

Vent Locations

640

XXXX / 051 /	VERRIDE	XX X DDD/HH:MM:SS
ABORT MODE	ELEVEN	DDD/HH:MM:SS
TAL 1X	ENTRY FCS	
ATO 2X	FILTER	ATMOSPHERE
ABORT 3X	AUTO 17X	NOM 20X
MAX THROT 4X	FIXED 18X	ALT 21X
	SSME REPOS 19 XXX	S POLE 24X
PROPLT DUMP	IMU STAT ATT DES	PRL
XXX ICNCT 5 XXXX	1S XXXX X 25X	SYS AUT DES
OMS DUMP	2S XXXX XXX 26X	1S 28X 31X
ARM 6X	3S XXXX 27X	2S 29X 32X
START 7X	ADTA	3S 30X 33X
STOP 8X	L 1S	H α M DES
9 QUAN / SIDE XXX	3S	XXXXXX ±XX . X XX . X 34X
OMS DUMP TTG XXX	R 2S	XXXXXX ±XX . X XX . X 36X
AFT RCS 13 XXX	4S	±XX . X XX . X 37X
14 TIME XXX	ET SEP	ROLL MODE XXXXXXXX
FWD RCS 15 XXX	AUTO 38X	AUTO SEL 42X
16 TIME XXX	SEP 39X	
	ET UMB DR	VENT DOOR CNTL
	CLOSE 40X	OPEN 43X
	RCS RM MANF	CLOSE 44X
	CL OVRD 41	
		(XX)

VERRIDE Display (SPEC 51)

a GNC software sequence that can be started by a master timing unit, major mode transition, velocity, or CRT entry.

During countdown, the vent doors are in their purge positions until T-25 seconds when the OPEN sequence is automatically called by the redundant set launch sequencer. The vent doors remain open during ascent, orbital insertion, and all the on-orbit phases. During entry preparation, the crew closes

Nominally, the system operates automatically except for the preentry configuration, which is commanded by the orbiter crew at the appropriate time. In the return-to-launch site (RTL) abort mode, major mode (MM) 602, automatic closure of all vent doors is commanded by GPC software sequence. In the BFS, the vent doors are also controlled by the crew with item entry on BFS OVERRIDE display SPEC 51.

PASS			BFS		
Major Mode	Command		Major Mode	Command	
	Open	Close		Open	Close
301	All doors open	All doors close then L1 and 2 and 8 and 9 auto reopen	301	All doors open	All doors close, then L1 and 2 and 8 and 9 auto reopen
302	All doors open	CMD all vent doors close	302 (602)	All doors open	If 1st CLS CMD, then CLS all vents; if not CMD ignored
303	All doors open	CMD all vent doors close	303 (603)	All doors open	If 1st CLS CMD, then CLS all vents; if not CMD ignored
At 304 transition		CMD all vent doors close	At 304 transition		If no CLS flag set, then CLS all vent doors
304	L1 and 2 and 8 and 9 open	CMD all vent doors close	304	L1 and 2 and 8 and 9 open	None
305 (Mach 2.4)	All doors open auto or manual	All vent doors will close only if post roll-out	305 (Mach 2.4)	All doors open auto or manual	None

Vent Door Software Overview

all vent doors except vents 1, 2, 8, and 9 portside. These vents are left open to vent any hazardous gases during deorbit burn and to prevent vehicle overpressurization should a rapid OMS/RCS leak occur. These vents are automatically closed before entry interface.

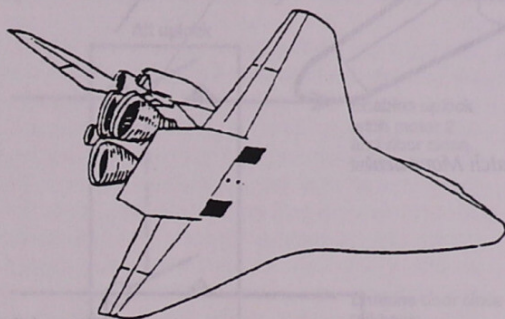
When the relative velocity of the orbiter reaches 2400 ft/s, all the doors are commanded open. After the orbiter has stopped on the runway, ground cooling may be required. This is accomplished in part by purging the vehicle with cooled air or nitrogen with the vent doors once again in their purge position.

External Tank Umbilical Doors

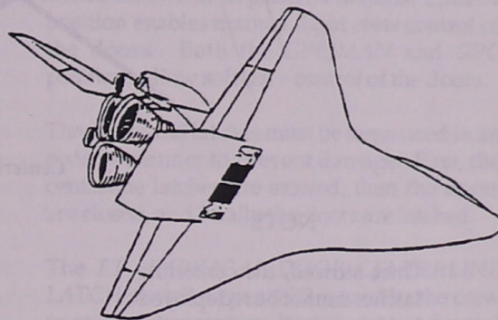
Electrical and fuel umbilicals between the external tank (ET) and the orbiter enter the Shuttle through two aft umbilical openings located on the underside of the orbiter. The umbilical cavities contain the orbiter/ET attachment points and the fuel and electrical disconnects. After the ET separates from the orbiter, the two aft umbilical openings are exposed. Two ET umbilical doors cover the exposed areas, shielding them from entry heating.

Each umbilical door is covered with reusable thermal protection system tiles in addition to an aerothermal barrier that requires approximately 6 psi to seal the door with adjacent thermal protection tiles. The left door covers the liquid hydrogen umbilical, and the right door covers the liquid oxygen umbilical. Each door is approximately 50 inches square. Each door is driven open and closed by two three-phase ac motors and is connected to the orbiter by two hinges. Two different types of latches, centerline and uplock, hold the doors open and closed respectively.

Two centerline latches, one forward and one aft, hold the ET doors open during ascent. In the latched position, the centerline latch blades fit into a notch on the outer edge of the left and right doors. The centerline latches must be disengaged from the doors before both ET doors can be closed. When unlatched, the two centerline latches retract into the body of the orbiter and are then considered stowed. Nominally, 6 seconds are required to stow the centerline latches. The centerline latches are driven to the stowed position by two three-phase ac motors.

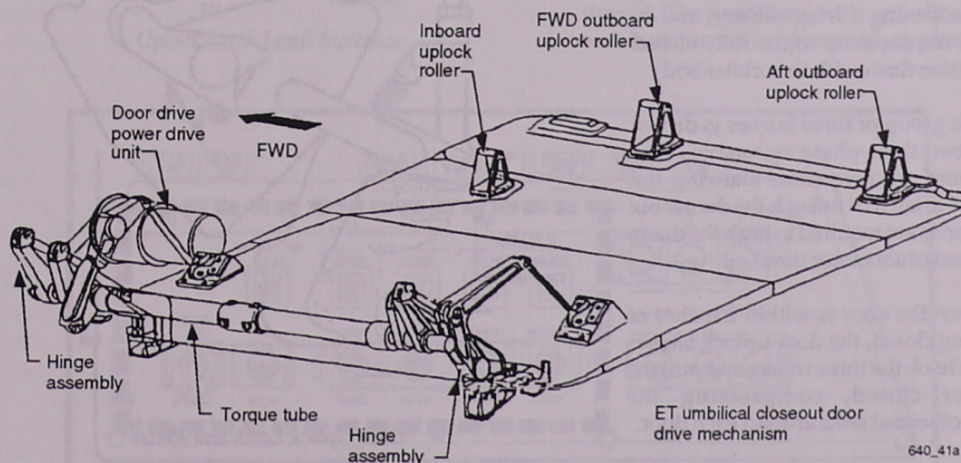


ET doors closed

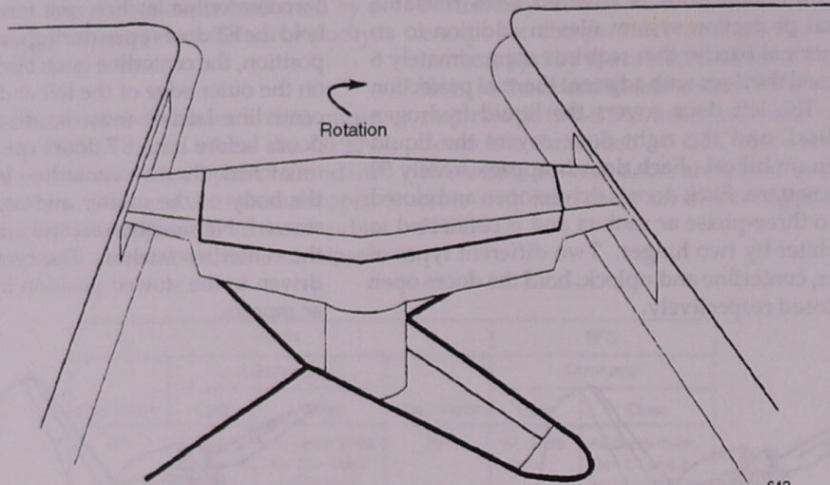


ET doors open

ET Door Positions



Right Side ET Umbilical Door



Centerline Latch Movement

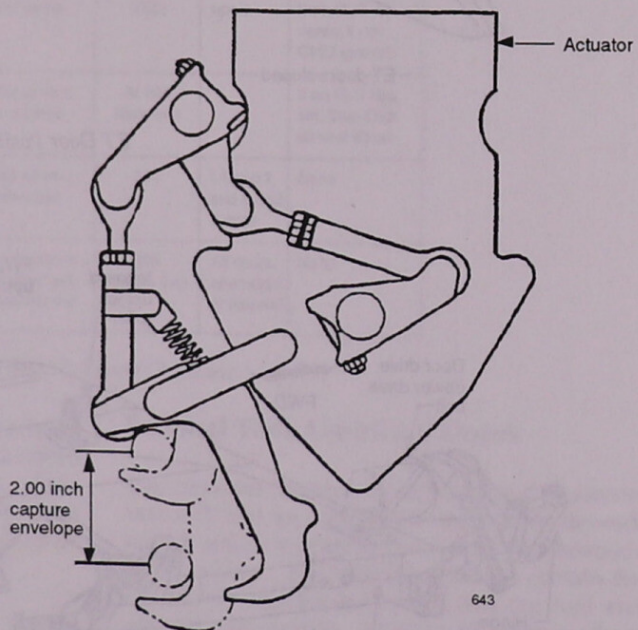
NOTE

Once stowed, the centerline latches cannot be redeployed by the crew; the task must be completed by ground crews.

Three uplock latches are located inside each umbilical cavity; the latches engage three uplock rollers located on each door. The latches are designed to prevent the doors from vibrating or reopening during reentry, and to pull the doors up to the fully closed position flush with the orbiter body.

Each group of three latches is driven by two three-phase ac motors. The motors are reversible, allowing the crew to latch or unlatch the doors. Six seconds are required to latch the doors closed (dual motor time).

When the door is within 2 inches of being closed, the door uplock latches can hook the three rollers and pull the door closed, compressing the aerothermal seals around each door.



Door Uplock Latch and Roller

CAUTION

Thermal damage will occur if the ET doors are not fully latched flush with the orbiter body.

The status of the uplock latches is provided by limit switches.

The door ready-to-latch limit switches enable the door uplock latch drive mechanisms. The left door ready-to-latch limit switches enable the left door uplock latches, and the right door ready-to-latch

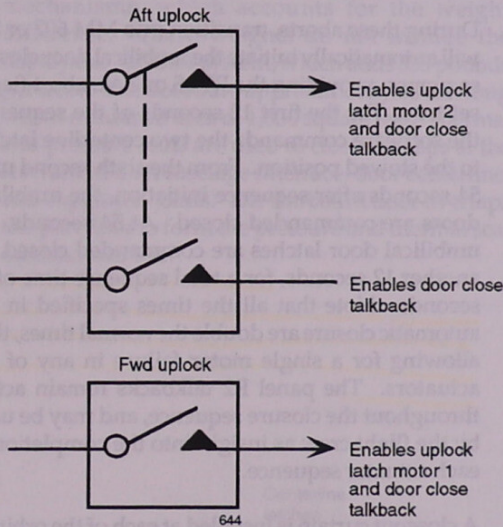
limit switches enable the right door uplock latches. Two out of three ready-to-latch indications are required to enable the door uplock latches.

ET Door Operations

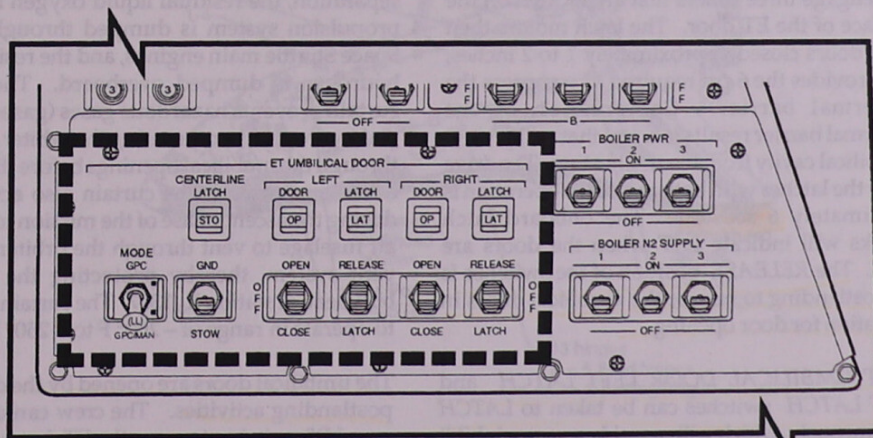
The ET doors are closed post OMS-1 burn after MPS vacuum inerting. The doors are controlled by the crew by switches on panel R2. The doors are also automatically controlled by the PASS or (BFS) software during TAL and RTL aborts, certain contingencies, or if selected by the crew on the GNC SPEC 51 OVERRIDE display. The *ET UMBILICAL DOOR MODE* switch on panel R2 in the *GPC/MAN* position enables manual flight crew control of the doors. Both the *GPC/MAN* and *GPC* positions allow software control of the doors.

The doors and latches must be sequenced in an orderly manner to prevent damage. First, the centerline latches are stowed, then the doors are closed, and finally the doors are latched.

The *ET UMBILICAL DOOR CENTERLINE LATCH* switch on panel R2 is used by the crew to stow the centerline latches during normal operations. Positioning the switch to *STOW* provides electrical power to redundant ac motors that operate an electromechanical actuator for each centerline latch. This will cause the latches to rotate and retract such that the latch blades will be flush with the orbiter thermal protection system mold line when stowed. The stow time for the centerline latches with both motors in operation is approximately



Uplock Latch Limit Switches



ET UMBILICAL DOOR Controls on Panel R2

6 seconds. The talkback above the switch will indicate barberpole when the latches are deployed, and *STO* when the latches are stowed. The microswitches that drive the talkback are located within the centerline latch drive mechanism and are activated based on the position of the latch. The *ET UMBILICAL DOOR CENTERLINE LATCH* switch is then taken back to the *GND* position, which removes power from the centerline latch motors.

The *ET UMBILICAL DOOR LEFT DOOR* and *RIGHT DOOR* switches on panel R2 are used by the crew to close the ET doors. Positioning the switches to *CLOSE* provides electrical power to redundant ac reversible motors, which drive the doors through a system of bellcranks and pushrods. With both motors in operation, the doors will close in approximately 24 seconds. As the doors move within 2 inches of being closed, two operations take place. First, microswitches within the door power drive unit inhibit power from the door drive motors. Second, two rollers mounted on the outboard edge of each door contact two ready to latch paddles in the umbilical cavity. The two ready to latch paddles drive three microswitches that enable the uplock latch motors and the onboard close talkback. Two of the three microswitch indications are needed to provide a *CL* indication on the door drive talkback.

The *ET UMBILICAL DOOR LEFT LATCH* and *RIGHT LATCH* switches on panel R2 are used by the crew to latch the ET doors. Positioning the switches to *LATCH* provides electrical power to redundant ac motors that drive the three uplock latches through a system of pushrods. The uplock latches engage three rollers that are located on the inside face of the ET door. The latch motors then pull the doors closed approximately 1 to 2 inches, which provides the 6 psi required to compress the aerothermal barrier. Compression of the aerothermal barrier results in a seal that will protect the umbilical cavity from reentry heating. The drive time for the latches with both motors in operation is approximately 6 seconds. The onboard latch talkbacks will indicate *LAT* when the doors are latched. The *RELEASE* position of the switches is used postlanding to release the umbilical doors in preparation for door opening.

The *ET UMBILICAL DOOR LEFT LATCH* and *RIGHT LATCH* switches can be taken to *LATCH* simultaneously, which will override a power inhibit to the latch motors resulting from insufficient ready-

to-latch indications. Mission Control has additional telemetry that will determine if a power inhibit exists because of missing ready-to-latch indications.

The *ET UMBILICAL DOOR MODE* switch on panel R2 positioned to *GPC* or *GPC/MAN* provides a backup method of stowing the centerline latches and closing the umbilical doors through the *GNC SPEC 51 OVERRIDE* display (*PASS* or *BFS*). Selecting item 40 (*ET UMB DR CLOSE*) in *PASS* or item 30 in *BFS* will bypass panel R2 switches and automatically close the ET doors. This software-driven method is automatically performed during *RTL*s and *TAL* aborts.

During these aborts, transition into MM 602 or 304 will automatically initiate the umbilical door closure sequence, providing the *RTL*s or *TAL* abort flag is set true. For the first 12 seconds of the sequence, the software commands the two centerline latches to the stowed position. From the sixth second until 54 seconds after sequence initiation, the umbilical doors are commanded closed. At 54 seconds, the umbilical door latches are commanded closed for another 12 seconds, for a total sequence time of 66 seconds. Note that all the times specified in the automatic closure are double the normal times, thus allowing for a single motor failure in any of the actuators. The panel R2 talkbacks remain active throughout the closure sequence, and may be used by the flight crew as insight into the completion of each actuator sequence.

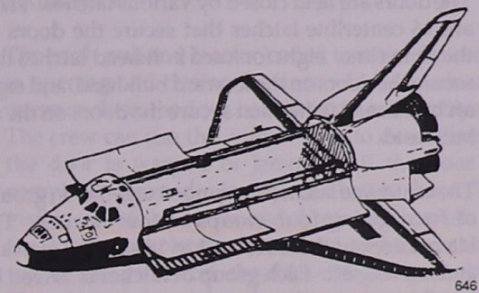
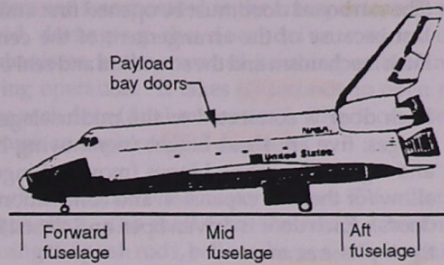
A closeout curtain is installed at each of the orbiter/external tank umbilicals. After external tank separation, the residual liquid oxygen in the main propulsion system is dumped through the three Space Shuttle main engines, and the residual liquid hydrogen is dumped overboard. The umbilical curtain prevents hazardous gases (gaseous oxygen and hydrogen) from entering the orbiter aft fuselage through the umbilical openings before the umbilical doors are closed. The curtain also acts as a seal during the ascent phase of the mission to permit the aft fuselage to vent through the orbiter purge and vent system, thereby protecting the orbiter aft bulkhead at station X₀ 1307. The curtain is designed to operate in range of -200° F to +250° F.

The umbilical doors are opened by the crew during postlanding activities. The crew can use only the panel R2 switches to open the ET doors.

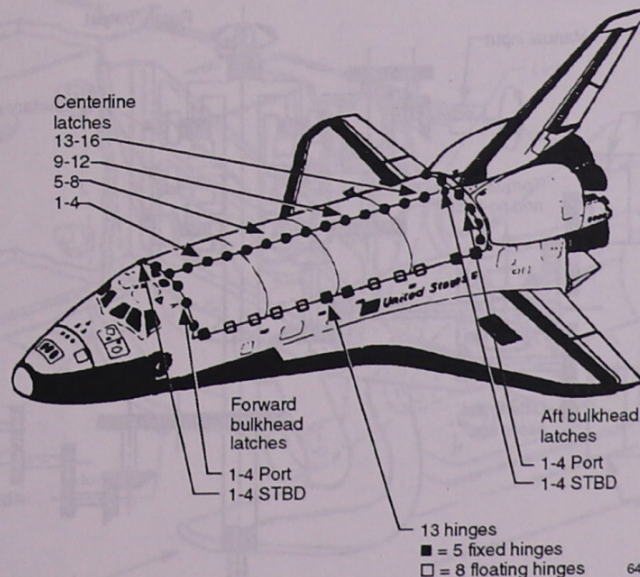
Payload Bay Door System

The payload bay doors provide an opening for payload deployment from and retrieval into the payload bay. The doors provide structural support for the orbiter midbody, and they house the ECLSS radiators that transfer heat from the vehicle to space.

There are two doors, port and starboard. Each door consists of five segments interconnected by expansion joints. The port door with attached systems weighs approximately 2,375 pounds, and the starboard door weighs about 2,535 pounds. The starboard door contains the centerline latch active mechanisms, which accounts for the weight difference. These weights do not include the deployable radiator system, which adds 833 pounds per door. The doors are approximately 60 feet long with a combined area of 1,600 square feet. Thermal and pressure seals are used to close the gaps at the forward and aft fuselage interface, door centerline, and expansion joints. The starboard door overlaps the port door to form the pressure and thermal seal on the centerline.



Payload Bay Doors Location



Payload Bay Door Latch Locations

The starboard door must be opened first and closed last because of the arrangement of the centerline latch mechanism and the structural and seal overlap.

Each door is connected to the midfuselage by 13 hinges; five are shear hinges (nonmoving hinges) and eight are floating hinges (moving hinges that allow for thermal expansion and contraction of the doors). Each door is driven open and closed by two three-phase ac motors.

The doors are held closed by various latches. There are 16 centerline latches that secure the doors on the centerline: eight forward bulkhead latches that secure the doors on the forward bulkhead, and eight aft bulkhead latches that secure the doors on the aft bulkhead.

The centerline latches are ganged together in groups of four, giving four groups of four latches. The latches are numbered from 1 to 16 starting forward and moving aft. Each group of latches is driven by a typical orbiter electromechanical actuator.

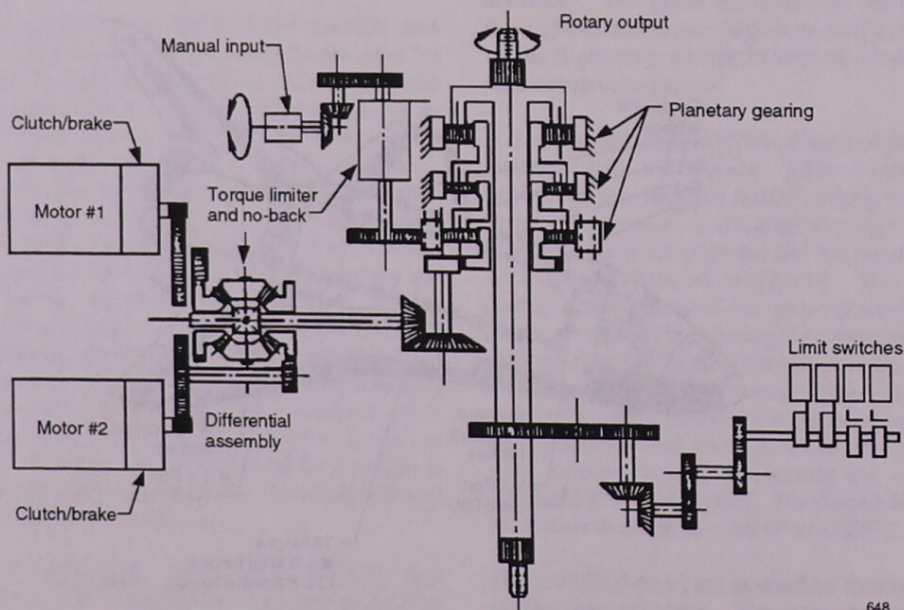
The motors are reversible, which allows the crew to latch or unlatch the doors.

The starboard door contains the centerline latch hooks, and the port door contains the centerline latch rollers. The hooks are the active portion of the centerline latch system; they rotate to grasp the latch rollers.

As the torque shaft rotates, the bellcrank and link cause the hook to rotate closed (or open), engaging the latch roller on the port door. Twenty seconds are required to open or close a group of centerline latches (dual-motor time).

The status of the centerline latch groups is provided by limit switches. There are two open and two closed limit switches associated with each centerline latch group. These limit-switch indicators relay the position of the latch group (i.e., latch group is open or closed). They also provide a method for enabling and disabling latch drive motors.

The bulkhead latches are ganged together in groups of four, giving a total of two groups of forward bulkhead latches, and two groups of aft bulkhead latches. Each group of latches is driven by a typical electromechanical actuator using two three-phase ac motors. The motors are reversible, which allows the crew to latch or unlatch the doors.



Payload Bay Door Centerline Latch Actuator Schematic

The latch hooks for the bulkhead latches are located on the forward and aft edges of each door, and the latch rollers are located on the forward and aft bulkheads. The hooks are the active portion of the bulkhead latch system; they rotate to grasp the latch roller.

As the torque shaft rotates, the linkage connecting the latches begins to move. This causes a staggered latch open or close sequence; **latch 1 closes first, then latch 2, 3, and 4.** Thirty seconds are required to open or close a group of bulkhead latches (dual-motor time).

The status of the bulkhead latch groups is provided by limit switches similar to those used by the centerline latches. There are two open and two closed limit switches for each bulkhead latch group. These limit-switch indicators relay the position of the bulkhead latch group (i.e., latch group is open or closed). They also provide a method for enabling or disabling the centerline latch drive motors and the payload bay door drive motors.

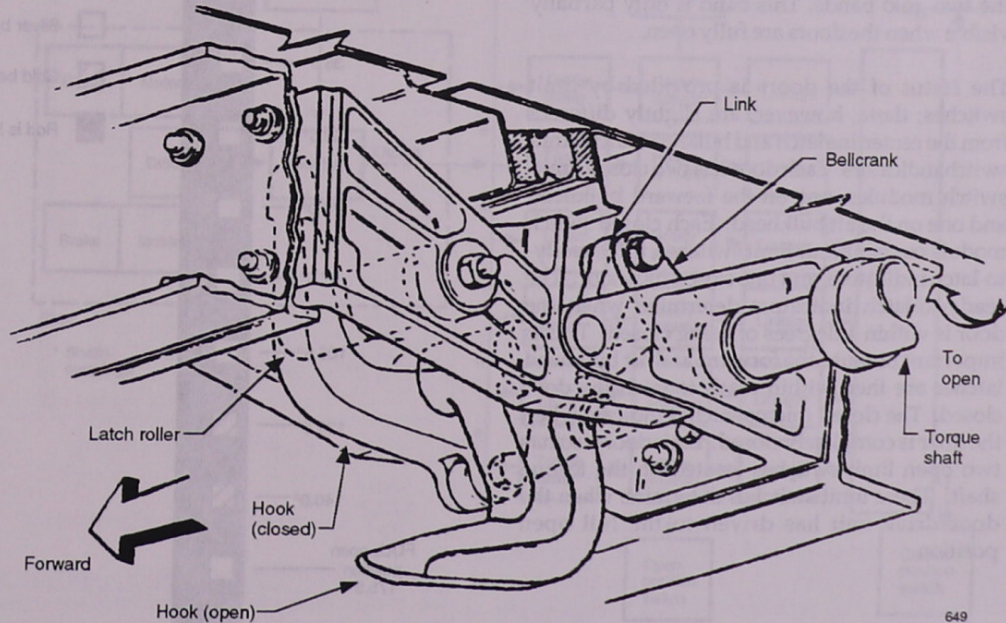
The doors are driven open or closed by a rotary actuator consisting of two three-phase ac motors per drive unit. (Each door contains its own.) Torque

limiters are incorporated in the rotary actuators to avoid damaging the door drive motors or mechanisms in the event of jamming or binding during operation. It takes **63 seconds** to open or close each door (dual-motor time). The doors open through an angle of **175.5 degrees**.

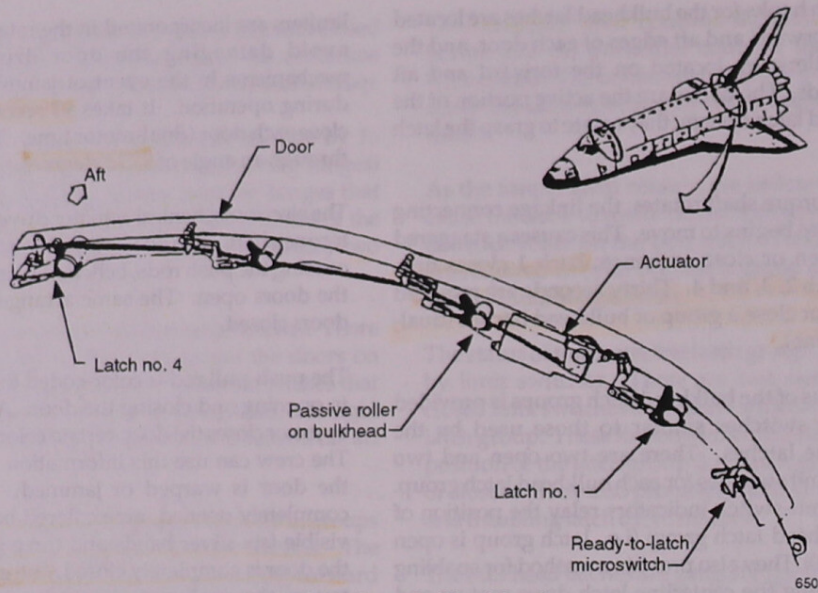
The electromechanical actuator drives a 55-foot-long torque shaft. The shaft turns the rotary actuators, causing the push rods, bellcranks, and links to push the doors open. The same arrangement pulls the doors closed.

The push-pull rod is color-coded to assist the crew in opening and closing the door. As the push rod opens or closes the door, certain colors are displayed. The crew can use this information to determine if the door is warped or jammed. **If the door is completely opened, nine colored bands should be visible (six silver bands and three gold bands).** **If the door is completely closed, one gold band at the top of the push rod should be partially visible.** **Therefore, if any of the silver bands are visible, the door is warped or jammed.**

Each band, gold or silver, represents the amount the doors are open or closed in degrees of rotation.



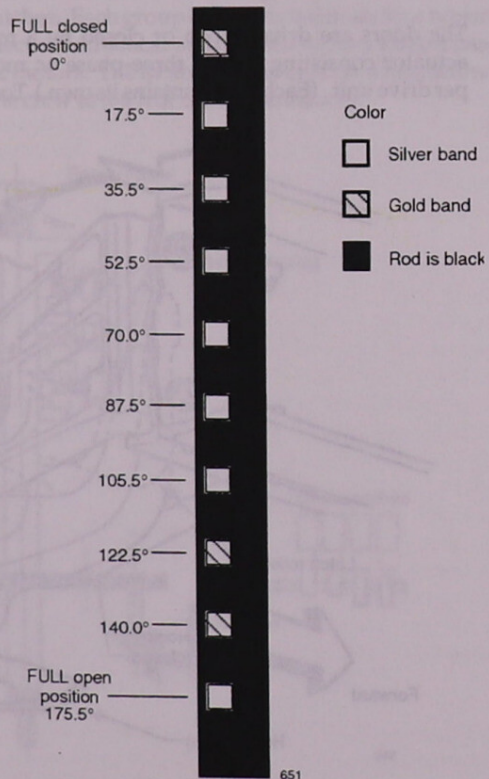
Payload Bay Door Centerline Latch



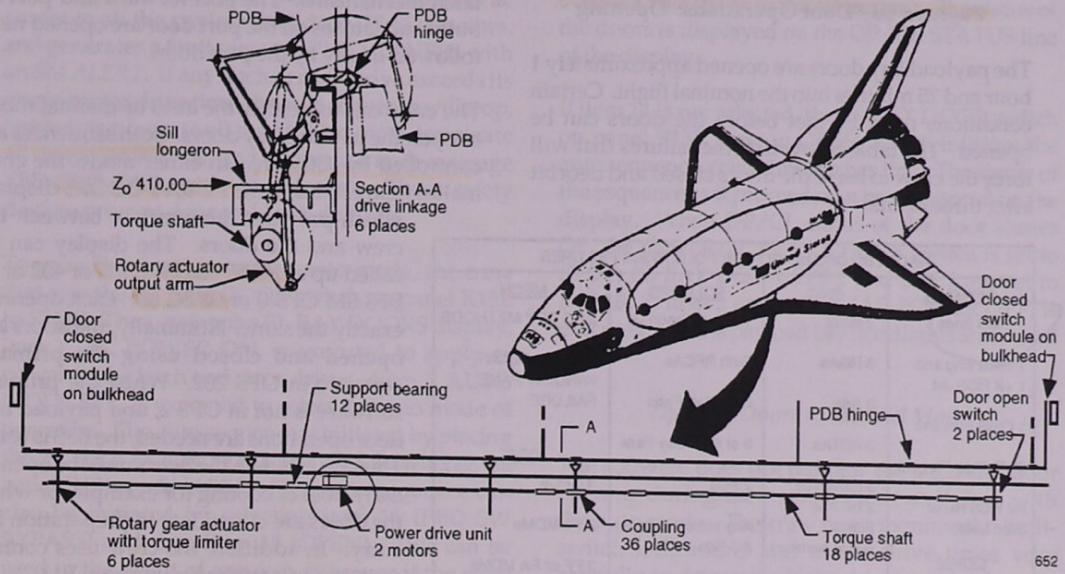
Payload Bay Door Bulkhead Latches

There are six push-pull rods per door. They can be located by looking along the sill longeron that runs along the entire length of the payload bay. There is actually a 10th band (silver) located below the two gold bands. This band is only partially visible when the doors are fully open.

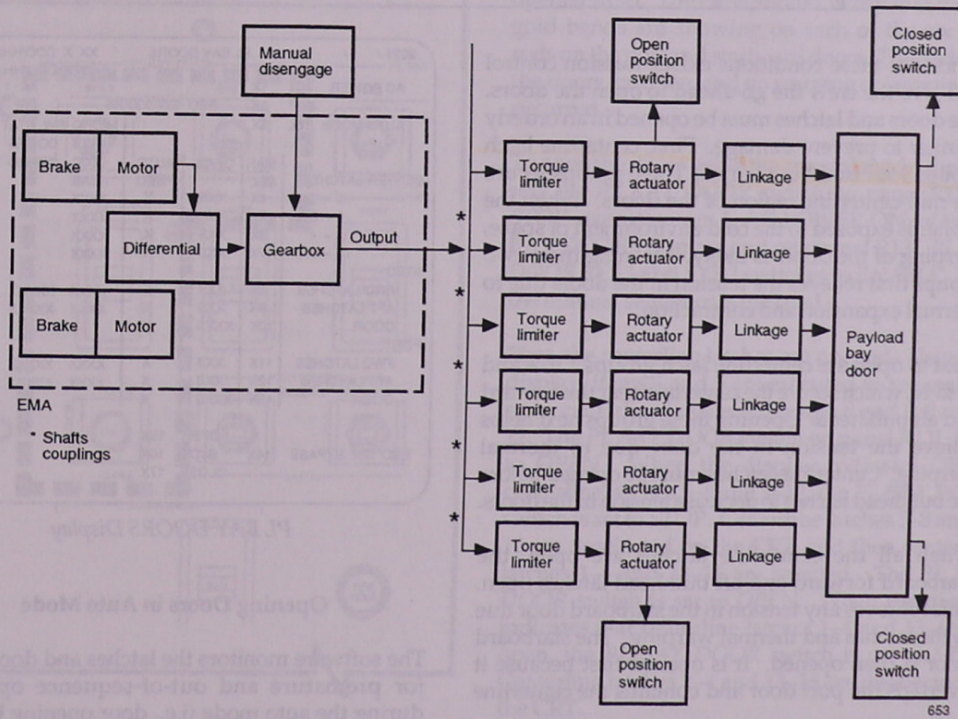
The status of the doors is provided by limit switches; these, however, are slightly different from the centerline latch and bulkhead latch limit-switch indicators. Each door has two closed limit-switch modules, one on the forward bulkhead and one on the aft bulkhead. Each closed switch module contains four limit switches, three ready-to-latch indicators, and one closed indicator. The ready-to-latch indicators determine when the door is within 4 degrees of being closed. This is important because the forward and aft bulkhead latches are then within reach to latch the door closed. The closed microswitches indicate when the door is completely closed. Each door also has two open limit switches located on the torque shaft. These limit switches determine when the door drive unit has driven to the full open position.



Push-Pull Rod Markings



Payload Bay Door Drive System



Payload Bay Door Drive System Mechanical Block Diagram

Payload Bay Door Operations: Opening

The payload bay doors are opened approximately 1 hour and 25 minutes into the nominal flight. Certain conditions must be met before the doors can be opened. The table below lists the failures that will force the crew to leave the doors closed and deorbit after three orbits.

RAD/PLBD OPS NO GO FOR FOLLOWING FAILURES			
OMS/RCS	GNC	ECLS/EPS	MECH
1 OMS Eng	2 IMUs	1 H ₂ O or Freon Lp	2 LG DPY METHODS
1 OMS Eng and 1 +X RCS Jet	3 RGAs	Both RFCAs	PRES or REDNT WINDOW PANE FAILURE
1 OMS Inlet line	3 AAs	Both Cab Fans	
OMS Prop Tk Leak	3 ADTAs	3 of 6 Av Bay Fans	DPS
Aft RCS He or Prop Leak	3 Elevon or 2 BF Pos Fdbks (same surface)	2 FCs	3 GPCs
COMM	2 FCS CH (same surface)	Any Mn or 3 phase AC Bus	2 PL MDMs
No Voice and No CMD		Any CNTL or MPC Bus	2 FF or FA MDMs
			APU/HYD
		3 IMU Fans	2 APU/HYD/WSB

If none of these conditions exists, mission control will give the crew the go-ahead to open the doors. The doors and latches must be opened in an orderly manner to prevent damage. First, centerline latch groups 5 to 8 and 9 to 12 open. These groups secure the mid-centerline region of the doors. When the orbiter is exposed to the cold environment of space, warping of the doors is likely. Opening these two groups first relieves the tension in the doors due to thermal expansion and contraction.

Next to open are centerline latch groups 1 to 4 and 13 to 16, which secure the centerline near the forward and aft bulkhead. Opening these groups next helps relieve the tension in the door due to thermal warping. Centerline latches must be opened before the bulkhead latches to decrease tension in the doors.

When all the centerline latches are open, the starboard forward and aft bulkhead latches open. This removes any tension in the starboard door due to the latches and thermal warping. The starboard door is then opened. It is opened first because it overlaps the port door and contains the centerline

latch mechanisms. The port forward and port aft bulkhead latches on the port door are opened next, followed finally by the port door.

The crew can use either the auto or manual mode to open the payload bay doors. Both sequences are controlled by software. In either mode, the crew makes item entries to the PL BAY DOORS display, which provides the interface between the crew and the doors. The display can be called up as PASS SM OPS 202 or 402 or as BFS SM OPS 0 or SPEC 63. Each operates exactly the same. Nominally, the doors are opened and closed using the primary software in OPS 202. When the primary software is not in OPS 2, and payload bay door operations are needed, the BFS is used. This occurs when the doors must be opened early (loss of cooling for example) or when the doors are closed late in preparation for entry. In addition, the crew uses control switches and talkbacks on panel R13L.

2021 / /		PL BAY DOORS			XX X DDD/HH:MM:SS BFS: DDD/HH:MM:SS	
AC POWER	ON 1X OFF 2X	PBD SW-XXXXX			MICRO-SW STAT	
AUTO MODE SEL	3X	MAN SEL	OP/CL	AUTO SEQ	LATS DOORS	CCOO CRRRO
CENTER LATCHES					ABAB	
5-8	4X	XXS	X	XXXX		
9-12	5X	XXS	X	XXXX		
1-4	6X	XXS	X	XXXX		
13-16	7X	XXS	X	XXXX		
STBD						
FWD LATCHES	8X	XXS	X	XXXX	XXXXX	
AFT LATCHES	9X	XXS	X	XXXX	XXXXX	
DOOR	10X	XXXX	X			
PORT						
FWD LATCHES	11X	XXS	X	XXXX	XXXXX	
AFT LATCHES	12X	XXS	X	XXXX	XXXXX	
DOOR	13X	XXXX	X			
PBD SW BYPASS	14X	OPEN 15X STOP 16X CLOSE 17X				

PL BAY DOORS Display

Opening Doors in Auto Mode

The software monitors the latches and door drives for premature and out-of-sequence operation during the auto mode (i.e., door opening before it is unlatched). If any of the latches or doors are out

of configuration, the auto mode stops, removes ac power to all the payload bay door (PLBD) motors, and generates a fault message PLBD CONFIG with an SM ALERT. If any latch or door drive exceeds its single-motor drive time, the auto sequence will stop, remove ac power to all the PLBD motors, terminate all drive commands, and generate a fault message PBD SEQ FAIL with an SM alert. These safety devices prevent door and latch damage.

To open the doors using the auto mode, the crew first sets the PL BAY DOOR switch on panel R13L to STOP. Then, using the PL BAY DOORS display, item 1, AC POWER ON, is executed to apply ac power to the latch and door drives. Item 3, AUTO MODE SEL, is executed to select the auto mode of operation. The auto sequence is initiated by placing the PL BAY DOOR SYS 1 and SYS 2 switches on panel R13L to ENABLE. (The auto sequence can also be initiated by selecting item 14 (PBD SW BYPASS) and then item 15 (OPEN). This can be used in the event of a switch failure or if the crew

does not want to go to the aft station). The status of the doors is displayed on the OP/CL STATUS line of the display.

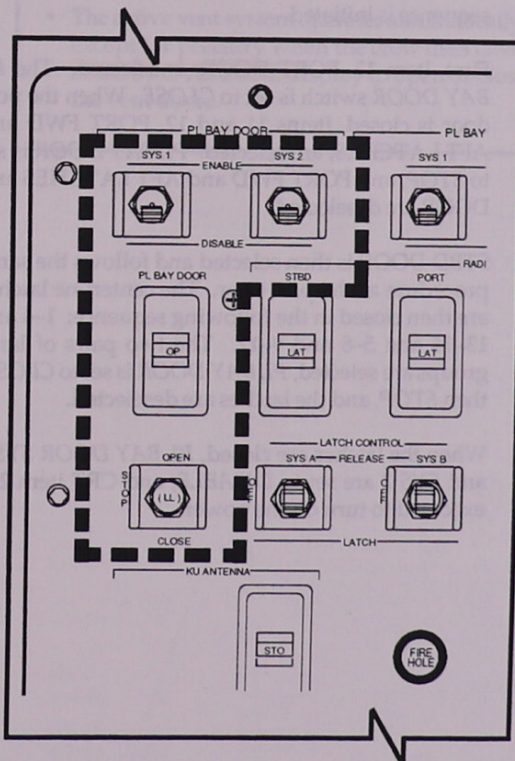
If item 14 is not selected, the PL BAY DOOR switch on panel R13L is set to OPEN, which initiates the auto sequence, centerline latches first. The status of the sequence as it proceeds can be monitored on the display. When OP/CL status of the door shows OP, the panel R13L PL BAY DOOR switch is set to STOP, PL BAY DOOR SYS 1 and SYS 2 are set to DISABLE, 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 crew should verify that the two gold bands are showing on each of the six push rods on the port and starboard doors. This indicates the doors are open, and no warping or jamming has occurred.

To open the doors using the manual mode, the crew sets the PL BAY DOOR switch on panel R13L to STOP, executes item 1, AC POWER ON, of the PL BAY DOORS display, and sets panel R13L PL BAY DOOR SYS 1 and SYS 2 switches to ENABLE. Then the manual sequence is initiated.

First, the centerline latches are opened. Using the display, items 4 and 5 are executed in sequence to open centerline latches 5 through 8 and 9 through 12. The PL BAY DOOR switch on panel R13L is set to OPEN. When the display indicates OP for centerline latches 5-8 and 9-12, the PL BAY DOOR switch is set to STOP. Centerline latches 5-8 and 9-12 are deselected on the CRT, and then centerline latches 1-4 and 13-16 are selected. The PL BAY DOOR switch is set to OPEN. When the display indicates that centerline latches 1-4 and 13-16 are open, the PL BAY DOOR switch is set to STOP. Centerline latches 1-4 and 13-16 are deselected on the CRT.



PL BAY DOOR Controls on Panel R13L

Next, the starboard forward and aft latches and door are opened. Items 8 and 9, STB FWD LATCHES and AFT LATCHES, are selected on the CRT. The *PL BAY DOOR* switch is set to *OPEN*. When the display indicates the latches are open, *PL BAY DOOR* is set to *STOP*. The latches are deselected, and item 10, STBD DOOR, is selected. The *PL BAY DOOR* switch is set to *OPEN* and then to *STOP* when the display shows OP. STBD DOOR is deselected on the CRT.

Finally, the port forward and aft latches and door are opened, using items 11, 12, and 13 to follow a sequence nearly identical to the one described above for the starboard door. The exception is that after the door is opened, and *PL BAY DOOR* switch is set to *STOP*, *PL BAY DOOR SYS 1* and 2 switches are set to *DISABLE* before deselecting PORT DOOR. Item 2 is then executed to turn AC POWER OFF, and the payload bay floods are also turned off.

Payload Bay Doors: Closing

The payload bay doors are closed approximately 2 hours and 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 bulkheads. 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 to 4, 13 to 16, 5 to 8, and 9 to 12.

The crew can use an auto or manual mode for closing the doors. The difference in monitoring between the two modes is the same as it is for opening the doors. Panel R13L and the *PL BAY DOORS* display are also used for closing the doors. The payload bay doors are normally opened and closed using the auto mode.

Closing Doors in Auto Mode

To close the doors using the auto mode, the crew sets the *PL BAY DOOR* switch on panel R13L to *STOP*. Item 1 on the *PL BAY DOORS* display is executed to turn ac power on, and item 3, *AUTO MODE SEL*, is executed. The auto sequence is initiated by placing the *PL BAY DOOR SYS 1* and *SYS 2* switches on panel R13L to *ENABLE* and then setting the *PL BAY DOOR* switch to *CLOSE*. The status of the sequence is displayed on the CRT. When the sequence is complete, the *PL BAY DOOR* switch is set to *STOP*, *PL BAY DOOR SYS 1* and *SYS 2* are set to *DISABLE*, and item 2 on the CRT is executed to turn ac power off.

Closing Doors in Manual Mode

To close the doors using the manual mode, the crew sets the *PL BAY DOOR* switch to *STOP*, executes item 1 on the display, and sets *PL BAY DOOR SYS 1* and *SYS 2* switches to *ENABLE*. Then the manual sequence is initiated.

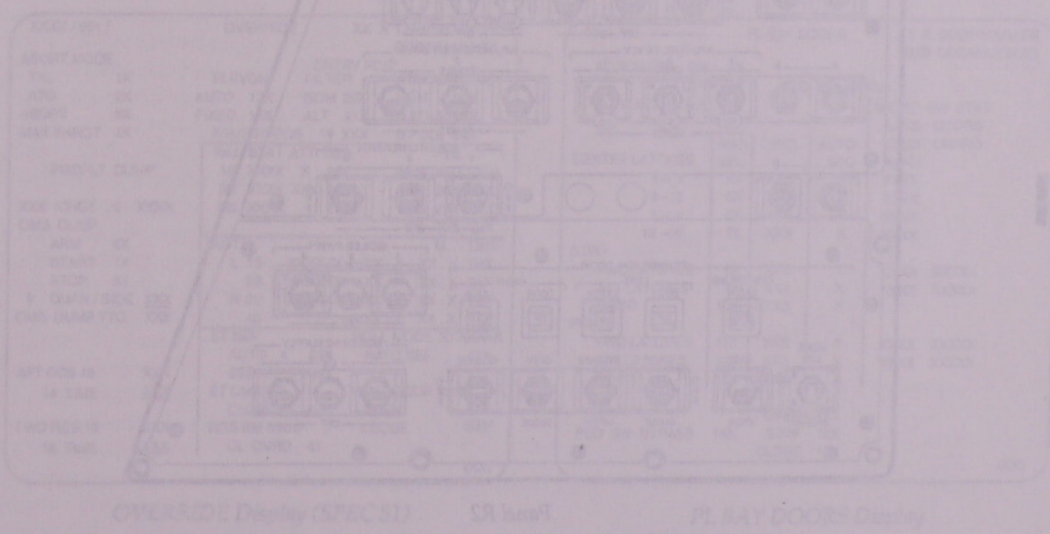
First, item 13, PORT DOOR, is selected. The *PL BAY DOOR* switch is set to *CLOSE*. When the port door is closed, items 11 and 12, PORT FWD and AFT LATCHES, are selected. *PL BAY DOOR* is set to *STOP*, and PORT FWD and AFT LATCHES and DOOR are deselected.

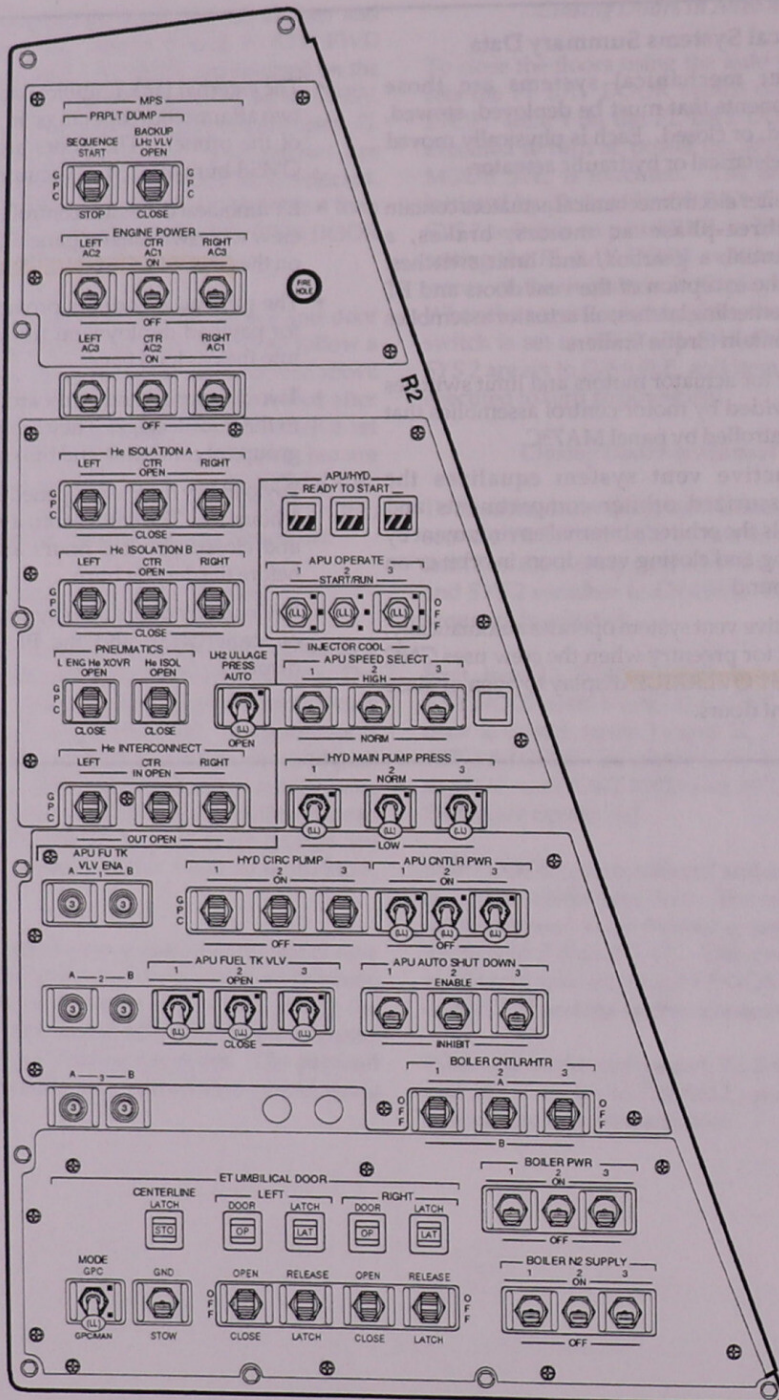
STBD DOOR is then selected and follows the same procedure as the port door. The centerline latches are then closed in the following sequence: 1-4 and 13-16 and 5-8 and 9-12. The two pairs of latch groups are selected, *PL BAY DOOR* is set to *CLOSE*, then *STOP*, and the latches are deselected.

When the latches are closed, *PL BAY DOOR SYS 1* and *SYS 2* are set to *DISABLE*, and CRT item 2 is executed to turn off the power.

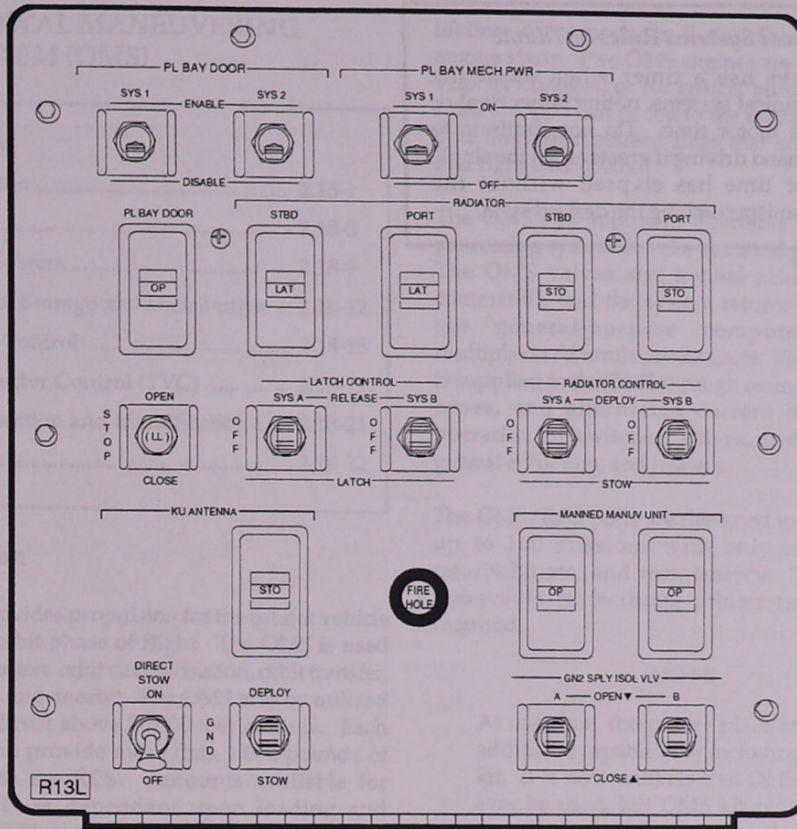
Mechanical Systems Summary Data

- 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 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 and 25 minutes into a nominal flight and closed about 2 hours and 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

XXXX / 051 /	VERRIDE	XX X DDD/HH:MM:SS
ABORT MODE	ENTRY FCS	DDD/HH:MM:SS
TAL 1X	ELEVON FILTER	ATMOSPHERE
ATO 2X	AUTO 17X	NOM 20X
ABORT 3X	FIXED 18X	ALT 21X
MAX THROT 4X	SSME REPOS 19 XXX	S POLE 24X
PROPLT DUMP	IMU STAT ATT DES	PRL
XXX ICNCT 5 XXXX	1S XXXX X 25X	SYS AUT DES
OMS DUMP	2S XXXX XXX 26X	1S 28X 31X
ARM 6X	3S XXXX 27X	2S 29X 32X
START 7X	ADTA H α M DES	3S 30X 33X
STOP 8X	L 1S XXXXXX ±XX . X XX . X 34X	
9 QUAN / SIDE XXX	3S XXXXXX ±XX . X XX . X 35X	
OMS DUMP TTG XXX	R 2S XXXXXX ±XX . X XX . X 36X	
AFT RCS 13 XXX	4S ±XX . X XX . X 37X	
14 TIME XXX	ET SEP ROLL MODE XXXXXXXX	
FWD RCS 15 XXX	AUTO 38X AUTO SEL 42X	
16 TIME XXX	SEP 39X	
	ET UMB DR VENT DOOR CNTL	
	CLOSE 40X OPEN 43X	
	RCS RM MANF CLOSE 44X	
	CL OVRD 41	

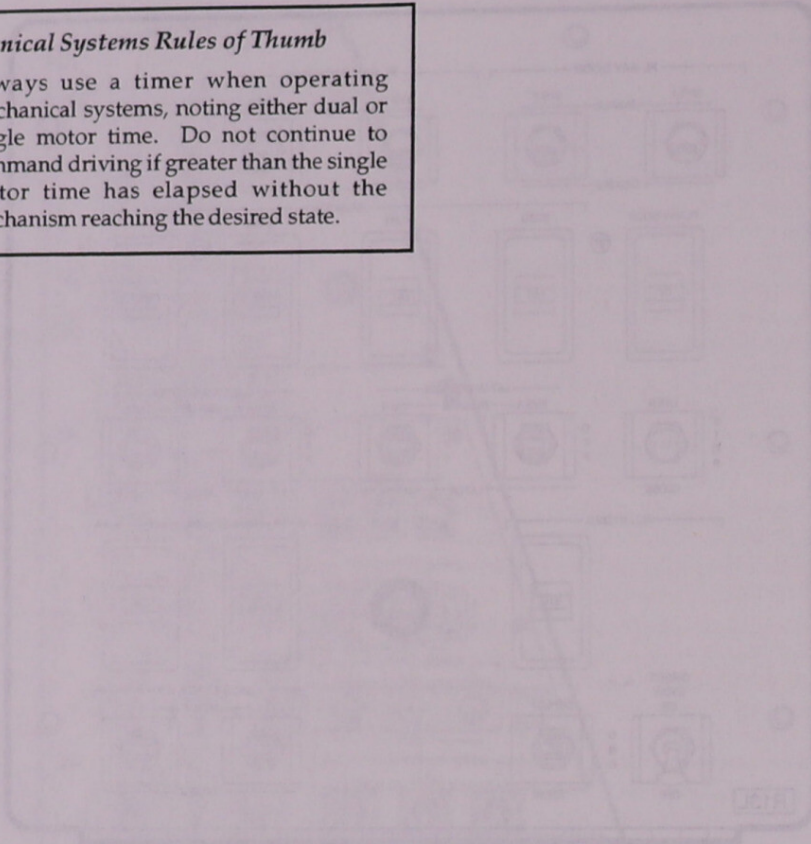
VERRIDE Display (SPEC 51)

2021 / /	PL BAY DOORS	XX X DDD/HH:MM:SS
AC POWER ON 1X		BFS DDD/HH:MM:SS
OFF 2X	PBD SW-XXXXX	
AUTO MODE SEL 3X		
CENTER LATCHES	MAN SEL	OP/CL
5-8	4X	XXS X
9-12	5X	XXS X
1-4	6X	XXS X
13-16	7X	XXS X
STBD		
FWD LATCHES	8X	XXS X
AFT LATCHES	9X	XXS X
DOOR	10X	XXS X
PORT		
FWD LATCHES	11X	XXS X
AFT LATCHES	12X	XXS X
DOOR	13X	XXS X
PBD SW BYPASS 14X	OPEN 15X	STOP 16X
	CLOSE 17X	

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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2.18 ORBITAL MANEUVERING SYSTEM (OMS)

CONTENTS	
Description	2.18-1
Engines	2.18-3
Helium System	2.18-9
Propellant Storage and Distribution ...	2.18-12
Thermal Control	2.18-18
Thrust Vector Control (TVC)	2.18-19
Fault Detection and Identification	2.18-21
Operations	2.18-22

Description

The OMS provides propulsion for the orbiter vehicle during the orbit phase of flight. The OMS is used for orbit insertion, orbit circularization, orbit transfer, rendezvous, and deorbit. The OMS may be utilized 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 are dependent upon 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

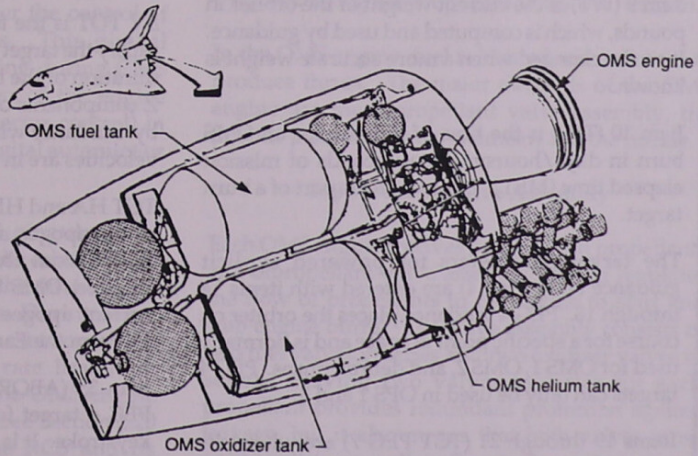
lifetime concerns make it desirable to minimize engine starts. Two OMS engines are used for large velocity changes, or for critical burns. Propellant from one pod can be fed to the engine in the other pod through crossfeed lines that connect the left and right OMS pods.

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.



Note: Shaded areas are part of RCS

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Orbital Maneuvering System

Maneuver Display

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

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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 degrees, 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

ΔV guidance. It is used to add or subtract orbital velocity and does not target the vehicle for a specific point in space. PEG 7 targets can be used in OPS 1, 2, or 3. PEG 7 delta velocities are in the LVLH coordinate frame.

Executing item 22 (LOAD) causes guidance to compute a burn solution on the basis of the target parameters that have been entered under PEG 4 or PEG 7. Executing item 23 (TIMER) sets up a timer, 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 gimbal position angles. Items 28 through 33 (PRI, SEC, OFF) permit selection of primary or secondary gimbal motors or turn off both gimbal motors.

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

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

ΔV TOT is the total change in velocity needed to satisfy the target requirements. TGO is the expected duration of the burn. Below that are the X, Y, and Z components of ΔV TOT. All of this is computed by Guidance when a target is loaded. These delta velocities are in the body axis coordinate frame.

TGT HA and HP are the altitudes in nautical miles 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 2 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	Post-deorbit coast

Maneuver Display Titles Associated With Major Mod

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 and up and down 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/sec² 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.

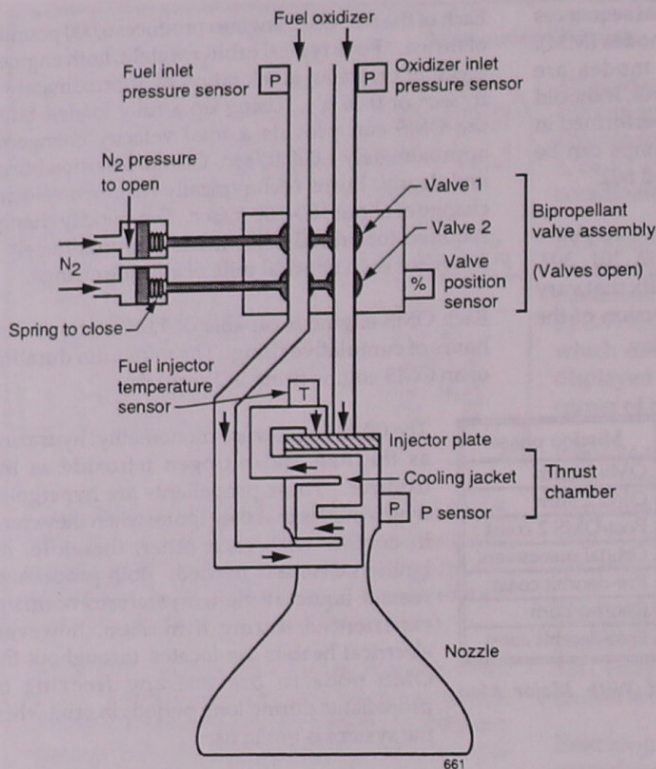
The OMS engines use monomethyl hydrazine as the fuel and nitrogen tetroxide as the oxidizer. These propellants are hypergolic, which means that they ignite when they come in contact with each other; therefore, no ignition device is needed. Both propellants remain liquid at the temperatures normally experienced 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.



Orbital Maneuvering System 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.

The bipropellant valves are ball valves that rotate from fully closed (0 percent) to fully open (100 percent). The valve position in percent for each set can be read by the crew 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.

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.

3011/ /019 GNC SYS SUMM 2										5 015/20:25:34	
										BFS 000/00:26:24	
OMS AFT QTY L R					OMS L R						
OXID 28.6 28.6					TK P HE 2610 2680						
FU 28.3 28.3					OXID 260 258						
FU INJ T 79 79					FU 267 258						
RCS			OXID		FU		JET ISOL		N2 TK P 2220 2220		
FWD	HE P	1464	1264						REG P	319 319	
	TK P	248	244						P VLV	CL CL	
	QTY	0	0						ENG IN P		
MANF			OXID		FU		JET ISOL		N2 TK P 2220 2220		
1	P	248	242						OXID	257 258	
2	P	248	244						FU	258 258	
3	P	250	246						VLV 1 - 2 - 2		
4	P	244	244						2	0 0	
5											
AFT			OXID		FU		JET ISOL		N2 TK P 2220 2220		
L	HE P	2800	2672						HE P	2744 2616	
	TK P	244	249						R TK P	247 247	
	QTY	63	63						QTY	62 61	
MANF			OXID		FU		JET ISOL		N2 TK P 2220 2220		
1	P	244	246						1	P 242 246	
2	P	246	250						2	P 250 246	
3	P	248	250						3	P 246 250	
4	P	246	250						4	P 246 242	
5									5	P 246 242	

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 C						
OMS	TK	OX	80	80	XFD	OX	68	68	67		
		FU	80	80	DRN	GMBL	LN	68	67		
ENG	I/F	OX	70	70							
		FU	70	70							
		OX VLV	71	71							
		FU INJ	81	81							
WEB KEEL			OX		FU		OX		BLD AFT FUS		
	UP	1	70	70						65 66	
	OB	2	70	70						65 67	
	Y	OB	74	74						OX QD 66 67	
		UP	74	74							
OX	DRN	PNL	1	67							
			2	67							
ENG	COVER		71	73							
	SERV	PNL	70	70							
	GSE	SERV	PNL	74	73						
TEST	HE/OX	1	70	70							
		2	70	70							
AFT RCS			OX		L R		OX		MANF 1		
DRN	PNL	1	68	66						69 68	
		2	68	66							
VERN	PNL	1	67	67							
		2	67	67							

OMS Parameters on SM SPEC 89 PRPLT THERMAL Display

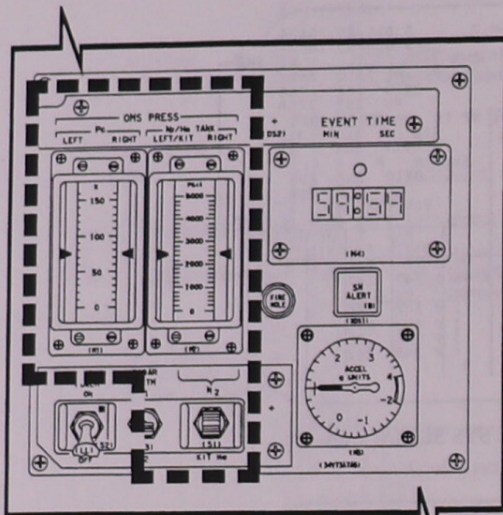
Thrust Chamber

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 PRESS P_c meter on panel F7. 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.

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



OMS PRESS Pc and N₂/He TANK Meters and Switch on Panel F7

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.

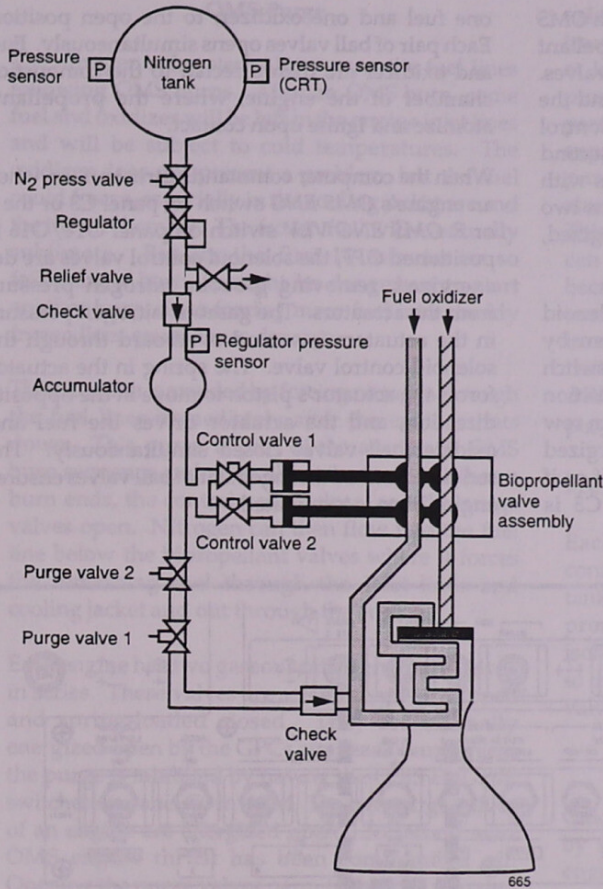
A spherical gaseous nitrogen storage tank is mounted next to the combustion chamber in each of the two engines to supply pressure to its engine pressure isolation valve. The tank contains enough nitrogen to operate the ball valves and purge the engine 10 times.

Each tank's pressure is monitored by two sensors. One is wired to directly transmit the tank pressure to the OMS PRESS N₂/He TANK LEFT/KIT, RIGHT meter on panel F7. The other sensor displays on the GNC SYS SUMM 2 display (N₂ TK P, L and R). 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.



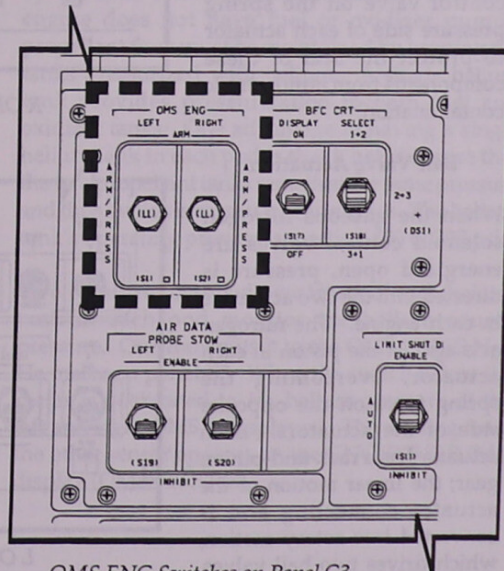
Nitrogen System

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 relieves 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 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.



OMS ENG Switches on Panel C3

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.

The right OMS engine gaseous nitrogen 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 gaseous nitrogen 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.

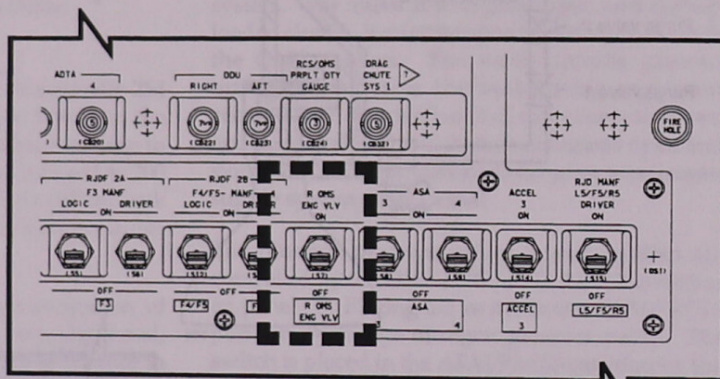
Check valves are installed in the vent port outlet of each gaseous nitrogen solenoid control valve on the spring pressure side of each actuator to protect the seal of these components from atmospheric contamination.

Ball Valve Actuation

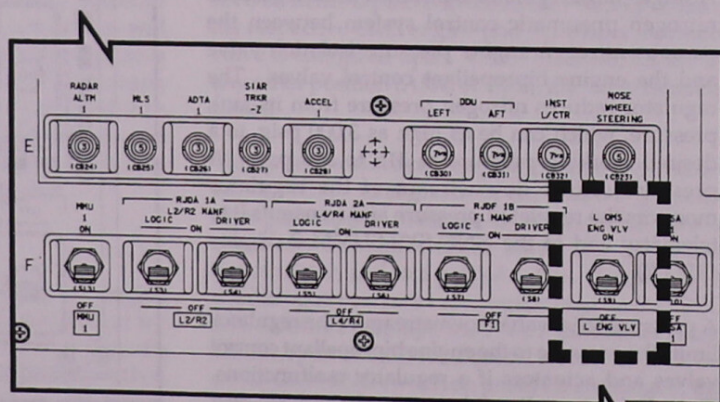
When the gaseous nitrogen solenoid control valves are energized open, pressure is directed into the two actuators in each engine. The nitrogen acts against the piston in each actuator, overcoming the spring force on the opposite side of the actuators. Each actuator has a rack-and-pinion gear; the linear 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 gaseous nitrogen pressure from the actuators. The gaseous nitrogen pressure in the actuators is vented overboard through the solenoid control valve. The spring in the actuator forces the actuator's piston to move in the opposite direction, and the actuator drives the fuel and oxidizer ball valves closed simultaneously. The series-redundant arrangement of ball valves ensures engine burn is terminated.



R OMS ENG VLV Switch on Panel O16



L OMS ENG VLV Switch on Panel O14

OMS Purge

The nitrogen subsystem also purges the fuel lines following OMS burns. After an OMS burn, some fuel and oxidizer will be left in the engine inlet lines and will be subject to cold temperatures. The oxidizer does not present a problem, but the fuel could freeze, especially in the cooling jacket around the thrust chamber. The frozen fuel will eventually sublimate. But for the first 10 minutes or so following a burn, it might be dangerous to start another burn, since forcing more fuel into already frozen lines could cause damage.

This situation is avoided by forcing nitrogen through the fuel lines immediately after the engine shuts down. This purge is part of the automatic OMS burn sequence and takes about 2 seconds. When a burn ends, the control valves close, and the purge valves open. Nitrogen can then flow into the fuel line below the bipropellant valves where it forces the remaining fuel through the inlet lines and cooling jacket and out through the engine.

Each engine has two gaseous nitrogen purge valves in series. These valves are solenoid-operated open and spring-loaded closed. They are normally energized open by the GPCs after each burn unless the purge is inhibited by having the *OMS ENGINE* switches on panel C3 in *ARM*. The two purge valves of an engine are energized open 0.36 second after OMS engine thrust has been commanded off. Opening the purge valves permits gaseous nitrogen to flow through the valves and check valve into the fuel line downstream of the ball valves. It then flows out through the combustion chamber and engine injector to space for 2 seconds. This purges the residual fuel from the combustion chamber and injector of the engine, permitting safe engine restart. The purge valves are then de-energized and spring-loaded closed. When the purge is completed, the gaseous nitrogen tank pressure isolation valve is closed by placing the respective *OMS ENG* switch on panel C3 to *OFF*. The check valve downstream of the purge valves prevents fuel from flowing to the engine purge valves during engine burns.

The automatic software will perform the purge only if the *OMS ENG* switch on panel C3 is in the *ARM/PRESS* position; that is, when the nitrogen pressure

valve is open. For that reason, the crew should leave both *OMS ENG* switches in *ARM/PRESS* for at least 2 seconds after an OMS burn so that the purge can be completed. When the nitrogen pressure valve is open, nitrogen for the purge is supplied by the tank. If the valve were closed, the purge would deplete the accumulator, and the OMS start capability of the accumulator would be lost. This is not normally a problem since the accumulator can be repressurized. But if the valve were closed because of an upstream leak, it would be important to save the nitrogen in the accumulator. The purge is not as important as the need to preserve the engine restart capability. With the *OMS ENG* switch in *ARM* or *OFF*, the valve is closed, and the engine purge is automatically inhibited.

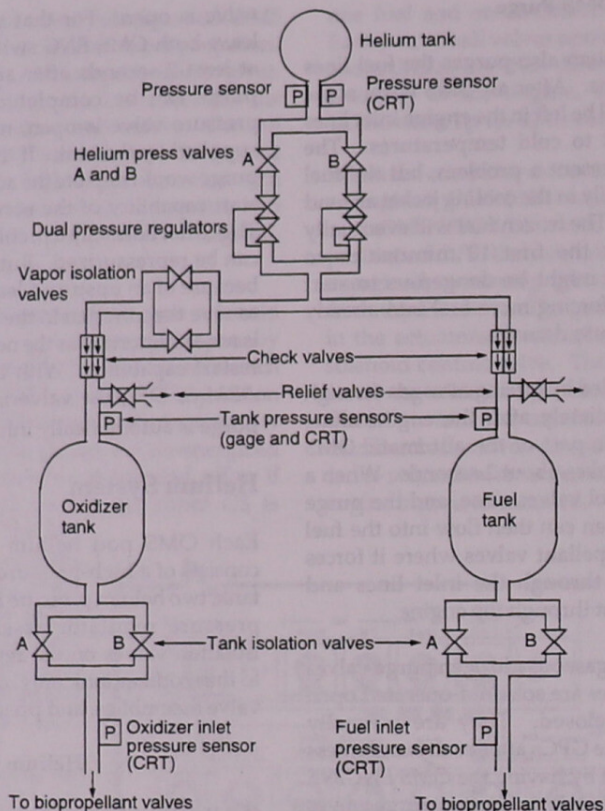
Helium System

Each OMS pod helium pressurization system consists of a high-pressure gaseous helium storage tank, two helium pressure isolation valves, two dual pressure regulator assemblies, parallel vapor isolation valves on the regulated helium pressure to the oxidizer tank only, dual series-parallel check valve assemblies, and pressure relief valves.

Helium Tanks

Oxidizer and fuel are supplied to each OMS engine by separate sets of propellant tanks. The OMS engine does not have fuel or oxidizer pumps; propellant flow must be maintained by keeping the tanks pressurized with helium. A single helium tank provides pressurization to both fuel and oxidizer tanks. One advantage to having a single helium tank in each pod is that it helps ensure that the two propellant tanks remain at the same pressure and thus avoids incorrect mixture ratios. The helium tank's operating pressure range is 4,800 to 390 psia.

Two pressure sensors downstream of each helium tank in each pod monitor the helium source pressure. One transmits it to the *OMS PRESS N₂/He* meter on panel F7. When the switch below the meter is positioned to *He*, helium pressure of the left and right OMS is displayed. 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.

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.

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.

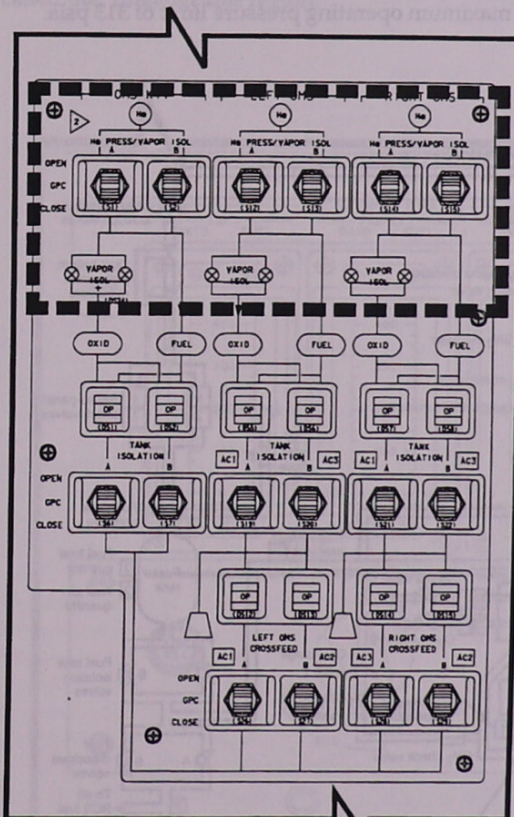
NOTE

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.

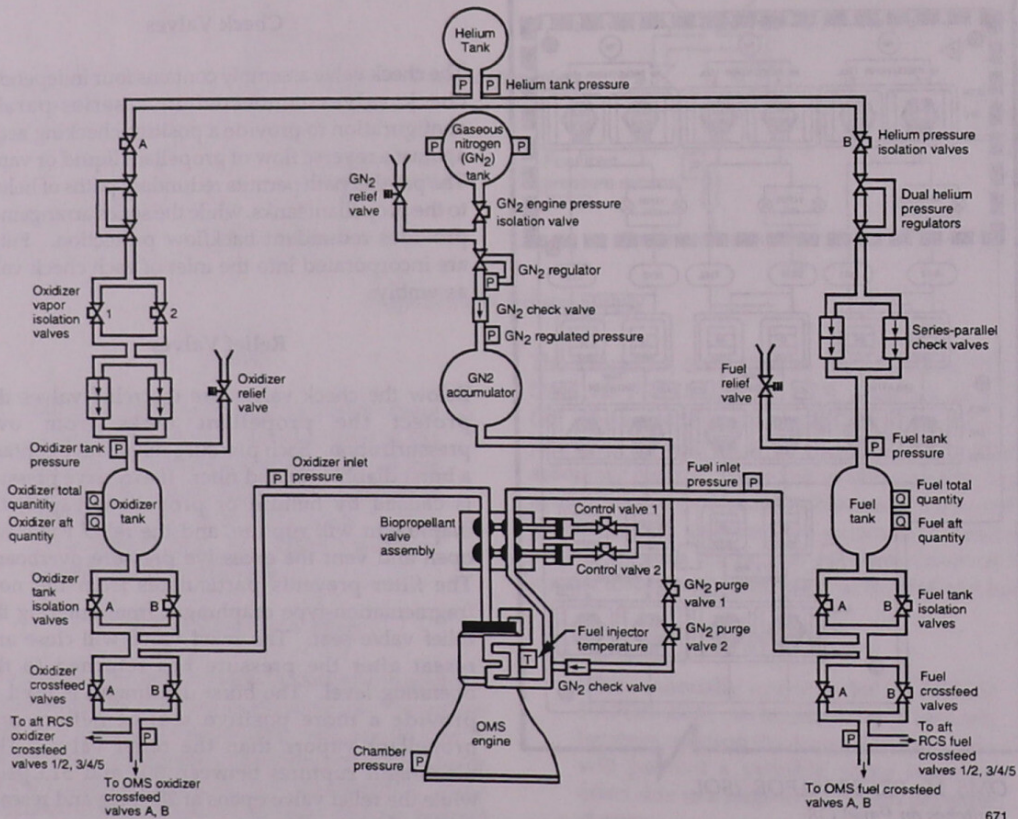
Propellant Storage and Distribution

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.



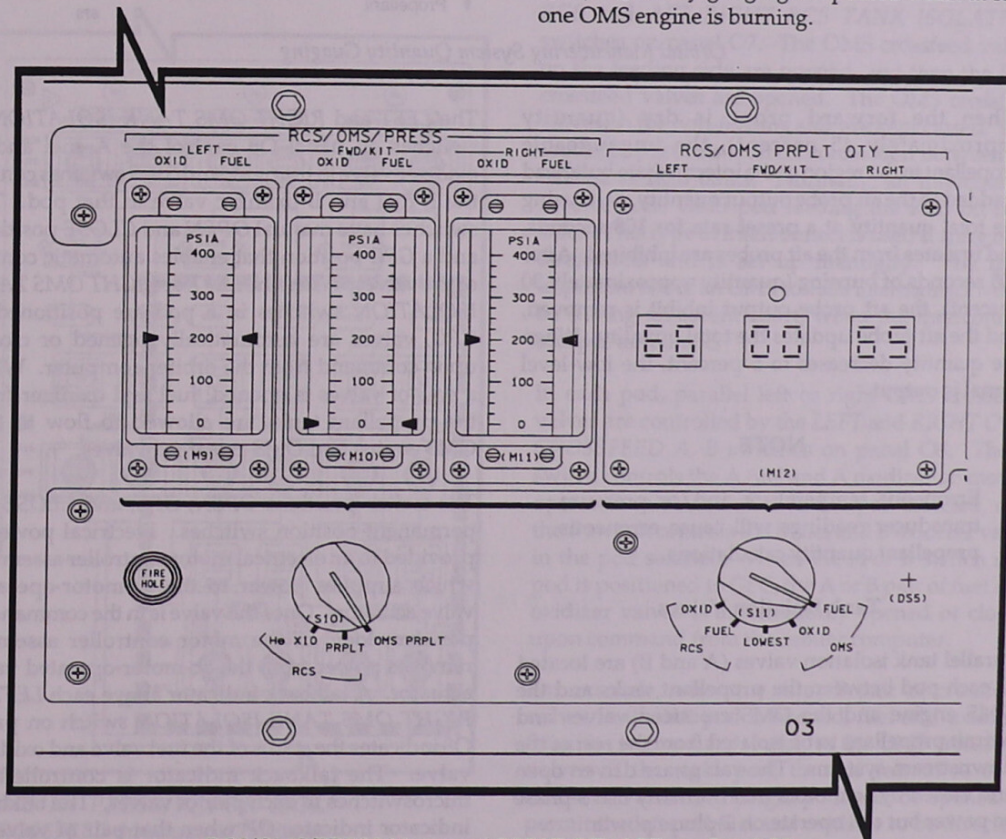
Orbital Maneuvering System Pressurization and Propellant Feed System for One Engine (Other Engine Identical)

Each propellant tank has one pressure sensor wired directly to the RCS/OMS/PRESS meters on panel O3. Selecting the OMS PRPLT position of the rotary switch below the bank of meters enables the crew to read fuel and oxidizer tank pressures. The same measurement is also displayed on the GNC SYS SUMM 2 display (TK P OXID, FU entries). If the tank pressure is lower than 232 psia or higher than 284 psia, the LEFT or RIGHT OMS red caution and warning light on panel F7 will be illuminated.

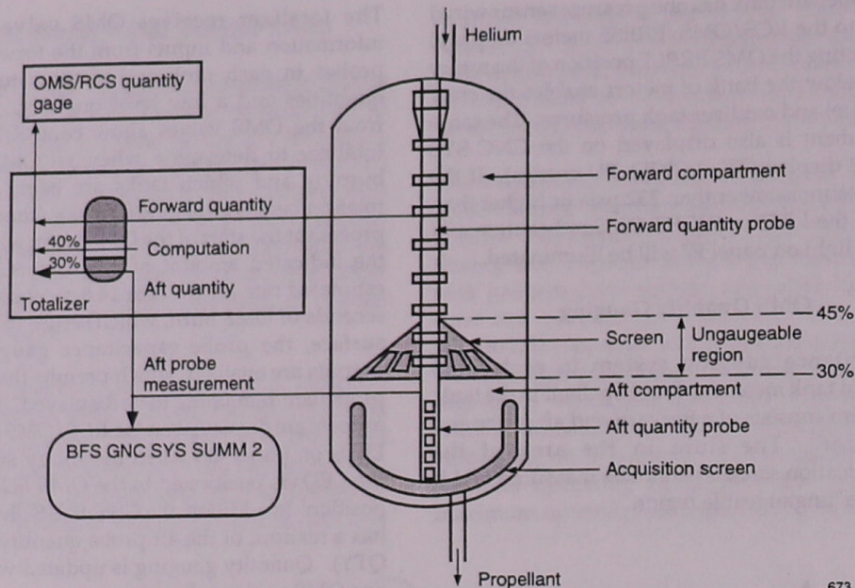
OMS Quantity Gauging

A capacitance gauging system in each OMS propellant tank measures the propellant in the tank. The system consists of a forward and aft probe and a totalizer. The fluid in the area of the communication screens cannot be measured and is called the "ungaugeable region."

The totalizer receives OMS valve operation information and inputs from the forward and aft probes in each tank and outputs total and aft quantities and a low level quantity. The inputs from the OMS valves allow control logic in the totalizer to determine when an OMS engine is burning and which tanks are being used. The totalizer begins an engine flow rate/time integration process at the start of the OMS burn, which reduces the indicated amount of propellants by a preset estimated rate for the first 14.8 seconds. After 14.8 seconds of OMS burn, which settles the propellant surface, the probe capacitance gauging system outputs are enabled, which permits the quantity of propellant remaining to be displayed. The totalizer outputs are displayed on the RCS/OMS PRPLT QTY LEDs on panel O3 when the rotary switch below the LEDs is positioned to the OMS FUEL or OXID position. In addition, the GNC SYS SUMM 2 display has a readout of the aft probe quantity (OMS AFT QTY). Quantity gauging is updated when at least one OMS engine is burning.



RCS/OMS/PRESS Meters and PRPLT QTY LEDs on Panel O3



Orbital Maneuvering System Quantity Gauging

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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.

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 3-phase ac power but can operate on 2-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.

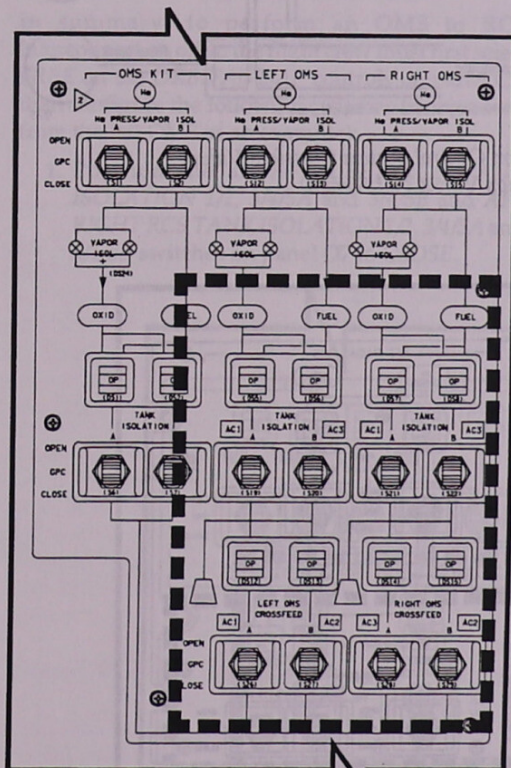
The switch positions *OPEN*, *GPC*, and *CLOSE* are permanent-position switches. Electrical power is provided to an electrical motor controller assembly, which supplies power to the ac-motor-operated valve actuators. Once the valve is in the commanded position, logic in the motor controller assembly 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 He PRESS/VAPOR ISOL
CROSSFEED Switches and Talkbacks

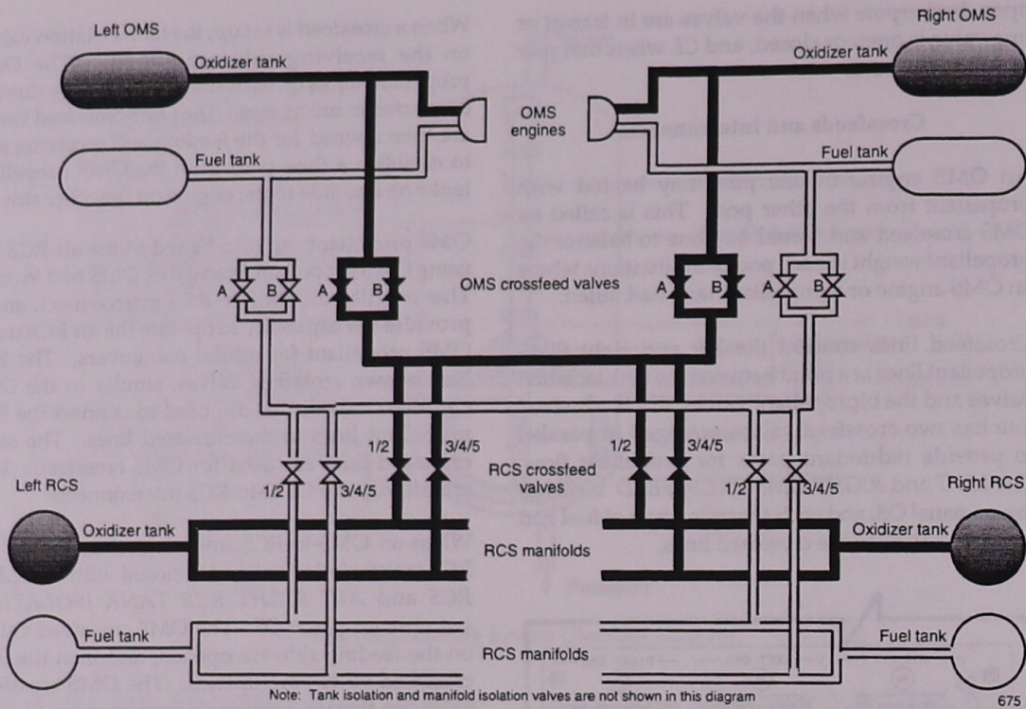
When a crossfeed is set up, the tank isolation valves on the receiving side are closed. (The OMS propellant tanks on each side should not be directly connected in most cases.) The OMS crossfeed valves are then opened for the feeding and receiving side to establish a flow path from the OMS propellant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

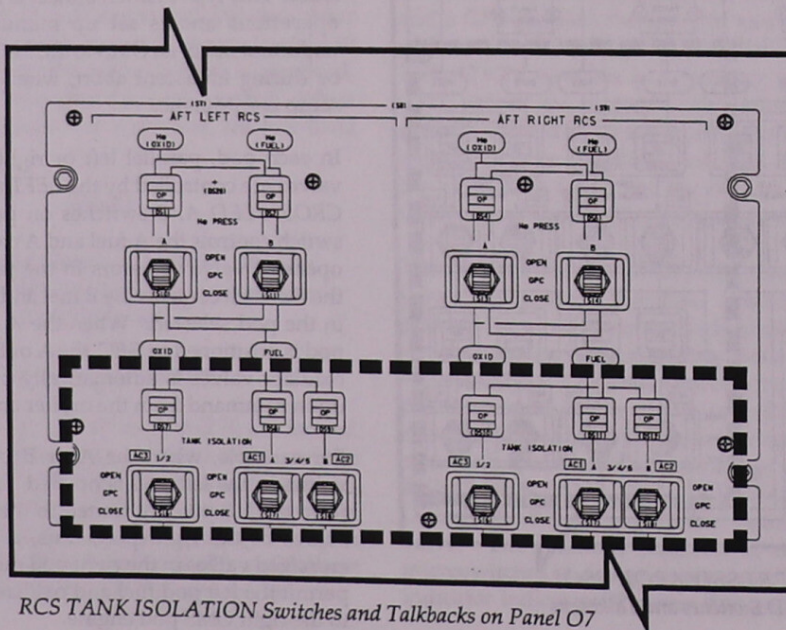
When an OMS-to-RCS interconnect is set up, the RCS tank isolation valves are closed with *AFT LEFT RCS* and *AFT RIGHT RCS TANK ISOLATION* switches on panel O7. The OMS crossfeed valves on the feeding side are opened, and then the RCS crossfeed valves are opened. The OMS crossfeed valves on the non-feeding 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.



*Orbital Maneuvering System and Reaction Control System Crossfeed Valves
(OMS and RCS Tank Isolation Valves Not Shown)*



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.

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.

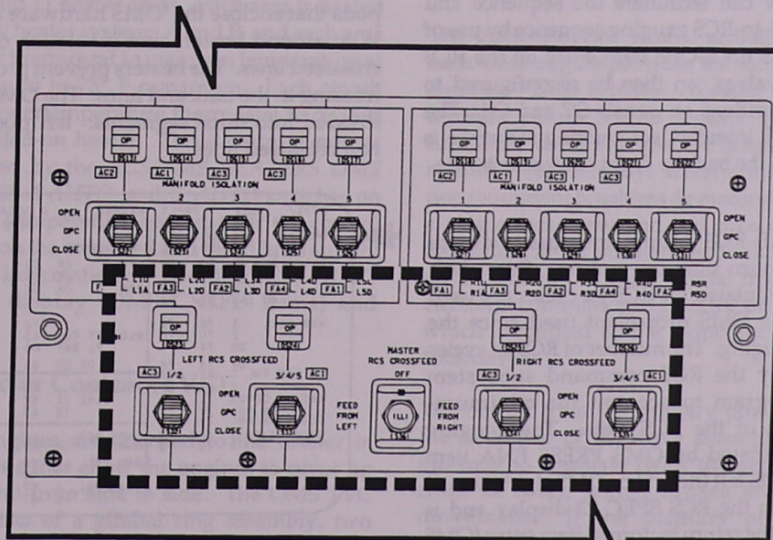
The OMS crossfeed fuel and oxidizer line pressures are monitored on telemetry and are transmitted to the RCS SPEC 23 display.

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*



RCS CROSSFEED Switches and Talkbacks on Panel O7

2011/023/ RCS					1 000/03:14:16				
RCS FWD 1					000/00:00:00				
L 2 4 PRI JET					OMS PRESS ENA				
R 3*					L OMS 5				
					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
		247	250
	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	

RCS Display (GNC SPEC 23)

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, since 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.

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.

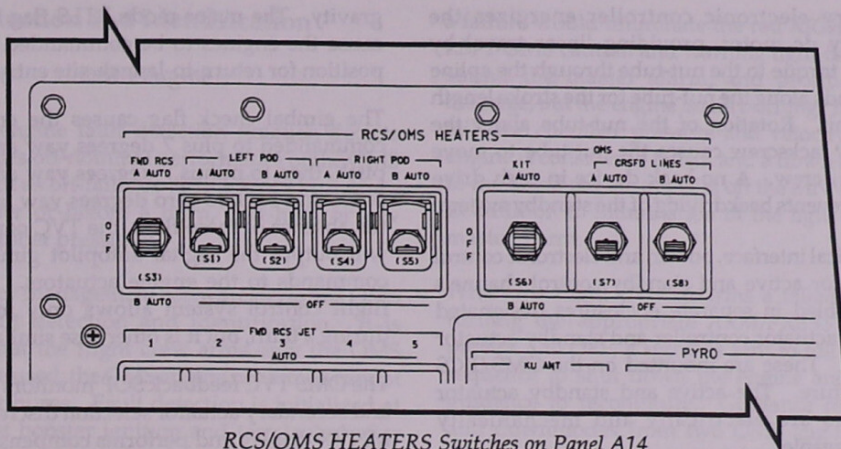
2011/089		PRPLT THERMAL		4 000/02:37:12	
				000/00:00:00	
POD	L R				
OMS TK	OX 80 80				
	FU 80 80				
ENG I/F	OX 70 70	XFD	OX 68 68 67		
	FU 70 70		GMBL LN 68 68 67		
	OX VLV 71 71		DRN OX 65 65 64		
	FU INJ 81 81				
WEB KEEL	1 70 70				
	2 70 70				
Y	OB 74 74				
	UP 74 74				
OX DRN PNL	1 67 67				
	2 67 67				
ENG COVER	71 73				
SERV PNL	70 73				
GSE SERV PNL	74 73				
TEST HE/OX	1 70 70				
	2 70 70				

OMS CRSFD	L	R	C
BLD AFT FUS	65	66	
PL BAY	65	67	
OX OD	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



RCS/OMS HEATERS Switches on Panel A14

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.

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 overtemperature 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 gimbil mounts that allow the engines to pivot up and down and from side to side. The OMS TVC system consists of a gimbil ring assembly, two gimbil actuator assemblies, and two gimbil actuator

controllers. The engine gimbil ring assembly and gimbil actuator assemblies provide OMS TVC by gimbaling the engines in pitch and yaw. Each engine has a pitch actuator and a yaw actuator. Each actuator is extended or retracted by one of a pair of dual-redundant electric motors and is actuated by general-purpose computer control signals.

The gimbil ring assembly contains two mounting pads to attach the engine to the gimbil ring and two pads to attach the gimbil ring to the orbiter. The ring transmits engine thrust to the pod and orbiter.

The pitch and yaw gimbil actuator assembly for each OMS engine provides the force to gimbil 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 plus or minus 6 degrees in pitch, and plus or minus 7 degrees in yaw with clearance provided for an additional 1 degree 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).

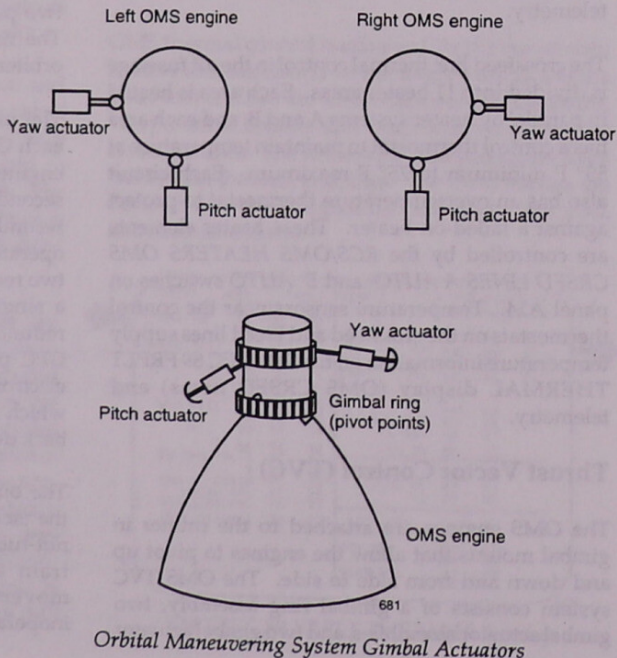
The flight crew can select either the primary or secondary motors of the pitch and yaw actuators by item entry (PRI 28,29 and SEC 30,31 on the MNVR display), or they can turn the actuator motors off. The actuator command outputs are selected by the TVC command SOP, depending on the flag that is present; 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 1-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 degrees yaw and 6 degrees pitch, then to minus 7 degrees yaw and 6 degrees pitch, and back to zero degrees 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.



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.

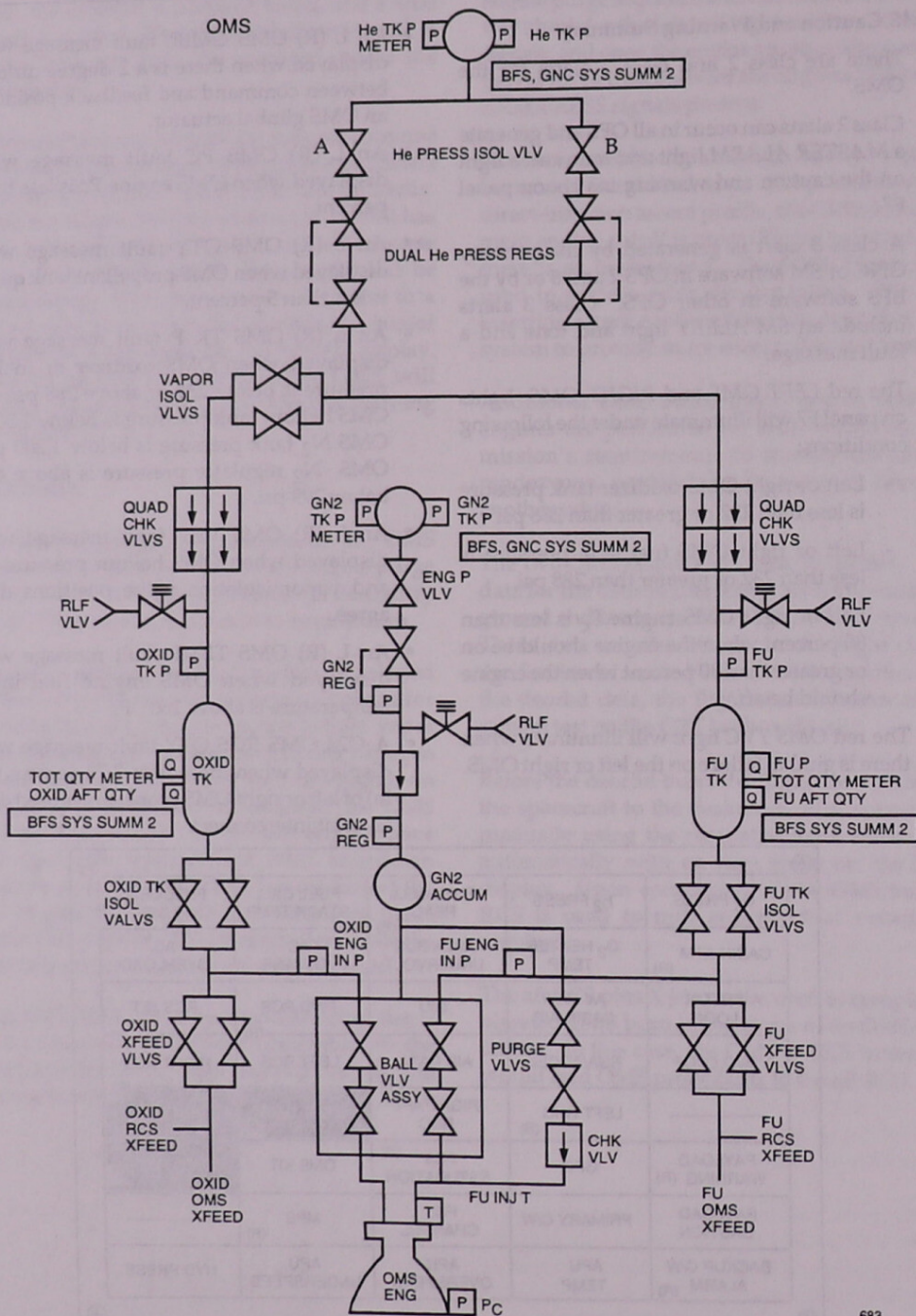
The aft RCS plus X jets can be used to complete any planned OMS burn in the event of an OMS engine failure. In this case, the OMS-to-RCS interconnect would feed OMS propellants to the aft RCS.

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-degree 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° 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.

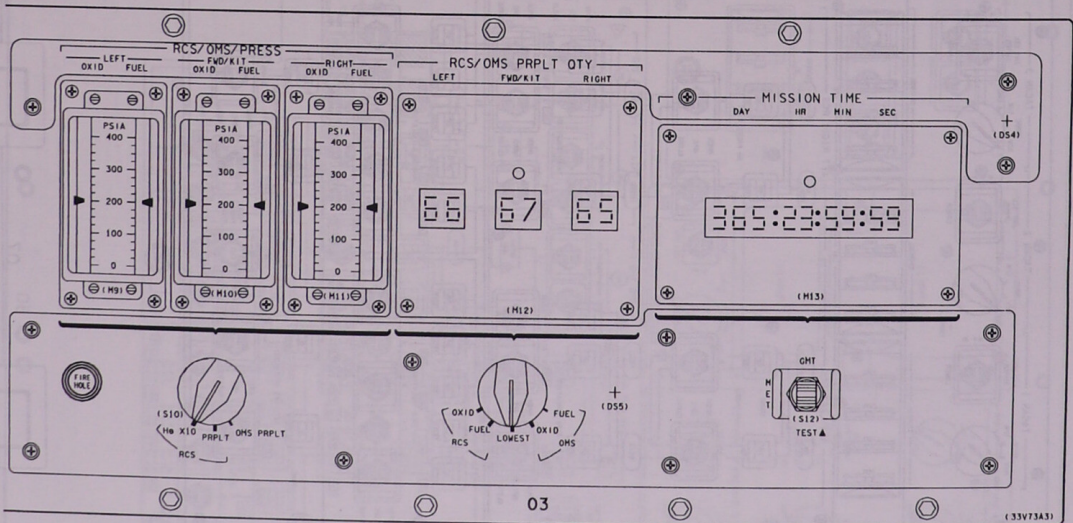
O ₂ PRESS	H ₂ PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O ₂ HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H ₂ O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS	RIGHT RCS (R)
_____	LEFT RHC (R)	RIGHT/AFT RHC	LEFT OMS (R)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

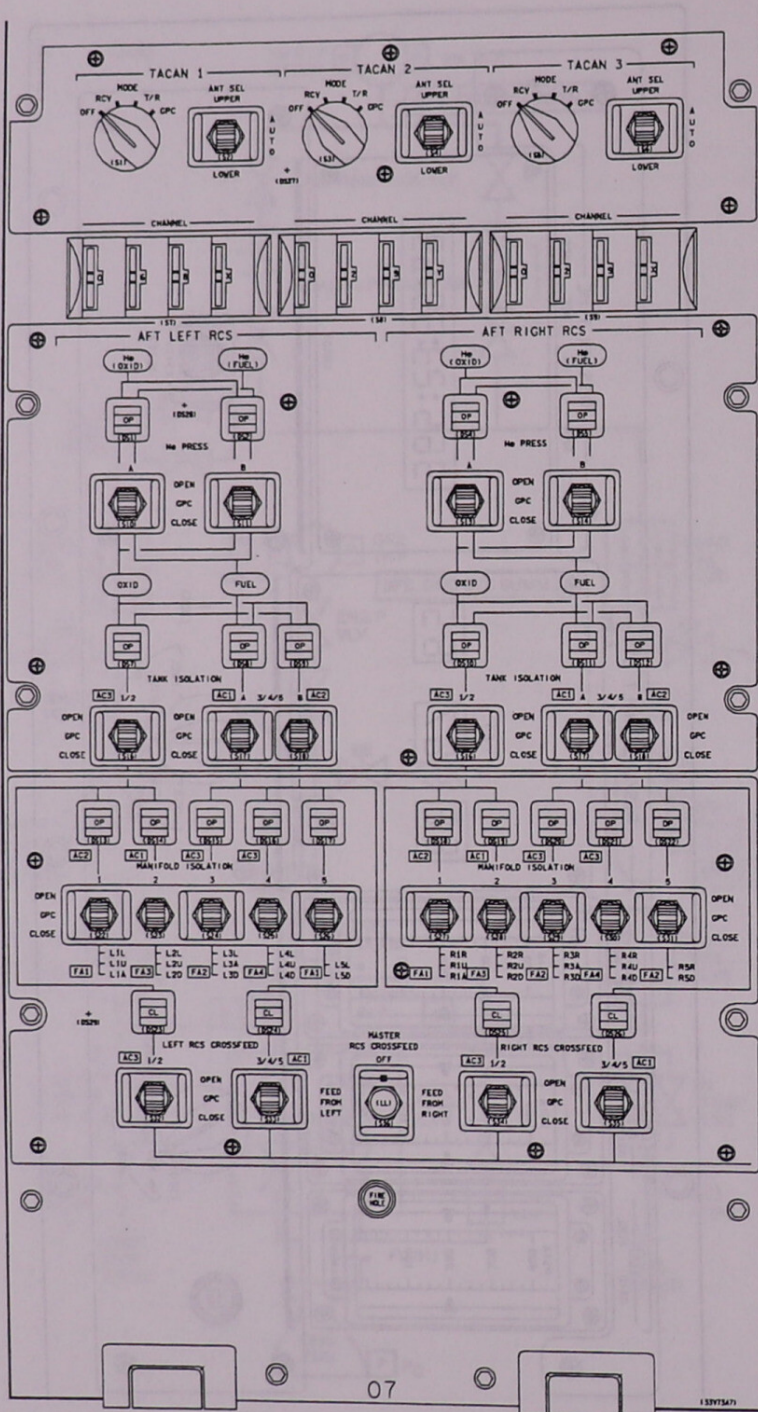


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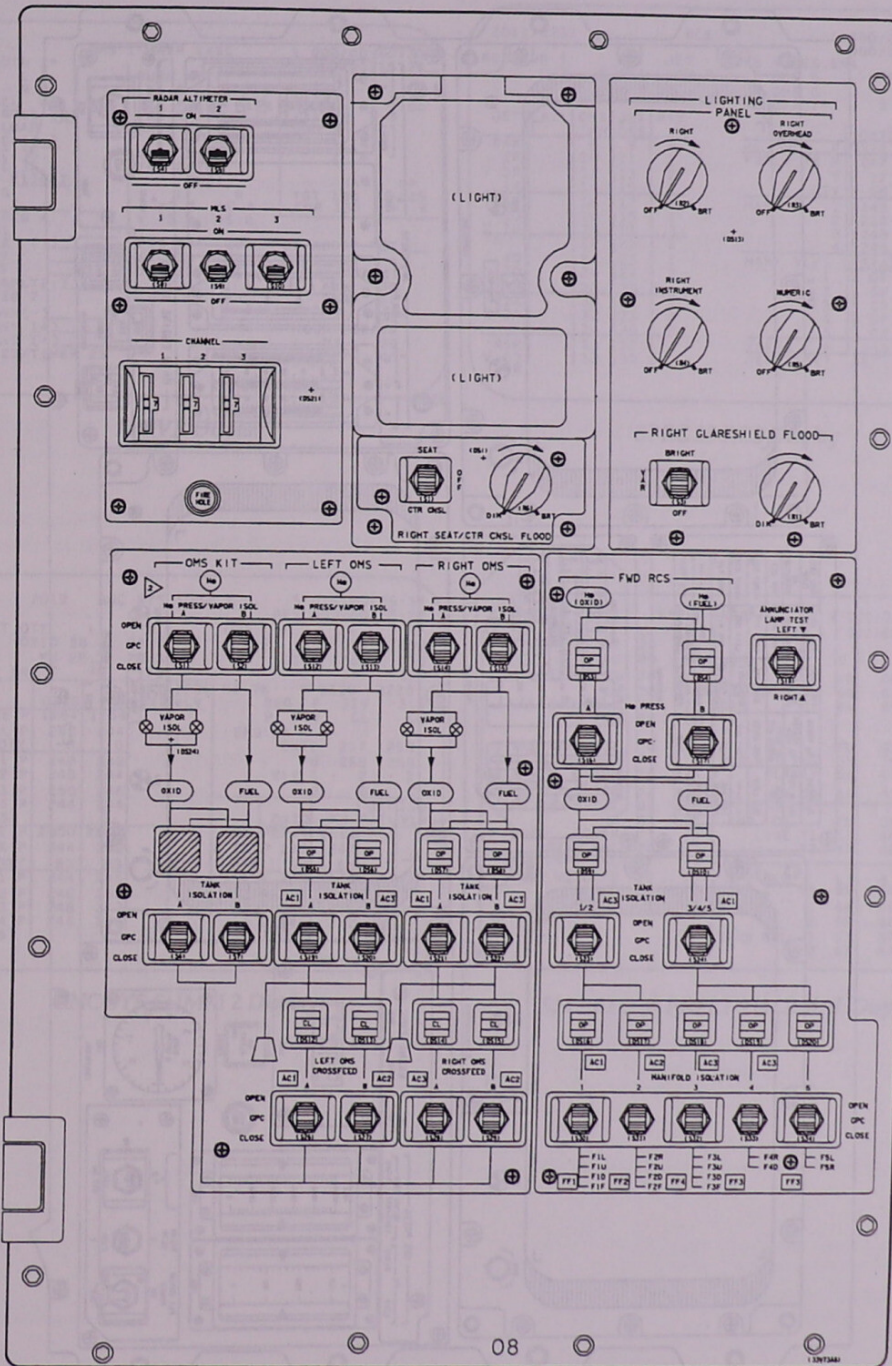
Orbital Maneuvering System



2.18-25



Panel O7



08

1041/ OMS 1 MNVR EXEC 1 000/00:40:23
OMS BOTH 1* L 2 BURN ATT 24 R 083
R 3 25 P 195
RCS SEL 4 26 Y 300
S TV ROLL 180 MNVR 27*
TRIM LOAD
6 P [-] 10.1
7 LV [-] 15.7
8 RV [-] 15.7
9 WT 217047
10 TIG

REI 4366
TFF 24:40
GMBL

L R
P +0.4 +0.4
Y +5.8 +5.8

35 ABORT TGT
FWD RCS
ARM 36
DUMP 37
OFF 38*
SURF DRIVE
ON 39
OFF 40*

HA HP
TGT 130
CUR 130 +129

526

MNVR Display

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

OMS-RCS QTY
R 0.00

JET	FAIL	DES INH	JET DES	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	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	PRPLT TK	P	OXID	FU
			3376	3360
			247	250
			77	79
			90	91
			242	246
			250	246
			248	248
			246	242
			1	OP 40
			2	OP 41
			3	OP 42
			4	OP 43
			5	OP 44
			254	254
			45	

526

SPEC 23 RCS Display

3011/ /019 GNC SYS SUMM 2 5 015/20:25:34
BFS 000/00:26:24

OMS AFT	QTY	L	R	OMS	TK	P	HE	2610	2680
OXID	28.6	28.6							
FU	28.3	28.3							
FU INJ	79	79							
RCS									
FWD	HE	P	1464	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	2800	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								

N2 TK	P	2220	2220
REG	P	319	319
P VLV	CL		CL
ENG IN	P		
OXID	257	258	
FU	258	258	
VLV	1	- 2	- 2
	2	0	0

HE	P	2744	2616
R TK	P	247	247
QTY		62	61
1	P	242	246
2	P	250	246
3	P	246	250
4	P	246	242
5			

242

GNC SYS SUMM 2 Display

2011/ /089 PRPLT THERMAL 4 000/02:37:12
000/00:00:00

OMS	TK	OX	80	80	OMS	CRSFD	L	R	C
ENG I/F	OX	70	70		XFD	OX	68	68	67
	FU	70	70		DRN	GMBL	LN	68	68
	OX VLV	71	71			OX	65	65	64
	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 QD	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	59	68
						DRN PNL	1	68	66
							2	68	66
						VERN PNL	1	67	67
							2	67	67

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SM SPEC 89 PRPLT THERMAL Display

OMS Summary Data

- The OMS provides propulsion for orbit insertion, orbit circularization, orbit transfer, rendezvous, and deorbit.
- The OMS engines are collocated with the aft RCS in two independent OMS/RCS pods on each side of the orbiter's aft fuselage. Each engine produces 6,000 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 gimbals that allow the engines to pivot up and down and from side to side (± 6 degrees pitch, ± 7 degrees 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.m.
130 lbs (80 lbs oxidizer, 50 lbs fuel)
uses 400 psi of helium for long burns.
- One OMS engine causes approximately 1 fps^2 acceleration.
- For OMS ignition, there must be power and command to at least one coil on both control valves.
- OMS TVC requires an enable discrete from the FF MDM, and commands from the FA MDM.
- FUEL INJECTOR TEMP message may be a signature of a bad temperature transducer or a fuel blockage.
- CHAMBER PRESSURE message may be a signature of a bad pressure transducer or an oxidizer blockage.
- There are several failures that inop OMS FDI (FA MDM commfault or Pc transducer failing high during the burn).
- Always check redundant sources to confirm any malfunction.
- Max blowdown on the OMS is approximately 39 percent.
- 1,000 lbs of OMS (approximately 8 percent) moves the X c.g. 1.5 inches aft and the Y c.g. 0.5 inches left or right.
- Max OMS quantity for landing = 22 percent/ side.

2.19 PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM (PDRS)

CONTENTS

Description	2.19-1
Remote Manipulator System (RMS)	2.19-1
Manipulator Positioning Mechanism	2.19-11
Payload Retention Mechanisms	2.19-14
Operations	2.19-18

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.

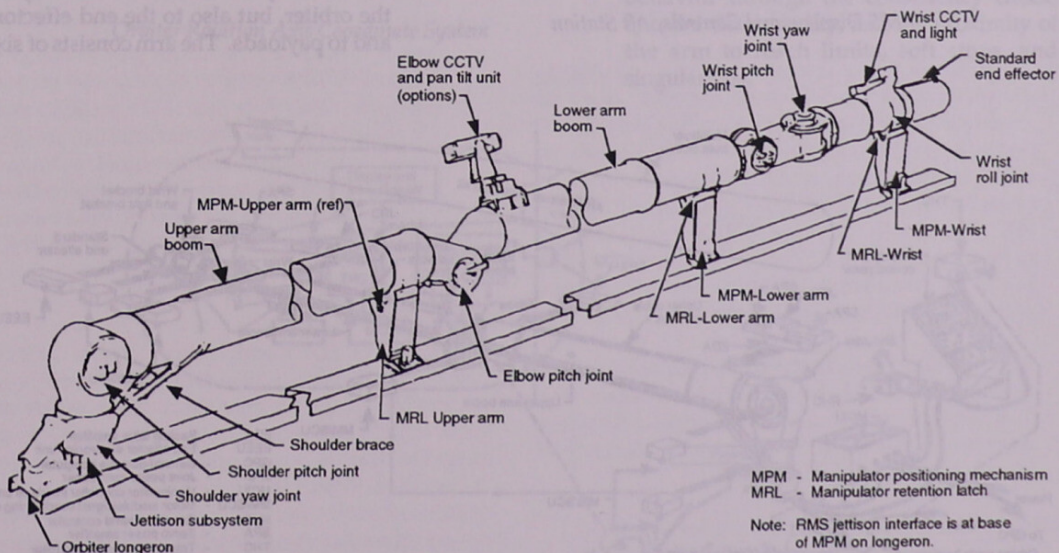
The PDRS includes the remote manipulator system, the manipulator positioning mechanisms, and

manipulator retention latches. The PDRS also interfaces with other orbiter systems, such as the SM GPC, the electrical power distribution system (EPDS), and the closed-circuit television.

Remote Manipulator System (RMS)

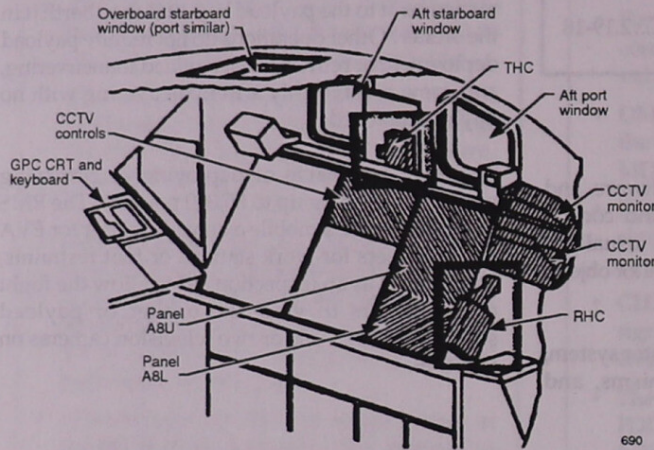
The RMS is the mechanical arm portion of the PDRS. The arm maneuvers a payload from the payload bay to its deployment position, and then releases it. The RMS can also grapple a free-flying payload, maneuver it to the payload bay, and then berth it in the orbiter. Other operations do not require payload deployment or retrieval, just payload maneuvering, and some involve only arm maneuvering with no payload attached.

The RMS is capable of deploying or retrieving payloads weighing up to 65,000 pounds. The RMS can also provide a mobile extension ladder for EVA crewmembers for work stations or foot restraints, and be used as an inspection aid to allow the flight crewmembers to view the orbiter or payload surfaces through one or two television cameras on the RMS.



RMS-Stowed Position and General Arrangement

The basic RMS configuration consists of a manipulator arm, an RMS display and control panel, including rotational and translational hand controllers at the orbiter port aft flight deck crew station, and a manipulator controller interface unit that interfaces with the orbiter SM GPC. The RMS itself is installed on the port longeron of the payload bay for those missions requiring it. Some payloads carried aboard the orbiter for deployment do not require the RMS.



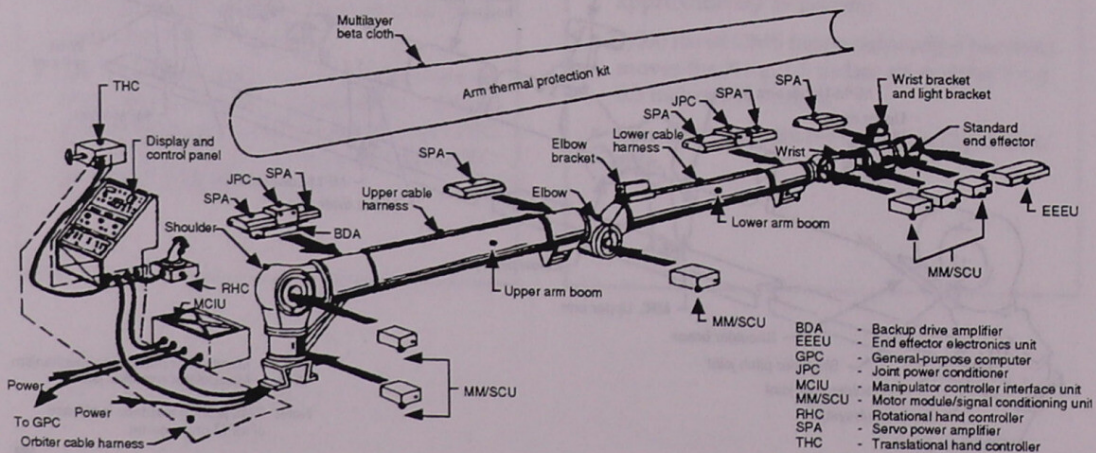
RMS Displays and Controls, Aft Station

NOTE

Original concepts called for an optional second arm to be placed along the starboard longeron. It is no longer under consideration; however, residual references to the starboard arm still exist on orbiter panels and controls.

The RMS structure is attached to a manipulator positioning mechanism (MPM) that attaches to the orbiter longeron. When cradled, the arm rests on three MPM pedestals that contain manipulator retention latches (MRLs) for securing the arm during launch, entry, and periods of arm inactivity. During launch, entry, and any other times the payload bay doors are closed, 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, so as not to interfere with payload clearances.

The RMS 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 and to payloads. The arm consists of six



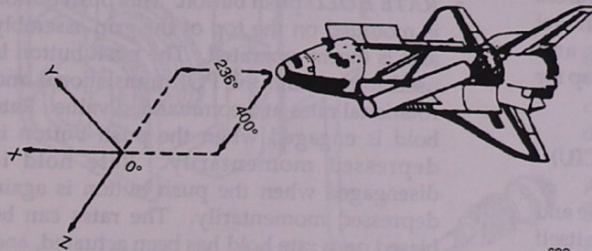
- BDA - Backup drive amplifier
- EEEU - End effector electronics unit
- GPC - General-purpose computer
- JPC - Joint power conditioner
- MCIU - Manipulator controller interface unit
- MM/SCU - Motor module/signal conditioning unit
- RHC - Rotational hand controller
- SPA - Servo power amplifier
- THC - Translational hand controller

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RMS Components

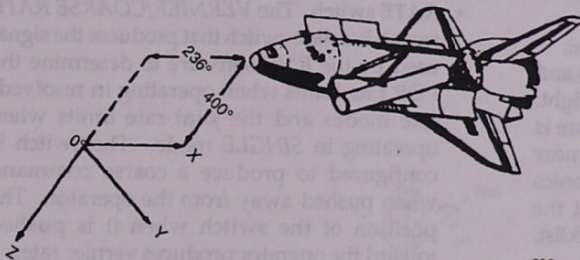
joints connected via structural members and has a payload capturing device on the end. It weighs 905 pounds, and the total system weighs 994 pounds.

On-orbit RMS operations are always performed by a team of two arm operators who equally divide each RMS task. The arm operator who controls the actual RMS trajectories is stationed on the port aft flight deck. The other operator is stationed on the starboard aft flight deck and controls CRT inputs, payload retention latch assemblies (PRLAs), and cameras.



Orbiter Body Axis Coordinate System

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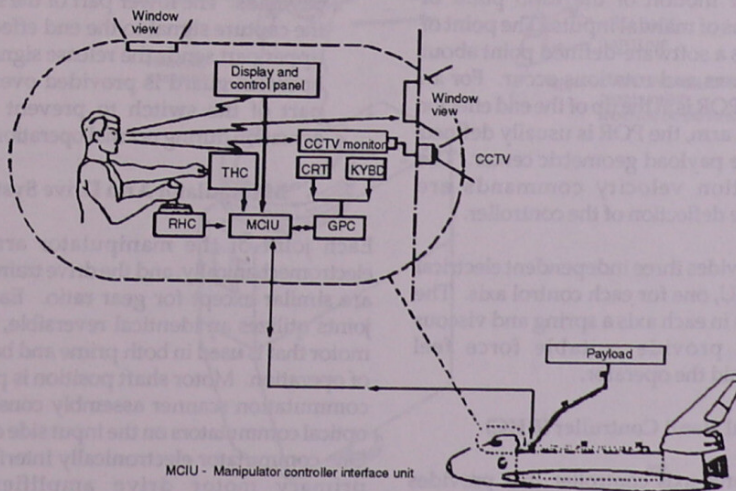


Orbiter Rotation Axis Coordinate System

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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 arm-based electronics are monitored. The MCIU checks the integrity of the communications link between itself and the arm-based electronics, displays and controls, 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 behavior through the consistency check, encoder data validity, and the proximity of the arm to reach limits, soft stops, and singularities.



MCIU - Manipulator controller interface unit

Shuttle RMS

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The RMS can only be operated in a weightless environment, since 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.

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. The MCIU is located behind panel L17; the spare is currently stowed in a middeck locker. In the near future the spare MCIU will be stowed in avionics bay 1, 2, or 3. 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 by means of manual inputs. The point of resolution (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 end effector (EE). For a loaded arm, the POR is usually defined to be at or near the payload geometric center. The point of resolution velocity commands are proportional to the deflection of the controller.

The controller provides three independent electrical inputs to the MCIU, one for each control 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)

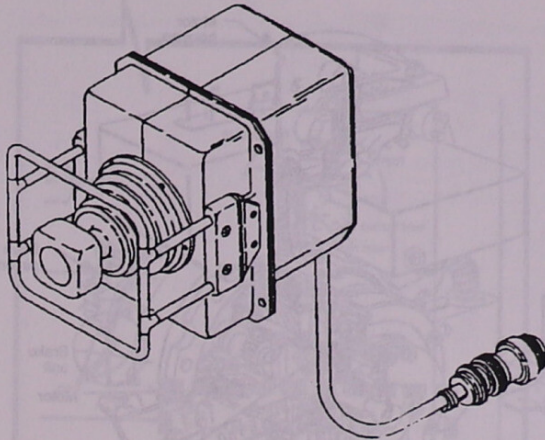
The RHC is a three-axis controller that provides electrical control signals for pitch, yaw, and roll control of the RMS. Control signals are proportional

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** push button. This push button is mounted on the top of the grip assembly and is thumb-operated. The push button is used to maintain the POR translational and rotational rates at a commanded value. Rate hold is engaged when the push button is depressed momentarily. Rate hold is disengaged when the push button 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 a coarse command when pushed away from the operator. The position of the switch when it is pushed toward the operator produces vernier rates.
- **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 utilizes 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.



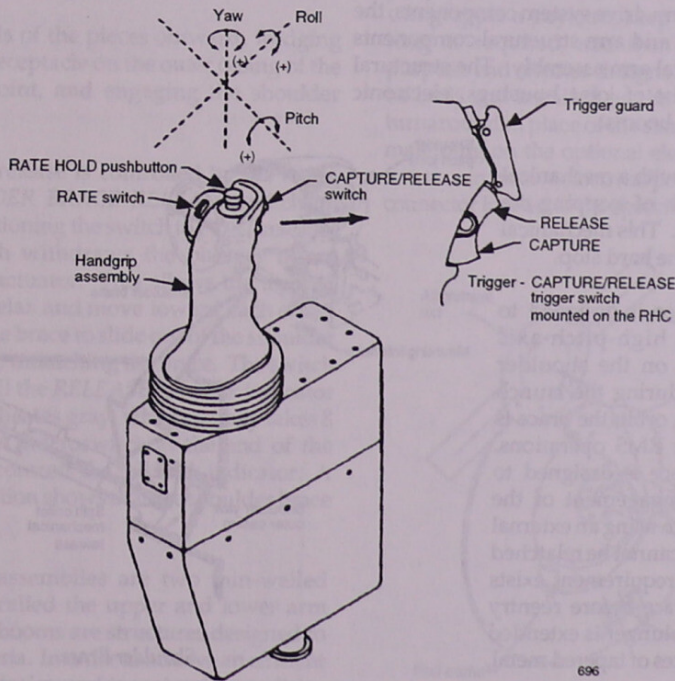
Translational Hand Controller

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.

The manipulator arm contains six servo power amplifiers (SPAs), one for each joint. Each SPA is associated with a motor module and a position encoder. The major function of the SPA is to provide a drive signal to the motor in response to digital



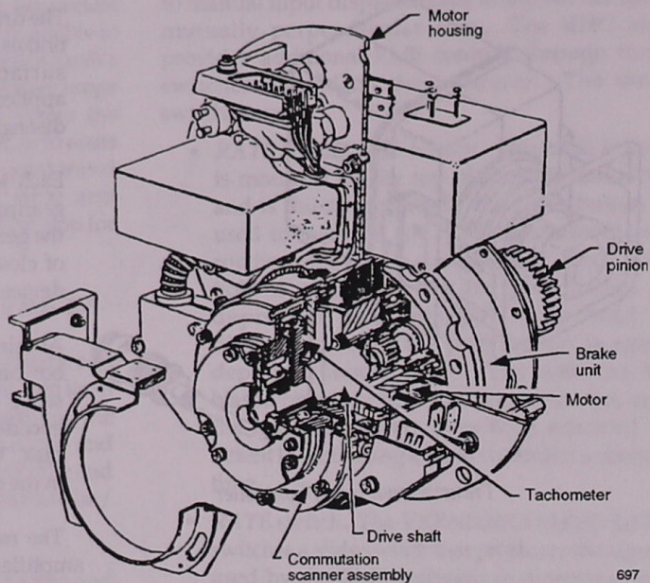
Rotational Hand Controller

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control signals generated by the GPC and supplied through the MCIU or to a direct drive command signal from the control panel.

The arm contains two joint power conditioners. One is located in the shoulder and serves the shoulder and elbow joints. The second is located in the wrist and serves the three wrist joints. The function of the conditioner is to convert the MN A +28 V dc to provide secondary regulated supply voltages at ± 15 V, +10 V, and +5.1 V dc to the SPA, motor commutators, and position encoders.

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.



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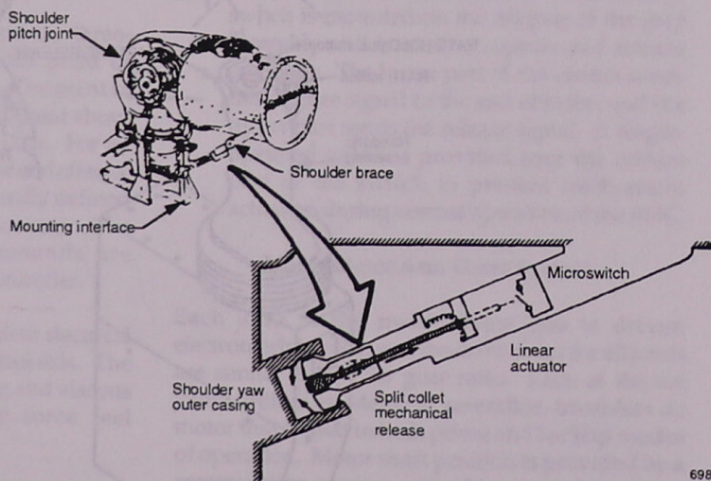
Motor Module

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.

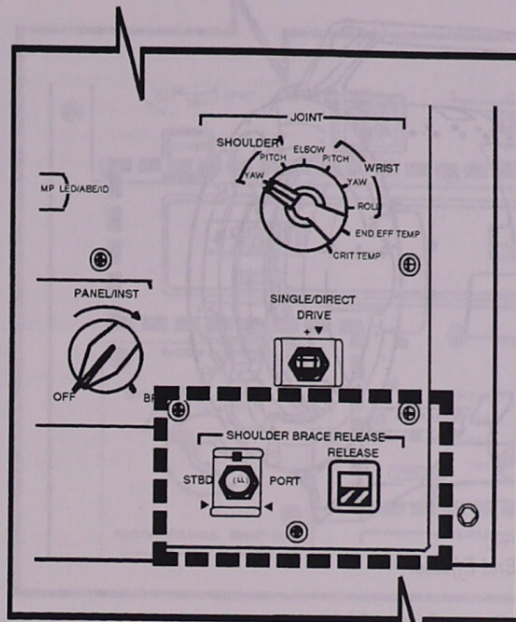
Each joint is fitted with a mechanical stop that is capable of stopping the joint from moving. This mechanical stop is known as the hard stop.

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 no requirement exists to relatch the brace before reentry and landing. A plunger is extended between two pieces of tapered metal,



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Shoulder Brace



SDER BRACE RELEASE Switch and Talkback Indicator on Panel A8U

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 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 until the *RELEASE* talkback indicator on panel A8U indicates gray, which usually takes 8 to 10 seconds. A microswitch at the end of the plunger's travel controls the talkback indicator. 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. In order to achieve an efficient stiffness/weight design and to maintain simplicity of construction, a circular section graphite/epoxy

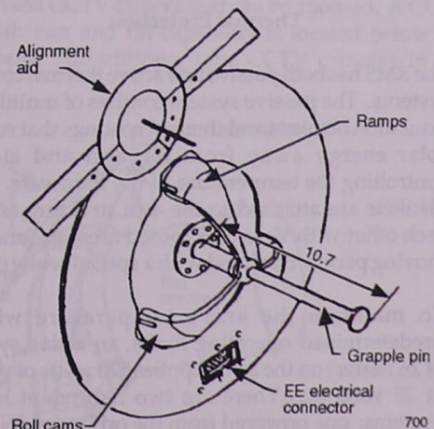
composite design is implemented. End flanges are made of aluminum alloy and are bonded and bolted to the graphite/epoxy tubular sections. Provisions are made for the installation of electrical cable harness assemblies along the length of each arm.

On top of the lower arm and immediately below the elbow joint interface is a mount for installation of an optional elbow CCTV camera and pan/tilt unit.

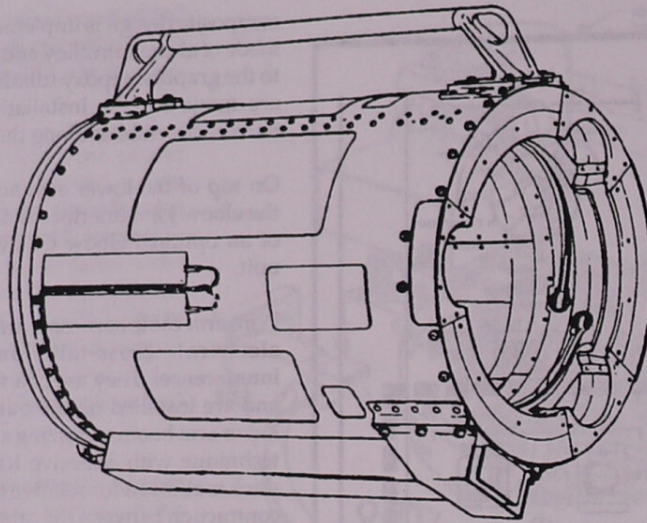
Wire arm cable harnesses are designed to minimize electrical cross-talk and electromagnetic interference. They are of a weight-efficient design and are installed on the outside of the upper and lower arm booms, utilizing a lightweight mounting technique with adhesive Kapton tape. Sufficient slack is allowed for relative thermal expansion and contraction between the cables and arm booms and for movement of the joints.

End Effectors

The RMS can operate with standard or special-purpose end effectors. The standard end effector can grapple a payload, keep it rigidly attached as long as required, and then release it. Special-purpose end effector designs are available and can be built and installed on the RMS during ground turnaround in place of the standard end effector. A male plug on the optional electrical flight grapple fixture can receive electrical power through a female connector located in the special purpose end effector.



Electrical Flight Grapple Fixture



Standard End Effector

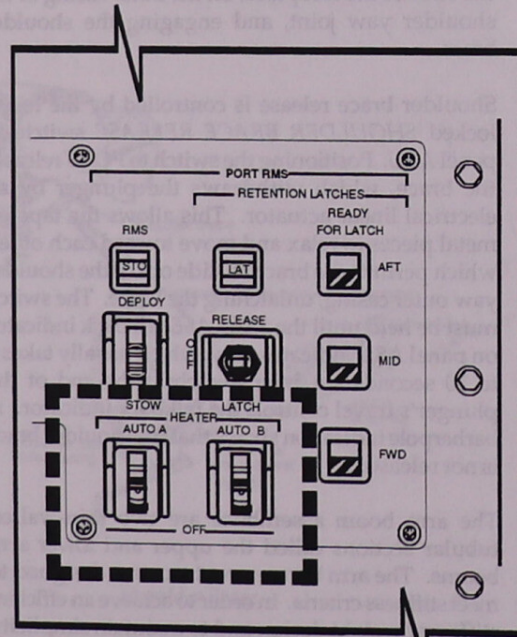
The standard end effector drive system captures or releases a payload using a rotating ring at the open end of the unit to close three wire snares around the payload-mounted grapple fixture. The entire snare ring is then pulled into the end effector until the grapple fixture base plate is flush against 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.

Thermal Protection

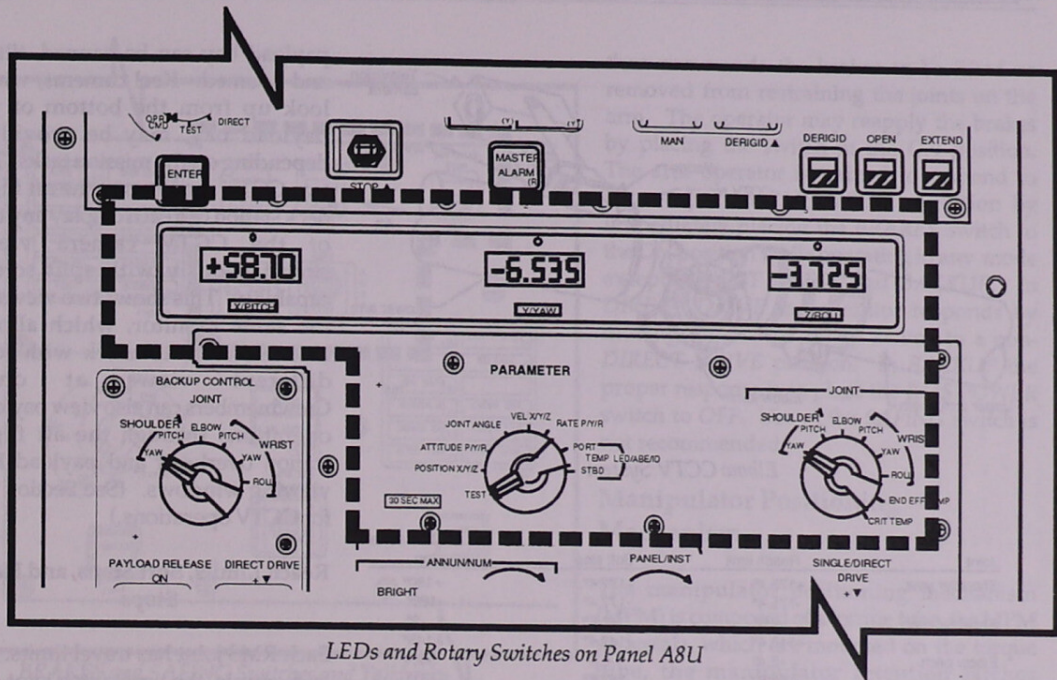
The RMS has both passive and active thermal control systems. The passive system consists of multilayer insulation blankets and thermal coatings that reflect solar energy away from the arm and aid in controlling the temperature of the hardware. The blankets are attached to the arm structure and to each 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 volts 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



PORT TMS HEATER Switches on Panel A8L



LEDs and Rotary Switches on Panel A8U

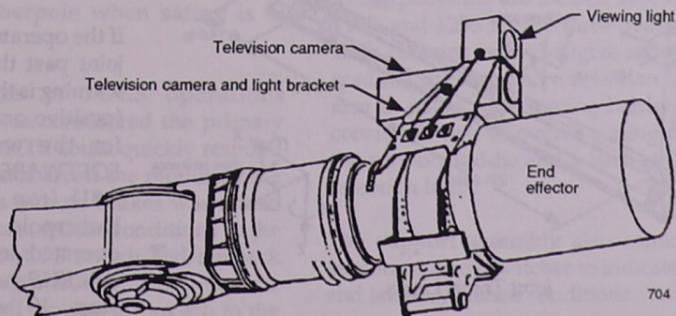
AUTO, the heaters are thermostatically controlled by 12 thermistors located along the arm. The heaters are automatically turned on at 14° F and off at 43° F.

- 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

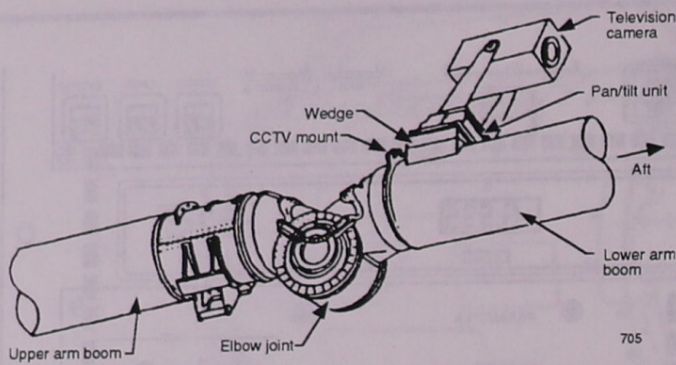
effectorelectronics' temperature, and LED 3 identifies the location of the thermistor to be in the end effector.

CCTV

The orbiter's CCTV aids the flight crew in monitoring PDRS operations. The arm has provisions on the wrist joint for a viewing light 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



Wrist CCTV and Light Configuration

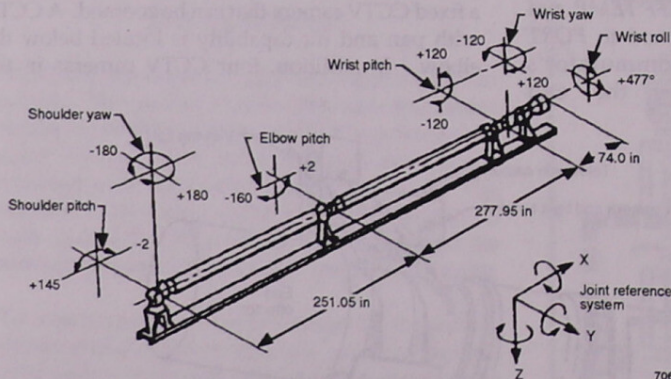


Elbow CCTV System

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°

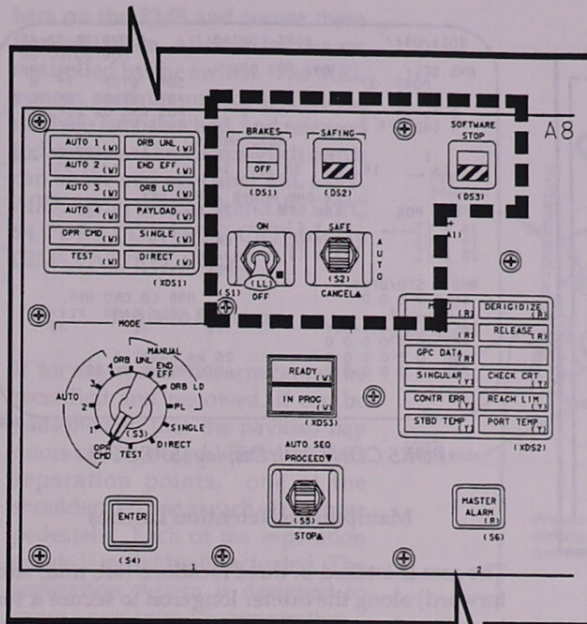
Reach Limits, Soft Stops, and Hard Stops

Each RMS joint has travel limits. As an example, the wrist pitch joint can be physically moved positive or negative 121.4 degrees to the mechanical hard stop. At positive or negative 114.4 degrees, 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* push button 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.



Joint Travel Limits

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 degrees 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 degrees. All joint angles equal 0 degrees when the arm is cradled.



BRAKES and SAFING Switches and Talkbacks and SOFTWARE STOP Talkback on Panel A8U

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 POWER* switch to *OFF*. Use of the *SAFING* switch is not recommended.

Manipulator Positioning Mechanism

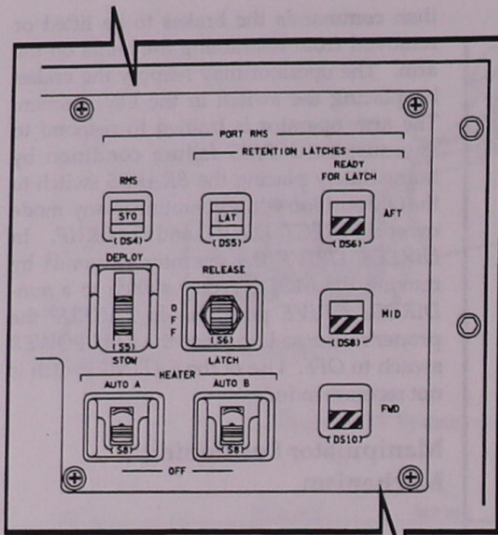
The manipulator positioning mechanism (MPM) is composed of a torque tube, the MPM pedestals, which are mounted on the torque tube, the manipulator retention latches (MRLs), and the jettison system.

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 degree 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 degree 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.

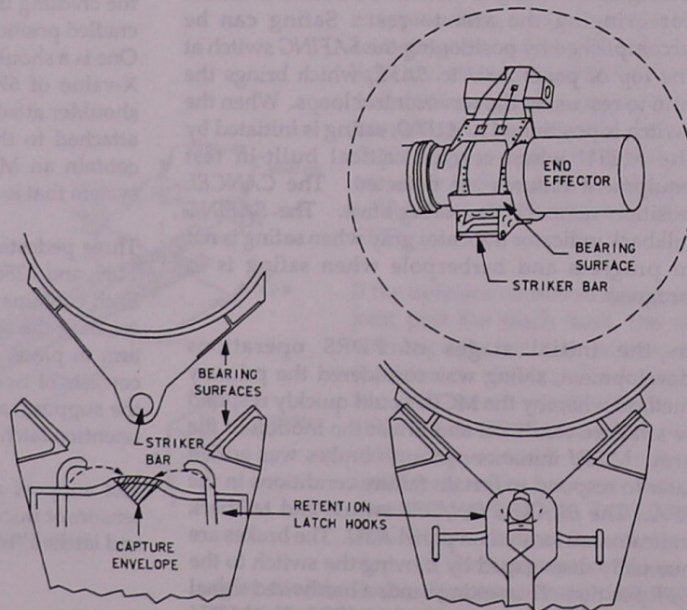


PORT RMS Controls on Panel A8L

MPM Torque Tube

The MPM drive system consists of dual redundant motors rotating a torque tube that in turn drives the rotary actuators that move the RMS pedestals. The torque tube rotates the arm from its stowed position to its operational position outside the payload bay. The drive mechanism has two overcenter lock components, one of which locks in the deployed position and the other which locks in the stowed position. The drive system contains microswitches needed for stow/deploy indications. Current flight rules prohibit loaded arm operations from the stowed configuration.

The *PORT RMS DEPLOY/STOW* switch is 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. Status of the shoulder MPM can be monitored on the SPEC 94 PDRS CONTROL display (RMS STO/DPLY SHLD).



RMS Retention Mechanism

2011/094/	PDRS CONTROL	4 000/02:32:45
RMS SEL:	RMS PWR OFF	000/00:00:00
PORT 1*	SOFT STOP	ENA INH 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		PDHS NTL 28* 29
	AUTO MODES	
1	2	3
13 _ _	14 _ _	15 _ _
		16 _ _
		17 START PT
		LAST PT _ _ _
	OPR CMD MODES / POR REF	
END POS	END ATT	24 PL INIT ID _0
18 X [] _ _ _ _	21 P [] _ _ _	
19 Y [] []	22 Y [] []	CMD CK 25
20 Z [] []	23 R [] []	
		POR DISPLAY 30 ORB
RMS STO/DPLY		ORB LD CMD REF
SHLD 0 0 0 0		NORM FLY-CAMR FLY-PL
		31 32 33
RMS LAT/REL/RDY		
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

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PDRS CONTROL Display (SPEC 94)

Manipulator Retention Latches

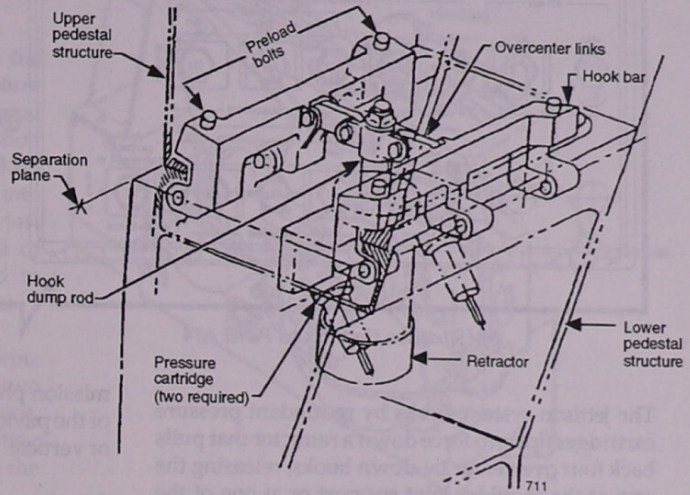
The arm is latched in three locations (aft, mid, and forward) along the orbiter longeron to secure it for launch and entry loads. The retention latches are dual rotating surfaces that are driven by redundant motors. When the three ready-to-latch indications are received, the operator positions the *PORT 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).

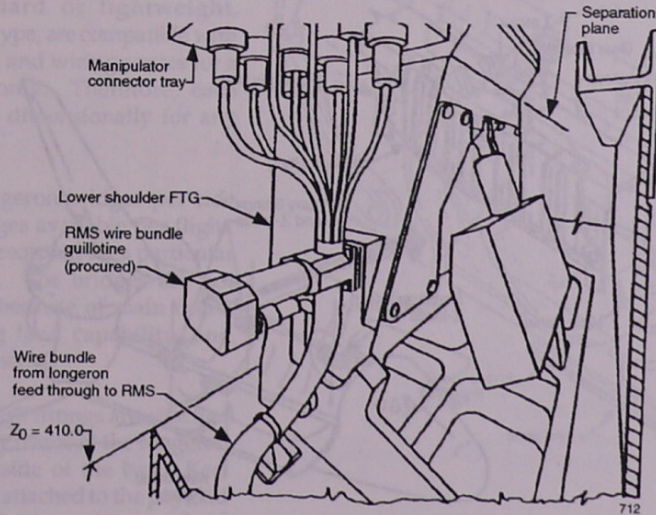
Jettison System

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.

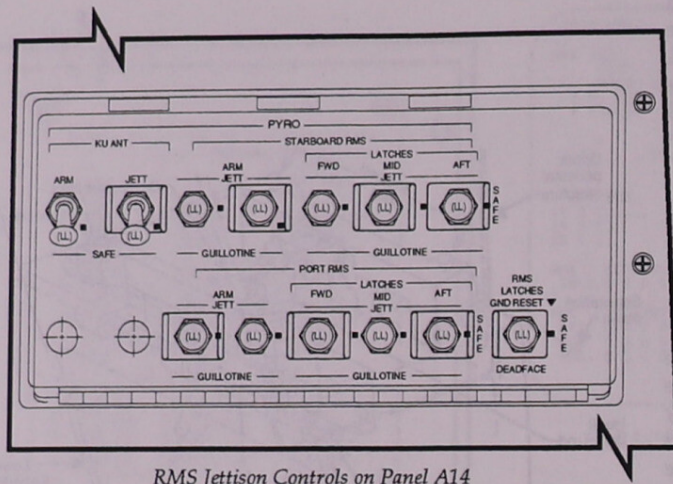
The shoulder attach point has a wire bundle that must be separated prior to shoulder support separation. The wire bundle is severed by a redundant pyro-operated guillotine prior to the activation of the support jettison system.



Jettison System



RMS Shoulder Wire Bundle



RMS Jettison Controls on Panel A14

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.

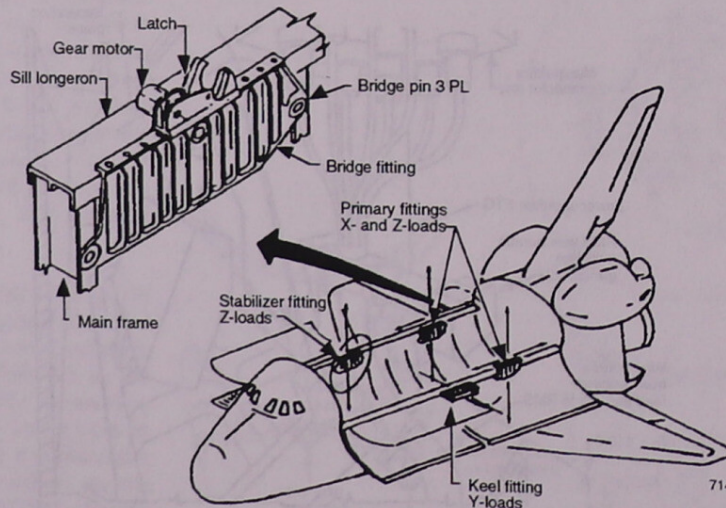
The *GUILLOTINE* switches for the RMS are located on panel A14.

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



Active Payload Retention System

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

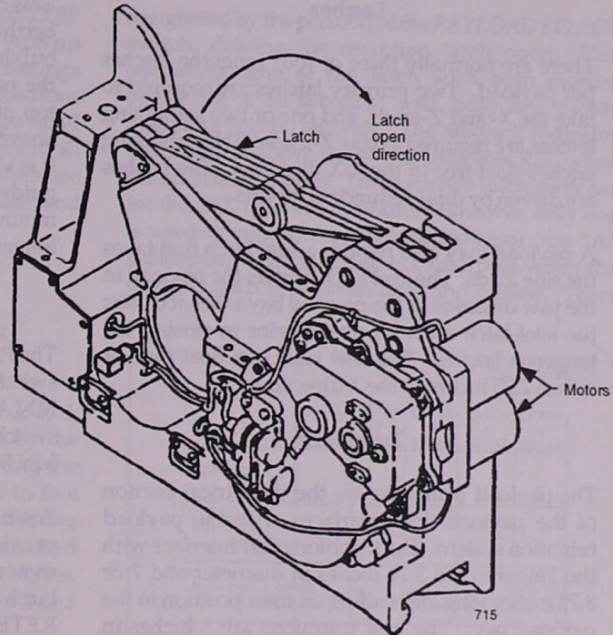
Bridge fittings are used to react to the loads imparted to the orbiter structure by the payload and provide a structural interface for both the payload retention latch assemblies (PRLAs) and active keel actuators (AKAs). Bridge fittings fall into standard and lightweight categories, just as the PRLAs 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.

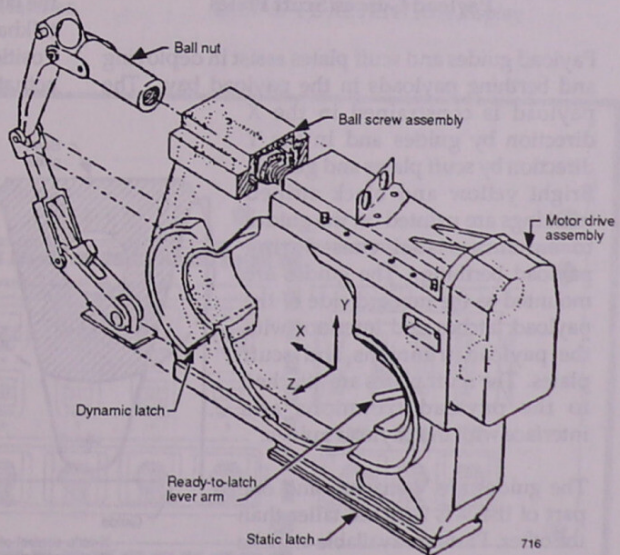
The standard and lightweight bridge fittings differ both in cross-sectional thickness and material. The standard fittings are made of titanium, and are thicker than their lightweight aluminum counterparts. Bridge fittings, whether they are standard or lightweight, longeron or keel type, are compatible 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 are attached to the payload bay frame at the longeron level and at the side of the bay. Keel bridge fittings are attached 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.

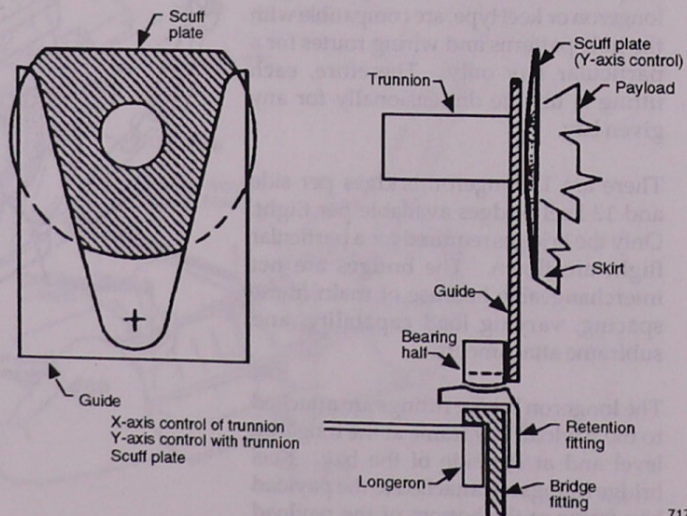
The guides are V-shaped, and one part of the V is 2 inches taller than the other. Parts are available to make either the forward or aft guide taller.

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



Orbiter Payload Guide, Active Retention Fitting

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.

NOTE

Payload retention latch wiring configurations are mission-dependent.

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.

Positioning a *PAYLOAD RETENTION LATCHES* switch to *RELEASE* enables ac power to the dual electric motors associated with the retention latches

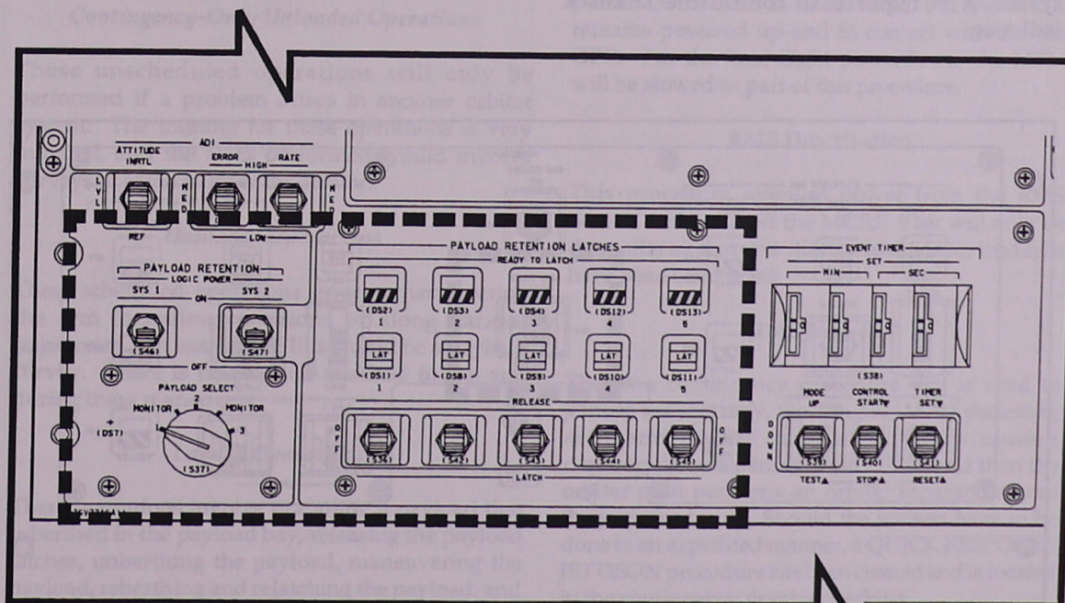
designated by the position of the *PAYLOAD SELECT* switch, driving the retention latch open. The operating time of the latch with both motors operating is 30 seconds; with only one motor operating it is 60 seconds. The talkback indicator immediately above the switch indicates *REL* when the latch is 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

2011/ /097 PL RETENTION 4 000/02:37:49
000/00:00:00

	LATCH 1 AB/AB	LATCH 2 AB/AB	LATCH 3 AB/AB	LATCH 4 AB/AB	LATCH 5 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

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DISP 97 PL RETENTION display



PAYLOAD RETENTION Switches and Talkbacks on Panel A6U

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.

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

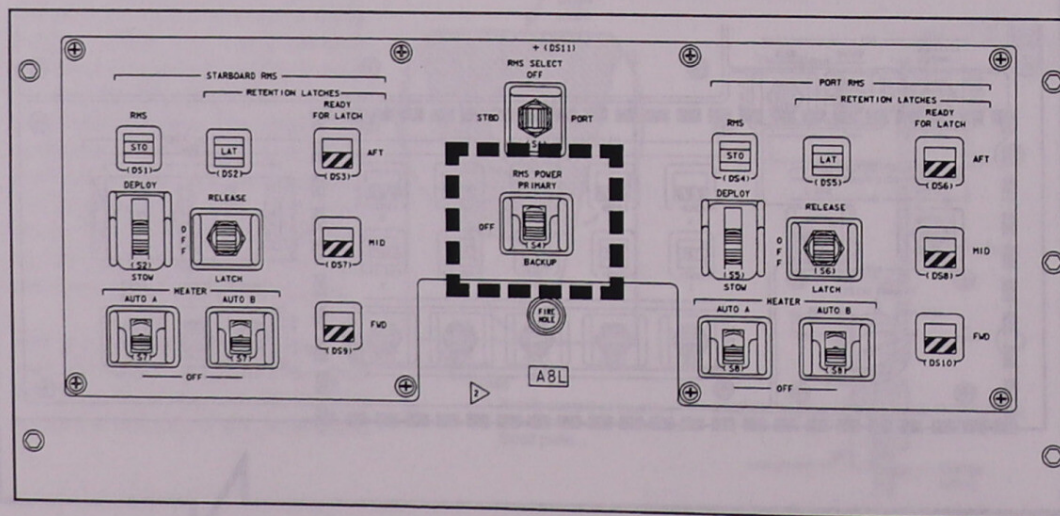
The RMS can perform a wide range of operations. This section gives an overview of these operations, as well as the actions required to configure the arm to support these operations.

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.



RMS POWER Switches 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.

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

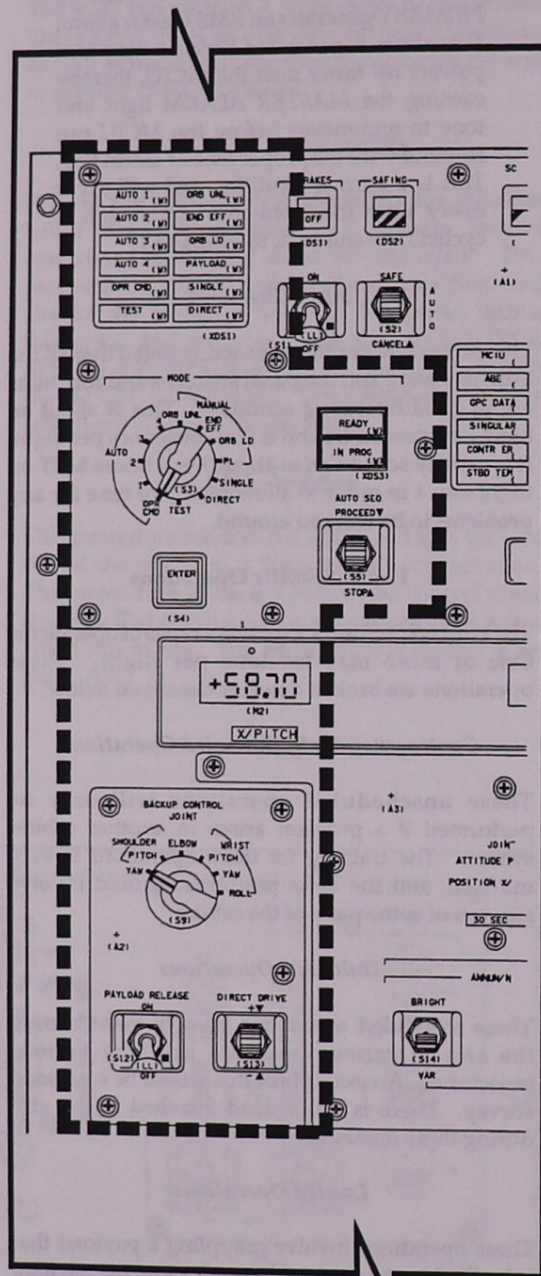
Operating the arm in a single joint mode allows only one joint at a time to be driven. Single joint operations are very painstaking and time consuming, and so are only used when absolutely necessary. Uncradling and cradling must be done via a single joint mode, since the arm is in the soft stop region 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*.

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



Mode Selection Rotary Switches and Lights on Panel A8U

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

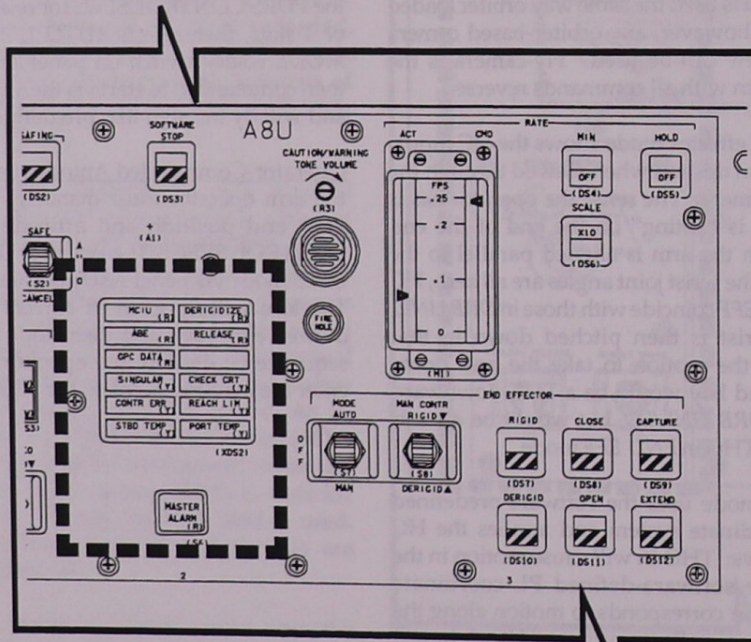
There are two types of auto modes: auto-commanded auto sequences and operator-commanded auto sequences. In either case, the SM GPC controls the arm trajectory.

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 pre-defined 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 cancelled by depressing the push button.
- The RMS C/W tone volume may be adjusted by the CAUTION/WARNING TONE VOLUME knob.

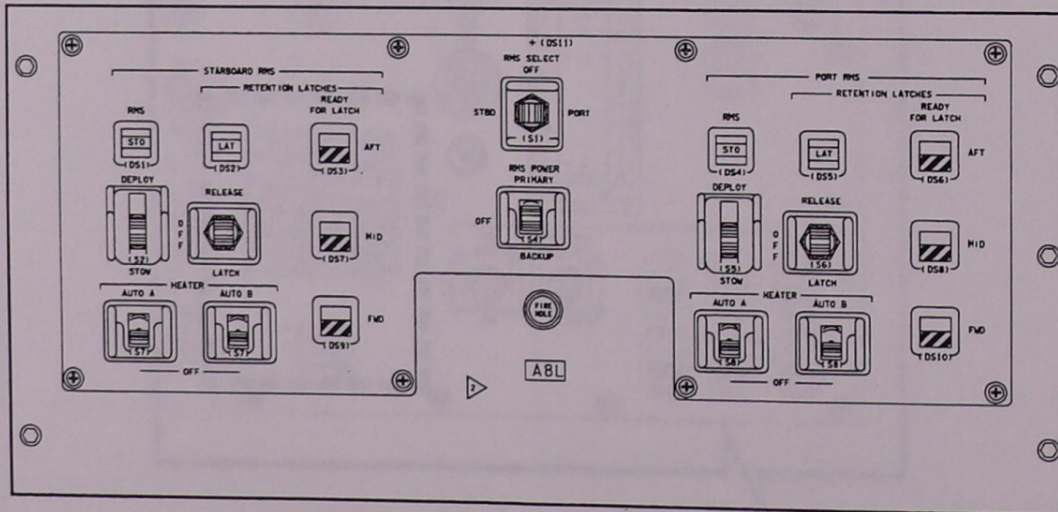


RMS Caution and Warning Lights on Panel A8U

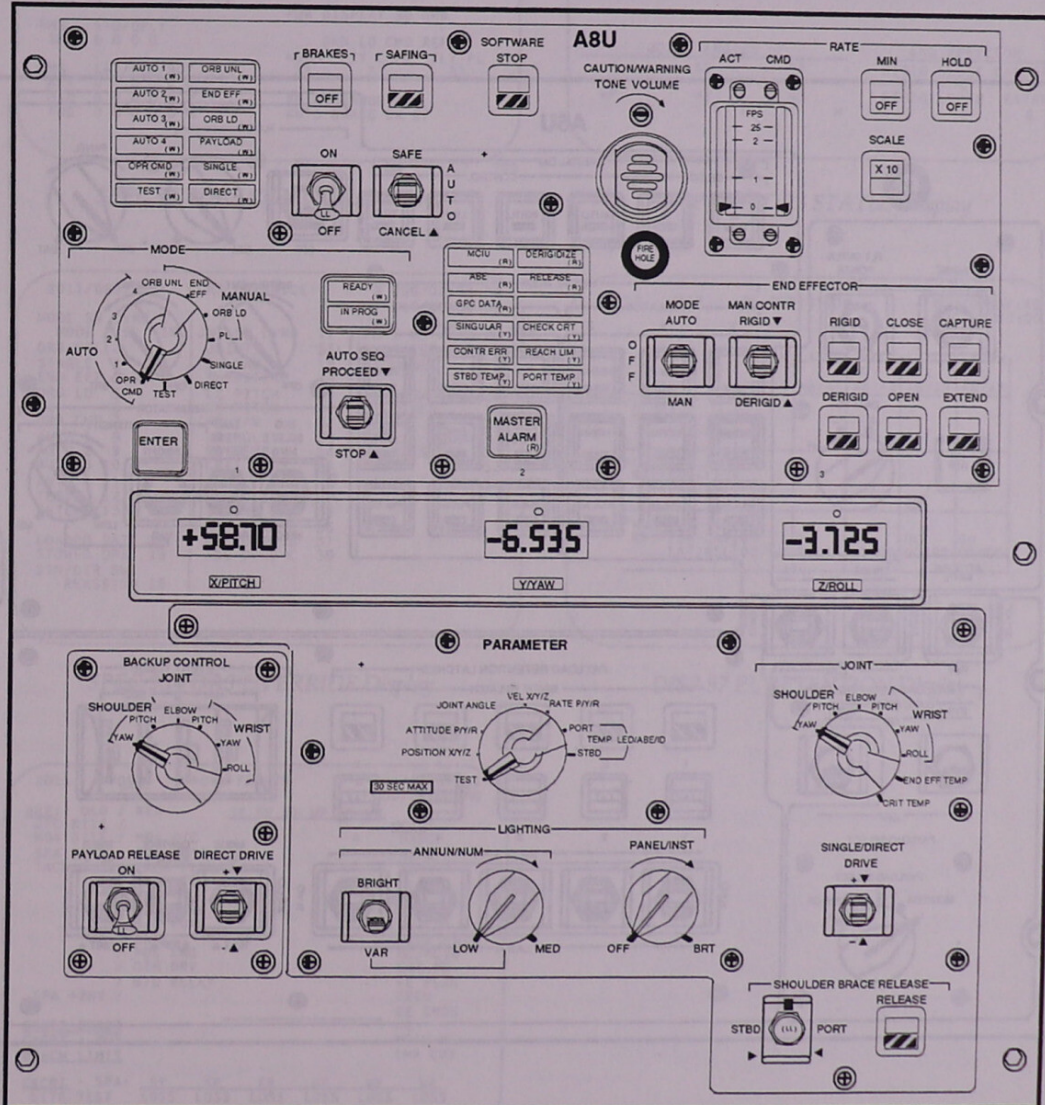
PDRS Summary Data

- 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.

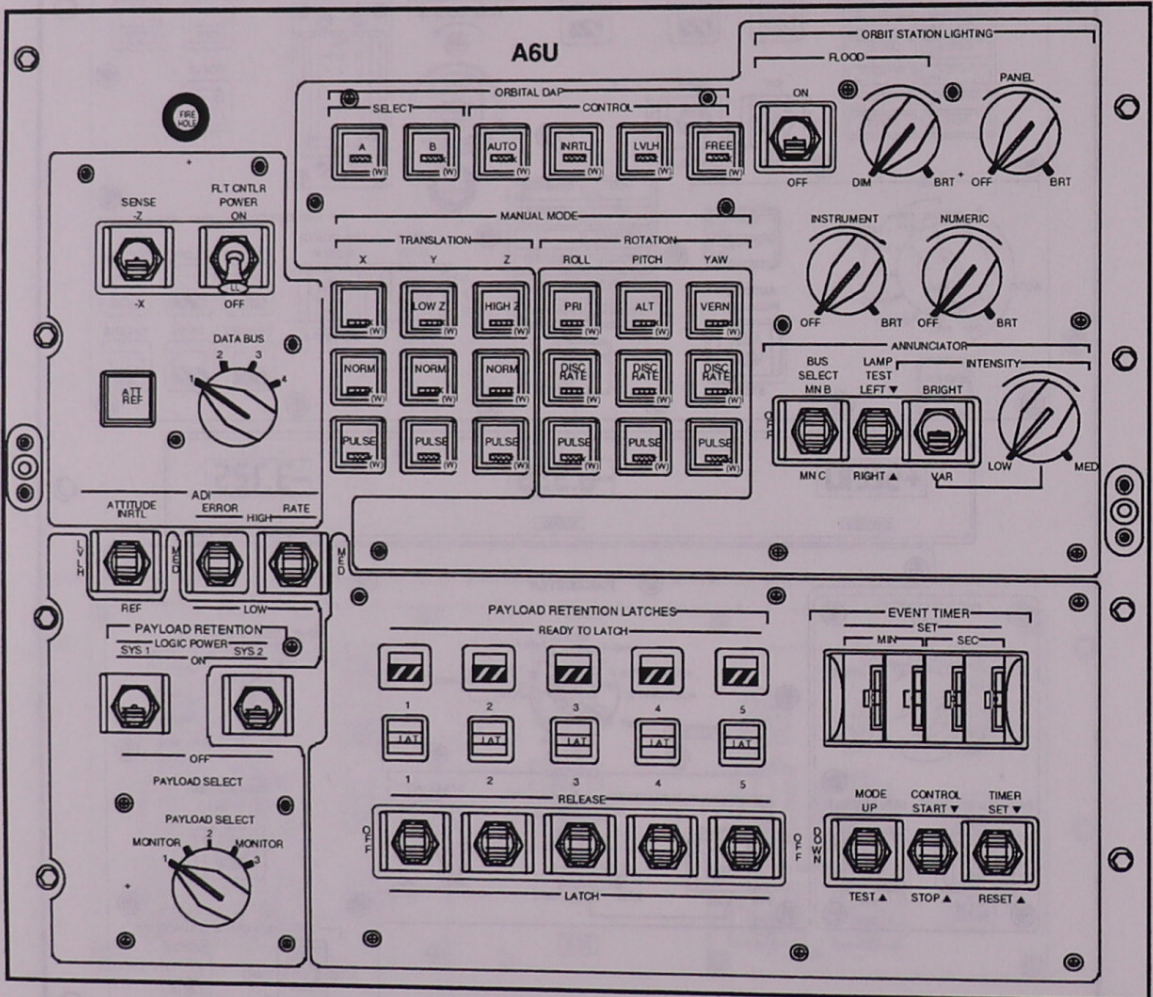
2. SYSTEMS
2.19 Payload Deployment and Retrieval System



Panel A8L



Panel A8U



Panel A6U

2. SYSTEMS
2.19 Payload Deployment and Retrieval System

```

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 4 17 START PT ---
                13 14 15 16 17 LAST PT

END POS      OPR CMD MODES / POR REF
18 X [ ]---- 21 P [ ]---- 24 PL INIT ID .0
19 Y [ ]      22 Y [ ]      CMD CK 25
20 Z [ ]      23 R [ ]

RMS STO/DPLY  POR DISPLAY 30 ORB
SHLD 0 0 0 0 0      ORB LD CMD REF
                NORM FLY-CAMR FLY-PL
                31 32 33

RMS LAT/REL/RDY
AFT 0 0 0 0 0 0
MID 0 0 0 0 0 0
FWD 0 0 0 0 0 0

                25 WR RANGE 4
                AUTO BRAKE CK 27
    
```

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SPEC 94 PDRS CONTROL Display

```

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

TRANS RATES  ACT      M      M      M
CMD          M      M      M

ROT RATES   ACT      M      M      M
CMD          M      M      M

                JOINT ANGLES      END EFFECTOR
                SY SP EP      RIGID CLOSE CAPTURE
                M M M      0 0 0
                WP WY WR M      DERIG OPEN EXTEND
                M M M      0 0 0
    
```

710

DISP 169 PDRS STATUS Display

```

2011/095/      PDRS OVERRIDE    4 000/02:33:08
                000/00:00:00
MODE SW OVDR 1
MODE SEL IND  JNT SW OVDR 17  RATE SW OVDR 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 OVDR 29
PL 6        WR PITCH 21     PROCEED 30
OPR CMD 7    WR YAW 22      STOP 31
AUTO 1 8     WR ROLL 23     HC AXIS CHG 32
AUTO 2 9     EE TEMP 24      THC 33
AUTO 3 10    CRIT TEMP 25     RHC 34

                MCIU OVERRIDE
                SAFING CAN 35
                ABE OVDR A 36
                ABE OVDR B 37
                ABE OVDR C 38

LOADED RATE 14
STOWED OPS 15
SIN/DIR SW  REASSIGN 16
    
```

711

SPEC 95 PDRS OVERRIDE Display

```

2011/ /097     PL RETENTION     4 000/02:37:49
                000/00:00:00
                LATCH LATCH LATCH LATCH LATCH
                1 2 3 4 5
                AB/AB AB/AB AB/AB AB/AB AB/AB
PL SEL 1
RDY-FOR-LAT / / / / /
LAT/REL

PL SEL 2
RDY-FOR-LAT / / / / /
LAT/REL

PL SEL 3
RDY-FOR-LAT 00 00 00 00 00
LAT/REL 00/00 00/00 00/00 00/00 00/00
    
```

718

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      MCIU:
SPA CMTR / SPA CMTR    MADC
TACH / TACH PLL      MCPC
/ TACH TCO           ICF
/ CPU
/ MDA DMND           ABE:
/ A/D CONV          COMM
/ BRAKE
/ POS ENG           CHECK CRT:
/ DIR DRV          DC/MCIU
/ B/U RELAY       EXT FS
                EE FLAG
                EEEU
                EE CMDS
                HC
                MCIU HC
                TMP CKT

CONTR ERROR
CKCRT - POS
REACH LIMIT

CKCRT - SPA:  SY SP EP WP WY WR
BITE TEST  LOSS LOSS LOSS LOSS LOSS LOSS
    
```

1070

DISP 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 due to the fact that 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.

2.20 REACTION CONTROL SYSTEM (RCS)

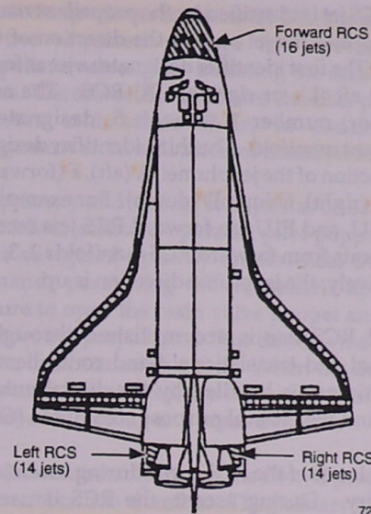
CONTENTS	
Description	2.20-1
Jet System	2.20-3
Propellant System	2.20-4
Helium System	2.20-9
Thermal Control	2.20-11
RCS Redundancy Management	2.20-12
Operations	2.20-17

Description

The orbiter's reaction control system (RCS) consists of forward and aft control jets, propellant storage tanks, and distribution networks located in three separate 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.

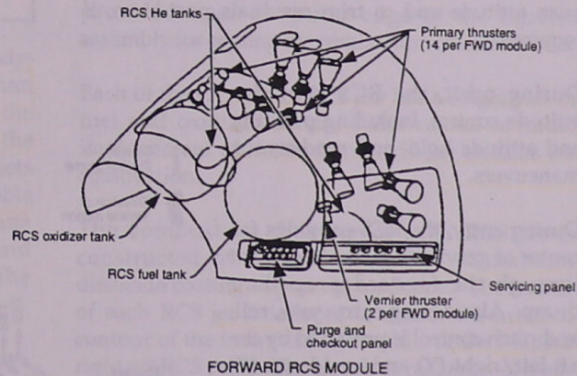
The RCS units provide propulsive forces from a collection of jet thrusters to control the motion of the orbiter. Each jet is permanently fixed to fire in a general direction: up, down, left, right, forward, or aft. The selective firing of individual jets or specific combinations of jets provides thrust for:

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

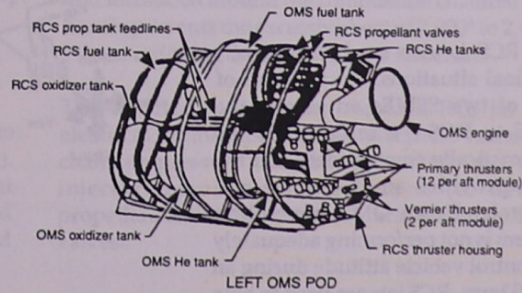


728

Forward, Left, and Right RCS Modules



FORWARD RCS MODULE



LEFT OMS POD

729

Left and Forward RCS Modules

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.

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.

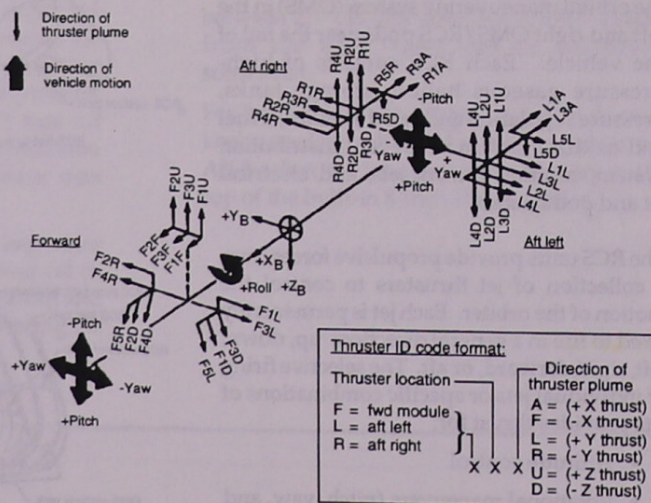
The RCS is also used during off-nominal situations. In the case of loss of two SSMEs on ascent, the OMS-to-RCS interconnect is automatically commanded, and the RCS provides single-engine roll control. If the OMS gimbaling system is not performing adequately to control vehicle attitude during an OMS burn,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



The thruster location number is actually the propellant manifold number. Manifold 5 jets are verniers.

RCS Jet Identification

NOTE

The loss of one down-firing vernier jet results in the loss of the entire vernier mode due to the loss of control authority. If one side-firing vernier jet is lost, control can be maintained, except for some RMS-loaded operations.

Two helium tanks supply gaseous helium pressure to the oxidizer and fuel tanks. The oxidizer and fuel are then supplied under pressure to the RCS jets. Nitrogen tetroxide (N_2O_4) is the oxidizer, and monomethyl hydrazine (MMH) is the fuel. The propellants are toxic, liquid at room temperature, and hypergolic (they ignite upon contact with each other). The propellants are supplied to the jets, where they atomize, ignite, and produce a hot gas and thrust.

CAUTION

On-orbit leak of MMH fuel may cause a module fire on entry when MMH mixes with atmospheric oxygen.

The primary jets are operable in a maximum steady-state mode of 1 to 150 seconds, with a maximum single-mission contingency of 800 seconds for the RCS aft (+X) jets and 300 seconds maximum for the RCS forward (-X) jets. The multiple primary jets provide redundancy. The vernier jets are operable in a steady-state mode of 1 to 125 seconds maximum and 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.

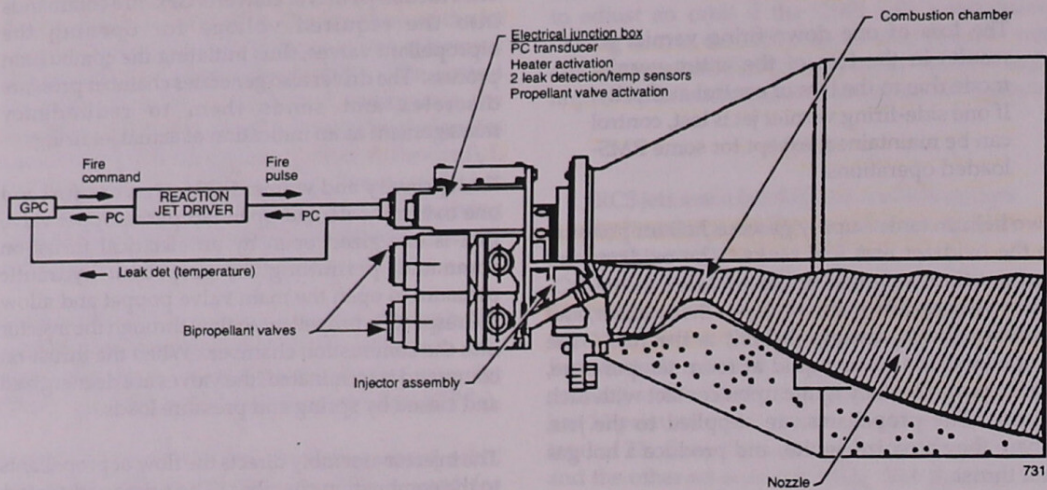
Each primary and vernier RCS jet has one fuel and one oxidizer solenoid-operated pilot poppet valve that is energized open by an electrical thrust-on command, permitting the propellant hydraulic pressure to open the main valve poppet and allow the respective propellant to flow through the injector into 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.

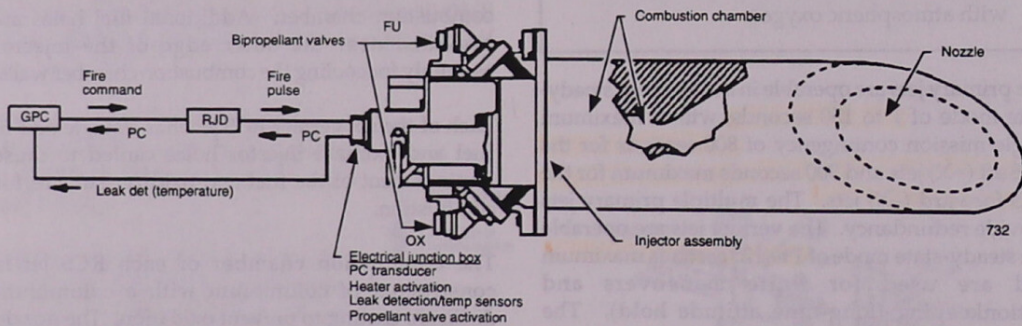
Each of the six vernier RCS jets has a single pair of fuel and oxidizer injector holes canted to cause impingement of the fuel and oxidizer streams for combustion.

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.



Primary Jet



Vernier Jet

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.

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

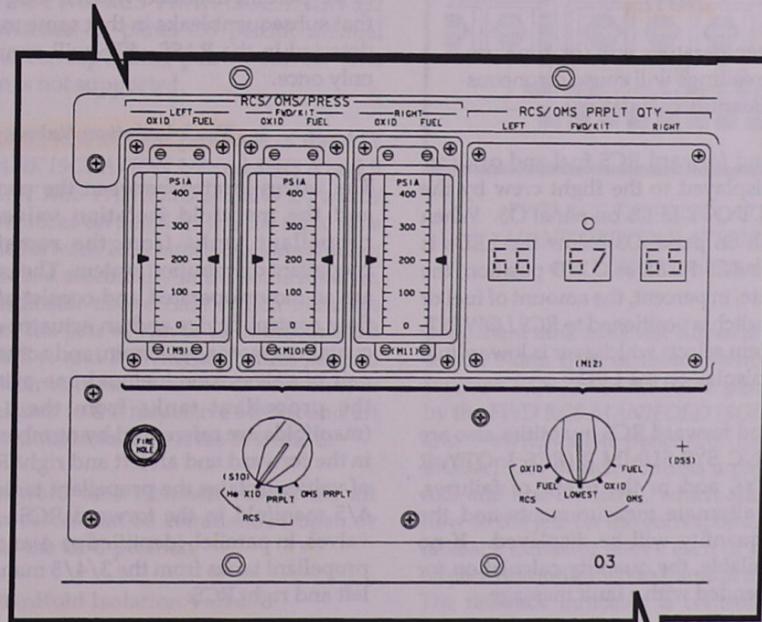
Each RCS module contains two propellant tanks, one for fuel and one for oxidizer. The nominal full load of the forward and aft RCS tanks in each pod is 1,464 pounds in the oxidizer tanks and 923 pounds in the fuel tanks.

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.

The left, forward, and right RCS fuel and oxidizer tank ullage pressures (pressures within an RCS propellant tank used for expelling propellant and calculating propellant volume) can be monitored on panel O3. When the left-hand rotary switch on panel O3 is positioned to *RCS PRPLT*, the pressures are displayed on the three RCS/OMS/PRESS meters. The *LEFT RCS*, *FWD RCS*, or *RIGHT RCS* red caution and warning light on panel F7 will illuminate if a module's tank ullage pressure is less than 200 psia or higher than 300 psia.



RCS/OMS/PRESS Meters and Rotary Switch and RCS/OMS PRPLT QYT 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.)

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.

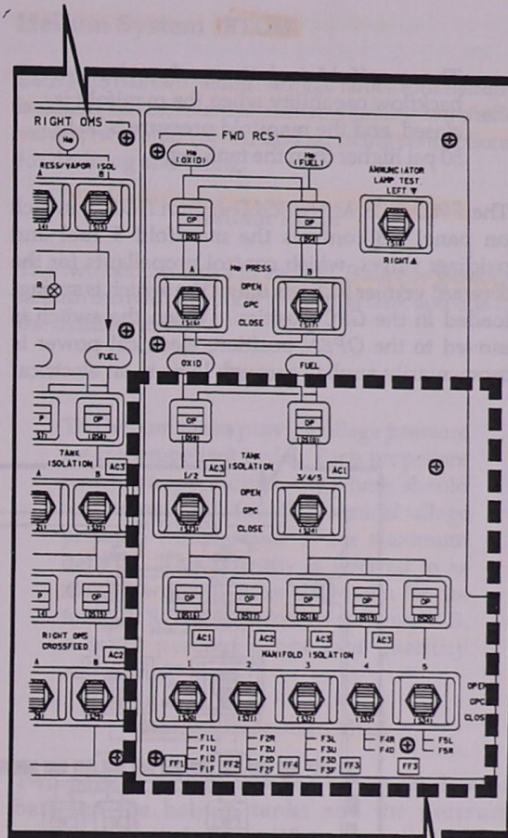
Microswitches in each pair of valves control talkback indicators above each tank's isolation switch on panel O8. The talkback indicator shows *OP* or *CL* when that pair of valves is open or closed and barberpole when the valves are in transit, or one valve is open, and the other is closed, or for some 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



FWD RCS TANK ISOLATION and MANIFOLD ISOLATION Switches and Talkbacks on Panel O8

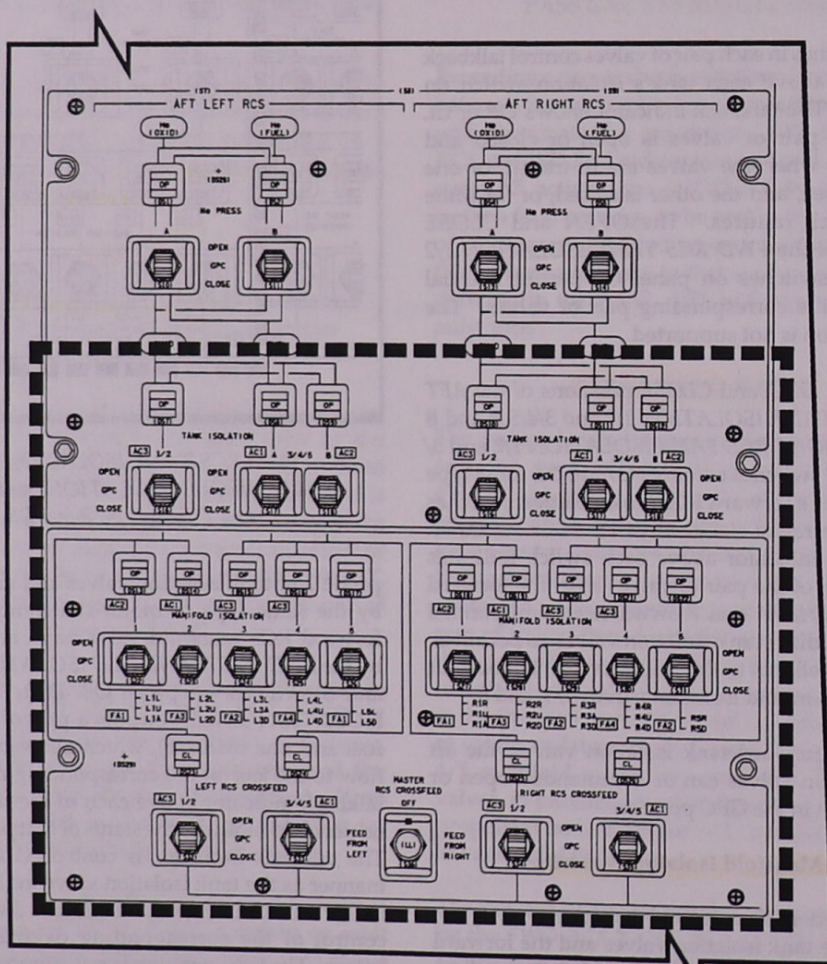
propellant tank isolation valves and are controlled by the same type of motor-switching logic. The forward RCS manifold valve pairs are controlled by the *FWD RCS MANIFOLD ISOLATION 1, 2, 3, 4,* and *5* switches on panel O8. Each *MANIFOLD ISOLATION* switch controls a pair of valves (one fuel and one 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 manual 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 position, electrical power is momentarily applied through logic in an electrical

load controller assembly to energize the solenoid valves open and magnetically latch the valves. To close the valves, electrical power is momentarily applied to energize the solenoids surrounding the magnetic latches of the valves, which allows spring and propellant pressure to force the valves closed. A position microswitch in each valve indicates valve position to an electrical controller assembly and controls a talkback indicator above the switch. When both valves are open, the indicator shows OP; when both valves are closed, it indicates CL. If one valve is open, and the other is closed, the talkback indicator shows barberpole.



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

The *AFT LEFT RCS MANIFOLD ISOLATION 1, 2, 3, 4, 5* and *AFT RIGHT RCS MANIFOLD ISOLATION 1, 2, 3, 4, 5* switches are on panel O7. The *OPEN, GPC, and CLOSE* positions of each switch are the same type as the forward switches and are controlled electrically in the same manner. The *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

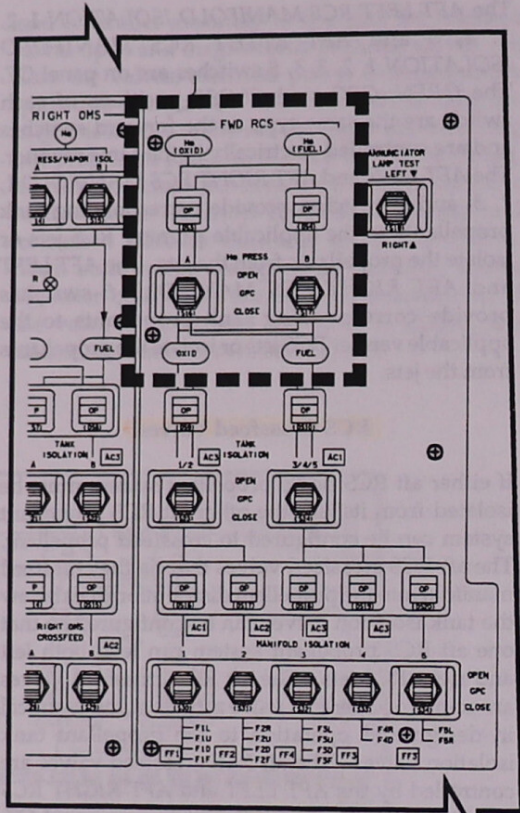
controller to energize a solenoid surrounding the magnetic latch of the two helium isolation valves, which allows spring and helium pressure to force the valve closed.

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.

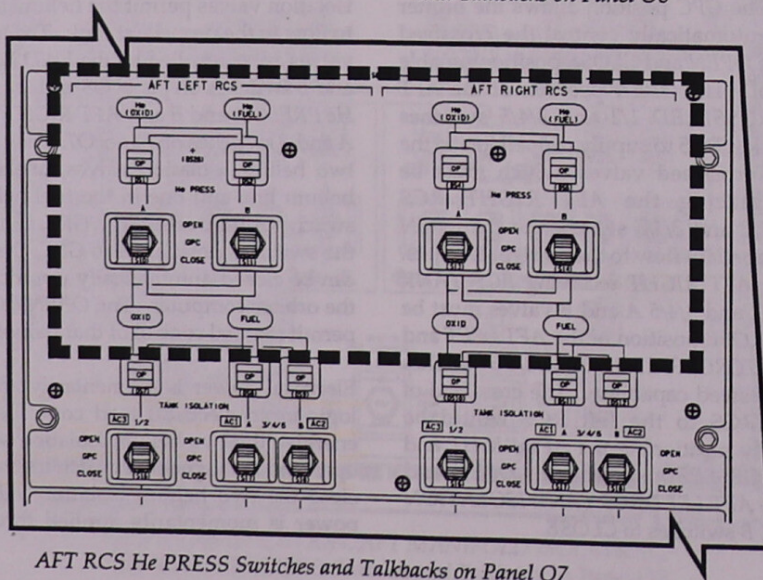
The RCS helium supply pressure is monitored on panel O3. When the rotary switch on panel O3 is positioned to *RCS He X10*, the forward and aft RCS helium pressures are displayed on the RCS/OMS/PRESS OXID and FUEL meters on panel O3.

Helium Pressure Regulators

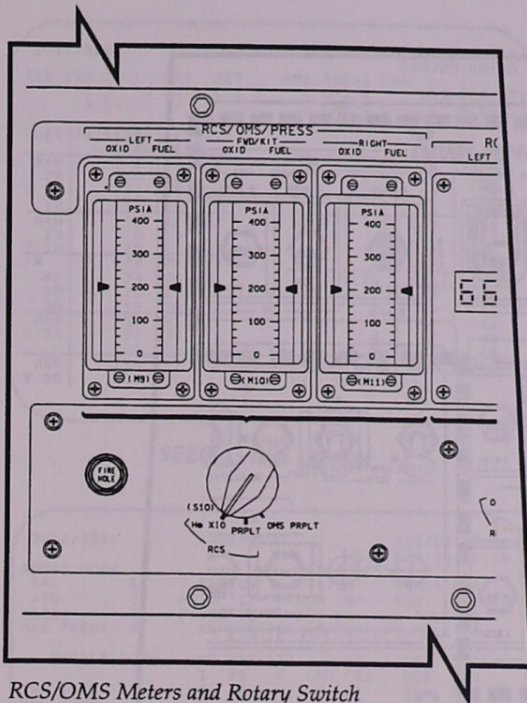
Helium pressure is regulated by two regulator assemblies, connected in parallel, downstream of the helium isolation valves. Each assembly contains two stages, a primary and a secondary, connected in series. If the primary stage fails open, the secondary stage regulates the pressure. The primary regulates the pressure at 242 to 248 psig, the secondary at 253 to 259 psig.



FWD RCS He PRESS Switches and Talkbacks on Panel O8



AFT RCS He PRESS Switches and Talkbacks on Panel O7



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

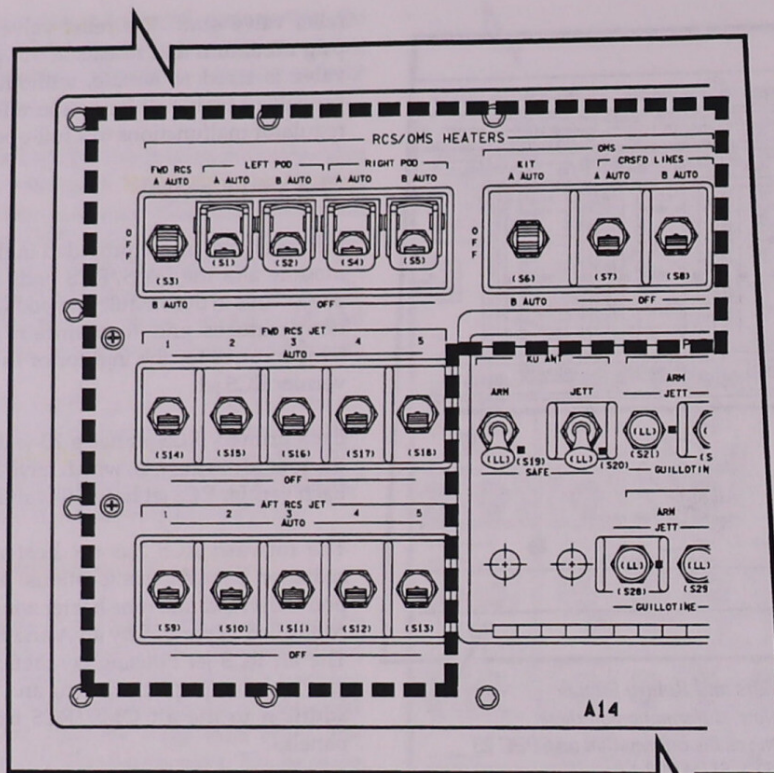
Electrical heaters are provided in the forward RCS module and the OMS/RCS pods to maintain the propellants in the module and pods at safe operating temperatures and to maintain safe operating temperatures for the injector of each primary and vernier RCS jet.

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.



RCS/OMS HEATERS Switches on Panel A14

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 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.

JET		FAIL	DES INH	JET DES	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	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	OXID	FU
PRPLT TK P	3376	3360
	247	250
	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
XFFED P	254	254
JET RESET	45	

SPEC 23 RCS Display

ABORT MODE	ELEVON	FILTER	ATMOSPHERE
TAL 1			
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

PROPLT DUMP	IMU	DES	ATT	AA	RGA	SURF	
INH ICNCT 5	1	25	2	LRU DES	DES	DES	
OMS DUMP 2	2	26		1	31	35	39
ARM 6	3	27		2	32	36	40
START 7				3	33	37	41
STOP 8				4	34	38	42
9 QUAN/SIDE 041							
OMS DUMP TTG 227							

AFT RCS 13	INH	AUTO	28	ROLL MODE
14 TIME 000		SEP	29	WRAP MODE 45
FWD RCS 15 <td>INH</td> <td>ET UMB DR</td> <td></td> <td>VENT DOOR CNTL</td>	INH	ET UMB DR		VENT DOOR CNTL
16 TIME 000		CLOSE 30		OPEN 43
				CLOSE 44

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.

Jet Fail-Leak

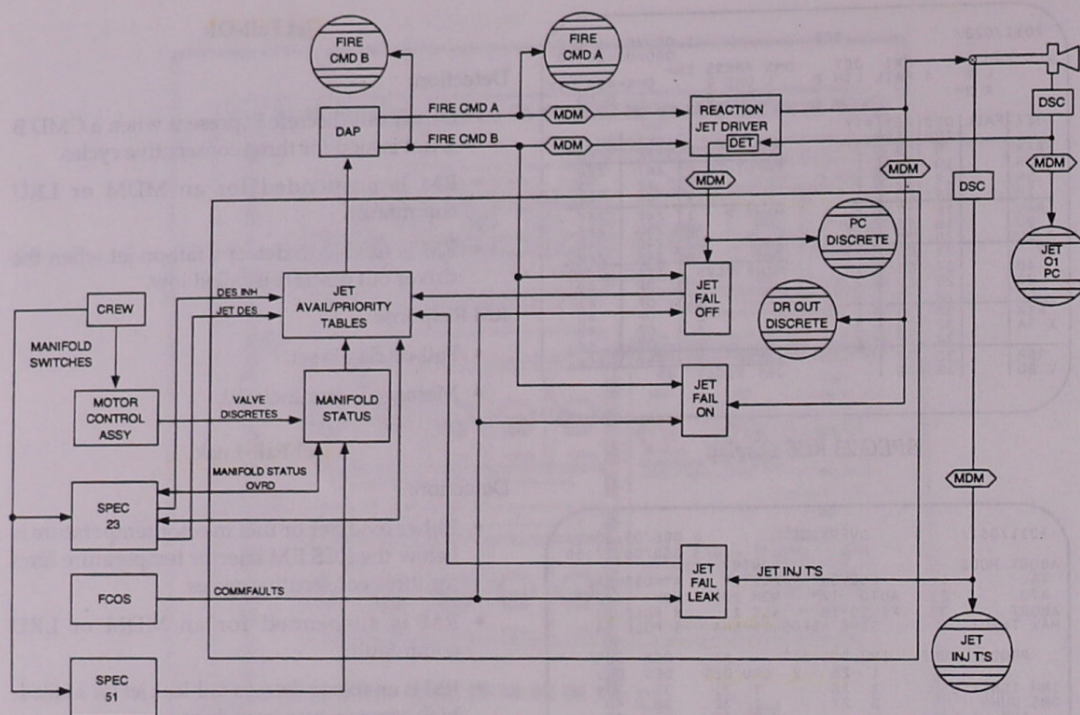
Detection:

- Either oxidizer or fuel injector temperature is below the RCS RM injector temperature limit for three consecutive cycles.
- RM is suspended for an MDM or LRU commfault.
- RM is unable to detect a fail-leak jet for a failed-high temperature transducer.
- A failed-low injector temperature transducer will trip RM.

RM Response:

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

Once RM has annunciated a failure for a jet, that failure will not be reannunciated until the fail flag is reset. The remaining failure modes that were not detected can be annunciated. Vernier jet failures are annunciated in OPS 2 and 8 only.



RCS Redundancy Management Schematic

Nomenclature

To clarify nomenclature, a few RCS RM definitions are listed below.

Deselected Jet — A jet that is not available and will not be commanded to fire.

Reselected Jet — A jet that was previously not available and is now available and could be commanded to fire.

Auto-Deselected Jet — A jet that has been deselected by RCS RM software. RM will auto-deselect a jet for fail-off and fail-leak detection.

Manually Deselected Jet — A jet that has been deselected by SPEC 23 item entry.

Manually Reselected Jet — A jet that is reselected via SPEC 23 item entry. This is the only method to reselect an individual jet that was auto-deselected by RCS RM. (A whole manifold of jets can be reselected via SPEC 51 and SPEC 23 item entry.)

Pod Counter — The internal RCS RM counter that counts the number of jets per pod that have been auto-deselected by RCS RM.

Pod (Fail) Limit — The PRI JET FAIL LIM on SPEC 23 (item 4) that limits the number of primary jets that can be auto-deselected per pod.

Pod Counter is Full — Pod counter equals pod fail limit. Typically, this means two jets have failed and have been auto-deselected in a pod.

Override a Manifold Open (Closed) — An action performed via item entry on SPEC 23 that toggles the RCS RM manifold status to open (closed). The RCS RM manifold status is an independent variable that may differ from the actual manifold valve position. Overriding a manifold closed will deselect all the jets on that manifold.

Deselection Candidate — Any jet that is annunciated fail-off or fail-leak by RCS RM becomes a deselection candidate, unless the jet has been deselection 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 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 announce all jet failures not previously announced 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 announced 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 deselection candidate, this jet will not be auto-deselected, as expected. If one of the jets on the same pod is then manually reselected, the pod counter is decremented to one, also as expected. However, the deselection candidate that could not previously be auto-deselected since the pod counter was at the limit will now be auto-deselected, and the pod counter will be incremented to two again. All deselect candidates remain "deselectable" until their fail-flags are cleared.

RCS Manifold RM

RCS RM contains an independent evaluation of RCS manifold valve status. Input to this processing includes the actual manifold valve status, commfault protection, and crew display item entry processing.

The RCS RM manifold status can differ from the actual valve positions. Manifold status is reevaluated when valve discretes change, a commfault occurs, or manifold status is changed by crew display item entries. A commfault is declared when the data path for the manifold valve microswitch discrete is failed. A commfault occurs when an MDM or GPC fails, or a BCE BYPASS is declared.

If RCS RM sets the manifold status to closed, all jets on the affected manifold will be removed from the availability table. Manifold status is set to closed by RCS RM in four cases: manually closing the valve, commfault, crew display item entry, and some dilemma cases.

RCS RM will set the manifold status to closed for MDM commfaults on the associated microswitch channelization. An I/O RESET will force RCS RM to reevaluate the manifold status. Thus, if an I/O RESET clears the commfault, the manifold status will be set to open.

Crew item entries on SPEC 23 can toggle a manifold status open or closed.

RCS Manifold RM can detect two failure modes: power fail and dilemma. Input to these failure detection processes are the four manifold microswitch discretes: OX OP, OX CL, FU OP, and FU CL.

Actual electrical bus voltages are not used in power fail determination. The manifolds are paired by common microswitch buses, and power fails are issued only if both manifolds indicate loss of power to their microswitches.

RCS RM Manifold Dilemma

Detection — Three cases of microswitch indications result in an RCS RM manifold dilemma:

- 1 OP indication + 1 or 0 CL indications
- 2 OP indications + 2 CL indications
- 0 OP indications + 0 CL indications (FRCS manifolds 1, 2, 4, and 5 only).

Indications can be OX and/or FU microswitches. These conditions must exist for three consecutive passes.

RM Response — Issue "RCS RM DLMA" message.

In summary, if the number of open indications is greater than the number of closed indications, the manifold status is open; otherwise, the manifold status is closed.

RCS Manifold Power Fail

Detection — All four manifold microswitch discretes are 0 for six consecutive passes. Power fail processing is performed on the following manifold pairs: FRCS M3/4, ARCS L1/R1, L2/R2, L3/R3, L4/R4, and L5/R5.

RM Response — Issue "RCS PWR FAIL" message. Manifold status is unchanged.

Forward manifolds 1, 2, and 5 are not analyzed for power fail conditions. If these manifolds suffer a power fail to their microswitches, an "RCS RM DLMA" will be issued, rather than an "RCS PWR FAIL."

Forward manifold 3 microswitches are redundantly powered by MN A FPC1 and MN C FMC3. Forward manifold 4 microswitches are powered only by MN C FMC3. Both MN A FPC1 and MN C 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.

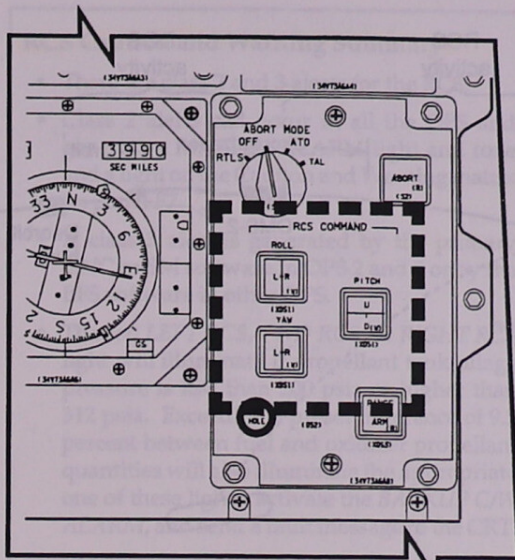
The DAP jet-select module determines which aft RCS jets (right, left, or both) must be turned on in response to the pitch, roll, and yaw jet commands from the entry flight control system. **The forward RCS jets are not used during entry.** After entry interface, only the four Y-axis and six Z-axis RCS 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 Five 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 degrees per second (14 degrees 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.

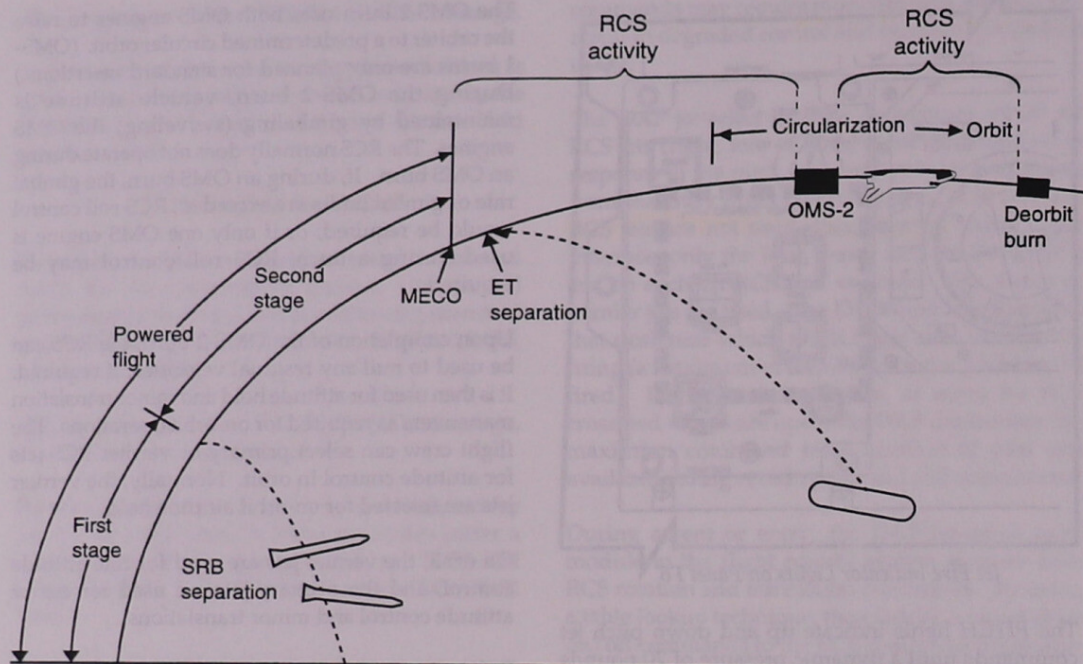
Upon completion of the OMS-2 burn, the RCS can be used to null any residual velocities, if required. It is then used for attitude hold and minor translation maneuvers as required for on-orbit operations. The flight crew can select primary or vernier RCS jets for attitude control in orbit. Normally, the 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).



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Nominal Ascent Profiles

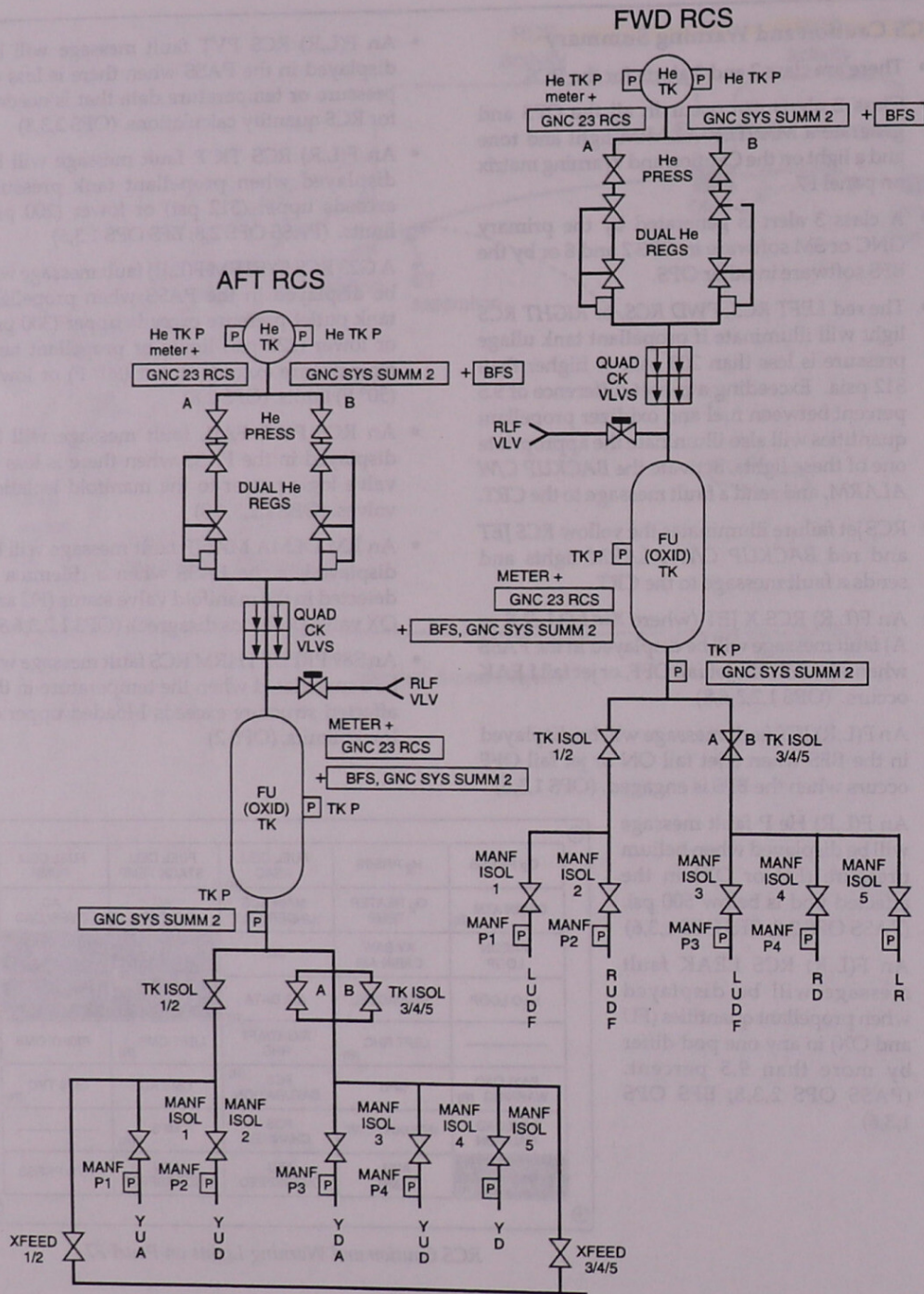
RCS Caution and Warning Summary

- There are class 2 and 3 alerts for the RCS.
- Class 2 alerts can occur in all the OPS and generate a MASTER ALARM light and tone and a light on the Caution and Warning matrix on panel F7.
- A class 3 alert is generated by the primary GNC or SM software in OPS 2 and 8 or by the BFS software in other OPS.
- The red *LEFT RCS*, *FWD RCS*, or *RIGHT RCS* light will illuminate if propellant tank ullage pressure is less than 200 psia or higher than 312 psia. Exceeding a preset difference of 9.5 percent between fuel and oxidizer propellant quantities will also illuminate the appropriate one of these lights, activate the *BACKUP C/W ALARM*, and send a fault message to the 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 ₂ PRESS	H ₂ PRESS	FUEL CELL REAC ^(R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM ^(R)	O ₂ HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS ^(R)	RCS JET
H ₂ O LOOP	RGA/ACCEL	AIR DATA ^(R)	LEFT RCS ^(R)	RIGHT RCS ^(R)
	LEFT RHC ^(R)	RIGHT/AFT RHC	LEFT OMS ^(R)	RIGHT OMS
PAYLOAD WARNING ^(R)	GPC	FCS ^(R) SATURATION	OMS KIT	OMS TVC ^(R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS ^(R)	
BACKUP C/W ALARM ^(R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

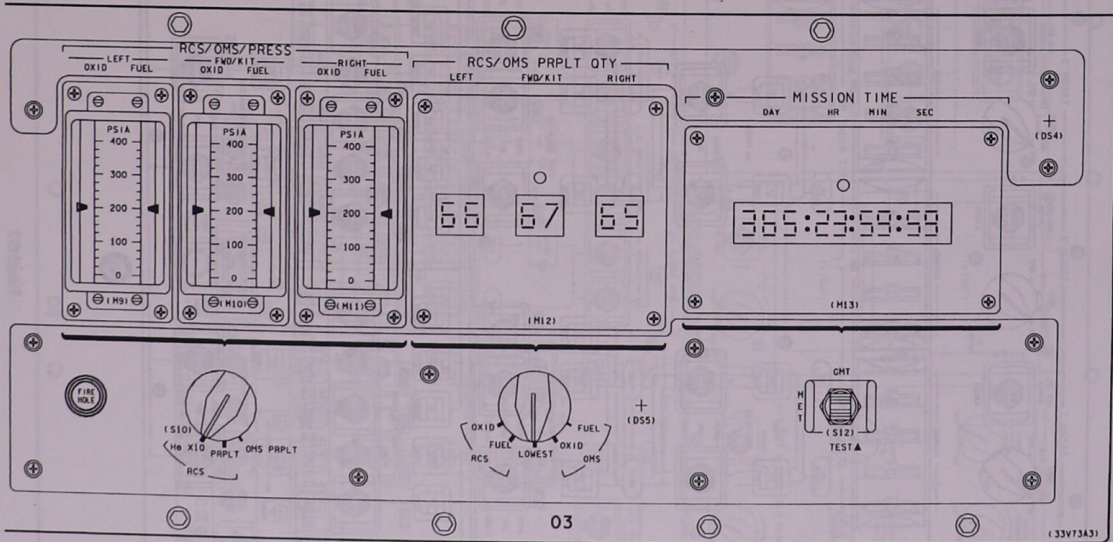
RCS Caution and Warning Lights on Panel F7



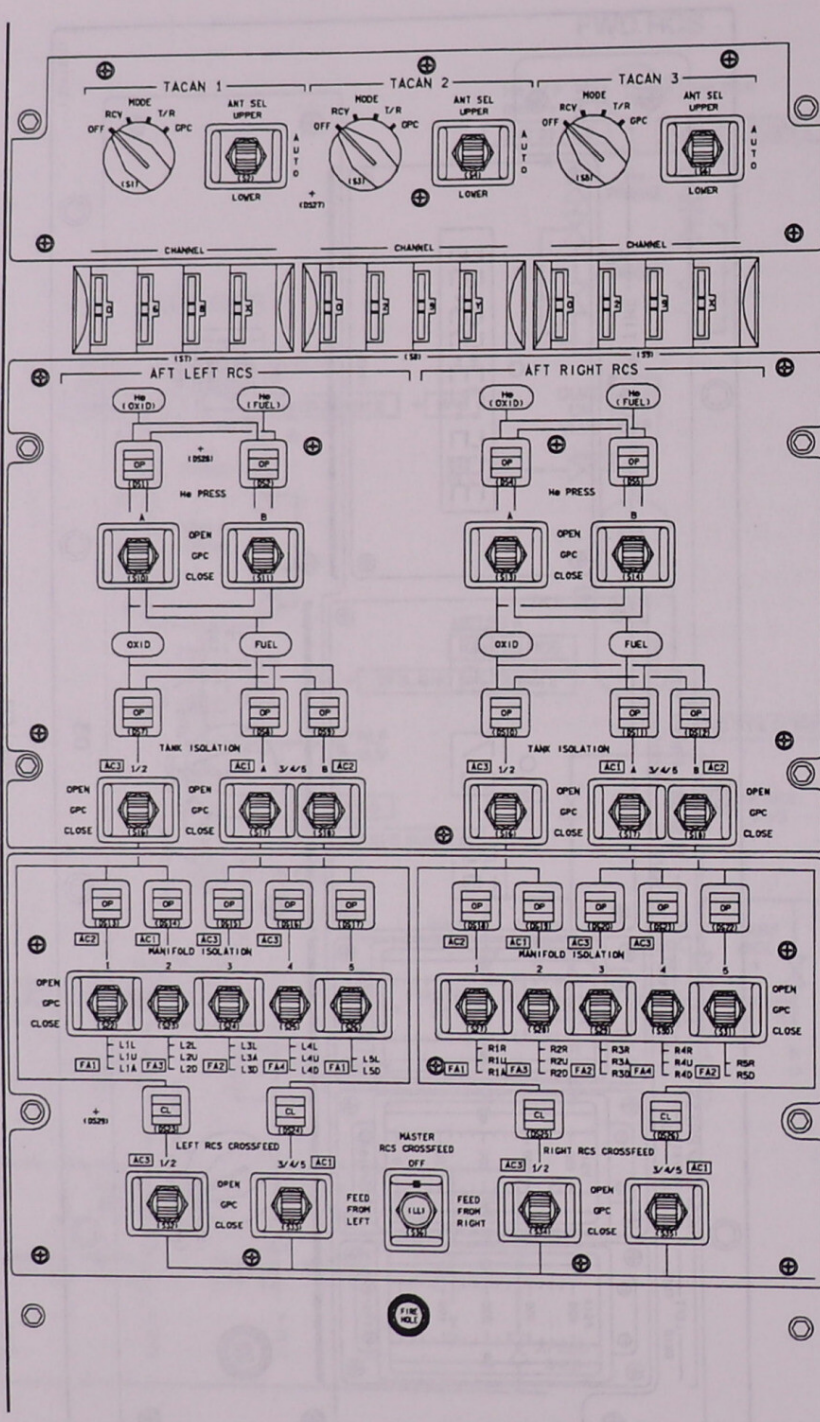
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Reaction Control System

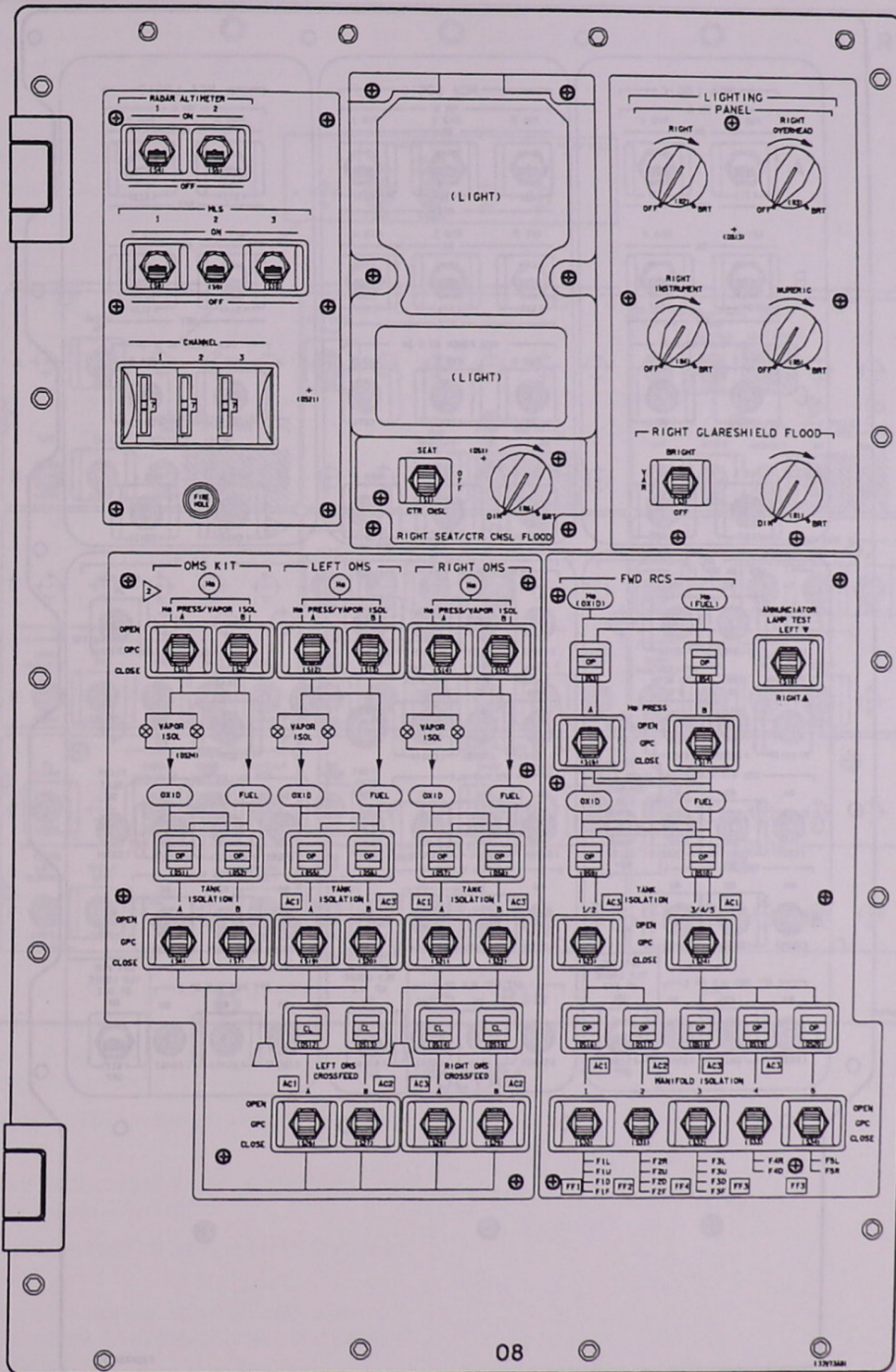
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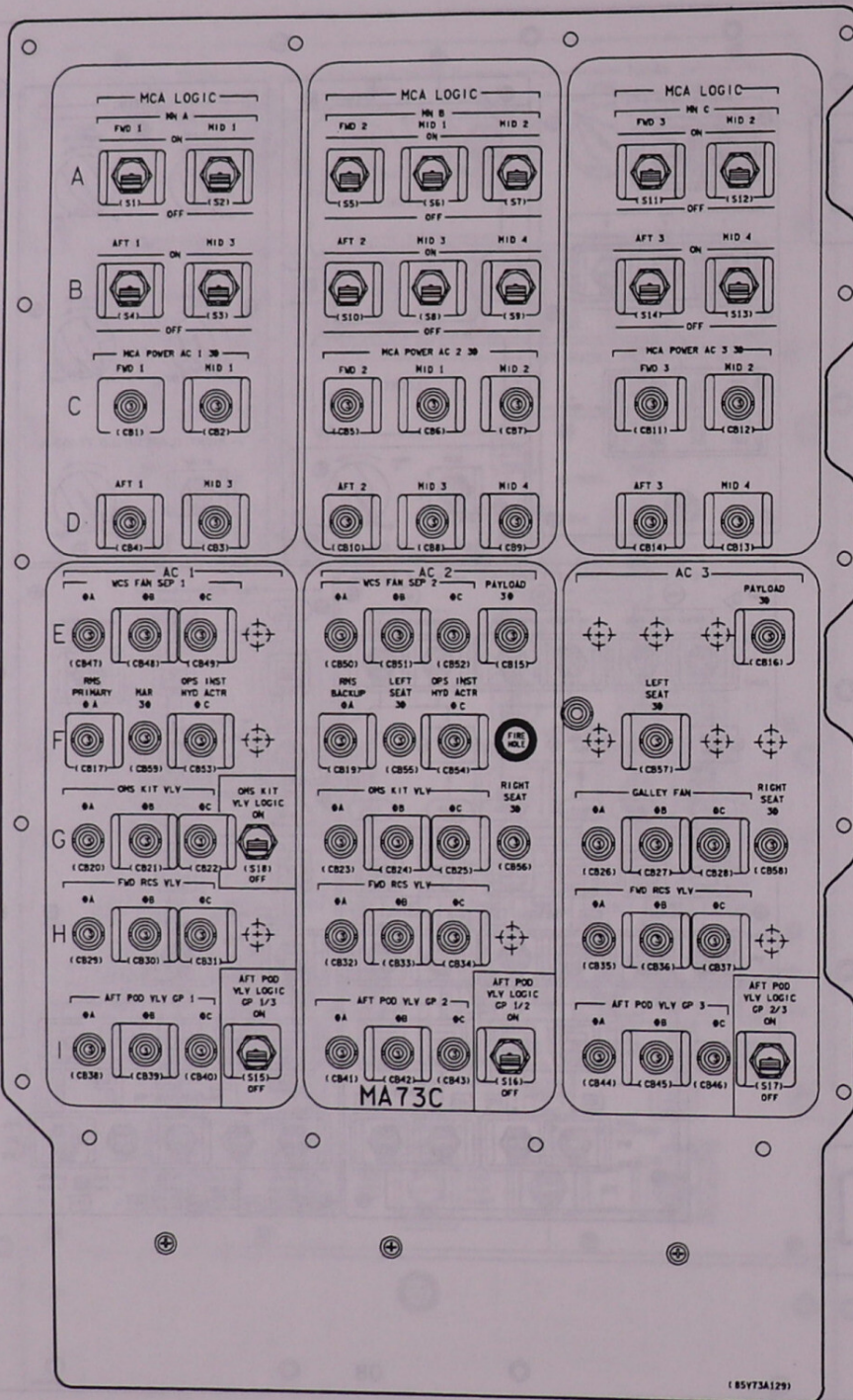
Panel O3



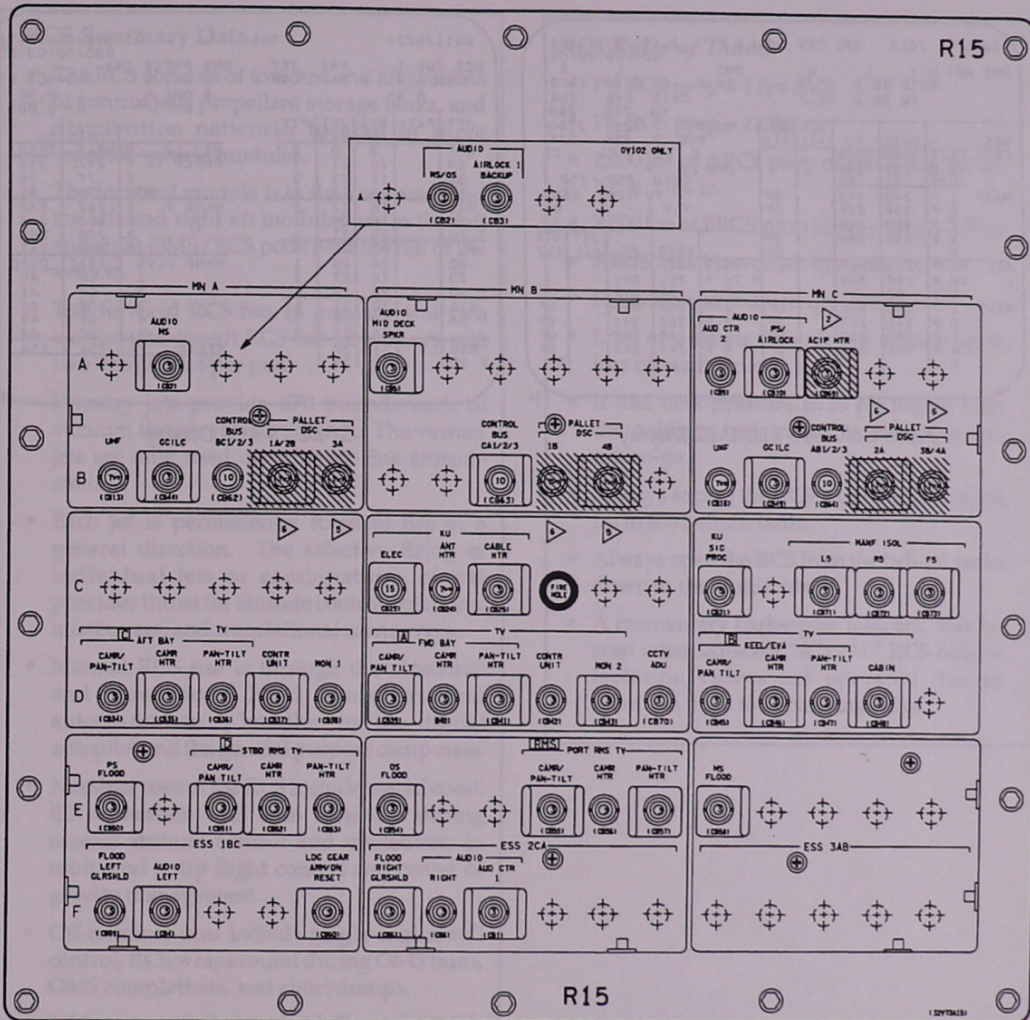
Panel O7



Panel O8



Panel MA73C



Panel R15

The propellants are liquid nitrogen and hydrazine.

- Propellant quantities are monitored on panel 03.
- Most RCS control switches are distributed over panel 05 and 06.
- Thermal control switches are located on panel 04.
- RCS information display and control is located through the GNC SYSTEM-112 and SPK 28 RCS displays.

2. SYSTEMS
2.20 Reaction Control System

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

OMS AFT QTY L R OMS TK P HE 4070 4070
OXID 30.2 30.2
FU 30.2 30.2

RCS	OXID	FU	JET	SOL	N2 TK P	REG P	HE	IN	P
FWD	HE P 3048	2968	FAIL	VLV	2260	324	4070	4070	2260
	TK P 247	248			260	CL			324
	QTY 67	67			258	CL			260
MANF	1 P 248	242		OP	258				260
	2 P 248	246		OP	260				260
	3 P 250	246		OP	1 - 3				0
	4 P 246	246		OP	2 - 0 - 2				
	5			OP					
AFT	HE P 3200	3144		OP	OXID	FU	JET	SOL	VLV
L	TK P 245	249			3216	3160			
	QTY 82	83			251	249			
MANF	1 P 246	246		OP	84	84			
	2 P 246	250		OP	1 P 242	246			OP
	3 P 250	250		OP	2 P 250	246			OP
	4 P 246	250		OP	3 P 246	258			OP
	5			OP	4 P 246	242			OP
					5				OP

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PASS GNC SYS SUMM 2 Display

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
R 3* R OMS 6 OMS-RCS QTY
OFF 7* R 0.00

JET	FAIL	DES	JET	PTY	OXID	FU
R4R		8	9	2	3376	3360
2R		10	11	1	247	250
Y 3R		12	13	2	T	77
JR		14	15	1	QTY	90
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	
RIA		30	31	1	3 OP 42	
X 3A		32	33	3	4 OP 43	
		34	35	2	5 OP 44	
R5R		36	37		XFEED P	254 254
V 5D		38	39		JET RESET	45

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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 ΔV .
- 1% RCS prop = 22 lbs.
- 1,000 lbs of ARCS prop moves X c.g. 1.2 in, Y c.g. ± 0.4 in.
- 1,000 lbs of FRCS prop moves X c.g. -3.5 in.
- ARCS max blowdown qty 24%.
- FRCS max blowdown qty 22%.
- Loss of a single downfiring vernier jet is loss of vernier mode.
- If fuel tank pressure is 20 psi higher than the oxidizer tank pressure, then verniers are no-go.
- Always secure the RCS from the manifolds up to the helium tanks.
- Always open the RCS from the helium tanks down to the manifolds.
- A momentary barberpole talkback may be seen when adjacent "A" or "B" RCS helium isolation valves are operated due to vibration from the operating valve.

2.21 SPACELAB

CONTENTS

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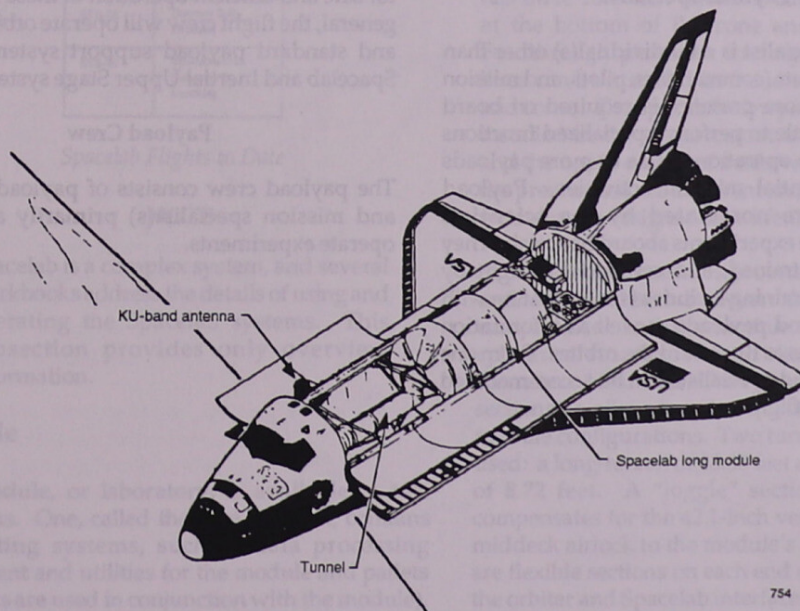
Description

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 mated 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.



Spacelab On Orbit

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 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 on board 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 on board is not required for primary payload mission success, but is determined by the Administrator of NASA to contribute to other approved NASA objectives or to be in the national interest.

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), and others as 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

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

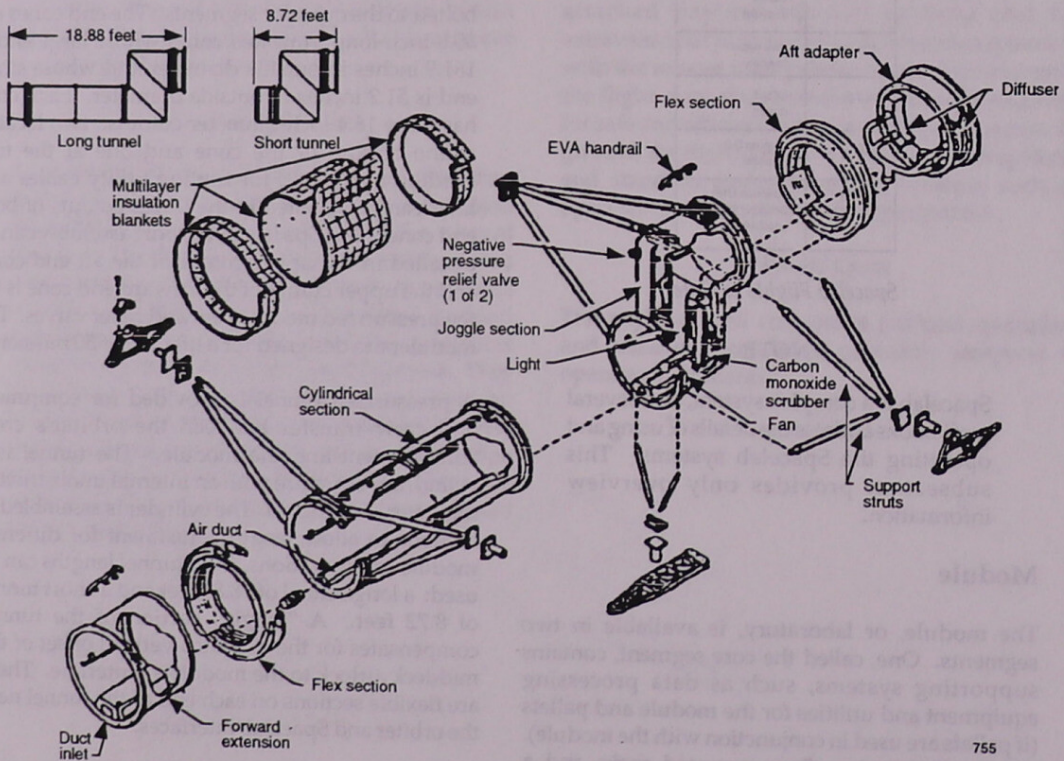
The module, or laboratory, is available in two segments. One, called the core segment, contains supporting systems, such as data processing equipment and utilities for the module and pallets (if pallets are used in conjunction with the module). The laboratory has floor-mounted racks and a workbench. 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.



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Spacelab Transfer Tunnel

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.

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.

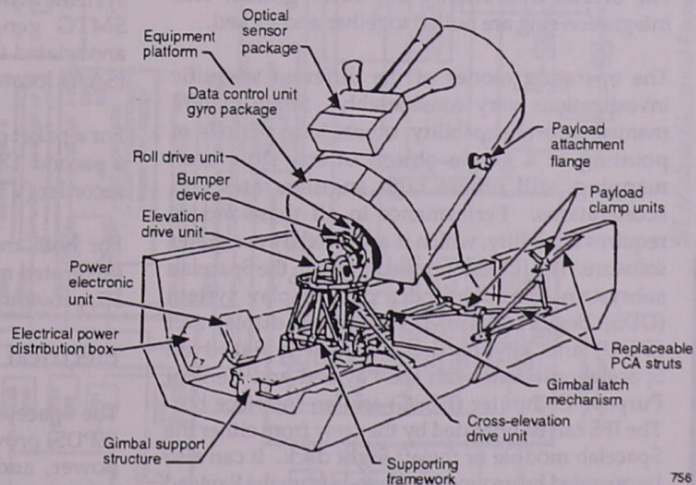
Cable ducts and cable support trays can be bolted to the forward and aft frame of each pallet to support and route electrical cables to and from the experiments and subsystem equipment mounted on the pallet. All ducts mounted on the starboard side of the pallet

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.

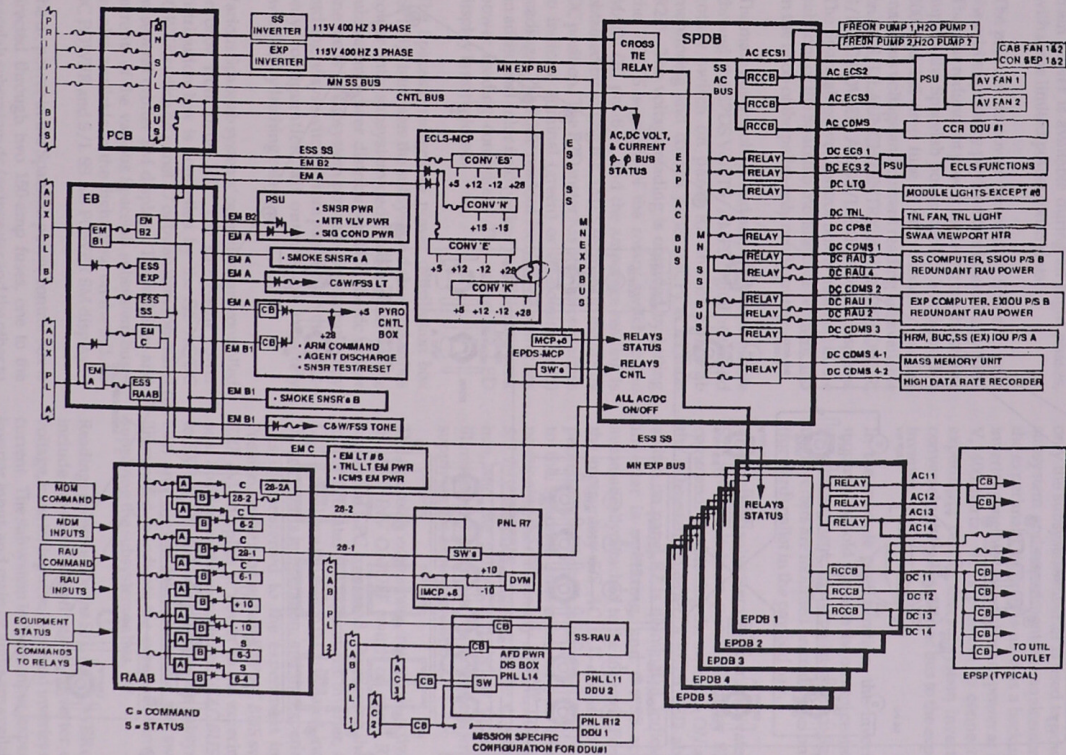
For a pallet configuration, in addition to the above, a second DDS will be in R12 and a video tape recorder (VTR) will be in R11.

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

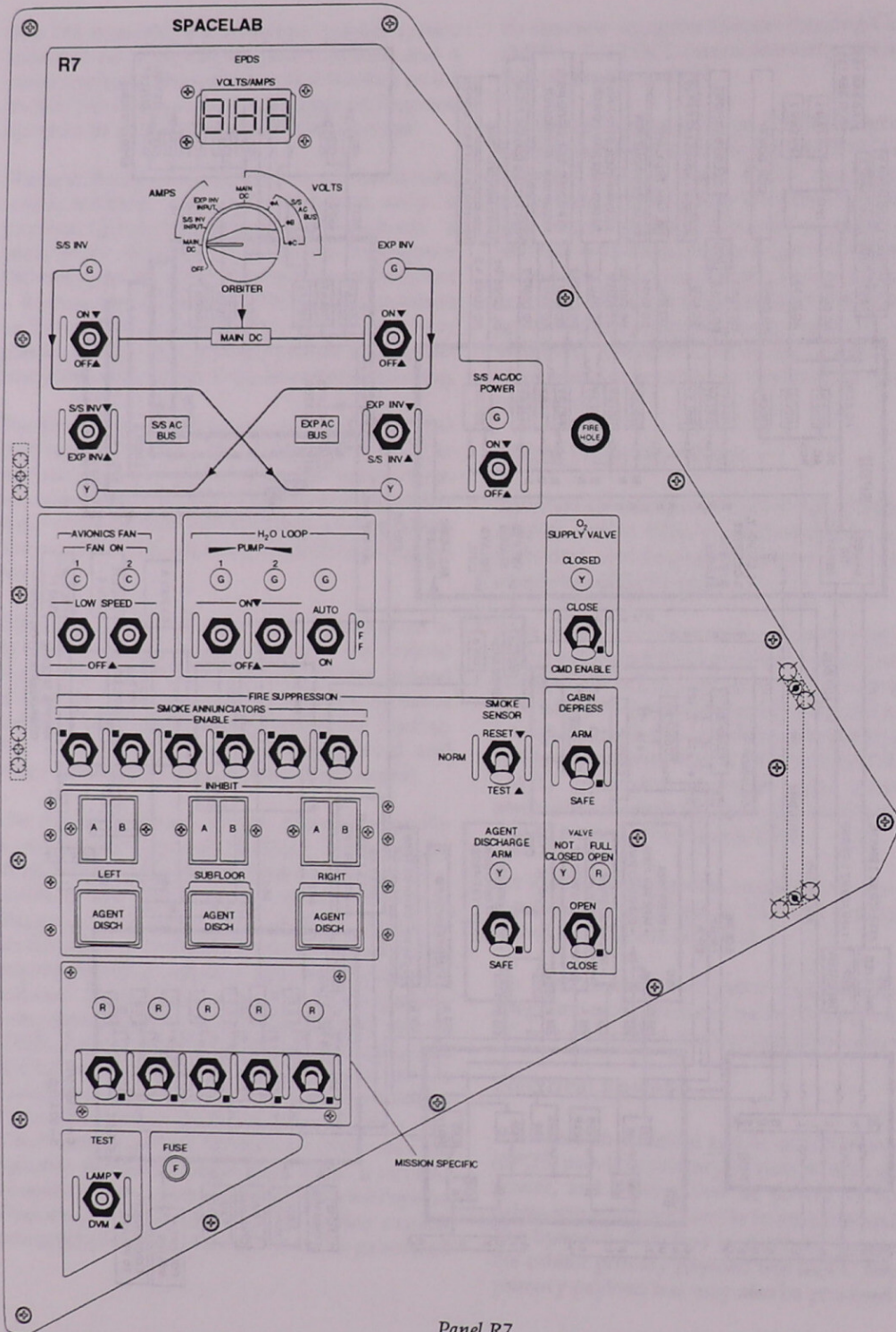
Electrical Power

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 Space lab 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

2.21-7



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



Panel R7

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.

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/S AC 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.

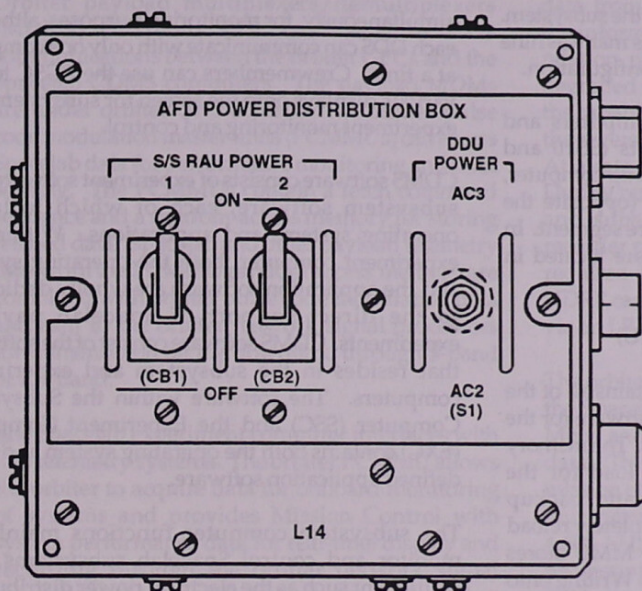
Emergency and essential dc power for the module configuration is provided by the orbiter auxiliary payload buses A and B to the Spacelab emergency box. The Spacelab emergency box supplies emergency and essential power for Spacelab critical environmental control subsystem sensors and valves, fire and 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.



Panel L14

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.

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).

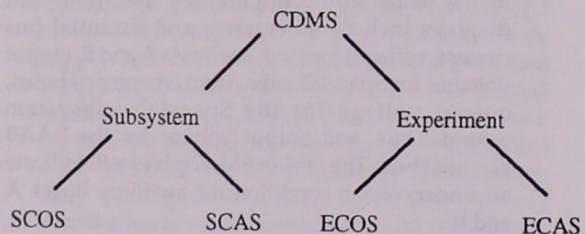
STS 50 was the first Spacelab mission utilizing the PGSC as a replacement for the data display unit (DDU). PGSC is a Gridcase 1530, 386-based laptop personal computer with an electroluminescent monochrome display. The PGSC communicates with the CDMS through the interface unit, which performs protocol 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_2 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_2 tank is pressurized to approximately 2300 psi. The GN_2 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_2/N_2 control panel regulate the air pressure in the cabin to 14.7 psi. This system also utilizes PPO_2 measurements to maintain the proper balance of O_2 and N_2 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 *H₂O 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.

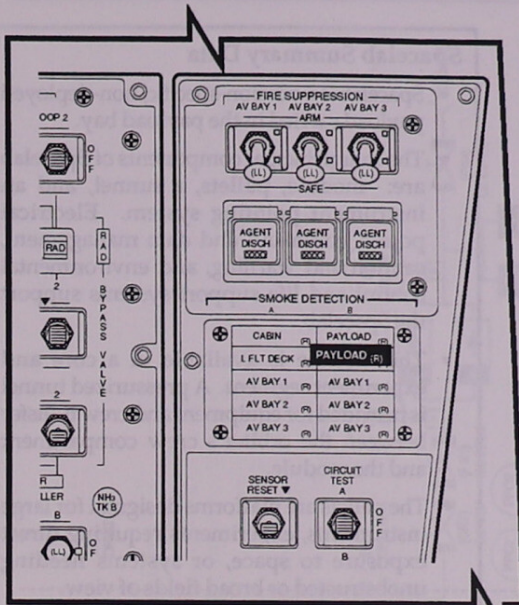
The Spacelab Freon coolant loop removes heat from any pallets that may be flown with the module and transfers the heat of the interloop heat exchanger to the Spacelab water loop system. The flow rate is approximately 3,010 pounds per hour. From the Spacelab water loop system, the water passes through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

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

Payload Caution and Warning Lights on Panel F7



Payload Fire/Smoke Detection Light on Panel L1

the 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.

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 *O₂ 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

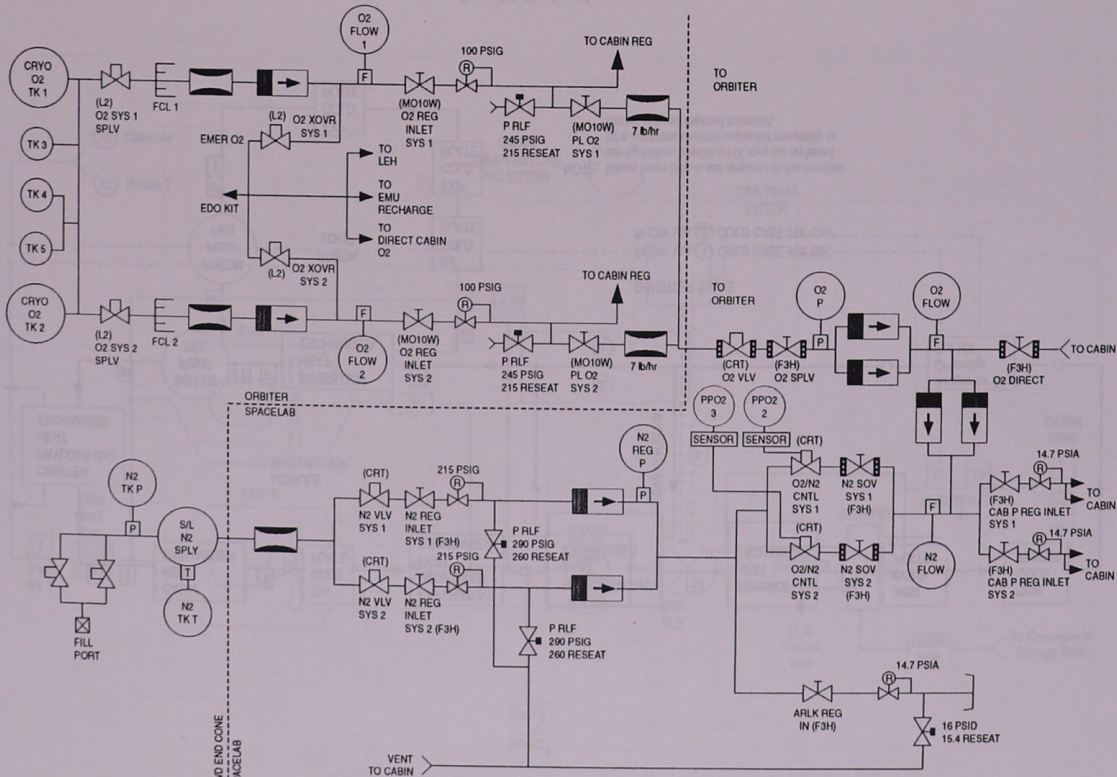
The environmental control subsystem provides thermal control of Spacelab experiments and subsystems. The Spacelab Freon coolant loop services the pallet systems and collects heat dissipated by the subsystem and experiment equipment. The coolant loop collects heat from the pallet-mounted subsystems and 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.

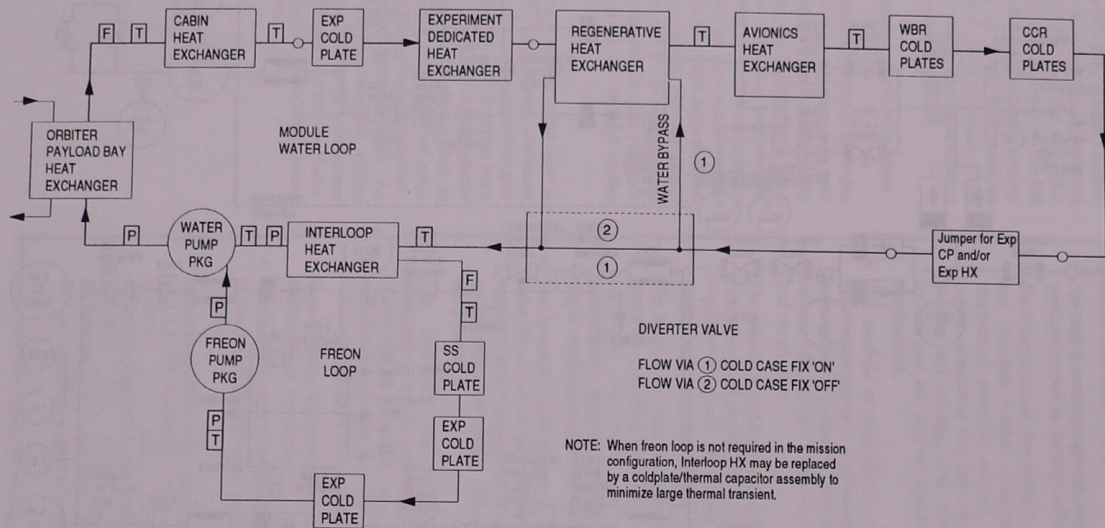
Spacelab Summary Data

- 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.

2.21-19



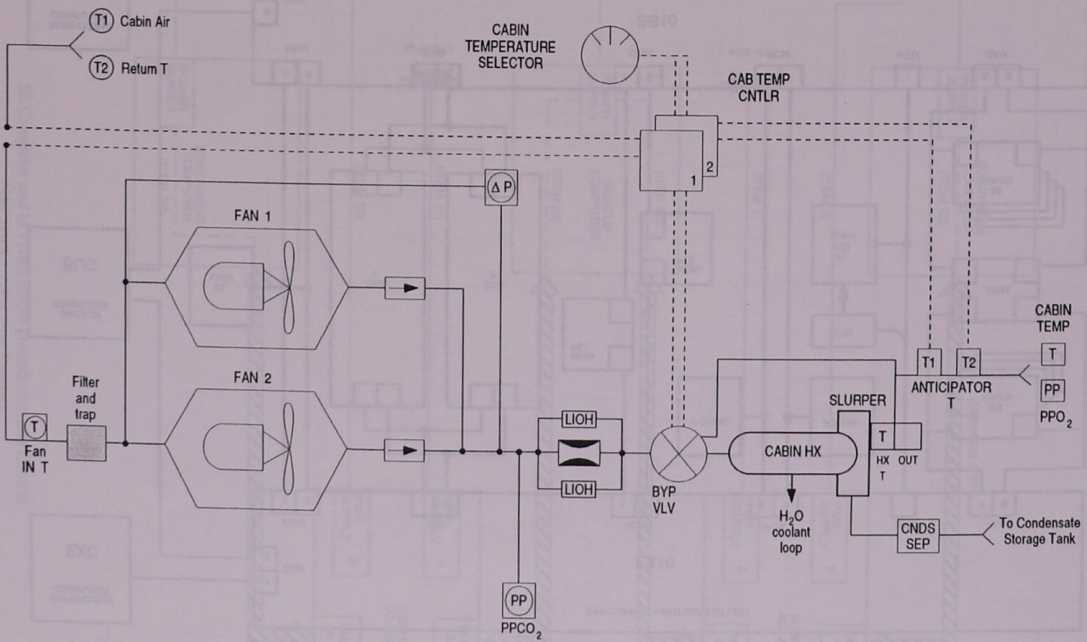
ECLS Spacelab/Orbiter Interface



Spacelab Coolant Loops

2.21-20

CDWZ 1/4/1993

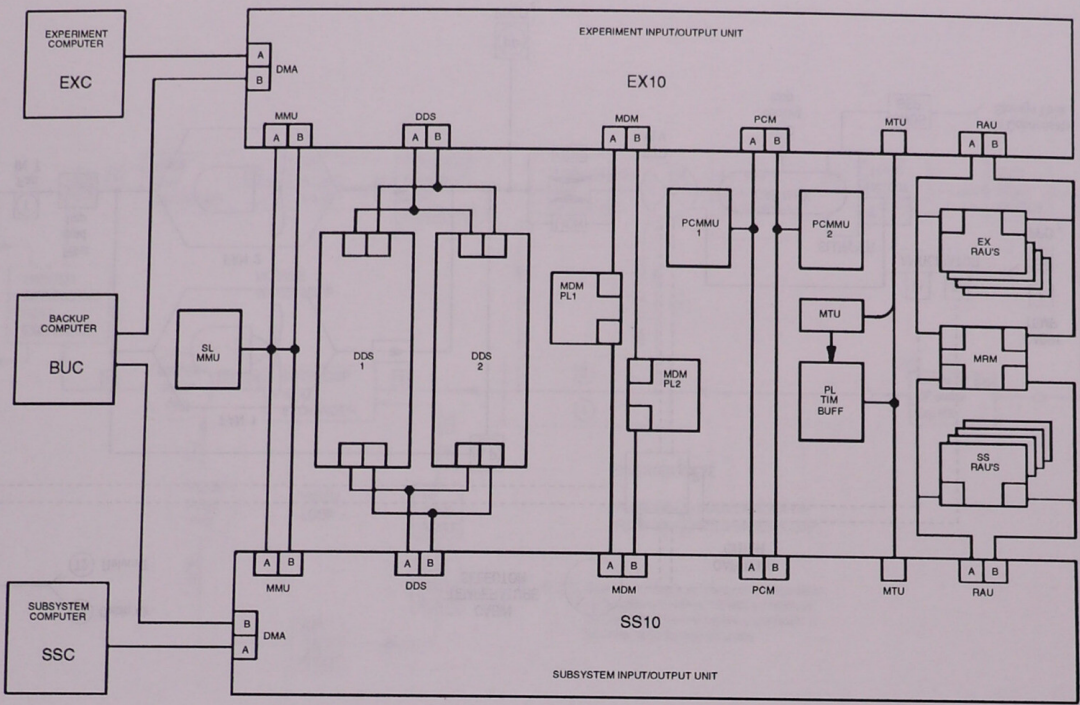


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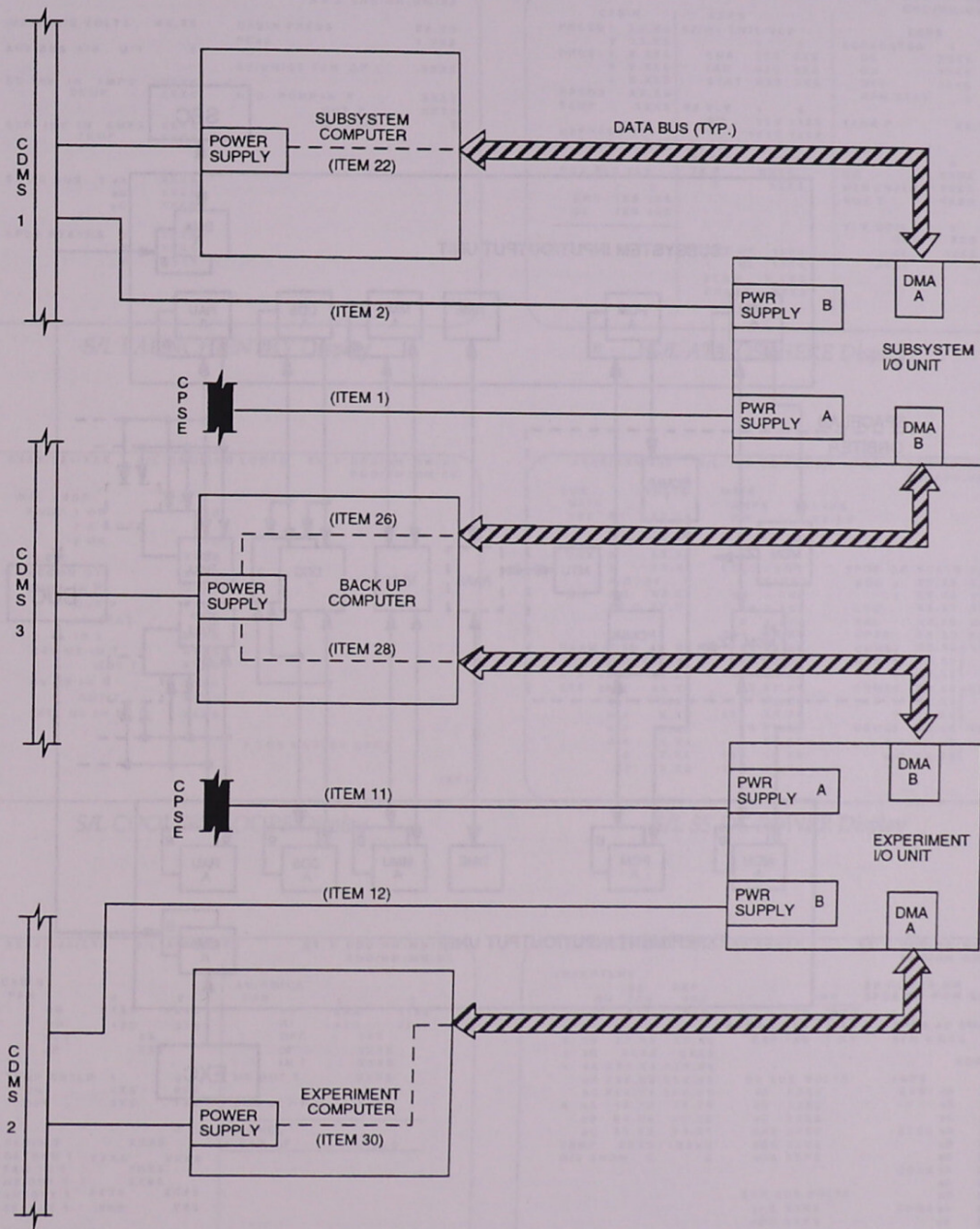
SCOM 1.0
November 1991

S/L Cabin Air Loop

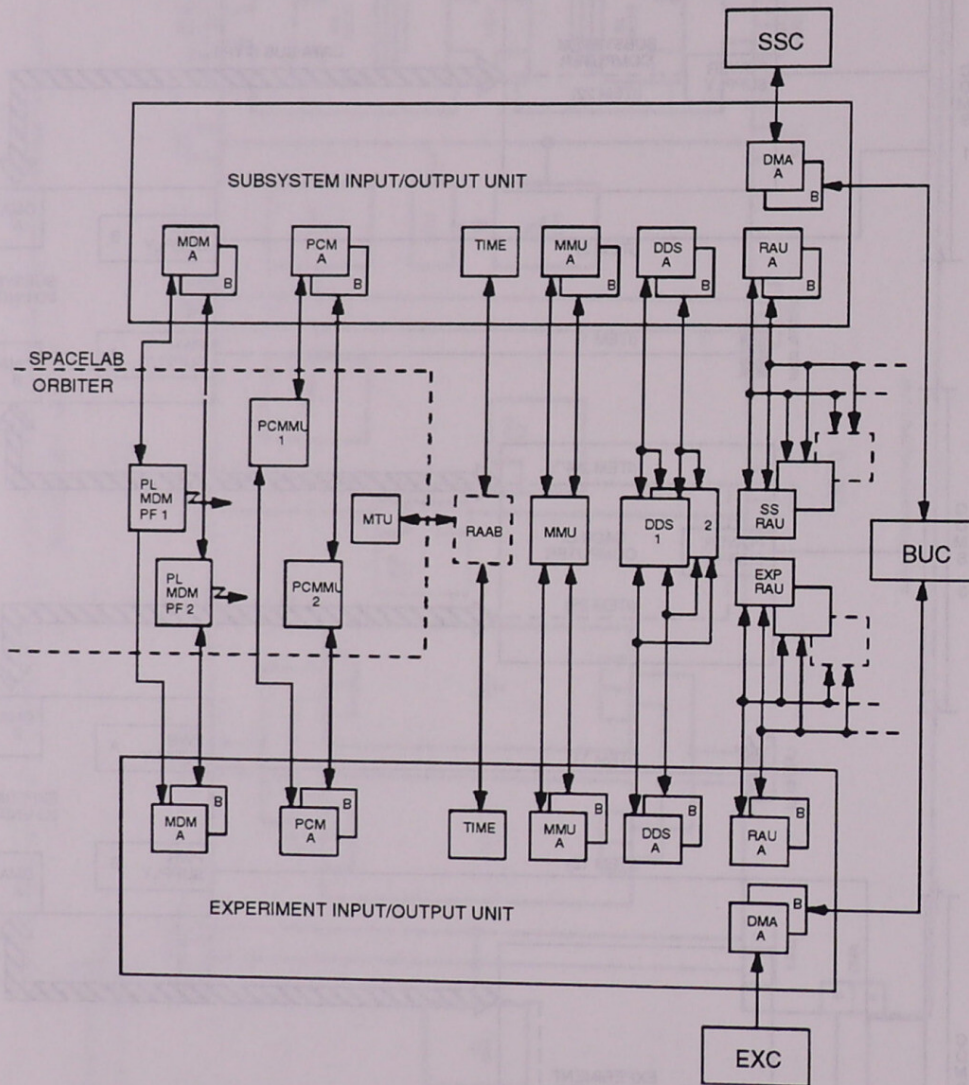
2. SYSTEMS
2.21 Spacelab



CDMS Redundancy



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



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	PP02	X.XXS
SS INV IN AMPS	XXXX	AVIONICS FAN ΔP	.XXXX
TEMP	XXXX	H2O PUMP IN P	XXXX
EXP INV IN AMPS	XXXX	OUT P	XXXX
TEMP	XXXX	ΔP STAT	S
SS AC BUS V φA	XXXX		
φB	XXXX		
φC	XXXX		
EPOB STATUS	1 XXXS		
	2 XXXS		
	3 XXXS		

(XX)

S/L LAUNCH/ENTRY Display

XXXX/229/XXX S/L ATMOSPHERE XX X DDD/HH:MM:SS DDD/HH:MM:SS			
CABIN	ASCS		
PRESS 1	XX.XS	02/N2 CNTL VLV	1 2
2	XX.XS		
PP02-1	X.XXS	ENA	5XS 7XS
-2	X.XXS	INH	6XS 8XS
-3	X.XXS	STAT	XXS XXS
PPC02	XX.XS		
TEMP	XXXX	N2 VLV	1 2
		OP	8XS 11XS
DEPRESS VLV	XXS	CL	10XS 12XS
STAT	XXS	FLOW	X.XXS
		REG P	XXXX
POS RLF VLV		TK P	XXXX
		T	XXXX
ENA	1 2		
CL	2XS 4XS		
		02 VLV OP	13XS
		CL	14XS
		FLOW	X.XXS
		PRESS	XXXX
		CNDS	1 2
		SEPARATOR	1 2
		CB	XXXX XXXS
		ON	15XS 17XS
		OFF	16XS 18XS
		RPM STAT	S S
		TANK P	XX.XS
		DUMP	
		CB	1 2
		HTR CNTLR	XXXX XXXS
		NOZ T	XXXX XXXS
		VLV COIL	1 2
		CMD	XXS XXS
		CL	19XS 20XS
		STAT	XXS

(XX)

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	XXXX		
ACCUM QTY	XXXX		
PUMP IN P	XXXX		
OUT P	XXXX		
ΔP STAT	S		
IN T	XXXX		
CAB HX IN T	XXXX		
OUT T	XXXX		
AV HX IN T	XXXX		
OUT T	XXXX		
INTL HX IN T	XXXX		
		7 ECS MASTER OFF	X

(XX)

S/L COOLING LOOPS Display

XXXX/XXX/208 S/L SS DC POWER XX X DDD/HH:MM:SS DDD/HH:MM:SS			
BUS	VOLTS	MAIN	AMPS
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	VOLTS
EM B	2 XX.XS	5K	X.XXS
SS C	XX.XS	ES	X.XXS
		E	X.XXS
		28K	XX.XS
RAAM P/S	AS BS	ES	XX.XS
BUS VOLTS		E	XX.XS
STX 28-1	XX.XS	12K	XX.XS
STX 28-2	XX.XS	ES	XX.XS
6-1	X.XS	E	XX.XS
6-2	X.XS	-12K	XX.XS
6-3	X.XS	ES	XX.XS
6-4	X.XS	E	XX.XS
10	XX.XS	15N	XX.XS
-10	XX.XS	-15N	XX.XS
		SPDB DC VOLTS	AMPS
		ECS 1	XX.XS XX.XS
		2	XX.XS XX.XS
		LTG	XX.XS XX.XS
		TNL	XX.XS XX.XS
		CPSE	XX.XS XX.XS
		CDMS1	XX.XS XX.XS
		RAU 3	XX.XS
		4	XX.XS
		CDMS2	XX.XS XX.XS
		RAU 1	XX.XS
		2	XX.XS
		CDMS3	XX.XS XX.XS
		4-1	XX.XS XX.XS
		4-2	XX.XS

(XX)

S/L SS DC POWER Display

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

(XX)

S/L AIR LOOPS Display

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

(XX)

S/L AC POWER Display

2.22 SPACEHAB

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Description

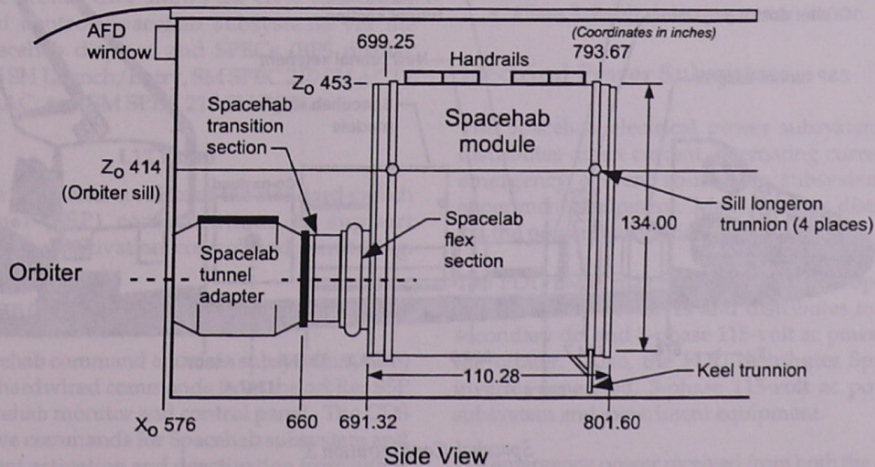
The Spacehab module is a pressurized experiment carrier designed to augment space shuttle middeck experiment accommodations. The Spacehab system consists of a module flown in the orbiter payload bay that is configured with middeck-type lockers, racks, and/or the logistics transportation system (LTS) 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

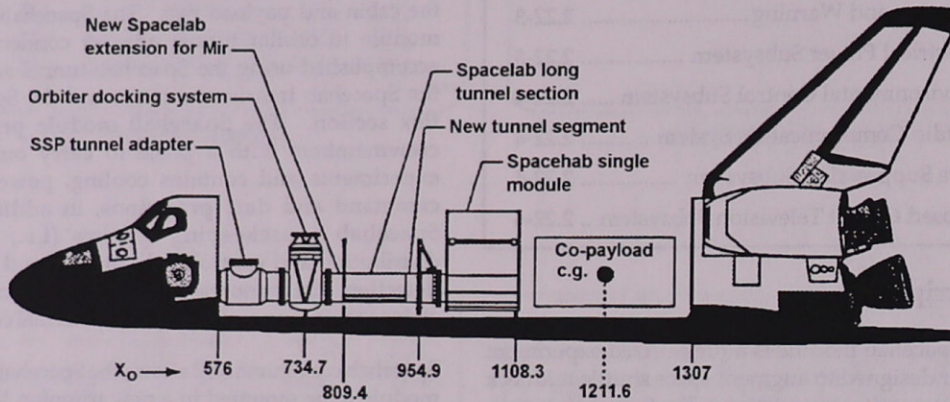


Spacehab Configuration 1

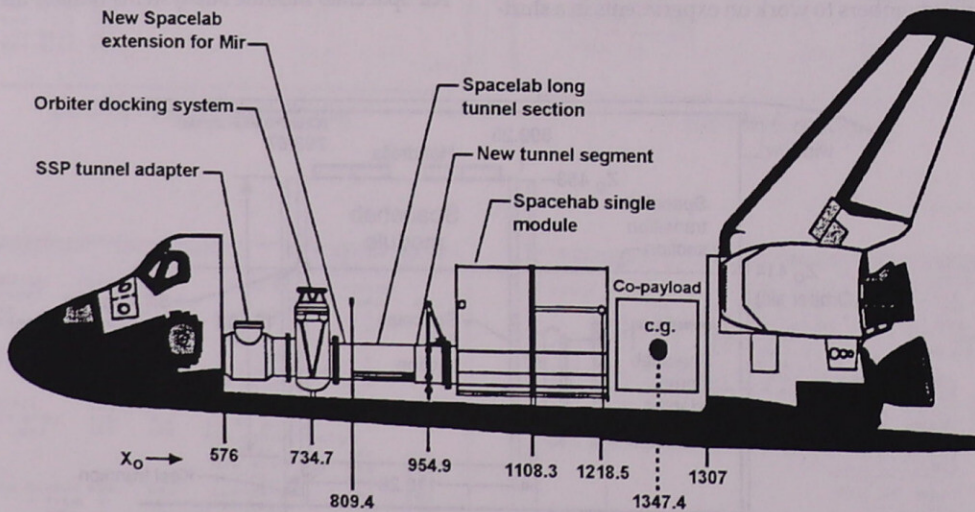
as configuration 1, except for a lower air exchange rate with the orbiter and the addition of two negative pressure relief valves (NPRVs).

Spacehab configuration 3 is a double module, consisting of one Spacehab module and one Spacehab module shell that are jointed 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.



Spacehab Configuration 2



Spacehab Configuration 3

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 H₂O 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 subsystems (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 (PLMDM), 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.

2.23 ORBITER DOCKING SYSTEM

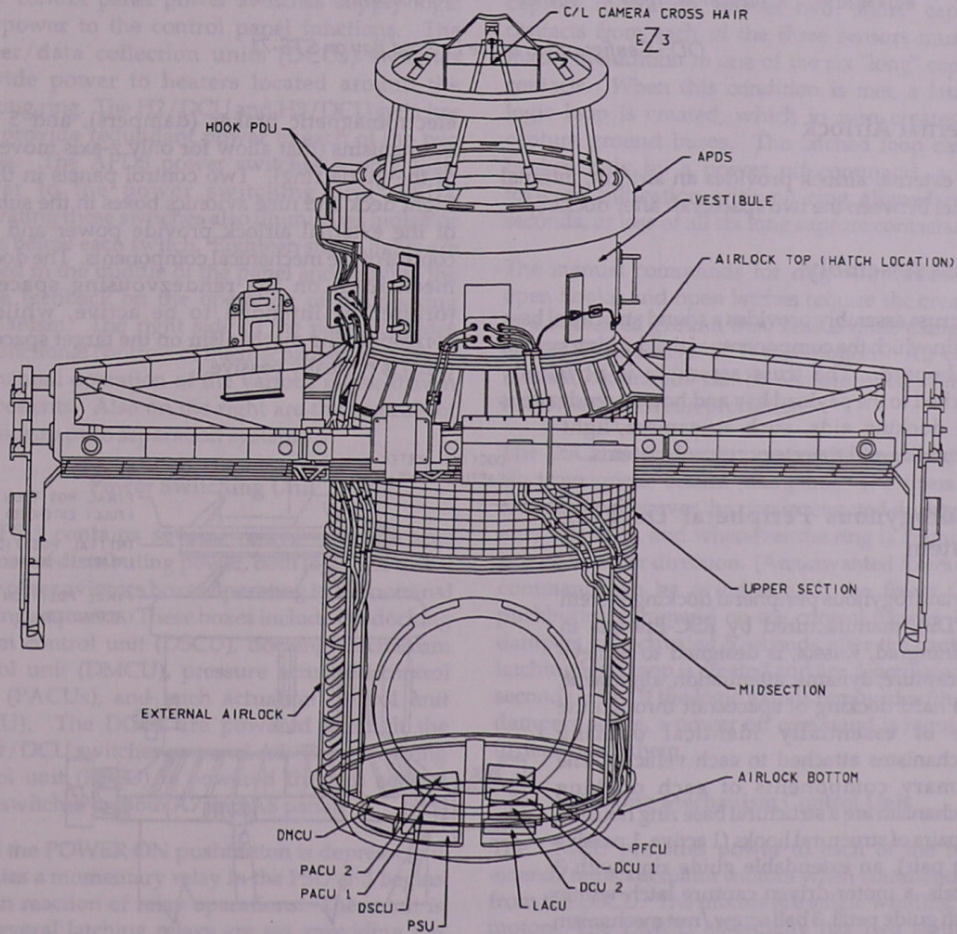
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Operational Notes of Interest	2.23-7

Description

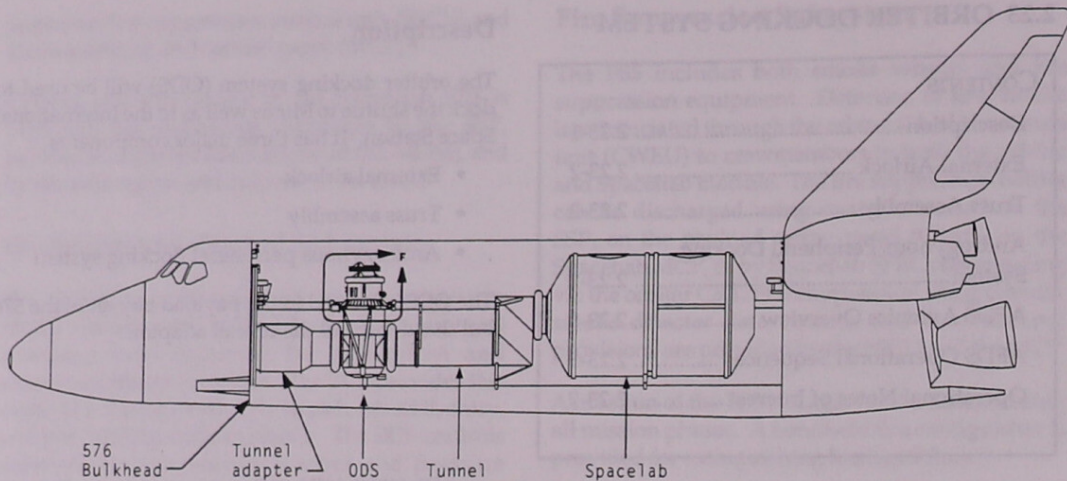
The orbiter docking system (ODS) will be used to dock the shuttle to Mir as well as to the International Space Station. It has three major components

- 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 (ODS) 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.

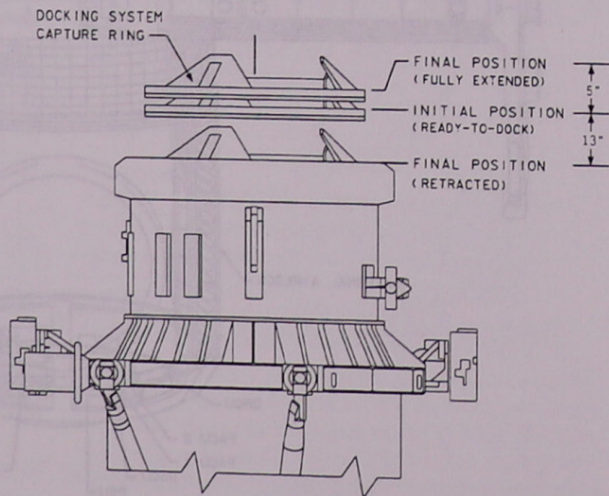
Truss Assembly

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) 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.

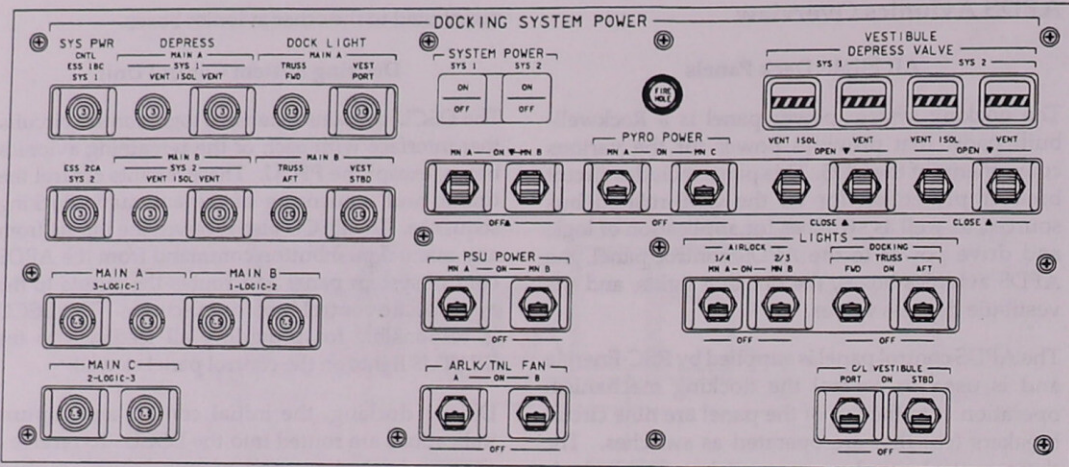
The manual commands for ring out, undocking, open hooks, and open latches require the creation of a dedicated ground bus. This is done using the APDS CIRC PROT OFF pushbutton. All other manual commands can be accomplished without removing the circuit protection.

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.

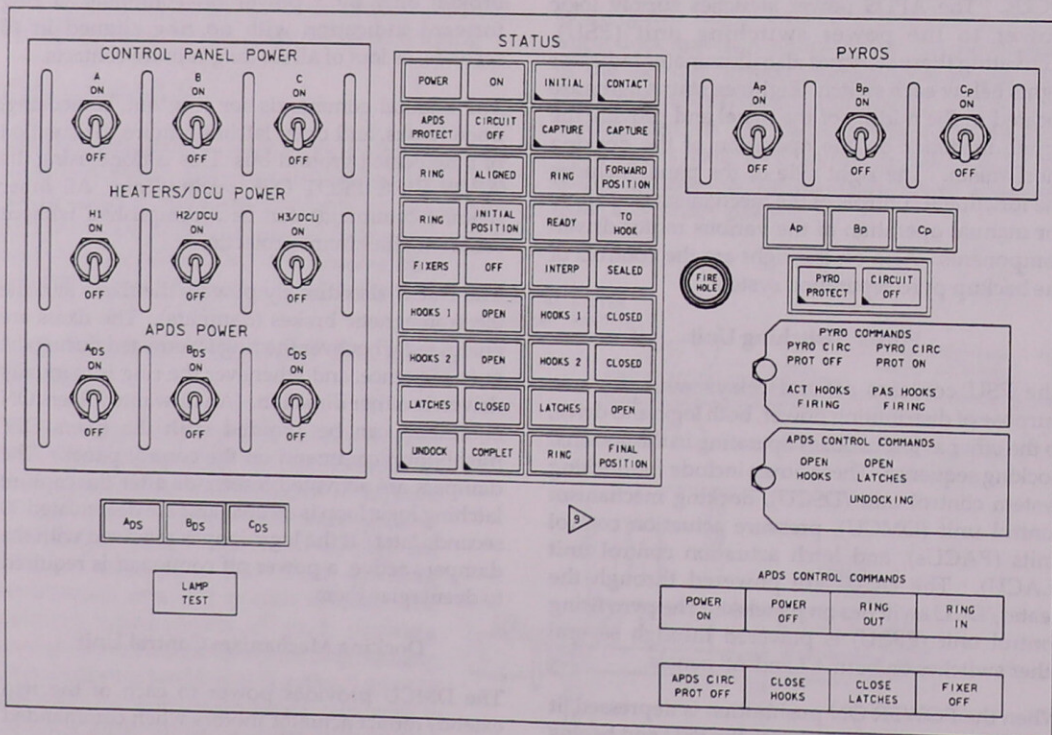
Docking Mechanism Control Unit

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

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Docking System Power Panel, Panel A7A3



APDS Control Panel, Panel A8A3

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.

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 ≈ 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.

2.24 STOWAGE

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Description

Various provisions are available for stowing loose onboard equipment and trash/waste materials during different phases of the flight. Provisions consist primarily of rigid and flexible containers.

Rigid containers include:

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

The flexible containers are as follows:

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

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

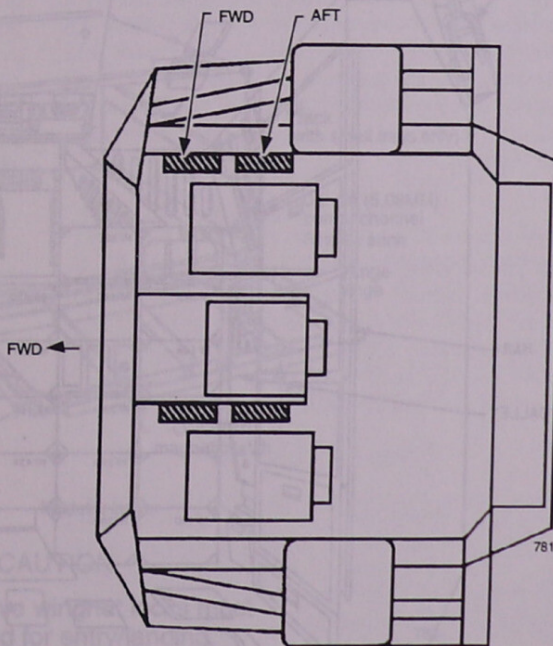
Rigid Containers

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 lockers, the crewmember needs only to lift the latch handle to unlock the lid of the container.

Modular Lockers

Some equipment on board 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.



Flight Deck FDF Containers

([hatched pattern] = Containers)

There are four sizes of trays: a single tray (two of which fit inside a locker), a double tray, a half-length single tray (four of which fit inside a locker), and a half-length double tray. Approximately 150 cubic feet of stowage space is available, almost 95 percent of it on the middeck.

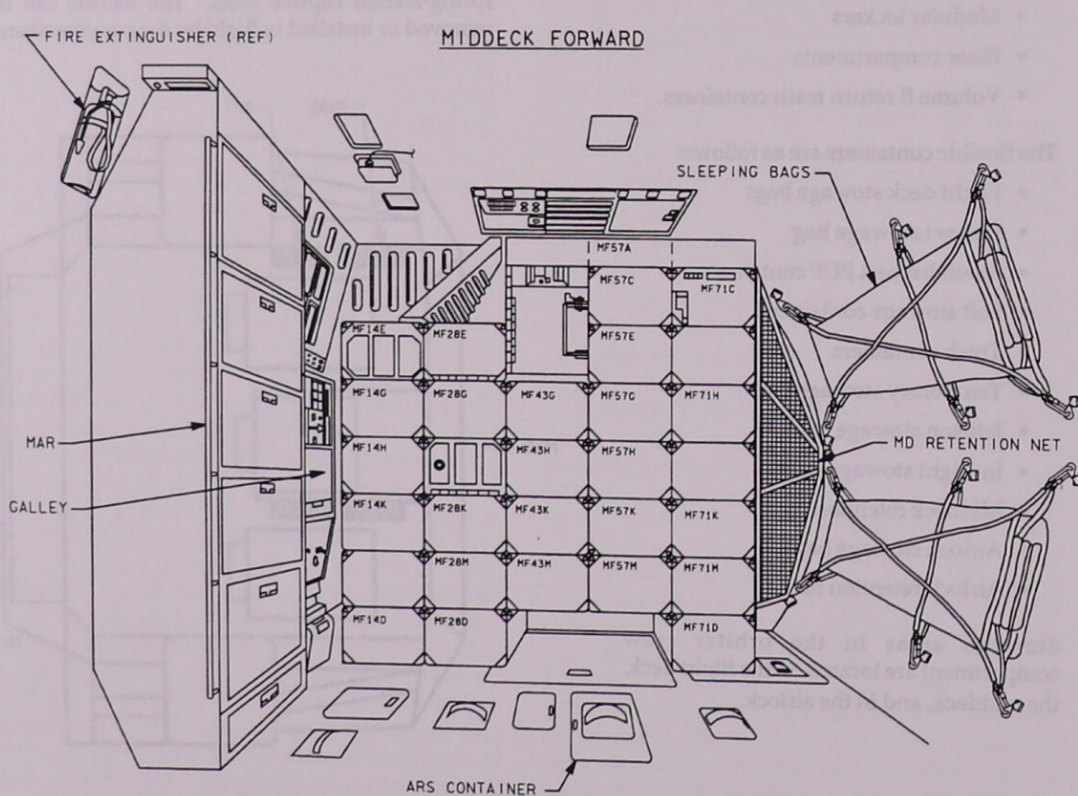
The lockers are made of either epoxy- or polyimide-coated Kevlar honeycomb material joined at the corners with aluminum channels. Inside dimensions are approximately 11 by 18 by 21 inches. The honeycomb material is approximately 0.25 inch thick, and was chosen for its strength and light weight. The lockers 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 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 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 locker door. For on-orbit operations, the door is held closed by double magnetic latches.



Middeck Forward Modular Lockers and Floor Compartment

The crewmember can open the door a full 180 degrees. 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 due to misalignment problems, the crewmembers can remove the locker and use turnbuckles to provide structural support.

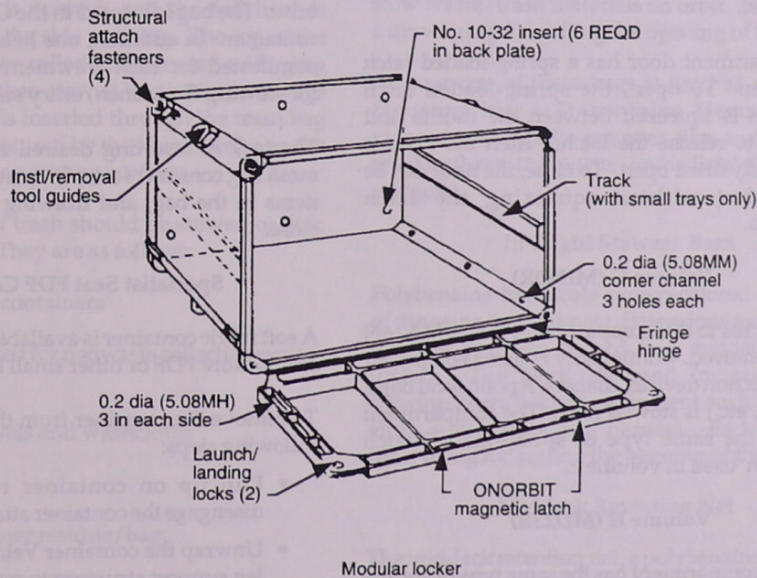
Floor Compartments

Six floor compartments are available. Volume F (MD76M), the wet trash compartment, provides 8 ft³ of stowage under the middeck floor. The CO₂

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.



CAUTION

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

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Schematic of Modular Lockers

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 carabiners, 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.

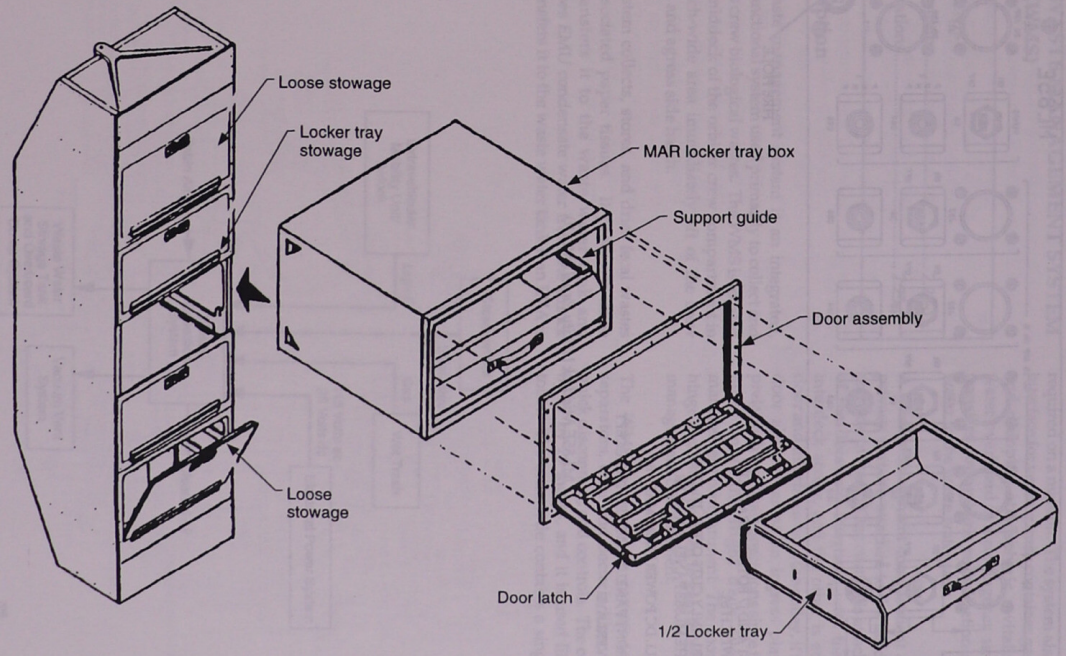
Middeck Accommodations Rack

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.

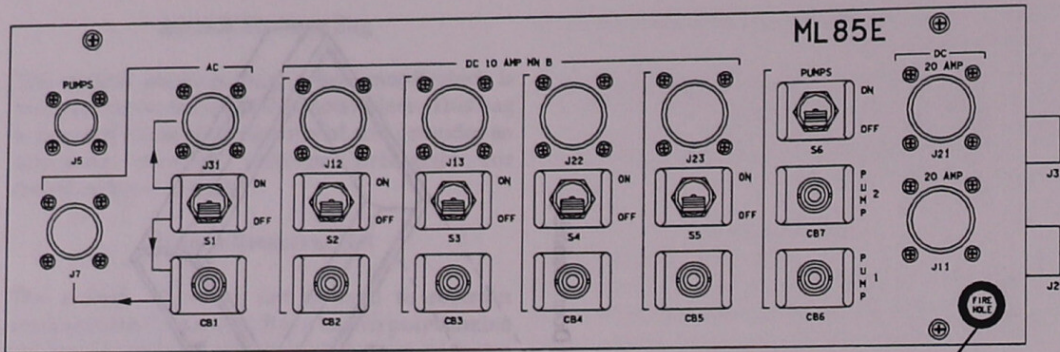
Thermal control for payloads in the MAR may be provided by either a water-to-air heat exchanger or water circulation through coldplates. These NASA provided designs can dissipate heat loads of up to 1000 watts. An approved payload-unique system, located in the MAR, that connects to the orbiter heat exchange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

Middeck Accommodations Rack (MAR) Locker Tray Assembly



2.2.4-7

784



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)

2.25 WASTE MANAGEMENT SYSTEM (WMS)

CONTENTS	
Description	2.25-1
Operations	2.25-5

Description

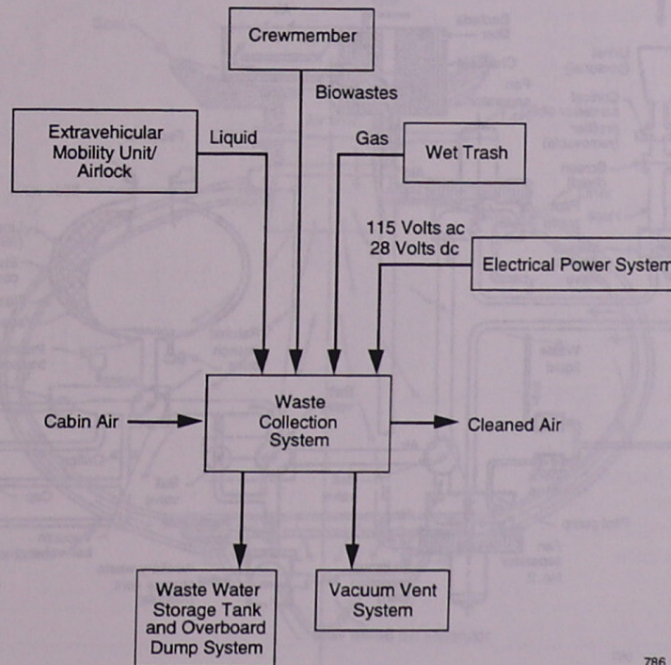
The waste management system is an integrated, multifunctional system used primarily to collect and process crew biological wastes. The WMS is located in the middeck of the orbiter crew compartment in a 29-inch-wide area immediately aft of the crew ingress and egress side hatch.

The system collects, stores, and dries fecal wastes and associated paper tissues. It processes urine and transfers it to the waste water tank and processes EMU condensate water from the airlock and transfers it to the waste water 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 waste water overboard in a contingency situation, and it transfers atmospheric revitalization system waste water to the waste water tank.

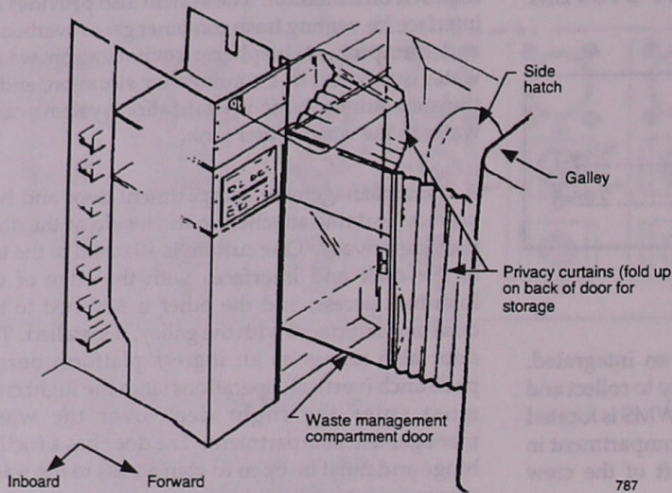
A waste management compartment door and two privacy curtains attached to the inside of the door provide privacy. One curtain is attached to the top of the door and interfaces with the edge of the interdeck access, and the other is attached to the door and interfaces with the galley, if installed. The 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



786

Waste Management System

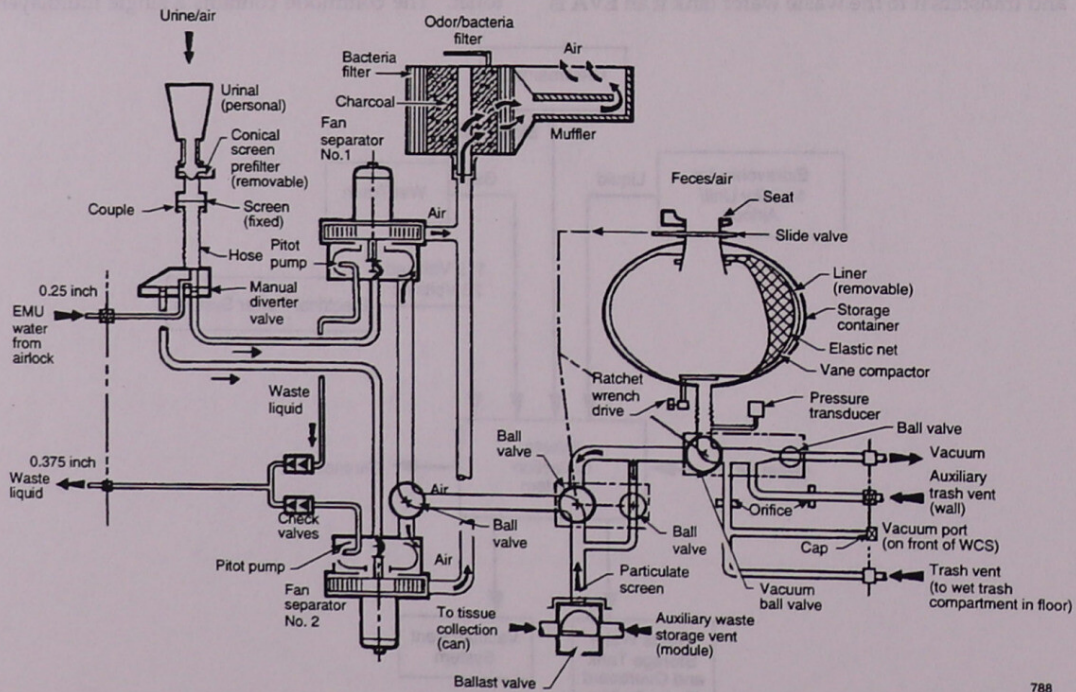


787

Waste Management System Privacy Curtains

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.

The urinal is essentially a funnel attached to a hose and provides the capability to collect and transport liquid waste to the waste water 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 waste water 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



788

Waste Management System

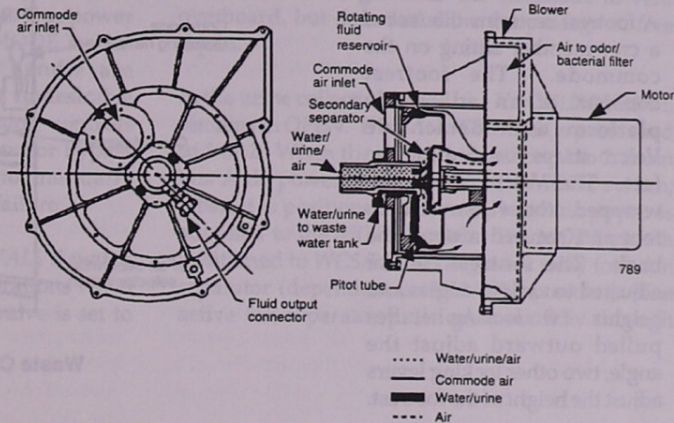
vacuum quick disconnect is used to vent liquid directly overboard from equipment connected to the quick disconnect through the vacuum line.

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.

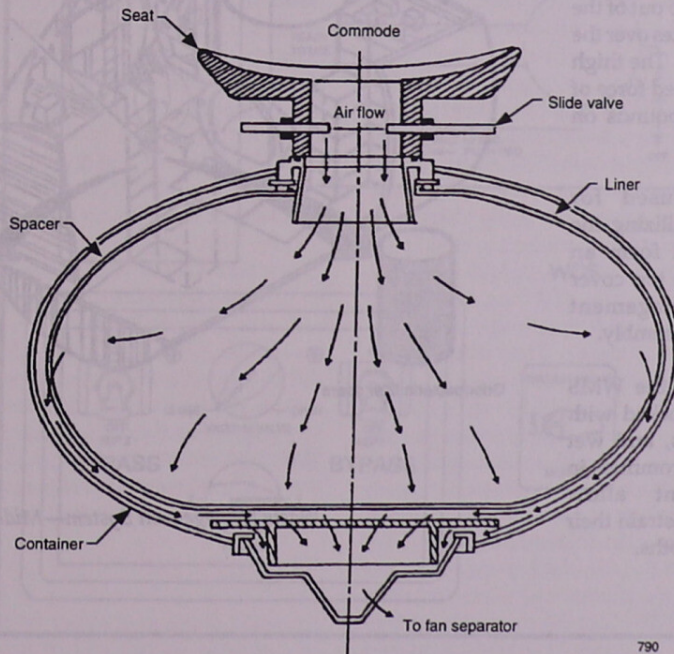
All waste management system gases are ducted from the fan separator into the odor and bacteria filter and then mixed with cabin air. The filter can be removed for in-flight replacement.

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



Waste Management System Fan Separator



Waste Management System Container Liner

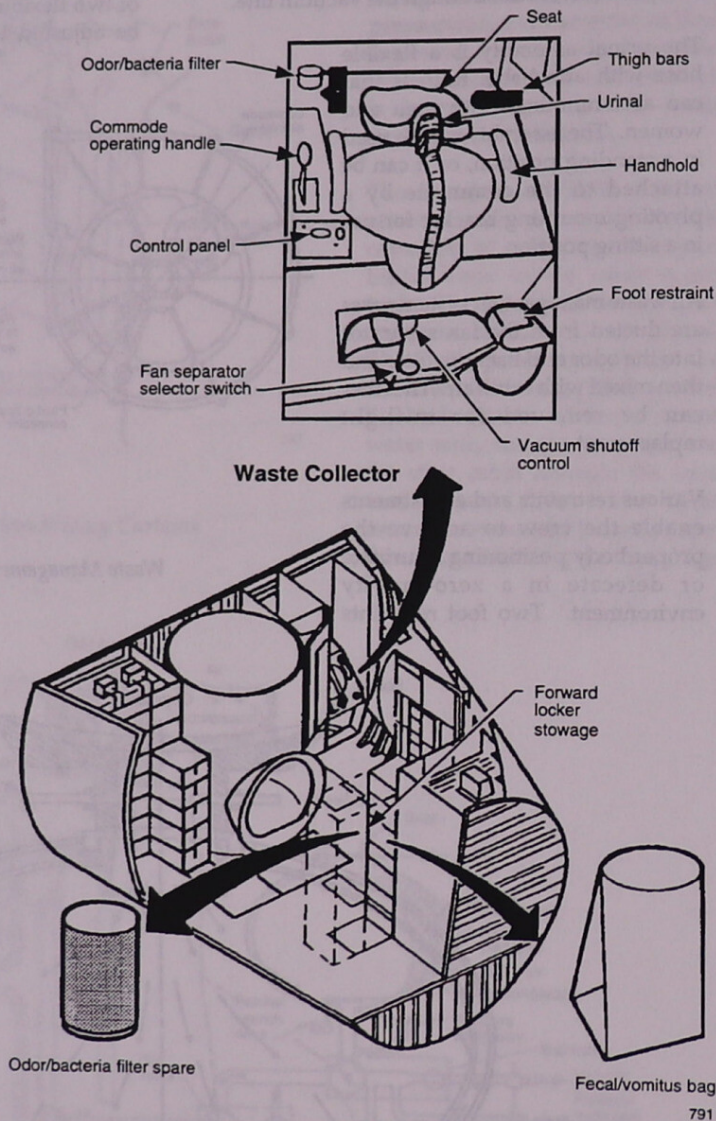
locking levers that are turned 90 degrees counterclockwise. The crewmember is restrained by slipping his or her feet under the toe bar restraint.

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—Middeck

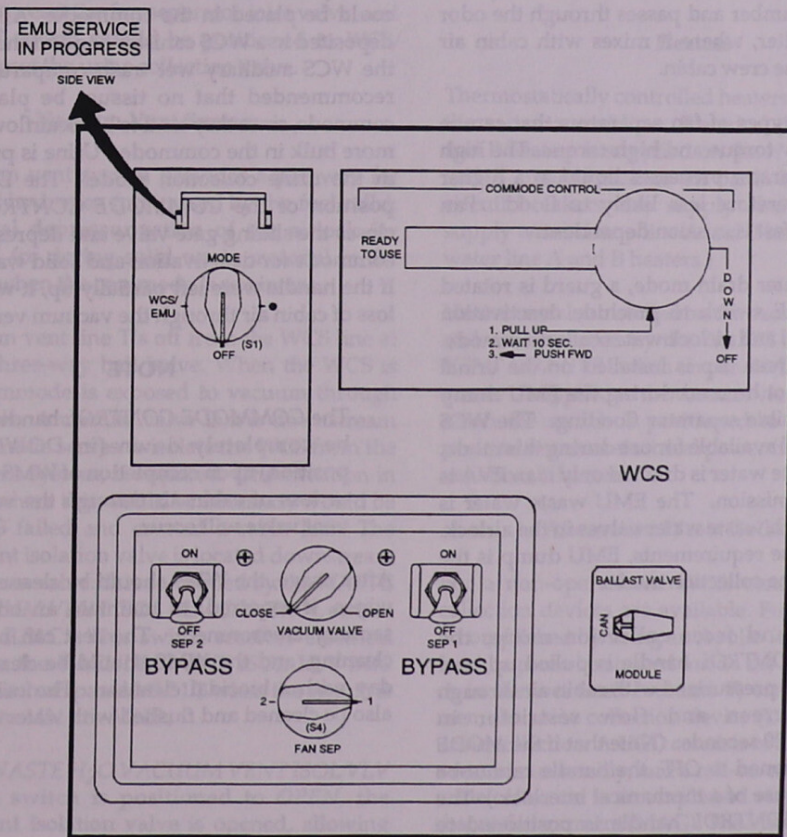
Operations

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



Waste Management System Controls

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 waste water outlet from each fan separator prevent backflow through the non-operating separator during separator operation and prevent backflow to the urinal and air outlet when the separators are off. The liquid and air mixture from the urinal line enters the fan separator axially and is carried to a rotating chamber. The mixture first contacts a rotating impact separator that throws the liquid to the outer walls of the rotating fluid reservoir. This centrifugal force causes the liquid to separate and draws it into a stationary pitot tube in a reservoir and directs the liquid through the dual check valves and into the waste water 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 waste water is dumped through waste water 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 *COMMODE 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 *COMMODE 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 *COMMODE 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 *COMMODE 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 *COMMODE 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 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 H₂O 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 H₂O 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 waste water crossite QD, which allows venting through the waste water dump line.

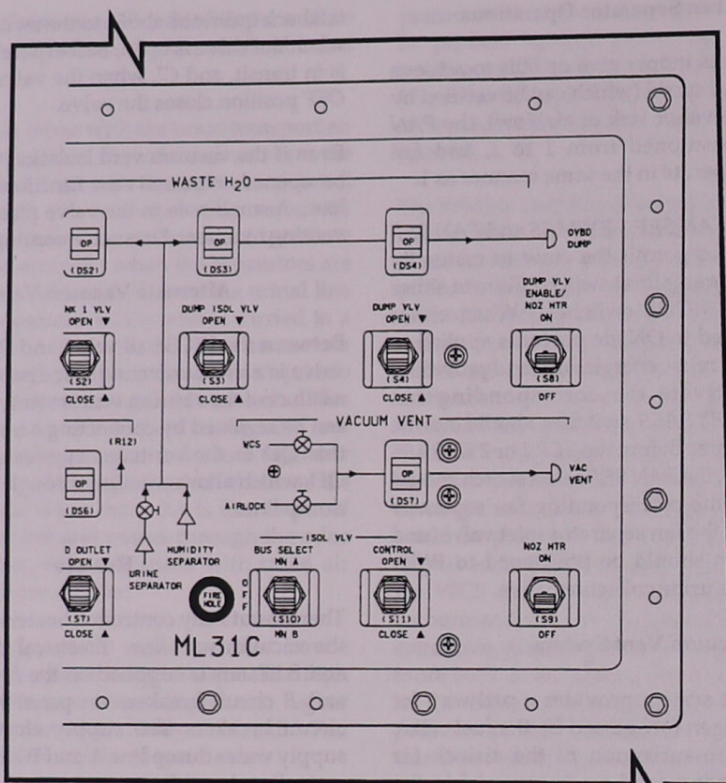
Heaters

Thermostatically controlled heaters are installed on the vacuum vent line. Electrical power for the A and B heaters is supplied on the *H₂O 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 waste water line A and B heaters.)

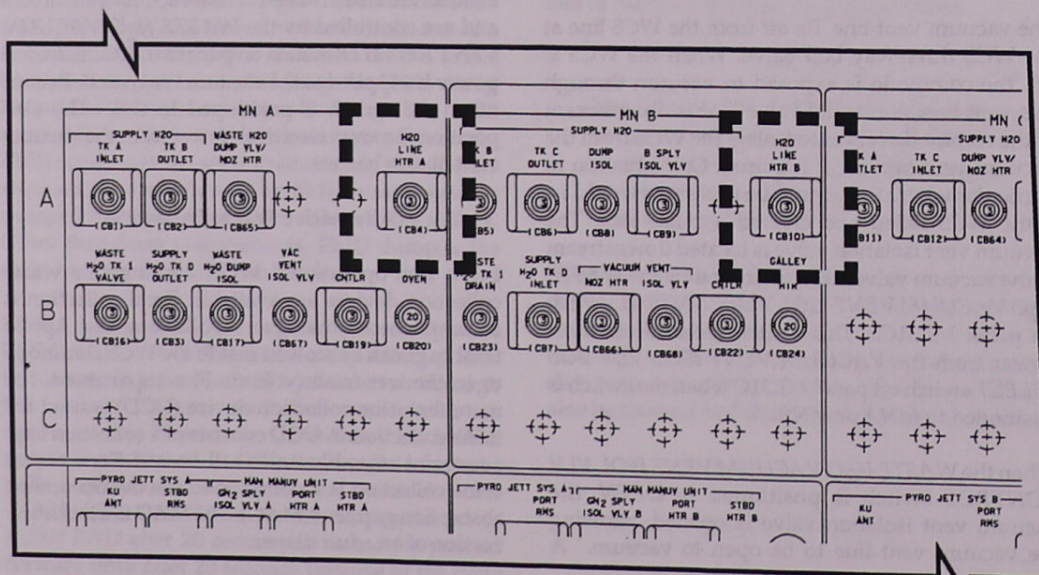
Heaters are also installed on the vacuum vent nozzle and are controlled by the *WASTE H₂O VACUUM VENT NOZ HTR* switch on panel ML31C. Electrical power is supplied to the vacuum vent nozzle heaters when the switch is positioned to *ON*. The *OFF* position removes electrical power from the vacuum vent 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



H₂O LINE HTR A and B Circuit Breakers on Panel ML86B

2.26 PAYLOAD AND GENERAL SUPPORT COMPUTER

CONTENTS

Description	2.26-1
Equipment	2.26-1

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 systems 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

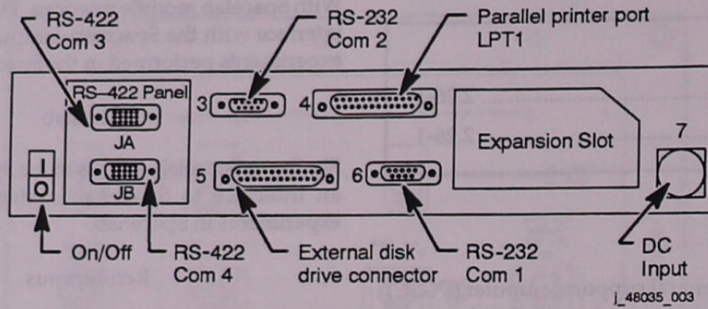
During missions that deploy or rendezvous with a payload or dock with Space Station, PGSCs are used as a tool to facilitate the orbiter's approach to its targets. Other tools used in conjunction with the PGSCs include:

- 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)

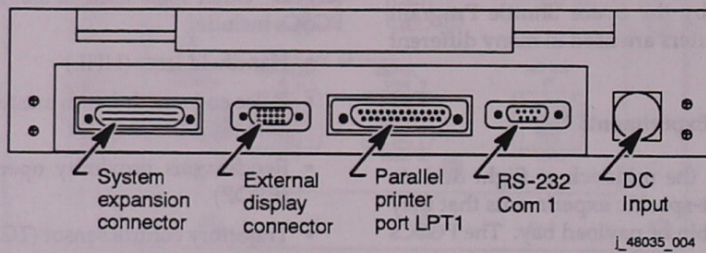
Equipment

Equipment flown to support PGSC activities includes:

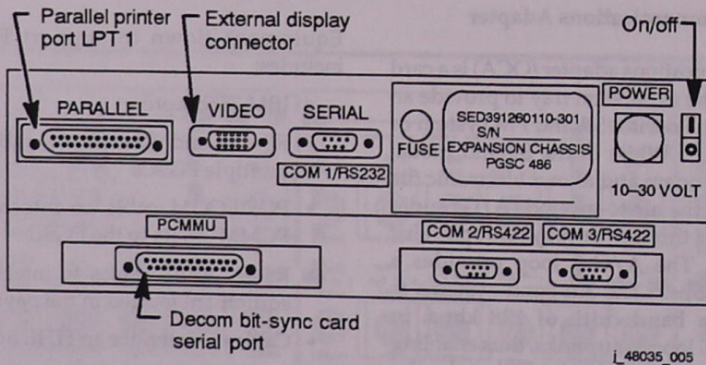
- IBM 755c laptop
- RS-422 and RS-232 Y - cables to interface multiple PGSCs
- PCDECOM cable to interface the orbiter PCMMU data to the PGSC
- RS-422 PDIP cables to interface PGSC with equipment located in the payload bay
- Cables to interface an HHL or TCS to a PGSC
- Expansion tray to provide additional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

3. FLIGHT DATA FILE

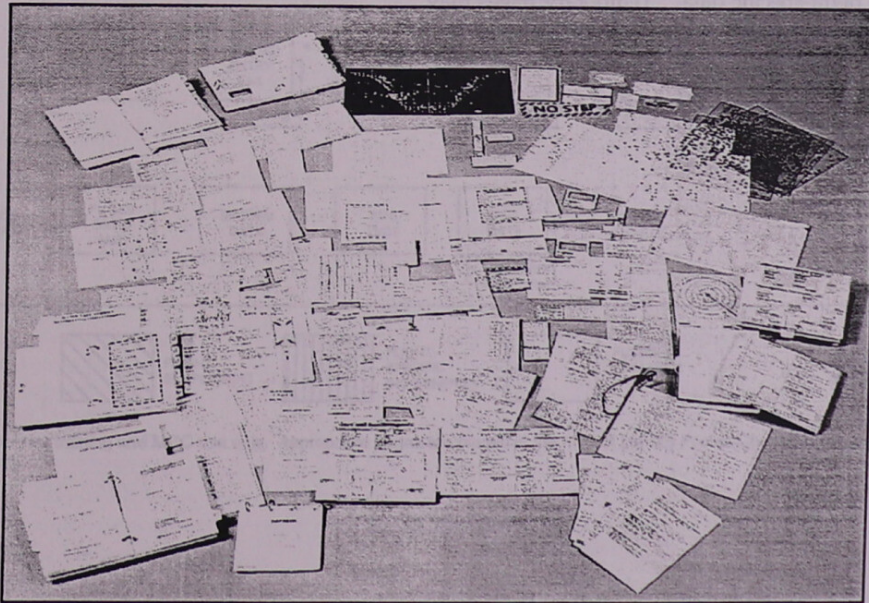
CONTENTS

3.1 Control Documents	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 guidelines and policies pertaining to the development, publication, fabrication, and validation of FDF under the authority of the Director of Mission Operations. The management process, policies, and guidelines under which the FDF is developed are contained in the Crew Procedures Management Plan (CPMP), 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.

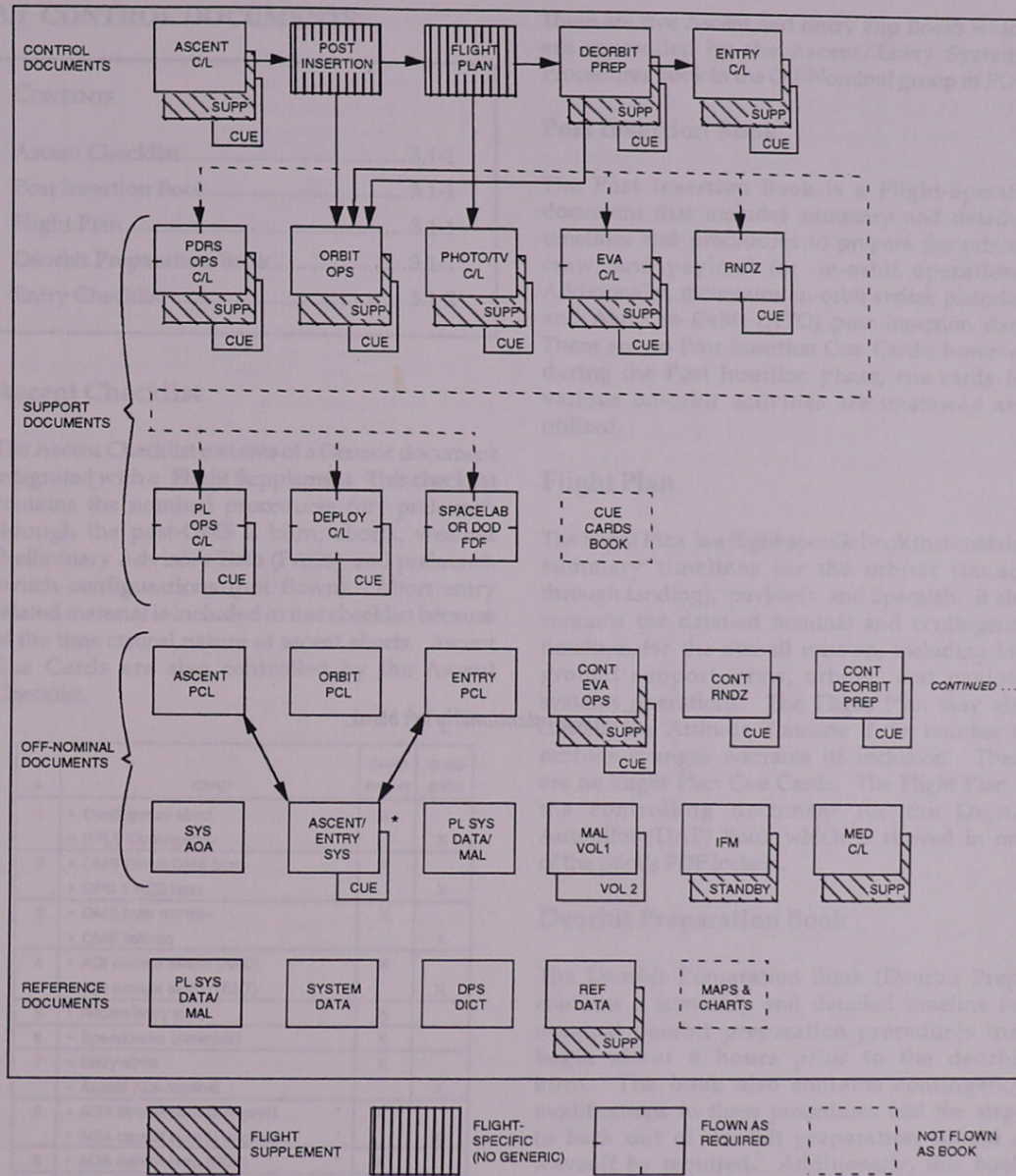
When a Spacelab module or pallet is flown, separate Control, Support, Off-Nominal, and Reference documents for Spacelab are flown.

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

- **Generic documents** — reflowed 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.

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	• Contingency abort • RTLS Contingency	X	X
2	• OMS 2/orbit OMS burn • OPS 1 RCS burn	X	X
3	• OMS burn monitor • OMS failures	X	X
4	• ADI err/rate switch (ASC) • ADI err/rate switch (ENT)	X	X
5	• Ascent/entry spec	X	
6	• Speedbrake command	X	
7	• Entry alpha • Ascent ADI-nominal	X	X
8	• AOA deorbit burn (2 engine) • AOA deorbit burn (1 engine)	X	X
9	• AOA deorbit burn (RCS)	X	
10	• (XXX) TAL redesignation • (XXX) TAL redesignation	X	X
11	• (XXX) TAL redesignation	X	
12	• Ascent/abort summary	X	
* Hinged Card			

Ascent Cue Cards

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	BACK
1	Deorbit burn flight rules • One orbit late available • One orbit late not available	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 • Deorbit burn (mixed Xfeed)	X	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; post landing 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	FRONT	BACK
1	• Card 1	X	
2	• Card 2	X	
3	• Card 3	X	
4	• Card 4	X	
5	• Card 5	X	
6	• Card 6	X	
7	• Card 7	X	
8	• Card 8	X	
9	• Card 9	X	
10	• Card 10	X	
11	• Card 11	X	
12	• Card 12	X	
13	• Card 13	X	
14	• Card 14	X	
15	• Card 15	X	
16	• Card 16	X	
17	• Card 17	X	
18	• Card 18	X	
19	• Card 19	X	
20	• Card 20	X	
21	• Card 21	X	
22	• Card 22	X	
23	• Card 23	X	
24	• Card 24	X	
25	• Card 25	X	
26	• Card 26	X	
27	• Card 27	X	
28	• Card 28	X	
29	• Card 29	X	
30	• Card 30	X	
31	• Card 31	X	
32	• Card 32	X	
33	• Card 33	X	
34	• Card 34	X	
35	• Card 35	X	
36	• Card 36	X	
37	• Card 37	X	
38	• Card 38	X	
39	• Card 39	X	
40	• Card 40	X	
41	• Card 41	X	
42	• Card 42	X	
43	• Card 43	X	
44	• Card 44	X	
45	• Card 45	X	
46	• Card 46	X	
47	• Card 47	X	
48	• Card 48	X	
49	• Card 49	X	
50	• Card 50	X	
51	• Card 51	X	
52	• Card 52	X	
53	• Card 53	X	
54	• Card 54	X	
55	• Card 55	X	
56	• Card 56	X	
57	• Card 57	X	
58	• Card 58	X	
59	• Card 59	X	
60	• Card 60	X	
61	• Card 61	X	
62	• Card 62	X	
63	• Card 63	X	
64	• Card 64	X	
65	• Card 65	X	
66	• Card 66	X	
67	• Card 67	X	
68	• Card 68	X	
69	• Card 69	X	
70	• Card 70	X	
71	• Card 71	X	
72	• Card 72	X	
73	• Card 73	X	
74	• Card 74	X	
75	• Card 75	X	
76	• Card 76	X	
77	• Card 77	X	
78	• Card 78	X	
79	• Card 79	X	
80	• Card 80	X	
81	• Card 81	X	
82	• Card 82	X	
83	• Card 83	X	
84	• Card 84	X	
85	• Card 85	X	
86	• Card 86	X	
87	• Card 87	X	
88	• Card 88	X	
89	• Card 89	X	
90	• Card 90	X	
91	• Card 91	X	
92	• Card 92	X	
93	• Card 93	X	
94	• Card 94	X	
95	• Card 95	X	
96	• Card 96	X	
97	• Card 97	X	
98	• Card 98	X	
99	• Card 99	X	
100	• Card 100	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	3.2-2
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 save 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

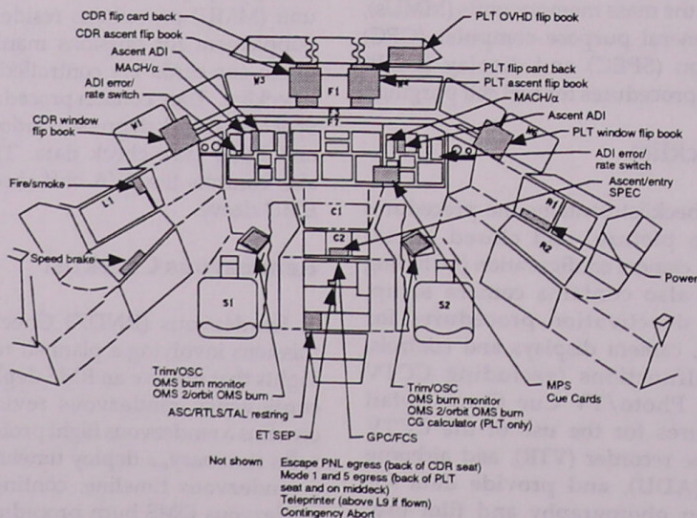
The Payload Operations (PL OPS) Checklist is a flight-specific document that contains payload systems procedures for on-orbit operations through deorbit preparation. There may be mission/payload-specific cue cards associated with this book.

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.



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	3.3-2
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 power down 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 with additional procedures.

Payload Systems Data and Malfunction Procedures Book

The Payload Systems Data and Malfunction Procedures (PL SYSDATA) Book is a flight-specific document that contains both off-nominal procedures and reference information for the mission's payloads to include 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 incorporating timelines and procedures.

Contingency Deorbit Preparation Book

The Contingency Deorbit Preparation (CONT Deorbit PREP) Book contains procedures and the switch list for emergency deorbit on orbit 2 or 3. It also contains the deorbit procedures used for loss of the flash evaporator, two fuel cells, 2 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 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 Flight Data File, 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 FDF articles or for inflight 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.

,	comma — read "... and ..."
/	slash — read "... and/or ..."
()	parentheses — read "... or ..."
»	or » chevron — read "exit"
✓	checkmark — read "vently ..." 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

Preliminaries

The development of the FDF for a mission normally starts about a 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 eight 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.

Basic

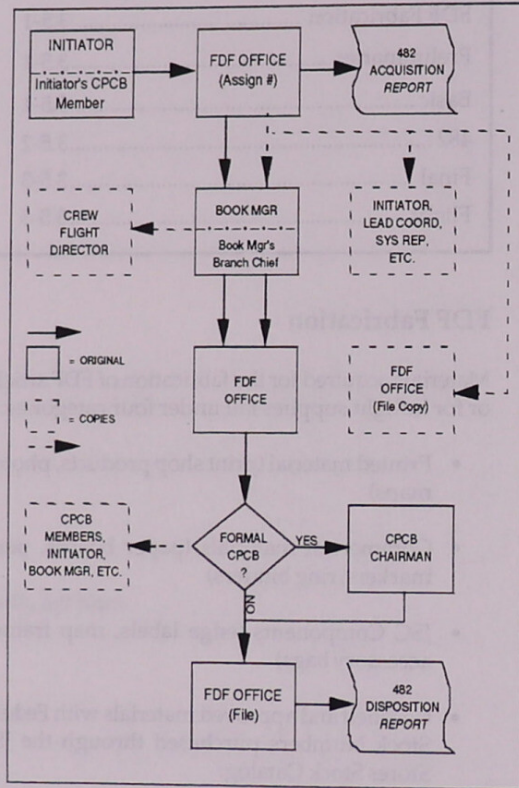
Approximately 4 months prior to the launch date, the Basic editions of all flight specific/supplement FDF are published. The documents are now under the configuration control of the CPCB and all changes must be requested through formal channels that include approval by cognizant personnel. Generic documents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

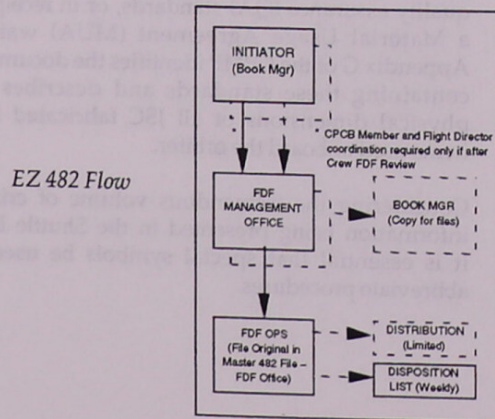
482

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 CPMF 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.



482 Flow



EZ 482 Flow

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.

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 seven copies of the three ascent related checklists, five 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 mementoes.

3. FLIGHT DATA FILE
3.5 Operational Use

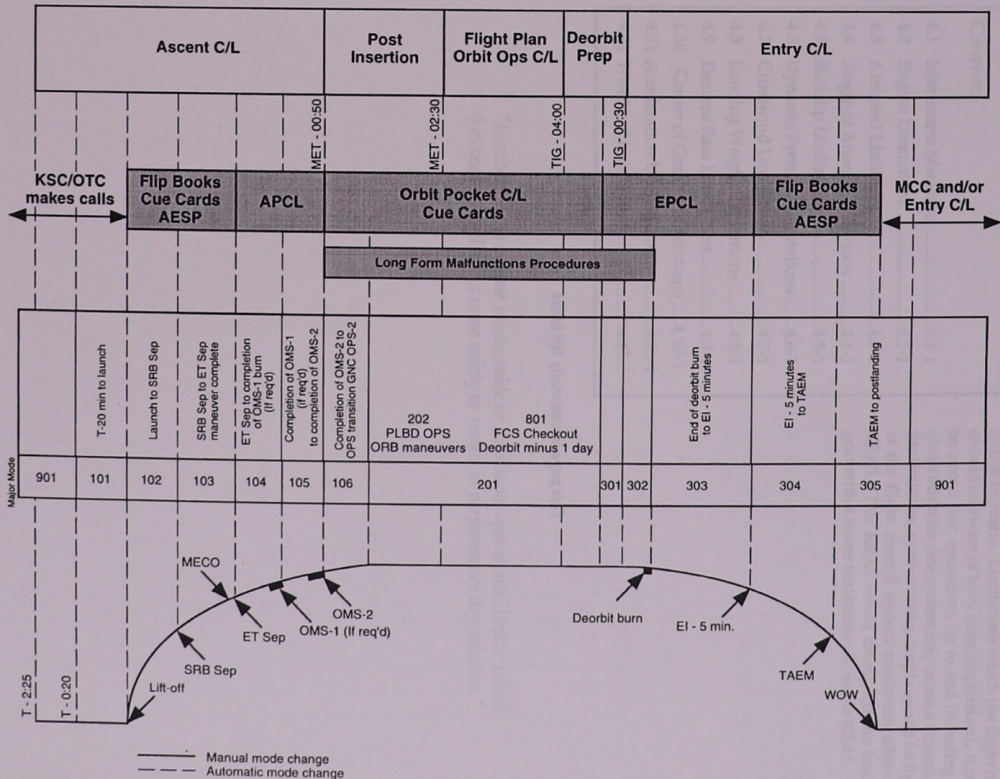
FLIGHT PHASE	EVENT	SOFTWARE			FLIGHT DATA FILE	
		MEMORY CONFIG	MAJOR MODE **		FLIGHT PROCEDURES	TROUBLESHOOTING PROCEDURES *
			GNC	SYSTEMS MGMT		
ASCENT	Precount	9	901	—	Ascent Checklist	
	Terminal Count	1	101	—		
	First Stage	1	102	—	Ascent Flip Book Cue Cards	CDR Flip Book Pilot Flip Book Pilot Overhead Flip Book Cue Cards
	Second Stage	1	103	—		
	Orbital Insertion	1	104	—	Ascent Checklist Cue Cards	Ascent Pocket Checklist
	Orbit Circularization	1	105	—		
	Post-Insertion Coast	1	106	—	Post-Insertion Checklist	Orbit Pocket Checklist STS Malfunction Procedures
	RTLS 2nd Stage	1	601	—	Ascent Flip Book	CDR Flip Book Pilot Flip Book Pilot Overhead Flip Book Cue Cards
	Glide RTLS-1	1	602	—		
	Glide RTLS-2	1	603	—		
ORBIT	Orbit Coast	2	201	—	Post Insertion Checklist Flight Plan Orbit Operations Checklist Payload Checklists Deorbit Preparation Checklist	Orbit Pocket Checklist Cue Cards STS Malfunction Procedures
	Orbital Maneuver	2	202	—		
	On-Orbit Checkout	8	801	—		
	Orbit Operations	4, 5	—	201,401		
	Payload Bay Door Operations	4, 5	—	202, 402		
ENTRY	Predeorbit Coast	3	301	—	Deorbit Preparation Checklist Entry Checklist	Entry Pocket Checklist Cue cards
	Deorbit Maneuver	3	302	—	Entry Checklist Cue Cards	
	Preentry Monitor	3	303	—	Cue Cards	CDR Flip Book Pilot Flip Book
	Early Entry	3	304	—		
	TAEM/Landing	3	305	—	Entry Checklist	Pilot Overhead Flip Book Cue Cards
	Post-Landing	9	901	—		

- * 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

3.5-5

SCOM 1.6
August 1996



Shuttle Mission Overview

4. OPERATING LIMITATIONS

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4.9 Descent Rate Limitations	4.9-1
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4.11 Acceleration Limitations	4.11-1
4.12 Weather Limitations	4.12-1

This section delineates limitations for selected orbiter systems, equipment, and operations. It is not all inclusive. Limitations which 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 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."

4.1 INSTRUMENT MARKINGS

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Description	4.1-1
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Panel F8 Meters	4.1-5
Panel F9 Meters	4.1-7
Panel O1 Meters	4.1-8
Panel O2 Meters	4.1-12
Panel O3 Meters	4.1-14

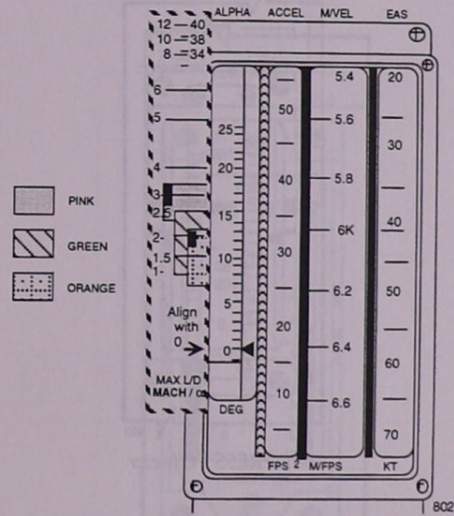
Description

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.

Panel F6 Indicator

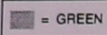
Alpha/Mach Indicator

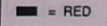
The maximum lift to drag (L/D) Mach/angle of attack (alpha) limits for the Alpha/Mach indicator are printed on an Entry Checklist cue card and affixed by Velcro to the indicator. The maximum L/Ds for Mach 3, 2.5, and 2 are indicated by black rectangles. The regions surrounding the maximum L/D zones are colored to show proper alpha ranges for those speeds. The Mach 3 to 2.5 region is shaded pink. The Mach 2.5 to 1 region is shaded green. The Mach 2 to .5 region is shaded orange. The color selection is strictly arbitrary.



Alpha/Mach Indicator with Cue Card Attached

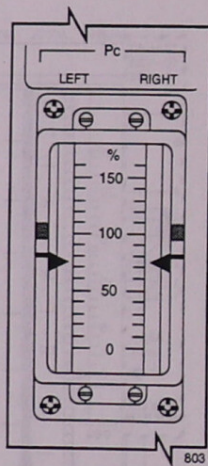
Panel F7 Meters

Normal operating ranges are indicated by:  = GREEN

High/low limits are indicated by:  = RED

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.

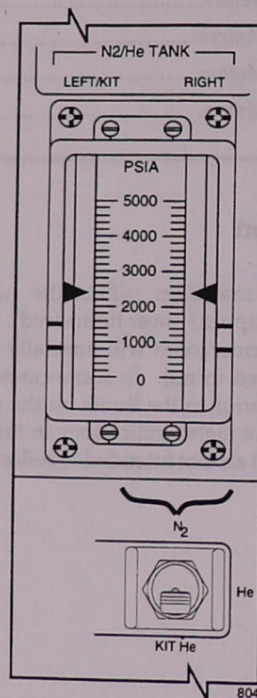


OMS PRESS PC Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
95 — 110% Pc (green)	Normal operating range
80% (red)	Low limit (Class 2 C/W); 72% allowed during ullage blowdown
105% Pc	= approximately 131 psia chamber pressure
80% Pc	= approximately 100 psia chamber pressure

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.



OMS PRESS N2/He TANK Meter

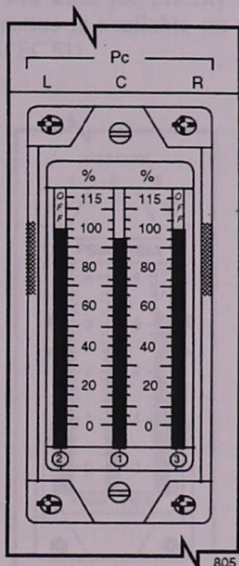
METER MARKINGS(S)	MARKING EXPLANATION(S)
1500 psia (yellow)	Low limit (Class 3 C/W)
750 psia (red)	110 psia above tank fail limit (640 psia)
1200 psia (unmarked)	Low limit (Class 3 C/W)
720 psia (red)	280 psia above tank fail limit (470 psia)

} He

} N₂

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.



MPS PRESS Pc Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
65 — 109% Pc (green)	Normal operating range (104% is the nominal maximum with power available up to 109%)
104% Pc	= approximately 3,126 psi chamber pressure
109% Pc	= approximately 3,276 psi chamber pressure

WARNING

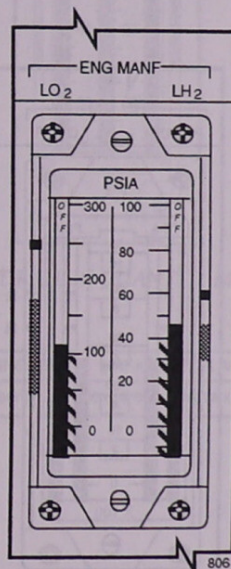
MPS performance has not been verified in flight beyond a power level of 104 percent.

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 LO₂ and LH₂ manifold pressures are measured by a single transducer in each LO₂ and LH₂ line between the ET and SSMEs. The data is sent directly to the meter and through an MDM to CRT display BFS GNC SYS SUMM 1.



MPS PRESS ENG MANF Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
45 — 175 psia (green)	Normal operating range for LO ₂
249 psia (red)	High limit (Class 2 C/W) for LO ₂
30 — 45 psia (green)	Normal operating range for LH ₂
60 psia (red)	High limit (Class 2 C/W) for LH ₂

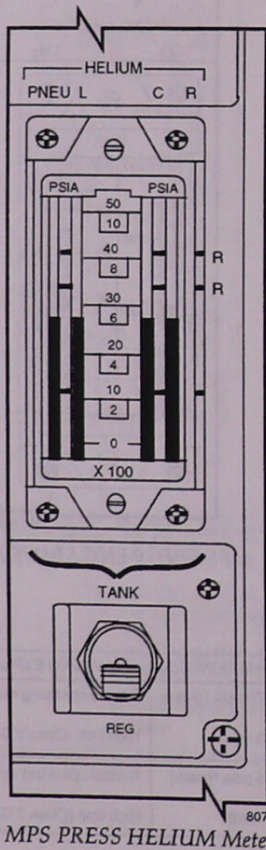
4. OPERATING LIMITATIONS
 4.1 Instrument Markings

MPS PRESS HELIUM Meter

The pneumatic, left, center, and right He tank pressures are measured by a single sensor in each system manifold. Data is 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 is 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.

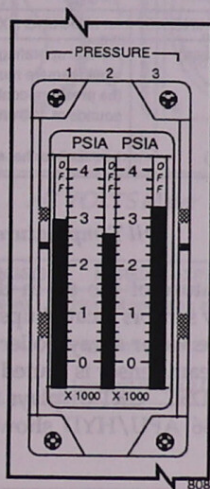
METER MARKINGS(S)	MARKING EXPLANATION(S)
(TANK)	(TANK)
1150 psia (red)	Low limit (Class 2 C/W)
(REGULATOR)	(REGULATOR)
810 psia (red)	High limit (Class 2 C/W)
680 psia (red)	Low limit (Class 2C/W)
R	Regulator



Panel F8 Meters

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 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).

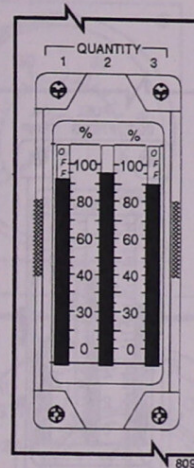


HYDRAULIC PRESSURE Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
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 Meter

A sensor located in each of the three hydraulic reservoirs provides the information displayed on the HYDRAULIC QUANTITY Meter 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.



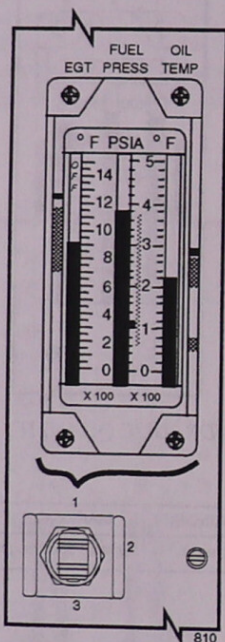
HYDRAULIC QUANTITY Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
40 — 80% (green)	Normal operating range

APU EGT, FUEL PRESS,
OIL TEMP Meter

APU EGT

There are two EGT sensors in each of the three APU turbines. Data from one sensor is routed through a DSC and displayed on the EGT meter and CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD. The redundant sensor does not provide data to the meter.



APU EGT, FUEL PRESS, OIL TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
700° — 1160° F (green)	Normal operating range
1260° F (red)	High limit (see NOTE)

NOTE

Data from the EGT transducers has often been unreliable. Consequently, EGT "out of limits" data from the transducers require verification from other sources and will not activate the C/W system.

Fuel Pressure

There are two sensors: one on the N₂ side and one on the fuel side. Both go to the CRT display, SPEC 86 APU/HYD, but only the N₂ side sensor goes to the meter via a DSC.

METER MARKINGS(S)	MARKING EXPLANATION(S)
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

Oil Temperature

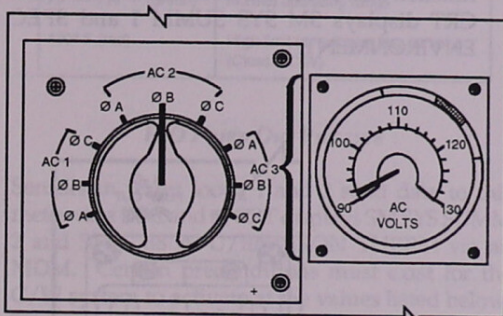
The temperature of the oil in the three APUs is measured by sensors located upstream and downstream of the water spray boilers. The data from the downstream sensor is routed to the OIL TEMP Meter via a DSC. CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD show data from both sensors.

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 running
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.

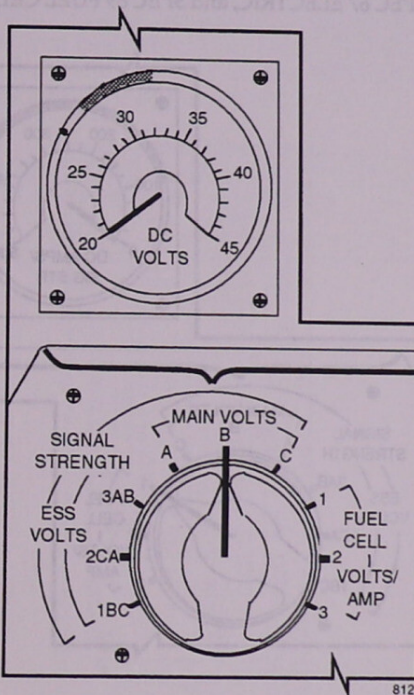


AC VOLTS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
115 — 119 (green)	Normal operating range
123 (red)	High limit (Class 2 C/W)
108 (red)	Low limit (Class 2 C/W)

DC VOLTS Meter

DC voltage is read directly at each fuel cell, main bus, and essential bus. The data is routed to the meter and to CRT displays SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS.

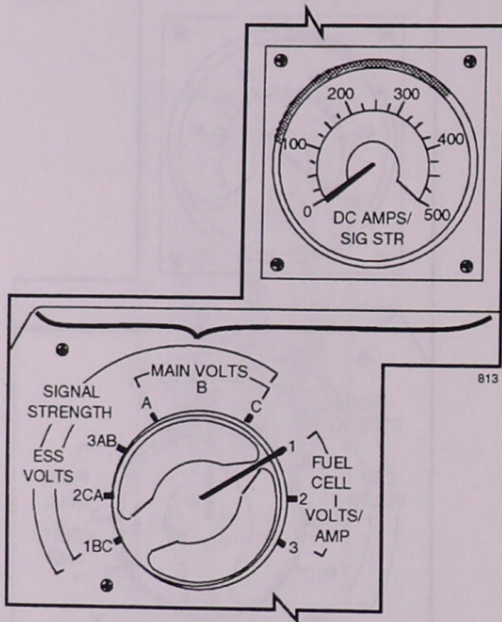


DC VOLTS Meter

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 which is also monitored on this meter.) Essential and main bus current are not monitored. The data also appears on CRT displays SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS.



DC AMPS/SIG STR Meter

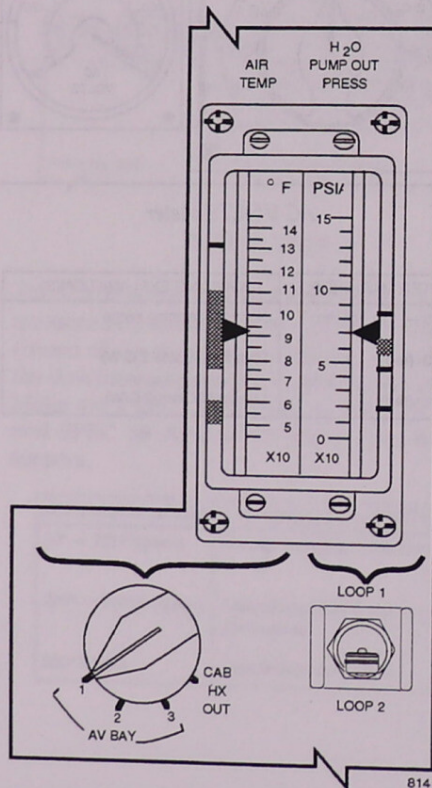
METER MARKINGS(S)	MARKING EXPLANATION(S)
90 — 350 A (green)	Normal operating range

Panel O1 Meters

AIR TEMP, H₂O PUMP OUT PRESS Meter

Cabin Heat Exchanger Air Temperature

Temperature data from a sensor downstream from the cabin heat exchanger is sent directly to the dual function AIR TEMP Meter and is also available on CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.



AIR TEMP, H₂O PUMP OUT PRESS Meter

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

Avionics Bay Air Temperature

Temperature data from a sensor located downstream of the avionics bay fans is sent directly to the AIR TEMP Meter. This data is 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)

H₂O 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 may be 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

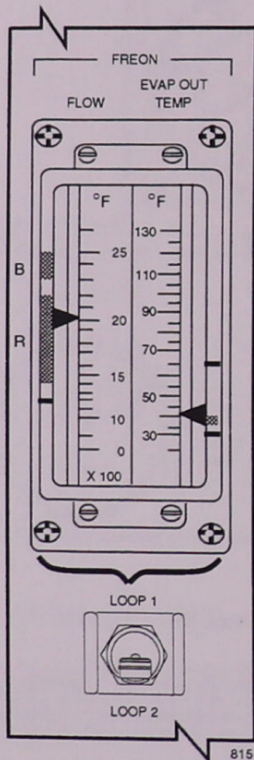
SM Alerts will occur at 75 psia (high) and 50 or 20 psia (low), depending on preconditions, for both loops.

4. OPERATING LIMITATIONS
4.1 Instrument Markings

**FREON FLOW,
EVAP OUT TEMP Meter**

Flow

A sensor located upstream from the H₂O/Freon Interchanger in Freon Loops 1 and 2 provides a readout of Freon interchanger flow directly to the meter and to 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

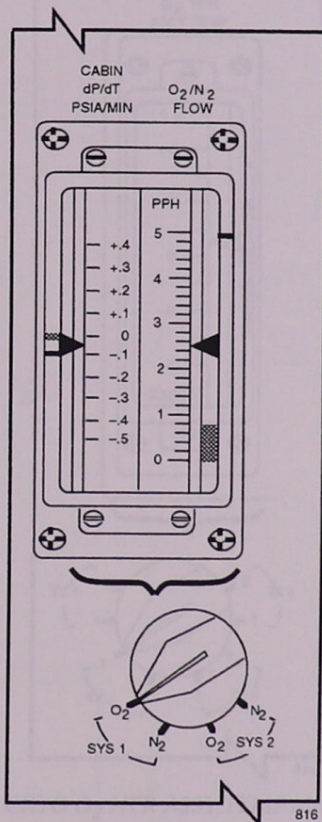
A sensor located downstream from the flash evaporator in each Freon Loop 1 and 2 provides data directly to the meter and to CRT displays SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM.

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,
O₂/N₂ FLOW Meter**

Cabin dP/dT

The indication on this meter is a direct readout of the dP/dT sensor. The data is 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.



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)

O₂/N₂ Flow

An O₂ and N₂ flow sensor in each of the two Pressure Control Systems (4 total) send data directly to the O₂/N₂ FLOW Meter. The readings are also available on CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.

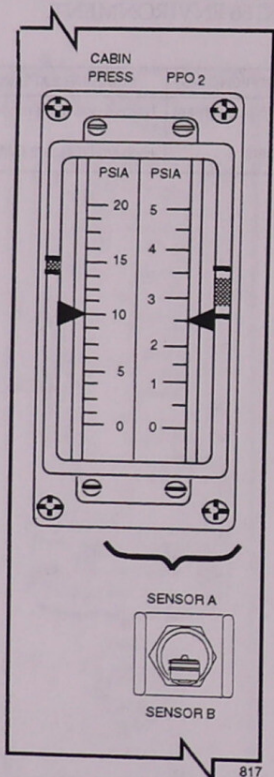
METER MARKINGS(S)	MARKING EXPLANATION(S)
0.0 — 0.75 pph (green)	Normal operating range
4.9 pph (red)	High limit (Class 2 C/W)

4. OPERATING LIMITATIONS
 4.1 Instrument Markings

CABIN PRESS, PPO₂ 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, PPO₂ Meter

PPO₂

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)

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)

Panel O2 Meters

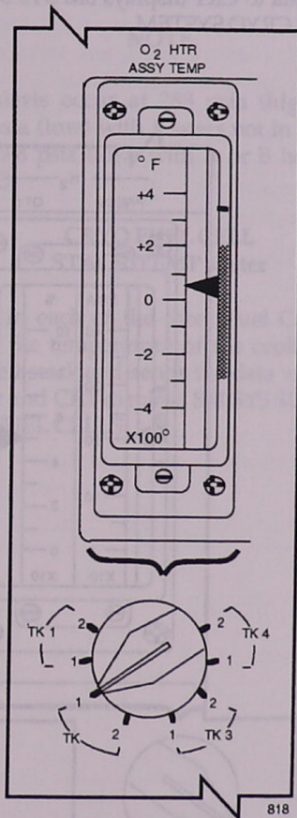
CRYO O₂ HTR ASSY TEMP Meter

A temperature sensor in each of the eight O2 tank heater assemblies monitors the temperature of warmed O2 and sends the data via a DSC to this meter and CRT displays SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM.

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.

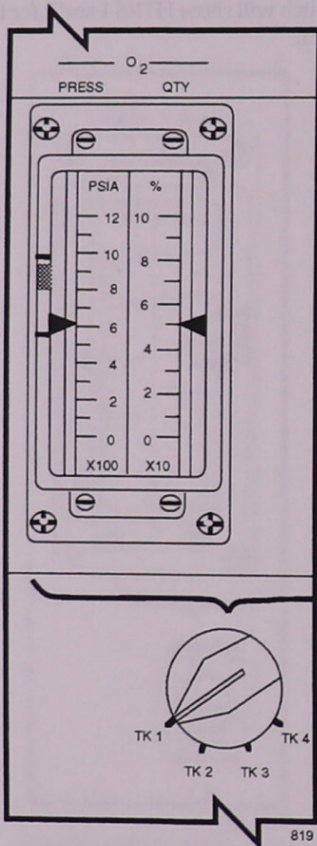


CRYO O₂ HTR ASSY TEMP Meter

4. OPERATING LIMITATIONS
4.1 Instrument Markings

CRYO O₂ PRESS Meter

One sensor for each of the O₂ 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.



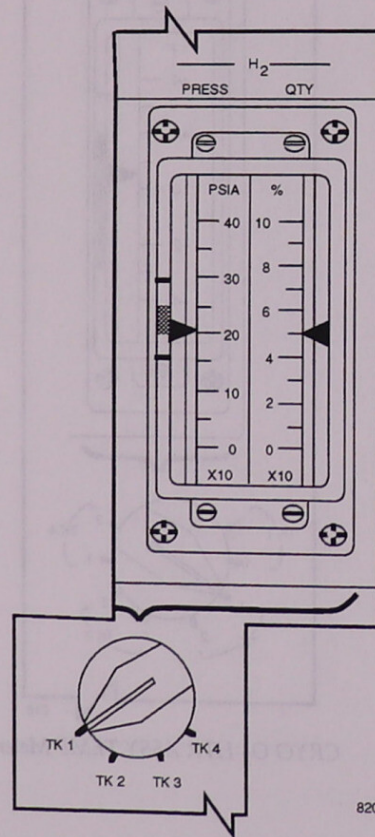
CRYO O₂ PRESS Meter

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 H₂ PRESS Meter

One sensor for each of the H₂ 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 H₂ 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

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

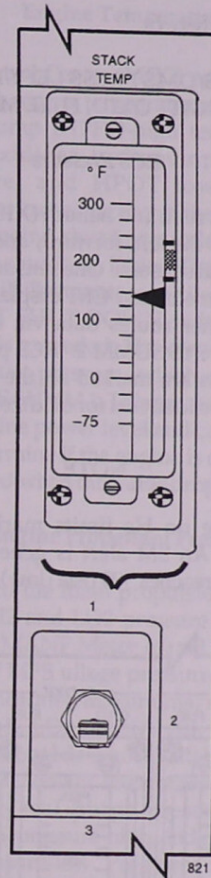
METER MARKINGS(S)	MARKING EXPLANATION(S)
200 — 250 psia (green)	Normal operating range
293.8 psia (red)	High limit (Class 2 C/W)
153 psia (red)	Low limit (Class 2 C/W)

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

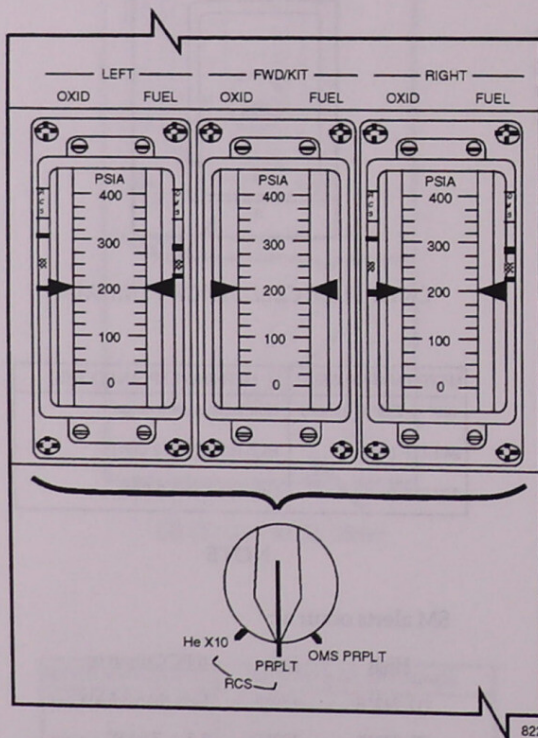
**RCS/OMS PRESS LEFT/FWD/
RIGHT OXID, FUEL Meter**

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).



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)

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	4.2-1
Orbital Maneuvering System	4.2-2
Reaction Control System	4.2-3

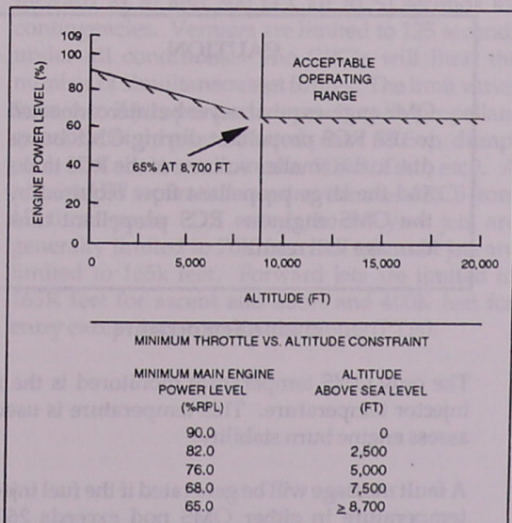
Space Shuttle Main Engines (SSME)

Power

The SSME are designed to operate from 65 percent Pc to 109 percent Pc above 8,700 MSL. The GPC's 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.



Pc Chart

823

Engine 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 the limits will result in a main engine shutdown unless the crew has inhibited the shutdown limits. The red main engine (ME) light will illuminate regardless of the position of the LIMIT SHUT DOWN switch if any one of these limits is exceeded. The crew has insight into the GH2 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 Propellant Pressure

In addition to the main propulsion system (MPS) manifold LH2 and LO2 pressure limits indicated on the ENG MANF Meter (panel F7), an SM alert will sound if MPS ullage pressure for LH2 or LO2 reaches the indicated maximums/minimums: LH2 46 psi/31.6 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 the limits will result in a main engine shutdown unless the crew has inhibited the shutdown limits. The red ME light will illuminate regardless of the position of the LIMIT SHUT DOWN switch. The crew has insight into the GO2 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 degrees.

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 GPC's 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.

Engine He Pressure

The first indication of a He leak will be an SM alert announced when the He dp/dt exceeds 20 psi for three cycles. The He dp/dt, along with other SSME He pressures, is available on BFS SYS SUMM 1 (He dp/dt is only available in OPS 1 and 3). In addition, MPS He Regulator A pressures are also available on the F7 meter.

ME He Tanks low	—	1150
Regs low	—	679
Regs high	—	810
Pneu He tank low	—	3800
Accum low	—	700

Engine AC Power

Main engine 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 electronic lockup can occur if the main engine controller loses both channels of Pc or fuel flow 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

If the hydraulic pressure drops to approximately 1200 psig a shuttle valve will shut off the inlet and outlet hydraulic lines to all five affected SSME control valves freezing the engine at the last commanded throttle position. This is reversible if system pressure recovers above approximately 1200 psig prior to the main controller issuing a throttle command. Engine throttle commands during this "soft lockup" will cause the engine to enter a "hard lockup" that is not reversible. The throttle will retain the last commanded position (prior to entry into "soft" lockup). The crew will see the corresponding amber MAIN ENGINE STATUS

light illuminate and an MPS HYD (L,R,C) message. Affected engine shutdown will be either automatic or manual based on a vehicle performance assessment by the Flight Dynamics Officer.

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 .7 degrees 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 degrees inboard or up during the maximum q-bar regime of ascent, then 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 125 seconds under all conditions. 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 yaw jets are generally limited to 70K feet. All other aft jets are limited to 165k feet. Forward jets are limited to 165K feet for ascent and abort and 400K feet for entry except for program test inputs (PTIs).

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 1405 lb of aft propellant is required for entry from orbital inclinations of 28.45 degrees through 30 degrees. An additional 200 lb is redlined for entry from inclinations greater than 30 degrees.

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	4.3-1

Ascent

The maximum airspeed (based on the q-bar limit of 819 psf) for OV 103, 104, and 105 is 492 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 465 KEAS.

There is no official minimum airspeed for ascent. There is, however, a minimum orbit (dictated by flight rule) that designates 80 nm as the minimum acceptable altitude. This altitude (given a minimum apogee of 155 nm) assures at least 48 hours before orbital decay to 400,000 ft. (A 105 nm X 85 nm 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 nm.

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.

Minimum 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.

Minimum airspeed is further limited by an uncontrollable pitch-up divergence. This pitch-up divergence always occurs at a slower speed than maximum L/D; however, at Mach 1.5 the limit is close to maximum L/D. The airspeed pitch-up divergence is not available onboard. Alpha must be monitored to avoid a pitch-up divergence. See section 4.4.

Landing

Maximum airspeed for lowering the gear is 312 KEAS.

Maximum speed at landing is based on 225 knots ground speed (KGS). This is protected by not landing faster than the targeted landing airspeed (205 KEAS if heavyweight). Unlike most orbiter limits, flight design does not add any pad to this

4. OPERATING LIMITATIONS
 4.3 Airspeed Limitations

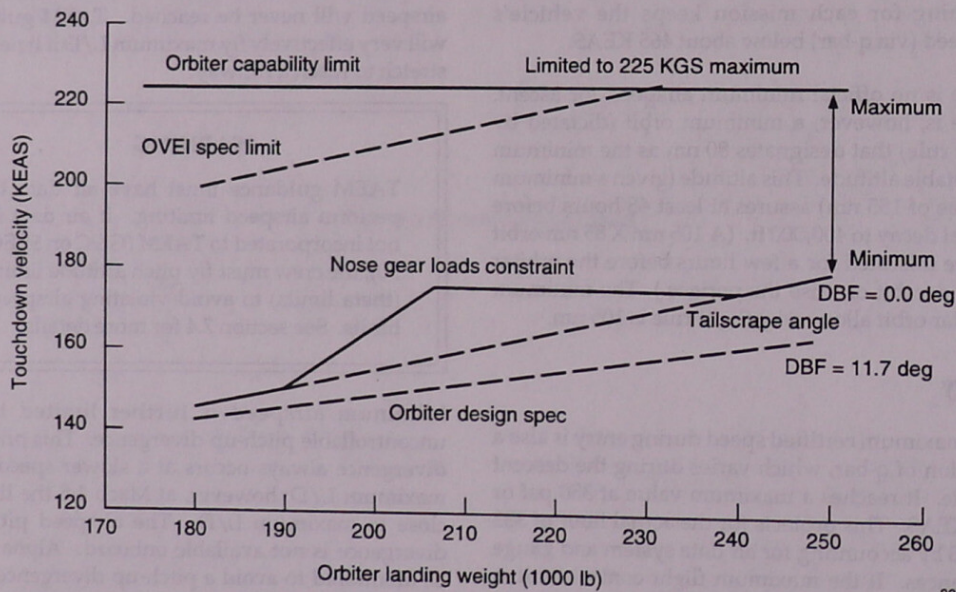
limit to protect for dispersions. When landing with a high density altitude and/or tail winds, the runway is declared GO for landing if the targeted touchdown speed of 205 KEAS results in a ground speed of 225 knots. In these cases, the expected ground speed will be discussed with the crew.

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. Body flap scrape can also be protected by limiting alpha to 14.7 degrees. 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 shuttle program is going through a reevaluation of derotation speeds and techniques, but the current technique is to derotate at 185 KGS using the beep trim on the RHC.

Maximum airspeed for drag chute deploy is 210 KEAS. Above this velocity, the drag chute shear pin will fail. This protects the orbiter from an inadvertent deploy on final.

The drag chute must be jettisoned between 40 and 60 KEAS to protect the main engine nozzle. Operationally, the crew can use ground speed. If ground speed goes below 40 knots before the drag chute is jettisoned, it should not be jettisoned



Orbiter Landing Speed Restrictions

4.4 ANGLE OF ATTACK LIMITATIONS

CONTENTS

Entry	4.4-1
Approach and Landing	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 usable alphas.

The minimum alpha used in the aero database is -10 degrees.

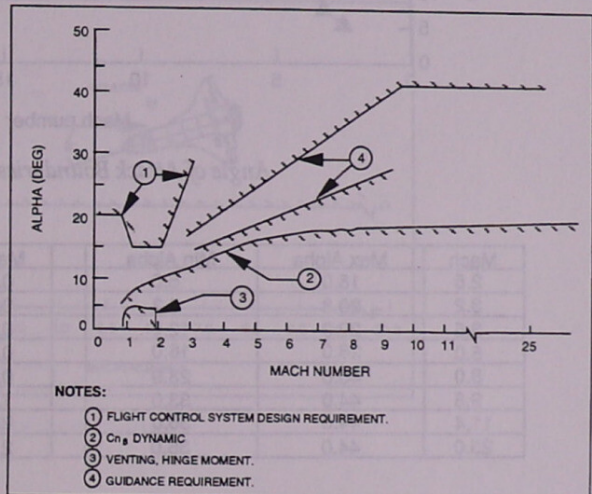
The maximum L/D alphas for various Mach numbers are:

Mach	Max L/D $\alpha = 17$
3	17
2	15
1	12
Subsonic	10.5

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

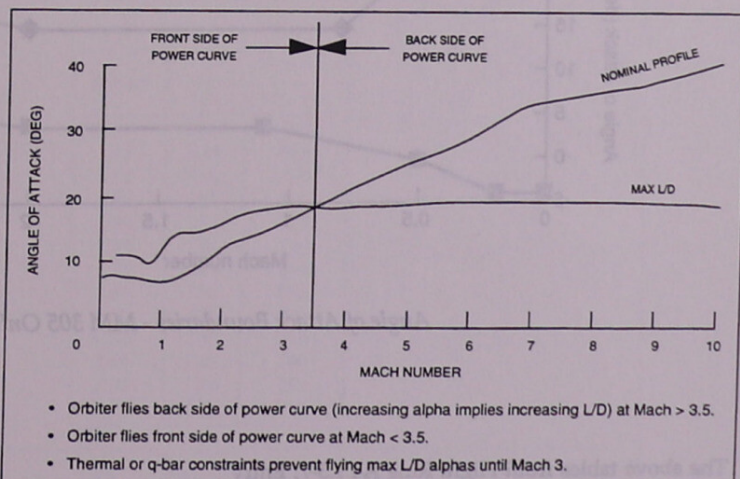
Approach and Landing

The maximum usable alpha during approach and landing is 20 degrees until final flare, when the alpha must be limited to about 14.7 degrees to prevent body flap or elevon scrape.



Orbiter Design Angle of Attack Limits

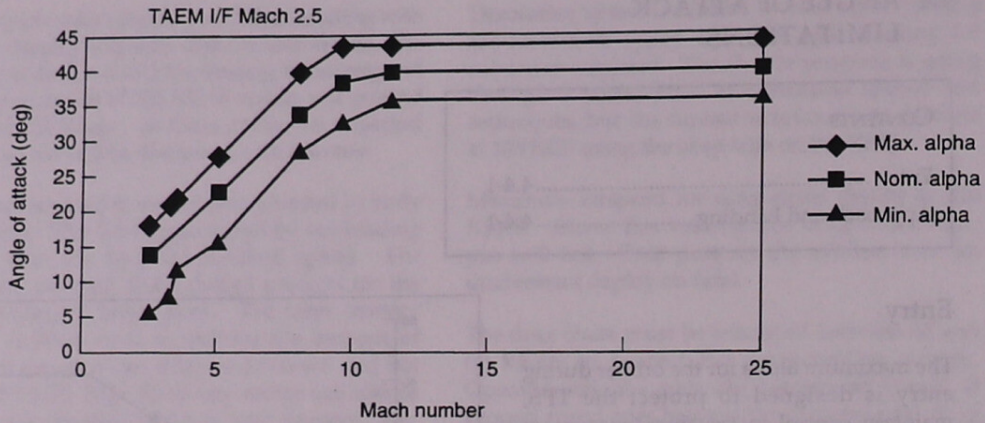
825



Orbiter Nominal Angle of Attack Profile

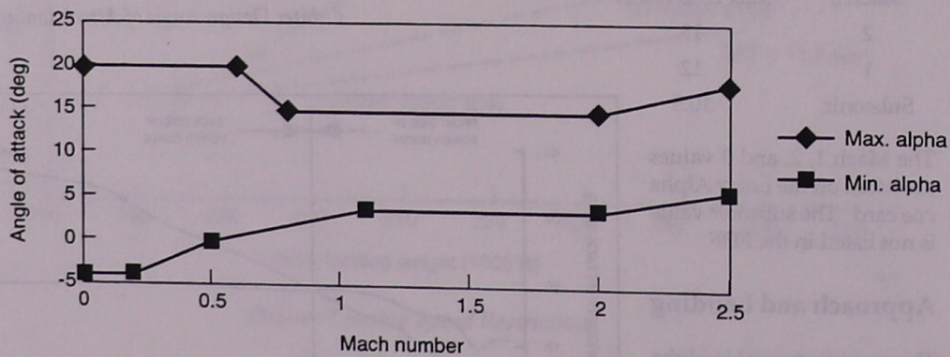
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4. OPERATING LIMITATIONS
4.4 Angle of Attack



Angle of Attack Boundaries - MM 304 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	0.5		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



Angle of Attack Boundaries - MM 305 Only

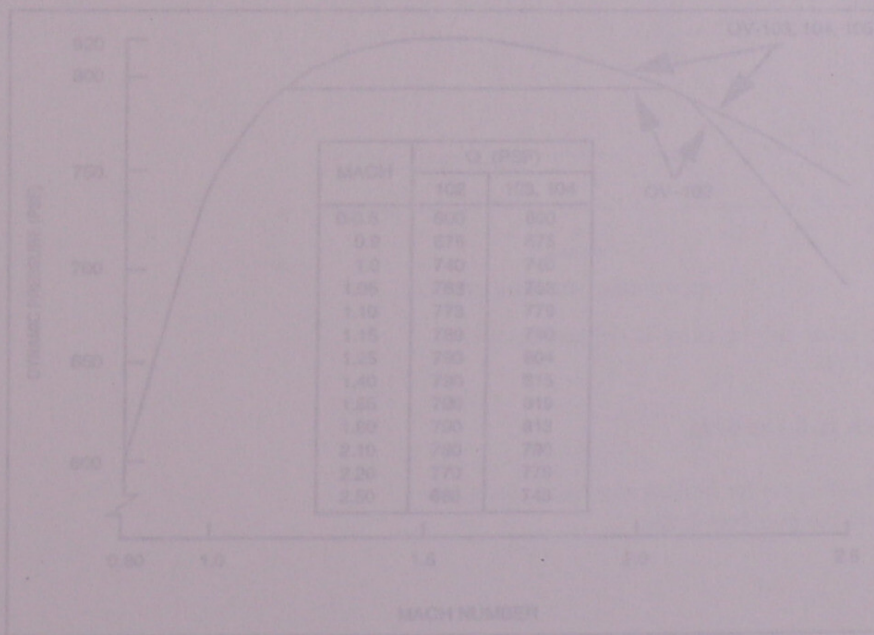
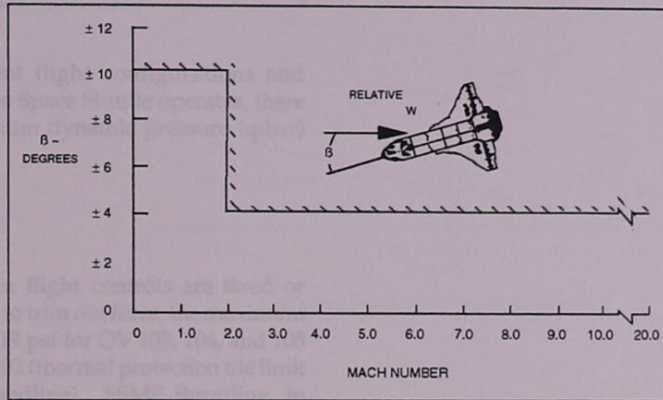
The above tables from Flight Rule A4.1.5-7, Entry Limits, list the normal angle of attack limits for the orbiter during entry.

4.5 SIDESLIP LIMITATIONS

Numerous sideslip limitations for the various ascent flight phases (SRB separation, ET separation, aborts, etc.) are available in the Shuttle Performance Assessment Databook (SPAD). During entry (2 < Mach < 12), the crew will manually trim to reduce

RCS jet firings if steady state sideslip exceeds 2 degrees, one or more yaw jets fire continuously, or if scaled A_y (sensed lateral acceleration) exceeds the 2 jet capability.

In the landing configuration the maximum sideslip angle is ± 5 degrees.



4.6 DYNAMIC PRESSURE LIMITATIONS

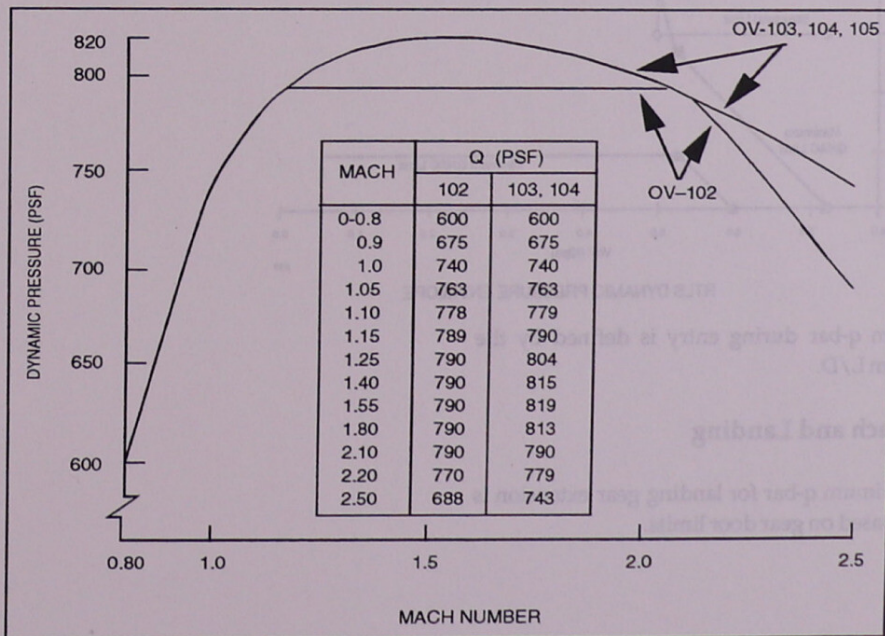
CONTENTS

Ascent.....	4.6-1
Entry.....	4.6-2
Approach and Landing.....	4.6-2

Due to the different flight configurations and regimes in which the Space Shuttle operates, there are multiple maximum dynamic pressure (q-bar) values.

Ascent

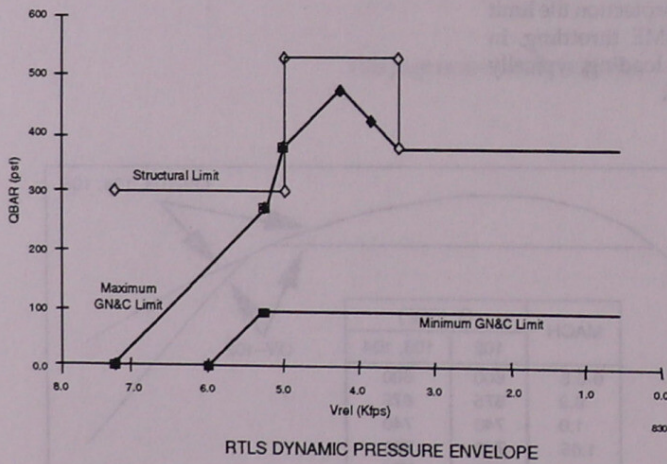
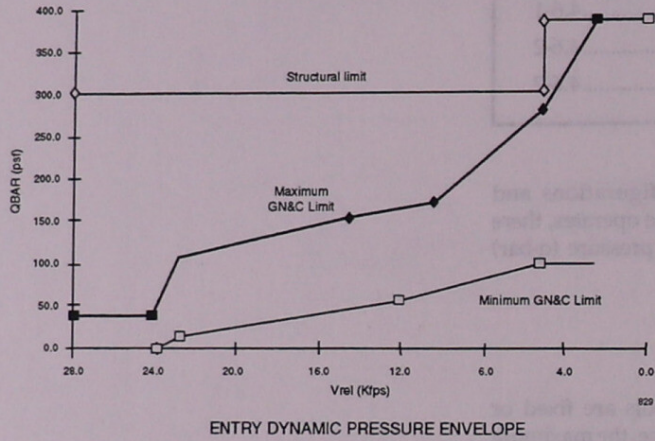
During ascent when flight controls are fixed or moved only slightly to trim out force, the maximum allowable q-bar is 819 psf for OV 103, 104, and 105 and 790 psf for OV 102 (thermal protection tile limit and flutter/buffet redline). SSME throttling, in conjunction with SRB propellant loading, typically keeps the pressure below 700 psf.



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Entry

Current limits for q-bar are as follows:



Minimum q-bar during entry is defined by the maximum L/D.

Approach and Landing

The maximum q-bar for landing gear extension is 330 psf based on gear door limits.

4.7 CROSSWIND LIMITATIONS

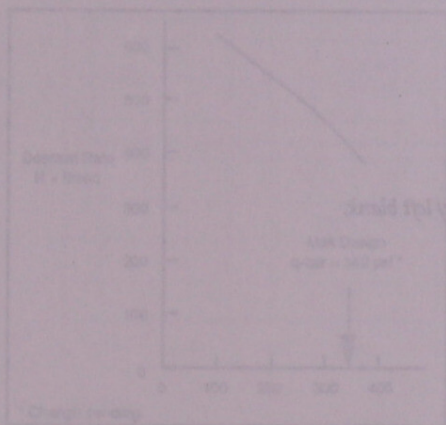
Although the orbiter design landing crosswind limit is 20 kts, Flight Rule A2.1.1-6 limits it to 15 kts, night (except RTLS) <12 kts, based on flight experience and Ames Vertical Motion Simulator simulations for lateral control and tire wear. Long duration missions or landings with one failed APU lower the crosswind limit to 12 and 10 kts respectively.

4.8 LANDING WEIGHT LIMITATIONS

Maximum Landing Weight

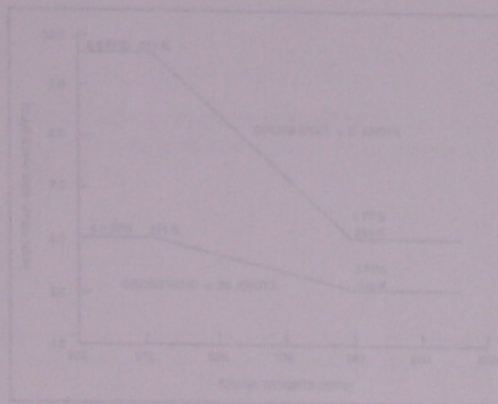
The maximum landing weight, based on the weight used to certify the main gear and tires is 239,903 lbs (which is officially accepted to be 240,000). Flight Rule (A4.1.4-3) limitations for nominal end of mission (EOM) landing weight is 230,000 lbs. Planned EOM weights above that value must have a flight-specific waiver. The abort landing weight for AOA and TAL was recently set at 248,000 lbs. The abort landing weight for RTLS is 256,000 lbs.

(H-dot) must not exceed 400 fpm. The following graph shows maximum H-dots for different dynamic pressures.



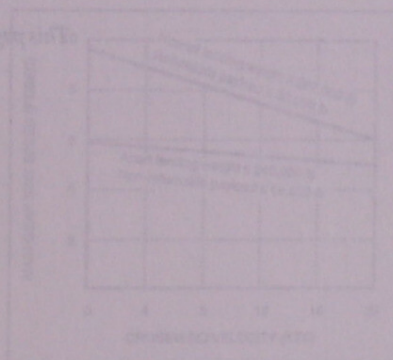
Main Gear Touchdown

The maximum rate of descent at main gear touchdown is 7.5 fpm for landing weights less than 211,000 lb and no crosswind. The following graph shows the rate of descent limits for various abort weights.



Main Gear Sink Rate

The type of payload returned in the payload bay also establishes the maximum allowable sink rate at main gear touchdown. The following graph shows the limit for crosswind and sink speed for the main gear for returnable and non-returnable payloads.



Landing Sink Rate vs. Crosswind Velocity

Nose Gear Touchdown

The maximum rate of descent at nose gear touchdown must not exceed 11.5 fpm (0.7 degrees per second) or the rate needed to prevent nose gear vertical loads in excess of 90,000 lbs. (Operational rate of descent average 5 fpm.)

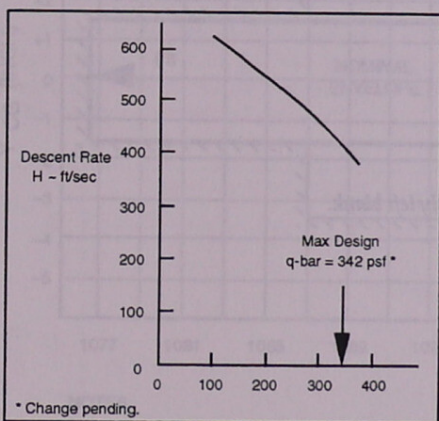
4.9 DESCENT RATE LIMITATIONS

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Entry	4.9-1
Main Gear Touchdown	4.9-1
Nose Gear Touchdown	4.9-1

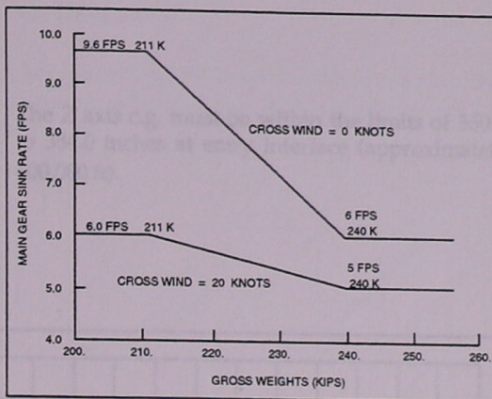
Entry

Below 100,000 ft the maximum rates of decent (H-dot) must not exceed 486 fps. The following graph shows maximum H-dots for different dynamic pressures.



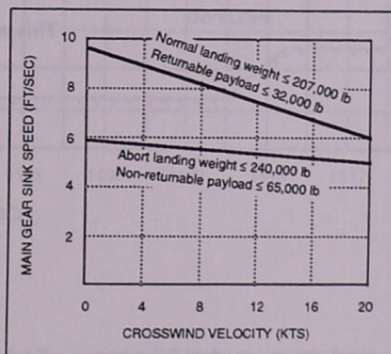
Main Gear Touchdown

The maximum rate of descent at main gear touchdown is 9.6 fps for landing weights less than 211,000 lb and no crosswind. The following graph shows the rate of descent limits for various orbiter weights.



Main Gear Sink Rate

The type of payload returned in the payload bay also establishes the maximum allowable sink rate at main gear touchdown. The following graph shows the limit for crosswind and sink speed for the main gear for returnable and non-returnable payloads.



Landing Sink Rate vs. Crosswind Velocity

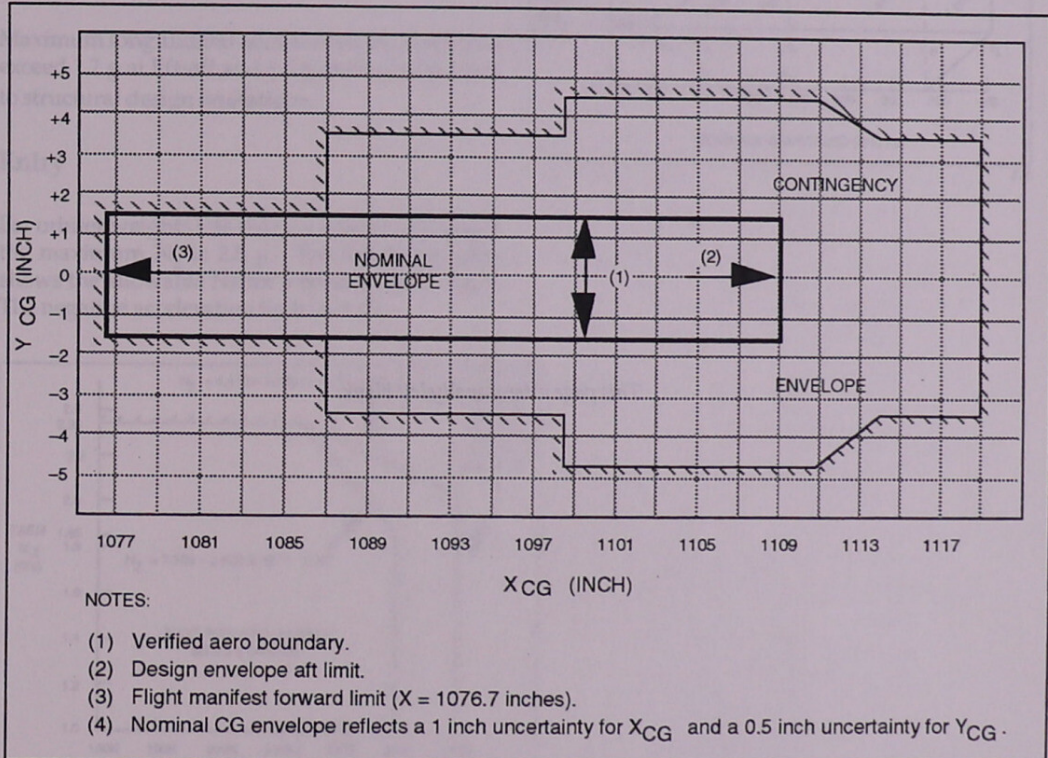
Nose Gear Touchdown

The maximum rate of descent at nose gear touchdown must not exceed 11.5 fps (9.9 degrees per second) or the rate needed to prevent nose gear vertical loads in excess of 90,000 lbs. (Operational rates of descent average 5 fps.)

4.10 CENTER OF GRAVITY LIMITATIONS

Although ground personnel will normally monitor and direct changes to the orbiter's c.g. for entry, the crew may in "lost comm" situations be required to perform this task. The X and Y axis c.g. envelopes for entry are shown on the following graph:

The Z axis c.g. must be within the limits of 360.0 to 384.0 inches at entry interface (approximately 400,000 ft).



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4.11 ACCELERATION LIMITATIONS

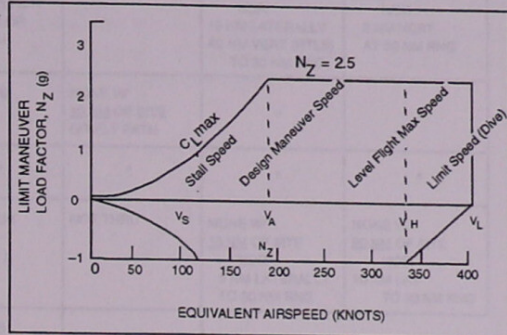
Vn Diagrams

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Ascent.....	4.11-1
Entry.....	4.11-1

The following Vn diagram demonstrates the acceleration limits in the TAEM region of entry.

Ascent

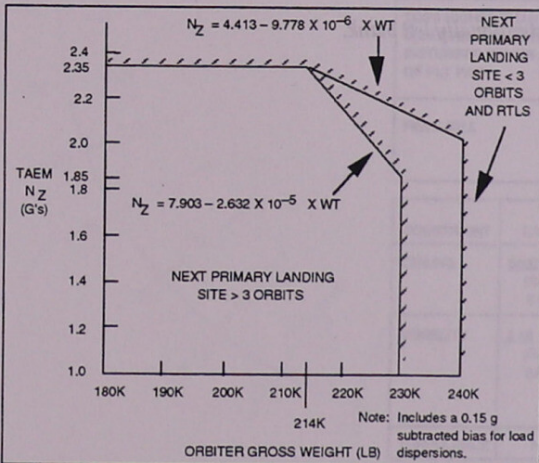
Maximum longitudinal acceleration (N_z) must not exceed 1.2 g at lift-off and 3.0 g during ascent due to structural design limitations.



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Entry

For orbiter weights less than, or equal to 211,000 lb, the maximum N_z is 2.5 g. The following graph shows the allowable N_z for various gross weights. The negative acceleration limit is -1.0 g.



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Orbiter Operational Maneuver Limits

4.12 WEATHER LIMITATIONS

Weather limitations for launch, abort landing, and end of mission landing are presented in the table on the right.

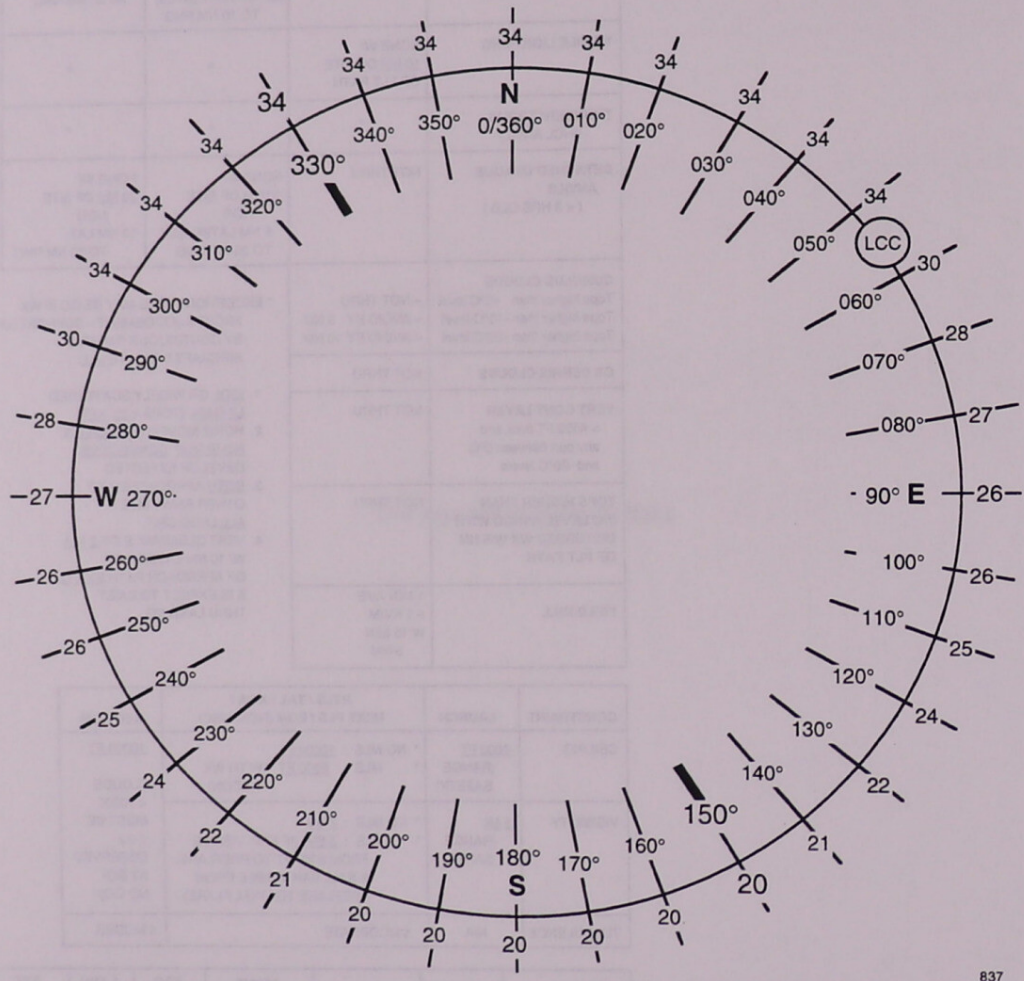
CONSTRAINT	LAUNCH	RTL5 / TAL	EOM / AOA
PRECIPITATION - VISIBLE RAIN/VIRGA - PRECIP ECHO ON RDR - CUMULONIMBUS OR TOWERING CU	NONE IN FLT PATH	NONE W/ 20 NM OF SITE NOR 10 NM LATERALLY & 2 NM VERT (RTL5) TO 30 NM RNG	NONE W/ 30 NM OF SITE NOR 2 NM VERT AT 30 NM RNG
VISIBLE LIGHTNING	NONE W/ 10 NM OF SITE OR FLT PATH	"	"
THUNDERSTORMS (INCL ANVIL)	"	"	"
DETACHED OPAQUE ANVILS (< 3 HRS OLD)	NOT THRU	NONE W/ 10 NM OF SITE NOR 5 NM LATERALLY TO 30 NM RNG	NONE W/ 20 NM OF SITE NOR 10 NM LAT TO 30 NM RNG
CUMULUS CLOUDS Tops higher than +5°C level Tops higher than -10°C level Tops higher than -20°C level	- NOT THRU - AVOID BY 5 NM - AVOID BY 10 NM	<p>* EXCEPTION: RTL5 MAY BE GO IF WX FRCST & JUDGEMENT - SUPPORTED BY CONTINUOUS RADAR & AIRCRAFT INDICATE ALL:</p> <ol style="list-style-type: none"> ISOL OR WIDELY SCATTERED LT RAIN (TOPS < 20 KFT) HORIZ MOVEM IS STABLE & NO SIGNIF CONVECTIVE DEVELOP EXPECTED BOTH APPROACHES TO OTHER RWY MEET ALL LNDG CRIT VERT CLEARANCE OF 2 NM W/ 10 NM LATERALLY OF APPROACH PATH EXISTS & IS EXPECT TO EXIST THRU LANDING 	
CB DEBRIS CLOUDS	NOT THRU		
VERT CONT LAYER > 4500 FT thick and any part between 0°C and -20°C levels	NOT THRU		
TOPS HIGHER THAN 0°C LEVEL ASSOC WITH DISTURBED WX W/5 NM OF PLT PATH	NOT THRU		
FIELD MILL	1 MIN AVE > 1 KV/M W 15 MIN 5 NM		

CONSTRAINT	LAUNCH	RTL5 / TAL / AOA / NEXT PLS / EOM (NON-KSC)	KSC EOM
CEILING	8000 FT (RANGE SAFETY)	* NO MLS : 10000 FT * MLS : 8000 FT (WITH WX RECON)	10000 FT (CLOUDS < 10000 MUST BE ≤ 0.2 OBSERVED AT GO/ NO GO)
VISIBILITY	5 MI (RANGE SAFETY)	* NO MLS : 7 SM * MLS : 5 SM (IF PAPI VISIBLE FROM 8000 FT TO PREFLARE, & BALL BAR VISIBLE FROM PREFLARE TO FINAL FLARE)	
TURBULENCE	N/A	≤ MODERATE	≤ MODER

CONSTRAINT	LAUNCH	DAY	NIGHT (except RTL5)	EDO (> 17 FD)	1 APU DOWN	KSC EOM
SURFACE WINDS	RTL5: 15 XW 17 KTS WITH STA RECON LCC: SEE COMPASS ROSE (NOTE 3)	HW: ≤ 25 KT XW: ≤ 15 KT INCL GUST GUST ≤ 10 KT TW: ≤ 15 KT ≤ 10 AVE (214 KT TIRE SPEED)	HW: ≤ 25 XW: ≤ 12 INCL GUST GUST ≤ 10 KT TW: ≤ 15 KT ≤ 10 AVE (225 KT TIRE SP)	12 XW	10 XW (LIGHT TURB)	HW ≤ 25 DAY: XW: ≤ 15 NIGHT: XW: ≤ 12

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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 Pre-Launch	5.1-1
5.2 Ascent	5.2-1
5.3 Orbit	5.3-1
5.4 Entry	5.4-1
5.5 Post Landing	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.

L-1000	ASP interface units (IUIs) are checked for proper operation. Along with Intercom (ICOM) loops A and B. If the ICOM recorder has been identified, it is installed and tested. TPS has already been installed with the paper loaded.	L-1005	CDR, FLT, and other flight crew members.
L-1030	ASP microprocessor module has been verified and performs external switch reconfiguration.	L-1040	CDR, FLT, and other flight crew members.
L-1035	The backup ASP verifies a check of the hardware and flight deck and installs certain cue cards, flight data, and checklists.	L-1045	Crew departs for the Pad.
L-1040	The backup ASP advises CDR and FLT when to the full down and aft position and then configure all seats for launch. Recreational hand controllers (RHCs) are adjusted, and speed brake thrust controllers are set full forward.	L-1050	Crew arrives at the White Room. ASP verifies the CDR and FLT launch/entry suit RASP/high equipment is properly configured prior to suit ingress, notes with main ingress and the installation of several FDF, monitors CDR/FLT communication with ground checks, notes with the post-ingress switch reconfiguration, and coordinates the launch/entry without equipment in the life support. The ASP verifies the launch/entry equipment configuration and external ingress suit, maintenance task report checks.
L-1045	The backup ASP verifies all non-flight equipment is installed from the crew compartment, verifies communication with the Launch Control Center (LCC) and equates.	L-1055	ASP verifies all non-flight equipment is installed from the crew compartment, verifies communication with the Launch Control Center (LCC) and equates.
L-1050	ASP reports post ABORT sign status when initiated by the Flight Director.	L-1060	After the hatch is closed, a refuel task check is performed.
L-1055	ASP Checklist is initiated. Checklist includes a communications check, potable/supply water quantity adjustment, LOH container installation, air sample,	L-1065	CRTs will already have the following display:

5.1 PRE-LAUNCH

Pre-Launch Procedures

Hr:Min (approx)

<p>■ L-33:00</p>	<p>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. TIPS has already been installed with the paper loaded.</p>	<p>L-4:55</p> <p>L-4:25</p> <p>L-3:55</p> <p>L-3:45</p> <p>L-3:15</p> <p>L-2:45</p>	<p>pre-ingress switch reconfiguration, ECLSS fuel cell payload "flow" position verification, navigation aids activation, and C/W memory clearing.</p> <p>Crew wake up.</p> <p>Crew breakfast and photo opportunity.</p> <p>CDR, PLT, MS2 get weather briefing. MS1/3 (PSs) don flight clothing and equipment.</p> <p>CDR, PLT, MS2 don flight clothing and equipment.</p> <p>Crew departs for the Pad.</p> <p>Crew arrives at the White Room; ASP verifies the CDR and PLT Launch/Entry Suit (LES)/flight equipment is properly configured prior to seat ingress, assists with their ingress and the installation of ascent FDF, monitors CDR/PLT communication air-to-ground checks, assists with the 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.</p>
<p>■ L-18:30</p>	<p>ASP insures crew module has been vacuumed and performs ascent switch list configuration.</p>		
<p>L-16:30</p>	<p>The backup ASP conducts a check of the middeck and flight deck and installs certain cue cards, flipbooks, and checklists.</p>		
<p>L-12:45</p>	<p>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 speed brake thrust controllers are set full forward.</p>	<p>L-1:45</p>	<p>ASP verifies all non-flight equipment is removed from the crew compartment, terminates communication with the Launch Control Center (LCC), and egresses.</p>
<p>L-8:15</p>	<p>Pad is cleared for tanking.</p>		
<p>L-5:35</p>	<p>ASP reports panel ABORT light status when initiated by the Flight Director.</p>	<p>L-1:30</p>	<p>After the hatch is closed, a cabin leak check is performed.</p>
<p>L-5:30</p>	<p>ASP Checklist is initiated. Checklist includes a communications check, potable/supply water quantity adjustment, LiOH canister installation, air sample,</p>	<p>L-1:20</p>	<p>CRTs will already have the following displays: (1) GNCGPCMEMORY</p>

5. NORMAL PROCEDURES SUMMARY
5.1 Pre-Launch

	(2) GNC 104 GND IMU CNTL/ MON		this activity is complete, the PLT configures for OMS interconnect with PASS and BFS. Displays for CRTs 1-3 are GNC L A U N C H T R A J, GNC SYS SUMM 1, BFS, GNC SYS SUMM 2.
	(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-26:00	PLT performs the MPS He reconfiguration by opening He and pneumatic isolation valves.
Min:Sec (approx)		L-25:00	The OMS/RCS crossfeed valves are configured for launch by the Launch Processing System.
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-19:00	Planned 10 min hold which synchronizes L and T time.
		T-9:00	Go for launch given, and event timers started.
L-50:00	CDR places the OMS ENG switches to ARM/PRESS for GN2 pressurization and opens the cabin vent isolation valve.	T-8:00	PLT connects essential buses to the fuel cells.
		T-7:30	Access arm retracts, and the crew makes final checks on seat positions, suit closures, and restraints.
L-45:00	All crewmembers conduct an A/G voice check with MCC and receive updates to ascent/abort data.		
		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-42:00	CDR initiates PASS/BFS transfer and closes the cabin vent isolation valve (if not already directed to do so by LCC).		
		T-5:00	Pilot starts APUs and verifies normal pressure. CDR turns off flash evaporator feedline heaters.
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-3:25	Main engine nozzles are gimballed during the next 30 sec. The crew may feel the motion/vibration.
		T-2:30	PLT clears the C/W with GNC 99 FAULT and BFS GNC 99 FAULT display on CRTs 2 and 3. Displays are then changed to GNC SYS SUMM 1 and BFS GNC LAUNCH TRAJ.
L-29:00	CDR initiates BFS to OPS 1 with BFS, puts GNC FAULTS display on CRT 3, and clears C/W.		
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		

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.

Powered Flight
CMS burns 5:2
Post Injection 5:4

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 cue card, No-Coms, Ascent Abort Mode Boundaries, and 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 BPS ASCENT TRAJ. CRT 3 is also used for both BPS GNC and SM SYS SUMM 1/2 as required.

Mission Elapsed Time (MET)

Min:Sec (approx)

001 Ensure that PCS (pitch and roll/yaw) are still in Auto. If not, select Auto. Otherwise BPS engage may be required for roll program at 007.

002 If 104 percent is programmed for launch, at a velocity of 60 Ips, the main engines are commanded to that level.

0:07

At a velocity ≥ 127 Ips the vehicle rolls, yaws, and pitches to the heads-down ascent attitude. Crew monitors and engages the BPS if maneuver not begun when required or not properly completed. CLR/PLT ascent VLM on ADI ATTITUDE switch.

0:20 to 0:30

(flight specific)

Crew monitors main engines shedding down to least maximum flight dynamic pressure and to adjust for sub-optimal performance. Thrust 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 g-bar phase is passed. Control Stick Steering (CSS) may now be selected in lieu of BPS engage if BASS guidance is not optimal.

2:00

ASCENT TRAJ display will indicate Pc < 50 when both SRB Pc's drop below 50 pct. SRB separation should occur shortly thereafter (no later than MET 2:09). When the SRB are separated GNC changes to MM 100. BPS commands flash separator system (PES) on via payload bus.

Post SRB separation the crew checks BASS and BPS IMBCCs converge to expected values to verify performance of Ascent Guidance.

5.2 ASCENT

CONTENTS	
Powered Flight	5.2-1
OMS Burns	5.2-2
Post Insertion	5.2-4

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 cue card, 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 ≥ 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 PASS and BFS TMECOs converge to expected values to verify performance of Ascent Guidance.

MET

Min:Sec (approx)

3:00 Crew verifies the flash evaporator is working properly ($T < 60^{\circ} \text{F}$ and decreasing on EVAP OUT T overhead meter).

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 time seen in simulations.

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 $> .7$ degree/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. The crew verifies OMS 1/2 targeting, using current orbit HA and HP displayed on GNC OMS 1 MNVR EXEC, to determine if an OMS 1 burn is required. For nominal MECO, no OMS 1 is required.

OMS Burns

SI OMS 1 targets will 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 seconds 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* push button 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.

CDR manually activates the FES and its heater prior to the OPS 2 transition and securing BFS. PLT activates the B heaters for the cryo O2 and H2 tanks.

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 prior to 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 since OMS engine thrust vector control (TVC) will fly the vehicle to the proper attitude. OMS TVC can be used to take out attitude errors up to the maximum error limit for OMS ignition to occur. (Limit is variable as a function of remaining ΔV and attitude error; however, an attitude error $\geq 90^\circ$ 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 nm 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 six 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) Purge the fuel cells.
- (5) Align IMU via star trackers (usually not completed until a night pass after post insertion phase is complete).
- (6) 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 is loaded into GPC 3 and "freeze dried" (taken off line to preserve an independent source of data) while GPC 5 retains BFS software but is placed in HALT. With SM software loaded, uplink for S-band and TDRSS is enabled with a DPS utility. Since only 3 CRTs can be assigned to the PASS, CRT 3 is deassigned, 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., don't 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.

- Activate galley (or water dispenser).

- Stow the escape pole.

- Activate the waste collection system (WCS).

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), activate APU lube oil heaters and tank/fuel line H2O heaters. Although the 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 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.

5. NORMAL PROCEDURES SUMMARY

5.2 Ascent

MET

Day/Hr:Min (approx)

			The MCC will uplink table maintenance block updates (TMBU) as required.
0/1:00	MSs unstow and activate the Payload General Support Computers (PGSCs).	0/1:35	CDR activates star trackers.
0/1:08	PLT verifies the payload electrical bus configuration (payload dependent).	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.
0/1:10	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.	0/1:37	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.
0/1:12	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.	0/1:50	PLT initiates the fuel cell automatic purge and verifies H2 and O2 flow increase on CRT display SM 69 FUEL CELLS.
0/1:18	CDR activates the radiators by placing both the RADIATOR BYPASS VALVE MODE and CONTROLLER LOOP (A) switches (2 each) in AUTOMATIC.	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), secures the flash evaporator and turns the high load evaporator off. Radiators are deployed at this point if required. CRT 1 is returned to GNC UNIV PTG display.
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.	0/1:56	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.
0/1:28	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.	0/1:57	PLT verifies the Main B Supply H2O Dump Isolation cb is closed then opens the supply H2O dump isolation valve to ensure redundant dump capability.
		0/2:00	PLT activates the APU steam vent heaters to remove any possible ice formation on the water spray boiler (WSB) vent openings.

MET	Day/Hr:Min (approx)	0/2:21	0/2:21	PLT performs the hydraulic thermal conditioning steps in the Orbit Operations Checklist which allows the GPCs to operate hydraulic circulation pumps when pressures or temperatures are below set limits. Payload electrical constraints may alter this activity.
	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.	0/2:24	MS resets C/W system from ascent to on-orbit operations. Limits for some systems are changed while others are inhibited.
	0/2:12	Crew configure controls for on-orbit operations by using panel diagrams in the Post Insertion Checklist that depict switch positions.	0/2:25	CDR performs automatic maneuver to the IMU alignment attitude. This is a time critical action. (The time depends on the flight profile).
	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, power is applied to the manipulator controller interface unit, RMS shoulder brace is released, heaters are activated, and if required by payload operations or constraints, the arm is deployed.	0/2:27	PLT switches the APU fuel pump and gas generator cooling from system A (activates during APU shutdown procedure) to system B for system verification.
	0/2:30		0/2:29	Fuel cell performance is plotted using with FUEL CELL PURGE cue card.
	0/2:45	IMU alignment (S TRK) is accomplished during orbit rise pass. CRT display GNC 21 IMU ALGN and GNC 23 TRK/CLAS CNTL are used for this activity.		
	0/3:10	An controller checkout initiated on each axis with the output verified on CRT 4 display GNC 25 RM OFST.		
	0/3:20	Ku-band antenna is deployed (1-2 sec). Antenna data is monitored on display SM ANTENNA.		

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. 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. 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.
- 0/2:45 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.
- 0/3:10 Aft controller checkout initiated in each axis with the output verified on CRT 4 display GNC 25 RM ORBIT.
- 0/3:20 Ku-band antenna is deployed (~23 sec). Antenna data is monitored on display SM ANTENNA.

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.

0/3:45 APU steam vent heaters are secured (initiated at MET 2 hr).

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 APU fuel pump/valve cooling (B) is secured on a call from the MCC. Unless there is a FD 1 deploy or other mission specific requirement, the first on-orbit meal is prepared and eaten at this time.

0/6:30 APU gas generator and fuel pump heaters (B) are activated 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 to exercise the redundant system).

(various times) Crew begins payload activities. This may include payload deploy, Spacelab activation, or secondary experiment activation depending on the type of mission.

0/8:00 Pre-sleep 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 pre-sleep activities is at the crew's discretion. Pre-sleep 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 turnaround time). Use CRT display SM 69 FUEL CELLS to monitor purge. All other purges will be uplinked from MCC.
- Conduct supply/waste water dump, monitored using CRT display SM 66 ENVIRONMENT (purges and dumps are not accomplished during star tracker use due to possible contamination)
- Configure cryo heaters and manifold valves as directed by MCC.
- Update SM checkpoints.
- Set CRT timer for crew wake up and C/W alert tone duration.
- Adjust the cabin temperature control as required.
- 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 pre-sleep if required.

Pre-sleep 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.
- Setup 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 wake up (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 post-sleep 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 post-sleep activities include:

- Reconfigure lighting and communications panels.
- Replace CO2 absorber (one of two canisters is replaced).
- Review TIPS messages.
- Install O2 bleed orifice (first post-sleep) to increase O2 to the middeck.
- Meal preparation and cleanup.
- General housekeeping.

Post-sleep 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 IMU's 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 OMS/RCS interconnect as required to preserve aft RCS propellant.
- Power primary RJD drivers (8) ON.
- Initiate supply/waste water dump (pre or post IMU alignment).
- Configure cryo heater/manifold valves per MCC instructions.
- Conduct another cryo O2 tank heater sensor check (see MET 0/3:50).

0/22:00

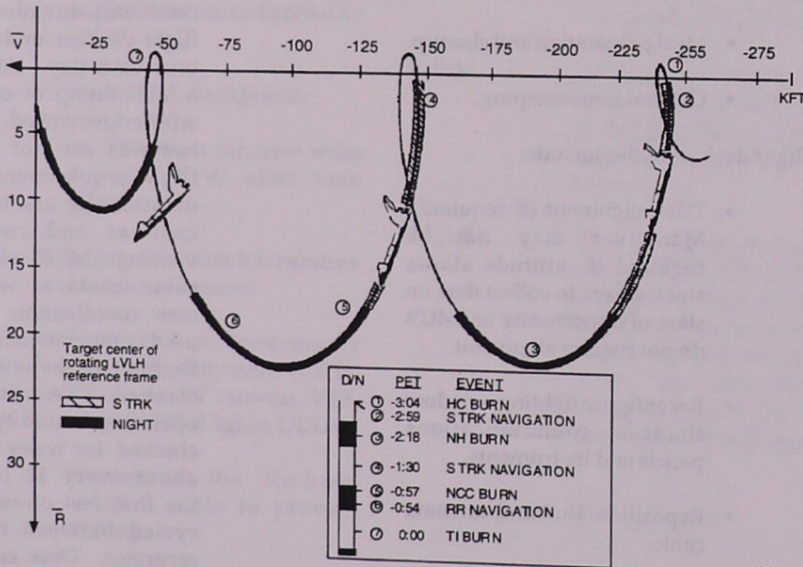
The crew begins a full workday on orbit with their flight specific activities. Each day, Photo/TV scenes will be activated per the P/TV Checklist. Normally, the crew will downlink live TV of flight deck or middeck activities once each day. At a minimum, a VTR dump of crew activities will be downlinked. When the PLB cameras are not required for flight requirements, MCC will occasionally ask 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. Additionally, the operating humidity separator is checked for water accumulation about every 12 hours during the first few on-orbit days and cycled between the A and B separator. 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 ≥ 4 and ≤ 6 fps, a +X RCS burn is used (thereby limiting the amount of forward RCS burned). If the delta V total < 4 fps, the burn is multi-axis (RCS) with no maneuver to burn attitude.

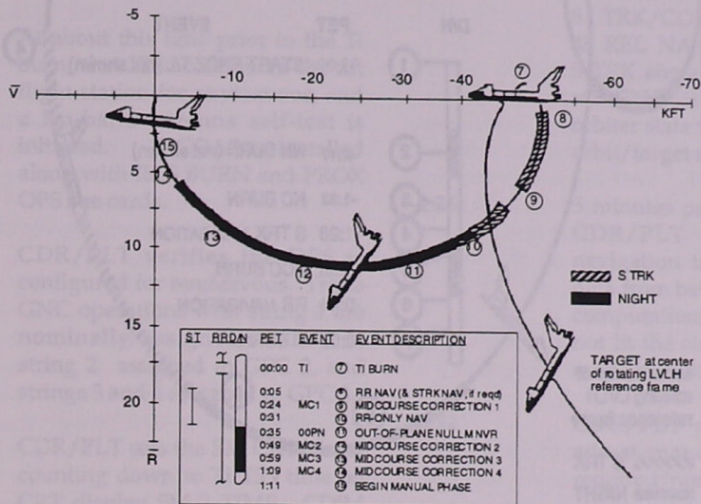
Rendezvous

This section summarizes the major events that occur during the final phases of a rendezvous. Flight specific rendezvous procedures are located in the Rendezvous Checklist. The Phase Elapsed Time (PET) below is referenced to Target Intercept (Ti) TIG. PET is used to track rendezvous events and is normally displayed on the CRT. Actual times will vary depending on flight profile.



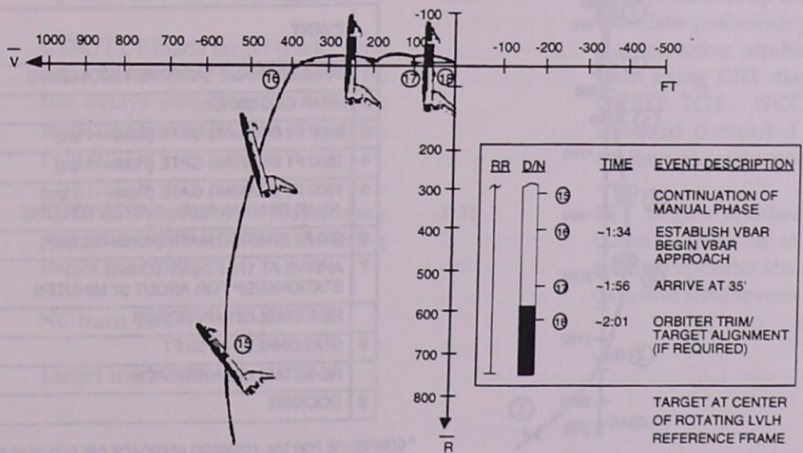
838

"Standard" Rendezvous Profile (2 Revs to Ti)



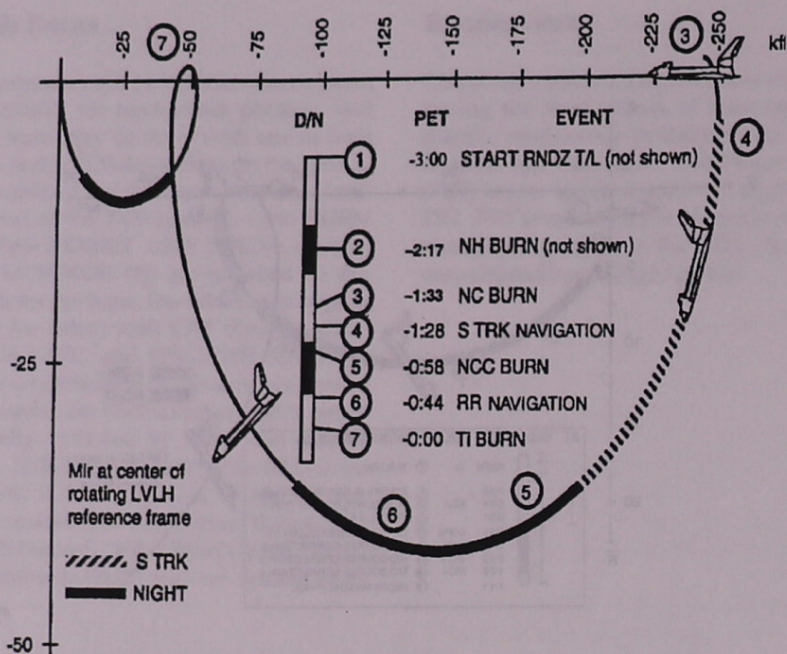
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Rendezvous Profile — Post Ti Burn

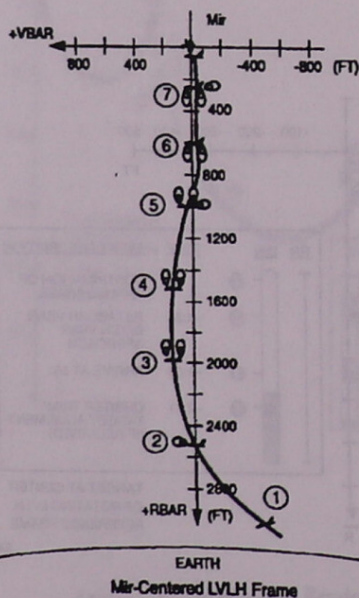


840

Rendezvous Profile — Manual Phase to Prox Ops (+V-Bar Approach)



Mir Rendezvous Profile (1-Rev to Ti)



EVENT
1 MANUAL PHASE TAKEOVER (MC4+2MIN)
2 RBAR CROSSING
3 2000 FT BRAKING GATE (Rdot= -4 fps)
4 1500 FT BRAKING GATE (Rdot= -3 fps)
5 1000 FT BRAKING GATE (Rdot= -1.5 fps) NEAR RBAR ARRIVAL; SWITCH TO LOWZ
6 600 FT BRAKING GATE (Rdot= -0.8 fps)*
7 ARRIVE AT 170 FT (INT-TO-INT) AND STATIONKEEP FOR ABOUT 37 MINUTES
RE-ESTABLISH APPROACH
8 STATIONKEEP AT 30 FT
RE-ESTABLISH APPROACH
9 DOCKING

* CONFIGURE FOR TAIL FORWARD APPROACH (180 DEG YAW) IF REQUIRED

Manual Phase +R-bar Approach

PET		
	Hr:Min (approx)	
-3:44	At about this time prior to the Ti burn, the CDR configures the aft flight station for rendezvous, and a Ku-band antenna self-test is initiated. -Z COAS is installed along with RCS BURN and PROX OPS cue cards.	-2:59 PLT initiates star tracker target acquisition with CRT displays GNC 21 IMU ALIGN, GNC 22 S TRK/COAS CNTL, and GNC 33 REL NAV. After evaluation, S TRK angle data is incorporated via GNC 33 REL NAV into the orbiter state vector to improve the orbit/target relative state.
-3:42	CDR/PLT verifies the DPS is configured for rendezvous. Triple GNC operations with string 1 are nominally assigned to GPC 1, string 2 assigned to GPC 2, and strings 3 and 4 assigned to GPC 3.	-2:36 5 minutes prior to orbital sunset, CDR/PLT ends star tracker navigation to prevent erroneous data from being fed to state vector computations. When the target is not lit the star tracker might take marks on a star.
-3:39	CDR/PLT sets the SM CRT Timer counting down to Ti TIG time on CRT display SM 2 TIME. CDR/PLT configures DAP A, B to A7, B7 (rendezvous DAP).	-2:32 CDR/PLT prepares for height adjust maneuver (NH) burn if required (nominally not required).
-3:37	CDR/PLT enables rendezvous navigation through CRT displays GNC 33 REL NAV and loads Base Time (TI TIG) on GNC 34 ORBIT TGT. CDR, PLT, and MS2 work together on targeting and burn set up and NAV state management.	-2:18 NH burn TIG (if required).
-3:29	CDR/PLT loads target track data into CRT display GNC UNIV PTG but delays initiating the target track until post NC (phasing) burn (-3:03).	-1:57 CDR/PLT configures for rendezvous radar (RR) acquisition when the range to the target is <150 k ft via switches on panel A1U (Ku) and CRT display GNC 33 REL NAV.
-3:24	CDR/PLT perform the preparatory procedures for an NC burn using the RCS or OMS.	-1:33 CDR/PLT sets up the computer to calculate preliminary solution for the corrective combination (NCC) burn using CRT display GNC 34 ORBIT TGT. NCC is the first onboard computed burn of the rendezvous sequence.
-3:04	NC burn TIG.	-1:31 PLT begins another star tracker target acquisition at orbital noon and incorporates star tracker angle data into rendezvous navigation.
-3:03	Target track initiated.	

PET

Hr:Min (approx)

-1:14	CDR/PLT initiates GPC computations of intermediate solution for the NCC burn. State vector updates should be small and stable. This burn solution will determine whether the NCC burn will be RCS (+ X or multi axis) or OMS depending on the delta V required.	-0:23	CDR/PLT performs RR automatic tracking acquisition if there has been no lock on prior to 60 k ft. Acquisition of a .5 sq m target is approximately 100 percent at 60 k ft.
-1:05	CDR/PLT terminates star tracker operations (5 minutes prior to sunset).	-0:20	CDR/PLT loads Ti delay burn inputs if rendezvous must be delayed. Ti delay burn PAD would have been provided by MCC earlier. Execution of this burn will establish the orbiter co-altitude with the target, but following along behind to allow extra time for rendezvous completion.
-1:04	MS activates the port RMS heaters A/B (2) if required for RMS operations.	-0:17	CDR/PLT initiates computation of the final Ti burn solution if the intermediate solution shows OMS or +X RCS burn will be required (reference delta V total). Final solution on GNC 34 Orbit TGT will be preceded by burn setup on GNC ORBIT MNVR EXEC.
-1:01	CDR/PLT computes NCC final solution and prepares for burn. Normally NCC delta V is less than 4 fps allowing the RCS to be used for a multi-axis burn.	-0:15	CDR/PLT prepares for rendezvous OMS/RCS burn as required. This may involve a maneuver to attitude if the delta V total >4 fps.
-0:57	NCC TIG.	-0:05	If the intermediate solution shows that Ti will be a multi-axis burn, the final Ti targeting is performed, as the vehicle has remained in attitude taking sensor data.
-0:55	CDR/PLT initiates -Z axis track of the target if the -Y star tracker is being used. -Z track is required for the radar to lock onto the target.	00:00	Ti TIG
-0:54	CDR/PLT initiates GPC computation of preliminary solution for Ti burn.	00:01	CDR/PLT computes preliminary MC 1 target solution with CRT display GNC 34 ORBIT TGT.
-0:52	CDR/PLT initiates RR navigation with CRT display GNC 33 REL NAV when lock on occurs. Radar range data is compared to REL NAV (as improved by star tracker data). Data checked for biases.		
-0:38	CDR/PLT initiates intermediate Ti burn solution when the state vector updates are small and stable. If		

delta V total is > 6 fps, an OMS burn will be required. If delta V total is ≥ 4 and ≤ 6 fps, a +X RCS burn is used. If the delta V total is < 4 fps, the burn is multi-axis RCS with no maneuver to burn attitude.

PET			This maneuver is performed at the node where the orbiter and target orbits cross (the actual time may vary).
Hr:Min (approx)			
00:03	CDR/PLT conducts post Ti navigation procedures when the maneuver to attitude is complete (usually -Z). CRT display GNC 33 REL NAV is used to incorporate RR data (star tracker data is not preferred post Ti since its accuracy is based on point light sources).	00:44	CDR/PLT conducts MC 2 final solution (TIG -5 min).
		00:45	CDR/PLT prepares for RCS burn.
00:04	MS powers up the RMS if required, and no rendezvous delay has been performed.	00:49	MC 2 TIG. MC 2 TIG will slip to satisfy an onboard targeting elevation angle constraint. After any slip, the MC 2 elapsed time is used to reference crew actions. The following PET times are valid only if MC 2 planned TIG = actual TIG.
00:05	MS maneuvers RMS to preliminary position for proximity operations.	00:50	CDR/PLT begins MC 3 preliminary solution if RR data available (if -Y star tracker was being used, a maneuver to -Z track is done).
00:12	CDR/PLT initiates GPC computation of MC 1 intermediate solution when the state vector updates are small and stable.	00:54	CDR/PLT initiates MC 3 final solution (-4 min TIG).
00:18	CDR/PLT initiates GPC computation of final MC 1 burn solution (-4 min to TIG).	00:58:30	MC 3 TIG.
00:20	CDR/PLT prepares for RCS burn.	1:00	CDR/PLT initiates preliminary MC 4 solution.
00:22	MC 1 TIG.	1:03	MS configures CCTV.
00:24	CDR/PLT initiates GPC computation of preliminary MC 2 burn solution with CRT display GNC 34 ORBIT TGT. Star tracker (if utilized) is terminated just prior to sunset. If no sensor data is available at any time during rendezvous, then the BREAKOUT procedures must be initiated.	1:05	CDR/PLT initiates final MC 4 solution (-4 min TIG).
		1:07	CDR/PLT prepares for RCS burn.
		1:09	MC 4 TIG.
		1:10	Manual trajectory control begins at about 22 minutes after MC 2. CDR/PLT establishes inertial line-of-sight rates by selecting inertial attitude hold and using the aft THC to keep the target stable in -Z COAS. The CDR will fire jets as required to get the orbiter/ target range rates within these braking gates: -4 fps at 2 k ft, -2 fps at 1.5k ft, and -1 fps at 1 k ft.
00:33	CDR/PLT initiates MC 2 intermediate solution when state vector updates are small and stable.		
00:36	CDR/PLT manually nulls out of plane component (YDOT) with THC, referencing CRT display GNC 33 REL NAV for target/orbiter relative state information.		

1:19 CDR configures DAP A, B to A8, B8 for proximity operations.

Proximity Operations

Proximity operations begin when the range to the target is <1,000 ft and the relative velocity is < 1 fps. Proximity operations may involve V-Bar (standard), R-Bar, or inertial approach.

1:20 CDR configures for V-Bar on CRT display GNC UNIV PTG (orbiter tail to earth and target on the -Z axis) but does not initiate track until V-Bar has been achieved. CDR/PLT enters command on GNC UNIV PTG, but leaves DAP in INTL so command is not performed. Braking gates are -0.5 fps for 500 ft, -0.4 fps for 400 ft, and -0.3 fps for 300 ft.

1:25-1:34 CDR initiates -XLV track when the orbiter reaches the target's V-Bar by selecting AUTO on the DAP. For an inertial approach, DAP will remain in INRTL. Normally at 200 ft DAP is transitioned to LOW Z (flight specific). MS begins to provide ranging and relative position information using the PLB CCTV camera angles.

01:50 CDR puts RR (Ku) in standby when the range to target is 80 ft (nominal break track distance). When range is 60 ft, CDR selects NORM Z and continues the approach to the target. MS utilizes the CCTV camera angles to provide ranging, R-dot and position cues to the CDR. Visual cues and MS calls are the CDR's only source of rendezvous data.

01:52 CDR nulls rates when target is in end effector camera field-of-view (if RMS required).

01:55 CDR maneuvers to proper RMS grapple or station keeping position as required.

01:58 MS grapples target. PLT disables rendezvous navigation, and CDR configures Ku-band for communications. MS powers RMS down as required.

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 pre-sleep activities the crew conducts entry planning, secures CRT 4 (if not required), and stows the Ku-band antenna.

Pre-sleep and post-sleep 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 post-sleep period or deorbit preparation. The O2 bleed air orifice is removed and stowed. 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 APU is prepared for operation.
- ON MCC GO 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 test is complete, the APU is shutdown and hydraulic thermal conditioning 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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Terminal Area Energy Management	5.4-7
Approach and Landing	5.4-8

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.
- 3:50 MSs continue entry stowage along with deactivation of the galley/water dispenser.
- 3:48 Ku-band antenna is stowed (if not already accomplished in last pre-sleep period).
- 3:45 Radiators are stowed (if deployed).
- 3:42 Compute N₂ quantity and identify depleted H₂ 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.

- 3:10 Crew begins the Entry Switch List verification by comparing crew compartment switch positions with diagrams in the Deorbit Prep book.
- 3:27 DPS is configured for deorbit preparation. Inactive GPCs are taken to STBY then RUN.
- 3:25 PLT prepares for hydraulic repressurization of the main engine thrust vector controls (engine bells must be properly stowed to prevent thermal damage).
- PLT activates APU water boiler steam vent heaters (at least 2 hr prior to APU start).
- 3:15 CDR, PLT power up FCS and DDU's for entry (RGAs and ASAs must be on prior to OPS 3 transition).
- 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 degree at entry interface (EI) using display GNC 22 S TRK/COAS CNTL and GNC 21 IMU ALIGN.

TIG

Hr:Min (approx)

- 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.
- 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.
- 1:58 MS deactivates star tracker and closes doors.
- 1:55 CDR, PLT, MSs perform entry switch list configuration and verification at this time. The following items will be performed or verified:

Forward Flight Deck

- Electrical power to brakes, brake heaters, anti-skid, and nose wheel steering (NWS) is applied.
- Verniers are secured.
- FES control is given to GPCs.
- One O2/N2 valve is opened in case of a cabin leak.
- Communications panels are configured to provide maximum redundancy.

Aft Flight Deck

- Activate entry monitoring equipment unique to particular vehicles (Aerodynamic Instrumentation Package and Shuttle Infrared Leaside equipment-OV102, Modular Auxiliary Data System-OVs 103 - 105.
- Secure hydraulic heaters.
- Secure the teleprinter (via dc utility power MN C) and remove the power cable.
- Connect an LES communications cable (dc Utility Power MN C).
- Open Ku-band circuit breakers.

Middeck

- Configure communications panel for entry.
- Pressure control system (PCS) is configured for N2 water tank ullage pressure.
- Close 14.7 cabin regulators (protects N2 if leak occurs)
- Close O2 regulators (so O2 flow goes only to LES).

TIG

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.
- 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).
- 1:39 Crew conducts entry review as required (15 min allotted).
- 1:24 CDR, PLT don LESSs.
- 1:10 Specialists don LESSs.
- 1:06 Final IMU alignment is performed by CDR to reset RM threshold prior to deorbit burn. This maximizes IMU RM, two-level attitude failure detection.
- 1:04 Crew begins fluid loading (containers filled in post-sleep).
- 0:59 CDR, PLT ingress seats.
- 0:57 CDR, PLT remove HUD covers.
- 0:53 Crew performs LES pressure integrity check.
- 0:50 Crew doffs and stows on-orbit communications headsets.
- 0:33 MS deactivates WCS.

Deorbit Burn

- 0:47 CDR, PLT stow all unnecessary FDF items and transition to the Entry Checklist for the nominal procedures.
- 0:46 CDR, PLT receive final deorbit update/uplink. Deorbit flight rules are verified with MCC. Exact time may vary.
- 0:40 CDR performs OMS TVC gimbal check (during AOS), using OMS MNVR EXEC display.

PLT initiates APU pre-start procedures (during AOS). BFS, SM SYS SUMM 2 is used to check APU status.
- CDR, PLT conduct horizontal situation configuration using CRT 2, GNC 50 HORIZ SIT; CRT 3 BFS, GNC 50 HORIZ SIT; and CRT 3, GNC 51 OVERRIDE for both PASS 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 in the pre-burn configuration.

MS3 removes and stows side hatch UV filter, locking device, and Pyro Box Safing pin.
- 0:25 PLT performs vent door closure with 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.

5. NORMAL PROCEDURES

5.4 Entry

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 lake bed availability and weather. CDR verifies the orbiter is in the deorbit burn attitude ± 5 degrees. 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.

PLT performs OMS/RCS reconfiguration by verifying the proper position of RCS switches and closing OMS HE and crossfeed valves; MS stows PGSC (SPOC).

CDR proceeds to OPS 303. CDR verifies the proper attitude, and initiates maneuver to the entry interface -5 min attitude. CDR also conducts OMS gimbal powerdown verifying after gimbals have driven to the proper entry position.

EI

Min:Sec (approx)

-20:00

CDR 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.

EI	Min:Sec (approx)	-6:00	The crew transitions to the Entry Maneuver cue card for nominal entry procedures.
-18:00	<p>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).</p> <p>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.</p> <p>CDR, PLT perform entry switch checks (using GNC 51 OVERRIDE on CRT 3 for some checks) and exercise brake pedals.</p>	-5:00	<p>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.</p> <p>Program test inputs (PTIs) are enabled on SPEC 50 when applicable</p>
-13:00	<p>PLT starts remaining (2) APUs, verifies nominal performance, then switches all 3 APUs to normal pressure and checks for uncommanded brake pressure on CRT 3 display BFS, SM THERMAL.</p> <p>PLT performs main engine hydraulic system repressurization to ensure the nozzles are properly stowed.</p>	-3:00	<p>PLT verifies <i>FWD RCS MANIFOLD ISOLATION</i> valve switches (4) are closed (unless forward RCS PTIs are scheduled).</p>
-11:00	<p>If required, PLT initiates hydraulic fluid conditioning on MCC's call and monitors surface position indicators for aerosurface cycling.</p>	Entry Interface	<p>+ = Time from EI - = Time to touchdown Min:Sec (approx)</p>
	<p>Crew makes burn report to MCC and updates new state vector if required. All crew members inflate anti-g suits if desired.</p>	+0:00	<p>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.</p>
	<p>All three CRTs are moded to GNC DEORB MNVR COAST (CRT 3 BFS). PLT transitions AC BUS sensors to MONITOR.</p>	+2:39	<p>Automatic elevon trim begins at a q-bar = 0.5 psf.</p>
		-29:35	<p>Aerosurface control begins at q-bar = 2.0 psf. CDR, PLT monitor elevon and aileron deflection angles on surface position indicator.</p>
		+3:32	
		-28:42	

5. NORMAL PROCEDURES

5.4 Entry

<p>+ = Time from EI - = Time to touchdown Min:Sec (approx)</p>			
+4:45		+15:51	
-27:29	Closed loop guidance initiated (CLG Init) at q-bar = ~8 psf or drag = ~3 fps ² . Guidance box appears on ENTRY TRAJ to indicate closed loop guidance.	-16:23 V _{REL} = 17 k fps (Mach = 17) Alt = 200 k ft	PASS and BFS TRAJ displays mode to ENTRY TRAJ 2.
+5:00		+17:00	
27:14	Roll RCS jets deactivated at q-bar = 10 psf.	-15:14 V _{REL} = 15 k fps (Mach = 15) Alt = 185 k ft	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).
+5:18		+17:57	
-26:56	First non-zero bank command issued by guidance at H-dot -240 ft/sec (CLG Init plus 15 to 30 sec).	-14:17 V _{REL} = 14 k fps (Mach = 14) Alt = 182 k ft	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 3. Drag is up to 33 fps ² and Gs up to 1.5.
+6:10		+18:57	
-26:04	Maximum surface temperature region begins (Mach 24 to 19). Actual drag should be within .5 fps ² of orbiter bug drag.	-13:17 V _{REL} = 12 k fps (Mach = 12) Alt = 176 k ft	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.
+8:04		+19:20	
-24:10	Pitch RCS jets deactivated at q-bar = 40.	-12:54 V _{REL} = 10.5 k fps (Mach = 10.5) Alt = 167 k ft	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 4. Alpha and drag start to ramp down, but Gs stay up over 1.3.
+11:49		+20:03	
-20:25	At drag = 11 fps, drag H updates begin in NAV filter. Crew monitors data on GNC 50 HORIZ SIT display.	-12:11 V _{REL} = 10 k fps (Mach = 10) Alt = 150 k ft	Speedbrake opens to 81 percent.
+13:40		+21:00	
-18:34	First roll reversal is issued by guidance when azimuth error (delta AZ) = ±10.5 degrees. Occurs at a flight-specific velocity between 23,000 and 6,200 fps, depending on crossrange.	-11:14 V _{REL} = 8.0 k fps (Mach = 8)	SSME repositioning for drag chute deploy. If GPC annunciates SSME REPOS FAIL, drag chute is emergency deploy only.
Note:	1 k fps = Mach 1.0		
+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.		
V _{REL} = 19 k fps (Mach = 19) Alt = 215 k ft			

+ = Time from EI

- = Time to touchdown

Min:Sec (approx)

+21:34

-10:40

$V_{REL} = 7.5$ k fps
(Mach = 7.5)
Alt = 144 k ft

MCC has sufficient tracking for state vector update. This time can vary depending on ground track and tracking station performance.

+21:41

-10:33

$V_{REL} = 7.3$ k fps
(Mach = 7.3)
Alt = 142 k ft

First TACAN acquisition.

+22:00

-10:14

$V_{REL} = 7$ k fps
(Mach = 7)
Alt = 138 k ft

MCC and the crew compare TACAN data to NAV. If acceptable, MCC tells the crew to take TACAN. GNC 50 HORIZ SIT display is used to check TACAN errors and accept TACAN data for use by the NAV filter.

+22:41

-09:33

$V_{REL} = 6$ k fps
(Mach = 6)
Alt = 131 k ft

PASS and BFS ENTRY TRAJ displays mode to GNC ENTRY TRAJ 5.

+23:30

-08:44

$V_{REL} = 5$ k fps
(Mach = 5)
Alt = 120 k ft

Air data probes are deployed. CDR, PLT begin aileron and rudder trim monitoring. The crew can check for good probe deploy discrettes 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.

+24:24

-07:50

(Mach = 4.0)
Alt = 102 k ft

CDR, PLT begin H-dot monitoring at Mach 4, verifying descent rate < -500 fps.

+25:00

-07:14

(Mach = 3.4)
Alt = 95 k ft

Using GNC 51 OVRD, GNC 50 HORIZ SIT, and instrument tapes the crew checks air data is close to NAV. MCC will give a GO to take air data to NAV and/or G&C using Items 25 and 28 on GNC 50 HORIZ SIT.

+25:30

-06:44

(Mach = 2.6)
Alt = 83 k ft

PLT verifies APUs operating nominally. CDR, PLT activate HUDs.

Terminal Area Energy Management (TAEM)

+25:40

-06:34

(Mach = 2.5)
Alt = 81 k ft

PLT verifies air data incorporated into guidance. If not, the CDR must take CSS control to avoid a transient when air data is incorporated. Software transitions automatically to OPS 305. Guidance enters TAEM phase. PASS and BFS ENTRY TRAJ displays are replaced with VERT SIT 1 displays.

+25:55

-06:19

(Mach = 2.4)
Alt = 80 k ft

Fuselage vents open.

5. NORMAL PROCEDURES

5.4 Entry

+ = 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) (>290°), TAEM guidance will command an uncontrollable pitch up between Mach 1.0 and 1.5.

+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. Speed brake "commanded" versus "actual" position is verified. Speed brake is now controlling energy. PLT flight controller is verified ON. This switch must be on for nose wheel steering (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. Declutter HUDs as required. Crew starts landing comm protocol.

Approach and Landing

+31:00

-1:14

300 KEAS (18 & 20 degree 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 % (actual will lag).

+31:41

-0:33

300 KEAS

Alt = 2 k ft

CDR initiates preflare and begins transition onto ball bar. PLT arms landing gear on call from CDR.

+31:51

-00:23

297 KEAS

Alt = 500 ft

Shuttle will be lined up on ball bar. MS2 checks speed brake command % (second smart speed brake reset).

+31:54

-0:20

288 KEAS

Alt = 300 ft

Pilot deploys the landing gear on call from CDR. PLT/MS2 check gear indicates down.

+32:04
-0:10
261 KEAS
Alt = 30-80 ft Final flare begins.

NWS FAIL light comes on, steer with rudder, RHC, and brakes. NWS2 may be available.)

+32:34
+00:20

+32:14
-00:00
195 or 205 KEAS

Main gear touchdown (195 KEAS GW <220,000 lb). CDR controls drift with rudder, maintains wings level with RHC. PLT and MS check speed brake opening. PLT checks HUD display for WOW lock on (WOWLON) (HUD recon-figures and airspeed moves to upper left corner of the display). Also, the velocity vector disappears.

CDR checks ground speed and decel on HUD. 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/sec². At 5000 feet of runway remaining, if groundspeed is greater than 140 knots, CDR applies maximum braking.

+32:15
+00:01
190 to 195 KEAS

PLT deploys drag chute on call from CDR. 190 KEAS (195 KEAS heavyweight).

+32:46
+00:32
60 KGS
(±20 kts)

PLT jettisons drag chute on CDR call.

+32:16
+00:02
185 KEAS

CDR initiates beep trim derotation, which targets 1.5 deg/sec.

+32:50
+00:36
40 KGS

CDR reduces braking to less than 6 ft/sec² until wheelstop.

+32:24
+00:10
145 to 155 KEAS

Nose gear touchdown (HUD reconfigures with a "G" showing up by the groundspeed). MS2 selects SRB SEP to AUTO/MAN or ET SEP to MAN and depresses the corresponding pushbutton to backup automatic 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 necessary. (If no load relief, RHC full forward. If

+32:56
+00:42

Orbiter stops; CDR reports "wheels stop" to MCC. Crew transitions to Post Landing Procedures in the Entry Checklist. At wheelstop, speed brake is closed.

5.5 POST LANDING PROCEDURES

- CDR and PLT safe RCS/OMS, and deactivate air data probe heaters.
- MS safes the landing gear.
- PLT, after notifying MCC, opens the ET umbilical doors and performs RCS/OMS valves checkout and safing.
- CDR activate the NH3 boiler as required (MCC call or C/W).
- 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.
- 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).

- 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 post landing activities. After medical evaluations, showers, visits with family and post landing 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 LCC.
- 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 save 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 post-landing, 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.

Three levels of protection exist to prevent loss of a Shuttle due to failures: component failure prevention, vehicle design, and training.

Component failure prevention is accomplished through a stringent process of equipment design, qualification tests, maintenance, checkout, quality control, and proper operation.

The Shuttle is designed to a "fail-ops/fail-safe" philosophy. This means that loss of any one component can be tolerated without compromising the mission, and loss of a second component will not result in loss of vehicle or crew. Obviously, this requires redundant systems and system components. Managing this redundancy adds to Shuttle complexity.

The third level of protection is the human element: crew, MCC, and LCC training. In order to quickly and correctly respond to performance or systems problems, as well as complex multiple failures, the flight crew and ground crews must be experts on Shuttle systems and how to control them. Prior to flight, both the ground teams and the crew participate in many hours of intense simulations to improve their teamwork and knowledge of Shuttle systems. A stringent certification process is also in place to ensure qualified and current personnel in all disciplines.

Failures tend to fall into two general categories: single component and multiple.

For single component failures, patience is important. Shuttle design should allow time to properly analyze what has happened and what steps are necessary to regain the lost component or to optimize remaining systems to protect against additional failures. A common error

among inexperienced personnel is to act too quickly, do the wrong thing, and make the situation worse.

Multiple failures are more difficult to deal with, since 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 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.

In order 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, will enhance the chances of a successful outcome when multiple failures are encountered.

6.1 LAUNCH ABORT MODES AND RATIONALE

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Mode 1 – Unaided Egress/Escape	6.1-1
Mode 2 – Aided Escape	6.1-1
Mode 3 – Aided Escape	6.1-2
Mode 4 – Aided Escape	6.1-2

A Shuttle launch may be scrubbed or aborted up to solid rocket booster (SRB) ignition. Normally, launch scrubs prior to Space Shuttle main engine (SSME) start are followed by an orderly safing procedure and crew egress, assisted by the closeout crew. A fully fueled Shuttle on the launch pad may present an extremely hazardous situation if toxic vapors, fire, or structural damage are present. A launch abort after SSME start is automatically controlled by the Ground Launch Sequencer (GLS). The most serious hazard here is the presence of excess hydrogen, resulting in a hydrogen fire, which is invisible to the eye and very dangerous. This situation occurred during a launch attempt for STS-41D.

In the event of an emergency at the launch pad, the NASA Test Director (NTD), who mans a console in the Launch Control Center (LCC) firing room, is in command. Priority is flight and ground crew egress and escape, followed by preventing destruction of the Shuttle, facilities, complex, and support equipment.

Should an abnormal event occur that terminates a flight or prelaunch operation and results in substantial damage to the Shuttle and/or injury to personnel, the NTD will declare a contingency situation. This alerts fire and rescue personnel and puts in motion pre-planned procedures to minimize further damage and injuries.

The NTD may also initiate action if an emergency condition exists that requires immediate action to prevent loss of life or destruction of equipment. In preparation for a potential emergency condition,

a hazardous condition may be declared if a threat to personnel health or safety exists. 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 which are preplanned and rehearsed by the flight crew, closeout crew, and all launch pad personnel. Defining these modes prior to the development of an emergency condition or contingency situation ensures standard procedures can be followed and minimizes risk of additional injury and damage.

Mode 1 – Unaided Egress/Escape

This escape mode may be initiated by the NTD or flight crew. The NTD will direct that the orbiter access arm (OAA) be returned to its position at the crew module hatch. The fire/rescue crew will be dispatched if the NTD decides it is safe to do so. Escape from the Shuttle vehicle and the pad is performed by the crew. This procedure is practiced in trainers and mockups in Houston and rehearsed during terminal countdown demonstration test (TCDDT) at KSC. Since crew complement varies from flight to flight, each crew must develop their own particular procedures. Use of 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 assuring 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

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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 cut off (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 aborts and contingency aborts. 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 yet 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 sub-orbital trajectory leading to a landing after a single revolution of 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 (RTL) 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"/>
PRESS TO MECO (104)	12200	SE OPS 3 BYD (109) (5)	<input type="text"/>
SE OPS 3 BYD (109)	12600	SE BYD (104) (5)	<input type="text"/>
SE BYD (104)	13800	2 ENG BEN (104) 6500	
NEG BEN (104)	15100	ABORT TAL BEN (2)	
SE PRESS (104)	17200	EO VI	<input type="text"/>
LAST PRE MECO TAL	23000	SE OPS 3 BYD (109) (12)	<input type="text"/>
LAST TAL		SE OPS 3 BEN (109) (11)	<input type="text"/>
AML	23800	SE BYD (104) (5)	<input type="text"/>
BYD	24300	SE BEN (104) (2)	<input type="text"/>
ROB	24700	SE MRN (109) (3)	<input type="text"/>
KIN	25200	2 ENG MRN (104) 7600	
HDS	25400	ABORT TAL MRN (3)	
		EO VI	<input type="text"/>
		SE OPS 3 BEN (109) (11)	<input type="text"/>
		SE BYD (104) (5)	<input type="text"/>
		SE BEN (104) (2)	<input type="text"/>
		SE MRN (109) (3)	<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 due to 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 will 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 and systems failures in this overlap region, since single engine completion capability is attained much earlier for TAL than RTLS. 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 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 at MECO without a pre-MECO abort selection.

SE OPS 3 (TAL site) 109

The single engine OPS 3 boundary represents the point at which flight will continue across the ocean to MECO for a subsequent OPS 3 TAL entry, instead of OPS 6 if two main engines fail. The intent of this boundary is to ensure single engine runway capability from the time Bermuda/east coast abort landing (BDA/ECAL) performance is available to MECO. This is accomplished by holding on to BDA/ECAL runway capability (OPS 6) until a TAL or emergency landing site (ELS) runway (OPS 3) can be reached on a single engine without descending below 265,000 feet (minimum droop altitude.) Going below this altitude violates ET heating constraints, and loss of vehicle is expected. Although European ELS sites can be used for the SE OPS 3 boundary, typical ELS sites 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.

For (relatively rare) cases, where BDA/ECAL capability does not overlap or no BDA/ECAL capability exists, the SE OPS 3 boundary may not ensure runway capability because the boundary may be called solely on the minimum droop altitude, without regard to TAL/ELS runway capability (bailout).

Single Engine (SE) 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.

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.

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

MRN TAL REDESIGNATION Cue Card

As an example, if a TAL to MORON (MRN) has been initiated due to an engine failure at $V_1 = 7830$ fps, the 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 and used to determine new abort mode boundaries.

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.

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. 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.

SYS FLIGHT RULES Card

	RTLS	TAL
OMS — 2 He TKS		
— 1 OX & FU TKS (diff pods)		X
— 2 OX or 2 FU TKS		X
APU/HYD — 2 ↓ & 1 failing	X	X
CABIN LEAK — (-EQ dP/dT > .15)	X	X
CRYO — ALL O ₂ (H ₂)	X	X
2 FREON LOOPS ↓	X	X
2 MAIN BUSES ↓	X	
THERMAL WINDOW PANE	X	

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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 will be required.

APU/HYD

With two APU/HYDs down and the third failing, a trajectory option with minimum time to the ground is desired. This enhances the potential to land prior to a complete loss of hydraulics.

Cabin Leak

Loss of cabin pressure integrity impacts both breathing oxygen and equipment cooling. A minimum time to the ground option is required.

Cryo

Loss of cryo O₂ or H₂ will result in a loss of fuel cells and all electrical power. An RTLS or TAL 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 nominal 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. This is accomplished by remotely detonating explosive charges aboard the vehicle.

Future plans call for the removal of the explosive charges on the ET, which will place responsibility for second stage range safety on the MCC/crew, with inputs from range safety at KSC.

In order 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

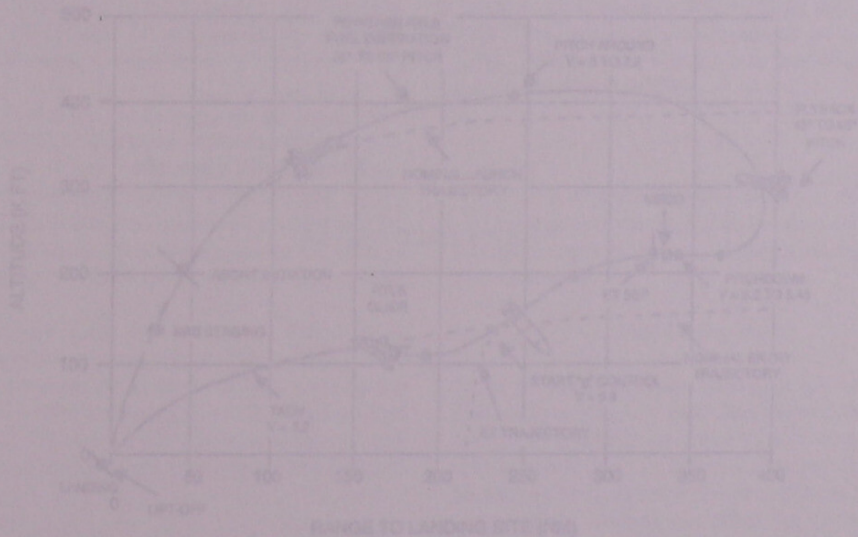
A deviation from nominal trajectory that is large enough to warrant FCO action must be corrected. First stage options are:

- 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

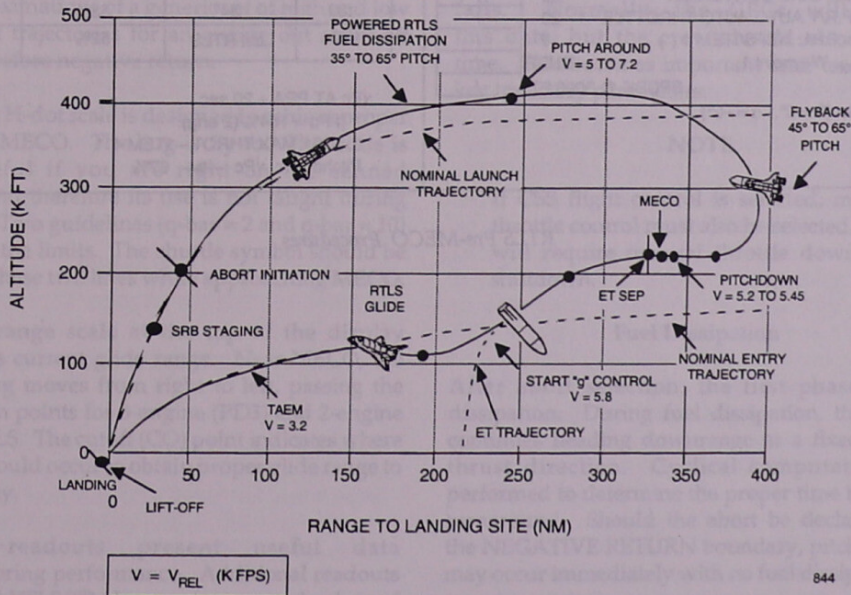
CONTENTS	
Powered RTLS.....	6.3-2
Gliding RTLS.....	6.3-6

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 liftoff 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 and 30 seconds (2+30) after lift-off. For RTLS systems aborts, selection occurs at 3 minutes and 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 push button reconfigures GNC software to RTLS. As a backup, the crew can enter OPS 601 PRO on any PASS keyboard.



Typical RTLS Profile

Powered RTLS

Powered RTLS (PRTL) begins when the abort is initiated and terminates at MECO. PRTL 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 PRTL is closed loop. Computed MECO conditions are compared to desired MECO targets to determine a

miss vector. This vector is then used to compute corrections in steering and throttle commands.

The crew monitors guidance using cue cards and CRT displays.

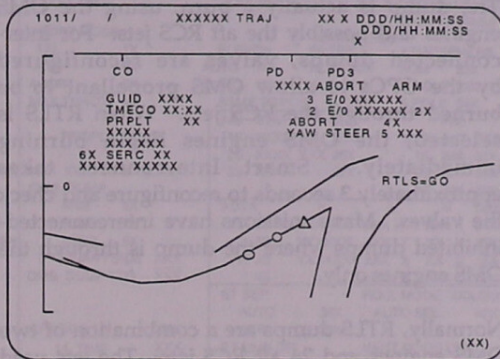
Should guidance not converge, the crew will see "GUID INHB" on the RTLS TRAJ display. MCC, in conjunction with the crew, will request CSS takeover if guidance does not converge within a reasonable time.

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 * 50K / * REMAINING * 40 / * After GUID CONVERGE: * 30 / * P,R/Y AUTO/AUTO THROTTLE * 20 / After PPA: √BFS ITEM 1 (*) 7 / √Bugs, V_{rel}, Waypoint 1 SURF / SPDBK @ 3000 FT /</p> <p>Pitchdown ($\beta = 0^\circ$, $\alpha = -2^\circ$)</p>	<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; text-align: center;"> <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	34°	53%	48°																																						
4:00	Last RTLS	52%	46°																																						

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RTLS Pre-MECO Procedures

The primary display for PRTLs is RTLS TRAJ. Some of the information on this display comes directly from NAV and is independent of guidance.



RTLS TRAJ Display

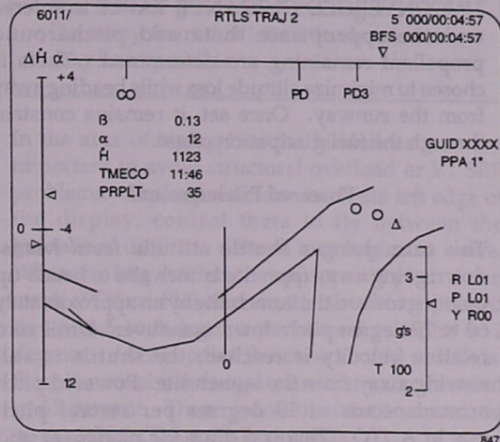
The central portion of the display is a plot of altitude versus horizontal component of V_{REL} , with the zero-velocity point at the end of the top trajectory line to the left of the screen midpoint. Shuttle position is plotted with a triangle. Predictors are generated to show 30 and 60 second positions. Trajectory lines are approximations of a generic set of high and low dispersed trajectories for an engine out at lift-off and just before negative return.

The Delta H-dot scale is designed to achieve proper H-dot at MECO. The bug is fly-to. This scale is only useful if you are right on the canned profile, and therefore its use is not taught during training. Two guidelines ($q\text{-bar} = 2$ and $q\text{-bar} = 10$) prescribe the limits. The shuttle symbol should be between these two lines while approaching MECO.

A delta range scale at the top of the display represents current glide range. Near MECO, the cut-off 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

In order to function properly, guidance needs to know the shuttle's speed and time when an engine fails. Normally, the GPCs will capture this data, but the crew should also note the time. This becomes important later to determine key trajectory parameters.

NOTE

If CSS flight control is selected, manual throttle control must also be selected. This will require manual throttle down and shutdown.

Fuel Dissipation

After abort selection, the first phase is fuel dissipation. During fuel dissipation, the shuttle continues heading downrange at a fixed inertial thrust direction. Cyclical computations are performed to determine the proper time to initiate turnaround. Should the abort be declared near the NEGATIVE RETURN boundary, pitch-around may occur immediately with no fuel dissipation.

For the crew to fly fuel dissipation phase in CSS, they must know the proper pitch angle (theta) and when to pitch around. Using the engine fail time, the RTLS cue card UNCONVERGED GUIDANCE TABLE is entered and the appropriate theta and pitcharound propellant remaining are determined. Theta is chosen to minimize altitude loss while heading away from the runway. Once set, it remains constant through the fuel dissipation phase.

Powered Pitch Around

This turn changes shuttle attitude from heads-down going away from the launch site to heads-up pointing toward the launch site by an approximately 60 to 70 degree pitch down maneuver. Until zero relative velocity is reached, the shuttle is still moving away from the launch site. Powered pitch around occurs at 10 degrees 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.

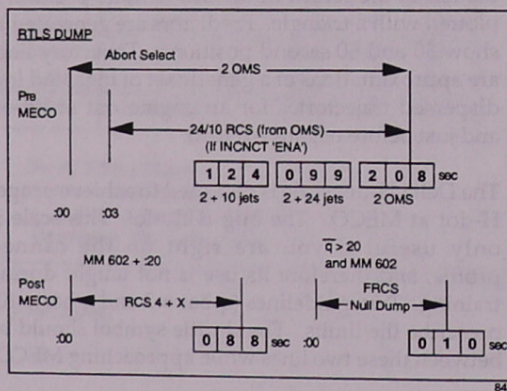
OMS Dump

OMS propellant onboard at launch is mission specific. Since 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. Many missions have interconnected-inhibited dumps where the dump is through the OMS engines only.

Normally, RTLS dumps are a combination of two OMS engines and 24 aft RCS jets. The jets used are four +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 RTL5 dumps. Interconnect can be inhibited or enabled by toggling ITEM 5.

XXXX / 051 /	OVERVERRIDE	XX X DDD/HH.MM.SS	DDD/HH.MM.SS
ABORT MODE	ELEVON	ENTRY FCS	ATMOSPHERE
TAL 1X	AUTO 17X	NOM 20X	NOM 22X
ATO 2X	FIXED 18X	ALT 21X	N POLE 23X
ABORT 3X	SSME REPOS 19 XXX	S POLE 24X	
MAX THROT 4X			
PROPLT DUMP	MU STAT ATT DES	PRL	
XXX ICNCT 5 XXXX	1S XXXX X 25X	SYS AUT DES	
OMS DUMP	2S XXXX XXX 26X	1S 28X 31X	
ARM 6X	3S XXXX 27X	2S 29X 32X	
START 7X	ADTA H α M DES	3S 30X 33X	
STOP 8X	L 1S XXXXXX ±XX.X XX.X 34X		
9 QUAN / SIDE XXX	3S XXXXXX ±XX.X XX.X 35X		
OMS DUMP TTG XXX	R 2S XXXXXX ±XX.X XX.X 36X		
	4S ±XX.X XX.X 37X		
AFT RCS 13 XXX	ET SEP	ROLL MODE XXXXXXXX	
14 TIME XXX	AUTO 38X	AUTO SEL 42X	
FWD RCS 15 XXX	SEP 39X		
16 TIME XXX	ET UMB DR	VENT DOOR CNTL	
	CLOSE 40X	OPEN 43X	
	RCS RM MANF	CLOSE 44X	
	CL OVRD 41		

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. When the bug reaches the appropriate pitch down mark (PD3 or PD), the shuttle should be pitched down at 5 to 8 degrees per second to alpha = -2 degrees. At this point the crew should null beta. Simultaneously, the engines are manually throttled to 67 percent. These procedures are summarized on the RTL5 CDR & PLT cue cards.

Onboard failures, such as electrical or DPS problems, can cause serious OMS/RCS valve reconfiguration problems. "Smart Interconnect" Software should reconfigure the valves or inhibit some or all of the jets to prevent any serious problems.

Shuttle abort dumps are complex procedures and must be executed correctly in a time-critical situation. Consult the Ascent/Aborts Flight Procedures Handbook for additional information.

Flyback

This phase is part of PRTL5 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 RTL5 PLT UNCONVERGED GUIDANCE TABLE. The shuttle pitch attitude must then be adjusted to fly back along or parallel to the guidelines on the RTL5 TRAJ display.

Powered Pitchdown

To satisfy altitude and flight path angle constraints at MECO, a positive angle of attack of about 30 degrees is required. However, to safely separate the ET, an alpha of -2 degrees is necessary. The transition between these attitudes is called powered pitchdown.

The maneuver must be completed rapidly (5 to 8 degrees per second) to avoid large sink rates, which could cause over-heating or over-stressing. Engines are throttled back to reduce trajectory impact.

MECO and ET SEP

Since the MECO time has been fixed by the GPCs, an attitude of alpha = -2 must be held until the delta-R bug reaches the CO mark, and the engines are shut down 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. Attitude is controlled by the RCS jets.

The shuttle is then ready for ET SEP, which will occur automatically, provided certain constraints are within limits.

	DESIGN TARGET	DESIGN TOLERANCES	VEHICLE LIMITS, DEG/SEC
Roll rate, P	0°/sec	+ 1.25°/sec	5 > P > -5
Pitch rate, Q	- .25°/sec	± 0.5°/sec	+ .25 > Q > -5
Yaw rate, R	0°/sec	+ .05°/sec	+ 5 > R > -5
Angle of attack, α	-4°	± 2°	-2° > α > -89° *
Side slip angle, β	0	± 2°	2° > β > -2° *
Roll angle ϕ	0	± 5°	None

* Limits, deg.

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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 due to 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 push button 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 $\alpha \geq +10$ degrees and time from ET SEP ≥ 10 seconds, the GPCs mode to MM 602 and the glide portion of RTLS (GRTLS) begins.

In CSS and manual throttle, a manual MECO must be performed using the MAIN ENGINE SHUT DOWN push buttons 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 α 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 $\alpha \geq +10$ degrees must also be manually performed. Generally, it is preferable to allow the DAP to perform these maneuvers automatically.

Gliding RTLS

The gliding portion of RTLS is very similar to the final portions of entry, which are discussed in detail in Section 7. Only significant differences are presented here.

Post-MECO Dumps

After MECO and ET SEP, the remaining MPS propellants must be dumped to assist in c.g. control and, for the liquid hydrogen, to reduce potential fire hazard. The MPS dump sequences are very similar for the nominal, TAL, and RTLS modes. The LO2 and LH2 are dumped simultaneously to save time.

The RTLS MPS dump starts immediately upon transition to MM 602. LO2 is dumped through the main oxidizer valves in the main engines and the 8-inch fill/drain line on the starboard side of the orbiter. LH2 is dumped through the 1.5-inch backup dump line and the 8-inch fill/drain line on the orbiter port side aft. To ensure a rapid LH2 dump, the LH2 manifold is pressurized with helium.

The onboard software also allows a post-MECO dump of RCS propellant through the RCS jets to satisfy maximum tank landing weight constraints and c.g. control.

Guidance

During GRTLS, guidance manages the shuttle's energy state to arrive at the runway with sufficient energy to complete a safe landing. GRTLS guidance is divided into five phases:

- Alpha Recovery
- N_z Hold
- Alpha Transition
- S-Turn
- GRTLS TAEM.

These phases provide for transition from a ballistic trajectory, through hypersonic gliding flight, to an energy management scheme designed to make the runway.

CDR	PLT
----- MECO ----- MECO -----	----- MECO ----- MECO -----
ET SEP (MECO + 14 sec) √MM602 (α > 10° and SEP + 10 sec) √P,R/Y, SPDBK, BDY FLP - AUTO α = 50° until - 1.8g, maintain 2.2g Adjust seat H-dot > -320 √ α vs Mach V = 5 AIR DATA PROBES (two) - DEPLOY, (√Heat) √RUD, AIL TRIM M = 3.2 √SPDBK → 65% M = 2.7 L HUD PWR - ON TRIM PANEL - OFF RHC/PNL - ENABLE * If M < 2.5; P CSS for ADTA to G&C incorp * M = 2.0 Ensure ADTA to G&C else THETA limits M = 0.9 P,R/Y - CSS, √SPDBK CMD vs POS √NWS - 1 Lock Inertia Reels POST LANDING: ENT, <u>POST LDG</u>	KEAS = 77 √SPDBK → 81% √ET DOORS - Closed and latched (MECO + 1:30) √ET SEP, SRB SEP - AUTO Adjust seat √TACANS, INCORPORATE * If KSC TACAN Fail: * TACAN Ch 97X (COF), ITEM 5 EXEC * [G51] √AIR DATA, INCORPORATE MM603 HYD MPS/TVC ISOL VLV (three) - CL (Hold 5 sec) √tb - CL H = 85K MLS (three) - ON If Rwy 33(15): MLS CH (three) - 6(8) I/O RESET M = 2.7 R HUD PWR - ON TRIM PANEL - OFF RHC/PNL - ENABLE M = 0.9 √R FLT CNTLR PWR - ON Lock Inertia Reels M = 0.7 √LG EXTEND ISOL VLV - OP H = 10K √BDY FLP - TRAIL LES Visors - Down POST LANDING: ENT, <u>POST LDG</u>

RTLS Post-MECO Procedures

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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 degrees) angle of attack using both RCS jets and aerodynamic controls.

Increasing dynamic pressure caused by the shuttle falling into the atmosphere causes more lift to be generated by the wings. The resultant lift produces a Z-axis acceleration (N_z). At about 1.65 g, the DAP starts to reduce alpha to hold an N_z of 2.2 g's. The shuttle N_z limit for RTLS is 2.0 - 2.5 g's (based on the vehicle's weight).

Roll jets are secured at q-bar = 10. Pitch jets are secured at q-bar = 40. Yaw jets are required until Mach = 1.0. When q-bar = 20, the speed brake is ramped open to about 80 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.

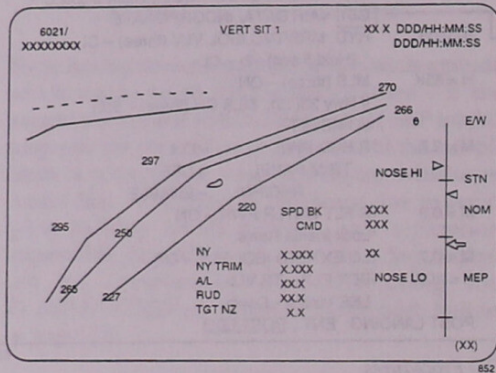
N_z Hold

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 degrees. The ADI pitch error needle displays alpha error during alpha transition phase. Guidance can downmode to the straight-in or minimum entry point (MEP) HAC if required due to low energy.

To fly the alpha transition in CSS, the display in the upper left corner of VERT SIT 1 is used. The shuttle symbol initially appears in this portion of the display, which represents an alpha versus Mach number profile. The dashed line is the nominal profile, and the solid line is the q-bar limit



GRTLs Vertical Situation 1 Display

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.

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.

Post landing procedures are the same as nominal end of mission, except that the hydraulic load test is not performed.

6.4 TRANSOCEANIC ABORT LANDING

CONTENTS

Nominal Transoceanic Abort Landing.....	6.4-1
Post MECO Transoceanic Abort Landing.....	6.4-4

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 ten 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* push button. 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

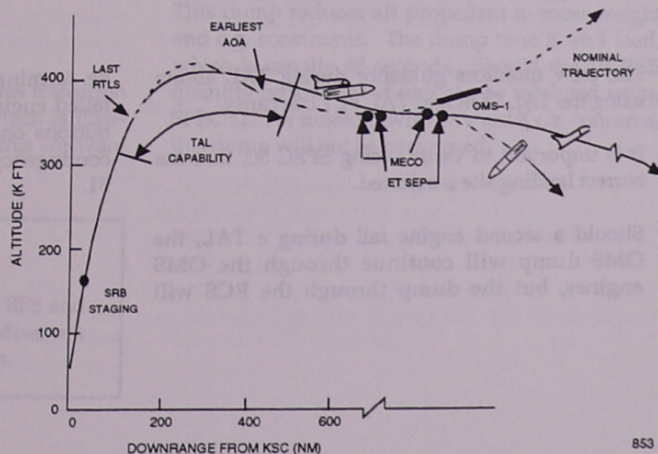
When TAL is selected, an abort dump begins immediately. OMS propellant is usually dumped through the OMS engines plus 24 aft RCS jets interconnected to the OMS propellant tanks. The OMS/RCS interconnects are determined preflight via I-loads for each abort scenario. They may be enabled or inhibited by 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 an inplane two-engine TAL or any three-engine TAL is initiated after an I-loaded velocity, there will not be enough time to complete the OMS dump. For these cases, the 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 (500 nm) at MECO.



TAL versus Nominal Ascent

6. EMERGENCY PROCEDURES
6.4 Transoceanic Abort Landing

TOP
BACK OF RTLS PLT

PILE

TAL CDR

If $V_1 > 23000$ manual MECO, go to Post MECO
ABORT TAL
 (G50) ✓SITE & RWY (PASS/BFS)

SITE	RWY	TACANS	ITEM 5	MLS	LENGTH
1	BEN 108	BEN 108	CBA 116 (DME)	6-	13720/12720
2	MRN 100	MRN 100	AOG 23	6-	12000/11800
3	ZZA 30L/20R	ZZA 64	ZZA 77 (DME)	6-	12327/12187
4	INL 0624	SHA 80 (DME)	CEN 37 (DME)	-	8499/8335
8	ECT 1725	STG 111 (DME)	LEA 98 (DME)	-	9499
11	BEN 36	BEN 108	-	6	13720
12	FFA 27	MRN 100	BZN 56	-	9698
13	MRN 20	MRN 100	-	6	12000
15	ZZA 30L	ZZA 64	-	6	12397
17	ESN 09R	-	BAG 78 (DME)	-	11310
14	KKG 15R	RIY 92	-	-	12779
16	JGG 31	-	NKW 87	-	12003
19	LAL 1523	LAL 45	TBM 109	-	10862

• If second eng fails: (TRAJ) ✓SERC ON
 (G50) ✓SITE (✓Redes card)

$V_1 = 15.0K$ Roll to Heads Up (If $V_1 < 20.3K$ at TAL select)
MECO BFS - C/O BUG ($V_1 - 24.0K$) **MECO**

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)

✓P = 10 ± 30, Y = 0 ± 30; RATES < .5"/sec
 PASS, OPS 301 PRO (✓304)
 • No joy in 68 sec: BFS - ENGAGE
 • BFS, OPS 301 PRO

MM304

✓Roll to Heads Up
 BFS, OPS 301 PRO (✓304)
 (G50) ✓SITE, RWY, TACAN
 SPDBK & ALT (PASS/BFS)

✓BUGS, HDG, RANGE, $\alpha = 43^\circ$

	50K	40K	30K	20K	10K	0K
Low energy: (TRAJ) 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	/	/	/	/	/
	SPDBK @ 3000 FT	/	/	/	/	/
V = 10 ✓SPDBK → 81%	ALT	/	/	/	/	/
V = 7 Go to ENTRY MANEUVERS	AIM PT	/	/	/	/	/
Cue Card	SPDBK	/	/	/	/	/

FB 2-14 ASC76/FIN

TAL CDR Procedures

TOP

HOOK

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
- When MPS PRPLT = 2%:
- MAN THROT, $P_c \rightarrow 67\%$
- Man Shltdn at C/O mark

✓AUTO THROT
 BFS - C/O BUG ($V_1 - 24.0K$) **MECO**

* If first SSME out at Press to ATO, subtract 200 fpm*

Legend:
 [Hatched] Lo-Energy ENA (42/31)
 [Solid] Lo-Energy ENA (42/man 37)
 [White] AUTO (43/40)
 [Diagonal] Hi-Energy (V₁ in KPFS)

200 ft

MM304

✓OMS DUMP
 ✓ET DOORS - Closed and latched (MM304 +1:30)

V = 19 HYD MPS/TVC ISOL VLV (three) - CL
 (hold 5 sec) ✓tb - CL

V = 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

FB 2-15 ASC76/FIN

HI-ENER TAL

TAL PLT Procedures

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* push buttons 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 degrees 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.

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 TAL is selected after this velocity, but before a velocity of approximately $\approx 20,000$ (I-load) fps, guidance will roll the shuttle immediately. The roll is performed at about 5 degrees per second. After $\approx 20,000$ fps until last pre-MECO TAL, the shuttle will not roll.

TAL MECO occurs about 2,800 nm 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 key 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.

About 3 minutes are available to complete the OPS transition between ET SEP and the start of dynamic pressure buildup depending on the altitude, flight path angle, and velocity at MECO. This period is critical. The shuttle is entering the atmosphere, and the TRANS DAP is not designed for atmospheric flight. All procedures must be completed quickly and accurately. Ignore all systems problems unless they are extremely critical until correct entry flight control is available.

Post-MECO Dumps

An MPS dump similar to the RTLS dump begins automatically at MM 304. The TAL LH2 MPS dump is unpressurized.

Once in MM 304, the OMS dump restarts to ensure separation with the ET. This dump adds about 100 fps ΔV to the shuttle's energy. (Several missions have used 200 fps ΔV .) For post-MECO TALs, the dump also ensures orbiter landing weight, c.g., and tank landing weight constraints are met.

The FRCS null jet dump typically starts at MM 304 to help control X c.g. location.

An aft RCS dump is commenced at $V_{REL} = 8$ 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 $V_1 \sim 21.5$ 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* push buttons.

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 ELSs, and the program has decided to try for an AOA rather than land at an ELS.

MECO velocity takes into account the ΔV due to SSME tailoff. This number is flight specific and depends upon inclination.

The boundaries chart shows approximate TAL site coverage for a range of early MECO conditions. Using the real time downrange abort evaluator (DAE), the MCC will determine the appropriate site and communicate data to the crew. Cue card boundaries are used for loss of communications.

High Energy TAL

MECO velocities between approximately 24.3 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 options in this window are to abort to an emergency landing site (ELS) or to bail out. For inclinations <57 degrees, 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 late 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.

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 late TAL procedures are identical to the nominal TAL.

6.5 ABORT ONCE AROUND

CONTENTS

Powered Flight	6.5-1
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 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 TARGETING 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.

Powered Flight

A pre-MECO AOA can be selected only indirectly by first selecting ATO. This provides the earliest AOA capability by performing a pre-MECO OMS dump, switching to abort MECO targets, and possibly enabling variable I-Y steering.

Abort Dump

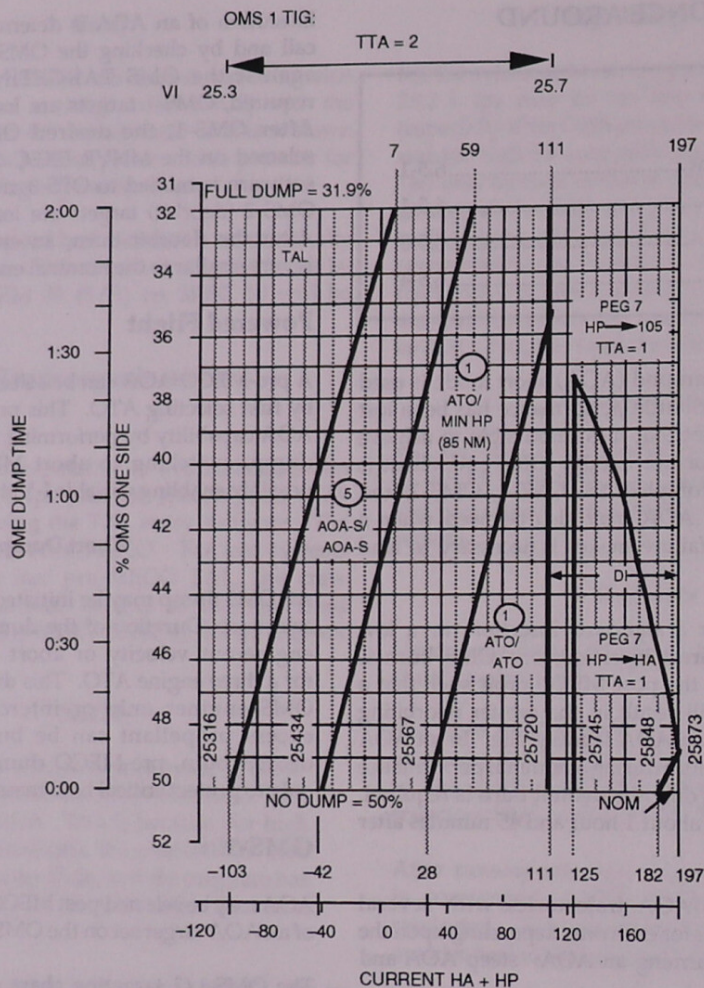
An OMS dump may be initiated upon ATO abort selection. Duration of the dump is a function of engine-out velocity or abort selection velocity for a three engine ATO. This dump may be either OMS engines only or interconnected. Since excess propellant can be burned during the deorbit burn, pre-MECO dumps are performed only to protect critical land masses from ET debris.

OMS-1

AOA may 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.

6. EMERGENCY PROCEDURES
6.5 Abort Once Around



IF 1 ENG & $\Delta V > 500$

1 OMS + FAILED OMS INTERCONNECTED TO RCS THC +X

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OMS 1/2 TGTING Cue Card

The OMS 1/2 TGTING cue card should be used in conjunction with the SYSTEMS FAILURE 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 exists 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 procedure avoids an APU shutdown and restart and conserves APU fuel.

OMS 2 TARGETING
(STD INSERTION)

FAILURE	OMS 2 TARGET
OMS - 1 PRPLT TK	PEG 7; TTA-1 CUTOFF Hp = 100
OMS - 2 N2 TKS (l'cnect to RCS) 2 OMS ENG 1 He TK EPS - MNA & B MNA & C	PEG 7; TTA-1 CUTOFF Hp = 80
OMS - 2 OX or 2 FU or 2 HE TKS 1 OX & 1 FU TK dff PODS	AOA/AOA-S
2 FREON LOOPS 2 H2O LOOPS 3 AV BAY FANS (BAYS 1,2) CABIN LEAK (BKUP dP/dT > .12)	AOA

ATO				
NOTE				
These tables only apply after ATO OMS 1 burn (ITGT = ①, AOA to EDW). Assumes OMS and ARCS deorbit				
DUAL POD - OMS REQUIRED				
Includes 7.8% unusable (3.9% 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	35	15	33	20
90	36	13	31	19
85	37	11	30	17
80	39	12	28	16
75	40	14	26	14
70	42	16	24	12
65	43	17	22	10

SINGLE POD - OMS REQUIRED				
Includes 3.9% 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	31	11	29	16
90	32	9	27	15
85	33	7	26	13
80	35	9	24	12
75	36	10	22	10
70	38	12	20	8
65	39	13	18	6

ΔV AVAILABLE FOR OMS 2
 OMS: 5 FPS/% PER POD
 LIFTOFF BLL DN PER POD **134**
 MIXED XFD **134**
 MAX BLDN (39%) PER POD **192**
 AFT RCS: ABOVE AFT QTY 1 **70** (Rev 3)
 2 **105** (Rev 3)
 FWD RCS: **49** (AVAIL FOR UPHILL IF HP ≥ 70)

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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 due to 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 co-variance 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. In order 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 nm 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.