYO SYSTEM).
		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, Spacelab 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) prior to the sleep period (this can be shortened to 2 hours for single shift and 1:30 for dual-shift operations if required). With the exception of the IMU alignment, the sequence of presleep activities is at the crew's discretion. Presleep activities on the flight deck include:

- IMU alignment maneuver may not be required if attitude allows star trackers to collect data on stars of opportunity or IMUs do not require alignment.
- Manually purge fuel cells (FD 1 only to save ground turn-around time). Use CRT display SM 69 FUEL CELLS to monitor purge. All other purges will be uplinked from MCC. Note: This could be accomplished postsleep on FD1. May vary, depending on mission.
- Conduct supply/wastewater dump, monitored using CRT display SM 66 ENVIRONMENT (purges and dumps are not accomplished during star tracker use due to possible contamination). Check with MCC if required presleep.
- Configure cryo heaters and manifold valves as directed by MCC.
- Install O2 bleed orifice. Note: This may be accomplished 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 (CRTs, TV power, TV cameras, VTR,

cabin and PLB lights, DDU's).

- Reposition the Ku-band antenna cable to prevent chafing.
- 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 also 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 of 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 will be 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. IMU alignment/COAS maneuvers and activities are scheduled for specific times. The sequence of other activities is up to the crew.

Middeck postsleep activities include:

- Reconfigure lighting and communications panels.
- Replace CO2 absorber (one of two canisters is replaced).
- Review TIPS messages.
- Install O2 bleed orifice (first postsleep) to increase O2 to the middeck, if not installed presleep.
- Meal preparation and clean-up.
- General housekeeping.

Postsleep flight deck activities include:

- IMU alignment (if required). Maneuver may not be required if attitude allows star trackers to collect data on stars of opportunity or IMUs do not require alignment.
- Reconfigure lighting, window shades, communications panels and instruments.
- Reposition Ku-band antenna cable.
- Power on CRTs (3).
- Deselect BFC CRT display.
- Adjust cabin temperature (if required).

- Configure active PCS O2/N2 controller to AUTO.
- Configure OMS/RCS interconnect as required to preserve aft RCS propellant.
- Power primary RJD drivers (8) ON.
- Initiate supply/wastewater dump (pre or post IMU alignment). Check with MCC.
- Configure cryo heater/manifold valves per MCC instructions.
- Fuel cell monitoring system operations record individual fuel cell voltage as an operational baseline. Data recorded and downlinked to MCC.

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).

### OMS (RCS) Burns

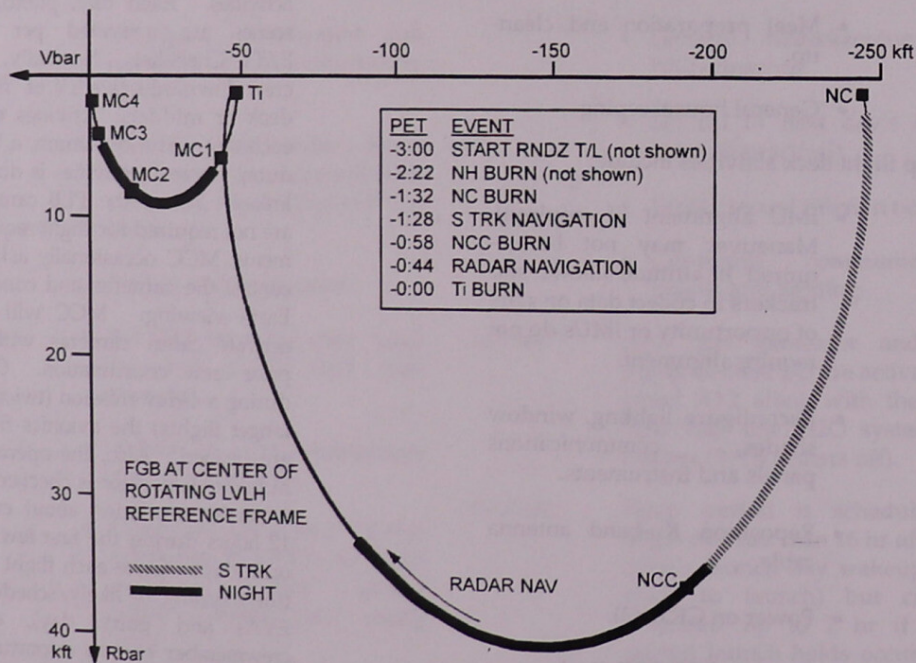
OMS/RCS burns are used on orbit to raise or lower the orbital altitude, for rendezvous phasing, and deorbit. The burn may be done with one or both OMS engines or the RCS, depending on the delta V required. Propellant for the burn can come from either OMS pod or the RCS system. OMS BURN cue cards (OMS-2/ORBIT 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 CRT displays GNC ORBIT MNVR EXEC and GNC SYS SUMM 2. 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  $\geq 4$  and  $\leq 6$  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

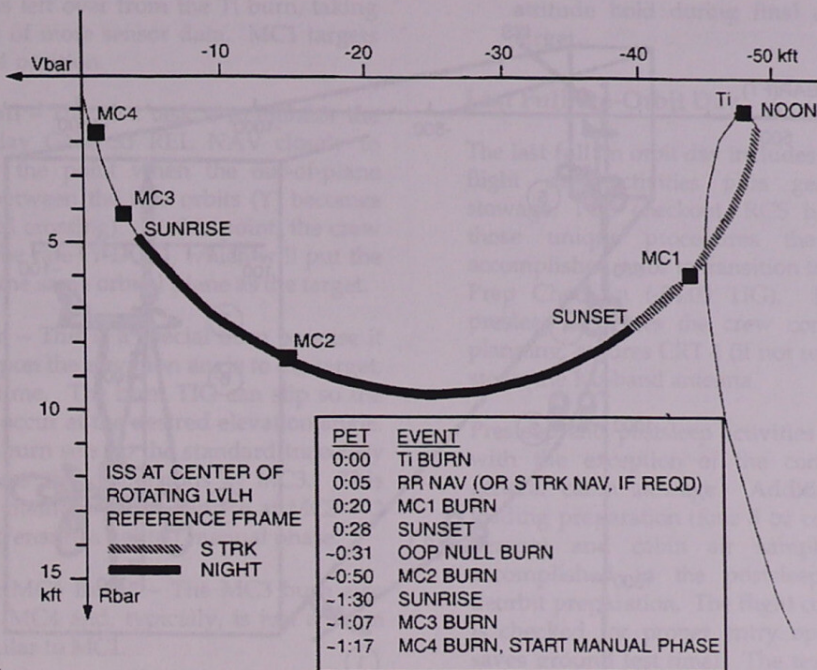
This section summarizes the major events that occur during the final phases of a rendezvous. Flight-specific rendezvous procedures are located in the Rendezvous Checklist. The phase elapsed time (PET) below is referenced to target intercept (Ti) TIG. PET is used to track rendezvous events and normally is displayed on the CRT. Actual times will vary, depending on flight profile.

**NH Burn** (not shown) - NH is a ground-targeted height adjust burn. This burn is actually not done, but is accommodated in the checklist, if necessary.

**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 are designed to place the orbiter 8 n. mi. behind the target (Ti point) in one or two revs.



Orbit Rendezvous Profile



1094.tif

### 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 will be used to improve the onboard filter (FLTR) state vector.

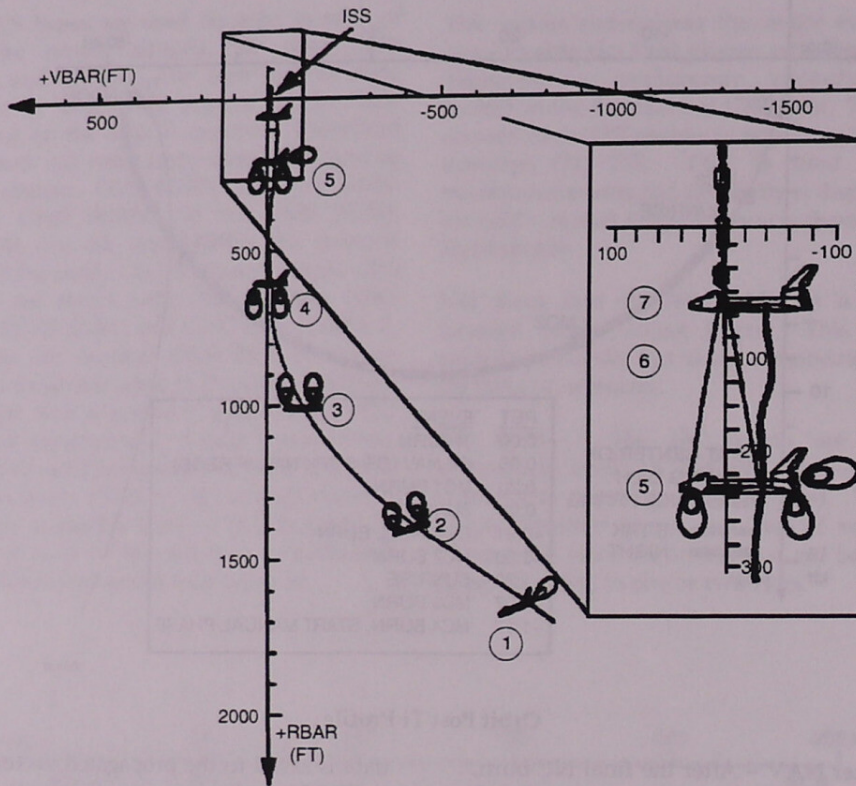
**NCC Burn** – This is the first onboard targeted burn. It uses the filter state vector updated by the two star tracker passes. This is a corrective combination burn that will try to create a node at and correct the transfer to the Ti point, 1200 feet below and 48,600 feet (8 n. mi.) behind the target.

**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 pass

data is saved to the propagated vector (FLTR to PROP transfer) to protect for a radar bias or failure.

**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.



EARTH  
 ISS-Centered LVLH Frame

	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

**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 CRT display GNC 33 REL NAV closely to watch for the point when the out-of-plane distance between the two orbits (Y) becomes zero (nodal crossing). 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 slip so the burn will occur at the desired elevation angle. The MC2 burn sets up the standard trajectory and reduces the dispersions at MC3. This burn will maintain latest sunrise at MC3 + 2 minutes to ensure a lighted manual phase.

**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.

### Last Full On-Orbit Day

The last full on orbit day includes the 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). Prior to the presleep activities the crew conducts entry planning, secures CRT 4 (if not required), 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) will be 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 OPS 8 if an APU is used and OFF if a circulation pump is used.
- CRT 1 display is GNC FCS/DED DIS C/O, and CRT 2 display is SM 86 APU/HYD.
- 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 (CRT display SM 87 HYD THERMAL).
- 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 (CRT 2 display GNC 40 SENSOR TEST). The orbiter is placed in free drift (CRT display GNC UNIV PTG). The crew then initiates the sensor tests (accelerometer assemblies (AAs), microwave landing system (MLS), 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 DDU's and head-up displays (HUDs) are tested and adjusted for entry. When the FCS checkout is complete, the DPS is returned to OPS 2 GNC (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 (CRT display GNC 23 RCS) 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, DDU's, and MDMs are then secured as required.



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  $N_i$  quantity and identify depleted  $H_i$  tanks.
- 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. Inactive GPCs are taken to STBY then RUN.
- 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 and DDU's 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.
- 2:58 Automatic maneuver to IMU alignment attitude is accomplished.
- 2:55 CDR initiates radiator bypass to retain Freon coldsoak. Alternate FES is checked out to save ground test time. PLBDs will not be closed until this check out 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 opened to allow all water tanks to feed the FES equally.
- 2:51 MS prepares for PLBD closing (PLB lights activated (as required), cameras/VTR readied, RMS TV camera positioned and RMS heaters secured (if RMS flown)).

-2:45	CDR, MS perform IMU alignment and verification, which ensures misalignments of less than .5° at entry interface (EI) using display GNC 22 S TRK/COAS CNTL and GNC 21 IMU ALIGN.	-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:
TIG			<u>Forward Flight Deck</u>
Hr:Min (approx)			<ul style="list-style-type: none"> <li>• Electrical power to brakes, brake heaters, anti-skid, and nose wheel steering (NWS) is applied.</li> <li>• Verniers are secured.</li> <li>• FES control is given to GPCs. Freon loop RADIATOR ISOLATION MODE switch is taken to OFF. Cb's for HUM SEP and IMU FAN signal conditioners are opened.</li> <li>• One O2/N2 valve is opened in case of a cabin leak.</li> <li>• Communications panels are configured to provide maximum redundancy.</li> </ul>
-2:40	PLT, MS close PLBDs using SM PL BAY DOORS display on CRT 4 (OPS 2) or BFS SM 63 PL BAY DOORS on CRT 3. When door closure is complete, CRT 4 is powered OFF.		
-2:25	MS performs post-PLBD closing procedures, which include securing PLB lights, deactivating/stowing cameras, powering CRT 3 ON, 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 maintain IMU alignment attitude or go to deorbit attitude depending on flight profile and TDRS position.		<u>Aft Flight Deck</u>
--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. CRT displays are normally: CRT 1 GNC DEORB MNVR COAST, CRT 2 GNC SYS SUMM 1, and CRT 3 BFS, GNC DEORB MNVR COAST.		<ul style="list-style-type: none"> <li>• Activate entry monitoring equipment unique to particular vehicles (Aerodynamic Instrumentation Package and Shuttle Infrared Leaside equipment-OV102, Modular Auxiliary Data System-OVs 103 - 105.</li> <li>• Secure hydraulic heaters.</li> <li>• Secure the teleprinter (via dc utility power MN C) and remove the power cable.</li> <li>• Connect an LES communications cable (dc Utility Power MN C).</li> </ul>

	• Open Ku-band circuit breakers.		RM, two-level attitude failure detection.
	<u>Middeck</u>	-1:04	Crew begins fluid loading (containers filled in post-sleep).
	• Configure communications panel for entry.	-0:59	CDR, PLT ingress seats.
	• Pressure control system (PCS) is configured for N2 water tank ullage pressure.	-0:57	CDR, PLT remove HUD covers.
	• Close 14.7 cabin regulators (protects N2 if leak occurs)	-0:53	Crew performs LES pressure integrity check.
	• Close O2 regulators (so O2 flow goes only to LES).	-0:50	Crew doffs and stows on-orbit communications headsets.
	• Remove and stow bleed orifice.	-0:33	MS deactivates WCS.
			<b>Deorbit Burn</b>
TIG		-1:03	All begin fluid loading per individual prescription.
Hr:Min (approx)			
-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.	-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.
-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 APU's are OFF).	-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 gibal check (during AOS), using OMS MNVR EXEC display.
-1:39	Crew conducts entry review as required (15 min allotted).		PLT initiates APU pre-start procedures (during AOS). BFS, SM SYS SUMM 2 is used to check APU status.
-1:24	CDR, PLT don LESs.		
-1:10	Specialists don LESs.		CDR, PLT conduct horizontal situation configuration using CRT 2, GNC 50 HORIZ SIT; CRT 3 BFS, GNC 50 HORIZ SIT; and CRT 3, GNC 51 OVERRIDE for both PASS
-1:06	Final IMU alignment is performed by CDR to reset RM threshold prior to deorbit burn. This maximizes IMU		

and BFS; then return CRT 2 to GNC DEORB MNVR COAST and CRT 3 to BFS, GNC DEORB MNVR COAST.

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.

-0:35 MS deactivates the galley and the WCS.

-0:25 PLT performs vent door closure with CRT 2 in GNC 51 OVERRIDE.

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.

TIG  
Hr:Min (approx)

-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 the orbiter is in the deorbit burn attitude  $\pm 5^\circ$ . 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  
Hr:Min (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. Deorbit burn monitoring and downmoding is discussed in Section 7 of this manual.

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.		CDR, PLT perform entry switch checks (using GNC 51 OVERRIDE on CRT 3 for some checks) and exercise brake pedals.
	PLT performs OMS/RCS reconfiguration by verifying the proper position of RCS switches and closing OMS HE and crossfeed valves; MS stows PGSC (SPOC).	-13:00	PLT starts remaining (2) APUs, verifies nominal performance, then switches all 3 APUs to normal pressure in preparation for the SSME hydraulic repress.
	CDR proceeds to OPS 303. CDR 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.	-11:00	PLT performs main engine hydraulic system repressurization to ensure the nozzles are properly stowed.  If required, PLT initiates hydraulic fluid conditioning on MCC's call and monitors surface position indicators for aerosurface cycling.
EI			Crew makes burn report to MCC and updates new state vector if required. All crew members inflate anti-g suits if desired.
Min:Sec (approx)			All three CRTs are moded to GNC DEORB MNVR COAST (CRT 3 BFS). PLT transitions AC BUS sensors to MONITOR.
-20:00	CDR initiates a secondary actuator check, if not previously performed during FCS checkout and time allows, using GNC 53 CONTROLS on CRT 1, BFS, SM SYS SUMM 2 on CRT 3, and GNC DEORB MNVR COAST on CRT 2.		
-18:00	PLT performs forward RCS dump with CRT 1 in GNC 23 RCS, CRT 2 in GNC DEORB MNVR COAST and CRT 3 in BFS, GNC SYS SUMM 2. 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).	-6:00	The crew transitions to the Entry Maneuver cue card for nominal entry procedures.
	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.	-5:00	CDR transitions GPCs to OPS 304 when verified at EI-5 attitude. Crew switches to AESP for malfunction procedures. CRT displays are: CRT 1 GNC ENTRY TRAJ, CRT 2 GNC SYS SUMM 1, CRT 3 BFS, GNC ENTRY TRAJ.  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).	+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 <sup>2</sup> of orbiter bug drag.
<b>Entry Interface</b>			
+ = Time from EI			
- = Time to touchdown			
Min:Sec (approx)			
+0:00	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 are monitored on CRTs 1 and 2. The BFS ENTRY TRAJ display is available on CRT 3 to compare PASS and BFS guidance. The PLT can call up BFS SYS SUMM displays as desired to check system operation.	+8:04 -24:10	Pitch RCS jets deactivated at q-bar = 40.
-32:14		+11:49 -20:25	At drag = 11 fps, 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.
		Note:	1 k fps = Mach 1.0
+2:39	Automatic elevon trim begins at a q-bar = 0.5 psf.	+14:42 -17:32	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.
-29:35		V <sub>rel</sub> = 19 k fps (Mach = 19) Alt = 215 k ft	
+3:32	Aerosurface control begins at q-bar = 2.0 psf. CDR, PLT monitor elevon and aileron deflection angles on surface position indicator.	+15:51 -16:23	PASS and BFSTRAJ displays mode to ENTRY TRAJ 2.
-28:42		V <sub>rel</sub> = 17 k fps (Mach = 17) Alt = 200 k ft	
+ = Time from EI			
- = Time to touchdown			
Min:Sec (approx)			
+4:45	Closed loop guidance initiated (CLG Init) at q-bar = ~8 psf or drag = ~3 fps <sup>2</sup> . Guidance box appears on ENTRY TRAJ to indicate closed loop guidance.	+17:00 -15:14	NAVAID power on is verified and I/O RESET performed. This insures NAVAIIDs will warm up before they are required (in case they were off due to a powerdown).
-27:29		V <sub>REL</sub> = 15 k fps (Mach = 15) Alt = 185 k ft	
+5:00	Roll RCS jets deactivated at q-bar = 10 psf.		
27:14			

+17:57	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 3.	+22:00	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.
-14:17	Drag is up to 33 fps <sup>2</sup> and Gs up to 1.5.	-10:14	
V <sub>REL</sub> =14 k fps (Mach = 14) Alt = 182 k ft		V <sub>REL</sub> =7 k fps (Mach = 7) Alt = 138 k ft	
+18:57	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.	+22:41	PASS and BFS ENTRY TRAJ displays mode to GNC ENTRY TRAJ 5.
-13:17		-09:33	
V <sub>REL</sub> =12 k fps (Mach = 12) Alt = 176 k ft		V <sub>REL</sub> =6 k fps (Mach = 6) Alt = 131 k ft	
+19:20	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 4.	+23:30	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.
-12:54	Alpha and drag start to ramp down, but Gs stay up over 1.3.	-08:44	
V <sub>REL</sub> =10.5 k fps (Mach = 10.5) Alt = 167 k ft		V <sub>REL</sub> =5 k fps (Mach = 5) Alt = 120 k ft	
+20:03	Speedbrake opens to 81 percent.		
-12:11			
V <sub>REL</sub> =10 k fps (Mach = 10) Alt = 150 k ft			
+21:00	SSME repositioning for drag chute deploy. If GPC annunciates SSME REPOS FAIL, drag chute is emergency deploy only.		
-11:14			
V <sub>REL</sub> =8.0 k fps (Mach = 8)			
+ = Time from EI			
- = Time to touchdown			
Min:Sec (approx)			
+21:34	MCC has sufficient tracking for state vector update. This time can vary depending on ground track and tracking station performance.	+25:00	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.
-10:40		-07:14	
V <sub>REL</sub> =7.5 k fps (Mach = 7.5) Alt = 144 k ft		(Mach = 3.4) Alt = 95 k ft	
+21:41	First TACAN acquisition.	+25:30	PLT verifies APUs operating nominally. CDR, PLT activate HUDs.
-10:33		-06:44	
V <sub>REL</sub> =7.3 k fps (Mach = 7.3) Alt = 142 k ft		(Mach = 2.6) Alt = 83 k ft	

**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

Fuselage vents open.

+ = Time from EI  
- = Time to touchdown  
Min:Sec (approx)

+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 VERT SIT display.

**WARNING**

If low energy, or flying a big heading alignment cone (HAC) (>320°), TAEM guidance will command an uncontrollable pitch up between Mach 1.0 and 1.5 if air data is not incorporated.

+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. 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. 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.



<p>+31:51 -00:23 297 KEAS Alt = 500 ft</p>	<p>Shuttle will be lined up on ball bar. MS2 checks speed brake command percent (second smart speed brake reset).</p>	<p>necessary. (If no load relief, RHC full forward. If NWS FAIL light comes on, steer with rudder, RHC, and brakes. NWS2 may be available.)</p>
<p>+31:54 -0:20 288 KEAS Alt = 300 ft</p>	<p>Pilot deploys the landing gear on call from CDR. PLT/MS2 check gear indicates down.</p>	<p>+32:34 +00:20 CDR checks ground speed and decel on HUD. Post</p>
<p>+32:04 -0:10 261 KEAS Alt = 30-80 ft</p>	<p>Final flare begins.</p>	<p>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<sup>2</sup>. At 5000 feet of runway remaining, if ground-speed is greater than 140 knots, CDR applies maximum braking.</p>
<p>+32:14 -00:00 195 or 205 KEAS</p>	<p>Main gear touchdown (195 KEAS GW &lt;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 air-speed moves to upper left corner of the display). Also, the velocity vector disappears.</p>	<p>+32:46 +00:32 60 KGS (±20 kts) PLT jettisons drag chute on CDR call.</p>
<p>+32:15 +00:01 195 KEAS</p>	<p>PLT deploys drag chute on call from CDR. 195 KEAS.</p>	<p>+32:50 00:36 40 KGS CDR reduces braking to less than 6 ft/sec<sup>2</sup> until wheelstop.</p>
<p>+32:16 +00:02 185 KEAS</p>	<p>CDR initiates beep trim derotation, which targets 1.5 deg/sec.</p>	<p>+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.</p>
<p>+32:24 +00:10 145 to 155 KEAS</p>	<p>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 discrettes 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</p>	

## 5.5 POSTLANDING PROCEDURES

- 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 landing gear.
- PLT, after notifying MCC, opens the ET umbilical doors. PLT initiates hydraulic load test on MCC call.
- CDR performs DPS transition to OPS 901 on MCC call; CRT 3 is moded to BFS, GNC BFS MEMORY.
- CDR performs the radiator reconfig and activates the NH3 boiler, as required (MCC call or C/W).
- 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).

## 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, check-out, 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.

4.1 SUMMARY

4.2 INTRODUCTION

4.3 PURPOSE

4.4 SCOPE

4.5 REFERENCES

4.6 DEFINITIONS

4.7 PROCEDURES

4.8 APPENDICES

## 6.1 LAUNCH ABORT MODES AND RATIONALE

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Mode 1 – Unaided Egress/Escapes.....	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/Escapes

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 .....	6.2-3
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 will usually result in a crew bailout.

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)	8300	2 ENG BYD (104)	5900
PRESS TO ATO (104)	10300	ABORT TAL BYD (5)	
NEG MRN (104)	11000	EO VI	<input type="text"/>
		SE OPS 3 BYD (109) (5)	<input type="text"/>
		SE BYD (104) (5)	<input type="text"/>
PRESS TO MECO (104)	12200	2 ENG BEN (104) 6500	
SE OPS 3 BYD (109)	12600	ABORT TAL BEN (2)	
SE BYD (104)	13800	EO VI	<input type="text"/>
NEG BEN (104)	15100	SE OPS 3 BYD (109) (12)	<input type="text"/>
SE PRESS (104)	17200	SE OPS 3 BEN (109) (11)	<input type="text"/>
		SE BYD (104) (5)	<input type="text"/>
		SE BEN (109) (2)	<input type="text"/>
LAST PRE MECO TAL	23000	2 ENG MRN (104) 7600	
LAST TAL		ABORT TAL MRN (3)	
AML	23800	EO VI	<input type="text"/>
BYD	24300	SE OPS 3 BEN (109) (11)	<input type="text"/>
ROB	24700	SE BYD (104) (5)	<input type="text"/>
KIN	25200	SE BEN (104) (2)	<input type="text"/>
HDS	25400	SE MRN (109) (3)	<input type="text"/>
			<input type="text"/>

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### 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.

A generic discussion of mode boundaries for a low-inclination flight is presented here. Flight-specific data is available from the Flight Dynamics Officers (FDO).

### Two-Engine TAL

Two-engine TAL is usually the first mode boundary reached that allows a downrange abort. It is the earliest inertial velocity ( $V_1$ ), or time in the trajectory at which AUTO guidance with 104% throttles may be used to successfully complete a TAL abort to the designated primary TAL landing site with two functioning engines. There is usually an overlap of RTLS and TAL capability. TAL is the preferred abort mode for engine failures in this overlap region, because single-engine completion capability is attained much earlier for TAL than RTLS. For severe systems failures in this overlap region, an RTLS may be preferred over TAL, because an RTLS will get the crew on the ground quicker than a TAL. The MCC voice call for this boundary usually has the TAL site name included in it (e.g., Two Engine Ben Guerir).

### Negative Return

The latest  $V_1$  or time in the trajectory at which AUTO guidance may be used to successfully complete an RTLS abort is NEGATIVE RETURN. Past this  $V_1$ , the orbiter will have too much downrange energy to successfully return to KSC. If there is an abort gap between NEGATIVE RETURN and TWO ENGINE TAL, the calls will be based on throttling the good engine(s) to maximum throttle - 109%.

### Press to ATO

This boundary represents the earliest engine out  $V_1$  or time in the trajectory at which the orbiter can achieve the design underspeed at MECO. 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. This boundary occurs on most missions and requires a pre-

MECO OMS dump (ATO) to achieve the design underspeed.

### Press to MECO

This is earliest engine out  $V_1$  in the trajectory where the orbiter can reach the design underspeed (see Press to ATO for design underspeed constraints) at MECO without a pre-MECO abort selection.

### SE OPS 3 (TAL site) 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.

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)

The SE TAL 104% boundary represents the lowest  $V_1$  or time where AUTO guidance with 104% throttles can achieve the desired TAL site range-velocity target line with the simultaneous failure of two main engines.

Both in-plane and out-of-plane TAL sites may be used. This complicates abort mode determination, and the TAL REDESIGNATION cue card, along with MCC calls, will be required. This card is used for sequential engine failures and indicates to the crew which TAL site is attainable.

1ST E.O. VI	7700	7800	7900	8000	8100	8200	8300
SE OPS 3 BEN (109) (11)	11200	11200	11200	11300	11300	11300	11300
SE BYD (104) (5)							
SE BEN (104) (2)	15900	15900	15800	15700	15600	15600	15500
SE MRN (104) (3)	17600	17500	17400	17300	17200	17000	16900

1ST E.O. VI	8400	8500	8600	8700	8800	8900	9000
SE OPS 3 BEN (109) (11)	11400	11400	11400	11400	11400	11500	11500
SE BYD (104) (5)							
SE BEN (104) (2)	15400	15400	15300	15200	15200	15100	15100
SE MRN (104) (3)	16800	16700	16600	16500	16500	16400	16400

1ST E.O. VI	9100	9200	9300	9400	9500	9600	9700
SE OPS 3 BEN (109) (11)	11500	11500	11500	11500	11600	11600	11600
SE BYD (104) (5)	15800	15700	15600	15500	15300	15200	15100
SE BEN (104) (2)	15100	15000	15000	15000	14900	14900	14900
SE MRN (104) (3)	16400	16400	16400	16400	16500	16500	16500

1ST E.O. VI	9800	9900	10000	10100	10200	10300
SE OPS 3 BEN (109) (11)	11600	11600	11600	11700	11700	11720
SE BYD (104) (5)	15000	14900	14700	14600	14500	14400
SE BEN (104) (2)	14900	14900	14900	14800	14800	14800
SE MRN (104) (3)	16600	16600	16700	16700	16700	16800

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### MRN TAL REDESIGNATION Cue Card

As an example, if a TAL to MORON (MRN) has been initiated because of an engine failure at  $V_1 = 7830$  fps, the new SE OPS 3 and single-engine TAL boundaries would be:

- 11,200 SE OPS 3 to Ben Guerir (BEN)
- 15,900 SE to Ben Guerir (BEN)
- 17,500 SE to MORON (MRN).

These velocities assume 109% or 104% throttle, as specified in parentheses, is selected on the remaining engine. These numbers are entered on the NO COMM MODE BOUNDARIES card.

### NOTE

If a TAL site redesignation is required, it must be quickly accomplished on SPEC 50 to begin heading to the selected site, thus reducing crossrange during the entry phase.

### WARNING

This redesignation must not be done just prior to or during the roll to heads-up maneuver; otherwise, an LOC can happen.

### Single-Engine Press

Single-engine press is the lowest  $V_1$  or time in the trajectory after which the critical underspeed can be attained with two simultaneous engine failures. Critical underspeed is the same as design underspeed minus the ET impact and NPSP constraints. Other criteria may be found in the Flight Rules.

### Last Pre-MECO TAL

This boundary is the latest  $V_1$  or time in the trajectory, with a single-engine failure, that AUTO guidance can be used to achieve the designated TAL landing site range/velocity (R-V) line. For such a late TAL declaration, the engines are throttled down at TAL initiation to provide for a longer pre-MECO OMS dump. LAST pre-MECO TAL is normally not called out by the MCC.

### Last TAL

Last TAL is the highest MECO velocity acceptable for successful completion of a TAL entry to a TAL site or an ELS. This abort option is applicable to the early MECOs where  $V_1$  is below the AOA range. LAST TAL is not an MCC callout.

### 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
<b>OMS</b> - 2 He TKs		
- 1 OX & FU TKS (diff pods)		X
- 2 OX or 2 FU TKS		X
<b>APU/HYD</b> — Impending loss of all capability	X	X
<b>CABIN LEAK</b> — (-EQ dP/dT > .15)	X	X
<b>CRYO</b> — ALL O <sub>2</sub> (H <sub>2</sub> )	X	X
<b>2 FREON LOOPS</b> ↓	X	X
<b>2 MAIN BUSES</b> ↓	X	
<b>THERMAL WINDOW PANE</b>	X	

### SYS FLIGHT RULES Card

#### OMS Capability

A severe loss of OMS capability can make it impossible to continue uphill and deorbit. For example, loss of two propellant tanks results in insufficient propellant to get to orbit. In this case, 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 O<sub>2</sub> or H<sub>2</sub> 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

Heating during TAL entries is severe. With a thermal window pane failure, RTLS is preferable due to its more benign heating characteristics.

### 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.

### 6.3 RETURN TO LAUNCH SITE

#### CONTENTS

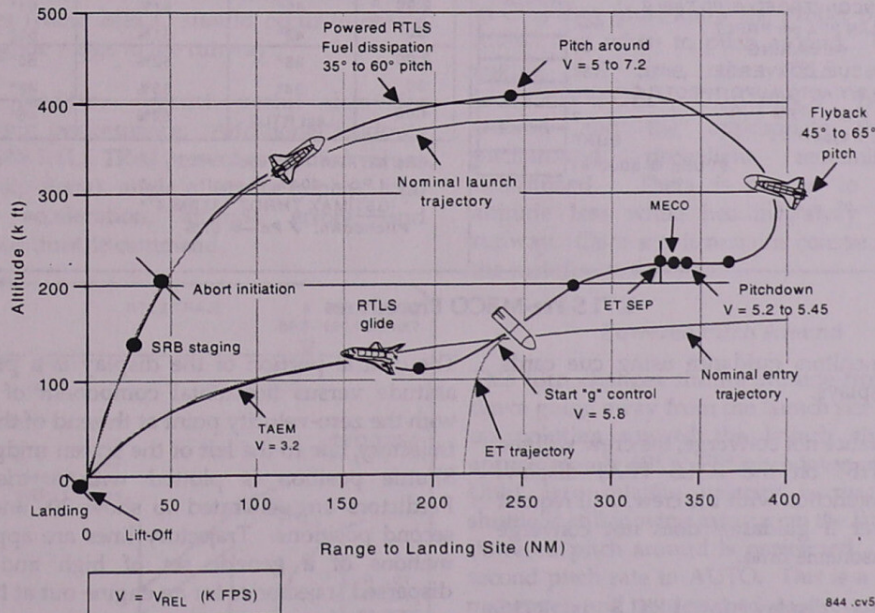
Powered RTLS .....	6.3-2
Gliding RTLS.....	6.3-6

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.



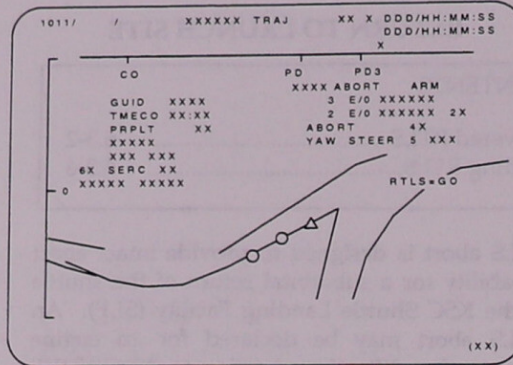
844.cv5

Typical RTLS Profile

### 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.



RTLS TRAJ Display

RTLS CDR	RTLS PLT																																																								
<p>Abort initiated: after 2:30 (2 eng) at 3:40 (3 eng)</p> <p>ABORT RTLS • No Joy • OPS 601 PRO</p> <p>✓ GUIDANCE STATUS on RTLS TRAJ Expect PPA when GUID % to go = 0 • If GUID 'INHIB': • ✓ UNCONVERGED GUID TABLE • MAN PPA per PRPLT • REMAINING • After GUID CONVERGE: • P,R/Y AUTO/AUTO THROTTLE After PPA: ✓ BFS ITEM 1 (*) ✓ Bugs, V<sub>rel</sub>, Waypoint 1</p> <table style="margin-left: 20px;"> <tr><th colspan="2">WINDS</th></tr> <tr><td>50K</td><td>/</td></tr> <tr><td>40</td><td>/</td></tr> <tr><td>30</td><td>/</td></tr> <tr><td>20</td><td>/</td></tr> <tr><td>7</td><td>/</td></tr> <tr><th colspan="2">SURF</th></tr> <tr><td>SPDBK @ 3000 FT</td><td>/</td></tr> </table> <p>Pitchdown (b = 0°, α = -2°)</p>	WINDS		50K	/	40	/	30	/	20	/	7	/	SURF		SPDBK @ 3000 FT	/	<p>If CSS: Man Throttle Man MECO ✓ Pc = 104% (2 eng) / 69% (3 eng) ✓ DUMP</p> <p style="text-align: center;">UNCONVERGED GUIDANCE TABLE</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>ENG OUT</th> <th>OUTBOUND INITIAL θ</th> <th>PITCHAROUND at % (8°/sec)</th> <th>FLYBACK INITIAL θ</th> </tr> </thead> <tbody> <tr> <td>Liftoff</td> <td>60°</td> <td>44%</td> <td>64°</td> </tr> <tr> <td>:30</td> <td>56°</td> <td>47%</td> <td>63°</td> </tr> <tr> <td>1:00</td> <td>57°</td> <td>47%</td> <td>63°</td> </tr> <tr> <td>:30</td> <td>56°</td> <td>48%</td> <td>62°</td> </tr> <tr> <td>2:00</td> <td>49°</td> <td>51%</td> <td>61°</td> </tr> <tr> <td>:30</td> <td>42°</td> <td>51%</td> <td>52°</td> </tr> <tr> <td>3:00</td> <td>38°</td> <td>52%</td> <td>50°</td> </tr> <tr> <td>:30</td> <td>34°</td> <td>53%</td> <td>48°</td> </tr> <tr> <td>4:00</td> <td>Last RTLS</td> <td>52%</td> <td>46°</td> </tr> </tbody> </table> <p>✓ Pc AT PPA + 20 sec • If Pc = 104% (2 eng): • G51 MAX THROT - ITEM 4 Pitchdown: ✓ Pc → 67%</p>	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°
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: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°																																																						

### RTLS Pre-MECO Procedures

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The crew monitors guidance using cue cards and CRT 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.

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.

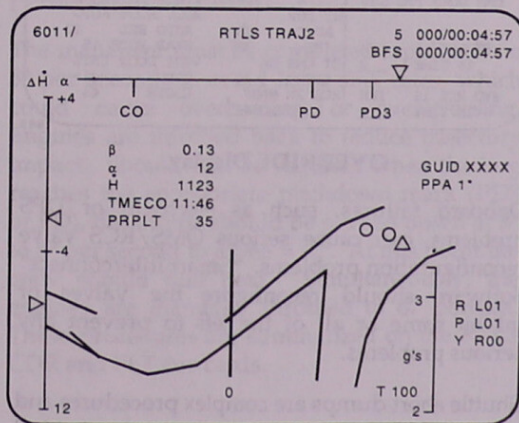
On the left side of the BFS ASC TRAJ there is a scale for delta H dot and angle of attack ( $\alpha$ ). The delta H dot scale is not used operationally and is not trained. The scale is intended to pro-

vide 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 very 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  $-4^\circ$ , which was intended to provide a reference during ET SEP while trying to maintain an AOA of  $-4^\circ$  for separation. However, the desired angle of attack for ET SEP is now  $-2^\circ$ , 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.



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  $60^\circ$  to  $70^\circ$  pitchdown maneuver. Until zero relative velocity is reached, the shuttle is still moving away from the launch site. Powered pitch around is performed at  $10^\circ$  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 CRT 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**

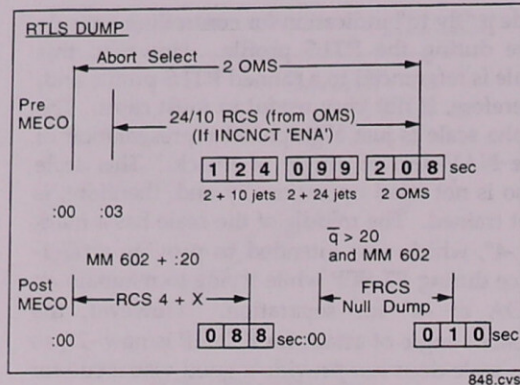
It is much better to pitch around slightly early than slightly late as late pitch-arounds may result in not reaching a nominal RTLS MECO state.

**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/	VERRIDE	2 008/04:13:37
		000/00:29:56
ABORT MODE	ELEVON	ENTRY FCS
TAL 1	AUTO 17*	FILTER
ATO 2	FIXED 18	NOM 20*
ABORT 3	SSME REPOS 19	ENA
MAX THROT 4		S POLE 24
PREFLT DUMP	IMU STAT	AIT DES
	1	3 25
	2	26
	3	27
INH ICNCT 5		2 29* 32
OMS DUMP		3 30* 33
ARM 6	ADTA	H
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
AFT RCS 13	ET SEP	ROLL MODE
14 TIME 0	AUTO 38	AUTO SEL 42
	SEP 39	WRAP MODE 45
FWD RCS 15	ET UMB DR	VENT DOOR CNTL
16 TIME 0	CLOSE 40	OPEN 43*
	RCS RM MANF	CLOSE 44
	CL OVRD 41	

**VERRIDE 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/Abort 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.

#### CAUTION

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  $30^\circ$  is required. However, to safely separate the ET, an alpha of  $-2^\circ$  is necessary. The transition between these attitudes is called powered pitchdown.

The maneuver must be completed rapidly ( $5^\circ$  to  $8^\circ$  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  $5^\circ$  to  $8^\circ$  per second to alpha =  $-2^\circ$ . 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 =  $-2^\circ$  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	$0^\circ$	$\pm 1.25^\circ/\text{sec}$	$20 > P > -20$
Pitch rate, Q	$-25^\circ/\text{sec}$	$\pm 0.5^\circ/\text{sec}$	$+25 > Q > -20$
Yaw rate, R	$0^\circ/\text{sec}$	$\pm 0.5^\circ/\text{sec}$	$+20 > R > -20$
Angle of attack, $\alpha$	$-2^\circ$	$\pm 0.05^\circ$	$-1.5^\circ > \alpha > -89^\circ$
Side slip angle, $\beta$	0	$\pm 2^\circ$	$+20 > \beta > -20$
Roll angle $\phi$	0	$\pm 5^\circ$	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  $\geq +10^\circ$  and time from ET SEP  $\geq 10$  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  $\geq +10^\circ$  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.

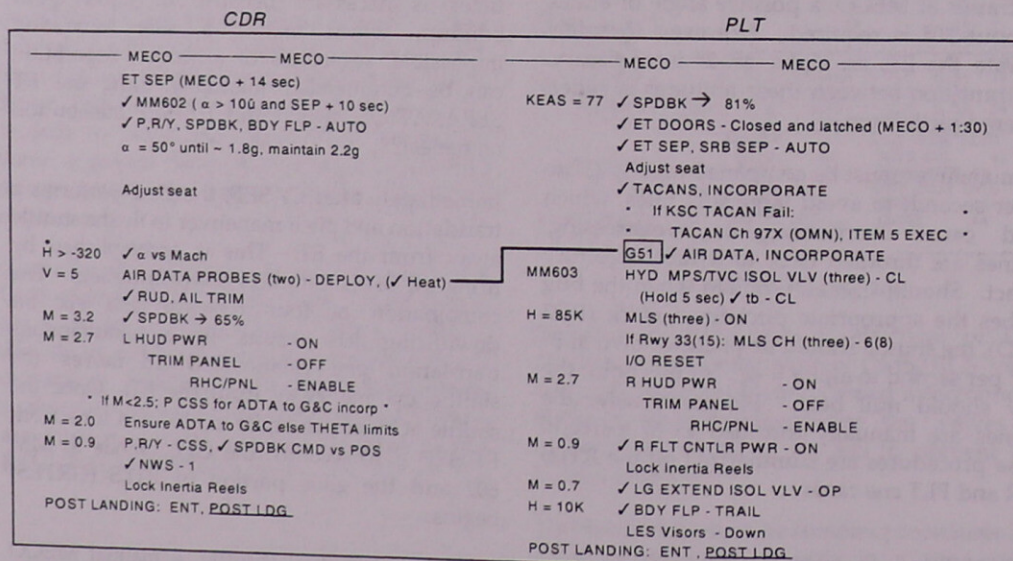
The RTLS MPS dump starts immediately upon transition to MM 602. LO2 is dumped through the main oxidizer valves in the main engines and the 8-inch fill/drain line on the starboard side of the orbiter. LH2 is dumped through the 1.5-inch backup dump line and the 8-inch fill/drain line on the orbiter port 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<sub>2</sub> Hold
- Alpha Transition
- S-Turn
- GRTLS TAEM



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### 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 ( $\alpha = 50^\circ$ ) 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  $q\text{-bar} = 10$ . Pitch jets are secured at  $q\text{-bar} = 40$ . 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.

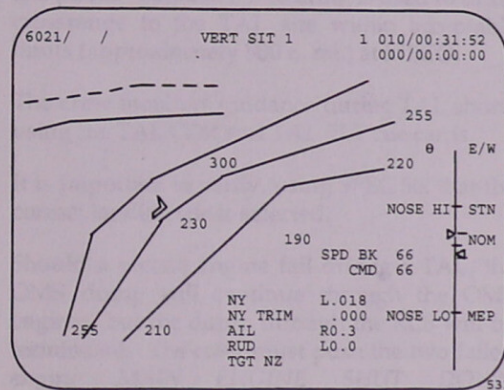
### Alpha Transition

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  $45^\circ$ . 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  $q\text{-bar}$  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.



GRTLS Vertical Situation 1 Display

### 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.

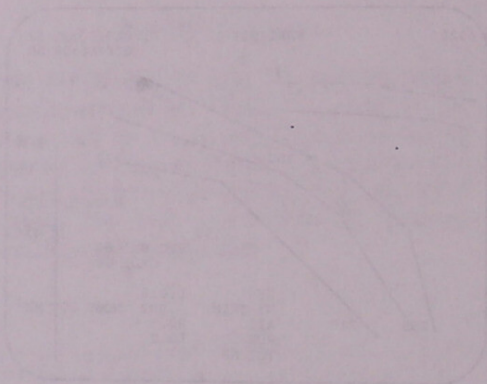
### GRTLS TAEM

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.



## 6.4 TRANSOCEANIC ABORT LANDING

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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*. The shuttle indicator (triangle) and predictors should follow the upper trajectory line on *BFS TAL TRAJ 2*.

### 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

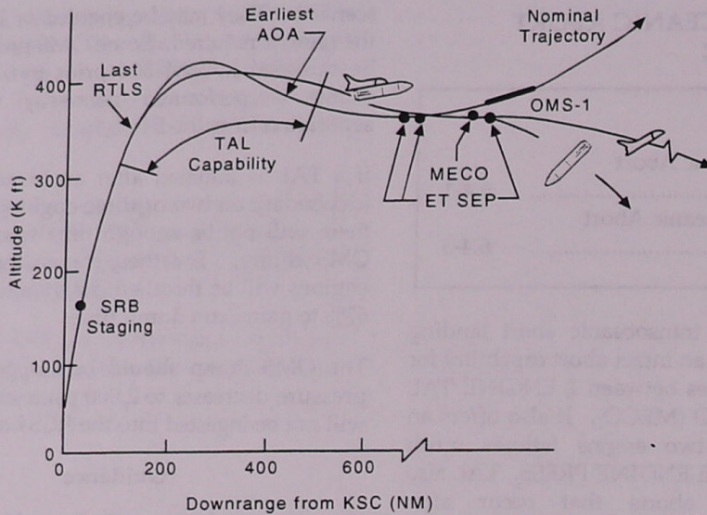
At abort selection, TAL guidance begins steering the shuttle toward the selected landing site plane. Variable I-Y steering is used to bring crossrange to the TAL site within acceptable limits (approximately 500 n. mi.) at MECO.

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

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**TAL CDR**

If  $V_1 > 23000$  manual MECO @ 23700, go to post MECO

ABORT TAL  
G50 ✓ SITE & RWY (PASS/BFS)

SITE	RWY	TACANS	ITEM 5	MLS	LENGTH
2	BEN 3618	BEN 108	CBA 116 (DME)	6	13720/12720
3	MRN 2002	MRN 100	AOG 23	6	12000/11800
4	ZZA 30/12R	ZZA 64	ZZA 77 (DME)	6	12397/12197
8	PSM 34	PSM 112	-	-	11318
9	YH2 24	UAW 38	BZN 56	-	8900
9	YJT 26	-	UWT 23	-	8500
10	YQX 22	YQX 74	-	-	9495
10	YJT 17	-	YJT 78	-	8278
11	RN 0624	SHA 80 (DME)	CRN 37 (DME)	-	9499/9036
12	BEN 36	BEN 108	RIV 92	6	13720
12	KOL 159	-	-	-	12779
13	MRN20	MRN 100	-	6	12000
13	ESH 03R	-	BAG 78 (DME)	-	11310
14	ZZA 30L	ZZA 64	-	6	12397
14	AOG 31	-	NKW 57	-	12000
15	BEJ 01/19R	BEJ 106	ESP 72	-	11219
15	LAL 1503	LAL 45	TRM 109	-	10865

\*LOXRNG

- If second eng fails:  TRA  ✓ SERC ON
- G50 ✓ SITE (✓ Redes card)

$V_1 = 15.0K$  ✓ Roll Heads Up

**MECO**

BFS - C/O BUG ( $V_1 - 24.0K$ )  
MECO-18s ✓ ET SEP, ✓ AUTO - Z TRANS  
MECO-35s ✓ MM104

- If not previously selected,  G51 ABORT TAL
- ✓ SITE for High or Low Energy (TAL PLT)
- $\theta > 15^\circ$ ,  $Y = 0 \pm 30^\circ$ ; RATES  $< .5^\circ/\text{sec}$
- 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)
- G50 ✓ SITE, RWY, TACAN
- S/B & ALTM (PASS/BFS)
- ✓ BUGS, HDG, RANGE,  $\alpha = 43^\circ$

**WINDS**

50K	/
38	/
28	/
20	/
12	/
7	/
3	/
1	/
SURF	/
SPDBK @ 3000 FT	/
ALT	/
AIM PT	/
SPDBK	/

- Low energy:  TRA ITEM 3 (Lo Energy ENA)
- If MECO  $V_1 < 20.4K$ :
- Pitch - CSS,  $\alpha = 40^\circ$
- At H = 400: AUTO
- If 42/man 37: Pitch - CSS at  $\alpha = 37^\circ$
- Pitch - AUTO at end of 2nd pullout
- SURF
- $V = 10$  ✓ SPDBK → 81%
- $V = 7$  Go to ENTRY MANEUVERS (Cue Card)

TAL CDR Procedures

**TAL PLT**

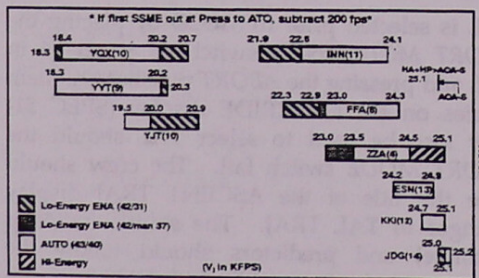
✓ OMS DUMP

- If second eng fail:
- 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,  $P_c \rightarrow 67\%$
- Man Shutdn at C/O mark

MECO --- BFS - C/O BUG ( $V_1 - 24.0K$ ) --- MECO



✓ OMS DUMP

- ✓ ET DOORS - Closed and latched (MM304 +1:30)
- $V = 19$  HYD MPS/VC ISOL VLV (three) - CL (hold 5 sec) ✓ tb - CL
- $V = 10$ 
  - If RCS  $< 57\%$  either side:
  - G51 AFT RCS INH, ITEM 13 EXEC
- $V = 7$ 
  - MLS (three) - ON (✓ channels)
  - I/O RESET
  - Go to ENTRY MANEUVERS (Cue Card)

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 OPS 3 after MECO and ET SEP, which is time-critical. The PASS computers obtain this software from upper memory.

#### CAUTION

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.

Because OPS 3 software is now in PASS upper memory, a reduced wait time until engaging BFS on the OPS 3 transition is being pursued. The 68 seconds mentioned above is a holdover from when the OPS 3 software had to be loaded from the mass memory units (MMUs). The maximum time it would take to try and load the software after attempting both MMUs 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  $\Delta V$  to the shuttle's energy. (Several missions have used 200 fps  $\Delta V$ .) 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.

The shortfield speed brake option is automatically selected for TAL. Should nominal speed brake be desired, an ITEM 39 (S/B) on SPEC 50 will be required.

#### Post MECO Transoceanic Abort Landing

An intact abort capability is available between  $V_i \sim 21.5$  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 (ELs), and the program has decided to try for an AOA rather than land at an ELS.

MECO velocity takes into account the  $\Delta V$  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. The only option in this situation is to abort to an ELS or to bail out. For inclinations  $<57^\circ$ , a high-energy TAL procedure is also 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.

#### 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  $\Delta V$  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

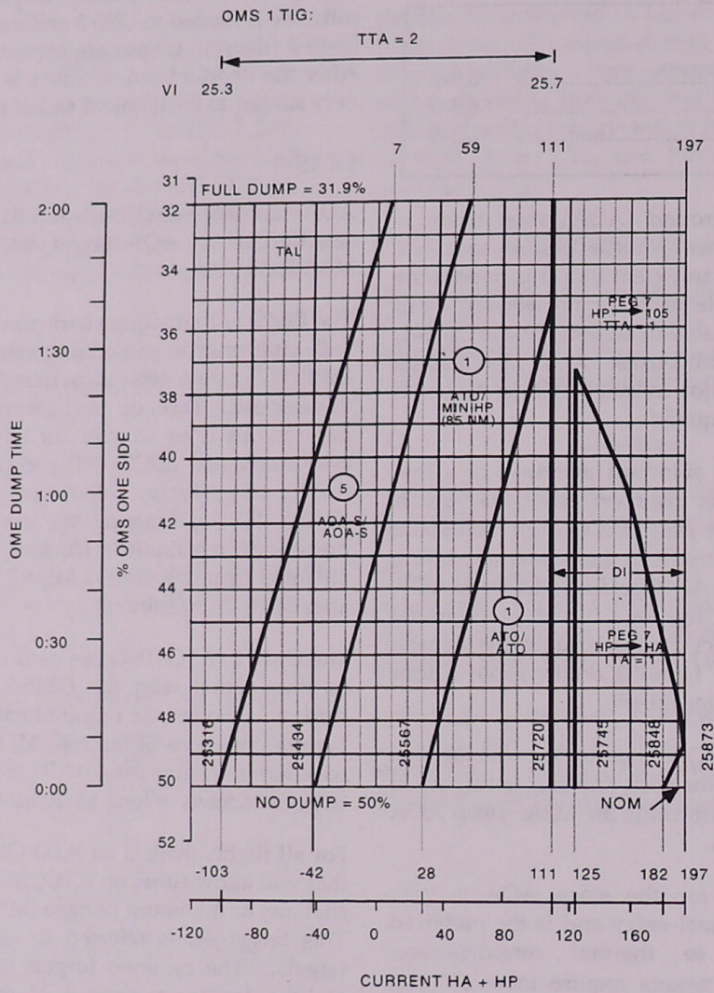
AOA can only be selected post MECO by crew selection of an AOA target set on the OMS MNVR display.

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.





IF 1 ENG &  $\Delta V > 500$   
 1 OMS + FAILED OMS INTERCONNECTED TO RCS THC +X  
 857

OMS 1/2 TGTING Cue Card

**OMS 2 TARGETING**  
(DIR INSERTION)

FAILURE	OMS 2 TARGET
OMS - 2 N2 TKs (Perform burn Single OMS Eng)	NOM
OMS - 2 OMS ENGS - 1 He TK - 2 He TKs - 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	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

**ATO**

**NOTE**  
These tables apply only after ATO OMS 1 burn  
(ITGT = ①, AOA to [KSC]). Assumes OMS and ARCS deorbit

DUAL POD - OMS REQUIRED				
Includes 8.8 % Unusable (4.4 % 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	37.6	22.6	41.9	26.5
90	38.2	19.1	39.0	22.1
85	39.9	17.5	35.9	19.0
80	41.8	17.3	34.4	16.0
75	43.8	18.7	31.2	13.0
70	45.7	20.9	27.9	10.4
65	47.0	22.3	25.3	8.8
60	47.9	23.6	24.3	8.8
55	48.4	24.7	25.5	8.8
50	49.0	25.9	25.7	8.8

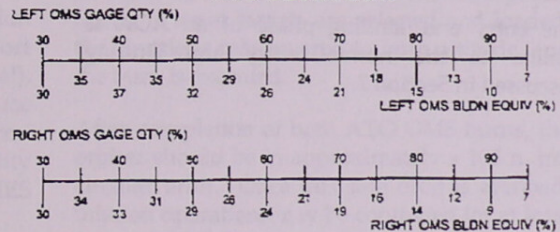
STS-101 OIGFCY

SINGLE POD - OMS REQUIRED				
Includes 4.4 % 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	33.1	18.2	37.5	22.1
90	33.8	14.7	34.6	17.6
85	35.5	13.1	32.5	14.6
80	37.4	12.9	30.0	11.6
75	39.4	14.3	26.8	8.6
70	41.3	15.5	23.5	6.0
65	42.6	17.9	20.9	4.4
60	43.5	19.2	19.9	4.4
55	43.9	20.3	21.1	4.4
50	44.6	21.5	21.3	4.4

**OMS**

He	%	He	%
4800	87.8	2890	40
4490	80	2490	30
4090	70	2090	20
3690	60	1690	10
3290	50	1290	0

**OMS BLOWDOWN**



**Post-ATO(1) 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/Abort 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 (usually the same as nominal), and may enable variable I-Y steering to reduce inclination. 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 identical to nominal ascent, 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.

## 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:

- $\bar{a}$  - 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:

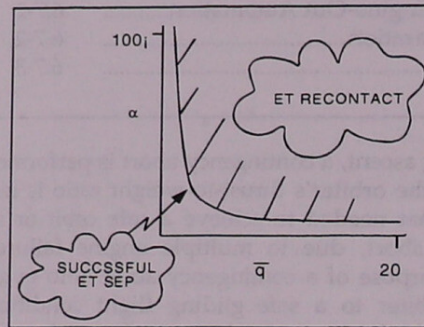
- RTLS abort declaration (if not previously selected)
- Maneuver to ET separation attitude (if required)
- ET separation
- Post-separation -Z translation
- Interconnected OMS dump (if required)
- Inhibit FRCS dump (if required)
- MM 602 transition

### 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,  $V_{\infty}$  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:

$$N_z \text{ target} = -H\text{-dot}/1000 + 0.65 \text{ at } \alpha = 1.0.$$

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<sub>1</sub> 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<sub>1</sub> 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<sub>1</sub> 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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APU/Hydraulics .....	6.8-2
Communications.....	6.8-5
Cryo .....	6.8-6
Data Processing System.....	6.8-6
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Orbital Maneuvering System/ Reaction Control System.....	6.8-14

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 save the affected system.

Procedures in the Ascent, Orbit, and Entry Pocket Checklists (PCL) are designed to save 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 emergency procedures for the orbiter 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, inter-connecting 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, 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 lock-up. Loss of two hydraulic systems in powered flight will result in two SSME hydraulic lock-ups, one of which will have no thrust vector control (TVC).

### APU Failure

- Hydraulic pressure goes to zero
- 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

Specific software and hardware caution and warnings occurring at the time of failure inform the crew if the shutdown was due to an overspeed or underspeed. MCC uses additional telemetry data to confirm the type of shutdown.

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 sensor problems are involved, reconfiguration of PRL may be required.

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 an overspeed will never be restarted.

### Hydraulic System Failure

- Pressure decrease on both CRT and meter (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 (~1200 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 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 CRT 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. If rpm does not shift when the controller is taken to high speed, the failure is real. 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, then the problem was in the controller. If temperatures continue to rise, APU shutdown may be required.

An APU will run for 4 to 5 minutes without lube oil cooling. 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.

#### Fuel Tank Valve Overtemp

- High valve temperature
- SM ALERT
- FU TK VLV APU message

When the fuel tank isolation solenoid valves are powered open without fuel flow for cooling, excessive heating can occur. High temperatures may cause hydrazine detonation. The crew should verify the fuel tank isolation valve switch is closed, then open the appropriate circuit breaker on panel R2 to remove power from the valve solenoid.

#### Priority Rate Limiting

- Possible differing hydraulic pressure on CRT and meter
- 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
- SMO 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 to monitor signal strength. If comm is not restored, the *ANTENNA* rotary switch on panel C3 is returned to *GPC*, and TDRS mode is configured since it provides the greatest coverage.

An in-flight maintenance procedure is available to bypass a completely failed ACCU.

Finally, the procedure provides steps to determine if MCC can uplink to a GNC GPC for state vector updates. If comm is not regained, the crew may have to deorbit without MCC direction to preserve IMU alignment entry limits.

### 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, an in-flight maintenance procedure may be performed to bypass the UHF power amplifier. 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 located under the payload bay. The cryo O2 system also supplies oxygen to the crew module for metabolic use and also 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, the location of the leak 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 caused by a control problem or a failure of the heater itself. MCC normally will alert the crew to these conditions. Redundant heaters are used if a heater problem is present. 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 caution and warning system. Failure signatures are presented 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.

FAILURE	CAUTION & WARNING		PROCEDURE	COMMENTS
	HARDWARE	SOFTWARE		
Generic PASS Fatal Software Error	GPC light CAM lights	GPC Fail message Down arrow on SYS SUMM	GPC Fail	GPC Continues to send commands over data bus
Fail to Halt	BP Output tb P Mode tb CAM lights GPC light CRT 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 CRT Big X Poll Fail	GPC Fail message Down arrow on SYS SUMM	GPC Fail	Like fail to halt, except talkbacks (tbs) do not turn barberpole (BP)
Generic PASS Fatal Software Error	Fail to quit or halt on all four GPCs simultaneously/all PASS driven CRTs 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 CRT 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 comm problems		BCE String x message M's on PFS 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 of X or QA MSG	I/O Error PCM	

DPS Failure Signatures

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.

#### 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

Restraining 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 TACAN
- 1 ADTA

#### BFS Failures

For most transient 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 CRT, 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 (CRT 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 avionics bay fans and freon pumps are switched. This prevents electrical transients. Should avionics bay temperatures exceed limits, activation of the alternate water loop is also 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 2 H2O loops or 2 Freon loops.

### Fire

- Siren
- Master alarm
- *SMOKE DETECTION* lights on panel L1
- Fault messages
- Smoke concentration on CRT display

If a fire is confirmed by checking the smoke concentration on the CRT display, the crew must protect themselves with helmets using the helmet retention assembly (HRA), then take 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
- CRT 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	<p><i>MASTER ALARM</i> Hardware caution &amp; warning <i>MAIN BUS UNDERVOLT</i> light and other lights on F7 matrix</p> <p>Fault messages MN volts = 0 CRT loss FC amps = 0</p>
FPC	<p><i>MASTER ALARM</i> Hardware caution &amp; warning <i>AC VOLTAGE</i> light, <i>FUEL CELL PUMP</i> light</p> <p>Fault messages AC volts = 0 AC amps = 0 MN volts good CRT loss Pump/motors</p>
AC	<p><i>MASTER ALARM</i> Hardware caution &amp; warning <i>AC VOLTAGE</i> light, other F7 lights</p> <p>Fault messages AC volts low AC amps low Pumps/motors</p>
ESS	<p><i>MASTER ALARM</i> Hardware caution &amp; warning</p> <p>Fault messages ESS volts low Bus loss ID <i>FUEL CELL PUMP</i> light on F7 matrix</p>
CNTL	<p>Control bus losses are difficult to diagnose. The signature could range from no indications to:</p> <p>SM Alert Fault messages, including SM CNTL/ESS V CNTL volts low Bus loss ID</p>
Panel/ Sub bus	<p>Equipment loss Bus loss ID</p>

### 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 O<sub>2</sub> or H<sub>2</sub> reactant valve fails closed, the fuel cell will fail from lack of fuel within 90 or 30 seconds, respectively.

#### Fuel Cell Cooling Loss

- MASTER ALARM
- FUEL CELL PUMP light (F7 matrix)
- FC PUMP message
- FC coolant pump DP 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 H<sub>2</sub> pump is running.
- If the coolant pump and the H<sub>2</sub> pump are not running, STACK T will decrease. EXIT T will increase slightly and stabilize.
- Combined coolant/H<sub>2</sub> 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 UNDERVOLTS 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.

#### 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 the flight control system properly in a highly augmented vehicle such as the orbiter. Since stability is negative in many flight regimes, 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 *VERRIDE*. This prevents a good channel from being bypassed in the event of a third failure.

#### Sensor Failures/Dilemmas

- SM ALERT
- 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 FDIR 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 protects against other electrical failures causing an engine shutdown. AC bus sensors are also taken off for AC power problems during ascent and entry, and for loss of main engine controller redundancy.

#### 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 He leg at a time. If the leak is isolated, the bad valve is kept closed and MCC evaluates He remaining 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
- Yellow *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 continues monitoring ascent. If the engine has failed, the shutdown pushbutton must be pressed to mode guidance for the engine failure.

#### Stuck Throttle

- SM ALERT
- Yellow *MAIN ENGINE STATUS* light on panel F7
- Static engine Pc
- SSME CMD (HYD, ELEC) message
- MCC call

SSME Pc is frozen in its last position for command path failure, loss of a hydraulic system, computer or sensor failures, and drifting valves. Procedures for these malfunctions are found on the MPS CMD/HYD/ELEC cue card. 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 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 only if first stage performance is low, and three engines are running.

For single stuck throttle, shutdown time varies for nominal ascent, TAL, and RTLS. The engine is usually shut down shortly before normal MECO to preserve the maximum amount of performance.

If two SSME throttles are stuck due to command path failures, they are shut down one at a time near MECO. The MPS *ENGINE POWER* switches (AC 1, 2, and 3) must be used for shutdown, followed by the *MAIN ENGINE SHUT DOWN* pushbuttons (AC/PB shutdown).

Two hydraulic or two electric lockups will cause the orbiter to exceed three g's in the latter part of ascent. One engine is shut down per the cue card or MCC call to prevent vehicle overstress.

Mixed failures require one engine to be shut down near MECO according to the following failure priority:

1. Command
2. Hydraulic
3. Electric

#### 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)

The software automatically defaults to a crew-initiated ET SEP if this switch fails to *MANUAL*, except for RTLS 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 CRT 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 He pressure decrease after the system has been secured. For this case, propellant is burned from the affected system to achieve blowdown capability. This amount of propellant remaining (39 percent OMS, 22 percent RCS) allows degraded use of the system even though the remaining helium is depleted.

A helium leg leak can be identified by the He 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 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

He 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 ENG PC message
- OMS light on panel F7

Depending on flight phase, the appropriate OMS BURN MONITOR cue card is used. Engine oxidizer/fuel inlet pressure is analyzed to determine whether the failure is real and if it was caused by a propellant problem upstream of the engine (PRPLT FAIL) or problems within the engine itself (ENG FAIL).

For engine failures, the remaining propellant can be used by the other engine or the RCS by setting up a crossfeed/interconnect. Propellant failures are more severe, since the remaining propellant is probably unusable. In some cases, where a partial blockage exists, it may be possible to feed the RCS jets using the remaining OMS propellant due to the reduced flow rate requirements.

#### RCS Jet Failures

- *MASTER ALARM*
- RCS light on panel F7
- RCS XJET 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.

Since the RCS jets have a great deal of redundancy, a single failed off jet usually has no major effect. The remaining jets take over per the software jet select priority. MCC will examine the telemetry data to determine

whether the failure is a transducer or an actual jet problem. If required, 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 pods or left and right RCS pods. The crossfeed valves and lines also allow the OMS and RCS systems to be inter-connected. 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. The software will also automatically deselect manifolds and reconfigure the system for DPS and electrical failures for some ascent aborts.

Generally, the automatic reconfiguration can handle single failures and some multiple failures for ascent aborts. The crew must ensure that valves are configured correctly 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 troubleshooting 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 cause this annunciation. For either case, operation on the secondary gimbal is initiated. A second gimbal failure may require securing 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 while a burn is not being performed may be overcome if the remaining gimbal system can be used to position the engine through the c.g. Gimbal power is then removed via an item entry on the MNVR display. The procedure protects against additional failures that might make the 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 L (C,R) main engine to close. Should a helium leak subsequently occur, and isolation procedures are attempted, closing the B helium isolation valve on the affected engine would result in an unplanned engine 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 has failed is the ullage pressure indication directly below the Helium dp/dt readout on BFS GNC SYS SUMM. With an APC/ALC down, LH2 ullage pressure 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 MPS command and data path problems or inhibit ET SEP. Because of this, should a set split occur during ascent, BFS engage may be required for throttling and ET SEP. Flight Rules permit reconfiguring the PASS GPCs after the set split if certain very specific conditions are met. For most cases, though, the BFS engage will be performed to ensure vehicle safety at MECO.

### Stuck Throttle in the Bucket

MCC uses the ARD to evaluate uphill capability for this case. Depending on throttle level and actual performance, it may be possible to continue into orbit. If not, the downmode preference is TAL, followed by RTLS. This is a real-time call and can only be made by the MCC.

### 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 will affect flight control for landing, 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 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, using a hydraulic circulation pump 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. 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 POWER-DOWN. 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

RCS is used to perform the remaining ascent and deorbit burns. If RCS is insufficient to accomplish a safe orbit insertion or deorbit, then RCS capability will be used to obtain the best performance possible. A staged deorbit burn using aerobraking to provide some of the deorbit deceleration may be possible.

#### OMS/RCS Leak with DPS/EPS Failures

Electrical failures affect the capability to operate the motor-driven OMS/RCS valves, and DPS failures affect software commands to the valves. EPS failures especially compromise leak isolation capability. If time permits, the OMS/RCS sliderule is used to determine which valves are operational for various failures. Some workarounds are available.

To work around a tank isolation valve that cannot be closed, the corresponding helium isolation valve should be closed. As pressure decreases in the affected propellant tank, flow will occur preferentially from another higher pressure tank.

During entry after  $q$ -bar = 20 psf, to attempt leak isolation, NO YAW JET may be temporarily selected and the entire RCS system secured. Even though some valves may remain open due to DPS/EPS failures, it still may be possible to isolate the leak if no jet fire commands are issued.

#### NOTE

Although NO Y JET is certified at  $q\text{-bar} = 20$  psf, it would be best if the RCS system is not secured until  $q\text{-bar} = 40$  psf. Before  $q\text{-bar} = 40$  psf, it is possible for a pitch jet to fire. With an RCS system only partially secured due to an EPS failure, evacuated tank legs are possible. This would complicate leak analysis due to a jet firing.

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 H<sub>2</sub> or O<sub>2</sub> is depleted. Emergency deorbit or ascent abort may be required, depending on leak rate.

#### BFS Self Engage

While this is not a multiple failure per sé, 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 will engage but the PASS does not shut down.