

2. SYSTEMS

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This section discusses in detail each of 26 orbiter systems as listed here in the Table of Contents. The subsections are organized alphabetically, with a detailed internal table of contents provided for each.

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

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

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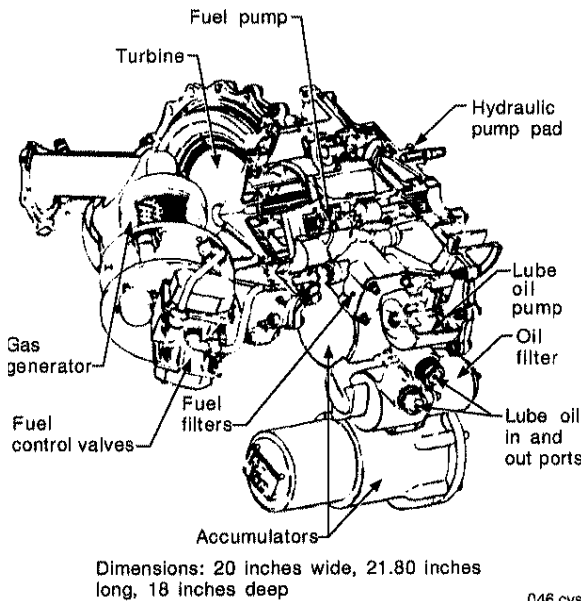
2.1 AUXILIARY POWER UNIT/ HYDRAULICS (APU/HYD)

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Each system provides hydraulic pressure to position hydraulic actuators for:

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



Auxiliary Power Unit

Description

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

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

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

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

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

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

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

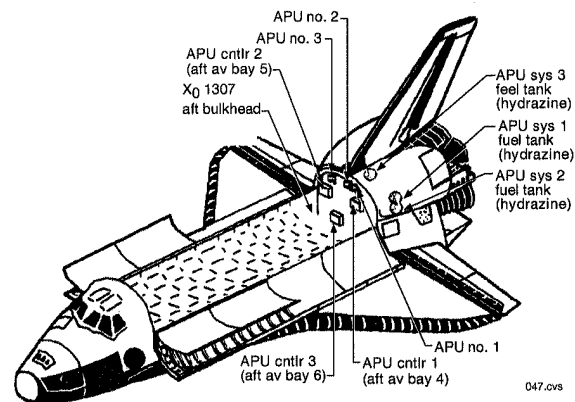
Fuel System

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

Fuel Tanks

The APU fuel tanks are mounted on supports cantilevered from the sides of the internal portion of the aft fuselage. The fuel is storable liquid anhydrous hydrazine. The hydrazine is stored in a fuel tank with a total capacity of

about 350 pounds. The fuel tank, which incorporates a diaphragm at its center, is serviced with fuel on one side and the pressurant (gaseous nitrogen) on the other. The nitrogen is the force acting on the diaphragm (positive expulsion) to expel the fuel from the tank to the fuel distribution lines and maintain a positive fuel supply to the APU throughout its operation. Each typical prelaunch fuel tank load is approximately 325 pounds. The fuel supply supports the nominal power unit operating time of 90 minutes in a mission or any defined abort mode, such as an abort once around, when the APUs run continuously for approximately 110 minutes. Under operating load conditions, an APU consumes approximately 3 to 3.5 pounds of fuel per minute



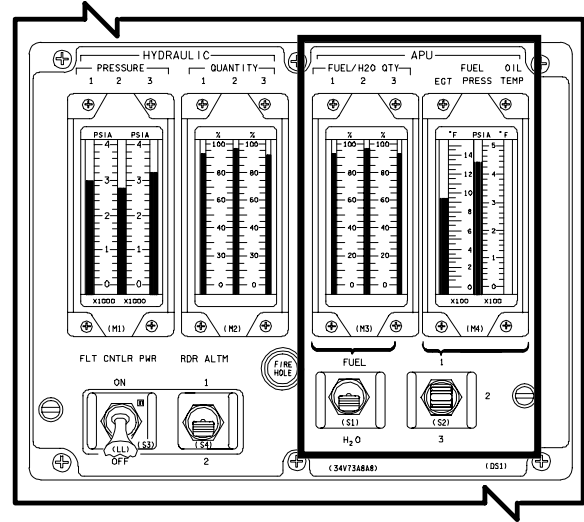
Auxiliary Power Unit Locations

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

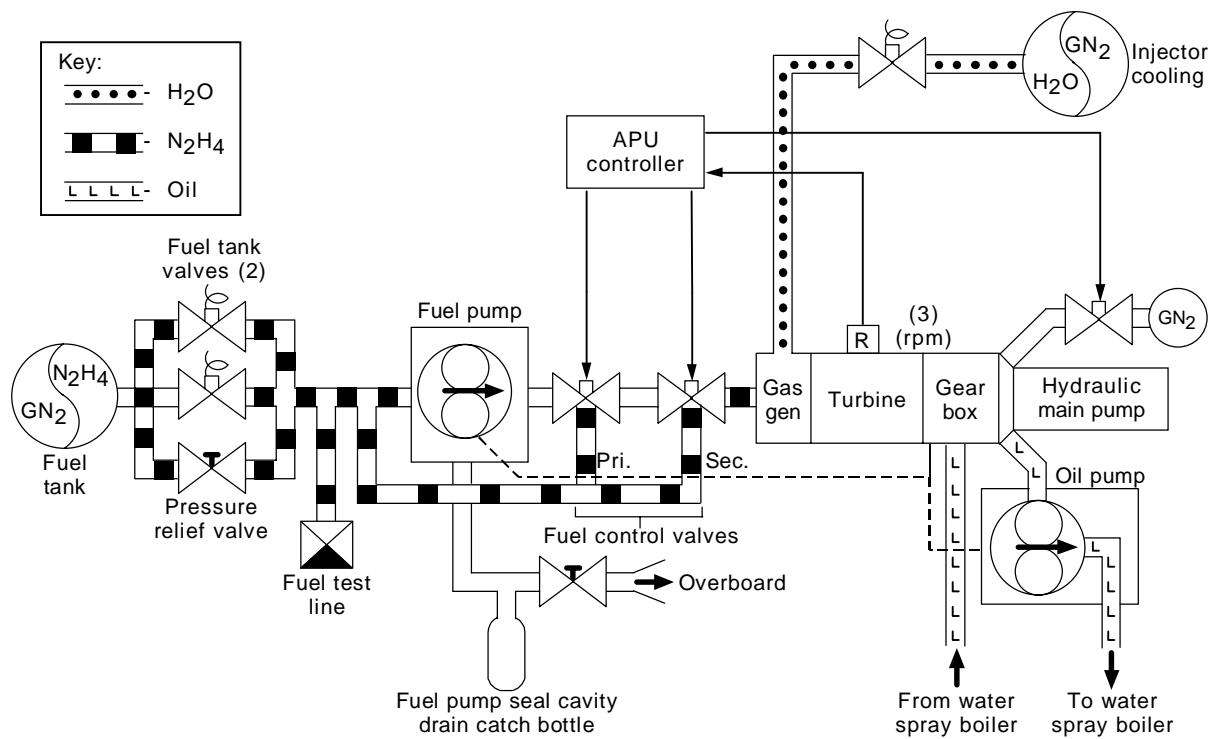
Each fuel tank's temperature and gaseous nitrogen pressure are monitored by the APU controller and transmitted to the GPC, where quantity is calculated and transmitted to the APU FUEL/H₂O QTY meters on panel F8. When the switch below the meters on panel F8 is positioned to *FUEL*, the quantity in APU fuel

tanks 1, 2, and 3 is displayed simultaneously in percent. The fuel quantity of 100 percent on the meter is equivalent to 350 pounds. Fuel pressure (psia) is shown on the FUEL PRESS meter on panel F8. Fuel quantity in percent is also displayed on the BFS SM SYS SUMM 2 display (FUEL QTY).

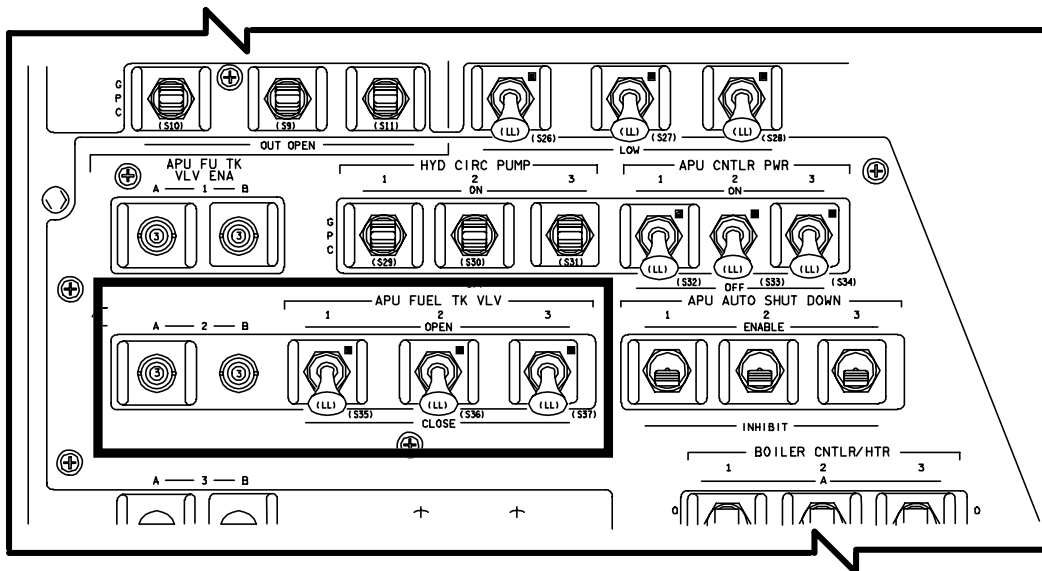
The gaseous nitrogen pressure in each fuel tank exerts a force on the tank's diaphragm to expel the hydrazine fuel under pressure to the fuel distribution system. Filters are incorporated into each distribution line to remove any particles. The fuel distribution line branches into two parallel paths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



APU Meters and Switches on Panel F8



Improved APU Fuel System Schematic



APU FUEL TK VLV Switches and Circuit Breakers on Panel R2

Fuel Tank Isolation Valves

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

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

The IAPU fuel tank isolation valves are cooled by fuel flow when the valves are open. Each valve has redundant temperature measurements (two per valve, four per APU). One temperature reading for each valve is displayed on the BFS SM SYS SUMM 2 display and the APU/HYD, DISP 86 display (Ops 201) beside the FU TK VLV AT and BT labels. There are two tank isolation valve circuit breakers per APU (one per valve) located on panel R2. These can be pulled to disconnect electrical power

from the solenoid if a valve fails open or shorts. The valve heating profile, when the fuel is stagnant, is gradual and, in the event of a failed open valve or short, permits adequate time for corrective action.

Fuel Pump

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

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

0001/ /079		SM SYS SUMM 2			5 008/23:29:22		
					BFS 000/00:00:00		
CRYO TK	1	2	3	4	5	MANF1	MANF2
H2 PRESS	208	208	206	206	206	208	207
O2 PRESS	816	815	814	814	814	815	815
HTR T1	-248	-248	-248	-248	-248		
T2	-248	-248	-248	-248	-248		
APU	1	2	3	HYD	1	2	3
TEMP EGT	942	942	942	PRESS	3064	3064	3064
B/U EGT	942	942	942	ACUM P	3080	3080	3080
OIL IN	250	250	250	RSVR T	116	153	142
OUT	264	264	264				
GG BED	511H	511H	511H	QTY	72	74	71
INJ	1271	1271	1271				
SPEED %	99	102	101	W/B			
FUEL QTY	59	60	62	H2O QTY	78	73	78
PMP LK P	14	14	14	BYP VLV	BYP	BYP	BYP
OIL OUT P	42	42	41				
FU TK VLV							
A T	63	65	62	THERM CNTL	1	28	
B T	63	65	62	H2O PUMP P	23	63	
AV BAY	1	2	3	FREON FLOW	2384	2384	
TEMP	97	97	83	EVAP OUT T	38	38	
A4 14	27.439	27.435			26.324	31.873	18.48

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APU Information on BFS SM SYS SUMM 2 Display

Fuel Control Valves

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

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

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

Gas Generator and Turbine

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

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

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

The temperatures of the gas generator bed, the gas generator fuel injector, and the turbine exhaust gas are visible on the BFS SM SYS SUMM 2 CRT display (*GG BED*, *INJ*, *TEMP EGT*). While the APU is running, the gas generator bed temperature transducer goes off-scale high at approximately 500° F. On orbit, when the APU is shut down, the gas generator bed temperature transducer is useful for monitoring the bed temperature when the bed is kept warm by heaters.

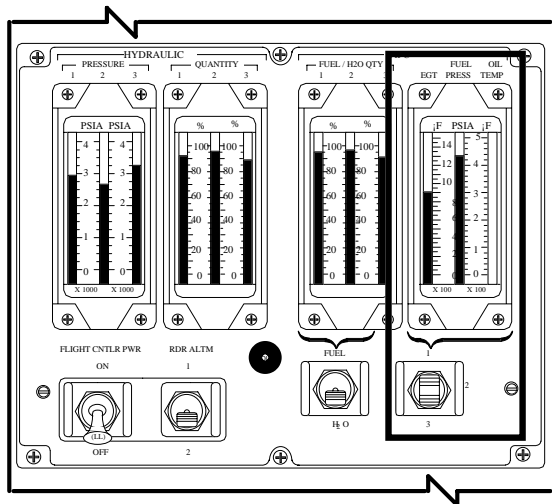
Lubricating Oil

The APU lube oil system is a scavenger-type system with a fixed-displacement pump. Each APU turbine through its gearbox drives a lube oil pump at 12,215 rpm. The system is pressurized with gaseous nitrogen to provide adequate suction pressure to start the lube oil pump under zero-gravity conditions. Each lube oil system has its own nitrogen gas storage vessel, which is pressurized to approximately 140 psia. The pressurization system for each lube oil system has a valve controlled by its corresponding APU controller. The gaseous

nitrogen pressurization valve for each power unit is energized open by its corresponding controller when the gearbox pressure is below 5.2 psi, plus or minus 1.3 psi, to ensure that gearbox pressure is sufficiently above the requirements for proper scavenging and lube pump operation.

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

The following information is transmitted to the BFS SM SYS SUMM 2 display by the APU controller via the GPC: lube oil pump outlet pressure (OIL OUT P) at approximately 45 psia, outlet temperature at approximately 270° F and return temperature from the water spray boiler (OIL IN, OUT) at approximately 250° F for each APU. The lube oil temperature of each APU is also monitored on the APU OIL TEMP meter on panel F8. The APU is selected by the switch below the meter.



APU OIL TEMP Meter and Switch on Panel F8
 (NOTE: EGT indicator on meter is driven by "TEMP EGT" transducer seen on BFS SYS SUMM 2 CRT display.)

Electronic Controller

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

APU Start

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

NOTE

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

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

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

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

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

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

CAUTION

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

APU Speed Control

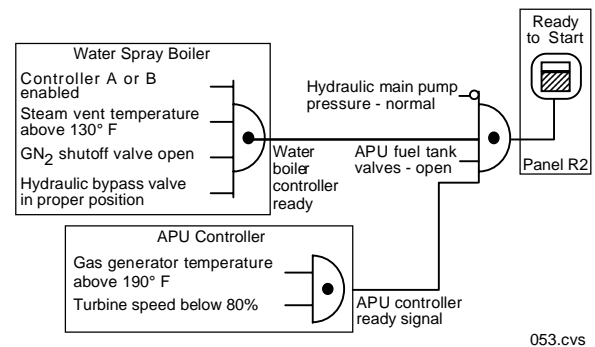
When the APU turbine speed exceeds the control target (103 percent for *NORMAL* and 113 percent for *HIGH*) the appropriate control valve closes. The fuel is then diverted through a bypass line back to the fuel pump inlet. When the turbine speed drops below the control target, the appropriate valve opens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

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

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

APU Auto Shutdown

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



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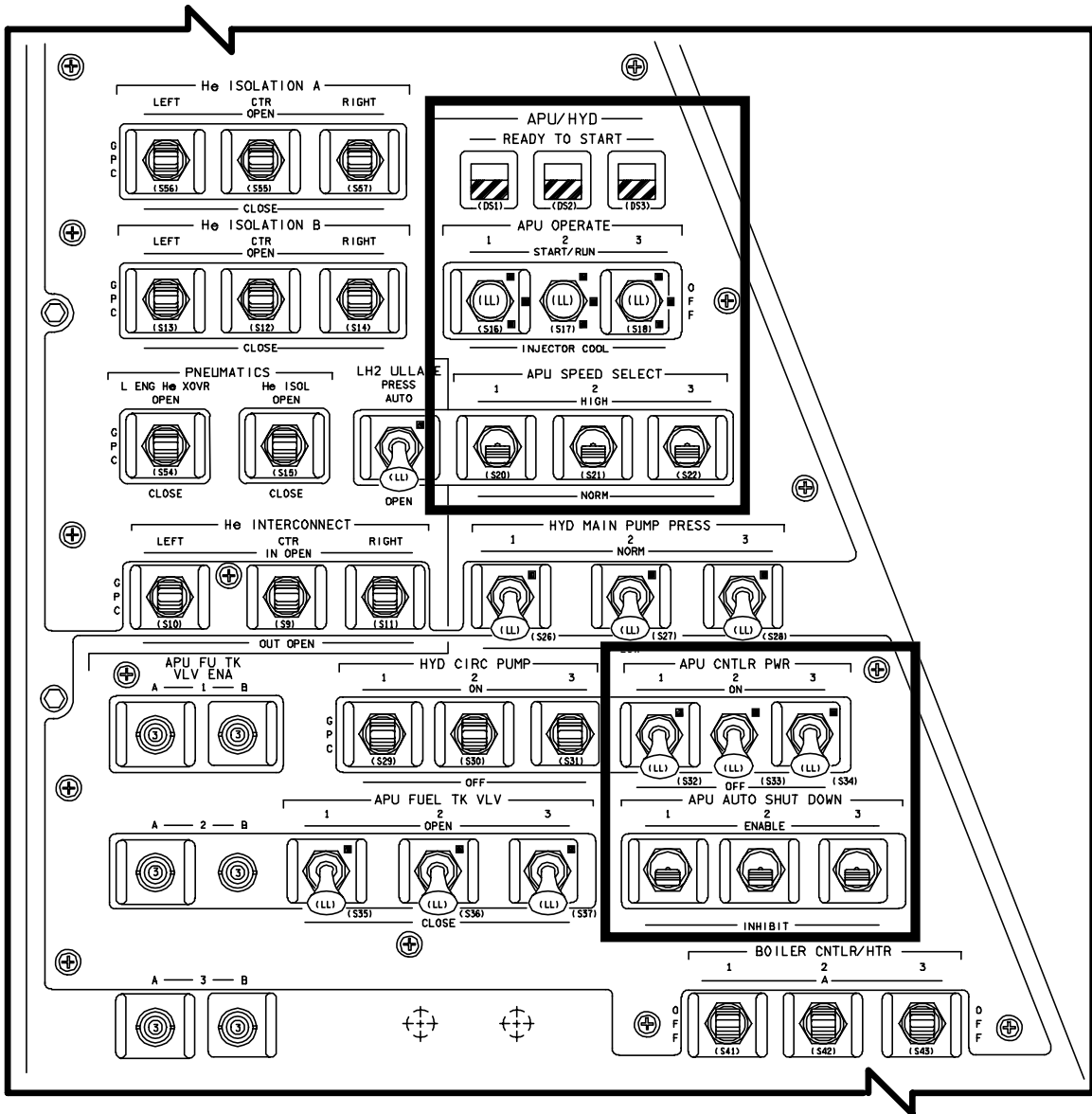
APU Ready-for-Start Talkback Indicator Logic

When an *APU AUTO SHUT DOWN* switch is positioned to *INHIBIT*, the automatic shutdown sequence for its APU controller is inhibited. If the turbine speed falls below 80 percent or rises

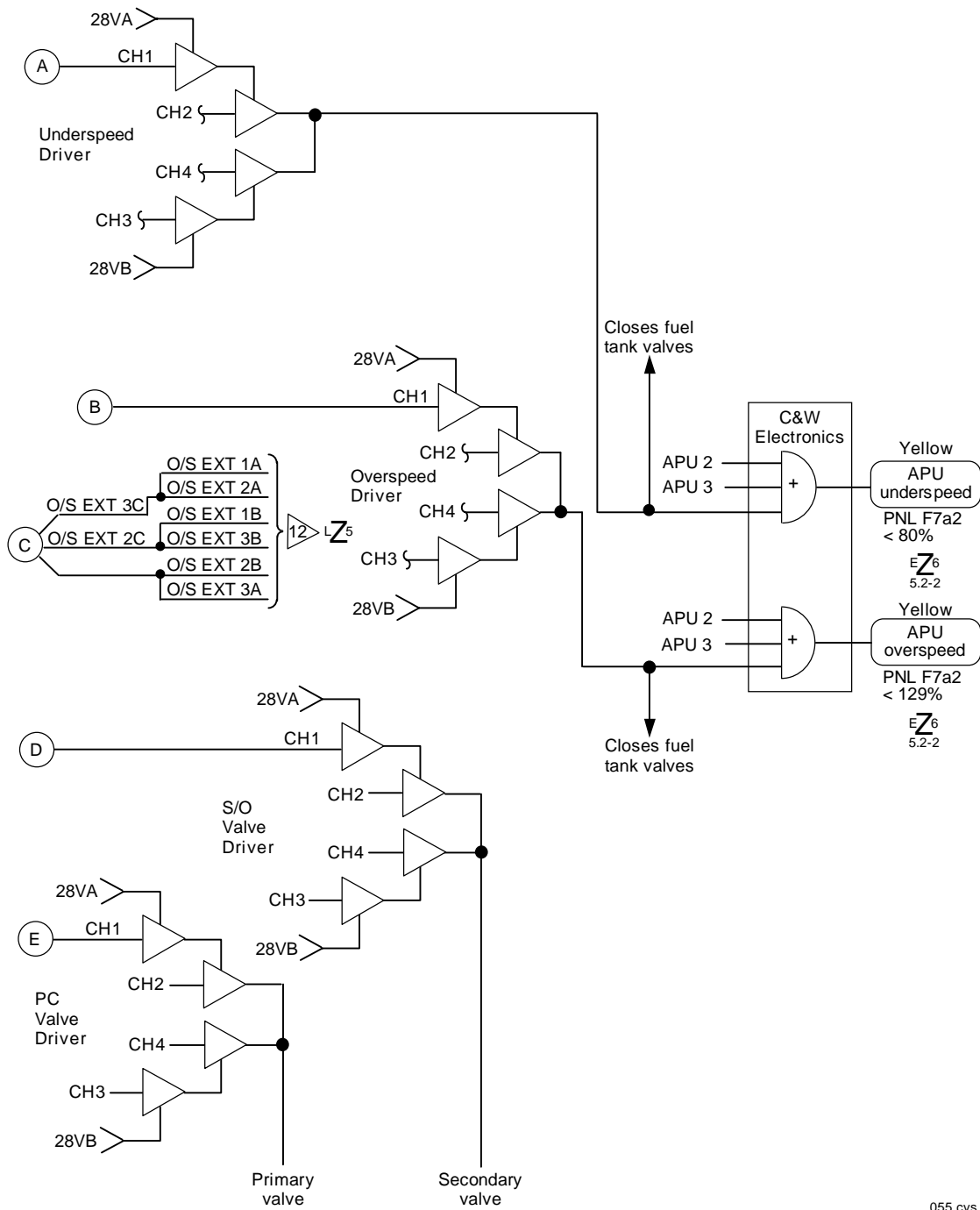
above 129 percent *APU UNDERSPEED* or *APU OVERSPEED* caution and warning lights on panel F7 will be illuminated, and a tone will be generated, even though the *APU AUTO SHUT DOWN* switch is in *INHIBIT*.

CAUTION

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



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



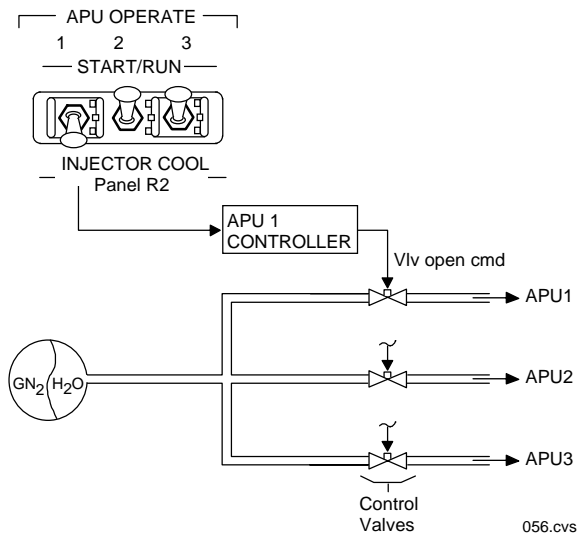
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APU Overspeed/Underspeed Detection

Injector Cooling System

The gas generator injector water cooling system is used only when the normal cool-down period of approximately 180 minutes is not available. The system sprays water to reduce the temperature of the gas generator injector branch passages to less than 400° F in the event that a

hot APU must be restarted after it has been recently shut down. The water cooling ensures that the hydrazine will not detonate in the fuel line leading into the injector due to heat soakback from the gas generator. The injector is cooled by circulating water through it. The water from the gas generator injector is exhausted into the aft fuselage.



APU Injector Cooling

A single water tank located in the aft fuselage of the orbiter serves all three APUs. The water tank is 9.4 inches in diameter and loaded with 9 pounds (plus or minus 0.5 pound) of water. The water tank is pressurized with gaseous nitrogen at a nominal pressure of 120 psi. The pressure acts on a diaphragm to expel the water through three 0.25-inch-diameter lines to three control valves. When the *APU OPERATE* switch on panel R2 for APU 1, 2, or 3 is positioned to *INJECTOR COOL*, the water valve of that unit opens and directs the water into the gas generator injector to cool it.

If the injector branch (internal) temperature of an APU is above 400° F from heat soakback, or if the catalytic bed heater temperature is above 430° F, the flight crew must cool the injector for 3.5 minutes before starting the APU. Operational data from hot APUs shows that the GG INJ temperature does not accurately reflect the drop in injector branch temperatures. The

crew is safe to attempt a restart if the GG INJ temperature is decreasing and at least 3.5 minutes of continuous injector cooling has been completed. A Class 3 alarm with message "APU 1 (2) Cooldown" will annunciate 225 seconds after APU injector cooling is initiated

CAUTION

Care must be taken not to delay in the *OFF* position when taking the *APU OPERATE* switch to *START/RUN*. If cooldown is terminated more than 2 to 3 seconds prior to starting the APU, the injector branch temperatures may increase above start limits, and detonation may occur without another cooldown cycle.

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

Fuel Pump and Gas Generator Valve Module Cooling

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

CAUTION

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

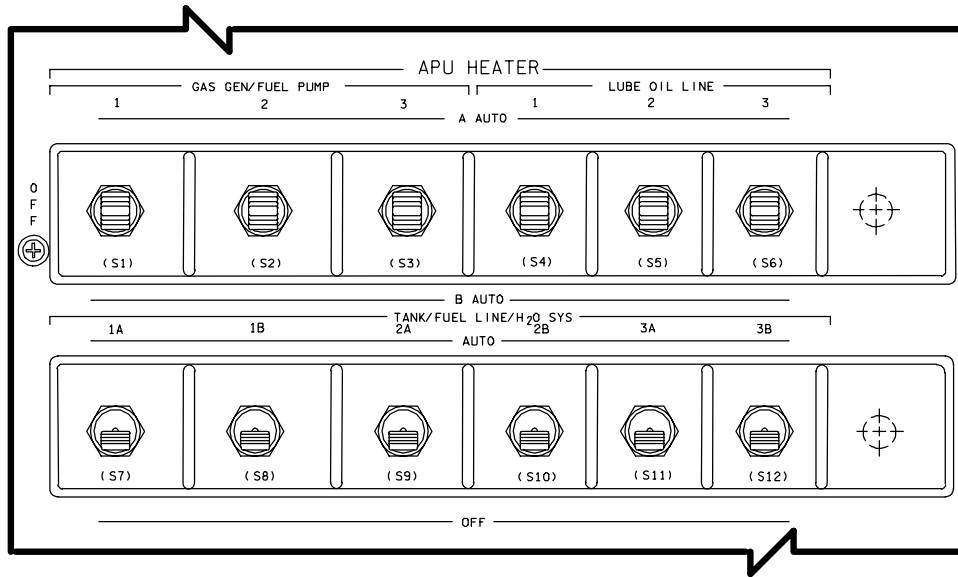
APU Heaters

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

The APU HEATER GAS GEN/FUEL PUMP 1, 2, 3 switches on panel A12 operate thermostatically controlled heaters located on the corresponding APU, fuel pump, and gas generator valve module, and provide power to the gas generator bed heater. The thermostats control a series of heaters on the gas generator valve module, fuel pump, and all the fuel lines

and the water lines from the fuel pump spray manifold to the gas generator valve module. The heaters are divided into redundant A and B systems for each APU. The A AUTO switch controls the A heater, and the A thermostat automatically controls the corresponding APU fuel pump heater, maintaining fuel pump and gas generator valve module temperatures at about 100° F. The gas generator bed heater is maintained between 360° and 425° F by a compactor in the APU controller, which receives its signal from the bed temperature transducer. The gas generator temperature range ensures efficient APU startup through efficient catalytic reaction. The B AUTO switch position provides the same capability for the B heater system. The gas generator and fuel pump heaters are automatically deactivated by the corresponding controller at APU start. The OFF position of each switch removes power from the respective heater circuits. These heater switches also provide redundant power to the gas generator and gearbox pressure signal conditioners for use while the APU controller is off.

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



APU HEATER Controls on Panel A12

Water Spray Boilers

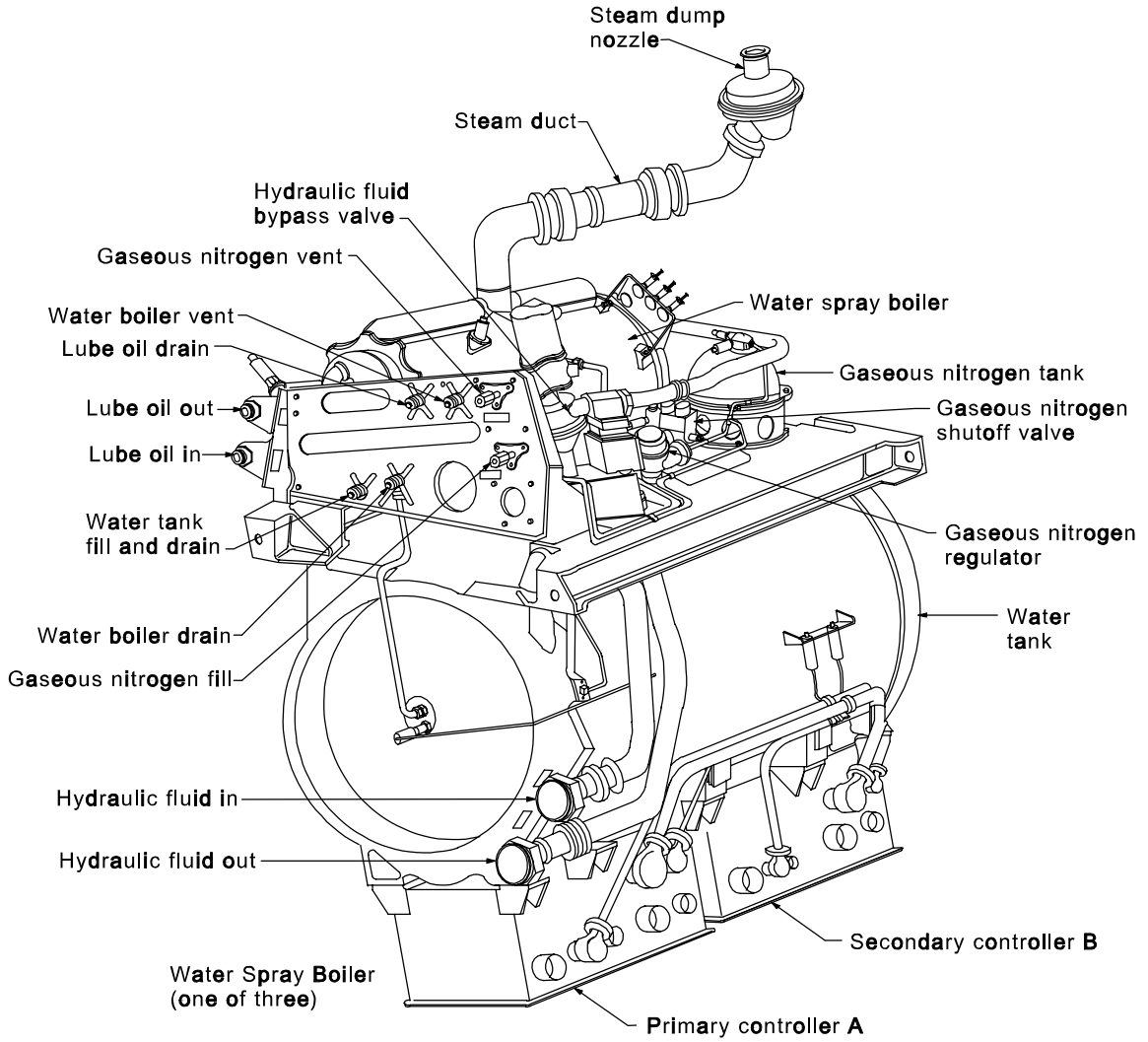
The water spray boiler (WSB) system consists of three identical independent water spray boilers, one for each APU and hydraulic system. The boilers are located in the aft fuselage of the orbiter. Each WSB cools the corresponding APU lube oil system and hydraulic system by spraying water onto their lines;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

Each WSB is 45 by 31 inches long by 19 inches wide, and including controller and vent nozzle, weighs 181 pounds. They are mounted in the orbiter aft fuselage between X₀ 1340 and 1400, at Z₀ 488 minus 15, and at Y₀ plus 15. Insulation blankets cover each boiler. The boiler's water capacity is 142 pounds.

Each WSB stores water in a bellows-type storage tank pressurized by gaseous nitrogen providing positive water expulsion to feed the boiler. Hydraulic fluid passes through the boiler three times. APU lube oil passes through the boiler twice. The hydraulic fluid tubes are sprayed with water from three water spray bars, and two water spray bars spray the APU lube oil. Separate water feed valves allow independent control of the hydraulic fluid spray bars and APU lube oil spray bars. Redundant electrical controllers provide completely automatic operation.

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

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



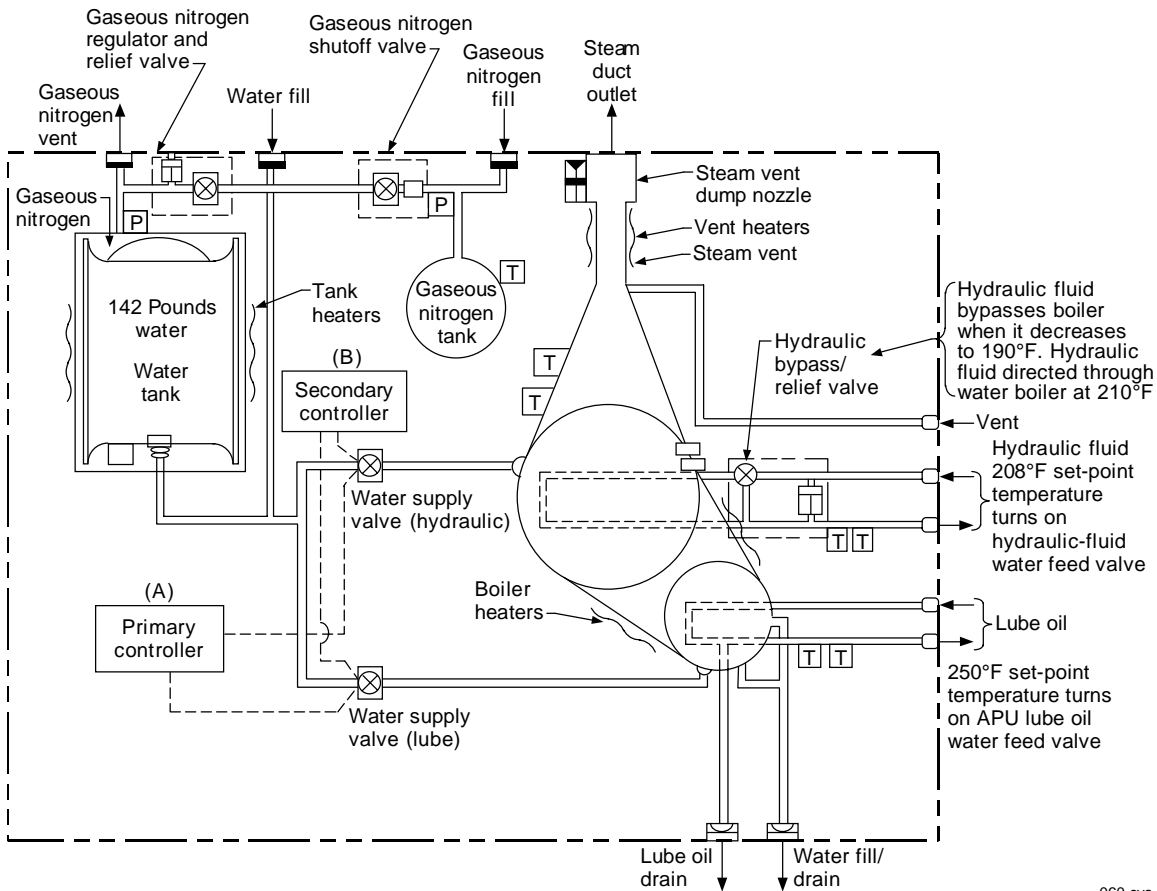
058.cvs

Water Spray Boiler Unit

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

059

SM APU/HYD Display (DISP 86)



Water Spray Boiler (One of Three)

Nitrogen Supply System

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

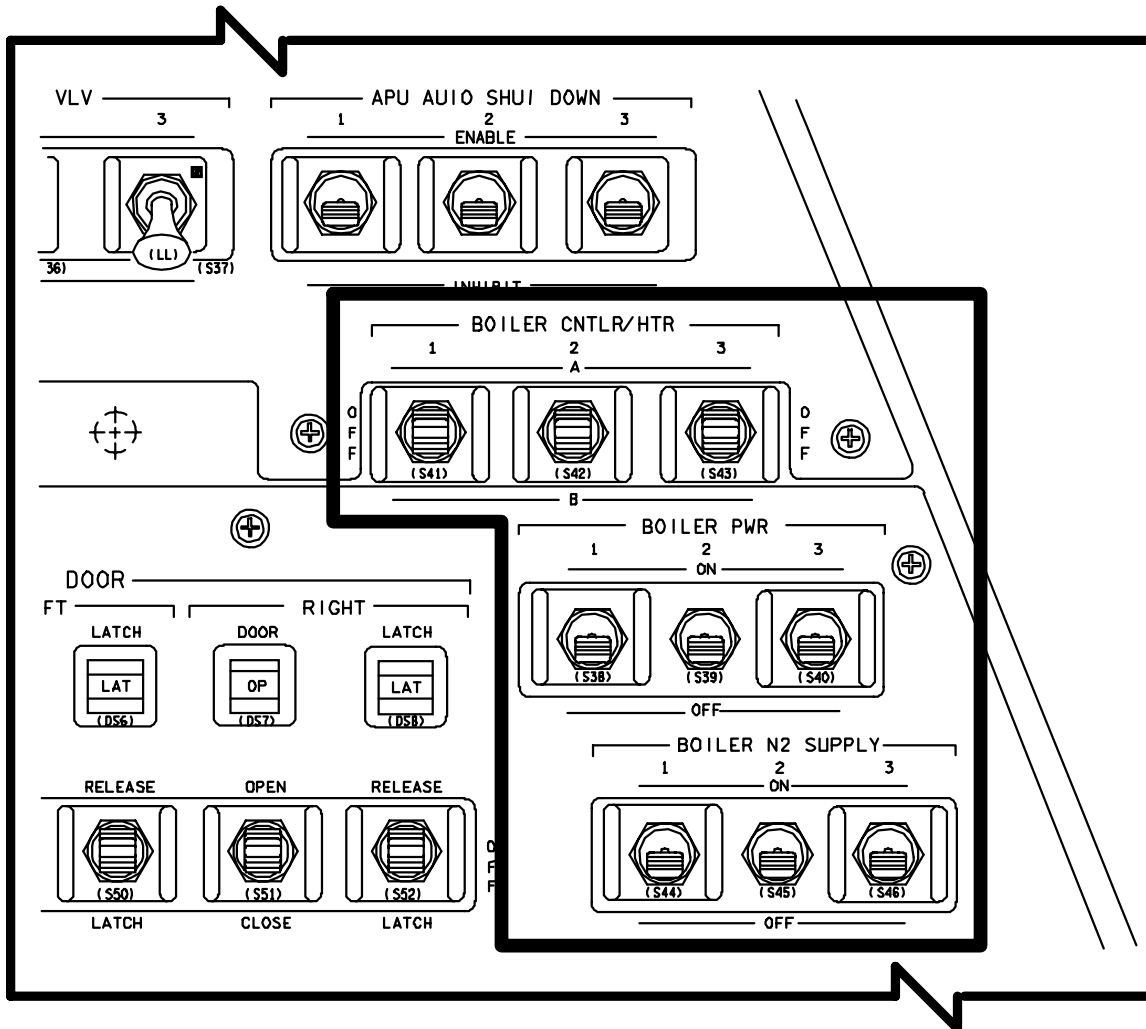
The nitrogen shutoff valve between the pressure valve and water storage tank of each boiler permits the pressure to reach the nitrogen regulator and water tank or isolates the nitrogen supply from the water tank. Each nitrogen valve is controlled by its respective *BOILER N2 SUPPLY 1, 2, or 3* switch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

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

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

Water Supply System

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



BOILER Switches on Panel R2

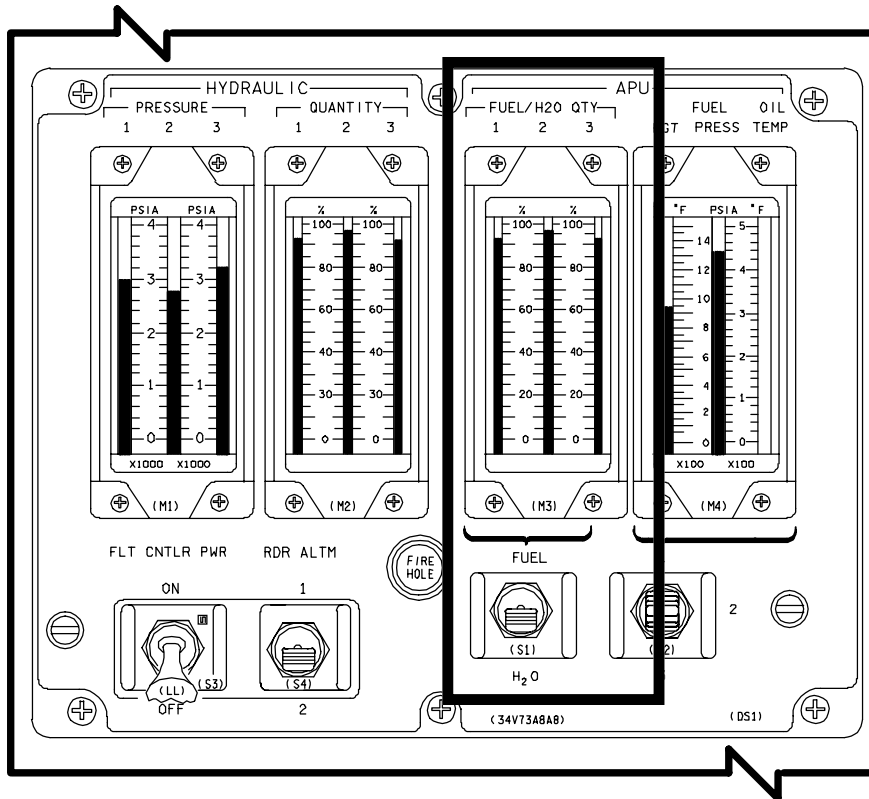
Redundant pressure and temperature sensors located downstream from the gaseous nitrogen pressure vessel and on the water tank for each boiler transmit the pressures and temperatures through each controller to the systems management general-purpose computer. The computer computes the water tank quantity from the pressure, volume, and temperature, and transmits the water tank quantity to panel F8 for each boiler. The switch below the meter on panel F8 is positioned to H_2O to allow the water quantity of each boiler to be displayed on the APU FUEL/ H_2O QTY 1, 2, or 3 meter. Water quantity is available when either the A or B controller is powered.

Downstream of the water storage tank, the feedwater lines to each water boiler split into

two parallel lines: one line goes to the hydraulic fluid flow section and one to the lube oil section of the WSB. The H_2O spray valves in each feedline are controlled independently by the boiler controller.

Temperature Control

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



APU FUEL/H2O QTY Meter and Switch on Panel F8

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

The core of each WSB is a stainless steel crimped-tube bundle. The hydraulic fluid section is divided into three 17-inch-long passes of smooth tubes (first pass-234 tubes, second pass-224 tubes, and third pass-214 tubes). The lube oil section of the APU comprises two passes with 103 crimped tubes in its first pass and 81 smooth tubes in the second pass. The tubes are 0.0125 of an inch in diameter with a wall thickness of 0.010 of an inch. Crimps located every 0.24 of an inch break up the internal

boundary layer and promote enhanced turbulent heat transfer. Although the second pass is primarily a low-pressure drop return section, approximately 15 percent of the unit's lube oil heat transfer occurs there. Three connected spray bars feed the hydraulic fluid section, while two spray bars feed the power unit's lube oil section in each boiler.

When the orbiter is in the vertical position on the launch pad, each boiler is loaded with up to 3.5 pounds of water, which is referred to as "pool mode" operation. When each APU/hydraulic system and WSB are in operation 5 minutes before lift-off, the APU lube oil tube bundle is immersed in the boiler water precharge. Liquid level sensors in each water boiler prevent the water feed valves from pulsing to avoid water spillage or loss. As the vehicle ascends during launch, the lube oil system of the APU heats up, eventually the boiler water precharge boils off, and the boiler goes into the spray mode about 8 minutes after launch. The hydraulic fluid usually does not heat up enough during ascent to require spray cooling.

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

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

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

Because of the unique hydraulic system fluid flows, control valves are located in the hydraulic system fluid line section of each WSB. Normally, hydraulic system fluid flows at up to 21 gallons per minute; however, the hydraulic system experiences 1- to 2-second flow spikes at up to 63 gallons per minute. If these spikes were to pass through the boiler, pressure drop would increase ninefold and the boiler would limit the flow of the hydraulic system. To prevent this, a relief function is provided by a spring-loaded poppet valve that opens when the hydraulic fluid pressure drop exceeds 48 psi and is capable of flowing 43 gallons per minute

at a differential pressure of 50 psi across the boiler. A temperature controller bypass valve allows the hydraulic fluid to bypass the boiler when the fluid temperature decreases to 190° F. At 210° F, the controller commands the bypass valve to direct the fluid through the boiler. When the hydraulic fluid cools to 190° F, the controller again commands the valve to route the fluid around the boiler. Bypass valve (BYP VLV) status is available on the following displays: SM SYS SUMM 2 (PASS AND BFS) and PASS DISP 86 APU/HYD.

Heaters

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

Main Hydraulic Pump

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

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

NOTE

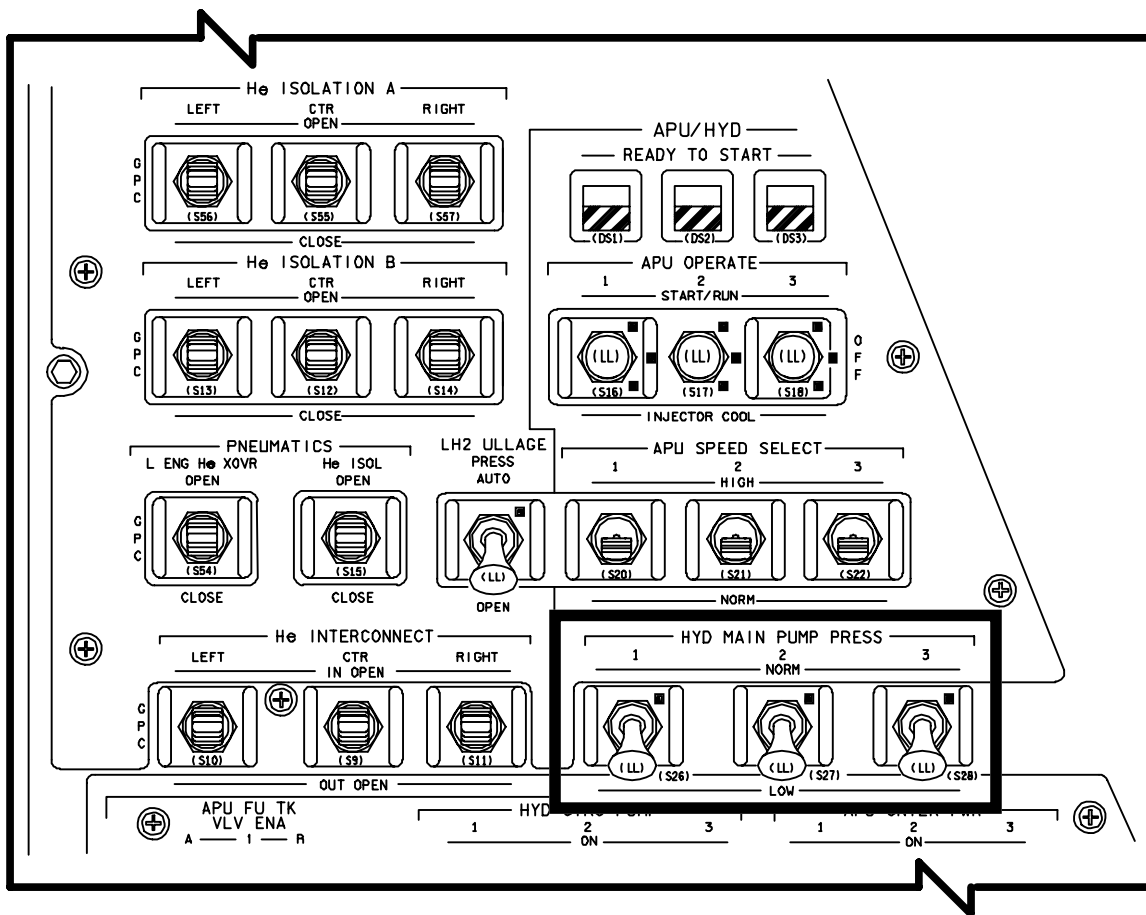
An APU cannot be successfully started with *HYD MAIN PUMP PRESS* positioned to *NORM*.

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

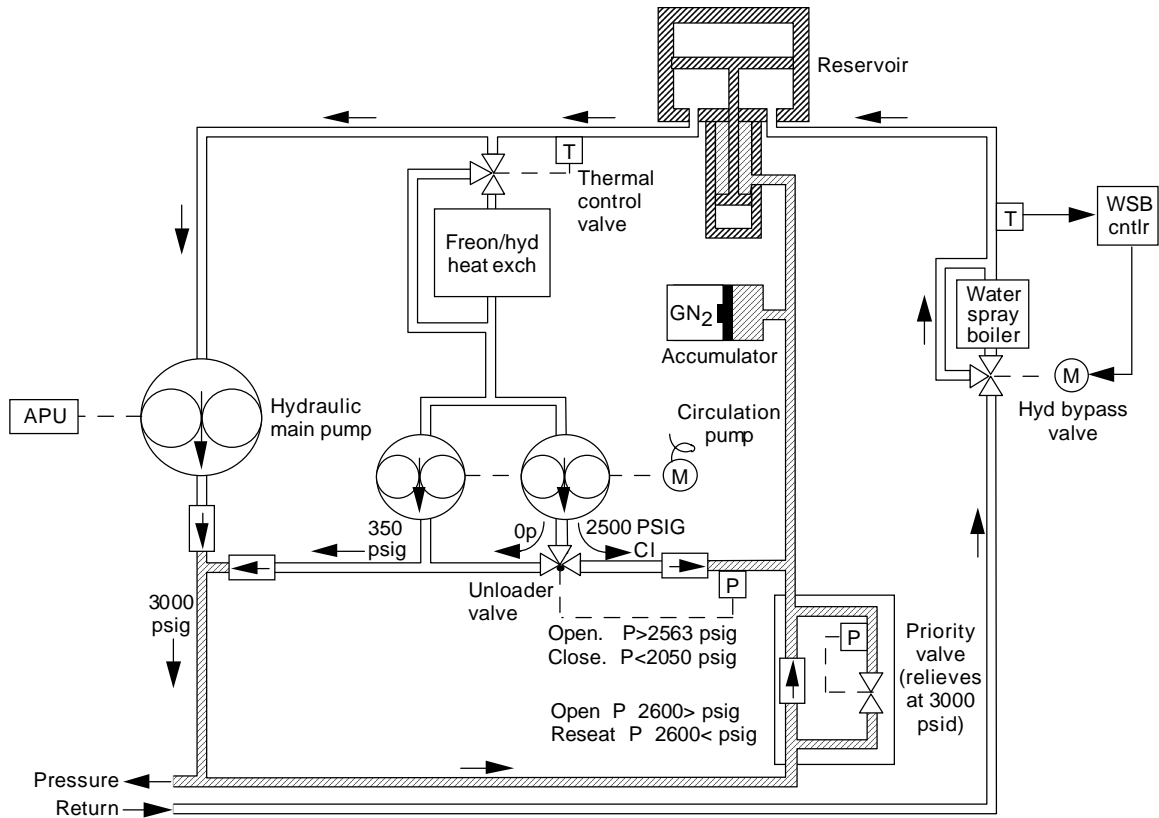
Main pump outlet pressure (HYD PRESS) can be seen by the crew on the BFS SM SYS SUMM

2 or PASS DISP 86 APU/HYD displays. A high-pressure relief valve in the filter module for each hydraulic system also relieves the hydraulic pump supply line pressure into the return line in the event the supply line pressure exceeds 3,850 psid.

A separate pressure sensor (sensor A) in the filter module for each hydraulic system monitors the hydraulic system source pressure and displays the pressure on the HYDRAULIC PRESSURE 1, 2, and 3 meters on panel F8. This hydraulic pressure sensor also provides an input to the yellow HYD PRESS caution and warning light on panel F7 if the hydraulic pressure of system 1, 2, or 3 is below 2,400 psi.



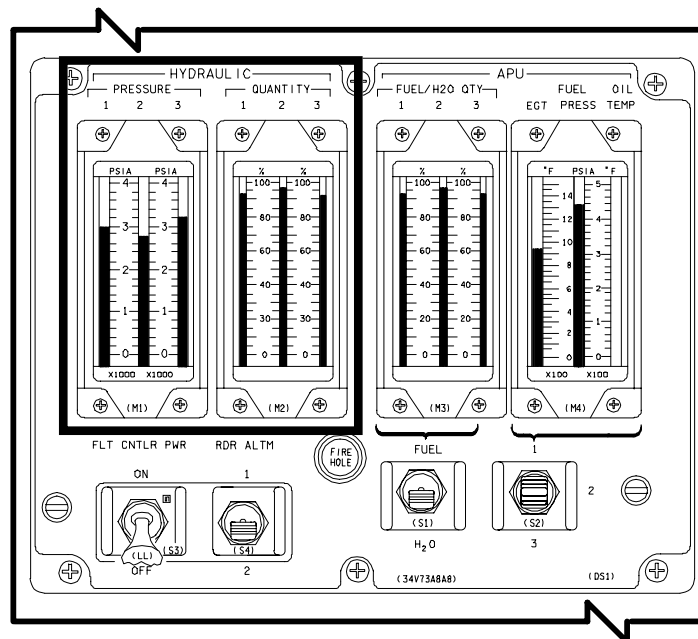
HYD MAIN PUMP PRESS 1, 2, 3 Switches on Panel R2



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

Pressure
 Return
 064.cvs

Hydraulic System (Control Section)



**HYDRAULIC PRESSURE and QUANTITY Meters on Panel F8
 (Driven by different sensor than CRT)**

Hydraulic Reservoir

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

The quantity in each reservoir is 8 gallons. The hydraulic fluid specification is MIL-H-83282, which is a synthetic hydrocarbon (to reduce fire hazards). The reservoir provides for volumetric expansion and contraction. The quantity of each reservoir is monitored in percent on the HYDRAULIC QUANTITY meters on panel F8. A pressure relief valve in each reservoir protects the reservoir from overpressurization and relieves at 120 psid.

Hydraulic Accumulator

The accumulator is a piston type precharged with gaseous nitrogen at 1,650 to 1,750 psi. The gaseous nitrogen capacity of each accumulator is 96 cubic inches, and the hydraulic volume is 51 cubic inches.

Circulation Pump and Heat Exchanger

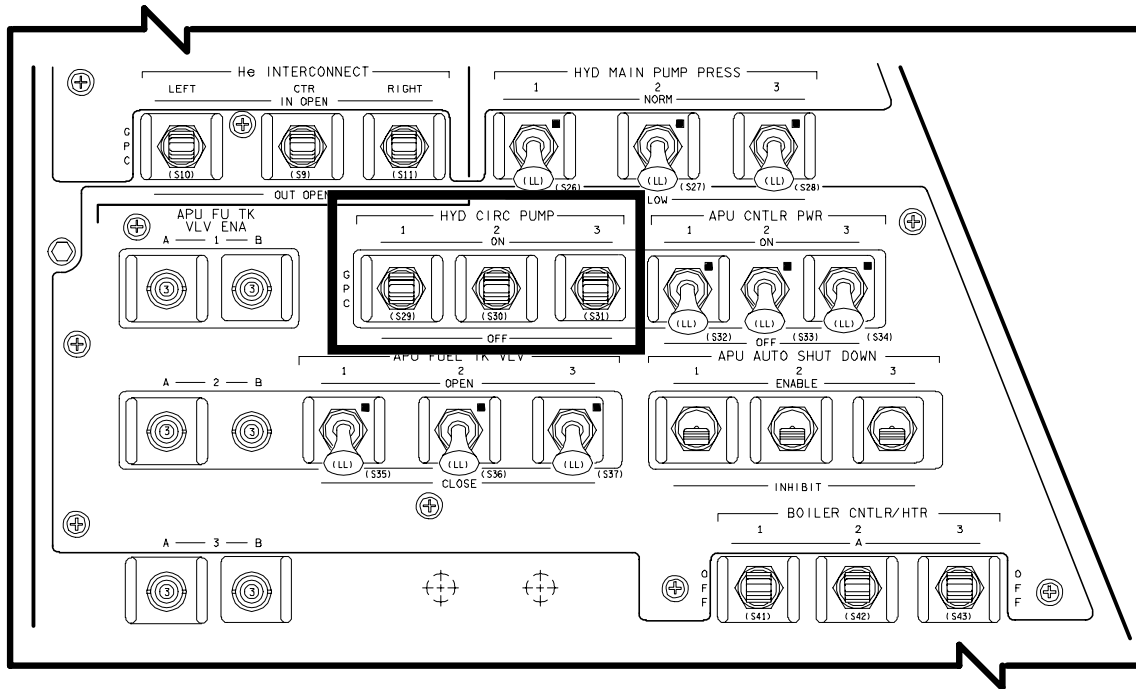
The circulation pump is actually two fixed-displacement gear-type pumps in tandem, driven by a single motor. One is a high pressure, low-volume pump (2,500 psig), which is used to maintain accumulator pressure while the hydraulic system is inactive in orbit. The other is a low pressure, high-volume pump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

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

0001/ /079		SM SYS SUMM 2			5 008/23:29:22		
					BFS 000/00:00:00		
					MANF1 MANF2		
CRYO TK	1	2	3	4	5		
H2 PRESS	208	208	206	206	206	208	207
O2 PRESS	816	815	814	814	814	815	815
HTR T1	-248	-248	-248	-248	-248		
T2	-248	-248	-248	-248	-248		
APU	1	2	3		HYD	1	2
TEMP EGT	942	942	942		PRESS	3064	3064
B/U EGT	942	942	942		ACUM P	3080	3080
OIL IN	250	250	250		RSVR T	116	153
OUT	264	264	264				142
GG BED	511H	511H	511H		QTY	72	74
INJ	1271	1271	1271			71	71
SPEED %	99	102	101		W/B		
FUEL QTY	59	60	62		H2O QTY	78	73
PMP LK P	14	14	14		BYP VLV	BYP	BYP
OIL OUT P	42	42	41				
FU TK VLV							
A T	63	65	62		THERM CNTL	1	28
B T	63	65	62		H2O PUMP P	23	63
AV BAY	1	2	3		FREON FLOW	2384	2384
TEMP	97	97	83		EVAP OUT T	38	38
A4 14		27.439	27.435			26.324	31.873
						18.48	

051

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



HYD CIRC PUMP Switches on Panel R2

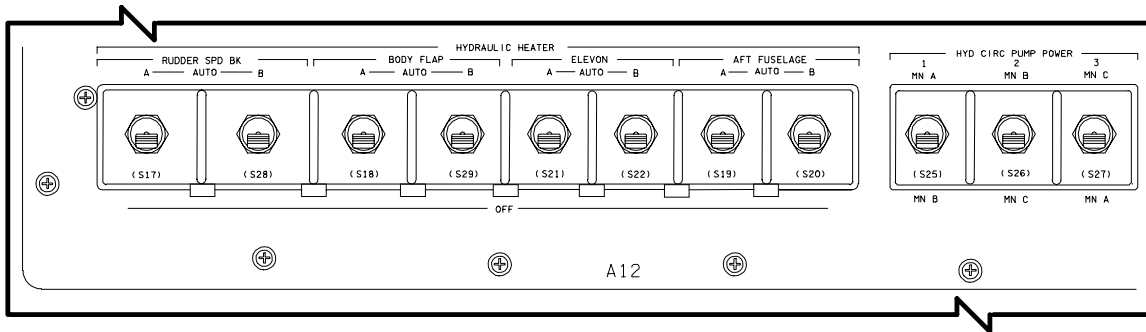
Each circulation pump can be manually turned on or off with the corresponding *HYD CIRC PUMP* switch on panel R2. If the switch is placed in GPC, the pump will be activated and deactivated by the SM GPC according to a control software program based on certain hydraulic line temperatures and/or accumulator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

The program also includes a timer to limit the maximum time a circulation pump will run, and a priority system to assure that only one circulation pump is on at a time (because of excessive power usage if more than one circulation pump is on). Each circulation pump uses 2 kW of electrical power. This software will also automatically provide for the

repressurization of the hydraulic accumulator when the pressure lowers to a value of 1,960 psi. In this contingency, the circulation pump will first receive the highest priority to operate and will be turned ON while other circulation pumps are operating in thermal mode (this means that two pumps can be operating simultaneously). After the pump has been repressurized, the accumulator above 1,960 psi, or a period of 2 minutes (this value can be changed by Mission Control Center uplink) has elapsed, the circulation pump will be commanded to OFF. It is possible to run all three circulation pumps at the same time to repressurize accumulators.

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

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



Hydraulic System Controls on Panel A12

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

SM HYD THERMAL Display (DISP 87)

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

Hydraulic Heaters

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

Operations

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

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

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

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

Two hours after lift-off, the steam vent heaters of the WSBs are turned on and left on for about 1.5 hours to eliminate all ice from the steam vents.

Two hours and twenty minutes into the flight, while in the Post Insertion Checklist, the hydraulic thermal conditioning is enabled by taking the hydraulic circulation pumps to GPC. Further, the HYD CIRC PUMP POWER switch(es) on panel A12 will be configured to distribute electrical loads when appropriate.

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

On the day before deorbit, one APU is started to supply hydraulic pressure for flight control system checkout. (Hydraulic pressure is needed to move the orbiter aerosurfaces as part of this checkout.) The associated WSB controller is activated, landing gear isolation valves 2 and 3 are closed, and one APU (selected by the Mission Control Center) is started. The hydraulic main pump is set to normal pressure (approximately 3,000 psi), and aerosurface drive checks are made. After about 5 minutes, the checks are complete, and the APU is shut down. Normally, the unit does not run long enough to require WSB operation. The landing gear isolation valves on hydraulic systems 2 and 3 are reopened after the APU is shut down.

At 2.5 hours before the deorbit burn, the boilers' steam vent heaters are activated to prepare the system for operation during atmospheric entry. At about the same time, the landing gear isolation valves on hydraulic systems 2 and 3 are closed, and the circulation pumps are turned off.

At 45 minutes before deorbit, the WSB water tanks are pressurized, the APU controllers are activated, and the main hydraulic pumps are set to low pressure. The pilot opens the fuel tank valves and looks for three gray APU/HYD READY TO START talkbacks. The pilot then closes the fuel tank valves. This procedure takes place while the crew is in contact with the ground so that flight controllers can observe APU status. Five minutes before the deorbit burn, one APU (selected by Mission Control) is started to ensure that at least one unit will be operating for entry. The hydraulic pump is left in low-pressure operation. The APU operates through the deorbit burn. At 13 minutes before entry interface (400,000-foot altitude), while the orbiter is still in free fall, the other two APUs are started, and all three hydraulic pumps are pressurized to normal. Two main engine hydraulic isolation valves are cycled open and then closed to ensure that the engines are stowed for entry. Two minutes later, if required, the aerosurfaces are put through an automatic cycle sequence to make sure warm hydraulic fluid is available in the aerosurface drive units.

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

APU/HYD Caution and Warning Summary

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

O ₂ PRESS	H ₂ PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O ₂ HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H 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

070

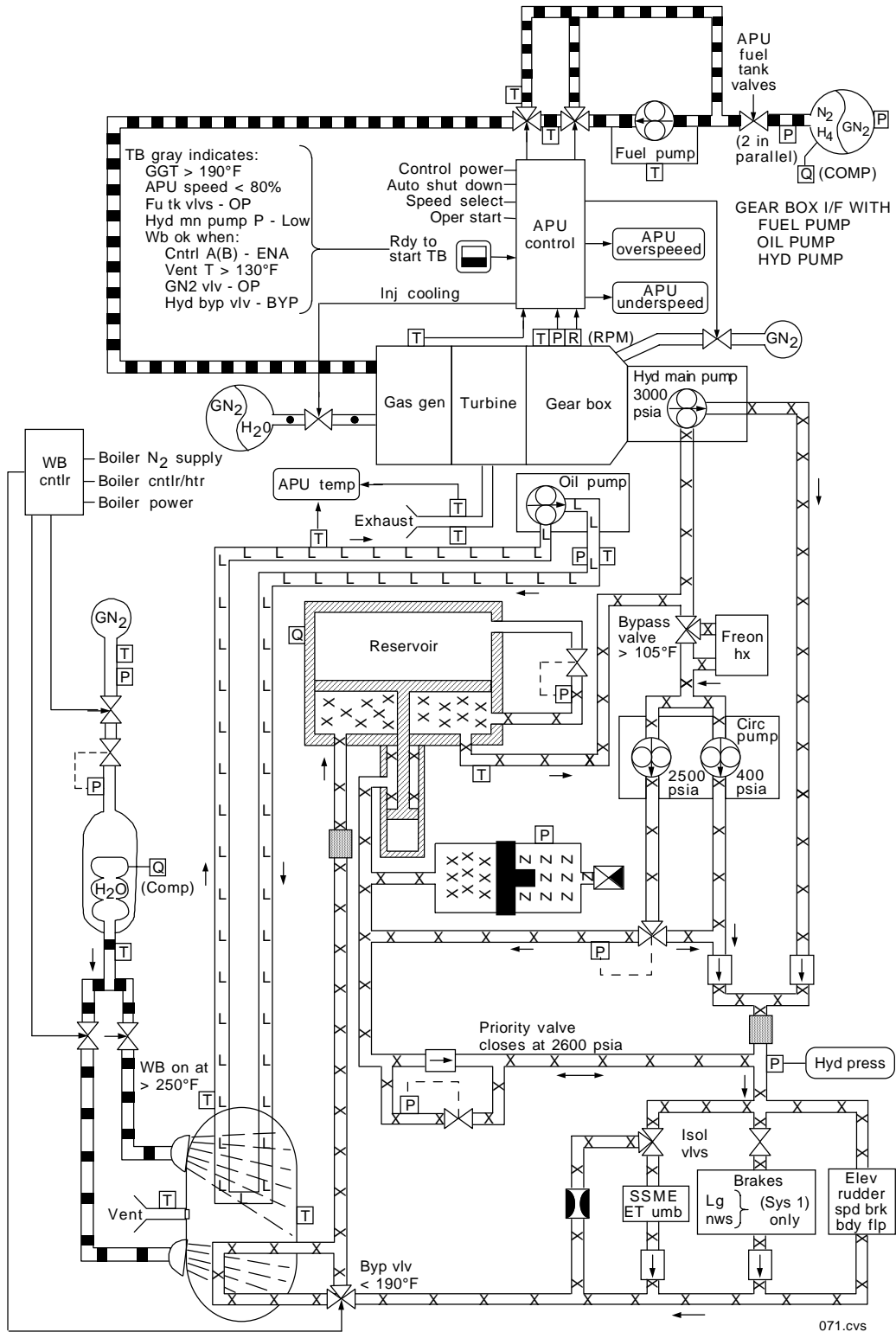
APU/HYD Caution and Warning Lights on Panel F7

APU/HYD Summary Data

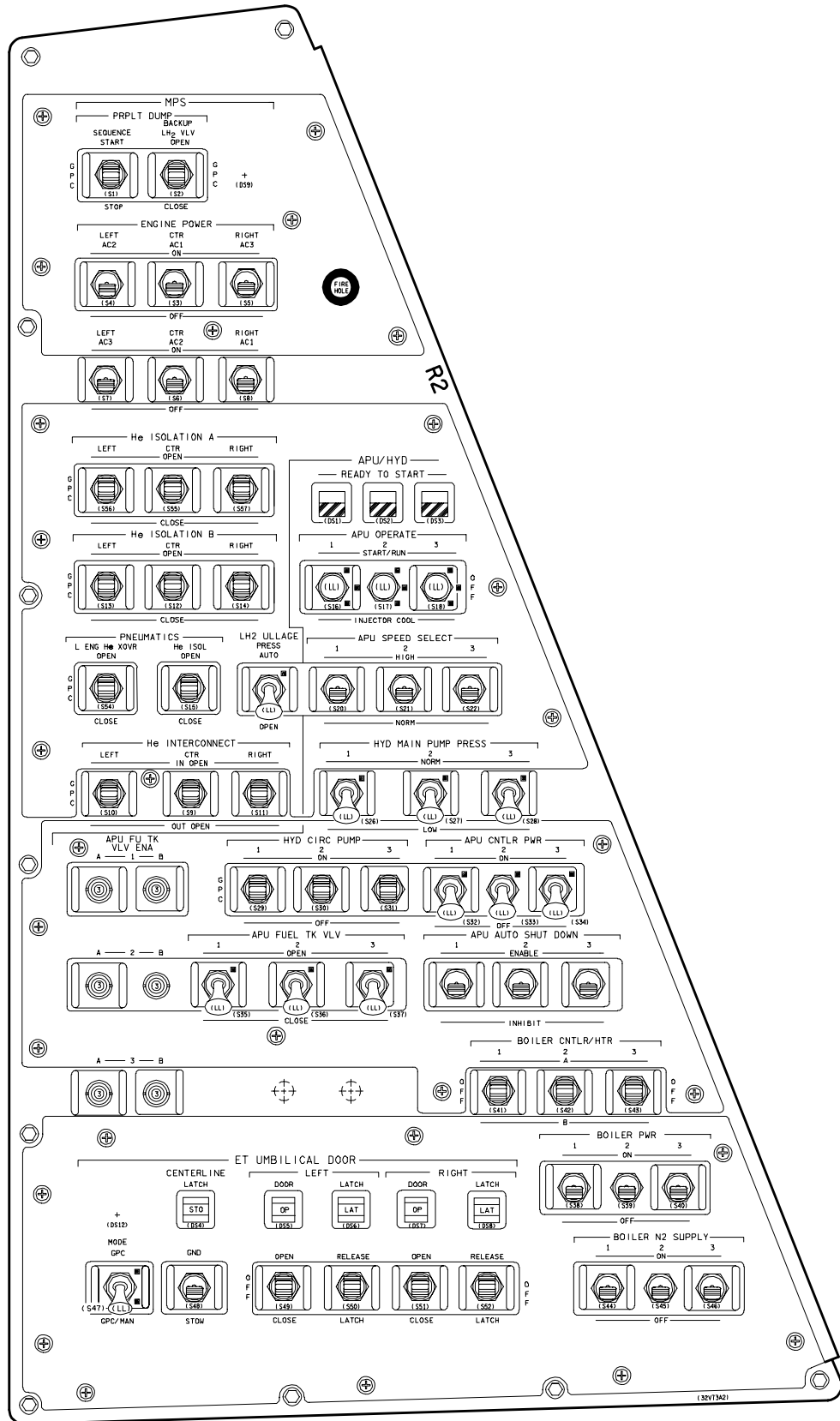
- The APU is a hydrazine-fueled, turbine-driven power unit that generates mechanical shaft power to drive a hydraulic pump that produces pressure for the orbiter's hydraulic system.
- The three orbiter hydraulic systems provide pressure to position hydraulic actuators for: gimbaling SSMEs, actuating SSME control valves, moving orbiter aerosurfaces, retracting ET disconnect umbilicals, deploying landing gear, and providing brake power, anti-skid, and nose wheel steering.
- The APUs are located in the aft fuselage of the orbiter.
- Each APU/HYD system has an independent water spray boiler for APU lube oil and hydraulic fluid cooling. Water is used after APU shutdown for injector cooling if a hot restart is required. The APUs share a central supply tank for injector cooling.
- The three APUs are started 5 minutes before lift-off. They continue to operate throughout the launch phase, and are shut down after the main engine propellant dump and stow are completed (post OMS-1). The APUs are restarted for entry: one APU prior to the deorbit burn, and the other two prior to entry interface.
- Each APU fuel tank load is approximately 325 pounds of hydrazine.
- APU/HYD controls are located on Panel R2; heater controls are on panel A12.
- CRTs that display APU/HYD information include the PASS and BFS SM SYS SUMM 2 display (DISP 79), APU/HYD display (DISP 86), HYD THERMAL (DISP 87), and APU/ENVIRON THERM (DISP 88).
- Several meters for monitoring APU/HYD parameters are located on panel F8.
- APUs can be manually shut down and restarted after completion of a full injector water cooling cycle (3.5 minutes), or after approximately 180 minutes of passive cooling on orbit.

APU/HYD Rules of Thumb

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

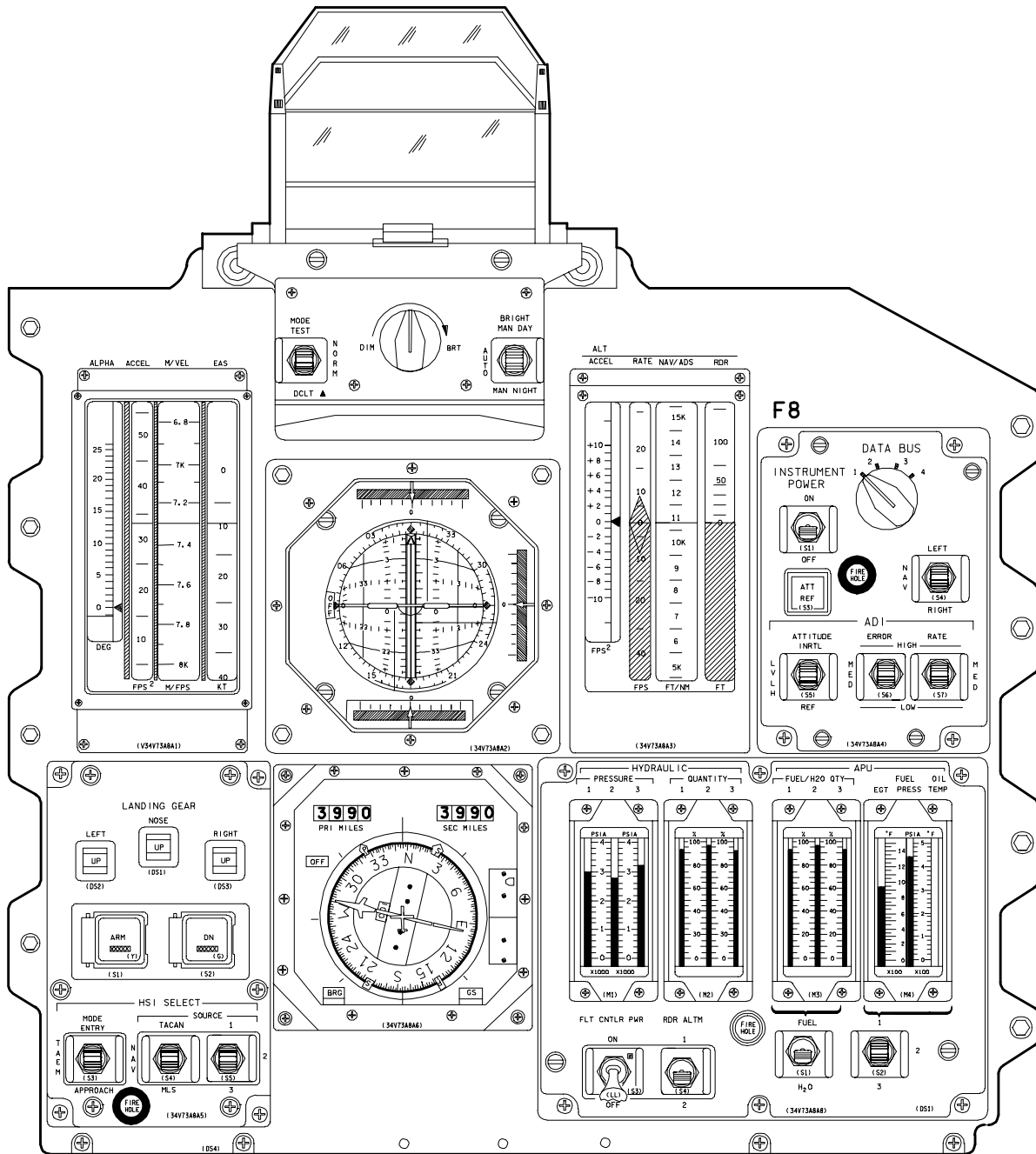


APU/Hydraulic Overview

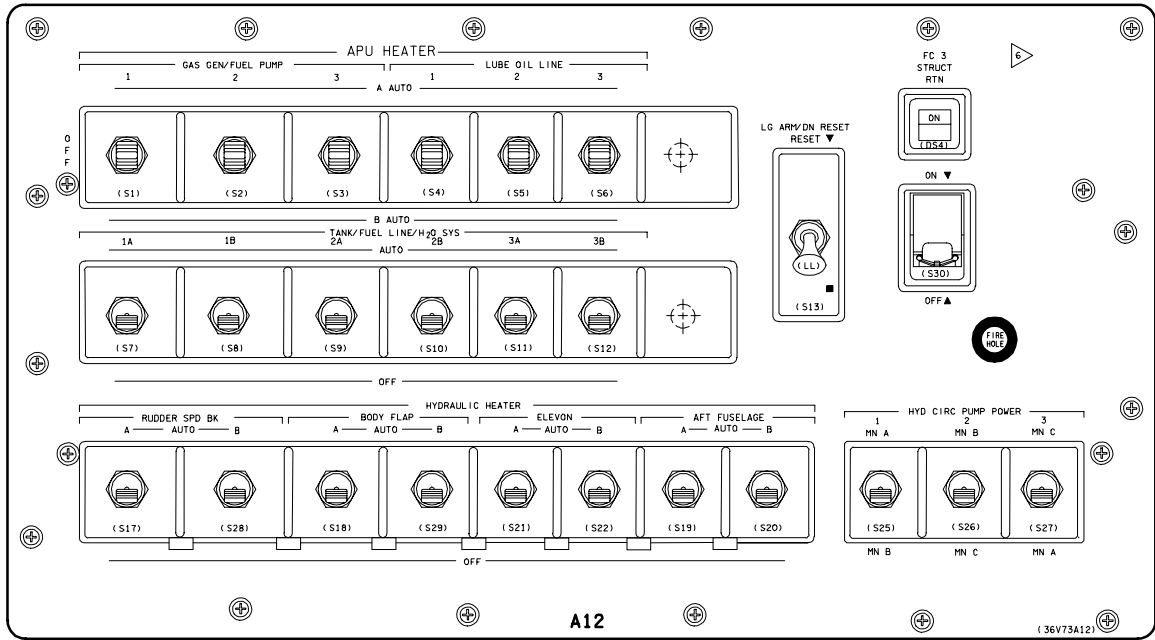


Panel R2

(327342)



Panel F8



Panel A12

0001/ /079		SM SYS SUMM 2			5 008/23:29:22		
					BFS 000/00:00:00		
					5 MANF1 MANF2		
CRYO TK	1	2	3	4			
H2 PRESS	208	208	206	206	206	208	207
O2 PRESS	816	815	814	814	814	815	815
HTR T1	-248	-248	-248	-248	-248		
T2	-248	-248	-248	-248	-248		
APU	1	2	3	HYD	1	2	3
TEMP EGT	942	942	942	PRESS	3064	3064	3064
B/U EGT	942	942	942	ACUM P	3080	3080	3080
OIL IN	250	250	250	RSVR T	116	153	142
OUT	264	264	264				
GG BED	511H	511H	511H	QTY	72	74	71
INJ	1271	1271	1271				
SPEED %	99	102	101	W/B			
FUEL QTY	59	60	62	H2O QTY	78	73	78
PMP LK P	14	14	14	BYP VLV	BYP	BYP	BYP
OIL OUT P	42	42	41				
FU TK VLV							
A T	63	65	62	THERM CNTL	1	28	
B T	63	65	62	H2O PUMP P	23	63	
AV BAY	1	2	3	FREON FLOW	2384	2384	
TEMP	97	97	83	EVAP OUT T	38	38	
A4 14	27.439	27.435	26.324	31.873	18.48		

051

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

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

068

SM HYD THERMAL Display (PASS DISP 87)

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

059

SM APU/HYD Display (PASS DISP 86)

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

078

APU/ENVIRON THERM (PASS DISP 88)

2.2 CAUTION AND WARNING SYSTEM (C/W)

CONTENTS	
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Operations.....	2.2-11
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Description

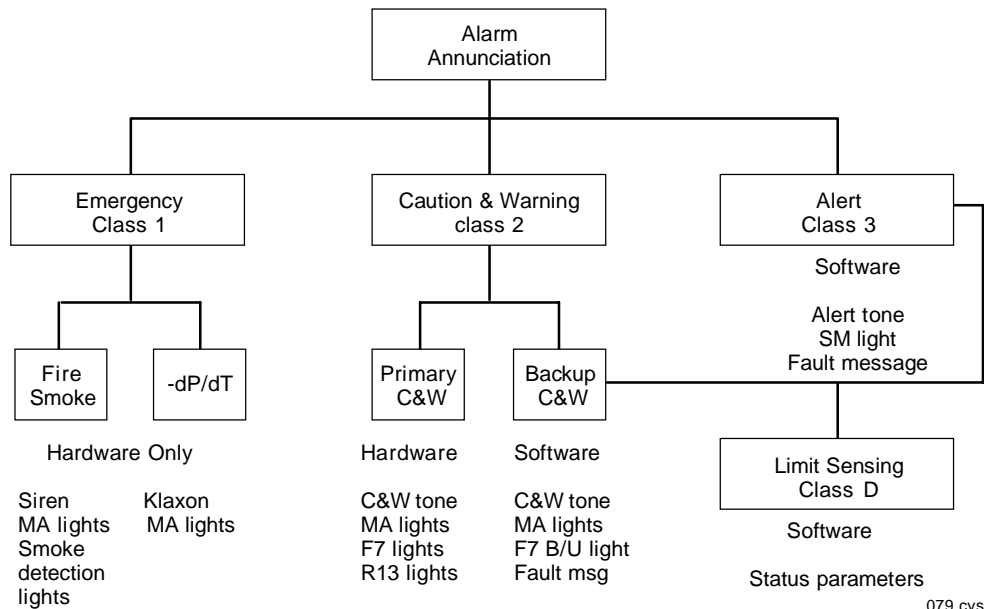
The caution and warning system warns the crew of conditions that may create a hazard to orbiter operation and/or crew. Under certain circumstances, the system also alerts the crew to situations that require time-critical (under 5 minutes) procedures to correct them. The system uses data such as temperature, pressure, flow rates, and switch positions to determine whether an alarm situation exists.

The system consists of software and electronics that provide the crew with visual and aural cues when a system exceeds predefined operating limits. Visual cues consist of four red MASTER ALARM lights, a 40-light array on panel F7, a 120-light array on panel R13U, and CRT messages. The aural cue is sent to the communications system for distribution to flight crew headsets or speaker boxes.

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

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

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



Caution and Warning Diagram

Alarms

Four alarm classes constitute the C/W system.

Class 1 - Emergency

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

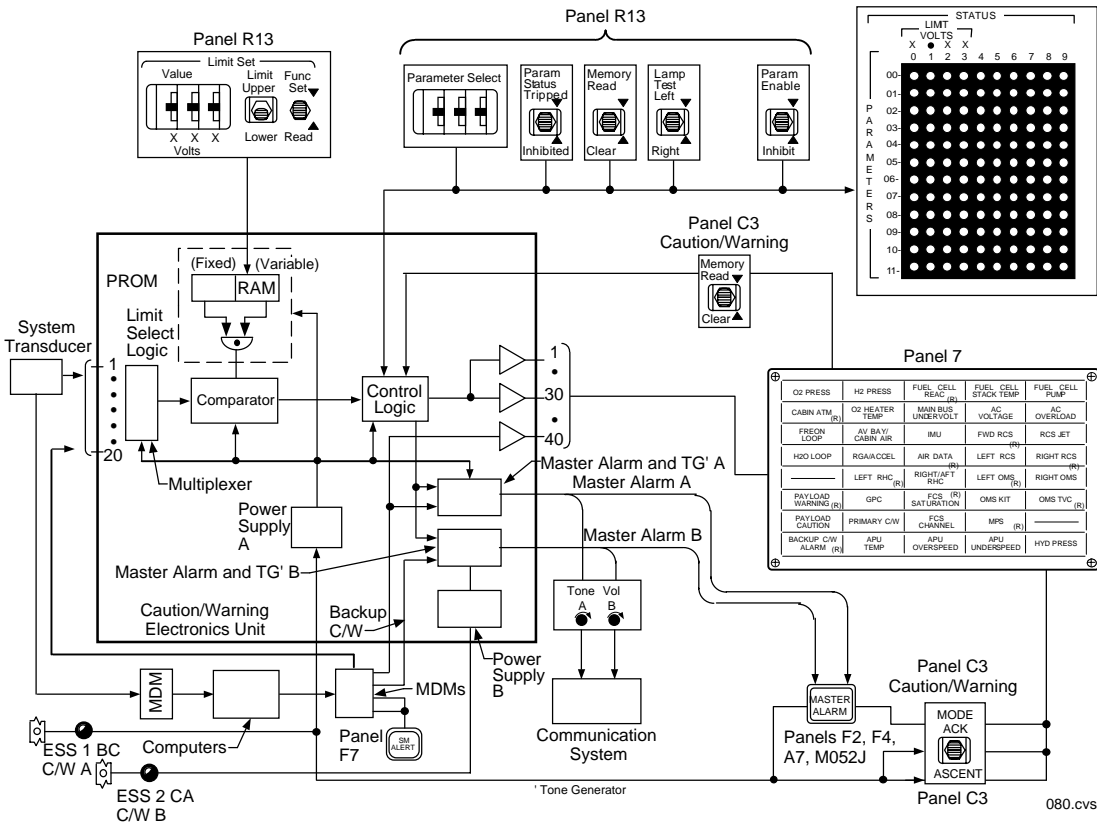
The emergency (class 1) aural alarms consist of a siren (activated by the smoke detection system) and a klaxon (activated by the delta pressure/delta time sensor that recognizes a rapid loss of cabin pressure), and they are annunciated by hardware. The siren's frequency varies from 666 to 1,470 hertz and

returns at a five-second-per-cycle rate. The klaxon is a 2,500-hertz signal with an on/off cycle of 2.1 milliseconds on and 1.6 milliseconds off, mixed with a 270-hertz signal with a cycle of 215 milliseconds on and 70 milliseconds off.

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

Class 2 - C/W

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



Caution and Warning System Overview

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

When a primary C/W alarm is issued, the appropriate lamp on the panel F7 annunciator matrix is illuminated, all four MASTER ALARM indicators are illuminated, the C/W tone sounds, and the appropriate lamp on the panel R13U parameter status light matrix is illuminated. No CRT fault message is generated by the primary C/W.

The primary C/W system receives power from power supply A from the C/W A circuit breaker powered by ESS 1BC on panel 013, and power supply B from C/W B circuit breaker powered by ESS 2CA on panel 013.

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

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

The backup C/W (class 2) system is part of the systems management fault detection and annunciation (FDA), GNC, and backup flight system software programs. Only the 69 backup C/W alarms that are produced by FDA (software that monitors parameters and initiates

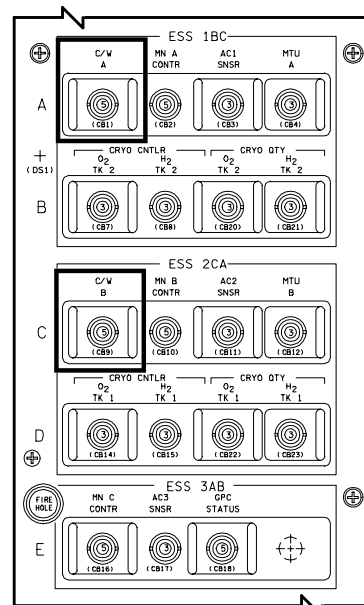
alarms) have limits that can be changed and displayed in engineering units accessed through the SM TABLE MAINTENANCE specialist function display (SPEC 60). The remaining backup C/W alarms that are produced by the guidance and navigation program are accessed through general-purpose computer read/write procedures. A backup C/W out-of-tolerance condition will trigger illumination of the four MASTER ALARM lights, illuminate the red BACKUP C/W ALARM light on panel F7, and display a message on the fault message line and fault summary page.

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

081.ovs

Caution and Warning Annunciator Matrix on Panel F7

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



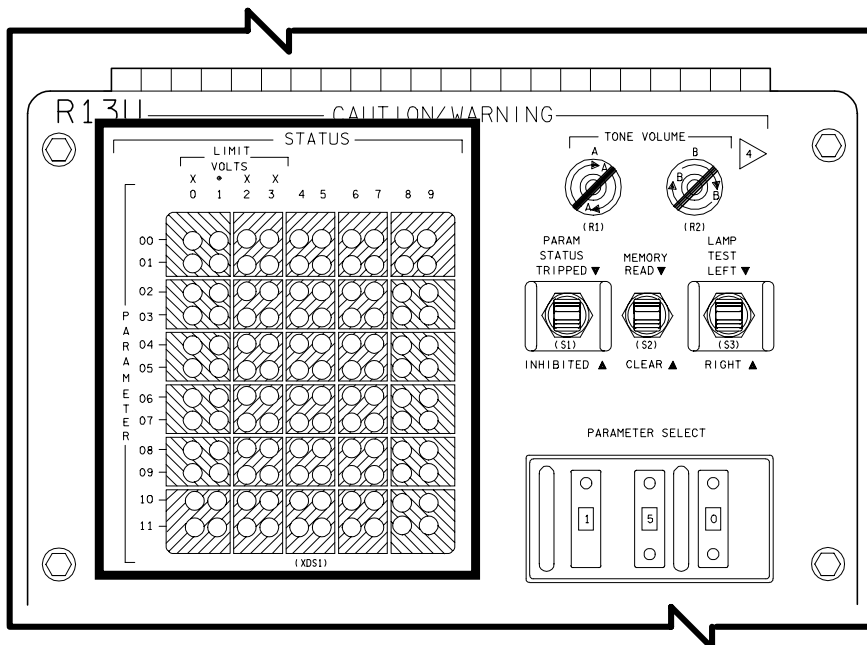
C/W Circuit Breaker on Panel 013

The class 2 (C/W) aural master alarm is activated by the primary (hardware) system, the backup (software) system, or both. The C/W tone is an alternating 375 hertz and 1,000 hertz at a 2.5 hertz rate. The alternating C/W alarm tone is generated when the hardware system detects an out-of-limit condition on any of the 120 parameters it monitors or when the software (backup) system detects a parameter that is out of limits.

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

C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME
0	CRYO O2 P TK1	25	GPC 3	50	CRYO H2 P TK1	*75	L RHC	100	L RHC
1	CRYO O2 HTR1 TK1	26	RCS LEAK/TK P - F	51	CRYO O2HTR 2 TK3	76	RCS TK P FU- R	101	FCS SATURATION
2	TC1 REAC O2	27	OMS ENG - L	52	FC3 REAC H2	*77	APU 2 OVERSPEED	102	FC2 COOL PUMP
3	DC VOLT MAIN A	28	APU 3 EGT	53	AC3 VOLT (φA, B, C)	78	MPS MANF P LH2	103	IMU
4	CAB PRESS	29	MPS HE TK P - R	54	CAB N2 FLOW 1	79	CRYO H2 P TK 4/5	104	AV BAY 3 TEMP
5	GPC 1	30	CRYO O2 P TK 4/5	*55	RCS LEAK/TK P - L	*81	FC3 STACK T	105	H2O LOOP 1 PUMP OUT P
6	RCS TK P OX - F	31	CRYO O2 HTR 2 TK2	56	OMS ENG - R	82	AC3 OVLD	106	FREON LOOP 1 FREON FLOW
7	OMS TK P OX - L	32	FC2 REAC H2	57	APU 3 OIL T	83	AV BAY 1 TEMP	107	FREON LOOP 1 EVAP OUT T
8	APU 1 EGT	33	AC1 VOLT (φA, B, C)	58	MS HE REG P - R	*85	RCS LEAK/TK P - R	108	APU 2 UNDERSPEED
9	MPS HE TK P - C	34	CAB PPO2 A	59	CRYO H2 P TK2	*87	APU 3 OVERSPEED	109	HYD 2 P
10	CRYO O2 P TK2	35	GPC 4	60	CRYO O2 HTR 1 TK4	*89	ADTA	110	R/AFT RHC
11	CRYO O2 HTR 2 TK1	36	RCS TK P OX - L	61	FC1 STACK T	*90	FC1 COOL PUMP	111	FCS CH BYPASS
12	FC1 REAC H2	37	OMS TK P OX - R	62	APU 1 OVERSPEED	91	RGAA/AA	112	FC3 COOL PUMP
13	DC VOLT MAIN B	38	APU 1 OIL T	63	MPS MANF PL O2	92	PL WARNING	*113	CAB HX OUT T
14	CAB O2 FLOW 1	39	MPS HE REG P - C	64	CRYO O2 HTR 2 TK2	93	RCS JET	114	HWO LOOP 2 PUMP OUT P
15	GPC 2	*40	CRYO O2 HTR 1 TK3	66	OMS TVC	94	PL CAUTION	115	FREON LOOP 2 FREON FLOW
16	RCS TK P FU - F	41	FC3 REAC O2	67	APU 2 OVERSPEED	95	APU 1 UNDERSPEED	116	FREON LOOP 2 EVAP OUT T
17	OMS TK P FU - L	42	AC2 VOLT (φA, B, C)	68	MPS HE REG P - L	96	HYD 1 P	117	APU 3 UNDERSPEED
18	APU 2 EGT	43	CAB PPO2 B	69	CRYO O2 P TK3	97		118	HYD 3 P
19	MPS HE TK P - L	44	GPC 5	70	CRYO O2 HTR 2 TK4				
20	CRYO O2 P TK34	45	RCS TK P FU - L	71	OMS TK P FU - R				
21	CRYO O2 HTR 1 TK2	46	OMS TK P FU - R	72	APU 2 OIL T				
22	FC2 REAC O2	47	APU 2 OIL T	73	MPS HE REG P - L				
23	DC VO MAIN C	48	MPS HE REG P - L	74					
24	CAB O2 FLOW 2	49							

Hardware Caution and Warning Table



Parameter Status Light Matrix on Panel R13U

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

Class 3 - Alert

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

Both guidance, navigation, and control (GNC) and systems management (SM) software sense out-of-limit conditions. These software systems also serve some less critical parameters and annunciate the systems management alert tone. The SM alert tone is a steady tone of 512 hertz of predefined duration generated in the C/W electronics when activated by inputs from the onboard computers.

Class 0 - Limit Sensing

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

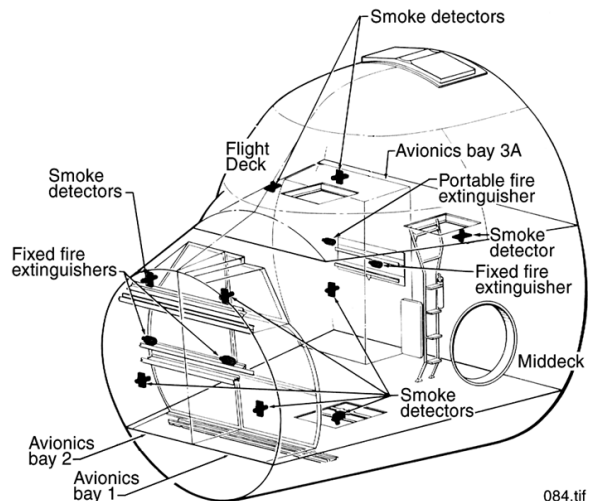
A down arrow displayed next to a parameter would indicate that the low limit for that parameter had been met or violated. In addition, the down arrow is used to indicate a state that does not agree with the nominal state; for example, a fan that is nominally on (e.g., HUM SEP fan) is off.

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

Smoke Detection and Fire Suppression

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

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



Smoke Detection and Fire Suppression System

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

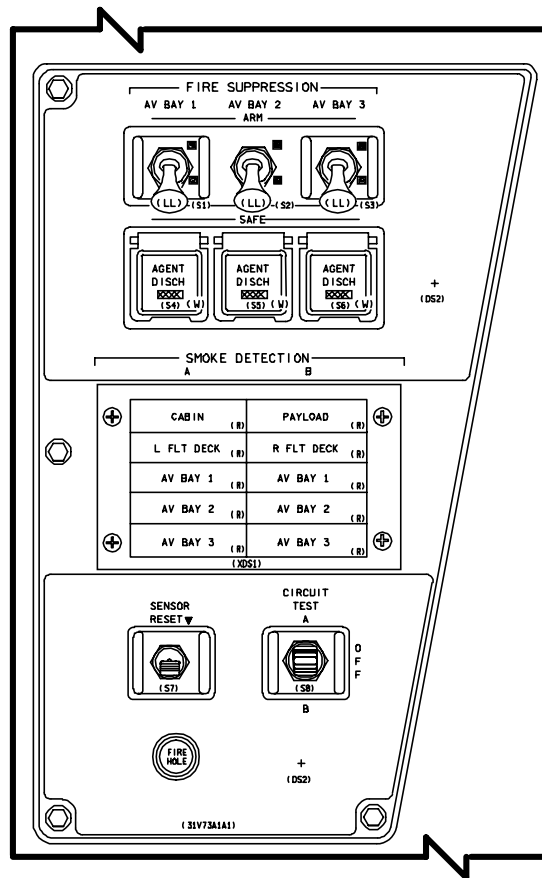
If an ionization detection element senses a smoke particle concentration of 2,000 (± 200) micrograms per cubic meter for at least 5 seconds and/or a rate of smoke increase of 22 micrograms per cubic meter per second for eight consecutive counts in 20 seconds, a trip signal illuminates the applicable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

0001/ /078	SM SYS SUMM 1	5	000/03:13:09
			BFS 000/00:00:00
SMOKE	1/A 2/B	DC VOLTS	1/A 2/B 3/C
CABIN	- 0.9	FC	31.1 31.1 31.1
L/R FD	- 0.4 0.2	MAIN	31.0 31.1 31.0
AV BAY 1-	1.2 - 0.0	CNTL AB	29.3 29.3 29.3
2-	0.6 0.3	BC	29.3 29.3 29.3
3-	0.1 - 0.9	CA	29.3 29.3 29.3
		ESS	29.8 29.8 29.8
CABIN		AC	
PRESS	14.7	VOLT ϕ A	117 117 117
dP/dT	+0.00	ϕ B	117 117 117
BU/EQ	-0.00 +0.00	ϕ C	117 117 117
PP02	3.02 3.02	AMPS ϕ A	4.4 4.1 2.7
FAN P	5.79	ϕ B	3.9 4.2 3.2
HX OUT T	49	ϕ C	2.4 3.2 4.8
N2 FLOW	0.0	FUEL CELL PH	
IMU FAN Δ P	4.62	AMPS	172 167 178
Δ V FC1 FC2 FC3		REAC VLV	0P 0P 0P
SS1	15 18 18	STACK T	+204 +203 +203
SS2	16 20 11	EXIT T	150 150 151
SS3	22 26 26	COOL P	61 61 61
TOTAL AMPS	510	PUMP	
KW	15		

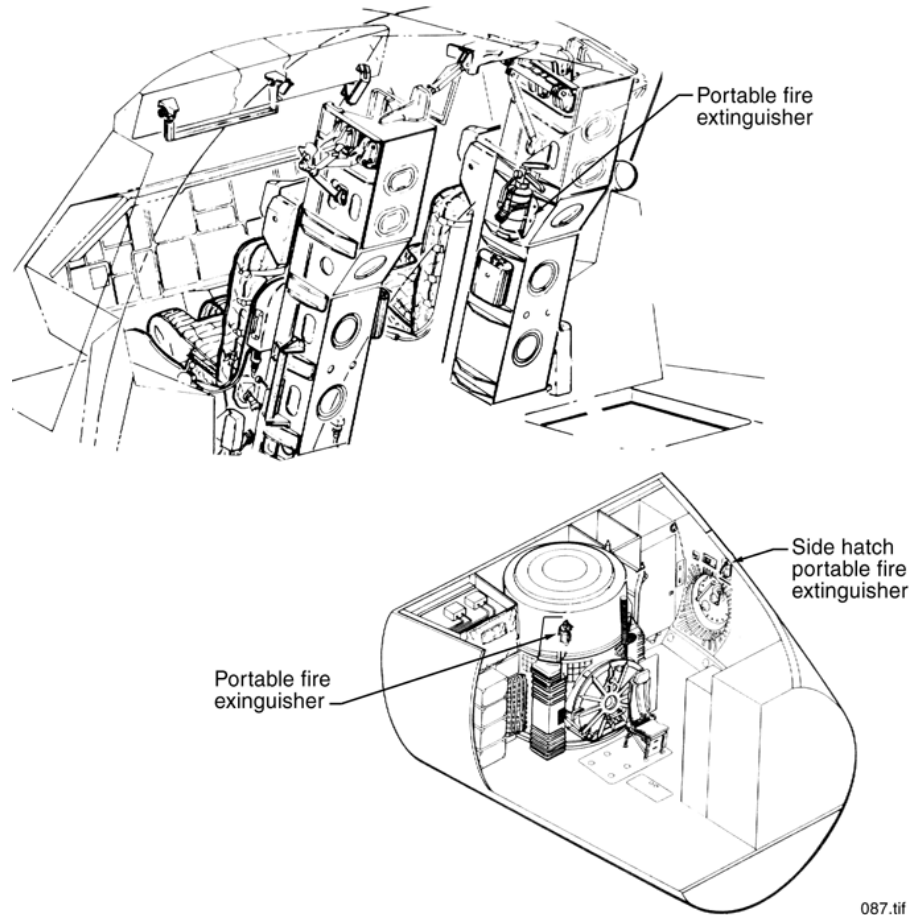
SM SYS SUMM 1 (DISP 78)

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

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



FIRE SUPPRESSION Switches and Push Buttons and SMOKE DETECTION Lights on Panel L1

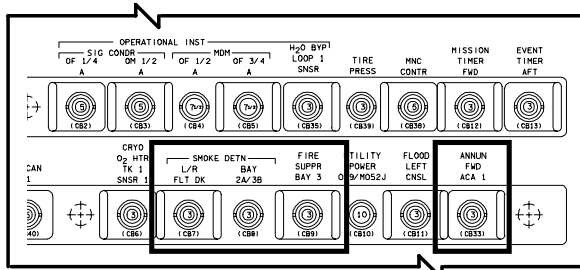


Fire Extinguisher Locations

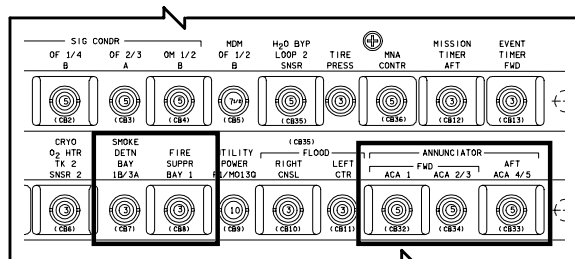
Fire suppression in the crew cabin avionics bays is provided by three Halon extinguisher bottles permanently mounted in avionics bays 1, 2, and 3A. Each bottle contains 3.74 to 3.8 pounds of Halon in a pressure vessel that is 8 inches long and 4.25 inches in diameter. To activate the applicable bottle in an avionics bay, the corresponding *FIRE SUPPRESSION* switch on panel L1 is positioned to *ARM*, and the corresponding *AGENT DISCH* pushbutton indicator on panel L1 is depressed for at least 2 seconds. The *AGENT DISCH* pushbutton indicator activates the corresponding pyro initiator controller, which initiates a pyrotechnic valve on the bottle to discharge the Halon into the avionics bay. The discharge of Halon will produce a noise of approximately 130 decibels in the avionics bay. The discharge will give a Halon concentration in the avionics bay of 7.5 to 9.5 percent. A 4 to 5 percent concentration is required to suppress a fire. This concentration will provide protection for approximately 72

hours. When the bottle is fully discharged, the pushbutton indicator white light will be illuminated. The white light will be illuminated if the pressure in an avionics bottle falls below 60 ± 10 psig.

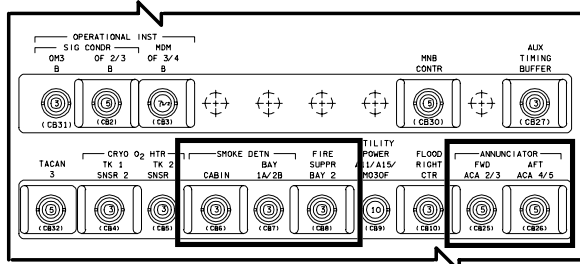
Red *SMOKE DETECTION* lights on panel L1 are illuminated by the following: the *CABIN* light is illuminated by a smoke detection ionization element in the ECLSS cabin fan plenum, the *L FLT DECK* light is illuminated by the crew cabin left flight deck return air duct smoke ionization element, the *R FLT DECK* light is illuminated by the crew cabin right flight deck return air duct smoke ionization element, and the *PAYLOAD* light is illuminated by the smoke detection ionization elements in the Spacelab pressurized module. The applicable smoke detection ionization element illuminates the applicable red *AV BAY* light on panel L1, activates the *C/W MASTER ALARM* red light, and sounds the siren in the crew cabin.



Fire and Smoke Subsystem Control Circuit Breakers on Panel 014



Fire and Smoke Subsystem Control Circuit Breakers on Panel 015



Fire and Smoke Subsystem Control Circuit Breakers on Panel 016

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

Three hand-held fire extinguishers are available in the crew cabin. Two are located in the crew cabin middeck, and one is on the flight deck. Each fire extinguisher nozzle is tapered to fit fire hole ports located in several display and control panels. The holes are of two types: a 1/2-inch diameter hole covered with a marked label, and an unmarked 1/2- to 1/4-inch diameter tapered hole. These holes give access to the volume immediately behind the individual panel. To suppress a fire behind a panel or within an avionics bay, the extinguisher nozzle should be inserted into the fire hole and the actuating mechanism depressed for 15 seconds. This will ensure a complete discharge. The extinguishing agent is Halon-1301 (monobromotrifluoromethane). Halon-1301 minimizes the major hazards of a conflagration: smoke, heat, oxygen depletion, and formation of pyrolysis products such as carbon monoxide. The fire extinguishers are 13 inches long. The portable fire extinguishers can also be used as a backup for extinguishers in the avionics bays. Consideration should be given to the reactive force on the crewmember when discharging the extinguishers on orbit.

Halon 1301

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

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

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

- 7 percent and below: 15 minutes
- 7 to 10 percent: 1 minute

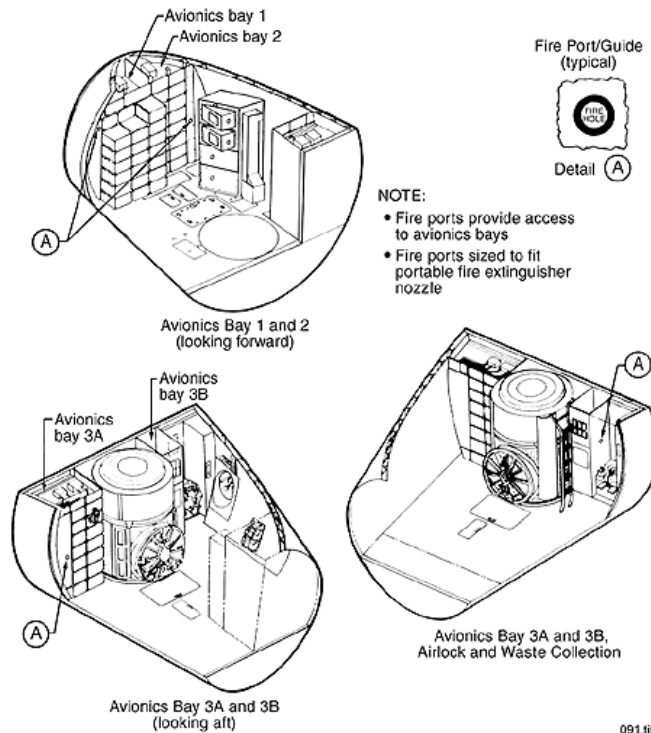
- 10 to 15 percent: 30 seconds
- Above 15 percent: prevent exposure.

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

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

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

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



Fire Port Locations

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

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

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

Rapid Cabin Depressurization

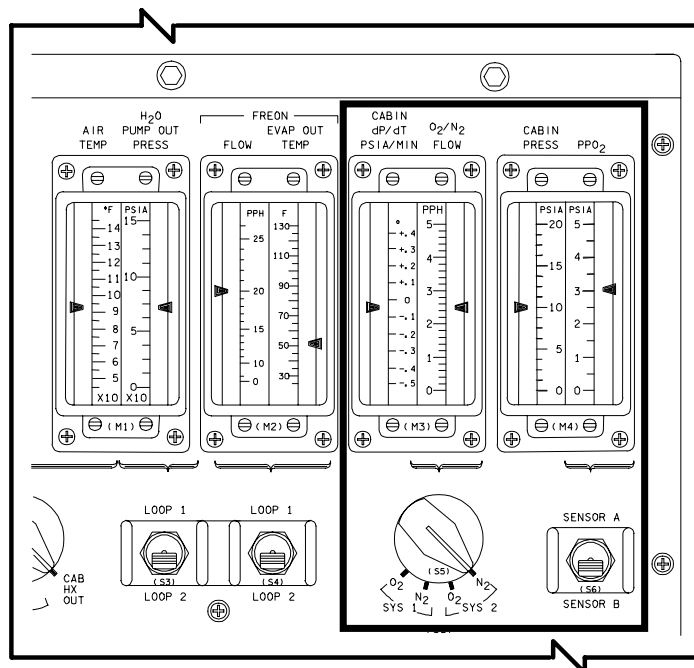
The cabin pressurization rate, dP/dT , senses the rate at which atmospheric pressure is changing in the orbiter (in psi/min). There will be an alarm issued only for a rapid cabin depressurization. If a dP/dT alarm was issued, it would indicate that air was leaking at a rate much higher than normal. The system alerts the crew to a rapid pressure change with respect to time by annunciation of the four *MASTER ALARM* pushbutton indicators and sounding of the klaxon (class 1 alarm).

A dP/dT alarm will be issued if the change in pressure versus change in time decreases at a rate of 0.08 psi per minute or greater. The normal cabin dP/dT is zero psi per minute (± 0.01 psi for all normal operations).

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

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

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



Cabin Pressure Meters and Switches on Panel O1

2011 / /066 ENVIRONMENT				4 000/02:33:38			
				000/00:00:00			
CABIN				AV BAY			
gP/dT +.01	CABIN P	14.7		1	2	3	
PPO2	AIRLK P	14.8		TEMP	90	90	78
A 3.04	FAN ΔP	5.55		FAN ΔP	3.80	3.77	3.92
B 3.04	HX OUT T	45L		SUPPLY H2O			
C 3.04	CABIN T	71		QTY A	67	PRESS	32
PFCO2 1.9				B	18	DMP LN T	77
				C	94	NOZ T A	64
				D	94		B 64
O2 FLOW	0.0L	0.0L		WASTE H2O			
REG P	100	100		QTY 1	15	PRESS	17
N2 FLOW	0.0L	0.0L				DMP LN T	58
REG P	202	202				NOZ T A	82
O2/N2 CNTL VLV	N2	O2					B 82
H2O TK N2 P	17	17		VAC VT NOZ T 224			
N2 QTY	131	131		CO2 CNTLR	1	2	
EMER O2	QTY	1		FILTER P		0.00L	
REG P	4L			PFCO2		- 0.0L	
				TEMP		32.0L	
				BED A PRESS	0.0L	0.0L	
IMU FAN	A	B	C	B PRESS	0.0L	0.0L	
HUMID SEP	*	*		ΔP	0.00L	0.00L	
				VAC PRESS		0.0L	

093

ENVIRONMENT Display (DISP 66)

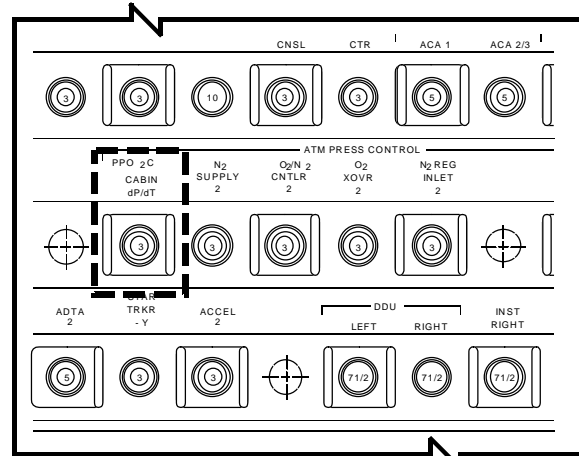
Operations

Primary C/W System

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

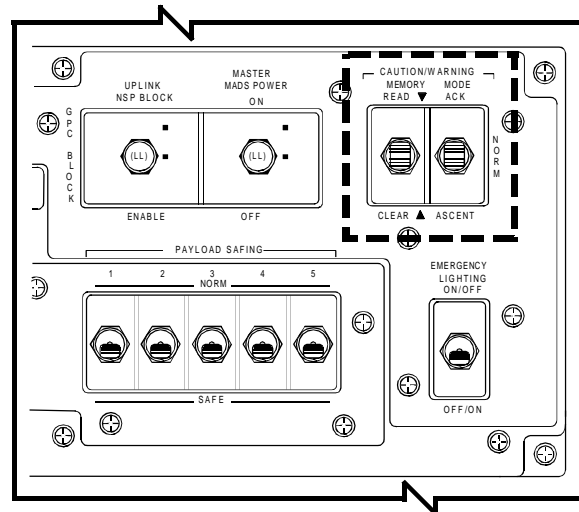
The primary C/W system receives 120 inputs directly from transducers through signal conditioners, or from the flight forward multiplexer/demultiplexers, and are fed into a multiplexing system. Of these 120 inputs, 95 come directly from transducers, five are from input/output processors, 18 are provided through multiplexer/demultiplexer software, and two are spares. These inputs can be either analog or bilevel. The analog signals are zero to 5 volts dc; the discretes are either zero, 5, or 28 volts dc. All of these inputs are designed to provide upper or lower limit detection. If the parameter has exceeded its limits, it will turn on the C/W tone, light the appropriate light on panel F7, illuminate the four red *MASTER ALARM* pushbutton indicators, and store the parameter in memory.

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



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

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



CAUTION/WARNING MEMORY and MODE Switches on Panel C3

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

Panel R13U

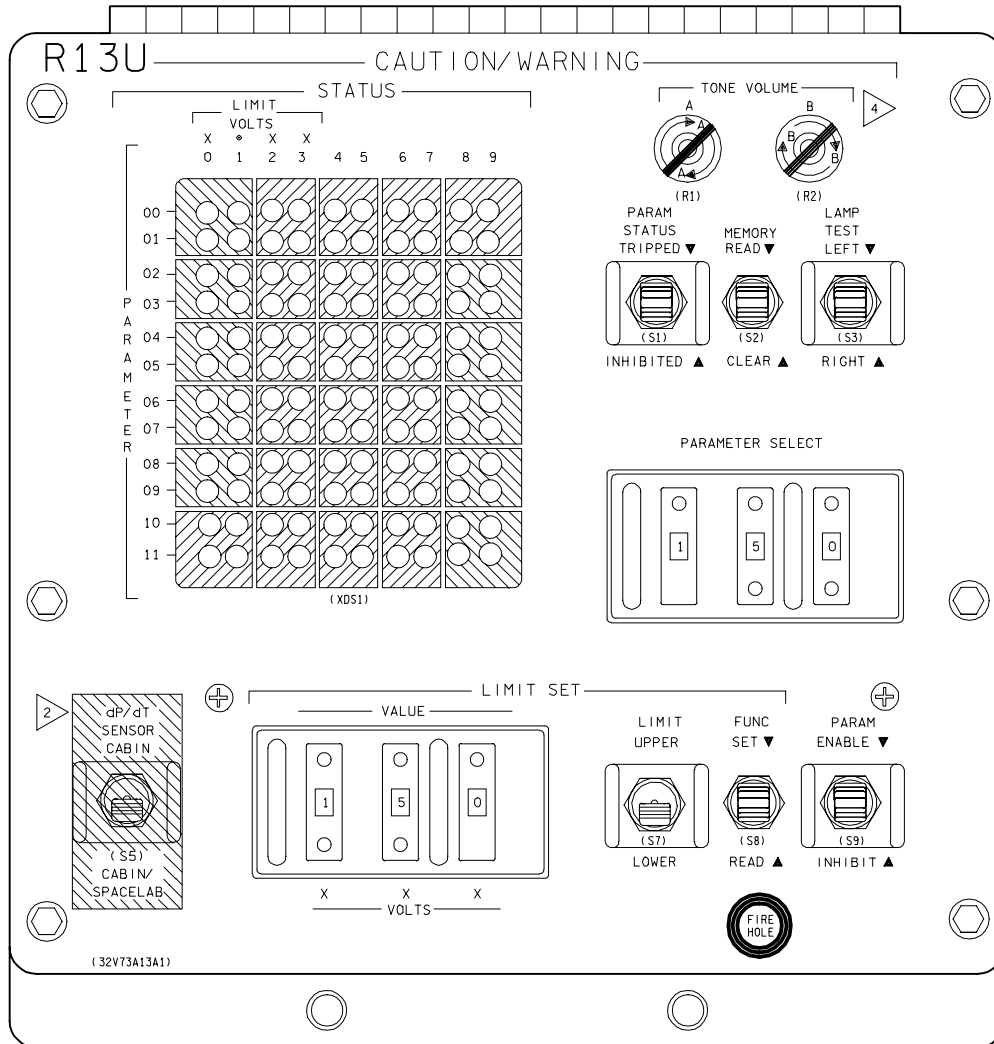
Each of the 120 status C/W red parameter lights on panel R13U receives an input from a specific parameter. A primary C/W parameter matrix cue card identifies the 120 input channels and correlates them to the panel F7 C/W annunciator light matrix. If an out-of-limit condition exists on a specific parameter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

Some limits, and the list of parameters monitored, change with flight phase. The crew

uses the PARAM ENABLE/INHIBIT and LIMIT switches on panel R13U to tailor the C/W system for their current configuration.

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

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



Panel R13U

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

The *CAUTION/WARNING LIMIT SET FUNC SET* switch position on panel R13U provides a signal to the C/W electronics unit, which sets the value specified by the *LIMIT SET VALUE* thumbwheels into the parameter as specified by the *PARAMETER SELECT* thumbwheels and *LIMIT SET LIMIT* switch. The *LIMIT SET FUNC READ* switch position on panel R13U provides a signal to the C/W electronics unit, which illuminates the lights under the *STATUS LIMIT VOLTS X.XX* columns on panel R13U that correspond to the voltage parameter limit specified by the

PARAMETER SELECT thumbwheels and the *LIMIT SET LIMIT* switch. The value read corresponds to the parameter's full-scale range on a scale of zero to 5 volts dc. The *LIMIT SET FUNC* switch center position disables the set and read functions.

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

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

inhibited. The center position disables the tripped and inhibited functions.

The *CAUTION/WARNING MEMORY READ* switch position on panel R13U provides a signal to the C/W electronics unit, which illuminates the C/W status lights on panel R13U that correspond to the parameters that are currently out of limits and that have been out of limits since the last positioning of this switch or the *CAUTION/WARNING MEMORY* switch on panel C3 to *CLEAR*. The *CLEAR* position on panel R13U or panel C3 provides a signal to the C/W electronics unit that clears from the memory any parameters that are presently within limits, but any parameters that are out of limits during this action remain in memory. The center position of the switch on panel R13U or panel C3 disables the clear and read functions.

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

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

Software (Backup) Caution and Warning

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

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

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

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

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

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

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

SPEC 60, SM Table Maintenance

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

Modules within both SM and GNC software monitor parameters and initiate alarms. To change the characteristics of the PASS GNC, BFS GNC, and BFS SM parameters, the crew would have to perform a GPC memory read/write procedure. (This procedure is described in the DPS HW/SW 2102 Training Manual.)

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

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

SPEC 60, which is a PASS SM SPEC, is available during SM OPS 2 and SM OPS 4. When the SM TABLE MAINT display is called up by its SPEC number (SPEC 60 PRO), each field will be blank except CHECKPT time and FDA ENA.

When SPEC 60 is called by pressing RESUME, the fields that were previously in use will retain their data. When a legal item entry is made, the new data will be displayed in the appropriate field and will overwrite any previous data.

contain the proper data. Otherwise, one of the LIMITS sections will be blank.

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

```

9011/060/      SM TABLE MAINT      4 000/02:31:37
SM COM BUFF RDY      000/00:00:00
PARAM
 I ID _____
 VALUE= [ ]

          ALERT          LIMITS          BACKUP C&W
        LOW          HI          LOW          HI
 2 [ ] _____ 3 [ ] _____ 11 [ ] _____ 12 [ ] _____
 4 [ ] _____ 5 [ ] _____
 6 [ ] _____ 7 [ ] _____
          8 FILTER _____          13 FILTER _____
          ENA 9 _____          ENA 14 _____
          INH 10 _____          INH 15 _____

CONSTANT
16 ID _____
17 VALUE= [ ]

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

SM TABLE MAINT CRT (SPEC 60)

Any backup C/W parameter may be accessed by entering its software ID number (see page 2.2-4) in item 1 of the SM TABLE MAINT display. The limits, noise filter value, and enable/inhibit status of alert parameters may be changed with items 2 through 10. The same characteristics of backup C/W parameters are available through items 11 through 15. These CRT parameters are discussed in more detail below.

PARAM ID (Item 1) and PARAM Value

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

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

Limits Alert Low and Hi (Items 2 through 7)

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

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

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

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

Backup C/W parameters have one set of limits. An asterisk next to item 11 indicates that there exists a backup C/W limit set for the parameter.

Limits Alert Filter (Item 8)

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

Limits Backup C/W Filter (Item 13)

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

Limits Alert ENA or INH (Items 9 and 10)

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

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

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

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

FDA ENA or INH (Items 19 and 20)

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

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

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

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

Constants

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

Constant ID (Item 16)

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

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

Constant Value (Item 17)

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

TMBU

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

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

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

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

Uplink

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

UL

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

Checkpoints

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

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

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

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

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

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

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

SM COMM BUFF - BSY, or RDY

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

Keypad entries are rejected if BSY is flashing.

CKPT RETRV ENA (SPEC 1, Item 12)

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

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

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

C/W Summary Data

- The C/W system consists of four alarm classes: emergency (class 1), C/W (class 2), alert (class 3), and limit sensing (class 0).
- Emergency alarms cover two situations: smoke detection/fire suppression and cabin pressure.
- Smoke detection and fire suppression capabilities are provided in the crew cabin avionics bays, the crew cabin, and the Spacelab pressurized module.
- Increased smoke particle concentration will illuminate *SMOKE DETECTION* lights on panel L1, illuminate four red *MASTER ALARM* lights on panels F2, F4, A7, and MO52J, and sound the siren in the crew cabin.
- Fire suppression in the crew cabin avionics bay is provided by one permanent Halon extinguisher bottle in avionics bays 1, 2, and 3A. The bottle is operated by switches on panel L1.
- Three portable hand-held extinguishers in the crew cabin are operated by inserting them into fire holes located in several display and control panels.
- A class 1 alarm (four *MASTER ALARM* pushbutton indicators and the sounding of the klaxon) is triggered when there is a rapid change in cabin pressure with respect to time.
- Class 2 alarms include primary (hardware) and backup (software) systems. The crew interfaces with the system primarily through the 40-light annunciator matrix on panel F7 and a 120-parameter monitor on panel R13U.
- Class 3 alerts warn the crew of a situation leading up to a class 2 alarm or of one that may require a long procedure.
- Class 0, a software system, consists of up and down arrows displayed on the CRT displays next to a parameter.
- The SPEC 60 TABLE MAINT display allows the crew to change limits, noise filter values, and status of backup C/W or alert system parameters.
- C/W information can be seen on the SM SYS SUMM 1 (DISP 78), and ENVIRONMENT (DISP 66) displays.
- Pressing the *MASTER ALARM* light will silence the alarm and reset the light.
- Pressing the ACK key will stop the fault messages from flashing. Subsequent pressing of ACK key will scroll through fault messages.
- Pressing the MSG RESET key will erase fault messages and extinguish the *SM ALERT* light.

C/W Rules of Thumb

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

F7 Light Summary

NOTE

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

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

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

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

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

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

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

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

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

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Caution and Warning Light Matrix on Panel F7

F7 Light Summary (continued)

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

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

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

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

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

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

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

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

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

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

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

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

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

SPARE: Available for future warning parameter growth.

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

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

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

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

F7 Light Summary (continued)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Fault Message Summary

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S86 APU FUEL 1(2,3)	S2,4		<ul style="list-style-type: none"> • APU FUEL QTY ↓ • APU FUEL TK P ↑↓ 	
S86 APU GBX P 1(2,3)	S2,4		<ul style="list-style-type: none"> • GBX P ↓ • OIL OUT P ↑↓ 	
T 1(2,3)	S2,4		<ul style="list-style-type: none"> • OIL OUT T ↑↓ • GBX BRG T ↑ 	
S88 APU H2O T 1(2,3)	S2,4		<ul style="list-style-type: none"> • APU H2O LN INT T ↑↓ 	
SM2 APU SPD HI 1(2,3)		SM	<ul style="list-style-type: none"> • TURBINE OVERSPEED 	<ul style="list-style-type: none"> • NO MAL
SM2 APU SPD LO 1(2,3)		SM	<ul style="list-style-type: none"> • TURBINE UNDERSPEED 	<ul style="list-style-type: none"> • NO MAL
S86 APU TEMP 1(2,3)	S2,4		<ul style="list-style-type: none"> • BACKUP EGT ↑ 	
SM2 APU TEMP		SM	<ul style="list-style-type: none"> • OIL TEMP ↑↓ 	
S88 APU TK T 1(2,3)	S2,4		<ul style="list-style-type: none"> • APU TK SURF T ↓ • APU TK SKIN T ↑↓ 	
S66 AV BAY 1(2,3) FAN	S2,4		<ul style="list-style-type: none"> • AV BAY 1(2,3) FAN ΔP ↑↓ 	
SM2 AV BAY FAN		SM		
BCE BYP FLEX	S2,4		<ul style="list-style-type: none"> • BCE BYPASS ON FLEX/FLEX PAIR 	
BCE BYP KU	S2,4		<ul style="list-style-type: none"> • PL 1 KU COMM/RADAR S10 FAIL 	<ul style="list-style-type: none"> • RADAR: GPC MODE NOT VALID UNLESS TRACKING, AUTO-TRACK MODE IS VALID • NO MAL
BCE BYP MCIU	S2,4		<ul style="list-style-type: none"> • GPC DETECTED I/O LOSS WITH MCIU 	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S62 BCE BYP OA	S2,4		<ul style="list-style-type: none"> • OA1, OA2, OR OA3 MDM OR MDM CARD FAIL 	
OFA	S2,4		<ul style="list-style-type: none"> • OF1 OR OF2 MDM OR MDM CARD FAIL 	
OFB	S2,4		<ul style="list-style-type: none"> • OF3 OR OF4 MDM OR MDM CARD FAIL 	
PDI	S2,4		<ul style="list-style-type: none"> • PDI INTERFACE TO SM GPC FAIL 	<ul style="list-style-type: none"> • MSG OCCURS AT SM OPS TRANSITION IF PDI POWER OFF
PL	S2,4		<ul style="list-style-type: none"> • PDI SSC OR EXC INTERFACE TO PCMMU FAIL 	<ul style="list-style-type: none"> • MSG OCCURS AT SM OPS TRANSITION IF PDI POWER OFF OR IF SPACELAB AND SSC OR EXC POWER OFF
PSP 1(2)	S2,4		<ul style="list-style-type: none"> • PSP 1(2) TO PL 1(2) MDM SERIAL I/O FAIL 	
BCE BYP PL1(2)	S2,4		<ul style="list-style-type: none"> • BCE BYPASS ON PL BUSES 	
BCE BYP SCA	S2,4		<ul style="list-style-type: none"> • BCE BYPASS ON SCA 	<ul style="list-style-type: none"> • NO MAL
BCE STRG 1	A	G1,2,3,6,8	G0,1,2,3,6	<ul style="list-style-type: none"> • ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 1 AND HAVE BYPASSED THAT ELEMENT <ul style="list-style-type: none"> • BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	ADTA	G1,3,6,8	G0,1,3,6	
	B	G1,2,3,6,8	G0,1,3,6	
	C	G1,2,3,6,8	G0,1,3,6	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
BCE STRG 1	D	G1,2,3,6,8	G0,1,3,6	<ul style="list-style-type: none"> ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT O STRING 1 AND HAVE BYPASSED THAT ELEMENT 	<ul style="list-style-type: none"> BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	IMU	G1,2,3,6,8	G0,1,3,6		
	MLS	G1,3,6,8			
	MTU	G1,2,3,6,8,0	G0,1,3,6		
	NSP	G1,2,3,6,8,0	G0,1,3,6		
	STKR	G2,3,8			
	TAC	G1,3,6,8	G0,1,3,6		
PASS		G0,1,3,6	<ul style="list-style-type: none"> BFS FAIL TO TRACK STRING 1 	<ul style="list-style-type: none"> NO MAL I/O RESET MAY RESTORE PASS/BFS COMM 	
BCE STRG 2	A	G1,2,3,6,8	G0,1,3,6	<ul style="list-style-type: none"> ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 1 AND HAVE BYPASSED THAT ELEMENT 	<ul style="list-style-type: none"> BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	ADTA	G1,3,6,8	G0,1,3,6		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
BCE STRG2 (Cont)	B	G1,2,3,6,8	G0,1,3,6	<ul style="list-style-type: none"> ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT O STRING 1 AND HAVE BYPASSED THAT ELEMENT 	<ul style="list-style-type: none"> BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	C	G1,2,3,6,8	G0,1,3,6		
	D	G1,2,3,6,8	G0,1,3,6		
	IMU	G1,2,3,6,8	G0,1,3,6		
	MLS	G1,3,6,8			
	MTU	G1,2,3,6,8,0	G0,1,3,6		
	TAC	G1,3,6,8	G0,1,3,6		
PASS		G0,1,3,6	<ul style="list-style-type: none"> BFS FAIL TO TRACK STRING 1 	<ul style="list-style-type: none"> NO MAL I/O RESET MAY RESTORE PASS/BFS COMM 	
BCE STRG 3	A	G1,2,3,6,8	G0,1,3,6	<ul style="list-style-type: none"> ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 1 AND HAVE BYPASSED THAT ELEMENT 	<ul style="list-style-type: none"> BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	ADTA	G1,3,6,8	G0,1,3,6		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
BCE STRG3	B	G1,2,3,6,8	G0,1,3,6	<ul style="list-style-type: none"> • ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT O STRING 1 AND HAVE BYPASSED THAT ELEMENT 	<ul style="list-style-type: none"> • BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	C	G1,2,3,6,8	G0,1,3,6		
	D	G1,2,3,6,8	G0,1,3,6		
	IMU	G1,2,3,6,8	G0,1,3,6		
	MLS	G1,3,6,8			
	MTU	G1,2,3,6,8,0	G0,1,3,6		
	NSP	G1,2,3,6,8,0	G0,1,3,6		
	STKR	G2,3,8			
	TAC	G1,3,6,8	G0,1,3,6		
	PASS		G0,1,3,6		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
BCE STRG 4	A	G1,2,3,6,8	G0,1,2,3,6	<ul style="list-style-type: none"> • ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 1 AND HAVE BYPASSED THAT ELEMENT 	<ul style="list-style-type: none"> • BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	ADTA	G1,3,6,8	G0,1,3,6		
	B	G1,2,3,6,8	G0,1,3,6		
	C	G1,2,3,6,8	G0,1,3,6		
	D	G1,2,3,6,8	G0,1,3,6		
	PASS		G0,1,3,6		
BDY FLP SW	L(R)	G3,6		<ul style="list-style-type: none"> • BODY FLAP DN(UP) SW DISAGREE 	<ul style="list-style-type: none"> • NO MAL • DEFAULT TO NO OUTPUT
BODY FLAP	CYCL	G1,3,6		<ul style="list-style-type: none"> • BODY FLAP LIMIT CYCLING BUT USABLE 	<ul style="list-style-type: none"> • NO MAL
	FAIL	G1,3,6		<ul style="list-style-type: none"> • BODY FLAP STALLED OR RUNAWAY 	
	HOLD	G1,3,6		<ul style="list-style-type: none"> • BODY FLAP ONE CH FAILED BUT USABLE 	
SMO BRAKE P 1/3 2/3			G0,1,3,6	<ul style="list-style-type: none"> • PRESSURE >180 PSI IN BRAKES DRIVEN BY HYDRAULIC SYSTEM 1/3 	
			G0,1,3,6	<ul style="list-style-type: none"> • PRESSURE >180 PSI IN BRAKES DRIVEN BY HYDRAULIC SYSTEM 2/3 	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S66 CAB AIRLK	PRES	S2,4	• AIRLOCK P ↑↓	• AP AIRLOCK TO AMB (PL)
S66 CAB HX OUT	TEMP	S2,4	• CAB HX OUT T	• NO MAL (NO LIMITS)
S66 CAB H2O N2	P1(2)	S2,4	• H2O TK N2 P ↓	
S66 CAB N2 FLO	1(2)	S2,4	• NW FLOW ↑	
SM1 CABIN N2		SM		
S66 CAB N2 QTY	1(2)	S2,4	• N2 SPLY QTY ↓	
S66 CAB N2 REG	P1(2)	S2,4	• N2 REG P ↑↓	
S66 CAB O2 EMR	SPLY	S2,4	• EMER O2 QTY AND REG P	• EMER O2 MSG ONLY WHEN EMER O2 TK MANIFESTED
S66 CAB O2 FLO	1(2)	S2,4	• O2 FLOW ↑	
SM 1 CABIN O2		SM		
S66 CAB O2 REG	P1(2)	S2,4	• O2 REG P ↑	
S66 CAB PPCO2		S2,4	• PPCO2 ↑	
S78 CABIN	DP/DT	S2,4	• CABIN PRESS RATE OF CHANGE ↓	
S66 CABIN	FAN	S2,4	• CABIN FAN ΔP ↑↓	
SM1 CABIN FAN		SM		
S66 CABIN	PRESS	S2,4	• CAB P ↑↓	
SM1 CABIN FAN		SM		
S66 CABIN	TEMP	S2,4	• CAB T ↑	
S78 CABIN O2	CONC	S2,4	• O2 CONC ↑	• NO MAL

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S66 CABIN PPO2	A(B,C)	S2,4	• PPO2 ↑↓	• NO MAL
SM1 CABIN PPO2		SM		
SM1 CABIN DP/DT	BU	SM	• S/W CAB P RATE OF CHANGE COMP ↓	• NOT IN PRELAUNCH OPS 0
S78 CABIN DP/DT	EQ	S2,4	• EQ CABIN PRESS RATE OF CHANGE ↓	
SM1 CABIN DP/DT EQ		SM		
S60 CHECKPT FAIL		S2,4	• SM CHECKPOINT FAILED ON WRITE OR RESTORE DUE TO AN I/O FAILURE BETWEEN THE GPC AND MMU, OR MMU WAS OFF/BUSY	• ATTEMPT RECOVERY USING MMU MALS
CIRC PUMP		S2,4	• CIR PUMP FAILS TO TURN OFF	• INHIBITS CONTINUATION OF PUMP CYCLING SEQ
S87 CIRC PMP P	1(2,3)	S2,4	• CIRC PUMP P ↑↓	
S67 CNTL BUS	V	S2,4	• DC CNTL VOLT ↓	
RPC		S2,4	• DC CNTL BUS RPC = OFF	
CM BUF BSY	CRT1(2,3,4)	S2,4	• DEU IPL REQUEST WHEN THE SM COMMON BUFFER IS CURRENTLY BUSY	• NO MAL • WAIT FOR CONTENDING OPERATION TO COMPLETE, THEN RETRY THE SM DEU IPL
SM1 CNTL/ESS V		SM	• DC VOLT CNTL ↓ • DC VOLT ESS ↓	
S66 CO2 RL SYS	MALF	S2,4	• EDO CO2 CNTLR 1(2) MALFUNCTION	(OV102 ONLY) MALFUNCTION SIGNAL DURATION IS 6 SEC; RESULTING SPEC 66 ↓ WILL ONLY APPEAR FOR 6 SEC (PNL MO51F CONTROLLER FAIL LIGHT WILL REMAIN LATCHED)
S66 CABIN	FAN	S2,4	• CABIN FAN ΔP ↑↓	
SM1 CABIN FAN		SM	•	
S66 CABIN	PRESS	S2,4	• CAB P ↑↓	
SM1 CABIN FAN		SM	•	
S66 CABIN	TEMP	S2,4	• CAB T ↑	
S78 CABIN O2	CONC	S2,4	• O2 CONC ↑	• NO MAL

MESSAGE			OPS AVAIL		CAUSE	COMMENTS
			PASS	BFS		
S66 CO2 RL SYS	PCO2		S2,4		• EDO CO2 RCRS CO2 PARTIAL PRESS ↑	• OV102 ONLY
S66 CO2 RL SYS	VACP		S2,4			• (OV102 ONLY) CURRENTLY NO FDA ANNUNCIATION
S66 CO2 RL SYS	FAN		S2,4			
S76 COMM CAM	TEMP		S2,4		• TV CAMERA OVERTEMP - YES ↓	• CAM TEMP MSG VALID ONLY WHEN CCTV IN SYNC MODE
	PA1	TEMP	S2,4		• POWER AMP 1 TEMP ↑	
	PA2	TEMP	S2,4		• POWER AMP 2 TEMP ↑	
S76 COMSEC 1	BITE		S2,4		• COMSEC XMIT AND/OR RCV FAILED	
S76 COMSEC 2	BITE		S2,4		• COMSEC XMIT AND/OR RCV FAILED	
CRT BITE	1(2,3,4)		ALL	ALL	• A BITE ERROR DETECTED IN INDICATED DEU	
SM2 CRYO H2 MANF PRESS				SM	• MANF P ↓	
				SM	• TK CNTLP ↑↓	
SM2 CRYO O2 HTR MANF PRESS				SM	• TK HTR ↑	
				SM	• MANF P ↓	
DAP RECONF			G2,8		• DESELECTION OF ONE OR MORE DOWNFIRING VERNIER JETS	• NO MAL • IF USING PRI RCS, MSG INDICATES FAILURE OF DOWNFIRING VERN JET W/O DOWNMODING • IF USING VERN RCS, OR UPON TRANS FROM PRI TO VERN RCS, DAP WILL DOWNMODE TO FREE DRIFT

MESSAGE			OPS AVAIL		CAUSE	COMMENTS
			PASS	BFS		
SM1 DC VOLT FC 1(2,3)				SM	• FC VOLT ↑↓	
S69 DELTA AMPS	1(2,3)		S2,4		• FC Δ AMPS ↑↓	
>3 DEU			ALL		• TOO MANY DEUs in COMMON SET	• NO MAL
DISPLAY SW	A		G2,8		• AFT ADI ERROR/RATE SW • AFT ADI ATT SEL SW	• NO MAL • MAY BE TRIGGERED BY COMM FAULT OR I/O RESET
	L		G1,2,3,6,8		• LH ADI ERROR/RATE SW • LH ADI ATT SEL SW • LH AIR DATA SW • LH HSI MODE/SOURCE/TRAN SW • LH RADAR ALT SW	• MOVE APPROPRIATE SW TO GREEN DOT DEFAULT POS • AIR DATA/RADAR ALT SW NOT READ IN OPS 1,2 OR 8 FOR PASS
	R		G1,2,3,6,8		• RH ADI ERROR/RATE SW • RH ADI ATT SEL SW • RH AIR DATA SW • RH HSI MODE/SOURCE/TRAN SW • RH RADAR ALT SW	
DK XMTR 1(2,3,4)				ALL	• BFS DK TRANSMITTER FAILED HIGH ON A PASS CONTROLLED CRT	• NO MAL • BFS WILL DOWNMODE AFFECTED DK BUS - NO COMMAND/LISTEN CAPABILITY ON THAT BUS • ASSIGN BFS TO AFFECTED CRT TO RECOVER BFS COMMAND/LISTEN CAPABILITY • BFS IS STILL ENGAGEABLE WITH FULL CAPABILITY
S67 ESS BUS V	1BC(2CA,3AB)		S2,4		• DC VOLT ESS ↓	

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
ET SEP	AUTO	G6		• ET SEP MODE SW FAIL	• NO MAL • SW DEFAULTS TO AUTO IN G6
	INH	G1,6	G1,6	• AUTO SEP INH G1 = BODY RATES & FDLN DISC VLVS G6 = BODY RATES, α AND β	• NO MAL • USE CUE CARDS FOR DISC VLVS
	MAN	G1		• ET SEP SW FAIL (RM)	• NO MAL • USE SPEC 51 OVERRIDE
S77 EVA-MMU T	PORT STBD	S2,4		• MMU/FSS TEMP OUT OF LIMITS	
S88 EVAP FDLN	TA(B)	S2,4		• FDLN FWD,MID,AFT,TOOPPING,ACCUM LINE A(B) AND HI LOAD LINE A(B) T $\uparrow\downarrow$	• FES FEEDLINE TEMPS
S88 EVAP HI LD	TEMP	S2,4		• FES HI LOAD NOZ AND DUCT T $\uparrow\downarrow$	• HI LOAD IB/OB DUCT T AND NOZ T
S88 EVAP OUT T	1(2)	S2,4		• OUT T $\uparrow\downarrow$	
SM2 EVAP OUT T			SM		
S88 EVAP TOP	TEMP	S2,4		• FES TOPPING NOZ AND DUCT T $\downarrow\uparrow$	• TOPPING EVAP L(R) FWD(AFT) DUCT T AND L(4) NOZ T
167 EXT A/L	PRES	S2,4		• EXT AIRLOCK P $\uparrow\downarrow$	• EXTERNAL AIRLOCK ONLY
F RCS	JET		G1,3,6	• F JET MANF 1(2,3,4) FAIL ON/OFF	• NO FAIL LK DETECTION IN BFS
	DJET	G1,2,3, 6,8		• F DOWN JET 1(2,3,4) FAIL ON/OFF/LK	• FAIL OFF DETECTION NOT PERFORMED IN MM101 & 012 FOR PASS
	FJET	G1,2,3, 6,8		• F FWD JET 1(2,3) FAIL ON/OFF/LK	
	LJET	G1,2,3, 6,8		• FLEFT JET 1(3,5) FAIL ON/OFF/LK	

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
F RCS	RJET	G1,2,3, 6,8		• F RIGHT JET 2(4,5) FAIL ON/OFF/LK	• FAIL OFF DETECTION NOT PERFORMED IN MM101 & 102 FOR PASS
	UJET	G1,2,3, 6,8		• F UP JET 1(2,3) FAIL ON/OFF/LK	• FAIL OFF DETECTION NOT PERFORMED IN MM101 & 012 FOR PASS
	He P	G2,8	G,1,3,6	• F He (FU OR OX) TK P 2 LOW	• PKT C/L - RCS LEAK ISOL
	LEAK	G,2,3,8	G1,3,6	• PROP/He LEAK	• OX/FU Δ QTY > 9.5%
	PVT	G2,3,8		• LOSS OF P OR T DATA FRO RCS QTY CALC	• NO MAL • QTY CALC SUSPENDED
TK P	G2,8	G1,3,6	• FWD RCS (FU OR OX) TK ULL PRESS HI/LOW	• QTY CALC SUSPENDED	
S69 FC AMPS	1(2,3)	S2,4		• FC AMPS $\uparrow\downarrow$	
SM1 FC AMPS 1(2,3)			SM		
S69 FC COOL P	1(2,3)	S2,4		• FC COOL P $\uparrow\downarrow$	
SM1 FC COOL P 1(2,3)			SM		
S69 FC DELTA V	1(2,3)	S2,4		• FC SUBSTACK $\Delta v > 150$ MV	
SM1 FC DELTA V 1(2,3)			SM		
S69 FC EXIT T	1(2,3)	S2,4		• FC EXIT T $\uparrow\downarrow$	
SM1 FC EXIT T 1(2,3)			SM		
S69 FC H2 FLOW	1(2,3)	S2,4		• FC H2 FLOW \uparrow	
S69 FC H2 PUMP	1(2,3)	S2,4		• FC H2 PUMP STATUS $\uparrow\downarrow$	

MESSAGE			OPS AVAIL		CAUSE	COMMENTS
			PASS	BFS		
S69 FC H2O ALT PRI RLF HTR LINE NOZ	1(2,3)	S2,4		• FC ALT H2O LN T ↑↓	• BOTH HTRS OFF OR BOTH HTRS INDICATING AUTO WILL ANNUNCIATE ALARM	
	1(2,3)	S2,4		• FC H2O LN T ↑↓		
	1(2,3)	S2,4		• FC HWO RLF VLV T ↑↓		
	HTR	S2,4		• FC H2O RLF HTR STATUS A,B ↑↓		
	LINE	S2,4		• FC H2O RLF LN T ↑↓		
	NOZ	S2,4		• FC H2O RLF NOZ T A(B) ↑↓		
S69 FC O2 FLOW	1(2,3)	S2,4		• FC O2 FLOW ↑		
S69 FC PH	1(2,3)	S2,4		• FC PH - PH ↓	• PH > BILEVEL	
SM1 FC PH 1(2,3)		SM		• FC PH HIGH		
S69 FC PRG LN	H2	S2,4		• FC H2 PURGE LN T 1(2) ↑		
	O2	S2,4		• FC O2 PURGE LN T ↑		
S69 FC PUMP	1(2,3)	S2,4		• FC COOL PUMP ΔP ↓		
SM1 FC PUMP 1(2,3)			SM			
FC PURGE	1(2,3)	S2,4		• FAILS FLOW CHECK AT PURGES AT END OF PURGE	• USE MAN FC PURGE PROC	
	SEQ	S2,4		• LOSS OF PWR TO PURGE LN HTRS AFTER AUTO SEQ INIT OR LOSS OF SWITCH FUNCTION	• USE MAN FC PURGE PROC • SEQ FAIL FLAG TERMINATES AUTO PURGE SEQ	
	TEMP	S2,4		• FC PURGE LINE TEMP TOO LOW TO PERFORM AUTO PURGE	• TERMINATES AUTO PURGE • USE MAN FC PURGE PROC	
S69 FC REAC	1(2,3)	S2,4		• FC REAC ↓	FC REAC VLV - CL	
SM1 FC REAC 1(2,3)			SM			
S69 FC READY	1(2,3)	S2,4		• FC READY ↓		

MESSAGE			OPS AVAIL		CAUSE	COMMENTS
			PASS	BFS		
S69 FC STACK T	1(2,3)	S2,4		• FC STACK T ↑↓		
SM1 FC STACK T 1(2,3)			SM			
S69 FC VOLTS	1(2,3)	S2,4		• FC VOLT ↑↓		
FCS CH	1(2,3,4)	G1	G1	• SRB CHANNEL BYPASS	• NO MAL • ROCK & TILT ACT A(B,C,D) CH FAIL • NO MAL • MPS ENG PITCH(YAW) CH FAIL • NO MAL • ELEV (RUD,S/B) ACT CH FAIL	
		G1,3,6	G1,6	• MPS CHANNEL BYPASS		
		G1,3,6	G1,3,6	• AERO CHANNEL BYPASS		
FCS SAT	POS	G3,6	G3,6	• L/R IB/OB ELEVON POSITION SATURATION	• NO MAL • ELEVON SAT (>+12 OR <-15 DEG)	
	MOM	G3,6	G3,6	• L/R IB/OB PRI DELTA PRESS	• NO MAL • IN RTLS EXPECT HINGE MOM >2400 PSI (80% SYS MAX)	
S67 FPC/FLC	1(2,3)	S2,4		• FWD PCA V ↓		
S88 FREON FLOW	1(2)	S2,4		• FLOW ↓	FCL ICH FLOW	
SM2 FREON FLOW			SM			
S88 FREON QTY	1(2)	S2,4		• ACCUM QTY ↓	• FREON LOOP ACCUM QTY	
S88 FREON RAD	T1(2)	S2,4		• CNTL OUT T 1(2) ↓	• RAD CONTROLLER OUT TEMP	
S88 FRN AFT CP	1(2)	S2,4		• AFT CP FREON FLOW ↓	• AFT CP FLOW	
S88 FRN PL HX	1(2)	S2,4		• PL HX FREON FLOW ↓	• PL HX FLOW	
S86 FU TK VLV	1(2,3)	S2,4		• APU FUEL TANK VLV TEMP ↑↓	•	
SM2 FU TK VLV APU			SM			

MESSAGE		OPS AVAIL		CAUSE	COMMENTS		
		PASS	BFS				
S76 GCIL	FAIL	S2,4		• GCIL CONFIG FAILED TO PNL			
S86 GG/FU PMP	1(2,3)	S2,4		• APU GG BED T ↑↓			
GPC	BITE	ALL	ALL	• S/W FORCED CLOSED PROCESS DUE TO GPC H/W (S/W) FAULT	• IN PASS		
				• BFS RESTART INDICATION	• IN BFS		
	CONF	ALL		• NBAT TGT GPCs NOT IN RUN OR NOT SPECIFIED	• NO MAL		
				• PROCEDURAL ERROR OR SWITCH ERROR			
	SUM	1	ALL		• BFS GPC FAIL CHECKSUM		
					• INDICATED GPC HAS FAILED		
2					ALL		
3					ALL		
4					ALL		
5	ALL		• GPC 5 HAS FAILED	• NO MAL			
GPC PWR			ALL	• PWR TRANSITIONS TO BFS GPC	• NO MAL • BFS WILL DISENGAGE • S/W DOES AUTO RESTART		
S68 H2 CNTL P	1(2,3,4,5)	S2,4		• CNTL P ↑↓			
HTR T	1(2,3,4,5)	S2,4		• HTR T ↑			
MANF	PRES	S2,4		• MANF P ↓			
	VLV	S2,4		• MANF VLV = CL			
TK P	1(2,3,4,5)	S2,4		• TK P ↑↓			

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
168 HW CNTL P	6(7,8,9)	S2,4		• CNTL P ↑↓	
HTR T	6(7,8,9)	S2,4		• HTR T ↑	
TK P	6(7,8,9)	S2,4		• TK P ↑↓	
S69 H2O LN PH		S2,4		• H2O LINE PH ↓	• PH > 9 BILEVEL
S88 H2O LOOP 1(2)	FLOW	S2,4		• ICH FLOW	• ACTIVE LOOP ONLY
	QTY	S2,4		• ACCUM QTY ↓↑	
	TEMP	S2,4		• PUMP OUT T ↑↓ • CAB HX IN T ↓ • ICH OUT T ↓	• H2O LOOP TEMPS
S88 H2O PUMP P	1(2)	S2,4		• P 1(2) ↑↓ OR ΔP 1(2) ↑↓	• ΔP HIGH ONLY FOR INACTIVE LOOP
SM2 H2O PUMP P			SM		• ΔP HIGH OR LOW FOR ACTIVE LOOP
HIGH G		G3,6		• HIGH G	• NO MAL
S66 HUMID SEP	A(B)	S2,4		• HUM SEP SPEED ↓	
SM2 HYD ACUMP P 1(2,3)			SM	• ACCUM P ↓	
S86 HYD PRESS	1(2,3)	S2,4		• HYD SYS SPLY P ↑↓	• NO MAL
SM2 HYD PRESS			SM		
SM2 HYD QTY 1(2,3)			SM	• RSVR QTY ↑↓	
S86 HYD RSVR Q	1(2,3)	S2,4		• RSVR QTY ↑↓	
S86 HYD RSVR T	1(2,3)	S2,4		• RSVR T ↓↑	
SM2 HYD RSVR T 1(2,3)			SM		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
ILLEGAL ENTRY	ALL	ALL	<ul style="list-style-type: none"> ILLEGAL KYBD ENTRY WITH RESPECT TO OPS SELECT/TRANSITION, DATA LOAD, INITIALIZATION, MEM RECONFIG, GPC ASSIGN, KYBD SYNTAX, FREEZE DRY LOAD, ETC 	NO MAL IF APPROPRIATE, KYBD INPUT SHOULD BE REENTERED	
S66 IMU FAN SM1 CABIN IMU	DP S2,4	SM	<ul style="list-style-type: none"> IMU FAN $\Delta P \uparrow \downarrow$ 		
S66 IMU FN SPD	A(B,C) S2,4		<ul style="list-style-type: none"> IMU FAN SPEED \downarrow 		
I/O ERROR	CRT1	ALL	ALL	<ul style="list-style-type: none"> ERROR IN DEU 1(2,3,4) MSG (I/O OR CHECKSUM) 	
	CRT2	ALL	ALL		
	CRT 3	ALL	ALL		
	CRT 4	ALL	ALL		
	D/L	ALL		<ul style="list-style-type: none"> I/O ERROR ON DOWNLIST INTERFACE WITH PCMMU 	
	FA1	G1,2,3, 6,8	G0,1,3, 6	<ul style="list-style-type: none"> INPUT/OUTPUT ERROR ON INDICATED UNIT HAS BEEN DETECTED 	BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE
	F2	G1,2,3, 6,8	G0,1,3, 6		
	F3	G1,2,3, 6,8	G0,1,3, 6		
F4	G1,2,3, 6,8	G0,1,3, 6			

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
ITEM RJCT PSP	S2,4		<ul style="list-style-type: none"> PCP CC CMD REJECTED DUE TO PSP CMD DATA TRANSMISSION IN PROGRESS 	<ul style="list-style-type: none"> NO MAL 	
S76 KU-GMBL A	TEMP S2,4		<ul style="list-style-type: none"> KU GMBL A TEMP \uparrow 		
GMBL B	TEMP S2,4		<ul style="list-style-type: none"> KU GMBL B TEMP \uparrow 		
GYRO	TEMP S2,4		<ul style="list-style-type: none"> KU BYRO TEMP \uparrow 		
XMTR	TEMP S2,4		<ul style="list-style-type: none"> KU XMTR TEMP \uparrow 		
L OMS	GMBL	G1,2,3	G1,3	<ul style="list-style-type: none"> PITCH (YAW) CMD/FEEDBACK $\Delta 2^\circ$ FOR 3.8 SEC 	<ul style="list-style-type: none"> NO MAL
	PC	G1,2,3, 6	G1,3,6		
	QTY	G1,2,3, 6,8		<ul style="list-style-type: none"> ENG FU OR OX TK LEVEL LOW 	
	TEMP		G1,3	<ul style="list-style-type: none"> ENG FU INJ T HI 	
	TK P	G2,8	G1,3	<ul style="list-style-type: none"> FU OR OX TK ULLAGE P HI/LOW 	
			G1,3,6	<ul style="list-style-type: none"> He OR N2 TK P LOW N2 REG P HI/LOW 	
	VLV	G2		<ul style="list-style-type: none"> He P/VAP ISOL VLV MISMATCH 	
S89 L OMS	TEMP S2,4		<ul style="list-style-type: none"> ENG FU INJ T HI/LOW 	<ul style="list-style-type: none"> NO MAL 	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
L RCS	JET	G1,3,6	• LEFT JET MANF 1(2,3,4) FAIL ON/OFF	• NO FAIL LK DETECTION IN BFS	
	AJET	G1,2,3,6,8	• L AFT JET 1(3) FAIL ON/OFF/LK	• FAIL OFF DETECTION NOT PERFORMED IN MM101 & 102 FOR PASS	
	DJET	G1,2,3,6,8	• L DOWN JET 2(3,4,5) FAIL ON/OFF/LK		
	LJET	G1,2,3,6,8	• L LEFT JET 1(2,3,4,5) FAIL ON/OFF/LK		
	UJET	G1,2,3,6,8	• L UP JET 1(2,4) FAIL ON/OFF/LK		
	He P	G2,8	G1,3,6	• L RCS AFT He (FU OR OX) TK PRESS - 2 LOW	• PKT CL - RCS LEAK ISOL
	LEAK	G2,3,8	G1,3,6	• PROP/He LEAK	• OX/FU ΔQTY > 9.5%
	PVT	G2,3,8		• LOSS OF P OR T DATA FOR RCS QTY CALC	• NO MAL • QTY CALC SUSPENDED
TK P	G2,8	G1,2,3,6	• L RCS AFT (FU OX OX) TK ULL PRESS HI/LOW		
XFEED	G1,3,6		• L RCS PROP TANK LOW PRESS	• FAILURE ON LEFT SIDE, AUTO XFEED FROM RIGHT	
S67 MAIN BUS V	A(B,C)	S2,4	• MN VOLTS ↑ ↓		
SM1 MAIN BUS V A(B,C)		SM			

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
MPS DATA	C(L,R)	G1,6	G1,6	• DATA PATH FAIL • NO MAL • REF AESP CUE CARDS
MPS ELEC	C(L,R)	G1,6	G1,6	• ELECTRONIC LOCKUP MODE FAIL • NO MAL • REF AESP CUE CARDS
MPS H2 OUT P C(L,R)			G1,6	• PREMATURE SSME SHUTDOWN • MPS GH2 OUT P ↓ • NO MAL • REF AESP CUE CARDS
MPS HYD	C(L,R)	G1,6	G1,6	• HYD LOCKUP MODE FAIL • NO MAL • REF AESP CUE CARDS
MPS He P C(L,R)		G1,6	G1,6	• MPS He TK P HI/LOW • HI LEAK RATE dP/dT • NO MAL • REF AESP, APCL
		G1,3,6		• INDICATED REG P HI/LOW • NO MAL • REF AESP, APCL, EPCL
MPS LH2/O2 MANF ULL		G1,6	G1,6	• MPS LH2 ENG MANF P HI • MPS LOX ENG MANF P HI • NO MAL • REF AESP CUE CARDS
		G1,6		• ET ULL P HI/LO •
MPS O2 OUT T C(L,R)			G1,6	• PREMATURE SSME SHUTDOWN • MPS OG2 OUT T ↓ • NO MAL • REF AESP CUE CARDS
MPS PNEU ACUM REG TK		G1,6	G1,6	• MPS PNEU ACUM PRESS LOW • NO MAL • REF AESP CUE CARDS
		G1,3,6		• MPS PNEU REG PRESS HI/LOW • NO MAL • REF AESP, APCL, EPCL
		G1,6		• MPS PNEU TANK PRESS LOW • NO MAL • REF AESP CUE CARDS
NAV EDIT		G2		• RNDZ NAV EDIT • NO MAL
		G3,6		• DRAG H, ADTA, OR TACAN NAV EDIT • BFS DOES NOT SUPPORT MLS • NO MAL

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
NAV EDIT (Cont)	ALT	G3,6	• ADTA ALT DATA NOT PROCESSING < M2.5 • DRAG H DATA NOT PROCESSING 85.2K FT < H < 140K FT	• NO MAL • MLS NAV EDIT MESSAGE (MLSNV) SEEN ONLY ON HUD
	TAC	G3,6	• TACAN DATA NOT PROCESSING <140K FT	• NO MAL
S76 NSP 1	BITE	S2,4	• NSP A/G 1 OR 2 XMIT AND/OR RCV VOICE MUX FAILED	
S76 NSP 2	BITE	S2,4	• NSP A/G 1 OR 2 XMIT AND/OR RCV VOICE MUX FAILED	
S68 O2 CNTL P HTR T TRP MANF TK P	1(2,3,4,5)	S2,4	• CNTL P ↑↓	
	1(2,3,4,5)	S2,4	• HTR T ↑	
	1(2,3,4,5)	S2,4	• HTR CUR SNSR = TRIP	
	PRESS	S2,4	• MANF P ↓	
	VLV	S2,4	• MANF VLV = CL	
168 O2 CNTL P HTR T TRTP TK P	6(7,8,9)	S2,4	• CNTL P ↑↓	
	6(7,8,9)	S2,4	• HTR T ↑	
	6(7,8,9)	S2,4	• TKP ↑↓	
	6(7,8,9)	S2,4	• TK P ↑↓	
OFF/BUSY MMU	1(2)	ALL	• AN MMU TRANSACTION IS REQUESTED WHEN THE MMU IS OFF/BUSY, FAILED OFF, OR SELECTED FOR IPL	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
G23 OMS/RCS	QTY	G2	• L(R) OMS TO RCS PROP TRANSFER EXCEEDS LIMIT	• NO MAL	
OTT ST IN		G3,6	G3,6	• INDICATED E/W LVL LESS THAN LVL REQD FOR OVHD APPROACH	• NO MAL • MSG TERMINATES < 45 NM FROM LDG OR E/W LVL AGAIN MATCHES PROFILE
S76 PA1 OUTPUT	LOW	S2,4		• PWR AMP OUTPUT ↓	
S76 PA2 OUTPUT	LOW	S2,4		• PWR AMP OUTPUT ↓	
168 PALLET H2 PRESS TK P O2 HTR PRESS TK P T V			S3,6	• H2 TK 6 (7,8,9) CNTL P ↑↓	
			S3,6	• H2 TK 6 (7,8,9) TK P ↑↓	
			S3,6	• O2 TK 6 (7,8,9) HTR T ↑	
			S3,6	• O2 TK 6 (7,8,9) CNTL P ↑	
			S3,6	• O2 TK 6 (7,8,9) TK P ↑	
	A	S2,4		• PALLET T ↑↓	
	B	S2,4		• PALLET V A ↓	
PDB CONFIG		S2,4		• PLBD OUT-OF-SEQUENCE CONFIG	• CAUSES TERMINATION OF AUTO SEQUENCE
S63 PDB CONFIG			SM		
PBD CONFIG		S2,4		• PLBD AUTO SEQ FAIL	• CAUSES TERMINATION OF AUTO SEQUENCE
S63 PDB CONFIG			SM		

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
S62 PDI DECOM FAIL		S2,4		<ul style="list-style-type: none"> • DECOM 1 FMT ↑ • DECOM 2 FMT ↑ • DECOM 3 FMT ↑ • DECOM 4 FMT ↑ 	<ul style="list-style-type: none"> • MSG OCCURS IF DECOM FDA ENA AND PL TLM FAIL FOR PDI DECOM FAILS • MSG ALSO OCCURS IF PL DEPLOYED, PI FAIL, OR PSP FAIL
S96 PDRS ABE		COMM	S2,4	• ABE/MCIU MISCOMPARE	
		JPC1	S2,4	• SHOULDER JPC FAIL	
		JPC2	S2,4	• WRIST JPC FAIL	
		SY SP EP WP WY WR	S2,4	<ul style="list-style-type: none"> • SPA PWR (COMMUTATOR, MDA) FAIL • TACH/PHASE LOCK LOOP FAIL 	• AUTO BRAKES APPLIED
		EE	S2,4	• EE CMDS ↓, EE FLAG ↓, EEEU FAIL ↓	
		T CK	S2,4	• MCIU TEMP MONITOR CIRCUIT FAIL	
		FS	S2,4	• MCIU EXTERNAL FRAME SYNC BITE OR BITE VERIFICATION FAILURE	
		HC	S2,4	<ul style="list-style-type: none"> • RHC (THC) HARDOVER (ANY AXIS) • MCIU HC ↓ (MULTIPLEXER MISMATCH) 	• S/W DOWNMODE TO IDLE IF IN MANUAL (TEST)

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
PDRS TEST		BRK C/W NMI FS LOSS	S2,4	• MCIU BITE VERIFICATION TEST FAILURE	
PDRS CNTL		SY SP EP WP WY WR	S2,4	<ul style="list-style-type: none"> • CONSISTENCY CK - JOINT RUNAWAY • TACH DATA FAIL 	• AUTO BRAKES APPLIED
PDRS DERIG			S2,4	• UNCOMMANDED DERIGIDIZE	• POSSIBLE EE STRUCT FAIL
S94 PDRS GPC			S2,4	• MCIU-DETECTED GPC COMM FAIL	<ul style="list-style-type: none"> • MCIU SAFING COMMANDED • S/W DNMODE TO 'SUSPEND'
S96 PDRS MCIU		MADC	S2,4	• MADC REF VOLT TEST FAIL	• AUTO BRAKES APPLIED
		MCPC	S2,4	• MCPC REF VOLT TEST FAIL	• AUTO BRAKES APPLIED
		ICF	S2,4	• ICF FAIL	• AUTO BRAKES APPLIED (MAY NOT BE IND)
PDRS RCH		SY SP EP WP WY WR	S2,4	• JOINT EXCEEDS POS OR NEG RCH LIMIT	<ul style="list-style-type: none"> • APPROX 2° PRIOR TO S/W STOP • APPROX 4° PRIOR TO HARDSTOP
PDRS REL			S2,4	• UNCOMMANDED P/L RELEASE	• POSSIBLE EE STRUCT FAIL

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
PDRS SING	SY	S2,4	• SY/WY WITHIN 3 FT OR COALIGNMENT	• LOSE ±Y DEG OF FREEDOM AT SINGULARITY
	EP	S2,4	• EP > -7.6°	• LOSE -X DEG OF FREEDOM AT SINGULARITY
	WY	S2,4	• WY WITHIN ±15° OF ±90° SING	• LOSE ROLL DEG OF FREEDOM AT SINGULARITY
PDRS CNTL	SY SP EP WP WY WR ALL	S2,4	• JOINT SLIPPAGE WITH THE BRAKES ON AND NOT IN DIRECT MODE	• SLIPPAGE GREATER THAN 0.5° PER JOINT OR SUM OF 2.0° FOR ALL JOINTS
PDRS TEMP	PORT STBD	S2,4	• JOINT/EE TEMP OUT OF LIMITS	
S94 PDRS WR R		S2,4	• PDRS WRIST ROLL RANGE CHECK FAILURE	
206 PL CL2		SM	• AV FAN ΔP ↑↓ • H2O PUMPS ΔP STAT ↓	• SEE ASCENT/ENTRY SYSTEMS PROCEDURES (SPACELAB MODULE CONFIGURATION ONLY)
PL CL3		SM	• AUX BUS A/B U/V ↓ • SS INV IN AMPS ↑ • SS TEMP ↑ • EXPINV IN APMPs ↑ • EXP TEMP ↑ • SS AC ΦA(B,C) V ↑↓ • MAIN BUS V	• SEE ASCENT/ENTRY SYSTEMS PROCEDURES

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
PNL TRIM	L(R)	G3,6	• LH(RH) +/- P/R/Y TRIM SW DISAGREE	• NO MAL	
PROBES		G3,6	• EITHER ADTA PROBE NOT DEPLOYED DURING 1 < M < 2.5	• NO MAL	
S89 PRPLT THRM	OMS	S2,4	• OX(FU) LN STRUCT T HI/LOW		
	POD	S2,4	• PROP AND STRUCT T HI/LOW		
	RCS	S2,4	• FWD AND L/R RCS STRUCT T HI/LOW		
L OMS	GMBL	G1,2,3	G1,3	• PITCH (YAW) CMD/FEEDBACK Δ2° FOR 3.8 SEC	• NO MAL
	PC	G1,2,3,6	G1,3,6	• ENG CHAMBER PRESS LOW	
	QTY	G1,2,3,6,8		• FU FU OR OX TK LEVEL LOW	
	TEMP		G1,3	• ENG FU INJ T HI	
	TK P	G2,8	G1,3	• FU OR OX TK ULLAGE P HI/LOW	
				G1,3,6	
	VLV	G2		• OMS R POD He/P VAP ISOL VLV MISMATCH	• NO MAL
S89 L OMS	TEMP	S2,4		• ENG FU INJ T HI/LOW	• NO MAL

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
L RCS	JET	G1,3,6	• RIGHT JET MANF 1(2,3,4) FAIL ON/OFF	• NO FAIL LK DETECTION IN BFS • FAIL OFF DETECTION NOT PERFORMED IN MM101 & 102 FOR PASS
	AJET	G1,2,3,6,8	• R AFT JET 1(3) FAIL ON/OFF/LK	
	DJET	G1,2,3,6,8	• R DOWN JET 2(3,4,5) FAIL ON/OFF/LK	
	RJET	G1,2,3,6,8	• R RIGHT JET 1(2,3,4,5) FAIL ON/OFF/LK	
	UJET	G1,2,3,6,8	• R UP JET 1(2,4) FAIL ON/OFF/LK	
	He P	G1,3,6	• R RCS AFT He (FU OR OX) TK PRESS - 2 LOW	• PKT CL - RCS LEAK ISOL
	LEAK	G2,3,8	G1,3,6 • PROP/He LEAK	• OX/FU ΔQTY > 9.5%
	PVT	G2,3,8	• LOSS OF P OR T DATA FOR RCS QTY CALC	• NO MAL • QTY CALC SUSPENDED
	TK P	G2,8	G1,2,3,6 • R RCS AFT (FU OX OX) TK ULL PRESS HI/LOW	
XFEED	G1,3,6	• R RCS PROP TANK LOW PRESS	• FAILURE ON RIGHT SIDE, AUTO XFEED FROM LEFT	
G23 RCS SYSTEM	F(L,R)	G2,8	• F(L,R) RCS FU OR OX TK TEMP	
		G2,8	• F(L,R) RCS FU OR OX TK OUT PRESS	
RCS PWR	FAIL	G1,1,2,3,6,8	• LOSS OF VLV LOGIC PWR TO MANF ISOL VLVs	OMS/RCS VLVs WITH tb - bp STUCK IN CURRENT POSITION

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
RM FAIL	ACC	G1,3,6	• FAIL	• NO MAL • DES/SEL AVAILABLE
	ADTA	G3,6	G3,6 • FAIL	• NO MAL • DES/SEL AVAILABLE
	IMU	G1,2,3,6,8	G1,3,6 • FAIL • COMM FAULT CAUSES BFS RM FAIL	• NO MAL • DES/SEL AVAILABLE
	MLS	G3,6	• FAIL	• NO MAL • DES/SEL AVAILABLE OPS 8 ONLY • NO CRT DAT OPS 3
	RGA	G1,3,6	• FAIL	• NO MAL • DES/SEL AVAILABLE
	TAC	G3,6	• FAIL	• NO MAL • DES/SEL AVAILABLE
	XFER		G1,3,6 • BFS NOT RECEIVE STATE VECTOR OR REFSMAT	• NO MAL
	G33 RNDZ RADAR	G2		• KU-BAND BREAKS TRACK WITH RADAR TARGET (GPC ANT STEERING MODE ONLY)
ROLL REF	G3	G3	• REF ROLL STATUS FAIL	• NO MAL
S86 RSVR/ACC P	1(2,3)	S2,4	• RSVR P ↓ • ACCUM P ↓	
SBTC/THC	A	G2,8	• AFT THC POS/NEG X/Y/Z OUTPUT A/B/C FAIL • AFT THC POS/NEG X/Y/Z OUTPUT DISAGREE	• NO MAL
	L	G3,6	• L SBTC CMD A(B,C) FAIL • L SBTC CMD A(B,C) DISAGREE	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
SBTC/THC	L	G2,3,8	<ul style="list-style-type: none"> FWD THC POS/NEG X/Y/Z OUTPUT A/B/C FAIL FWD THC POS/NEG X/Y/Z OUTPUT DISAGREE 	• NO MAL
	R	G3,6	<ul style="list-style-type: none"> R SBTC CMD A(B,C) FAIL R SBTC CMD A(B,C) DISAGREE 	
SEL AUTO		G2	• UNIV PTG MNVR T-30 & NOT AUTO	• NO MAL
SENSE SW		G2	• AFT SENSE SW DEFAULT	• NO MAL • DEFAULT POS IS '-Z'
212 SL LINK ERR		S2,4	<ul style="list-style-type: none"> ANY OF THE FOLLOWING MDM SERIAL I/O LINK ERROR CONDITIONS OCCURRED FOR SSC OR EXC: NO SL RESP ↓ GPC NO MATCH ↓ SL LENGTH ↓ AR NO MATCH ↓ SR NO MATCH ↓ MSG RJECT (ITEM OR GNC) ↓ MSG LINK BUSY ↓ MSG LINK DSBL ↓ 	• SL MAL, CDMS, MDM/MTU/PCMMU
212 SL LINK TERM		S2,4	<ul style="list-style-type: none"> MDM SERIAL I/O LINK TO SPACELAB TERMINATED. CAUSED BY ANY OF THE FOLLOWING FOR SSC OR EXC: NOP IND ↓ COMM ↓ LINK INTRPT ↓ 	• SL MAL, CDMS, MDM/MTU/PCMMU
SM1 SMOKE ALRM			SM	ANY SMOKE CONC ↑

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
SM1 SMOKE BAY	1A	S2,4	• AV BAY 1 SENSOR A CONC ↑	• NO MAL
	1B	S2,4	• AV BAY 1 SENSOR B CONC ↑	
	2A	S2,4	• AV BAY 2 SENSOR A CONC ↑	
	2B	S2,4	• AV BAY 2 SENSOR B CONC ↑	
	3A	S2,4	• AV BAY 3 SENSOR A CONC ↑	
	3B	S2,4	• AV BAY 3 SENSOR B CONC ↑	
SM1 SMOKE CAB	LFD	S2,4	• LEFT FLT DECK SMOKE CONC ↑	• NO MAL
	RFD	S2,4	• RIGHT FLT DECK SMOKE CONC ↑	
	HX	S2,4	• RETURN AIR CAB HX SMOKE CONC ↑	
SPD BRK		G3,6	• SPEED BRAKE POSITION > 20% FROM AUTO SCHEDULE DURING 0.95 < M < 9.8	• NO MAL
S66 SPLY H2O	PRES	S2,4	• SUPPLY H2O IN P ↓↑	
	QTY	S2,4	• SUPPLY QTY TK A(B,C,D) ↓ C(D) ↑	
	TEMP	S2,4	• SPLY DUMP LINE T ↑↓ • SPLY NOZ T A(B) ↑	
SSME FAIL	C(L,R)	G1,6	G1,6	• PREMATURE ME SHUTDOWN • IN MM101, MSG ANNUNCIATED BY BFS ONLY
SSME REPOS FAIL		G3	G3	<ul style="list-style-type: none"> MORE THAN ONE MPS/TVC ISOL VLV FAILED TO INDICATE OPEN LESS THAN TWO APU/HYD SYSTEMS INDICATED GOOD <ul style="list-style-type: none"> NO MAL SSME REPOSITIONING FOR DRAG CHUTE DEPLOY IS NOT COMPLETE MM304 AND 3.5 < MACH < 8

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
SUMWORD ICC 1(2,3,4,5)	ALL		• SUMWORD MISCOMPARE IN DATA FROM INDICATED GPC	
SW TO MEP	G3,6	G3	• MEP ALERT	• NO MAL
TFL LOAD FAIL	S2,4	ALL	• READ COMPARE ERROR • UNSUCCESSFUL LOAD	• NO MAL • MAY BE RESULT OF GROUND UPLINK
TGT ΔT	G2		• REQUESTED TRANSFER TIME CAUSED SINGULARITY IN TARGETING ALGORITHM	
TGT EL ANG	G2		• EXCEEDED MAX NUMBER OF ITERATIONS ON TPI TIG FOR GIVEN ELEVATION ANGLE	• NO MAL
TGT ITER	G2		• LAMBERT TGT TRANSFER ANGLE NEAR SINGULARITY POINT • PARABOLIC TRANSFER • MAX NUMBER OF ITERATIONS	
S87 THERMAL HYD	S2,4		• HX OUT T ↓	
S87 THERMAL CNTL 1(2,3)	S2,4		• LN T ELEV RD/SPBK/BDY FLP ↑↓	• HYD CIRC PUMP NOT MAINTAINING HYD THERMAL ENVIR
SM0 THRM APU APU EVAP		SM	• GG BED ↓, APU INJ T ↓	• APCL, EPCL - THERM HTR
		SM	• APU FU FEED LN T ↑↓, PUMP IN T ↑↓, PUMP OUT T ↑↓, FU TEST LN T ↑↓, FU SERVICE LN T ↑↓, PUMP DRN LN T ↑↓, PUMP BYP LN T ↑↓, GGVM SPLY LN T ↑↓, H2O LN INJ ↑↓	
		a	• FES NOZ, DUCT OR FDLN T ↑↓	• ONLY SELECTED DUCTS AND FDLN Ts ARE SENSED FOR STATUS

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
SM0 THRM (Cont) FRN H2O HYD PRPLT		SM	• ACCUM QTY ↓ • RAD OUT T ↑↓	• NO ASC/ENT PKT C/L
		a	• H2O SPLY IN P ↑↓	
		a	• H2O BLR T ↑↓	• NO MAL • ACL, EPCL - THERM HTR
		a	• OMS FU/OX BLD/DRAIN LN T • OMS POD RCS HOUSING • OMS RCS STRUCT T • OX ENG IN OR ENG FU FDLN T	
TIME MTU TONE	ALL		• AUTOMATIC TIME SOURCE CHANGE	
	ALL		• TIME MGT TIME TONE	• NO MAL
SM0 TIRE PRESS		G3,6	• NOSE GEAR/MLG TIRE PRESS ↓	
S66 VAC VNT NZ	TEMP	S2,4	• VACUUM VENT NOZ T	• NO MAL (NO LIMITS)
SM2 W/B QTY 1(2,3)		SM	• HYD SYS H2O BOILER FLUID QTY 40%	
S66 WASTE H2O	PRES	S2,4	• WASTE LIQ P ↑↓	
	QTY	S2,4	• WASTE QTY ↑↓	• NO MAL FOR QTY HIGH
	TEMP	S2,4	• WASTE NOZ T ↑↓ • DUMPLINE T ↑↓	
S86 WSB P 1(2,3) Q 1(2,3) T 1(2,3)	S2,4		• REG P ↑↓ • N2 P ↓	
	S2,4		• H2O QTY ↓	
	S2,4		• TK T ↓ • BLR T ↑↓	

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2.3 CLOSED CIRCUIT TELEVISION (CCTV)

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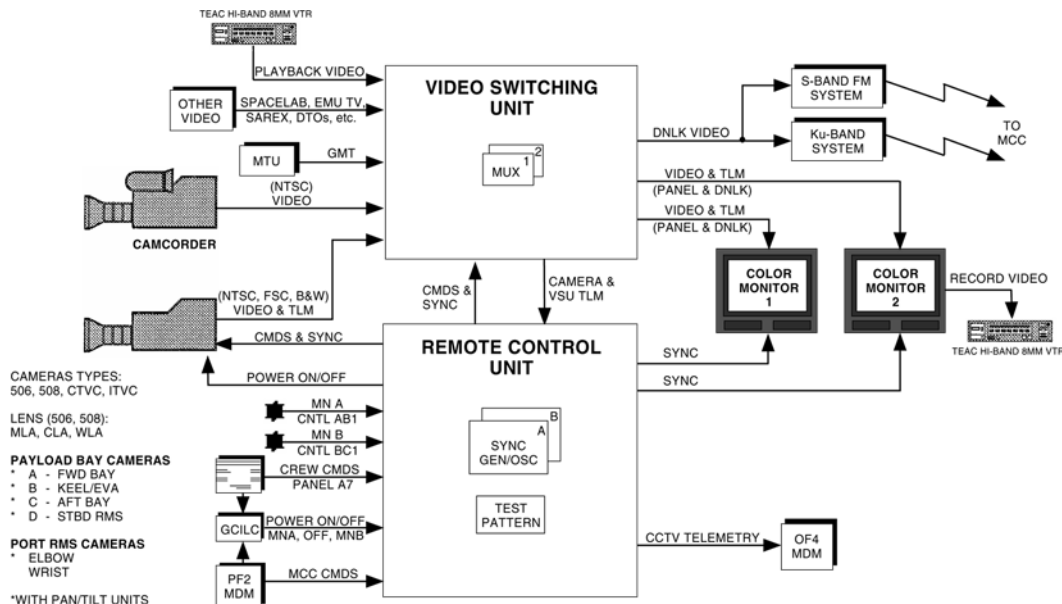
configurations are specified in the Flight Requirements Document for each shuttle flight.

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

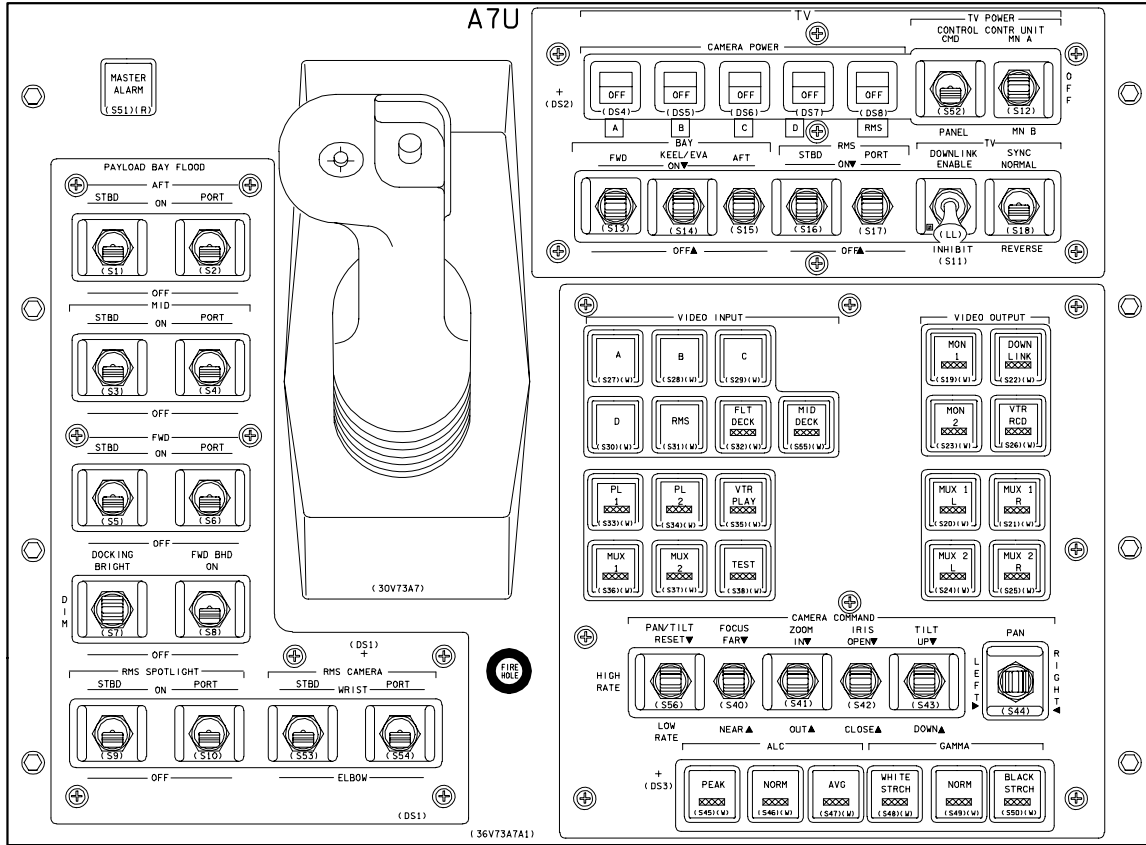
Description

The closed circuit television (CCTV) system is used on orbit to provide support to orbiter and payload activities. This support includes transmitting real-time and recorded video from the orbiter to MCC through either the S-band FM or Ku-band communications systems. Mission requirements for CCTV and camera

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



CCTV System Overview



Panel A7U

Video Processing Equipment

The video control unit (VCU) is the central processor/controller for the CCTV system. The VCU consists of two line replaceable units (LRUs): the remote control unit (RCU) and the video switching unit (VSU). Both LRUs are located behind panels R17 and R18 in the aft flight deck. These units are forced air cooled by cabin fans, although neither LRU includes a temperature sensor.

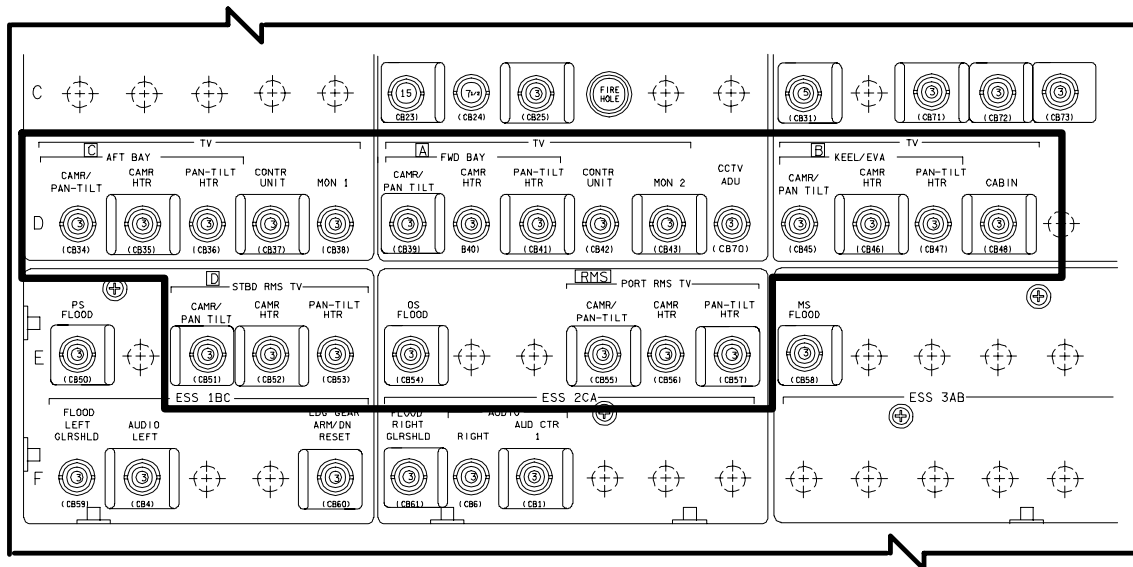
Remote Control Unit

The RCU receives all CCTV commands from both the crew and MCC. A ground command interface logic (GCIL) control switch located on panel A7U determines whether MCC can send commands to the CCTV system. When the TV POWER CONTROL switch is in the CMD position, MCC can uplink commands to the CCTV system, and the crew will be able to use all panel A7U TV switches except the TV POWER CONTR UNIT MN A / OFF / MN B switch. This TV POWER CONTR UNIT switch

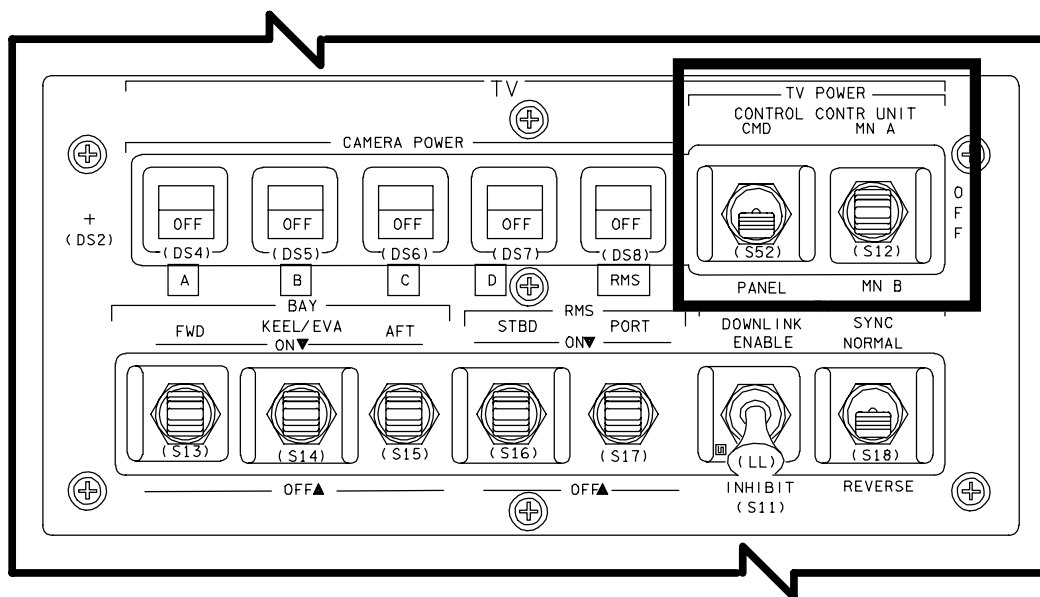
enables GCIL drivers to power up the VCU through either DC Main A or B via panel R14. The GCIL drivers prevent the crew and MCC from activating or deactivating the VCU simultaneously. When the GCIL TV POWER CONTROL switch is in PANEL, the crew can configure the TV POWER CONTR UNIT switch to provide VCU power or to turn the VCU off. All uplink commands to the CCTV system are inhibited when the GCIL switch is in PANEL.

Uplink commands to the RCU must pass through payload 2 mutimultiplexer/demultiplexer (PF2 MDM). The VCU power MN A / OFF / MN B commands to the GCIL drivers use PF1 or PF2 MDM like all other GCIL commands. However, if the GCIL Main C circuit power provided from panel R14 were to fail, the RCU will inhibit all uplink CCTV commands, except for the VCU power-on commands.

The crew can send any uplink CCTV command by executing a real-time command (RTC) on SPEC 1 of the SM GPC. The TV POWER CONTROL switch must be in the CMD position



CCTV Circuit Breaker on Panel R14



TV POWER Controls on Panel A7U

for crews to use this feature. Crews do not carry any CCTV specific RTCs in any Flight Data File (FDF) documents. This capability would only be used if MCC were unable to uplink commands or for functions not available from panel A7U.

The RCU includes two independent video sync generators. The sync generators are tied to the power on logic and TV SYNC NORMAL/ REVERSE switch on panel A7U. When the TV SYNC switch is in NORMAL, sync generator A

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

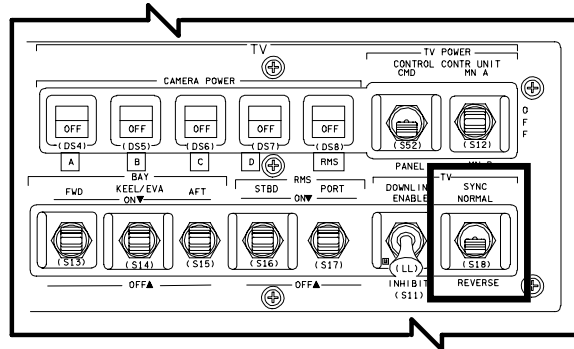
In addition to generating master sync signals, the RCU also generates a full-field test signal, better known as a test pattern. The test pattern is black and white. The test pattern can be selected as a video source from panel A7U or via an uplink command.

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

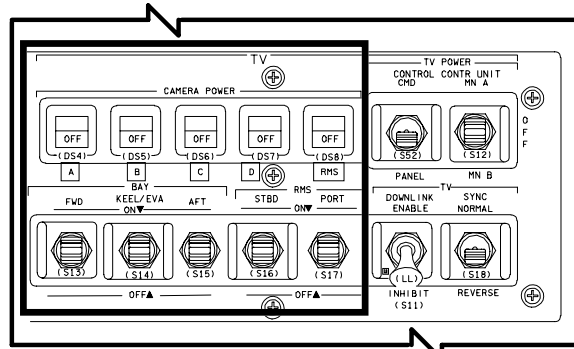
The crew activates payload bay cameras using the TV CAMERA POWER switches located at the top of panel A7U. These switches are momentary in both the ON and OFF positions. The ON/OFF talkbacks are set by the RCU. The talkbacks indicate the status of a 28 V dc discrete signal that enables a remote power controller (RPC) to provide panel R15 circuit breaker power to a payload bay camera and pan/tilt unit. The talkback status can be misleading because the talkback can indicate ON when the circuit breaker that provides power to the camera is out. Crews should always use these switches to power off the cameras prior to deactivating the VCU to ensure correct camera powerdown.

There are two remote manipulator system (RMS) camera switches to note. In addition to the RMS PORT TV CAMERA POWER switch, another RMS camera switch is located directly below the aft RHC on panel A7U. The RMS CAMERA WRIST/ELBOW select switches toggle between the wrist (end effector) and elbow cameras. Only the RMS CAMERA PORT

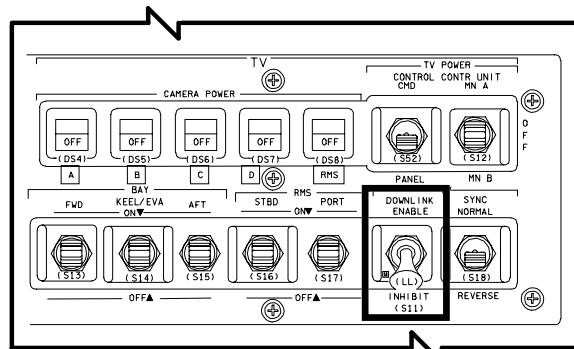
WRIST/ELBOW switch is operational when the RMS is flown. Only one RMS camera can be activated at a time. Cycling the switch powers off one camera and powers on the other. MCC cannot select between the wrist and elbow cameras nor can MCC identify the position of the switch using downlinked telemetry.



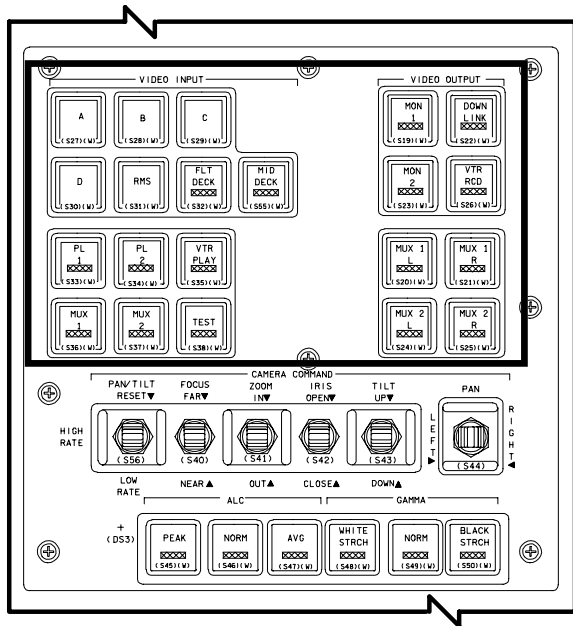
TV SYNC Switch on Panel A7U



CAMERA POWER Switches and Talkbacks on Panel A7U



TV DOWN LINK Switch on Panel A7U



VIDEO INPUT and OUTPUT Push buttons on Panel A7U

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

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

Video Switching Unit (VSU)

The VSU can accommodate up to 13 video inputs and 7 outputs. However, panel A7U

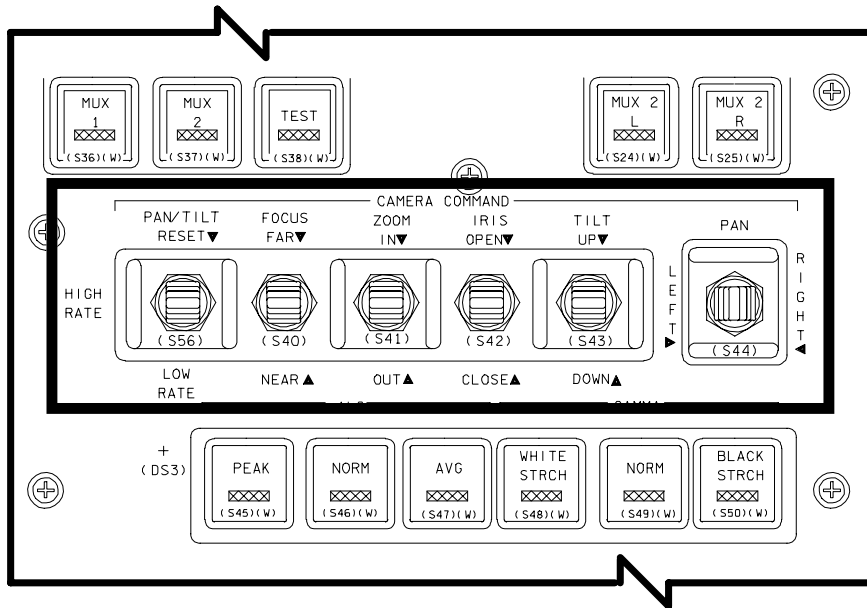
only provides for 10 inputs and 4 outputs. Adding pushbuttons to expand the VSU operational capability has been determined by the Space Shuttle Program (SSP) as being too expensive for the increase in capability and is not planned.

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

CAMERA COMMAND Controls on Panel A7U

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

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



CAMERA COMMAND Controls on Panel A7U

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

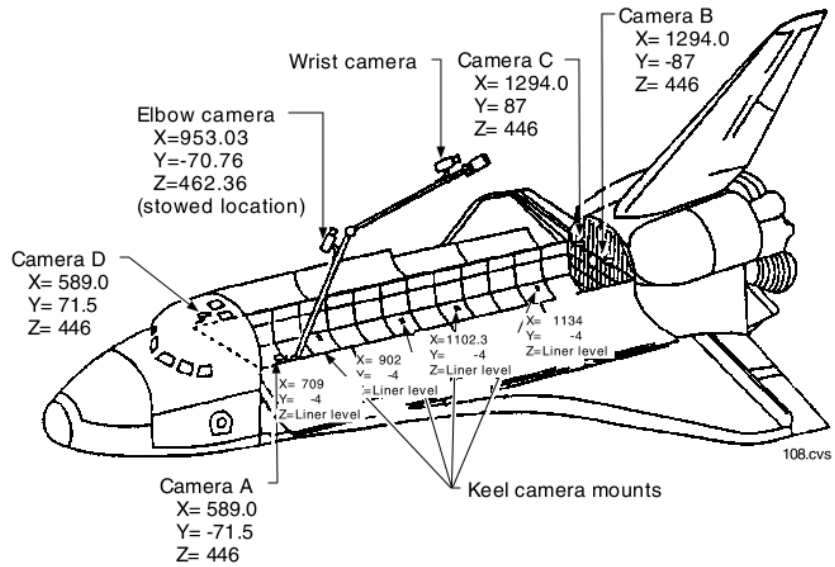
The asynchronous mode does not mean that the CCTV system is no longer sync'd together. CCTV cameras are still slaved to the RCU, as is

the VSU. Since almost all payload customers require a GMT timetag in recorded and real-time video, crews and flight controllers must coordinate the use of async mode.

The VSU includes the capability to interleave digitized voice in the downlink video. The PL BAY OUTLETS ICOM A and B switches will send either or both ICOM audio loops for digitization and interleaving with downlink video. This feature was provided in an effort to create lip sync between the audio and video. An uplinked command is required to enable the delta modulator to digitize these voice loops. This feature degrades the quality of the downlink video; the digital voice can be seen as distorted vertical color bands along the left side of the picture. This feature is no longer used.

CCTV Cameras

There are four types of CCTV cameras flown in the payload bay. The cameras are designated as -506, -508, color television camera (CTVC), and intensified television camera (ITVC). The first camera flown onboard the orbiter was the -506 camera. The -508 is an improved version of the -506. The CTVC first flew on STS-61. The ITVC is expected to fly first in mid-1995. The -506 and -508 cameras are expected to be phased out in 1996.



Payload Bay CCTV Camera Locations



CCTV Lens (Color/Monochrome Lens Assembly Model)

Each payload bay camera has two names associated with its position. Camera ports were labeled before CCTV operations were finalized. Crews insisted upon naming cameras in a manner where camera ID could be more easily identified with the camera's location in the payload bay. The two names for each camera location are listed below:

- | | |
|----------------|-------|
| FWD BAY | A |
| KEEL/EVA BAY | B |
| AFT BAY | C |
| RMS STBD | D |
| RMS PORT WRIST | WRIST |
| RMS PORT ELBOW | ELBOW |

Some missions require additional cameras in the payload bay. These keel cameras are usually positioned in one of four keel camera mounts. Occasionally, these cameras are mounted on payload support structures and are used to assist with berthing operations.

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

Field sequential color (FSC) was selected by the SSP as the color video standard instead of the National Television Standards Committee (NTSC) standard because NTSC cameras in the 1970s were much larger and consumed more power than their FSC counterparts. In addition, FSC cameras performed well for the Apollo program in the late 1960s and early 1970s. Today, miniaturization of electronics allows NTSC cameras (both CCTV and camcorders) to occupy a smaller volume and consume less power than in years past. By the end of 1994, the SSP is expected to retire the FSC lens assemblies and use only black and white or NTSC cameras.

-506, -508 Cameras

The -506 and -508 cameras compose the rear half of the old CCTV camera assembly, with the lens assembly occupying the front half. The imaging device within the camera is a silicon intensified target vidicon (tube). This vidicon provides excellent low-light performance, especially when used in conjunction with a monochrome lens assembly (MLA). The combination of MLA with the -508 camera is sensitive to 0.01 lux. The -508 and MLA combination is manifested for use where low-light capability is required.

The -506 and -508 cameras are monochrome, providing an RS-170 (black and white) video signal. The color lens assembly (CLA) and wide-angle lens assembly (WLA) have a rotating color wheel composed of primary color filters (green, blue, red). A green filter passes green component light into the camera in one

field, a blue filter passes blue light on the next field, followed by a red filter passing red light on the third field. The process is then repeated. The end result of this process is FSC video. Equipment at MCC (and converters in the orbiter's color monitors) sync up to the green field. Green, blue, and red color fields are processed. Since the video signal is composed of 60 fields per second, 20 fields of green, blue, and red appear every second. The contrast changes every field if the scene includes brightly colored objects (such as a blue ocean). This causes flicker because the filters are blocking the other primary color wavelengths on alternating fields. For video scenes of stationary objects, the color quality is quite good. As objects move relative to the camera, color quality and motion rendition degrade. The color along the perimeter of moving objects is not sharp (individual green, blue, and red lines are visible). Essentially, the only differences between the CLA and WLA are the field of view and zoom capabilities, as shown below.

Lens	Focal length (zoom)	Zoom ratio	Focus distance	F-stop (iris)
Monochrome	18mm to 108mm	6:1	2.5 ft to ∞	f1.6 to f16
Color	18mm to 108mm	6:1	2.5 ft to ∞	f1.6 to f16
Wide Angle	8.2mm to 25mm	3:1	2 ft to ∞	f3.5 to f22

Zoom	Focus	FOV (horizontal)	
		MLA & CLA	WLA
Out	Far	40.9°	83.3°
In	Far	6.6°	29.5°

CCTV Lens Data

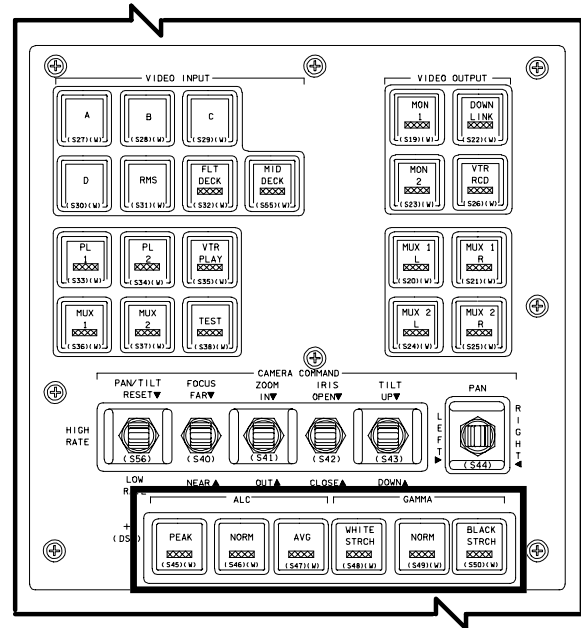
The -506 and -508 cameras have automatic light control (ALC) circuitry to provide control of the camera lens' iris and the camera's silicon target high voltage supply. There are three ALC settings for these cameras: peak, normal, and average. To select an ALC mode, the crew will use panel A7U ALC and Gamma pushbuttons (PEAK, NORM, AVG). MCC/INCO can also select ALC settings via uplink commands. The ALC settings shift the camera's dynamic range from white (peak), to neutral (normal), to black (average).

The peak ALC setting is most sensitive to incoming light; therefore, the iris will allow less light to enter the lens than with an ALC setting of normal. The average ALC setting will command the iris to open more and increase the voltage gain when compared to the ALC setting of normal. When crews or MCC require direct control of the iris, the iris switch on panel A7U just above the ALC AVG PBI or an iris open/close command by MCC can be used to disable the ALC. This mode is called semi-manual. The camera operator has total control of the iris but does not control the vidicon gain since the auto gain control (AGC) is still enabled.

Additional video processing circuits can be activated. Gamma correction circuits can be used to provide additional output gain (or attenuation). Gamma circuits provide an exponential gain as opposed to a constant gain. The white stretch is selected by the WHITE STRCH pushbutton on panel A7U. The white stretch exponent is less than one (0.667), thus providing an attenuation. This provides for better contrast and detail within brightly lit objects, such as a payload reflecting sunlight. The black stretch is selected by the BLACK STRCH pushbutton. The black stretch exponent is greater than one (2.0), thus the circuit provides additional gain. This setting provides for better detail and contrast of dimly lit objects and is best suited for applications such as star gazing or lightning observations at night. The gamma setting of normal is selected by the gamma NORM pushbutton. Gamma normal bypasses the gamma circuit, providing no additional gain or attenuation.

A semi-manual mode is available in both the -506 and -508 cameras. The camera operator can select semi-manual mode by executing a manual iris command. The -508 camera further requires that gamma normal be selected. A full-manual mode is a feature of the -508 camera only. This is selected using white or black stretch gamma and having the ALC disabled by sending a manual iris command. The white and black stretch provides fixed voltage gain to the silicon target of the camera when the ALC setting is disabled. This feature provides for full control of the camera (iris and silicon target gain) by disabling the ALC and AGC. **CAUTION:** both semi- and full-manual modes leave the cameras vulnerable to damage by the Sun if sunlight

passes through the viewing area of the camera. Crews and flight controllers must be aware of the Sun's position when using these manual modes. Do not leave a camera unattended in any manual mode!



ALC and GAMMA Pushbutton and Panel A7U

Color Television Camera (CTVC)

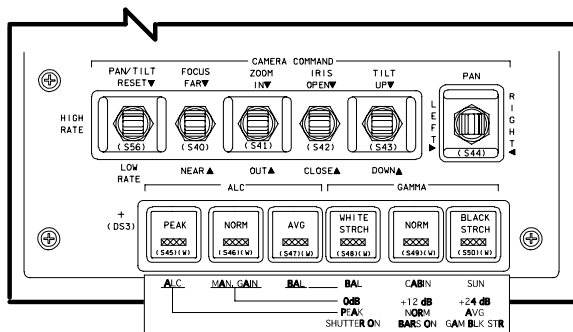
Unlike the -508 and -506 cameras that employ a special lens assembly (CLA or WLA) to provide a color (FSC) video signal, CTVC provides an RS-170A (NTSC) color video signal that does not require additional processing in MCC prior to distribution to the media. NTSC is the color video standard in North America, Japan, and other areas. Great Britain and France are among nations with television standards other than NTSC.

The CTVC is approximately the same size and shape as the -508 camera with a CLA or MLA lens. The CTVC does not have interchangeable lenses like the -508 camera. The CTVC lens is encased within the CTVC housing. The CTVC has a maximum horizontal field-of-view of 77° and a minimum of about 9°.

The CTVC uses three charge-coupled devices (CCDs) to take discrete samples of light passing through a prism after entering the lens. The red, green, and blue (RGB) light separated by the prism are directed to (RGB) CCDs. The CCDs are strobed by the camera's timing circuits to

provide RGB component signals. The RGB signals are processed independently to provide color balancing. Payload bay floodlights, compact portable lights (CPLs) in the cabin, and sunlight are composed of different light spectra. The CTVC includes bay, cabin, and sun color balance settings to compensate for the different wavelength components of fluorescent, tungsten, and solar lighting, respectively. A color-coded decal was created to assist crews in operating the CTVCs. The ALC options are coded red, MAN GAIN in green, BAL in blue, and miscellaneous in black. This menu system for configuring the CTVCs provides control of the CTVC's operating modes using existing PBLs and uplink commands.

The CTVCs have ALC settings essentially identical to the -508 and -506 cameras. ALC settings can be disabled by using the iris command switch on panel A7U or by selecting a manual gain setting. There are three manual gain settings with the CTVC: 0 dB; +12 dB; and +24 dB. The gain settings not only fix the output gain by the specified amount but also fix the iris to its current position. If the crew or MCC sends a manual iris command when in an ALC setting, the ALC is disabled, and the camera is moded to manual gain of 0 dB. The scene will immediately appear darker because the AGC will be disabled once the iris command is received by the camera.



CTVC Decal

The CTVCs also include some miscellaneous settings, sometimes referred to as the "all-off" menu. A shutter can be activated to reduce vertical smearing caused by bright light. Color bars can be generated for the crew to calibrate the color monitors. Since the color bars are generated within the camera (as opposed to the B&W test pattern of the VCU), the color bars

could be used to inspect noise in the CCTV system if video appears degraded onboard. Gamma can be toggled between black stretch and linear.

The power on defaults are manual gain of 0 dB, color balance of sun, and gamma black stretch. The CCTV activation cue card instructs crews to select the applicable color balance for the environment and then select ALC of average.

The CTVCs provide full-level output at 20 lux and are designed to operate in a medium to bright light environment. These cameras operate poorly in low light. Colors cannot be distinguished in low light, so there was no need to design these cameras for that environment. Because CCTV camera operations are required for a low-light environment, a black and white camera was designed to meet these needs and operate similarly to the CTVC.

Intensified Television Camera (ITVC)

The ITVC is essentially a black and white version of the CTVC. The ALC, manual gain, and gamma settings are exactly the same. However, the ITVC only has one CCD (instead of the CTVC's three) and is optimized for a low-light environment. Instead of color balance, the ITVC includes day and night operating modes. The night mode provides additional gain, which can be used with any ALC setting as well as manual gain settings. This feature allows a high gain option without sacrificing the ALC protection, particularly around orbit sunrise. A combination of night mode and manual gain 24 dB will make the ITVC sensitive down to 0.03 lux and provide a full-level output at around 0.2 lux. If the night mode is used with daylight, the video will appear granular (noisy). The daylight mode essentially deactivates the night mode.

The ITVCs also include an aperture compensation that provides finer detail in low-light conditions. Although the ITVCs have been designed to work well in low light, these cameras are not quite as sensitive to light as are the -508 cameras coupled with the MLA. When the fleet inventory of ITVCs is sufficient, the -506 and -508 cameras are expected to be removed from service. Currently, there is no operations decal to assist in ITVC ALC/Gamma PBI operations.

Power-on defaults are similar to the ITVC. Manual mode of 0 dB is displayed on panel A7U and night operation mode and gamma black stretch are active in the background. The ITVCs will be configured using a menu based system that has ALC/Gamma PBI commands very similar to those of the CTVCs.

CCTV Camera Lens Control

Each CCTV camera type uses the same switches and command sequences to adjust the camera's field-of-view. Just above the six ALC/Gamma pushbutton indicators (PBIs) is a row of switches used to send commands to the cameras and pan/tilt units.

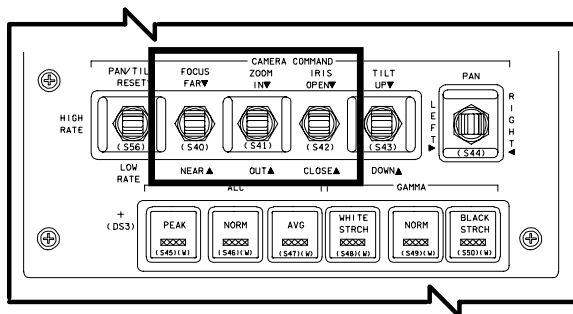
Lens commands are used to adjust the lens and iris settings. The focus, zoom, and iris commands provide the crew and MCC with direct control of lens settings. The CTVC and ITVC insert lens data into the video. The color monitors are able to display the lens data in the upper portion of the monitor's display. This data is also available to INCO in the MCC. In addition to changing the field-of-view, the zoom function can affect the apparent scene brightness when the camera is in an ALC mode. As bright objects increase or decrease in size, the ALC adjusts accordingly to increase or decrease the amount of light entering the lens. The -506 and -508 cameras tend to bloom in the presence of bright objects. Changing the field-of-view can usually reduce the blooming without changing the camera's auto or manual operating modes. The IRIS switch provides manual control of the iris to the user. Use of this switch disables ALC. When using this switch, crews must not leave the payload bay cameras unattended. Direct sunlight can permanently damage these cameras if a camera's iris remains open.

Pan/Tilt Units (PTUs)

The PTUs are used with cameras A, B, C, D, and RMS elbow. The PTUs are used to change the cameras field-of-view by moving a camera about two axes. The PTUs can pan and tilt 170° in either direction, positive or negative, when any CCTV camera is attached. However, a -506 or -508 camera with a WLA will limit tilt to plus and minus 150°.

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

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



Focus, Zoom, and Iris Control



Pan/Tilt Unit with Camera Thermal Blankets

Cabin Cameras

Although all CCTV cameras are compatible with the TV outlets located on panels O19 and MO58F, there are no plans to regularly use these cameras in the flight deck or middeck areas. Camcorders have replaced the CCTVs in the orbiter's crew compartment. In addition to providing excellent real-time video, the camcorders can also record and play back video without using an external video recorder.

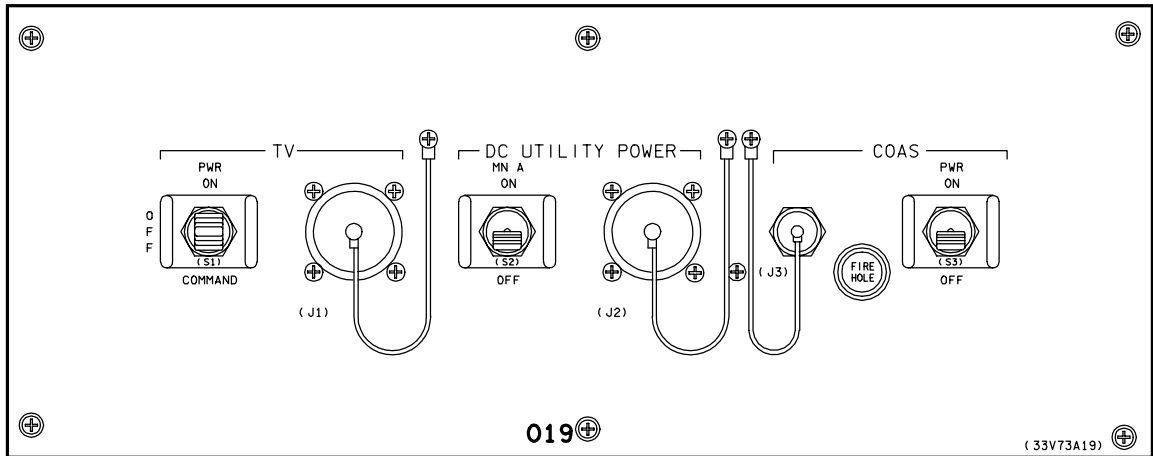
CCTV cameras will be used in the Spacelab module because these cameras can be remotely commanded by crews and MCC, unlike camcorders. If a CTVC is used in a Spacelab module, the crew should select a manual gain of +12 dB before manually adjusting the iris of the lens. Direct sunlight is not a concern, so crews should manually adjust the camera for the best possible picture.

Camcorders

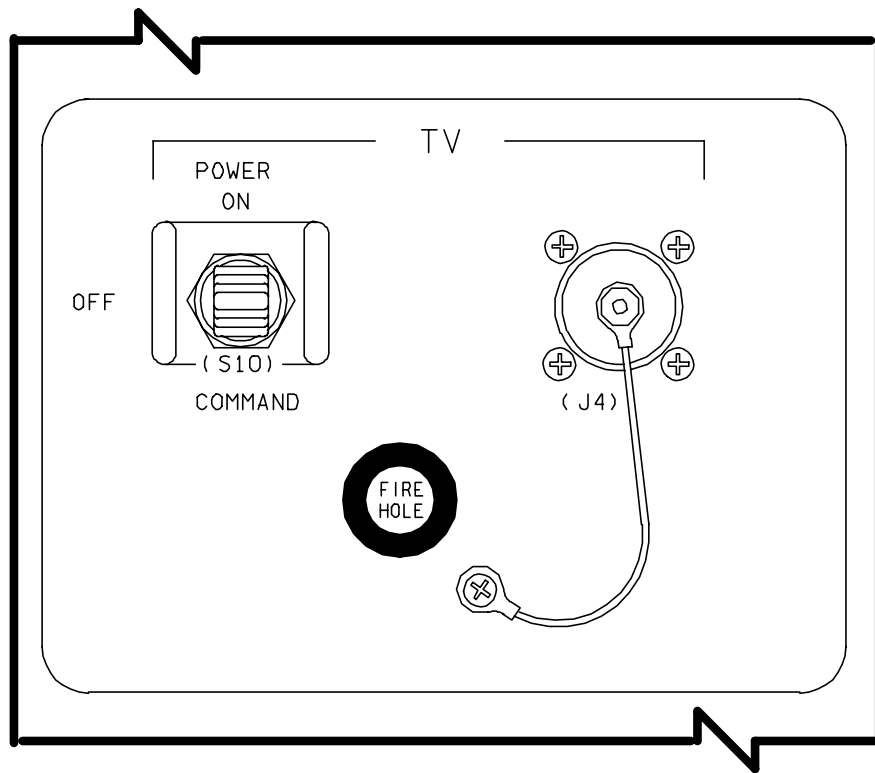
The Canon A1 Hi-Band 8mm camcorder was the first camcorder selected for use on the orbiters back in 1990. In 1992, the Canon L1 Hi-Band 8mm camcorder gradually replaced the Canon A1. The Canon L1 camcorder uses removable lenses that can be changed in flight. As

camcorder models become commercially obsolete (no longer manufactured), the SSP is expected to phase-in new commercial-off-the-shelf (COTS) camcorders and other video equipment and accessories as necessary. Detailed model-specific camcorder features can be found in the Photo/TV Reference Manual.

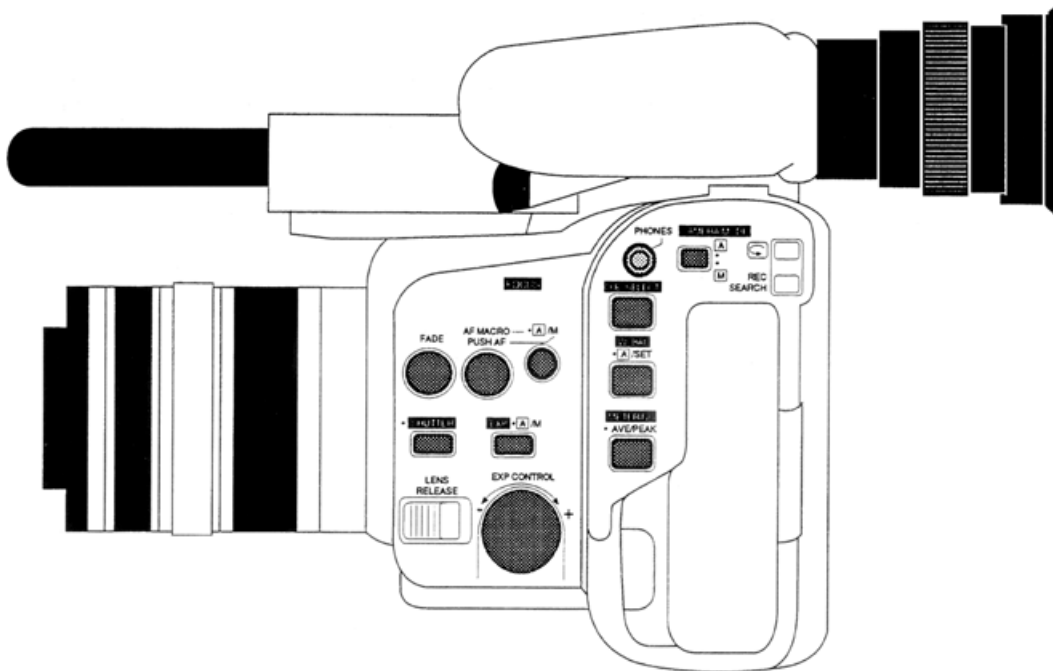
Camcorders cannot interface directly with the CCTV system. COTS video equipment almost exclusively uses unbalanced video signals. Unbalanced video signals are referenced to a chassis ground (two lines, positive and ground). The orbiter's CCTV system uses balanced video signals that have a neutral reference (three lines: positive, negative, and ground). A VIU-C (video interface unit) is required to convert the camcorder's unbalanced signal to a balanced signal compatible with the CCTV system. The VIU-C also converts the orbiter's 28 V dc power to 6 volts in order to power the camcorders. The VIU-C adjusts the sync voltage level within the the camcorder's video signal to prevent overmodulation of downlink video. The VIU-C has three connectors: 28 V dc in and balanced video out (to O19 and MO58F); unbalanced video out (to portable LCD monitor); and 6 V dc out and unbalanced video in (from camcorder).



Cabin Camera Power Connectors/Control on Panel O19



Cabin Camera Power Connectors/Controls on Panel MO58F

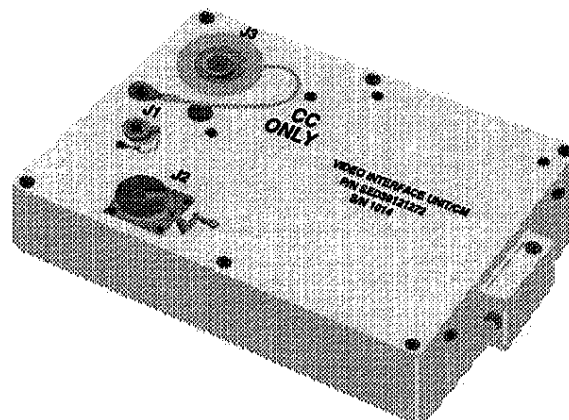


Canon L1 Hi-Band 8 mm Camcorder

A transformer can be used with a camcorder to record video from a connector on the rear panel of the color monitors. The transformer is required to convert the balanced output video of the monitor to an unbalanced signal usable by the camcorder. This transformer is usually Velcroed to the side of the VIU-C. The combination of VIU-C and transformer is referred to as the VIU-CM.

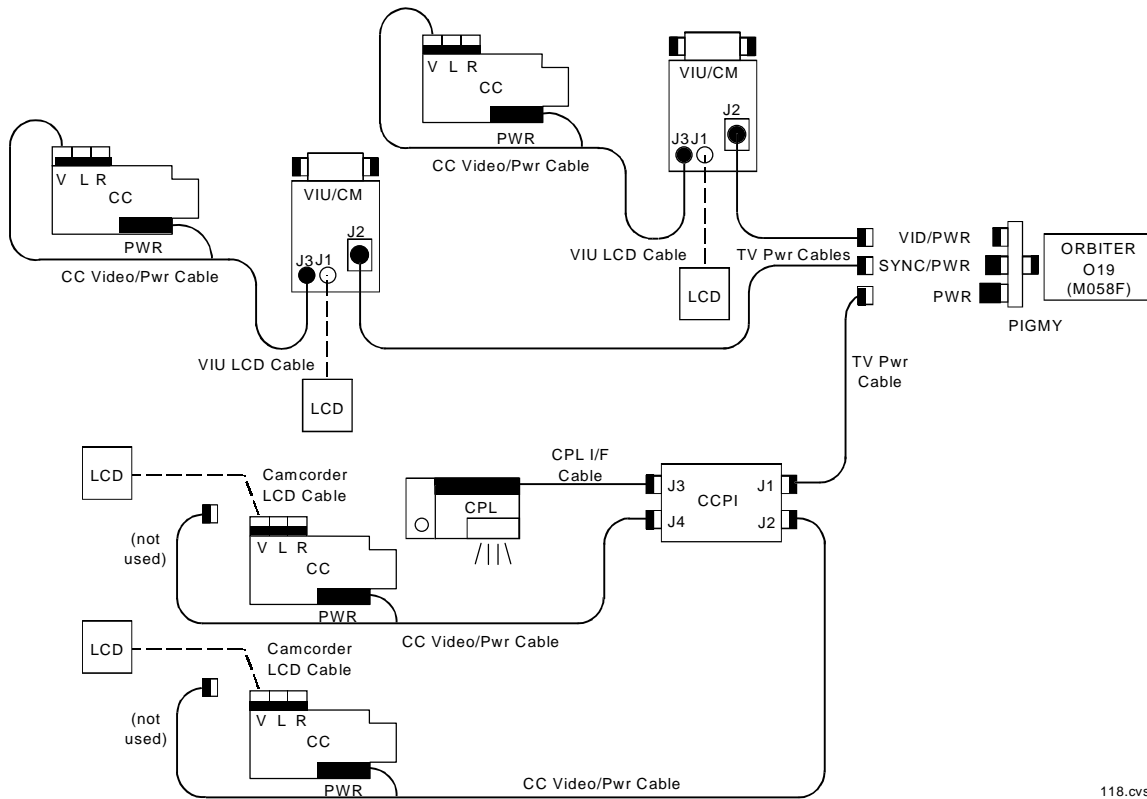
In addition to providing real-time video like a CCTV camera, the camcorders have a built-in Hi-band 8mm video cassette recorder. The blank video cassettes flown have two-hour record duration. The camcorders can record or play back audio in addition to video. However, the camcorder's audio, like the video, is unbalanced and the orbiter audio is balanced. The audio signal level of the camcorder to and from the audio system creates a volume imbalance. The ICOM recorder (currently a Sony cassette recorder) is required to balance the signal values and to convert audio signals between balanced and unbalanced formats. Although the camcorder can record and play back stereo audio signals, the orbiter audio system is not capable of transmitting or receiving stereo (one audio channel only).

The camcorders can be powered by the VIU-C or by two other means. A battery pack can be used, but battery power only lasts from 20 to 40 minutes, depending on how the camcorder is used. The camcorder power interface (CCPI) device can be connected to a TV camera port on either O19 or MO58F. The CCPI, using a different cable, can also draw power from a dc utility power outlet, freeing the camera ports. The CCPI only provides power, it cannot be used to route video. The CCPI can provide power to one or two camcorders plus a compact portable light (CPL).



Video Interface Unit/CM (VIU/CM)

Multiple Camcorder w/Pigmy Cable and CCPI



118.cvs

Camcorder Setup from Photo/TV Checklist

Video Tape Recorders (VTRs)

Video tape recorders have flown on every space shuttle mission to date. More than one video camera is flown and because the orbiter is unable to downlink video to MCC continuously, the CCTV system must be able to record video to document activities. The SSP has flown an interim VTR that uses U-Matic (3/4-inch) video cassettes. These tapes could record up to 30 minutes of video. The Office of Aerospace Technology (OAST) has supplied a similar VTR when more than one VTR was required for a mission. The VTRs were placed in a VTR bucket, which not only secured the VTR but also provided input/output configuration and power. The VTR buckets were placed in an aft flight deck panel (usually R11 or L10). Each VTR bucket would occupy half a panel. The OAST VTR was last flown on STS-51. Since STS-53, every mission has manifested at least one modified Teac Hi-Band 8mm video cassette recorder. The payload video console will replace loose video taping equipment used onboard.

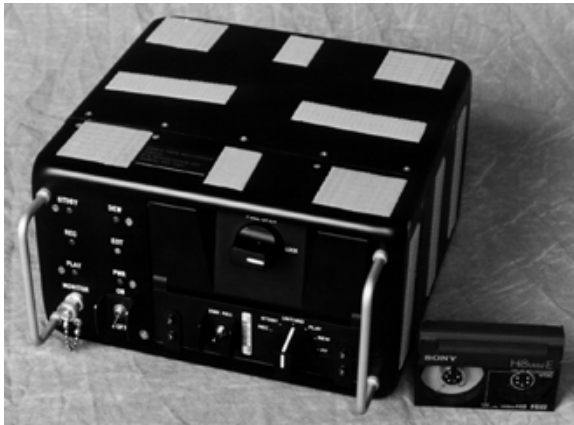
Teac 8mm VTR

Although the Teac Hi-Band 8mm VTR is a video cassette recorder (VCR), the term VTR is applied to this piece of equipment as a matter of convention. This VTR is loose equipment; therefore, it does not require securing in an aft flight deck panel. The 8mm VTR is stowed with its cables and accessories in a locker on the flight deck or middeck.

The 8mm VTR has connectors on the front and rear of the VTR chassis. The rear panel of the VTR has three connectors. The POWER & VIDEO OUT receptacle is used to accept 28 V dc and output a video signal. The VIDEO IN connector receives a video signal from the J3 connector on the rear of a color television monitor. This allows the VTR to record video routed from the VSU to the color monitor. The AUDIO ATU/HIU connector provides an interface to an ATU via the ADS/VTR (audio distribution system) cable or a headset interface unit (HIU) in order to record or playback audio.



TEAC 8mm VTR Rear Panel



8 mm Video Tape Recorder (8 mm VTR)

The MONITOR connector on the front faceplate provides video to an LCD monitor. Tape counter and VTR mode indications will appear on the LCD screen. Six LEDs are present on the front faceplate. VTR modes of standby (STBY), record (REC), and PLAY are indicated by the illuminated LED. A power-on LED will indicate if 28 V dc is reaching the VTR. An end-of-tape (EOT) LED will indicate when the video cassette has reached its limit. A humidity sensor can activate the DEW LED. If condensation is present inside the VTR, the VTR will unthread the tape and will not operate.

Two switches and two rotary knobs are also located on the front faceplate. The ON/OFF switch enables or disables power to the VTR. The EMK REC is a momentary switch that can be used to record a 1 kHz tone when recording video. This tone can be used as an aural cue (marker) when playing back the video with audio. The PULL OPEN/LOCK knob is used to

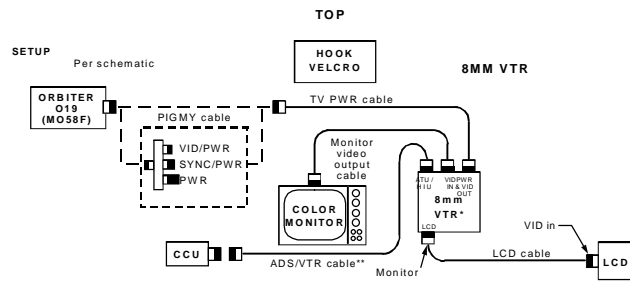
secure a door that prevents contaminants from entering the VTR during operations. When the door is opened, the tape counter on the LCD monitor is zeroed. Finally, a mode select knob allows the user to select operating modes for the the VTR. The knob must be in the UNTHRD (unthread) position to remove a tape. All modes except unthread are indicated on the LCD monitor.

The 8mm VTR is powered from panel O19 or MO58F TV camera power port. The camcorders and VTRs have been using the source for power, so a pigmy cable was constructed to provide multiple power outlets. The pigmy cable plugs into the flight deck or middeck camera port and has three connectors with unequal cable extensions on the other end. The VID/PWR connector provides 28 V dc power and allows video to be routed to the VSU as flight deck or middeck video. The VID/PWR connector has the shortest cable extension. The SYNC/PWR connector provides 28 V dc power and provides a sync/command signal that could be routed via a TV interface panel (TVIP) or a payload data interface panel (PDIP) for CCTV cameras in the payload bay that require synchronization with the CCTV system. This sync signal is usually required when more than one keel camera is used. The longest extension of the three has a PWR connector, which provides only 28 V dc power.

Camera overtemp alerts from the SM GPC can be inhibited by SM SPEC 60. The ITEM 1 allows the crew to enter a seven-digit parameter address. The current value of the term specified will be displayed underneath ITEM 1. ITEM 10 allows the crew to inhibit the caution and warning (C&W) system from annunciating alarms as a result of parameter violations. The sequence for inhibiting TV camera overtemperature sensing by SM is provided on the 8mm VTR cue card. MCC can also perform this task via a TMBU.

Payload Video Console (PVC)

The PVC is designed to mount two Teac Hi-band 8mm VTRs on panel R12. This will free up an inboard locker stowage container and reduce the number of cables the crew must configure for CCTV support. Configuration of the PVC, which includes what video to route, VTR operating modes, and audio configuration will



* Handheld MIC (HMM) and very lightweight headset (VLHS)/HIU can also be connected to 8mm VTR audio ATU/HIU port
 ** ADS/VTR cable RCD/PLBK sw left in PLBK at allk times
 *** /MCC PRIOR TO PWR ON FOR SYNC/ASYNC CONFIG ***

ACTIVATION

VTR PWR - ON
 A7 Go to ACTIVATION, OPERATION (Cue Card, TV)
 LCD PWR - ON (as reqd)

OPERATION

RECORD VIDEO

VTR ✓Tape Installed
 A7 VID OUT - MON 2
 VID IN - as reqd
 VTR Control sw - STDBY
 Control sw - REC (as reqd)
 ✓REC LED

- WITH AUDIO

ADS/VTR Cable
 ORB - COMM CCU
 VTR - ATU/HIU
 Cable sw - PLBK
 ATU AUD PWR - AUD
 Desired loops - T/R or REC, tw - 0
 Other loops - OFF

OPERATION (C oncluded)

TOP
 BACK OF '8MM vtr'
HOOK
VELCRO

PLAYBACK NOTES

For extended onboard playback of VTR or other async inputs, S76 COMM alerts may be avoided by inhibiting Camr overtemp C&W
 SPEC 60 ITEM + 0 Z 4 0 8 4 Z EXEC, 10 EXEC
 Advise MCC or C/W Enable status

After plyback completion, Camr overtemp detection must be enabled
 SPEC 60 ITEM 1 + 0 Z 4 0 8 4 Z EXEC, 9 EXEC
 Advise MCC or C/W Enable status

VIDEO PLAYBACK (DNLK)

VTR ✓Tape Installed
 Rewind tape position (as reqd)
 O19 ✓PIGMY - Vid/pwr if reqd
 A7 VID OUT - MON 1(2)
 VID IN - FLT DECK
 I TV DNK - ENA
 [VID OUT - DNK]
 [VID IN - FLT DECK]
 VTR Control sw - PLAY
 ✓PLAY - LED

- WITH AUDIO

ADS/VTR Cable
 ORB - COMM CCU
 (if MHA; CCU pwr - ON)
 VTR - ATU/HIU
 Cable sw - PLBK
 ATU AUD PWR - AUD
 Desired loops - T/R
 Other loops - Not T/R
 AUD XMIT/COM MODE - VOX/VOX
 AUDVOX SENS - MAX

ACTIVATION

VTR Control sw - UNTHRD
 Remove, mark, stow tape at reqd
 PWR - OFF
 LCD PWR - OFF (as reqd)
 A7 Go to DEACTIVATION (Cue Card, TV) as reqd
 ATU Reconfig as reqd

8mm VTR Cue Card (Front and Back)

be controlled by the crew using a portable computing device. Most recording and playback features can be commanded by MCC. This will allow for video recording and playback during crew sleep periods. The PVC is expected to first fly in 1996.

Special Purpose Video

On many missions, additional video sources are used above and beyond the payload bay, RMS, and cabin cameras (camcorders) in order to meet mission success. Keel (berthing and/or prox ops) cameras will be installed on rendezvous missions. These cameras are usually stationary CCTV cameras (no PTU) although mission-unique video cameras have been flown in the payload bay. Pressurized modules (Spacelab and Spacehab) include camera ports that can provide cabin or experiment video from the module to the orbiter CCTV system. Video can also be received via RF carrier (S-band FM) from an EVA crewmember or a deployed satellite, such as SPAS.

Spacelab

The Spacelab module, in addition to providing camera ports for sending video, includes a video analog switch (VAS) that can be configured by MCC or the crew to route video to and from the orbiter CCTV. The VAS can also downlink video directly to the Ku-band system (PL

analog, channel 3) and bypass the orbiter CCTV system. The VAS is used to route video and activate cameras in the module. Video recording equipment is installed in experiment racks for experiment video recording. Instead of using switches and pushbuttons for camera configuration and routing, the crew uses a payload and general support computer (PGSC) to input commands to the Spacelab experiment computer. Commands are then sent via a remote access unit (RAU) to the Spacelab video equipment.

The Spacelab module TV connectors include extra pins that are used to specify camera addresses not available in the orbiter. This provides for remote commanding of these cameras from MCC or from panel A7U. Therefore, cables designed for the orbiter cannot be used in Spacelab for use with standard orbiter CCTV cameras. Orbiter cables can be used with camcorders (with a VIU-C).

Additional information on the Spacelab CCTV system can be found in the S COMM 2102 training workbook.

EMU/Payload TV

The EVA crew can transmit television signals from an EMU suit if special equipment is attached to the helmet. The EMU camera is a CCD imaging device that sends its signal to an RF (S-band) transmitter. A receiver demodu-

lates the TV signal from the carrier. This receiver uses one of the two orbiter S-band FM antennas to receive the EMU TV signal. The receiver will be located in the middeck. The output of the receiver will be routed to panel MO58F to be distributed as middeck video. EMU TV was last attempted on STS-49. The S-band FM system was used with good results to receive video from the SPAS on STS-51.

Airborne Digitizer Unit (ADU)

The ADU is used to capture a snapshot (still picture) of video. Once a frame of video is captured by this device, the video image is digitized and encrypted for downlink through Ku-band, S-band FM, or S-band PM communication systems. This unit was used during DOD missions. The equipment remains certified for flight, although it is very unlikely it will be flown again on any upcoming NASA flights.

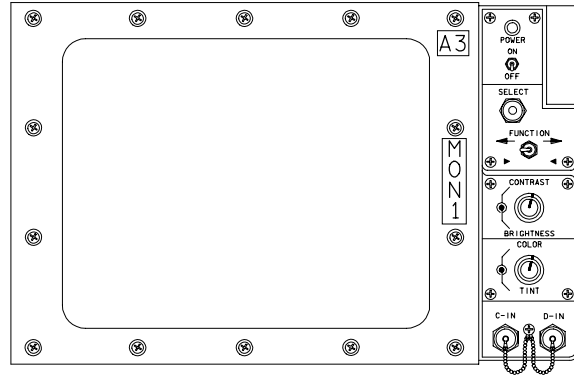
Monitors

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

Color Television Monitor (CTVM)

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

Each monitor uses a graphical menu for configuration control. The menu can be displayed by activating either the FUNCTION or SELECT controls. The menu will be displayed for 10 seconds after the last command (FUNCTION or SELECT) is executed. The FUNCTION switch is used to move through different menu headings. The SELECT pushbutton allows the user to toggle between different options within each menu heading.



CCTV Color Monitor

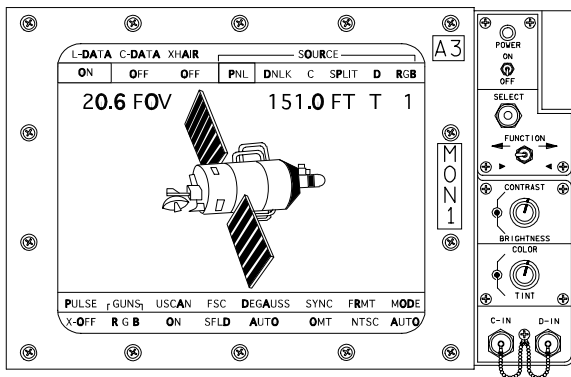
The menu can be used to enable viewing of CTVC/ITVC lens data, CCTV camera data, and crosshairs. Data and crosshairs that appear green are characters generated within the color monitor and can be activated by selecting GRN for camera data and crosshairs by turning on lens data. White characters are generated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

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

Two ground checkout menu functions are located on the lower left portion of the menu (PULSE-X ON/OFF and GUNS R G B). USCAN ON/OFF enables or disables the underscanning

feature. When ON, the underscan allows viewing of edge-to-edge video (horizontal and vertical) with no loss of image data. In other words, you see what the camera sees. When OFF, about 5 percent of each horizontal and vertical edge is lost. In addition, the top line of the upper menu and the bottom line of the lower menu cannot be seen when USCAN is OFF. The FSC function selects between 6FLD (6 field) and 3FLD (3 field). This feature determines how often FSC color will be updated to the screen. 6FLD is the default and preferred setting, except for viewing FSC video of objects in rapid motion. This function only applies to cameras with WLA or CLA lenses. The DEGAUSS function will dissipate magnetic fields that build up around the monitor as the orbiter moves at high speed through the Earth's magnetic field, but only when DEGAUSS is in the default AUTO position. AUTO engages the degaussing circuitry every 10 minutes. OFF disables this feature.

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



CCTV color monitor with menu and L-Data

Video format can be selected manually or automatically. The CTVMs default to AUTO MODE in which the monitor determines the video format from data embedded in the CCTV camera video. CTVCs will use the NTSC format, -506 and -508 cameras will use FSC, and

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

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

Portable LCD Monitor

Portable LCD monitors are flown to display video at a VTR or a camcorder. Sony XV-M30 and FDM-330 LCD monitors have been used by the SSP for those purposes. Some modifications have been made to these monitors, which makes disconnecting cables from the LCD monitor more difficult in an effort to reduce accidental cable disconnections.



LCD Color Monitor

Viewfinder Monitor

The viewfinder monitor is used with a CCTV camera within the cabin or a module, such as Spacelab. This monitor is a 3.8-inch (diagonal) black and white portable monitor that can be connected via a power cable to a CCTV camera. The monitor is used to adjust the camera when a CCTV color monitor is not available for the task. This usually applies to cameras in the Spacelab module or cabin middeck areas. The viewfinder monitor includes brightness and contrast controls. The viewfinder monitor is usually mounted to the top or side of the CCTV camera.

Payload Bay Camera Operations

The CCTV ACTIVATION cue card includes activation procedures for the CCTV system and payload bay cameras. This cue card also includes steps that can command the cameras to different operating modes. The steps indicated are good guidelines for setting up cameras in a safe (ALC active) configuration. However, crews should not hesitate to command cameras out of their normal operating modes. Since lighting conditions on orbit are quite dynamic, ALC modes, manual gain modes, and gamma settings may require changes. Crews should take the initiative and adjust the cameras to provide the best possible video of the object(s) in view. CCTV camera operation is more of an art than a science when it comes to minimizing blooming without sacrificing contrast and clarity. However, please note the caution block, as the CCTV cameras (in particular the -506 and -508) are susceptible to damage by direct sunlight while in a manual mode.

CCTV Accessories

The CCTV system has many accessories that aid in CCTV operations. Light shades are used to reduce the amount of sunlight entering the flight deck. Shades are also available for reducing glare caused by cabin lights. Portable lighting, such as the compact portable light (CPL), is used to brighten areas for short durations. The shuttle photoflood uses fluorescent tubes powered by the orbiter 115 V ac 400Hz supply.

The ICOM recorder is a Sony WM-DC6 stereo audio cassette recorder. This device is used to record and playback voice from the orbiter audio system and the camcorder. ICOM recorder procedures are located in the Orbit Ops FDF.

Camcorders can share the same mounts, arms, and clamps with the photo equipment. These portable structures provide a secure base to position the camcorders in a microgravity environment.

Crews work with the engineering and flight controller organizations to improve CCTV operations. These improvements usually result in new cables or interface units that increase the CCTV system's capabilities. This cooperation has helped make CCTV one of the most frequently changing orbiter systems. The monitors, camcorders, and VTRs flown today are different from those flown as recently as 1992. The CTVCs and ITVCs are expected to fully replace the -506 and -508 cameras sometime in 1995. The payload video console is expected to fly in 1996, and a high-definition television camera is expected to fly in 1998.

TV

ACTIVATION A3 MON 1(2) PWR - ON
 A7 TV DNLK - ENABLE
 TV PWR - PNL, MN A, CMD
 *** √MCC PRIOR TO PWR ON FOR SYNC/ASYNC CONFIG ***

OPERATION

CTVC
 A7 TV CAMRs PWR - ON
 MON 1(2) - A (B, C, D, ...)
 BAL - SUN (OR AS REQD)
 ALC - AVG
 (REPEAT FOR OTHER TVs AS REQD)

MLA/CLAW/LA
 A7 TV CAMRs PWR - ON
 MON 1(2) - A (B, C, D, ...)
 ALC - AVG
 GAMMA - NORM
 (REPEAT FOR OTHER TVs AS REQD)

CC
 019, TV PWR - ON
 MO58F CC - ON

CAUTION
 DO NOT LEAVE CAMRs UNATTENDED IN MAUAL MODE
 DIRECT SUNLIGHT WILL DAMAGE CAMERAS

Manual Mode:
 A7 Man Gain - 0 dB (or as reqd)
 IRIS - OP/CL

Manual OFF:
 A7 ALC - AVG (or as reqd)

Multiplex ON:
 A3 CTVM 1(2) Mode - Auto
 A7 Mon 1(2) - Mux 1(2)
 Mux 1(2)L - Sel Camr
 Mux 1(2)R - Sel Camr
 *** Multiplex display will be B/W ***

IF Multiplex OFF:
 A7 Mon 1(2) - Sel any Video Input

TV DNLK:
 Coordinate Dnlk w/MCC
 Config Audio (if reqd)
 A7 On MCC Go: DNLK - Sel Video Input

DEACTIVATION A7 TV Camr Pwr(s) - OFF
 TV Pwr - PNL, OFF, CMD
 MON 1(2) Pwr - OFF

Manual Mode:
 A7 IRIS - OP/CL

Full Manual Mode:
 A7 IRIS - OP/CL
 GAMMA - WHT STRCH/BLK STRCH

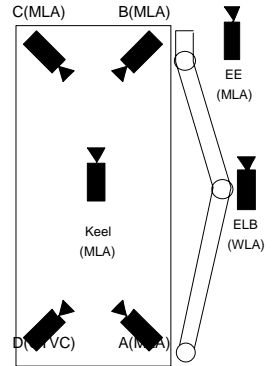
Semi (Full) Manual OFF:
 A7 ALC pb - Press

Multiplex:
 A3 √CTVM 1(2) Mode - Auto
 A7 Mon 1(2) - Mux 1(2)
 Mux 1(2)L - Sel Camr
 Mux 1(2)R - Sel Camr

Multiplex OFF:
 A7 Mon 1(2) - Sel any Video Input

TV DNLK:
 Coordinate Dnlk w/MCC
 Config Audio (if reqd)
 A7 On MCC Go: DNLK - Sel Video Input

TV DNLK:
 Coordinate Dnlk w/MCC
 Config Audio (if reqd)
 A7 On MCC Go: DNLK - Sel Video Input



FWD
 ↓

TV Cue Card From Photo/TV Checklist

CCTV System Summary

- The CCTV system is used on orbit to support payload and orbiter activities by using real-time and recorded video.
- The CCTV system is composed of CCTV cameras, pan/tilt units, color monitors, camcorders, video tape recorders, video processing equipment, and accessories.
- All CCTV functions can be controlled by the crew. Most CCTV functions can be configured by MCC via uplink commands. Both crew and MCC can command all CCTV camera functions.
- CCTV equipment is powered from circuit breakers located on panel R15.
- Crews use panel A7U to control the CCTV system.
- The video control unit is the heart of the CCTV system and is the central processor. The VCU is composed of the remote control unit and the video switching unit.
- The -506 and -508 cameras use one of three lens assemblies: monochrome, color, and wide-angle color.
- The CTVC provides NTSC color video. In addition to CCTV camera data, CTVCs also provide lens data.
- The ITVC generates black and white video. This CCTV camera is designed to operate in a low-light environment.
- The ALC and gamma PBIs on panel A7U perform different tasks with the CTVCs and ITVCs than with the -506 and -508 cameras.
- Camcorders are now used to provide cabin video. Camcorders require special interface equipment to operate in the orbiter.
- The Teac Hi-Band 8mm VTR is the VTR used by the SSP to record payload bay camera video. These VTRs are loose equipment and are stowed in lockers for ascent and entry. These VTRs record video from an output port on the color monitors and playback through flight deck and middeck camera ports.
- Two 10-inch color monitors display video onboard. The monitors are located on panel A3 and provide connectors for VTRs to use for recording. The monitors are configured via a display menu system.
- CCTV accessories, such as window and light shades, portable lights, mounting arms, ICOM recorders, and a wide variety of cables are used to improve the quality of CCTV video.

2.4 COMMUNICATIONS

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Description

The orbiter communication system transfers the following types of information:

- Telemetry information to the ground about orbiter operating conditions and configurations, systems, and payloads
- Commands from the ground to the orbiter systems to perform a function or configuration change
- Documentation from the ground that is printed out on the orbiter's thermal impulse printer system (TIPS)
- Voice communications among the flight crew members and between the flight crew and ground.

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

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

uplinks (UL), and signals from the orbiter to the ground are called downlinks (DL).

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

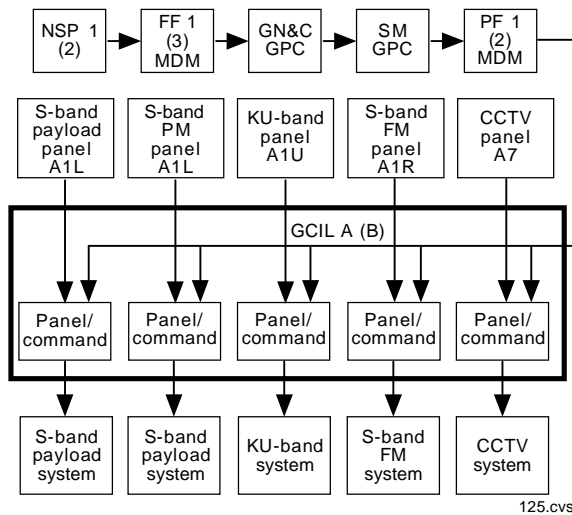
The orbiter communication system is divided into several smaller systems: S-band phase modulation (PM), S-band frequency modulation (FM), Ku-band, ultrahigh frequency (UHF), payload communications, audio, and closed-circuit television. (CCTV is discussed separately in Section 2.3.)

The S-band FM, S-band PM, Ku-band, and UHF systems are used to transfer information between the orbiter and the ground. The payload communication system is used to transfer information between the orbiter and its payloads either through hardline or RF links. The audio systems transfer voice communications throughout the orbiter, and the closed-circuit television system is used for visually monitoring and recording activities.

The ground command interface logic (GCIL), also referred to as the ground command interface logic controller, controls selected functions of the S-band PM, S-band FM, Ku-band, payload communication, and CCTV systems. Commands are sent to the orbiter from the ground through S-band system uplink or Ku-band system forward link. All commands, whether sent on S-band or Ku-band, are routed to the onboard GPC through the network signal processor (NSP) and associated FF MDM. The GCIL takes commands for these systems from the GPC via the PF MDMs, for ground commands or from the appropriate panel for crew control.

With the exception of audio and UHF, each of the communications systems has an associated *CONTROL* switch with the positions *PANEL* and *CMD*. When the switch is set to *PANEL*, the system can be accessed by the crew using panel switches. When the switch is set to *CMD*, control is by ground command via GCIL. The

locations and operations of these switches are provided in the individual communications systems discussions that follow.



Ground Command Interface Logic

NOTE

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

S-Band Phase Modulation

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

- Command channel: used to send commands from ground to orbiter.
- Voice channel(s): used for one-way and two-way voice communications between ground and orbiter. One of the two voice channels can be used for thermal impulse printer system signals from ground to orbiter.
- Telemetry channel: carries real-time orbiter and payload operational telemetry data to ground.
- Turnaround tone ranging channel: used to determine slant range from a known

point to the orbiter. Tones are transmitted from the ground to the orbiter where they are "turned around" and transmitted back to ground from the orbiter on a coherent RF carrier. Slant range can be computed from net total two-way phase delay of the major tone for the "round trip."

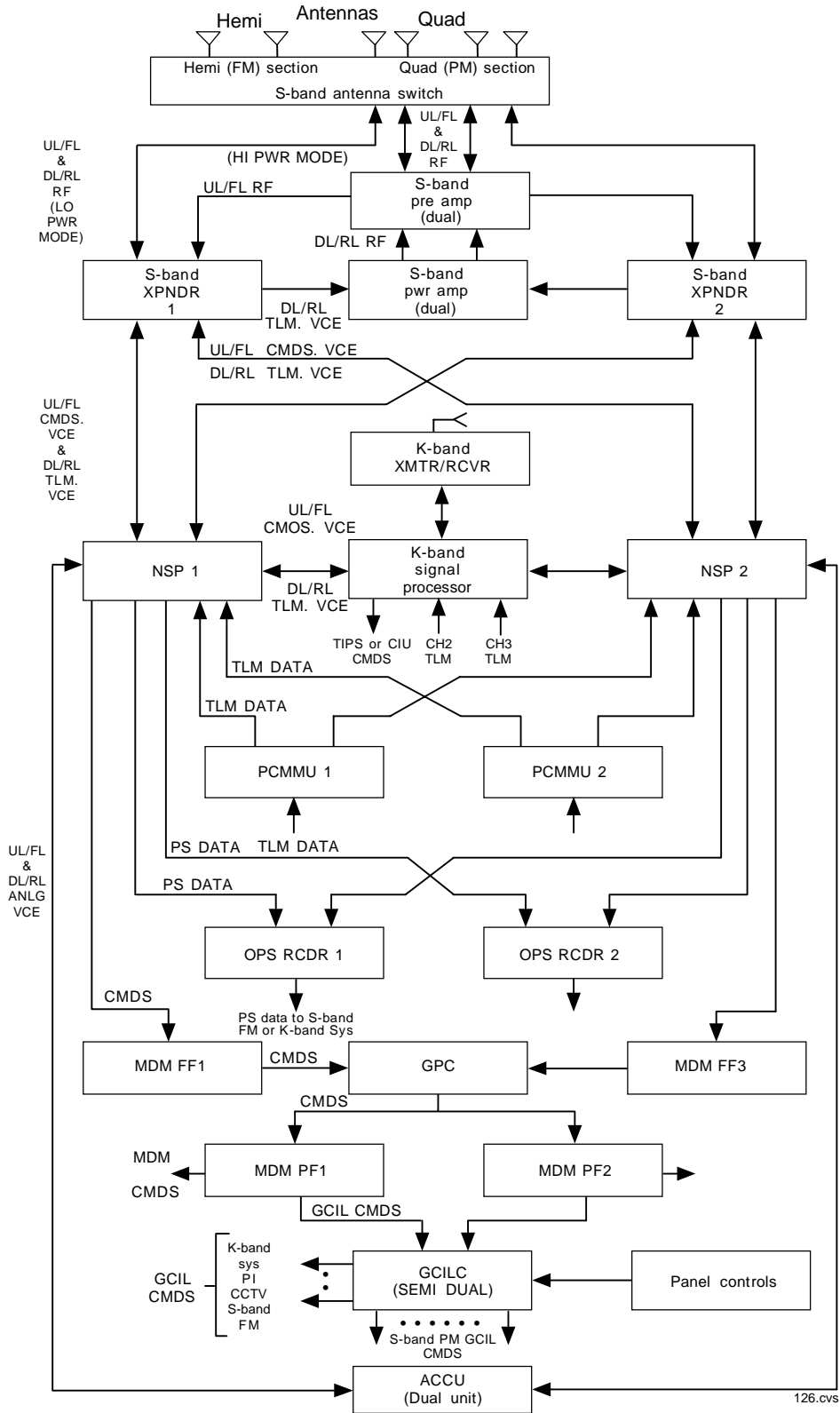
- Two-way Doppler tracking: used to aid in tracking the orbiter. An RF carrier, of precisely known frequency, is transmitted to the orbiter.

A characteristic of RF signals in the S-band range is that "line-of-sight" must exist between transmitting and receiving antennas to permit communications. With the availability of the east and west TDRS, potential total S-band PM support time using direct and relay links will be as much as 80 percent of mission time. (For some missions, vehicle attitude constraints imposed by experiment requirements may cause the loss of portions of that potential support time because the required orbiter attitudes may at times be incompatible with orbiter S-band PM quad antenna patterns.)

A fully operational TDRS system provides east and west satellites that are both supported by the WSGT facility. The east and west satellites are approximately 130° apart in geosynchronous orbits. In the S-band mode, the TDRS single access antenna is gimballed but does not automatically track the orbiter. It is sequentially commanded by the ground to follow the orbiter position. There is a zone of exclusion (ZOE) where the orbiter, operating at normal altitudes, will not be in line-of-sight with either satellite. The ZOE is geographically over the Indian Ocean region.

S-Band Forward Link

The S-band forward link operates through the STDN or TDRS. It is phase modulated on a center carrier frequency of either 2,106.4 MHz (primary) or 2,041.9 MHz (secondary) for NASA. The two frequencies would prevent interference if two users were in operation at the same time and place, since one user could select the high frequency, and the other could select the low frequency.



S-Band PM System Interfaces and Data Flow

The forward link originates from Mission Control through the NASA STDN ground stations used for launch, lift-off, ascent, or landing, or through the WSGT via the TDRS system to the orbiter. The high data rate is 72 kilobits per second, consisting of two air-to-ground voice channels at 32 kbps each and one command channel at 8 kbps, two-way Doppler, and two-way tone ranging. The low data rate is 32 kbps, consisting of one air-to-ground voice channel at 24 kbps and one command channel of 8 kbps, two-way Doppler, and two-way ranging. The two-way ranging does not operate through the TDRS.

S-Band Return Link

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

The S-band PM return link can originate from one of two S-band PM transponders aboard the orbiter, each of which can use one frequency, but not both at the same time. The link transmits the data through the NASA STDN ground stations used for launch, lift-off, ascent, or landing, or through the TDRS and TDRS system via the WSGT to Mission Control.

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

The S-band return link low data rate of 96 kbps consists of one air-to-ground voice channel at 32 kbps and one telemetry link at 64 kbps, two-way Doppler, and two-way ranging. As noted, the two-way Doppler and two-way ranging are used in the same manner as in the high-data-rate mode.

Department of Defense Links

The Department of Defense S-band forward link is phase modulated on a center carrier frequency of either 1,831.8 MHz (primary) or 1,775.5 MHz (secondary) from the Air Force Satellite Control Facility (AFSCF) through its own ground stations (SGLS ground stations). It does not operate through the TDRS because the S-band power amplifiers are not powered in the SGLS mode.

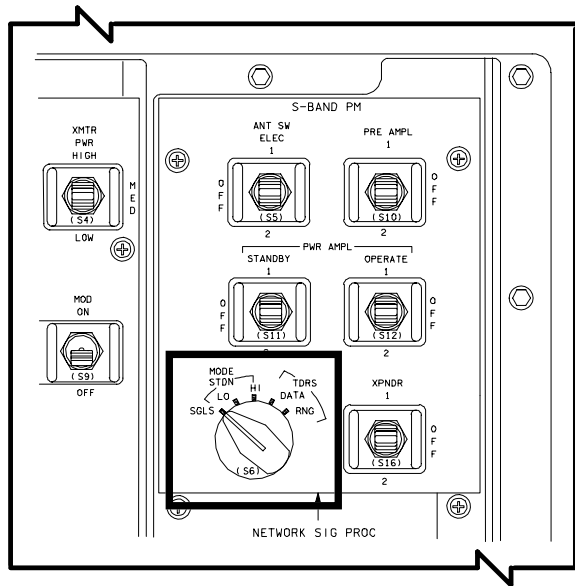
The Department of Defense S-band return link is phase modulated on a center carrier frequency of 2,287.5 MHz (primary) or 2,217.5 MHz (secondary) through the SGLS mode to the AFSCF ground stations, and also does not operate through the TDRS. The two S-band return link frequencies also would prevent interference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

S-Band PM Power Modes

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

Four quadrant S-band PM antennas covered with a reusable thermal protection system are located approximately 90° apart on the forward fuselage outer skin of the orbiter. On the flight deck viewed through the forward windows, the quadrant antennas are to the upper right, lower right, lower left, and upper left. These antennas are the radiating elements for transmitting the S-band PM return link and for

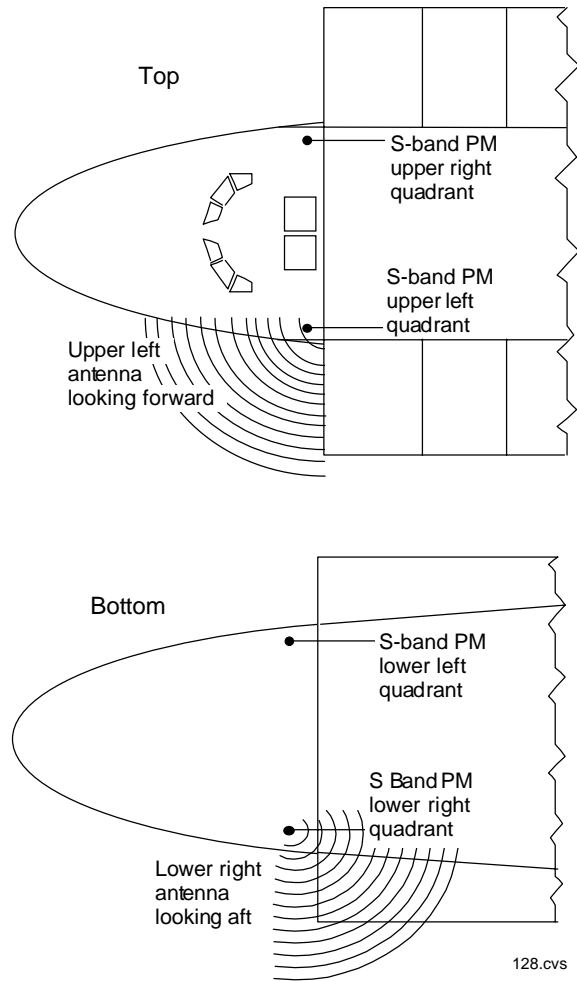
receiving the S-band PM forward link. Each quad antenna is a dual-beam unit that can "look" forward or aft for both transmission and reception without any physical movement, effectively creating eight antennas for the S-band PM system. These antenna are controlled by the antenna switch electronics via GCIL. Crew switch for S-band PM ANT SW ELEC is on A1L.



S-BAND PM MODE Rotary Switch on Panel A1L

S-Band PM Antennas

The antenna is selected automatically under GPC control, by real-time command from the ground, or manually by the flight crew using the S-BAND PM ANTENNA rotary switch on panel C3. When the switch is set to GPC, antenna selection is automatic, and the antenna switching commands are sent to the switch assembly through the payload multiplexers/demultiplexers (PF MDMs). Other positions selectable by the switch are LL FWD (lower left forward), LL AFT (lower left aft), UL FWD (upper left forward), UL AFT (upper left aft), UR FWD (upper right forward), UR AFT (upper right aft), LR FWD (lower right forward), and LR AFT (lower right aft). Antenna selection is based on the computed line of sight to the NASA STDN ground station, the AFSCF ground station, or the TDRS in view, depending on the orbiter communication mode. The current antenna selection is shown on the OPS 201

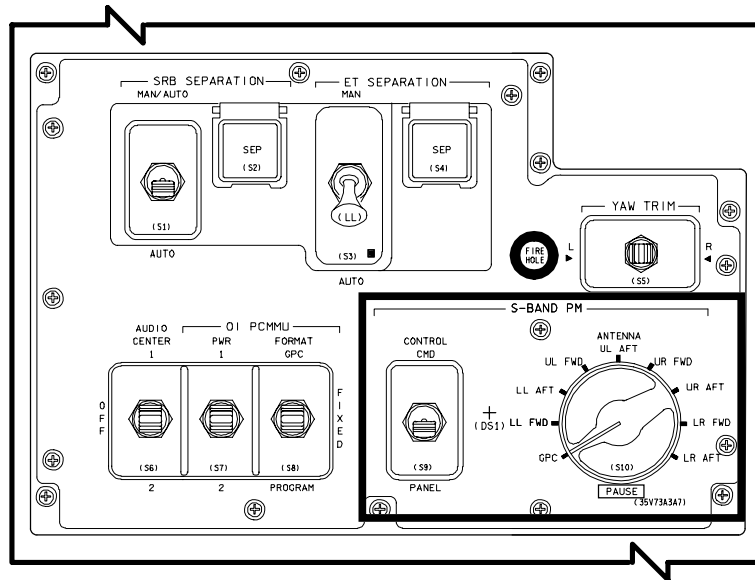


128.cvs

S-Band PM Antenna Locations

ANTENNA display. Also on the display are related items such as the S-band ground station in view, TDRS in line of sight, and whether GPC antenna selection is enabled or inhibited. Also displayed is the antenna electronics unit performing antenna selections.

GPC control can be inhibited to permit ground control to select an antenna other than the one currently selected by the GPC. The ground sends a command load to inhibit GPC control and a real-time command (RTC) to select the desired antenna. GPC control is restored by sending a load to enable the GPC mode. The crew can perform the same functions by selecting the ANTENNA display, executing Item 18 (GPC INH), and then selecting the desired antenna by RTC via keyboard. Using GPC OVRD (item 19), the crew can force the S-band antenna management software to the



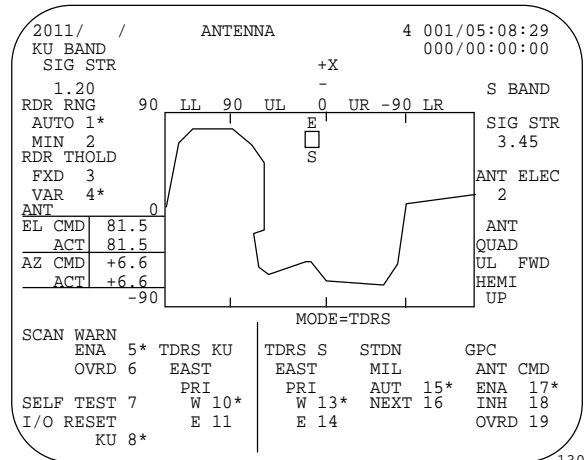
S-BAND PM System Switches on Panel C3

TDRS mode. An asterisk will be displayed by item 19 while GPC override is in effect. To restore GPC control, item 17 (GPC ENA) is executed.

Other S-band PM fields on the ANTENNA display allow prime selection of a TDRS west or east, items 13 and 14, respectively. These items select the chosen TDRS as prime; if this TDRS is not in view, it selects the other TDRS. If both are in view, the prime is selected. No change is made to TDRS selection if neither is in view. Similar logic holds true for Ku-band system, items 10 and 11.

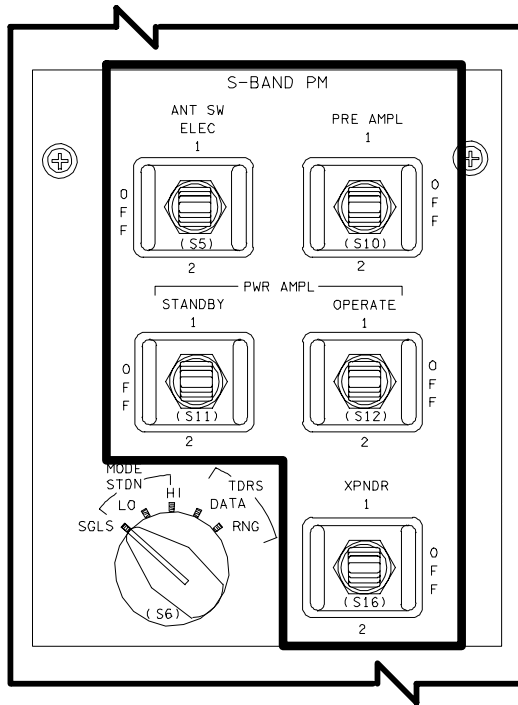
2011/ /076	COMM/RCDR	4 001/05:08:04
S-BAND PM		000/00:00:00
XPND 2	KU-BAND	
MODE TDRS	PA TEMP	+91
FREQ LO	GMBL TEMP A	+80
PREAMP 2	B	+82
PWR AMPL	GYRO TEMP	+1.46
OPER 2	PWR OUT	26
STBY 1	FR SYNC	YES
PWR OUT 1	MODE	COMM
2	TV CAM OVER-TEMP	NO
TEMP 1	GCIL CONFIG	CMD
2	169	
NSP	RECORDERS	
BIT/FR SYNC 1 NO	MODE	OPS 1 OPS 2 PL
2 YES	TRK	STBY RCDA STBY
FAIL SAFE ENA	DIR	FWD FWD FWD
DATA XMIT HI	%TAPE	55 200 0
RCV HI	TAPE STOP	RUN STOP
UL DATA S	TEMP	48 90 48
CODING XMIT ON	BITE	
RCV ON	RCDR INPUT	D/VO
BITE 1 GOOD	COMSEC BITE	1 FAIL
2 GOOD		2 GOOD

COMM/RCDR (DISP 76) Display



OPS 201 ANTENNA Display

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



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

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

Power Amplifiers

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

The power amplifiers use a traveling wave tube, which has a filament that must be warmed up before high voltage is applied to the tube. A 140-second timer provides the delay when the

OPERATE mode is selected from a cold start. With the system in STANDBY, the filament is kept heated, ready for "instant on" operation.

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

NOTE

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

The COMM/RCDR display, DISP 76, also shows power amplifier status (PWR AMPL OPER, STBY, and PWR OUT and TEMP).

Transponders

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

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

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

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

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

A C-band skin-tracking mode also is provided from the ground station to track the orbiter and, again, is used only in view of the NASA STDN ground station associated with launch, lift-off, ascent or landing, or in view of SGLS mode ground stations. This capability does not operate through the TDRS.

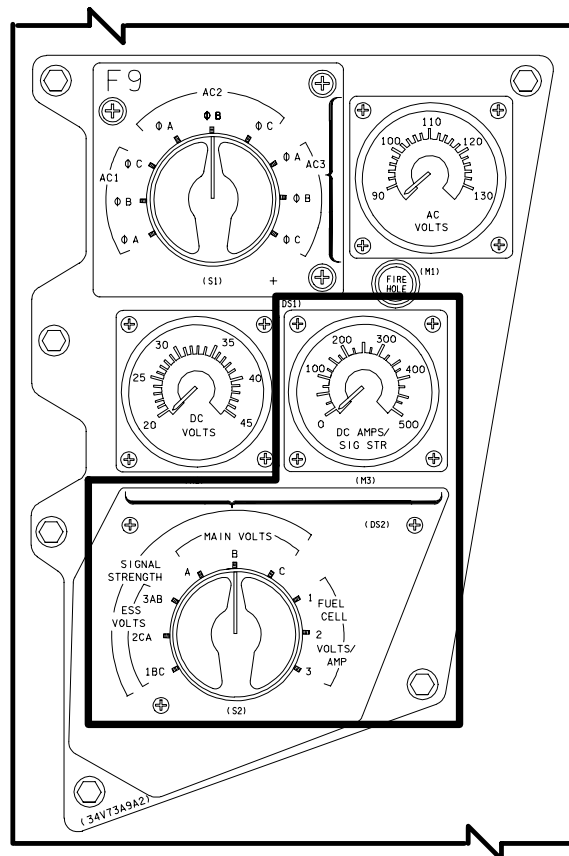
The S-BAND PM XPNDR switch is located on panel A1L; this function is generally handled by ground command via the GCIL. If the S-BAND PM CONTROL switch on panel C3 is set to PANEL, the XPNDR selection is made from panel A1L.

The COMM/RCDR display, DISP 76 in OPS 201, gives transponder status (XPND and MODE). The OPS 201 ANTENNA display also shows the mode for active transponders.

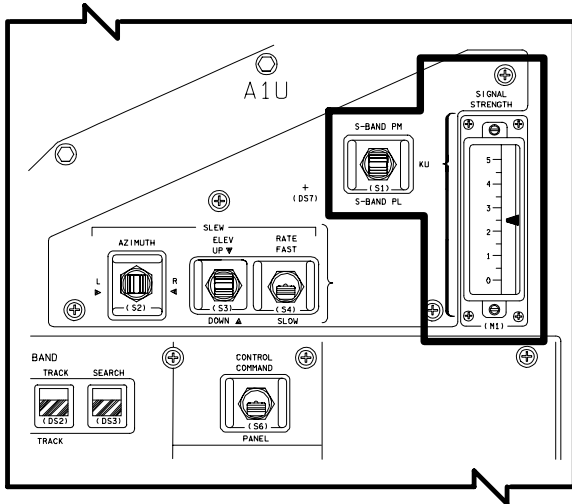
Received S-band PM RF signal strength is shown on the DC AMPS/SIG STR meter on panel F9 when the rotary switch below the meter is set to SIGNAL STRENGTH, and on the SIGNAL STRENGTH indicator on panel A1U when the switch to the left of the indicator is set to S-BAND PM. Signal strength is also shown on the OPS 201 ANTENNA DISPLAY (SIG STR); however, during launch and landing, the display is not available.

NOTE

The panels F9 and A1U signal strength indications come from the transponder receiver, whereas OPS 201 ANTENNA display signal strength comes from OI MDM OF3 data.



DCAMPS/SIG STR Meter and Rotary Switch on Panel F9



SIGNAL STRENGTH Indicator and Switch on Panel A1U

Network Signal Processors

The two onboard network signal processors (NSPs) receive commands (forward link) and transmit telemetry data (return link) to the selected S-band transponder. Only one signal processor operates at a time; the other provides a redundant backup. The selected processor receives one or two analog voice channels from the onboard audio central control unit, depending on whether one (in the low-data-rate mode) or both (in the high-data-rate mode) of the air-to-ground channels are being used. Both voice channels are downlinked only if the NSP is high data rate on both forward and return links. It converts them to digital voice signals, time-division-multiplexes them with the telemetry from the pulse code modulation master unit, and sends the composite signal to the S-band PM transponder for transmission on the return link. On the forward S-band PM link, the NSP does just the reverse. It receives the

composite signal from the S-band transponder and outputs it as either one or two analog voice signals to the audio central control unit. The composite signal from the S-band transponder and outputs it as either one or two analog voice signals to the audio central control unit. The composite forward link also has ground commands that the NSP decodes and sends through the FF MDMs (nominally NSP 1 to FF 1 and NSP 2 to FF 3) to the onboard computers, which route the commands to the intended onboard systems. The NSP data routing/processing modes are controlled by the NETWORK SIG PROC switches on panel A1L.

NOTE

The NSP can also route return link (telemetry and voice) and receive forward link (commands and voice) via the Ku-band system.

Communications Security

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

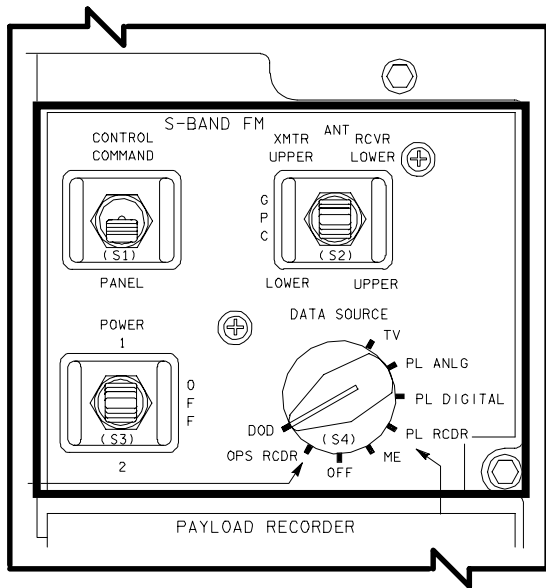
The NSP routes data of the indicated type through the COMSEC encryptor or decryptor as appropriate if "ENC" and gets the data back from the COMSEC line-replaceable unit encrypted/decrypted; if "CLR", the indicated data are handled directly by the NSP, and the COMSEC is bypassed.

The three ENCRYPTION switches on panel A1L provide power and routing control for encrypted data through the NSP.

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

* Data rate determined by NSP downlink DTA RATE switch.

** HDR only.



S-BAND FM Switches on Panel A1R

S-Band Frequency Modulation

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

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

The FM signal processor is commanded to select one of seven sources for output to the S-band FM transmitter, which transmits it to the S-band FM return link through the STDN ground station used for launch, lift-off, ascent, or landing, or the DOD AFSCF ground station.

Depending on the setting of the DATA SOURCE switch, the S-band FM return link transfers:

- Real-time SSME data from the engine interface units during launch at 60 kbps each (ME)
- Real-time video (TV)
- Operations recorder dumps of high- or low-data-rate telemetry at 1,024 kbps (OPS RCDR)
- Payload recorder at 25.5 kbps or 1,024 kbps (PL RCDR)
- Payload analog at 300 hertz or 4 MHz (PL ANLG)
- Payload digital data at 200 bps or 5 Mbps (PL DIGITAL)
- DOD data at 16 kbps or 256 kbps in real time or 128 kbps or 1,024 kbps of playback (DOD).

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

S-Band FM Antennas

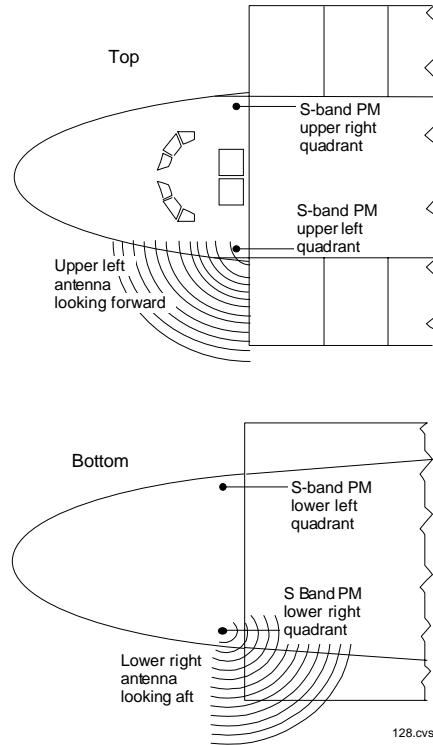
Two hemispherical S-band FM antennas covered with a reusable thermal protection system are located on the forward fuselage outer skin of the orbiter approximately 180° apart. On the flight deck, the hemispherical antennas are above the head (upper) and below the feet (lower) and radiate the S-band FM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

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

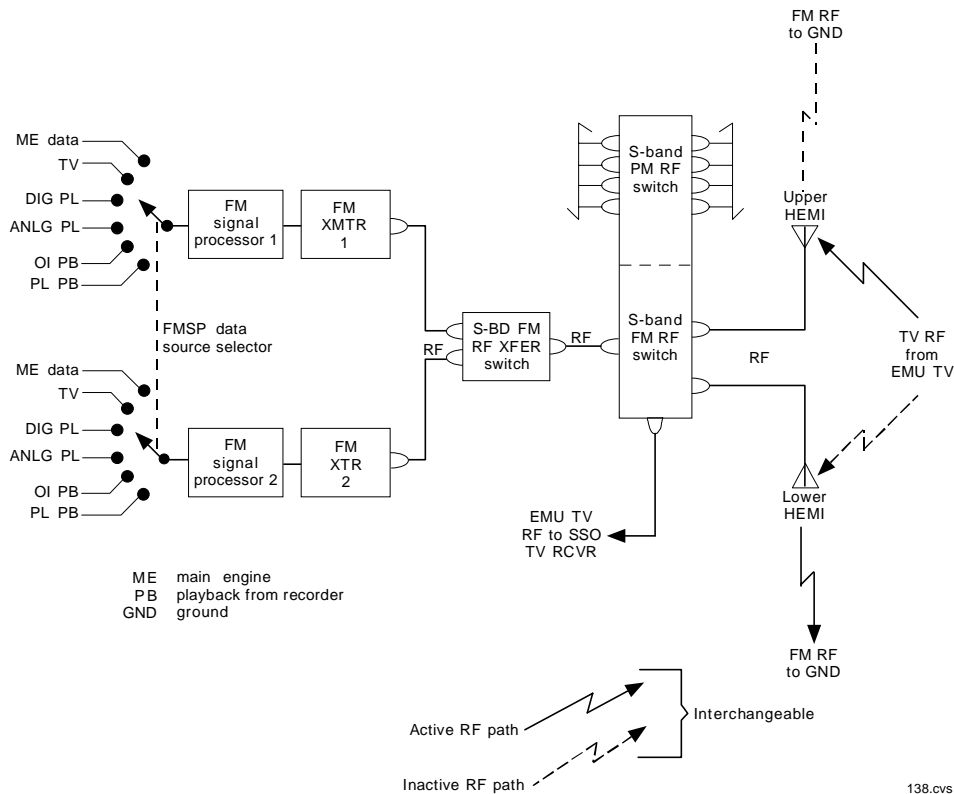
transmitter is active. The antenna selection is based on the computed line of sight to the NASA STDN ground station used for launch, lift-off, ascent, or landing, or the AFSCF ground stations.

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

The hemi antenna switch has a port that can route RF television from the astronaut's extravehicular mobility unit (EMU) to the orbiter's closed-circuit television system. An extravehicular mobility TV unit can transmit television on one hemi antenna/antenna switch path to the orbiter while the S-band FM system is routing FM downlink telemetry to ground on the other hemi antenna/antenna switch path. This requires an EMU TV receiver that is manifested for specific flights.



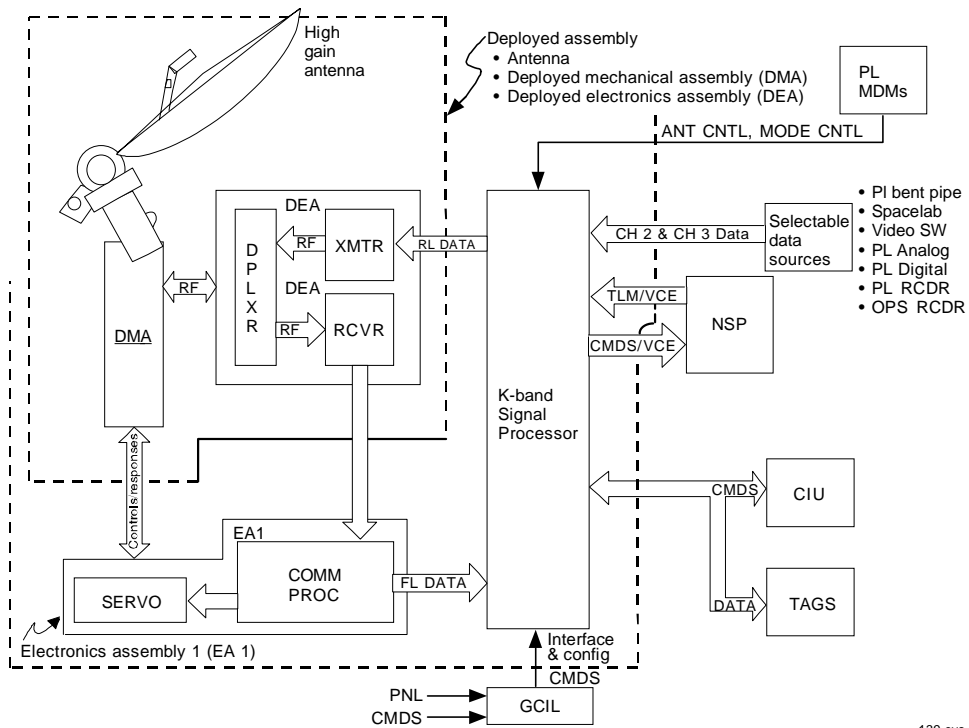
S-Band FM Antenna Locations



S-Band FM System Block Diagram

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Ku-Band Communications System

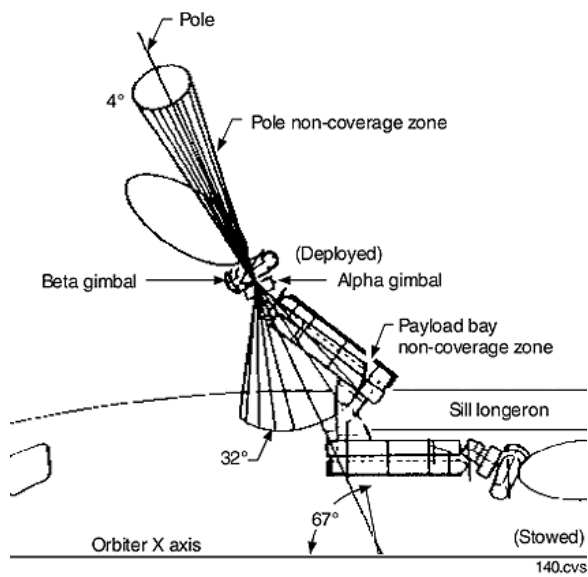
Ku-Band System

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

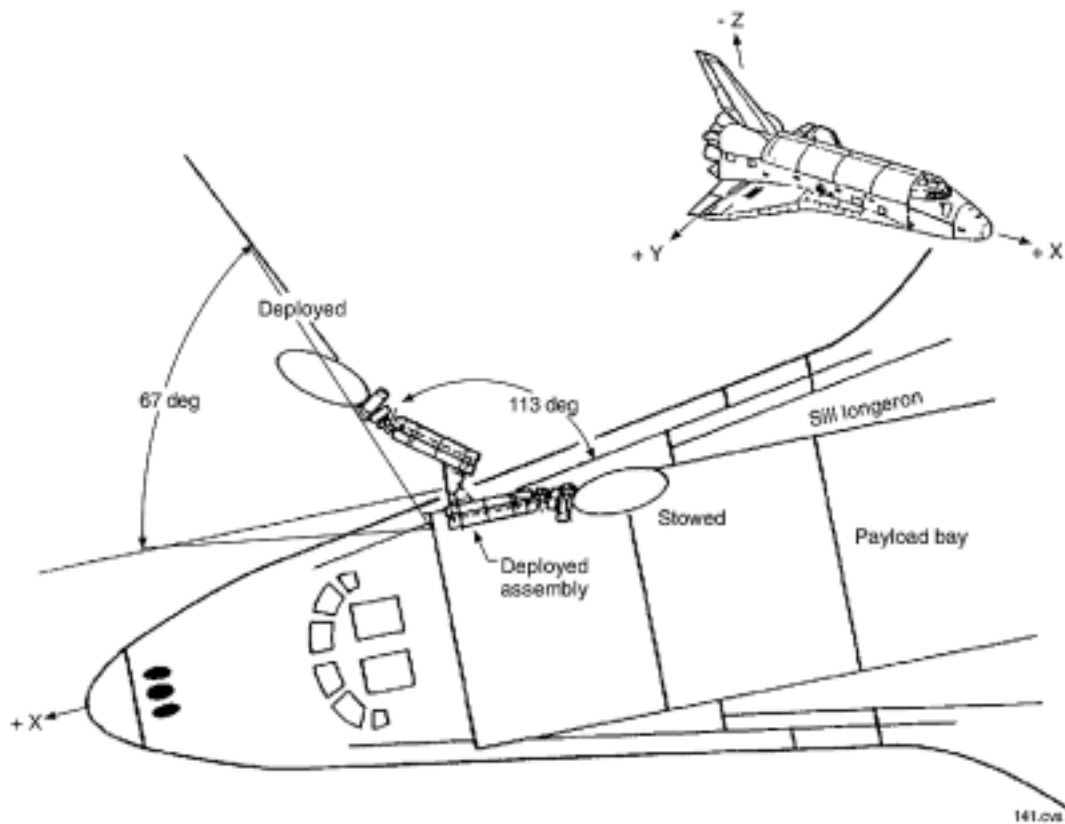
When the Ku-band antenna is deployed and activated in the communications mode, the NSP directs the return link data stream to both the Ku-band signal processor and the S-band transponder. The forward link is only accepted by the NSP from the Ku-band signal processor or the S-band transponder. This depends on whether S-band or Ku-band has been selected through GCIL, by the ground, or by the NSP UPLINK DATA switch on panel A1L. For Ku-band, the return link data stream from the network signal processor is directed through the

Ku-band signal processor and antenna to the TDRS in view, via the TDRS and DOMSAT systems, to Mission Control. The process is reversed for the Ku-band forward link. If the Ku-band forward link is lost, and the ground has enabled the fail-safe, the system reverts to S-band PM uplink mode. It is possible to run the downlink through the Ku-band and the forward link through the S-band, and vice versa.

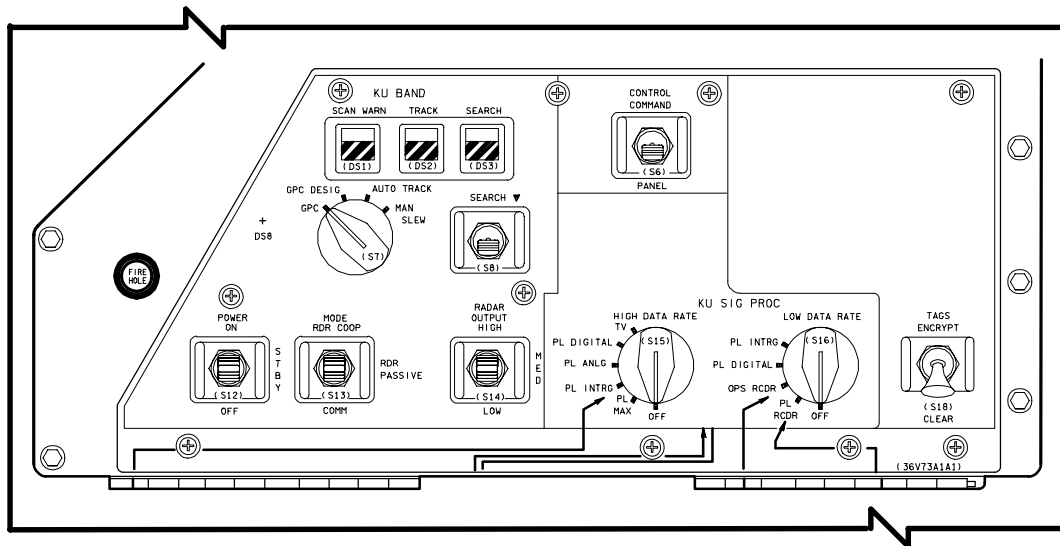
The Ku-band system return link consists of channel 1, modes 1 and 2, plus one channel 2, modes 1 and 2, and one channel 3. Channel 1, modes 1 and 2, consists of 192 kbps of operational data (128 kbps of operational data telemetry and payload interleaver plus two air-to-ground voice links at 32 kbps each) plus one of the following selections from channel 2, modes 1 and 2: (1) payload digital data from 16 kbps to 2 Mbps, (2) payload digital data from 16 kbps to 2 Mbps, (3) operations recorder playback from 60 kbps to 1,024 kbps, or (4) payload recorder playback from 25.5 kbps to 1,024 kbps. It also includes one of the following from channel 3: mode 1 attached payload digital data (real-time or playback) from 2 Mbps to 50 Mbps, mode 2 television (color or black and white) composite video, or mode 2 real-time attached payload digital data or payload analog data.



Ku-Band Antenna Non-Coverage Zones



Ku-Band Deployed Assembly Location



KU-BAND Controls on Panel A1L

The Ku-band system forward link consists of a mode 1 and 2 through the TDRS in view. Mode 1 consists of 72-kbps data (two air-to-ground voice streams at 32 kbps each and 8 kbps of command), 128-kbps thermal impulse printer system (TIPS), and 16-kbps synchronization. Mode 2 consists of 72-kbps operational data (two air-to-ground voice streams at 32 kbps each and 8 kbps of command).

The Ku-band system can handle greater quantities of data than the S-band systems. It transmits three channels of data, one of which is the same interleaved voice and telemetry processed by the S-band PM system. Two of the seven possible sources of information sent on the other two channels are: payload analog, payload digital, payload interleaver bent-pipe, payload recorder, operations recorders, television, and Spacelab (if flown). Data sources are selectable by two KU SIG PROC rotary switches on panel A1U, one for HIGH DATA RATE and one for LOW DATA RATE.

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

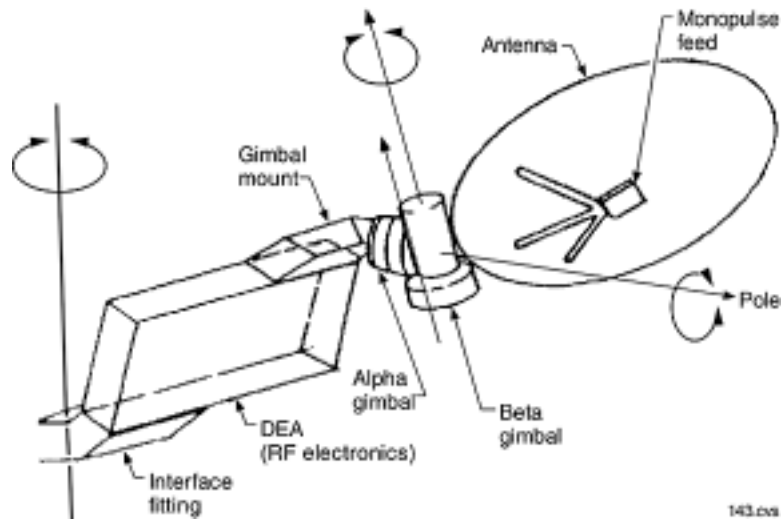
Three modes can be selected by the MODE switch on panel A1U. In the COMM (communications) mode, incoming signals go through an internal electronics assembly (EA1)

to the Ku-band signal processor, which processes and routes Ku-band data. Voice and commands are sent to the network signal processor. A separate output from the Ku-band signal processor is directed to the TIPS or the payload system if the Ku-band uplink is in the high data rate mode. In the

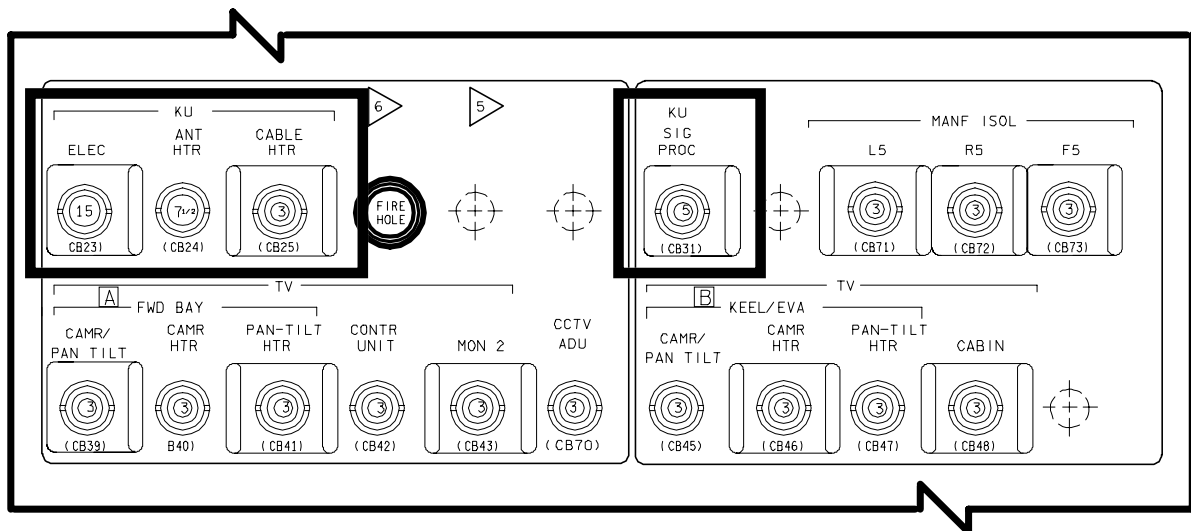
RDR COOP and RDR PASSIVE modes, incoming signals are routed from the deployed electronics assembly to EA2, the radar signal processor. The signal is processed to provide target angle, angle rate, range, and range rate information. This status information is then routed to EA1 to be used for target tracking.

Ku-Band Deployed Assembly

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



Ku-Band Deployed Assembly



KU-BAND Circuit Breakers on Panel R15

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

The antenna can be steered in several selectable modes under manual control by the flight crew using panel A1U or automatically by the SM

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

At times, the Ku-band system, in view of a TDRS, is interrupted because the orbiter blocks the Ku-band antenna's view to the TDRS or because orbiter attitude requirements or

payloads' radiation sensitivities prohibit its use. In addition, the Ku-band antenna beta cabling may periodically require positioning to ensure that it does not become twisted in a way that could cause the antenna to bind.

When the Ku transmitter is enabled and outputting an RF carrier and when it is inhibited, the ground can control via ground uplink command to the SM GPC and Ku system. This control is called Ku antenna "masking." These masking modes are used to provide protection from Ku radiation for payloads and for crewmembers during EVAs and certain payload operations. The types of masking, commandable from the ground, include: 1) inhibiting the Ku transmitter when a specified beta gimbal angle is exceeded (beta MASK) or when both a specified beta gimbal angle and the orbiter hardware obscuration zone are exceeded (beta +MASK), 2) specifying an EVA protection zone, where the transmitter is disabled, within certain elevation and azimuth angle pointing of the antenna relative to a coordinate system, based on the orbiter's X, Y, and Z axes. New Ku software also modes the Ku system to standby mode, if the antenna remains near the beta stops for a certain period of time, to prevent excessive antenna gimbaling and cable binding.

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

Ku-Band Antenna Deployment and Stowage

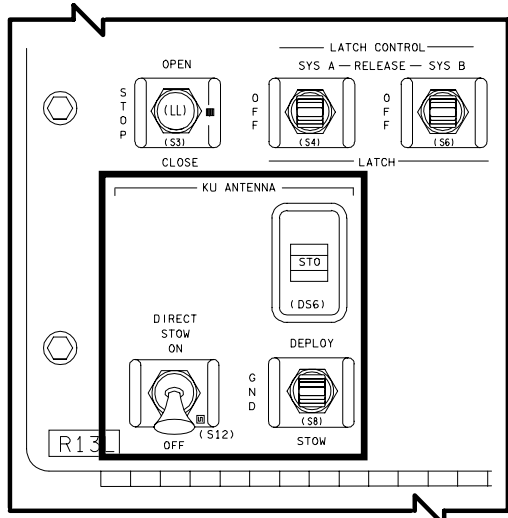
When the shuttle reaches orbit, before the Ku-band antenna is deployed, the KU ANT HTR circuit breaker on panel R15 is closed to energize thermostatically controlled heaters for the deployed electronics assembly, gimbals, and antenna assembly. During Ku-band activation, the KU ELEC and KU SIG PROC circuit breakers on panel R15 are closed. (There is also a CABLE HTR circuit breaker on panel R15. The Ku-band system was originally designed to have a cable heater, but it was never installed. Therefore, this circuit breaker is always left open.) These circuit breakers provide electrical power to the Ku-band electronic elements, electronics assemblies 1 and 2, the signal processor assembly, and Ku-band portions of panels A1U and A2. Actual deployment

involves the KU ANTENNA controls and associated talkback on panel R13L. The antenna is locked in the stowed position to clear the adjacent payload bay doors and radiators when they are closed or moving.

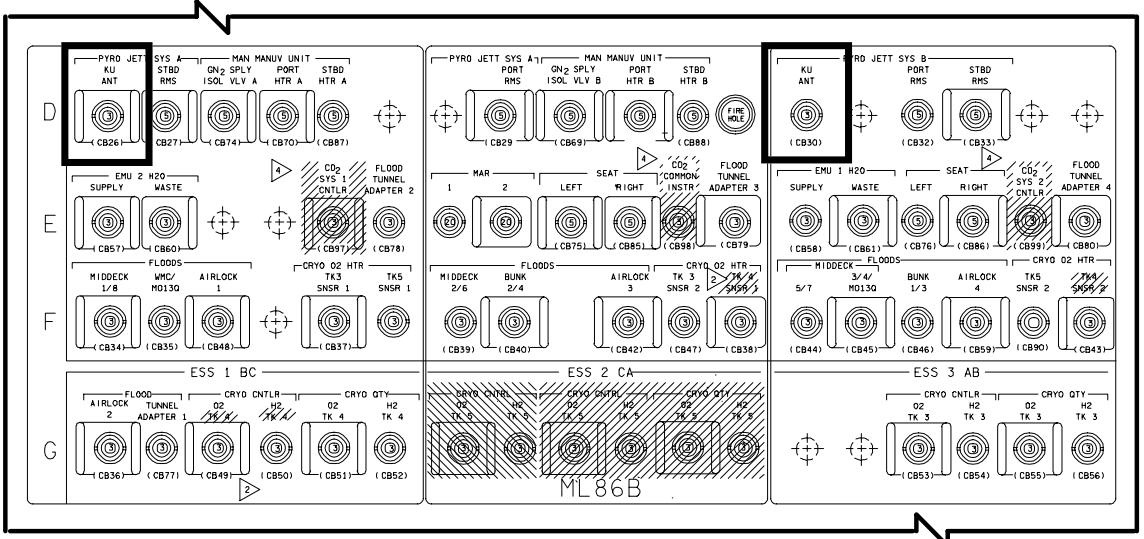
Twenty-three seconds are normally required to deploy or stow the assembly. In the deployed position, the assembly forms a 67-degree angle with the orbiter X axis. Activating the Ku electronics and taking the KU BAND POWER switch on panel A1U to ON frees the antenna gimbals by removing the gimbal locking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

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

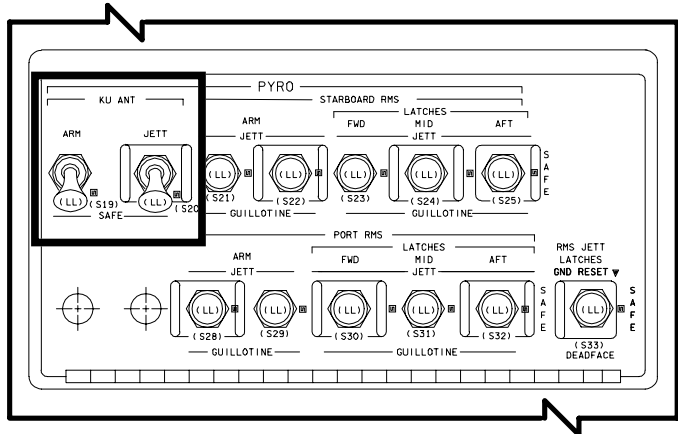
If neither the normal stow nor the DIRECT STOW can position the assembly inside the payload bay, the assembly can be jettisoned. To jettison the deployed assembly, the crew closes the MN A and MN C PYRO JETT SYS A and SYS B KU ANT circuit breakers on panel ML86B to provide redundant jettison power. The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



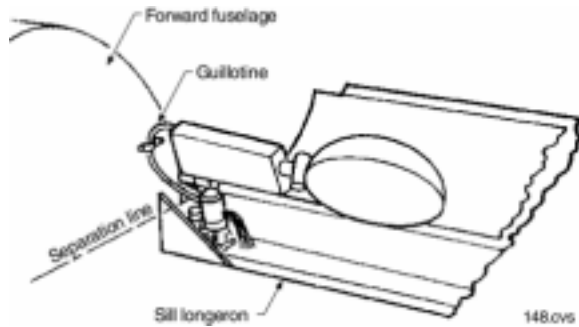
KU ANTENNA Switches and Talkback on Panel R13L



PYRO JETT KU Circuit Breakers on Panel ML86B



KU ANT Switches on Panel A14



Ku-Band Antenna Jettison Separation

Ku-Band Rendezvous Radar

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

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

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

target or cooperative target transmitter that is triggered by the radar-initiated pulse. The latter provides a longer range capability.

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

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

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

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

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

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

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

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

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

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

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

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

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

The Ku-band system has body and inertial antenna stabilization modes. When the body is stabilized, the antenna beam remains in a fixed relationship to the orbiter X, Y, and Z axes during orbiter attitude changes. When the system is inertially stabilized, the antenna beam

remains aligned to a point in inertial space, regardless of the orbiter attitude changes. Both of these modes are effective only when the radar angle-tracking system is not tracking a target. In the target angle-tracking mode, the system aligns the antenna beam to the target, and antenna movement is independent of orbiter attitude changes.

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

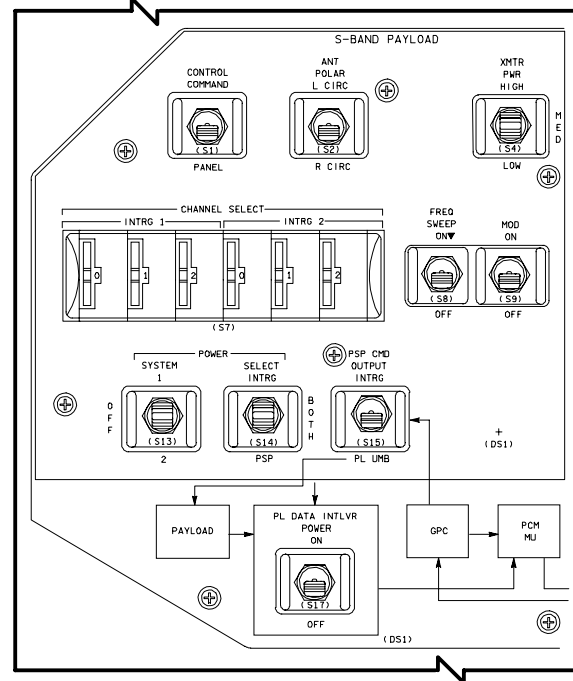
The COMM/RCDR display, DISP 76, provides the status of Ku-band temperatures (PA, GMBL, GYRO), power out (in watts), frame sync, and mode (COMM or RDR), to flight crews.

Payload Communication System

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

Communication with an attached payload takes place through the payload patch panel at the crew compartment flight deck aft station, which is connected to payloads in the payload bay. All command and telemetry signals that meet the payload communication system specifications can be processed onboard. Incompatible signals can be sent to the ground through Ku-band or directly to payload ground stations. This method of transmission, referred to as bent-pipe telemetry, means that no onboard signal processing occurs before the telemetry is sent to the Ku-band system. Payload telemetry can go directly to the S-band FM or Ku-band systems for transmission to the ground, payload analog, or payload digital, to the payload recorder for later transmission, or to the payload data interleaver to be interleaved with other payload data. The system also processes commands and provides payload telemetry to the pulse code modulation master unit (PCMMU), where the

data can be accessed for display on various payload-related controls and displays.

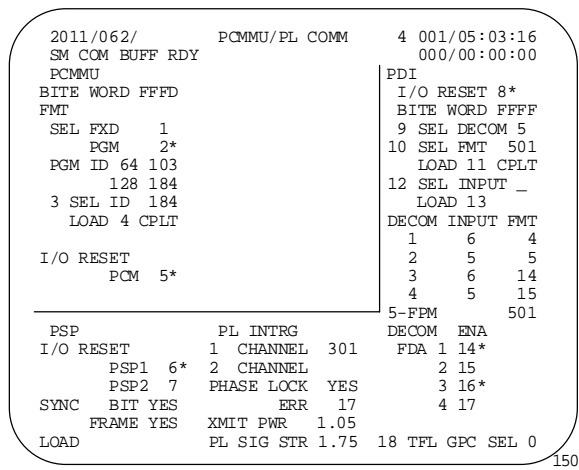


S-BAND PAYLOAD Switches on Panel A1L

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

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

The basic elements in the payload communication system are the payload interrogator (PI), payload signal processor (PSP), communication interface unit (CIU), payload data interleaver (PDI), pulse code modulation master unit (PCMMU), and payload recorder (PL RCDR). These elements are in the forward avionics bays. Commands to the payload communication system are routed through the GCILC from the payload MDMs 1 and 2, although these MDMs are also used for orbiter commanding. Status and control of payload communication systems can also be accessed by the PCMMU/PL COMM display (SPEC 62).



PCMMU/PL COMM Display (SPEC 62)

Payload Interrogator

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

The main carrier frequency of the detached payload telemetry is demodulated by the payload interrogator. The telemetry is routed directly to the Ku-band system for transmission to the ground (bent-pipe telemetry) and to the payload signal processor. The payload signal processor demodulates the telemetry from the subcarrier and sends it to the payload data

interleaver to be interleaved with other payload data. Hardline payload commands are routed through the payload signal processor and then output through the payload patch panel directly to an attached payload. Detached RF commands are routed through the payload signal processor and then through the payload interrogator for transmission to the payload through the payload antenna.

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

When the payload outputs a data rate that is not compatible with the payload signal processor or communication interface unit, payload telemetry is throughput to the PDI without processing.

Payload Signal Processor

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

The PI and PSP are commanded through GCILC/MCC or selected by the crew (A1L) using the two power switches.

Communication Interface Unit

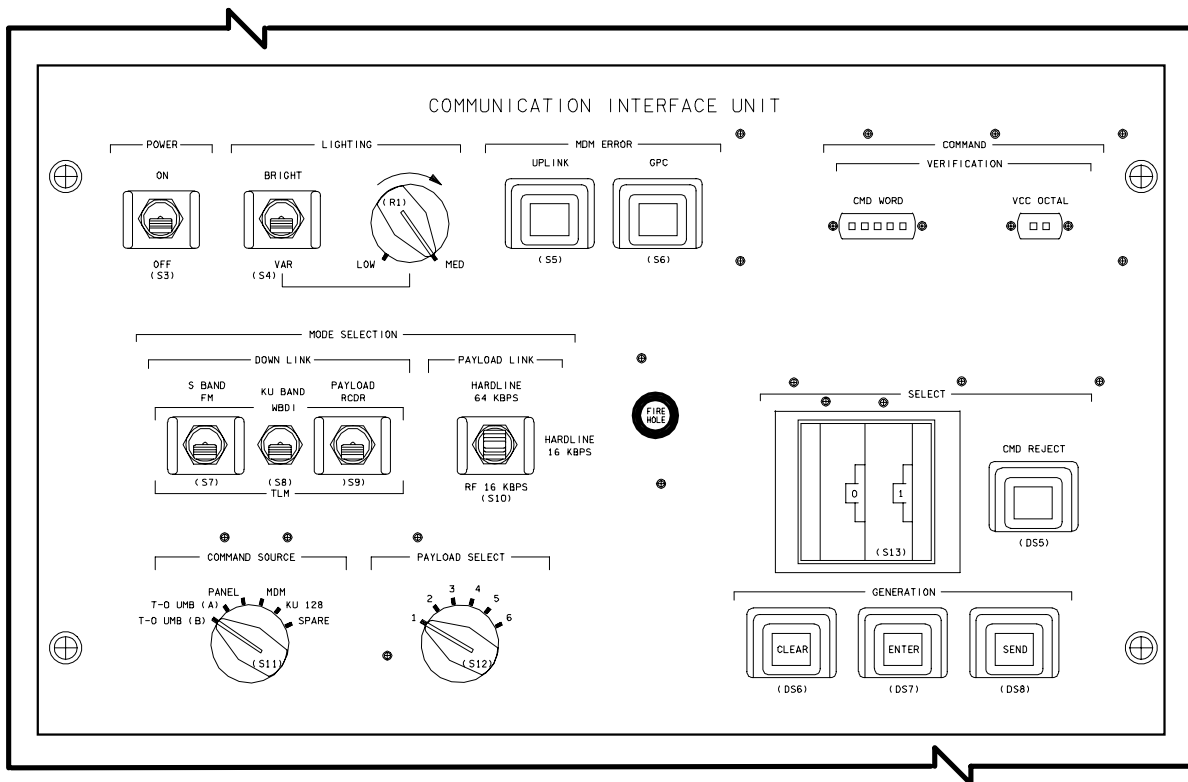
The communication interface unit sometimes replaces the payload signal processor. The payload signal processor may be retained to act as a backup. The communication interface unit is commonly used with the inertial upper stage, although it may be used with other payloads compatible with SGLS. The communication interface unit interfaces indirectly with the payload data interleaver through the patch panel because the communication interface unit is treated as an attached payload accessed through a patch panel input of the payload data interleaver. The payload signal processor is

hard-wired directly to the payload data interleaver. This provides a command and telemetry path between the orbiter guidance, navigation, and control, GPC, and an SGLS-compatible payload or between the flight crew and an SGLS-compatible payload. The communication interface unit passes commands and telemetry to either attached or detached payloads. COMMUNICATION INTERFACE UNIT controls are on panel L11.

Payload Data Interleaver

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

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



COMMUNICATION INTERFACE UNIT Controls on Panel L11

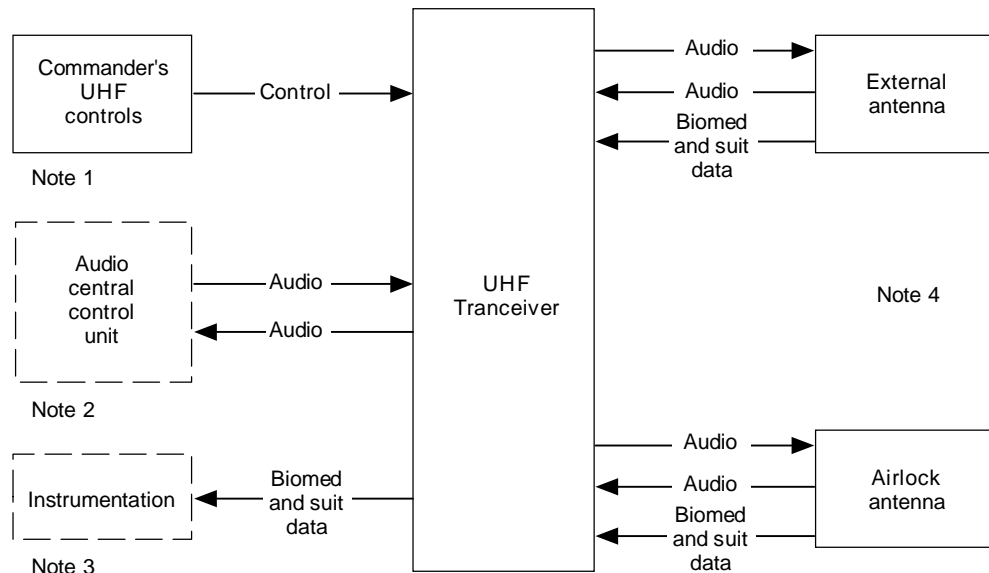
Ultrahigh Frequency System

The UHF system is used as a backup for the S-band PM and Ku-band voice communications, and is primary during EVA operations. For communications with MCC through the STDN or SGLS ground stations, the UHF system operates in a simplex mode, which means that the orbiter flight crew can transmit or receive, but cannot do both simultaneously. The UHF system may also be used for air traffic control and two-way voice with chase aircraft during landing operations.

The UHF transceiver takes the voice signal from the audio central control unit and routes it through the external UHF antenna on the bottom of the orbiter forward fuselage for transmission to the ground station. The incoming UHF signal goes through the external antenna to the UHF transceiver, which demodulates it and routes it as an audio signal

to the audio central control unit for distribution in the orbiter.

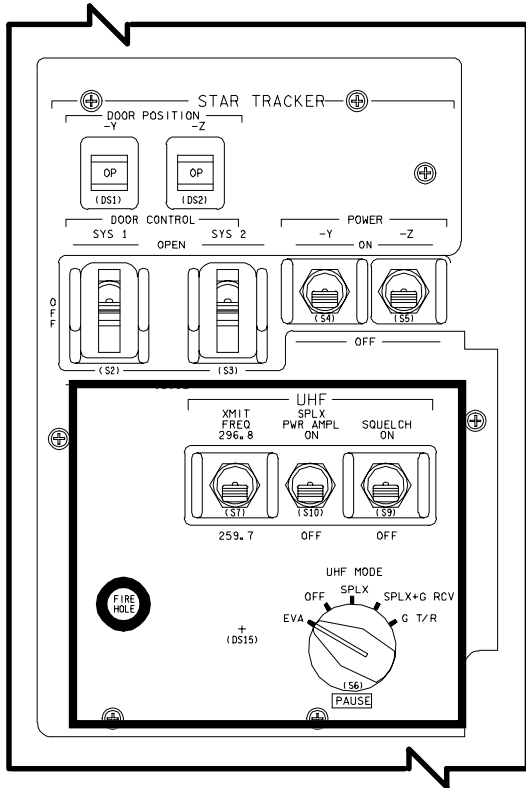
Part of the UHF configuration is controlled through three two-position toggle switches on panel O6 labeled XMIT FREQ, SPLX PWR AMPL, and SQUELCH. The XMIT FREQ switch selects one of the two UHF frequencies, 296.8 MHz primary or 259.7 MHz secondary, for external transmission. The SPLX PWR AMPL switch enables or inhibits the UHF power amplifier circuit. When the switch is positioned to ON, the UHF system transmits 10 watts of power through the antenna. When the switch is positioned to OFF, the power transmission is reduced to 0.25 watts by bypassing the power amplifier circuit. (An airlock antenna is used by EVA astronauts in extravehicular mobility units to check out their transceivers before exiting the airlock.) The SQUELCH switch permits ON or OFF selection of UHF squelch.



- Note 1 — Selects UHF mode, XMT FREQ, power, and squelch
- Note 2 — May be either A/G-1, A/G-2, or A/A
- Note 3 — Biomed/suit data received from EVA backpacks and routed to the orbiter instrumentation system
- Note 4 — External antenna is for communication with locations external to orbiter
— Airlock antenna is for communication with EMUs in airlock

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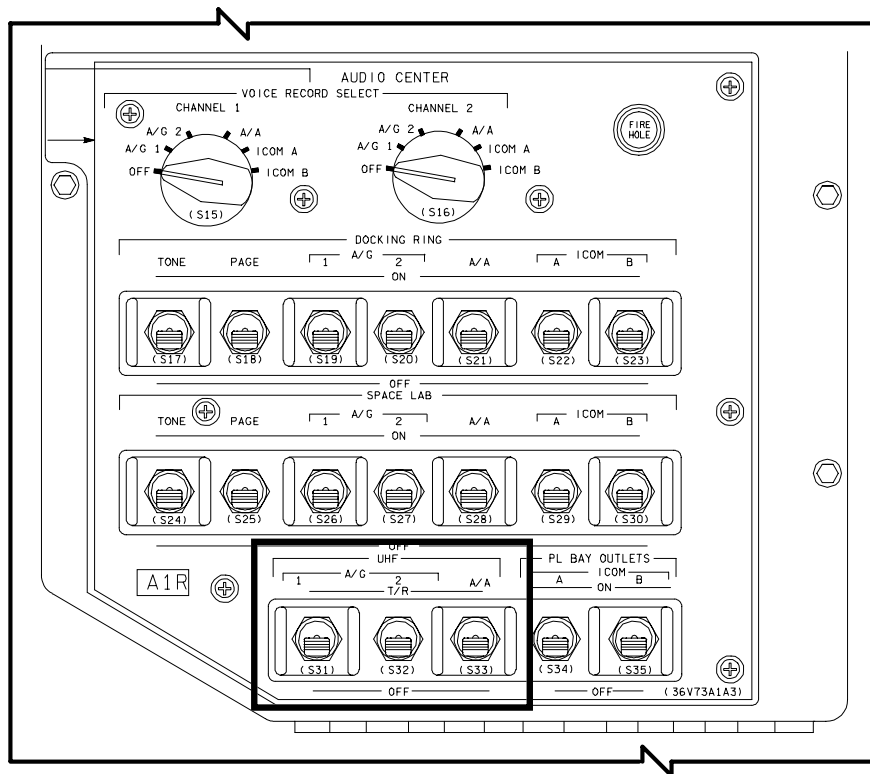
UHF Subsystem Functional Block Diagram



UHF System Controls on Panel O6

A five-position UHF MODE rotary switch on panel O6 activates power to the UHF transceiver and is used to select any of the following modes of UHF transmission. When the rotary switch is positioned to EVA, EVA transmissions are made on one frequency selected by the XMIT FREQ switch. The return signal is received on two other frequencies. The OFF position removes all electrical power. When the rotary switch is positioned to SPLX, transmission and reception are both on the frequency selected by the XMIT FREQ switch. Positioned to SPLX + G RCV, transmission and reception are the same as in simplex except that reception of the UHF guard (emergency) frequency (243.0 MHz) also is possible. In the G T/R position, transmission and reception are both on the UHF guard (emergency) frequency.

Three two-position UHF toggle switches located on the bottom of the AUDIO CENTER portion of panel A1R control routing of audio from the audio central control unit to the UHF transceiver. The switches are labeled T/R for transmit/receive, OFF for blocking UHF audio to and from the UHF transceiver, A/G for the air-to-ground channels, and A/A for the air-to-air channel.



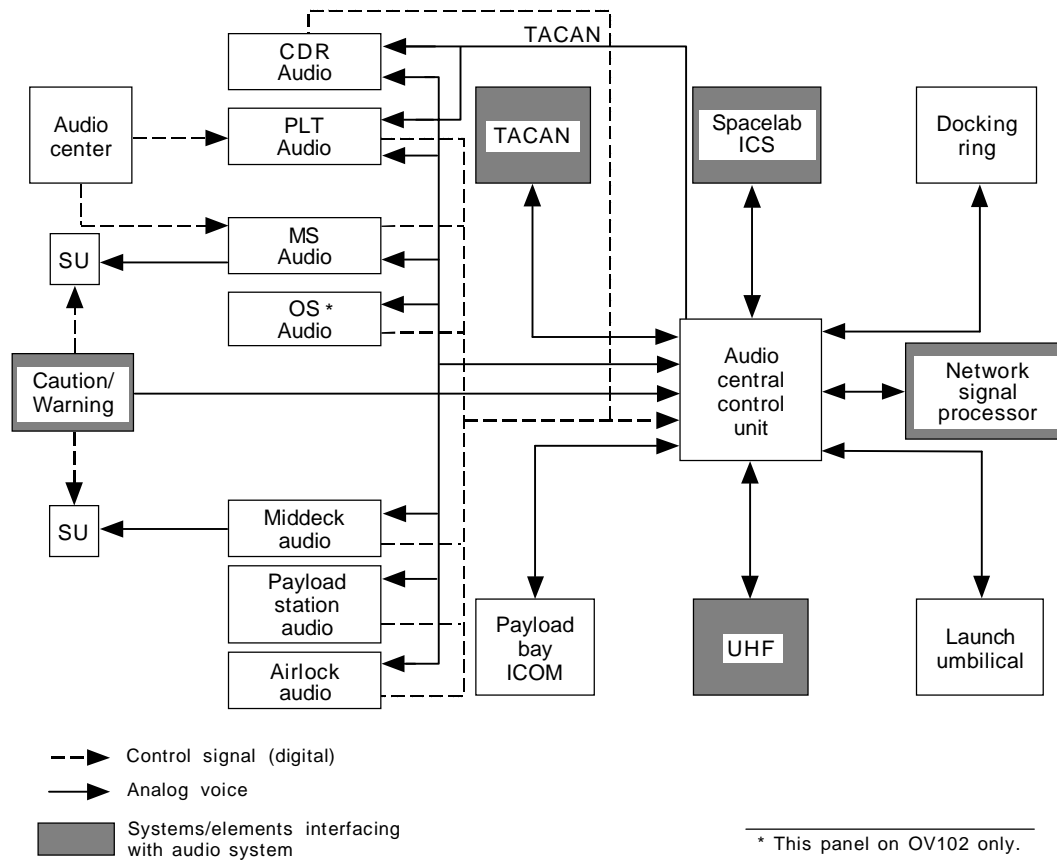
UHF Controls on Panel A1R

For normal EVA operations, the orbiter transmits 296.8 MHz and receives 259.7 and 279.0 MHz. The EVA astronauts are transmitting voice and biomedical/suit data on their respective frequencies. The biomedical/suit data is routed through the OI system once it is removed from the UHF carrier. The astronaut configured for mode A transmits on 259.7 MHz. The astronaut configured for mode B transmits on 279.0 MHz. Each of the two EVA astronauts receives the other on the respective transmitted frequencies. Every 2 minutes, biomedical data are replaced with suit telemetry data for 15

The UHF system may be used after entry during the approach and landing phase of the mission. UHF air-to-ground voice communications may take place between the orbiter, the landing site control tower, and chase planes (if used).

Audio Distribution System

The audio distribution system gathers audio signals from multiple sources and routes them throughout the orbiter. It provides the means by which crew members communicate with each other and with external locations, such as



Audio Loops and System Interface

seconds. EVA conversations are routed to Mission Control via the S-band PM or Ku-band system on A/G 1 or A/G 2, depending on the configuration of the UHF A/G 1 and A/G 2 switches on panel A1R. As a backup procedure only when the orbiter is over a UHF ground station, the EVA astronauts, orbiter, and ground can switch to the 259.7-MHz UHF, simplex.

Mission Control, through the S-band PM, Ku-band, and UHF systems. It also interfaces with the caution and warning system for reception of C/W (tone) signals and with the three tactical air navigation (TACAN) sets for monitoring the TACAN audio identification codes. The external communications are facilitated by routing AG1/2 through the network signal

processor. The audio distribution system outputs audio for one or both of the A/G loops to the network signal processor where it is digitized and sent to the S-band PM and Ku-band systems for downlink to MCC. Uplink digitized A/G audio is routed through the S-band PM or Ku-band systems and the network signal processor where it is converted to analog for use in the audio distribution system. This system also provides connections to the UHF transceiver via the AA loop for external communications with MCC through ground base sites which support UHF. As previously stated, UHF is also used as prime voice communications with EVA crewmembers. Normally in the EVA mode, the AG1 loop is routed to and from the audio distribution system. The audio distribution system routes audio signals to an onboard Spacelab module, docking ring, operations recorder, payload bay stations, and the video distribution system under control of switches on panel A1R.

The major elements of the audio distribution system include:

1. Audio central control unit (ACCU) - acts as central "switchboard" to gather and route audio signals throughout the orbiter; internally redundant line-replaceable unit.
2. Audio terminal unit (ATU) - control panels at crew stations that permit crewmembers to select audio talk/listen buses and to control external/internal communication keying modes and listen volume levels.
3. Speaker unit (SU) - two speaker units are provided with the orbiter communications system. One is mounted on the flight deck aft A2 panel. A second speaker unit is mounted on the mid-deck ceiling panel MO29J. Both are connected to and subject to an associated ATU configuration.
4. Audio center panel - control center for extending audio buses to docking ring, Spacelab, payload bay outlets, video distribution system, and the UHF system, and for selecting up to two voice signals for recording on the operations recorder.

5. Loose communications equipment - miscellaneous small, stowable items such as the headset interface unit (HIU), headset/helmet cables, wireless crew communications unit (WCCU), and handheld or wireless handheld mic.
6. Crew communications umbilical (CCU) jack - individual panel-mounted jacks at crew stations where mating headset plugs give the crew access to audio buses. At each CCU location is an associated ON/OFF switch to control power to the headset interface unit or wireless communications unit utilizing that jack.

The eight loops in the audio system are (1) air-to-ground 1, (2) air-to-ground 2, (3) air-to-air, (4) intercom A, (5) intercom B, (6) paging, (7) C/W, and (8) TACAN. A/G 1 and A/G 2 are used to communicate with the ground through the S-band PM and Ku-band systems and UHF during EVA operations. (In the NSP low-data-rate mode or while used with other loose communications gear such as the thermal impulse printer system, A/G 2 is not available for voice communications.) A/A is used, by convention, to communicate with the ground and with EVA astronauts through the UHF system. Intercoms A and B are used to communicate from station to station within the orbiter and Spacelab. The paging loop allows one crewmember to send voice transmissions to all active stations. The C/W loop sounds different tones for different malfunctions or emergencies. The TACAN loop, accessible only at the commander's and pilot's stations, is used to identify TACAN ground stations for navigation.

Audio Central Control Unit

The ACCU, the heart of the audio system, is located in the crew compartment middeck forward avionics bay. (There are two redundant ACCUs, but only one is used at any given time.) The unit identifies, switches, and distributes analog audio signals among the various audio distribution system components. Both digital and audio signals are received and processed by the ACCU. The digital signals are

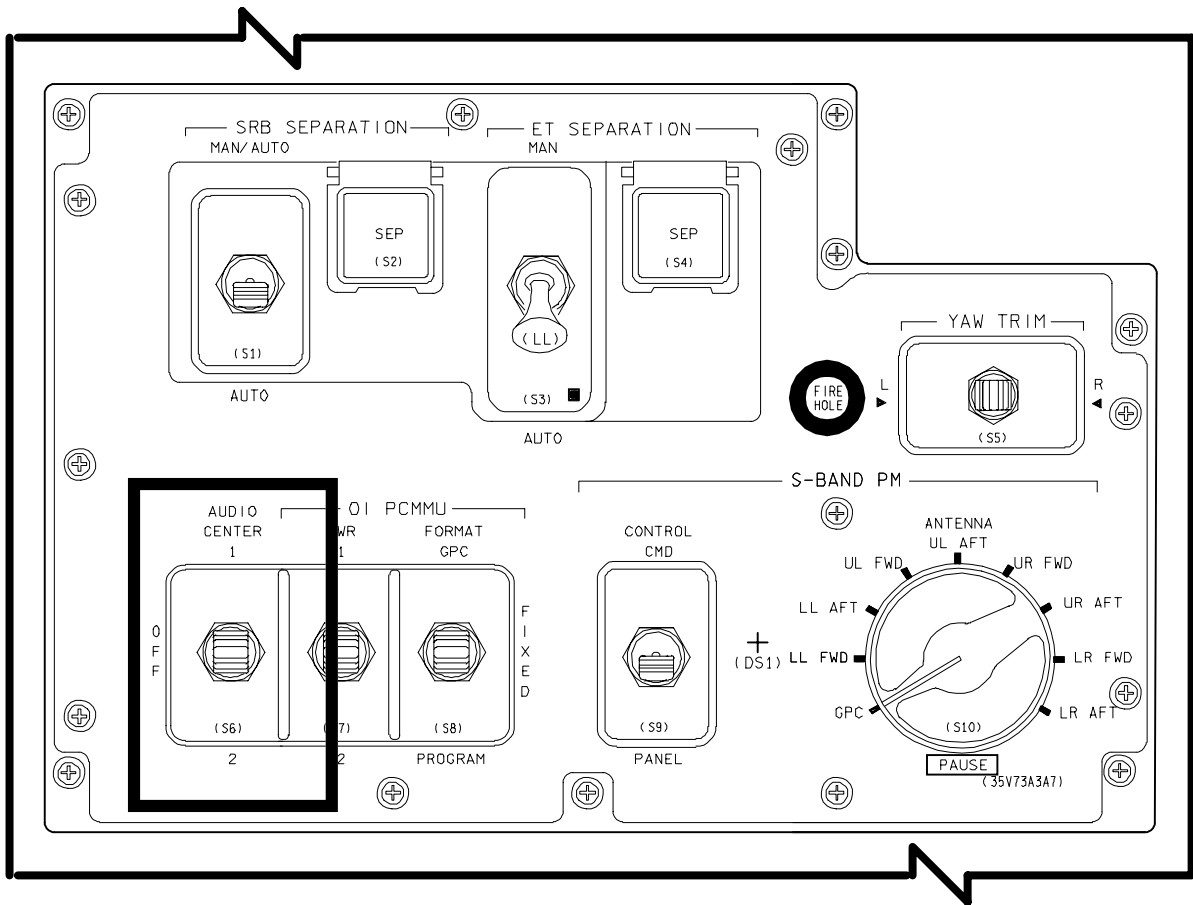
used to control the internal configuration of the ACCU per the switch positions on the ATUs and other devices. The audio signals are keyed and routed in response to this internal configuration. Other devices include the audio center panel and the NSP. It is through these devices that audio is routed to the ultrahigh frequency, S-band PM, and Ku-band transmitters and receivers for communications external to the orbiter.

The *AUDIO CENTER* selection switch is on panel C3. Setting the switch to 1 applies primary power to the control center unit from the *ESS 2CA AUD CTR 1* circuit breaker on panel R14. Selecting 2 applies power to the secondary unit electronics from *MN C AUD CTR 2* circuit breaker on panel R14. OFF removes all power from the ACCU.

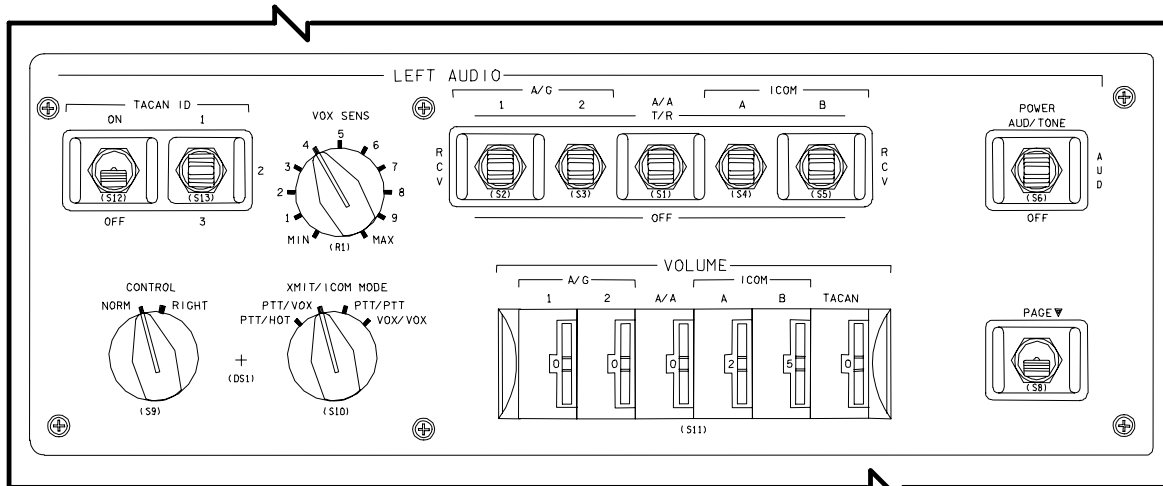
NOTE

With the *AUDIO CENTER* selection switch OFF, all normal audio functions will be inoperative. However, the commander and pilot can communicate via headset if one of their *ATU CONTROL* switches is set to the alternate position. This is also true for any two stations that share ATUs through the audio control switch position (i.e., mission specialist and payload specialist, airlock CCU 1 and 2, and middeck ATU).

The ACCU circuitry activates signals from the launch umbilical connection intercom A and B channels. Any crew station ATU can then be configured to transmit and receive intercom signals from the ground through the umbilical. (Only intercom signals are processed through the umbilical.)



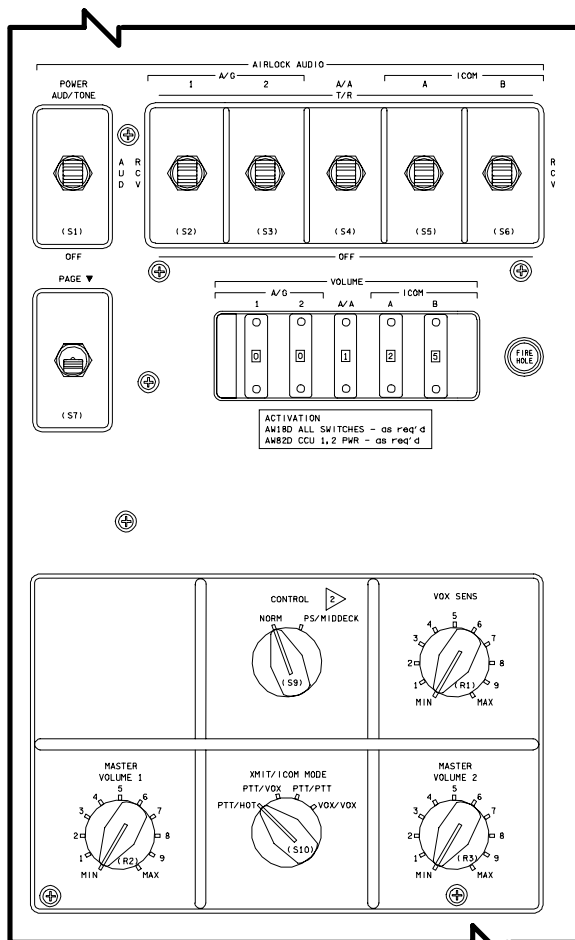
AUDIO CENTER Selection Switch on Panel C3



Commander's Audio Terminal Unit of Panel 05

Audio Terminal Units

Up to eight ATUs are used in the crew compartment to select access at each station and to control the volume of various audio signals. Audio terminal unit panels are located at the following crew stations: commander, panel O5 (LEFT AUDIO); pilot, panel O9 (RIGHT AUDIO); mission station, panel R10 (MISSION STATION AUDIO); payload station, panel L9 (PAYLOAD STATION AUDIO); middeck, panel M042F (MID DECK SPEAKER AUDIO); and airlock, panel AW18D (AIRLOCK AUDIO). These panels control signals to headsets or communication carrier assemblies through the communications umbilical. Orbiter OV-102 has two additional ATUs. One is in the flight deck (OS AUDIO), mounted on panel A13 for use with the flight deck speaker unit. (On all other orbiters, the MISSION STATION AUDIO audio terminal unit is used with the flight deck speaker unit.) The second ATU, in the middeck, is AIRLOCK 1 BACKUP, which is mounted at the MO58F position and acts only as a backup for the airlock CCU1 headset CONTROL function. (The AIRLOCK AUDIO CCU 2 headset connection uses the MIDDECK SPEAKER AUDIO audio terminal unit as a control function backup.)



Audio Terminal Unit on Panel AW18D

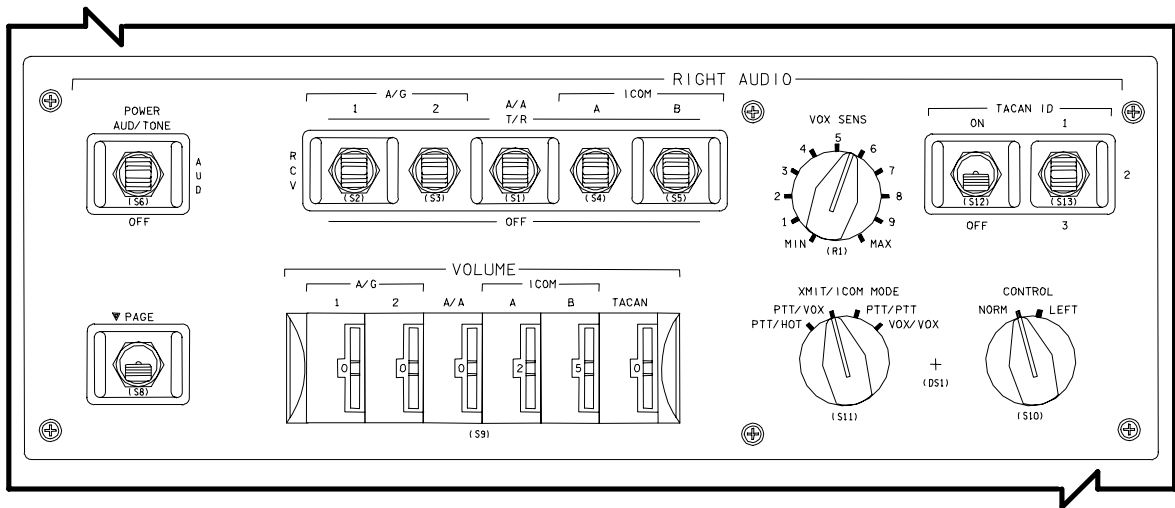
Each ATU has a three-position power switch to control all signals to or from the ATU. The switch positions are AUD/TONE, AUD, and OFF. In the AUD/TONE position, all available

functions of the ATU are armed, and transmission and receptions may be made through the ATU, depending on the position of other switches on the ATU. C/W tone signals are sent to the ACCU to allow C/W audio to reach the ATU, the CCU, and the speaker unit. The AUD position has the same functions as AUD/TONE except that C/W signals are blocked from the ATU. The OFF position shuts off power to the ATU power supply, for the ATU amplifiers. Klaxon (cabin air pressure) and siren (fire) C/W signals go directly to a speaker unit, even with the speaker power off.

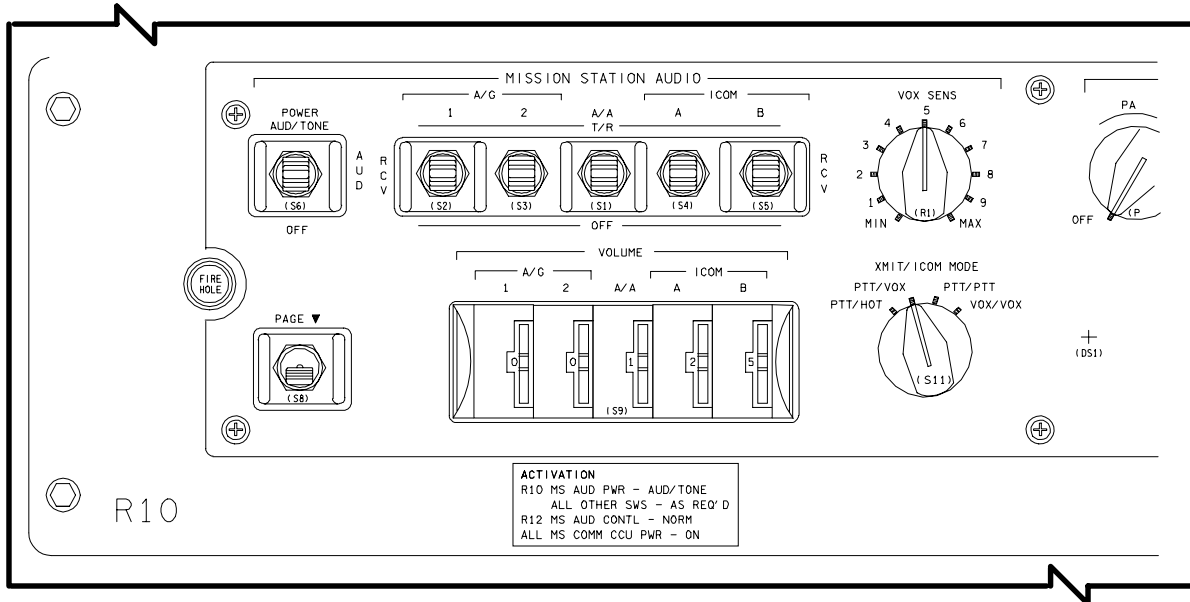
Each ATU has a two-position, spring-loaded-off PAGE switch that must be held in the PAGE position to activate the circuit. When activated, the circuit enables the ATU to transmit to all other ATUs, the EVA transceiver, and the attached payload circuit (e.g., Spacelab). Any

number of stations may use the paging circuit simultaneously, and the circuit may be used regardless of the position of the other channel control switches.

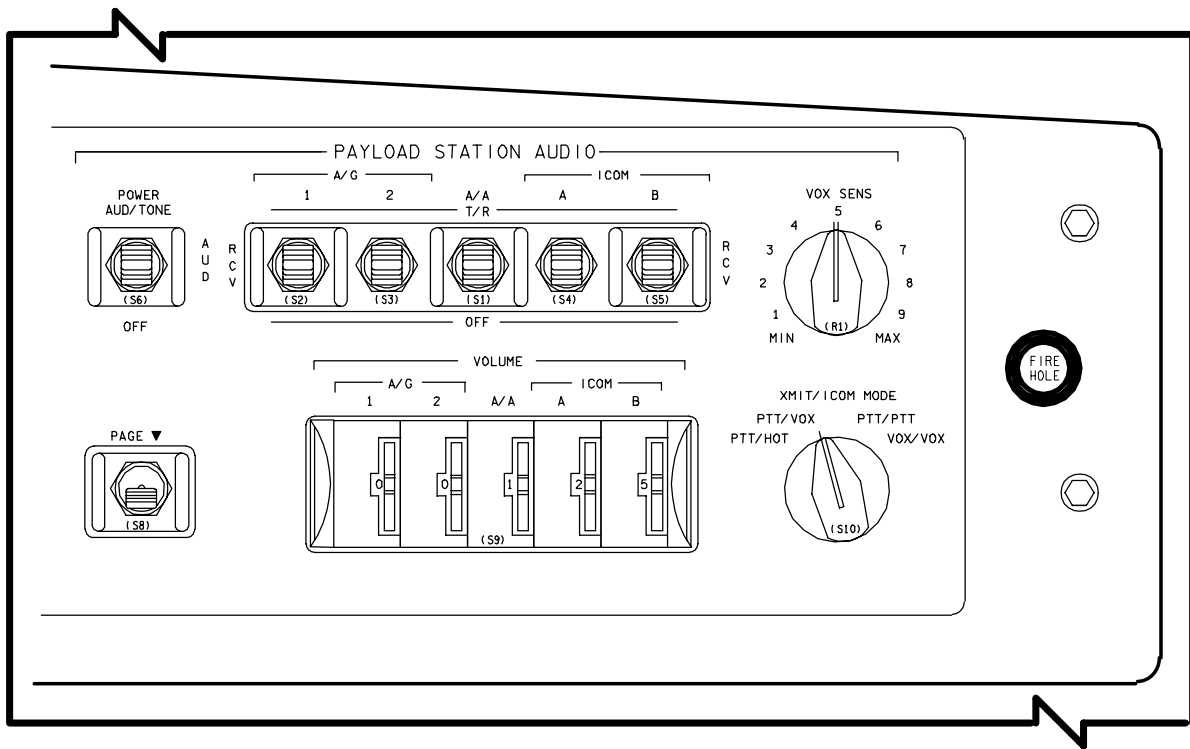
On all ATUs, the two air-to-ground channels, the air-to-air channel, and intercom channels A and B have individual three-position control switches for selecting access to particular channels for transmission or reception. The switch positions are T/R, RCV, and OFF. The T/R position permits transmission or reception over the selected channel. The RCV position deactivates transmission capability on the selected channel and permits only reception of signals. The OFF position deactivates transmission and reception on the selected channel. These control switches do not turn on any transmitter or receiver but allow access to a transmitter or receiver.



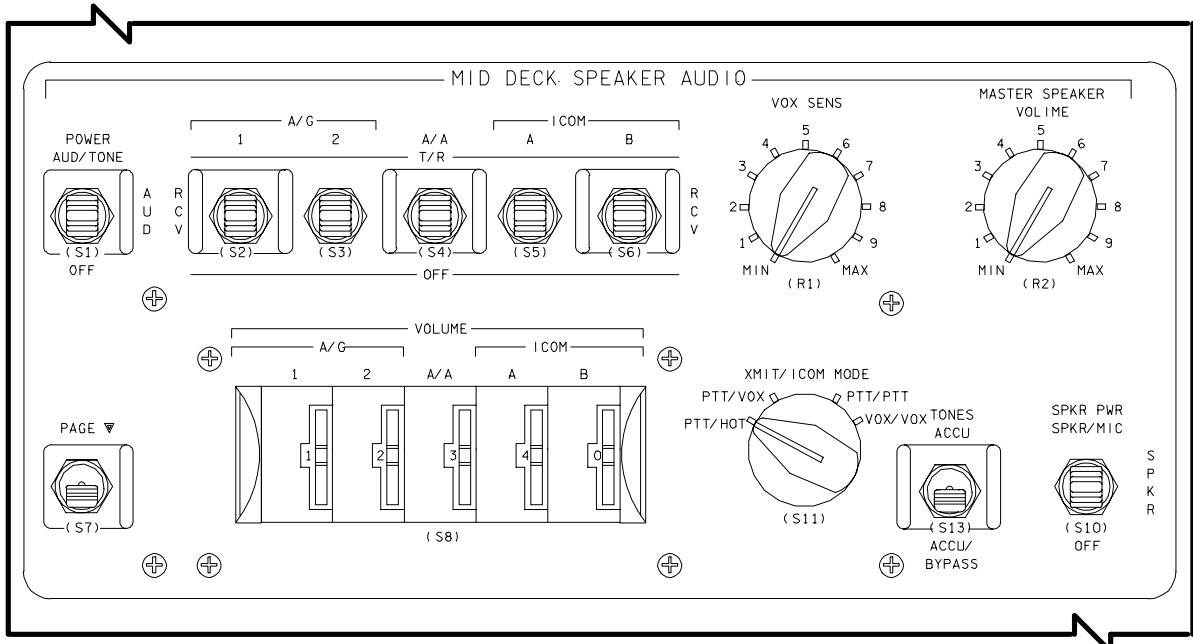
Pilot's Audio Terminal Unit on Panel O9



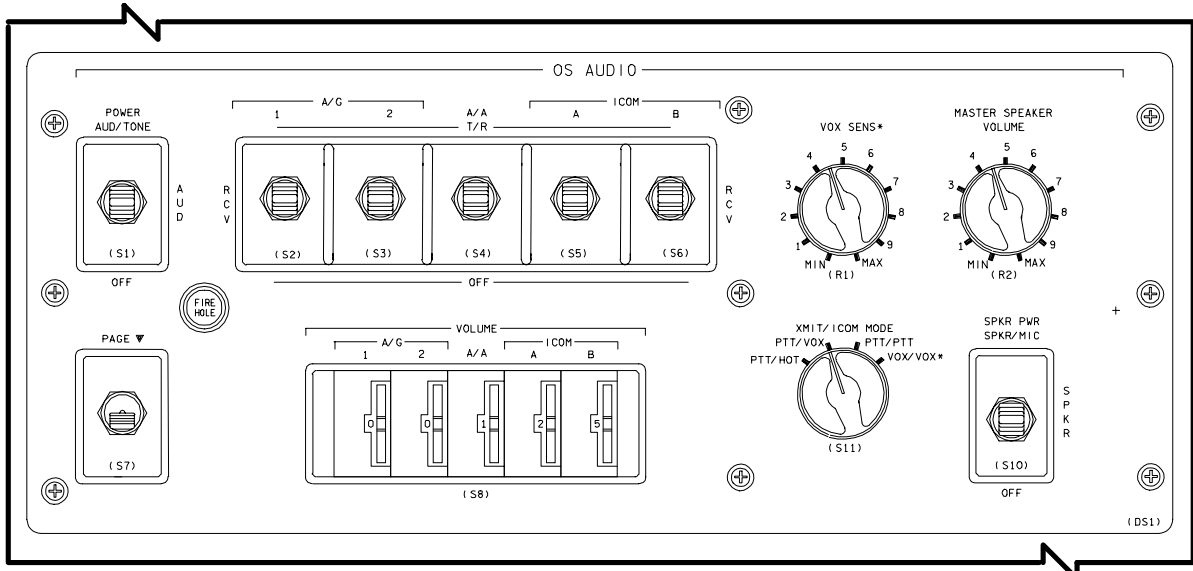
Audio Terminal Unit on Panel R10



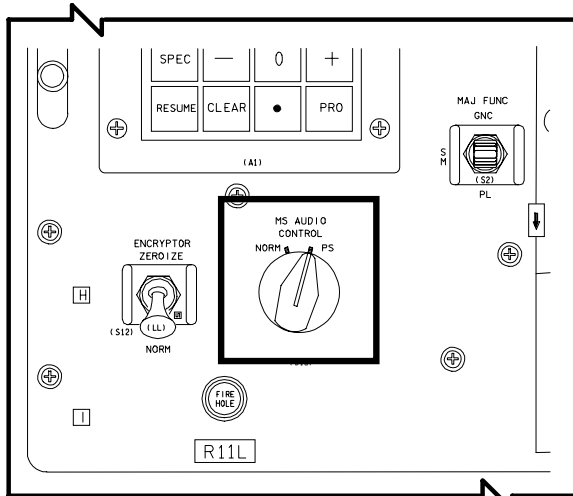
Audio Terminal Unit on Panel L9



Audio Terminal Unit on Panel MO42F



Audio Terminal Unit on Panel A13 (OV-102)



MS AUDIO CONTROL Switch on Panel R11L

Each channel control switch has a thumbwheel VOLUME control to adjust signal intensity on the related channel. The thumbwheels cover a range of approximately 27 decibels in 3-decibel increments.

The XMIT/ICOM MODE rotary switch controls four combinations of external and intercom transmissions. In the PTT/HOT mode, transmission through A/G 1, A/G 2, and A/A requires manual keying of the headset interface unit, microphone, or WCCS leg unit XMIT PTT button; intercom A and B will be hot mike. In the PTT/VOX mode, A/G 1, A/G 2, and A/A require PTT of the XMIT button, while intercom A and B are voice keyed. In the PTT/PTT mode, all voice channels are voice keyed. In the VOX/VOX mode, all voice channels are voice keyed.

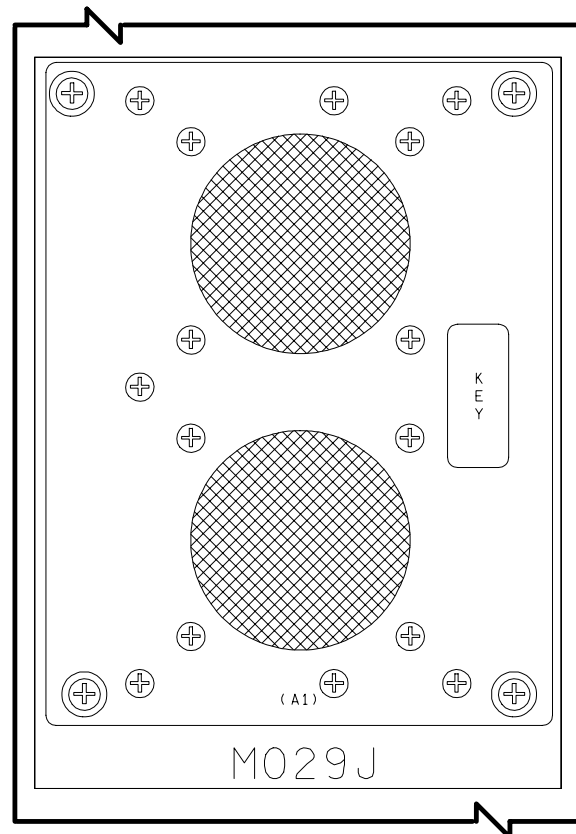
The VOX SENS rotary potentiometer on the ATUs regulates the volume of the signal required for voice keying. The MAX setting requires a lower decibel level to key the circuit than the MIN setting.

Volume control of all incoming signals to speakers is adjusted by the MASTER SPEAKER VOLUME controls on panels A13 and MO42F. The MASTER VOLUME 1 and 2 potentiometers on panel AW18D control volume to the respective CCU outlets in the airlock.

Four ATUs (on panels O5, O9, AW18D, and R10) allow a crewmember at a malfunctioning ATU to switch the CCU jack to an alternate

ATU. The left may be switched to the right (commander's to pilot's ATU), or right ATU control may be switched to the left (pilot's to commander's ATU). The commander's and pilot's CONTROL knobs are located on panels O5 and O9. Mission specialist ATU may be switched to the payload specialist's ATU using the MS AUDIO CONTROL switch on panel R11L. Airlock ATU control may be switched to the middeck and payload specialist's ATUs using the CONTROL rotary switch on panel AW18D. Orbiter OV-102 uses the AIRLOCK 1 BACKUP ATU for airlock CCU 1 alternate control.

When the CONTROL switch is in the NORM position, control of the ATU is from the panel to which the knob belongs. The other position of the knob indicates the ATU to which control can be transferred. The CONTROL knob changes all ATU functions to the alternative ATU except the master volume control. This redundancy protection is used in the event of a failure or malfunction of any of the four audio terminal units that have a CONTROL knob.



Speaker Unit on Panels A2 and M02J

NOTE

If an ATU loses power, switching to the other CONTROL position will restore listen capability but not talk capability.

Speaker Units

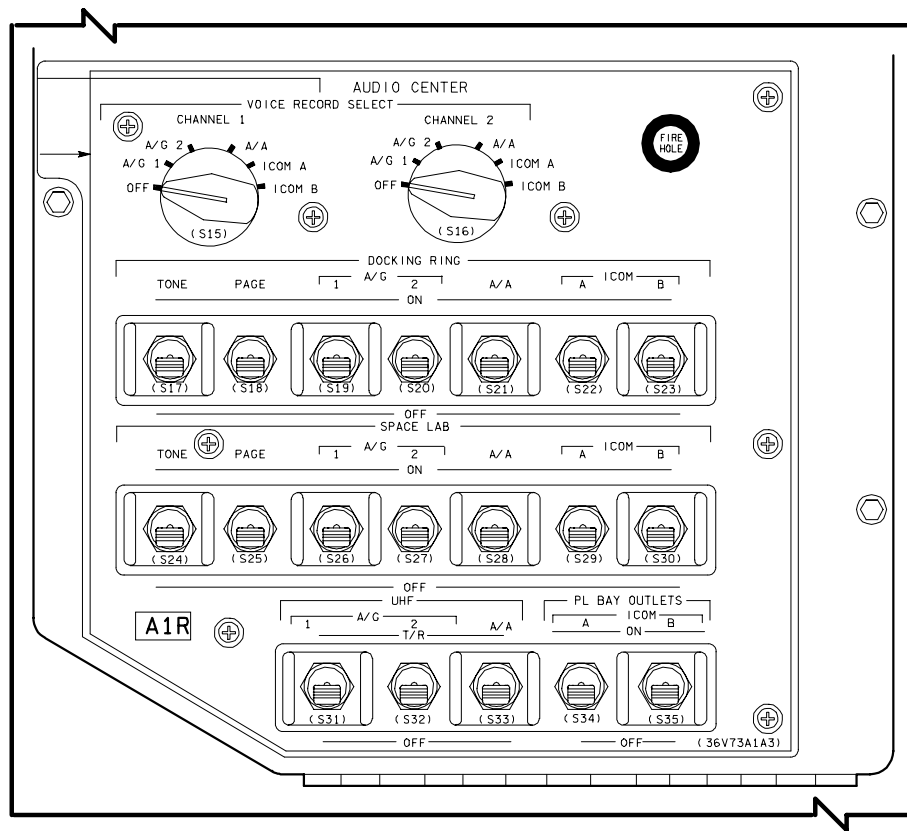
An SU is located on panels A2 and MO29J. They are controlled by the ATU on panels R10, A13, and MO42F in orbiters OV-103, -104, and -105. They are controlled by the ATU on panels A13 and MO42F in orbiter OV-102. In addition to the features of the other ATUs, the speaker unit ATU has a three-position SPKR PWR switch. Only the OFF and SPKR positions are used. In the OFF position, no signals go through the ATU. In the SPKR position, audio selected on the associated ATU, including C/W tones, are enabled. The SPKR/MIC position is not used. The top speaker is used for audio and the bottom is dedicated to the klaxon/siren.

The KEY light illuminates when a microphone on the associated ATU is keyed (PTT, VOX, etc.)

Audio Center Panel

The AUDIO CENTER controls on panel A1R have four functions: UHF control, voice interface capability with external vehicles, the payload bay comm outlets, and operations recorder selection. All switches on the panel send digital impulses to the ACCU, enabling the selected functions to communicate with Spacelab, the payload bay, and operations recorders. Sets of toggle switches labeled

DOCKING RING, SPACE LAB, and PL BAY OUTLETS electrically connect the particular function to the audio distribution system. The DOCKING RING and SPACE LAB subpanels have seven switches to enable the following functions: A/A, A/G 1, A/G 2, ICOM A, ICOM B, PAGE, and TONE (C/W). The UHF switches control A/G 1, A/G 2, and A/A channels to the UHF transceiver. The PL BAY OUTLETS subpanel has two ON/OFF switches, one for intercom A and one for B. The PL BAY OUTLETS switches also route ICOM A and B to the CCTV system for interleaving with the video signals.



AUDIO CENTER Controls on Panel A1R

Two rotary knobs labeled *VOICE RECORD SELECT* control various audio signals to be sent to the operational recorders through the NSP. *A/G 1*, *A/G 2*, *A/A*, and *ICOM A* or *B* audio can be sent to either recorder. Any two signals may be recorded at the same time, one on channel 1 and the other on channel 2. Either channel may be turned off. A recorder input (RCDR INPUT) parameter on orbiter display S76 indicates whether the recorder is recording data (DATA) only or data plus the voice selected on the AUDIO CENTER panel (D/VO).

Loose Communications Equipment

Launch and Entry Helmets

During launch and entry, each flight crewmember wears a launch and entry helmet to lessen the severe noise levels encountered at launch and to allow intelligible air-to-ground communications. A communications carrier assembly headset containing microphones and earphones fits over the crewmember's head, and a connector and cable interface with the headset interface unit, connected through communications cables to respective audio terminal units. The microphones can be positioned to suit the individual crewmember. For emergency egress, a pull-away connection is used between the communications carrier assembly and headset interface unit, in addition to the standard communications carrier assembly/headset interface unit twist-on connector.

The helmets have redundant noise-canceling microphones and electrically isolated earphones. When air is inhaled, the demand breathing regulator shuts off the microphones to avoid transmitting breathing sounds.

NOTE

An improper face seal will cause enough oxygen flow to cut off microphones.

Headset Interface Unit

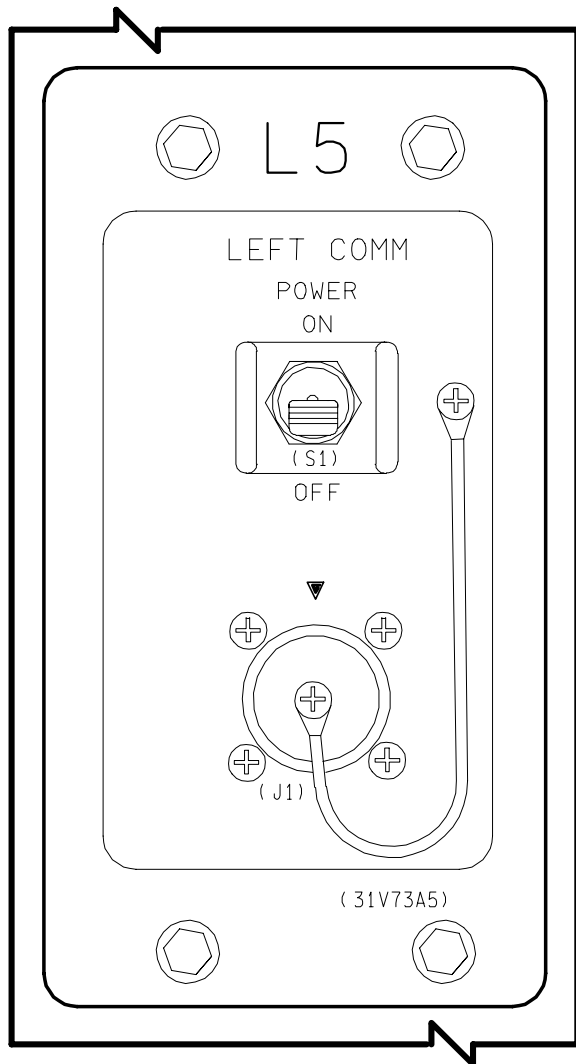
The headset interface unit has separate push-to-talk (PTT) buttons for transmit and intercom modes and a volume control that determines the level of sound heard through the earphone

(microphone sound level is determined by automatic gain control circuitry within the audio terminal unit). (Push-to-talk means that a pushbutton must be depressed to allow a crewmember to talk through the system.) The XMIT pushbutton allows access to intercom and external circuits, while the ICOM pushbutton is for intercom only. The volume control knob acts in series with the loop volume controls on the associated audio terminal unit. In addition, the commander and pilot have PTT switches on their rotational hand controllers for transmit (XMIT) keying.

The headset interface unit provides volume control and PTT capabilities to the communications carrier assembly used for EVA, and to the communications carrier assembly. The headset interface unit has a clip that attaches to the crew's flight suits.



Headset Interface Unit



**Crewman Communications Umbilical
on Panel L5**

Cables

The communication cables vary in configuration depending on seat location. Each seat has two 4-foot communication cables or a 14-foot length, as required. One 4-foot cable is flown as a spare. The cables connect to crewman communications umbilical (CCU) outlets at various locations in the crew compartment. Each CCU has a specific audio terminal unit that controls communication loop configurations. The CCU associated with the ATU on panel O5 is located on panel L5 (*LEFT COMM*); for O9 on R6 (*RIGHT COMM*); for R10 on A11 (*MS COMM*), for L9 on A15 (*PS COMM*), and for MO42F on MO39M (*MID DECK COMM*); two others for the airlock ATU are located on panel AW82D (*CCU 1* and *CCU 2*).

Each CCU outlet has a power switch that controls the associated microphone power. Leaving CCU power off confines an individual to a listen-only mode, independent of audio terminal unit configuration.

Multiple Headset Adapter

A multiple headset adapter may be plugged into the CCU outlets. The three CCU outlets on the adapter allow up to three crewmembers to share one CCU outlet. When any one person connected to a multiple headset adapter keys (in PTT mode) or activates the voice-operated transmitter, all three individuals' microphones will be keyed, and individuals sharing the multiple headset adapter will hear each other talking on the side tone.

Wireless Communications Units

On orbit, the crew may use wireless communication units in place of communication cables. A wireless unit consists of one wall unit (audio interface unit) and two leg units (crew remote units) worn by crewmembers during orbital operations. The wall unit connects to a CCU outlet and remains attached to the crew compartment wall. Each wall unit transmits on a unique pair of UHF frequencies. Leg units may be configured to work with any wall unit. A leg unit may be converted into a wireless handheld microphone by attaching a noise-cancelling mic at the headset connector. Each wall unit is identified by a letter enclosed in a box. Each unit is stowed with its cabling attached. The wall unit has a 23-inch cable to interface with the CCU outlet, and the leg unit has a 22-inch cable attached to a lightweight headset.

NOTE

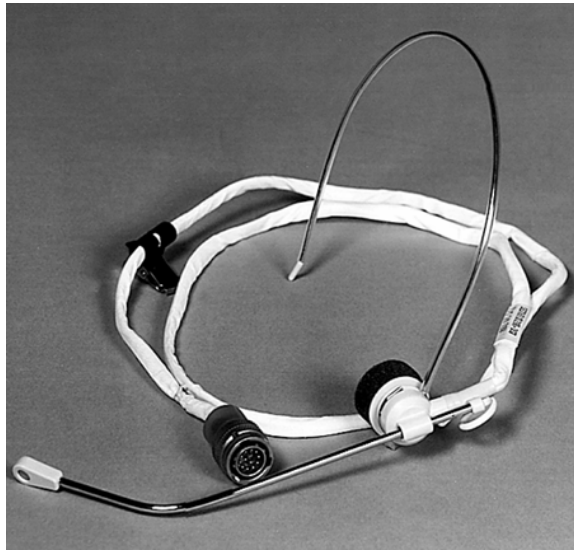
If the two leg units are set to use the same frequency, one of the units' transmit signals will be muted.

When the wireless unit is unstowed, part of the assembly necessary is to insert and tighten the flexible antenna in the bottom of each wall and leg unit. The wall unit receives power from the CCU outlet. All other switches are set as required; typically, the individual communication loops are used. The leg unit is attached to

the crewmember's leg with a wraparound elastic strap. The rotary ON/OFF/VOLUME knob (unlabeled) is turned clockwise past the ON/OFF detent, and the volume is set as desired. Each leg unit is powered by a replaceable lithium battery pack. A weak battery is identified by a continuous beeping sound when the leg unit is powered on. A single battery pack provides about 35 hours of service. Sliding a new battery pack into the unit causes both the electrical connector and mechanical connector to latch.

Very Lightweight Headset

The very lightweight headset is the interface between the leg unit and crewmember. A single-strand wire headband holds the earphone against the ear and supports a thin boom holding a noise-cancelling microphone near the mouth. A cable and connector are attached to the crewmember's leg unit. The lightweight headset cable and connector also can interface with the headset interface unit.



Very Lightweight Headset

Handheld Microphone

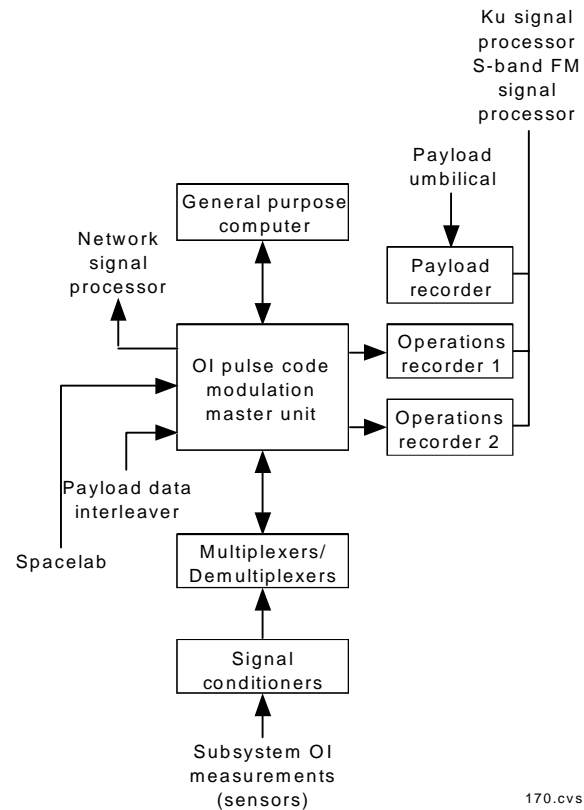
The handheld microphone is a noise-canceling microphone that connects directly to any CCU outlet. The microphone is used primarily with the SUs located at panels A2 and MO29J. To avoid feedback when using the speakers, one ATU and its corresponding CCU outlet on the aft flight deck and one ATU and associated CCU on the middeck are equipped with a

speaker muting capability. On OV103, OV104, and subsequent vehicles, muting is controlled through ATUs at panels R10 and MO42F. On OV102, the muting ATUs are located at panels A13 and MO42F.

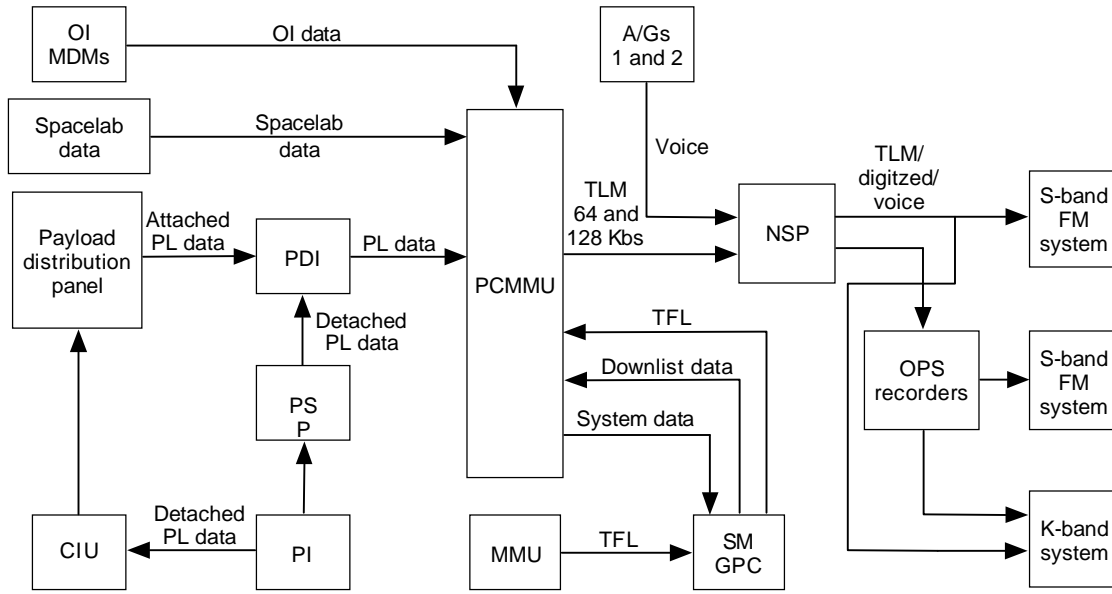
Two PTT pushbuttons are provided for XMIT and ICOM audio modes. When used to record audio on the videotape recorder, either can be used. The pushbuttons should face the operator to ensure that the noise-canceling feature of the microphone remains functional. The handheld microphone is equipped with a 7-foot cable that can connect at any CCU or to other cables. The microphone/SU configuration is used for on-orbit communication configurations.

Instrumentation

Orbiter operational instrumentation (OI) collects, processes, and routes information from transducers and sensors throughout the orbiter and its payloads. More than 3,000 data parameters are monitored.



Simplified Instrumentation Data Flow



- | | |
|------------------------------------|---|
| A/G — Air-to-Ground | PCMMU — Pulse Code Modulation Master Unit |
| CIU — Communication Interface Unit | PDI — Payload Data Interleaver |
| GPC — General Purpose Computer | PI — Payload Interrogator |
| MDM — Multiplexer/Demultiplexer | PL — Payload |
| MMU — Mass Memory Unit | PSP — Payload Signal Processor |
| NSP — Network Signal Processor | SM — Systems Management |
| OI — Operational Instrumentation | TFL — Telemetry Format Load |
| OPS — Operations | TLM — Telemetry |

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Operational instrumentation System Overview

AREA	CHARACTERISTICS
Signal Conditioning	<ul style="list-style-type: none"> • 14 DSCs conditioning approximately 1,200 channels, plus EDO DSCs (up to 4) • 6 WBSC to MDM • Approximately 45 high-level transducers • Distributes data to PCM data system panel displays, C/W, flight-critical MDMs
PCM Data System	<ul style="list-style-type: none"> • Acquires data through 7 OI MDMs, approximately 2,800 measurements • Receives and provides data to 5 computers • Accepts payload data through PDI or payload data bus (Spacelab) • Provides output data in 64 and 128-kbps formats • Provides synchronization to PDI and NSP • Provides data to NSP and T-0 umbilical
Payload Data Recorders	<ul style="list-style-type: none"> • Receives data directly from payload or PLSP • Provides data to GPCs and PCM • Stores 3 channels of engine data at 60-kbps rate • Stores interleaved voice and data at 96, 128, or 192-kbps rates • Stores payload data • Provides for playback of recorded data during and after mission
Master Timing	<ul style="list-style-type: none"> • Provides time reference to computers, OI PCM, display panel, and payload • Provides synchronization to instrumentation and other subsystems

OI System

The instrumentation system consists of transducers, 14 dedicated signal conditioners (additional dedicated signal conditioners (DSCs) for extended duration orbiter (EDO) missions), 7 MDMs, 2 PCMMUs, 2 operational recorders, 1 payload recorder, master timing equipment, and onboard checkout equipment.

The OI system senses, acquires, conditions, digitizes, formats, and distributes data for display, telemetry, recording, and checkout. It provides for pulse code modulation recording, voice recording, and master timing for onboard systems.

Instrumentation equipment, except sensors and selected dedicated signal conditioners, is located in the forward and aft avionics bays. Sensors and DSCs are located throughout the orbiter in areas selected on the basis of accessibility, minimum harness requirements, and functional requirements. Abbreviations used to designate the locations of equipment are as follows: OA refers to operational aft, OF to operational forward, OL to operational left, OR to operational right, and OM to operational mid.

Dedicated Signal Conditioners

Dedicated signal conditioners acquire and convert various sensor data from thousands of orbiter sensors into a 0-5 V dc pulse acceptable to MDMs. Sensors requiring DSCs include frequency, temperature, rate, voltage, current, and analog parameters.

There are 14 orbiter DSCs, 4 in forward avionic locations (OFs), 3 in the aft avionic bays (OAs), 3 under the payload bay (MID) (OMs), and 4 in the right and left tail sections (ORs and OLs). There can be up to four additional DSCs flown with the EDO.

Multiplexer/Demultiplexers (MDMs)

MDMs can operate in two ways. As multiplexers, they take data from several sources, convert the data to serial digital signals (a digitized representation of the applied voltage), and interleave the data into a single data stream. As demultiplexers, the MDMs take interleaved serial digital information, separate and convert it to analog, discrete, or serial digital, and send each separate signal to its appropriate destination.

The OI MDMs act only as multiplexers. Upon request from the pulse code modulation master unit (PCMMU), the MDMs send these interleaved streams to the PCMMU through the OI data buses. When the MDM is addressed by the PCMMU, the MDM selects, digitizes, and sends the requested data to the PCMMU in serial digital form. The PCMMU/OI MDM interface is based on demand and response; that is, the OI MDMs do not send data to the PCMMU until the PCMMU makes the request. There are seven OI MDMs, four OFs, and three OAs for forward and aft multiplexing of DSC and direct data signals.

Pulse Code Modulation Master Unit (PCMMU)

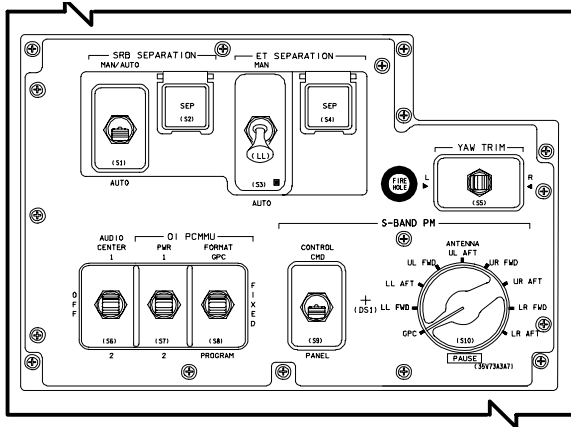
The PCMMU receives data from the OI MDMs, downlist data from the GPCs under control of flight software, and payload telemetry from the payload data interleaver and Spacelab. It then interleaves the data, formats data according to programmed instructions stored within the PCMMU (the telemetry format load, or TFL), and sends the interleaved data to the network signal processor to be combined with the analog air-to-ground voice data from the audio central control unit for transmission through the S-band PM downlink and Ku-band system return link, channel one. Telemetry from the PCMMU is also sent through the network signal processor to the operational recorders for storage and subsequent downlink on the S-band FM or Ku-band system. OI and payload data collected by the PCMMU are available to the GPCs for display and monitoring purposes upon request. All data received by the PCMMU are stored in memory and periodically updated.

The PCMMU has two formatter memories: programmable read only (PROM) and random access (RAM). The read-only memory is hard coded; the RAM is reprogrammed several times during flight. The PCMMU uses the formatters to load data from the computers and OI MDMs into PCM telemetry data streams for downlinking

NOTE

When the PCMMU is powered off (as when switching to the alternate unit), the TFL changes to the fixed format loaded in the PROM.

One of the two redundant PCMMUs and network signal processors operates at a time. The one used is controlled by the crew through the flight deck display and control panel. The primary port of each MDM operates with PCMMU 1 and the secondary port operates with PCMMU 2.



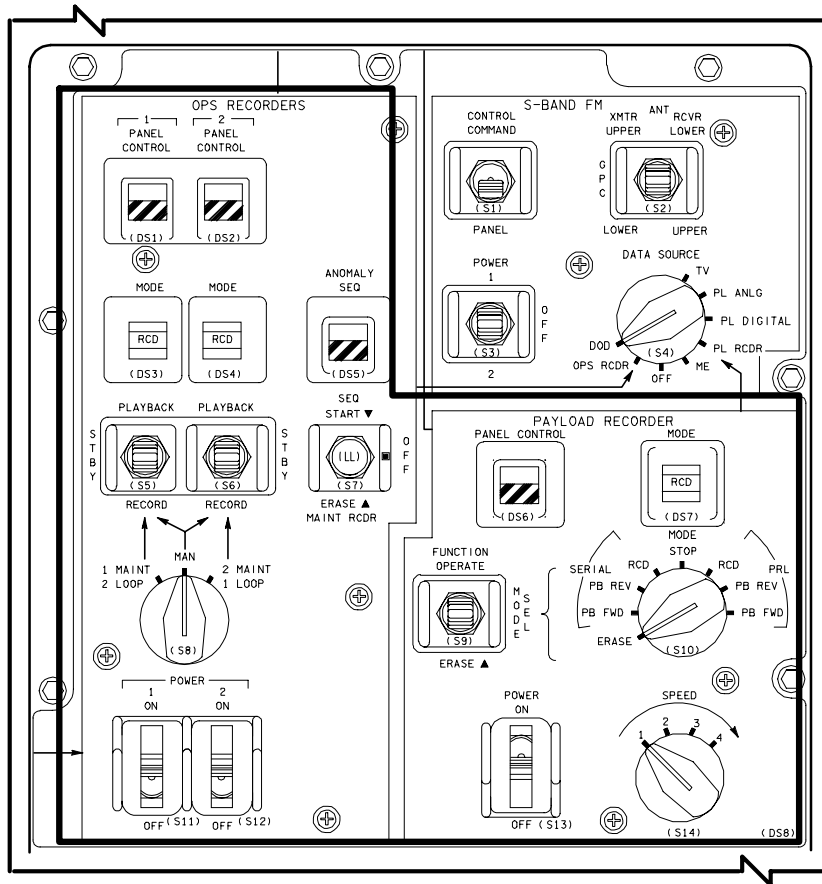
OI PCMMU Controls on Panel C3

The PCMMUs receive a synchronization clock signal from the master timing unit. If this signal is not present, the PCMMU provides its own timing and continues to send synchronization signals to the payload data interleaver and network signal processor.

The OI PCMMU controls are located on panel C3.

Master Timing Unit

The master timing unit is a stable crystal-controlled timing source. It provides synchronization for instrumentation, payloads, and other systems. The master timing unit is described in more detail in Section 2.6.



Recorder Controls on Panel A1R

Operations Recorders

Two recorders are used for serial recording and dumping of digital voice and pulse code modulation (PCM) data from the OI systems. The recorders normally are controlled by ground command, but they can be commanded

by the flight crew through the flight deck display and control panel keyboard or through the OPS RECORDERS switches on panel A1R or commanded via uplink. The input to the recorders is from the network signal processor, in main engine data at 60 kbps.

The operations recorders can be commanded to dump recorded data from one recorder while continuing to record real-time data on the other. The dump data are sent to the FM signal processor for transmission to the ground station through the S-band FM transmitter on the S-band FM return link or to the Ku-band signal processor. When the ground has verified that the received data are valid, the operations recorders can use that track on the tape to record new data. If ground is controlling recorders, the crew cannot, unless ground sets a "crew reset" command or its equivalent from SPEC 1.

Recorder speeds of 7.5, 15, 24, and 120 inches per second are provided by hardwire program plug direct command. The tape recorders contain a minimum of 2,400 feet of 0.5-inch by 1-mil magnetic tape.

Recorder functions can be summarized as follows:

- Data in, recorder 1
 - Accept three parallel channels of engine data at 60 kbps during ascent.
 - Accept 192 kbps of interleaved PCM data and voice that serially sequences from track 4 to track 14 (high data rate), 128 kbps data only (high data rate), or 96 kbps data and voice (low data rate).
 - Accept real-time data from network signal processor. Recording time is 32 minutes for parallel record and 5.8 hours for serial record on tracks 4 through 14 at a tape speed of 15 inches per second.
- Data in, recorder 2
 - Accept 192 kbps of interleaved PCM voice and data that serially sequences from track 1 to track 14 (high data rate), 128 kbps data only (high data rate), or 96 kbps data and voice (low data rate).
 - Accept real-time data from network signal processor. Recording time is 7.5 hours at a tape speed of 15 inches per second for serial record on 14 tracks.

- Data out, recorder 1
 - Play back in-flight engine interface unit data and network signal processor digital data through S-band FM transponder or Ku-band transmitter.
 - Play back in-flight anomaly PCM data for maintenance recording.
 - Play back data serially to ground support equipment to T-0 ground support equipment umbilical.
- Data out, recorder 2
 - Play back digital data through S-band FM transponder or Ku-band transmitter in flight.
 - Play back anomaly PCM data in flight for maintenance recording.
 - Play back preflight and postflight data serially to GSE T-0 umbilical.

Payload Recorder

The payload recorder records and dumps payload analog and digital data through the S-band FM or Ku-band transmitter. The recorder can record one of three serial inputs or a maximum of 14 parallel digital or analog inputs or combinations of analog and digital data (up to 14 inputs) from the payload patch panel. In flight, all data dumps are serial; capability for parallel dumps does not exist. There are 14 selectable tape speeds; however, only four speeds, selectable by a program plug, are available per flight. Total recording time ranges from 56 minutes to 18 hours 40 minutes depending on tape speed.

The recorder normally is controlled by ground command, but can be commanded by the flight crew using the *PAYLOAD RECORDER* switches on panel A1R.

Thermal Impulse Printer System

The thermal impulse printer system (TIPS) is a high speed gray shade recorder employing a fixed thermal head to produce hard copies of line scan or raster scan information. It replaces the teleprinter and text and graphics systems

previously flown on the shuttle. The TIPS thermal head reproduces images by bombarding thermal paper with heat pulses. The more pulses directed at one spot, the darker it becomes. One TIPS is flown in a middeck locker and can also be used as a printer for the PGSC computer. Electrical power is provided from an ac outlet on panel ML85E (MUP). TIPS can receive text data over S-band PM or Ku-band (voice channel) via STDN or TDRS. TIPS can also receive text and graphics data through Ku-band mode one (128kbps) via TDRS. The voice channel input for TIPS is accomplished through the PS COMM outlet on panel A15 nominally via A/G 2. The voice channel data transfer rate of 600 baud requires up to 90 seconds per 11 inch page depending on the number of lines. The Ku-band mode 1 input is received through the Ku-band Data Uplink Port behind the old TAGS small compartment door. When the Ku-band voice channel is used, it takes approximately 44 seconds to print 11 inches of text or dithered (laser printer style) graphics at 200 dots per inch (dpi) resolution.

True gray scale graphics data will require about 4 minutes and 9 seconds per 11 inch page at 200 dpi.

To minimize crew workload, the TIPS power, communications, and Ku-band cables are routed and secured pre-launch. The procedures for connecting the three cables, reconfiguring the panel L9 ATU, and activating the TIPS are in the Orbit Ops Checklist. An illuminated green POWER pushbutton and ON LINE and READY lights indicate the TIPS is ready to print. TIPS must be ready to print when an uplink is transmitted since the MCC has no ground command over TIPS. If TIPS is not ready to print when an uplink is initiated or if it runs out of paper prior to the end of a transmission, the data will have to be retransmitted when TIPS is back on-line. The unit does not have the capability to store data for printing at a later time. Three additional 165 foot rolls of thermal paper are stowed for changeout on orbit. The crew should replace the roll when the red warning strip appears along the edge of the paper.



Thermal Impulse Printer System

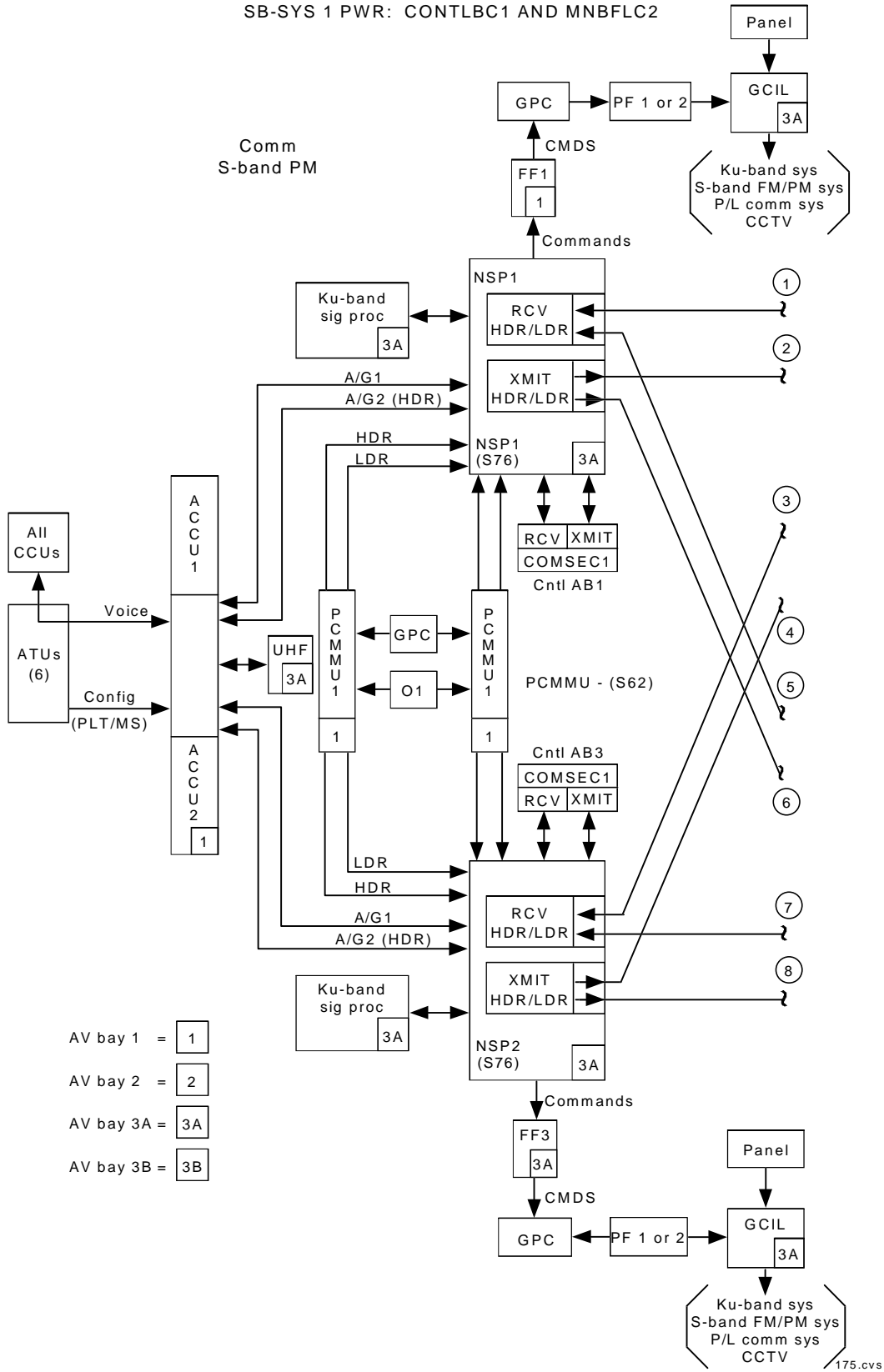
Communications System Summary

- The orbiter communications system transfers information between the orbiter and the ground, either through hardline or radio frequency links.
- The system is divided into several smaller systems: S-band phase modulation, S-band frequency modulation, Ku-band, UHF, payload communications, audio, and CCTV.
- The S-band PM system provides two-way communication between the orbiter and the ground, through either an STDN/SGLS ground station or a relay satellite. It provides channels for five functions: command, voice, telemetry, turnaround tone ranging, and two-way Doppler tracking.
- Four quadrant S-band antennas provide a selection of eight directions.
- The S-band FM system cannot receive information. It is used to downlink data directly to the ground from seven different sources: SSME interface units, the video switching unit, the operations recorder, the payload recorder, payload analog, or payload digital.
- There are two hemispherical S-band FM antennas.
- The Ku-band system provides for on-orbit communication between the orbiter and the ground. It can also be used as a radar system for tracking objects in space.
- The Ku-band antenna is deployed when the payload bay doors are opened, and stowed when they are closed. The antenna is steerable.
- TV data can be downlinked over Ku-band and S-band FM only.
- The payload communication system is used to transfer information between the orbiter and its payloads.
- The UHF system is used as a backup for the S-band PM and Ku-band voice communications. UHF is used as the primary communications link with EVA astronauts.
- The audio distribution system gathers audio signals from multiple sources and routes them throughout the orbiter. It may be used as a means by which crewmembers communicate with each other.
- The major elements of the audio distribution system are: the ACCU, ATU, SU, audio center, CCU, and loose communications equipment.
- Orbiter operational instrumentation (OI) collects, routes, and processes information from transducers and sensors throughout the orbiter and its payloads.
- The OI system consists of transducers, 14 DSCs (plus EDO DSC if flown), 7 MDMs, 2 pulse code modulation master units, encoding equipment, 2 operations recorders, 1 payload recorder, master timing unit, and onboard checking equipment.
- Additional communication equipment includes the thermal impulse printer system.
- Major communications equipment and control panels are A1R, A1U, A1L, R13L, O5, O6, O9, R10, L9, and R12. Others are found on panels A13, A14, A15, L5, F9, C3, R11L, R15, MO29J, MO42F, and AW18D.
- Specific communications system CRTs are OPS 201 ANTENNA, COMM/RCDR (DISP 76), and PC MMU/PL COMM (SPEC 62).

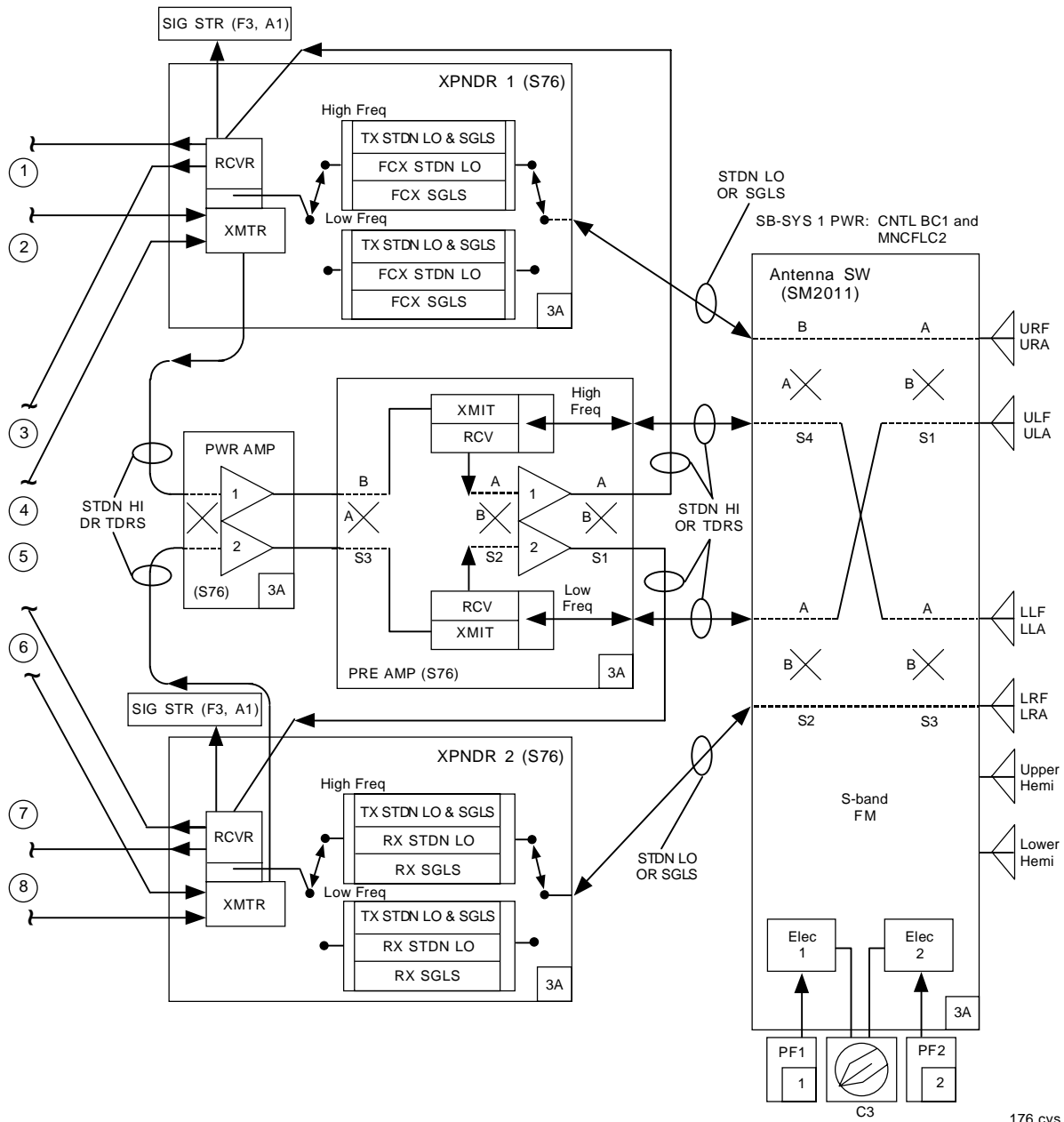
SITE ID	SITE TYPE	UPLINK DATA RATE ENCRYPTED OR CLEAR	DOWNLINK DATA RATE		UHF	TV	COMMENTS
			ENCRYPTED	CLEAR			
MIL	STDN	HI/LO	HI/LO	HI/LO	√	√	
PDL	STDN	HI/LO	HI/LO	HI/LO			
BDA	STDN	HI/LO	HI/LO	HI/LO	√		
NHS	SGLS	HI/LO	HI/LO	HI/LO			
DKR					√		
MAD	STDN	HI/LO	HI/LO	HI/LO			EMERGENCY USE
OAK	SGLS	HI/LO	HI/LO	HI/LO	√		
IOS	SGLS	HI/LO	HI/LO	HI/LO	√		
CAN	STDN	HI/LO	HI/LO	HI/LO			EMERGENCY USE
GTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011
HTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011
VTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011
DFRF	STDN	HI/LO	HI/LO	HI/LO		√	NO ID ON 2011
GDS	STDN	HI/LO	HI/LO	HI/LO	√	√	NO ID ON 2011
CTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011

Comm S-Band PM Table

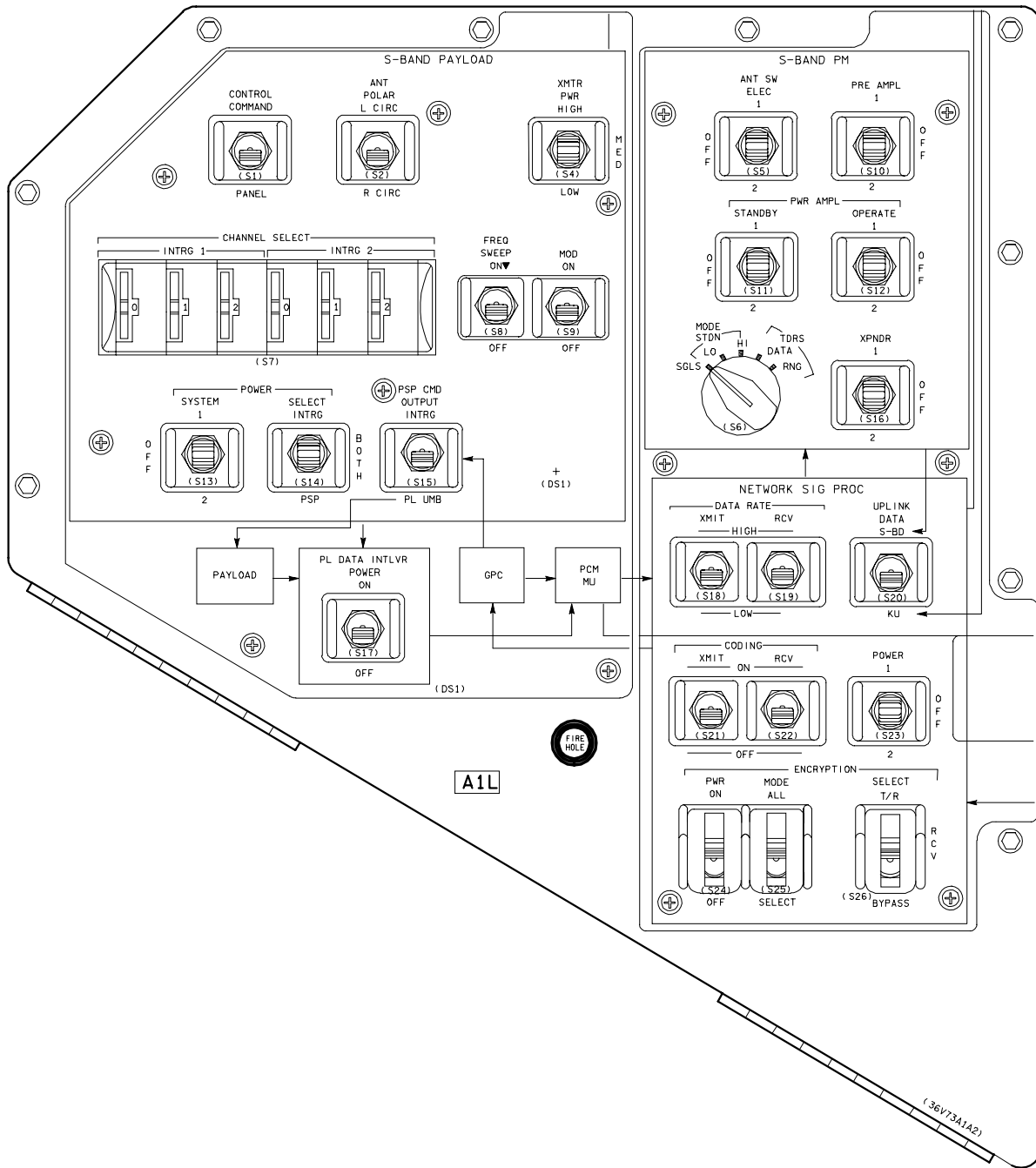
SB-SYS 1 PWR: CONTLBC1 AND MNBFLC2



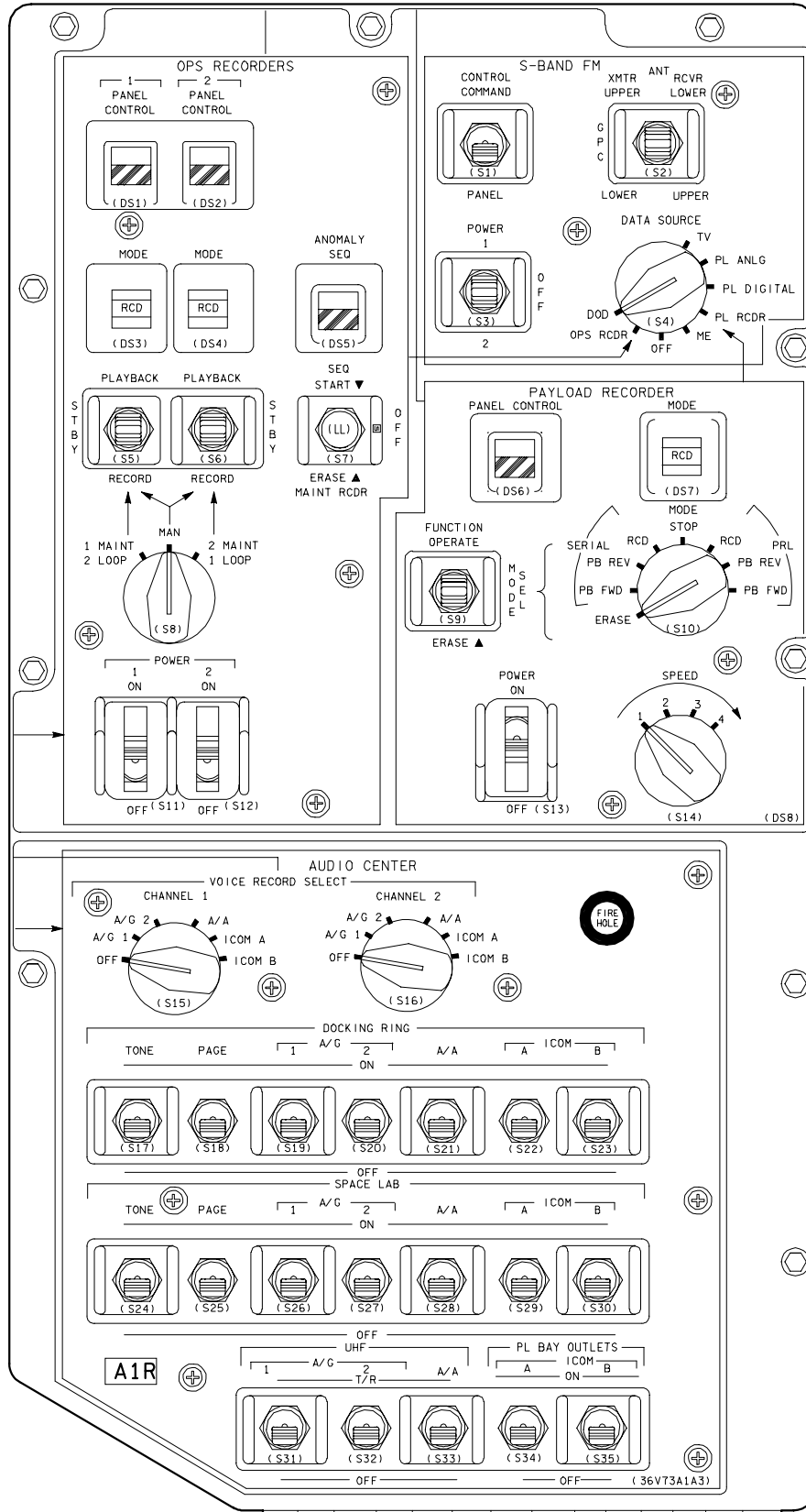
S-Band System 1 Power



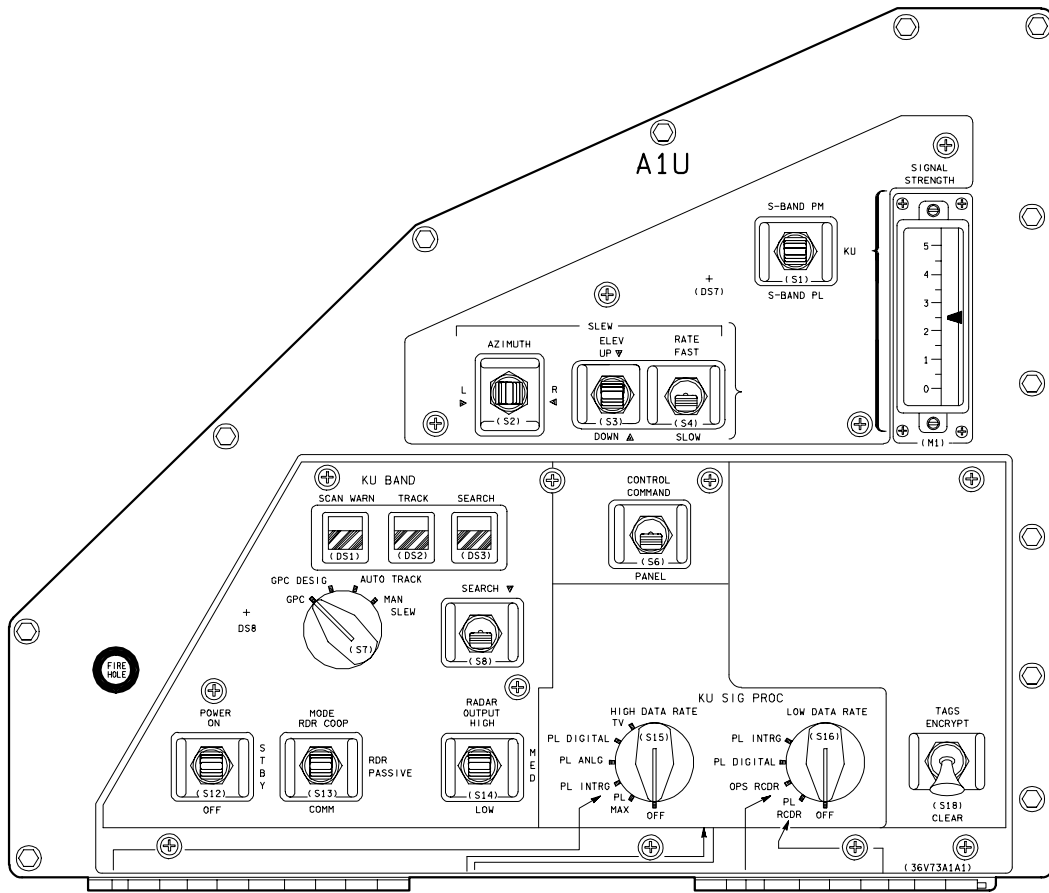
S-Band System 2 Power



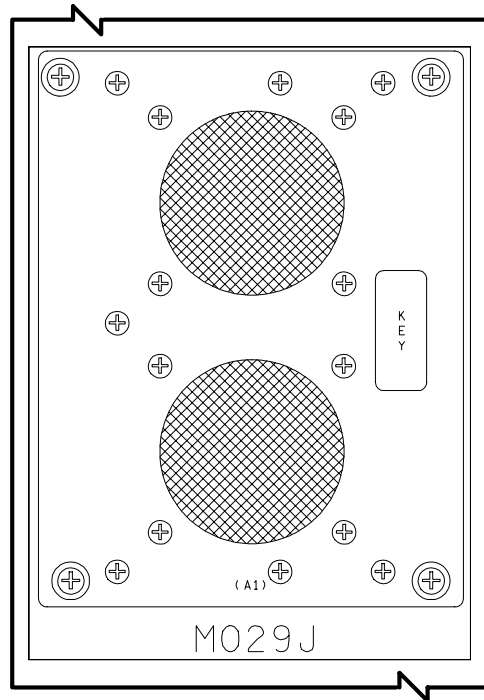
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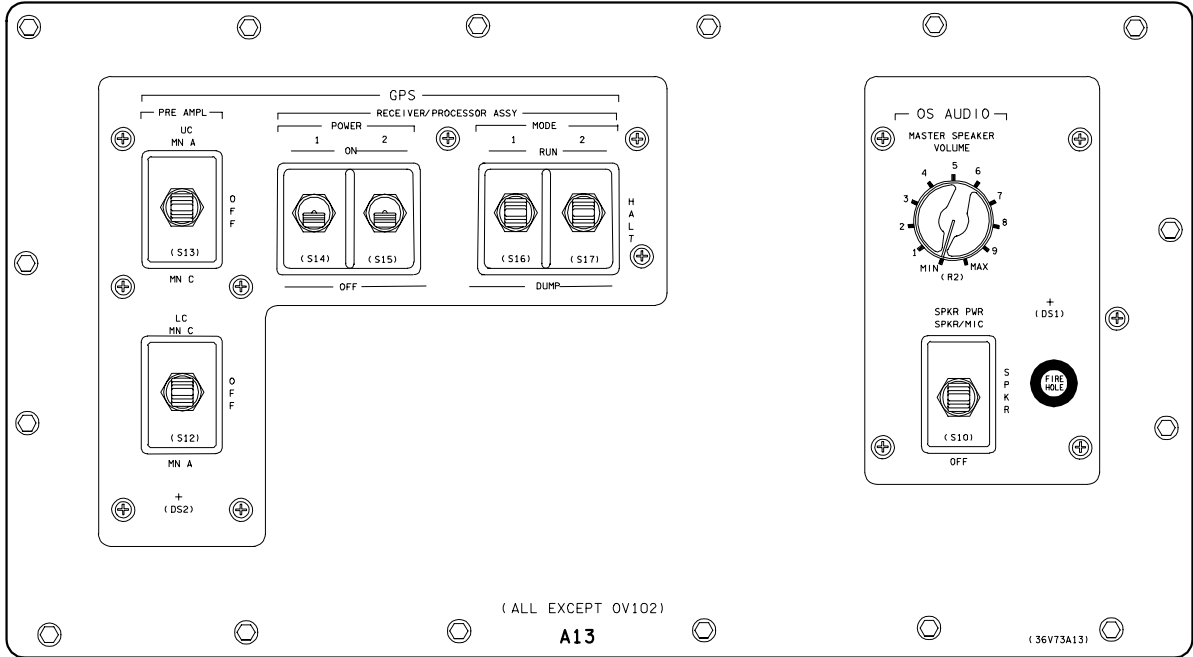
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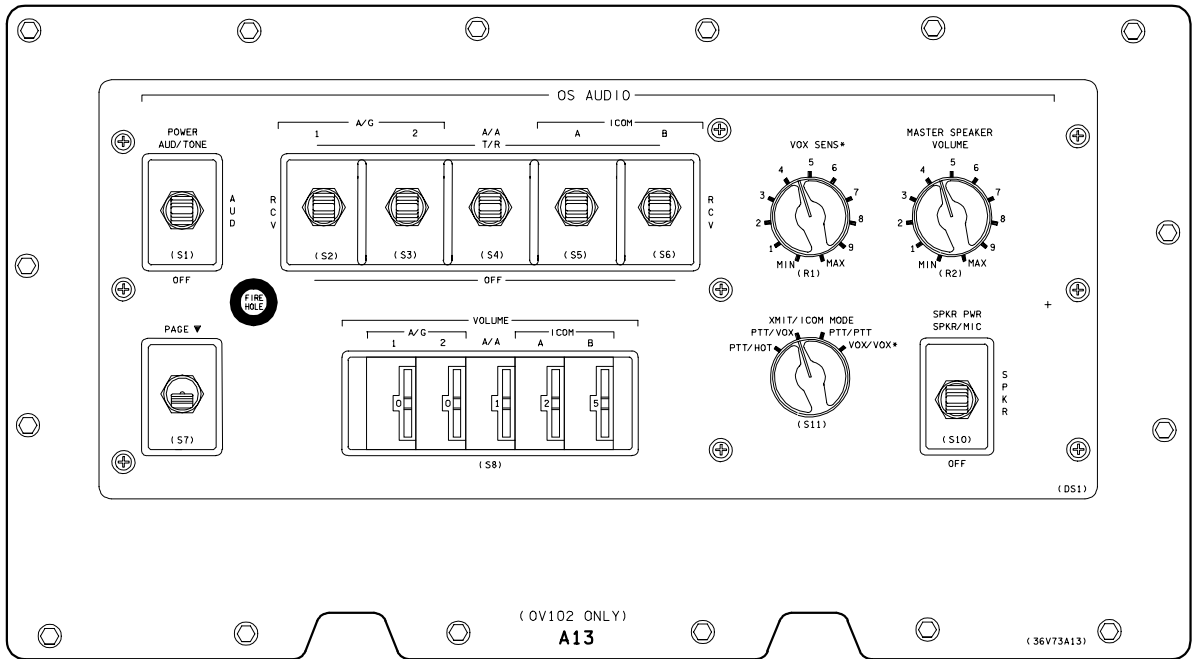
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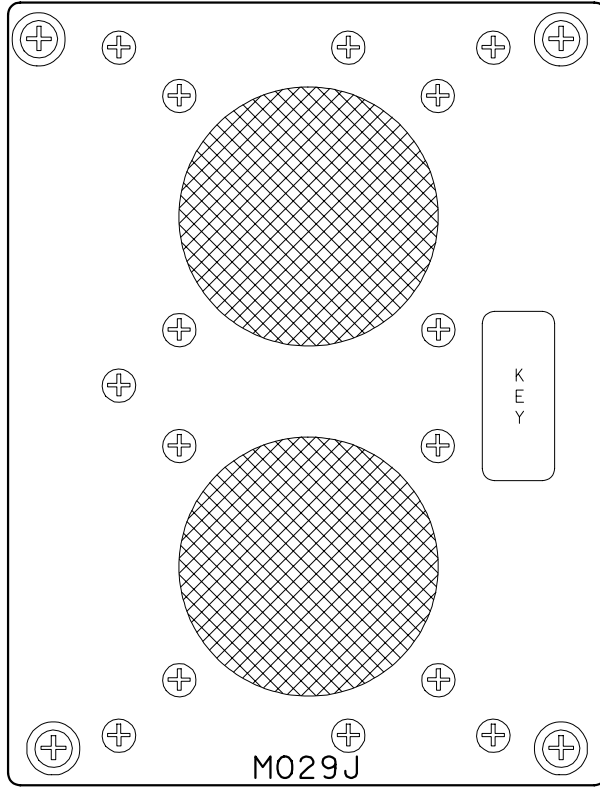
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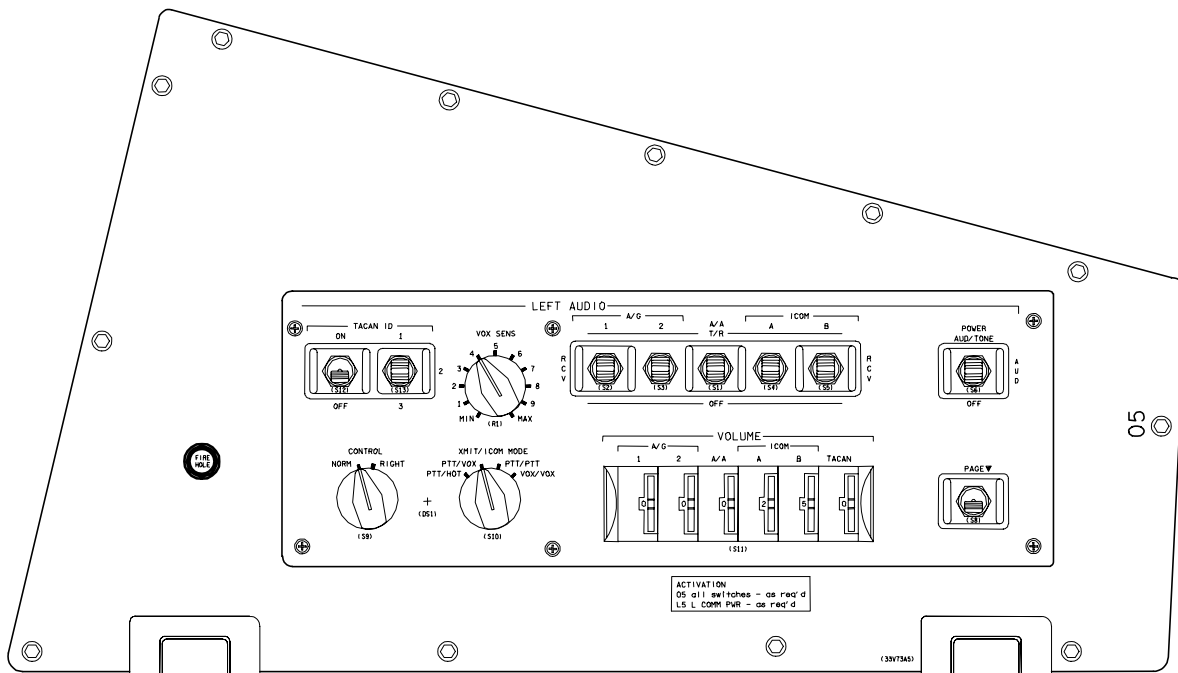
Panel A13



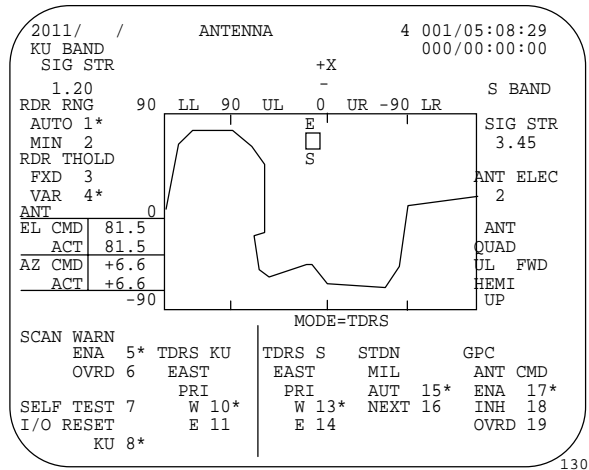
Panel A13 (OV102 only)



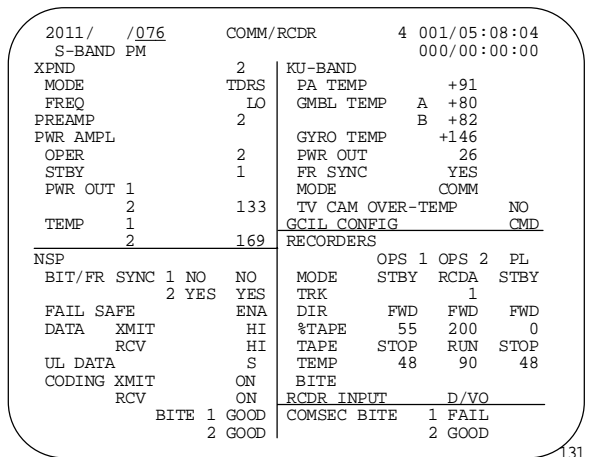
Panel M029J



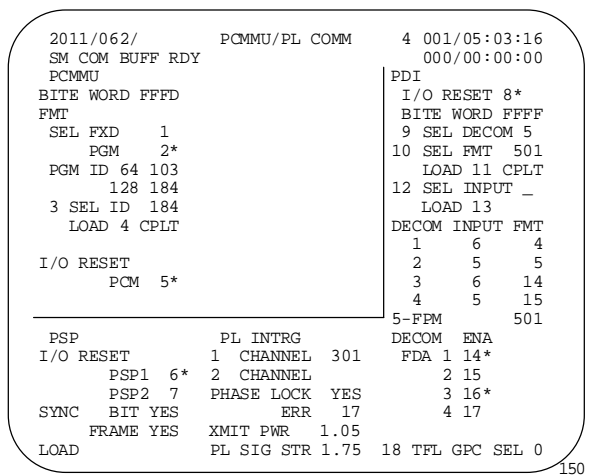
Panel O5



OPS 201 ANTENNA Display



COMM/RCDR (DISP 76) Display



PCMMU/PL COMM Display (SPEC 62)

Communications System Rules of Thumb

- When the TDRS has an elevation of greater than $+70^\circ$ or less than -60° relative to the orbiter (as shown on OPS 201), there is a risk of degraded communications as the orbiter nose or tail blocks line of sight between the orbiter antenna and the TDRS.
- Power amplifiers are specified to have a minimum power output of 100 watts. Flight experience has shown that a good downlink can be sustained with a power out of 65 watts. Power amplifiers require 140 seconds to warm up if not in a standby state.
- Payload interrogator output power, when in low power mode, will read zero. This measurement is meaningless as the output power is too small to be output by the instrumentation system.

2.5 CREW SYSTEMS

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Description

Several types of equipment and systems that the crew uses are not covered in other sections of this manual, since they are not necessarily part of any of the larger systems. These items and systems, which focus on crew efficiency and comfort, are discussed in this section. Where appropriate, operations are described within each separate subject area.

Crew Clothing/Worn Equipment

The crew clothing/worn equipment consists of items that provide for the personal needs of all crewmembers. Prior to each flight, crewmembers select clothing and worn equipment from a list of required and optional flight equipment.

Crew clothing used during on-orbit activities includes such items as trousers, jackets, shirts, sleep shorts, soft slippers, and underwear.

Optional worn/carry-on equipment includes scissors, sunglasses, HP48 calculators, gray tape, flashlight, Swiss army knife, pens and pencils, and chronographs.

Personal Hygiene Provisions

Personal hygiene and grooming provisions are furnished for both male and female flight crewmembers. Ambient warm water for washing comes from a personal hygiene hose (PHH) attached to the galley auxiliary port. Other personal hygiene provisions are stowed in middeck lockers and/or the airlock stowage bag at launch and are removed for use on orbit.

A personal hygiene kit is furnished for each crewmember for brushing teeth, hair care, shaving, nail care, etc. Additional grooming and hygiene items are available for female crewmembers in the female preference bags.

Two washcloths and one towel per crewmember per day are provided. In addition, wet wipes, dry wipes, tissues, and Wash 'N Dri's are provided for personal hygiene. The Wash 'N Dri's are located in Volume G (spares), a middeck locker, and in the galley. Wet wipes and dry wipes are stowed in the waste management compartment (WMC) and in a middeck locker. Rubber grommets in the waste management compartment allow crewmembers to restrain their towels and washcloths.

If the WMS becomes nonfunctional, contingency equipment is located in Volume G. This equipment consists of Wash 'N Dri's, urine collection devices, diapers, and Apollo fecal bags.

Sleeping Provisions

During a one-shift operations mission, all crewmembers sleep simultaneously. At least one crewmember wears a communication headset to ensure reception of ground calls and orbiter caution and warning alarms.

A 24-hour period is normally divided into an 8-hour sleep period and a 16-hour wake period for each crewmember. Three hours are allocated for pre/post sleep activities in which crewmembers perform housekeeping, orbiter cleaning, sleep and wake preparation, personal hygiene, and food preparation and eating activities.

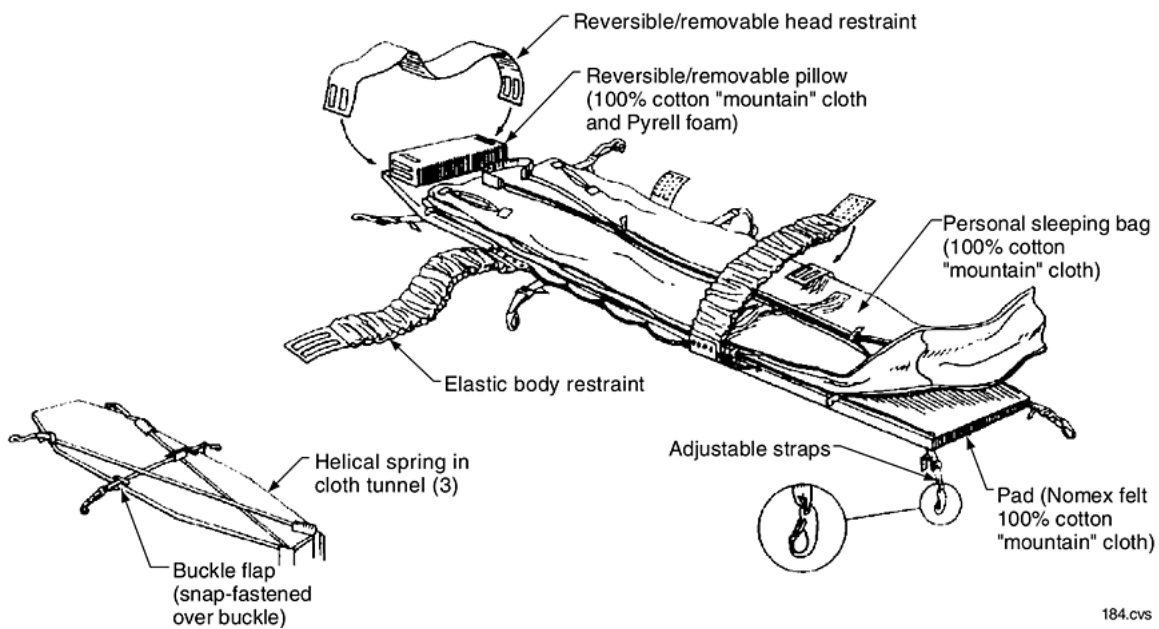
Sleeping provisions for flight crewmembers consist of sleeping bags and liners, or rigid sleep stations with one sleeping bag and two liners per bunk. Sleeping bags are installed on the starboard middeck wall and relocated for use on orbit. Some sleeping bags can remain on the starboard wall, and some can be attached via pip pins to the middeck lockers. Others can be relocated to the airlock, Spacelab, or flight deck (crew preference). A sleeping bag is furnished for each crewmember and contains a support pad with adjustable restraining straps and a reversible/removable pillow and head restraint.

Six adjustable straps permit the sleeping bag to be adjusted to its proper configuration. Three helical springs above the adjustable straps on one side of the bag relieve loads exerted by the crewmember on the crew compartment structure. Six pip pins allow the bag to be attached to the middeck locker face in either a horizontal or vertical configuration. Two elastic adjustable straps restrain the upper and lower parts of the body in the bag. Velcro strips on the ends of both sides of the head restraint attach it to the pillow. A double zipper arrangement permits the sleeping bag to be opened and closed from the bottom to the top of the bag. One zipper on each side of the sleeping bag allows the bag to be attached to a support pad for better rigidity.

A sleep kit is provided for each crewmember and is stowed in the crewmember's clothing locker during launch and entry. Each kit contains eye covers and ear plugs for use as required during the sleep period.

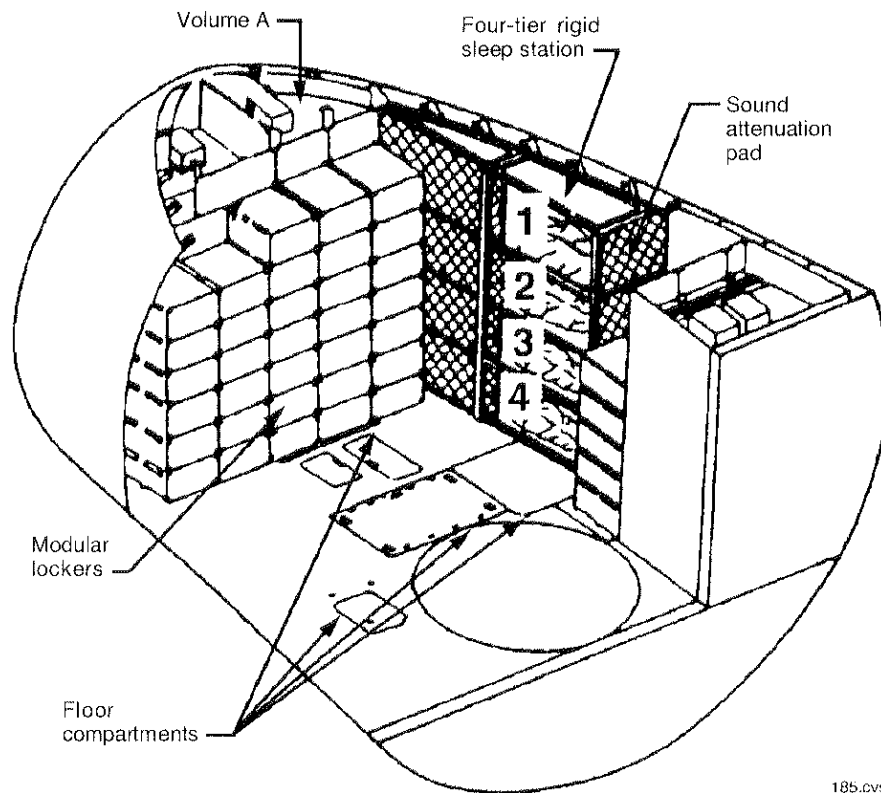
For 24-hour operations missions, the four-tier, rigid sleep station is flown. If manifested, it is installed on the starboard side of the middeck.

The four-tier rigid sleep stations contain a sleeping bag/liner, personal stowage provisions, a light, and a ventilation inlet and outlet in each of the tiers. The cotton sleeping bag is installed on the ground in each tier and held in place by six spring clips. The light in each tier is a single fluorescent fixture with a brightness control knob and an off position. The air ventilation inlet duct is an air diffuser similar to an automobile ventilation duct. It is adjusted by moving the vane control knob. The air ventilation outlet duct is located in the fixed panel at each tier and is opened or closed by moving the vane control knob. The air inlet is located at the crewmember's head. The outlet is at the feet. All crewmembers' heads are toward the airlock and their feet toward the avionics bay.



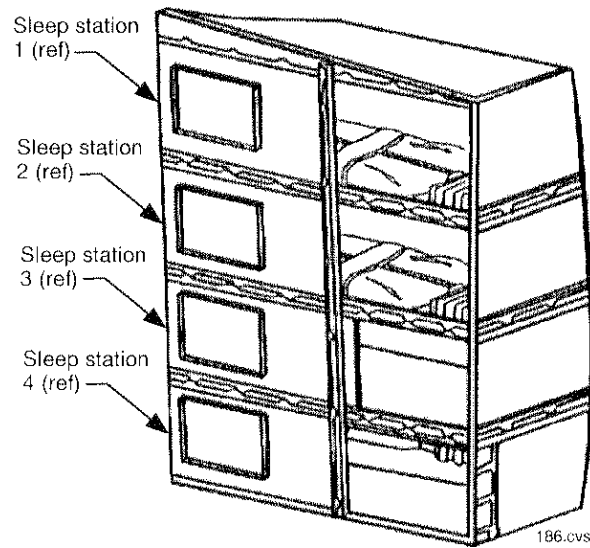
184.cvs

Operational Sleeping Bag



185.cvs

Four-Tier Horizontal Sleep Station



186.cvs

Four-Tier Rigid Sleep Station

Exercise Equipment

Three types of exercisers are available for use in flight: the treadmill, the cycle ergometer, and the rower. Only one type is flown per mission, with selection dependent on crew preference, availability of on-orbit space, and science objectives. All exercisers are designed to minimize muscle loss in the legs and maintain cardiovascular fitness in a zero-g environment.

The treadmill, which consists of a conveyor running track with force cords, waistbelt, and shoulder straps, attaches to the starboard side of the middeck floor with quick disconnects. The running track is coupled to a rapid onset braking system that applies increased drag to the track once a crewmember reaches a preset speed. Resistance can be adjusted by dialing the speed control knob. The force cords, waistbelt, and shoulder straps restrain the crewmember to the running track. A physiological monitor is used to track heart rate, distance run, and time run while exercising. Because of the space required for operation, the treadmill is now seldom flown.

The cycle ergometer (CE) attaches to the treadmill/entry middeck floor studs. The mounting frame is reconfigured on orbit to attach to standard seat floor studs on the flight deck or middeck. The CE uses a standard flywheel and braking band system to generate the required resistive force. Cycling resistance can be controlled electronically by a control panel or computer-driven exercise protocol or a manual adjustment similar to those found on exercise cycles used at home or in gymnasiums. An accessories bag, which is strapped to the top of the ergometer for launch and entry, contains the attachable hardware as well as crew clothing and shoes necessary for nominal operations.

The rower is undergoing a design upgrade and operational information is not yet available.

Housekeeping Equipment

In addition to time scheduled for sleep periods and meals, each crewmember has housekeeping tasks that require from 5 to 15 minutes of time at intervals throughout the day. These include cleaning of the waste management compartment, the dining area and equipment, floors and walls (as required), and the cabin air filters;

trash collection and disposal; and changeout of the crew compartment carbon dioxide (lithium hydroxide) absorber canisters. (Changeout of the canisters is discussed in Section 2.9.)

The materials and equipment available for cleaning operations are biocidal cleanser, disposable gloves, general-purpose wipes, and a vacuum cleaner. The vacuum is stowed in a middeck locker, and the remaining hardware is stowed primarily in the waste management compartment. Additional wipes are located in the hygiene locker, and an additional pair of gloves is located in each personal hygiene kit.

The biocidal cleanser is a lotion-type detergent formulation in a container approximately 2 inches in diameter and 6 inches long with a built-in dispenser. The cleanser is squirted on the surface to be cleaned and wiped off with dry, general-purpose wipes. It is used primarily for periodic cleansing of the waste collection system urinal and seat. It can be used to clean the dining area and equipment and to clean walls and floors. Disposable plastic gloves are worn while using the biocidal cleanser.

The vacuum cleaner is provided for general housekeeping and cleaning of the crew compartment air filters and Spacelab filters (on Spacelab missions). It has a normal hose, extension hose, and several attachments. It is powered by the orbiter dc electrical power system. A muffler to reduce noise is part of the vacuum cleaner assembly.

Trash management operations include routine stowage of wet and dry trash, such as expended wipes, tissues, and food containers. (Wet trash includes all items that could offgas.) The equipment available for trash management includes three trash bags, trash bag liners, wet trash volumes, and the waste collection system (WCS) coffee canister.

Three trash bags for dry trash are located in the crew compartment: one on the inside of the WMC door, one on an aft middeck locker, and one on the port side of the flight deck. Each bag contains one installed disposable trash bag liner and seven spare liners (located outside the installed liner but inside the trash bag). When the liner becomes full, it is removed and stowed in a jettison stowage bag. A new liner is then installed.

The WMC wet trash compartment has a volume of 1.85 cubic feet and is vented overboard for odor control. Trash from the WMC is inserted into the circular opening of the auxiliary wet trash compartment and is contained by an elbow bag. Tissues, as well as used WCS coffee canister bags, are disposed of in this wet trash compartment. The coffee canister, which is about the same size and shape as an off-the-shelf can of coffee, is installed near the WMC during post insertion. Trash bags are inserted in the canister and are filled with wipes used for fecal collection. After each WCS use, a used trash bag is disposed of in the WMC wet trash, and a new one is retrieved from the stowage volume on the WMC wall and installed in the canister.

An 8-cubic-foot wet trash stowage compartment is available under the middeck floor (Volume F). This compartment is vented overboard (3 lb/day) for odor control. Any item that can create an odor is considered to be wet trash and is disposed of there.

Restraints and Mobility Aids

Restraints and mobility aids are provided in the orbiter to enable the flight crew to perform all tasks safely and efficiently during ingress (1-g, orbiter vertical), egress (1-g, orbiter horizontal), and orbital flight (orbiter orientation arbitrary).

Mobility aids are located in the crew compartment for movement of the flight crewmembers during ingress, egress, and orbital flight. These devices consist of permanent and soft handholds, a platform in the middeck, and an interdeck access ladder.

Restraints consist of foot loop restraints, seat restraints, retention nets, Velcro, tape, snaps, cable restraints, clips, bungees, and tethers.

Foot loop restraints are cloth loops attached to the crew compartment decks by adhesive to provide stability in zero g. Before launch, the foot loop restraints are installed by the crew compartment configuration drawings (CCCD) or vehicle integration test team (VITT) personnel on the floor areas of the aft flight deck work stations, middeck, and near the waste management system and galley. Spares are stowed in the modular lockers. To install a foot restraint,

the protective backing on the underside of the restraint is removed, and the restraint is placed in its desired location. The foot loop restraints are easily used by placing a foot in the loop.

Seat restraints are similar to foot loop restraints. They can be installed prelaunch, and spares are manifested in the same locker as the foot restraints. One adhesive patch is placed on one side of the seat, and the other patch is placed on the opposite side. A restraint strap is placed over the seat back and attached to each patch via clips.

A brown mesh middeck retention net, attached to the forward middeck lockers and the starboard wall (no sleep station), is used to restrain the inflight stowage bags, as well as other hardware. The airlock stowage net, also made of brown mesh net, can restrain this equipment in the airlock if the sleep station is manifested, or if the crew determines they wish to stow this hardware in the airlock.

Velcro, tape, snaps, cable restraints, clips, bungees, and tethers are all manifested in the IFM locker and can be utilized for a variety of purposes.

Stowage Containers

Temporary Stowage Bag

The temporary stowage bag is used to restrain, stow, or transport loose equipment temporarily. One is installed on the flight deck.

Inflight Stowage Bags

Ten inflight stowage bags are manifested, one per crewmember plus spares. These brown mesh bags are used to stow suits, boots, and harnesses on orbit.

Flight Deck Stowage Bags

The flight deck stowage bags provide restraint for flight deck items when those items are not immediately returned to locker stowage compartments. These bags are manifested in the Flight Data File (FDF) locker and are installed on orbit on the back of the CDR and PLT seats (one per seat).

Jettison Stowage Bags

The jettison stowage bags are used for restraining dry trash or early return items, such as FDF, film, and cassettes. (See Section 2.24 for further details on all stowage bags.)

Reach and Visibility Aids

Reach and visibility aids are hardware items that assist the flight crew in monitoring and manipulating displays and controls throughout various phases of flight. These aids consist of CDR/PLT adjustable mirrors, CDR/PLT two axis (Z and X) seat adjustment, wicket tabs, and an auxiliary reach mechanism.

The adjustable mirrors are installed at launch on handholds located between windows 2 and 3 for the CDR and windows 4 and 5 for the PLT. During ascent and entry, the CDR and PLT use the adjustable mirrors to facilitate seeing controls that are in the obscured areas of their vision envelope. On orbit, mirrors can be removed and stowed, if desired.

To install the adjustable mirror, place the split clamp halves around the handhold, fit the handwheel stem into both clamp halves, and tighten the handwheel clockwise. To adjust the mirror, loosen the mirror-lock knob (counterclockwise), move the mirror to the desired orientation, and tighten the mirror-lock knob.

The CDR/PLT seats provide the CDR and PLT with the capability to move their seats along the orbiter Z- (vertical) and X- (longitudinal) axes to facilitate the reach and visibility of controls during the ascent and entry phase of flight. Seat movement for each axis is provided by a single ac motor. The total travel distances for the Z- and X-axes are 10 and 5 inches respectively. Seat adjustment controls are located on the left side of the seat pan. The controls consist of a three-position toggle switch for power bus selection and one spring-loaded, three-position toggle switch each for control of horizontal and vertical seat movement.



Adjustable Mirror



Seat Power and Controls

To operate the CDR/PLT seat, the crewmember must first assign ac power to his or her seat motors by moving the *POWER BUSS SEL* switch to AC2 (up) or AC3 (down). To move the seat along the horizontal axis, crewmembers must actuate the *HORIZ CONTR* toggle switch FWD to move the seat forward and AFT to move the seat aft. Similarly, to move the seat along the vertical axis, the crewmember must actuate the *VERT CONTR* toggle switch UP to move the seat upward and DN to move the seat downward.

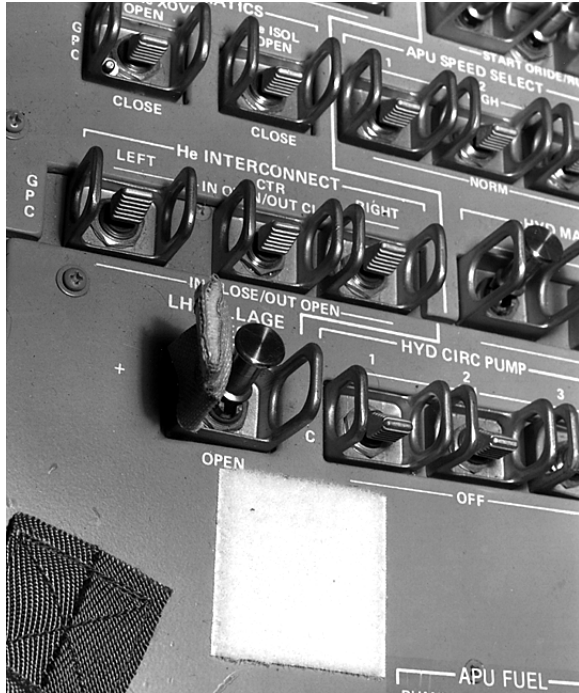
If the seat motors fail to work, and seat adjustment is needed, manual adjustment capability is provided. However, manual seat adjustment can take place only on orbit and is accomplished with a special seat adjustment tool provided in the in-flight maintenance tool kit. Manual horizontal and vertical seat adjustment control locations are under the seat pan cushion and on the aft side of the fixed seat structure.

The seat adjustment tool is a ratchet-driven, 3/16-inch Allen wrench inserted into the vertical or horizontal manual adjustment to move the seat along the Z- or X-axis.

Wicket tabs are devices that help the crewmember activate controls when his or her vision is degraded. The tabs provide the crewmember with tactile cues to the location of controls to be activated as well as a memory aid to their function, sequence of activation, and other pertinent information. Wicket tabs are found on controls that are difficult to see on panels O8, C3, and R2 during the ascent and entry flight phases.

The auxiliary reach mechanism, sometimes known as the "swizzle stick," is a short adjustable bar with multipurpose end effectors that are used to actuate controls that are out of the reach of seated crewmembers. The reach aid is used to push in and pull out circuit breakers, move toggle switches, and turn rotary knobs. It is stowed on the inboard side of the PLT seat. It may be used during any phase of flight, but is not recommended for use during ascent because of the attenuation and switch-cueing difficulties resulting from acceleration forces.

Operation of the reach aid consists of extending it and actuating controls with the end effector. To extend the reach aid, the crewmember depresses the spring-loaded extension tab and pulls the end effector out to the desired length.



Wicket Tabs on Panel R2



Wicket Tabs on Panel C3

The reach and visibility envelope of each crewmember is limited by the LES. Tactile cues are restricted by the LES pressure glove. Visibility is reduced because of the helmet and neck ring, and reach is restricted by the bulk of the LES and the parachute and harness. Crewmembers should practice techniques that enable them to adjust their reach and visibility envelope. The helmet can be swiveled on the neck ring. The neck ring tie down may be adjusted to help open up downward field of view. Mirrors, the auxiliary reach mechanism

(swizzle stick), and other crewmembers can aid in locating and actuating controls. Seat headrest pads and helmet pads may be used to adjust the position of the head in the seat and in the helmet. The CDR and PLT seats may be adjusted as necessary.

Photographic Equipment

Five still camera systems and one motion picture camera are used on orbit to document crew activities, meet payload requirements, and record Earth observations. Additional cameras can be stowed as required. Nikon 35mm and Hasselblad 70mm single lens reflex (SLR) cameras are flown for still photography. The Kodak/Nikon electronic still camera stores digital still images on removeable hard drives. Images can be downlinked for printing and distribution. An Arriflex 16mm camera is used for motion picture photography. When stowage and weight provisions allow, an Aero Linhof 4X5 aerial photography camera or a NASA-developed electronic still camera may be flown.

Additional camera systems may be flown for specific experiments or as part of an ongoing NASA evaluation of new cameras and technology. Periodically, the IMAX Corporation manifests its 70mm motion picture camera aboard the shuttle as a commercial payload.

Two slightly modified Nikon professional 35mm F4S autofocus SLR cameras are nominally manifested for each mission. The F4 provides state-of-the-art metering for automatic ambient light and flash exposure and exposures as brief as 1/8000 of a second. The camera incorporates a "full information" LCD viewfinder display. Interchangeable autofocus lenses of various focal lengths, including 28mm f/2.8, 24-50mm f/4.5 and 35-70mm f/2.8 zoom are available. A 300mm telephoto and 2X converter can be flown for photographing the shuttle external tank post-jettison. Manual focus lenses can be used on the F4, with the camera indicating when proper focus is achieved. The camera motor drive advances the film after each exposure or permits continuous exposure at 3.4 or 5.7 frames per second. It operates on six AA batteries. The F4 flash (SB-24) operates on four AA batteries. The F4 cameras are used primarily for in-cabin crew activities and experiments. They may also be used for payload deployments and Earth

observations. A wide variety of negative (print) and positive (slide) color 35mm films can be manifested for a mission. The 36 exposure rolls run the gamut of ISOs (ASAs) from 50 to 1600. Special purpose IR and black and white films may be flown as required.

One or two factory modified Nikon F3 35mm cameras are manifested for scheduled EVA missions or flights having a high probability of an EVA. A special camera thermal cover, sport finder eyepiece, and tabs to assist the EVA crew with camera operations are also manifested. This camera permits manual or automatic exposure. An EVA 35mm camera is loaded with a 36 exposure roll of 100 ISO negative film. Two lenses have been qualified for the harsh EVA environment. They are a 28mm f/2, and a 35mm f/1.4.

Two 70mm SLR medium format (2.25 in square) cameras are usually flown on each shuttle mission. The cameras are Hasselblad 500 EL/Ss (EL/Xs with minor modifications). Only manual exposure is available with the 70mm cameras. Two Minolta handheld reflected light spotmeters are manifested to provide exposure information as required. Interchangeable magazines provide approximately 95 exposures on Kodak 100 ISO Professional 70mm perforated positive film. Occasionally, color infrared film is used for Earth observations. Each magazine has a detachable data recording device that prints flight-specific data on the edge of the film. Interchangeable lenses, including 40mm f/4, 50mm f/4, 100mm f/3.5, and 250mm f/5.6, are part of the standard complement. The camera motor drive operates on five AA batteries. It permits single frame automatic film advance or a continuous rate of about one frame per second. The 70mm cameras are used exclusively for photography of payload bay activities and Earth observations. The Nikon flash can also be used with the 70mm cameras via photographic "pc" cords.

The 70mm camera can also be used EVA with a body lubricated especially for EVA usage. A 30mm f/3.5 or 60mm f/3.5 lens is available for EVA photography. A thermal cover encloses the camera, lens, and magazine.

Motion picture filming is accomplished with an Arriflex professional 16mm through-the-lens viewing rotary shutter camera with integral

light meter. The crystal-controlled camera motor transports film at 24 frames per second. The nominal shutter speed is 1/48 second. The camera utilizes an interchangeable 10 – 100mm f/2 zoom or 5.9mm f/1.8 wide angle lens. Both lenses permit manual exposure. The zoom lens aperture can be controlled by inputs from the camera light meter for automatic exposure as well. Interchangeable magazines are reloaded in flight with 380 ft rolls of 100 or 500 ISO Kodak tungsten light balanced color negative film. A full magazine will provide about 10.5 minutes of filming. Color correction filters must be used whenever sunlight is the main subject light. The camera is normally powered by a NASA developed 15 V dc battery containing 40 AA batteries. The camera may also be powered from the orbiter, via an adapter cable and the inflight maintenance (IFM) "breakout box." A rarely flown accessory provides variable frame rates for the Arriflex and bar code time data on the film. A photoflood light is available and is used during interior filming. The Arriflex is used primarily to document in-cabin and payload bay activities.

The Aero Linhof is a manual exposure 4X5 camera that is manifested approximately every other mission if stowage space and weight constraints allow. The camera produces large (4 in. by 5 in.) images on Kodak 100 ISO thin base positive film. Each removable magazine contains approximately 185 exposures. The camera uses a 90mm f/5.6 wide angle and a 250mm f/5.6 lens. Camera power is supplied by orbiter 28 V dc. An attachable viewfinder can be used to estimate the field-of-view (FOV) of the lens in use. The Linhof camera is used primarily for Earth observations photography.

Most of the photography and cinematography conducted in the orbiter are handheld. With the exception of flash photography, however, many of the images and scenes the crew captures on film can be improved through the use of the multiuse brackets, clamps, and baseplate adapter. Twenty-two mounts throughout the flight deck, middeck, and airlock permit the crew to mount cameras and accessories. The baseplate adapters (crew installed) provide quick mounts in windows 9 and 10. The multiuse clamp is used on switchguards or other structures to provide an attachment base for a multiuse arm. The multiuse arm is a

modified commercial device that attaches to a camera and a wall mount or clamp. The arm permits universal pointing of the camera until the center "elbow" knob is tightened. When the knob is secure, the camera is held rigidly at the selected orientation (zero g). Multiuse equipment is also used to mount the camcorder, and photo flood.

Sighting Aids

Sighting aids include all items used to aid the flight crew within and outside the crew compartment. The sighting aids include the crew optical alignment sight (COAS), binoculars, adjustable mirrors, and spotlights. (The COAS is discussed in detail in Section 2.13.)

Five models of binoculars are available for on-orbit use. Two models are routinely flown on each mission. Binocular models include the Zeiss 8X20, Fuji 10X40 gyro stabilized day/night, Fuji 14X40 gyro stabilized, Fuji 16X70, and the Zeiss 20X60 mechanically stabilized.

The spotlight is a high-intensity, handheld flashlight powered by a battery pack consisting of five 1.2-volt one-half D size nickel-cadmium batteries. The spotlight produces a 20,000-candlepower output with a continuous running time of 1.5 hours. The lamp is a 6-volt tungsten filament and cannot be replaced in flight.

The high intensity search light (HISL) is used in conjunction with the rangefinders during visual acquisition of satellites. It provides crewmembers with the capability to detect and maintain visual contact with a payload for effective rendezvous and station keeping at 700 to 1000 feet when on the dark side. The light is portable and has a stainless steel camera mounting rail on the handle that interfaces to the multiuse mounting brackets on the orbiter. The light is aimed out the aft, or overhead, windows of the flight deck.

Window Shades and Filters

Window shades and filters are provided for installation on the orbiter windows to minimize crewmember exposure to sunglare during ascent, entry, and orbital flight phases.

The window shades and filters are stowed in a compartmented bag attached to a mounting pallet on the starboard side of the aft middeck.

To install the W1 through W6 window shades, the crewmember unrolls the shade (white surface outboard) over the window and mates the Velcro with the Velcro on the window frame. Removal of the shades is accomplished by just the reverse. Demate the Velcro, and roll the shade up as compactly as possible (blue surface visible). Insert into window shade holders and close the holders by mating Velcro together.

Aft window shades and filters are installed simply by placing the correct shade or filter in the appropriate window (reflective side outboard) and securing it to the mating Velcro on the window ledges.

To remove a window shade from the window shade stowage container, the crewmember must unfasten the securing straps and pull the Velcro-restrained closure panel away from the desired stowage pouch.

Interdeck light shades are provided to minimize light leakage between the flight deck and middeck during in-cabin photography. The light shade is attached with Velcro to the flight deck floor around the interdeck access. Adjustable louvers are provided to regulate the amount of light between the flight deck and the middeck.

The side hatch viewport is the only optical-quality window on OV 102, 103, 104, and 105. Unlike the 10 windows on the flight deck, the side hatch viewport does not provide protection from solar ultraviolet (UV) rays, which can cause serious injury in as little as 10 seconds. Therefore, a removable UV filter must be placed on the side hatch viewport for on-orbit operations. The filter is held against the viewport by Velcro and is normally installed post insertion and removed during deorbit preparations.

Shuttle Orbiter Medical System

The shuttle orbiter medical system (SOMS) is required to provide medical care in flight for minor illnesses and injuries. It also provides support for stabilizing severely injured or ill crewmembers until they are returned to Earth.

The SOMS is provided in two separate packages: the medications and bandages kit (MBK) and the emergency medical kit (EMK). The MBK is blue with blue Velcro and a blue strap. The EMK is also blue with red Velcro and a red strap.

The medical kits are stowed in a middeck modular locker. If the kits are required on orbit, they are unstowed and installed on the locker doors with Velcro. The kits have a patch of Velcro on the bottom to match the Velcro on the outside of the doors.

Each kit contains pallets and a pocket inside the back. Pockets containing medications and equipment are mounted on each side of the pallets. The MBK pallet designators are E, F, and G. The E pallet contains pills, capsules, and suppositories. The F pallet contains bandage materials for covering or immobilizing body parts. The G pallet contains medications to be administered by topical application.

The EMK pallet designators are A, B, C, and D. The A pallet contains medications to be administered by injection. The B pallet contains emergency items and equipment for performing minor surgeries. The C pallet contains diagnostic/therapeutic items consisting of instruments for measuring and inspecting the body. The D pallet contains dental items, injectables, and intravenous fluid/administration sets.

The onboard medical checklist and medical checklist flight supplement specify the location of medications/equipment in the two medical kits by an alphanumeric code. The first character is the alphanumeric code of the pallet (A through G). The second character is the side of the pallet (1 or 2). The third and fourth characters are the number of the specific pocket on the pallet. The pallets are appropriately marked.

The medical accessory kit supplements the SOMS kit by providing additional storage capability for crew-specific and/or mission-specific medications, such as toxin antidotes, additional I.V. fluid, etc.

The SOMS also includes a resuscitator and patient/rescuer restraints. The resuscitator consists of a mask with a retaining cap, a manually activated/demand regulated oxygen supply valve, a 6-foot hose, and a quick disconnect

fitting. The resuscitator assembly is stored in a middeck locker with the EMK and MBK.

The resuscitator is emergency hardware to be utilized, along with the patient/rescuer restraints, in the case of a crewmember becoming ill as called out for in JSC-17327, Medical Checklist – All Flights.

The resuscitator provides the capability to deliver 100 percent oxygen, control ventilation, and perform CPR for extended periods of time.

The resuscitator valve can supply 100 percent supplemental oxygen in two ways: (1) at 40 LPM positive pressure for unconscious patients, and (2) on demand flow for conscious patients.

The resuscitator, upon unstowage, can be connected to the orbiter oxygen supply on the middeck connections on panels MO32M and MO69M and the flight deck connection on panel C6. Oxygen flow can be checked by depressing the O₂ trigger arm. Following verification of O₂ flow, a crewmember will position and tighten the resuscitator mask over the crewmember's face using the head cap and elastic straps.

The patient/rescuer restraints consist of one belt with two pip pins for the patient and two belts with two pip pins for the rescuer. They are designed to interface into the holes in the middeck locker latches.

The patient/rescuer restraint system is emergency hardware to be utilized in the case of a crewmember becoming ill. The restraints are stored in a middeck locker with the EMK and MBK.

The patient restraints will restrain the patient in the mid-calf area and the chest area. The restraints can be easily tightened to fit the patient. The rescuer restraint will wrap around the rescuer's waist and will have two extensions from the waist belt with pip pins on the end to fasten into the locker latches. This will allow the rescuer and patient to remain stationary.

The diagnostic equipment onboard and information from the flight crew will allow diagnosis and treatment of injuries and illnesses through consultation with flight surgeons in Mission Control.

Operational Bioinstrumentation System

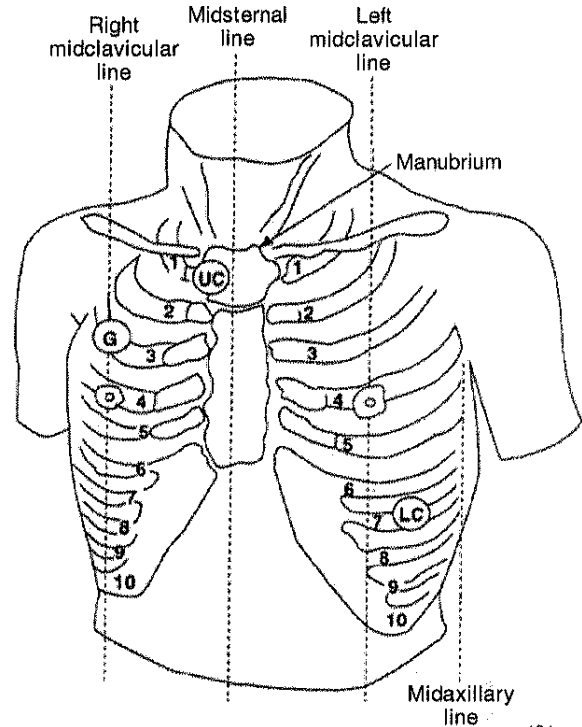
The operational bioinstrumentation system (OBS) provides an amplified electrocardiograph (ECG) analog signal from any crewmember aboard the orbiter to the avionics system, where the signal is converted to digital signal and transmitted to the ground in real time or stored on tape for dump at a later time. On-orbit use is limited to crewmembers in EVA or to contingency situations (only at the request of the flight surgeon).

The OBS electrodes are attached to the skin with electrode paste to establish electrical contact. The electrode is composed of a plastic housing containing a non-polarizable pressed pellet. The housing is attached to the skin with double-sided adhesive tape, and the pellet contacts the skin. There are three electrodes on the harness, marked LC (lower chest), UC (upper chest), and G (ground).

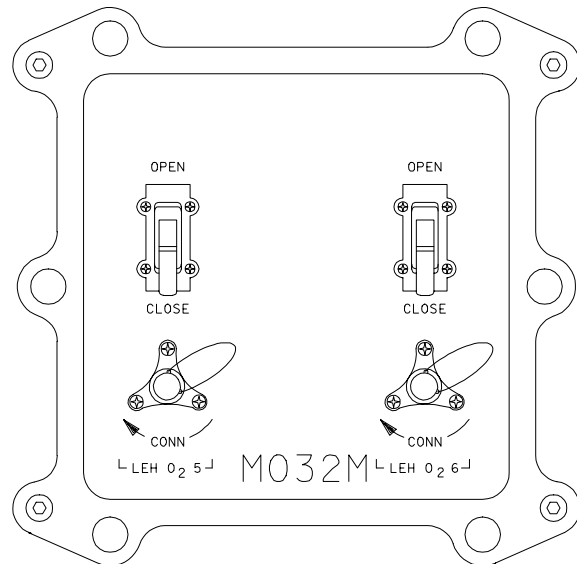
The ECG signal conditioner is a hybrid microcircuit with variable gain (adjusted for each crewmember before flight). It provides a zero- to 5-volt output and has an ON/OFF switch within the input plug, which is actuated when the intravehicular activity (IVA) biomed cable is plugged in. The unit has batteries that will not be replaced in flight.

The IVA biomed cable connects to the signal conditioner and is routed under the IVA clothing to connect to the biomed seat cable. The biomed seat cable is routed to one of the *BIOMED* input connectors located on panel A11, A15, or M062M. Rotary control switches on panel R10 provide circuits from the biomed outlets to the orbiter's network signal processor for downlink or recording. The two rotary switches on panel R10 are *BIOMED CHANNEL 1* and *CHANNEL 2*. Extravehicular activity positions provide circuits from the EVA UHF transceiver.

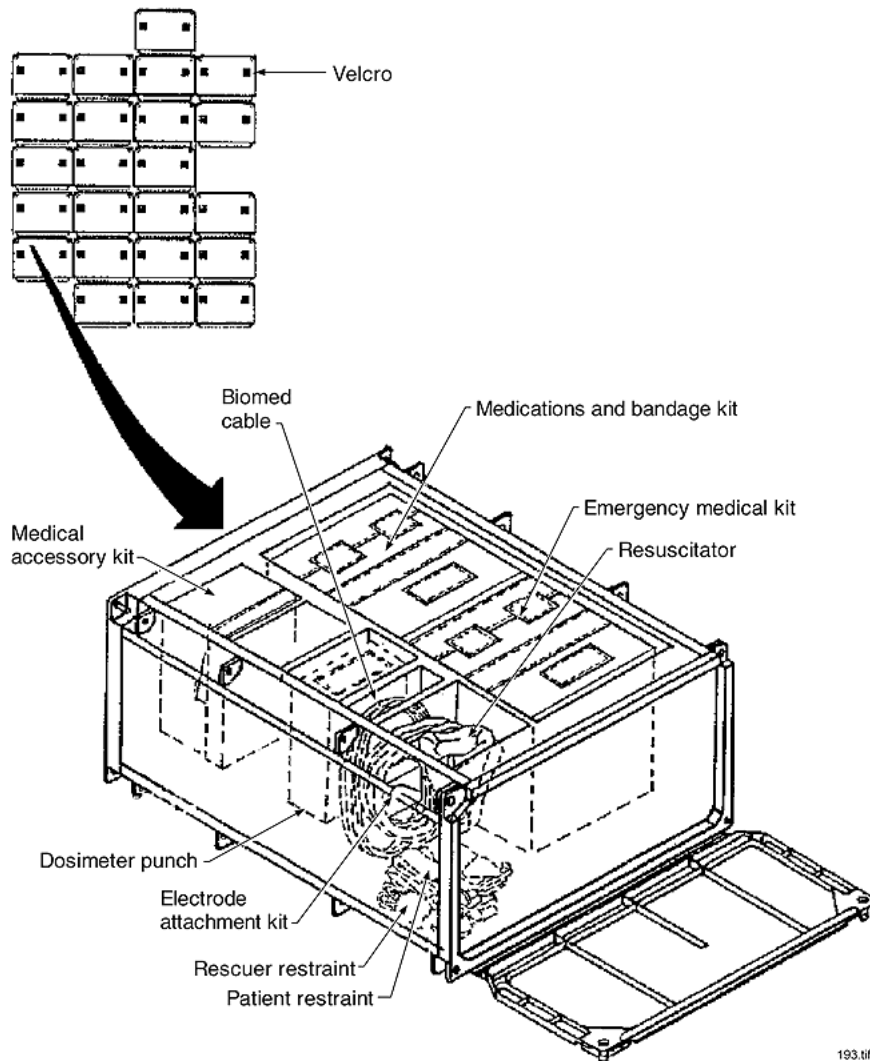
The electrode application kit contains components to aid in the application of electrodes. The components include wet wipes, double-sided adhesive tape, electrode paste, and a cue card illustrating electrode placement.



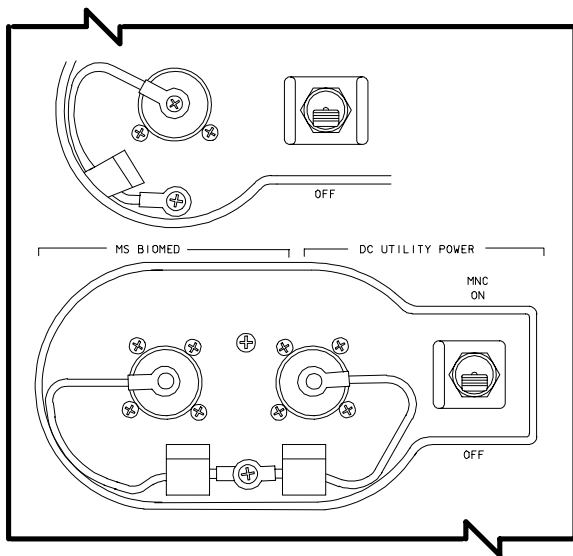
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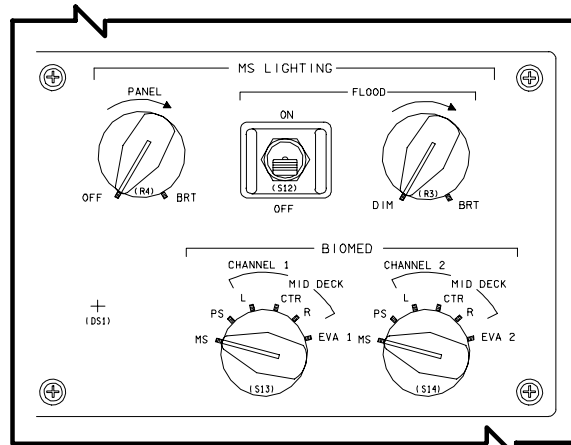
Panel M032M



Modular Locker Equipment and Locations



MS BIOMED Input Connector on Panel A11



BIOMED Rotary Switches on Panel R10

Radiation Equipment

The harmful biological effects of radiation must be minimized through mission planning based on calculated predictions and monitoring of dosage exposures. Preflight requirements include a projection of mission radiation dosage, an assessment of the probability of solar flares during the mission, and a radiation exposure history of flight crewmembers. In-flight requirements include the carrying of passive dosimeters by the flight crewmembers and, in the event of solar flares or other radiation contingencies, the readout and reporting of the active dosimeters.

There are four types of active dosimeters: pocket dosimeter high (PDH), pocket dosimeter low (PDL), pocket dosimeter FEMA (PDF), and high-rate dosimeter (HRD). All four function in the same manner and contain a quartz fiber positioned to zero by electrostatic charging before flight. The unit discharges according to the amount of radiation received; as the unit discharges, the quartz fiber moves. The position of the fiber along a scale is noted visually. The PDH unit's range is zero to 100 rads. The PDF and PDL units' ranges are zero to 200 millirads, and the HRD unit's range is zero to 600 rads.

The rad is a unit based on the amount of energy absorbed and is defined as any type of radiation that is deposited in the absorbing media. Radiation absorbed by humans is expressed in roentgen equivalent in man, or rems. The rem is determined by multiplying rads times a qualifying factor that is a variable depending on wavelength, source, etc. For low-inclination orbits (35° and lower), the qualifying factor is approximately equal to one; therefore, the rem is approximately equal to the rad. In space transportation system flights, the doses received have ranged from 0.05 to 0.07 rem, well below flight crew exposure limits.

The flight crew's passive dosimeters are squares of fine-ground photo film sandwiched between plastic separators in a light-proof package. Radiation striking the silver halide causes spots on the film, which can be analyzed after the flight. Included in the badge dosimeters are thermoluminescent dosimeter chips, which are analyzed on Earth.

Passive radiation dosimeters are placed in the crew compartment before launch by ground support personnel and removed after landing for laboratory analysis. Each flight crewmember carries a passive dosimeter at all times during the mission. The remaining dosimeters are stowed in a pouch in a middeck modular locker. If a radiation contingency arises, the PDL, PDH, HRD and PDF active dosimeters will be unstowed, read, and recorded for downlink to the ground.

Air Sampling System

The air sampling system provides a method for obtaining cabin atmosphere samples to allow postflight analysis of the gas environment within the crew module. The air sampling system consists of an air sample bottle. The air sampling system is stowed in a modular locker for ascent, unstowed for sampling, and restowed for entry.

The air bottle is a steel cylinder. The end of the cylinder is fitted with a valve operated by the valve knob. A screw cap covers the air inlet to prevent dust from contaminating the air sample. This cap is tethered to the valve.

The air bottle is evacuated preflight and is operated by removing the dust cap, turning the valve knob counterclockwise until full open, and then turning it clockwise until full close. The time it takes to open and close the valve is sufficient to fill the cylinder with cabin gas. When the valve is opened, a hissing sound may not always be heard because of cabin noise or valve variations.

Two air sample bottles are nominally manifested. One is to be utilized for fire/smoke in the cabin, and the other is used for air sampling during deorbit prep, or if a crewmember notices either an unusual odor and/or excessive sneezing and/or watery eyes in a particular area of the cabin. If this occurs, Mission Control should be notified for a microbial sample to be taken of that location post flight.

2.6 DATA PROCESSING SYSTEM (DPS)

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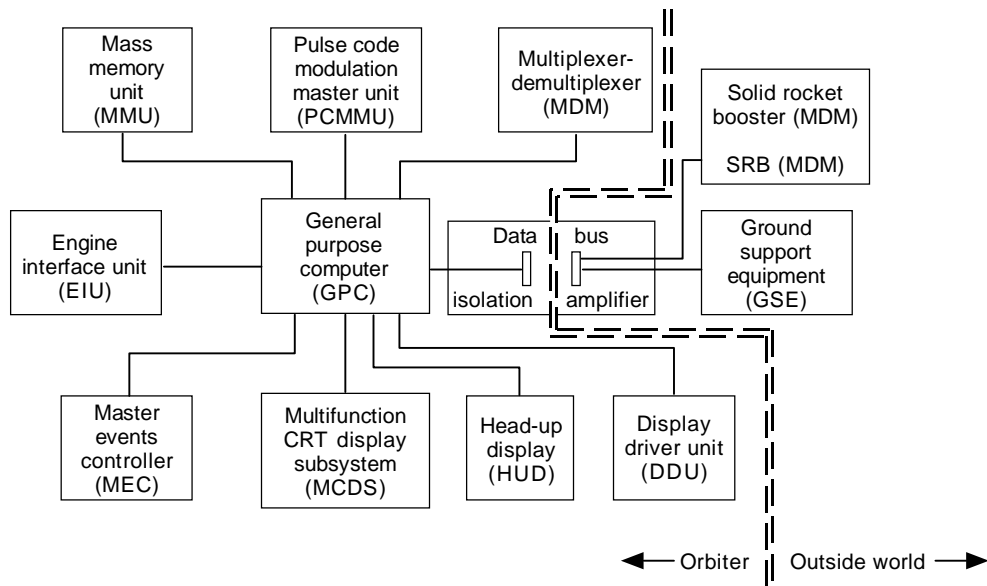
Description

The DPS, consisting of various hardware components and self-contained software, provides the entire shuttle with computerized monitoring and control. DPS functions are:

- Support the guidance, navigation, and control of the vehicle, including calculations of trajectories, SSME burn data, and vehicle attitude control data.

- Monitor and control vehicle subsystems, such as the electrical power system and the environmental control and life support system.
- Process vehicle data for the flight crew and for transmission to the ground, and allow ground control of some vehicle systems via transmitted commands.
- Check data transmission errors and crew control input errors; support annunciation of vehicle system failures and out-of-tolerance system conditions.
- Support payloads with flight crew/ software interface for activation, deployment, deactivation, and retrieval.
- Process rendezvous, tracking, and data transmissions between payloads and the ground.

The DPS hardware consists of five general-purpose computers (GPCs), two mass memory units (MMUs) for large-volume bulk storage, and a network of serial digital data buses to accommodate the data traffic between the GPCs and vehicle systems. The DPS also includes 20 orbiter and 4 SRB multiplexers/demultiplexers (MDMs) to convert and format data from the various vehicle systems, 3 SSME interface units to command the SSMEs, 4 multifunction CRT



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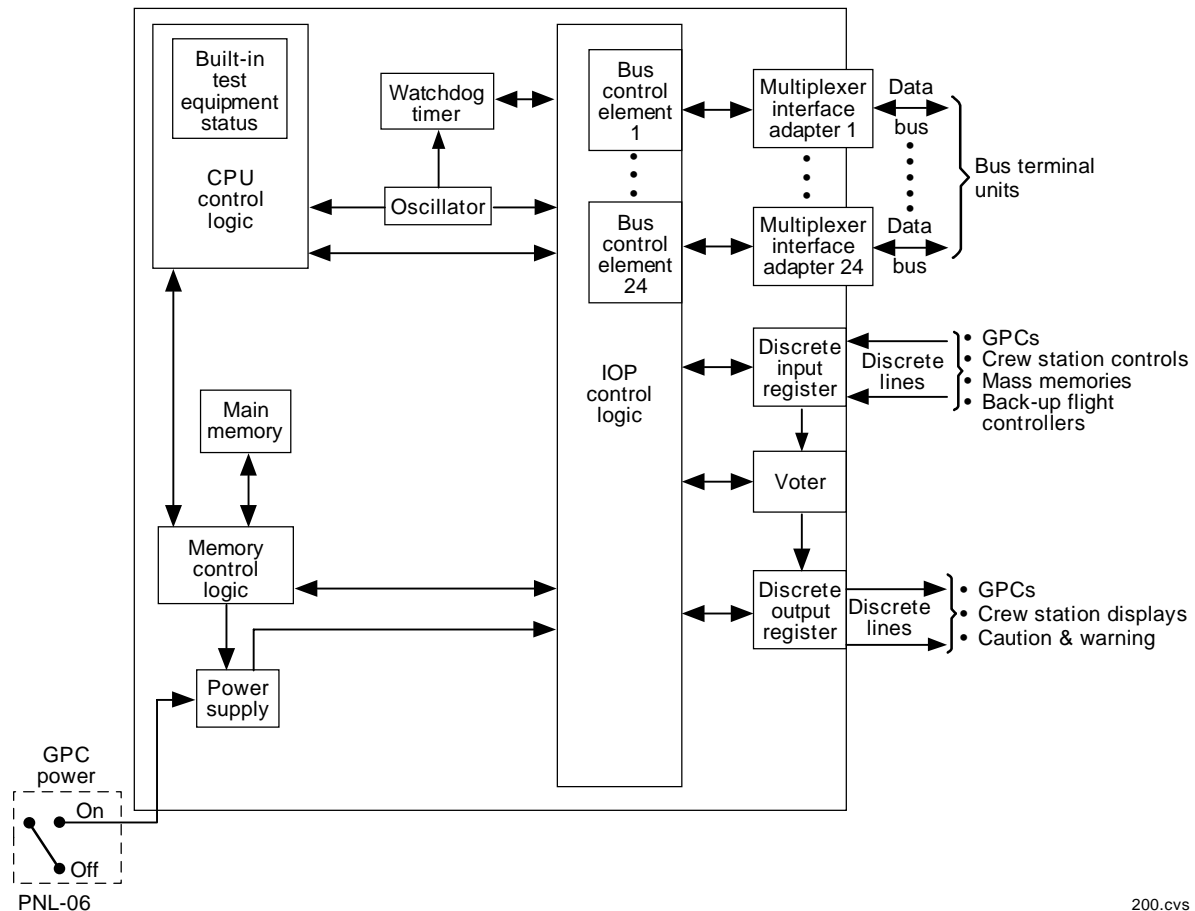
Data Processing System Interfacing Hardware

display systems used by the flight crew to monitor and control the vehicle and payload systems, 2 data bus isolation amplifiers to interface with the ground support equipment/launch processing system and the SRBs, 2 master events controllers, and a master timing unit.

DPS software accommodates almost every aspect of space shuttle operations, including orbiter checkout, prelaunch and final count-down for launch, turnaround activities, control and monitoring during launch, ascent, on-orbit activities, entry, and landing, and aborts or other contingency mission phases. A multi-computer mode is used for the critical phases of the mission, such as launch, ascent, orbit, entry, landing, and aborts.

General Purpose Computers (GPCs)

The orbiter has five identical IBM AP-101S GPCs. The GPCs receive and transmit data to and from interfacing hardware via the data bus network. GPCs also contain the software that provides the main on-board data processing capability. Up to four of the systems may run identical software. The fifth system runs different software, programmed by a different company, designed to take control of the vehicle if an error in the primary software or other multiple failures cause a loss of vehicle control. The software utilized by the four primary GPCs is referred to as PASS (primary avionics software system); the fifth GPC is referred to as BFS (backup flight system).



General Purpose Computer Functional Block Diagram

GPCs 1 and 4 are located in forward middeck avionics bay 1, GPCs 2 and 5 are located in forward middeck avionics bay 2, and GPC 3 is located in aft middeck avionics bay 3. The GPCs receive forced-air cooling from an avionics bay fan. (There are two fans in each avionics bay, but only one is powered at a time.)

CAUTION

If both fans in an avionics bay fail, the computers will overheat within 25 minutes (at 14.7 psi cabin pressure) or 17 minutes (at 10.2 psi) after which their operation cannot be relied upon. An operating GPC may or may not survive for up to an additional 30 minutes beyond the certifiable thermal limits.

Each GPC consists of a central processing unit (CPU) and an input/output processor (IOP) stored in one avionics box. The boxes are 19.55 inches long, 7.62 inches high, and 10.2 inches wide; they weigh approximately 68 pounds. The main memory of each GPC is volatile (the software is not retained if power is interrupted), but a battery pack preserves software contents when the GPC is powered off. The memory capacity of the GPCs is 256 k half-words, but only the lower 128 k half-words are normally used for software processing.

The CPU controls access to GPC main memory for data storage and software execution and executes instructions to control vehicle systems and manipulate data.

The IOP formats and transmits commands to the vehicle systems, receives and validates response data transmissions from the vehicle systems, and maintains the status of interfaces with the CPU and the other GPCs.

The 24 data buses are connected to each IOP by bus control elements (BCEs) that receive, convert, and validate serial data in response to requests for available data to be transmitted or received from vehicle hardware.

For timing, each GPC contains an oscillator that sends signals to internal components to regulate operations. The GPC also uses the oscillator to

maintain an internal clock to keep track of Greenwich mean time (GMT) and mission elapsed time (MET) as a backup to the timing signal from the master timing unit (MTU).

Each GPC contains a watchdog timer. The watchdog timer is an incrementing clock register in the GPC that is reset about once every second by a signal from the CPU. If the register ever overflows, then a problem exists and is annunciated by a self-fail indication from that GPC. The PASS set does not utilize this hardware feature since it operates in synchronization with each of its GPCs to ensure proper functioning. Since the BFS operates essentially standalone relative to the PASS set synchronization, the BFS mechanization does utilize the watchdog timer function to serve as a check on its operation.

The PASS GPCs use a hardware "voter" to monitor discrete inputs from the other GPCs. Should a GPC receive a fail vote from two or more of the other GPCs, it will cause the GPC to annunciate a self-fail indication that also causes the GPC to inhibit any fail votes of its own against the other GPCs.

GPC Controls

The *GENERAL PURPOSE COMPUTER* hardware controls are located on panel O6. Each of the five GPCs reads the position of its corresponding *OUTPUT* and *MODE* switches and *INITIAL PROGRAM LOAD* pushbuttons from discrete input lines that go directly to the GPC. Each GPC has *OUTPUT* and *MODE* talkback indicators on panel O6 that are driven by GPC output discretes.

Each GPC has a *GENERAL PURPOSE COMPUTER POWER* switch on panel O6. Positioning a switch to ON enables power from three essential buses, ESS 1BC, 2CA, and 3AB. The essential bus power controls remote power controller (RPCs), which permit main bus DC power from the three main buses (MN A, MN B, and MN C) to power the GPC. There are three RPCs for each GPC; thus, any GPC will function normally, even if two main or essential buses are lost. Each computer uses 560 watts of power.

Each *GENERAL PURPOSE COMPUTER OUTPUT* switch on panel O6 is a guarded switch with *BACKUP*, *NORMAL*, and *TERMINATE* positions. The switch provides a hardware override to the GPC that precludes that GPC from outputting on the flight-critical buses. The switches for the PASS GNC GPCs are positioned to *NORMAL*, which permits them to output. The backup flight system switch (GPC 5) is positioned to *BACKUP*, which precludes it from outputting until it is engaged. The switch for a GPC designated on-orbit to be a systems management (SM) computer is positioned to *TERMINATE*, since the GPC is not to command anything on the flight-critical buses.

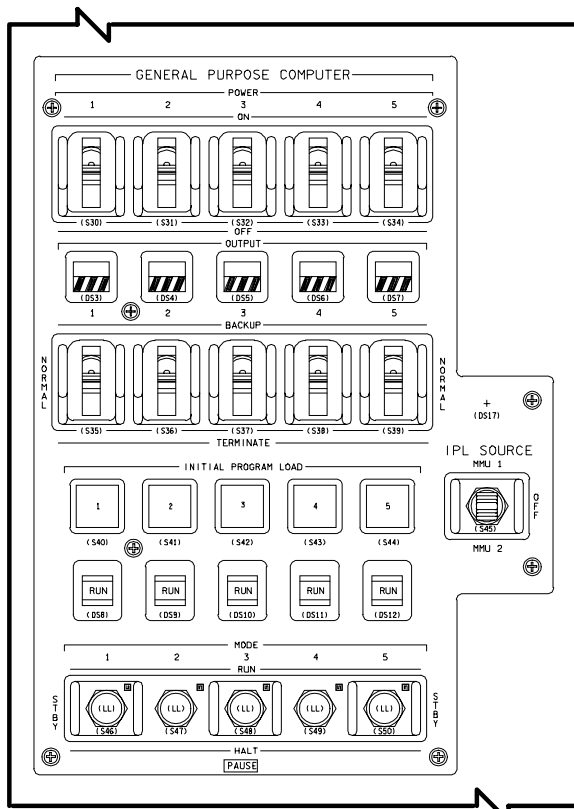
process software. The *MODE* switch is lever-locked in the *RUN* position. The *HALT* position initiates a hardware-controlled state in which no software can be executed. A GPC that fails to synchronize with others is either powered *OFF* or moded to *HALT* as soon as possible to prevent the failed computer from outputting erroneous commands. The talkback indicator above the *MODE* switch for that GPC indicates barberpole when that computer is in *HALT*.

In *STBY*, a GPC is also in a state in which no *PASS* software can be executed, but it is in a software-controlled state. The *STBY* mode allows an orderly startup or shutdown of processing. It is necessary, as a matter of procedure, for a *PASS* GPC that is shifting from *RUN* to *HALT* or vice versa to be temporarily (more than 3 seconds) in the *STBY* mode before going to the next state. The *STBY* mode allows for an orderly software cleanup and allows a GPC to be correctly initialized (when reactivated) without an initial program load. If a GPC is moded to *RUN* or *HALT* without pausing in *STBY*, it may not perform its functions correctly. There is no *STBY* indication on the talkback indicator above the *MODE* switch.

The *RUN* position permits a GPC to support its normal processing of all active software and assigned vehicle operations. Whenever a computer is moded from *STBY* to *RUN*, it initializes itself to a state in which only system software is processed (called OPS 0). If a GPC is in another operational sequence (OPS) before being moded out of *RUN*, that software still resides in main memory; however, it will not begin processing until that OPS is restarted by flight crew keyboard entry. The *MODE* talkback indicator always reads *RUN* when that GPC switch is in *RUN*, and no failures exist.

Placing the backup flight system GPC in *STBY* does not stop BFS software processing or preclude BFS engagement; it only prevents the BFS from commanding the payload buses used by BFS systems management software.

The *PASS* GPC/BUS STATUS display (DISP 6) indicates the current mode of each *PASS* GPC in the common set. The display does not differentiate between *STBY* and *HALT*; only *RUN* or *HALT* is displayed (GPC MODE).



GENERAL PURPOSE COMPUTER Hardware Controls

The talkback indicator above each *OUTPUT* switch on panel O6 indicates gray if that GPC output is enabled and barberpole if it is not.

Each GPC receives *RUN*, *STBY*, or *HALT* discrete inputs from its *MODE* switch on panel O6, which determines whether that GPC can

2011/ /006		GPC/BUS STATUS					2 008/02:56:10 000/00:11:10	
GPC	1	2	3	4	5			
MODE	RUN	RUN	HALT	RUN	HALT			
OPS	G2	G2	0	S2	0			
STRING 1	FF *			↓				
	FA *			↓				
2	FF	*		↓				
	FA	*		↓				
3	FF *			↓				
	FA *			↓				
4	FF	*		↓				
	FA	*		↓				
PL 1	↓	↓		*				
2	↓	↓		*				
LAUNCH 1	↓	↓		*				
2	↓	↓		↓				
CRT 1	*			↓				
2		*		↓				
3		↓		↓				
4	↓	↓		*				

GPC/BUS STATUS Display (DISP 6)

The *INITIAL PROGRAM LOAD* pushbutton for a GPC on panel O6 activates the initial program load command discrete input when depressed. When the input is received, that GPC initiates an initial program load (IPL) from the MMU specified by the *IPL SOURCE* switch on panel O6. The talkback indicator above the *MODE* switch for that GPC indicates *IPL*.

During non-critical periods in orbit, only one or two GPCs are used for GNC tasks, and another is used for systems management and payload operations.

A GPC on orbit can also be "freeze-dried"; that is, it can be loaded with the software for a particular memory configuration and then moded to *HALT*. Before an OPS transition to the loaded memory configuration, the freeze-dried GPC can be moded back to *RUN* and the appropriate OPS requested.

NOTE

Because all BFS software is loaded into the BFS GPC at the same time, the BFS GPC is sometimes referred to as being freeze-dried on orbit when it is placed in *HALT*. The BFS GPC can be moded to *RUN* prior to entry and will begin processing entry software following the OPS 3 request without having to access a mass memory unit. The term freeze-dry or freeze-dried is most often used with respect to the PASS GPCs.

GPC Modes of Operation

GPC modes of operation are redundant set, common set, and simplex. Redundant set operations refer to the mode in which two or more GPCs are concurrently receiving the same inputs, executing the same GNC software, and producing the same outputs. This mode uses a maximum amount of intercomputer communications, and the GPCs must maintain a high level of synchronization (called redundant set synchronization).

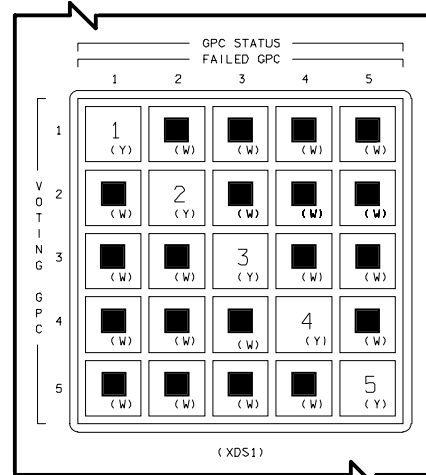
During redundant set operations, each GPC outputs only certain portions of its total software output to its interfacing hardware. Therefore, although each GPC "thinks" it is performing all its operations, only the GPC responsible for supporting a specific group of hardware will be able to actually transmit its data and commands. The redundant set GPCs compare all calculations to ensure that individual outputs are the same.

Common set operations occur when two or more GPCs communicate with one another while they are performing their individual tasks. They do not have to be performing the same major function (although they can be), but they do maintain common set synchronization. Any GPC operating as a member of the redundant set is also a member of the common set.

A simplex GPC is in *RUN*, but not a member of the redundant set. Systems management and payload major functions are always processed in a simplex GPC.

GPCs running together in the same GNC OPS are part of a redundant set performing identical tasks from the same inputs and producing identical outputs. Therefore, any data bus assigned to a commanding GNC GPC (except the instrumentation buses because each GPC has only one dedicated bus connected to it) is heard by all members of the redundant set. These transmissions include all CRT inputs and mass memory transactions, as well as flight-critical data. If one or more GPCs in the redundant set fail, the remaining computers can continue operating in GNC. Each GPC performs about 1.2 million operations per second during critical phases.

Each computer in a redundant set operates in synchronized steps and cross-checks results of processing hundreds of times per second. Synchronization refers to the software scheme used to ensure simultaneous intercomputer communications of necessary GPC status information among the PASS computers. If a GPC operating in a redundant set fails to meet any redundant synchronization point, the remaining computers will immediately vote it out of the redundant set. If a GPC has a problem with one of its multiplexer interface adapter receivers during two successive reads of response data, or does not receive data while other members of the redundant set do receive data, the GPC with the problem will fail-to-sync. A failed GPC is either powered OFF or moded to HALT as soon as possible by the crew.



**GPC STATUS Matrix on Panel O1
(W=white; Y=yellow)**

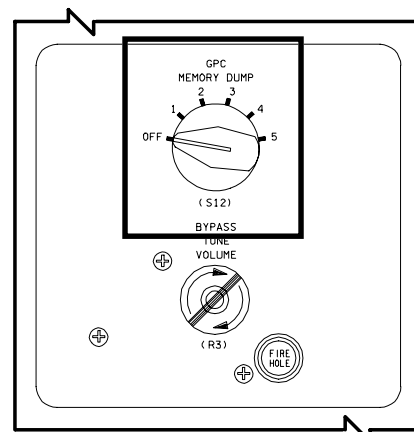
GPC Failure Indications

GPC failure votes are annunciated in a number of ways. Each GPC has discrete output lines for fail votes against each of the other GPCs that go to the other GPCs and the GPC status matrix. A GPC FAIL detection will cause a class 2 GPC fault message with illumination of the *MASTER ALARM*. Error indications may be displayed on DISP 18 GNC SYS SUMM 1 and DISP 6 GPC/BUS STATUS displays.

The GPC *STATUS* matrix (sometimes referred to as the GPC fail CAM) on panel O1 is a 5-by-5 matrix of lights. Each light corresponds to a GPC's fail vote against another GPC or itself. For example, if GPC 2 sends out a failure vote against GPC 3, the second white light in the third column is illuminated. The off-diagonal votes are votes against other GPCs. The yellow diagonal lights from upper left to lower right are self-failure votes. Whenever a GPC receives two or more failure votes from other GPCs, it illuminates its own yellow light and resets any failure votes that it made against other GPCs (any white lights in its row are extinguished). Any time a yellow matrix light is illuminated, the GPC caution and warning light on panel F7 is illuminated, in addition to *MASTER ALARM* illumination, and a GPC fault message is displayed on the CRT.

RCS		JET	ISOL	GNC SYS SUMM 1		1 000/02:46:03					
MANE	FAIL	VLV	SURF	POS	MQM	DPS	1	2	3	4	5
F1		OP	L OB			GPC					
2		OP	IB			MDM FF					
3		OP	R IB			FA					
4		OP	OB								
5		OP	AIL								
L1		OP	RUD			FCS CH 1 2 3 4					
2		OP	SPD BRK								
3		OP	BDY FLP								
4		OP									
5		OP				NAV 1 2 3 4					
R1		OP				IMU					
2		OP		CNTRLR 1 2 3		ACC					
3		OP	RHC L			RGA					
4		OP	R			TAC					
5		OP	A			MLS					
			THC L			ADTA					
			A								
			SBTC L								
			R								

**DPS Parameters on GNC SYS SUMM 11
Display (DISP 18)**



**GPC MEMORY DUMP Switch on
Panel M042F**

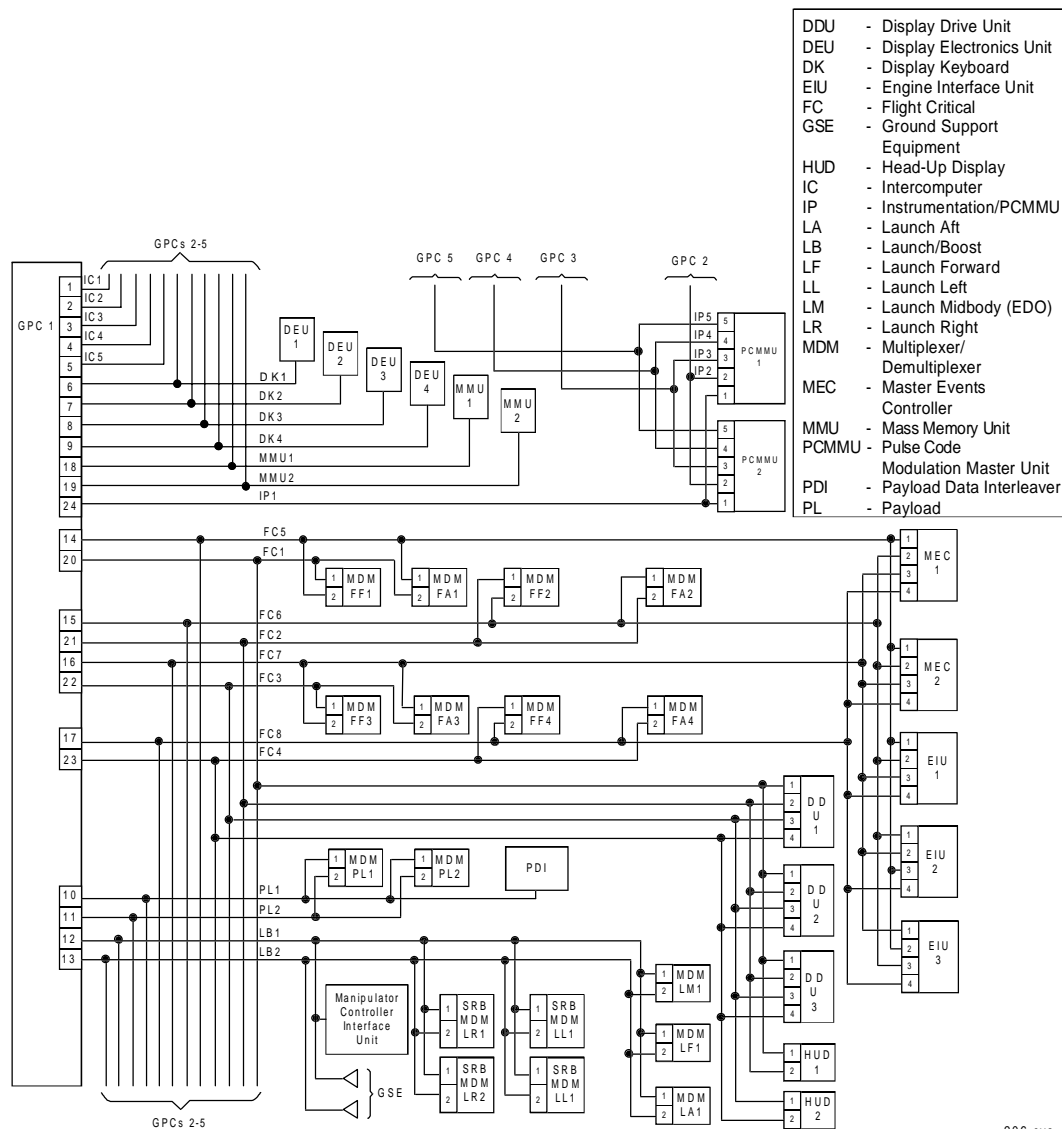
A failed GPC's memory contents can be dumped by powering ON, switching the computer to *TERMINATE* and *HALT*, and then selecting the number of the failed GPC on the GPC MEMORY DUMP rotary switch on panel M042F. The GPC is then moded to *STBY* to start the dump. After 2 to 8 minutes, the dump is stopped by moding the GPC to *HALT* and the output to *NORM*. This process is referred to as a hardware-initiated, standalone memory (HISAM) GPC memory dump.

Data Bus Network

The data bus network supports the transfer of serial digital commands and data between the

GPCs and vehicle systems. The network is divided into seven groups that perform specific functions:

1. Flight-critical (FC) data buses that tie the GPCs to the flight-critical multiplexer/demultiplexers (MDMs), display driver units, head-up displays, engine interface units, and master events controllers
2. Payload data buses that tie the GPCs to the payload MDMs and the payload data interleaver (PDI), and possibly mission-dependent flex MDMs or sequence control assemblies



Data Bus Network

3. Launch data buses that tie the GPCs to ground support equipment, launch forward, launch aft, launch mid, and SRB MDMs, and the manipulator controller interface unit (MCIU) used by the remote manipulator system
4. Mass memory data buses for GPC/MMU transactions
5. Display/keyboard data buses for GPC/display electronics unit transactions
6. Instrumentation/pulse code modulation master unit (PCMMU) data buses
7. Intercomputer communication data buses.

Although all data buses in each group except the instrumentation/PCMMU buses are connected to all five GPCs, only one GPC at a time transmits commands over each bus. However, several GPCs may receive data from the same bus simultaneously.

Each data bus, with the exception of the intercomputer communication data buses, is bidirectional; that is, data can flow in either direction. The intercomputer communication data bus traffic flows in only one direction (a PASS software constraint, not a hardware restriction).

Flight-Critical Data Buses

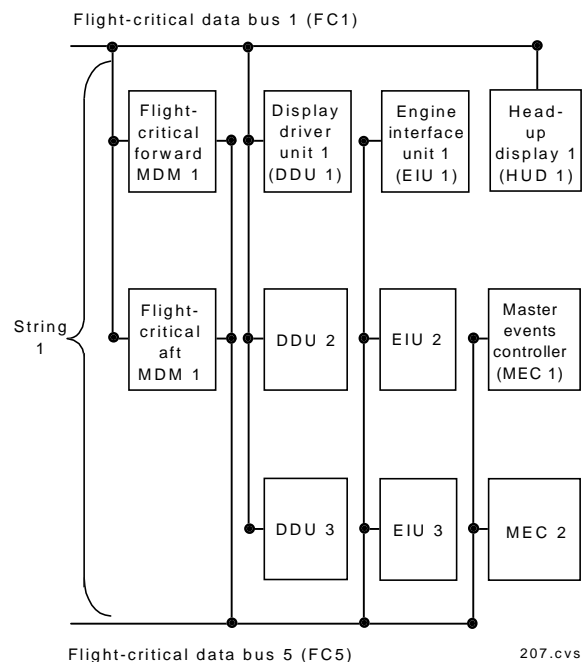
There are eight FC data buses directed into groups of two, referred to as an FC string. Each FC string can be commanded by a different GPC. Multiple units of each type of GNC hardware are wired to a different MDM and flight-critical bus. FC1, 2, 3, and 4 connect the GPCs with the four flight-critical forward (FF) MDMs, the four flight-critical aft (FA) MDMs, the three display driver units, and the two head-up displays. The other four, FC5, 6, 7, and 8, connect the GPCs to the same four FF MDMs, the same four FA MDMs, the two master events controllers, and the three main engine interface units.

A string is composed of two FC data buses: one from the first group (FC1, 2, 3, or 4) and one from the second group (FC5, 6, 7, or 8). Vehicle

hardware is segmented into these groups to facilitate GPC command of these components for redundancy, to allow for nominal mission operations in the event of a loss of one string caused by a GPC or MDM failure, and to allow for safe return to Earth in the event of the loss of a second string.

String 1 consists of FC data buses 1 and 5, MDMs FF1 and FA1 and their hard-wired hardware, controls, and displays, the three engine interface units, the two master events controllers, the three display driver units, head-up display 1, and their associated displays. This distribution of hardware is fixed and cannot be changed. The other three strings are defined in a similar manner.

During ascent and entry, when there are four PASS GNC GPCs in the redundant set, each is assigned a different string to maximize redundancy. All flight-critical hardware units are redundant, and the redundant units are on different strings. The string concept provides failure protection during dynamic phases by allowing exclusive command of a specific group of vehicle hardware by one GPC, which can be transferred to another GPC in case of failure. All or part of one string can be lost, and all avionics functions will still be retained through the other strings.



Components of String 1

With four PASS GNC GPCs in a redundant set, each GPC is responsible for issuing commands over the string assigned to it; that is, it is the commander of that string. The other GNC GPCs will monitor or listen on this string. When the string's commanding GPC sends a request for data to the hardware on the string, all the other GNC GPCs will hear and receive the same data coming back on the string. This transaction (one commanding GPC and multiple listening GPCs) is occurring in parallel with the other three strings. Therefore, all GNC GPCs will get a copy of all of the data from all four strings. Once all the data are received from the string, the GPCs then agree (or disagree) that the data are consistent.

Payload Data Buses

Two payload data buses interface the five GPCs with the two payload MDMs (also called payload forward MDMs), which interface with orbiter systems and payloads. A PDI is connected to payload data bus 1. Additionally, on some flights, one or two flex MDMs and/or sequence control assemblies connect the payload data buses to communicate with other payload equipment.

Each payload MDM is connected to two payload data buses. Safety-critical payload status parameters may be hard-wired; then these parameters and others can be recorded as part of the vehicle's system management, which is transmitted and received over two payload buses. To accommodate the various forms of payload data, the PDI integrates payload data for transmission to ground telemetry. PDI configuration commands and status monitoring is accomplished via payload data bus 1.

Launch Data Buses

Two launch data buses are used primarily for ground checkout and launch phase activities. They connect the five GPCs with the ground support equipment/launch processing system, the launch forward (LF1), launch mid (LM1), and launch aft (LA1) MDMs aboard the orbiter, and the two left and right SRB MDMs (LL1, LL2, LR1, and LR2). Launch data bus 1 is used on orbit for interface with the remote manipulator system controller by the SM GPC.

Mass Memory Data Buses

Each of two MMUs interfaces with its data bus via a multiplexer interface adapter, which functions just like the ones in the GPCs. Each data bus is connected to all five GPCs. Each MMU is connected to only one mass memory data bus.

In addition, each MMU has a separate discrete line called the "ready discrete" that goes to each of the GPCs. If the discrete is on, it tells the GPC the mass memory unit is ready for a transaction. When the discrete is off, the MMU is either busy with another transaction or is powered off.

Note that all MMU operations and transmissions to the GPCs are on an on-demand basis only. There is no insight into the state of the MMU (other than the ready discrete) unless a specific transaction is requested. This includes the status of the MMU's built-in test equipment (BITE), which is only updated for MMU read or write.

Display/Keyboard Data Buses

The four display electronics unit keyboard (DK) data buses, one for each display electronics unit, are connected to each of the five GPCs. The computer in command of a particular display/keyboard data bus is a function of the current *MAJOR FUNC* switch setting of the associated CRT, current memory configuration, GPC/CRT keyboard entries, and the position of the backup flight control CRT switches. (These topics are discussed in more detail under "Operations.")

Instrumentation/Pulse-Code Modulation Master Unit (PCMMU) Buses

The five instrumentation/PCMMU data buses are unique in that each GPC has its own individual data bus to two PCMMUs. All the other data buses interface with every GPC.

Flight controllers monitor the status of the vehicle's onboard systems through data transmissions from the vehicle to the ground. These transmissions, called downlink, include GPC-collected data, payload data, instrumentation data, and onboard voice. The GPC-collected data, called downlist, includes a set of parameters chosen before flight for each mission phase.

The system software in each GPC assimilates the specified GNC, systems management, payload, or DPS data according to the premission-defined format for inclusion in the downlist. Each GPC is physically capable of transmitting its downlist to the current active PCMMU over its dedicated instrumentation/PCMMU data bus. Only one PCMMU is powered at a time. It interleaves the downlist data from the different GPCs with the instrumentation and payload data according to the telemetry format load programmed in the PCMMU. The resulting composite data set, called the operational downlink, is transmitted to one of two network signal processors (NSPs). Only one NSP is powered at a time. In the NSP, the operational downlink is combined with onboard recorded voice for transmission to the ground. The S-band and Ku-band communications systems transmit the data either to the space flight tracking and data network remote site ground stations or through the Tracking and Data Relay Satellite (TDRS) system to Mission Control.

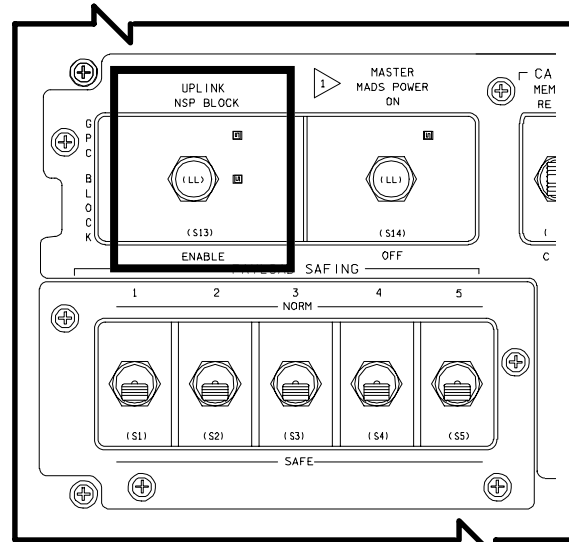
Uplink is the method by which ground commands originating in Mission Control are formatted, generated, and transmitted to the orbiter for validation, processing, and eventual execution by onboard software. This capability allows ground systems to control data processing, change modes in orbiter hardware, and store or change software in GPC memory and mass memory.

From Mission Control consoles, flight controllers issue commands and request uplink. The command requests are formatted into a command load for transmission to the orbiter either by the STDN sites or by the TDRS system. The S-band or Ku-band transponder receivers aboard the orbiter send the commands to the active NSP. The NSP validates the commands and, when they are requested by the GPCs through a flight-critical MDM, sends them on to the GPC. The GPCs also validate the commands before executing them. Those GPCs listening directly to the flight-critical data buses then forward uplink commands for those GPCs not listening to the FC buses over the intercomputer communication data buses.

The PCMMU also contains a programmable read-only memory for accessing subsystem data, a random-access memory in which to store

data, and a memory in which GPC data are stored for incorporation into the downlink.

To prevent the uplink of spurious commands from somewhere other than Mission Control, the flight crew can control when the GPCs accept uplink commands, and when uplink is blocked. The *GPC BLOCK* position of the *UPLINK* switch on panel C3 inhibits uplink commands during ascent and entry when the orbiter is not over a ground station or in TDRS coverage.



UPLINK Switch on Panel C3

Intercomputer Communication Data Buses

There are five intercomputer communication (IC) data buses. The following information is exchanged over these buses for proper DPS operation: input/output errors, fault messages, GPC status matrix data, display electronics unit major function switch settings, GPC/CRT keyboard entries, resident GPC memory configuration, memory configuration table, operational sequences, master timing unit, time, internal GPC time, system-level display information, uplink data, and state vectors.

All GPCs processing PASS software exchange status information over the IC data buses. During launch, ascent, and entry, GPCs 1, 2, 3, and 4 are usually assigned to perform GNC tasks, operating as a redundant set, with GPC 5 as the backup flight system. Each of the PASS GPCs acts as a commander of a given IC data bus and initiates all data bus transactions on that data bus.

The four PASS GPCs are loaded with the same software. Interconnecting the four IC buses to the four PASS GPCs allows each GPC access to the status of data received or transmitted by the other GPCs so that identical results among the four PASS GPCs can be verified. Each IC bus is assigned to one of the four PASS GPCs in the command mode, and the remaining GPCs operate in the listen mode for the bus. Each GPC can receive data from the other three GPCs, pass data to the others, and perform any other tasks required to operate the redundant set.

Multiplexers/Demultiplexers (MDMs)

The MDMs convert and format (demultiplex) serial digital GPC commands into separate parallel discrete, digital, and analog commands for various vehicle hardware systems. The MDMs also convert and format (multiplex) the discrete, digital, and analog data from vehicle systems into serial digital data for transmission to the GPCs. Each MDM has two redundant multiplexer interface adapters (MIAs), each connected to a separate data bus. The MDM's other functional interface is its connection to the appropriate vehicle system hardware by hard-wired lines.

There are 20 MDMs aboard the orbiter; 13 are part of the DPS, connected directly to the GPCs and named and numbered according to their location in the vehicle and hardware interface. The remaining seven MDMs are part of the vehicle instrumentation system and send vehicle instrumentation data to the PCMMUs. (They are termed operational instrumentation (OI) MDMs.)

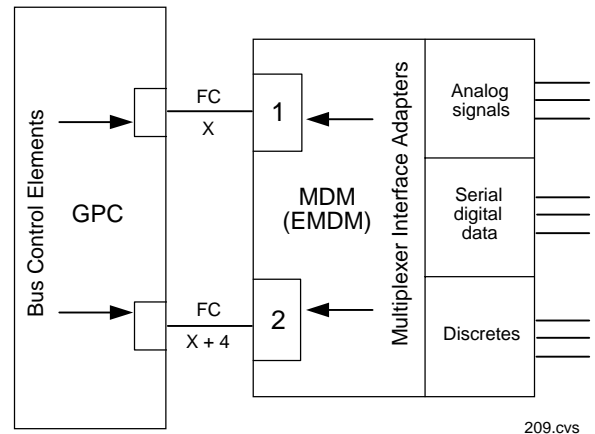
The DPS MDMs consist of flight-critical forward (FF) MDMs 1 through 4, flight-critical aft (FA) MDMs 1 through 4, payload (PL) MDMs 1 and 2, and GSE/LPS launch forward (LF1), launch mid (LM1), and launch aft (LA1). One or two flex MDMs (FMDMs) may also be connected to the PL data buses, depending on the payload needs for a particular flight.

Of the seven operational instrumentation MDMs, four are located forward (OF1, OF2, OF3, and OF4), and three are located aft (OA1, OA2, and OA3).

Also recall, there are four SRB MDMs; i.e., SRB launch left (LL) MDMs 1 and 2 and launch right (LR) MDMs 1 and 2.

The system software in the redundant set GPC activates a GNC executive program and issues commands to authorized buses and MDMs to request a set of input data. Each MDM receives the command from the GPC assigned to command it, acquires the requested data from the GNC hardware wired to it, and sends the data to the GPCs.

Each FC data bus is connected to a flight forward and flight aft MDM. Each MDM has two MIAs, or ports, and each port has a channel through which the GPCs can communicate with an MDM; however, the GPCs can interface on the FC data buses with only one MIA port at a time. Port moding is the software method used to control the MIA port that is active in an MDM. Initially, these MDMs operate with port 1; if a failure occurs in port 1, the flight crew can select port 2. Since port moding involves a pair of buses, both MDMs must be port moded at the same time. The control of all other units connected to the affected data buses is unaffected by port moding. Port moding is a software-only process and does not involve any hardware changes.



GPC/MDM Interfaces

Payload data bus 1 is connected to the primary MIA port of payload MDM 1, and payload data bus 2 is connected to the primary port of payload MDM 2. Payload data bus 1 is connected to the secondary MIA port of payload

MDM 2, and payload data bus 2 is connected to the secondary port of payload MDM 1. Which bus is used to communicate with each MDM is controlled by port moding.

The two launch data buses are also connected to dual launch MDM multiplexer interface adapter ports. The flight crew cannot switch these ports; however, if an input/output error is detected on LF1 or LA1 during prelaunch, an automatic switchover occurs.

The hardware controls for the MDMs are the *MDM PL1, PL2, PL3, FLT CRIT AFT*, and *FLT CRIT FWD* power switches on panel O6. These *ON/OFF* switches provide or remove power for the four aft and four forward flight-critical MDMs and PL1 and PL2 MDMs. The *PL3* switch is unwired and is not used. There are no flight crew controls for the SRB MDMs.

Each MDM is redundantly powered by two main buses. The power switches control bus power for activation of a remote power controller (RPC) for each main power bus to an MDM. The main buses power separate power supplies in the MDM. Loss of either the main bus or MDM power supply does not cause a loss of function because each power supply powers both channels in the MDM. Turning off power to an MDM resets all the discrete and analog command interfaces to subsystems.

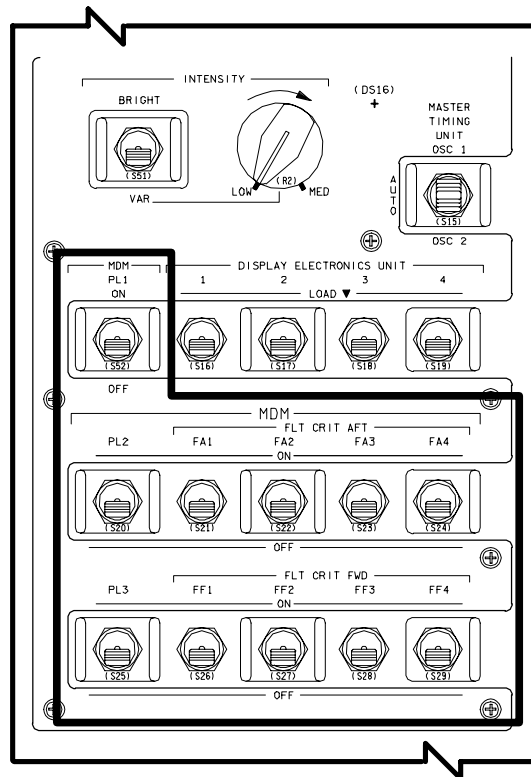
The SRB MDMs receive power through SRB buses A and B; they are tied to the orbiter main buses and are controlled by the master events controller circuitry. The launch forward, mid, and aft MDMs receive their power through the preflight test buses.

The FF, PL, LF, and LM MDMs are located in the forward avionics bays and are cooled by water coolant loop cold plates. LA and FA MDMs are in the aft avionics bays and are cooled by Freon coolant loop cold plates. MDMs LL1, LL2, LR1, and LR2 are located in the SRBs and are cooled by passive cold plates.

Module (or card) configuration in an MDM was dictated by the hardware components to be accessed by that type of MDM. A flight-critical forward and aft MDM are not interchangeable. However, flight-critical MDMs of the same type may be interchanged with another and the payload MDMs may be interchanged.

Each MDM is 13 by 11 by 7 inches and weighs about 38.5 pounds. MDMs use less than 80 watts of power.

Enhanced MDMs (EMDMs) were installed in OV 105. EMDMs will be installed in the other vehicles only as MDMs require replacement. The presence of EMDMs is transparent to the crew except in the case of an MDM OUTPUT message. With MDMs, the message means there is a problem with an MDM or a GPC. An MDM OUTPUT message with EMDMs means it is most likely a GPC problem. Crews flying with a combination of MDMs and EMDMs will receive assistance from flight controllers in interpreting an MDM OUTPUT message.



MDM Power Switches on Panel O6

Mass Memory Units

There are two mass memory units (MMUs) aboard the orbiter. Each is a coaxially mounted, reel-to-reel read/write digital magnetic tape storage device for GPC software and orbiter systems data.

Computing functions for all mission phases requires approximately 600,000 half-words of computer memory. The orbiter GPCs are

loaded with different memory configurations from the MMUs. In this way, software can be stored in MMUs and loaded into the GPCs when actually needed.

To fit the required software into the available GPC memory space, programs are subdivided into eight memory configurations corresponding to functions executed during specific flight and checkout phases. Thus, in addition to the central memory in the GPCs themselves, 34 million bytes of information can be stored in each of the two MMUs. Critical programs and data are loaded in both MMUs and protected from erasure.

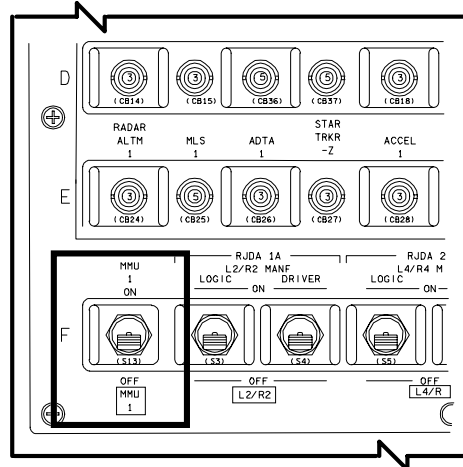
The principal function of the MMU, besides storing the basic flight software, is to store background formats and code for certain CRT displays and the checkpoints that are written periodically to save selected data in case the systems management GPC fails.

Operations are controlled by logic and the read and write electronics that activate the proper tape heads (read or write/erase) and validate the data.

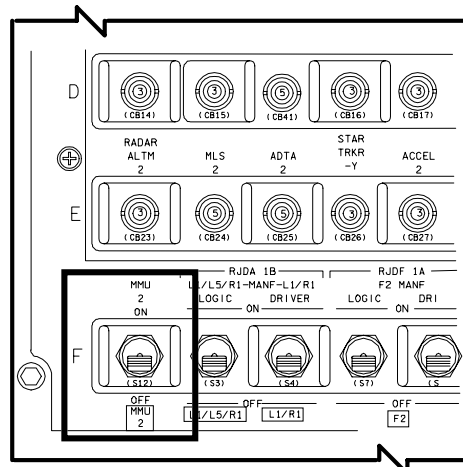
Each MMU interfaces with its mass memory data bus through MIAs that function like the ones in the GPCs. Each mass memory data bus is connected to all five computers; however, each MMU is connected to only one mass memory data bus. All MMU operations are on an on-demand basis only.

The power switches are located on panel O14 for MMU 1 and panel O15 for MMU 2. The MMU 1 switch on panel O14 positioned to ON allows control bus power to activate an RPC, which allows MNA power to MMU 1. The MMU 2 switch on panel O15 positioned to ON operates in a similar manner with MNB power. An MMU uses 20 watts of power in standby and 70 watts when the tape is moving.

MMU 1 is located in crew compartment middeck avionics bay 1, and MMU 2 is in avionics bay 2. Each unit is cooled by water coolant loop cold plates. Each MMU is 7.6 inches high, 11.6 inches wide and 15 inches long and weighs 25 pounds.



MMU 1 Power Switch on Panel O14



MMU 2 Power Switch on Panel O15

Multifunction CRT Display System

The multifunction CRT display system allows onboard monitoring of orbiter systems, computer software processing, and manual control for flight crew data and software manipulation.

The system is composed of three types of hardware: four display electronics units (DEUs), four display units (DUs) or CRTs, and three keyboard units, which together communicate with the GPCs over the display/keyboard data buses.

The system provides almost immediate response to flight crew inquiries through displays, graphs, trajectory plots, and

predictions about flight progress. The crew controls the vehicle system operation through the use of keyboards in conjunction with the display units. The flight crew can alter the system configuration, change data or instructions in GPC main memory, change memory configurations corresponding to different mission phases, respond to error messages and alarms, request special programs to perform specific tasks, run through operational sequences for each mission phase, and request specific displays.

Three identical keyboards are located on the flight deck: one each on the left and right sides of the flight deck center console (panel C2) and one on the flight deck at the side aft flight station (panel R11L). Each keyboard consists of 32 momentary double-contact pushbutton keys. Each key uses its double contacts to permit communication on separate signal paths to two DEUs. Only one set of contacts on the aft station keys is actually used because this keyboard is wired to communicate with only the aft display electronics unit.

There are 10 number keys, six letter keys (used for hexadecimal inputs), two algebraic keys, a decimal key, and 13 special function keys. Using these keys, the flight crew can ask the GPC more than 1,000 questions about the mission and condition of the vehicle. (Keyboard operations are discussed in detail later in this section.)

Each of the four DEUs responds to computer commands, transmits data, executes its own software to process keyboard inputs, and sends signals to drive displays on the CRTs (or display units). The units store display data, generate the GPC/keyboard unit and GPC/display unit interface displays, update and refresh on-screen data, check keyboard entry errors, and echo keyboard entries to the CRT.

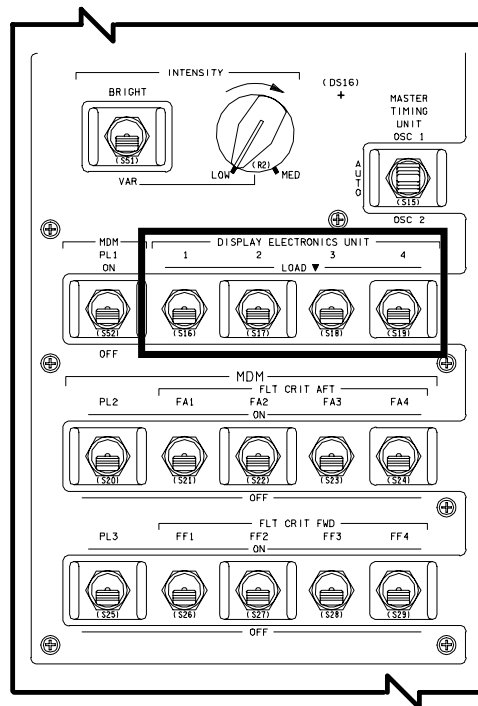
There are three CRTs on flight deck forward display and control panel F7 and one at the side aft flight deck station on panel R11L. Each CRT is 5 by 7 inches.

The display unit uses a magnetic-deflected, electrostatic-focused CRT. When supplied with deflection signals and video input, the CRT displays alphanumeric characters, graphic symbols, and vectors on a green monochrome

phosphorous screen activated by a magnetically controlled beam. Each CRT has a brightness control for ambient light and flight crew adjustment.

The DEUs are connected to the display/keyboard data buses by MIAs that function like those of the GPCs. Inputs to the DEU are from a keyboard or a GPC.

Positioning the *DISPLAY ELECTRONICS UNIT* 1, 2, 3, 4 switches on panel O6 to LOAD initiates a GPC request for a copy of DEU software stored in mass memory before operations begin. If the GPC software in control of the CRT is designed to support a DEU load (or IPL) request, then information is sent from the mass memory to the GPC and then loaded from the GPC into the DEU memory.



**DISPLAY ELECTRONICS UNIT
Switches on Panel O6**

It is possible to do in-flight maintenance and exchange CRT 4 with CRT 1 or 2. CRT 3 cannot be changed out because of interface problems with the orbiter jettison T-handle. Also, either individual keys or the entire forward keyboard can be replaced by the aft keyboard. The DEUs are located behind panels on the flight deck. DEUs 1 and 3 are on the left, and DEUs 2 and 4 are on the right. DEU 4 can replace any of the

others; however, if DEU 2 is to be replaced, only the cables are changed because 2 and 4 are next to each other.

The display electronics units and display units are cooled by the cabin fan system. The keyboard units are cooled by passive heat dissipation.

Master Timing Unit

The GPC complex requires a stable, accurate time source because its software uses Greenwich mean time (GMT) to schedule processing. Each GPC uses the master timing unit (MTU) to update its internal clock. The MTU provides precise frequency outputs for various timing and synchronization purposes to the GPC complex and many other orbiter subsystems. Its three time accumulators provide GMT and mission elapsed time (MET), which can be updated by external control. The accumulator's timing is in days, hours, minutes, seconds, and milliseconds up to 1 year.

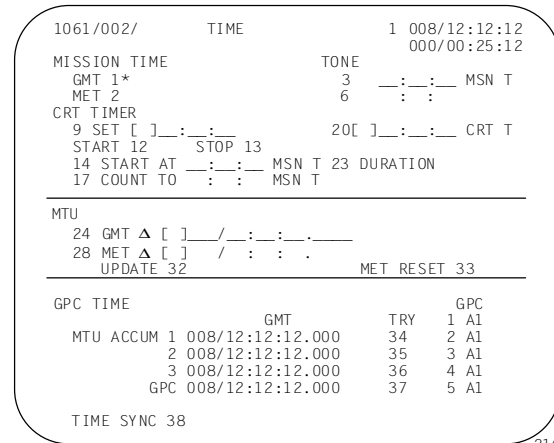
The MTU is a stable, crystal-controlled frequency source that uses two oscillators for redundancy. The signals from one of the two oscillators are passed through signal shapers and frequency drivers to the three GMT/MET accumulators.

The MTU outputs serial digital time data (GMT/MET) on demand to the GPCs through the accumulators. The GPCs use this information for reference time and indirectly for time-tagging GNC and systems management processing. The MTU also provides continuous digital timing outputs to drive the four digital timers in the crew compartment: two mission timers and two event timers. In addition, the MTU provides signals to the PCMMUs, COMSECs, payload signal processor, and FM signal processor, as well as various payloads.

The GPCs start by using MTU accumulator 1 as their time source. Once each second, each GPC checks the accumulator time against its own internal time. If the time is within tolerance (less than one millisecond), the GPC updates its internal clock to the time of the accumulator, which is more accurate, and continues. However, if the time is out of tolerance, the GPC will try the other accumulators and then the lowest numbered GPC until it finds a successful comparison.

The PASS GPCs do not use the MET that they receive from the master timing unit because they compute MET on the basis of current GMT and lift-off time.

The TIME display (SPEC 2) provides the capability to observe the current MTU and GPC clock status, synchronize or update the MTU and GPC clocks, and set CRT timers and alert tone duration and timers.

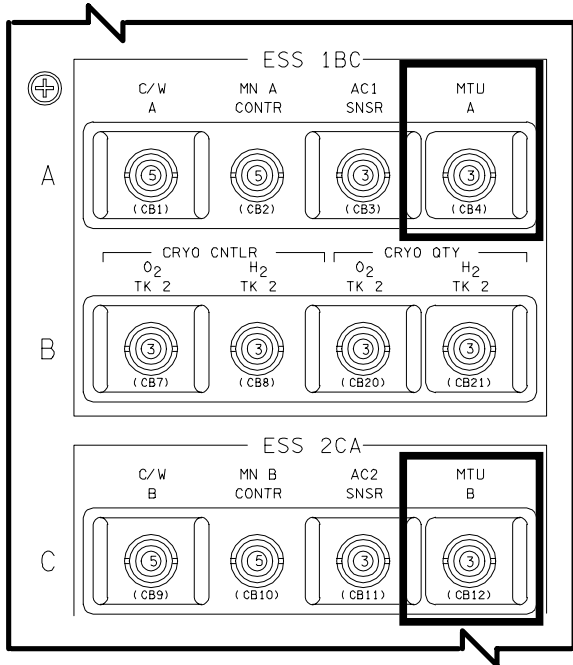


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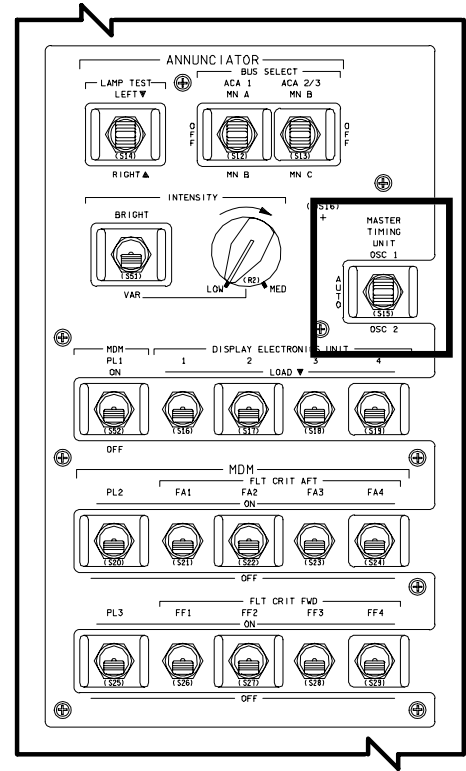
TIME Display (SPEC 2)

The MTU is redundantly powered by the ESS 1BC MTU A and ESS 2CA MTU B circuit breakers on panel O13. The MASTER TIMING UNIT switch on panel O6 controls the MTU. When the switch is in AUTO, and a time signal from one oscillator is out of tolerance, the MTU automatically switches to the other oscillator. For nominal operations, the MTU is using oscillator 2 with the switch in AUTO. The OSC 1 or OSC 2 position of the switch manually selects oscillator 1 or 2, respectively.

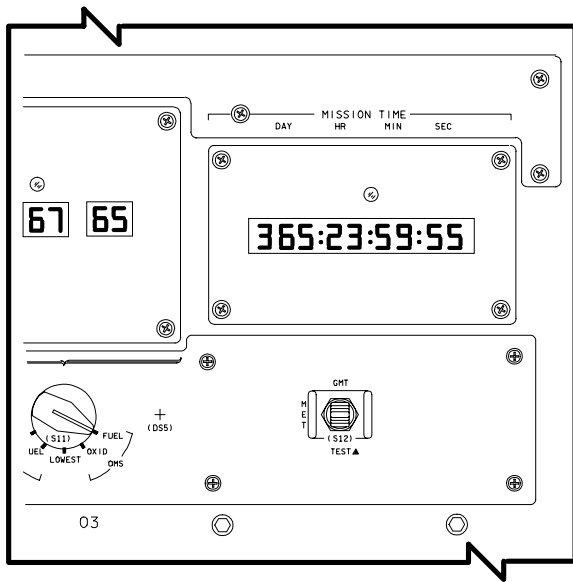
The MTU is located in crew compartment middeck avionics bay 3B and is cooled by a water coolant loop cold plate. The hardware displays associated with the master timing unit are the mission and event timers. MISSION TIME displays are located on panels O3 and A4. They can display either GMT or MET in response to the GMT or MET positions of the switch below the displays. The forward EVENT TIME display is on panel F7, and it is controlled by the EVENT TIME switches on panel C2. The aft EVENT TIME display is on panel A4, and its EVENT TIME control switches are on panel A6U.



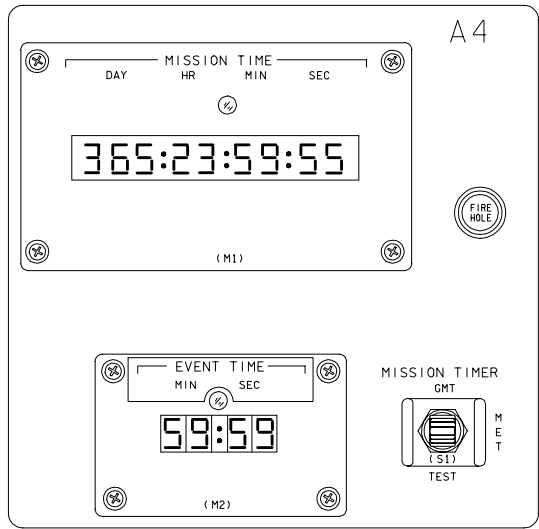
ESS 1BC MTU A and ESS 2CA MTU B Circuit Breakers on Panel O13



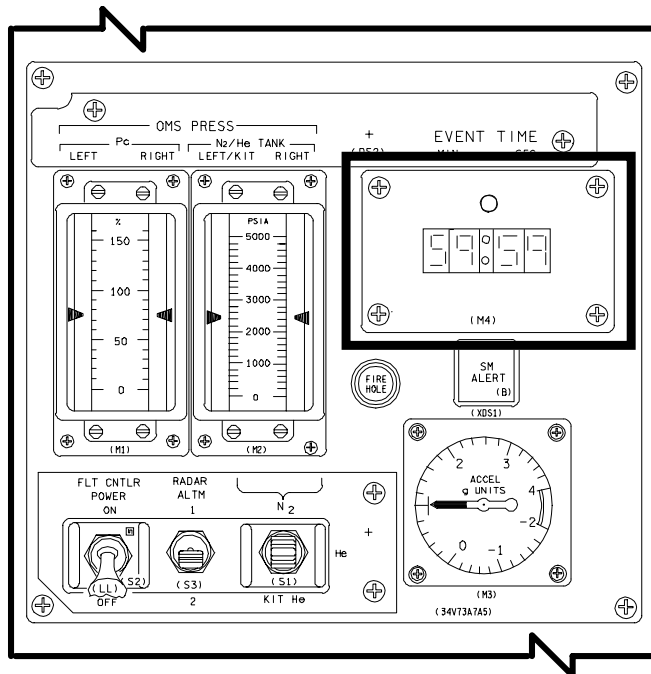
MASTER TIMING UNIT Switch on Panel O6



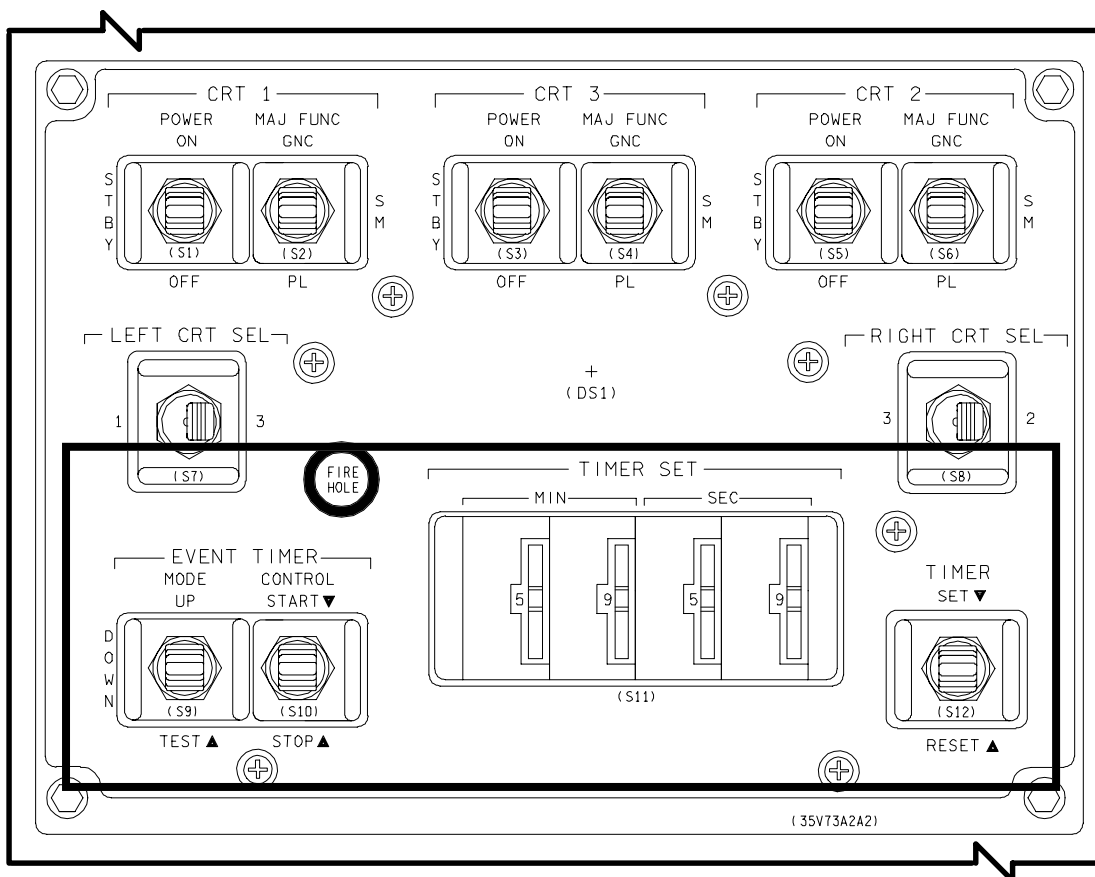
MISSION TIME Display and Switch on Panel O3



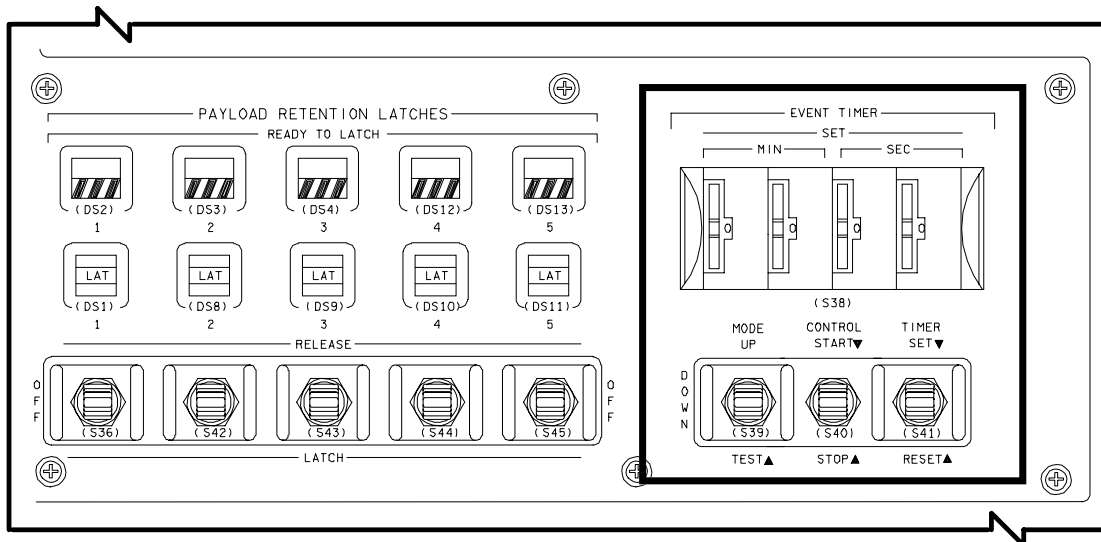
MISSION TIME and EVENT TIME Displays and MISSION TIMER Switch on Panel A4



EVENT TIME Display on Panel F7



EVENT TIMER Switches and TIMER SET Thumbwheels on Panel C2



EVENT TIMER Switches on Thumbwheels on Panel A6U

Software

Primary Avionics Software System (PASS)

The PASS (also referred to as primary flight software) is the principal software used to operate the vehicle during a mission. It contains all the programming needed to fly the vehicle through all phases of the mission and manage all vehicle and payload systems.

Since the ascent and entry phases of flight are so critical, four of the five GPCs are loaded with the same PASS software and perform all GNC functions simultaneously and redundantly. As a safety measure, the fifth GPC contains a different set of software, programmed by a company different from the PASS developer, designed to take control of the vehicle if a generic error in the PASS software or other multiple errors should cause a loss of vehicle control. This software is called the backup flight system (BFS). In the less dynamic phases of on-orbit operations, the BFS is not required. The information provided below describes how the PASS software relates to the DPS and the crew. Much of the material is common between PASS and BFS; therefore, only BFS differences are discussed immediately after the PASS discussion.

DPS software is divided into two major groups, system software and applications software. The two groups are combined to form a memory configuration for a specific mission phase. The

programs are written in HAL/S (high-order assembly language/shuttle) specifically developed for real-time space flight applications.

System software is the GPC operating system software that controls the interfaces among the computers and the rest of the DPS. It is loaded into the computer when it is first initialized. It always resides in the GPC main memory and is common to all memory configurations. The system software controls GPC input and output, loads new memory configurations, keeps time, monitors discretes into the GPCs, and performs many other DPS operational functions.

The system software consists of three sets of programs. The flight computer operating system (FCOS) (the executive) controls the processors, monitors key system parameters, allocates computer resources, provides for orderly program interrupts for higher priority activities, and updates computer memory. The user interface programs provide instructions for processing flight crew commands or requests. The system control program initializes each GPC and arranges for multi-GPC operation during flight-critical phases.

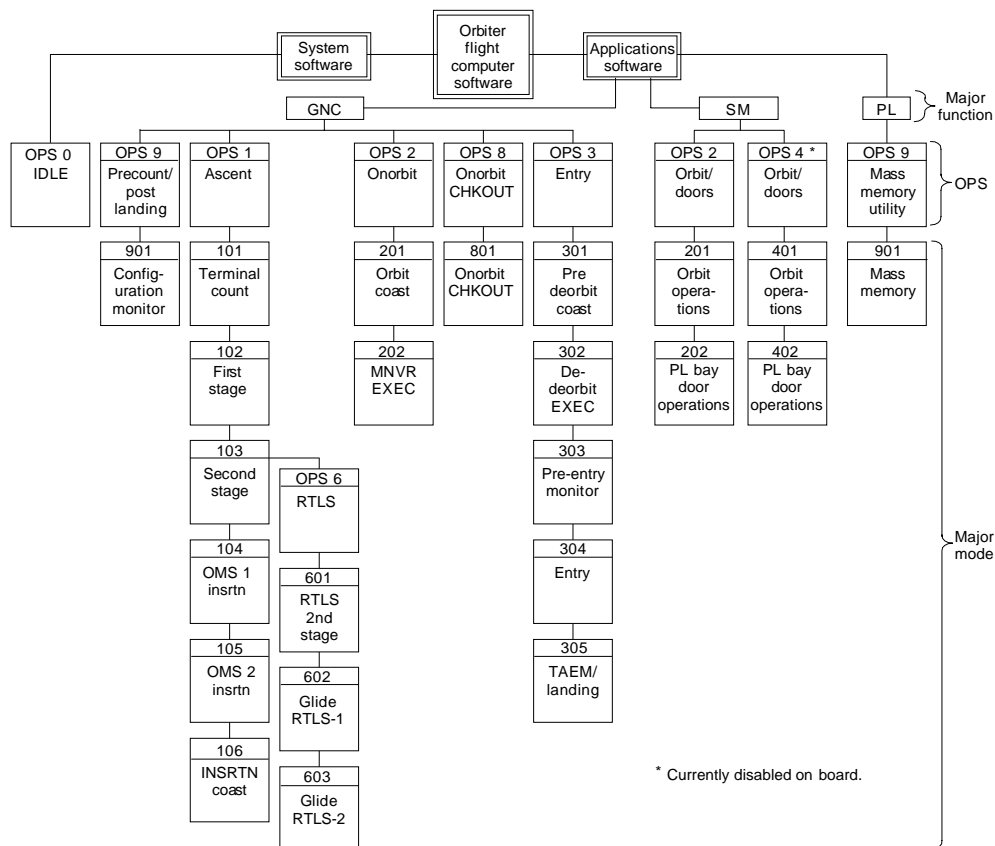
One of the system software functions is to manage the GPC input and output operations, which includes assigning computers as commanders and listeners on the data buses and exercising the logic involved in sending commands to these data buses at specified rates and upon request from the applications software.

The applications software performs the functions required to fly and operate the vehicle. To conserve main memory, the applications software is divided into three major functions:

- **Guidance, navigation, and control (GNC):** specific software required for launch, ascent to orbit, maneuvering in orbit, entry, and landing. This is the only major function where redundant set synchronization can occur.
- **Systems management (SM):** tasks that monitor various orbiter systems, such as life support, thermal control, communications, and payload operations. SM is a simplex major function; only one GPC at a time can actively process an SM memory configuration.
- **Payload (PL):** this major function currently contains mass memory utility software. The PL major function is usually *unsupported* in flight, which

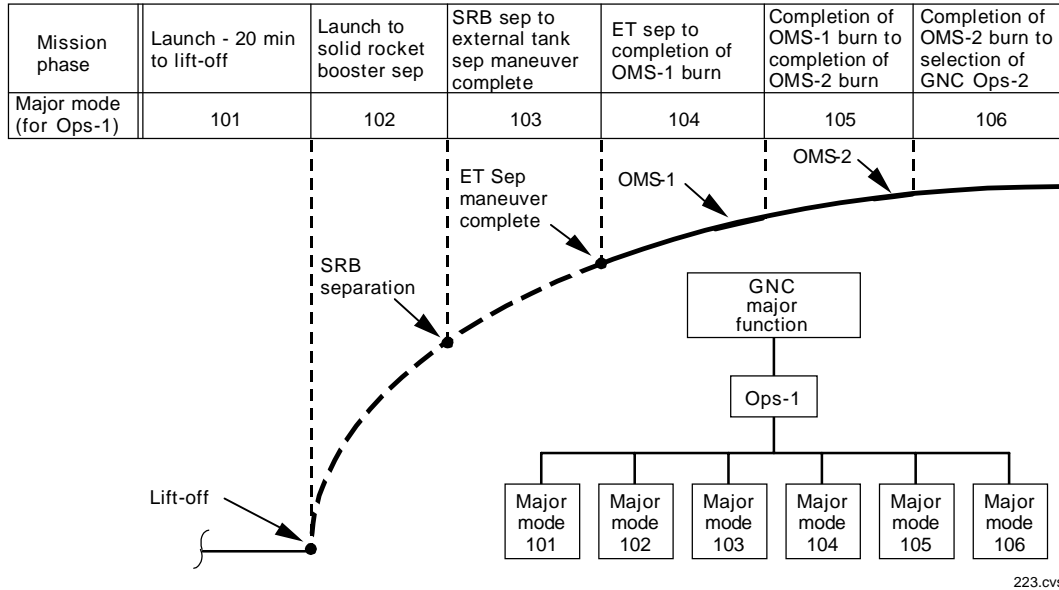
means that none of the GPCs are loaded with PL software. It is only used in vehicle preparation at KSC, and is also a simplex major function. Note that software to support payload operations is included as part of the SM GPC memory configuration.

Major functions are divided into mission phase oriented blocks called operational sequences (OPS). Each OPS of a major function is associated with a particular memory configuration that must be loaded separately into a GPC from the MMUs. Therefore, all the software residing in a GPC at any given time consists of system software and an OPS major function; i.e., one memory configuration. Except for memory configuration 1, each memory configuration contains one OPS. Memory configuration 1 is loaded for GNC at launch and contains both OPS 1 (ascent) and OPS 6 (RTLS), since there would be no time to load in new software for a return to launch site (RTLS) abort.



222.cvs

Orbiter Flight Computer Software



Major Modes

During the transition from one OPS to another, called an OPS transition, the flight crew requests a new set of applications software to be loaded in from the MMU. Every OPS transition is initiated by the flight crew. When an OPS transition is requested, the redundant OPS overlay contains all major modes of that sequence.

Major modes are further subdivisions of an OPS, which relate to specific portions of a mission phase. As part of one memory configuration, all major modes of a particular OPS are resident in GPC main memory at the same time. The transition from one major mode to another can be automatic (e.g., in GNC OPS 1 from precount MM 101 to first stage MM 102 at lift-off) or manual (e.g., in SM OPS 2 from on-orbit MM 201 to payload bay door MM 202 and back).

Each major mode has an associated CRT display, called a major mode display or OPS display, that provides the flight crew with information concerning the current portion of the mission phase and allows flight crew interaction. There are three levels of CRT displays. Certain portions of each OPS display can be manipulated by flight crew keyboard input (or ground link) to view and modify system parameters and enter data. The specialist function (SPEC) of the OPS software is a block of displays associated with one or more operational sequences and enabled by the flight crew to monitor and modify system parameters

through keyboard entries. The display function (DISP) of the OPS software is a group of displays associated with one or more OPS. These displays are for parameter monitoring only (no modification capability) and are called from the keyboard. Display hierarchy and usage are described in detail later in this section.

Backup Flight System

Even though the four PASS GPCs control all GNC functions during the critical phases of the mission, there is always a possibility that a generic software failure could cause loss of vehicle control. Therefore, the fifth GPC is loaded with the BFS software. To take over control of the vehicle, the BFS monitors the PASS GPCs to keep track of the current state of the vehicle. If required, the BFS can take over control of the vehicle upon the press of a button. The BFS also performs the SM functions during ascent and entry because the PASS GPCs are all operating in GNC. BFS software is always loaded into GPC 5 before flight, but any of the five GPCs could be made the BFS GPC if necessary.

Since the BFS is intended to be used only in a contingency, its programming is much simpler than that of the PASS. Only the software necessary to complete ascent or entry safely, maintain vehicle control in orbit, and perform SM functions during ascent and entry is included. Thus, all the software used by the BFS can fit

into one GPC and never needs to access mass memory. For added protection, the BFS software is loaded into the MMUs in case of a BFS GPC failure and the need to IPL a new BFS GPC.

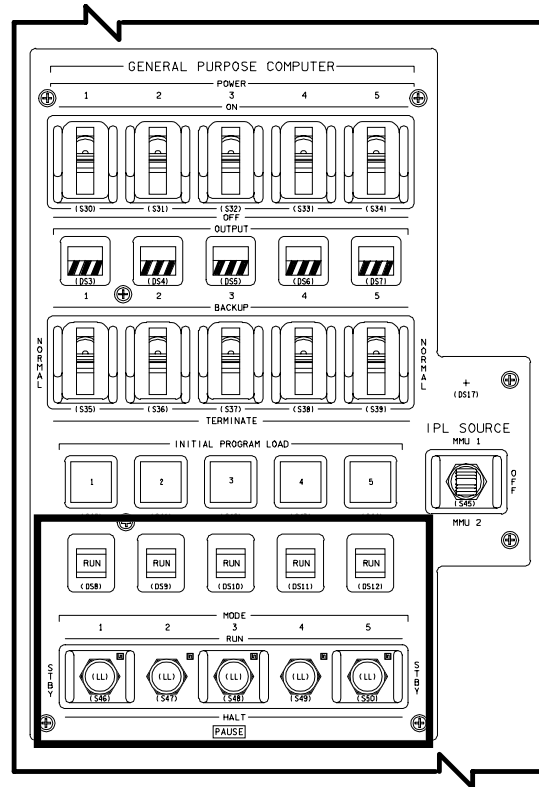
The BFS, like PASS, consists of system software and applications software. System software in the BFS performs basically the same functions as it does in PASS. These functions include time management, PASS/BFS interface, multifunction CRT display system, input and output, uplink and downlink, and engage and disengage control. The system software is always operating when the BFS GPC is not in *HALT*.

Applications software in the BFS has two different major functions, GNC and systems management, but all its applications software resides in main memory at one time, and the BFS can process software in both major functions simultaneously. The GNC functions of the BFS, designed as a backup capability, support the ascent phase beginning at MM 101 and the deorbit/entry phase beginning at MM 301. In addition, the various ascent abort modes are supported by the BFS. The BFS provides only limited support for on-orbit operations via MM 106 or MM 301. Because the BFS is designed to monitor everything the PASS does during ascent and entry, it has the same major modes as the PASS in OPS 1, 3, and 6.

The BFS SM contains software to support the ascent and entry phases of the mission. Whenever the BFS GPC is in the *RUN* or *STBY* mode, it runs continuously; however, the BFS does not control the payload buses in *STBY*. The SM major function in the BFS is not associated with any operational sequence and is always available whenever the BFS is active.

Even though the five general-purpose computers and their switches are identical, the *GENERAL PURPOSE COMPUTER MODE* switch on panel O6 works differently for a GPC loaded with BFS. Since *HALT* is a hardware-controlled state, no software is executed. The *STBY* mode in the BFS GPC is totally different from its corollary in the PASS GPCs. When the BFS GPC is in *STBY*, all normal software is executed as if the BFS were in *RUN*; the only difference is that BFS command of the payload data buses is inhibited in *STBY*. The BFS is normally put in *RUN* for ascent and entry, and in

STBY whenever a *PASS* systems management GPC is operating. If the BFS is engaged while the *MODE* switch is in *STBY* or *RUN*, the BFS takes control of the flight-critical and payload data buses. The *MODE* talkback indicator on panel O6 indicates *RUN* if the BFS GPC is in *RUN* or *STBY* and displays barberpole if the BFS is in *HALT* or has failed.



**GENERAL PURPOSE COMPUTER MODE
Switches and Talkbacks on Panel O6**

Pre-engage, the BFS is synchronized with the PASS set using flight-critical I/O so that it can track the PASS and keep up with its flow of commands and data. Synchronization and tracking take place during OPS 1, 3, and 6. During this time, the BFS listens over the flight-critical data buses to the requests for data by PASS and to the data coming back. The BFS depends on the PASS GPCs for acquisition of all its GNC data and must be synchronized with the PASS GPCs so that it will know when to receive GNC data over the FC buses. When the BFS is in sync and listening to at least two strings, it is said to be tracking PASS. As long as the BFS is in this mode, it maintains the current state vector and all other information necessary to fly the vehicle in case the flight crew needs to

engage it. When the BFS GPC is tracking the PASS GPCs, it cannot command over the FC buses but may listen to FC inputs through the listen mode. The BFS uses the MTU (like PASS) and keeps track of GMT over the flight-critical buses for synchronization. The BFS also monitors some inputs to PASS CRTs and updates its own GNC parameters accordingly.

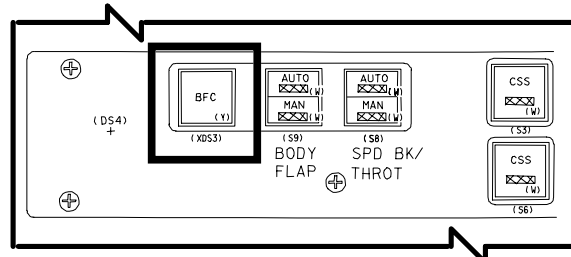
The BFS GPC controls its own instrumentation/PCMMU data bus. The BFS GPC requirements strictly forbid use of the IC data bus to monitor or to transmit status or data to the other GPCs. The mass memory data buses are not used except during initial program load, which uses the same IPL SOURCE switch on panel O6 as used for PASS IPL.

The BFC lights on panels F2 and F4 remain unlighted as long as PASS is in control, and the BFS is tracking. The lights flash if the BFS loses track of the PASS and goes standalone. The flight crew must then decide whether to engage the BFS or try to initiate BFS tracking again by an I/O RESET on the keyboard. When BFS is engaged and in control of the flight-critical buses, the BFC lights are illuminated and stay on until the BFS is disengaged.

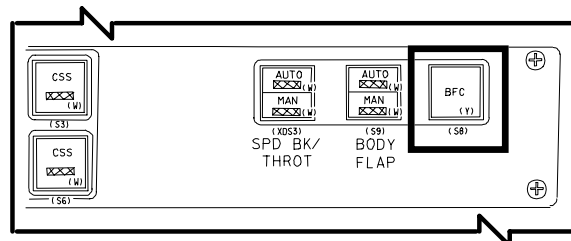
Since the BFS does not operate in a redundant set, its fail votes from and against other GPCs are not enabled; thus, the GPC STATUS light matrix on panel O1 for the BFS GPC does not function as it does in PASS. The BFS can illuminate its own light on the GPC STATUS matrix if the watchdog timer in the BFS GPC times out when the BFS GPC does not complete its cyclic processing.

To engage the BFS, which is considered a last resort to save the vehicle, the crew presses a BFS ENGAGE momentary pushbutton located on the commander's and pilot's rotational hand controllers (RHCs). As long as the RHC is powered, and the appropriate OUTPUT switch on panel O6 is in BACKUP, depressing the ENGAGE pushbutton on either RHC engages the BFS and causes PASS to relinquish control. There are three contacts in each ENGAGE pushbutton, and all three contacts must be made to engage the BFS. The signals from the RHC are sent to the backup flight controller, which handles the engagement logic.

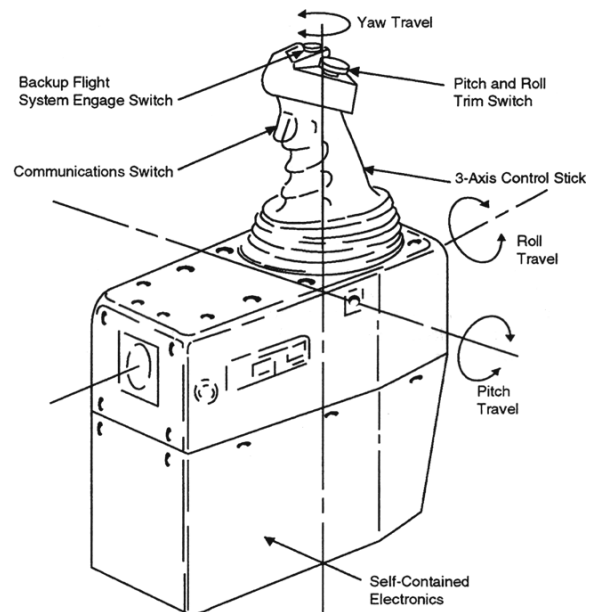
When the BFS is engaged, the BFC lights on panels F2 and F4 are steadily illuminated, the BFS's OUTPUT talkback indicator on panel O6 turns gray, all PASS GPC OUTPUT and MODE talkback indicators on panel O6 display barber-pole, the BFS controls the CRTs selected by the BFC CRT SELECT switch on panel C3, big X and poll fail appear on the remaining PASS-controlled CRTs, and all four GPC STATUS matrix diagonal indicators for PASS GPCs are illuminated on panel O1.



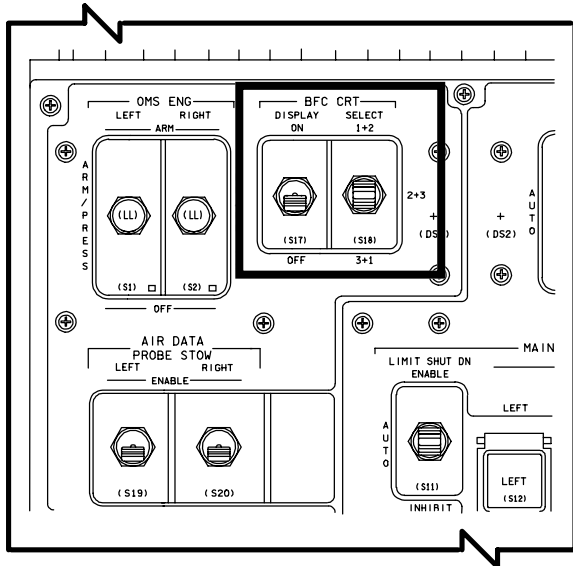
BFC Light on Panel F2



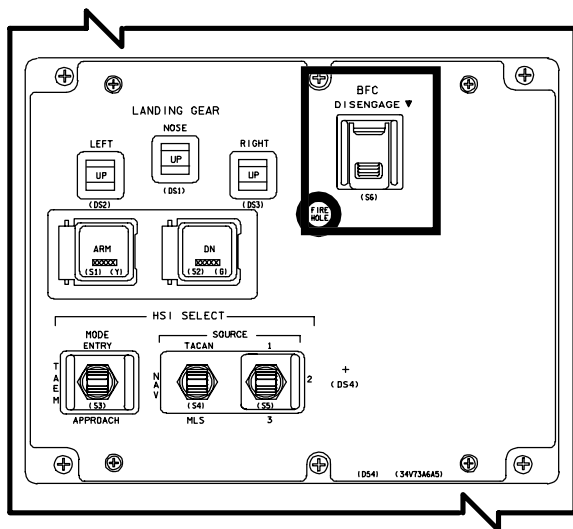
BFC Light on Panel F4



Rotational Hand Controller



BFC CRT DISPLAY and SELECT Switches on Panel C3



BFC DISENGAGE Switch on Panel F6

When the BFS is not engaged, and the *BFC CRT DISPLAY* switch on panel C3 is positioned to ON, the BFS commands the first CRT indicated by the *BFC CRT SELECT* switch. The *BFC CRT SELECT* switch positions on panel C3 are 1 + 2, 2 + 3, and 3+1. When the BFS is engaged, it assumes control of the second CRT as well.

If the BFS is engaged during ascent, the PASS GPCs can be recovered on orbit to continue a normal mission. This procedure takes about 2 hours, since the PASS inertial measurement unit reference must be reestablished. The BFS is

disengaged after all PASS GPCs have been hardware-dumped and reloaded with PASS software. Positioning the *BFC DISENGAGE* switch on panel F6 to the UP position disengages the BFS. The switch sends a signal to the BFCs that resets the engage discrettes to the GPCs. The BFS then releases control of the flight-critical buses as well as the payload buses if it is in *STBY*, and the PASS GPCs assume command.

After disengagement, the PASS and BFS GPCs return to their normal pre-engaged states. Indications of the PASS engagement and BFS disengagement are as follows: BFC lights on panels F2 and F4 are out, BFS's *OUTPUT* talkback on panel O6 displays barberpole, all PASS *OUTPUT* talkback indicators on panel O6 are gray, and BFS releases control of one of the CRTs.

If the BFS is engaged, there is no manual thrust vector control or manual throttling capability during first- and second-stage ascent. If the BFS is engaged during entry, the speed brake can be positioned using the speed brake/throttle controller, and the body flap can be positioned manually. Control stick steering (CSS) by either the commander or pilot is required during entry.

Pre-engage, the BFS supplies attitude errors on the CRT trajectory display, whereas PASS supplies attitude errors to the attitude director indicators; however, when the BFS is engaged, the errors on the CRT are blanked, and attitude errors are supplied to the attitude director indicators.

Operations

The crew interfaces with the five GPCs via four CRTs and various dedicated display instruments. This section first discusses crew operations using PASS, and then discusses crew operations using the BFS.

CRT Switches

Switches on panel C2 designate which keyboard controls each forward display electronics unit. When the LEFT CRT SEL switch is positioned to 1, the left keyboard controls the left CRT 1; if the switch is positioned to 3, the left keyboard controls the center CRT 3. When the RIGHT CRT SEL switch on panel C2 is positioned to 2, the right keyboard controls the right CRT 2; if positioned to 3, it controls the center CRT 3.

Thus, flight crew inputs are made on the keyboards, and data are output from the GPCs on the CRT displays.

NOTE

If the *LEFT CRT SEL* and *RIGHT CRT SEL* switches are both positioned to 3, key-strokes from both keyboards are interleaved.

The aft station panel R11L keyboard is connected directly to the aft panel R11L display electronics unit and CRT (or DU); there is no select switch.

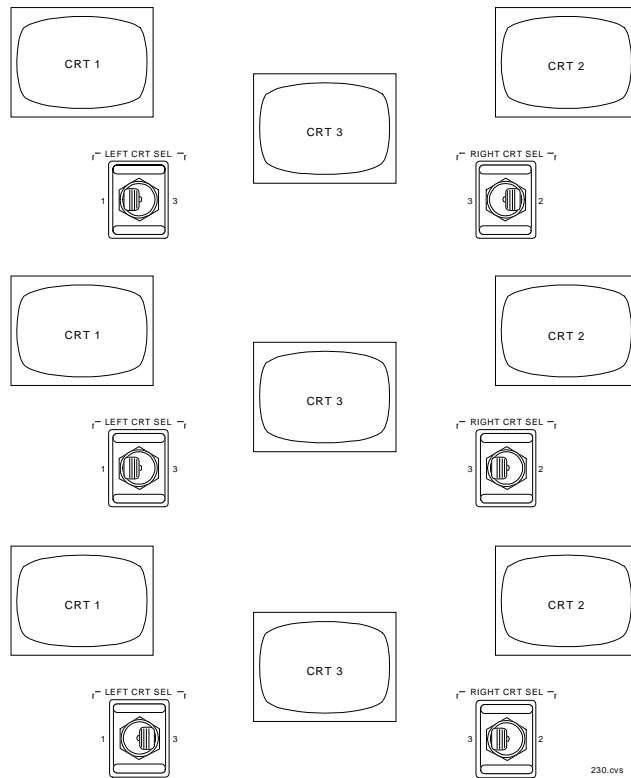
Each CRT has an associated power switch. The *CRT 1 POWER* switch on panel C2 positioned to *STBY* or *ON* allows control bus power to activate remote power controllers and sends MN A power to CRT 1. The *STBY* position warms up the CRT filament, only. The *ON* position provides high voltage to the CRT. The *CRT 2 POWER* switch on panel C2 functions the same as the *CRT 1* switch, except that CRT 2 is powered from MN B. The *CRT 3 POWER* switch on panel C2 functions the same as the *CRT 1* switch, except that CRT 3 is powered from MN C. The *CRT 4 POWER* switch on

panel R11L functions the same as the *CRT 1* switch, except that CRT 4 is powered from MN C. The respective keyboards receive 5 volts of ac power to illuminate the keys. Each DEU/DU pair uses about 290 watts of power when on and about 20 watts in standby.

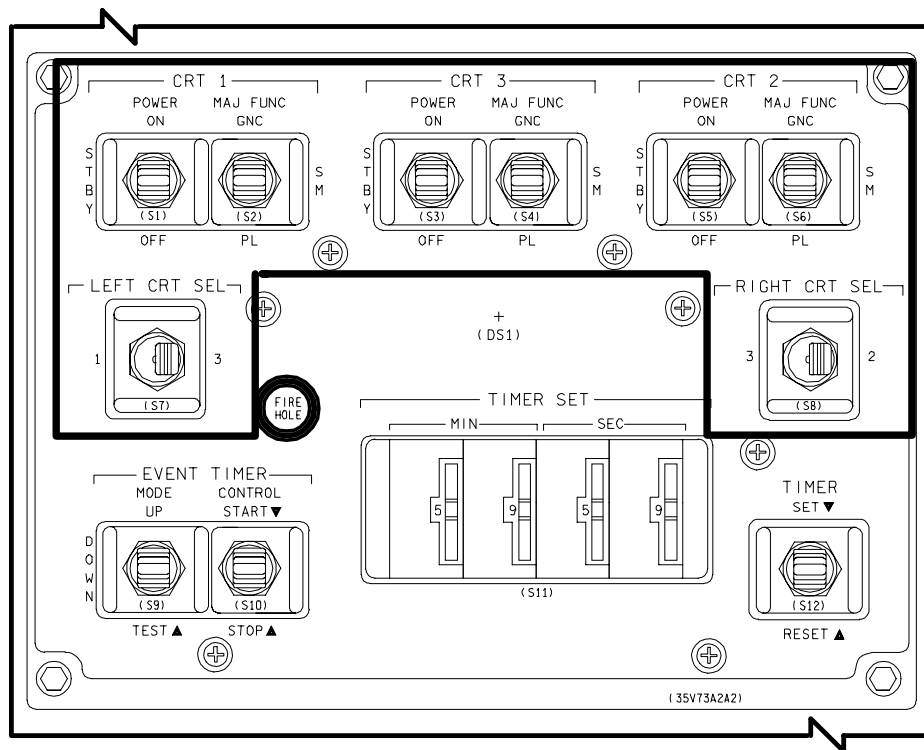
NOTE

Crewmembers should always check that keyboard information is accepted on the proper CRT prior to executing the item.

Each CRT has an associated *MAJ FUNC* switch. The *CRT 1, 3, 2, MAJ FUNC* switches on panel C2 tell the GPCs which of the different functional software groups is being processed by the keyboard units and what information is presented on the CRT. The *CRT 4 MAJ FUNC* switch on panel R11L functions in the same manner. This three-position toggle switch allows the crew access to the *GNC, SM, or PL* software on a desired CRT. The GPC loaded with the desired major function applications software will then drive this CRT. Each major function accesses an independent set of display data and functional software.



Possible CRT/Keyboard Assignments in the Forward Flight Station



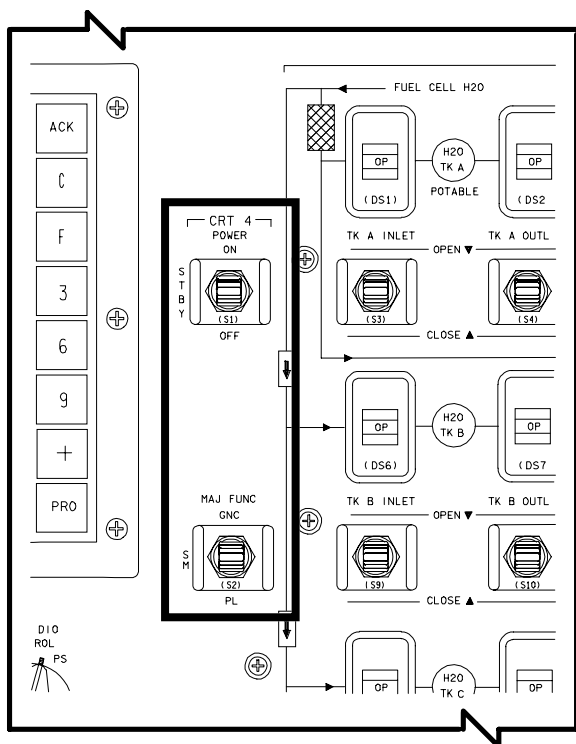
CRT Switches on Panel C2

Display Hierarchy

CRT display organization consists of three levels of crew software displays within any given major function. The display types parallel the different types of modules used in the GPC software. The established display hierarchy within applications software is operational sequences (OPS), specialist functions (SPEC), and display (DISP) functions. Each has a type of CRT page associated with it.

The OPS is the highest level of crew software control within a major function. Each memory configuration contains one or more OPS. Each OPS allows the crew to accomplish an associated mission phase task. Several operational sequences are defined, each covering some portion of the mission. For example, OPS 1 contains ascent software, OPS 2 contains on-orbit software, and OPS 3 contains entry software.

Each operational sequence is further divided into major modes. Each major mode has an associated display that allows direct crew interface with the software. These are OPS pages, and are also referred to as major mode pages.



CRT 4 POWER and MAJ FUNC Switches on Panel R11L

Specialist functions (SPECs) are second in the hierarchy. A SPEC allows crew execution of other activities in conjunction with a particular OPS. SPEC displays, like major mode displays, allow direct crew interface with the software. Each SPEC has an associated display that will overlay the major mode display when called. When a SPEC is called, its display rolls in on top of the major mode display, which is still active underneath. The SPEC provides access to an associated portion of the software located in the GPC. Some SPECs are contained in systems software, whereas others are resident in the applications load. A SPEC can be associated with a major function or an OPS, but the systems software SPECs can be obtained in most OPS and major functions. (The list of SPECs and their availability can be found in the DPS Dictionary.)

Display functions (DISPs) are the lowest level of software. Each DISP has an associated display that presents the status of a predefined set of parameters. Unlike major mode displays or SPECs, a DISP cannot initiate a change in software processing because DISP displays do not permit direct crew interface with the software. They provide information only.

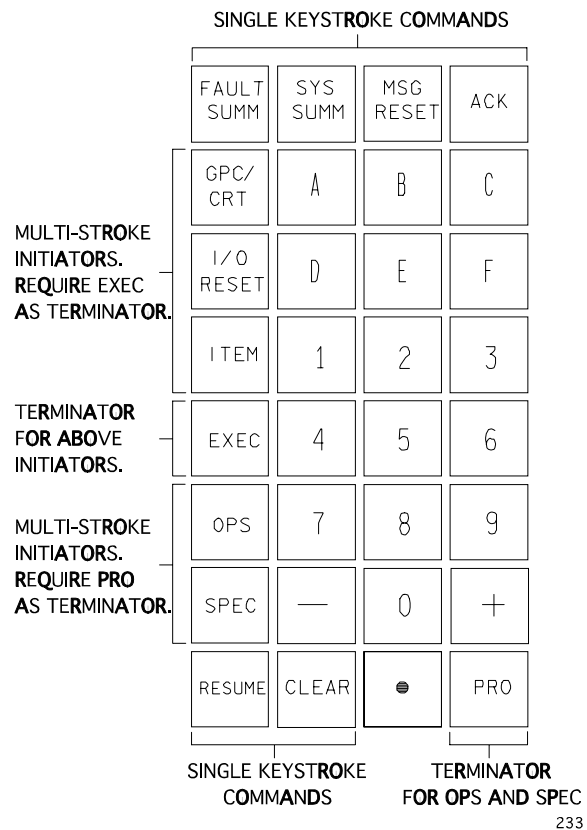
When called, a DISP will overlay the major mode display and the SPEC, if one is active. Both the SPEC and the major mode display are overlaid, and access to them can be easily regained. The method of terminating the processing of SPECs and DISPs will be discussed later.

The Keyboard

Each keyboard is composed of a 4 x 8 matrix of 32 pushbutton keys. This matrix consists of:

- Sixteen alphanumeric keys: 0 through 9 and A through F, for a hexadecimal numbering system
- Two sign keys (+ and -) serving the dual roles of sign indicators and delimiters. A delimiter is used to separate discrete keyboard entries from their associated data.
- One decimal point key for use in entering data with decimal notation

- Thirteen special function keys: some of these keys are single stroke commands, and some are keys that start or finish a multi-stroke command sequence. A key that starts a command sequence is a command initiator and requires a command terminator key to be depressed to tell the DEU the keyboard entry is complete.



Multifunction CRT Display System Keyboard Unit Found on Panels C2 and R11L

Each of these keys is discussed below.

ACK acknowledges receipt of a fault message on the fault message line by causing the message to become static and by extinguishing the SM ALERT light and software-controlled tones. If multiple messages are indicated on the CRT, each subsequent press of the ACK key will bring up the next oldest unacknowledged message and clear out the last acknowledged one.

MSG RESET operates as a single keystroke command that clears both the currently annunciated fault message and the buffer message indicator (if any) from the fault

message line. The fault message line is the second to the last line on the CRT. Depressing this key will also extinguish all software-driven caution and warning annunciators, software-controlled tones, and the SM ALERT light. An ILLEGAL ENTRY message can only be cleared with the MSG RESET key.

SYS SUMM is used to invoke the SYS SUMM display. The particular display called is determined by the selected major function and active OPS.

FAULT SUMM is used to invoke the FAULT display. It operates as a single keystroke command. The FAULT display can be accessed in every major function and OPS.

GPC/CRT initiates a multistroke keyboard entry, allowing the selection of a particular GPC to drive a DEU/DU set.

I/O RESET attempts to restore a GPC's input/output configuration to its original status prior to any error detection. It is a command initiator and requires a terminator keystroke.

ITEM is used as a multi-keystroke command initiator for changing the value of defined parameters or implementing configuration changes on a given display (OPS or SPEC).

EXEC acts as a multi-keystroke terminator to command the execution of the action specified on the scratch pad line. It is the terminator for the initiators above it (GPC/CRT, I/O RESET, and ITEM keys). EXEC may also be a single keystroke command to enable an OMS burn.

OPS serves as a multi-keystroke initiator to load a desired OPS load from mass memory into one or more GPCs. It is also used to transition from major mode to major mode within an OPS.

SPEC acts as a multi-keystroke initiator to select a defined SPEC or DISP display within a given OPS. In addition, this key provides the capability to freeze a display on the CRT. A single depression of the SPEC key freezes the display so it may be statically viewed. The display will remain frozen until another key (other than ACK, MSG RESET, or another SPEC) is entered.

PRO (Proceed) serves as a terminator to the OPS and SPEC keys. The completed command sequence initiates the selection of a desired OPS, SPEC, or DISP display.

RESUME is used to terminate a displayed SPEC or DISP. CRT control is restored to the underlying display upon depression of this key.

CLEAR clears the last echoed keystroke from the bottom line (scratch pad line) of the CRT. For each depression, one additional keystroke is removed, proceeding from right to left. After a command sequence is completed, a single depression of the CLEAR key will erase the static command from the scratch pad line.

Display Selection Procedures

The crew can select a variety of CRT displays. Some of the different ways to select an OPS display and its available SPEC and DISP displays are as follows:

- Selection of the major function is done by placing the MAJ FUNC switch (on panel C2) associated with the CRT in use in the GNC, SM, or PL position.
- An OPS is loaded from the MMU via a three-step keyboard entry. A new OPS is called from mass memory by its first major mode. The OPS is loaded into the GPC that is currently driving the DEU/DU on which the keyboard entry is done. Once the OPS is loaded, access is provided to major modes in that OPS. Major mode displays are advanced by the same keyboard command. The steps for selecting an OPS display are as follows:
 1. *Depress the OPS key.*
 2. *Key in the three numbers of the desired OPS.* The first digit defines the OPS and the next two digits specify the major mode.
 3. *Depress the PRO key.* Once the OPS is loaded into one or more GPCs, that software can be accessed at any time through any CRT in the proper major function.

Selection of a major mode does not involve a mass memory access. Advancing major modes is done by the same keyboard command as loading an OPS. The first digit will be the same as the OPS number, but the last two digits specify the major mode. For example, to go to GNC MM 202, enter OPS 2 0 2 PRO.

Within each OPS, certain SPEC and DISP displays are available. The steps for selecting a SPEC or a DISP are as follows:

1. *Depress the SPEC key.* The SPEC key is used in calling both SPEC and DISP displays.
2. *Key in the SPEC or DISP number omitting all leading zeros.* SPEC and DISP numbers have three digits. They are differentiated by their numbering scheme. The display is a DISP only if the first digit is a 9, or if the last digit is a 6 through 9. To illustrate the method for keying in SPEC and DISP numbers, DISP number 106 would be keyed in as "106"; SPEC number 034 would be keyed "34"; DISP number 066 would be keyed "66"; and SPEC number 001 would be keyed "1."
3. *Depress the PRO key.*

OPS and Major Mode Transitions

Transitions from major mode to major mode or to another OPS are accomplished by either automatic transitions or proper command entry.

- **Automatic transitions:** Some major mode transitions occur automatically, usually as a function of some mission event. Examples of automatic transitions are between major modes 101 and 102 (SRB ignition) and between major modes 102 and 103 (SRB separation). Selection of an RTLS abort also results in an automatic OPS transition.
- **Command entry:** Proper command entry (OPS XXX PRO) is almost always used to transition from one OPS to another. In most cases, it is also a legal transition operation for proceeding from one major mode to the next (e.g.; 301 to 302).

Display Sequencing, Overlaying, and Retention

Certain rules have been established for proceeding from one display to another. These can be categorized into treatment of proper display sequencing, the overlaying of current displays by new displays, and the display retention hierarchy.

SPEC and DISP Displays

The hierarchy of overlaying SPECs and DISPs makes sense if one remembers that a SPEC allows crew interaction and control of specialized operations, whereas a DISP provides display information only. Both SPECs and DISPs overlay the current major mode display when called.

A SPEC need not be previously selected in order to call a DISP. If a DISP is on the CRT, and another SPEC or DISP is called, the current DISP is terminated. The terminated DISP can only be viewed again by entering its calling command once more.

If a SPEC is selected, and a DISP is called to overlay it, the SPEC is retained underneath the DISP. If another SPEC is then selected, the underlying SPEC as well as the DISP over it is terminated. The terminated SPEC can only be viewed again if it is recalled.

The RESUME key is used as a single keystroke entry to terminate the SPEC or DISP currently being displayed and to restore the underlying display. If the display being terminated is a DISP, CRT control will be restored to the underlying SPEC, or to the OPS display if no SPEC has been selected. If a SPEC display is terminated, CRT control is restored to the major mode display. It is advisable to press RESUME after viewing any SPEC or DISP to avoid confusion and to decrease the possibility of attempting to retain more SPEC displays than the software allows. Also, certain ground command functions may not be possible when corresponding SPECs are active or underlying a DISP. The RESUME key cannot be used to transition from one major mode display to another or to page backwards through major mode displays.

Display Retention Hierarchy

- Major mode transitions: Both SPECs and DISPs are retained during a major mode transition. If a SPEC or DISP is overlaying the major mode display, the new major mode display can't be seen until the overlaying displays are terminated with the RESUME key.
- Major function change: OPS and SPEC displays on the CRT screen are retained within their major function when major function positions are switched. When the crew returns to the first major function, the SPEC last viewed will appear on the screen. Depression of the RESUME key will restore the underlying OPS. If no SPEC had been selected, return to a major function would restore the last major mode display. DISP displays are not retained at major function switch transitions.
- OPS transition: SPECs, DISPs, and major mode displays are not retained through an OPS transition, since this involves loading an entirely new module of applications software in the GPC. The SPECs may be called again if they are available in the new OPS.

Standard Display Characteristics

Standard Display Features

Two discrete brightness intensities for displayed characters are designated "bright" and "overbright." The bulk of all material is displayed in the "bright" intensity. Special messages and special characters, such as parameter status indicators, are displayed in "overbright" to direct the crew's attention during their display scan.

Certain words and messages are designed to flash on and off. Fault messages will flash, indicating a message that needs to be acknowledged. Command initiators are designed to flash until the command is completed, and an incorrect keyboard entry will result in a flashing "ERR" to the right of the erroneous entry.

Formatting Similarities

OPS number: The four-digit field in the upper left corner of the first line designates the number of the OPS display being processed. The first digit represents the OPS; the next two digits indicate the major mode. The last digit is always a "1," and it is not used when making keyboard entries.

SPEC number: Directly to the right of the OPS number is a three-digit field. This field displays the number of the SPEC overlaying the OPS. This field is blank if no SPEC is selected.

DISP number: The last field in the upper left corner represents the DISP number. It is a three-digit field. This field is blank if no DISP is currently being displayed.

Display title: Centered on the top line of the display is the title of the display. Portions of some titles are dynamic and will specify the mission phase.

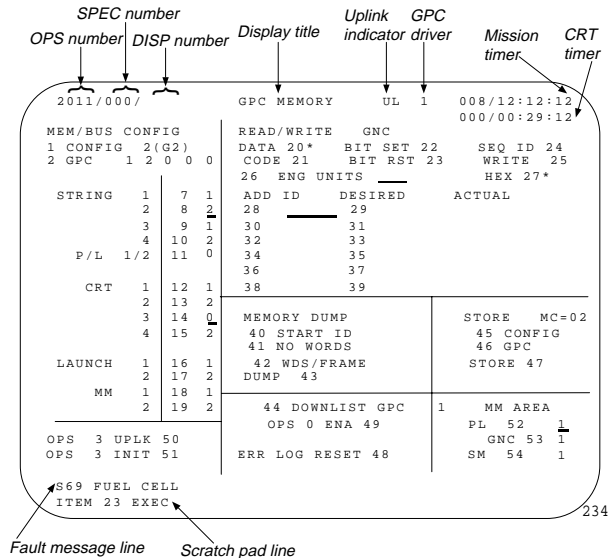
Uplink indicator: Directly to the right of the display title is a two-space field. When an uplink to the GPC is in progress, a flashing "UL" will be displayed. Otherwise this field is blank.

GPC driver: To the right of the uplink indicator is a one-digit field. A number in this field indicates the particular GPC (1, 2, 3, 4, or 5) that is commanding the CRT.

GMT/MET clock: This field displays time in days, hours, minutes, and seconds (DDD/HH:MM:SS). The field is updated every second. The time displayed may be either GMT or MET selectable via a keyboard entry to the SPEC 2 TIME display.

CRT timer: Directly below the GMT/MET clock is a CRT timer field also displayed in days, hours, minutes, and seconds (DDD/HH:MM:SS). This field is also updated every second, and can be set via a keyboard entry to the TIME SPEC display.

Fault message line: The second line from the bottom is reserved for fault messages. Illegal keyboard entry messages and systems fault messages are displayed on this line. In the case of system faults, a number in parentheses to the far right on this line indicates the number of fault messages that have not been viewed and acknowledged (further discussion of fault messages is covered in a later section).



Formatting Conventions Common to All Displays

Scratch pad line: The bottom line of the display echoes keyboard entries made by the crew. Command initiators (OPS, SPEC, ITEM, GPC/CRT, and I/O RESET) will flash on the scratch pad line until the command is terminated. The keystrokes remain on the scratch pad line in a static mode until (a) a new command is initiated, (b) the CLEAR key is depressed, or (c) the MAJOR FUNC switch position is changed. Keyboard syntax errors detected by the DEU will result in a flashing "ERR" on the scratch pad line following the keyboard entry.

Specially Defined Symbols

These symbols include an asterisk and a set of parameter status indicators. Parameter status indicators are displayed in "overbright" intensity for quick recognition. These special symbols are defined as follows:

M: This symbol indicates missing data. It is displayed directly to the right of the affected parameter. The parameter value may be blanked, or the last value received by the GPC may be displayed. If data are missing for a parameter that has no numerical value associated with it, then an M is used to indicate the parameter status.

H: This symbol indicates that a parameter is off-scale high. This indicates a transducer limit has

been reached, and the scale is registering its highest possible value. The actual parameter being measured may, in fact, be higher than the recorded data, but the instrument in use does not have the capacity to measure the value. Off-scale high indicators do not appear on the display until several (normally two) consecutive readings have verified this finding. This symbol is displayed to the right of the data affected.

L: This symbol indicates off-scale low parameters. This means that the parameter value displayed is the lowest possible reading due to transducer limitations. The actual value of the parameter may exceed the displayed value, but the range of the hardware is not defined to evaluate this reading. As with the "H," the off-scale low indicator is not displayed until a set number of consecutive readings have verified this status.

Up arrow: This symbol, displayed to the right of the affected parameter, indicates a parameter driven out-of-limits high. The value displayed is a true reading but has equaled or exceeded the operational high limit established by the software. The fault detection and annunciation (FDA) software keeps track of the low and high limits for each parameter and annunciates any violation of these limits to the crew by displaying the appropriate "up arrow" or "down arrow" next to the parameter on the appropriate display.

Item Configuration Change

This operation allows the crew to choose any of a number of options or to initiate a specific action as defined by the particular display format. Typical purposes of this operation include selecting or deselecting an item, initiating and executing an action, and altering software configurations. The procedure used in performing an item configuration change within a selected display is as follows:

1. *Depress the ITEM key.*
2. *Key in the item number.*
3. *Depress the EXEC key.*

Item Data Entry

This operation allows the crew to load data into the software. Typical purposes of this operation include initializing parameters, changing software limits, and specifying memory locations. The procedure used in performing an item data entry is as follows:

1. *Depress the ITEM key.*
2. *Key in the item number.* Item numbers are ordered sequentially (1, 2, 3, . . .) on each display. They are located next to the parameter to which they are assigned. Some item numbers must be inferred by their surrounding item numbers.
3. *Key in a delimiter ("+" or "-").* A delimiter serves to separate item number codes from their corresponding data. The delimiter whose sign corresponds to the sign of the data should be used, but if no sign is associated with the data, it doesn't matter which delimiter is used. A "[]" after the data field indicates that the entry is sign-dependent.
4. *Key in the data.* Data size specifications depend on the format established for that particular data load. Usually, the data size will be indicated with an underline for each digit. As a general rule, leading and trailing zeros need not be entered. Remember that the sign of the delimiter is the sign of the data.
5. *Depress the EXEC key.*

Multiple Data Entries

Multiple item configuration changes cannot be done; however, multiple item data entries can. Multiple data entries can be made with separate command strings, but because this is time-consuming, the software allows more than one data entry to be made with one command sequence. The procedure is the same as described above except step 4 (after data are keyed in). Add step 4a to make more than one item data entry at once.

- 4a. *Key in a delimiter.* Consecutive data entries may be loaded by using a delimiter to separate each parameter. Item entries are incremented sequentially so the item number need not be entered for each parameter following the one already entered. Just hit another delimiter, and the next item number will appear, ready to receive its associated data. To skip an item number, hit a delimiter twice. In this way, any amount of item numbers may be skipped until the desired item number is reached.

Both the "+" and the "-" keys may be used interchangeably as delimiters. However, when skipping item numbers, it is a good idea to use the delimiter corresponding to the sign of the next data entry if there is any sign associated with it. Using the sign key corresponding to the next data entry ensures that the GPC receives the proper data entry.

An example of a multiple item data keyboard entry is:

```
ITEM 7 + 2 + 1 + + 2 + - - 2 EXEC
```

In this example, Items 7, 8, 10, and 13 have no sign associated with them so the sign of the delimiters doesn't matter. Although there was room for four item entries here, the actual number allowed on the scratch pad line is a function of the size of the data.

This entry will appear on the scratch pad line of the corresponding CRT as:

```
ITEM (07) + 2 (08) + 1 (10) + 2 (13) - 2 EXEC.
```

All item operations will be one of these two basic manipulations. However, data size and form will differ for each display.

Remember, only OPS and SPEC displays allow item operations. A DISP display does not.

Special Operations and Displays

GPC/CRT Assignment

GPC assignment to a particular DEU/CRT set is determined via a predefined table of assignments. This table is stored in all the common set GPCs' systems software and can be manipulated by the crew. There is a table for each memory configuration (MC) that is valid when that MC is active (loaded in one or more GPCs), and the particular major function is selected. This table can be changed using the GPC MEMORY display (SPEC 0). The current GPC driver for a CRT is controlled by the *MAJ FUNC* switch. That is, the position of the *MAJ FUNC* switch (*GNC*, *SM*, or *PL*) will determine the GPC with which the DEU communicates. In some cases, a redundant set of GPCs is formed for *GNC*, and the *GNC* CRTs are normally split among them. This is done with the predefined table. The table is looked at by the GPCs when they are loaded with the applications software, and that is when the assignments take effect.

Another way to change the current GPC assignment logic is with the GPC/CRT key. The GPC/CRT key allows the crew to reassign a CRT to a different GPC commander. The steps for selecting a GPC to command a given DEU/CRT are as follows:

1. Depress the GPC/CRT key.
2. Key in the desired GPC number (1, 2, 3, 4, or 5)
3. Key in the desired CRT number (1, 2, 3, or 4). No delimiter is needed between the GPC and the CRT numbers.
4. Depress the EXEC key.

An assignment is not executed if the GPC being assigned doesn't have the applications software in memory to support the DEU/CRT in its current major function. If the GPC specified by a keyboard entry is not a valid assignment, the reassignment does not occur, and the current GPC driver retains the CRT. Thus, if a CRT is in *GNC*, and an attempt is made to assign a GPC that is not in the redundant set to drive it, a redundant set (or valid) GPC will drive the CRT instead of the invalid GPC. If GPC 4 is the *SM* machine (nominal configuration), then it is the

only valid GPC to drive a CRT whose *MAJ FUNC* switch is in *SM*.

The payload's major function is usually *unsupported*. This means that none of the GPCs have payload applications software loaded in them. Any GPC can be assigned to drive a CRT in an unsupported major function. The GPC that was driving the CRT in the previous major function will retain the CRT when it is placed in *PL*.

If the keyboard entry specifies a valid GPC, it will override any assignment made by the software. The keyboard entry assignment will remain in effect whenever the *MAJ FUNC* switch is in a position supported by that GPC. A new assignment can be made via the keyboard.

The GPC/CRT key can also be used to isolate a DEU from communication with all GPCs. This is accomplished by using "0" for the number of the GPC. The *PASS* set can drive only three of the four CRTs at one time, so at least one DEU is always isolated from *PASS*.

The DEU drives a big X over an isolated CRT to remind the crew that the DEU is not receiving data. The DEU also annunciates a *POLL FAIL* message to inform the crew that the GPC is no longer successfully polling the DEU (not attempting to communicate with the DEU).

Memory Configurations

After a GPC has been IPL'd, the only software resident is the systems software, and the GPC is in *OPS 0* when moded to *RUN*. Any applications software is loaded in from the MMU during an *OPS* transition. There are two levels of applications software: the major function base (MFB) and the *OPS* overlay. The MFB is that software common to all *OPS* in a particular major function. For *GNC*, the MFB contains flight-critical software and data that are retained from one mission phase to another, such as the current state vector and inertial measurement unit processing. When a GPC is transitioned from one *OPS* to another in the same major function (e.g., from *GNC OPS 1* [ascent] to *OPS 2* [orbit]), the MFB remains in main memory, and only the *OPS* overlay is loaded from the MMU and written over the old *OPS*. Of course, when the major function changes (e.g., when GPC 4 is transitioned from

GNC OPS 1 to SM OPS 2), a new MFB is loaded in from the MMU along with the OPS overlay.

The controls for performing an OPS transition (i.e., loading a new memory configuration into the GPC from the MMU) are on the GPC MEMORY display (SPEC 0), which is also the OPS 0 OPS display. Item 1 determines the memory configuration (CONFIG) to be loaded. Currently, there are eight different memory CONFIGs, besides memory CONFIG 0, which is post-IPL OPS 0 (no applications software loaded).

MCC	ABBREV	
1	(G1)	GNC OPS 1 and 6 combined (ascent and aborts)
2	(G2)	GNC OPS 2 (on orbit)
3	(G3)	GNC OPS 3 (entry)
4	(S2)	SM OPS 2 (on orbit)
5	(S4)	SM OPS 4 (on orbit [not used])
6	(P9)	PL OPS 9 (preflight)
No MC 7		
8	(G8)	GNC OPS 8 (on orbit checkout)
9	(G9)	GNC OPS 9 (preflight/postflight)

Memory Configurations

Nominal Bus Assignment Table

Associated with each memory configuration is a nominal bus assignment table (NBAT). It is displayed via items 7-19 on SPEC 0 whenever a memory configuration is entered, and it tells which GPCs are in the target set and which GPCs are to be in command of each data bus. The nominal assignments are already loaded in GPC main memory preflight. However, these bus assignments may be changed any time, including when an OPS transition is performed.

An example of a typical nominal bus assignment table is shown on SPEC 0 GPC MEMORY for GNC OPS 3.

MEM/BUS CONFIG		READ/WRITE	GNC	SEQ ID
1	CONFIG 2(G2)	DATA 20*	BIT SET 22	24
2	GPC 1 2 0 0 0	CODE 21	BIT RST 23	WRITE 25
STRING	1 7 1	26	ENG UNITS	HEX 27*
2	8 2	ADD ID	DESIRED	ACTUAL
3	9 1	28	29	
4	10 2	30	31	
P/L 1/2	11 0	32	33	
CRT	1 12 1	34	35	
2	13 2	36	37	
3	14 0	38	39	
4	15 2			
LAUNCH	1 16 1	MEMORY DUMP		STORE MC=02
2	17 2	40 START ID		45 CONFIG
MM	1 18 1	41 NO WORDS		46 GPC
2	19 2	42 WDS/FRAME		STORE 47
		DUMP 43		
OPS 3 UPLNK	50	44 DOWNLIST GPC 1		MM AREA
OPS 3 INIT	51	OPS 0 ENA 49		PL 52 1
		ERR LOG RESET 48		GNC 53 1
				SM 54 1

Sample NBAT Data on GPC MEMORY Display (SPEC 0)

- Items 2-6 determine which GPCs will be in the OPS. They are referred to as the "target" GPCs. In this case, GPCs 1-4 are in a redundant set. If a GPC is not to be in that OPS, a 0 is entered in that GPC's item number, which is one more than the GPC number. (Item 2 is for GPC 1, etc.)
- The commanders of the flight-critical data buses or strings are entered in items 7-10. (String 1 is FF1 and FA1, etc.) In this case, each GPC is set to command its same-numbered string.
- The two PL buses are assigned together. For OPS 1 and 3 they are assigned to GPC 1 via item 11 in case the BFS fails. When the BFS is in RUN (as it is for entry), it commands the PL data buses.
- CRTs 1, 2, 3 are assigned to GPCs 1, 2, 3 respectively, via items 12-14. Since the PASS can only control three CRTs at a time, no GPC is assigned to CRT 4 during entry. Note that CRT assignments are for a particular major function only.
- The launch data buses are assigned via items 16 and 17. Since they have no function during entry, they are deassigned.
- Items 18 and 19 show that GPC 1 will command mass memory bus 1 for the OPS 3 transition, and GPC 2 will command mass memory bus 2, either if the transaction fails on mass memory bus 1 or if MMU 2 is prime selected on SPEC 1 DPS UTILITY.

MMU Assignment

Since there are two identical MMUs, there must be a method to tell the GPCs which one to use for a particular transaction. This is done on DPS UTILITY SPEC 1 display via items 1 through 8. Only one MMU (and its data bus) is assigned to each major function. A post-IPL OPS 0 GPC also has an MMU assigned to it for requesting freeze-dry software for a memory store. This display is initialized with all assigned to MMU 1, and execution of any of the item numbers causes the appropriate MMU to be assigned.

Note that each of the pairs of item numbers is mutually exclusive.

When a GPC needs to access mass memory, this table tells it which MMU to use. For example, the SM GPC may need to call a roll-in SPEC or take a checkpoint (discussed later). In the case of OPS transitions, if the MMU selected is busy or fails twice, then the other is automatically tried. For a GNC OPS transition where a redundant set is involved, one GPC is assigned to each mass memory bus via items 18 and 19 on SPEC 0 GPC MEMORY. The indicated GPC will command the mass memory bus selected by item 1 or 2 on SPEC 1 DPS UTILITY, then the other GPC will command the next mass memory bus if the first transaction fails. Of course, all GPCs in the redundant set will be listening over both buses and receive the overlay.

2011/001/	DPS UTILITY	1 008/12:12:12
		000/00:25:12
MMU ASSIGN	PORT ASSIGN	UL CNTL
1 2		
GNC 1* 2	STRING 1 15* 16	AUTO 35*
SM 3* 4	2 17* 18	ENA 36
PL 5* 6	3 19* 20	INH 37
OPS 0 7* 8	4 21* 22	
	P/L 1/2 23* 24	IPL SOURCE SW
MMU STATUS		MASK 38*
1 RDY		
2 RDY	VAR PARAM ID LIST	
	25 9ABA	
MMU SOURCE/BUS	26 9ABB	G3 ARCHIVE
GPC/MMU 9*	27 9ABC	LOAD 48
MMU/MMU 10	28 9ABD	RETRIEVE 49*
GPC/LDB 11	29 9ABE	
	30 9ABF	GROUND OPS
CKPT RETRV	31 9ACA	GSE POLL ENA 50
ENA 12	32 9ACB	SM GSE INH 51
	33 9ACC	SM C/O ENA 52
RTC	34 9ACD	GNC C/O ENA 53
13		BFC C/O ENA 54
CMD 14		ALT PL9 TB 55

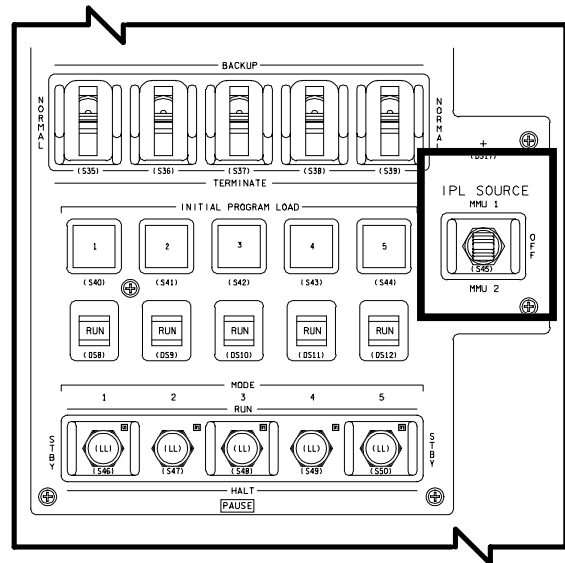
DPS UTILITY Display (SPEC 1)

Software Memory Source Selection

During an initial program load (IPL), an MMU is selected as the software source via the IPL SOURCE switch on panel O6. This switch is a three-position toggle switch that will be either in the MMU 1 or MMU 2 position during the IPL sequence. At all other times, this switch will nominally be in the OFF position.

The controls for selecting the memory source for an OPS transition and the bus over which it is loaded into the GPCs are on SPEC 1 DPS UTILITY (items 9 through 11). The display is initialized with item 9 selected, which is almost always used. As part of the GPC status exchanged at common set sync, each GPC

exchanges its current resident memory configuration. When a request is made for a memory configuration, the software determines whether or not another GPC already has the requested OPS or a current major function base. If another GPC already has any of the requested software, the lowest numbered such GPC will be used as a source for the other GPCs. Such a GPC-to-GPC overlay of software will be done over the mass memory data buses. An overlay that is not available from a GPC will be loaded from an MMU. Note that the major function base may come from another GPC and the OPS overlay from mass memory. For transitions to OPS 3, the G3 archive (stored in the upper 128 k of main memory prelaunch) is simply copied to lower memory and executed.



IPL SOURCE Switch on Panel O6

If there is a problem with both of the mass memory data buses, then item 11 may be selected if there is a GPC source for both overlays. In this case, the GPC-to-GPC overlay is done over the launch data buses.

Memory reconfiguration may be forced from an MMU, regardless of other GPC sources, by selection of item 10 on the DPS UTILITY display. In this case, whether both are required or not, both the major function base and the OPS overlay will be loaded from mass memory. This would only be used if the software in a current GPC was suspect for some reason.

If there is no usable GPC source and the selected MMU is off or being used for another memory transaction, the class 3 fault message OFF/BUSY MMU 1 (2) is initiated. The current status of each MMU is shown on the DPS UTILITY display as either RDY (ready to respond) or BSY (off or currently responding to a GPC command).

Resetting I/O Configurations

When a GPC detects an error or is missing data from a piece of equipment, a fault message will be displayed on the CRTs, the *SM ALERT* light and tone will be activated, and further attempts by the GPC to communicate with the equipment will be terminated. Two common causes of detected errors or missing data are the powering down of equipment or an error in a data transmission. In these two cases, if the equipment is to be powered up, or if the error has been corrected, it is desirable to restore the GPC's data input to the nominal configuration. Restoring input is done through the I/O RESET key in the affected major function. If an I/O RESET is performed only on a GNC GPC, the entire redundant set of GNC GPCs will be restored to nominal I/O configuration. If it is performed on the SM GPC, only the SM GPC's I/O configuration will be restored to nominal. To reset I/O configurations, the procedure is as follows:

- Select desired *MAJ FUNC*.
- Depress the I/O RESET key.
- Depress the EXEC key.

If the powered down equipment has been powered on, or if a problem with a piece of equipment has been fixed, an I/O RESET will resume communication, and it will not cause another fault message annunciation. If the GPC still has a problem communicating with any piece of its assigned equipment, a fault message will reannunciate after an I/O RESET. This termination of attempts by the GPC to communicate with its assigned equipment is called a commfault (i.e., the input element has been bypassed by the GPC) and the resultant loss of input data to applications software is also referred to as a commfault.

Systems Summary Displays

Systems summary displays provide general systems status information that can be accessed quickly to aid immediate diagnosis of a problem. They are designed to support the caution and warning (C/W) matrix located on panel F7. When a C/W alarm occurs, the crew can call a systems summary display that has general information from several systems to pinpoint the problem to a specific system, then continue troubleshooting the problem on system-specific SPECS, DISPs, and hardware panels. The systems summary displays are DISPs and provide information only.

The systems summary displays are major function-specific and are called with the SYS SUMM key. If a CRT's *MAJ FUNC* switch is in GNC, and the SYS SUMM key is pressed, then GNC SYS SUMM 1 will appear on that CRT. GNC SYS SUMM 1 is DISP 18 so it may also be called with a SPEC 18 PRO, but it is faster to use the SYS SUMM key.

There are four PASS systems summary displays: GNC SYS SUMM 1, GNC SYS SUMM 2, SM SYS SUMM 1, and SM SYS SUMM 2.

The SYS SUMM key is a toggle function in each major function. In SM on-orbit, hitting SM SYS SUMM will cause SM SYS SUMM (DISP 78) to appear on the CRT. If SYS SUMM is depressed again, SM SYS SUMM 2 (DISP 79) will appear, and if SYS SUMM is depressed once more, SM SYS SUMM 1 reappears.

The same toggle function exists in GNC between GNC SYS SUMM 1 (DISP 18) and GNC SYS SUMM 2 (DISP 19).

RCS		JET	ISOL								
MANF	FAIL	VLV	SURF	POS	MOM	DPS	1	2	3	4	5
F1		OP	L OB			GPC					
2		OP	IB			MDM FF					
3		OP	R IB			FA					
4		OP	OB								
5		OP	AIL								
L1		OP	RUD			FCS CH	1	2	3	4	
2		OP	SPD BRK								
3		OP	BDY FLP								
4		OP									
5		OP				NAV	1	2	3	4	
R1		OP				IMU					
2		OP	CNTLR	1	2	3	ACC				
3		OP	RHC	L			REG	P			
4		OP		R			TAC				
5		OP		A			MLS				
			THC	L			ADTA				
				A							
			SBTC	L							
				R							

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PASS GNC SYS SUMM 2, available in GNC OPS 1, 6, 2, 8 and 3

CRYO TK		1	2	3	4	5	MANF1	MANF2
H2 PRESS	211	211	238	238	145L	238	238	
O2 PRESS	834	833	858	858	515L	858	858	
HTR T1	-221	-221	-212	-194	-194			
T2	-221	-221	-212	-194	-194			

APU	1	2	3	HYD	1	2	3
TEMP EGT	20	15	11	PRESS	65	65	65
B/U EGT	16	15	15	RSVR T	72	72	72
OIL IN	51	59	57	P	0	0	0
OUT	56	54	59	QTY	55	55	55
SPEED %	0	0	0	W/B			
FUEL QTY	89	88	85	H2O QTY	97	94	92
PMP LK P	15	15	15	BYP VLV	BYP	BYP	BYP
OIL OUT P	24	24	24	THERM CNTL	1	2	
				H2O PUMP P	50	50	
AV BAY				FREON FLOW	2000	2000	
TEMP	50	88	82	EVAP OUT T	50	50	
FAN ΔP	3.59	3.64	3.67				

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PASS SM SYS SUMM 2, available in SM PS 2

Fault Detection and Annunciation

Five classes of alarms have been established. Class 1, Emergency, has no interface with software. Class 2, Caution and Warning (C/W), is the second highest alarm class. It is divided into primary (hardware-driven) and backup (software-driven) systems. An alarm of the software-driven class will result in the annunciation of the *BACKUP C/W ALARM* light on the C/W matrix on panel F7, the *MASTER ALARM* lights, and an associated tone. In addition, a fault message will be displayed upon the fault message line of the CRT. Class 3, Alert, triggers the *SM ALERT* light and corresponding tone. A fault message is displayed upon the fault message line. Class 5, Operator Errors, is the lowest priority alarm and is caused only by a crew entry error. It results in an *ILLEGAL ENTRY* fault message being displayed. Class 0, Limit Sense, provides a status indicator (down arrow, up arrow) to the right of the affected parameter on an appropriate CRT. No fault message, tone, or light is triggered.

The output of a fault message to the fault message line results in several indications requiring crew interface. Although generally the crew keyboard responses are similar, the effects of these responses differ for each class alarm.

The crew response to a class 2 backup fault message is:

1. Depress the *MASTER ALARM* pushbutton indicator. This will

RCS		OXID	FU	JET	ISOL						
MANF	FAIL	VLV	FAIL	VLV	VLV	N2 TK	P	REG	P	CL	CL
FWD	HE	P3048	2968								
	TK	P 247	248			ENG IN	P				
	QTY	67	67			OXID	258	258			
MANF	1	P 248	242		OP	FU	260	260			
	2	P 248	246		OP	VLV	1 - 3	0			
	3	P 250	246		OP		2	0 - 2			
	4	P 246	246		OP						
	5				OP						
AFT	HE	P3200	3144			HE	P3216	3160			
L	TK	P 245	249			R TK	P 251	249			
	QTY	82	83			QTY	84	84			
MANF	1	P 246	246		OP	1	P 242	246		OP	
	2	P 246	250		OP	2	P 250	246		OP	
	3	P 250	250		OP	3	P 246	258		OP	
	4	P 246	250		OP	4	P 246	242		OP	
	5				OP	5				OP	

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GNC SYS SUMM 2, available in GNC OPS 2 and 8

SMOKE		1/A	2/B	DC VOLTS	1/A	2/B	3/C	
CABIN		0.0		FC	30.6	30.1	31.0	
L/R FD		0.0	0.0	MAIN	30.6	30.1	31.0	
AV BAY	1	0.3	0.3	ESS	29.6	29.6	29.3	
	2	0.3	0.4					
	3	0.3	0.3	CNTL	1	29.4	29.4	29.6
					2	29.4	29.4	29.4
					3	29.4	29.4	29.4
PRESS		14.0		AC				
qP/dT-EQ		+0.0	+0.000	VOLT φA	118	118	117	
O2 CONC				φB	117	117	118	
PP02	3.00	3.00		φC	117	117	118	
FAN ΔP	5.00			AMPS φA	4.3	6.3	2.1	
HX OUT T	46			φB	5.5	6.6	2.2	
O2 FLOW	0.0	0.0		φC	3.1	5.0	3.2	
N2 FLOW	0.0	0.0		FUEL CBL				
IMU FAN	A	B	C	AMPS	180	232	146	
AV FC1	FC2	FC3		REAC VLV	OP	OP	OP	
SS1	22	21	22	STACK T	+202	+206	+200	
SS2	22	22	23	EXIT T	150	152	149	
SS3	23	21	21	COOL P	61	60	61	
TOTAL AMPS	557			PUMP				
KW	17							

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PASS SM SYS SUMM 1, available in SM OPS 2

extinguish the *MASTER ALARM* light and caution and warning tone.

2. *Depress the ACK key* (on the keyboard). The fault message will cease flashing. If the crewmember can examine the message while it flashes, this step is unnecessary. Depress the *ACK* key again to look at the next message in a stack if required.
3. *Depress the MSG RESET key*. Depression of this key removes the fault message from the fault message line. In addition, the *BACKUP C/W* light is extinguished. (Hardware-driven lights remain on until the problem is corrected.)

The crew response to a class 3 fault message is:

1. *Depress the ACK key*. This will cause the fault message to become static. Depression of the *ACK* key will also extinguish the *SM ALERT* light and tone. (The tone duration is set to a crew-selected length and may have stopped before the *ACK* key is pressed.) Depress the *ACK* key again to look at the next message in a stack if required.

2. *Depress the MSG RESET key*. This will remove the fault message from the fault message line. If the *ACK* key had not been depressed, the *MSG RESET* key would extinguish the *SM ALERT* light and tone.

A class 5 fault message displays a flashing "ILLEGAL ENTRY" on the fault message line. The crew response is simply to depress the *MSG RESET* key. This clears the fault message from the fault message line. The *ACK* key will not clear an "ILLEGAL ENTRY." It will cause messages stacked under the "ILLEGAL ENTRY" display to be acknowledged and cleared.

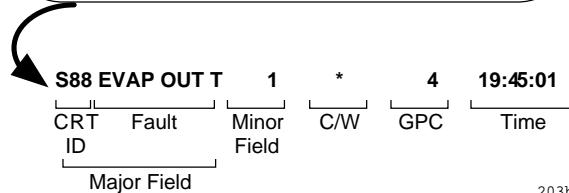
Some illegal keyboard entries are detected by the DEU before being sent to the GPCs. When this occurs, a flashing "ERR" appears immediately to the right of the erroneous entry on the scratch pad line. The crew response is simply to depress the *CLEAR* key. Upon depression of the *CLEAR* key, the "ERR" and the last keystroke will disappear. Subsequent depressions of the *CLEAR* key will remove single keystrokes, proceeding from right to left. This feature enables the crew to *CLEAR* back to the portion of the command that was incorrect, correct it, and proceed. This type of error is not identified by class, since it is not GPC-detected and is known simply as a DEU-detected error.

RCS	JET	ISOL				DPS	1	2	3	4	5
MANF	FAIL	VLV	SURF	POS	MOM						
F1	OP	L	OB			GPC					
2	OP	R	IB			MDM	FF				
3	OP	R	IB			FA					
4	OP		OB								
5	OP		AIL								
L1	OP		RUD			FCS	CH	1	2	3	4
2	OP		SPD	BRK							
3	OP		BDY	FLP							
4	OP										
5	OP					NAV		1	2	3	4
R1	OP					IMU					
2	OP		CNTLR	1	2	3	ACC				
3	OP		RHC	L			RG				
4	OP			R			TAC				
5	OP			A			MLS				
			THC	L			ADTA				
				A							
			SBTC	L							
				R							

Fault Messages

Fault messages associated with alarm classes 2, 3, and 5 follow a standard format of five fields.

The major field is a 14-character field. The first three characters identify the display on which more information about the annunciated failure can be found. An S or a G, followed by a two digit number, indicates the major function (G for GNC and S for SM) and the number of the SPEC or DISP. If no display is associated with the fault, this field is blank. In the example below, "S88" is the CRT ID and means that information on the fault can be found on SPEC 88 in SM.



Sample CRT Fault Message

The remaining characters identify the problem or subsystem group associated with the fault. In the example, "EVAP OUT T" is the FAULT portion of the major field and indicates a fault in the flash evaporator subsystem.

The minor field is a four-character field that further identifies the fault. It will specify the subdivision, direction, location, parameter, or specific unit of the subsystem or problem identified in the major field. In the example fault message, "1" is the minor field message and means that the temperature sensor 1 is the area in which the fault was detected.

The C/W field is used only with caution and warning class 2 backup messages. An asterisk appears in this column across from the corresponding fault to denote that the condition is a class 2 backup alarm.

The GPC field identifies the GPC that detected this fault. This characteristic aids the crewmember in locating or identifying internal GPC or I/O errors.

The far right field is the TIME field. This field indicates the time at which the fault occurred. The time is MET and is displayed in hours, minutes, and seconds (HH:MM:SS).

A complete listing of all possible fault messages can be found in the Flight Data File Reference Data Book and in Section 2.2.

A class 5 alarm is annunciated by an "ILLEGAL ENTRY" in the major field, and all other fault message fields are blank. When a class 5 message is received, it is displayed instantaneously on the fault message line of the CRT where the error occurred, rather than on all CRTs like class 2 and 3 errors. To get rid of the class 5 message, a MSG RESET must be done to the CRT where the error occurred. Class 2 backup and class 3 messages are extinguished by a MSG RESET on any CRT.

The Fault Summary Display

A historical summary of class 2 backup and class 3 fault messages is provided via the FAULT display (DISP 99). Class 5 errors are not displayed as they are caused by illegal crew entries to a single DEU. The FAULT display is a DISP available in all OPS. It is selected for viewing by depression of the FAULT SUMM key.

3021/	/099	FAULT		1	006/09:39:31
					000/00:00:00
CRT	FAULT	C/W	GPC	TIME	
ID					

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FAULT Display (DISP 99)

The PASS fault summary display consists of up to 15 fault message lines. They appear in reverse chronological order. The oldest message appears on the bottom line. When a new fault message is generated, it appears on the top line. The other messages are pushed down, and the 15th message (the oldest) disappears.

The only difference between the fault messages on the FAULT display and the fault message on the fault message line is the TIME field. On the FAULT display, the time field includes days as well as hours, minutes, and seconds (DDD/HH:MM:SS).

Sometimes, a subsystem failure or malfunction results in the output of several fault messages, some of which may be identical. The fault detection and annunciation logic can prevent the annunciation of identical fault messages. When a fault message is generated, its major and minor fields are compared to those of the top message of the display. If the fields are the same, and if the new fault message has occurred within a 4.8 second window, the new message is inhibited.

The last message displayed on the fault message line of any CRT is not necessarily the most recent fault message. Unless the fault message line was cleared with a MSG RESET, the crewmember will not see any new messages that came in after the flashing or frozen message. In that case, the crewmembers can see if a new message has been annunciated by looking at a two-character field. This field is called the buffer message indicator and is

located in the last field on the far right of the fault message line.

The buffer message indicator serves to indicate the number of messages in the fault buffer on the FAULT display since the last MSG RESET. This number includes class 2 backup and class 3 messages only. Class 5 messages and the currently displayed messages are not included in this counter. The number is enclosed by parentheses. If no fault messages are in the stack, this field is blank. To view any of these messages, the crewmember may depress the ACK key to display subsequent messages or look at the FAULT display. A MSG RESET clears both the fault message line and the buffer message indicator.

In addition to using the FAULT SUMM key, the FAULT display may also be selected by the keyboard entry "SPEC 99 PRO." However, this command will clear all fault messages from the FAULT display and the fault message lines. This capability is useful if and when the fault messages displayed are no longer significant (i.e., they are old, or they have been dealt with).

Crew Software Interface with the BFS

The crew software interface with the BFS is designed to be as much like PASS as possible, but there are some differences. This section covers the differences between the PASS's and BFS's crew and CRT interfaces. If something is not mentioned in this section, it can be assumed to operate the same as the PASS interface.

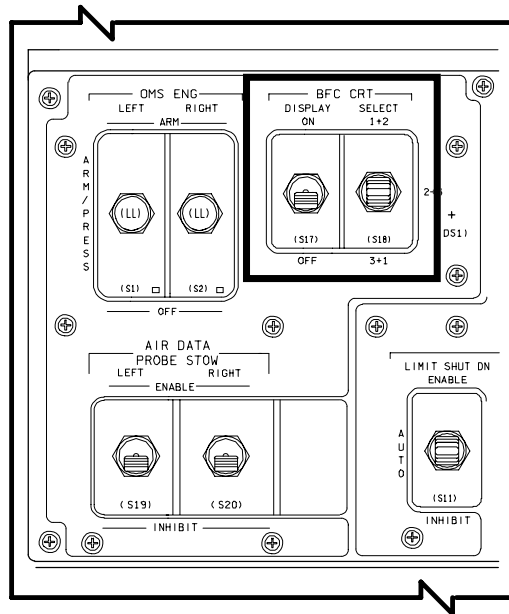
BFC CRT Switches

Panel C3 contains two switches relevant to BFS operations. The *BFC CRT DISPLAY* switch is a two-position ON/OFF switch. In the ON position, the CRT(s) specified by the *BFC CRT SELECT* switch is driven by the BFS computer. (The *BFC CRT SELECT* switch controls CRT assignment to the BFS computer.) The switch is read by the GPC only when the *BFC CRT DISPLAY* switch is in the ON position. The *BFC CRT SELECT* switch has three positions. In each position, the first digit is the CRT commanded by the BFS pre-engage. Post-engaged, the BFS also commands a second CRT indicated by the second number. For example, when the *BFC*

CRT SELECT switch is in the 1 + 2 position, CRT 1 is connected to the BFS GPC prior to engaging the BFS. After the BFS is engaged, this switch position allows the BFS computer to command both CRT 1 and CRT 2. In the 2 + 3 position, CRT 2 is commanded by the BFS GPC prior to engaging the BFS. Post-engaged, this switch allows CRT 2 and CRT 3 to be supported by the BFS computer. In the 3 + 1 position, CRT 3 is driven by the pre-engaged BFS GPC. Upon engaging the BFS, both CRT 3 and CRT 1 will be assigned to the BFS computer.

During ascent and entry, one CRT will normally be assigned to the BFS via the *BFC CRT SELECT* switch. The nominal position of the switch is the 3+1 position. However, this switch position may be changed at any time, pre-engage or post-engage. If the BFS is engaged with the *BFC CRT DISPLAY* switch OFF, the BFS will automatically assume command of CRTs 1 and 2.

No set of *BFC CRT* switches exists for the CRT in the aft station.



BFC CRT DISPLAY and SELECT Switches on Panel C3

BFS Functions of the MAJ FUNC Switch

The *MAJ FUNC* switches on panels C2 and R11L are also functional for the BFS. However, the display data and functional software accessed by the three-position switch are slightly differ-

ent. The BFS functions of the MAJ FUNC switch are defined as follows:

- *GNC*: Flight critical software including limited guidance, navigation, and control software is contained in this major function. The BFS GNC major function contains only that software necessary for safe orbital insertion and return, including ascent abort logic.
- *SM*: This major function contains limited nonredundant systems management and payload software. There is no room in the BFS for the redundancy management found in PASS. When the MAJ FUNC switch is set in the SM position, the THERMAL display is invoked. This display is unique to the BFS.
- *PL*: This major function is not functional for the BFS. Should the MAJ FUNC switch be set in this position, no display change would occur. If the *BFC CRT DISPLAY* switch is turned on, allowing the BFS to drive a CRT already in the PL major function, the CRT will be blank except for time and GPC driver fields because the BFS has no software to support this major function.

BFS ENGAGE Push Button

The BFS ENGAGE pushbutton is located on the commander's and pilot's rotational hand controllers (RHCs). During the dynamic flight phases (ascent and entry), the commander and pilot usually rest a hand on or near the RHC. In this way, BFS engagement can occur as quickly as possible. If the crew delays engagement during these flight phases, they could lose control of the vehicle, or the BFS' navigation calculations could degrade very quickly so that control would be essentially lost after engagement.

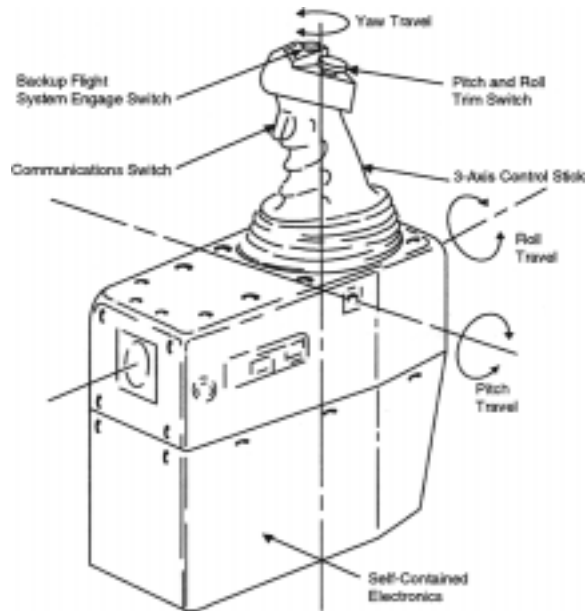
Some force (8 lb) is required to depress this pushbutton to prevent inadvertent engages. While on-orbit, the pushbutton is essentially disabled by reconfiguring the BFS OUTPUT switch. The BFS cannot track PASS while it is in OPS 2 and is moded to HALT on-orbit. If the BFS needs to be engaged on-orbit, the BFS must be "awakened", and the only software that will

be of any use is entry and systems management software.

Keyboard and Display Differences for the BFS

The keyboard operates exactly the same way for the BFS as for the PASS. A few additional capabilities need to be mentioned.

- The GPC/CRT key: In addition to the *BFC CRT DISPLAY* switch, this key provides the capability to assign a CRT to (or isolate a CRT from) the BFS GPC. Both methods can be used interchangeably, but as long as the *BFC CRT DISPLAY* switch is working, it is the fastest method of allowing the BFS to drive a CRT or to change BFS CRTs. The *BFC CRT DISPLAY* switch allows PASS to automatically begin driving the CRT again when the BFS is turned off. When the BFS is assigned a CRT with the GPC/CRT key, it is the same as deassigning that screen from PASS with a GPC/CRT OX EXEC. PASS must be reassigned to resume commanding of that CRT.
- The BFS INDICATOR: When the BFS is commanding a CRT, the BFS indicator will appear on the CRT being commanded. On the second line of every BFS display a three-character space field has been reserved for the message "BFS." This field is located directly below the GPC indicator. The BFS indicator is displayed in the overbright intensity and is intended to prevent possible confusion of a PASS display with a BFS display. Often the BFS display will be identical or very close to the corresponding PASS display.



Rotational Hand Controller

1011/ /018		GNC SYS SUMM 1		5 000/02:46:03	
				BFS 000/00:00:00	
SURF	POS	MDM		DPS	1 2 3 4
L OB				MDM FF	
IB				FA	
R IB				PL	
OB					
AIL				FCS CH	1 2 3 4
RUD					
SPD BRK					
BDY FLP					
MPS	L	C	R	NAV	1 2 3 4
HE TK P	4280	4230	4240	IMU	
REG P A	784	768	768	TAC	
B	776	766	770	ADTA	
dP/dT					
ULL P LH2	42.5	42.7	42.9	MPS PNEU HE P	
LO2	21.1	21.0	20.8	TK	4350
				REG	798
				ACUM	760
GH2 OUT P	70↓	50↓	40↓	MANF P LH2	46
GO2 OUT T	79↓	97↓	70↓	LO2	110

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BFS Indicator on CRT

BFS Display Sequencing

The BFS is designed to operate in the same manner as the PASS where possible. BFS requirements, however, demanded a distinction be made between BFS pre-engage and BFS post-engage major mode transitions and associated display sequencing.

BFS pre-engage major mode display sequencing is either automatic, or it may be performed in the same manner as that of the PASS. Before the BFS is engaged, the BFS CRT is listening to the PASS CRT across the display/keyboard (DK) buses and updating its software accordingly.

This is called DK listening and the BFS can hear PASS item entries, PASS major mode transitions, and PASS GPC/CRT assignments. On the other hand, the PASS doesn't know that the BFS exists, so it never DK listens to the BFS. Therefore, BFS major mode transitions are performed automatically as a function of the major mode transitions performed on a PASS keyboard. If the BFS does not follow the PASS major mode transitions, then the BFS must receive a manual OPS XXX PRO on its CRT.

BFS post-engage major mode display sequencing is the same as that of the PASS. After the BFS is engaged, the BFS GPC is on its own. It no longer listens to the PASS GPCs. Therefore, major mode display sequencing has been designed to be the same as that of the PASS.

Three operational sequences are defined for BFS GNC; one operational sequence is defined for the BFS SM. Transactions to and from these OPS displays differ considerably from the PASS. BFS keyboard and CRT peculiarities are outlined as follows:

- BFS GNC OPS 0 - BFS MEMORY display: This display is forced to the CRT when BFS is not processing either GNC OPS 1 or 3. Nominally, this occurs prior to ascent and again prior to entry. This display corresponds to the PASS GPC MEMORY display and performs the same functions for the BFS. It also performs some of the same functions as PASS SPEC 2, the TIME SPEC, in that

time updates can be performed along with selection of GMT or MET to be displayed. GPC MEMORY is the default display for PASS OPS 0, and the BFS MEMORY display is the default display for BFS GNC OPS 0.

- BFS GNC OPS 1 and 6 - Ascent: This OPS must be manually selected via a keyboard assigned to the BFS prelaunch. BFS GNC OPS 1 is available for use during the ascent portion of the mission. The OPS 6 transition is automatic upon abort selection with the ABORT rotary switch and pushbutton, or an OPS 601 PRO may be used.

0001/000/		BFS MEMORY		5 008/12:12:12	
				BFS 000/00:29:12	
READ/WRITE					
DATA 1*	BIT SET 3	SEQ ID 5			
CODE 2	BIT RST 4	WRITE 6			
7 ENG UNITS HEX 8*					
ADD ID	DESIRED	ACTUAL			
9	10				
11	12				
13	14				
15	16				
17	18				
19	20				
MEMORY DUMP			LAUNCH BUS 1 26	TFL ENA	
21 START ID			2 27	29	
22 NUMBER WDS		OFF 28*			
23 WDS/FRAME					
DUMP 24		PASS/BFS XFER ENA 25			
BFS TIME UPDATES		UPDATE 38	MISSION TIME		
30 GMT D[]	/	: : . .	GMT 39		
34 MET D[]	/	: : . .	MET 40		

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BFS MEMORY Display

- BFS GNC OPS 3 - Entry: This OPS must be manually selected from BFS GNC OPS 0 or BFS GNC OPS 1. BFS GNC OPS 3 is available for use during the entry portion of the mission. It is a legal transition to go from the BFS GNC OPS 1 to BFS GNC OPS 3 (for aborts), but nominally, the transition will be from BFS GNC OPS 0. In both cases, the manual keyboard entry "OPS 301 PRO" is required.

The major mode displays for BFS OPS 1, 3, and 6 are similar, if not identical, to their PASS counterparts. A complete listing of PASS and BFS displays can be found in the DPS Dictionary.

BFS Special Operations and Displays

In the pre-engaged mode, the BFS GPC performs BCE and MDM bypasses when PASS data are bypassed, or it sets its own bypasses. The I/O RESET command when made via the BFS keyboard restores those I/O configurations set by the BFS GPC. That is, a BFS "I/O RESET EXEC" restores the bypasses set by the BFS GPC. In addition, the I/O RESET operation attempts to synchronize the BFS with the PASS GPC listen commands so the BFS can track PASS.

Post-engage, the only bypasses set are those detected by the BFS GPC. The "I/O RESET EXEC" command functions to restore those bypasses.

The BFS systems summary displays operate the same way the PASS displays work. The BFS display numbers are the same as their PASS counterparts and some of the displays themselves are identical. However, three of the BFS SYS SUMM displays are unique to the BFS.

- GNC SYS SUMM. The GNC SYS SUMM consists of two DISPs. GNC SYS SUMM 1 is display format and content unique to BFS. It is called via the SYS SUMM key or by the command "SPEC 18 PRO." GNC SYS SUMM 2 is identical to the GNC SYS SUMM 2 display available in the PASS OPS 2 and 8. It is called by the command "SPEC 19 PRO" or by depressing the SYS SUMM key twice.

1011/ /018		GNC SYS SUMM 1		5 000/02:46:03	
				BFS 000/00:00:00	
SURF		POS	MDM	DPS 1 2 3 4	
L OB				MDM FF	
IB				FA	
R IB				PL	
OB					
AIL					
RUD				FCS CH 1 2 3 4	
SPD BRK					
BDY FLP					
MPS	L	C	R	NAV 1 2 3 4	
HE TK P	4280	4230	4240	IMU	
REG P A	784	768	768	TAC	
B	776	766	770	ADTA	
dP/dt					
ULL P LH2	42.5	42.7	42.9	MPS PNEU HE P	
LO2	21.1	21.0	20.8	TK	4350
				REG	798
				ACUM	760
GH2 OUT P	70↓	50↓	40↓	MANF P LH2	46
GO2 OUT T	79↓	97↓	70↓	LO2	110

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BFS GNC SYS SUMM 1, available in GNC OPS 1, 6, and 3 (Unique to BFS)

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

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BFS GNC SYS SUMM 2, available in GNC OPS 1, 6, and 3 (Identical to PASS GNC SYS SUMM 2 except shaded lines)

- SM SYS SUMM. There are two SM SYS SUMM displays. SM SYS SUMM 1 is identical to the PASS SM SYS SUMM 1, while BFS SM SYS SUMM 2 is a unique display. They are called in the same manner as the PASS SM SYS SUMM displays.
- THERMAL. This is a systems summary DISP available as the SM OPS 0 display in BFS. It is forced to the screen anytime the MAJ FUNC switch is placed in the SM position (unless an SM SPEC is called up over it). This display is unique to the BFS. It cannot be obtained with a SPEC key, and it never requires a keyboard entry.

0001/ /079 SM SYS SUMM 2 5 008/23:29:22									
BFS 000/00:00:00									
CRYO TK	1	2	3	4	5	MANF1	MANF2		
H2 PRESS	208	208	206	206	206	208	207		
O2 PRESS	816	815	814	814	814	815	815		
HTR T1	-248	-248	-248	-248	-248				
T2	-248	-248	-248	-248	-248				
APU	1	2	3	HYD	1	2	3		
TEMP EGT	942	942	942	PRESS	3064	3064	3064		
B/U EGT	942	942	942	ACUM P	3080	3080	3080		
OIL IN	250	250	250	RSVR T	116	153	142		
OUT	264	264	264	GG BED	511H	511H	511H	QTY	72 74 71
INJ	1271	1271	1271	INJ	1271	1271	1271		
SPEED %	99	102	101	W/B					
FUEL QTY	59	60	62	H2O QTY	78	73	78		
PMP LK P	14	14	14	BYP VLV	BYP	BYP	BYP		
OIL OUT P	42	42	41	FU TK VLV					
A T	63	65	62	THERM CNTL	1	28			
B T	63	65	62	H2O PUMP P	23	63			
AV BAY	1	2	3	FREON FLOW	2384	2384			
TEMP	97	97	83	EVAP OUT T	38	38			
A4 14	27.439	27.435	26.324	31.873	18.48				

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BFS SM SYS SUMM 2, available in SM OPS 0 (unique to BFS)

BFS Fault Messages

Several crew interface characteristics of fault annunciation in the BFS differ from those in the PASS.

- The BFS FAULT display. The BFS FAULT display functions in the same manner as the PASS. The BFS FAULT display is composed of 20 fault lines as compared to 15 in the PASS. The C/W field displays an asterisk when the message annunciated is a class 2 backup

0001/ /078 SM SYS SUMM 1 5 000/03:13:09									
BFS 000/00:00:00									
SMOKE	1/A	2/B	DC VOLTS	1/A	2/B	3/C			
CABIN	- 0.9		FC	31.1	31.1	31.1			
L/R FD	- 0.4	0.2	MAIN	31.0	31.1	31.0			
AV BAY 1-	1.2	- 0.0	CNTL AB	29.3	29.3	29.3			
2-	0.6	0.3	BC	29.3	29.3	29.3			
3-	0.1	- 0.9	CA	29.3	29.3	29.3			
CABIN			ESS	29.8	29.8	29.8			
PRESS	14.7		AC						
dP/dT	+ .00		VOLT φA	11.7	11.7	11.7			
BU/EQ	- .00	+ .00	φB	11.7	11.7	11.7			
PPO2	3.02	3.02	φC	11.7	11.7	11.7			
FAN P	5.79		AMPS φA	4.4	4.1	2.7			
HX OUT T	49		φB	3.9	4.2	3.2			
N2 FLOW	0.0		φC	2.4	3.2	4.8			
IMU FAN ΔP	4.62		FUEL CELL PH						
AV FC1	FC2	FC3	AMPS	172	167	178			
SS1	15	18	18	REAC VLV	OP	OP	OP		
SS2	16	20	11	STACK T	+204	+203	+203		
SS3	22	26	26	EXIT T	150	150	151		
TOTAL AMPS	510		COOL P	61	61	61			
KW	15		PUMP						

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BFS SM SYS SUMM 1, available in SM OPS 0 (Unique to BFS)

alarm. The BFS FAULT display provides a history of only class 2 backup and class 3 messages annunciated by the BFS GPC itself.

- BFS Unique CRT IDs. In BFS SM, all messages referring to SM SYS SUMM 1 or SM SYS SUMM 2 are indicated by the CRT IDs SM1 and SM2. Fault messages referring to the THERMAL display are indicated by the CRT ID SM0.

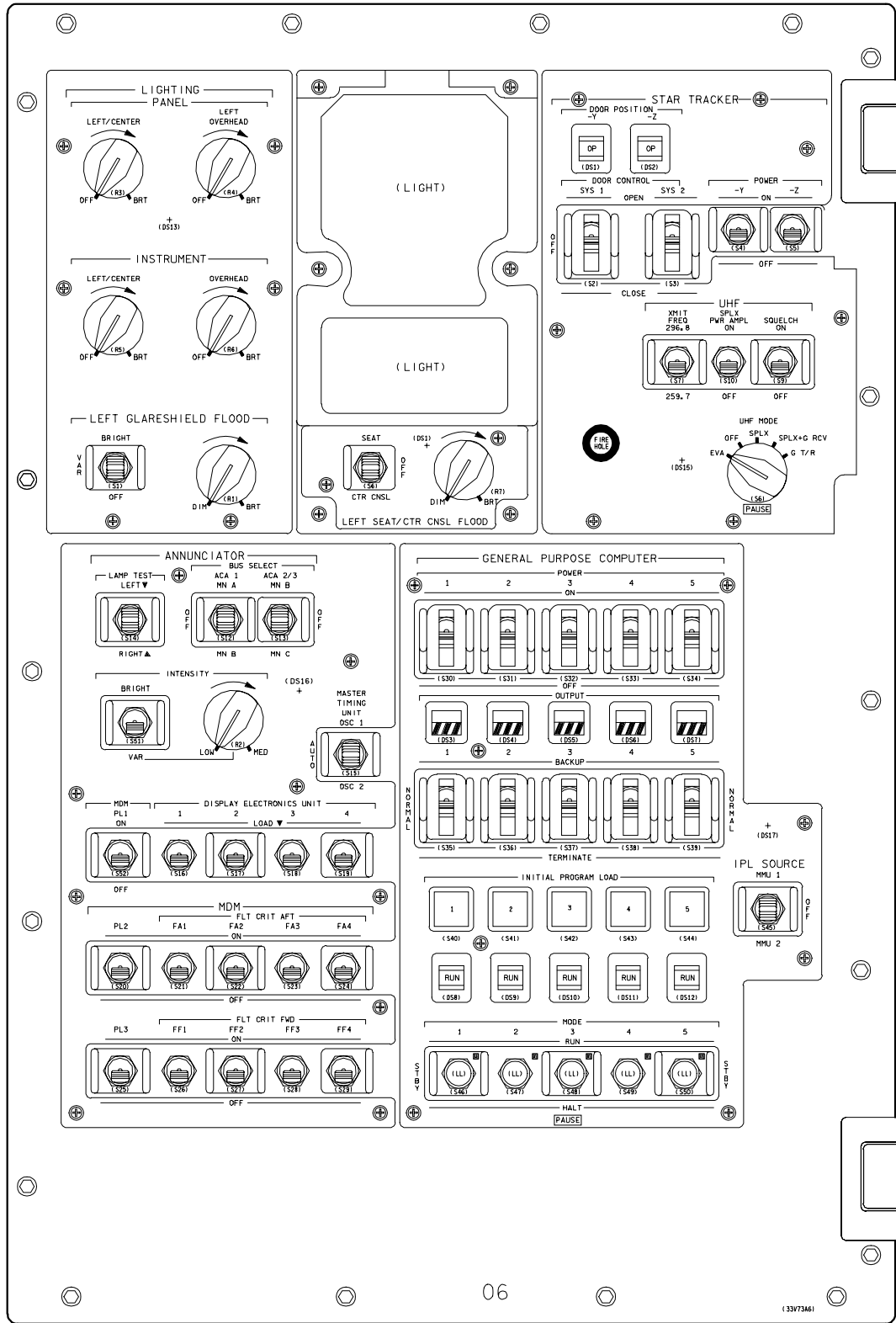
0001/		THERMAL		5 000/00:00:00			
				BFS 000/00:00:00			
HYD	SYS TEMP	BDYFLP	RD/SB	L OB	L IB	R IB	R OB
	PRIME	+ 99	+ 79	+ 76	+ 79	+ 76	+ 79
	STBY 1	+ 89	+ 79	+ 79	+ 79	+ 79	+ 79
BRAKE PRESS							
		HYD SYS	1/3	92	92	92	92
			2/3	92	92	92	92
HTR TEMP	L/A	R/B	FREON LOOP	1	2		
PRFLT			ACCUM QTY	34	34		
POD			RAD OUT T	109	109		
OMS CRSFD			H2O SUP P	0			
EVAP				TIRE PRESS			
HI LOAD			MG	LEFT	RIGHT		
TOP DUCT			IB	429 420	418 418		
NOZ			OB	421 421	416 416		
FDLN			NG	397 397	381 381		
		1	2	3			
HYD BLR/HTR							
APU							
GG/FU PMP HTR	H		H		H		
TK/FU LN HTR							
PUMP/VLV							

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**BFS THERMAL, available in SM OPS 0
(unique to BFS)**

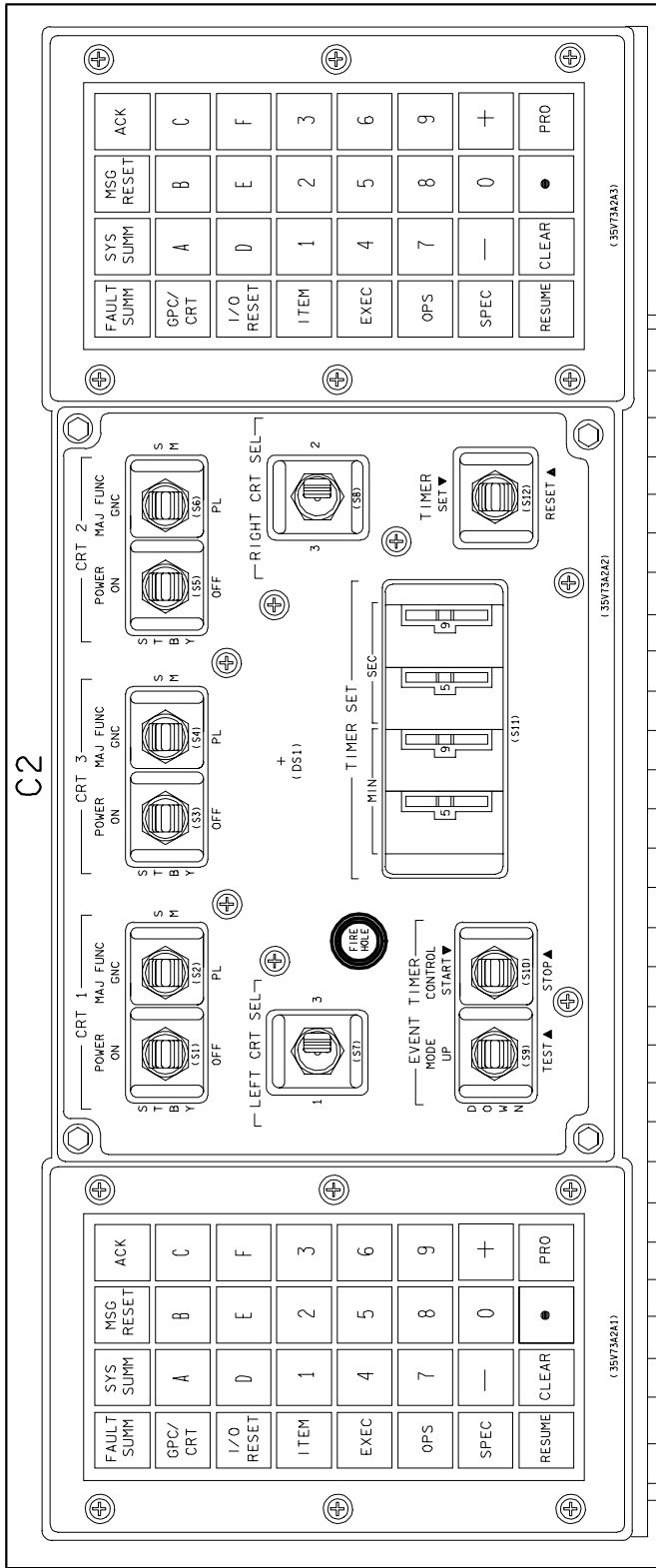
DPS Summary Data

- The DPS combines various hardware components and self-contained software to provide computerized monitoring and control.
- DPS hardware includes five GPCs, two mass memory units, a data bus network, 20 MDMs, four CRTs, and other specialized equipment.
- Each of the five GPCs consists of a CPU and an IOP stored in one avionics box. During ascent/entry, four of the GPCs are loaded with identical PASS software; the fifth is loaded with different software, the BFS.
- The data bus network transfers data between the GPCs and vehicle systems. There are seven types of data buses: flight-critical, payload, launch, mass memory, display/keyboard, instrumentation/PCMMU, and intercomputer communication.
- The 13 DPS MDMs convert data to appropriate formats for transfer between the GPCs and vehicle systems. OV 105 has all EMDMs.
- Two mass memory units provide bulk storage for software and data.
- Four CRTs (three on panel F7 and one on panel R11L) and associated keyboards provide the means for flight crew interaction with the GPCs.
- The two types of DPS software, system software and applications software, combine to form a memory configuration for a specific mission phase.
- The system software is operating software that always resides in GPC main memory.
- The applications software performs the functions required to fly and operate the vehicle. It is divided into three major functions: guidance, navigation, and control (GNC); systems management (SM); and payload (PL).
- Major functions are divided into mission phase oriented blocks called operational sequences (OPS).
- OPS are further divided into blocks called major modes (MM), which relate to specific portions of a mission phase.
- There are three levels of CRT displays: major mode or OPS, specialist (SPEC), and display (DISP).
- The four PASS GPCs control all GNC functions during ascent/entry mission phases; the fifth GPC is loaded with backup flight system (BFS) software to take over in case of PASS GPC failure.
- The BFS contains a limited amount of software; there are some operational differences between BFS and PASS.
- The BFS is engaged by pushbutton on the rotational hand controller.
- A GPC FAIL detection will display a class 2 GPC FAULT message with illumination of the MASTER ALARM. The GPC STATUS matrix (sometimes referred to as the computer annunciation matrix (CAM)) on panel O1 lights to indicate failure votes; any time a yellow matrix light is illuminated, the GPC caution and warning light on panel F7 also lights.
- Most DPS control switches are located on panels O6 and C2. Others may be found on panels C3, R11L, F2, F4, F6, and F7.
- CRT displays relevant to the DPS are: GPC/BUS STATUS (SPEC 6), GPC MEMORY (SPEC 0), DPS UTILITY (SPEC 1), and TIME (SPEC 2).



Panel O6

133V73461



Panel C2

2011/ /006 GPC/BUS STATUS 2 008/02:56:10
000/00:11:10

	GPC	1	2	3	4	5
MODE	RUN	RUN	HALT	RUN	HALT	
OPS	G2	G2	0	S2	0	
STRING 1	FF	*				↓
	FA	*				↓
2	FF		*			↓
	FA		*			↓
3	FF	*				↓
	FA	*				↓
4	FF					↓
	FA		*			↓
PL 1	↓	↓		*		
2	↓	↓		*		
LAUNCH 1	↓	↓		*		
2	↓	↓		*		
CRT 1	*					↓
2		*				↓
3		↓				↓
4	↓	↓		*		

202

GPC/BUS STATUS (SPEC 6)

2011/001/ DPS UTILITY 1 008/12:12:12
000/00:25:12

MMU ASSIGN	PORT ASSIGN	PRI	SEC	UL CNTL
1 2		15*	16	AUTO 35*
GNC 1* 2	STRING 1	2	17*	18 ENA 36
SM 3* 4		3	19*	20 INH 37
PL 5* 6		4	21*	22
OPS 0 7* 8	P/L 1/2	23*	24	IPL SOURCE SW MASK 38*

MMU STATUS	VAR PARAM ID LIST
1 RDY	25 9ABA
2 RDY	26 9ABB
	27 9ABC
MMU SOURCE/BUS	28 9ABD
GPC/MMU 9*	29 9ABE
MMU/MMU 10	30 9ABF
GPC/LDB 11	31 9ACA
	32 9ACB
CKPT RETRV	33 9ACC
ENA 12	34 9ACD
RTC	
13	
CMD 14	

G3 ARCHIVE
LOAD 48
RETRIEVE 49*

GROUND OPS
GSE POLL ENA 50
SM GSE INH 51
SM C/O ENA 52
GNC C/O ENA 53
BFC C/O ENA 54
ALT PL9 TB 55

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DPS UTILITY (SPEC 1)

2011/000/ GPC MEMORY 1 008/12:12:12
000/00:29:12

MEM/BUS CONFIG	READ/WRITE	GNC	SEQ ID
1 CONFIG 2(G2)	DATA 20*	BIT SET 22	24
2 GPC 1 2 0 0 0	CODE 21	BIT RST 23	WRITE 25
	26 ENG UNITS		HEX 27*
STRING 1	ADD ID	DESIRED	ACTUAL
2	28	29	
3	30	31	
4	32	33	
P/L 1/2	34	35	
	36	37	
CRT 1	38	39	
2			
3			
4			
LAUNCH 1	40 START ID		
2	41 NO WORDS		
MM 1	42 WDS/FRAME		
2	DUMP 43		
	44 DOWNLIST GPC 1		
	OPS 0 ENA 49		
OPS 3 UPLNK 50			
OPS 3 INIT 51	ERR LOG RESET 48		

MEMORY DUMP	STORE MC=02
40 START ID	45 CONFIG
41 NO WORDS	46 GPC
42 WDS/FRAME	STORE 47
DUMP 43	

MM AREA
PL 52 1
GNC 53 1
SM 54 1

238

GPC MEMORY (SPEC 0)

1061/002/ TIME 1 008/12:12:12
000/00:25:12

MISSION TIME	TONE	MSN T
GMT 1*	3	___:__:__ MSN T
MET 2	6	: : :
CRT TIMER		
9 SET []_:_:___	20 []_:_:___	CRT T
START 12	STOP 13	
14 START AT _:_:___	MSN T 23	DURATION
17 COUNT TO : : :	MSN T	

MTU
24 GMT Δ []_:_:___
28 MET Δ [] / : : .
UPDATE 32
MET RESET 33

GPC TIME	GMT	TRY	GPC
MTU ACCUM 1	008/12:12:12.000	34	1 A1
2	008/12:12:12.000	35	2 A1
3	008/12:12:12.000	36	3 A1
GPC 008/12:12:12.000		37	4 A1

TIME SYNC 38

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TIME (SPEC 2)

DPS Rules of Thumb

- Always HALT fail to sync GPCs and reassign their CRTs to good GPCs to avoid inadvertent entries (NBATs /restrings, burn targets, etc.).
- Before OPS transitions and restrings, always verify the appropriate NBAT is what you want it to be; never assume that it is correct! Also check the proper major function and GPC switch configuration.
- Make sure you have the correct memory configuration called up before you start making NBAT changes.
- During OPS transitions, keep "hands off" everything, including all switches and CRT entries.
- Clear the Fault Message line as soon as you have seen the message or use the ACK key to display subsequent messages.
- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both MODE and OUTPUT talkbacks are barberpole). If not, take the offending GPC to HALT (or if this doesn't work, power it OFF) immediately to avoid I/O problems on the flight critical strings.
- It is a very good idea to resume SPECS and DISPs from CRTs when not using them or before going to another major function on that CRT.
- It is important to be able to identify GPC failures. The information you provide will affect Mission Control analysis and its ability to plan for subsequent failures (both DPS and non DPS).
- Always hard assign CRTs (both PASS and BFS) via PASS CRTs (BFS will DK listen). You can cause dual CRT commanders if you try to assign BFS to a CRT that a PASS CRT is still driving.
- Always distribute your CRTs among different GPCs. On orbit, always be sure to minimize SM usage on all CRTs at the same time; if you lose SM, you also lose PASS CRT interface. The same is true if in single GPC GNC OPS, such as Spacelab missions.
- When using the GPC MODE switch, always take your hand off between positions. On past missions, there have been problems with the switch being in essentially two positions at the same time. This problem can occur on other orbiter switches too. It is a good idea to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.
- The CRT SEL switch should always be checked before making a keyboard entry, and data should always be checked on the CRT scratch pad line before it is entered.
- When moding PASS GPCs into the common set (i.e., STBY to RUN), always pause 10 seconds before and after switch throws to avoid a possible fail-to-sync and to ensure proper common set initialization.

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2.7 DEDICATED DISPLAY SYSTEMS

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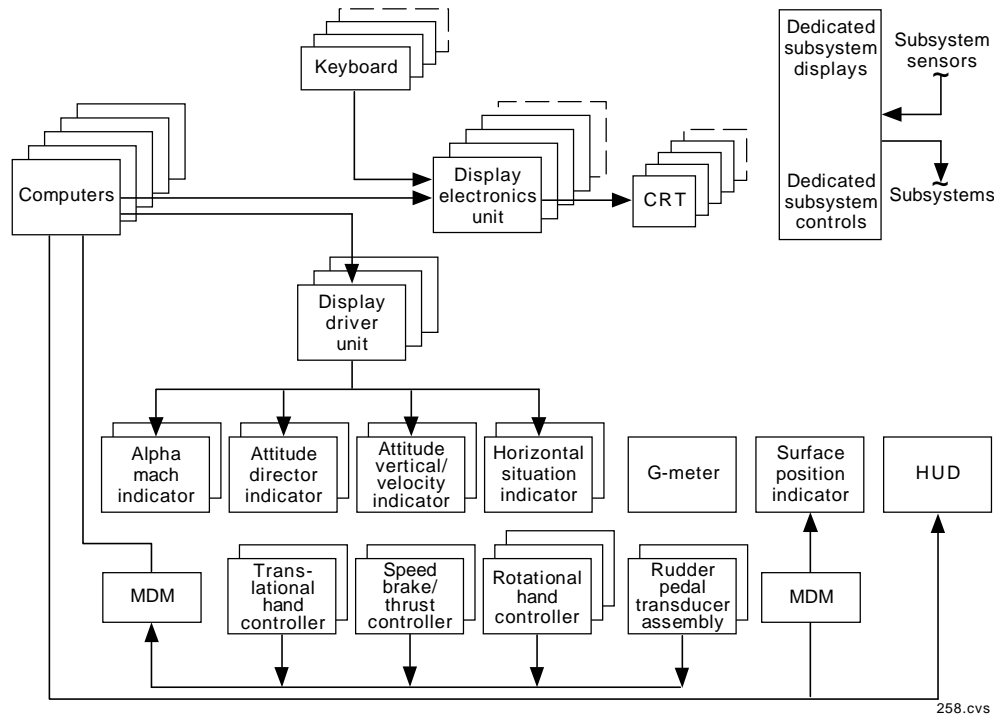
performance. The data on the dedicated displays may be generated by the navigation or flight control system software or more directly by one of the navigation sensors. The dedicated displays are located in front of the commander's and pilot's seats and on the aft flight deck panel by the aft-facing windows.

The dedicated displays are:

- Attitude director indicators on panels F6, F8, and A1U
- Horizontal situation indicators on panels F6 and F8
- Alpha/Mach indicators on panels F6 and F8
- Altitude/vertical velocity indicators on panels F6 and F8
- Surface position indicator on panel F7
- Reaction control system activity lights on panel F6
- G-meter on panel F7
- Head-up display on the glareshield in front of the commander's and pilot's seats

Description

Dedicated displays provide the flight crew with information required to fly the vehicle manually or to monitor automatic flight control system



Dedicated Display and Control System

Not all the dedicated displays are available in every operational sequence or major mode. Their availability is related to the requirements of each flight phase.

Display Driver Unit

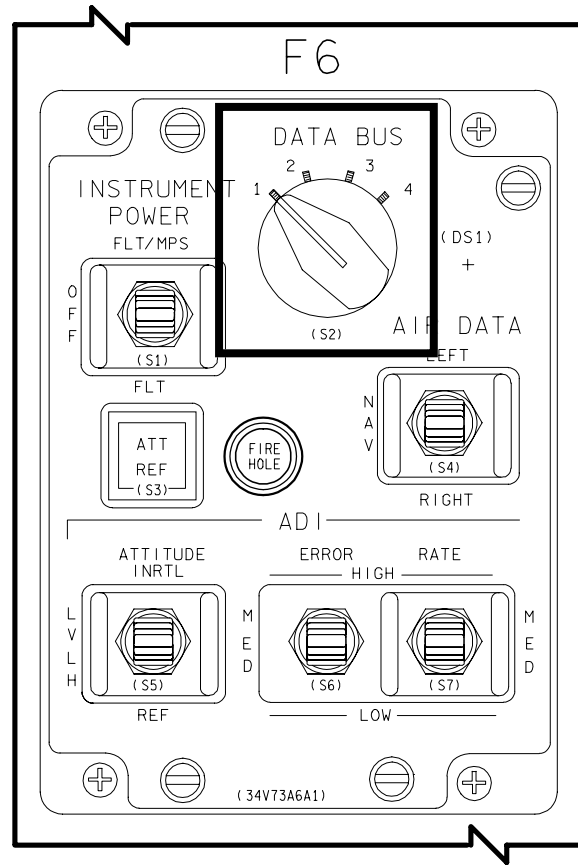
The display driver unit (DDU) is an electronic mechanism that connects the GPCs and the primary flight displays. The display driver unit receives data signals from the computers and decodes them to drive the dedicated displays. The unit also provides dc and ac power for the attitude director indicators and the rotational and translational hand controllers. It contains logic for setting flags on the dedicated instruments for such items as data dropouts and sensor failures.

All display parameters, regardless of their origin, are ultimately processed through the dedicated display subsystem operating program (SOP) software (except the g-meter, which is totally self-contained). The display parameters are then routed to the respective displays through either a DDU or multiplexer/demultiplexer (MDM); DDUs send data to the attitude director indicator, horizontal situation indicator, alpha/Mach indicator, and altitude/vertical velocity indicator displays; MDMs provide data for the surface position indicator and reaction control system activity lights. In addition, the HUD electronic units generate video symbology for the head-up display.

The orbiter contains three display driver units: at the commander's station, at the pilot's station, and at the aft station. One unit interfaces with the attitude director indicator, horizontal situation indicator, altitude/vertical velocity indicator, and alpha/Mach indicator displays on panel F6 at the commander's station, and the second interfaces with the same instruments on panel F8 at the pilot's station. The third interfaces with the attitude director indicator at the aft flight station.

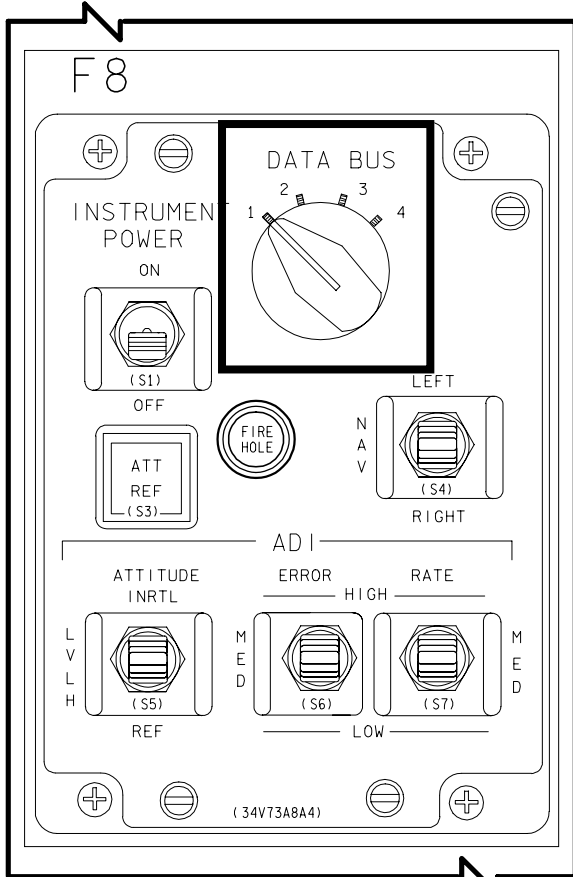
Each display driver unit has an associated *DATA BUS* rotary switch. The commander's switch is on panel F6, and the pilot's is on panel F8. The switch for the aft flight station is on panel A6U. Switch positions 1, 2, 3, and 4 allow the flight crew to select any one of four forward flight-critical data buses (FC1 through 4) as the

data source for that display driver unit and its dedicated displays. (Because the flight-critical data buses are assigned to specific orbiter GPCs, the *DATA BUS* select switch also provides a means of assessing the health of individual computers, if they are assigned to FC1, 2, 3, or 4. See Section 2.6 for detailed data bus information.)

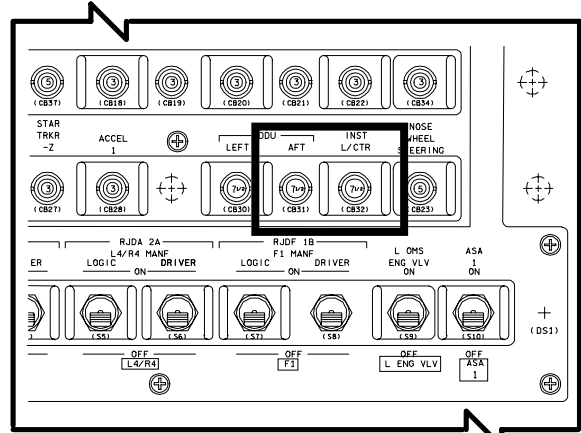


DATA BUS Switch on Panel F6

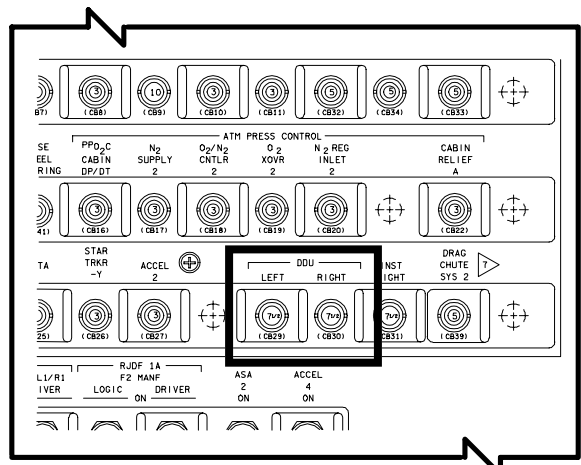
The commander's attitude director indicator is powered from the *MN A DDU LEFT* circuit breaker on panel O14 and the *MN B DDU LEFT* circuit breaker on panel O15 through DDU 1 power supply D, which provides ac and dc power. The pilot's attitude director indicator is powered from the *MN B DDU RIGHT* circuit breaker on panel O15 and the *MN C DDU RIGHT* circuit breaker on panel O16 through DDU 2 power supply D, which also provides ac and dc power. The aft flight station attitude director indicator is powered from the *MN A DDU AFT* circuit breaker on panel O14 and the *MN C DDU AFT* circuit breaker on panel O16 through DDU 3 power supply D, which provides ac and dc power.



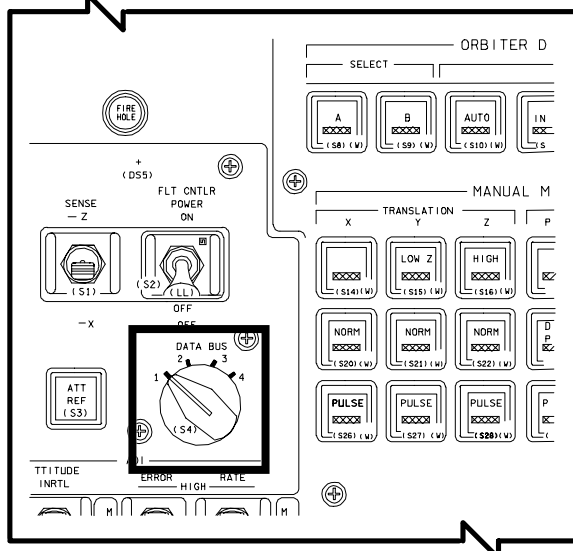
DATA BUS Switch on Panel F8



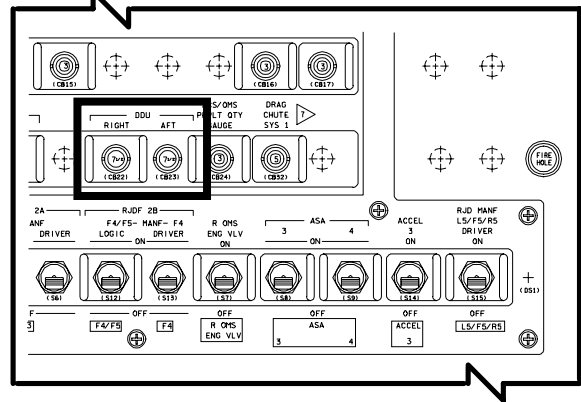
MN A DDU Circuit Breakers on Panel 014



MN B DDU Circuit Breakers on Panel 015



DATA BUS Switch on Panel A6U



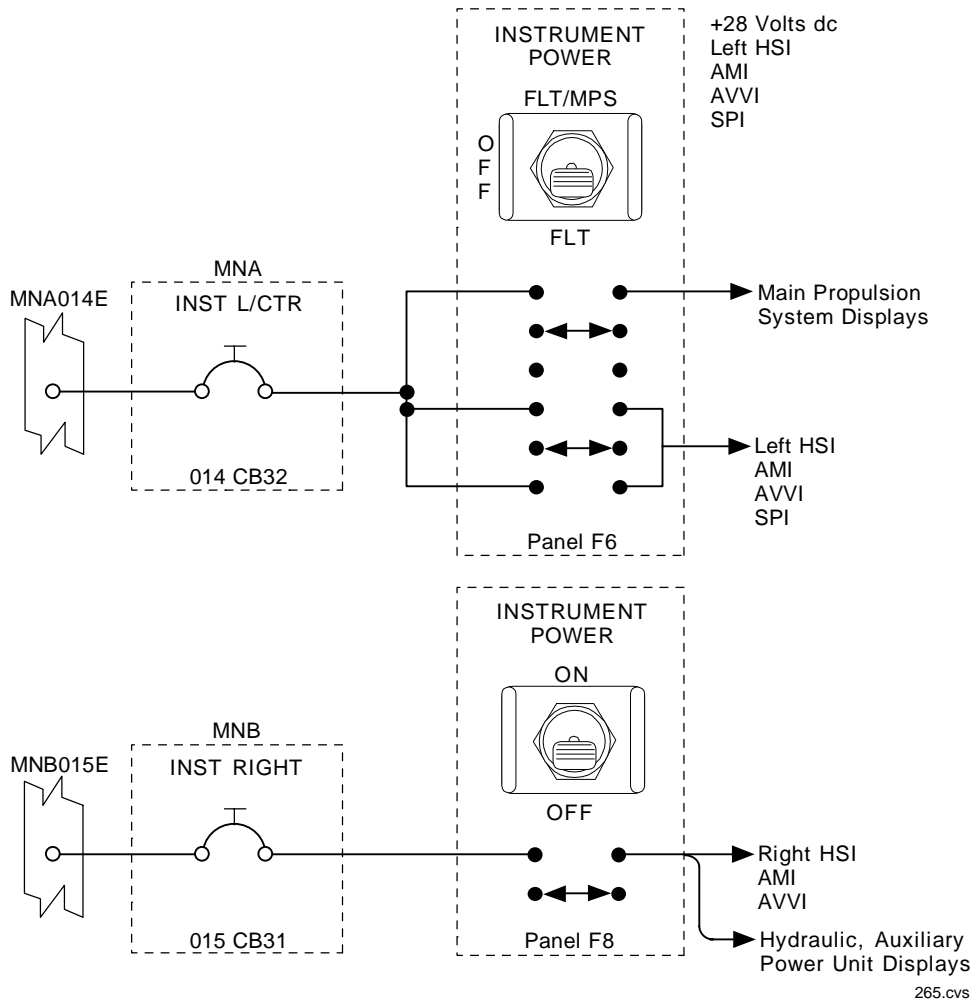
MN C DDU Circuit Breakers on Panel 016

The *INSTRUMENT POWER* switch on panel F6 supplies main bus A power to the commander's horizontal situation indicator, alpha/Mach indicator, and altitude/vertical velocity indicator displays, the single surface position indicator, and the main propulsion instruments when positioned to *FLT/MPS*. The *INSTRUMENT POWER* switch on panel F8 supplies main bus B power to the pilot's horizontal situation indicator, alpha/Mach indicator, and altitude/vertical velocity indicator displays and the hydraulic and auxiliary power unit displays. The switch on panel F8 is a two-position *ON/OFF* switch.

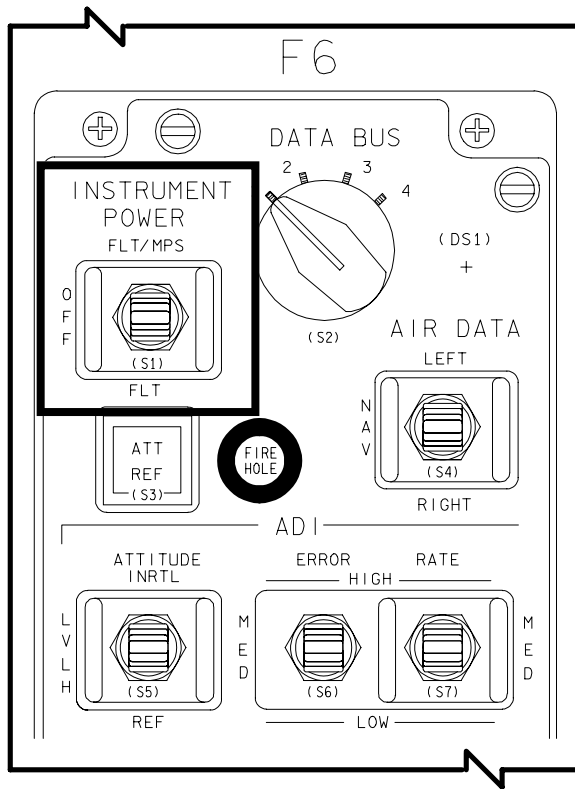
The reaction control system activity lights receive power from annunciator control assemblies.

Attitude Director Indicator (ADI)

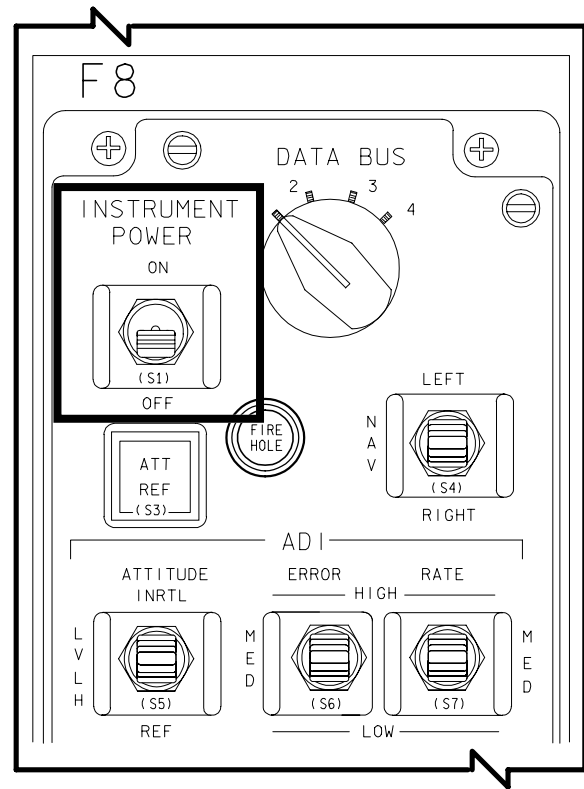
The commander's and pilot's attitude director indicators are supported throughout the mission; the aft attitude director indicator is active only during orbital operations. The indicators give the crew attitude information as well as attitude rate and attitude errors, which can be read from the position of the pointers and needles.



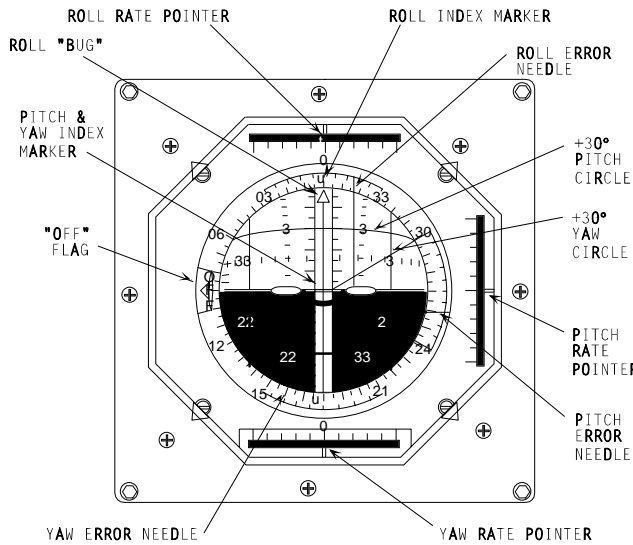
Power for Alpha/Mach Indicator, Altitude/Vertical Velocity Indicator, Horizontal Situation Indicator, and Surface Position Indicator



INSTRUMENT POWER Switch on Panel F6



INSTRUMENT POWER Switch on Panel F8



Attitude Director Indicator Displays 360-Degree Maneuvers in Roll, Pitch, and Yaw

- Positive Roll Command - Ball Rotates Counterclockwise
- Positive Pitch Command - Ball Rotates From Top to Bottom
- Positive Yaw Command - Ball Rotates From Left to Right
- Error Needle Deflections to Positive Commands
 - Roll - Left
 - Pitch - Down
 - Yaw - Left
- Rate Pointer Deflection to Positive Commands
 - Roll - Right
 - Pitch - Up
 - Yaw - Right

Attitude Director Indicator

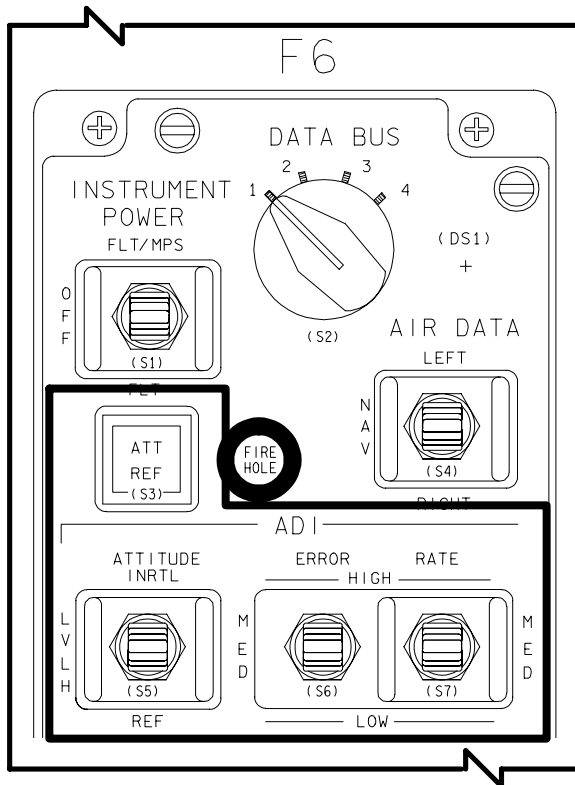
The orbiter's attitude is displayed to the flight crew by an enclosed ball (sometimes called the eight ball) that is gimbaled to represent three degrees of freedom. The ball, covered with numbers indicating angle measurements (a 0 is added as the last digit of each), moves in response to software-generated commands to

depict the current orbiter attitude in terms of pitch, yaw, and roll.

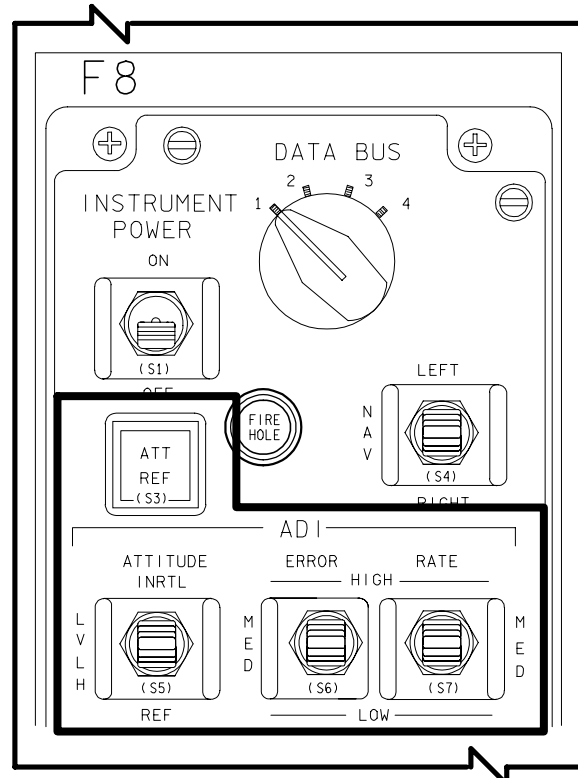
Each attitude director indicator has a set of switches by which the crew can select the mode or scale of the readout. The commander's switches are located on panel F6, the pilot's on panel F8, and the aft switches on panel A6U.

The *ADI ATTITUDE* switches determine the unit's frame of reference: *INRTL* (inertial), *LVLH* (local vertical/local horizontal), and *REF* (reference). The *INRTL* position allows the flight crew to view the orbiter's attitude with respect to the inertial reference frame, useful in locating stars. The *LVLH* position shows the orbiter's attitude from an orbiter-centered rotating reference frame with respect to Earth. The *REF* position is primarily used to see the orbiter's attitude with respect to an inertial reference frame defined when the flight crew last depressed the *ATT REF* pushbutton above the *ADI ATTITUDE* switch. The *REF* position is useful when the crew flies back to a previous attitude or monitors an OMS burn for attitude excursions. The switches on panels F6 and F8 are active during ascent, orbital, and transition flight phases but have no effect during entry, the latter part of a return to launch site, or when the backup flight system is driving the attitude director indicators. The switch on panel A6U, like the aft attitude director indicator, is operational only in orbit.

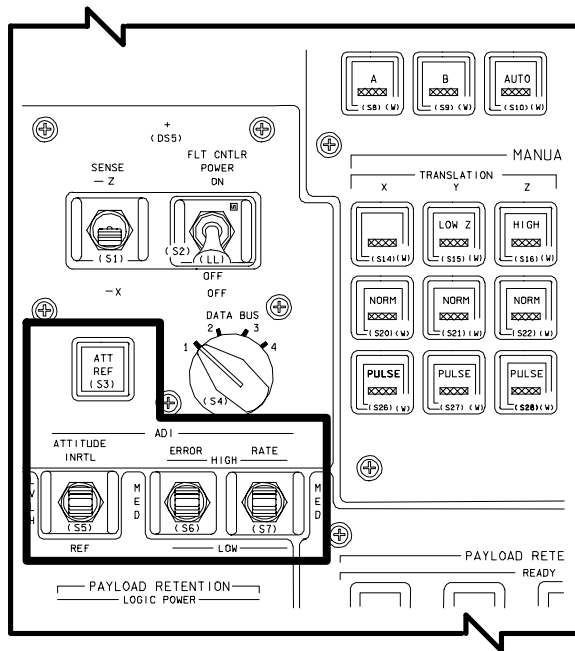
Each attitude director indicator has a set of three rate pointers that provide a continuous readout of vehicle body rotational rates. Roll, pitch, and yaw rates are displayed on the top, right, and bottom pointers respectively. The center mark on the graduated scale next to the pointers shows zero rates; the rest of the marks indicate positive (right or up) or negative (left or down) rates. The *ADI RATE* switch for each indicator unit determines the magnitude of full-scale deflection. When this switch is positioned to *HIGH* (the coarsest setting), the pointer at the end of the scale represents a rotation rate of 10° per second. When the switch is positioned to *MED*, a full-range deflection represents 5° per second. In the *LOW* position (the finest setting), a pointer at either end of the scale is read at a rate of 1° per second. These pointers are "fly to" in the sense that the rotational hand controller must be moved in the same direction as the pointer to null a rate.



Commander's ADI Switches and ATT REF Pushbutton on Panel F6



Pilot's ADI Switches and ATT REF Pushbutton on Panel F8



Aft ADI Switches and ATT REF Pushbutton on Panel A6U

Attitude director indicator rate readings are independent of the selected attitude reference. During ascent, the selected rates come directly from the solid rocket booster or orbiter rate gyros to the attitude director indicator processor for display on the rate pointers. During entry, only the pitch rate follows the direct route to the attitude director indicator display. The selected roll and yaw rates first flow through flight control, where they are processed and output to the attitude director indicator as stability roll and yaw rates. (This transformation is necessary because, in aerodynamic flight, control is achieved about stability axes, which in the cases of roll and yaw differ from body axes.) The rate needles strictly display vehicle rate information in all major modes except while in TAEM (MM 305, 603). For ascent, orbit, and most of entry, the HIGH position represents 10° per second, MED represents 5° per second, and LOW represents 1° per second. During TAEM, the ADI rate needles can be used to help fly the proper HAC profile as long as the rate switch is in MED (see table A).

Three yellow needles on each attitude director indicator display vehicle attitude errors. These needles extend in front of the attitude director indicator ball, with roll, pitch, and yaw arranged just as the rate pointers are. Like the rate indicators, each error needle has an arc-shaped background scale with graduation marks that allow the flight crew to read the magnitude of the attitude error. The errors are displayed with respect to the body axis coordinate system and, thus, are independent of the selected reference frame of the attitude display.

The attitude director indicator error needles are driven by flight control outputs that show the difference between the required and current vehicle attitude. These needles are also “fly to,” meaning that the flight crew must maneuver in the direction of the needle to null the needle. For example, if the pitch error needle points down, the flight crew must manually pitch down to null the pitch attitude error. The amount of needle deflection indicating the number of degrees of attitude error depends upon the position of the ADI ERROR RATE switch for each attitude director indicator and the flight phase. For ascent, orbit, and transition, in the HIGH position, the error needles represent 10°, MED represents 5°, and LOW represents 1°. For entry, the needles signify different errors in different phases (see table B).

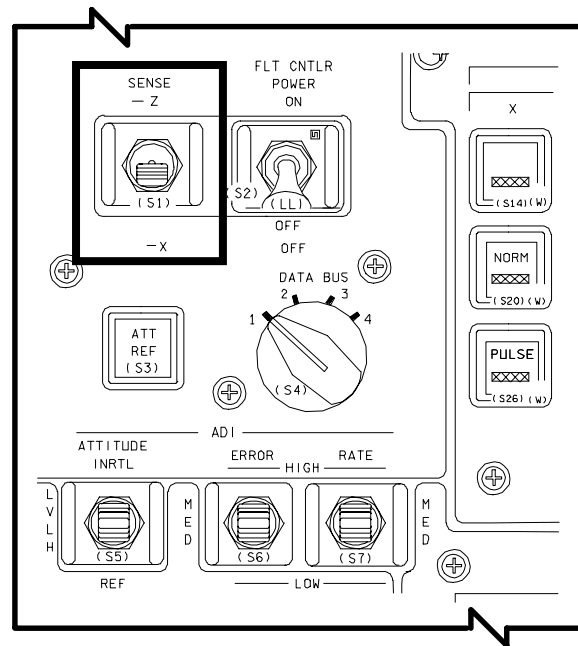
The SENSE switch on panel A6U allows the flight crew to use the aft attitude director indicator, rotational hand controller, and translational hand controller in a minus X or minus Z control axis sense. These two options of the aft attitude director indicator and hand controllers correspond to the visual data out of the aft viewing (negative X) or overhead viewing (negative Z) windows.

Each attitude director indicator has a single flag labeled OFF on the left side of the display whenever any attitude drive signal is invalid. There are no flags for the rate and error needles; these indicators are driven out of view when they are invalid.

MISSION PHASE	ROLL	PITCH	YAW
Ascent (101-106, 601)			
On-orbit (201, 202, 801)			
Transition/entry (301-304, 602)	(deg/s)	(deg/s)	(deg/s)
High	10	10	10
Medium	5	5	5
Low	1	1	1
TAEM to HAC intercept (305, 603)			
High	10 (deg/s)	10 (deg/s)	10 (deg/s)
Medium	Time to HAC intercept (10 sec)	Time to HAC intercept (10 sec)	Time to HAC intercept (10 sec)
Low	1 (deg/s)	1 (deg/s)	1 (deg/s)
HAC intercept to prefinal (305, 603)			
High	10 (deg/s)	10 (deg/s)	10 (deg/s)
Medium	Stowed	Altitude error (±5000 feet)	Altitude error (±5000 feet)
Low	1 (deg/s)	1 (deg/s)	1 (deg/s)
Prefinal to 7000 ft (305, 603)			
High	10 (deg/s)	10 (deg/s)	10 (deg/s)
Medium	Stowed	Altitude error (±1000 feet)	Altitude error (±1000 feet)
Low	1 (deg/s)	1 (deg/s)	1 (deg/s)
7000 ft to landing (305, 603)	(deg/s)	(deg/s)	(deg/s)
High	10	10	10
Medium	5	5	5
Low	1	1	1

(A) ADI Rate Switch vs. Full Range Deflection

MISSION PHASE	ROLL	PITCH	YAW
Ascent/ (101-106, 601)			
On orbit (201, 202, 801)			
Transition (301, 303)	(Deg)	(Deg)	(Deg)
High	10	10)
Medium	5	5	10
Low	1	1	5
			1
ENTRY (MM 304, 602)	(Deg)	(Deg)	(Deg)
High	25	10)
Medium	25	5	2.5
Low	10	1	2.5
			2.5
MM 603 IPH = 4.6			
TAEM (MM 305, 603)	(Deg)	(g's)	(Deg)
High	25	1.25)
Medium	25	1.25	2.5
Low	10	0.5	2.5
			2.5
IPH ≠ 4,5 WOWLON = 0			
WOWLON = 1			
Rollout (MM 305, 603)	(Deg)	(Deg/s)	(Deg)
High	20	10)
Medium	5	5	2.5
Low	1	1	2.5
			2.5



SENSE Switch on Panel A6U

(B) ADI Error Switch vs. Full Range Deflection

Horizontal Situation Indicator (HSI)

The horizontal situation indicator for the commander (panel F6) and pilot (panel F8) displays a pictorial view of the vehicle's position with respect to various navigation points and shows a visual perspective of certain guidance, navigation, and control parameters, such as direction, distance, and course/glide path deviation. The flight crew uses this information to control or monitor vehicle performance. The horizontal situation indicators are active during the entry and landing and ascent/return to launch site phases.

Each horizontal situation indicator provides an independent source to compare with ascent and entry guidance, a means of assessing the health of individual navigation aids during entry, and information needed by the flight crew to fly manual ascent, return to launch site, and entry.

HSI Ascent Displays

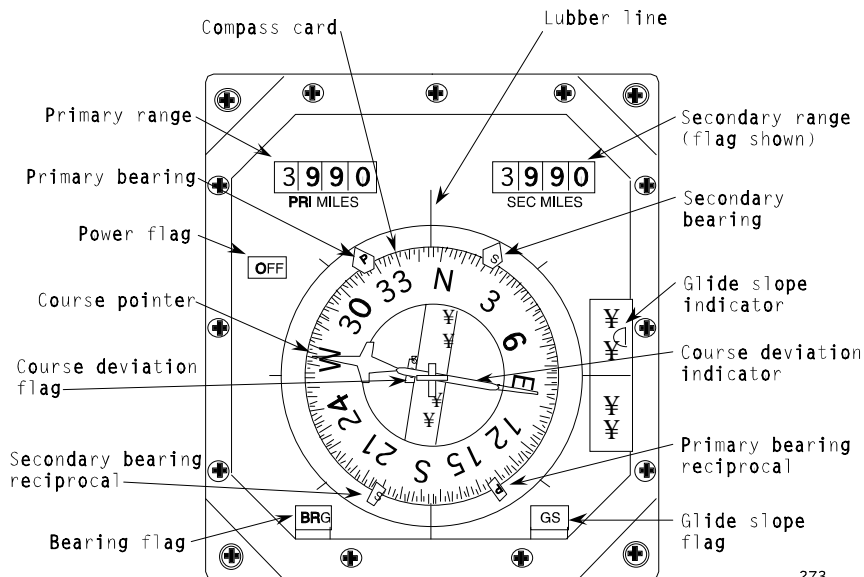
During ascent major modes 102 and 103 (first and second stage) and return to launch site, the horizontal situation indicator provides information about the target insertion orbit. The compass card displays heading with respect to target insertion orbit, and north on the compass card points along the target insertion orbit plane. The heading of the body plus X axis with respect to the target insertion orbit is read at the lubber line.

The course pointer provides the heading of the Earth-relative velocity vector with respect to the target insertion orbit plane. The course deviation indicator deflection indicates the estimated sideslip angle, the angle between the body X axis and the relative velocity vector.

The primary bearing pointer during major modes 102 and 103 (pre-TAL abort) is fixed on the compass card at a predetermined value to provide a turnaround heading in the event of a return to launch site (RTLS) abort. During RTLS major mode 601, or post-TAL abort, MM103, the pointer indicates the heading to the landing site runway. The secondary bearing provides the heading of the inertial velocity vector with respect to the target insertion orbit plane.

HSI Entry Displays

The commander's horizontal situation indicator switches are on panel F6, and the pilot's are on panel F8. The *HSI SELECT MODE* switch selects the mode: *ENTRY*, *TAEM*, or *APPROACH*. These Area Navigation modes are different from the Guidance phases with virtually identical names (Entry, TAEM, and Approach and Landing). The *ENTRY* position enables HSI mode auto switching from Entry through Approach. The *HSI SELECT SOURCE* switch selects TACAN, navigation, or microwave scanning beam landing system (MLS); the



Horizontal Situation Indicator

1, 2, 3 switch selects one of the three TACAN or MLS units. When the *HSI SELECT SOURCE* switch is positioned to *NAV*, the HSI is supplied with data from the navigation processor, and the 1, 2, 3 switch is not used.

SOURCE switch selects TACAN, navigation, or microwave scanning beam landing system (MLS); the 1,2,3 switch selects one of the three TACAN or MLS units. When the *HSI SELECT SOURCE* switch is positioned to *NAV*, the HSI is supplied with data from the navigation processor, and the 1,2,3 switch is not used.

In *TACAN* or *MLS*, the horizontal situation indicator is supplied with data derived from the unit specified by the 1, 2, 3 switch.

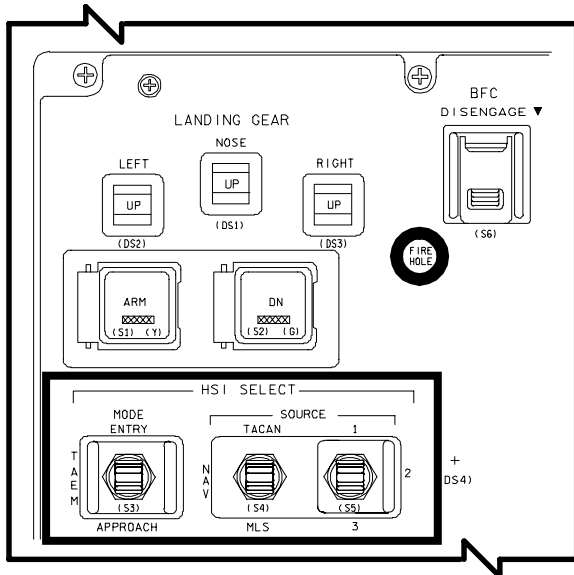
HSI Display Parameters

Each horizontal situation indicator displays magnetic heading (compass card), selected course, runway magnetic heading, course deviation, glide slope deviation, primary and secondary bearing, primary and secondary range, and flags to indicate validity.

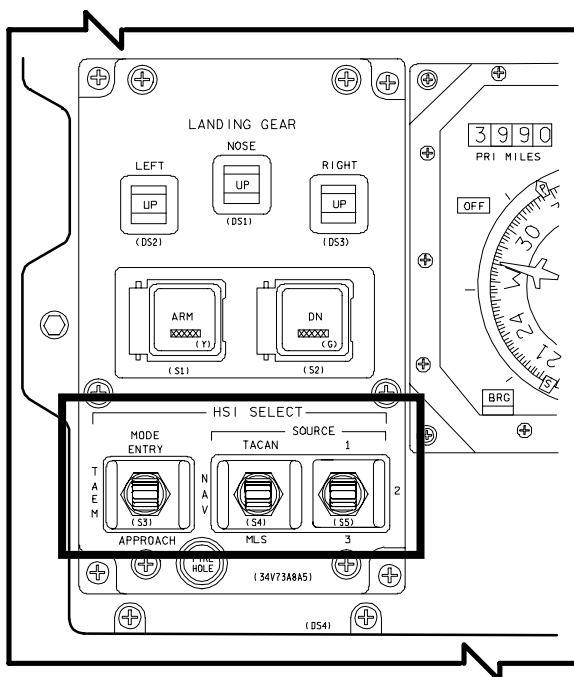
Each horizontal situation indicator consists of a case-enclosed compass card measuring 0° to 360°. At the center of the card is an aircraft symbol, fixed with respect to the case and about which the compass card rotates.

The magnetic heading (the angle between magnetic north and vehicle direction measured clockwise from magnetic north) is displayed by the compass card and read under the lubber line located at the top of the indicator dial. (A lubber line is a fixed line on a compass aligned to the longitudinal axis of the craft.) The compass card is positioned at 0° (north) when the heading input is zero. When the heading point is increased, the compass card rotates counterclockwise.

The course pointer is driven with respect to the horizontal situation indicator case rather than the compass card. Therefore, a course input (from the display driver unit) of zero positions the pointer at the top lubber line, regardless of compass card position. To position the course pointer correctly with respect to the compass card scale, the software must subtract the vehicle magnetic heading from the runway azimuth angle (corrected to magnetic north). As this subtraction is done continuously, the course pointer appears to rotate with the compass card, remaining at the same scale position. An increase in the angle defining runway heading results in a clockwise rotation of the course pointer.

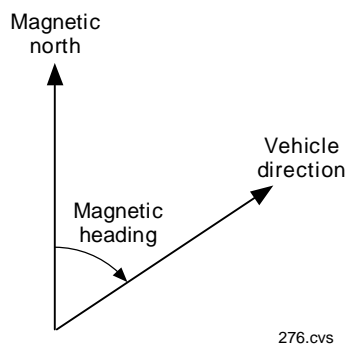


Commander's HSI SELECT Switches on Panel F6



Pilot's HSI SELECT Switches on Panel F8

Course deviation is an angular measurement of vehicle displacement from the extended runway centerline. On the HSI, course deviation is represented by the deflection of the deviation bar from the course pointer line. Full scale on the course deviation scale is $\pm 10^\circ$ in terminal area energy management and $\pm 2.5^\circ$ during approach and landing. The course deviation indicator is driven to zero during entry. When the course deviation input is zero, the deviation bar is aligned with the end of the course pointer. With the pointer in the top half of the compass card, an increase in course deviation to the left (right) causes the bar to deflect to the right (left). Therefore, the course deviation indicator is a fly-to indicator for flying the vehicle to the extended runway centerline. Software processing also ensures that the course deviation indicator remains fly to, even when the orbiter is heading away from the runway.



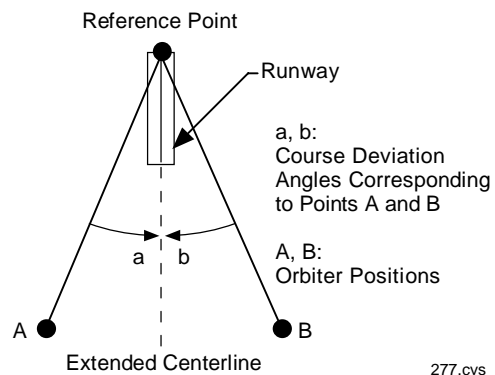
**Horizontal Situation Indicator
Heading Geometry**

In course deviation geometry, if the orbiter is to the left of the runway, it must fly right (or if the orbiter is to the right of the runway, it must fly left) to reach the extended runway centerline. The corresponding course deviation bar would deflect to the right (or to the left in the latter case). The reference point at the end of the runway is the microwave landing system station. The sense of the course deviation indicator deflection is a function of vehicle position rather than vehicle heading.

Glide slope deviation, the distance of the vehicle above or below the desired glide slope, is indicated by the deflection of the glide slope pointer on the right side of the horizontal situation indicator. An increase in glide slope deviation above (below) the desired slope

deflects the pointer downward (upward); the pointer is a fly-to indicator.

The “desired glide slope” is actually only a conceptual term in horizontal situation indicator processing. At any instance, glide slope deviation is really the difference between the orbiter altitude and a reference altitude computed by Area Nav. This reference altitude may be slightly different than the reference altitude computed by Guidance. Also included in the reference altitude equation are factors for a “heavy orbiter” and for high winds.

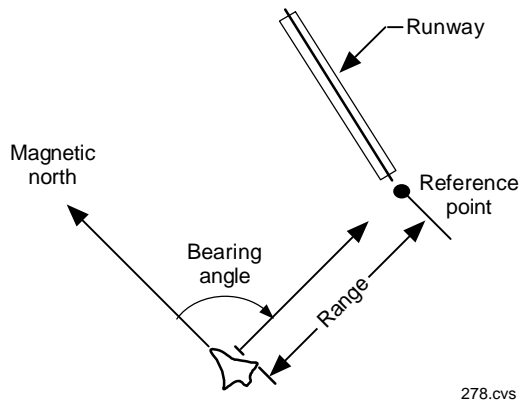


Course Deviation Geometry

The glide slope indicator computation is not made during entry or below 1,500 feet during approach and landing; therefore, the pointer is stowed, and the glide slope indicator flag is displayed during those intervals.

The primary and secondary bearing pointers display bearings relative to the compass card. These bearings are angles between the direction to true or magnetic north and to various reference points as viewed from the orbiter. For the bearing pointers to be valid, the compass card must be positioned in accordance with vehicle heading input data.

When the bearing inputs are zero, the pointers are at the top lubber line, regardless of compass card position. Like the course pointer, the bearing pointer drive commands are developed by subtracting the vehicle heading from the calculated bearing values. This allows the pointers to be driven with respect to the horizontal situation indicator case but still be at the correct index point on the compass card scale.



278.cvs

Horizontal Situation Indicator Bearing and Range Geometry

When the bearing inputs are increased, the pointers rotate clockwise about the compass card. The pointer does not reverse when it passes through 360° in either direction.

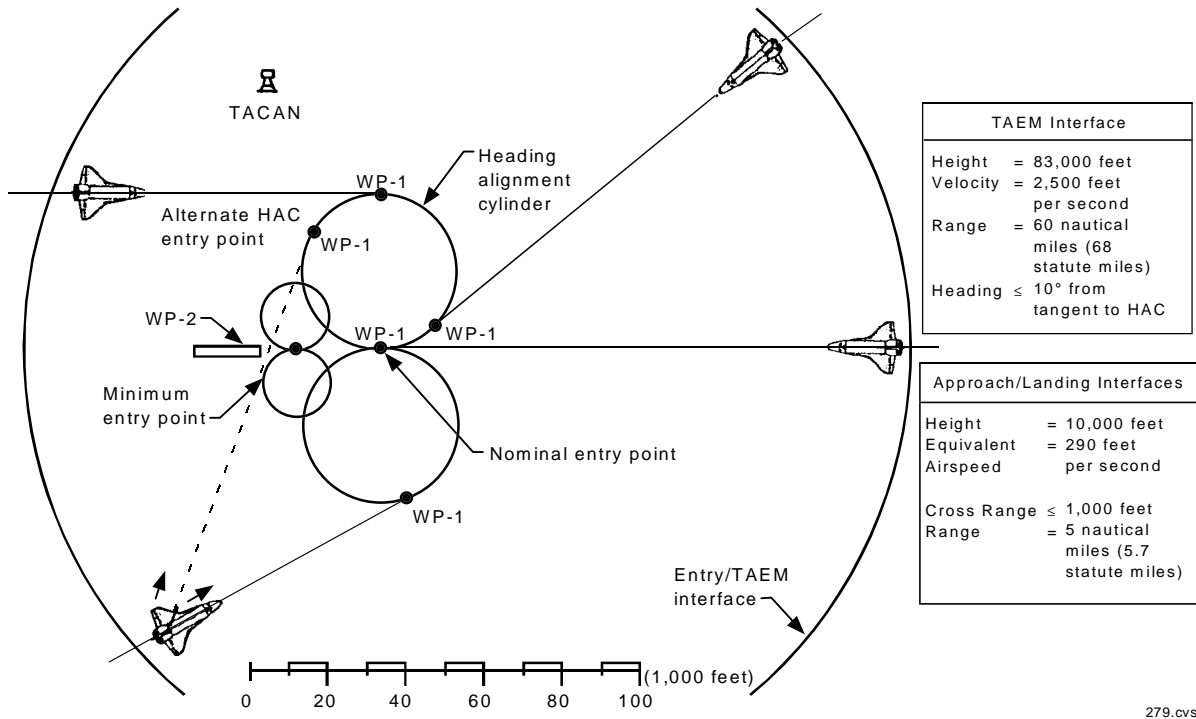
For example, if the primary bearing is 190° , and the secondary bearing is 245° , the bearing reciprocals are always 180° from (opposite) the pointers. The definition of primary and secondary bearing varies with the flight regime.

The horizontal situation indicator is capable of displaying two four-digit values in the upper left (primary range) and right (secondary range) side of its face. Each display ranges from zero to 3,999 n. mi. (4,602 statute miles). Although their meaning depends on the flight regime, both

numbers represent range in nautical miles (n. mi.) from the vehicle to various points relative to the primary and secondary runways.

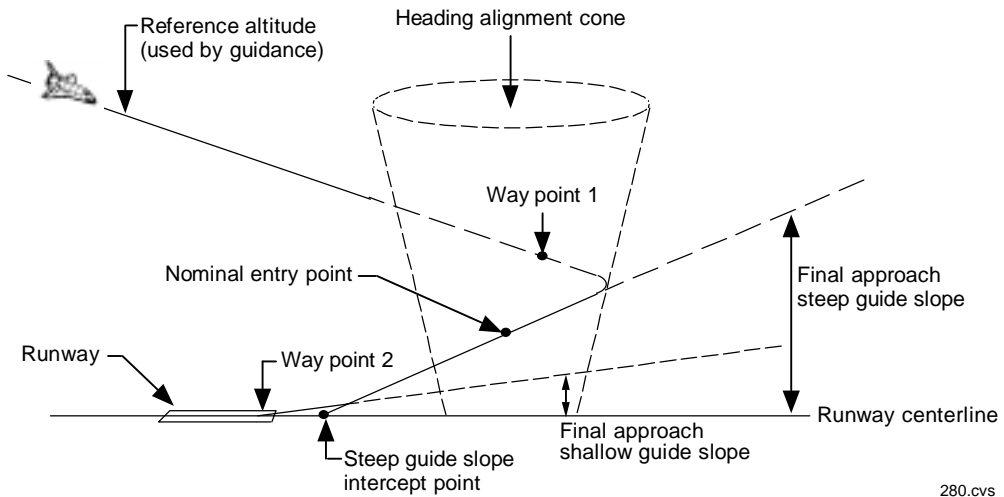
The horizontal situation indicator has four flags — *OFF*, *BRG* (bearing), *GS* (glide slope), and *CDI* — and two barberpole indications that can respond to separate display driver unit commands, identifying invalid data. *OFF* indicates that the entire horizontal situation indicator display is invalid because of insufficient power. *BRG* indicates invalid course, primary bearing, and/or secondary bearing data. *GS* indicates invalid glide slope deviation. *CDI* indicates invalid course deviation data. Barberpole in the range slots indicates invalid primary or secondary range data.

When the *HSI SELECT SOURCE* switch on panel F6 or F8 is positioned to *NAV*, the entire horizontal situation indicator display is driven by navigation-derived data from the orbiter state vector. This makes the horizontal situation indicator display dependent on the same sources as the navigation software (IMU, selected air data, selected navigational aids), but the display is independent of guidance targeting parameters. When the switch is in the *NAV* position, the *SOURCE 1, 2, 3* switch is not processed.



279.cvs

HSI Flight Path Geometry-Top View



280.cvs

HSI Flight Path Geometry-Side View

The TACAN or MLS position of the HSI SELECT SOURCE switch should be used only when TACAN or microwave landing system data are available. TACAN data are used during entry to update the navigation state, and are usually acquired about 300 n. mi. from the landing site. MLS has a range of 20 n. mi. and would be selected after the orbiter is on the heading alignment cone.

The glide slope deviation pointer is stowed when the entry mode is selected, and the off flag is displayed. The glide slope indicator in TAEM indicates deviations from the guidance reference attitude $\pm 5,000$ feet. The glide slope indicator during approach and landing indicates guidance reference altitude $\pm 1,000$ feet. The glide slope indicator is stowed below 1,500 feet and the off flag is in view.

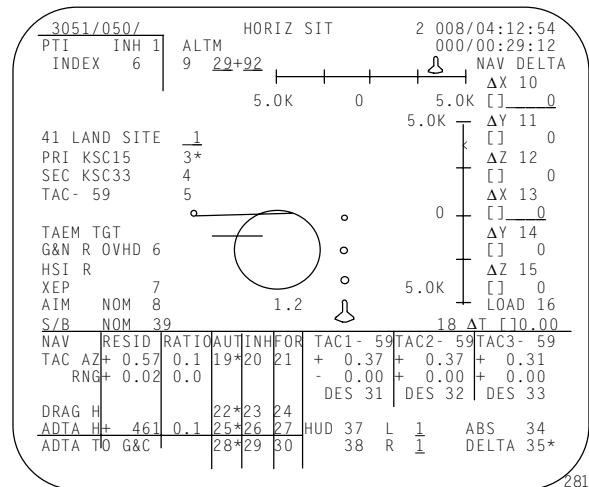
In the entry mode, the compass card heading indicates the magnetic heading of the vehicle's relative velocity vector. In terminal area energy management and approach, the compass card indicates magnetic heading of the body X axis.

In the entry mode, the course deviation indicator is driven to zero with no flag. In terminal area energy management, the course deviation indicator indicates the deviation from the extended runway centerline, $\pm 10^\circ$. In approach, the course deviation indicator indicates the deviation from the extended runway centerline, $\pm 2.5^\circ$.

In the entry mode, the primary bearing indicates the great circle bearing to the heading alignment cone (HAC) tangency point (way point 1) for the nominal entry point at the selected landing runway. The secondary bearing provides identical data relevant to the secondary landing runway. In terminal area energy management (TAEM), the primary bearing indicates the bearing to way point 1 on the selected HAC for the primary runway while the secondary bearing indicates the center of the HAC for the primary runway. In approach, the primary and secondary bearings indicate the bearing to the touchdown point at the primary runway (way point 2).

In the entry mode, the primary range indicates the spherical surface range to way point 1 for the primary runway via the HAC for the nominal entry point. The secondary range

provides identical information relevant to the secondary runway. In TAEM, the primary range indicates the horizontal distance to way point 2 on the primary runway via way point 1. The secondary range indicates the horizontal distance to the center of the selected HAC. In approach, the primary and secondary ranges indicate the horizontal distance to way point 2 on the primary runway.



HORIZ SIT Display (SPEC 50)

The HORIZ SIT display (SPEC 50) allows the flight crew to configure the software for nominal winds or high head winds. The "XEP" item 7 entry determines the distance from the runway threshold to the intersection of the glide slope with the runway centerline or aim point. The high-wind aim point or close in aim point pushes the intercept point closer to the threshold. The distance selected is factored into the computation of reference altitude from which the glide slope deviation is derived.

Alpha/Mach Indicator

The two alpha/Mach indicators are located to the left of the attitude director indicators on panels F6 and F8. The alpha Mach indicators consist of four tape meters displaying angle of attack (ALPHA), vehicle acceleration (ACCEL), vehicle velocity (M/VEL), and equivalent airspeed (EAS). The two units are driven independently but can have the same data source.

ALPHA displays vehicle angle of attack, defined as the angle between the vehicle plus X axis and the wind-relative velocity vector (negative wind

vector). *ALPHA* is displayed by a combination moving scale and moving pointer. For angles between -4° and $+28^\circ$, the scale remains stationary, and the pointer moves to the correct reading. For angles less than -4° or greater than $+28^\circ$, the pointer stops (at -4 or $+28^\circ$), and the scale moves so that the correct reading is adjacent to the pointer. The *ALPHA* tape ranges from -18° to $+60^\circ$ with no scale changes. The negative scale numbers (below zero) have no minus signs; the actual tape has black markings on a white background on the negative side, and white markings on a black background on the positive side.

The M/VEL scale displays one of the following: Mach number, relative velocity, or inertial velocity. Mach number is the ratio of vehicle airspeed to the speed of sound in the same medium. The relative velocity is in feet per second in relation to the launch site. Inertial velocity is in feet per second and does not consider the rotational speed of the surface. The actual parameter displayed is always Mach number; the tape is simply rescaled above Mach 4 to read relative velocity (MM 102, 304, 305, 602, 603) or inertial velocity (MM 103, 601). The scale ranges from zero to 27, with a scale change at Mach 4.

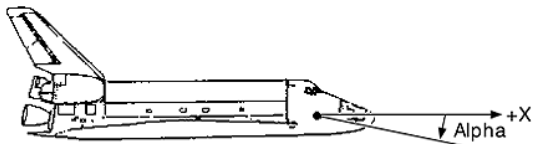
HSI Mode	Bearing		Range		Course Deviation (CDI)	Glide Slope Deviation (GSI)	Compass Card (Heading)
	Primary	Secondary	Primary	Secondary			
Entry	Spherical bearing to WP-1 for NEP at <u>primary</u> landing runway	Spherical bearing to WP-1 for NEP at <u>secondary</u> landing runway	Spherical surface range to WP-2 on <u>primary</u> runway via WP-1 for NEP	Spherical surface range to WP-2 on <u>secondary</u> runway via WP-1 for NEP	A valid software zero (no flag)	GS pointer stowed; flag displayed	Magnetic heading of vehicle relative velocity vector
TAEM	Bearing to WP-1 on selected HAC for primary runway	Bearing to center of selected HAC for primary runway	Horizontal distance to WP-2 on primary runway via WP-2 for selected EP	Horizontal distance to center of selected HAC for primary runway	Deviation from extended runway centerline (full scale = $\pm 10^\circ$)	Deviation from guidance reference altitude for TAEM (full scale = ± 5000 ft)	Magnetic heading of body X-axis
Approach	Bearing to WP-2 at primary runway	Bearing to WP-2 at primary runway	Horizontal distance to WP-2 on primary runway	Horizontal distance to WP-2 on primary runway	Deviation from extended runway centerline (full scale = $\pm 2.5^\circ$)	Deviation from guidance reference altitude for A/L (full scale = ± 1000 ft) Not computed below 1500 ft, flag deploys	Magnetic heading of body X-axis

HSI Function Matrix

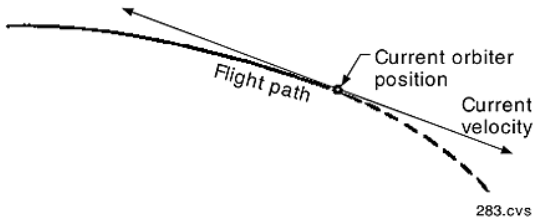
The *ACCEL* scale displays vehicle drag acceleration, which is the deceleration along the flight path, normal acceleration, which is acceleration in the normal axis, or total load factor. This is a moving tape upon which acceleration is read at the fixed lubber line. The tape range is -50 to $+100$ with a scale change at zero feet per second squared. Minus signs are assumed on the *ACCEL* scale also; the negative region has a black background and the positive side has a white background. (Normal acceleration and total load factor are measured in g's, with 10 equal to 1 g, 20 equal to 2 g's, etc.)

The *EAS* scale is used to display equivalent airspeed. On the moving-tape scale, equivalent airspeed is read at the fixed lubber line. The tape range is zero to 500 knots, and scaling is 1 inch per 10 knots.

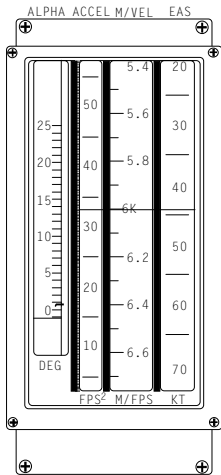
Each scale on the alpha/Mach indicator displays an *OFF* flag if the indicator malfunctions, invalid data are received at the display driver unit, or a power failure occurs (all flags appear).



Angle of attack



Acceleration

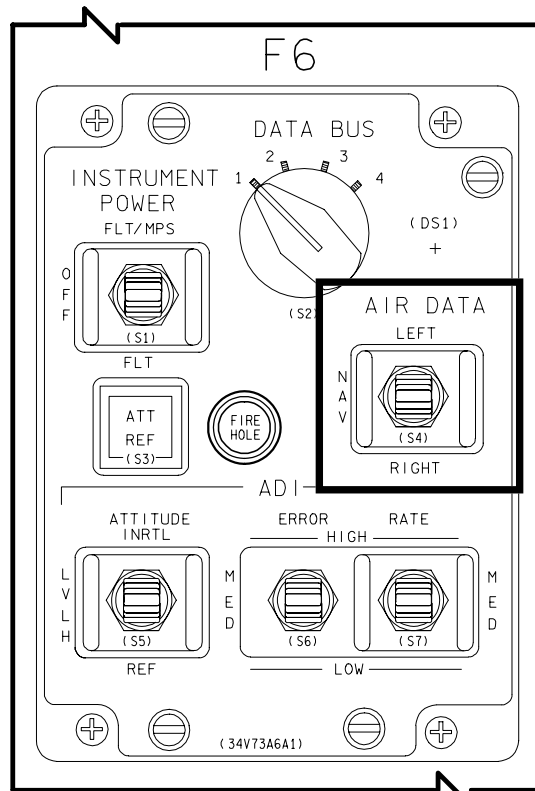


- Alpha -18 to +60 degrees
- Acceleration -50 to +100 feet per second
- M/vel mach 0 to 4; 4,000 to 27,000 feet per second
- Equivalent airspeed 0 to 500 knots
- Failure warning flags
 - Malfunction within indicator
 - Malfunction in received data
 - Power failure (all flags appear)

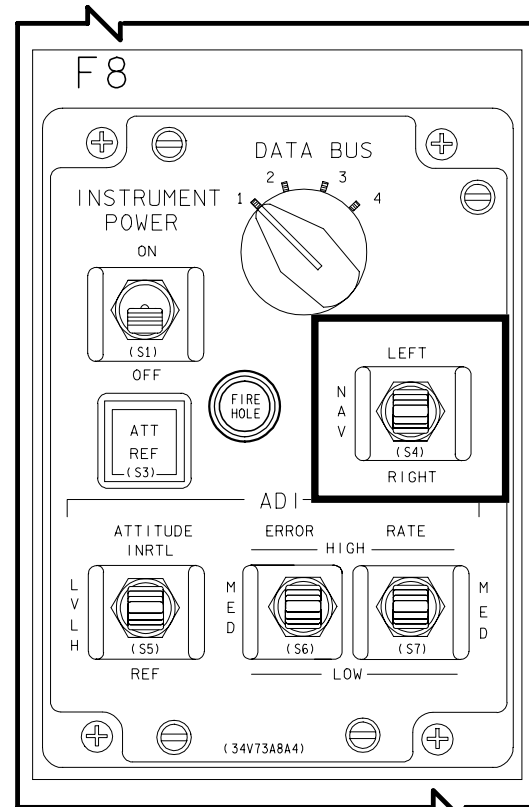
Alpha/Mach Indicator

The *AIR DATA* switch on panel F6 for the commander and panel F8 for the pilot determines the source of data for the alpha/Mach indicator and altitude/vertical velocity indicator. The *NAV* position of the *AIR DATA* switch displays the same parameters (*ALPHA*, *MACH*, and *EAS*) that are sent to guidance, flight control, navigation, and other software users; *ACCEL* comes from navigation software.

The *LEFT* and *RIGHT* positions of the *AIR DATA* switch select data from the left or right air data probe assembly after successful deployment of the left and right air data probes at Mach 5 for *ALPHA*, *M/VEL*, and *EAS* display. However, the data will not be accurate until the velocity is less than Mach 3.5, due to calibration of the probes. *ACCEL* is always derived from navigation software during entry. It is driven to zero during terminal area energy management and approach and landing.



Commander/s AIR DATA switch on Panel F6



Pilot's AIR DATA Switch on Panel F8

Altitude/Vertical Velocity Indicator

The altitude/vertical velocity indicators (AVVIs) are located on panel F6 for the commander and panel F8 for the pilot. These indicators display vertical acceleration (*ALT ACCEL*), vertical velocity (*ALT RATE*), altitude (*ALT*), and radar altitude (*RDR ALT*).

The *ALT ACCEL* indicator, which displays altitude acceleration of the vehicle, is read at the intersection of the moving pointer and the fixed scale. The scale range is -13.3 to 13.3 feet per second squared, and the scaling is 6.67 feet per second squared per inch. Software limits acceleration values to ± 12.75 feet per second squared.

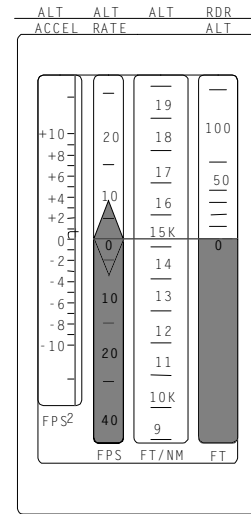
The *ALT RATE* scale displays vehicle altitude rate, which is read at the intersection of the moving tape and the fixed lubber line. The scale range is $-2,940$ to $+2,940$ feet per second with scale changes at -740 feet per second and $+740$ feet per second. The negative and positive regions are color-reversed: negative numbers are white on a black background and positive numbers are black on white.

The *ALT* scale, a moving tape read against a fixed lubber line, displays the altitude of the vehicle above the runway (barometric altitude). The scale range is $-1,100$ feet to $+165$ n. mi., with scale changes at -100 , 0 , 500 feet, and $+100,000$ feet. The scale is in feet from $-1,100$ to $+400,000$ and in n. mi. from $+40$ to $+165$. Feet and nautical miles overlap from $+40$ to $+61$ n. mi..

The *RDR ALT* scale is a moving tape read against a fixed lubber line. It displays radar altitude (corrected to wheels) during major mode 305, below 9,000 feet (normally not locked on until below 5,000 feet; prior to radar altimeter lock-on, the meter is "parked" at 5,000 feet). The scale ranges from zero to 9,000 feet with a scale change at 1,500 feet. Each scale on the altitude/vertical velocity indicator displays an *OFF* flag in the event of indicator malfunction, invalid data received at the display driver unit, or power failure (all flags appear).

With the *AIR DATA* source switch in the *NAV* position, the *ALT ACCEL*, *ALT RATE*, and *ALT* scales are navigation-derived. The *RDR ALT* indicator is controlled by the *RADAR ALTM* switch on panel F7 for the commander and

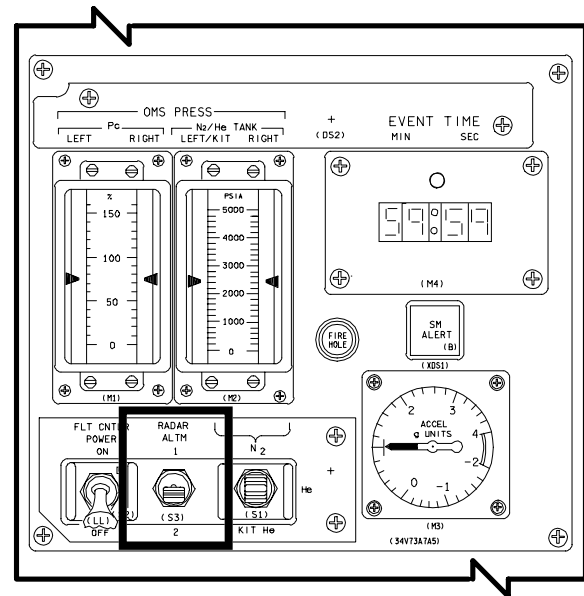
panel F8 for the pilot. *RADAR ALTM* positioned to 1 selects radar altimeter 1; 2 selects radar altimeter 2.



- Altitude acceleration -13.3 to $+13.3$ feet per second
- Altitude rate $-2,940$ to $+2,940$ feet per second
- Altitude $-1,100$ feet to 165 nautical miles
- Radar altitude 0 to $9,000$ feet
 - Malfunction within indicator
 - Malfunction in received data
 - Power failure (all flags appear)

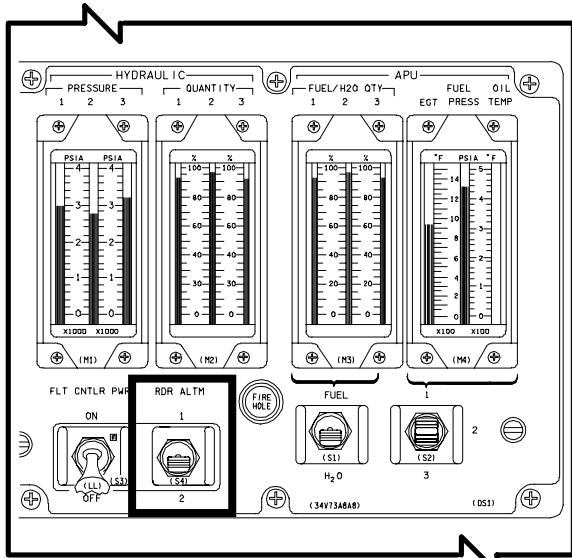
286.cvs

Altitude/Vertical Velocity Indicator



Commander's RADAR ALTM Switch on Panel F7

The *AIR DATA* switch is positioned to *LEFT* or *RIGHT* to select the left or right air data probe after air data probe deployment at Mach 5. The *ALT* and *ALT RATE* scales receive information from the selected air data probe. *ALT ACCEL* receives navigation data. The *RDR ALT* scale receives data based on the *RADAR ALTM* select switch position.



Pilot's RADAR ALTM Switch on Panel F8

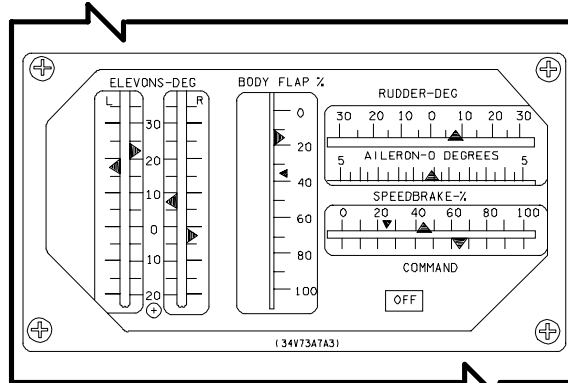
Surface Position Indicator

The surface position indicator is a single display on panel F7 that is active during entry and the entry portion of return to launch site. The indicator displays the actual and commanded positions of the elevons, body flap, rudder, aileron, and speed brake.

The four elevon position indicators show the elevon positions in the order of appearance as viewed from behind the vehicle (from left to right: left outboard, left inboard, right inboard, right outboard). The scales all range from +20 to -35°, which are also the software limits to the elevon commands. The pointers are driven by four separate signals and can read different values, but normally the left pair is identical and the right pair is identical. Positive elevon is below the null line, and negative is above.

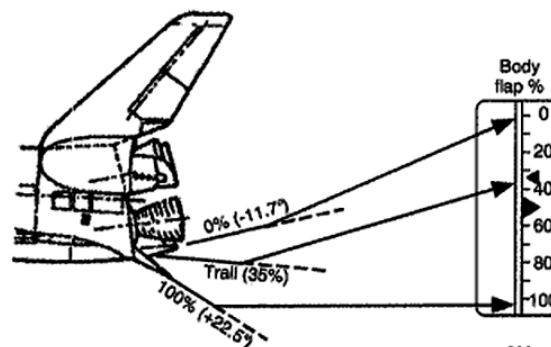
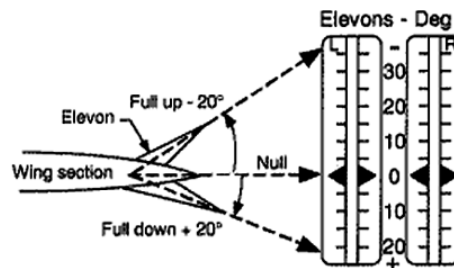
The body flap scale reads body flap positions from zero to 100 percent of software-allowed travel. Zero percent corresponds to full up (-11.7°); 100 percent corresponds to full down (+22.5°). The small pointer at 34 percent is fixed and shows the trail position.

Rudder position is displayed as if viewed from the rear of the vehicle. Deflection to the left of center represents left rudder. The scale is +30° (left) to -30° (right), but software limits the rudder command to ±27.1°.



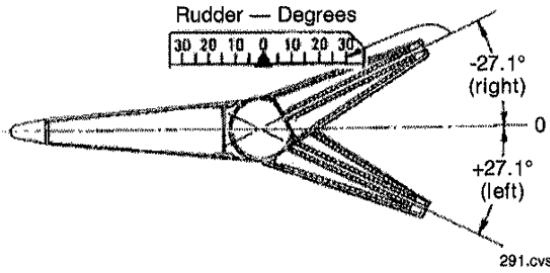
Surface Position Indicator on Panel F7

The aileron display measures the effective aileron function of the elevons in combination. Aileron position equals the difference between the average of the left and right elevon divided by two. Deflection of the pointer to the right of center indicates a roll-right configuration (left elevons down, right elevons up) and vice versa. The scale is -5° to +5°, with -5° at the left side. The aileron command can exceed ±5° (maximum ±10°), in which case the meter saturates at ±5°.



290.cvs

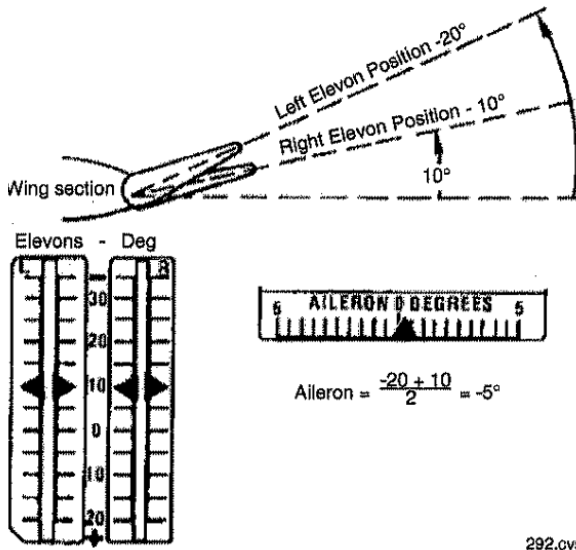
Surface Position Indicator Elevon Travel



Surface Position Indicator Rudder Travel

The speed brake position indicator indicates the actual position on the upper scale and commanded position on the lower scale. The position ranges zero to 100 percent; zero percent is fully closed, and 100 percent is fully open, which corresponds to 98° with respect to the hinge lines. The small point at 25 percent is fixed and represents the point at which the speed brake surfaces and the remainder of the tail form a smooth wedge.

The speed brake command is scaled identically to position and has the same travel limits. It always represents the speed brake auto guidance command. The *OFF* flag is set only for internal meter problems or during OPS 8 display checkout.



Surface Position Indicator Aileron Travel

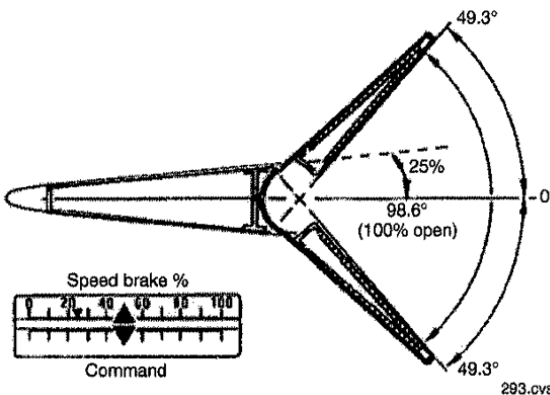
Flight Control System Pushbutton Indicators

The flight control system's pushbutton indicators transmit flight crew moding requests to the digital autopilot (DAP) in the flight control software and reflect selection by illuminating the effective DAP state. These indicators are located on panel F2 for the commander and panel F4 for the pilot.

The pushbutton indicators are used to command and reflect the status of the pitch and roll/yaw control modes. The *PITCH* and *ROLL/YAW* indicators transmit moding requests to the digital autopilot and indicate the effective state of the pitch and roll/yaw DAP channels by lighting.

AUTO indicates that control is automatic, and no crew inputs are required. *CSS* is control stick steering; crew inputs are required, but are smoothed by the DAP (stability augmentation, turn coordination).

The *SPD BK/THROT* (speed brake/throttle) pushbutton indicator has two separate lights, *AUTO* and *MAN*, to indicate that the DAP speed brake channel is in the automatic or manual mode. The pushbutton light indicator transmits only the *AUTO* request.

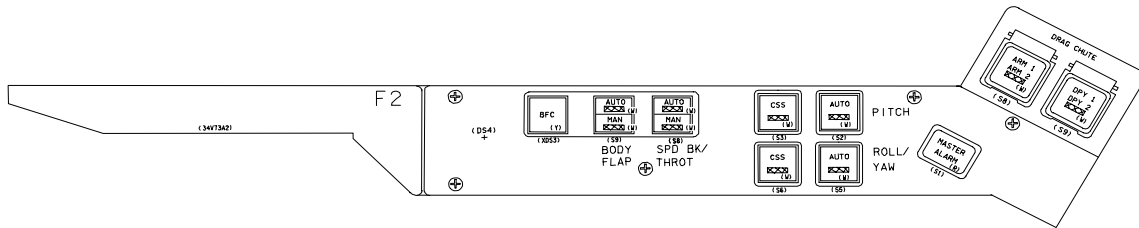


Surface Position Indicator Top View of Open Speed Brake

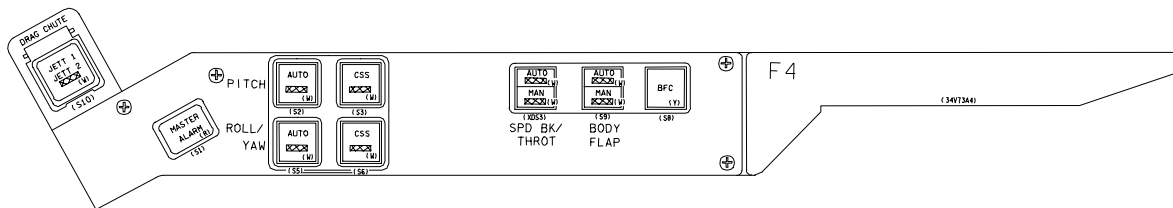
The *BODY FLAP* pushbutton indicator also has separate *AUTO* and *MAN* lights, indicating the state of the body flap channel. Like the *SPD BK/THROT* pushbutton indicator, the *BODY FLAP* indicator transmits only the *AUTO* request.

Entry Flight Control System Mode Pushbutton Indicator Light Logic

LIGHTS	LEFT/RIGHT LIGHT LOGIC	CAUSES
<i>PITCH AUTO</i>	Both on or both off } Auto, CSS mutually exclusive	<i>PITCH AUTO</i> pushbutton indicator depressed
<i>PITCH CSS</i>		<i>PITCH CSS</i> pushbutton indicator depressed or RHC out of detent in pitch
<i>ROLL/YAW AUTO</i>	Both on or both off } Auto, CSS mutually exclusive	<i>ROLL/YAW AUTO</i> pushbutton indicator depressed
<i>ROLL/YAW CSS</i>		<i>ROLL/YAW CSS</i> pushbutton indicator depressed or RHC out of detent in roll or yaw
<i>SPD BK/THROT</i>	Both on or both off } Auto, man. mutually exclusive	Neither SBTC takeover pushbutton depressed or <i>AUTO</i> pushbutton depressed
<i>MAN</i>		Either SBTC takeover pushbutton depressed
<i>BODY FLAP</i>	Both on or both off } Auto, man. mutually exclusive	<i>AUTO</i> pushbutton indicator depressed
<i>MAN</i>		<i>MAN</i> pushbutton depressed



Commander's Flight Control System Pushbutton Light Indicators on Panel F2



Pilot's Flight Control System Pushbutton Light Indicators on panel F4

Reaction Control System Command Lights

The *RCS COMMAND* lights on panel F6 are active during OPS 104-106 and OPS 602 and 603. Their primary function is to indicate reaction control system (RCS) jet commands by axis and direction; secondary functions are to indicate when more than two yaw jets are commanded, and when the elevon drive rate is saturated.

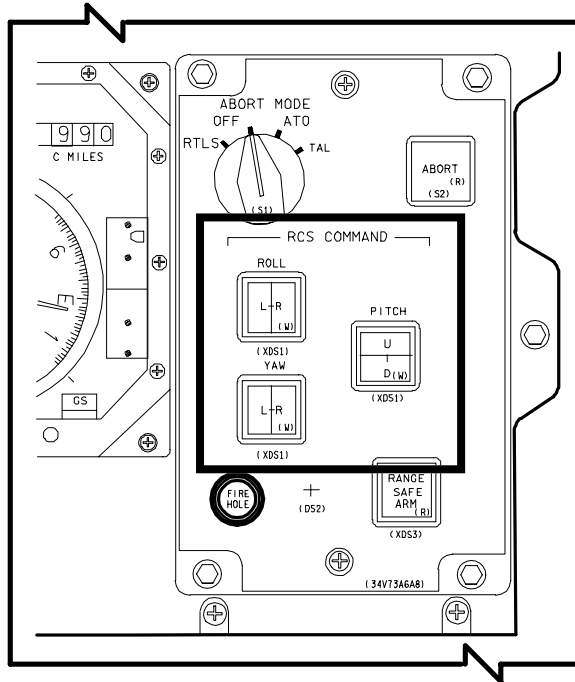
During major modes 301 through 304, until the roll jets are no longer commanded (dynamic pressure exceeds 10 pounds per square foot), the *ROLL L* and *R* lights indicate that left or right roll jet commands have been issued by the

DAP. The minimum light-on duration is extended so that the light can be seen even during minimum-impulse firings. When dynamic pressure is greater than or equal to 10 pounds per square foot, the *ROLL* lights are quiescent until 50 pounds per square foot, after which time both lights are illuminated whenever more than two yaw jets are commanded on.

The *PITCH U* and *D* lights indicate up and down pitch jet commands until dynamic pressure equals 40 pounds per square foot, after which the pitch jets are no longer used. When dynamic pressure is 50 pounds per square foot

or more, the *PITCH* lights, like the *ROLL* lights, assume a new function: both light whenever the elevon surface drive rate exceeds 20° per second (14° per second if only one hydraulic system is left).

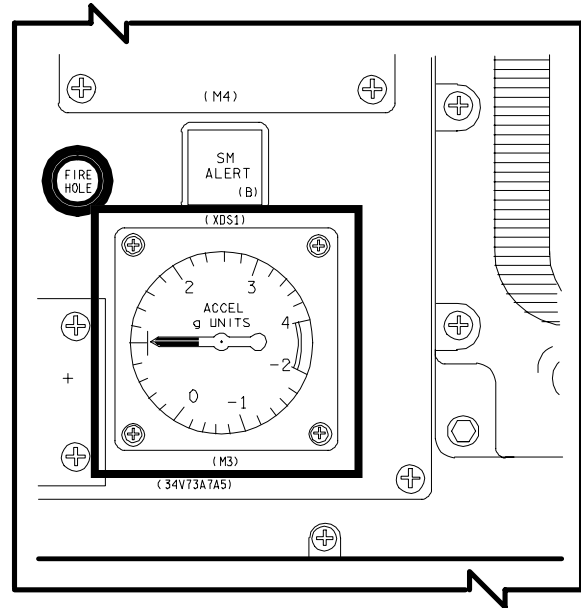
The *YAW L* and *R* lights function as yaw jet command indicators throughout entry until the yaw jets are disabled at Mach 1. The yaw lights have no other functions.



RCS COMMAND Lights on panel F6

G-Meter

The g-meter is a self-contained accelerometer and display unit mounted on panel F7. It senses linear acceleration along the Z axis (normal) of the vehicle. A mass weight in the unit is supported vertically by two guide rods and is constrained by a constant-rate helical spring. The inertial force of the mass is proportional to the inertial force of the vehicle and, hence, to the input acceleration, under conditions of constant acceleration. Displacement of the mass is translated to pointer displacement through a rack-and-pinion gear train, the output of which is linear with input acceleration. The display indicates acceleration from -2 g's to +4 g's. The g-meter requires no power and has no software interface. Like all the dedicated displays, it has an external variable incandescent lamp.



G-METER on Panel F7

Head-Up Display

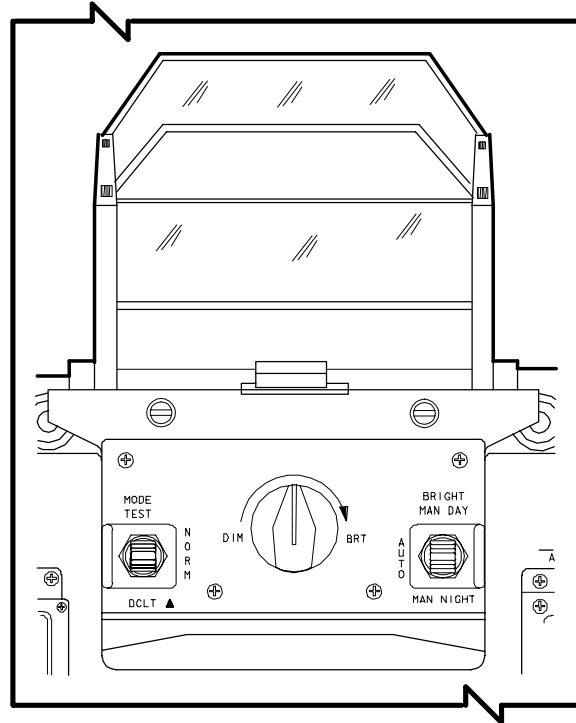
The head-up display (HUD) is an optical miniprocessor that cues the commander and/or pilot during the final phase of entry and particularly in the final approach to the runway. With minimal movement of their eyes from the forward windows (head up) to the dedicated display instruments (head down), the commander and pilot can read data from head-up displays located in the front of them on their respective glareshields. The head-up display presents the same data presented on several other instruments, including the attitude director indicator, surface position indicator, alpha/Mach indicator, and altitude/vertical velocity indicator.

The head-up display allows out-of-the-window viewing by superimposing flight commands and information on a transparent combiner in the window's field of view. Since the orbiter avionics systems are digital, and minimal impact on the orbiter was paramount, the head-up display drive electronics were designed to receive data from the orbiter data buses. The head-up display drive electronics utilize, to the maximum extent possible, the same data that drive the existing electromechanical display devices. The orbiter display device uses a CRT to create the image, which is then projected through a series of lenses onto a combining glass.

Each head-up display is a single-string system, but it is connected to two data buses for redundancy. It is an electronic/optical device with two sets of combiner glasses located above the glareshield in the direct line of sight of the commander and the pilot. Essential flight information for vehicle guidance and control during approach and landing is projected on the combiner glasses and focused at infinity.

The images, generated by a small CRT and passed through a series of lenses, are displayed to the flight crew on the combiners as lighted symbology. The transmissiveness of the combiner allows the crew to look through it and see actual targets like the runway.

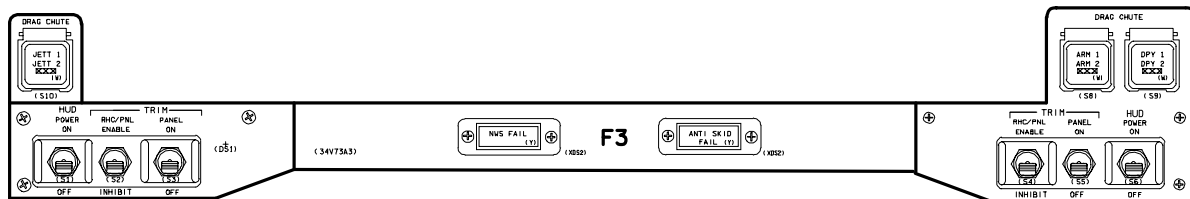
For instance, if the crew is 9,000 feet on the final approach course in a solid overcast, the base of which is at 8,000 feet, the lighted outline of the runway would be displayed on the combiner. However, when the orbiter exits the overcast at 8,000 feet, the lighted outline of the runway would be superimposed on the real runway. As the orbiter proceeds down the steep glide slope, the velocity vector is superimposed over the glide slope aim point. At preflare altitude, flare triangles move up to command the pullout. The pilot maintains the velocity vector symbol between the triangles. After a short period of stabilized flight on the shallow glide slope, the guidance diamond commands a pitch-up until the nose is about 8° above the horizon, which is essentially the touchdown attitude. After touchdown, during the rollout phase, the crew maintains the approximate touchdown attitude, +6° theta (nose above the horizon), until 186 knots equivalent airspeed and then commands a derotation maneuver.



**Head-Up Display and Controls on Panel F6
(Identical on Panel F8)**

The head-up display has proved to be a valuable landing aid and is considered the primary pilot display during this critical flight phase.

A *HUD POWER ON/OFF* switch located on the left side of panel F3 provides and terminates electrical power to the commander's head-up display on panel F6. A second switch is located on the right side of panel F3 for the pilot's head-up display on panel F8.



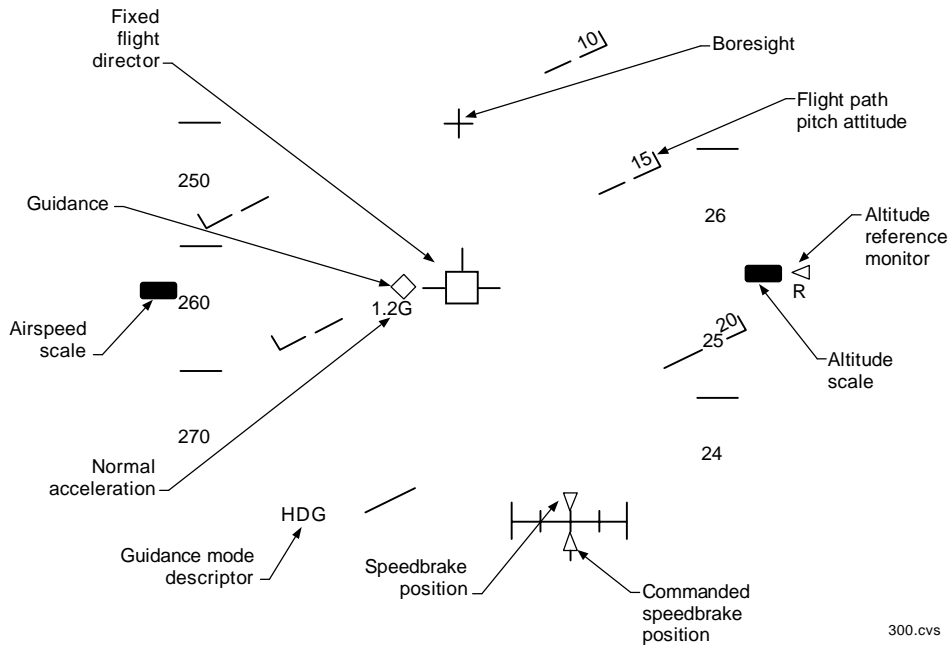
Panel F3

WARNING

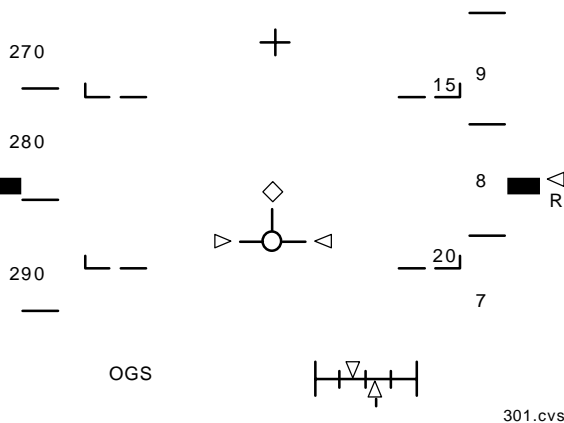
A generic hardware problem has been identified in several HUD units. At 13 KFT, the flight director symbol is uncaged to become a velocity vector (⊖). Cycling HUD POWER after this transition may result in erroneous symbol positioning. Flying these false cues would result in landing short of the runway, at a very high sink rate. (Ref: JSC Memo DF6-90-053)

provided. The *TEST* position forces up a test display for 5 seconds. Selection of the momentary *DCLT* position initiates a symbol blanking routine. Successive selections of *DCLT* will serially remove display elements in the following order. The first activation removes the runway symbology. The second activation removes the airspeed and altitude tapes (replacing them with digital values) and the horizon/pitch attitude scales, but leaves the horizon line when within FOV. The third declutter level removes all symbology except for the boresight. A fourth declutter attempt will return the HUD to its original form with all symbols displayed.

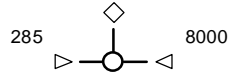
A three-position *MODE* switch is located below the HUD. In the *NORM* position, automatic sequencing of formats and symbology is



Approach and Land Display (TAEM Heading Phase); No Declutter



Approach and Land Display (Declutter Level 1)



OGS



Note: Horizon is displayed when
in the HUD FOV.

302.cvs

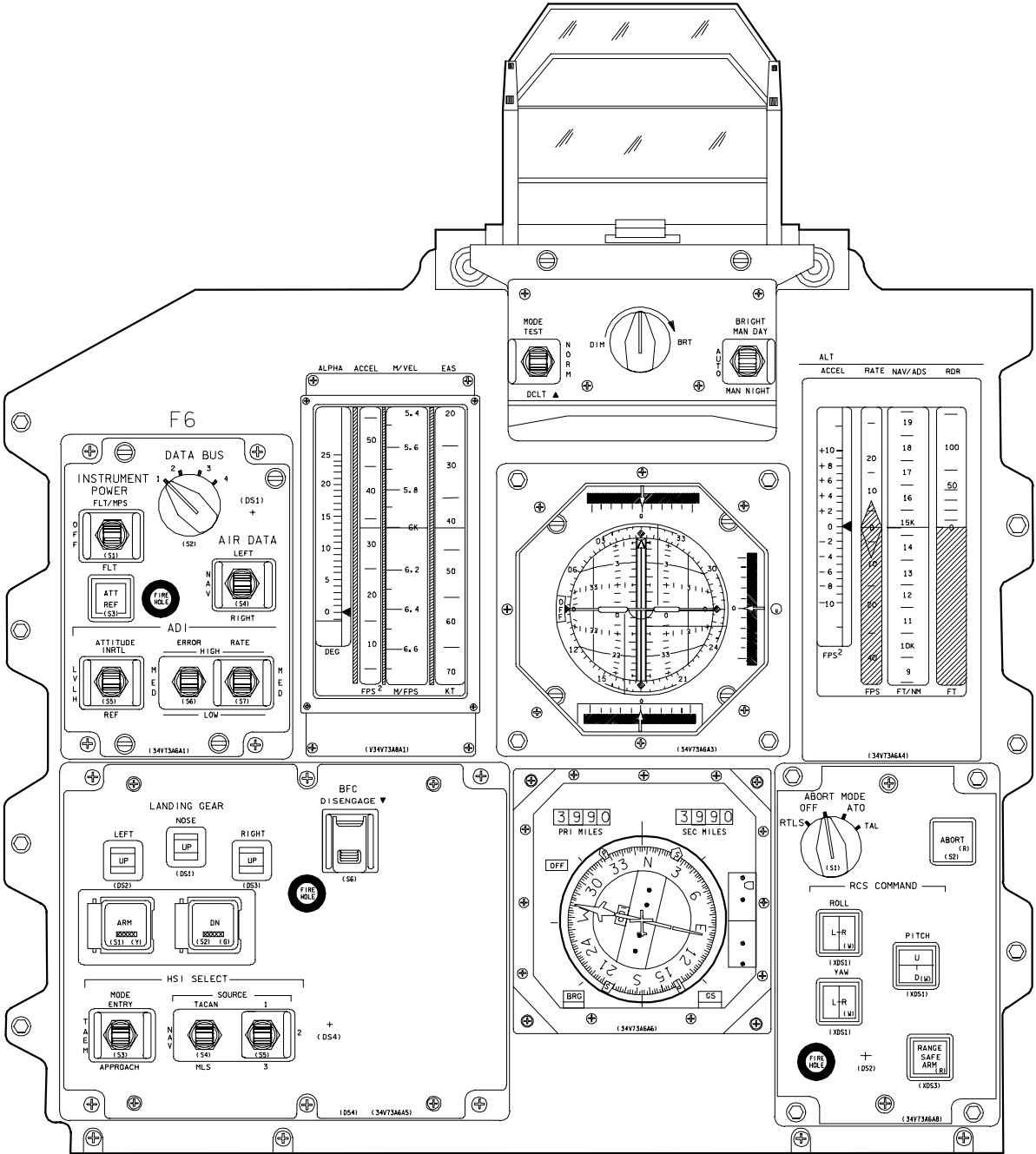
Approach and Land Display (Declutter Level 2)



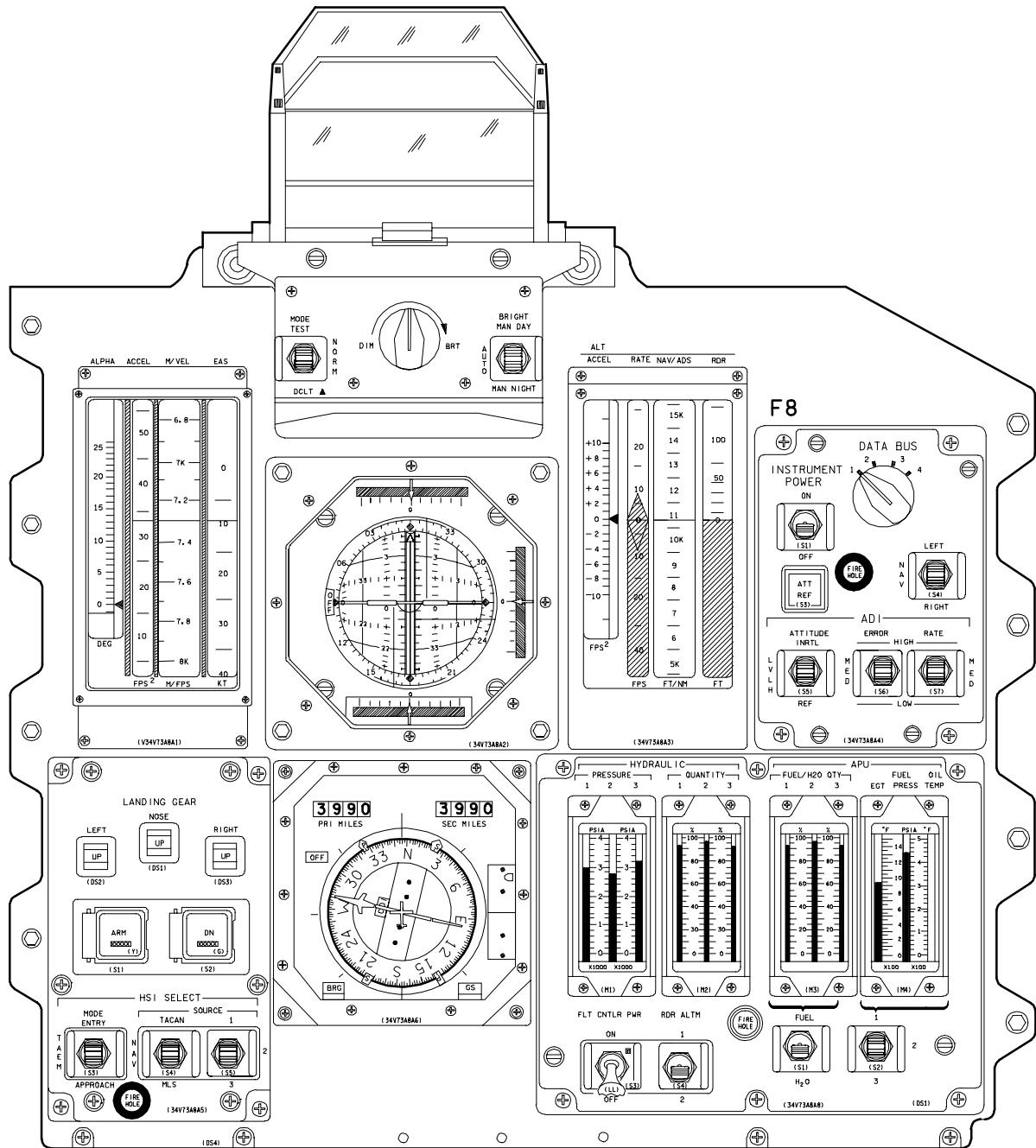
Approach and Land Display (Declutter Level 3)

Dedicated Display Systems Summary Data

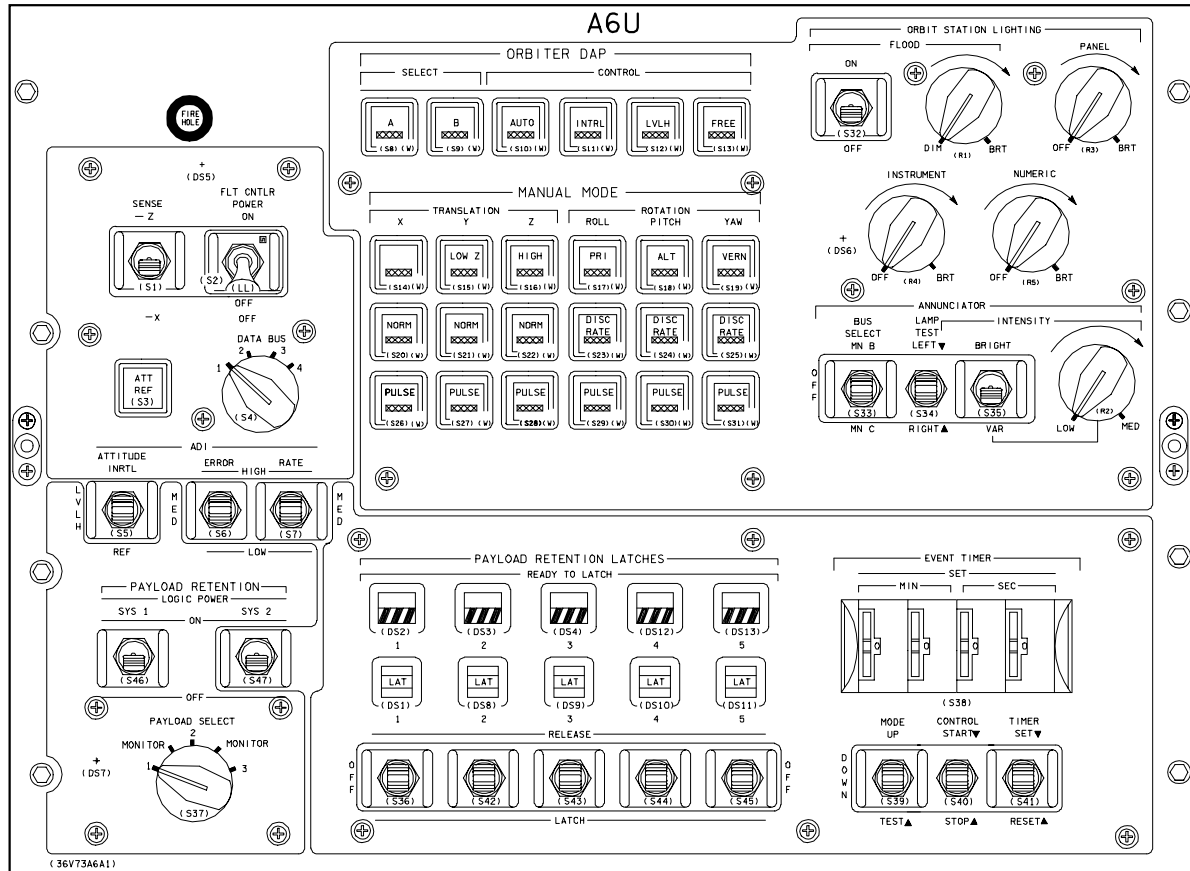
- Dedicated displays are located in front of the commander's and pilot's seats and on the aft flight deck panel by the aft-facing window (panels F6, F8, and A1U).
- Dedicated displays include: attitude director indicators, horizontal situation indicators, alpha/Mach indicators, altitude/vertical velocity indicators, surface position indicator, RCS activity lights, g-meter, and head-up displays.
- Circuit breakers for dedicated displays are located on panels O14, O15, and O16.
- Power switches for the commander's dedicated displays are on panel F6; for the pilot's displays on panel F8.
- The attitude director indicators display orbiter attitude by an enclosed ball gimbaled to represent three degrees of freedom.
- The horizontal situation indicators visually display certain guidance, navigation, and control parameters such as directions, distances, and course/glide path deviation.
- The alpha Mach indicator displays angle of attack, acceleration, vehicle velocity, and equivalent airspeed.
- The altitude/vertical velocity indicators display vertical acceleration, vertical velocity, barometric altitude, and radar altitude.
- The surface position indicator on panel F7 displays actual positions of the elevons, body flap, rudder, aileron, and speedbrake. Speedbrake commanded position is also displayed.
- The g-meter is a self-contained accelerometer and display unit on panel F7.
- The head-up display cues the commander and/or pilot during final phases of entry by superimposing flight commands and information on a transparent combiner in the window's field of view. Power switches are located on panel F3.
- The ADI ball is mechanically frozen when the ball is at 270° or 90° in yaw.
- During ascent powered flight (MM 102-103) or RTLS powered flight (MM 601), active displays include the ADI, HSI, AMI, and AVVI.
- Post MECO, the ADI is the only active display (MM 104-106).
- During RTLS gliding flight (MM 602-603), all displays are driven as in the nominal TAEM/approach phases (MM 304, 305).
- On orbit, when in the Flight Control System (FCS) checkout mode (MM 801), all displays can be driven by test software to allow the crew to verify correct operation prior to entry.
- The ACCEL tape on the alpha/Mach indicator, the error and rate needles on the ADI, and the HSI indicate different parameters in different major modes.



Panel F6



Panel F8



Panel A6U

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2.8 ELECTRICAL POWER SYSTEM (EPS)

CONTENTS

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Power Reactants Storage and Distribution System	2.8-1
Fuel Cell System	2.8-10
Electrical Power Distribution and Control	2.8-20
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EPS Caution and Warning Summary	2.8-31
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Description

The electrical power system (EPS) consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter vehicle, and fulfill all the orbiter external tank, solid rocket booster, and payload power requirements, when not connected to ground support equipment. The EPS operates during all flight phases. For nominal operations, very little flight crew interaction is required by the EPS.

The EPS is functionally divided into three subsystems: power reactants storage and distribution (PRSD), three fuel cell power plants (fuel cells), and electrical power distribution and control (EPDC).

Through a chemical reaction, the three fuel cells generate all 28-volt direct-current electrical power for the vehicle from launch minus 3 minutes and 30 seconds through landing roll-out. Prior to that, electrical power is provided by ground power supplies and the onboard fuel cells.

Power is controlled and distributed by assemblies located in the forward, mid, and aft sections of the orbiter. Each assembly is a housing for electrical components such as remote switching

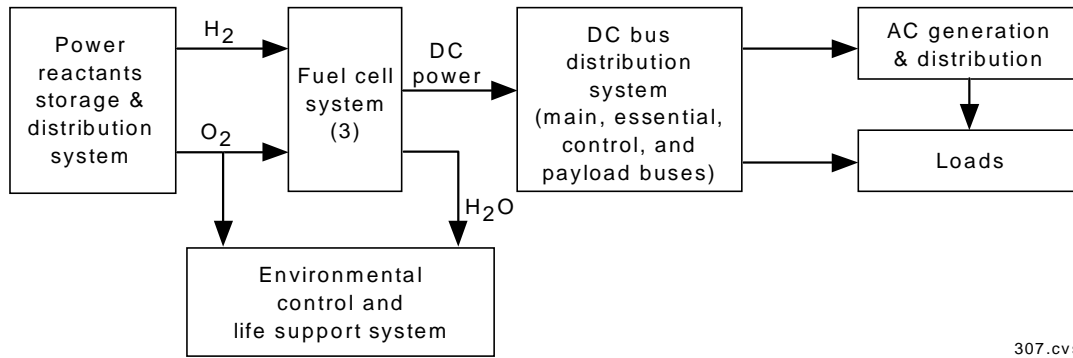
devices, buses, resistors, diodes, and fuses. Each assembly usually contains a power bus or buses and remote switching devices for distributing bus power to subsystems located in its area.

Power Reactants Storage and Distribution System

The power reactants storage and distribution system stores the reactants (cryogenic hydrogen and oxygen) and supplies them to the three fuel cells that generate all the electrical power for the vehicle during all mission phases. In addition, the subsystem supplies cryogenic oxygen to the environmental control and life support system (ECLSS) for crew cabin pressurization. The hydrogen and oxygen are stored in tanks at cryogenic temperatures (-285°F for liquid oxygen and -420° F for liquid hydrogen) and supercritical pressures (above 731 psia for oxygen and above 188 psia for hydrogen).

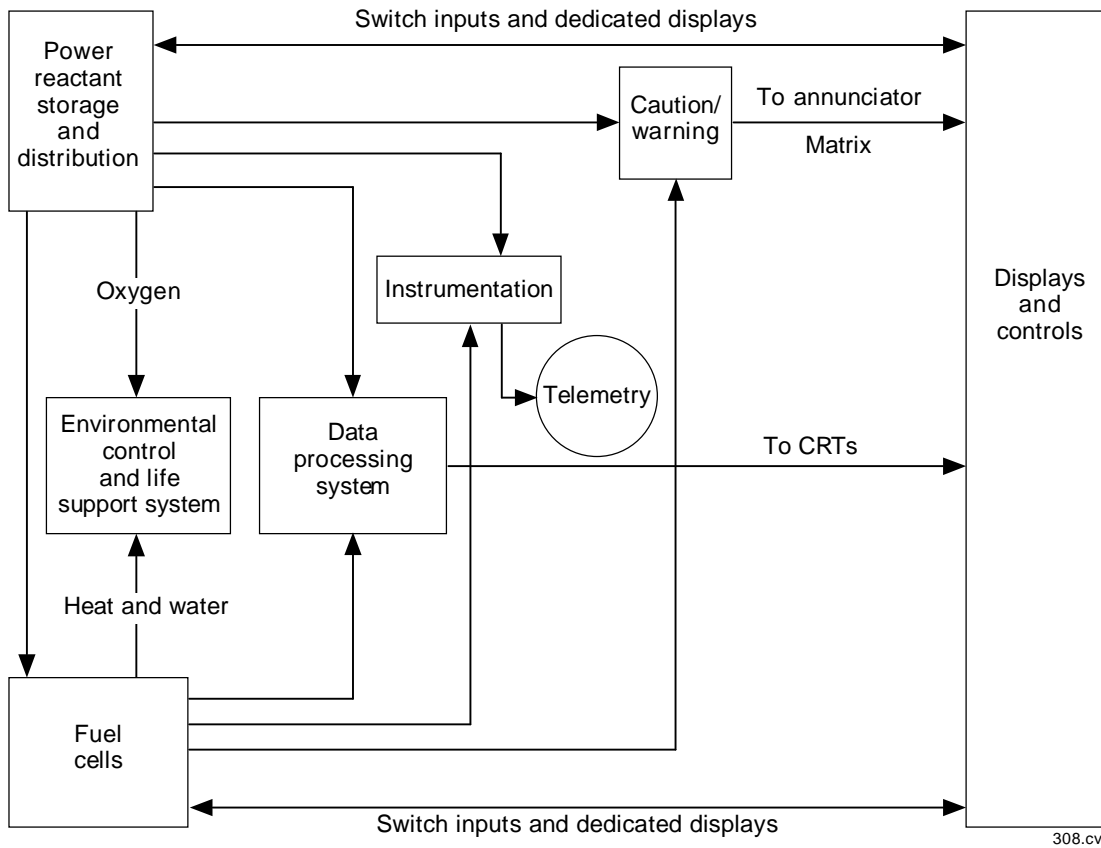
The PRSD system components are located in the orbiter midbody underneath the payload bay or on a payload bay pallet for 10+ day missions in extended duration orbiter (EDO) vehicles. The system stores the reactants hydrogen and oxygen in double-walled, thermally insulated spherical tanks with a vacuum annulus between the inner pressure vessel and outer tank shell. Each tank has heaters to add energy to the reactants during depletion to control pressure. Each tank is capable of measuring quantity remaining.

The tanks are grouped in sets of one hydrogen and one oxygen tank. The number of tank sets installed depends on the specific mission requirement and vehicle. Up to five tank sets can be installed in the midfuselage under the payload bay liner of OVs-102, -103, -104, and -105. Up to four additional tank sets can be flown on the EDO pallet in the payload bay of OV-102 and -105. OV-105 may be configured at a later date to fly up to four additional tank sets (total of eight additional sets). Switches to control these tanks are already installed.



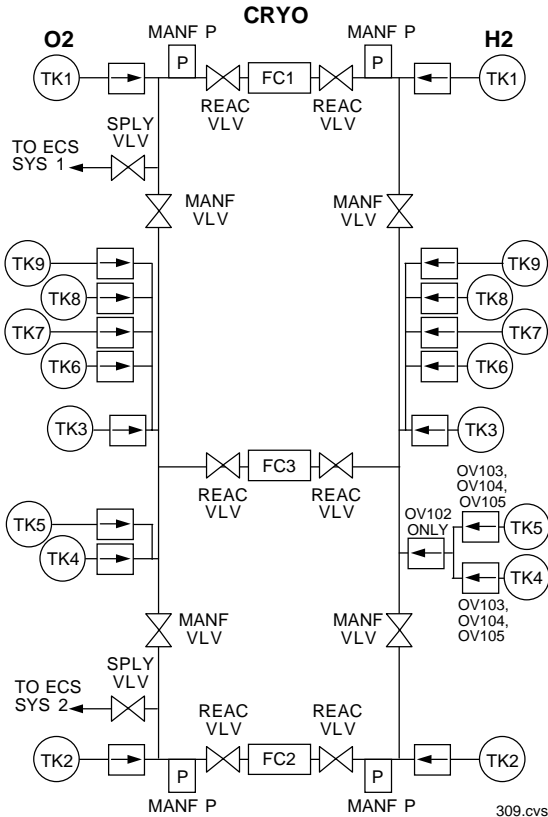
307.cvs

The Electrical Power System



308.cvs

Electrical Power System Interfaces



The PDRS System

Cryogenic Storage Tanks

All oxygen tanks are identical and consist of inner pressure vessels of Inconel 718 and outer shells of aluminum 2219. The inner vessel is 33.435 inches in diameter and the outer shell is 36.8 inches in diameter. Each tank has a volume of 11.2 cubic feet and stores up to 781 pounds of oxygen. The dry weight of each tank is 215 pounds. Maximum fill time is 45 minutes.

All hydrogen tanks also are identical. Both the inner pressure vessel and the outer shell are constructed of aluminum 2219. The inner vessel's diameter is 41.51 inches and the outer shell's is 45.5 inches. The volume of each tank is 21.39 cubic feet, and each stores up to 92 pounds of hydrogen. Each tank weighs 227 pounds dry. Maximum fill time is 45 minutes.

The inner pressure vessels are kept supercold by minimizing conductive, convective, and radiant heat transfer. Twelve low-conductive supports suspend the inner vessel within the outer shell. Radiant heat transfer is reduced by a shield between the inner vessel and outer shell

(hydrogen tanks only), and convective heat transfer is minimized by maintaining a vacuum between the vessel and shell. During ground operations, a vacuum ion pump maintains the required vacuum level and is also used as a vacuum gauge to determine the vacuum's integrity. The pump consists of an electrical power supply and an anode, which absorbs free ions between the tank walls.

Cryogenic Tank Heaters

Each hydrogen tank has one heater probe with two elements; each oxygen tank has two heater probes with two elements on each probe. As the reactants are depleted, the heaters add heat energy to maintain a constant pressure in the tanks.

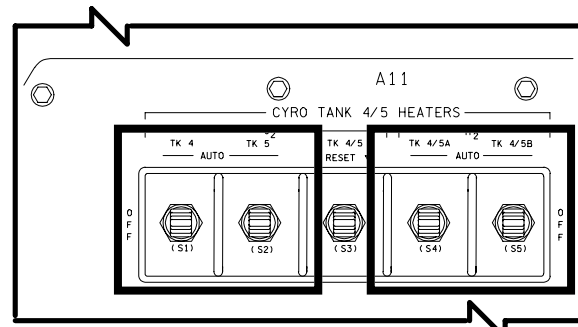
The heaters operate in automatic and manual modes. In the automatic mode, the heater is controlled by a tank heater controller. Each heater controller receives a signal from a tank pressure sensor. If pressure in a tank is less than or equal to a specific pressure, the controller turns the heater on. When the

pressure in the tanks goes above the upper limit, the respective controller turns the heater off. The O₂ TK1, 2, 3, and H₂ TK1, 2, 3 heater switches are located on panel R1; switches for the O₂ and H₂ TK4 heaters (tanks 4/5 on OV-102) are on panel A11. (On OV-102, the oxygen and hydrogen tank 4 B heaters are disconnected, and the logic and power are used for the tank 5 A heaters.) OV-103, -104, and -105 heater switches for tank set 5 are on panel A15. The heater switches for EDO pallet tanks 6-9 are located on panel A15 in both EDO configured vehicles. OV-105 also has heater switches for tank sets 10-13 on panel A11 for the future use of a second EDO pallet.

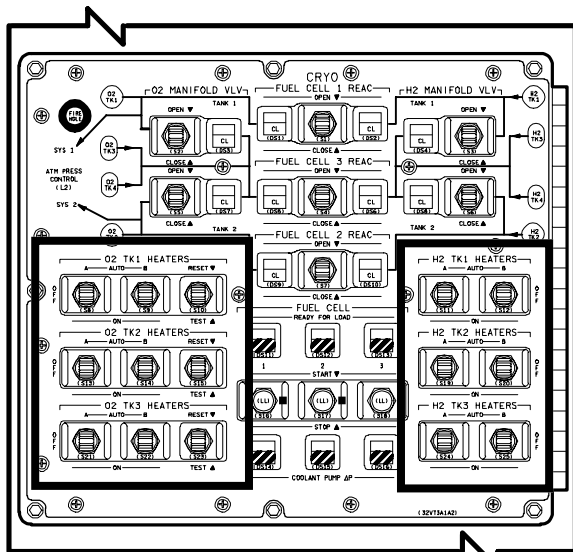
low pressure before the heaters will turn on. Once the heaters are on, a high pressure signal from either tank will turn off the heaters in both tanks.

In the manual mode, the flight crew controls the heaters by using the *ON OFF* positions for each heaters switch on panel R1, A11, or A15. Pressure in each tank is shown as O₂ TK P and H₂ TK P on the DISP 68 CRYO SYSTEM or DISP 168 CRYO PALLET displays. Pressure is also displayed on the CRYO O₂ and H₂ PRESS meters on panel O2. The specific tank (1, 2, 3, or 4) is selected by the rotary switch below the meters. Tank 5 TK P is also displayed on OV-105.

Heater controller psia		
Pressure limits (psia)	Low	High
H ₂ tank 1, 2	200-206	220-226
H ₂ tank 3-9	217-223	237-243
O ₂ tank 1,2	803-819	838-854
O ₂ tank 3-9	832-848	866-882

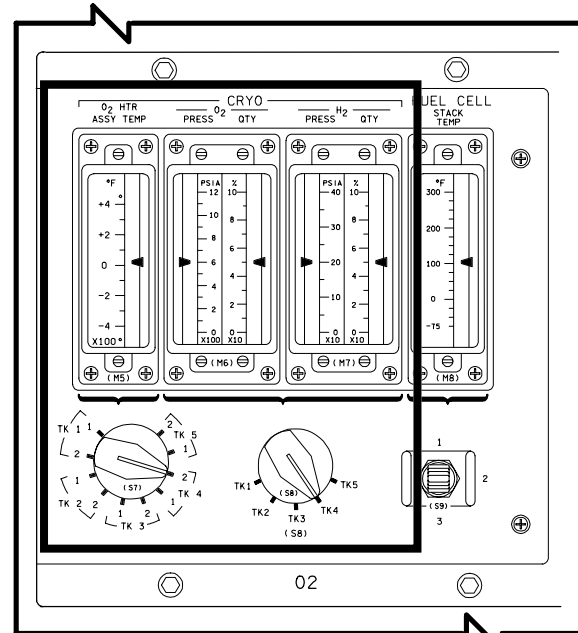


CRYO TANK 4 HEATER Switches on Panel A11



O2 and H2 TK HEATERS Switches on Panel R1

Dual-mode heater operation is available for pairs of oxygen and hydrogen tanks. If the heaters of both tanks 1 and 2, or tanks 3 and 4, are placed in the automatic mode, the tank heater logic is interconnected. In this case, the heater controllers of both tanks must sense a



Cryogenic System Meters and Switches on Panel O2

Each tank set has a hydrogen/oxygen control box that contains the electrical logic for the hydrogen and oxygen heaters and controllers. The control box is located on cold plates in the midbody under the payload bay envelope. On OV-102, a single control box controls tanks 4 and 5.

2011/ /068		CRYO SYSTEM					4 000/02:34:40 000/00:00:00	
O2	TK							
P	827	826	871	826	826			
TK P	828	828	871	828	828			
QTY	99	99	100	100	100			
T	-249	-249	-249	-249	-249			
HTR T 1	-249	-249	-182	-249	-249			
2	-249	-249	-182	-249	-249			
HTR 1A								
CUR 1B				4/5				
SNSR 2A								
2B				4/5				
MANF P	871	871						
VLV	OP	OP						
H2								
P	215	213	224	213	213			
TK P	215	214	224	214	214			
QTY	97	97	99	99	99			
T	-417L	-417L	-417L	-417L	-417L			
HTR T	-417L	-417L	-417L	-417L	-417L			
MANF P	222	222						
VLV	OP	OP						

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DISP 68 CRYO SYSTEM Display (on orbit)

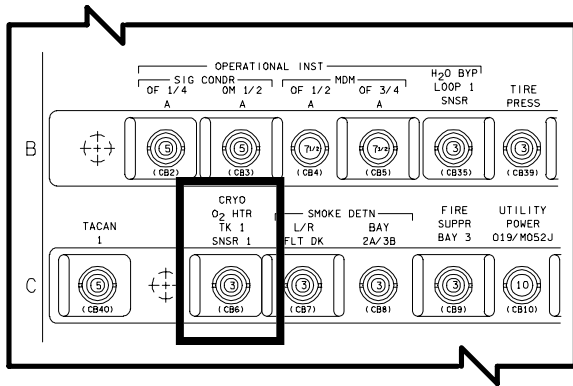
The CRYO O₂ HTR ASSY TEMP meter on panel O2, in conjunction with the rotary switch below it, selects one of the two heaters in each tank and permits the temperature of the heater element to be displayed. The range of the display is from -425° F to +475° F. The temperature sensor in each heater also is hard-wired directly to the caution and warning system, which drives the yellow O₂ HEATER TEMP light on panel F7. This light is illuminated if the temperature is at or above 344° F. A signal also is sent to the GPCs where software checks the limit; if the temperature is at or above 349° F, the BACKUP C/W ALARM light on panel F7 is illuminated. This signal also is displayed on DISP 68 CRYO SYSTEM and transmitted to the ground.

2011/ /168		CRYO PALLET				4 000/02:38:52 000/00:00:00	
O2	TK						
P	515L	515L	515L	515L	PALLET		
TK P	0L	0L	0L	0L	STB		
QTY	- 5L	- 5L	- 5L	- 5L	STB		
T	-417L	-417L	-417L	-417L	POP		
HTR T 1	-417L	-417L	-417L	-417L	POP		
2	-417L	-417L	-417L	-417L			
HTR 1A					PALLET		
CUR 1B					PPO		
SNSR 2A							
2B							
H2							
P	145L	145L	145L	145L			
TK P	0L	0L	0L	0L			
QTY	- 6L	- 6L	- 6L	- 6L			
T	-417L	-417L	-417L	-417L			
HTR T	-417L	-417L	-417L	-417L			

314

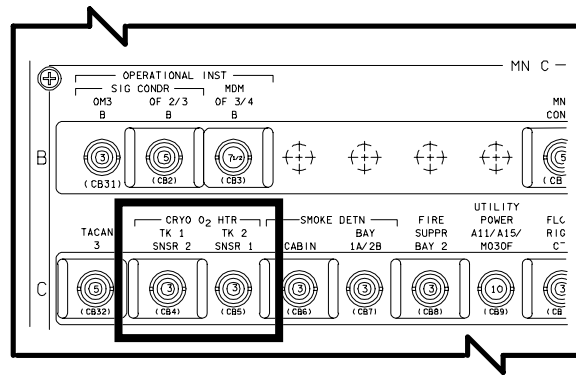
DISP 168 (CRYO PALLET)

Two current level detectors are built into the circuit of each oxygen tank heater to interrupt power in case of electrical shorts. The second detector is redundant. Each detector is divided into A and B detectors, which monitor the heater A current and the heater B current respectively. The detectors are powered by circuit breakers on panels O14, O15, O16, and ML86B. The detectors monitor the current in and out of a heater. If the current difference is 0.9 amp or greater for 1.5 milliseconds, a trip signal is sent to the heater logic to remove power from the heaters regardless of the heater switch position. If one element of a heater causes a "trip-out," power to both elements is removed. The O₂ TK 1, 2, 3 HEATERS RESET/TEST switches on panel R1 and the O₂ RESET/TEST switches on panels A11 and A15 can be used to reapply power to that heater by positioning them to RESET. The TEST position will cause a 1.5-amp delta current to flow through all four detectors of a specified oxygen tank, causing them to trip out. During on-orbit operations, the flight crew will be alerted to a current level detector trip-out by an SM ALERT, S68 CRYO 02 message, or S168 CRYO message.



Cryogenic System Heater Sensor Circuit Breaker on Panel O14

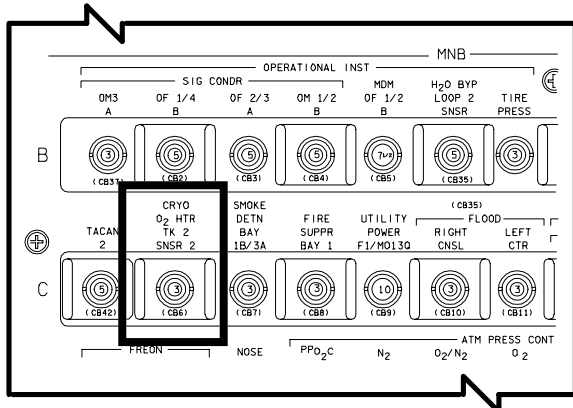
Each oxygen and hydrogen tank has a quantity sensor powered by a circuit breaker. These are identified on panel O13 as *CRYO QTY O₂* (or *H₂*) *TK 1* and *TK 2* and on panel ML86B as *CRYO QTY O₂* (or *H₂*) *TK 3*, *TK 4*, and *TK 5*. Data from the quantity sensors are sent to panel O2, where the rotary switch below the meters is used to select the tank for display on the *CRYO O₂* (or *H₂*) *QTY* meters. The range of the meters is zero to 100 percent. The data are also displayed on DISP 68 or DISP 168.



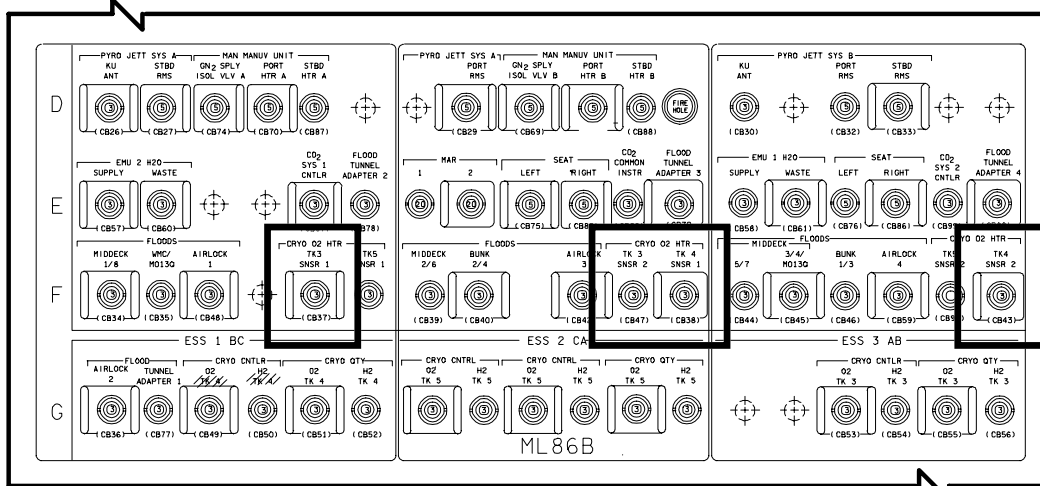
Cryogenic System Heater Sensor Circuit Breaker on Panel O16

There are two pressure sensors for each oxygen and hydrogen tank. One sensor transmits its data to the tank heater controllers, the caution and warning matrix on panel F7, and is displayed as "P" on DISPs 68 and 168. The yellow O₂ *PRESS* light is illuminated if oxygen tank pressure is below 540 psia or above 985 psia. The yellow H₂ *PRESS* light illuminates if hydrogen tank pressure is below 153 psia or above 293.8 psia. Data from the other sensor is displayed as TK P on DISPs 68 and 168 and the *PRESS* meters on panel O2. The *SM ALERT* and *BACKUP C/W ALARM* lights on panel F7 are also driven by the data. The range of the O₂ meter is 0 to 1,200 psia. The H₂ meter's range is 0 to 400 psia. The range of "P" displayed on the *PASS* and *BFS SM SYS SUMM 1* and DISPs 68 and 168 is 515 to 1,215 psia for oxygen and 145 to 305 psia for hydrogen.

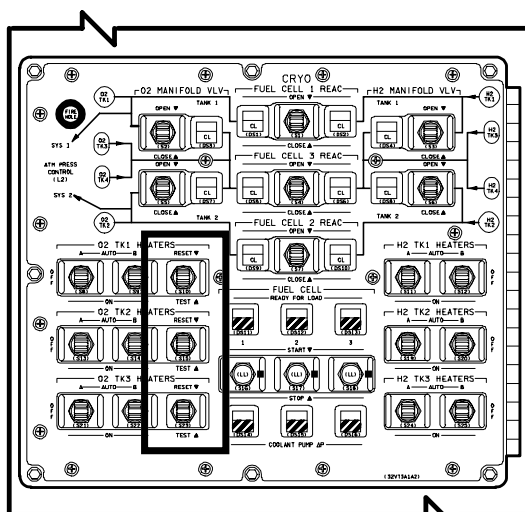
The data from oxygen and hydrogen fluid temperature sensors is displayed on DISP 68 or DISP 168 and transmitted to the ground.



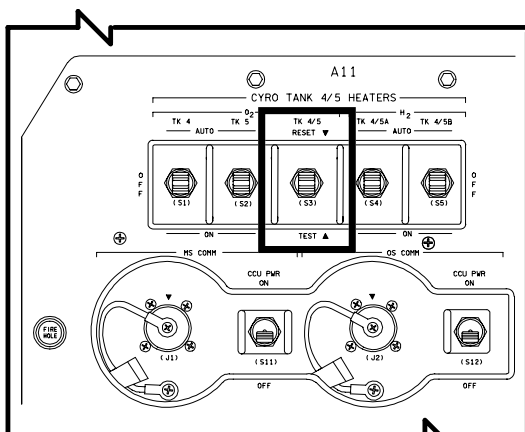
Cryogenic System Heater Sensor Circuit Breaker on Panel O15



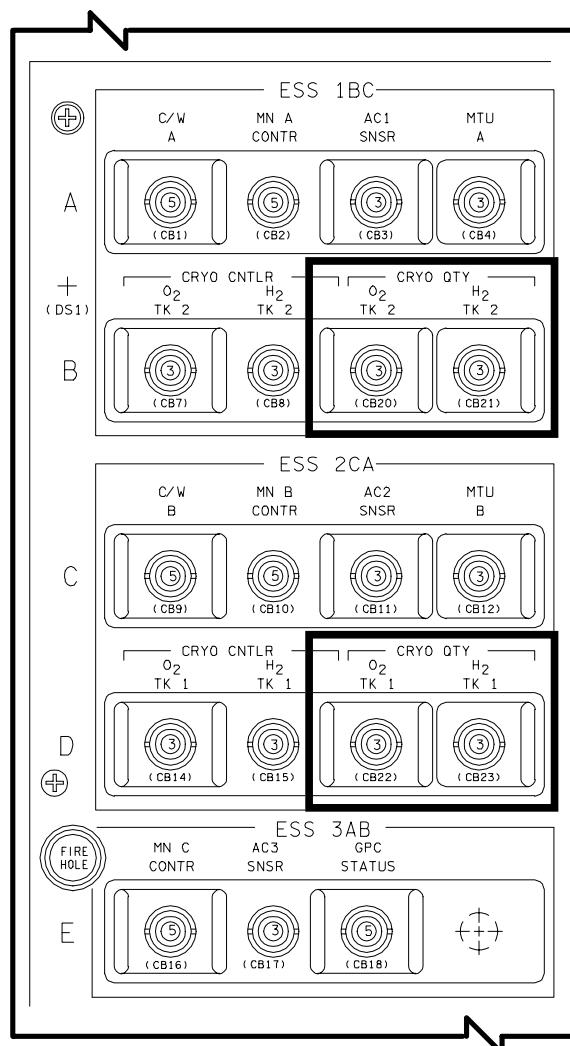
Cryogenic System Heater Sensor Circuit Breaker on Panel ML86B



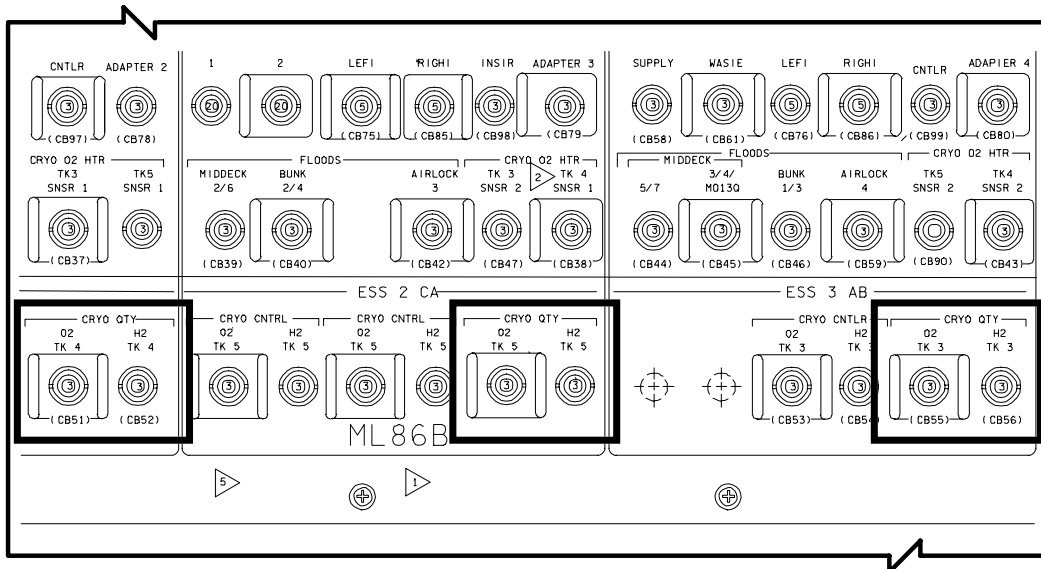
O2 TK1, TK2 HEATERS RESET/TEST Switches on Panel R1



O2 TK 4/5 RESEST/TEST SWITCH ON Panel A11 (OV-102)



Cryogenic Tank Quantity Sensor Circuit Breakers on Panel O13



Cryogenic Tank Quantity Sensor Circuit Breakers on Panel ML86B

Reactant Distribution

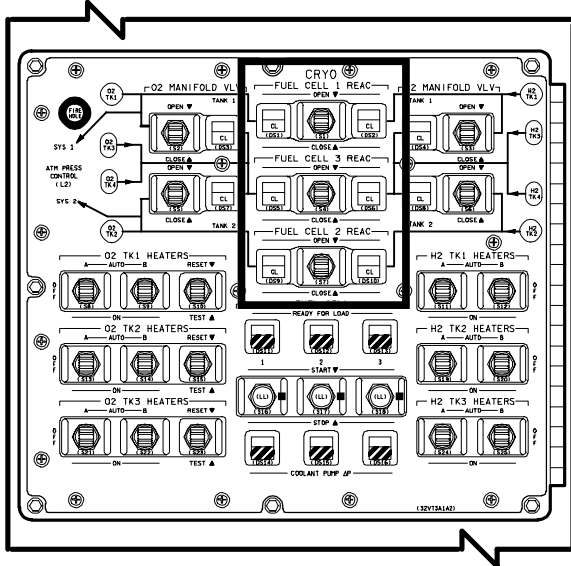
The cryogenic reactants flow from the tanks through a relief valve/filter package and a valve module. They then flow to the fuel cells through a common manifold. Hydrogen is supplied to the manifold from the tank at a pressure of 200 to 243 psia and oxygen is supplied at 803 to 883 psia. The pressure of the reactants will be essentially the same at the fuel cell interface as it is in the tanks, since only a small decrease in pressure occurs in the distribution system.

Each tank has a relief valve/filter package module that contains the tank relief valve and a 12-micron filter. The filter removes contaminants that could affect the performance of components within the PRSD and the fuel cells. The valve relieves excessive pressure overboard that builds up in the tank. The oxygen tank relief valve relieves at 1,005 psia and the hydrogen tank relief valve relieves at 302 psia. Tanks one and two also have a manifold relief valve that relieves pressure in the manifold lines. The manifold relief valves are a built-in safety device in the event a manifold valve and fuel cell reactant valve are closed because of a malfunction. The reactants trapped in the manifold lines would be warmed up by the internal heat of the orbiter and overpressurize. The manifold relief valve will open at 290 psi for hydrogen and 975 psi for oxygen to relieve pressure and allow the trapped reactants to flow back to their tanks.

The reactants flow from the relief valve/filter packages through four reactant valve modules: two hydrogen (hydrogen valve modules 1 and 2) and two oxygen (oxygen valve modules 1 and 2). The valve modules contain a check valve for each cryogenic tank line to prevent the reactants from flowing from one tank to another in the event of a leak. (This prevents a total loss of reactants. However, hydrogen tank 5 on OV-102 shares a common check valve with tank 4. A leak in either tank will drain the other as well. For this reason, unless the EDO pallet is flown on OV-102, hydrogen tanks 4 and 5 are used first.) The oxygen valve modules also contain the environmental control and life support system atmosphere pressure control system 1 and 2 oxygen supply valves. Each module also contains a manifold valve and fuel cell reactant valves.

Each fuel cell has two reactant valves—one for hydrogen and one for oxygen. The valves are controlled by the *FUEL CELL 1, 3, 2 REAC* switches on panel R1. When the switch is positioned to *OPEN*, the hydrogen and oxygen reactant valves for that fuel cell are opened and reactants are allowed to flow from the manifold into the fuel cell. When the switch is positioned to *CLOSE*, the hydrogen and oxygen reactant valves for that fuel cell are closed, isolating the reactants from the fuel cell and rendering that fuel cell inoperative. Each *FUEL CELL REAC* switch on panel R1 also has two talkback indicators, one on each side of the switch. The

corresponding talkback indicates *OP* when the valve is *OPEN* and *CL* when the valve is closed. There is redundant capability to close the *REAC VALVES* via the *FUEL CELL REAC VLV* circuit breakers and switches on panel C3.



FUEL CELL 1, 3, 2 REAC Switches and Talkbacks on Panel R1

WARNING

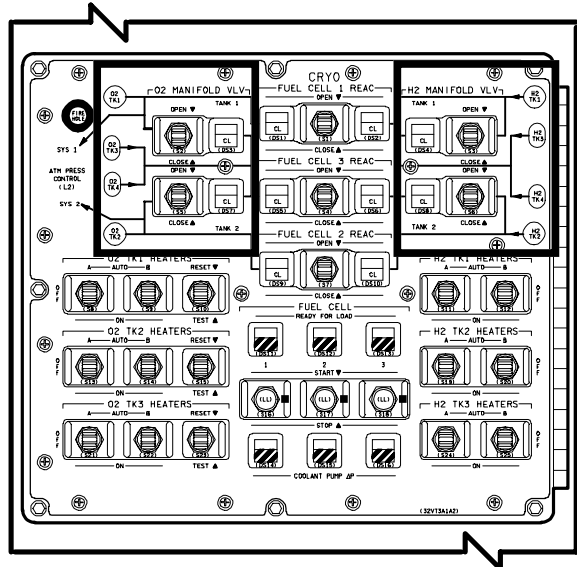
The *FUEL CELL REAC* switches on panel R1 are in a vertical column with *FUEL CELL 1 REAC* on top, *FUEL CELL 3 REAC* in the middle, and *FUEL CELL 2 REAC* on the bottom. This was done to allow the schematic to be placed on the panel. Because the switches are not in numerical order, it is possible to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

It is critical to have reactants available to the fuel cells. When any fuel cell reactant valve is closed, the red *FUEL CELL REAC* light on panel F7 is illuminated and a caution/warning tone is sounded. The computers sense the closed valve, which causes the *BACKUP C/W ALARM* light on panel F7 to be illuminated, an *SM ALERT* to occur, and a closed indication to be displayed on DISP 69 and SM SYS SUMM 1. This alerts the flight crew that the fuel cell will be inoperative within approximately 20 to 30

seconds for a hydrogen valve closure and 130 seconds for an oxygen valve closure. The time varies with power loading.

The O_2 and H_2 *MANIFOLD VLV* switches on panel R1 control the respective hydrogen and oxygen manifold valves. When the two hydrogen and two oxygen manifold valves are in the *CLOSE* position, fuel cell 1 receives reactants from cryogenic tank set 1, fuel cell 2 receives reactants from cryogenic tank set 2, and fuel cell 3 receives reactants from cryogenic tank sets 3 and above. ECLSS atmosphere pressure control system 1 receives oxygen from oxygen tank 1, and system 2 receives oxygen from oxygen tank 2. When the switches are positioned to *CLOSE*, the talkback indicator associated with each switch indicates *CL*.

With both H_2 and O_2 *MANIFOLD VLV 1* switches positioned to *OPEN* and the *MANIFOLD VLV 2* switches positioned to *CLOSE*, cryogenic tanks 1, 3 and above supply hydrogen to fuel cells 1 and 3, and oxygen cryogenic tanks 1, 3 and above supply oxygen to fuel cells 1 and 3, as well as to ECLSS atmosphere pressure control system 1. The talkback indicator associated with each *MANIF VLV 1, 2* switch indicates *OP, CL*, respectively. O_2 and H_2 TK 2 continue to supply fuel cell 2.



O2 and H2 MANIFOLD VLV Switches and Talkbacks on Panel R1

CAUTION

There are no relief valves for O₂ and H₂ manifold 3's with manifold valves 1 and 2 closed. This configuration should be avoided except for leak isolation and troubleshooting

When the H₂ and O₂ MANIFOLD VLV 2 switches are positioned to OPEN, and the MANIFOLD VLV 1 switches are positioned to CLOSE, hydrogen cryogenic tanks 2 and 3 and above supply hydrogen to fuel cells 2, 3, and oxygen cryogenic tanks 2 and 3 and above supply oxygen to fuel cells 2 and 3, as well as to ECLSS atmosphere pressure control system 2. The talkback indicator associated with each MANF VLV 1, 2 switch indicates OP, CL, respectively. H₂ and O₂ tank 1 continue to supply fuel cell 1.

With the H₂ and O₂ MANIFOLD VLV 1 and 2 switches positioned to OPEN, all hydrogen cryogenic tanks are available to supply hydrogen to all three fuel cells, and all oxygen cryogenic tanks are available to supply oxygen to all three fuel cells, as well as to ECLSS atmosphere pressure control systems 1 and 2. Because tank sets 1 and 2 are regulated at a slightly lower pressure, tank sets 3 and above will feed before tank set 1 and 2. Reactants will be supplied to the fuel cells by the tank(s) with the highest pressure.

Manifold pressure data from two pressure sensors located in the respective hydrogen and oxygen valve modules is displayed on DISP 68 CRYO SYSTEM. This information is also sent to the systems management computer where its lower limit is checked. If the respective hydrogen and oxygen manifold pressures are below 150 psia and 200 psia respectively, an SM ALERT will occur.

Data for installed EDO pallet cryo tank sets can be monitored during ascent and entry on CRT display BFS SPEC 168 CRYO PALLET. On orbit the data is available on SM SPEC 168 CRYO PALLET.

Fuel Cell System

The three fuel cells are located under the payload bay area in the forward portion of the orbiter's midfuselage. Each fuel cell is 14 inches high, 15 inches wide, 40 inches long, and weighs 255 pounds. Each fuel cell is reusable and restartable.

The three fuel cells are individually coupled to the PRSD subsystem, the active thermal control system (ATCS), the supply water storage subsystem, and the electrical power distribution and control (EPDC) subsystem. The fuel cells generate heat and water as by-products of electrical power generation. The excess heat is directed to fuel cell heat exchanger, where it is rejected to the Freon coolant loops. The water is directed to the supply water storage subsystem for the environmental control and life support system.

ACCESSORIES	POWER
<ul style="list-style-type: none">• Reactant flow monitor• Heat rejection• Water rejection• Thermal control• Cell performance monitor• Electrical control unit	96 cells Converts H ₂ & O ₂ into: <ul style="list-style-type: none">• Power• Potable water• Heat

Fuel Cell Block Diagram

The nominal voltage and current range of each fuel cell is 2 kW at 32.5 volts dc, 61.5 amps to 12 kW at 27.5 volts dc, 436 amps. Each is capable of supplying up to 10 kW maximum continuous power in nominal situations, 12 kW continuously in off-nominal situations (with one or more fuel cells failed), and up to 16 kW for 10 minutes. The average on-orbit power consumption of the orbiter is approximately 14 kW, leaving additional capability available for payloads. Each fuel cell is serviced between flights and reused until it has accumulated 2,000 hours of on-line service.

The orbiter's three fuel cells operate as independent electrical power sources, each supplying its own isolated, simultaneously operating dc bus. Each fuel cell consists of a power section and an accessory section. The power section, where hydrogen and oxygen are transformed into electrical power, water, and

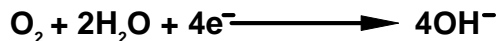
heat, consists of 96 cells contained in three substacks. Manifolds run the length of these substacks and distribute hydrogen, oxygen, and coolant to the cells. The cells contain an oxygen electrode (cathode), and a hydrogen electrode (anode) that are separated by a porous matrix saturated with potassium hydroxide electrolyte.

The accessory section monitors the reactant flow, removes waste heat and water from the chemical reaction, and controls the temperature of the stack. The accessory section consists of the hydrogen and oxygen flow system, the coolant loop, and the electrical control unit.

The fuel cell generates power through an electrochemical reaction of hydrogen and oxygen. At the hydrogen electrode (anode), hydrogen is oxidized according to the following reaction:



forming water and releasing electrons. At the oxygen electrode (cathode), oxygen is reduced in the presence of water. It forms hydroxyl ions according to the following relationship:



The net reaction consumes one oxygen molecule and two hydrogen atoms in the production of two water molecules, with electricity and heat formed as by-products of the reaction.

The fuel cell coolant system circulates a liquid fluorinated hydrocarbon and transfers the waste heat from the cell stack through the fuel cell heat exchanger to the Freon coolant loop system in the midfuselage. Internal control of the circulating fluid maintains the cell stack at a load-dependent operating temperature of approximately 200° F.

When the reactants enter the fuel cells, they flow through a preheater (where they are warmed from a cryogenic temperature to 40° F or greater), a 6-micron filter, and a two-stage, integrated dual gas regulator module. The first stage of the regulator reduces the pressure of the hydrogen and oxygen to 100 to 120 psia. The second stage reduces the oxygen pressure to a range of 60 to 62 psia and maintains the hydrogen pressure at 4.5 to 6 psia differential below the oxygen pressure. The regulated

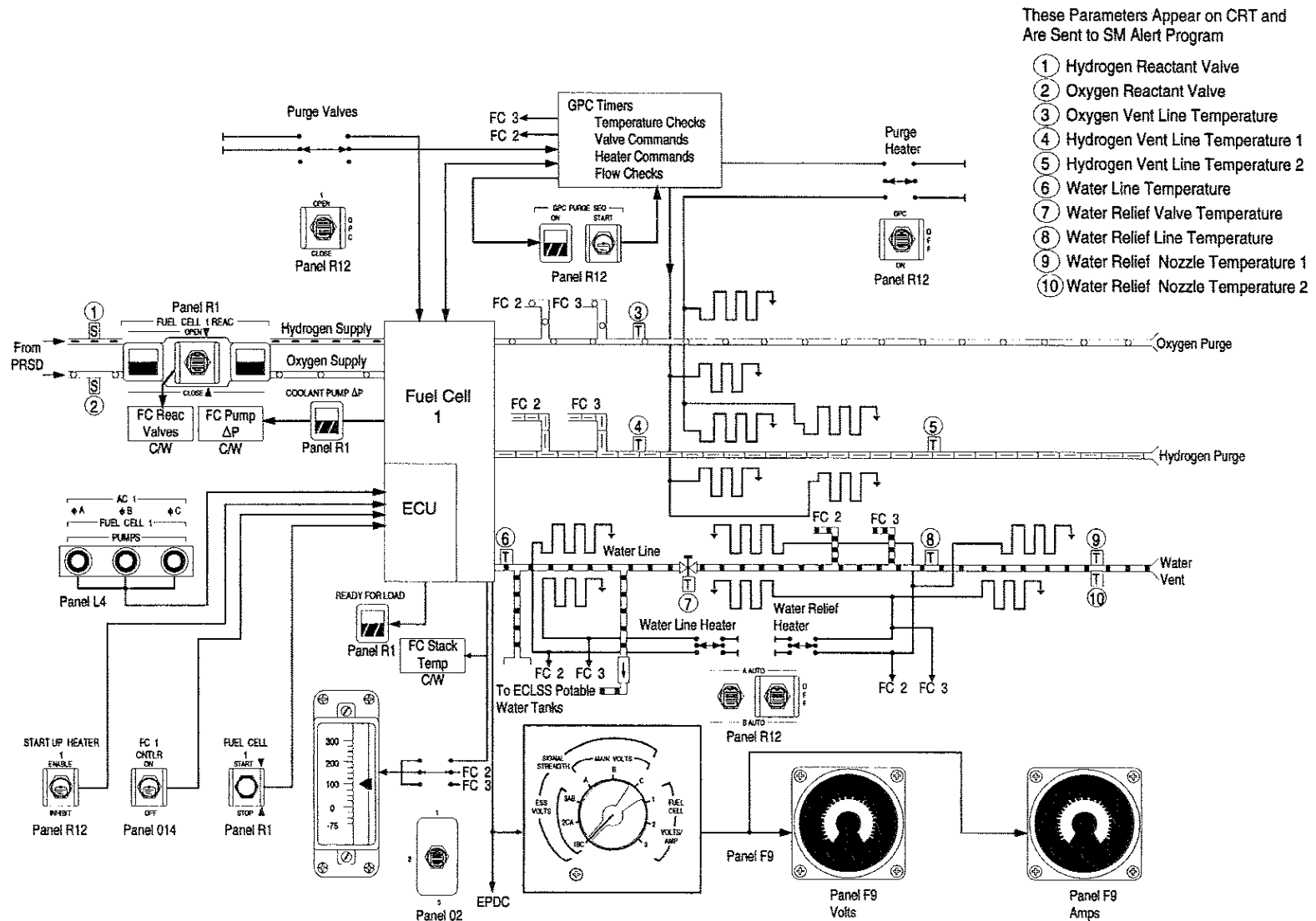
oxygen lines are connected to the accumulator, which maintains an equalized pressure between the oxygen and the fuel cell coolant. If oxygen and hydrogen pressure decrease, the coolant's pressure is also decreased to prevent a large differential pressure inside the stack that could deform the cell stack structural elements.

Upon leaving the dual gas regulator module, the incoming hydrogen mixes with the hydrogen-water vapor exhaust from the fuel cell stack. This saturated gas mixture is routed through a condenser, where the temperature of the mixture is reduced, condensing a portion of the water vapor to form liquid water droplets. The liquid water is then separated from the hydrogen-water mixture by the hydrogen pump /water separator. A centrifugal water separator extracts the liquid water and pressure-feeds it to potable tanks in the lower deck of the pressurized crew cabin. Water from the potable water storage tanks can be used for crew consumption and for cooling the Freon loops by feeding the flash evaporator system.

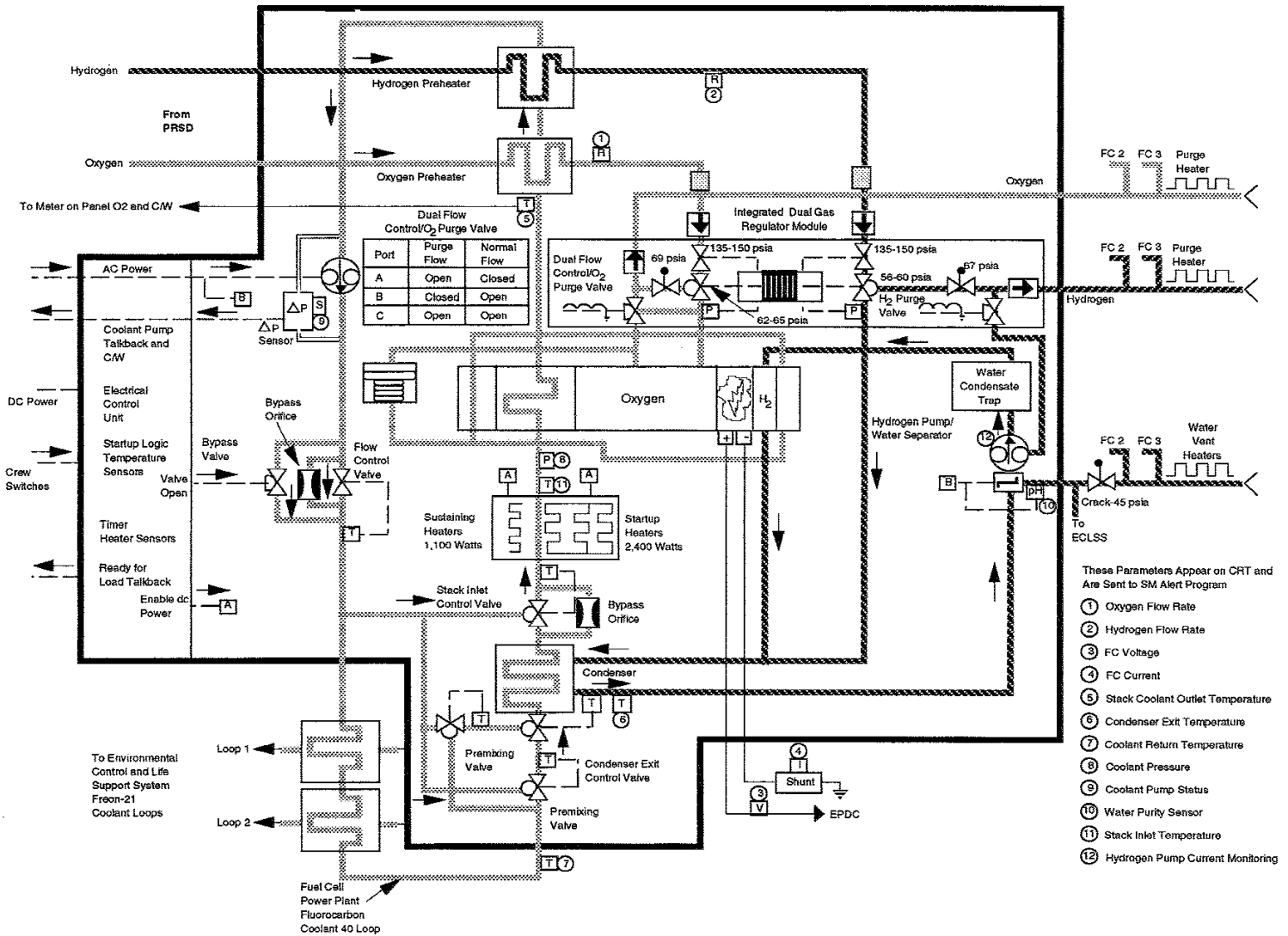
The hydrogen pump uses three-phase ac power to circulate the hydrogen gas back to the fuel cell stack, where some of the hydrogen is consumed in the reaction. The remainder flows through the fuel cell stack, removing the product water vapor formed at the hydrogen electrode. The hydrogen-water vapor mixture then combines with the regulated hydrogen from the dual gas generator module and the loop begins again. The performance at the pump is monitored via the H₂ pump status voltage display on DISP 69.

The oxygen from the dual gas regulator module flows directly through two ports into a closed-end manifold in the fuel cell stack, achieving optimum oxygen distribution in the cells. All oxygen that flows into the stack is consumed, except during purge operations.

Reactant consumption is directly related to the electrical current produced: if there are no internal or external loads on the fuel cell, no reactants will be used. Because of this direct proportion, leaks may be detected by comparing reactant consumption with current produced. An appreciable amount of excess reactants used indicates a probable leak.



Fuel Cell 1 Typical Display and Controls



Fuel Cell - Typical

Water Removal

Water and electricity are the products of the oxidation/reduction reaction of oxygen and hydrogen that takes place in the fuel cells. The water must be removed or the cells will become saturated with water, decreasing reaction efficiency. With an operating load of about 7 kW, it takes only 110 amp-hr or approximately 20 minutes to flood the fuel cell with produced water, thus effectively halting power generation. Hydrogen is pumped through the stack and the portion that is not consumed in the reaction acts as a carrier gas, picking up and removing water vapor on the way. After being condensed, the liquid water is separated from the hydrogen by the hydrogen pump/water separator and discharged from the fuel cell to be stored in the ECLSS potable water storage tanks.

Product water is routed to tank A; when tank A is full, it is routed to tank B, then tanks C and D. An alternate water delivery path is also available to deliver water to the ECLSS tanks if the primary path is lost. If water tanks are full, or there is line blockage, the water relief valves open at 45 psia to allow the water to vent overboard through the water relief line and nozzle. Check valves prevent water tanks from discharging through an open relief valve.

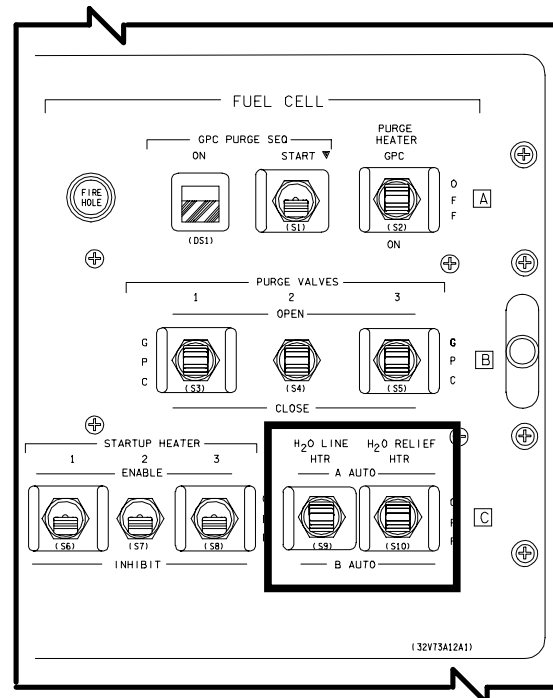
For redundancy, two thermostatically activated heaters are wrapped around the discharge and relief lines to prevent blockage caused by the formation of ice in the lines. Two switches on panel R11U, *H₂O LINE HTR* and *H₂O RELIEF HTR*, provide the flight crew with the capability to select either *A AUTO* or *B AUTO* for the fuel cell water discharge line heaters and the water relief line and vent heaters respectively.

Thermostatically controlled heaters will maintain the water line temperature above 53° F when required. The normal temperature of product water is approximately 140° to 150° F. Thermostatically controlled heaters also maintain the water relief valve's temperature when in use between 70° to 100° F.

Fuel cell 1, 2, or 3 dc voltage and current can be monitored on the DC VOLTS and DC AMPS/SIG STR meters on panel F9, using the rotary switch below the meters to select a specific fuel cell, and on DISP 69. Temperature sensors located on the fuel cell water discharge

line, relief valve, relief line, and vent nozzle are displayed on the DISP 69 FUEL CELLS.

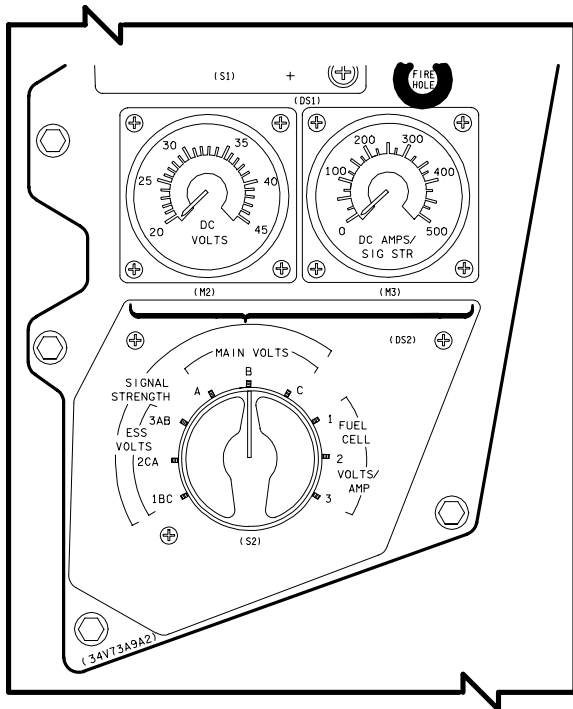
If the potassium hydroxide electrolyte in any fuel cell migrates into the product water, a pH sensor located downstream of the hydrogen pump/water separator will sense the presence of the electrolyte and alert the crew via an *SM ALERT* and display on DISP 69. A common pH sensor is located downstream of the interface between each fuel cell's primary water path, prior to entering the ECLSS supply H₂O tanks.



H₂O LINE and H₂O RELIEF HTR Switches On Panel R11U

2011/ /069		FUEL CELLS			4 000/02:35:11 000/00:00:00		
		FC					
		1	2	3			
VOLTS		31.3	31.2	31.2	H2O RLF	LINE T	72
AMPS		161	164	163		NOZ T A	244
						B	244
FLOW O2		2.7	2.7	2.6		HTR SW	A
H2		0.5	0.5	0.5	PURGE LN	O2 T	32
REAC O2		OP	OP	OP		H2 T1	40
H2		OP	OP	OP		T2	40
					H2O LINE	PH	
STACK T		+204	+204	+204			
EXIT T		151	151	151			
COOL T		73	73	73			
P		61	61	61			
PUMP					PH		
H2 PUMP		0.4	0.4	0.4	ΔV	SS1	15
RDY		RDY	RDY	RDY		SS2	18
						SS3	20
							22
H2O					ΔAMPS		- 3
PRI LN T		144	144	144			+ 1
VLV T		93	93	93			+ 2
ALT LN T		79	79	79			

FUEL CELLS CRT Display (DISP 69)



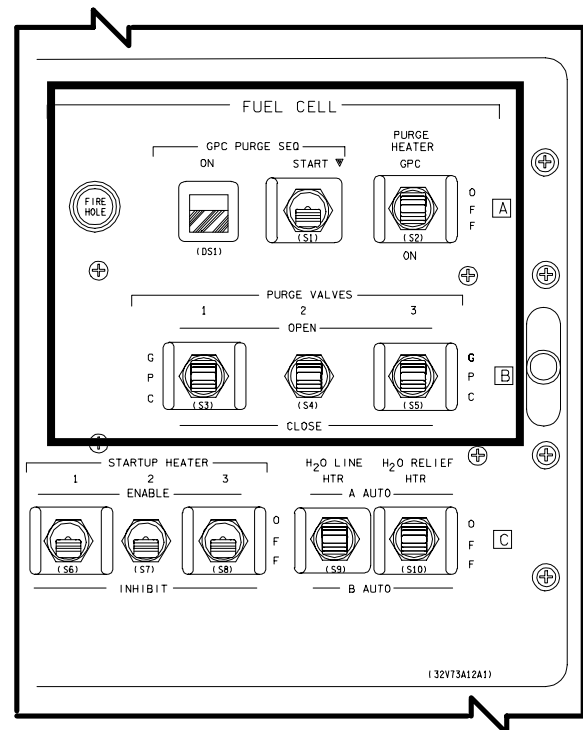
DC VOLTS and DC AMPS Meters and Rotary Switch on Panel F9

Fuel Cell Purge

During normal fuel cell operation, the reactants are present in a closed-loop system and either consumed in the production of electricity or recirculated through the stack. Any inert gases or other contaminants will accumulate in and around the porous electrodes in the cells and reduce the reaction efficiency and electrical load support capability. Purging is performed periodically to cleanse the cells. The purge sequence can be controlled manually by the crew, automatically by flight software, or via commands sent by Mission Control. When a purge is initiated by opening the purge valves, the oxygen and hydrogen systems become open-loop systems; increased flows allow the reactants to circulate through the stack, pick up the contaminants, and blow them overboard through the purge lines and vents. Electrical power is produced throughout the purge sequence. No more than 10 kilowatts (350 amps) should be required from a fuel cell being purged because of the increased reactant flow and preheater limitations.

Fuel cell purge can be activated automatically or manually by the use of switches on panel R11U.

At the initiation of either an auto or manual purge, the purge line heaters are turned on to heat the purge lines and ensure that the reactants will not freeze in the lines. The hydrogen reactant is the more likely to freeze because it is saturated with water vapor. Depending on the orbit trajectory and vehicle orientation, the heaters may require 27 minutes to heat the lines to the required temperatures. Due to limitations on the hydrogen and oxygen preheaters in the fuel cells, the crew checks the fuel cell current to ensure each fuel cell has a load of less than 350 amps. As the current output of the fuel cell increases, the reactant flow rates increase and the preheaters raise the temperature of the reactants to a minimum of 40° F in order to prevent the seals in the dual gas regulator from freezing prior to purging. At loads greater than 350 amps, additional flow during a purge would exceed the maximum flow the preheaters are capable of warming. The crew also checks that the fuel cell is not shut down, that time to deorbit is more than 3 hours, and, for an automatic purge, that an SM OPS transition is not scheduled within the next hour. An SM OPS transition will halt the automatic purge sequence.



FUEL CELL Purge Switches on Panel R11U

The purge lines from all three fuel cells are manifolded together downstream of their purge valves and associated check valves. The line leading to the purge outlet is sized to permit unrestricted flow from only one fuel cell at a time.

NOTE

If more than one fuel cell is purged simultaneously, back pressure may build in the purge line. Due to the sizing of the hydrogen and oxygen purge lines, the back pressure in the H_2 line can cause the hydrogen pressure to rise above the oxygen pressure. Although the dual gas regulator is designed to prevent this from happening, it would not be advisable to expose all three fuel cells to this condition at the same time. If there is a generic problem with the dual gas regulator, this could cause all three fuel cells to fail simultaneously.

For an automatic purge, the FUEL CELL PURGE heater switch is positioned to GPC and the FUEL CELL PURGE VALVES 1, 2, and 3 switches on panel R11U are positioned to GPC. The FUEL CELL GPC PURGE SEQ switch is then positioned to START and must be held until 3 seconds after the talkback indicator beside the switch indicates gray. The automatic purge sequence will not begin if the indicator indicates barberpole. First, the GPC turns the purge line heaters on and monitors the temperature of the lines. The one oxygen line temperature sensor must register at least 69° F and the two hydrogen line temperature sensors 79° F and 40° F respectively, before the purge valves will open. When the proper temperatures have been attained, the GPC will open the hydrogen and oxygen purge valves for fuel cell 1 for 2 minutes and then close them, and repeat the process for fuel cells 2 and 3. If the temperatures are not up to the minimum limit after 27 minutes, the GPC will issue an SM ALERT, display the data on DISP 69, and stop the auto sequence. Thirty minutes after the fuel cell 3 purge valves have been closed (to ensure that the purge lines have been totally evacuated of water vapor by the heaters), the GPC will turn off the purge line heaters. This provides sufficient time and heat to bake out any remaining water vapor. If the heaters are turned off before 30 minutes have elapsed, water vapor left in the lines may freeze. The

GPC purge sequence start can also be initiated using the SPEC 60 SM TABLE MAINT display. The sequence is normally performed by Mission Control uplink on orbit.

A manual fuel cell purge would also be initiated by the flight crew using the switches on panel R11U. In the manual mode, the three fuel cells must be purged separately. The FUEL CELL PURGE HEATER switch is positioned to ON for the same purpose as in the automatic mode, and the flight crew verifies that the temperatures of the oxygen line and two hydrogen lines are at the same minimum temperatures as in the automatic mode before the purge sequence is initiated. The FUEL CELL PURGE VALVE 1 switch is then positioned to OPEN for 2 minutes and the flight crew observes that the oxygen and hydrogen flow rates increase on DISP 69. The switch is then positioned to CLOSE, and a decrease in the oxygen and hydrogen flow rates is observed on DISP 69, confirming the purge valves are closed. Fuel cell 2 is purged in the same manner using the FUEL CELL PURGE VALVES 2 switch. Fuel cell 3 is then purged in the same manner using the FUEL CELL PURGE VALVES 3 switch. After the 30-minute line bakeout period, the FUEL CELL PURGE HEATER switch is positioned to OFF. Manual purges use different heaters than automatic purges. At least one manual purge is scheduled per flight

Fuel Cell Cooling/Temperature Control

In order to cool the fuel cell stack during its operations, distribute heat during fuel cell start-up, and warm the cryogenic reactants entering the stack, the fuel cell circulates fluorinated hydrocarbon throughout the fuel cell. The fuel cell coolant loop and its interface with the ECLSS Freon coolant loops are identical in fuel cells 1, 2, and 3.

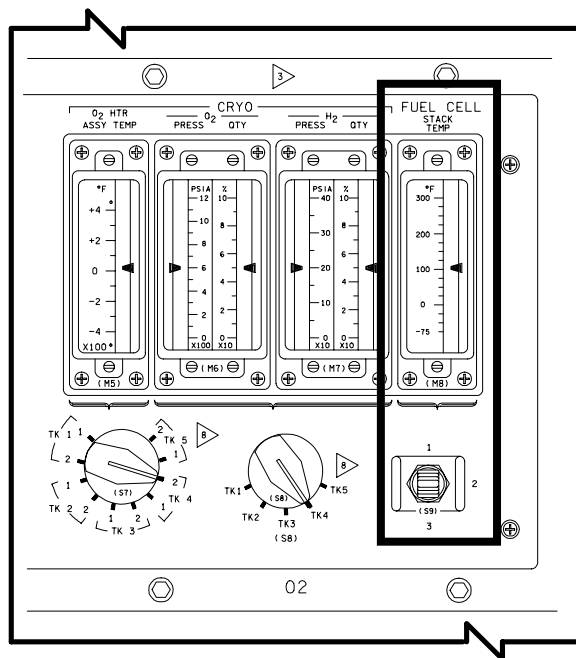
The temperature of the coolant returning from the Freon coolant loops is sensed before it enters the fuel cell. This is displayed as COOL T on DISP 69. It then enters the fuel cell and passes through a 75-micron filter. After the filter, two temperature-controlled mixing valves allow some of the hot coolant to mix with the cool returning coolant to prevent the condenser exit control valve from oscillating. The control valve adjusts the flow of the coolant through the condenser to maintain the hydrogen-water vapor exiting the condenser at a temperature between 148° and 153° F.

The stack inlet control valve maintains the temperature of the coolant entering the stack between 177° and 187° F. The accumulator interfaces with the oxygen cryogenic reactant to maintain an equalized pressure between the oxygen and the coolant (the oxygen and hydrogen pressures are controlled at the dual gas regulator) to preclude a high pressure differential in the stack. The pressure in the coolant loop is sensed before the coolant enters the stack and is displayed as COOL P on DISP 69.

The coolant is circulated through the fuel cell stack to absorb the waste heat from the hydrogen/oxygen reaction occurring in the individual cells. After the coolant leaves the stack, its temperature is sensed and the data is displayed on the FUEL CELL STACK TEMP meter through the three-position switch located below the meter on panel O2 and on the DISP 69 display as STACK T. The yellow FUEL CELL STACK TEMP, the red BACKUP C/W ALARM light, and the SM ALERT light on panel F7 will be illuminated if fuel cell and stack temperatures exceed upper or lower limits. The hot coolant from the stack flows through the oxygen and hydrogen preheaters where it warms the cryogenic reactants before they enter the stack.

The coolant pump utilizes three-phase ac power to circulate the coolant through the loop. The differential pressure sensor senses a pressure differential across the pump to determine the status of the pump. The FUEL CELL PUMP light on panel F7 will be illuminated if fuel cell 1, 2, or 3 coolant pump delta pressure is lost and a fault message will be sent to the CRT. If the coolant pump for fuel cell 1, 2, or 3 is off, the BACKUP C/W ALARM light will be illuminated and a fault message and a $\Delta P \downarrow$ will be displayed.

The temperature-actuated flow control valve downstream from the pump adjusts the coolant flow to maintain the fuel cell coolant exit temperature between 190° and 210° F. The stack inlet control valve and flow control valve have bypass orifices to allow coolant flow through the coolant pump and to maintain some coolant flow through the condenser for water condensation, even when the valves are fully closed due to the requirements of thermal conditioning. The hot coolant that is not used at the mixing valves exits the fuel cells to the fuel cell heat exchanger where it transfers its excess heat to be dissipated through the ECLSS Freon coolant loop systems in the midfuselage.

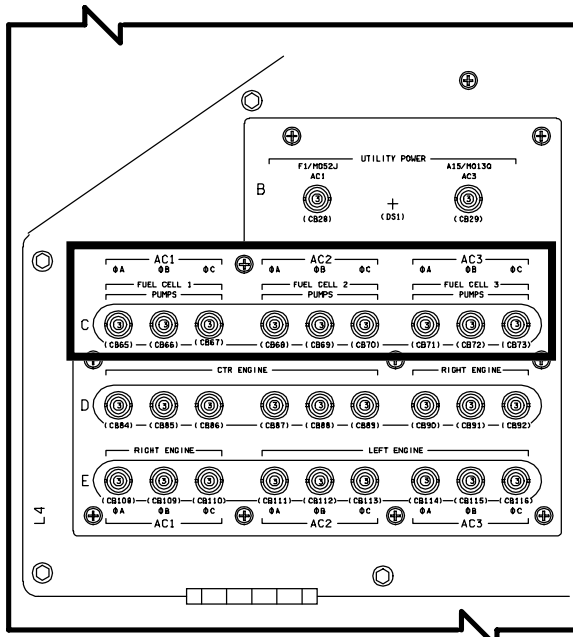


FUEL CELL STACK TEMP Meter and FUEL CELL 1, 2, 3 Switch on Panel O2

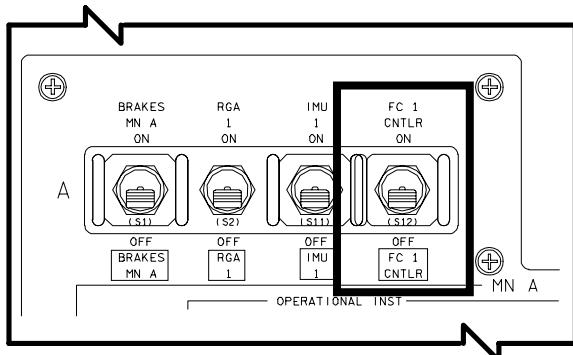
Electrical Control Unit

The electrical control unit located in each fuel cell power plant contains the startup logic, heater thermostats, 30-second timer, and interfaces with the controls and displays for fuel cell startup, operation, and shutdown. The unit controls the supply of ac power to the coolant pump, hydrogen pump/water separator and the pH sensor. It also controls the dc power supplied to the flow control bypass valve (open only during startup) and the internal startup and sustaining heaters. It also controls the status of the FUEL CELL 1, 2, 3 READY FOR LOAD and COOLANT PUMP AEP talkback indicators on panel R1.

The nine fuel cell circuit breakers that connect three-phase ac power to the three fuel cells are located on panel L4. Each fuel cell electrical control unit receives its power from an essential bus through the FC CNTLR switch on panels O14, O15 and O16.



FUEL CELL Circuit Breakers on Panel L4



FC1 CNTLR Switch on Panel O14

Cell Performance Monitor

As fuel cell life increased with the introduction of the third substack, the likelihood of individual cell failures caused by “wearout” or age increased. Consequently, the cell performance monitor (CPM) was designed to detect individual cell performance problems or imminent failures such as cell crossover.

Crossover is defined as an uncontrolled mixing of the reactants that results in the generation of excessive product heat. The combination of hydrogen and oxygen requires little heat to explode. During normal fuel cell operation, hydrogen and oxygen are diffusely mixed to produce electricity. The matrix, a fibrous asbestos blotter device within each cell, holds

the KOH electrolyte and limits the H_2/O_2 mixing. A crossover occurs when the matrix fails to do its job. A manufacturing flaw in the matrix or an impurity in the matrix fibers may cause a pin hole to develop after hours and hours of exposure to the caustic KOH in the presence of the waste heat within the cell.

As the direct combination of the reactant molecules occurs at the pin hole, increased waste heat may cause the pin hole to burn and enlarge allowing more reactants to combine. If this reaction continues, it might uncontrollably propagate and possibly result in a violent explosion. A crossover may proceed rapidly or gradually. Before the introduction of the cell performance monitor prior to STS-9, the electrical performance indicators of a crossover-distressed cell were not detectable, since the lost electrical performance of the substack with the degraded cell was picked up by the healthy substacks.

The cell performance monitor compares each half substack voltage and calculates a delta volts measurement. By comparing both halves of a substack, the cell performance monitor can detect cell changes. Since all the cells in a substack are producing the same current, both halves of the substack should be at approximately identical voltages. Ideally $\Delta V = 0$ but small fluctuations are common. A significant voltage loss in any one cell will produce a change in the ΔV with 300 mV being a critical performance loss. ΔV can be either positive or negative, so the cell performance monitor converts the positive/negative ΔV between the upper and lower substack halves to an absolute value and then outputs that value (0 to 500 mV). To provide margin and accommodate the absolute value, the C/W limit is set at 150 mV. The output is then converted to a 0 to 5 V dc signal for telemetry and crew display systems by a “times 10” amplifier. Calibration curves rescale this to electronic units (EU) (0 to 50 mV).

Every 7.5 minutes the cell performance monitor performs a self-test to ensure data accuracy and to prevent fuel cell shutdown due to faulty data. During the self-test period:

- The voltage measurement of the substack halves ceases.

- A test signal of 50 mV is input to the voltage measurement logic.
- The output of the “times 10” amplifier is examined for 425 to 575 mV.
- If the test fails, the output voltage is driven to 5 volts until the next self-test is performed 7 ± 1 minute later. A test voltage of 50 mV is introduced and the sequence repeats itself.
- If the self-test is passed, the unit resumes substack half voltage measurements.

Fuel Cell Start

The *FUEL CELL START/STOP* switches on panel R1 are used to initiate the start sequence or stop the fuel cell operation. When a switch is held in its momentary *START* position, the control unit connects the three-phase ac power to the coolant pump and hydrogen pump/water separator (allowing the coolant and the hydrogen-water vapor to circulate through these loops) and connects the dc power to the internal startup and sustaining heaters and the flow control bypass valve. The switch must be held in the *START* position until the *COOLANT PUMP AEP* talkback shows gray (approximately three to four seconds), which indicates that the coolant pump is functioning properly by creating a differential pressure across the pump. When the *COOLANT PUMP AEP* talkback indicates barberpole, the coolant pump is not running.

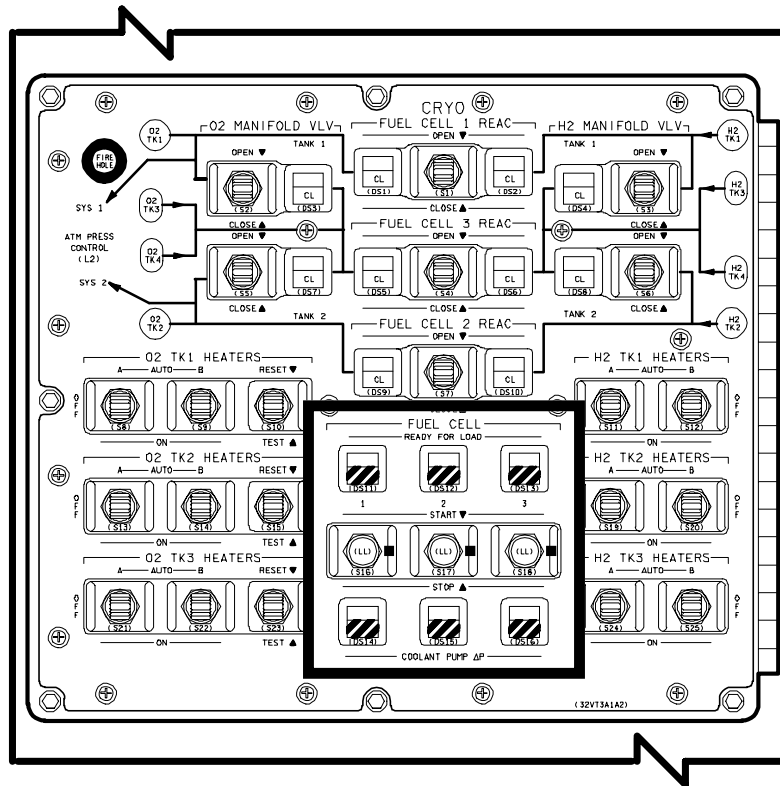
The *READY FOR LOAD* talkback for each fuel cell will show gray after the 30-second timer times out or when the stack-out temperature is

above 187° F, whichever occurs last. Stack-out temperature can be monitored on the SM SYS SUMM 1 (STACK T) and DISP 69 FUEL CELLS displays (STACK T). It can also be monitored on the FUEL CELL STACK OUT TEMP meter on panel O2, using the switch beneath the meter to select the fuel cell. When the *READY FOR LOAD* talkback shows gray, the fuel cell is up to the proper operating temperature and is ready for loads to be attached to it. It should not take longer than 25 minutes for the fuel cell to warm up and become fully operational; the actual time depends on the fuel cell's initial temperature. The *READY FOR LOAD* indicator remains gray until the *FUEL CELL START/STOP* switch for each fuel cell is placed to *STOP*, the *FC CNTLR* switch on the overhead panel is placed to *OFF* or the essential bus power is lost to the electrical control unit.

2011/ /078		SM SYS SUMM 1		4 000/14:44:12		
				000/00:00:00		
SMOKE	1/A 2/B	DC VOLTS	1/A	2/B	3/C	
CABIN	0.0	FC	30.6	30.1	31.0	
L/R FD	0.0 0.0	MAIN	30.6	30.1	31.0	
AV BAY	1 0.3 0.3	ESS	29.6	29.6	29.3	
	2 0.3 0.4					
	3 0.3 0.3	CNTL	1 29.4	29.4	29.6	
CABIN			2 29.4	29.4	29.4	
PRESS	14.0		3 29.4	29.4	29.4	
dP/dT-EQ	+1.00 +1.000	AC				
O2 CONC		VOLT	φA	118	118	117
PP02	3.00 3.00		φB	117	117	118
FAN ΔP	5.00		φC	117	117	118
HX OUT T	46	AMPS	φA	4.3	6.3	2.1
O2 FLOW	0.0 0.0		φB	5.5	6.6	2.2
N2 FLOW	0.0 0.0		φC	3.1	5.0	3.2
IMU FAN	A B C	FUEL CEL				
ΔV FC1	FC2 FC3	AMPS	180	232	146	
SS1	22 21 22	REAC VLV	0P	0P	0P	
SS2	22 22 23	STACK T	+202	+206	+200	
SS3	23 21 21	EXIT T	150	152	149	
TOTAL AMPS	557	COOL P	61	60	61	
	KW 17	PUMP				

243

SM SYS SUMM 1 (DISP 78)



FUEL CELL START/STOP Switches and READY FOR LOAD and COOLANT PUMP P Talkback Indicators on Panel R1

Electrical Power Distribution and Control

The electrical power distribution and control subsystem controls and distributes ac and dc electrical power to the orbiter subsystems, the solid rocket boosters, the external tank, and payloads. The 28 volts dc generated by each of the three fuel cells is distributed to a main dc bus. The three main dc buses (MN A, MN B, and MN C) are the prime sources of power for the vehicle's dc loads. Each of the three dc main buses supplies power to three solid-state (static), single-phase inverters, each of which powers one three-phase alternating-current bus; thus, the nine inverters convert dc power to 117 +3. -1 volt rms, 400-hertz ac power for distribution to three ac buses (AC 1, AC 2, and AC 3) for the vehicle's ac loads.

Bus System

The three main dc buses are main A (MN A), main B (MN B), and main C (MN C). Three ac buses, AC 1, AC 2, and AC 3, supply ac power

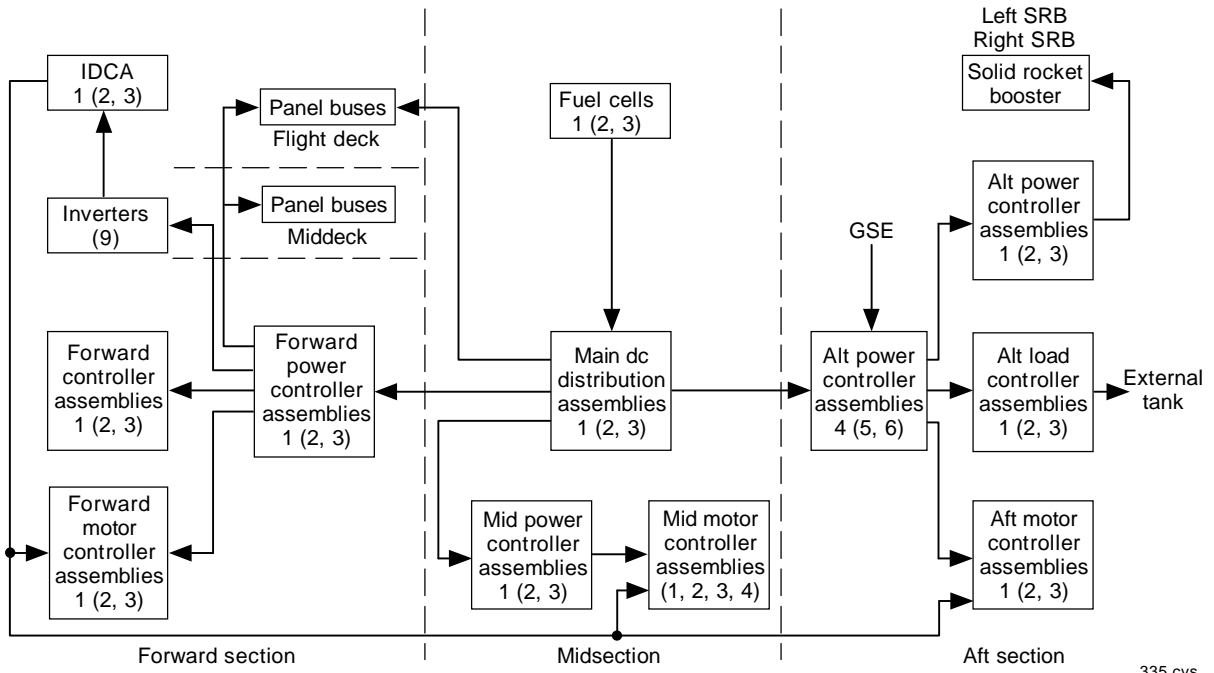
to the ac loads. Three essential buses, ESS1BC, ESS2CA, and ESS3AB, supply dc power to selected flight crew controls and electrical loads that are deemed essential. Nine control buses - CNTL AB 1, 2, 3; CNTL BC 1, 2, 3; and CNTL CA 1, 2, 3 - are used to supply control power to flight crew controls. Two preflight buses, PREFLT 1 and PREFLT 2, are used only during ground operations.

Depending on the criticality of orbiter electrical equipment, some electrical loads may receive redundant power from two or three main buses. If an electrical load receives power from two or three sources, it is for redundancy only and not for total power consumption.

DC Power

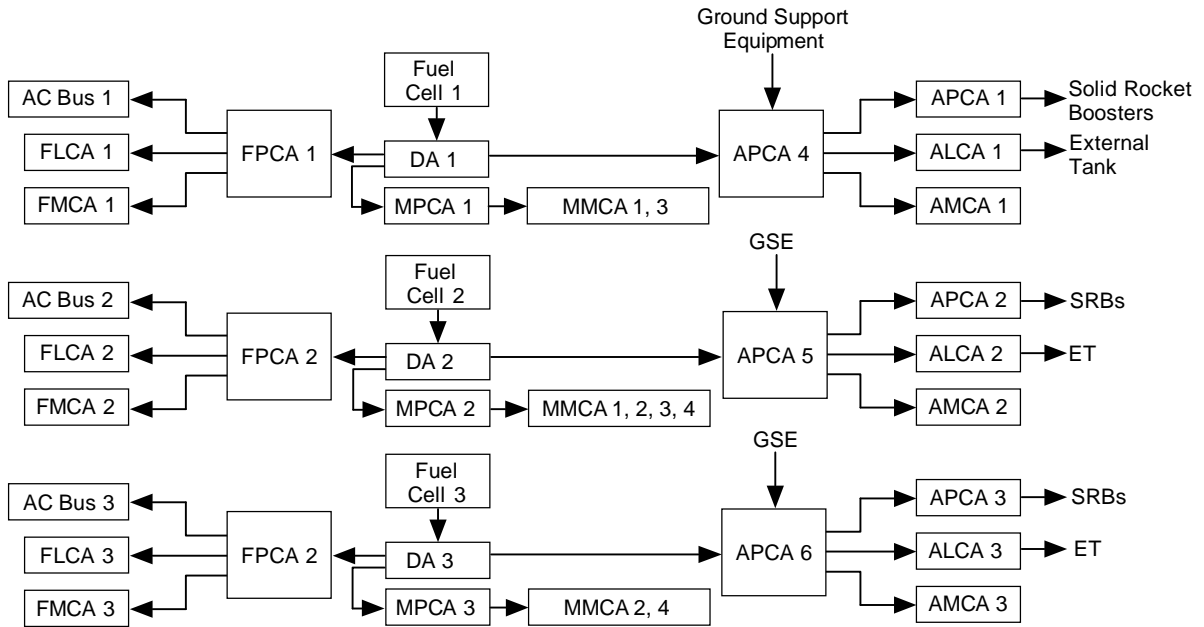
Main Buses

The main buses distribute dc electrical power from the fuel cells to locations throughout the orbiter. Distribution assemblies handle the routing of main bus power.



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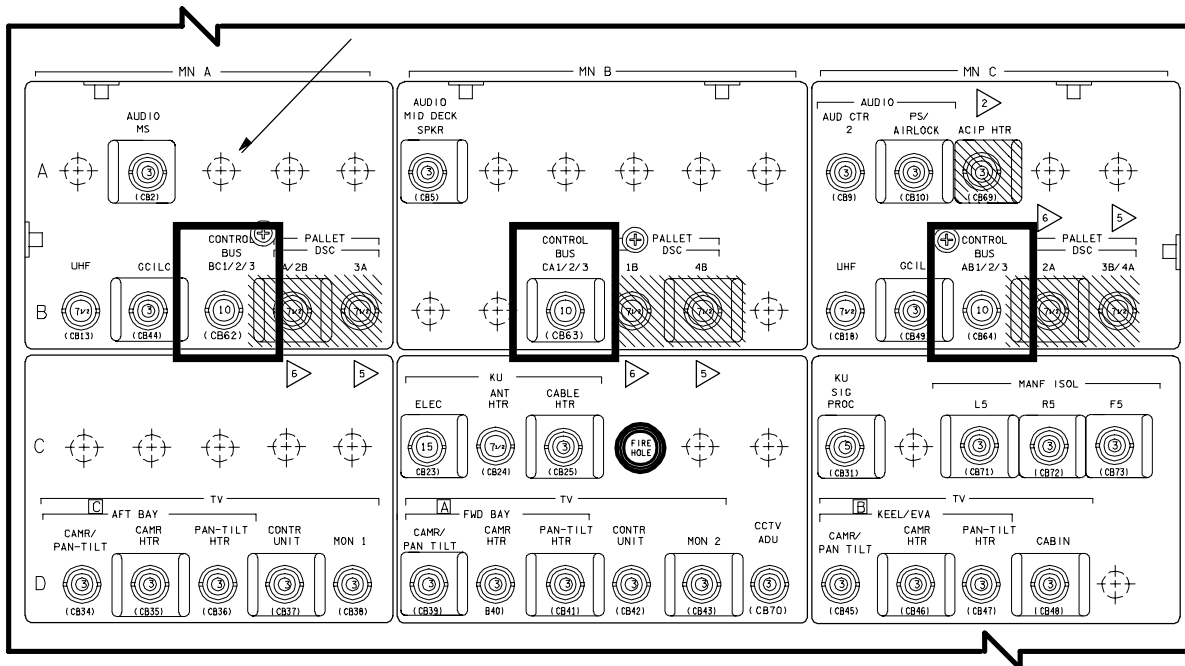
Electrical Power Distribution Block Diagram



- DA - Distribution Assembly
- FLCA - Forward Load Controller Assembly
- FMCA - Forward Motor Controller Assembly
- FPCA - Forward Power Controller Assembly
- MPCA - Mid Power Controller Assembly
- MMCA - Mid Motor Controller Assembly
- APCA - Aft Power Controller Assembly
- ALCA - Aft Load Controller Assembly
- AMCA - Aft Motor Controller Assembly

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Direct Current Power Distribution Diagram



CONTROL BUS Circuit Breakers on Panel R15

Essential Buses

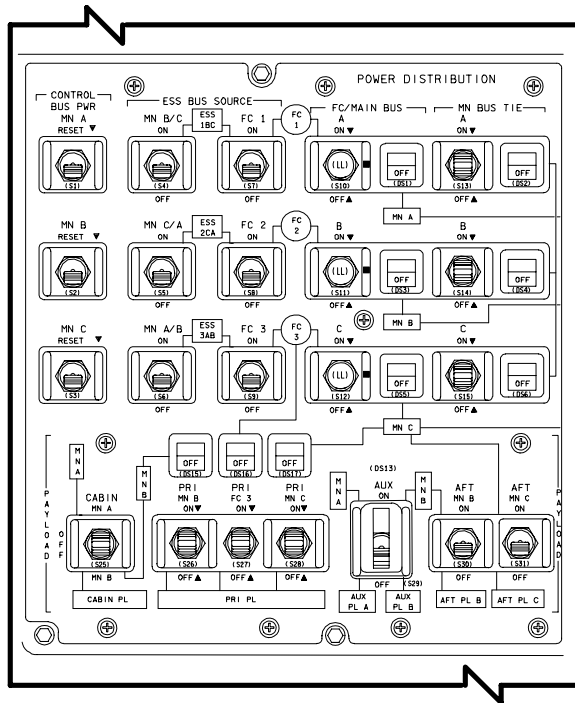
Essential buses supply power to switches that are necessary to restore power to a failed main dc or ac bus and to essential electrical loads and switches. In some cases, essential buses are used to power switching discretely to multiplexers/demultiplexers. Examples of the selected flight crew switches and loads are the EPS switches, GPC switches, TACAN, radar altimeter and microwave scan beam landing system power switches, the caution and warning system, emergency lighting, audio control panel, and master timing unit.

Three essential buses, ESS1BC, ESS2CA, and ESS3AB receive power from three redundant sources. For example, ESS1BC receives dc power from fuel cell 1 through the ESS BUS SOURCE FC 1 switch on panel R1 via a fuse when the switch is positioned to ON, and from main dc buses B and C through remote power controllers (RPC) when the ESS BUS SOURCE MN B/C switch on panel R1 is positioned to ON. Electrical power is then distributed from the essential bus in distribution assembly 1 through fuses to the corresponding controller assemblies and to the flight and middeck panels.

Control Buses

Nine control buses supply control power to the display and control panel switches on the flight deck and in the middeck area. A control bus does not supply operational power to any system loads. Each control bus receives power from each main dc bus for redundancy. The main buses identified in the control bus name are connected through RPCs and diodes. For example, CNTL BC1 is powered by MN B and MN C through remote power controllers. The "unnamed bus", which in this example is MN A, provides power to the control bus through a circuit breaker and a fuse. The number in each control bus name does not refer to a power source for the bus; it is merely a numeric designator for the bus.

The control buses are enabled by the CONTROL BUS PWR MN A, MN B, and MN C switches on panel R1 and the MN A CONTROL BUS BC1/2/3, the MN B CONTROL BUS CA1/2/3 and the MN C CONTROL BUS AB1/2/3 circuit breakers on panel R15.



**Bus Control Switches and Talkbacks
on Panel R1**

The RPCs are powered continuously unless one of the *CONTROL BUS PWR MN A*, *MN B*, *MN C* momentary switches on panel R1 is positioned to the *RESET* position, which turns the corresponding RPCs power off and resets the RPC if it has been tripped off. An *SM ALERT* light is illuminated if the control bus voltage is less than 24.5 volts dc and a fault message is sent to the CRT. The Mission Control Center can monitor the status of each RPC.

Payload Buses

Payload buses are provided to supply dc electrical power to the payloads. Fuel cell 3 may be connected to the primary payload bus by positioning the *PRI FC3* momentary switch on panel R1 to the *ON* position. The talkback indicator above the switch will indicate *ON* when fuel cell 3 is connected to the *PRI PL* bus. The *PRI PL* bus is the prime bus for supplying power to the payloads. Fuel cell 3 may be disconnected from the payload bus by positioning the *PRI FC3* switch to the *OFF* position. The talkback indicator above the switch will indicate *OFF*.

A second source of electrical power for the *PRI PL* bus may be supplied from the *MN B* bus by

positioning the *PRI MN B* momentary switch on panel R1 to the *ON* position. The talkback indicator above this switch will indicate *ON*. The *MN B* bus may be removed from the *PRI PL* bus by positioning the switch momentarily to *OFF*. The talkback indicator will indicate *OFF*. A third possible source of electrical power for the *PRI PL* bus may be supplied from the *MN C* bus through the *PRI MN C* switch on panel R1, positioned momentarily to the *ON* position. The talkback indicator will indicate *ON*. The *MN C* bus may be removed from the *PRI PL* bus by positioning the switch momentarily to *OFF*. The talkback indicator will indicate *OFF*.

NOTE

Main buses B and C can be tied via the *PRI PL* bus. This is referred to as a "backdoor bus tie."

Two additional payload buses are located in the aft section of the payload bay at the aft bulkhead station. The aft payload B bus may be powered up by positioning the *AFT MN B* switch on panel R1 to *ON*. The aft payload C bus may be powered up by positioning the *AFT MN C* switch on panel R1 to *ON*. The *OFF* position of each switch removes power from the corresponding aft payload bus.

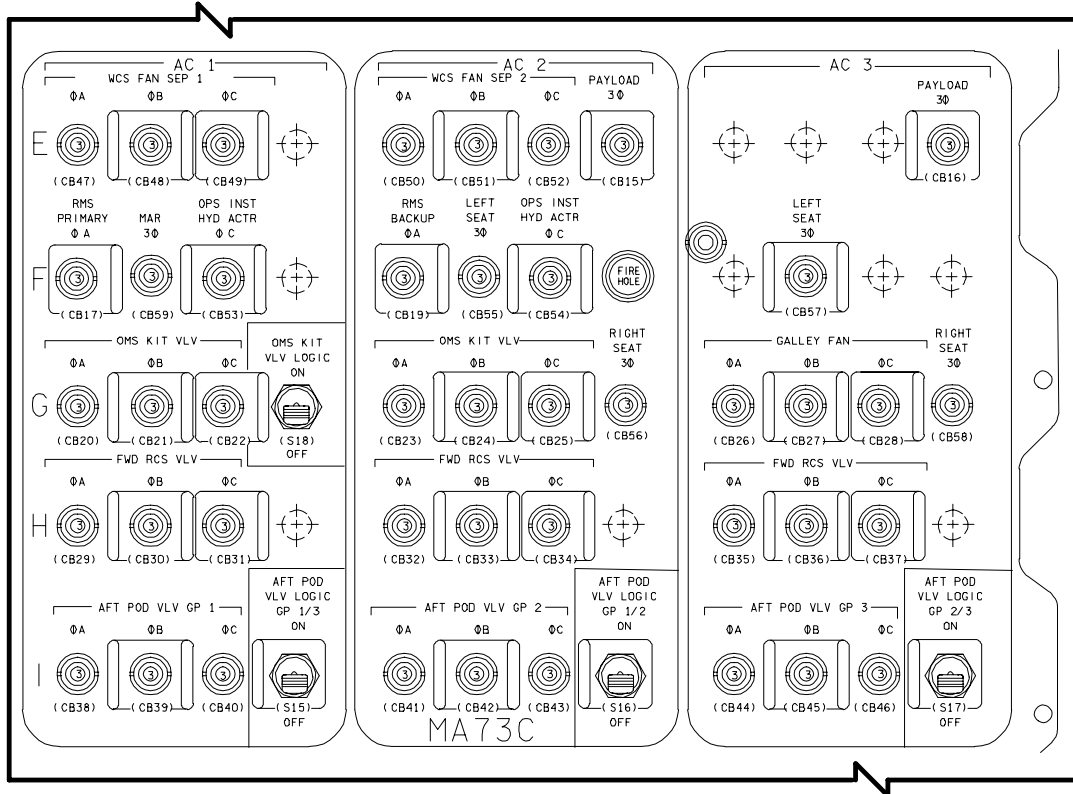
The *AUX* switch on panel R1 permits main bus A and main bus B power to be supplied to the *AUX PL A* and *AUX PL B* buses when the switch is positioned to *ON*. The auxiliary payload buses can provide power for emergency equipment or controls associated with payloads. The *OFF* position removes power from the *AUX PL A* and *PL B* buses. The two auxiliary payload buses may be dioded together to form one bus for redundancy.

The *CABIN* switch on panel R1 provides *MN A* or *MN B* power to patch panels located behind the payload specialist and mission specialist stations on the aft flight deck. These patch panels supply power to the payload-related equipment located on panels at these stations. Two three-phase circuit breakers, *AC 2 PAYLOAD 3φ* and *AC 3 PAYLOAD 3φ* on panel MA73C, provide ac power to the payload patch panels.

AC Power Generation

Alternating-current power is generated and made available to system loads by the electrical power distribution and control subsystem using three independent ac buses, AC 1, AC 2, and AC 3. The ac power system includes the ac inverters for dc conversion to ac and inverter distribution and control assemblies containing the ac buses and the ac bus sensors. The ac

1 routes power to AC 1 from MN A, INV PWR 2 to AC 2 from MN B, and INV PWR 3 to AC 3 from MN C. All three inverters of AC 1 receive MN A bus power when the INV PWR 1 switch is positioned to ON, and all three must be in operation before the talkbacks above the switches indicate ON. The indicators will show OFF when main bus power is not connected to the inverters. The INV/AC BUS 1, 2, 3 switches on panel R1 are used to apply each inverter's output to its



AC2 Cabin PAYLOAD 3Ø AND AC3 Cabin PAYLOAD 3Ø Circuit Breakers on Panel MA73C

power is distributed from the inverter distribution and controller assemblies to the flight and middeck display and control panels and from the motor controller assemblies to the three-phase motor loads.

Each ac bus consists of three separate phases connected in a three-phase array. Static inverters, one for each phase, are located in the forward avionics bays. Each inverter has an output voltage of 116 to 120 volts rms at 400 hertz, ± 7 hertz.

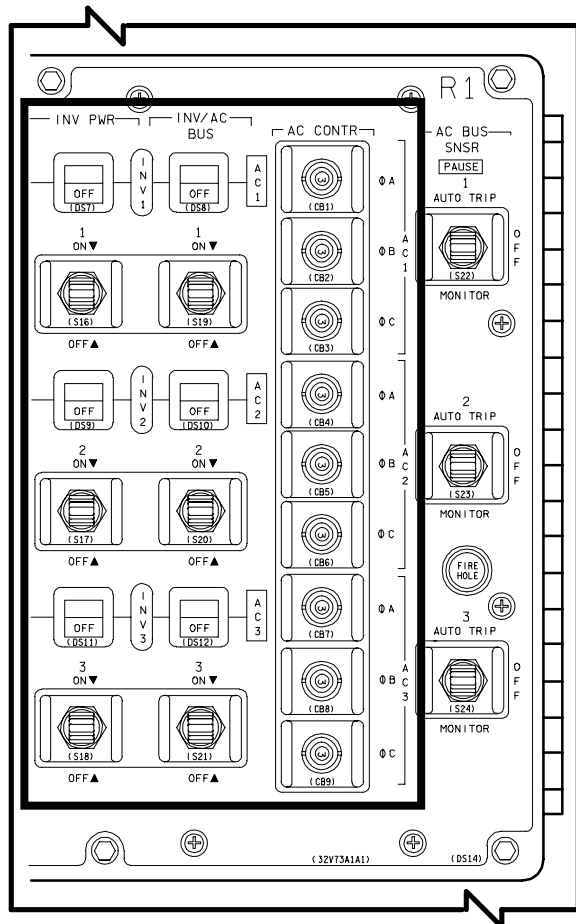
Input power to the inverters is controlled by the INV PWR 1, 2, 3 switches on panel R1. INV PWR

respective ac bus. An indicator above each switch shows its status, and all three inverters must be connected to their respective ac buses before the indicators show ON. The talkback indicators will show OFF when any of the phases are not connected to their respective ac bus.

The INV PWR and INV/AC BUS switches and talkbacks must have control power from the AC CONTR circuit breakers on panel R1 in order to operate. Once ac power has been established, these circuit breakers are opened to prevent any inadvertent disconnection, whether by switch failure or accidental movement of the INV PWR or INV/AC BUS switches.

Electrical Power Distribution and Control Assemblies

Electrical power is controlled and distributed by assemblies. Each assembly (main distribution assembly, power controller assembly, load controller assembly, and motor controller assembly) is in an electrical equipment container.



INV PWR and INV/AC BUS Switches and Talkbacks, and AC CONTR Circuit Breakers on Panel R1

Distribution Assemblies

The dc power generated by each of the fuel cells is supplied to a corresponding distribution assembly (DA). Fuel cell 1 powers DA 1, fuel cell 2 powers DA 2, and fuel cell 3 powers DA 3. Each distribution assembly contains remotely controlled motor-driven switches called power contactors used for loads larger than 125 amps. The power contactors are rated at 500 amps. They control and distribute dc power to a

corresponding mid power controller assembly, forward power controller assembly, and aft power controller assembly.

The FC MAIN BUS A switch on panel R1 positioned to ON connects fuel cell 1 to the MN A DA 1 and controllers and disconnects fuel cell 1 from the MN A DA 1 and controllers when positioned to OFF. The talkback indicator next to the FC MAIN BUS A switch will indicate ON when fuel cell 1 is connected to main bus A distribution assembly and controllers, and OFF when fuel cell 1 is disconnected from main bus A distribution assembly and controllers. The FC MAIN BUS B and C switches and talkback indicators on panel R1 function in the same manner. The No. 1 distribution assembly and all No. 1 controllers go with fuel cell 1 and MN A bus, all No. 2 controllers and DA 2 go with fuel cell 2 and MN B, and all No. 3 controllers and DA 3 go with fuel cell 3 and MN C.

Power Controllers

Power contactors are also located in the aft power controller assemblies to control and distribute ground-supplied 28-volt dc power to the orbiter through the T-0 umbilical before the fuel cells take over the supply of orbiter dc power.

Each of the mid, forward, and aft power controller assemblies supplies and distributes dc power to a corresponding motor controller assembly and dc power to the orbiter through the T-0 umbilical before the fuel cells take over the supply of orbiter dc power.

Each of the mid, forward, and aft power controller assemblies supplies and distributes dc power to a corresponding motor controller assembly and dc power to activate the corresponding ac power system.

Remote Power Controllers

Each power controller assembly contains RPCs and relays. The RPCs are solid-state switching devices used for loads requiring current in a range of 3 to 20 amps. The RPCs are current protected by internal fuses and also have the capability to limit the output current to a maximum of 150 percent of rated value for 2 to 3 seconds. Within 3 seconds, the RPC will trip out, removing the output current. To restore

power to the load, the RPC must be reset. This is accomplished by cycling a control switch. If multiple control inputs are required before a RPC is turned on, hybrid drivers are usually used as a logic switch, which then drives the control input of the RPC.

Load Controllers

Each load controller assembly contains hybrid drivers, which are solid-state switching devices (no mechanical parts) used as logic switches and for low-power electrical loads of less than 5 amps. When the drivers are used as a logic switch, several control inputs are required to turn on a load. Hybrid drivers are also used in the mid power controller assemblies. The hybrid drivers are current protected by internal fuses. Hybrid relays requiring multiple control inputs are used to switch three-phase ac power to motors.

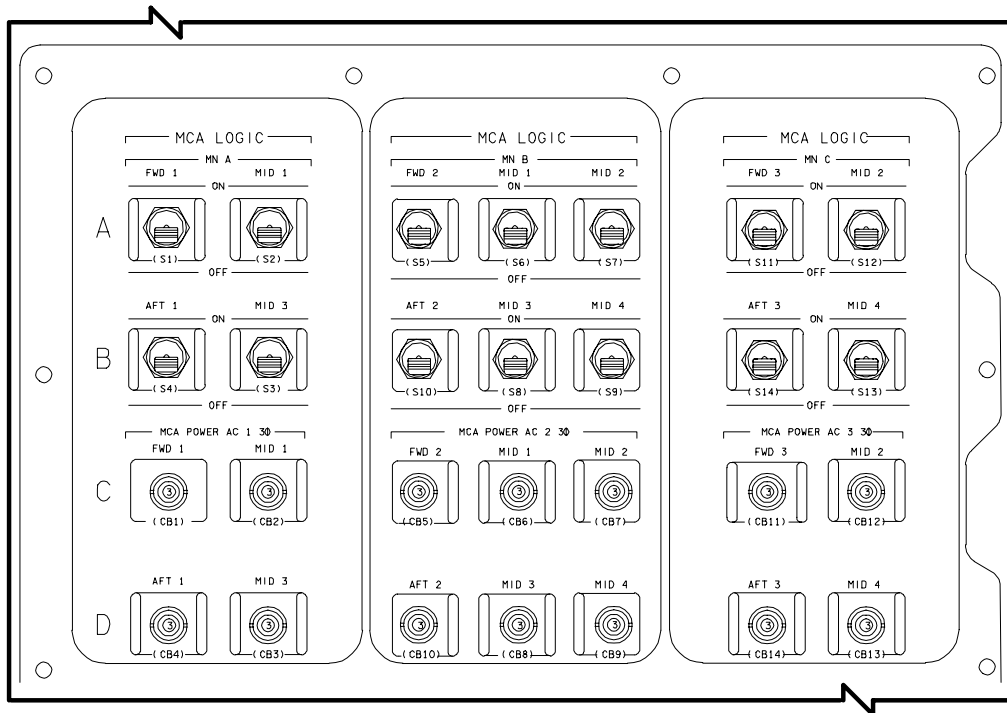
Relays are also used for loads between 20 amps and 135 amps in power controller assemblies and motor controller assemblies.

In the midbody, there are no load controller assemblies; therefore, the mid power controller assemblies contain remote power controllers, relays, and hybrid drivers.

Aft power controller assemblies 4, 5, and 6 were added to accommodate additional electrical loads in the aft section. Assemblies 4, 5, and 6 are powered by fuel cell 1/MN A, fuel cell 2/MN B, and fuel cell 3/MN C respectively.

Motor Controllers

There are 10 motor controller assemblies used on the orbiter: three are in the forward area, four are in the midbody area, and three are in the aft area. Panel MA73C contains the controls for the motor controller assemblies. Their only function is to supply ac power to noncontinuous ac loads for ac motors used for vent doors, air data doors, star tracker doors, payload bay doors, payload bay latches, ET doors and latches, RMS deploy motors and latches, and reaction control system/orbital maneuvering system motor-actuated valves. Each motor controller assembly contains main dc buses, ac buses, and hybrid relays that are remotely controlled for the application or removal of ac power to ac motors. The main dc bus is used only to supply control or logic power to the hybrid relays so the ac power can be switched on or off. The hybrid relays permit major electrical power distribution buses to be located close to the major electrical loads, which



Motor Controller Assembly Controls on Panel MA37C

minimizes use of heavy electrical feeders to and from the pressurized crew compartment display and control panels. This reduces the amount of spacecraft wiring and weight, and permits more flexible electrical load management. If a main bus is lost, the hybrid relays using that main bus will not operate. In some cases, the hybrid relays will use logic power from a switch instead of the motor controller assembly bus.

The three forward motor controller assemblies (FMC 1, FMC 2, and FMC 3) correspond to MN A/AC 1, MN B/AC 2, and MN C/AC 3 respectively. Each FMC contains a main bus, an ac bus, and an RCS ac bus. The main bus supplies control or logic power to the relays associated with both the ac bus and RCS ac bus. The ac bus supplies power to the forward left and right vent doors, the star tracker Y and Z doors, and the air data left and right doors. The RCS ac bus supplies power to the forward RCS manifold and tank isolation valves.

The aft motor controller assemblies (AMC 1, AMC 2, and AMC 3) correspond to MN A/AC 1, MN B/AC 2, and MN C/AC 3 respectively. Each aft motor controller assembly contains a main bus and its corresponding ac bus and a main RCS/OMS bus and its corresponding RCS/OMS ac bus. Both main buses are used for control or logic power for the hybrid relays. The ac bus is used by the aft RCS/OMS manifold and tank isolation and crossfeed valves, the aft left and right vent doors, and the ET umbilical doors.

The mid motor controller assemblies (MMC 1, MMC 2, MMC 3, and MMC 4) contain two main dc buses and two corresponding ac buses. MMC 1 contains main bus A and B and their corresponding buses, AC 1 and AC 2. MMC 2 contains MN B and C and AC 2 and AC 3 buses. MMC 3 contains the same buses as MMC 1, and MMC 4 contains the same buses as MMC 2. Loads for the main buses/ac buses are vent doors, payload bay doors and latches, radiator panel deployment actuator and latches, RMS deploy motors and latches, and payload retention latches.

Component Cooling

The electrical components in the midbody are mounted on cold plates and cooled by the Freon coolant loops. The power controller assemblies, load controller assemblies, motor controller

assemblies, and inverters located in forward avionics bays 1, 2, and 3 are mounted on cold plates and cooled by the water coolant loops. The inverter distribution assemblies in forward avionics bays 1, 2, and 3 are air-cooled. The load controller assemblies, power controller assemblies, and motor controller assemblies located in the aft avionics bays are mounted on cold plates and cooled by the Freon system coolant loops.

Bus Tie

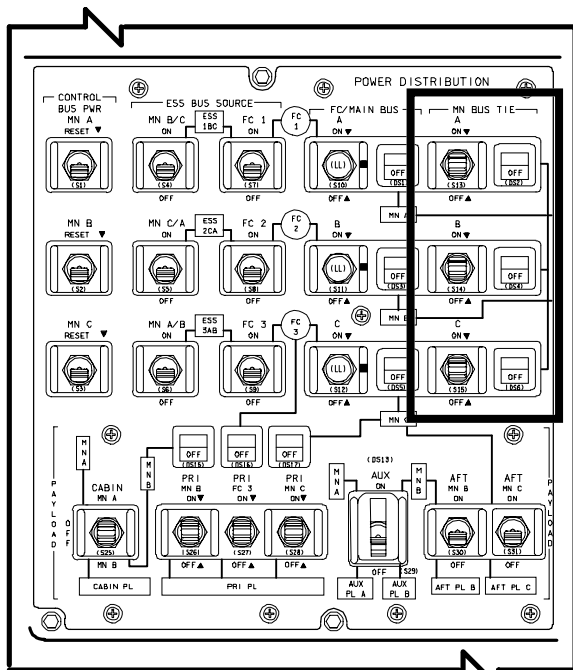
In the event of an electrical failure, or to load share between fuel cells, any main bus can be connected to another main bus through the use of the *MN BUS TIE* switches on panel R1 and power contactors in the distribution assemblies. For example, main bus A can be connected to main bus B by positioning both the *MN BUS TIE A* and the *MN BUS TIE B* switch to *ON*. The talkback indicators next to the switches will indicate *ON* when main bus A is connected to main bus B. Other indications of an effective bus tie are matching voltages for the two buses. To disconnect main bus A from main bus B, the *MN BUS TIE A* and *B* switches must be positioned to *OFF*; the talkback indicators next to the switches will then indicate *OFF*.

NOTE

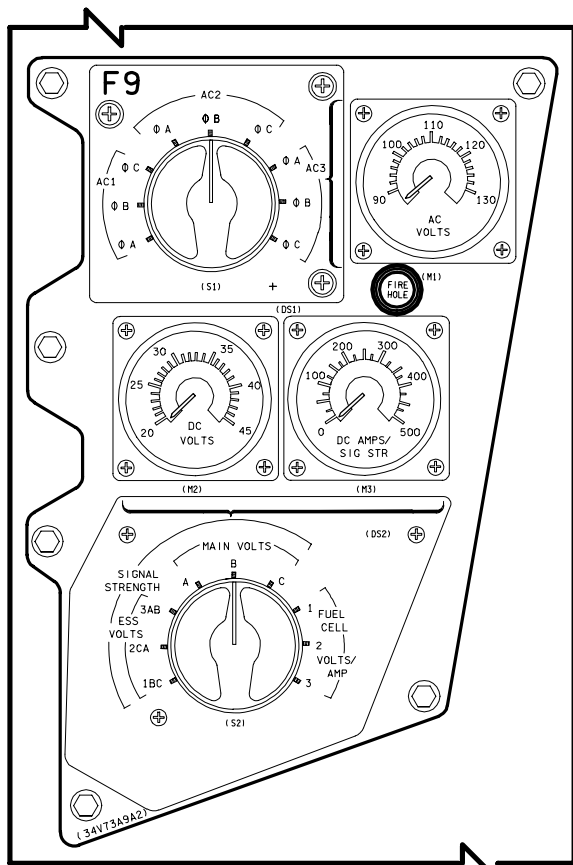
It is also possible to tie the main buses B and C together via the PRI switches. This is done by connecting each main bus to the primary payload bus.

Instrumentation and System Monitoring

Main bus A, B, or C voltages can be displayed on the DC VOLTS meter on panel F9 by selecting *MAIN VOLTS A*, *B*, or *C* on the rotary switch beneath the meter. The *MAIN BUS UNDERVOLT* red caution and warning light on panel F7 will be illuminated if main bus A, B, or C voltage is 26.4 volts dc, informing the crew that the minimum equipment operating voltage limit of 24 volts dc is being approached. A *BACKUP C/W ALARM* light will also be illuminated at 26.4 volts dc. An *SM ALERT* light will be illuminated at 27 volts dc or less, alerting the flight crew to the possibility of a future low-voltage problem. A fault message also is transmitted to the CRT.



MN BUS TIE Switches on Panel R1



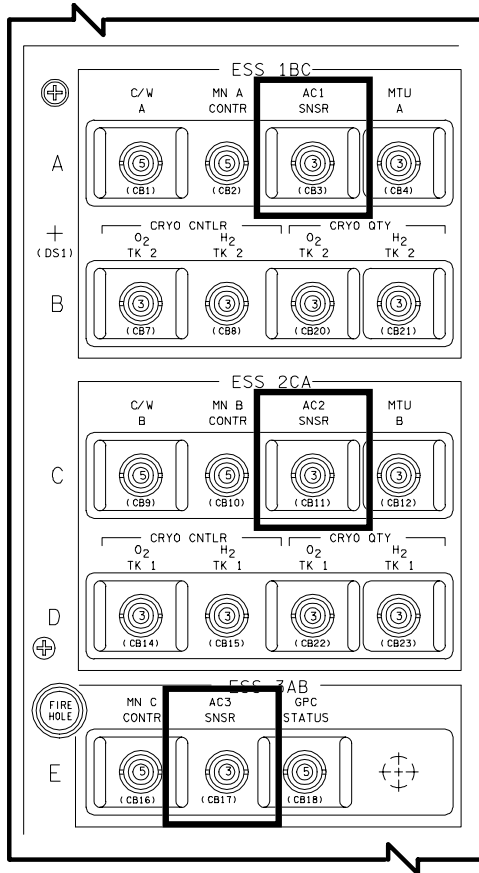
EPS Meters and Switches on Panel F9

The nominal fuel cell voltage is 27.5 to 32.5 volts dc, and the nominal main bus voltage range is 27 to 32 volts dc, which corresponds to 12- and 2-kilowatt loads respectively. If buses are tied, they will indicate the same voltage.

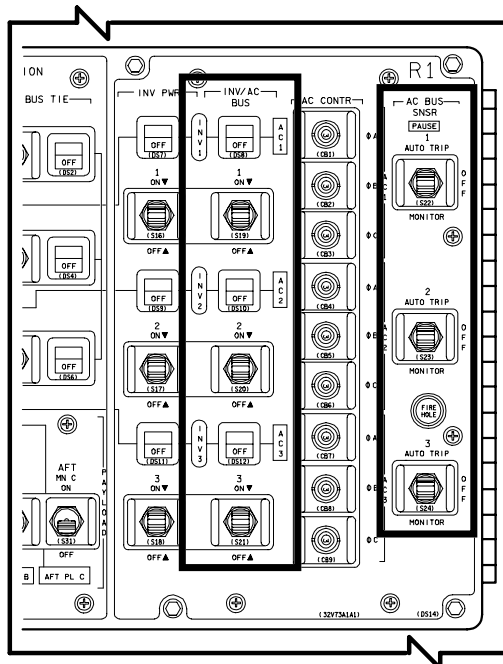
The ESS bus voltage can be monitored on the DC VOLTS meter on panel F9 by selecting *ESS VOLTS 1BC, 2CA, 3AB* on the rotary switch below the meter. An *SM ALERT* light will be illuminated to inform the flight crew if the essential bus voltage is less than 25 volts dc. A fault message also is displayed on the CRT.

Each ac bus has a sensor, switch, and circuit breaker for flight crew control. The AC 1, 2, and 3 *SNSR* circuit breakers located on panel O13 apply essential bus power to their respective AC BUS *SNSR 1, 2, 3* switch on panel R1 and operational power to the respective *INV/AC BUS* switch and indicator. The AC BUS *SENSR 1, 2, 3* switch selects the mode of operation of the ac bus sensor: *AUTO TRIP, MONITOR, or OFF*. The ac bus sensor monitors each ac phase bus for over- or undervoltage, and each phase inverter for an overload signal. The overvoltage limits are bus voltages greater than 123 to 127 volts ac for 50 to 90 milliseconds. The undervoltage limits are bus voltages less than 102 to 108 volts ac for 6.5 to 8.5 milliseconds. An overload occurs when any ac phase current is greater than 14.5 amps for 10 to 20 seconds, or is greater than 17.3 to 21.1 amps for 4 to 6 seconds.

When the respective AC BUS *SNSR* switch is in the *AUTO TRIP* position, and an overload or overvoltage condition occurs, the ac bus sensor will illuminate the respective yellow AC OVERLOAD or AC VOLTAGE caution and warning light on panel F7 and trip off (disconnect) the inverter from its respective phase bus for the bus/inverter causing the problem. There is only one AC VOLTAGE and one AC OVERLOAD caution and warning light; as a result, all nine inverters/ac phase buses can illuminate the lights. The CRT or the AC VOLTS meter and rotary switch beside it on panel F9 would be used to determine which inverter or phase bus caused the light to illuminate. The phase causing the problem would approach 0 amps after the bus sensor disconnects the inverter from the bus. Because of the various three-phase motors throughout the vehicle, there will be an induced voltage on the disconnected phase if only one phase has loss of power.



AC 1, 2, 3 SNSR Circuit Breakers on Panel O13



AC BUS SNSR Switches and INV/AC BUS Switches and Talkback Indicators on Panel R1

Before power can be restored to the tripped bus, the trip signal to the *INV/AC BUS* switch must be removed by positioning the *AC BUS SNSR* switch to OFF, then back to the *AUTO TRIP* position, which extinguishes the caution and warning light. The *INV/AC BUS* switch is then positioned to ON, restoring power to the failed bus. If the problem is still present, the sensor trip sequence will be repeated.

If an undervoltage exists, the yellow *AC VOLTAGE* caution and warning light on panel F7 will be illuminated, but the inverter will not be disconnected from its phase bus.

When the *AC BUS SENSER 1, 2, 3* switches are in the *MONITOR* position, the ac bus sensor will monitor for an overload, overvoltage, and undervoltage and illuminate the applicable caution and warning light; but it will not trip out the phase bus/inverter causing the problem.

NOTE

AC BUS SNSR switches are placed in *MONITOR* for ascent and entry to prevent an AC bus problem from causing an *AUTO-TRIP*, which could result in the loss of SSME controllers on ascent, or landing gear prox boxes on entry.

When the *AC BUS SNSR* switches are OFF, the ac bus sensors are non-operational, and all hardware caution and warning and trip-out capabilities are inhibited. The *BACKUP C/W ALARM* light will be illuminated for overload or over- and undervoltage conditions. The *SM ALERT* will occur for over- and undervoltage conditions. A fault message also is sent to the CRT.

Operations

Prelaunch

During prelaunch operations, the onboard fuel cell reactants (oxygen and hydrogen) are supplied by ground support equipment to assure a full load of onboard reactants before lift-off. At T minus 2 minutes 35 seconds, the ground support equipment filling operation is terminated. The ground support equipment supplies hydrogen and oxygen to the PRSD manifold at pressures greater than the tank

heater control range pressures (approximately 280 psia for hydrogen and 960 psia for oxygen). This helps to prevent cryo tank heater cycling during powered flight. The ground support equipment supply valves close automatically to transfer to onboard reactants.

The fuel cells will be on when the crew boards the vehicle. Until T minus 3 minutes and 30 seconds, power to the orbiter is load shared with the fuel cells and ground support equipment, even though the fuel cells are on and capable of supplying power. Main bus power is supplied through the T-0 umbilicals, MN A through the left-side umbilical and MN B and C through the right-side umbilical to aft power controllers (APCs) 4, 5, and 6. From APCs 4, 5, and 6, the ground support equipment power is directed to the distribution assembly where the power is distributed throughout the vehicle. The power for the PREFLT 1 and PREFLT 2 test buses is also supplied through the T-0 umbilical. These test buses are scattered throughout the orbiter and are used to support launch processing system control of critical orbiter loads, although they also power up the essential buses in the APCs when on ground support equipment. As in the main bus distribution, essential bus power from the APCs is directed to the distribution assemblies and then distributed throughout the vehicle. At T minus 3 minutes 30 seconds, the ground turns off the ground support equipment power to the main buses, and the fuel cells automatically pick up the vehicle electrical loads.

Indication of the switchover can be noted on the CRT display and the DC AMPS meter. The fuel cell current will increase to approximately 220 amps; the oxygen and hydrogen flow will increase to approximately 4.6 and 0.6 pound per hour respectively; and the fuel cell stack temperature will increase slightly. At T minus zero, the T-0 umbilical is disconnected with the preflight test bus wires live.

Prelaunch and On-Orbit Tank Heater Management

Before lift-off, the *O2 TK1 HEATERS A*, *O2 TK2 HEATERS A*, *H2 TK1 HEATERS A*, and *H2 TK 2 HEATERS A* switches on panel R1 are set on *AUTO*. As part of the Post OMS 1 Burn procedures, all the switches on O2 and H2 tanks 1 & 2 are positioned to *AUTO*, while the other tank heaters remain *OFF*. On orbit, the cryo tank heaters are managed to provide for tank quantity balancing. When hydrogen tanks 4 and 5 are installed on OV-102, they are depleted first due to their common check valve. Because the tank 3 and 4/5 heater controller pressure limits are higher than those of tanks 1 and 2, tanks 3 and 4/5 supply the reactants to the fuel cells when all tank heaters are set to *AUTO*. For entry, tanks 1 and 2 supply the reactants to the fuel cells.

Fuel Cell Operating Modes

Fuel cell standby consists of removing the electrical loads from a fuel cell but continuing operation of the fuel cell pumps, controls, instrumentation, and valves, while electrical power is supplied by the remaining fuel cells. A small amount of reactants is used to generate power for the fuel cell internal heaters. If the temperature in the fuel cell compartment beneath the payload bay is lower than 40° F, the fuel cell should be left in *STANDBY* instead of being shut down to prevent it from freezing.

Fuel cell shutdown, after standby, consists of stopping the coolant pump and hydrogen pump/water separator by positioning that *FUEL CELL START/STOP* switch on panel R1 to the *STOP* position.

Fuel cell safing consists of closing the fuel cell reactant valves and consuming the reactants inside the fuel cell by either leaving the fuel cell connected to its main bus or by keeping the pump package operating with the internal heaters.

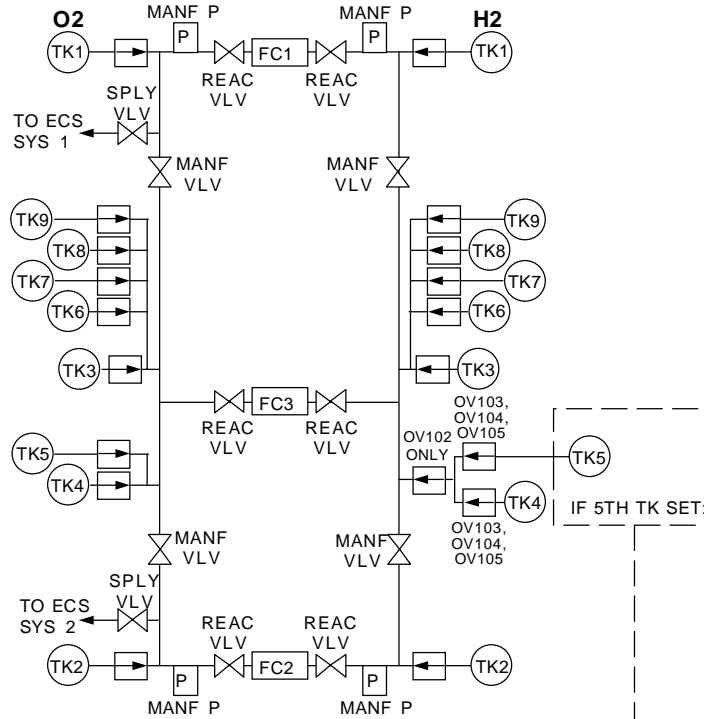
EPS Caution and Warning Summary

- The *SM ALERT* will illuminate if a cryo heater current level sensor detects a short on a heater circuit.
- The yellow *O₂ PRESS* and the red *BACKUP C/W ALARM* lights illuminate if oxygen tank pressure is below 540 psia or above 985 psia.
- The yellow *H₂ PRESS* and the red *BACKUP C/W ALARM* lights illuminate if hydrogen tank pressure is below 153 psia or above 293.8 psia.
- When any fuel cell reactant valve is closed, the red *FUEL CELL REAC* light is illuminated, a tone is sounded and the *BACKUP C/W ALARM* is illuminated.
- The yellow *FUEL CELL STACK TEMP* light will illuminate if fuel cell and stack temperatures are below 170.7° F or above 241.9° F. The red *BACKUP C/W ALARM* and blue *SM ALERT* will also light for similar limits.
- The yellow *FUEL CELL PUMP* light will illuminate if fuel cell 1, 2, or 3 coolant pump delta pressure is lost. If the coolant pump for fuel cell 1, 2, or 3 is off, the *BACKUP C/W ALARM* will be illuminated.
- The yellow *O₂ HEATER TEMP* light on panel F7 illuminates if the temperature sensor senses the oxygen tank temperature is at or above 344° F. Software checks the limit; if it is above 349° F, the *BACKUP C/W ALARM* light illuminates as well.
- The red *MAIN BUS UNDERVOLT* light and the *BACKUP C/W ALARM* illuminate if main bus A, B, or C voltage is 26.4 volts dc.
- The yellow *AC VOLTAGE* light illuminates for an overvoltage or undervoltage condition in the ac bus. The red *BACKUP C/W ALARM* will also illuminate.
- The yellow *AC OVERLOAD* light illuminates for an overload condition in the ac bus.

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

346.cvs

EPS Caution and Warning Lights on Panel F7

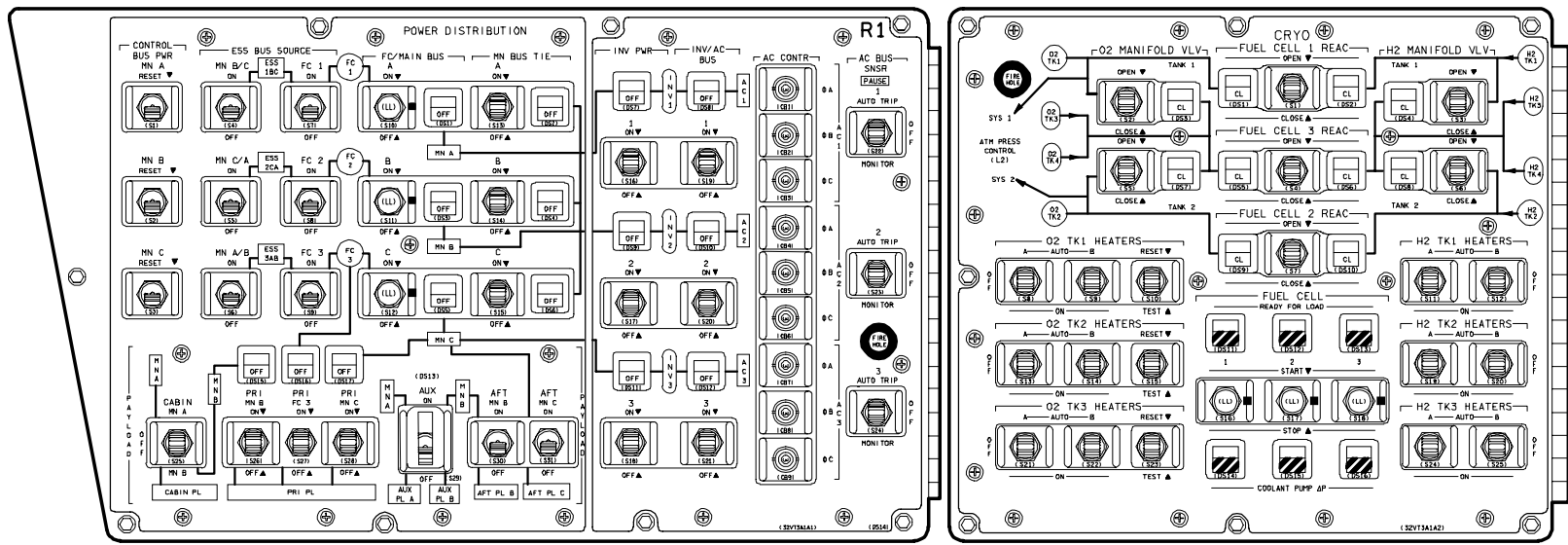


02/H2 HTR LOSS (ALL EXCEPT OV 102)										
BUS LOSS	PAIRED				PAIRED					
	TK1		TK2		TK3		TK4		TK5	
	A	B	A	B	A	B	A	B	A	B
MNA DA1	A/M		AUTO	A/M	A/M	A/M	AUTO	A/M	A/M	
MNB DA2										
MNC DA3	AUTO	A/M	A/M	A/M			A/M		AUTO	A/M
CNTL AB1		MAN			MAN					
AB2		A/M			A/M					
CNTL BC1			MAN				MAN			MAN
BC2				MAN				MAN		
BC3								MAN		A/M
CNTL CA1	MAN					MAN			MAN	A/M
CA2	A/M					A/M			A/M	
CA3				A/M				A/M		
ESS 1BC	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO	AUTO	AUTO	AUTO
2CA	AUTO	AUTO	AUTO*	AUTO*	AUTO	AUTO	AUTO*	AUTO*	AUTO*	AUTO*
3AB					AUTO	AUTO	AUTO*	AUTO*	AUTO*	AUTO*

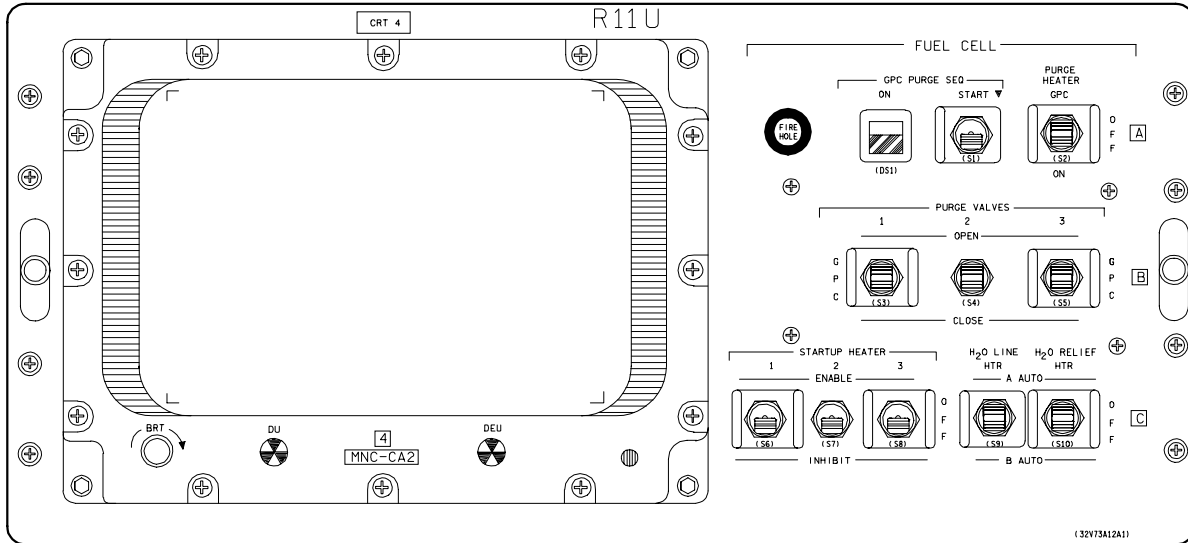
* Auto operation regained if both A and B HTR SW of other paired tank(s) are not in auto. A/M = Auto and manual loss.

02/H2 HTR LOSS (OV 102 ONLY)																		
BUS LOSS	PAIRED				PAIRED						PAIRED				PAIRED			
	TK1		TK2		TK3		TK4		TK5		TK6		TK7		TK8		TK9	
	A	B	A	B	A	B	O2	H2A	H2B	O2	H2A	H2B	A	B	A	B	A	B
MNA DA1	A/M		AUTO	A/M	A/M	A/M	AUTO	AUTO	A/M	A/M	AUTO	A/M	A/M			A/M		A/M
MNB DA2																		
MNC DA3	AUTO	A/M	A/M	A/M			A/M	A/M			A/M							
CNTL AB1		MAN			MAN											MAN		MAN
AB2		A/M			A/M											A/M		
AB3																		
CNTL BC1			MAN				MAN	MAN										
BC2				MAN					MAN	AUTO	MAN	A/M						
BC3											MAN							
CNTL CA1	MAN					MAN							MAN	A/M		MAN	A/M	
CA2	A/M					A/M												
CA3				A/M					A/M	A/M								
ESS 1BC	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO
2CA	AUTO	AUTO	AUTO*	AUTO*	AUTO	AUTO	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*
3AB					AUTO	AUTO	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*

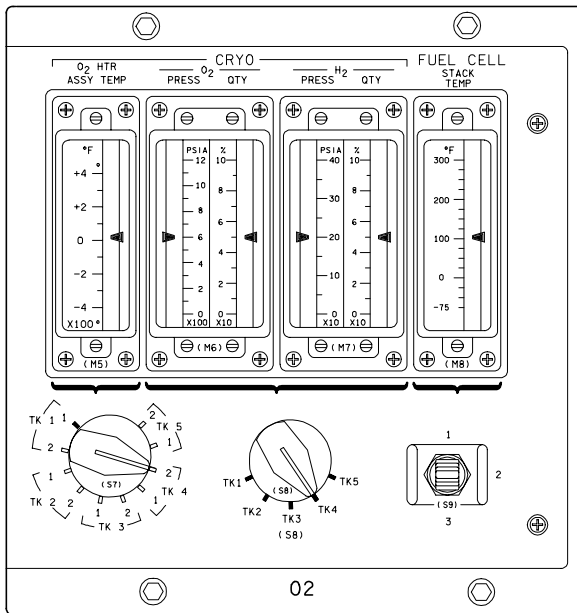
* Auto operation regained if both A and B HTR SW of other paired tank(s) are not in auto. TK1 paired with TK2, and TK3 paired with TK4/5. A/M = Auto and manual loss.



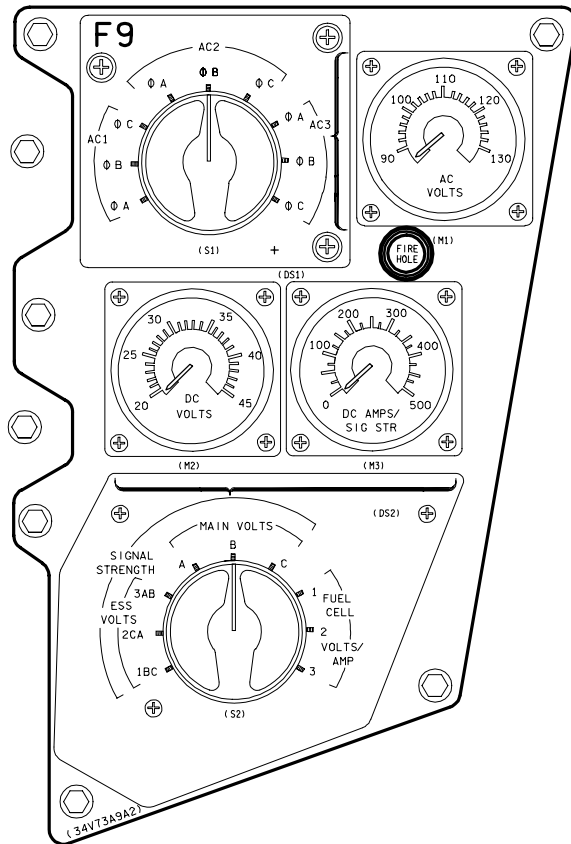
Panel R1



Panel R11U



Panel O2



Panel F9

2011/ /078		SM SYS SUMM 1		4 000/14:44:12			
		000/00:00:00					
SMOKE	1/A 2/B	DC VOLTS	1/A	2/B	3/C		
CABIN	0.0	FC	30.6	30.1	31.0		
L/R FD	0.0 0.0	MAIN	30.6	30.1	31.0		
AV BAY	1 0.3 0.3	ESS	29.6	29.6	29.3		
	2 0.3 0.4						
	3 0.3 0.3	CNTL	1 29.4	29.4	29.6		
CABIN			2 29.4	29.4	29.4		
PRESS	14.0		3 29.4	29.4	29.4		
dP/dT-EQ	+0.0 +0.00	AC					
O2 CONC		VOLT	φA	118	118	117	
PP02	3.00 3.00		φB	117	117	118	
FAN ΔP	5.00		φC	117	117	118	
HX OUT T	46	AMPS	φA	4.3	6.3	2.1	
O2 FLOW	0.0 0.0		φB	5.5	6.6	2.2	
N2 FLOW	0.0 0.0		φC	3.1	5.0	3.2	
IMU FAN	A B C	FUEL CEL					
ΔV FC1	FC2 FC3	AMPS	180	232	146		
SS1	22 21 22	REAC VLV	0P	0P	0P		
SS2	22 22 23	STACK T	+202	+206	+200		
SS3	23 21 21	EXIT T	150	152	149		
TOTAL AMPS	557	COOL P	61	60	61		
KW	17	PUMP					

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PASS SM SYS SUMM 1

2011/ /06Z		ELECTRIC			4 000/02:33:00		
		000/00:00:00					
DC	1/A 2/B 3/C	AC	1	2	3		
VOLT	FC 31.1 31.1 31.1	V	φA	117	117	117	
	MN 31.0 31.0 31.0		φB	117	117	117	
PCA FWD	30.5 30.6 30.5		φC	117	117	117	
AFT	30.7 30.7 30.7	AMP	φA	4.5	4.2	2.8	
ESS	29.8 29.8 29.8		φB	3.9	4.3	3.2	
			φC	2.5	3.2	4.7	
CNTL	1 29.3 29.3 29.3	OVLD					
	2 29.3 29.3 29.3	O/U V					
	3 29.3 29.3 29.3	PAYLOAD DC AMPS					
AMPS	FC 176 175 170	AFT B				0.3	
	FWD 86 64 114	C				-	0.0L
	MID 4 35 9						
	AFT + 35 + 24 + 17						
TOTAL AMPS	521						
KW	16.2						

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DISP 67 (ELECTRIC)

0001/ /078		SM SYS SUMM 1		5 000/03:13:09			
		BFS 000/00:00:00					
SMOKE	1/A 2/B	DC VOLTS	1/A	2/B	3/C		
CABIN	- 0.9	FC	31.1	31.1	31.1		
L/R FD	- 0.4 0.2	MAIN	31.0	31.1	31.0		
AV BAY	1- 1.2 - 0.0	CNTL	AB 29.3	29.3	29.3		
	2- 0.6 0.3		BC 29.3	29.3	29.3		
	3- 0.1 - 0.9		CA 29.3	29.3	29.3		
CABIN		ESS	CA 29.8	29.8	29.8		
PRESS	14.7	AC					
dP/dT	+0.0	VOLT	φA	117	117	117	
BU/EQ	-0.0 +0.0		φB	117	117	117	
PP02	3.02 3.02		φC	117	117	117	
FAN P	5.79	AMPS	φA	4.4	4.1	2.7	
HX OUT T	49		φB	3.9	4.2	3.2	
			φC	2.4	3.2	4.8	
N2 FLOW	0.0	FUEL CELL PH					
IMU FAN	ΔP 4.62	AMPS	172	167	178		
ΔV FC1	FC2 FC3	REAC VLV	OP	OP	OP		
SS1	15 18 18	STACK T	+204	+203	+203		
SS2	16 20 11	EXIT T	150	150	151		
SS3	22 26 26	COOL P	61	61	61		
TOTAL AMPS	510	PUMP					
KW	15						

085

BFS SM SYS SUMM 1

0001/ /079		SM SYS SUMM 2		5 008/23:29:22			
		BFS 000/00:00:00					
CRYO TK	1 2 3 4 5	MANF1	MANF2				
H2 PRESS	208 208 206 206 206	208	207				
O2 PRESS	816 815 814 814 814	815	815				
HTR T1	-248 -248 -248 -248 -248						
T2	-248 -248 -248 -248 -248						
APU	1 2 3	HYD	1 2 3				
TEMP EGT	942 942 942	PRESS	3064 3064 3064				
B/U EGT	942 942 942	ACUM P	3080 3080 3080				
OIL IN	250 250 250	RSVR T	116 153 142				
OUT	264 264 264						
GG BED	511H 511H 511H	QTY	72 74 71				
INJ	1271 1271 1271	W/B					
SPEED %	99 102 101	H2O QTY	78 73 78				
FUEL QTY	59 60 62	BYP VLV	BYP BYP BYP				
PMP LK P	14 14 14						
OIL OUT P	42 42 41	THERM CNTL	1 28				
FU TK VLV		H2O PUMP P	23 63				
A T	63 65 62	FREON FLOW	2384 2384				
B T	63 65 62	EVAP OUT T	38 38				
AV BAY	1 2 3						
TEMP	97 97 83						
A4	14 27.439 27.435	26.324	31.873	18.48			

051

BFS SM SYS SUMM 2

2011/ /068		CRYO SYSTEM					4 000/02:34:40	
		TK					000/00:00:00	
O2	1	2	3	4	5			
P	827	826	871	826	826			
TK P	828	828	871	828	828			
QTY	99	99	100	100	100			
T	-249	-249	-249	-249	-249			
HTR T 1	-249	-249	-182	-249	-249			
HTR T 2	-249	-249	-182	-249	-249			
HTR 1A								
CUR 1B				4/5				
SNSR 2A								
SNSR 2B				4/5				
MANF P	871	871						
VLV	OP	OP						
H2								
P	215	213	224	213	213			
TK P	215	214	224	214	214			
QTY	97	97	99	99	99			
T	-417L	-417L	-417L	-417L	-417L			
HTR T	-417L	-417L	-417L	-417L	-417L			
MANF P	222	222						
VLV	OP	OP						

313

DISP 68 (CRYO SYSTEM)

2011/ /168		CRYO PALLET				4 000/02:38:52	
		TK				000/00:00:00	
O2	6	7	8	9			
P	515L	515L	515L	515L	PALLET		
TK P	0L	0L	0L	0L	STB		
QTY	- 5L	- 5L	- 5L	- 5L	STB		
T	-417L	-417L	-417L	-417L	POP		
HTR T 1	-417L	-417L	-417L	-417L	POP		
HTR T 2	-417L	-417L	-417L	-417L			
HTR 1A					PALLET		
CUR 1B					PPO		
SNSR 2A							
SNSR 2B							
H2							
P	145L	145L	145L	145L			
TK P	0L	0L	0L	0L			
QTY	- 6L	- 6L	- 6L	- 6L			
T	-417L	-417L	-417L	-417L			
HTR T	-417L	-417L	-417L	-417L			

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DISP 168 (CRYO PALLET)

2011/ /069		FUEL CELLS			4 000/02:35:11	
		FC			000/00:00:00	
O2	1	2	3			
VOLTS	31.3	31.2	31.2	H2O RLF LINE T	72	
AMPS	161	164	163	NOZ T A	244	
				B	244	
FLOW O2	2.7	2.7	2.6	HTR SW	A	
H2	0.5	0.5	0.5	PURGE LN	O2 T	32
REAC O2	OP	OP	OP	H2 T1	40	
H2	OP	OP	OP	T2	40	
				H2O LINE PH		
STACK T	+204	+204	+204			
EXIT T	151	151	151			
COOL T	73	73	73			
P	61	61	61			
PUMP				PH		
H2 PUMP	0.4	0.4	0.4	ΔV	SS1	15 18 18
READY	RDY	RDY	RDY		SS2	16 20 11
					SS3	22 26 26
H2O				ΔAMPS	- 3	+ 1 + 2
PRI LN T	144	144	144			
VLV T	93	93	93			
ALT LN T	79	79	79			

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DISP 69 (FUEL CELLS)

EPS Summary Data

- The EPS, which operates during all flight phases, consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter vehicle.
- The fuel cell picks up full power load support after ground equipment is turned off at T minus 3 minutes 30 seconds, supporting power requirements for the solid rocket booster, orbiter, and some payloads.
- EPS subsystems are: power reactants storage and distribution, fuel cells, and electrical power distribution and control.
- The power reactants storage and distribution system stores cryogenic hydrogen and oxygen and supplies them to the fuel cells. It also supplies oxygen to the ECLSS. The components are located in the orbiter midbody underneath the payload bay.
- The fuel cell system (three fuel cells) transforms hydrogen and oxygen to electricity through a chemical reaction. The system also supplies potable water to the ECLSS. It consists of a power and an accessory section.
- The electrical power distribution and control system distributes electrical power throughout the orbiter. It has five types of assemblies: power control, load control, motor control, main dc distribution, and ac distribution and control.
- The EPS requires very little flight crew interaction during nominal operations.
- The majority of the EPS controls are on panels R1 and R11U. Power sources and circuit breakers are distributed on panels O13, O14, O15, O16, ML86B, R15, and MA73C. Heaters are controlled from panel R1, A11 and A15.
- Meters for monitoring EPS parameters are located on panels F9 and O2.
- CRTs that display EPS data are BFS SM SYS SUMM 1 & 2, DISP 67 (ELECTRIC), DISP 68 (CRYO SYSTEM), DISP 69 (FUEL CELLS), PASS SM SYS SUMM 1 & 2, and DISP 168 (CRYO PALLET).

EPS Rules of Thumb

- Never close a circuit breaker or reset an RPC found out of configuration without MCC coordination.
- Loss of cooling to a fuel cell requires crew action within 9 minutes to prevent a catastrophic loss of crew/vehicle due to possible fuel cell fire and explosion.
- Fuel cell run limit prior to shutdown for loss of cooling is 9 minutes at a 7 kW nominal load. Run time is inversely proportional to fuel cell load.
- Any interruption of continuous ac power during ascent may result in the loss of main engine controller redundancy. Reconfiguration of ac powered equipment prior to MECO should be avoided.
- Never connect or reconnect power to a known shorted or failed component; this includes switch throws, circuit protection device resets, or bus ties.
- Three oxygen and hydrogen tanks are good for up to 8 days on orbit; five oxygen and hydrogen tanks are good for up to 12 days on orbit; eight oxygen and hydrogen tanks are good for up to 18 days on orbit. Exact duration varies with crew complement and power load.
- A fuel cell hydrogen pump uses 0.3 amps/AC phase; a coolant pump uses 0.5 amps/AC phase.

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2.9 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS)

CONTENTS

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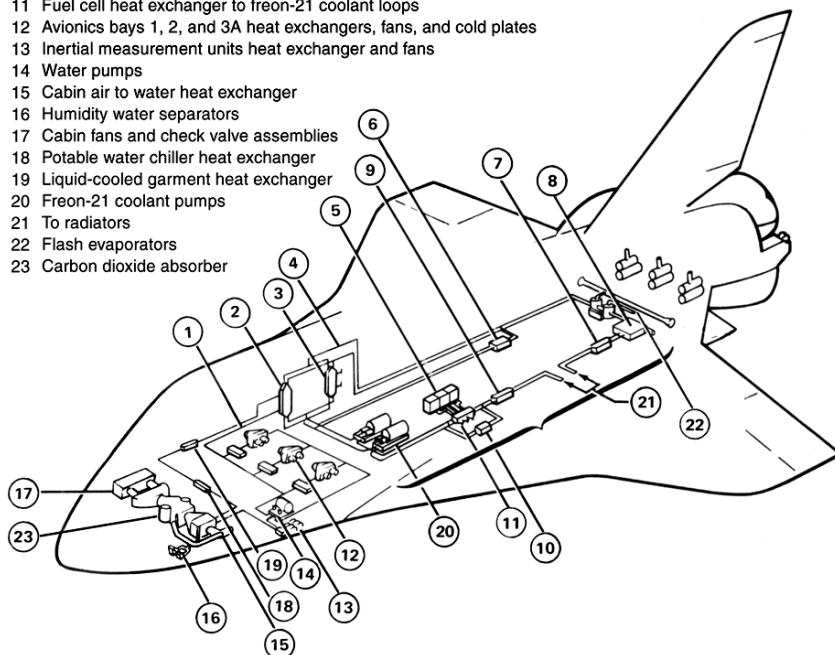
Description

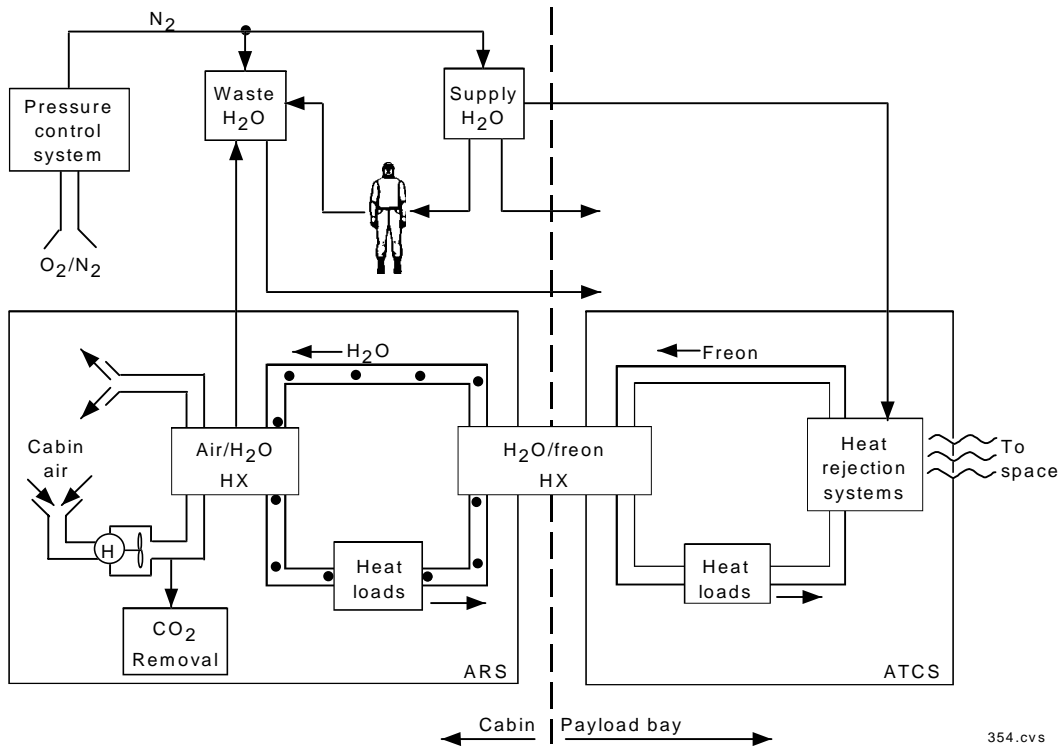
The ECLSS maintains the orbiter's thermal stability and provides a pressurized, habitable environment for the crew and onboard avionics. The ECLSS also manages the storage and disposal of water and crew waste.

ECLSS is functionally divided into four systems:

1. **Pressure control system**, which maintains the crew compartment at 14.7 psia with a breathable mixture of oxygen and nitrogen. Nitrogen is also used to pressurize the supply and wastewater tanks.
2. **Atmospheric revitalization system**, which uses air circulation and water coolant loops to remove heat, control humidity, and clean and purify cabin air.
3. **Active thermal control system**, which consists of two Freon loops that collect waste heat from orbiter systems and transfer the heat overboard.
4. **Supply and wastewater system**. The supply water system stores water produced by the fuel cells for drinking, personal hygiene, and orbiter cooling. The wastewater system stores crew liquid waste and wastewater from the humidity separator. The system also has the capability to dump supply and wastewater overboard.

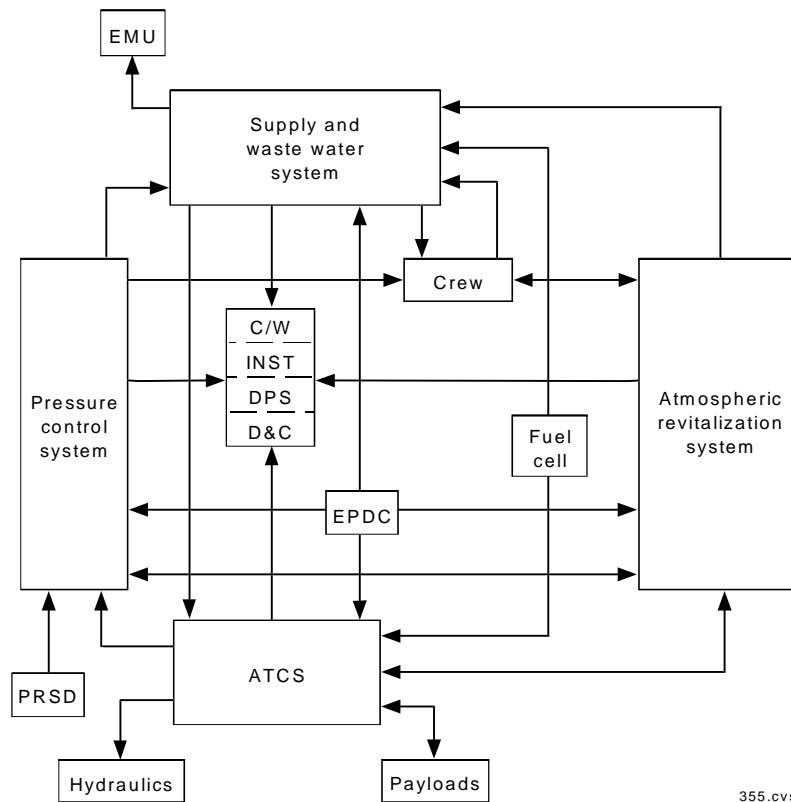
- 1 Water coolant loops
- 2 Interchanger heat exchanger
- 3 Payload heat exchanger
- 4 Freon- 21 coolant loops
- 5 Fuel cell power plants
- 6 Aft avionics bay and cold plates
- 7 Ground support equipment heat exchanger
- 8 Ammonia boiler
- 9 Hydraulic heat exchangers to radiators
- 10 Midbody cold plates
- 11 Fuel cell heat exchanger to freon-21 coolant loops
- 12 Avionics bays 1, 2, and 3A heat exchangers, fans, and cold plates
- 13 Inertial measurement units heat exchanger and fans
- 14 Water pumps
- 15 Cabin air to water heat exchanger
- 16 Humidity water separators
- 17 Cabin fans and check valve assemblies
- 18 Potable water chiller heat exchanger
- 19 Liquid-cooled garment heat exchanger
- 20 Freon-21 coolant pumps
- 21 To radiators
- 22 Flash evaporators
- 23 Carbon dioxide absorber





354.cvs

Environmental Control and Life Support System Overview



355.cvs

Environmental Control and Life Support System Interfaces

The crew compartment provides a life-sustaining environment for the flight crew. The crew cabin volume with the airlock inside the mid-deck is 2,475 cubic feet (2,325 cubic feet for the orbiter cabin and 150 cubic feet for the airlock). For EVA, the airlock is depressurized and repressurized. Under normal circumstances, the cabin may be depressed to 10.2 psia to ease pre-breathe requirements prior to an EVA. When the airlock is located outside the middeck in the payload bay, the crew cabin volume is 2,625 cubic feet. The external airlock volume varies and is based on mission-specific configuration. The external airlock is covered in detail in the Orbiter Docking System (ODS) section of this document.

Most ECLSS parameters can be monitored during ascent and entry on BFS DISP 78 (SM SYS SUMM 1) and BFS DISP 79 (SM SYS SUMM 2) displays. On orbit ECLSS parameters are also available on SM DISP 66 (ENVIRONMENT) and SM DISP 88 (APU/ENVIRON THERM) displays.

0001/ /079		SM SYS SUMM 2		5 008/23:29:22	
				BFS 000/00:00:00	
				5 MANF1 MANF2	
CRYO TK	1 2 3 4	208 208 206 206	206 206 208 207		
H2 PRESS		816 815 814 814	814 814 815 815		
O2 PRESS		-248 -248 -248 -248	-248 -248 -248 -248		
HTR T1					
T2					
APU	1 2 3			HYD	1 2 3
TEMP EGT	942 942 942			PRESS	3064 3064 3064
B/U EGT	942 942 942			ACUM P	3080 3080 3080
OIL IN	250 250 250			RSVR T	116 153 142
OUT	264 264 264				
GG BED	511H 511H 511H			QTY	72 74 71
INJ	1271 1271 1271				
SPEED %	99 102 101			W/B	
FUEL QTY	59 60 62			H2O QTY	78 73 78
PMP LK P	14 14 14			BYP VLV	BYP BYP BYP
OIL OUT P	42 42 41				
FU TK VLV					
A T	63 65 62			THERM CNTL	1 28
B T	63 65 62			H2O PUMP P	23 63
AV BAY	1 2 3			FREON FLOW	2384 2384
TEMP	97 97 83			EVAP OUT T	38 38
A4 14	27.439 27.435				18.48

ECLSS Parameters on the BFS SM SYS SUMM 2 (DISP 79) Display

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

APU/ENVIRON THERM Display (DISP 88)

2011/ /066		ENVIRONMENT		4 000/02:33:38	
				000/00:00:00	
CABIN		AV BAY	1 2 3		
dP/dT +.01	CABIN P 14.7	TEMP	90 90 78		
PP02	AIRLK P 14.8	FAN ΔP	3.80 3.77 3.92		
A 3.04	FAN ΔP 5.55	SUPPLY H2O			
B 3.04	HX OUT T 45L	QTY A 67	PRESS 32		
C 3.04	CABIN T 71	B 18	DMP LN T 77		
PPC02 1.9		C 94	NOZ T A 64		
		D 94	B 64		
O2 FLOW	0.0L 0.0L	WASTE H2O			
REG P	100 100	QTY 1 15	PRESS 17		
N2 FLOW	0.0L 0.0L		DMP LN T 58		
REG P	202 202		NOZ T A 82		
O2/N2 CNTL VLV	N2 02		B 82		
H2O TK N2 P	17 17		VAC VT NOZ T 224		
N2 QTY	131 131				
EMER O2 QTY	1 1	CO2 CNTLR	1 2		
REG P	4L	FILTER P	0.00L		
		PPC02	- 0.0L		
		TEMP	32.0L		
		BED A PRESS	0.0L 0.0L		
		B PRESS	0.0L 0.0L		
		ΔP	0.00L 0.00L		
		VAC PRESS	0.0L		
IMU FAN	A B C ΔP				
HUMID SEP	* * 4.5				

ENVIRONMENTAL Display (DISP 66)

2011/ /078		SM SYS SUMM 1		4 000/14:44:12	
				000/00:00:00	
SMOKE	1/A 2/B	DC VOLTS	1/A 2/B 3/C		
CABIN	0.0	FC	30.6 30.1 31.0		
L/R FD	0.0 0.0	MAIN	30.6 30.1 31.0		
AV BAY	1 0.3 0.3	ESS	29.6 29.6 29.3		
	2 0.3 0.4				
	3 0.3 0.3	CNTL	1 29.4 29.4 29.6		
CABIN		2	29.4 29.4 29.4		
PRESS	14.0	3	29.4 29.4 29.4		
dP/dT-EQ	+1.00 +.000	AC			
O2 CONC		VOLT φA	118 118 117		
PP02	3.00 3.00	φB	117 117 118		
FAN ΔP	5.00	φC	117 117 118		
HX OUT T	46	AMPS φA	4.3 6.3 2.1		
O2 FLOW	0.0 0.0	φB	5.5 6.6 2.2		
N2 FLOW	0.0 0.0	φC	3.1 5.0 3.2		
IMU FAN	A B C	FUEL CEL			
ΔV FC1 FC2 FC3		AMPS	180 232 146		
SS1 22 21 22		REAC VLV	OP OP OP		
SS2 22 22 23		STACK T	+202 +206 +200		
SS3 23 21 21		EXIT T	150 152 149		
TOTAL AMPS	557	COOL P	61 60 61		
KW	17	PUMP			

ECLSS Parameters on the BFS SM SYS SUMM 1 (DISP 78) Display

The pressure control system normally pressurizes the crew cabin to 14.7 ± 0.2 psia. It maintains the cabin at an average 80-percent nitrogen (130 pounds) and 20-percent oxygen (40 pounds) mixture that closely resembles the atmosphere at sea level on Earth. The system also provides the cabin atmosphere necessary to cool cabin-air-cooled equipment. Oxygen partial pressure is maintained automatically between 2.95 and 3.45 psi, with sufficient nitrogen pressure of 11.5 psia added to achieve the cabin total pressure of 14.7 ± 0.2 psia. Positive and negative pressure relief valves protect the structural integrity of the cabin from over- and underpressurization respectively. The pressure control system nitrogen is used to pressurize the supply and wastewater tanks. The system also provides breathing oxygen directly to the launch and entry suit helmets and to emergency breathing masks.

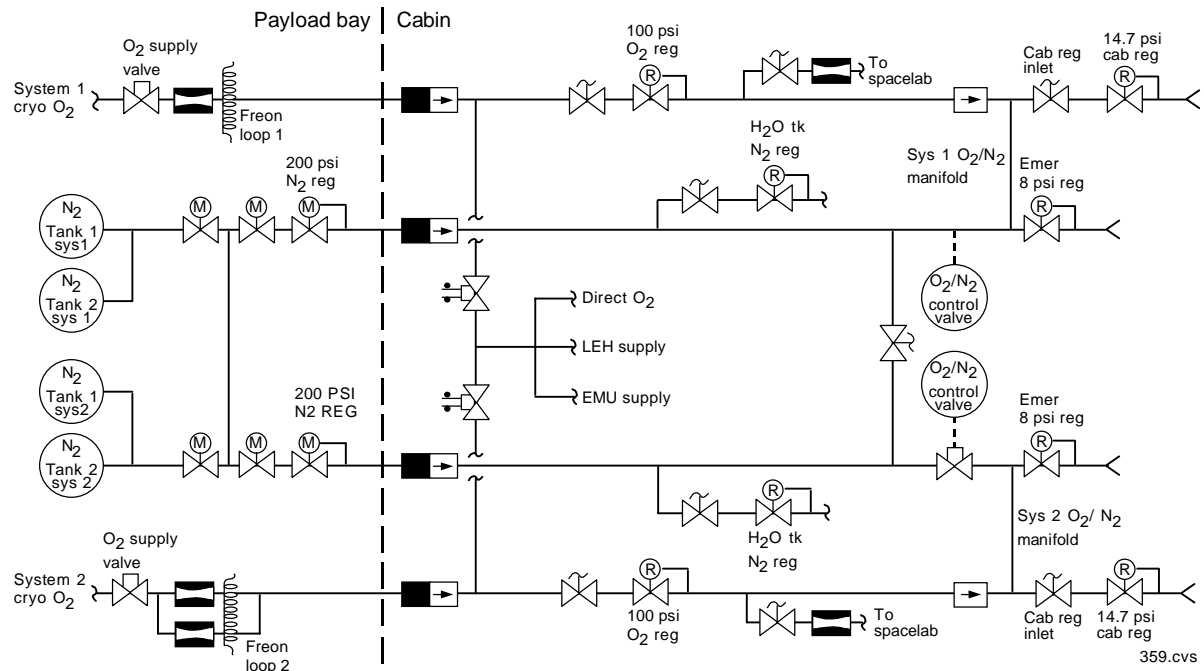
Cabin pressure is maintained by either of two pressure control systems (designated PCS 1 and PCS 2). Each pressure control system consists of a liquid oxygen storage system and a gaseous nitrogen storage system. The PCS oxygen is supplied from the electrical power system's (EPS) cryogenic oxygen in the midfuselage of the orbiter. The cryogenic supercritical oxygen storage system is controlled by electrical heaters within the tanks and supplies oxygen to the ECLSS pressure control system at a pressure of 803 to 883 psia in a gaseous state. The nitrogen storage tanks are serviced to a nominal pressure of 2,964 psia at 80° F. Normal on-orbit operations use one oxygen and one nitrogen supply system.

Cabin pressure is controlled by the nitrogen/oxygen control and supply panels, the PPO₂ sensor, and pressure relief valves. The nitrogen/oxygen control panel selects and regulates primary (pressure control system 1) or secondary (pressure control system 2) oxygen and nitrogen. The system 1 and system 2 nitrogen/oxygen supply panels are located in the lower forward portion of the midfuselage. Both O₂ and N₂ supply systems 1 and 2 have a crossover capability. This allows the respective systems to be tied together.

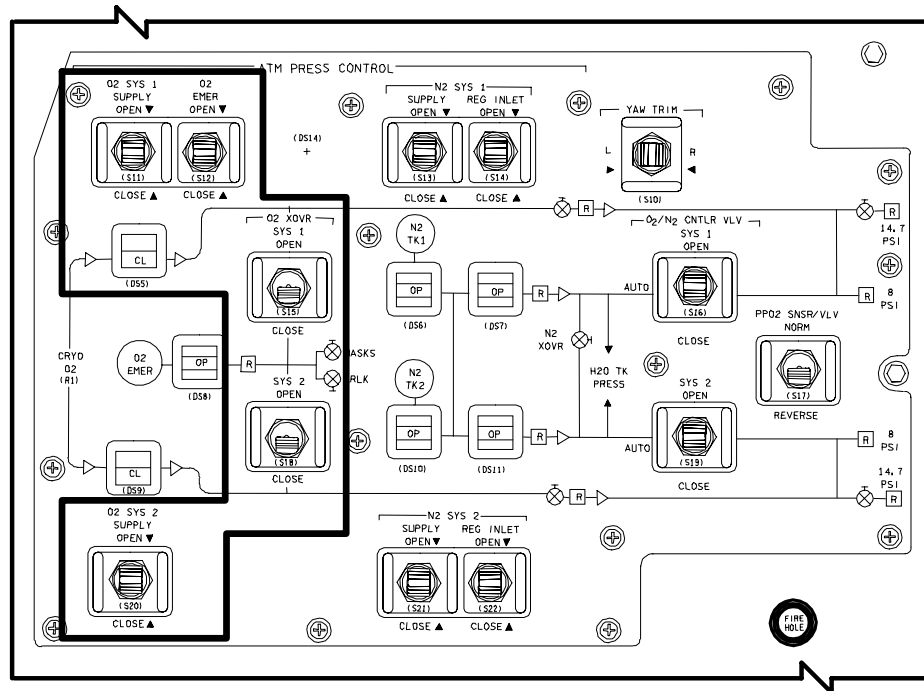
The oxygen supply system provides the "makeup" cabin oxygen gas for flight crew consumption and makeup for cabin leakage. The nitrogen system provides nitrogen for pressurizing the cabin and the potable and wastewater tanks. Each crew member uses an average of 1.76 pounds of oxygen per day. Up to 7.7 pounds of nitrogen and 9 pounds of oxygen are used per day for normal loss of crew cabin gas to space and metabolic usage. The potable and wastewater tanks are pressurized to 17 psig in order to expel water from the tanks for use by the crew or dumping overboard.

Oxygen System

Oxygen from the power reactant storage and distribution system (cryogenic oxygen supply system) is routed to the pressure control oxygen system 1 and system 2 supply valves. These valves are controlled by the *ATM PRESS CONTROL O2 SYS 1 SUPPLY* and *O2 SYS 2 SUPPLY* switches on panel L2. When one of the switches is momentarily positioned to *OPEN*, the corresponding valve opens to permit oxygen to flow through an oxygen restrictor at a maximum flow of approximately 25 pounds per hour for either system 1 or 2. The Oxygen restrictor also functions as a heat exchanger with the Freon



Pressure Control System



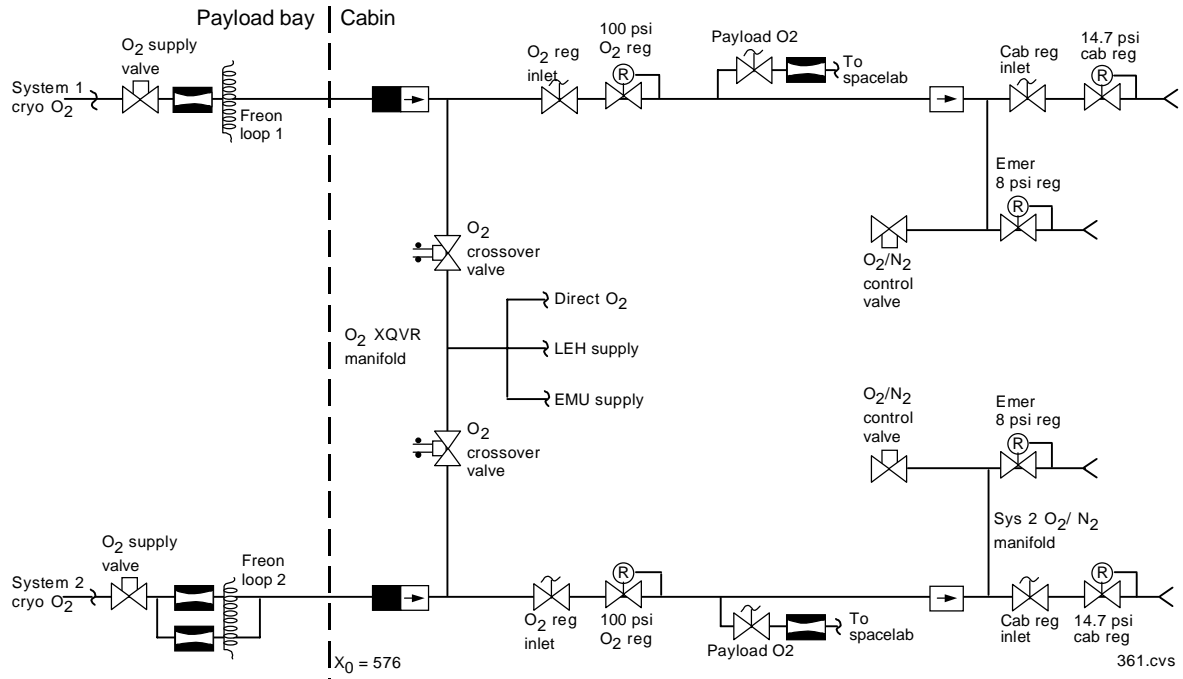
ATM PRESS CONTROL O2 SYS SUPPLY and XOVR Switches and Talkbacks on Panel L2

coolant loop, warming the oxygen supplied to the oxygen regulator of that system before it flows into the cabin. Freon loop 1 warms system 1 oxygen, and loop 2 warms system 2. A talkback indicates *OP* when the O₂ supply valve is open. When the switch is momentarily positioned to *CLOSE*, the valve is closed, isolating that oxygen supply system. The talkback indicates *CL*.

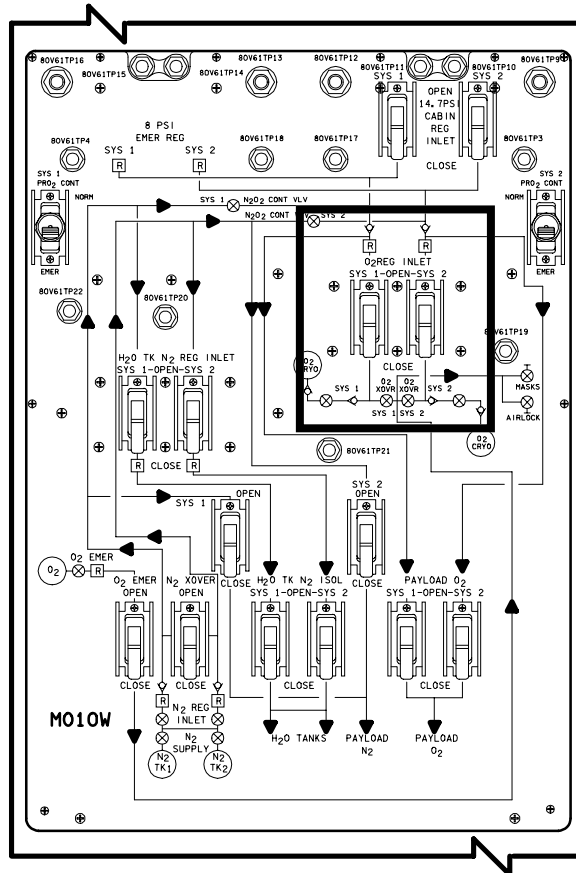
Next, the oxygen piping penetrates the bulkhead and enters the crew compartment. A check valve downstream of the Freon loop heat exchanger prevents oxygen from flowing from one supply source to the other when the crossover valves are open. Downstream of the oxygen check valve, oxygen systems 1 and 2 are connected by a crossover valve that permits system 1 and system 2 to be interconnected. The crossover valves are controlled by the *ATM PRESS CONTROL O2 XOVR SYS 1* and *SYS 2* switches on panel L2. When one of the switches is positioned to *OPEN*, the associated oxygen supply system is directed to the launch and entry helmet O₂ supply 1 and 2 manual valves, airlock oxygen 1 and 2 extravehicular mobility unit, and direct O₂. If both switches are positioned to *OPEN*, oxygen supply systems 1 and 2 are interconnected. When a switch is positioned to *CLOSE*, that oxygen supply

system is isolated from the crossover feature. The crossover valves are normally open.

Downstream of the oxygen crossover line is an oxygen regulator inlet manual valve. When the valve is manually positioned to *OPEN* by the O₂ *REG INLET* switch on panel MO10W, oxygen is directed to a regulator, which reduces the oxygen supply pressure to 100 ± 10 psig. Each regulator valve is composed of a manual toggle ON/OFF valve, a regulator, and a relief valve. The relief valve relieves pressure at 245 psig and reseats at 215 psig. The relief pressure is vented into the crew cabin. The regulated O₂ then passes through another check valve that prevents downstream nitrogen from entering the oxygen system. The oxygen enters a manifold that is shared by the nitrogen system. This manifold is connected to its 14.7 psi cabin regulator inlet manual valve and the 8 psi regulator. Between the oxygen regulator and the oxygen check valve, the oxygen is fed to the payload oxygen manual valve for use by the payload if required. This valve, as well as the 14.7 cabin pressure manual valve, is located on panel MO10W. "Make up" O₂ for metabolic usage is provided by a bleed orifice inserted on orbit into LEH quick disconnect 8 on panel MO69M.

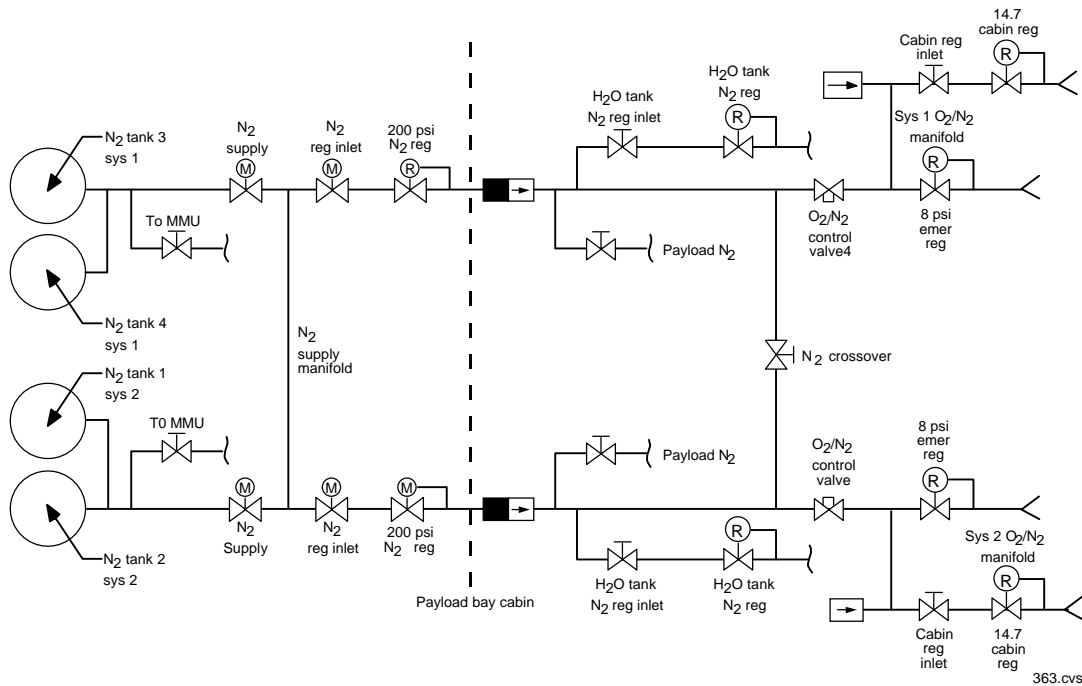


Oxygen System



O₂ REG INLET Switches on panel MO10W

Note: OV-102 has tanks 2, 3, and 4 on Sys 1; OV-103 and -105 have an additional tank 3 on Sys 2.



Nitrogen System for Nominal Mission OV-104

Nitrogen System

Gaseous nitrogen is supplied from two nitrogen systems, consisting of either two or three nitrogen tanks (depending on orbiter) per system that are permanently mounted in the payload bay. System 1 is mounted on the port side and system 2 is on the starboard side. All four orbiters have been modified to perform extended duration orbiter (EDO) missions. OV-104 is the only orbiter with four nitrogen tanks; OV-102, -103, and -105 each have five tanks. In all configurations, tanks 1 and 2 are installed on the forward end of the payload bay, and tanks 3 and 4 are installed on the aft end. Tanks 1 and 2 (one or both) on system 1 may be installed only as a mission kit.

OV-102

- System 1 tanks 2, 3, 4
- System 2 tanks 1, 2

OV-103, -105

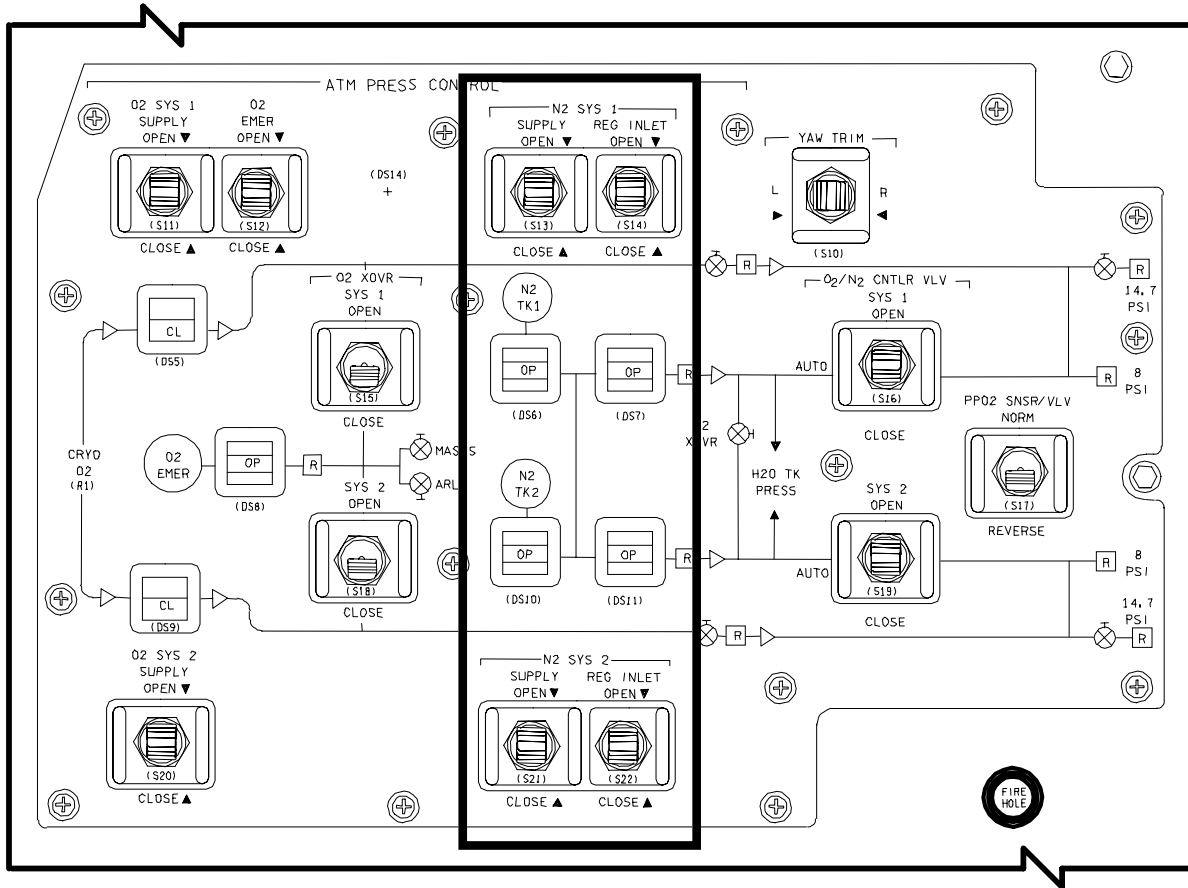
- System 1 tanks 3, 4
- System 2 tanks 1, 2, 3

OV-104

- System 1 tanks 3, 4
- System 2 tanks 1, 2

The nitrogen supply tanks are constructed of filament-wound Kevlar fiber with a titanium liner. Each nitrogen tank is serviced to a nominal pressure of 2,964 psia at 80° F, with a volume of 8,181 cubic inches. The nitrogen tanks in each system (two or three nominally, four on EDO missions) are manifolded together.

The primary and secondary nitrogen supply systems are controlled by the atmosphere pressure control nitrogen supply valves in each system. Each valve is controlled by its corresponding *ATM PRESS CONTROL N2 SYS 1* and *SYS 2 SUPPLY* switch on panel L2. When a switch is momentarily positioned to *OPEN*, nitrogen flows to both atmosphere pressure control system regulator inlet valves, since both sets of tanks are manifolded together downstream of the supply valve. A talkback near the switch indicates barberpole when the motor-operated valve is in transit, and *OP* when the supply valve is open. When the switch is positioned to *CLOSE*, that nitrogen supply system is isolated from the nitrogen system regulator inlet valve, and the talkback indicator shows *CL*.



ATM PRESS CONTROL N2 SYS SUPPLY and REG INLET Switches and Talkbacks on Panel L2

The nitrogen regulator inlet valve in each nitrogen system is controlled by its respective *ATM PRESS CONTROL N₂ SYS REG INLET* switch on panel L2. When the switch is positioned to *OPEN*, that system's nitrogen at source pressure is directed to the system's nitrogen regulator. A talkback indicator below the *SYS 1* switch and above the *SYS 2* switch indicates barberpole when the motor-operated valve is in transit, and *OP* when the valve is open. When the switch is positioned to *CLOSE*, the supplied nitrogen is isolated from the system's nitrogen regulator, and the talkback indicator indicates *CL*.

The nitrogen regulators in supply systems 1 and 2 reduce the pressure to 200 ± 15 psig. Each nitrogen regulator is a two-stage regulator with a relief valve. The relief valve relieves pressure at 295 psig into the vacuum vent line and reseats at 245 psig.

The pressure regulated nitrogen of each system is directed to the nitrogen manual crossover valve, the manual water tank regulator inlet valve, the payload manual nitrogen supply valve, and the oxygen and nitrogen controller valve in each system. The manual valves are controlled from panel MO10W, and the controller valve is controlled from the panel L2 *O₂/N₂ CNTLR VLV* switch.

The nitrogen crossover manual valve connects both regulated nitrogen systems when the valve is open and isolates the nitrogen supply systems from each other when closed. Normally, the valve is always closed. A check valve between the nitrogen regulator and nitrogen crossover valve in each nitrogen-regulated supply line prevents back flow from one nitrogen source supply to the other if the nitrogen crossover valve is open. The nitrogen system can supply at least 125 lb/hr from each system.

Oxygen/Nitrogen Manifold

The O₂/N₂ control valve controls the flow of either N₂ or O₂ into the O₂/N₂ manifold, depending on the partial pressure of oxygen in the cabin. Whatever gas (O₂/N₂) is in the O₂/N₂ manifold will flow into the cabin when the cabin pressure drops below 14.7 psia, and the 14.7 regulator valve is open. This “makeup” flow will continue as long as the cabin pressure is less than 14.7. An 8 psia emergency regulator provides flow to maintain a cabin pressure of 8 psia in the event of a large cabin leak. There is no regulator inlet valve to isolate the 8 psia emergency regulator; therefore, it is always configured to provide flow.

The 14.7 psi cabin regulator regulates the cabin pressure to 14.7 ± 0.2 psia and is capable of a maximum flow of 75 to 145 lb/hr. The 8 psi emergency regulator is designed to regulate to 8 ± 0.2 psia and is also capable of a maximum flow of 75 to 145 lb/hr. Both the 14.7 and 8 psi regulators flow into the cabin through a port in panel MO10W located above the waste management system compartment. Regulators consist of two stages: a low-flow regulator (0 to 0.75 lb/hr) for small demand when the cabin pressure is near 14.7 psia and a high flow regulator (0.75 to at least 75 lb/hr) for high demand when cabin pressure is significantly below 14.7 psia.

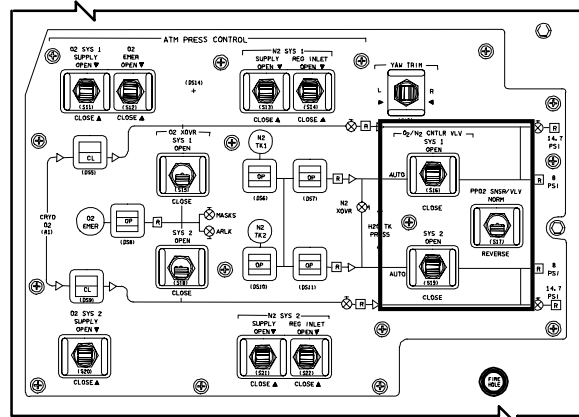
NOTE

Crewmembers should be aware that the regulators make a noticeable sound when they flow oxygen or nitrogen into the cabin. It is most noticeable in the vicinity of the waste management system compartment. Additionally, use of the WCS during high N₂ flow is not advisable due to the possibility of hypoxia.

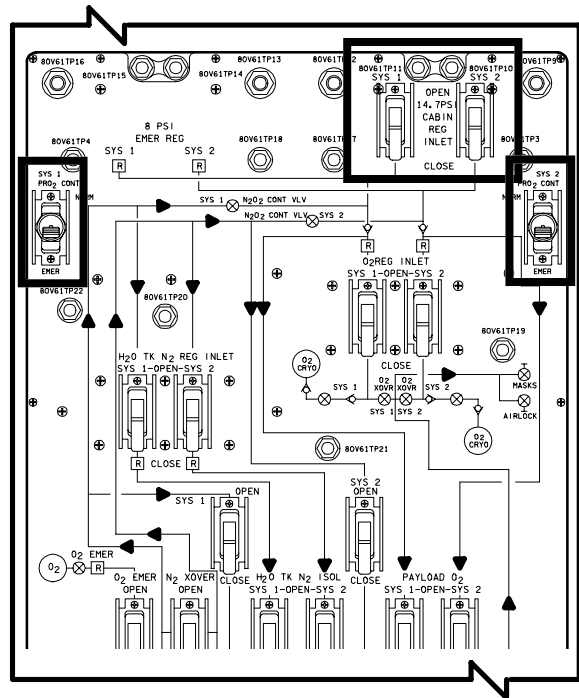
PPO₂ Control

The partial pressure of oxygen (PPO₂) in the crew cabin is controlled automatically during orbit by one of two O₂/N₂ controllers. Two PPO₂ sensors (A and B) located under the mission specialist station provide inputs to the PPO₂ control systems 1 and 2 controller and switches, respectively.

When either the SYS 1 or SYS 2 PPO₂ CONT switch on panel MO10W is positioned to NORM, and the PPO2 SNSR/VLV switch on panel L2 is also positioned to NORM, electrical power is supplied to the corresponding ATM PRESS CONTROL O₂/N₂ CNTLR VLV switches on panel L2 for system 1 or 2. When the O₂/N₂ CNTLR VLV switch on panel L2 is positioned to AUTO, electrical power automatically energizes or deenergizes the corresponding O₂/N₂ control valve.



PPO₂ SNSR/VLV and O₂/N₂ CNTRL VLV Switches on Panel L2



PPO₂ CONT and CABIN REG INLET Switches on Panel MO10W

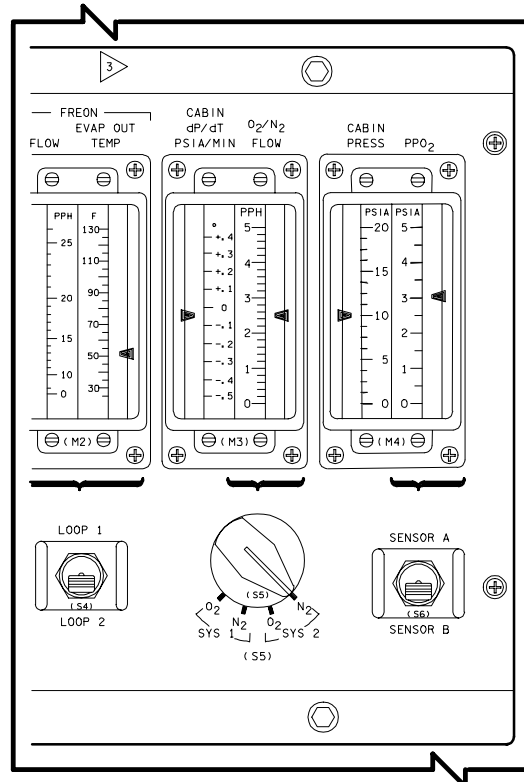
When the corresponding PPO₂ sensor determines that oxygen is required in the crew cabin to maintain the level above 2.95 psi, the O₂/N₂ control valve is automatically closed. When the 200-psi nitrogen in the manifold drops below 100 psi, the corresponding oxygen system flows oxygen through its check valve into the manifold and through the 14.7 psi cabin regulator into the crew cabin. When the PPO₂ sensor determines that the oxygen in the crew cabin is at 3.45 psi, the corresponding O₂/N₂ control valve is automatically opened. The 200-psi nitrogen enters the O₂/N₂ manifold and closes the corresponding oxygen system's check valve and flows through the 14.7 psi regulator into the crew cabin whenever the cabin pressure drops below 14.7 psia ± 0.2. The OPEN and CLOSE positions of the O₂/N₂ CNTLR VLV SYS 1 and SYS 2 switches on panel L2 permit the flight crew to manually control the O₂/N₂ valve in each system and manually switch between O₂ and N₂ systems. The REVERSE position of the PPO₂ SNSR/VLV switch on panel L2 allows O₂/N₂ CNTLR SYS 1 to control O₂/N₂ CNTLR VLV SYS 2, and vice versa.

The SYS 1 and SYS 2 PPO₂ CNTLR switches were designed to control the PPO₂ level (via the O₂/N₂ CNTLR) of the cabin between the normal range (2.95-3.45 at 14.7 psi) or the emergency range (1.95-2.45 at 8 psi). The control range can be determined by positioning the switch in NORM or EMER. The EMER position is procedurally never used.

The oxygen systems 1 and 2 and nitrogen systems 1 and 2 flows can be monitored via the O₂/N₂ FLOW meter on panel O1. The flow of the selected system is displayed on the meter in pounds per hour.

PPO₂ sensors A and B monitor the oxygen partial pressure and the signal to the SENSOR switch on panel O1. When the switch is positioned to SENSOR A, oxygen partial pressure from sensor A is monitored on the PPO₂ meter on panel O1 in psia. If the switch is set on SENSOR B, oxygen partial pressure from sensor B is monitored. The cabin pressure sensor output is routed directly to the CABIN PRESS meter on panel O1 and is displayed in psia. These parameters can also be viewed on CRT displays SM SYS SUMM 1 (PPO2) and DISP 66, ENVIRONMENT (PPO2 A, B, C).

If the change in pressure versus change in time (dP/dT) decreases at a rate of 0.08 psi per minute or greater, a klaxon will sound in the crew cabin, and the MASTER ALARM pushbutton light indicators will be illuminated. The normal cabin dP/dT is zero psi per minute plus or minus 0.01 psi.



Meters and Switches on Panel O1
(Transducers also supply information for SM SYS SUMM 1, DISP 66, and C/W.)

2011/ /078		SM SYS SUMM 1		4 000/14:44:12		
				000/00:00:00		
SMOKE	1/A 2/B	DC VOLTS	1/A 2/B 3/C			
CABIN	0.0	FC	30.6 30.1 31.0			
L/R FD	0.0 0.0	MAIN	30.6 30.1 31.0			
AV BAY	1 0.3 0.3	ESS	29.6 29.6 29.3			
	2 0.3 0.4	CNTL 1 29.4 29.4 29.6				
	3 0.3 0.3	2 29.4 29.4 29.4				
		3 29.4 29.4 29.4				
CABIN		AC				
PRESS	14.0	VOLT φA	118 118 117			
dP/dT-EQ	+0.00 +0.000	φB	117 117 118			
O2 CONC		φC	117 117 118			
PPO2	3.00 3.00	AMPS φA	4.3 6.3 2.1			
FAN ΔP	5.00	φB	5.5 6.6 2.2			
HX OUT T	46	φC	3.1 5.0 3.2			
O2 FLOW	0.0 0.0	FUEL CEL				
N2 FLOW	0.0 0.0	AMPS	180 232 146			
IMU FAN	A B C	REAC VLV	OP OP OP			
ΔV FC1 FC2 FC3		STACK T	+202 +206 +200			
SS1 22 21 22		EXIT T	150 152 149			
SS2 22 22 23		COOL P	61 60 61			
SS3 23 21 21		PUMP				
TOTAL AMPS	557					
KW	17					

The SM SYS SUMM 1 display is an SM display (DISP78) available in SM OPS and 4

Water Tank Regulator Inlet Valve

The H₂O TK N₂ REG INLET valve in each nitrogen system permits nitrogen to flow to its regulator and H₂O TK N₂ ISOL SYS 1, 2 valve. The REG inlet and isolation manual valves are on panel MO10W. The regulator in each nitrogen system reduces the 200 psi supply pressure to 15.5 to 17.0 psig. Each regulator is a two-stage regulator with the second stage relieving pressure into the crew cabin at a differential pressure of 18.5 ± 1.5 psig.

Airlock Depressurization and Equalization Valves

The airlock pressure is maintained equal with cabin pressure via the airlock equalization valves located on the cabin/airlock hatch. During normal operations the airlock hatch is open. The airlock depressurization valve is used to depressurize the cabin to 10.2 psia and to depressurize the airlock for EVA.

Atmospheric Revitalization System

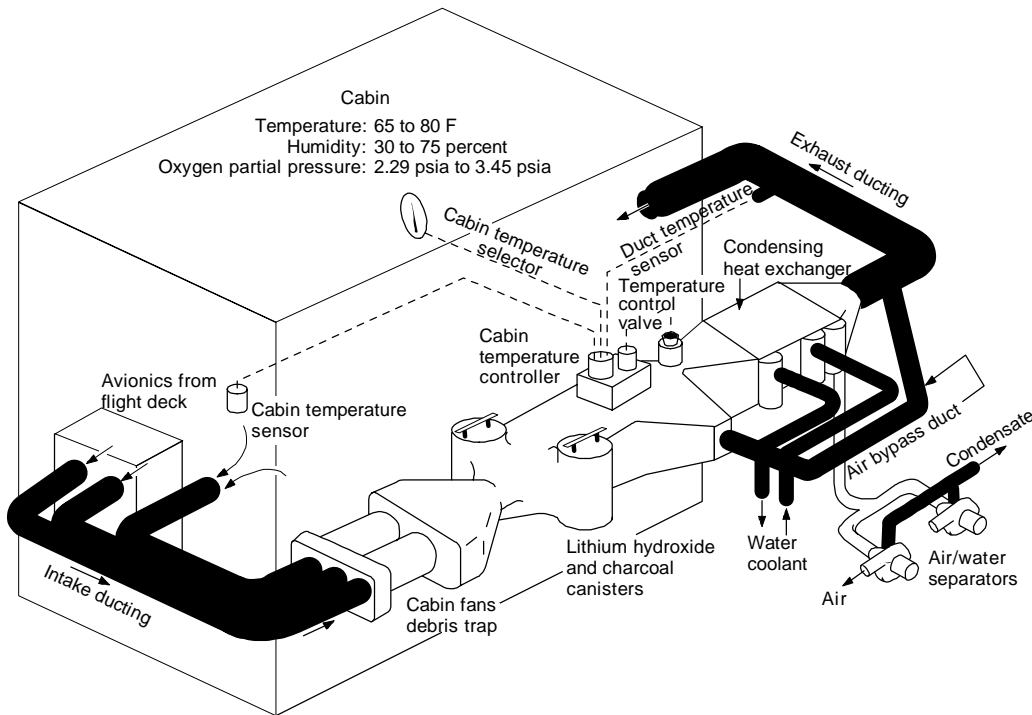
The atmospheric revitalization system (ARS) circulates air and water throughout the cabin to control ambient heat, relative humidity (between 30 and 65 percent), carbon dioxide,

and carbon monoxide levels. The ARS also provides cooling for cabin avionics.

Cabin air is circulated around the cabin to remove heat and humidity. The heated air is then ducted (via cabin fans) to the cabin heat exchanger, where it is cooled by the water coolant loops. The water coolant loop system collects heat from the cabin heat exchanger, the inertial measurement unit heat exchanger, some of the cold plated electronic units in the avionics bays, and the avionics bay heat exchangers. It transfers heat to the Freon/water heat exchanger of the active thermal control system. The active thermal control system expels the heat overboard.

Cabin Air Flow

Except for ducting, all air loop components are located under the middeck floor. The air circulated through the flight crew cabin also picks up odor, carbon dioxide, debris, and additional heat from electronic units in the crew cabin. Based on the crew cabin volume of 2,300 cubic feet and 330 cubic feet of air per minute, one volume crew cabin air change occurs in approximately 7 minutes, and approximately 8.5 air changes occur in 1 hour.



Cabin Air

The heated cabin air is drawn through the cabin loop and through a 300-micron filter by one of two cabin fans. Each cabin fan (A and B) is controlled by its respective *CABIN FAN* switch on panel L1. Normally, only one fan is used.

Each fan is powered by a three-phase, 115-volt ac motor. These 495-watt motors produce a nominal flow rate of 1,400 lb/hr through the cabin air ducting. A check valve located at the outlet of each fan prevents air from backflowing through the nonoperating fan. This flapper-type check valve will open if there is a 2 inch H₂O (.0723 psi) differential pressure across the valve. A cabin fan will not start on two phases of ac. However, if the cabin fan is already operating when a phase of ac is lost, the fan will continue to run on two phases of ac. A cabin fan can be started on 2-1/2 phases of ac, with the extra half phase provided by the induced voltage generated by other rotating equipment (that is, fans and pumps) running on that ac bus. If a phase of ac is lost with a short, then the induced voltage will not be usable, and starting the cabin fan will not be possible.

Lithium Hydroxide Canisters

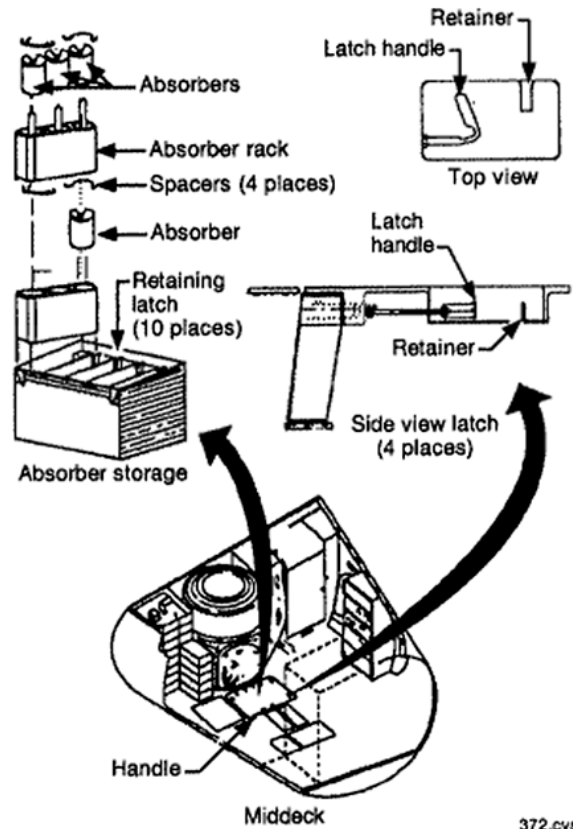
The cabin air leaves the cabin fan at a rate of about 1,400 lb/hr. An orifice in the duct directs approximately 120 lb/hr to each of two lithium hydroxide canisters, where carbon dioxide is removed, and activated charcoal removes odors and trace contaminants. The canisters are changed periodically on a predetermined schedule, generally one or two times a day, through an access door. (For larger crews, the canisters are changed more frequently.) Each canister is rated at 48 man-hours. Up to 30 spare canisters are stored under the middeck floor in a locker between the cabin heat exchanger and water tanks.

CAUTION

During lithium hydroxide canister changeout, the cabin fan(s) should be turned off. Dust from the canisters kicked up by a cabin fan has caused eye and nose irritation. Lithium hydroxide dust may also be a contributing factor to humidity separator failures.

OV-102 utilizes lithium hydroxide canisters only during launch and landing. On orbit, the regenerable carbon dioxide system (RCRS),

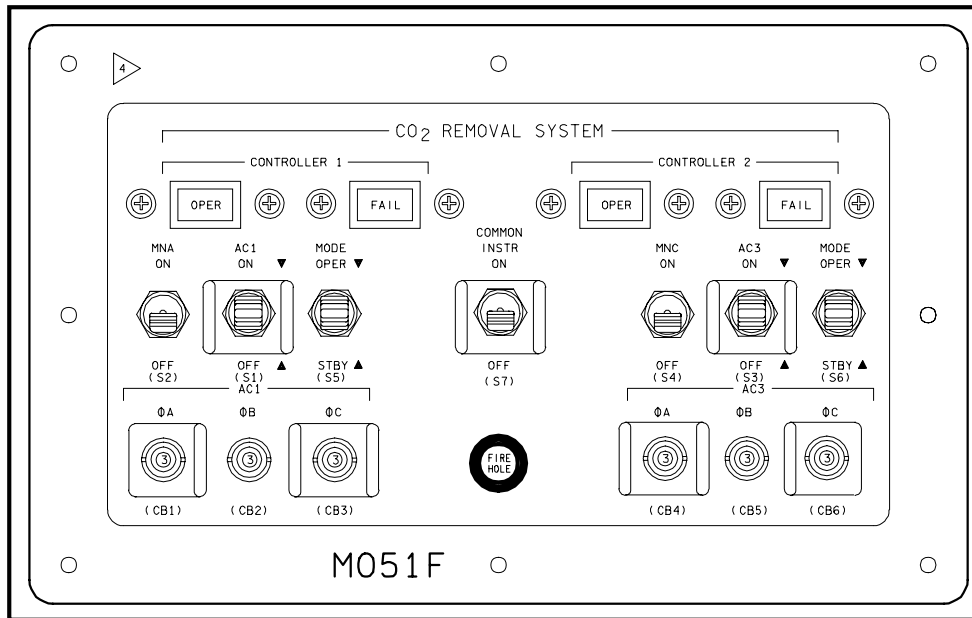
incorporated as part of the EDO modifications, is the primary system. LiOH canisters also provide backup to the RCRS on this vehicle. OVs-104 and -105 are also capable of supporting the RCRS. OV-103 is not configured for RCRS and has only the LiOH system for carbon dioxide removal.



Carbon Dioxide Absorbers

Regenerable Carbon Dioxide Removal System

The ability to use the RCRS in the EDO orbiters solved a major weight and volume stowage problem encountered when attempting to conduct 10 to 16 day duration missions for a crew of up to seven astronauts. Carbon dioxide removal is accomplished by passing cabin air through one of two identical solid amine resin beds. The resin consists of a polyethylenimine (PEI) sorbent coating on a porous polymeric substrate. Upon exposure to carbon dioxide laden cabin air, the resin combines with water vapor in the air to form a hydrated amine which reacts with carbon dioxide to form a weak bicarbonate bond. Water is required for the process since dry amine cannot react with the carbon dioxide directly. While one bed adsorbs carbon dioxide, the other bed regenerates with



CO₂ Removal System Panel MO51F

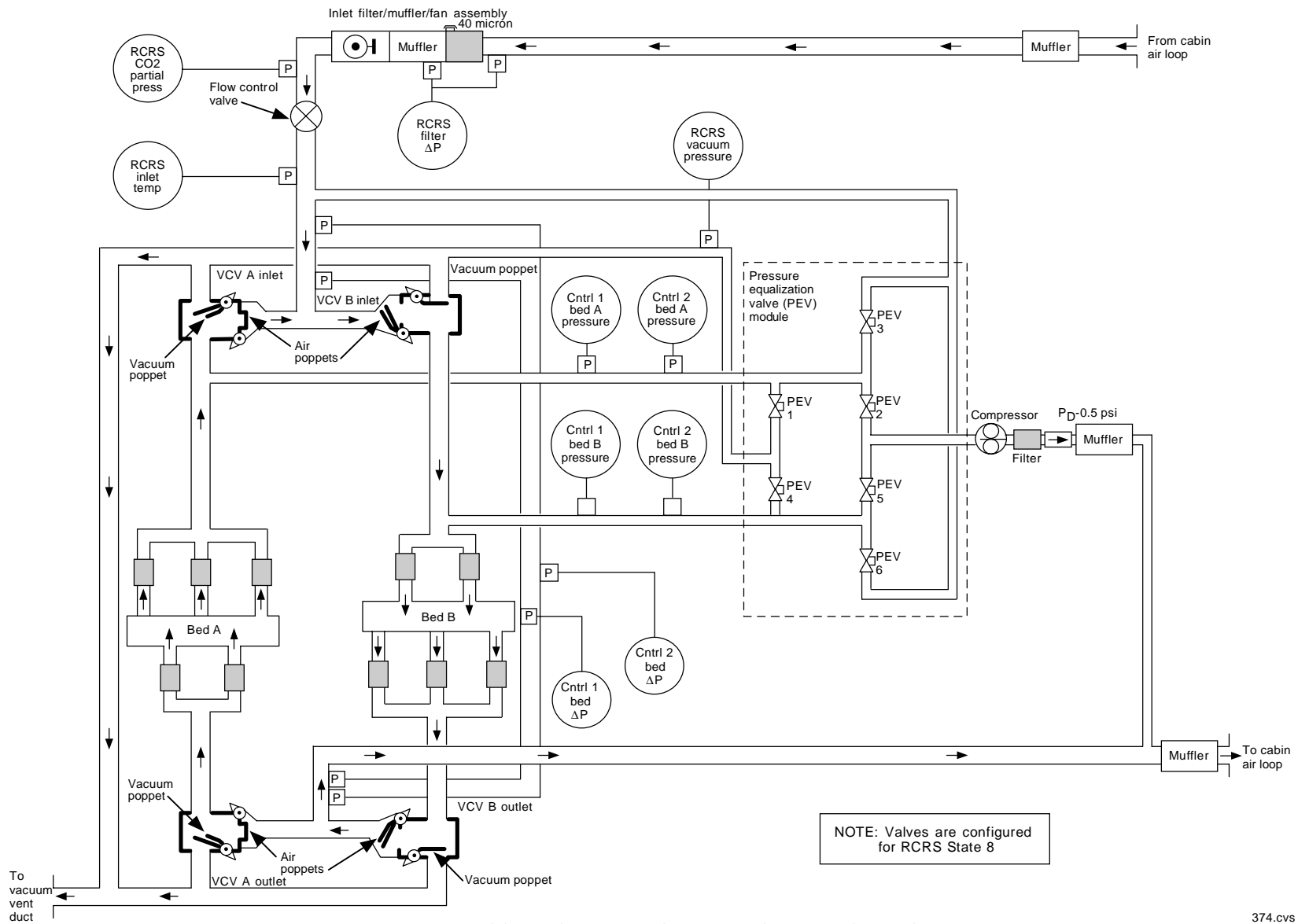
thermal treatment and vacuum venting. This latter requirement prevents the use of the RCRS during ascent or entry. The adsorption/regeneration process runs continuously with the beds automatically alternating processes every 13 minutes. A full cycle is made up of two 13 minute cycles. An RCRS configured vehicle uses a single LiOH canister for launch and another for entry. An activated charcoal canister in the other CO₂ absorber slot removes odors. It is changed out mid mission on 10+ day flights.

The RCRS is located in volume D under the middeck floor. In addition to the two chemical beds, the major components of the RCRS include a set of vacuum cycle and pressure equalization valves, an RCRS fan, an airflow control valve, an ullage-save compressor, and two redundant controllers (1 and 2). The airflow control valve is set prelaunch for either a crew size of "4" or "5 to 7" crewmembers. These two positions select airflow through the RCRS of 72 or 110 lb/hr respectively. The control switches for the RCRS are located on panel MO51F. Both ac and dc power for the 1 and 2 controllers are operated from this panel. Each controller has a three position momentary switch for selection of *OPER* or *STBY*. This panel also has status lights for each controller which illuminate *OPER* or *FAIL* as appropriate. Crew insight into RCRS operation is found on SPEC 66 ENVIRONMENT in OPS 2 or 4.

The scrubbed air is then forced through the rest of the ARS. Cabin air is then directed to the crew cabin heat exchanger where heat is transferred to the water coolant loop. Humidity condensation that forms in the heat exchanger is pushed by the air flow to the slurper. One of two humidity separators draws air and water from the slurper. In the humidity separator, centrifugal force separates the water from the air. The fan separator removes up to approximately 4 pounds of water per hour. The water is routed to the wastewater tank, and the air is ducted through the exhaust for return to the cabin.

There are two fan separators (A and B) controlled individually by *HUMIDITY SEP A* and *B* switches on panel L1. Normally, only one fan separator is used. The relative humidity in the crew cabin is maintained typically between 30 and 65 percent in this manner.

A small portion of the revitalized and conditioned air from the cabin heat exchanger is ducted to the carbon monoxide removal unit, which converts carbon monoxide to carbon dioxide. A bypass duct carries warm cabin air around the cabin heat exchanger and mixes it with the revitalized and conditioned air to control the crew cabin air temperature in a range between 65° and 80° F.

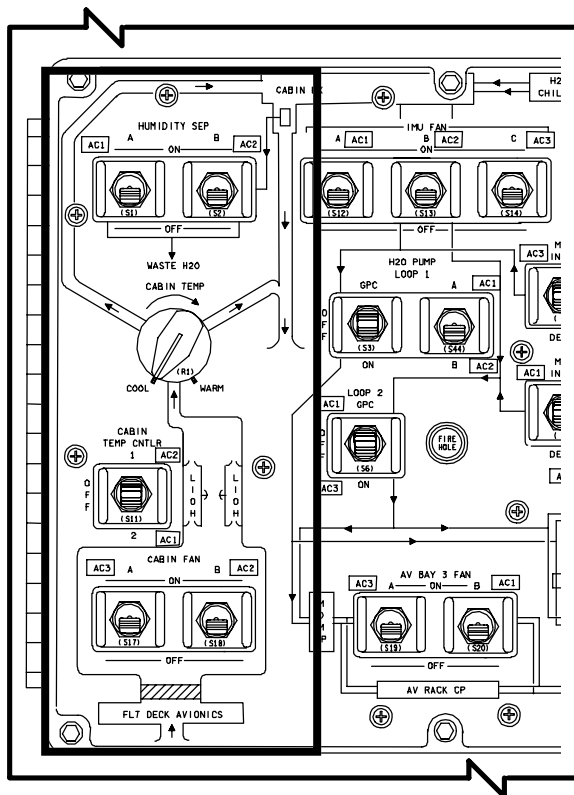


Regenerable Carbon Dioxide Removal System (RCRS)

Cabin Air Temperature Control

The cabin temperature control valve is a variable position valve that proportions the volume of air that bypasses the cabin heat exchanger. The valve may be positioned manually by the crew, or automatically by one of the two cabin temperature controllers. The cabin temperature controller is a motor-driven actuator that adjusts the cabin temperature control valve to achieve the temperature selected by the *CABIN TEMP* rotary switch on panel L1. The cabin temperature control valve and the two controllers are located in the ECLSS bay below panel MD44F.

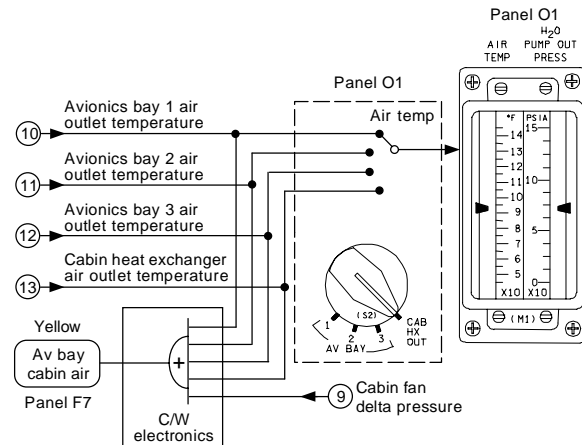
When the *CABIN TEMP CNTLR* switch on panel L1 is positioned to 1, it enables controller 1. The rotary *CABIN TEMP* switch elects and automatically controls the bypass valve by diverting 0 to 70 percent of the air flow around the cabin heat exchanger, depending on the position of the switch.



HUMIDITY SEP, CABIN TEMP, CABIN TEMP CNTLR, and CABIN FAN Switches on panel L1

The controllers are attached to a single bypass valve by an actuator arm. If controller 1 malfunctions, the actuator arm linkage must be removed from controller 1 by the flight crew at panel MD44F and connected manually to controller 2 before the *CABIN TEMP CNTLR* switch on panel L1 is positioned to 2. This enables controller 2 and permits the rotary *CABIN TEMP* switch to control controller 2 and the single bypass control valve. The *CABIN TEMP CNTLR* switch's *OFF* position removes electrical power from both controllers, the rotary switch, and automatic control of the single bypass valve. For ascent and entry, the *CABIN TEMP* is set to full *COOL* to ensure maximum air cooling during these relatively warm phases of flight.

The air from the cabin heat exchanger and the bypassed air come together in the supply duct downstream of the heat exchanger and are exhausted into the crew cabin through the CDR and PLT consoles and through various station duct outlets into the crew cabin.



376.cvs

Avionics Bay and Cabin Heat Exchanger Temperature Monitoring and Caution/Warning, Crew Cabin Air

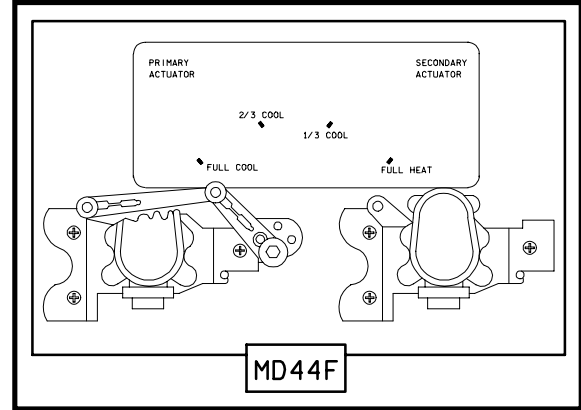
Cabin Temperature Monitoring

The cabin heat exchanger outlet temperature is transmitted to a rotary switch below the *AIR TEMP* meter on panel O1. When the switch is positioned to *CAB HX OUT*, the temperature can be monitored on the meter. The cabin heat exchanger outlet temperature provides an input to the yellow *AV BAY/CABIN AIR* caution and

warning light on panel F7. The light is illuminated if the cabin heat exchanger outlet temperature is above 145° F, if avionics bay 1, 2, or 3 temperatures exceed 130° F, or if the cabin fan delta pressure is less than 4.2 inches of water or above 6.8 inches of water.

Manual Temperature Control

If cabin temperature controllers 1 and 2 or the *CABIN TEMP* rotary switch on panel L1 are unable to control the single bypass valve, the flight crew can position the single bypass valve actuator drive arm to the desired position and pin the bypass valve arm to one of four fixed holes (*FULL COOL*, *FULL HEAT*, etc.) on panel MD44F. The *FULL COOL* position establishes the maximum cabin air flow rate to the cabin heat exchanger, the *2/3 COOL* position establishes a flow rate that provides approximately two-thirds of the maximum cooling capability, the *1/3 COOL* position establishes a flow rate that provides approximately one-third of the maximum cooling, and the *FULL HEAT* position establishes the minimum cabin air flow rate to the cabin heat exchanger.



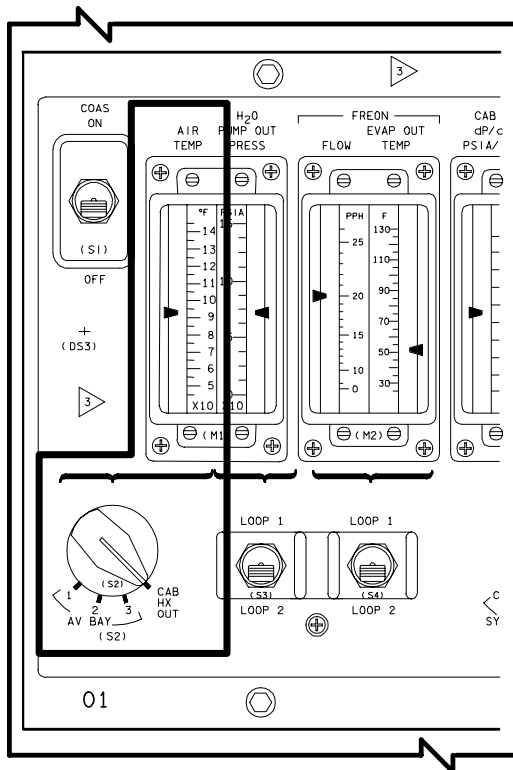
Manual Temperature Controls on Panel MD44F

Avionics Bay Cooling

Cabin air is also used to cool the three avionics equipment bays and some of the avionics units in the bays. Each of the three avionics equipment bays in the middeck has a closeout cover to minimize air interchange and thermal gradients between the avionics bay and crew cabin; however, the covers are not airtight. For all practical purposes, the air circulation is closed loop within the bay. The electronic avionics units in each avionics bay meet outgassing and flammability requirements to minimize toxicity levels.

Each of the three avionics equipment bays has identical air-cooling systems. Two fans per bay are controlled by individual *AV BAY 1, 2, 3 FAN A* and *B* switches on panel L1. Normally, only one fan is used at a time. When the *A* or *B* switch for an avionics bay is positioned to *ON*, the fan draws air from the floor of the avionics bay through the applicable air-cooled avionics units and a 300-micron filter into the avionics bay fan.

The avionics bay fan outlet directs the air through that avionics bay heat exchanger, located beneath the middeck crew compartment floor. The water coolant loops flow through the heat exchanger to cool the fan outlet air, and the cooled air is returned to the avionics bay. A check valve in the outlet of the fan that is not operating prevents a reverse flow through that fan.

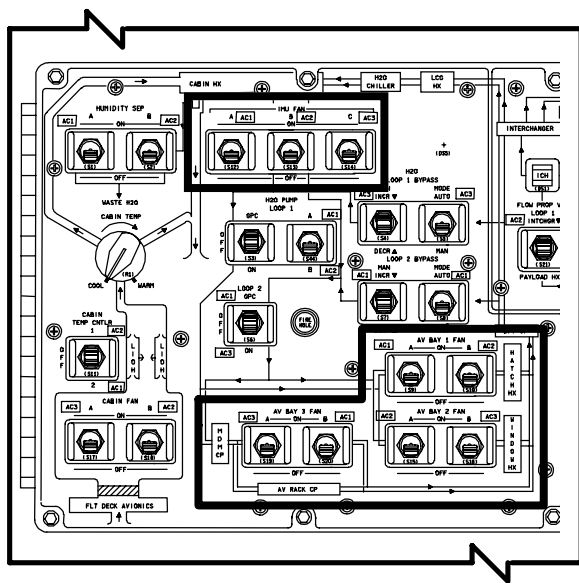


AIR TEMP Meter and Switch on Panel O1

The air outlet from the fan in each avionics bay is monitored and transmitted to a rotary switch on panel O1. When the switch is positioned to AV BAY 1, 2, or 3, that avionics bay's fan outlet temperature can be displayed on the AIR TEMP meter. The air outlet temperature of each avionics bay also provides an input to the yellow AV BAY/CABIN AIR caution and warning light on panel F7. This light is illuminated if any of the avionics bay outlet temperatures are above 130° F. The OFF position of the A or B switch removes power from that avionics bay fan.

Inertial Measurement Unit (IMU) Cooling

The three IMUs are cooled by one of three fans drawing cabin air through a 300-micron filter and across the three IMUs. The fans are located in avionics bay 1. The fan outlet air flows through the IMU heat exchanger located on the flight deck and is cooled by the water coolant loops before returning to the crew cabin. Each IMU fan is controlled by the IMU FAN switches on panel L1. The ON position turns the corresponding fan on, and the OFF position turns it off. Normally, one fan is sufficient because one fan cools all three IMUs. A check valve is installed on the outlet of each fan to prevent a reverse air flow through the fans that are not operating.



IMU FAN and AV BAY FAN Switches on Panel L1

Spacelab Air Revitalization

If the payload bay contains the Spacelab module, a kit is installed to provide ducting for the flow of cabin air from the middeck through the airlock and tunnel to the module. Information about the kit and its operation is provided in Section 2.21.

Water Coolant Loop System

The water coolant loops circulate water through the crew compartment to collect excess heat and transfer it to the Freon coolant loops. Two complete, separate water coolant loops flow side by side and can operate at the same time, although only one is active at any given time. Loop 2 is normally the active loop. The only difference between loops 1 and 2 is that loop 1 (the backup) has two water pumps, and loop 2 has one pump. The water pumps are located in the ECLSS bay below the forward lockers. The pumps are powered by three-phase, 115-volt ac motors.

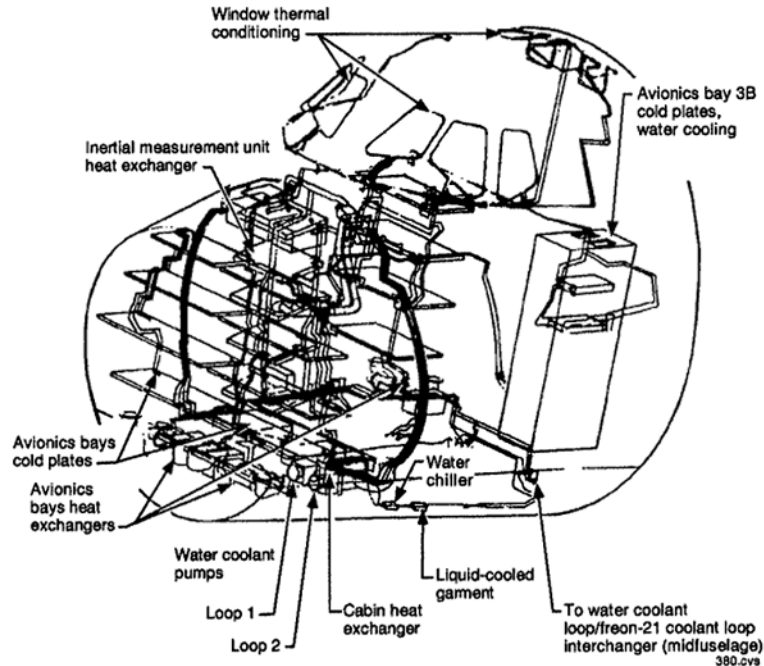
Some electronic units in each of the avionics equipment bays and in the cabin are mounted on cold plates. The water coolant loops flow through the cold plates, and the heat generated by the electronics unit is transferred to the cold plate and then to the water coolant loop, which carries heat from the electronic unit. The cold plates mounted on the shelves in each avionics equipment bay are connected in a series-parallel arrangement with respect to the water coolant loop flow.

Status of the water loops can be monitored on the APU/ENVIRON THERM display (DISP 88), which is available in SM OPS 2 and 4. The information is found in the items under H2O LOOP.

2011/ /088	APU/ENVIRON THERM	4	000/02:36:51
FREON LOOP	1	27	000/00:00:00
ACCUM QTY	27	27	H2O LOOP
FREON FLOW	2193	2190	PUMP OUT P
PL HX FLOW	290	286	OUT T
AFT CP FLOW	279	278	P
RAD IN T	97	96	ICH FLOW
RAD OUT T	38	38	OUT T
EVAP OUT T	38	38	CAB HX IN T
EVAP TEMP	DUCT	NOZ	ACCUM QTY
HI LOAD INBD	259		APU FUEL T
OUTBD	259	312	TK SURF
TOPPING	FWD	257	TK HTR
	AFT	257	TEST LN 1
	L	162	50
	R	162	50
EVAP FDLN T	A		
	FWD	80	80
	MID 1	80	80
	MID 2	79	75
	AFT	75	79
	TOPPING	75	79
	ACCUM	75	79
	HI LOAD	75	79
			H2O LN INJ+
			71
			92
			+ 72

078

APU/ENVIRON THERM Display (DISP 88)



Crew Cabin Water Coolant Loops

Water Loop Pumps

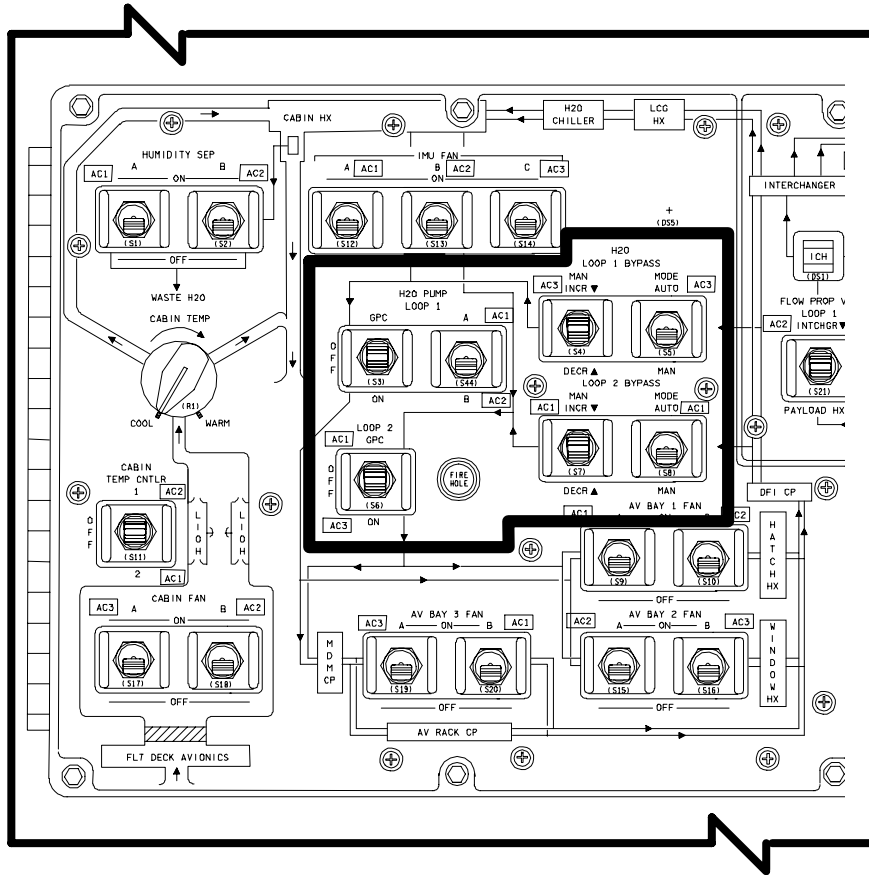
The water pumps in coolant loop 1 are controlled by the H_2O PUMP LOOP 1 A and B switch on panel L1 in conjunction with the H_2O PUMP LOOP 1 GPC, OFF, ON switch beside it. The GPC position enables the general-purpose computer to command the loop 1 pump, which is selected by the H_2O PUMP LOOP 1 A or B switch, to circulate water through water coolant loop 1. The ON position energizes the loop 1 pump. A ball-type check valve downstream of each water pump in loop 1 prevents reverse flow through the non-operating pump. The OFF position removes electrical power from both the A and B pumps of loop 1.

Water pump 2 is controlled by the H_2O PUMP LOOP 2 switch on panel L1. When the switch is positioned to GPC, water pump 2 is commanded by the GPC to circulate water through water coolant loop 2. The ON position energizes water pump 2 to circulate water through water coolant loop 2. The OFF position removes electrical power from water coolant loop 2 pump.

Water Loop Flow

Water loops 1 and 2 are routed side by side through the same areas. Downstream of each

water pump, water flow splits into three parallel paths. One is through the avionics bay 1 air/water heat exchanger and cold plates. A second is through the avionics bay 2 air/water heat exchanger and cold plates, payload bay floodlight cold plates, and thermal conditioning of the crew cabin windows. A third is through the crew cabin MDM flight deck cold plates, the avionics bay 3A air/water heat exchanger and cold plates, and the avionics bay 3B cold plates. The three parallel paths in each coolant loop then rejoin upstream of the Freon/water heat interchanger. The flow path splits again with one parallel path in each water coolant loop flowing through the Freon/water interchanger, where the water loop is cooled. The cooled water then flows through the liquid-cooled garment heat exchanger, potable water chiller, cabin heat exchanger, and IMU heat exchanger to the respective water coolant loop 1 and 2 pump package. The other parallel path in each water coolant loop, containing warm water, bypasses the interchanger and heat exchanger, rejoining the loop at the loop pump package. A valve installed in the bypass path controls the amount of bypass flow, thus controlling the mixed water temperature out of the pump package.



H₂O Loop Switches on Panel L1

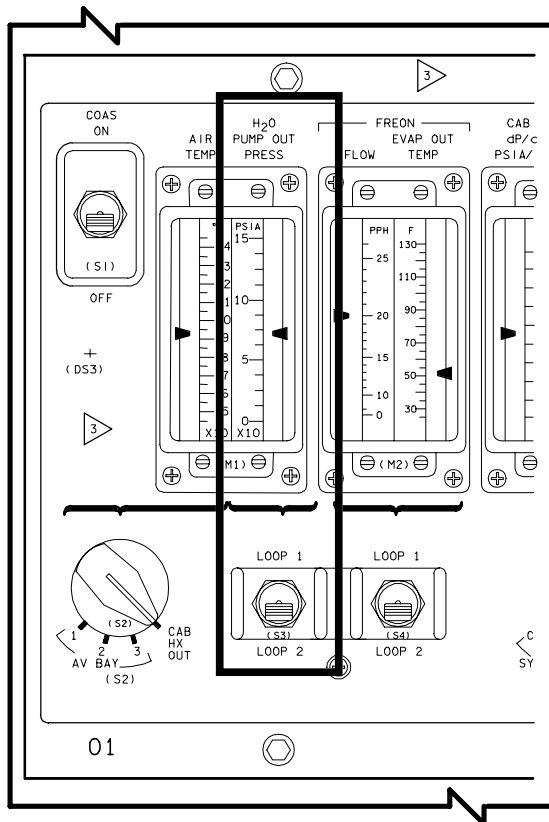
The bypass valve is controlled by bypass controllers. The bypass controller in each water coolant loop is enabled by corresponding H₂O LOOP 1 and 2 BYPASS MODE switches on panel L1. When the switch is positioned to AUTO, the water bypass controller and bypass valve automatically control the amount of water in the coolant loop that bypasses the Freon/water interchanger and heat exchangers. When the water pump's outlet temperature is 65.5° F, the loop's bypass valve is fully closed, and all the loop flow is directed to the Freon/water interchanger to provide maximum cooling.

When the bypass controller senses that the water pump's outlet temperature is 60.5° F, the controller bypasses a maximum amount of water around the Freon/water interchanger, reducing the heat rejection rate and increasing the water temperature out of the pump outlet. When the H₂O LOOP BYPASS MODE switch for the coolant loop is positioned to MAN, the flight

crew sets the corresponding H₂O LOOP MAN INCR/DECR switch on panel L1 to manually control the bypass valve in that water coolant loop.

The bypass valve is manually adjusted before launch to provide a flow of approximately 950 pounds per hour through the Freon/water interchanger, and the control system remains in the manual mode until post insertion. On orbit, the active water coolant loop's H₂O LOOP BYPASS MODE switch is set to AUTO and the bypass valve automatically controls the loop so that the water pump's outlet temperature remains at 63° F.

The accumulator in each water coolant loop provides a positive pressure on the corresponding water pump inlet and accommodates thermal expansion and dampens pressure surges in that water coolant loop when the pump is turned on or off. Each accumulator is pressurized with gaseous nitrogen at 19 to 35 psi.



H₂O PUMP OUT PRESS Meter and Switch on Panel O1 (The same transducer feeds SM DISP 88)

NOTE

For normal operations, only one water loop is active (usually loop 2). Running two water loops for long periods of time is undesirable. Two operating loops will flow too much water through the Freon/water interchanger and result in a significant increase in the cabin temperature. This occurs because two active water loops are capable of picking up more heat than the two Freon loops can carry away. Over time, the water loops will start to heat up, and cooling efficiency will decrease.

The pressure at the outlet of the water pump in each water coolant loop is monitored and transmitted to the H₂O PUMP OUT PRESS meter on panel O1. The appropriate loop is selected by the switch below the meter. When the switch is positioned to LOOP 1 or LOOP 2, the corresponding water coolant loop's pressure in psia is monitored on the meter.

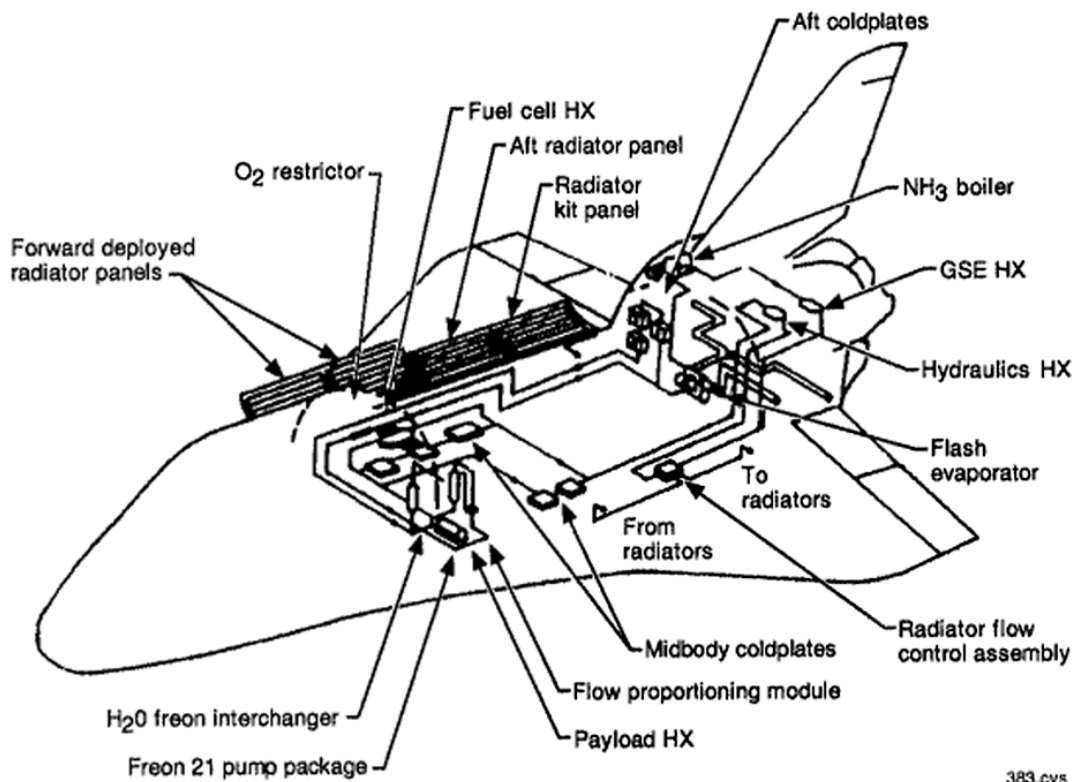
The yellow H₂O LOOP caution and warning light on panel F7 will be illuminated if the outlet pressure of the water coolant loop 1 pump is less than 19.5 psia or greater than 79.5 psia, or if the outlet pressure of the loop 2 pump is less than 45 psia or greater than 81 psia. The pump inlet and outlet pressure of each coolant loop are monitored and transmitted to the systems management GPC for CRT readout on the DISP 88 APU/ENVIRON THERM display (PUMP OUT P).

Active Thermal Control System

The active thermal control system provides orbiter heat rejection during all phases of the mission after solid rocket booster separation. The system consists of two complete, identical Freon coolant loops, cold plate networks for cooling avionics units, liquid/liquid heat exchangers, and three heat sinks: radiators, flash evaporators, and ammonia boilers.

Freon Loops

Two Freon coolant loops transport excess heat from the water/Freon interchanger, fuel cell heat exchanger, payload heat exchanger, and midbody and aft avionics electronic units. The Freon loops then deliver the heat to the heat sinks. Each loop has a pump package consisting of two pumps and an accumulator. The pump package is located in the midbody of the orbiter below the payload bay liner. One pump in each loop is active at all times. The metal bellows-type accumulator in each loop is pressurized with gaseous nitrogen to provide a positive pressure on the pumps and permit thermal expansion in that coolant loop. When the accumulator bellows is fully extended, approximately 80 lb of Freon is in the accumulator (normally only 20 to 30 percent of this amount is used). A ball check valve downstream of the pumps in each coolant loop prevents a reverse flow through the non-operating pump in the loops. The pumps in each coolant loop are controlled individually by the FREON PUMP switches on panel L1. When either switch is positioned to A or B, the corresponding Freon pump in that loop operates. The OFF position of each switch prohibits either Freon pump in that coolant loop from operating.



Active Thermal Control System Component Locations

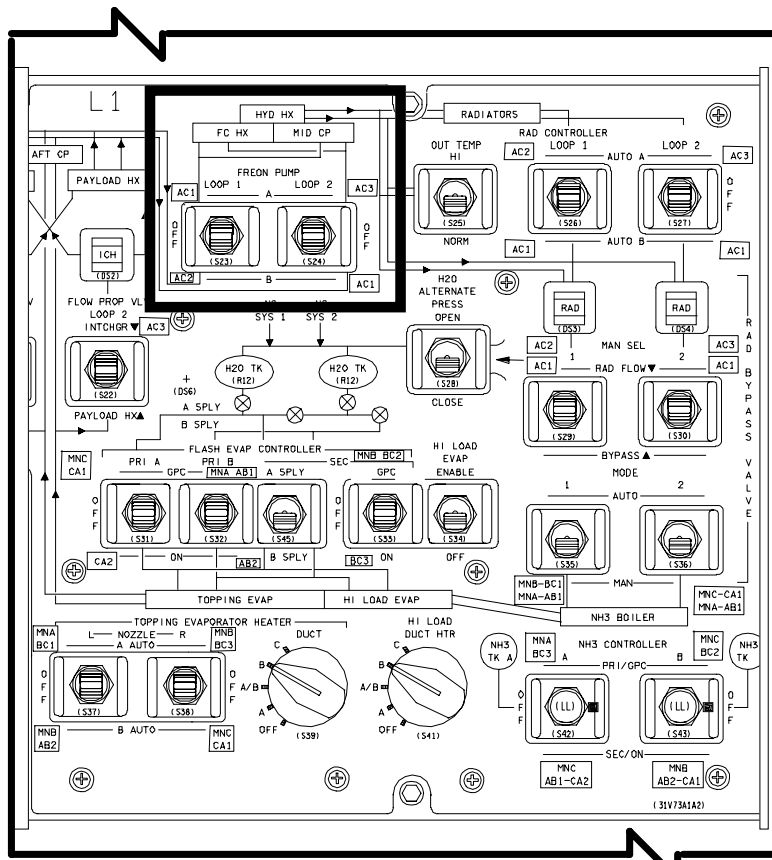
When a Freon pump is operating, Freon is routed in parallel paths through the fuel cell heat exchanger and the midbody cold plate network to cool electronic avionics units. The Freon coolant converges to one flow path before entering the hydraulics heat exchanger.

The Freon flows from the hydraulic fluid heat exchanger to the radiators, which are bypassed through a bypass valve during ascent and entry unless cold soak cooling from the radiators is being used. The warmest portion of the Freon loop is at the outlet of the hydraulic system heat exchanger.

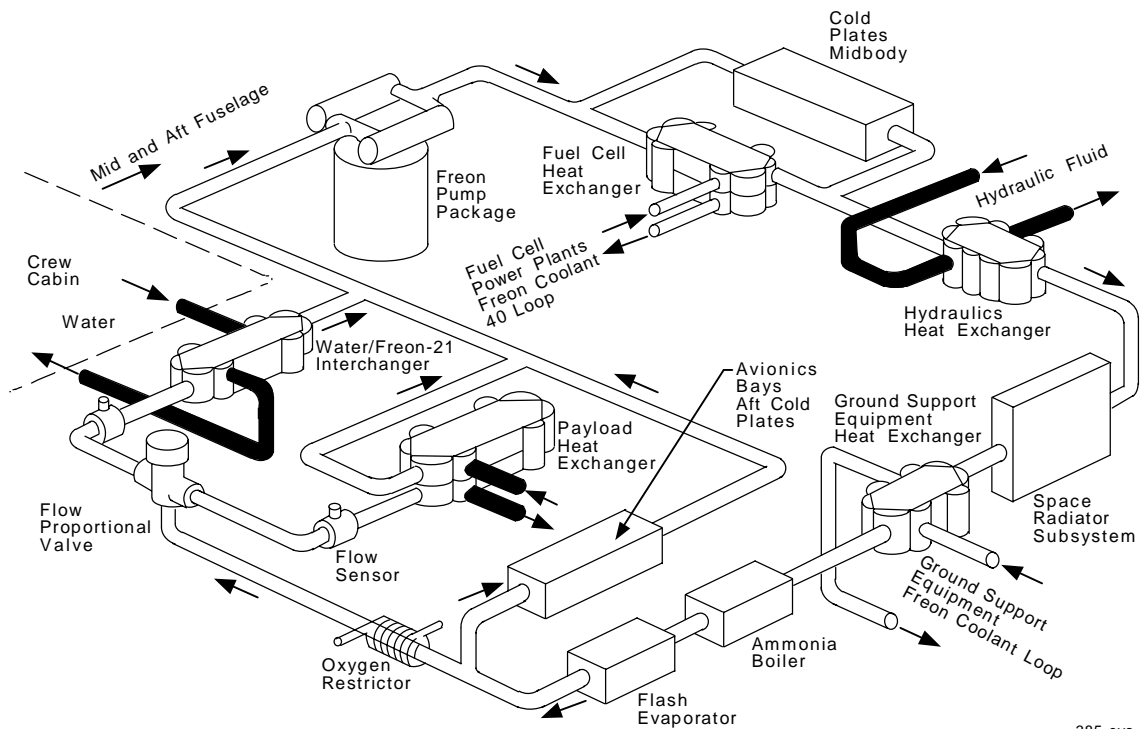
When the payload bay doors are opened on orbit, radiators located on the inside of the payload bay doors are used for heat rejection to space. The Freon coolant flows through the ground support equipment heat exchanger used for ground cooling, ammonia boilers, and flash evaporator located in the aft fuselage. It is then divided into two parallel paths. One path flows through the ECLSS oxygen restrictor to warm the cryogenic oxygen from the power reactant storage and distribution system for the ECLSS to

40° F. It then flows through a flow-proportioning valve module in the lower forward portion of the midfuselage into parallel paths to the payload heat exchanger and atmospheric revitalization system interchanger (both located in the lower forward portion of the midfuselage) and returns to a series flow. The second path flows through aft avionics bays 4, 5, and 6 to cool electronic avionics equipment in each avionics bay. It also flows through cold plates to cool four rate gyro assemblies and then returns to a series flow. The parallel paths return in series to the Freon coolant pump in that Freon coolant loop.

The FREON FLOW meter on panel O1 permits the crew to monitor the Freon flow to the Freon/water interchanger. The switch below the meter selects the loop to be monitored. Freon loop status can also be monitored under the FREON LOOP area on the APU/ENVIRON THERM display (DISP 88) and the BFS THERMAL display (FREON Loop 1, 2) in OPS 1. The yellow *FREON LOOP* caution and warning light on panel F7 will illuminate if Freon flow in either loop is less than 1200 pph.



FREON PUMP Switches on Panel L1



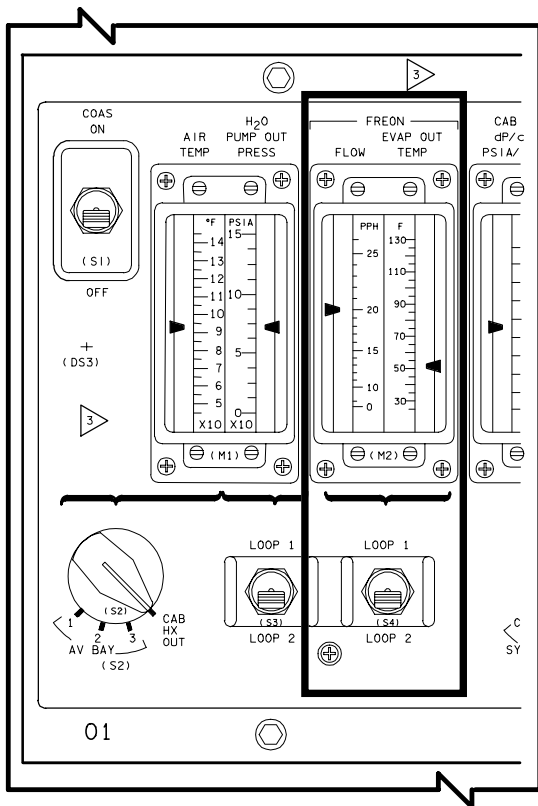
Freon Coolant Loop

Radiators

Radiators act as a heat sink for the coolant loops. The radiator system consists of four radiator panels attached to the inside of each payload bay door. The two forward radiator panels on each payload bay door are deployable when the doors are opened on orbit. The heat rejection requirements of the orbiter for a specific mission will determine if the forward radiators are to be deployed. The third and fourth radiator panels are fixed to the aft underside of the aft right and left payload bay doors and are not deployable.

The maximum heat rejection capability is 61,100 Btu per hour. When the payload bay doors are closed, the radiators are usually bypassed.

The radiator panels on the left and right sides are configured to flow in series, while flow within each panel is parallel through a bank of tubes connected by an inlet and outlet connector manifold. The radiator panels on the left side are connected in series with Freon coolant loop 1. The radiator panels on the right side are connected in series with Freon coolant loop 2.



FREON FLOW Meter and Switch on Panel O1

The radiator panels provide an effective heat dissipation area of 1,195 square feet on orbit. Each radiator panel is 10 feet wide and 15 feet long. The Freon tubing in the radiator panels is more than 1 mile long.

For ascent, the radiators are normally bypassed since the doors are closed. Radiator flow is established shortly before the doors are opened on orbit. During deorbit preparations, prior to closing the doors, the Freon in the radiators is "cold-soaked" by positioning the orbiter in a tail Sun attitude. This cold soak is saved for use as a heat sink during the latter stages of entry.

0001/ THERMAL		5 000/00:00:00	
		BFS 000/00:00:00	
HYD SYS TEMP	BDYFLP RD/SB	L OB	L IB R IB R OB
PRIME	+ 99 + 79	+ 76	+ 79 + 76 + 79
STBY 1	+ 89 + 79	+ 79	+ 79 + 79
BRAKE PRESS			
HYD SYS 1/3		92	92 92 92
2/3		92	92 92 92
HTR TEMP	L/A R/B	FREON LOOP	1 2
PRPLT		ACCUM QTY	34 34
POD		RAD OUT T	109 109
OMS CRSFD		H2O SUP P	0
EVAP		TIRE PRESS	
HI LOAD		MG LEFT	RIGHT
TOP DUCT		IB	429 420 418 418
NOZ		OB	421 421 416 416
FDLN		NG	397 397 381 381
		1	2 3
HYD BLR/HTR			
APU			
GG/FU PMP HTR	H	H	H
TK/FU LN HTR			
PUMP/VLV			

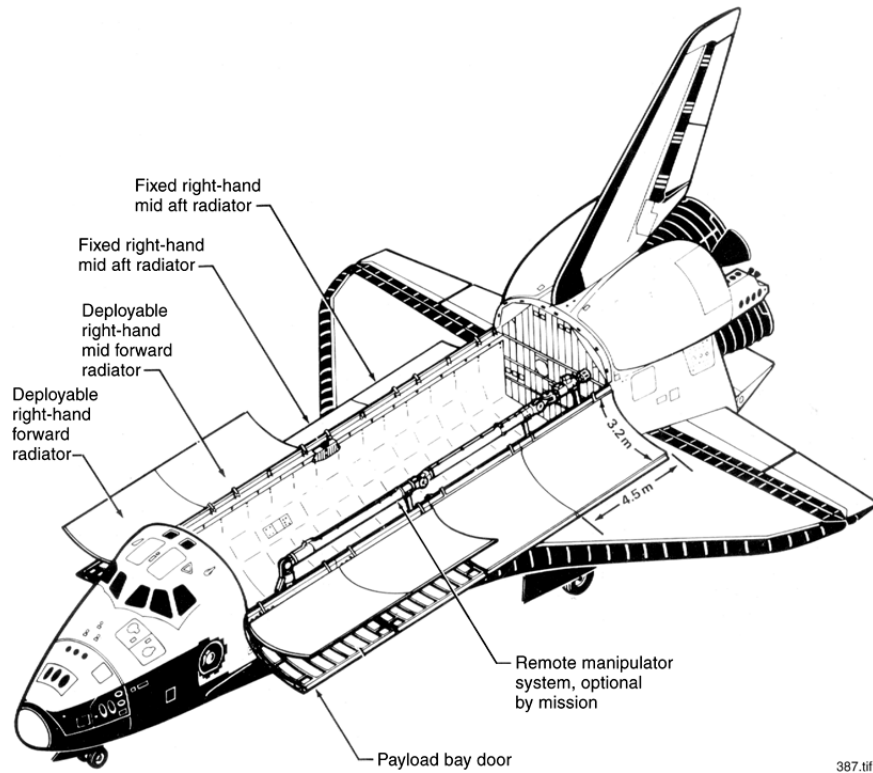
255

BFS THERMAL DISPLAY

Radiator Mounting and Construction

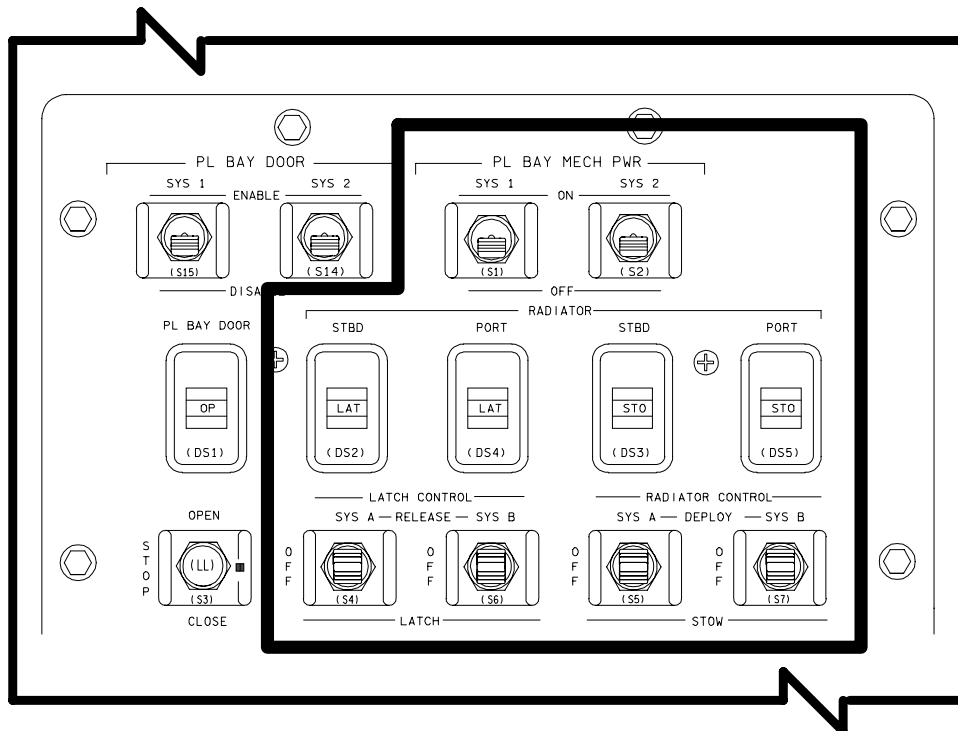
The deployable radiators are secured to the inside of the right and left payload bay doors by six motor-operated latches. When the payload bay doors are opened on orbit, and the mission dictates that the deployable radiators be deployed, the six motor-driven latches unlatch the radiators from the payload bay doors, and a motor-driven torque-tube-lever arrangement deploys the forward radiators at 35.5° from the payload bay doors. Deploying the forward radiators provides more surface area, and thus greater heat rejection.

The aft fixed radiator panels are attached to the payload bay doors by a ball joint arrangement at 12 locations to compensate for movement of the payload bay door and radiator panel caused by the thermal expansion and contraction of each member.



387.tif

Payload Bay Radiators



RADIATOR DEPLOY and STOW Switches and Talkbacks on Panel R13L

The radiator panels are constructed of an aluminum honeycomb face sheet 126 inches wide and 320 inches long. The forward deployable radiator panels are two-sided and have a core thickness of 0.9 of an inch. They have longitudinal tubes bonded to the internal side of both face sheets. Each of the forward deployable panels contains 68 tubes spaced 1.9 inches apart.

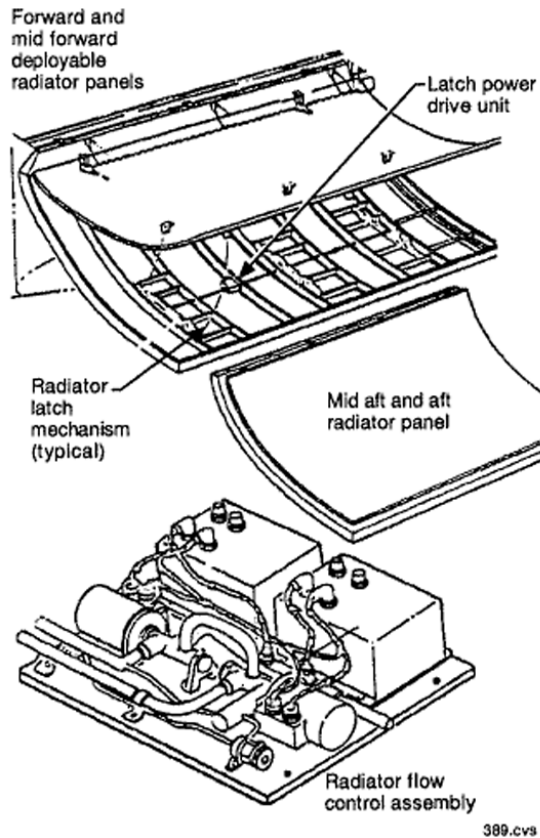
Each tube has an inside diameter of 0.131 of an inch. Each side of the forward deployable radiator panels has a coating bonded by an adhesive to the face sheet consisting of silver-backed Teflon tape for proper emissivity properties. The aft fixed panels are one-sided, and their cores are 0.5 inch thick. They have tubes only on the exposed side of the panel and a coating bonded by an adhesive to the exposed face sheet. The aft panels contain 26 longitudinal tubes spaced 4.96 inches apart. Each tube has an inside diameter of 0.18 inch. The additional thickness of the forward radiator panels is required to meet deflection requirements when the orbiter is exposed to ascent acceleration.

Radiator Deploy Systems

There are two radiator deploy systems, each of which drives one of two motors on each door. The systems drive the radiator panels away from the payload bay doors (deployed) or to the stowed position, using two reversible three-phase ac motors. It takes 40 seconds to deploy or stow the radiators.

The crew deploys and stows the radiators using switches on panel R13L. To deploy, the *PL BAY MECH PWR SYS 1* and *SYS 2* switches are positioned to *ON* to provide power to the panel switches. Both *RADIATOR LATCH CONTROL* switches are set concurrently to *RELEASE*; after 30 seconds, they are set to *OFF*. The *RADIATOR CONTROL* switches are then both concurrently set to *DEPLOY*; after 50 seconds, they are set to *OFF*. The *PL BAY MECH PWR* switches are then set to *OFF*.

To stow the radiators, the *PL BAY MECH PWR* switches are again positioned to *ON*. The *RADIATOR CONTROL* switches are both concurrently set to *STOW*, and after 50 seconds to *OFF*. The *LATCH CONTROL* switches are then positioned to *LATCH*, and after 30 seconds, to *OFF*. The *PL BAY MECH PWR* switches are then positioned to *OFF*.



Radiators and Radiator Flow Control Valve Assembly

Single Radiator Operations

It is possible to deploy either the port side or the starboard side radiator independently. This cannot be done directly with switches, because each controls motors on both sides. In order to deploy only one radiator, circuit breakers must be pulled to disable motors on one side. Single radiator operations may be done in case of a contingency situation, such as failure of one radiator or necessary Ku-Band antennae pointing, or a planned situation, such as flying in an attitude such that one door must remain partially closed to protect against debris strikes.

Radiator Flow Control

A radiator flow control valve assembly in each Freon coolant loop controls the temperature of that loop through the use of variable flow control, which mixes hot bypassed Freon coolant flow with the cold Freon coolant from the radiators. The radiator bypass valve allows Freon to either flow through the radiator or bypass the radiator completely.

In the automatic mode, the *RAD CONTROLLER LOOP 1* and *LOOP 2* switches on panel L1 are positioned to *AUTO A* or *AUTO B* to apply electrical power to the corresponding radiator flow controller assembly. The *RAD CONTROLLER MODE* switch is positioned to *AUTO*, and the *RAD CONTROLLER OUT TEMP* switch on panel L1 is positioned to *NORM* or *HI*.

With the *RAD CONTROLLER OUT TEMP* switch on panel L1 positioned to *NORM*, the radiator outlet temperature in Freon coolant loops 1 and 2 is automatically controlled at 38° F ($\pm 2^\circ$); in *HI*, the temperature is automatically controlled at 57° F ($\pm 2^\circ$).

NOTE

The flash evaporator is activated automatically when the radiator outlet temperature exceeds 41° F to supplement the radiators' ability to reject excess heat.

The talkback indicators below the *RAD CONTROLLER* switches on panel L1 indicate the position of the bypass valve in that Freon coolant loop. The indicators show *BYP* when the bypass valve in that Freon coolant loop is in the bypass position, barberpole when the motor-operated bypass valve is in transit, and *RAD* when the bypass valve is in the radiator flow position.

When the *RAD CONTROLLER MODE* switch on panel L1 is positioned to *MAN* for the Freon coolant loop selected, the automatic control of the radiator bypass valve in that loop is inhibited, and the flight crew controls the bypass valve manually using the *RAD CONTROLLER LOOP 1*, *LOOP 2*, *RAD FLOW BYPASS* switches on panel L1.

When the switch is positioned to *BYPASS*, the loop's motor-operated bypass valve permits that Freon coolant loop to bypass the radiators. When the switch is positioned to *RAD FLOW*, the valve permits coolant to flow through the radiators. The *RAD CONTROLLER LOOP 1* and *2* talkback indicators for the Freon coolant loop indicate *BYP* when the bypass valve in that loop is in bypass, and barberpole when it is in transit.

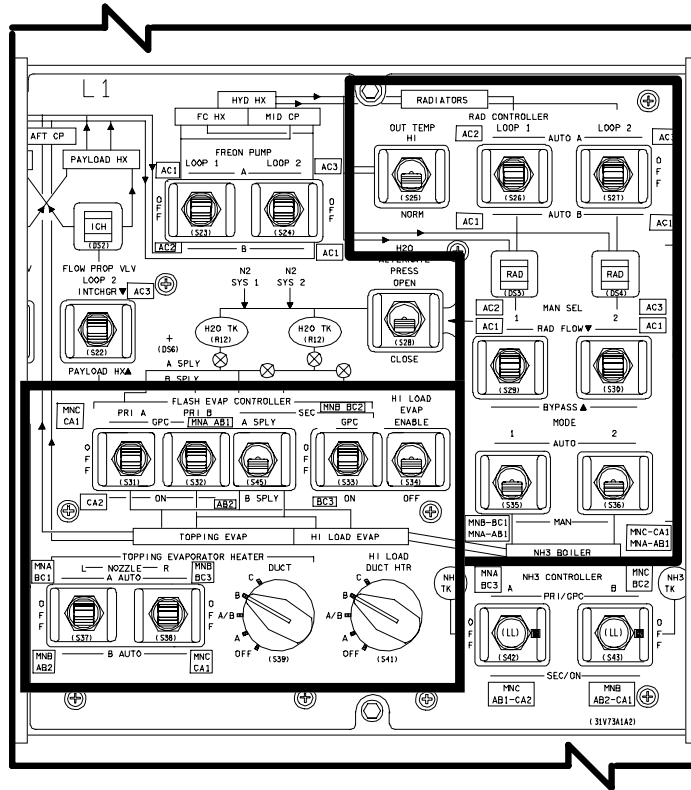
NOTE

The flow control valve cannot be controlled manually; it can only be controlled automatically using the controller. The bypass valve, however, can be operated manually or automatically.

Flash Evaporator System

The flash evaporators reject heat loads from Freon coolant loops 1 and 2 by evaporating supply water in a vacuum. The flash evaporators are used during ascent above 140,000 feet, and they supplement the radiators on orbit if required. They also reject heat loads during deorbit and entry to an altitude of approximately 100,000 feet.

The flash evaporators are located in the aft fuselage of the orbiter. There are two evaporators, a high-load evaporator and a topping evaporator. Two major differences are that the high-load evaporator has a higher cooling capacity and only one overboard vent on the left side of the vehicle. The topping evaporator vents steam equally to the left and right sides of the orbiter, which is non-propulsive. The evaporators are cylindrical shells with dual water spray nozzles at one end and a steam exhaust duct at the other end. The shell is composed of two separate finned packages, one for each Freon loop. The hot Freon from the coolant loops flows around the finned shell, and water is sprayed onto the shell by water nozzles from either evaporator. The water vaporizes, cooling the Freon coolant loops. In the low-pressure atmosphere above 100,000 feet, water vaporizes quickly. Changing water liquid to vapor removes approximately 1,000 Btu per hour per pound of water. The water for the evaporators is obtained from the potable water storage tanks through water supply systems A and B.



RAD CONTROLLER SWITCHES AND Talkbacks and FLASH EVAP CONTROLLER Switches on Panel L1

Flash Evaporator Controllers

The flash evaporators have three controllers: primary A, primary B, and secondary. The primary A and B controllers have two separate, functionally redundant shutdown logic paths (undertemperature and rate of cooling). Secondary has no shutdown. The flash evaporator controllers are enabled by the *FLASH EVAP CONTROLLER* switches on panel L1. The *PRI A* switch controls primary controller A, the *PRI B* switch controls primary controller B, and the *SEC* switch controls the secondary controller.

When the *PRI A*, *PRI B*, or *SEC* switch is positioned to *GPC*, the corresponding controller is turned on automatically during ascent by the BFS computer as the orbiter ascends above 140,000 feet. During entry, the BFS computer turns the corresponding controller off as the orbiter descends to 100,000 feet. The *ON* position of the switch provides electrical power directly to the corresponding flash evaporator controller. The *OFF* position of the switch removes all electrical power and inhibits flash evaporator operation.

The primary A controller controls water flow to the flash evaporator from water supply system A through water feed line A. The primary B controller controls water flow to the flash evaporator from water supply system B through water feed line B.

NOTE

When a primary controller is enabled, both evaporators can be used simultaneously.

The secondary controller controls water flow to the high load flash evaporator from water supply system A through feed line A if the *FLASH EVAP CONTROLLER SEC* switch on panel L1 is in the *A SPLY* position, and if the *HI LOAD EVAP* switch is in the *ENABLE* position. If the switch is in the *B SPLY* position, and the *HI LOAD EVAP* switch is in the *ENABLE* position, the secondary controller controls water flow to the flash evaporator from water supply system B through feed line B. When the secondary controller is used, and the *HI LOAD EVAP* switch is *OFF*, both the A and B water supply systems will feed the topping evaporator

in an alternate pulsing fashion. When the secondary controller is used, and the *HI LOAD EVAP* switch is in the *ENABLE* position, the topping evaporator is disabled.

The primary A and B controllers modulate the water spray in the evaporator to keep the Freon coolant loops' evaporator outlet temperature stable at 39° F. The secondary controller modulates the water spray in the evaporator to control the Freon coolant loops' evaporator outlet temperature at 62° F. The temperature sensors are located at the outlets of both evaporators.

The applicable flash evaporator controller pulses water into the evaporators, cooling the Freon. The steam generated in the topping evaporator is ejected through two sonic nozzles at opposing sides of the orbiter aft fuselage to reduce payload water vapor pollutants on orbit and to minimize venting thrust effects on the orbiter's guidance, navigation, and control system.

The high-load evaporator is used in conjunction with the topping evaporator during ascent and entry when higher Freon coolant loop temperatures impose a greater heat load that requires a higher heat rejection. The *HI LOAD EVAP* switch on panel L1 must be in the *ENABLE* position for high-load evaporator operation. After leaving the high-load evaporator, Freon flows through the topping evaporator for additional cooling. The steam generated by the high-load evaporator is ejected through a single sonic nozzle on the left side of the orbiter aft fuselage. The high-load evaporator would not normally be used on orbit because it has a propulsive vent and might pollute a payload.

NOTE

Norm jets are required to control vehicle attitude when the FES high load is used on orbit.

FES Auto Shutdown

Each primary controller has an automatic shutdown capability to protect the evaporator from over- or undertemperature conditions. The evaporator's outlet temperature is monitored to determine whether a thermal

shutdown of the evaporator is warranted. If the evaporator outlet temperature goes below 37° F for 20 seconds or more, an undertemperature shutdown of the evaporator occurs. If the evaporator outlet temperature is greater than 41° F for 55 seconds, an overtemperature shutdown of the evaporator occurs. If the evaporator is shut down, electrical power to the affected controller must be recycled to reenable operations.

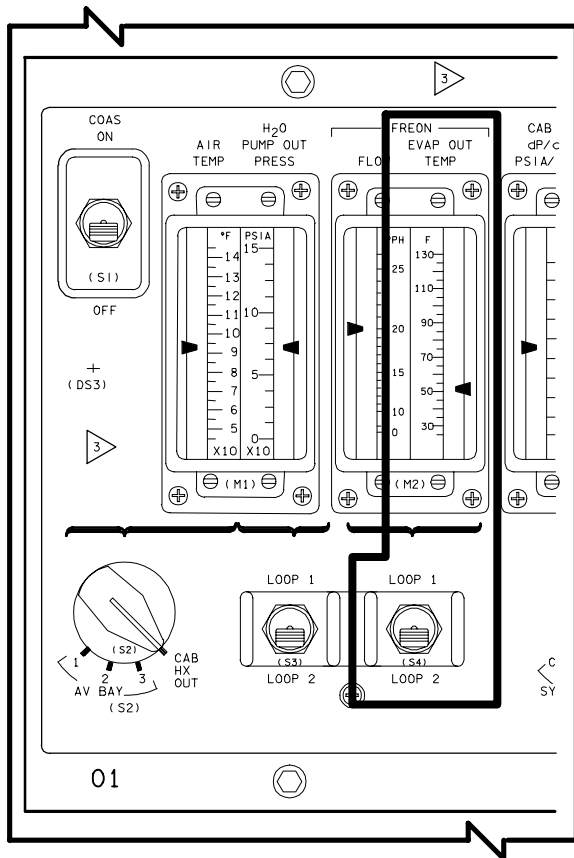
Temperature Monitoring

The evaporator outlet temperature of Freon coolant loops 1 and 2 is transmitted to panel O1. When the switch below the FREON meter on panel O1 is positioned to *LOOP 1* or *LOOP 2*, the evaporator outlet temperature of Freon coolant loops 1 or 2 can be monitored in degrees Fahrenheit on the FREON EVAP OUT TEMP meter or on the DISP 79 SM SYS SUMM 2 display (EVAP OUT T). If the outlet temperature drops below 32.2° F or rises above 64.8° F, the red *FREON LOOP* caution and warning light on panel F7 will be illuminated. (The upper limit for ascent is 115° F.)

FES Heaters

Electrical heaters are employed on the topping and high-load flash evaporators' steam ducts to prevent freezing. The *HI LOAD DUCT HTR* rotary switch on panel L1 selects the electrical heaters. Switch positions *A* and *B* provide electrical power to the corresponding thermostatically controlled heaters on the high-load evaporator steam duct and steam duct exhaust. The *A/B* position provides electrical power to both thermostatically controlled heaters. The *C* position provides electrical power to both thermostatically controlled C heaters. The *OFF* position removes electrical power from all the heaters.

The *TOPPING EVAPORATOR HEATER DUCT* rotary switch on panel L1 selects the thermostatically controlled electrical heaters on the topping evaporator. Positions *A* and *B* provide electrical power to the corresponding heaters, while *A/B* provides electrical power to both A and B heaters. The *C* position provides power to the C heaters and part of the B heaters. The *OFF* position removes electrical power from all the heaters.



FREON EVAP OUT TEMP Meter and Switch on Panel O1

0001/ /079		SM SYS SUMM 2				5 008/23:29:22		
CRYO TK	1	2	3	4	5	BFS 000/00:00:00		
H2 PRESS	208	208	206	206	206	208	207	MANF1 MANF2
O2 PRESS	816	815	814	814	814	814	815	815
HTR T1	-248	-248	-248	-248	-248	-248	-248	-248
HTR T2	-248	-248	-248	-248	-248	-248	-248	-248
APU	1	2	3	HYD	1	2	3	
TEMP EGT	942	942	942	PRESS	3064	3064	3064	
B/U EGT	942	942	942	ACUM P	3080	3080	3080	
OIL IN	250	250	250	RSVR T	116	153	142	
OUT	264	264	264	QTY	72	74	71	
GG BED	511H	511H	511H					
INJ	1271	1271	1271	W/B				
SPEED %	99	102	101	H2O QTY	78	73	78	
FUEL QTY	59	60	62	BYP VLV	BYP	BYP	BYP	
PMP LK P	14	14	14					
OIL OUT P	42	42	41					
FU TK VLV								
A T	63	65	62	THERM CNTL	1	28		
B T	63	65	62	H2O PUMP P	23	63		
AV BAY	1	2	3	FREON FLOW	2384	2384		
TEMP	97	97	83	EVAP OUT T	38	38		
A4 14	27.439	27.435			26.324	31.873	18.48	

The SM SYS SUMM 2 display is an SM display (DISP 79) available in the BFS and in PASS SM OPS 2 and 4

The topping evaporator's left and right nozzle heaters are controlled by the *TOPPING EVAPORATOR HEATER L(R) NOZZLE* switches on panel L1. When the switches are positioned to *A AUTO* or *B AUTO*, electrical power is provided to the corresponding left and

right nozzle heaters, and the corresponding nozzle temperature is maintained between 40° and 70° F. The *OFF* position removes electrical power from both heater systems.

FES Water Dumps

The flash evaporator topping evaporator can be used to dump excess water from the supply water storage tanks, if required, on orbit. When the *RAD CONTROLLER OUT TEMP* switch on panel L1 is placed in *HI*, the radiator flow control valve assembly controls that radiator outlet at 57° F. Since the topping evaporator controls to 39° F, water is used up at a rate of about 25 lb/hr, thus dumping excess water.

Ammonia Boilers

The ammonia boiler system acts as a heat sink by using the low boiling point of ammonia to cool the Freon coolant loops when the orbiter is below 400,000 feet during entry or on the ground after landing. The resultant superheated vapor is vented overboard. Two complete, individual ammonia storage and control systems feed one common boiler containing ammonia passages and the individual Freon coolant loops 1 and 2. Each system consists of a storage tank, an isolation valve, an overboard relief valve, two control valves, a controller, three temperature sensors, a pressure sensor and a feedline to the boiler.

The ammonia boiler is a shell-and-tube system with a single pass of ammonia on the ammonia side and two passes of each Freon coolant loop through the boiler. The ammonia flows in the ammonia tubes and the Freon coolant loop flows over the tubes, cooling the Freon coolant loops. When the ammonia flows over the warm Freon coolant lines in the boiler, it immediately vaporizes, and the heat and boiler exhaust are vented overboard in the upper aft fuselage of the orbiter next to the bottom right side of the vertical tail.

The ammonia system is normally used during entry if the radiators have not been cold-soaked. If radiator cooling is used during entry, the ammonia system is activated post-landing when radiator outlet temperatures reach 55° F. The ammonia boiler operations are used post-landing until a ground cooling cart is connected to the ground support equipment heat exchanger.

Storage Tanks

Each ammonia boiler storage tank contains a total of 49 pounds of ammonia (approximately 30 minutes of cooling), all of which is usable. Each tank is pressurized with gaseous helium at a maximum operating pressure of 550 psia. Downstream of each ammonia storage tank to the common boiler are three control valves: a normally closed isolation valve, a normally open secondary control valve, and a normally open primary control valve. A relief valve in each ammonia boiler storage system provides overpressurization protection of that ammonia storage tank.

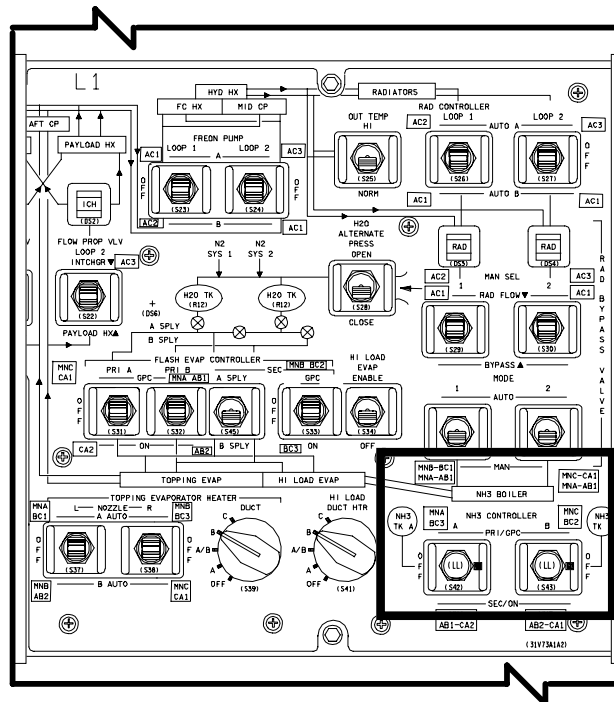
Primary Ammonia Boiler Controller

The primary controller in the ammonia system energizes the ammonia system isolation valve, permitting ammonia to flow to two motor-operated controller valves. The controller also commands the primary motor-operated valve to regulate the flow to the ammonia boiler. Ammonia boiler supply systems A and B are enabled by the corresponding NH_3 CONTROLLER switches on panel L1. If required, one of the switches (usually B) is positioned to PRI/GPC before entry, which enables the GPC to control electrical power to the primary and secondary

controllers within the ammonia controllers. When the orbiter descends through 120,000 feet, the backup flight system computer commands the selected ammonia system controller on.

Ammonia Boiler Control Sensors

Three temperature sensors are located on each Freon coolant loop. One sensor is associated with the primary controller and its motor-operated valve to regulate ammonia system A flow to maintain Freon coolant loop 1 and 2 temperatures at the outlet of the ammonia boiler at $35^\circ F, \pm 3^\circ F$. A second sensor is associated with the ammonia system A controller fault detection logic. If the Freon coolant loop 1 temperature drops below $31.25^\circ F$ for longer than 10 seconds, the fault detection logic automatically inhibits the primary controller, which removes power from the ammonia system A isolation valve and the primary control valve. The logic switches to the secondary controller in the ammonia system A controller, which energizes a redundant coil in the ammonia system supply A isolation valve and closes the secondary control valve. It commands the isolation valve to full open and allows the secondary controller to control the secondary control valve to regulate the ammonia A flow to the ammonia boiler.



NH_3 CONTROLLER Switches on Panel L1

The third sensor is associated with the secondary controller and secondary motor-operated valve. It regulates ammonia supply system A flow to maintain the Freon coolant loop 1 and 2 temperatures at the outlet of the ammonia boiler at 34° F. This automatic switchover is only from the primary to the secondary.

Secondary Controller

When the NH_3 CONTROLLER A or B switch on panel L1 is positioned to SEC/ON, the A or B ammonia system controller is electrically powered and enabled directly (no computer command is required). The secondary controller in the ammonia system controller energizes the system's isolation valve open, permitting ammonia to flow to two motor-operated controller valves. The secondary controller commands the primary controller's motor-operated valve to the open position and the secondary controller's motor-operated valve to regulate the ammonia flow to the ammonia boiler. The three temperature sensors on each Freon coolant loop operate and control Freon coolant loop 1 and 2 temperature in the same manner as in the PRI/GPC mode. Fault detection logic does not exist in the secondary controller.

The OFF position of the NH_3 CONTROLLER switches removes all electrical power from the ammonia system controller, rendering the ammonia system inoperative.

Supply and Wastewater Systems

The supply water system provides water for flash evaporator system cooling, crew consumption, and hygiene. The supply water system stores water generated by the fuel cells, and the wastewater system stores waste from the crew cabin humidity separator and from the flight crew. Four supply water tanks and one wastewater tank are located beneath the crew compartment middeck floor.

Data on the supply and wastewater system can be monitored on the ENVIRONMENT display (DISP 66) under H₂O SUPPLY and WASTE items and on the BFS THERMAL display (H₂O SUP P).

Supply Water System

The supply water system consists of four water tanks that are pressurized with nitrogen from

the pressure control system. Each of the four potable water tanks has a usable capacity of 168 pounds, is 35.5 inches in length and 15.5 inches in diameter, and weighs 39.5 pounds dry.

The three fuel cells generate a maximum of 25 pounds of potable water per hour (about 0.81 pound of water per kilowatt hour). The product water from all three fuel cells flows to a single water relief control panel. The water can be directed to potable water tank A or to the fuel cell water relief nozzle. Normally, the water is directed to water tank A.

The product water lines from all three fuel cells were modified to incorporate a parallel (redundant) path of product water to potable water tank B in the event of a blockage of the primary water path to the tanks. If such a blockage were to occur, pressure would build up and relieve through the redundant paths to potable water tank B.

Instrumentation

Temperature sensors are installed on each of the redundant paths; in addition, a pressure sensor is transmitted to telemetry and can be monitored on the BFS THERMAL display. A pH sensor is located at the common product water outlet of the water relief panel. It provides a redundant measurement of fuel cell health and water purity. A single measurement of water purity in each fuel cell is also provided. If a single fuel cell pH sensor indicated high, the flight crew would be required to sample the potable water to verify the proper pH.

Hydrogen Separators

The hydrogen-enriched water from the fuel cells flows through the single water relief panel through two hydrogen separators to potable water tank A. The separator removes 85 percent of the excess hydrogen. The hydrogen separators consist of a matrix of silver palladium tubes, which have an affinity for hydrogen. The hydrogen is dumped overboard through a vacuum vent. The redundant water line to tank B does not pass through the hydrogen separator. Water passing through the hydrogen separators can be stored in all four potable water tanks: A, B, C, and D.

2011/ /066 ENVIRONMENT 4 000/02:33:38 000/00:00:00			
CABIN		AV BAY 1 2 3	
dP/dT +.01	CABIN P 14.7	TEMP	90 90 78
PP02	AIRLK P 14.8	FAN ΔP	3.80 3.77 3.92
A 3.04	FAN ΔP 5.55	SUPPLY H2O	
B 3.04	HX OUT T 45L	QTY A 67	PRESS 32
C 3.04	CABIN T 71	B 18	DMP LN T 77
PPC02 1.9		C 94	NOZ T A 64
		D 94	B 64
O2 FLOW 0.0L 0.0L		WASTE H2O	
REG P 100	100	QTY 1 15	PRESS 17
N2 FLOW 0.0L 0.0L			DMP LN T 58
REG P 202	202		NOZ T A 82
O2/N2 CNTL VLV N2 02			B 82
H2O TK N2 P 17	17	VAC VT NOZ T 224	
N2 QTY 131	131	CO2 CNTLR 1 2	
EMER O2 QTY 1		FILTER P	0.00L
REG P 4L		PPC02	- 0.0L
		TEMP	32.0L
		BED A PRESS	0.0L 0.0L
		B PRESS	0.0L 0.0L
		ΔP	0.00L 0.00L
		VAC PRESS	0.0L
IMU FAN *	4.5		
HUMID SEP *			

H₂O System Parameters on the ENVIRONMENT Display (DISP 66)

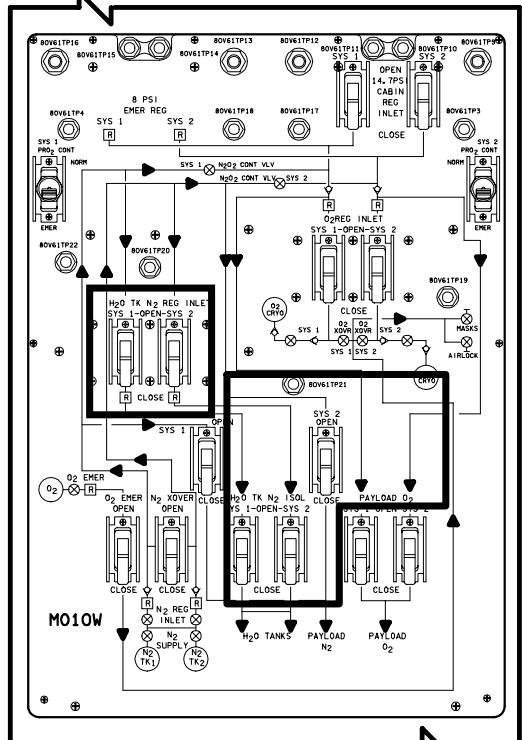
0001/ THERMAL 5 000/00:00:00 BFS 000/00:00:00			
HYD SYS TEMP	BDYFLP RD/SB	L OB	L IB R IB R OB
PRIME	+ 99 + 79 + 76 + 79 + 76 + 79		
STBY 1	+ 89 + 79 + 79 + 79 + 79 + 79		
BRAKE PRESS			
HYD SYS 1/3	92	92	92 92
2/3	92	92	92 92
HTR TEMP	L/A R/B	FREON LOOP 1 2	
PRPLT		ACCUM QTY 34 34	
POD		RAD OUT T 109 109	
OMS CRSFD		H2O SUP P 0	
EVAP			
HI LOAD		TIRE PRESS	
TOP DUCT		MG LEFT RIGHT	
NOZ		IB 429 420 418 418	
FDLN		OB 421 421 416 416	
		NG 397 397 381 381	
HYD BLR/HTR	1 2 3		
APU			
GG/FU PMP HTR	H H H		
TK/FU LN HTR			
PUMP/VLV			

BFS THERMAL Display

Microbial Filter

The water entering tank A, which is sterilized before launch, passes through a microbial filter that adds approximately one-half parts per million iodine to the water to prevent microbial growth. The water stored in tank A is normally used for flight crew consumption; tanks B, C, and D are used for flash evaporator cooling. The water from the microbial check valve is also directed to a galley supply valve. If the water tank A inlet valve is closed, or tank A is full, water is directed to tank B through a 1.5 psid check valve where it branches off to tank B. If the tank B inlet valve is closed, or tank B is full of water, the water is directed through another 1.5 psid check valve to the inlets to tanks C and D.

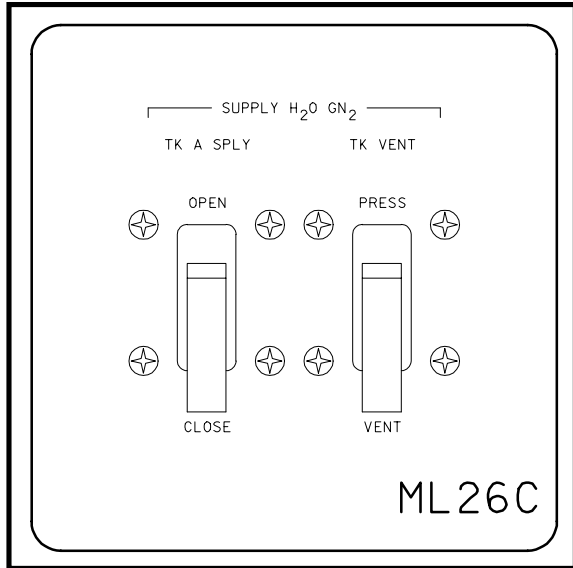
Each potable water tank has an inlet and outlet valve that can be opened or closed selectively to use water; however, the tank A outlet valve normally remains closed to isolate the treated water from the untreated water in the other tank.



Nitrogen Supply System Valves on Panel MO10W

Tank Pressurization

Each potable water and wastewater tank is pressurized with gaseous nitrogen from the crew compartment nitrogen supply system. The nitrogen and water are separated by a metal bellows. Nitrogen supply systems 1 and 2 can be used individually to pressurize the water tanks with nitrogen at 15.5 to 17.0 psig. Nitrogen supply system 1 is controlled by the H₂O TK N₂ REG INLET and H₂O TK N₂ ISOL SYS 1 manual valves on panel MO10W. Nitrogen supply system 2 is controlled by the SYS 2 manual valves on panel MO10W. The regulator in each nitrogen supply system controls the nitrogen pressure to the tanks at 15.5 to 17 psig, and a relief valve in each nitrogen supply system will relieve into the crew cabin if the nitrogen supply increases to 18.5 ± 1.5 psig, to protect the tanks from overpressurization.



Manual Valves on Panel ML26C

Tank Depressurization

All the tanks can be vented to cabin pressure, but tank A is normally depressed for ascents, as described here. For only tank A, inlet nitrogen pressure is controlled by the *SPLY H₂O GN₂ TK A SPLY* and *TK VENT* manual valves on panel ML26C. When the tank A supply valve is closed, the tank is isolated from the nitrogen supply. When the tank A valve is opened, the tank is pressurized by the crew cabin atmosphere. For launch, the tank A supply valve is closed, and the tank vent is opened, which lowers tank A pressure. The fuel cell water head pressure is lower to help prevent flooding of the fuel cells during ascent. On orbit, the tank A supply valve is opened, and the tank A vent to the cabin is closed, allowing nitrogen supply pressure to tank A.

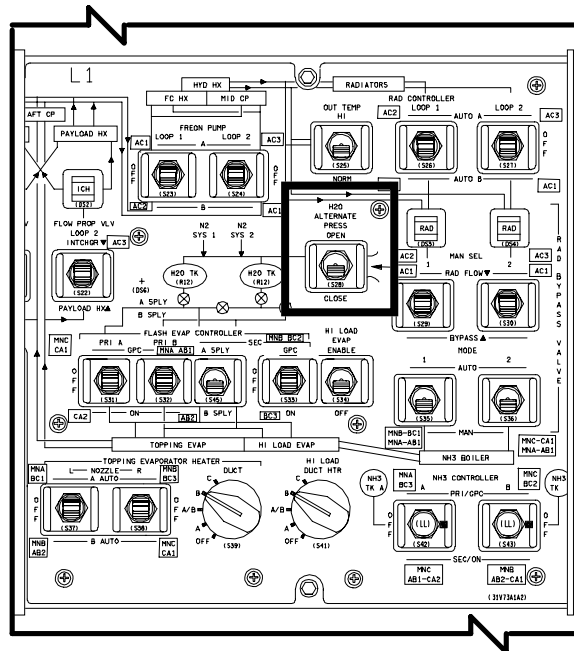
Alternate Water Pressurization

If neither nitrogen supply system 1 nor 2 can be used to pressurize the water tanks, the *H₂O ALTERNATE PRESS* switch on panel L1 can be positioned to *OPEN*, which would apply the crew cabin pressure to the water tanks.

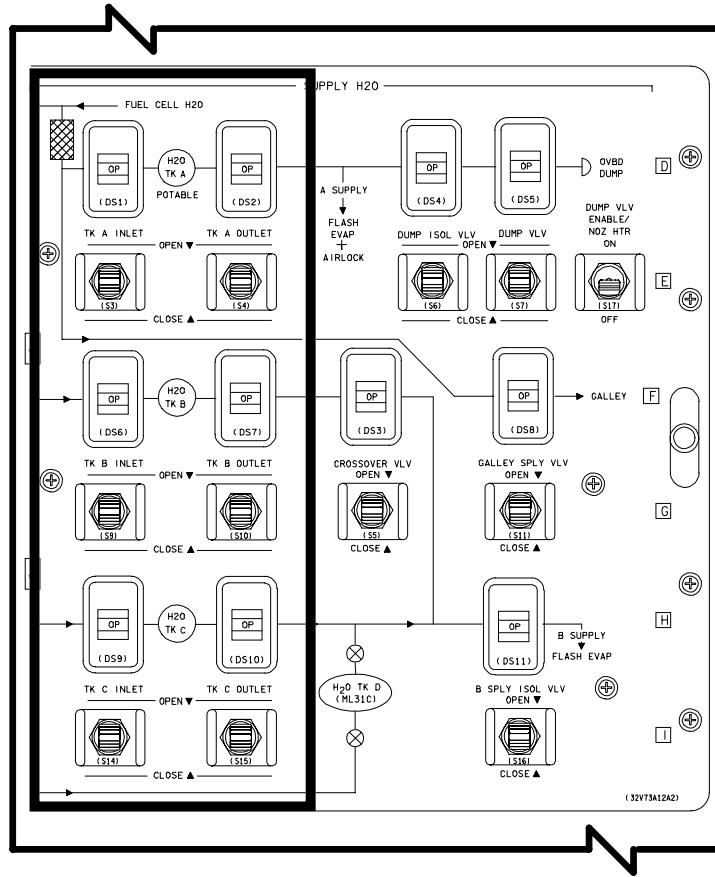
Normally, this switch is positioned to *CLOSE* to isolate the cabin pressurization system from the water tank pressurization system.

Supply Water Tank Inlet Valves

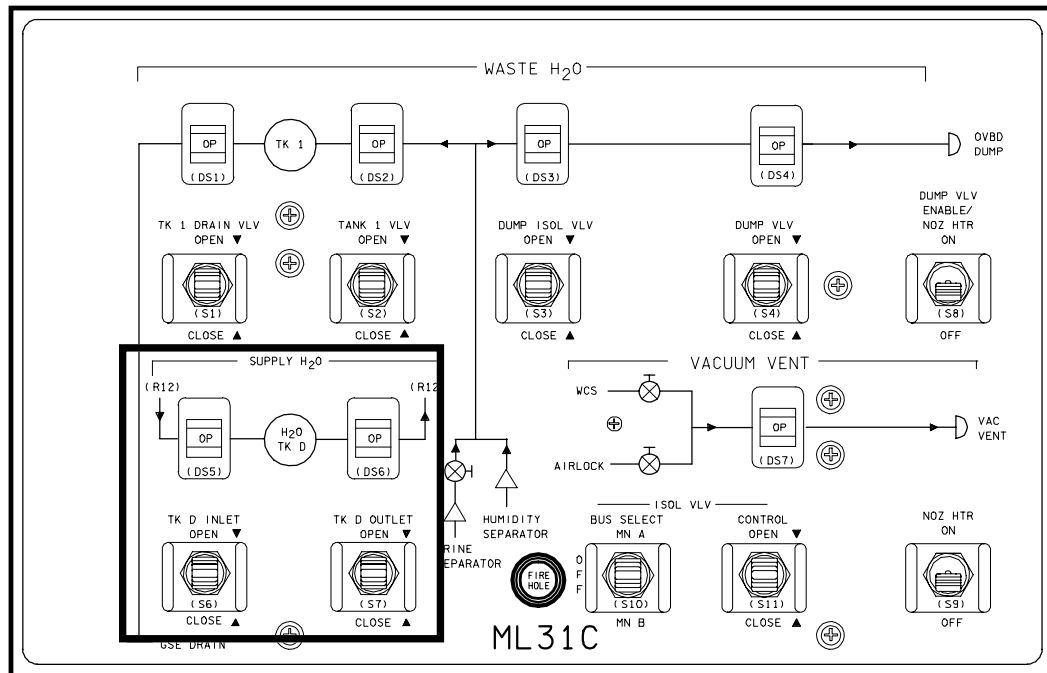
Potable water tank A, B, and C valves are controlled from panel R11L, and tank D valves are controlled from panel ML31C. When the *SUPPLY H₂O TK A INLET*, *TK B INLET*, or *TK C INLET* switch on panel R11L is positioned to *OPEN*, the inlet valve for the tank permits water into that tank. A talkback indicator above the corresponding switch indicates *OP* when the corresponding valve is open, barberpole when the valve is in transit, and *CL* when that valve is closed. When the switch is positioned to *CLOSE*, the water inlet to that tank is isolated from the inlet water supply. The *SUPPLY H₂O TK D INLET* switch and talkback indicator are located on panel ML31C and operate in the same manner as the switches and talkbacks for tanks A, B, and C.



H₂O ALTERNATE PRESS Switch on Panel L1



TKT and OUTLET Switches and Talkbacks on Panel R11L



TK INLET and OUTLET Switches and Talkbacks on Panel ML31C

Tank Outlet Valves

Positioning the *SUPPLY H2O TK A, B, or C OUTLET* switch on panel R11L to *OPEN* permits water from the corresponding tank to flow from the tank into the water outlet manifold due to the tank nitrogen pressurization system. A talkback indicator above the switch would indicate *OP* when that valve is open, barberpole when it is in transit, and *CL* when it is closed. The *CLOSE* position of each switch isolates that water tank from the water outlet manifold. The *SUPPLY H2O TK D OUTLET* switch and talkback indicator are located on panel ML31C and operate in the same manner as the tank A, B, and C switches and talkback indicators on panel R11L.

If the potable water tank B outlet valve is opened (normally tank A is used only for crew consumption), water from the corresponding tank is directed to the water outlet manifold. The tank A and B water is then available to the extravehicular mobility unit fill in the airlock, to the flash evaporator water supply system A, and to the water dump. The tank A outlet valve is normally closed to prevent contamination of the water in tank A. Thus, tank B would supply water to flash evaporator water supply system A and to the EMU fill in the airlock. If it is necessary to provide space for storing water in tank A and/or B, tank A and/or B water can be dumped overboard.

An external airlock water transfer valve and line will be installed on the orbiters with docking capability. The valve and line will provide capability to transfer water from the orbiter's supply H₂O system to Mir or the space station. This configuration is covered in more detail in the ODS section of this document

Tank C or D is normally saved full of water for contingency purposes. If the tank C or D outlet valve is opened, water from either tank is directed to the water outlet manifold. The water is then available to the flash evaporator B water supply.

Supply Water Crossover Valves

A crossover valve installed in the water outlet manifold is controlled by the *SUPPLY H2O CROSSOVER VLV* switch on panel R11L. When the switch is positioned to *OPEN*, the crossover valve opens and allows tank A or B (also C or D) to supply flash evaporator water supply

systems A and B, the EMU fill in the airlock, and water dump. A talkback indicator above the switch indicates *OP* when the crossover valve is opened, barberpole when the valve is in transit, and *CL* when the valve is closed. The *CLOSE* position isolates the water manifold between the tank A and B outlets and the tank C and D outlets.

Supply Isolation Valve

Water from supply system A is routed directly to the flash evaporator. Water from system B is routed to an isolation valve in the system. The valve is controlled by the *SUPPLY H2O B SPLY ISOL VLV* switch on panel R11L. When the switch is positioned to *OPEN*, water from supply system B is directed to the flash evaporator. A talkback above the switch indicates *OP* when the valve is opened, barberpole when it is in transit, and *CL* when the valve is closed. The *CLOSE* position isolates water supply system B from the flash evaporator.

Supply Water Dumps

Potable water from all the tanks can be dumped overboard, if necessary, through a dump isolation valve and a dump valve. Potable water from tank C or D can also be dumped overboard, if necessary, through the crossover valve and through the dump isolation valve and dump valve. The overboard dump isolation valve is located in the crew cabin, and the dump valve is located in the midfuselage. The dump isolation valve is controlled by the *SUPPLY H2O DUMP ISOL VLV* switch on panel R11L. The dump valve is controlled by the *SUPPLY H2O DUMP VLV* switch on panel R11L.

The *SUPPLY H2O DUMP VLV ENABLE/NOZ HTR* switch on panel R11L must be positioned to *ON* to supply electrical power to the *SUPPLY H2O DUMP VLV* switch. The *ON* position also applies power to the nozzle heaters, which warm the nozzles to prevent freezing when the dump valve is opened. When the *DUMP VLV* and *DUMP ISOL VLV* switches are positioned to *OPEN*, the corresponding valve is opened, which allows potable water to be dumped overboard. A talkback indicator above each switch indicates *OP* when the corresponding valve is open, barberpole when it is in transit,

and CL when it is closed. Closing either valve inhibits the dumping of potable water. At the completion of the dump, each switch is positioned to *CLOSE* to close the corresponding valve. The nozzle heater is then deactivated by placing the *SUPPLY H2O DUMP VLV ENABLE/NOZ HTR* switch to *OFF*.

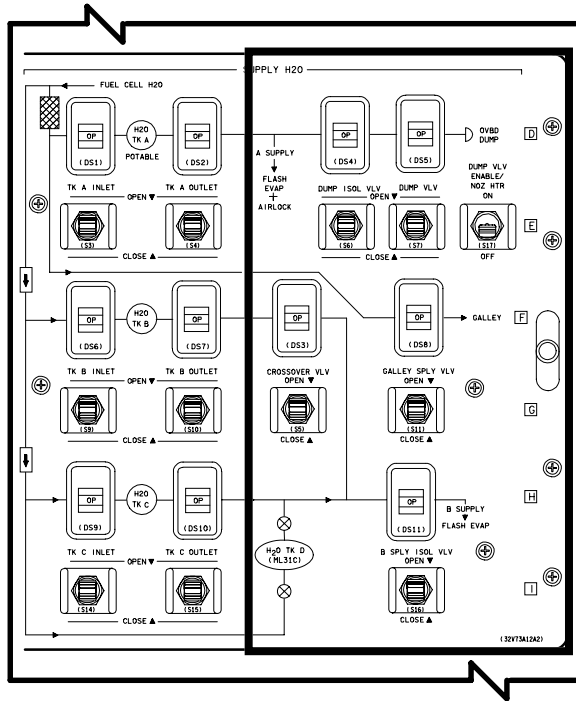
Contingency Crosstie

A contingency crosstie connection exists in the supply water overboard dump line between the dump isolation valve and dump valve. A corresponding crosstie connection exists in the wastewater overboard dump line between the dump isolation valve and dump valve. These crosstie connections permit the joining of the wastewater system through a flexible hose to the supply water system for emergency dumping of wastewater through the supply water dump (and vice versa).

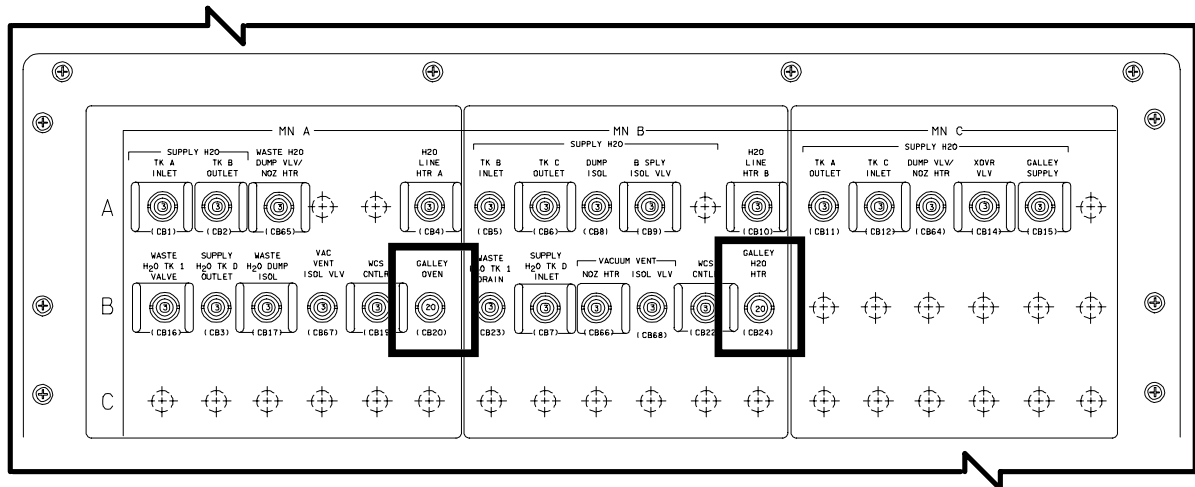
Dump Nozzle Heaters

The supply water dump nozzle employs a heater to prevent freezing of the supply water dump nozzle at the midfuselage. The dump nozzle heater is powered when the *SUPPLY H2O DUMP VLV ENABLE/NOZ HTR* switch on panel R11L is positioned to *ON*. When the switch is positioned to *OFF*, it removes electrical power from the nozzle heater, as well as the *SUPPLY H2O DUMP VLV* switch, which causes the dump valve to close.

The supply water line upstream of the water dump nozzle has electrical heaters on the line to prevent supply water from freezing. The A and B heaters on the line are thermostatically controlled and are powered by the *H₂O LINE HTR A* and *B* circuit breakers on panel ML86B. (These circuit breakers also provide power to thermostatically controlled heaters on the wastewater line and the waste collection system vacuum vent line.)

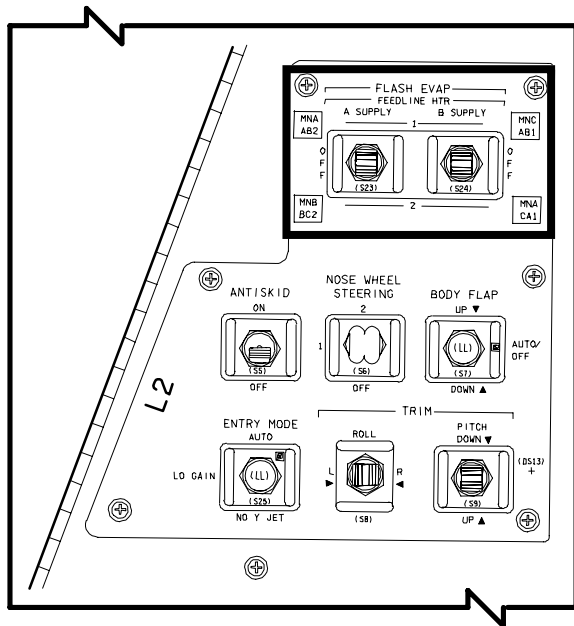


SUPPLY H2O CROSSOVER VLV, ISOL VLV, and DUMP VLV Switches and Talkback on Panel R11L



H2O LINE HTR Circuit Breakers on Panel ML86B

The supply water feed lines to the flash evaporators are approximately 100 feet long. To prevent the water in the lines from freezing, redundant heaters are installed along the length of the water lines. The heaters are controlled by the *FLASH EVAP FEEDLINE HTR A SUPPLY* and *B SUPPLY* switches on panel L2. When a switch is positioned to 1, it enables the thermostatically controlled heaters on the corresponding supply line to automatically control the temperature on that line. When a switch is positioned to 2, it enables the redundant thermostatically controlled heater system on the corresponding supply line. The *OFF* position of each switch inhibits heater operation on the corresponding supply line.

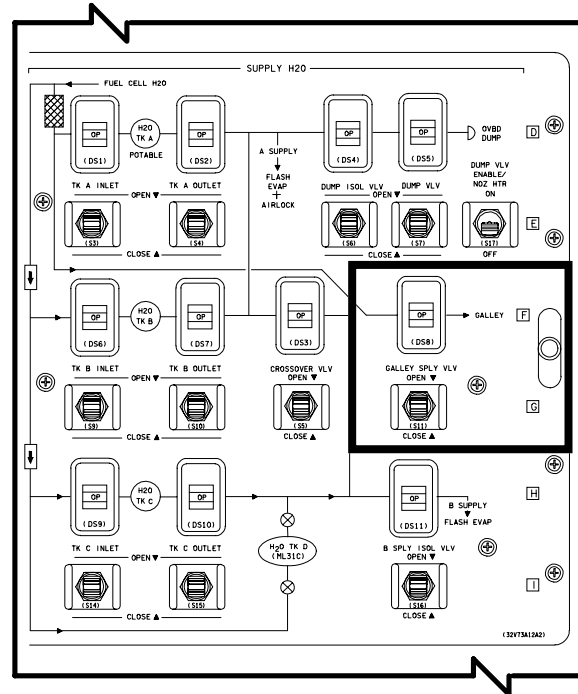


FLASH EV AP FEEDLINE HTR Switches on Panel L2

Galley Water Supply

The galley supply valve in the supply water line from the microbial filter of tank A permits or isolates the supply water from the galley or water dispenser. When the *SUPPLY H2O GALLEY SUP VLV* switch on panel R11L is positioned to *OPEN*, supply water is routed through parallel paths: one path flows through the atmospheric revitalization system water coolant loop water chiller for cooling of the supply water, and the other path bypasses the water chiller with ambient temperature water. A talkback indicator above the switch indicates

OP when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. The *CLOSE* position of the switch isolates the potable supply water from the middeck ECLSS supply water panel.



GALLEY Water Supply Switch and Talkback on Panel R11L

If the galley is not available/manifested for a flight, the chilled water and ambient water are connected to an Apollo water dispenser to dispense ambient and chilled water for drinking and food reconstitution.

Wastewater System

A single wastewater tank receives wastewater from the humidity separator and the waste management system. The tank is located beneath the crew compartment middeck floor next to the potable water tanks.

The wastewater tank holds 168 pounds, is 35.5 inches long and 15.5 inches in diameter, and weighs 39.5 pounds dry. It is pressurized by gaseous nitrogen from the same source as the potable water tanks.

Wastewater is directed to the wastewater tank 1 inlet valve, which is controlled by the *WASTE H₂O TANK 1 VLV* switch on panel ML31C.

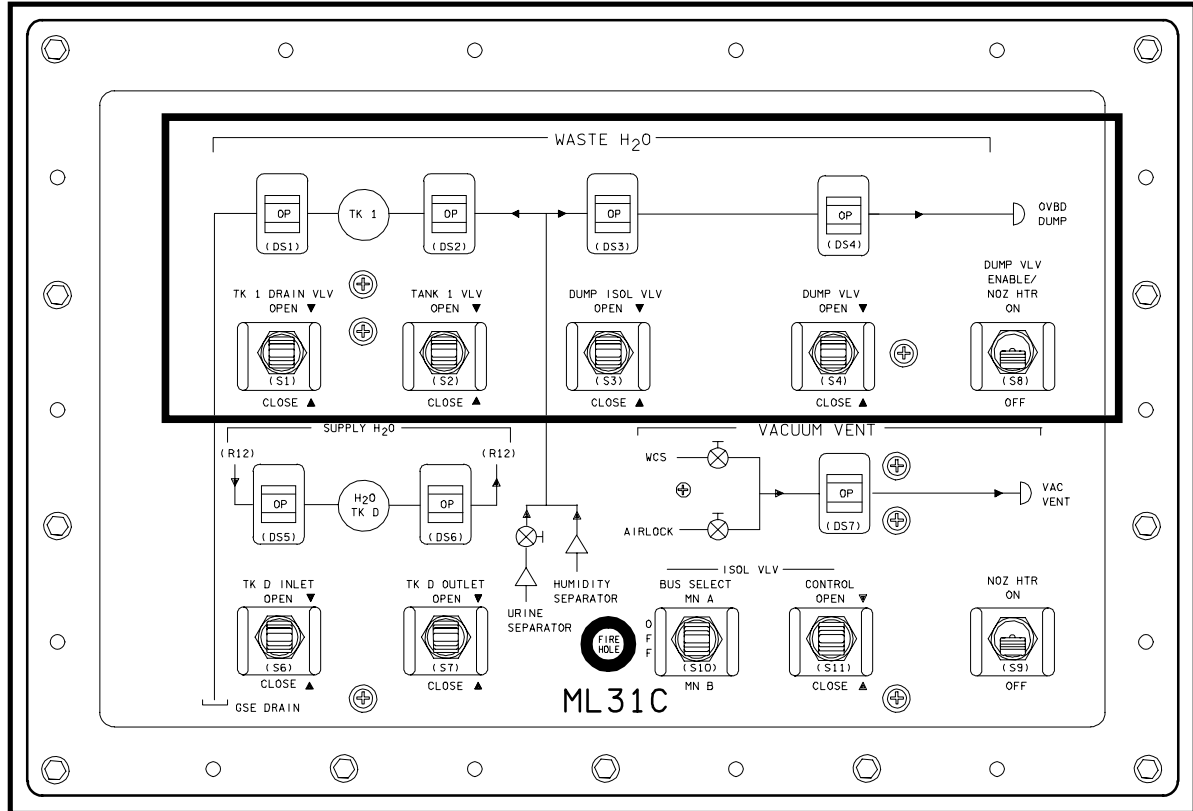
When the switch is positioned to *OPEN*, wastewater is directed to the wastewater tank. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. Positioning the switch to *OFF* closes the wastewater tank inlet, isolating the wastewater tank from the wastewater collection system. When the valve is open, wastewater from the tank can also be directed to the wastewater dump for overboard dumping. The waste tank outlet (or drain) is always closed, except for ground draining of the tank.

Wastewater Dumps

The wastewater dump isolation valve and wastewater dump valve in the wastewater dump line allow wastewater to be dumped overboard through the wastewater dump. The *WASTE H₂O DUMP ISOL VLV* switch on panel ML31C positioned to *OPEN* allows wastewater to be directed to the wastewater dump valve. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed.

In order for wastewater to be dumped overboard, the wastewater dump valve must be opened. It is controlled by the *WASTE H₂O DUMP VLV ENABLE/NOZ HTR* and *WASTE H₂O DUMP VLV* switches on panel ML31C. When the *WASTE H₂O DUMP VLV ENABLE/NOZ HTR* switch is positioned to *ON*, electrical power is supplied to the wastewater dump heaters and the *WASTE H₂O DUMP VLV* switch.

When the *WASTE H₂O DUMP VLV* switch is positioned to *OPEN*, the dump valve allows wastewater to be dumped overboard. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. If wastewater is dumped overboard, the *DUMP ISOL VLV* switch is positioned to *CL* upon completion of the dump. The *WASTE H₂O DUMP VLV* is positioned to *CLOSE*, and the *WASTE H₂O DUMP VLV ENABLE/NOZ HTR* switch is set to *OFF*.



WASTE H₂O System Switches and Talkbacks on Panel ML31C

CAUTION

If the *DUMP VLV ENABLE/NOZ HTR* switch is positioned to *OFF* before the *DUMP VLV* switch is positioned to *CLOSE*, the dump valve will remain open. The heaters at the wastewater dump prevent wastewater from freezing at the overboard dump.

The wastewater dump line, upstream of the waste dump nozzle, has electrical heaters on the line to prevent wastewater from freezing. The thermostatically controlled A and B heaters are powered by the *H₂O LINE HTR A* and *B* circuit breakers on ML86B. (These circuit breakers also provide power to thermostatically controlled heaters on the supply water line and waste collection system vacuum vent line.)

Contingency Crosstie

The contingency crosstie quick disconnect in the wastewater overboard dump line between the dump isolation valve and dump valve permits wastewater to be joined with the supply water system through a flexible hose for emergency dumping of supply water through the wastewater dump or using wastewater for the flash evaporators.

Wastewater Tank Draining

The wastewater tank 1 drain valve controls the draining of the wastewater tank during ground operations through the ground support equipment flush and drain. When the *WASTE H₂O TK 1 DRAIN VLV* switch on panel ML31C is positioned to *OPEN*, the valve permits the draining and flushing of the wastewater tank. The drain line is capped during flight. A talkback indicator above the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed.

Operations

Pressure Control System

For ascent, both 14.7 psia cabin regulator inlet valves are closed to isolate the 14.7 psia cabin regulators. If a cabin leak develops, this

configuration conserves nitrogen by not allowing any makeup flow into the cabin until the cabin pressure drops below 8 psia. The O₂ regulator inlet valves are closed, directing all the O₂ to the O₂ crossover manifold to supply the launch and entry suit helmets. The O₂/N₂ control valve on pressure control system 1 is open to allow N₂ to pressurize the O₂/N₂ manifold. The O₂/N₂ control valve on pressure control system 2 is closed. This would normally allow oxygen to flow to the O₂/N₂ manifold, but since the oxygen regulators are closed, nothing is configured to flow through the emergency 8 psia regulators on pressure control system 2. The crew will close the visors of their launch and entry suit helmets shortly before lift-off and breathe 100 percent O₂ until shortly after solid rocket booster separation.

The pressure control system remains in the ascent configuration until early in the flight plan when the orbit pressure control system configuration is performed. The pressure control system configuration to system 1 is called for in the flight day 1 EZ activities block. The 14.7 psia cabin regulator inlet valve on the selected pressure control system is opened. This enables the cabin regulator to automatically maintain the cabin pressure at 14.7 psia. The O₂ regulator inlet valve is opened, and the selected system O₂/N₂ control valve is taken to *AUTO*. This enables the O₂/N₂ controller to control whether O₂ or N₂ flows into the O₂/N₂ manifold based on cabin PPO₂ level. During the postsleep activities on flight day 2, an O₂ bleed orifice is installed in launch and entry helmet QD-5. The O₂ bleed orifice is sized based on number of crew and compensates for the crew's metabolic O₂ usage by flowing O₂ directly into the cabin. This helps keep the PPO₂ level stable when the cabin pressure is greater than 14.7 psia and the cabin regulators are not flowing. A reconfiguration to pressure control system 2 is performed halfway through the mission.

A 10.2 psia cabin protocol was developed by the flight surgeons to minimize the risk of decompression sickness (bends) for crewmembers preparing for an EVA. The EVA crewmembers must prebreathe pure O₂ before they go EVA to help flush N₂ out of their body tissue. The following 10.2 cabin protocol options have been developed:

- Option 1
 - 60-minute initial prebreathe on launch and entry suit helmet
 - 12 hours at 10.2 psia cabin pressure
 - 75-minute final prebreathe in suit
- Option 2
 - 60-minute initial prebreathe on launch and entry suit helmet
 - 24 hours at 10.2 psia cabin pressure
 - 40-minute final prebreathe in suit
- Option 3
 - 4-hour prebreathe in suit

For scheduled EVAs, option 1 or 2 is chosen to minimize the in-suit prebreathe just prior to the EVA. The cabin is depressurized to 10.2 psia using the airlock depressurization valve located in the airlock. Since there is no 10.2 psia cabin regulator, the cabin pressure and the PPO₂ levels must be manually managed during 10.2 psia cabin operations.

The pressure control system configuration is the same for entry as it was for ascent.

Atmospheric Revitalization System

The atmospheric revitalization system is already configured for ascent at crew ingress. One cabin fan, one humidity separator, one inertial measurement unit fan, and one fan in each avionics bay are already operating. The cabin temperature control valve is positioned in the *FULL COOL* position by powering the controller and adjusting the rotary switch to the *COOL* position. Once the *FULL COOL* position is reached, cabin temperature controller 1 is unpowered. The humidity separators and the IMU fan signal conditioners are unpowered to protect against an ac to ac bus short, which could cause loss of a main engine controller. (The wire bundle that carries power to these signal conditioners did short on STS-6.) Water loop 2 is on, and water loop 1 is off during ascent. Both water bypass valves are positioned to flow approximately 950 lb/hr through the Freon/water interchanger.

If no failures occur during ascent, then no actions are required to manage the atmospheric revitalization system in OV 103 and 104 (OV 105 if flown without the RCRS) with the exception of scheduled LiOH canister change outs. During the post insertion period for RCRS configured vehicles, the crew will activate the system. Every 13 minutes the RCRS will automatically switch chemical beds between regeneration and adsorption as part of a 26 minute full regeneration cycle with no further crew actions for nominal operations. Mid-mission (on 10+ day flights) the activated charcoal canister will be changed out. The operating cabin fan(s) should be turned off for removal and installation of canisters.

The orbit fan and pump configuration is the same on orbit as for ascent, except water loop 1 is set to the *GPC* position and the *BYPASS* controller for water loop 2 is set to the *AUTO* position. While in SM OPS 2 (or SM OPS 4), the *GPC* position enables the inactive water loop to be cycled on periodically. This periodic cycling prevents the inactive water loop from freezing in the Freon/water interchanger. The cycling sequence is initiated any time an OPS transition is made into SM OPS 2 (or SM OPS 4). When an OPS transition is made, the pump will receive a 6-minute “*ON*” command, then remain off for 4 hours. The pump will cycle on for 6 minutes every 4 hours.

The pump on water loop 2 is powered by AC3 when its switch is in the *ON* position. The *GPC* position of the *WATER PUMP LOOP 2* switch provides an alternate power source for the pump during ascent and entry. When the backup flight system computer has control of the payload MDMs, the *GPC* position powers the loop 2 pump with AC1 power. Since water loop 2 has only one pump, this enables the pump to remain powered even if AC3 should fail. The *GPC* position of the *WATER LOOP 1 PUMP* switch has no special function during ascent and entry; it acts just like the *OFF* position.

If the situation arises where no PASS SM or BFS computers are available, the water loop pumps can still be commanded on in the *GPC* position using real-time commands. The real time commands can be issued by a ground uplink or crew inputs on DPS UTILITY SPEC 1. The real-

time commands must be issued through the computer that has control of the payload MDMs. It would take a severe loss of system redundancy for the use of real-time commands to ever be required.

Cooling Management

Depending on the mission phase, the Freon cooling loops are cooled four different ways. Prior to launch, cooling is provided by the ground support equipment. After lift-off, there is no active means of cooling until after solid rocket booster separation. It takes the orbiter slightly more than 2 minutes to reach an altitude where water evaporation provides effective cooling. Until that time, sufficient "thermal inertia" is in the Freon loops to limit the temperature increase so that no active heat rejection is required.

At solid rocket booster separation, the flash evaporator system receives a GPC "ON" command from the BFS and begins providing active cooling. The flash evaporator system continues to be the primary cooling source through the ascent phase and on into the post insertion timeframe. During the Post Insertion checklist procedures, flow is initiated through the radiators, the payload bay doors are opened, and the radiators become the primary source of cooling. The topping flash evaporator system may be left on to provide supplemental cooling when necessary. If the orbiter is in a warm attitude, the radiator panels may not be effective enough to provide the desired cooling. The flash evaporator system can provide the additional cooling necessary to achieve the desired Freon loop temperatures.

During the deorbit prep procedures, the radiators are "cold soaked" for use later during entry. The radiator coldsoak process stores cool Freon in the radiator panels. This is accomplished by changing the radiator control temperature from 38° to 57° F. The flash evaporator system is reactivated to cool the Freon loops from 57° to 39° F. Since less cool Freon from the radiator panels is required to achieve the 57° F RAD OUT temperature, the Freon stays in the radiator

panels longer and becomes even cooler. After being in this configuration for a little over an hour, the radiators are bypassed, and the flash evaporator system begins providing all the cooling. The flash evaporator system provides the cooling during the rest of the deorbit, through entry interface, and on down to V = 12k (approximately 175,000 ft). Additionally, during deorbit prep for RCRS configured vehicles, the crew will replace the LiOH canister, and deactivate the RCRS. The operating cabin fan(s) should be turned off during this procedure.

At V = 12k, the radiators are put through their auto startup sequence, and radiator flow is reinitiated. Below 100,000 ft, the atmospheric pressure is too high for the flash evaporator system to cool effectively. Normally, the radiator coldsoak is used as the primary source of cooling from this point through rollout.

Once radiator coldsoak is depleted, the ammonia boilers are used as the primary cooling source until the ground support equipment cooling cart hookup is complete. Then the ammonia cooling is deactivated, and ground support equipment cooling is initiated.

For ascent aborts, the thermal management of the Freon cooling is somewhat different. The flash evaporator system still provides the cooling after solid rocket booster separation. The cooling management during the entry portion changes. The ammonia boilers provide the cooling during the lower stages of the abort entry. The ammonia is used for cooling during the entry phase of an ascent abort because the orbiter lifts off without a radiator coldsoak, and the flash evaporator system functions normally only at low atmospheric pressure (above 100,000 ft).

For a transoceanic abort landing or an abort once around, the ammonia boiler receives a GPC "ON" command from the BFS at MM 304 and 120,000 ft. For a return to launch site abort, the ammonia boiler receives a GPC "ON" command from the BFS at external tank separation (MM 602). The ammonia boiler will provide the cooling from this point through landing. The ammonia boilers can provide cooling for approximately 1 hour.

ECLSS Caution and Warning Summary

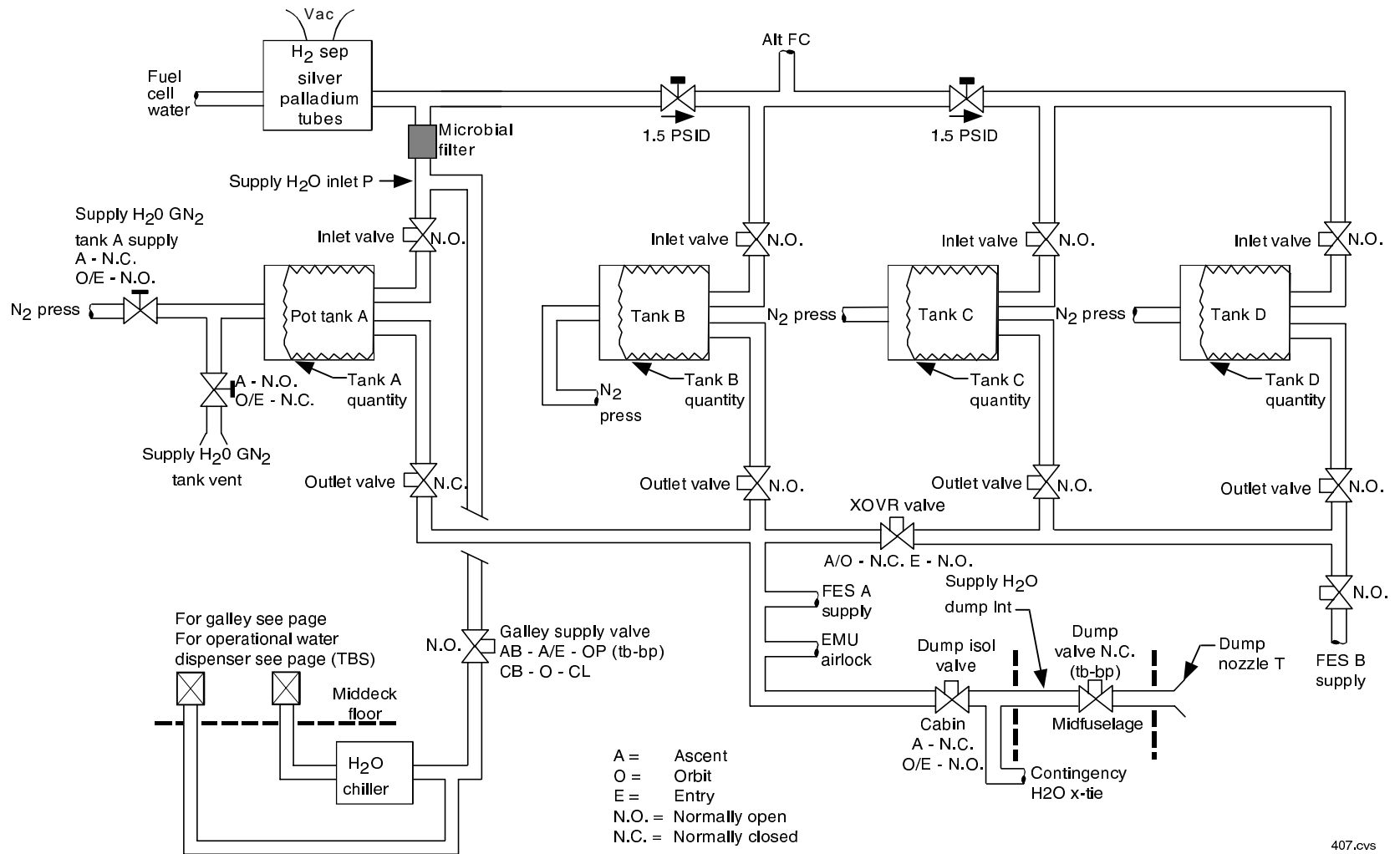
- The red *CABIN ATM* caution and warning light on panel F7 is illuminated for any of the following monitored parameters: (1) cabin pressure below 13.8 psia or above 15.2 psia, (2) PPO₂ below 2.7 psia or above 3.6 psia, (3) oxygen flow rate above 4.9 pounds per hour, and (4) nitrogen flow rate above 4.9 pounds per hour.
- The yellow *AV BAY/CABIN AIR C/W* light will illuminate for the following conditions: any avionics bay temperature higher than 130° F, the heat exchanger out temperature higher than 145° F, or cabin fan delta P below 4.2 inches of water or greater than 6.8 inches.
- The yellow *H₂O LOOP C/W* light will illuminate if the outlet pressure of water coolant loop pump 1 is less than 19.5 psia or greater than 79.5 psia, or if pump 2 pressure is less than 45 psia or greater than 81 psia.
- The yellow *FREON LOOP* light will illuminate if Freon flow in either coolant loop is less than 1200 pph, or if either loop's evap out temperature is less than 32.2° F or greater than 64.8° F (upper limit for ascent is 115° F.)

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 (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

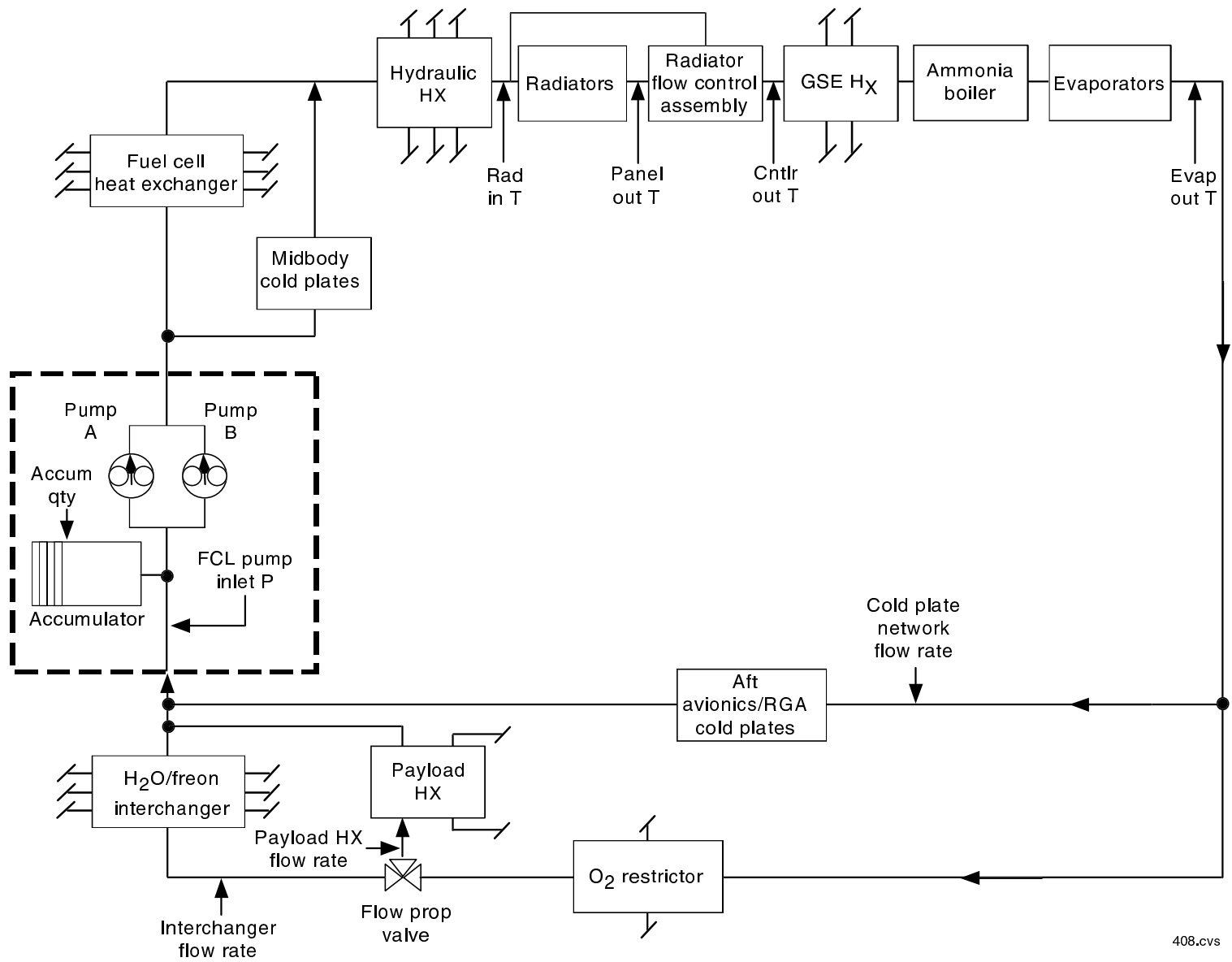
ECLSS Caution and Warning :Lights on Panel F7

ECLSS Summary Data

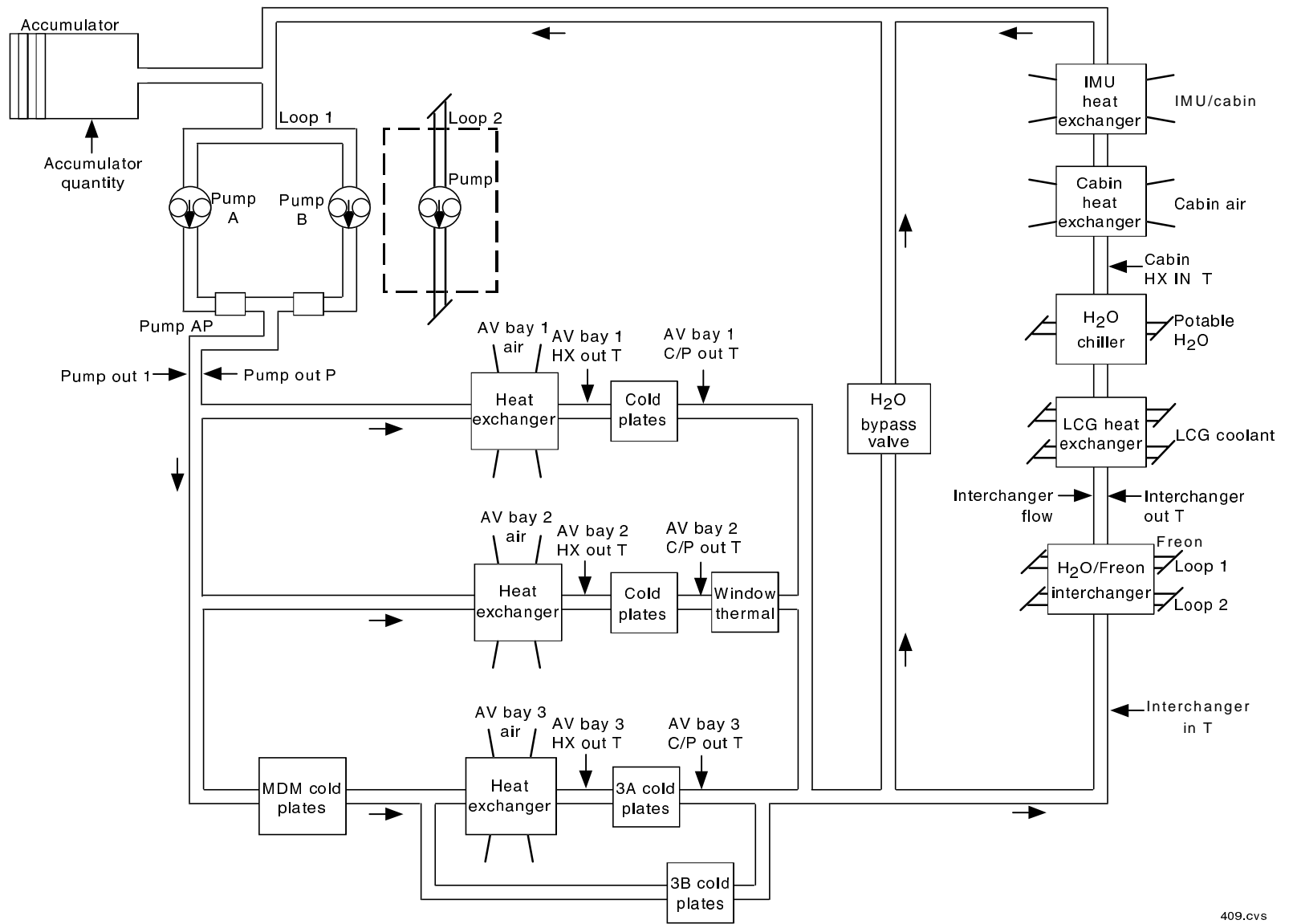
- The functions of the ECLSS are to maintain the orbiter's thermal stability, provide a pressurized, habitable environment for the crew and onboard avionics, and store water and liquid waste.
- The four components of the ECLSS are the pressure control, atmospheric revitalization, active thermal control, and supply and wastewater systems.
- The pressure control system pressurizes the crew cabin at 14.7 psia, pressurizes the supply and wastewater tanks, and provides breathing oxygen directly to the launch and entry suit helmets, and emergency breathing masks.
- The main components of the pressure control system are oxygen and nitrogen systems, tanks, and valves.
- The atmospheric revitalization system circulates air through the crew compartment to control relative humidity between 30 and 65 percent, maintain carbon dioxide and carbon monoxide at non-toxic levels, air filtration, control temperature and ventilation in the crew compartment, and provide avionics cooling. The water loop provides cooling for the crew and avionics.
- The atmospheric revitalization system consists of cabin air loops, water coolant loops, fans, and heat exchangers and interchangers.
- The active thermal control system provides orbiter heat rejection during all phases of the mission.
- The active thermal control system consists of two complete, identical Freon coolant loop systems, cold plate networks for cooling avionics units, liquid/liquid heat exchangers, and radiators, flash evaporators, and ammonia boilers.
- The supply water system stores potable water generated by the fuel cells. The supply water is used for flash evaporator system cooling, crew consumption, and hygiene.
- The wastewater system stores waste from the crew cabin humidity separator and from the crew.
- Four supply water tanks and one wastewater tank are located beneath the crew compartment middeck floor.
- Panels that control the major portion of ECLSS functions are panels L1, L2, MO10W, and R11L. Panels ML31C, ML86B, MA73C, R13L, MO51F, and MD44F also control ECLSS functions.
- ECLSS status can be monitored on panel O1 and on the following CRT displays: ENVIRONMENT (DISP 66), SM SYS SUMM 1, SM SYS SUMM 2, APU/ENVIRON THERM (DISP 88), and BFS THERMAL.



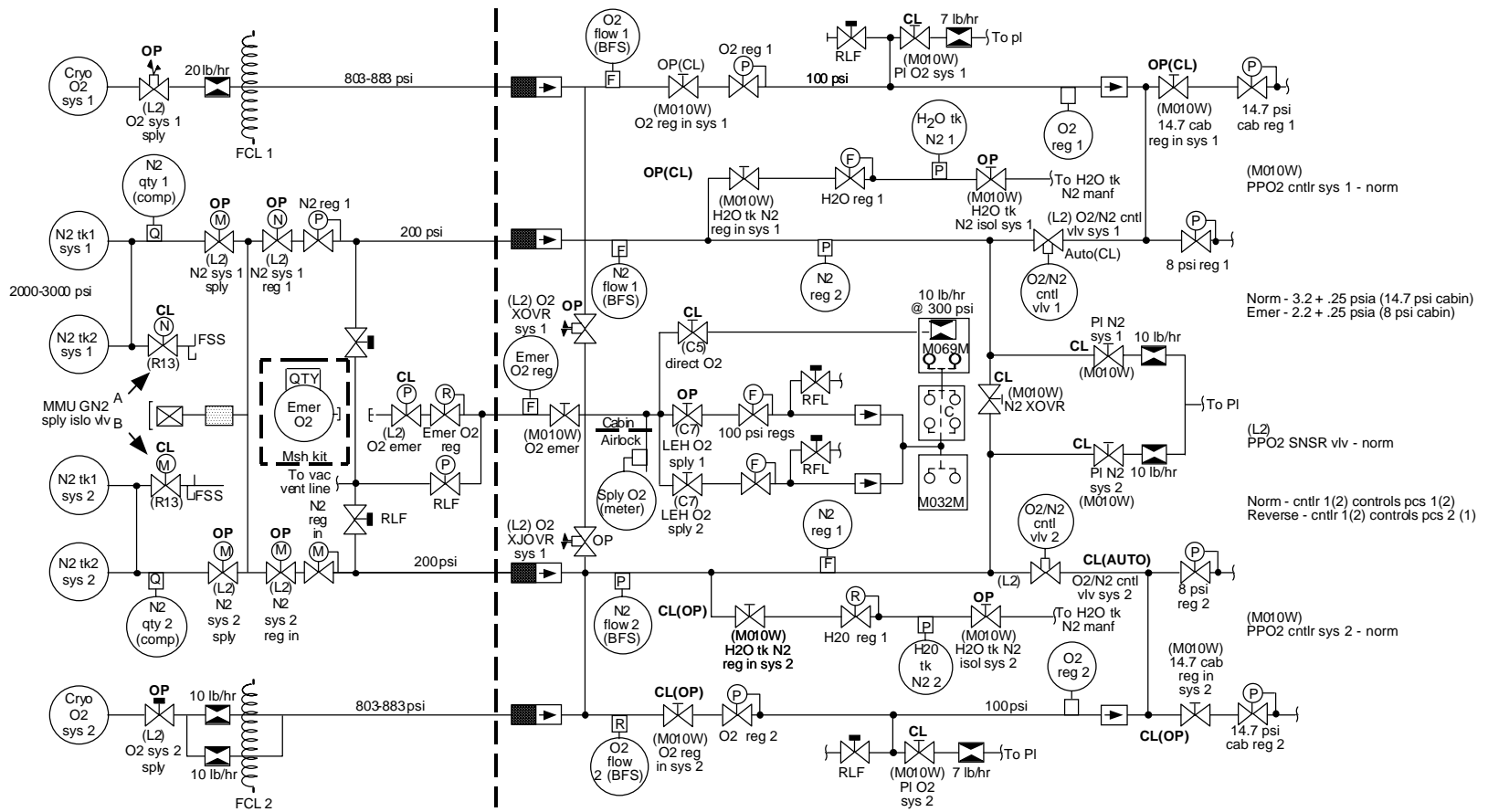
Supply Water Storage System



Freon Flow



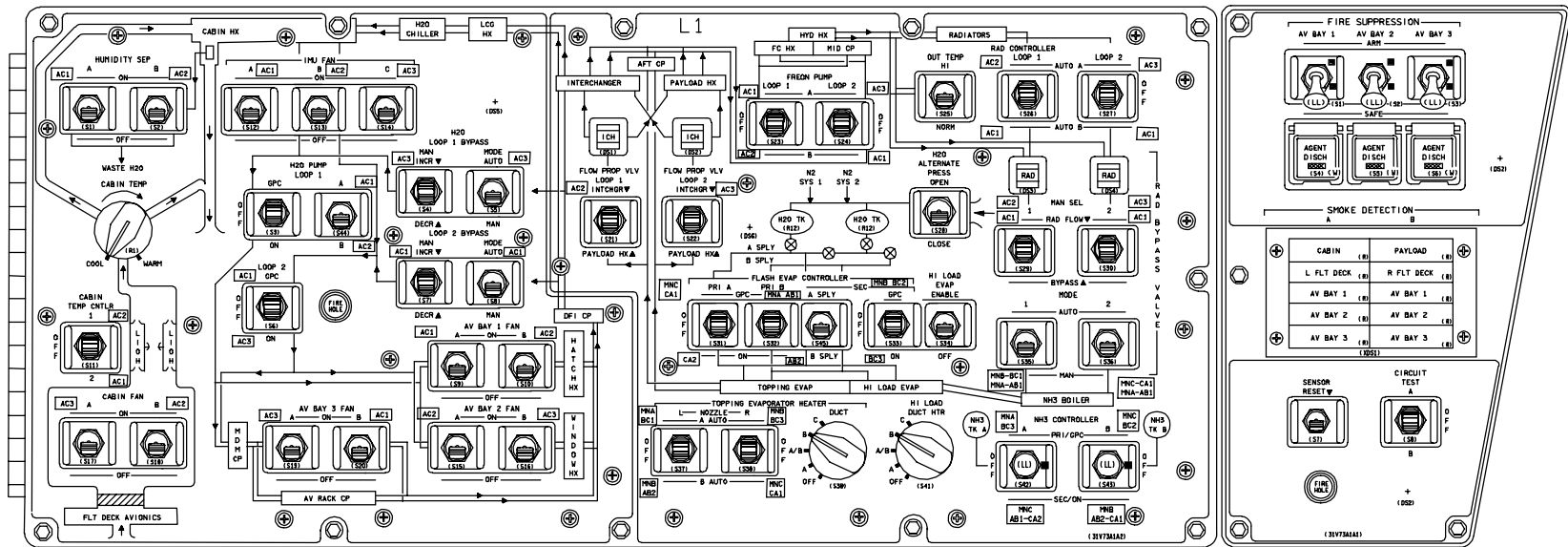
Water Loops



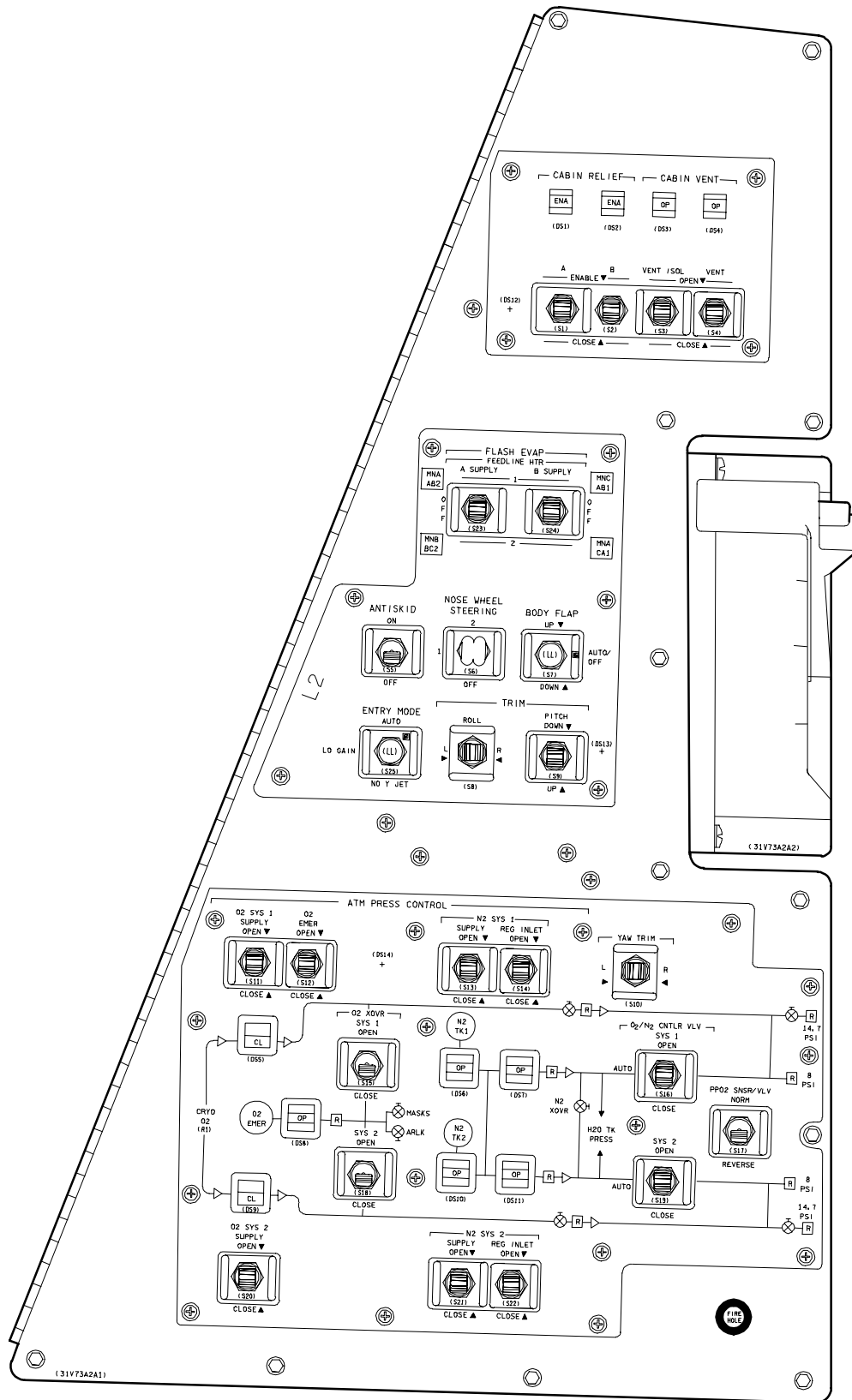
Norm - 3.2 + .25 psia (14.7 psi cabin)
 Emer - 2.2 + .25 psia (8 psi cabin)

Norm - cntnr 1(2) controls pcs 1(2)
 Reverse - cntnr 1(2) controls pcs 2 (1)

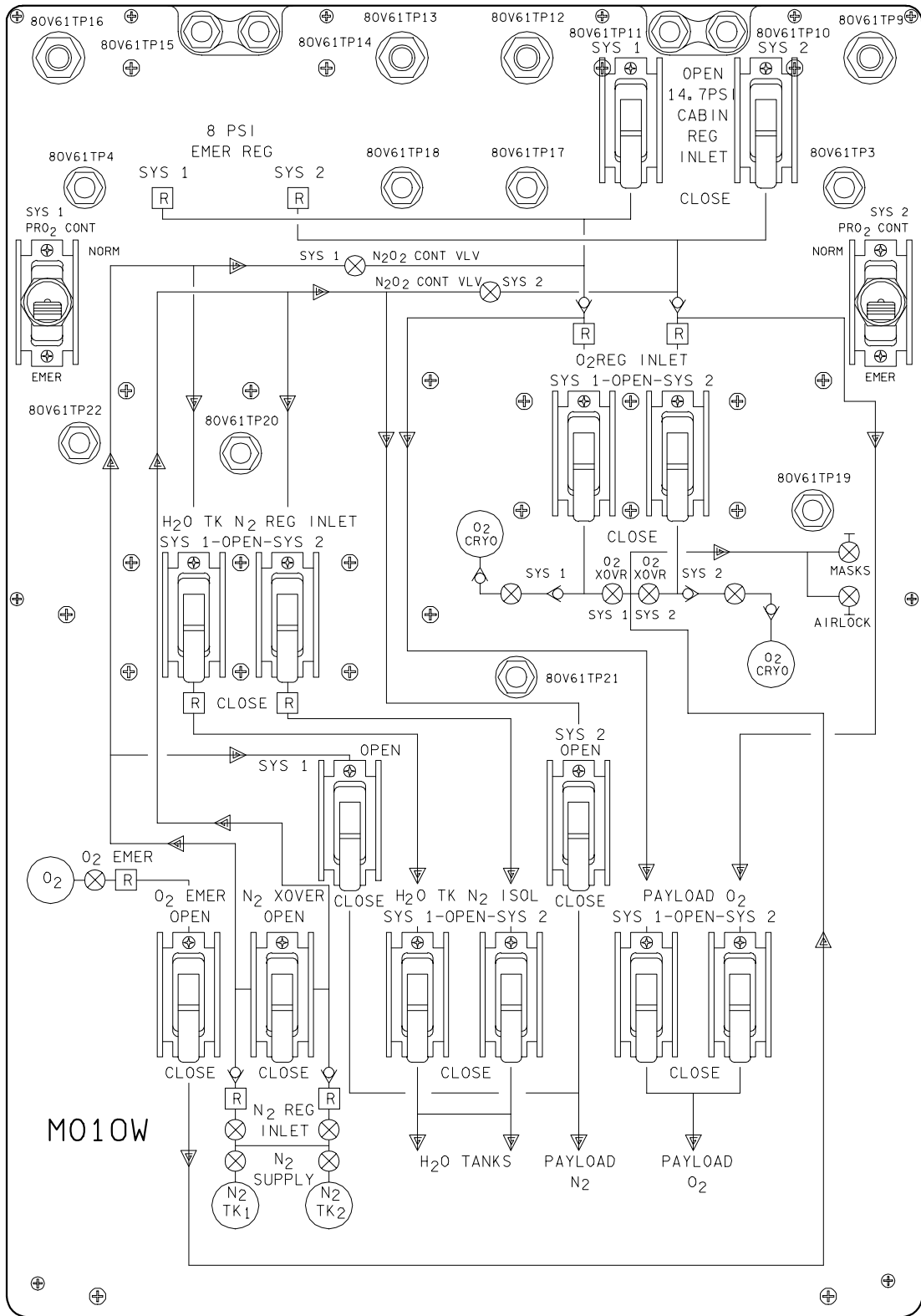
Pressure Control System (Orbit)



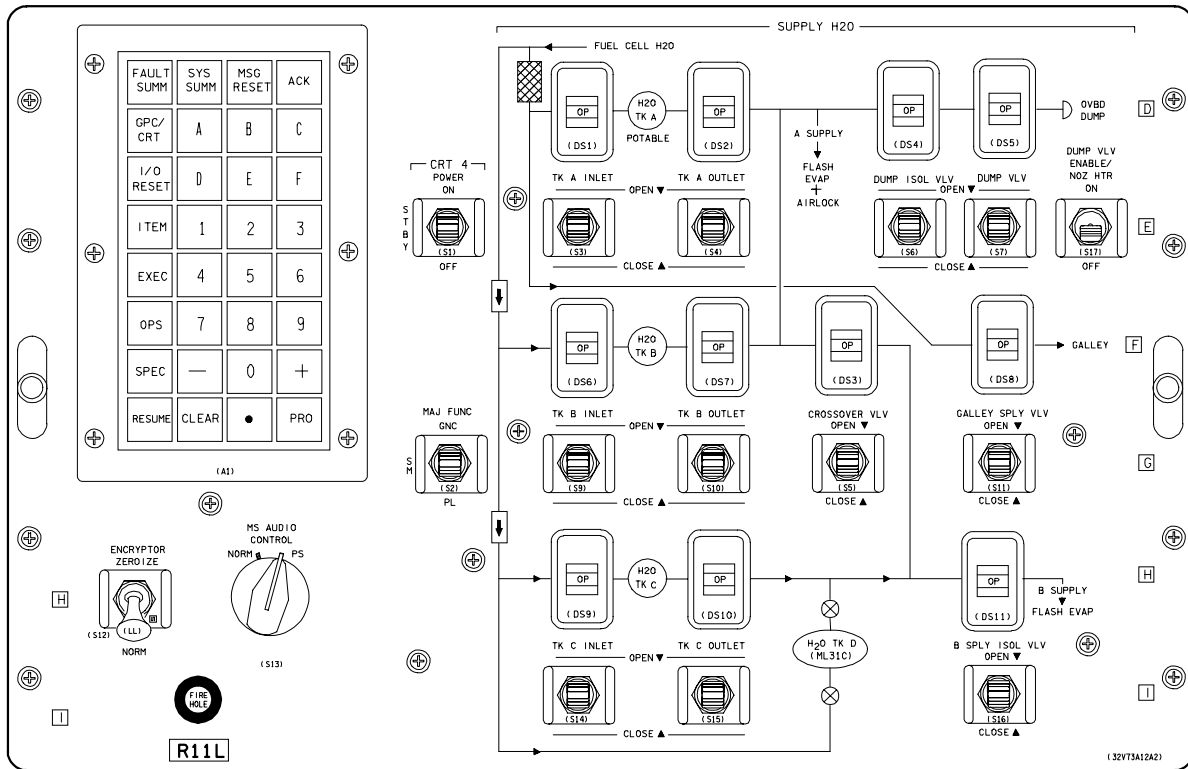
Panel L1



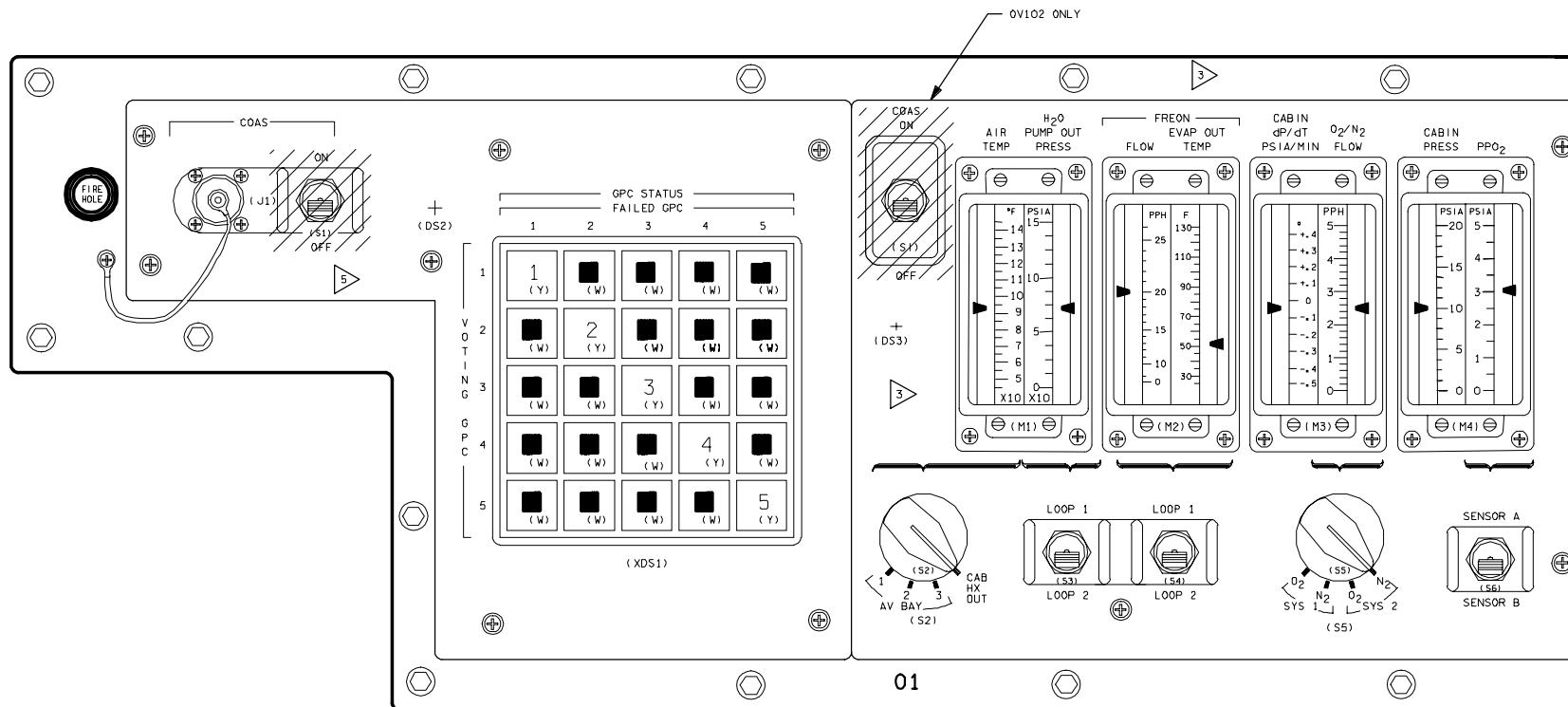
Panel L2



Panel MO10W



Panel R11L



Panel O1

2011/ /066 ENVIRONMENT				4 000/02:33:38			
				000/00:00:00			
CABIN				AV BAY 1 2 3			
dP/dT +.01 CABIN P 14.7				TEMP 90 90 78			
PP02 AIRLK P 14.8				FAN ΔP 3.80 3.77 3.92			
A 3.04 FAN ΔP 5.55				SUPPLY H2O			
B 3.04 HX OUT T 45L				QTY A 67 PRESS 32			
C 3.04 CABIN T 71				B 18 DMP LN T 77			
PPC02 1.9				C 94 NOZ T A 64			
				D 94 B 64			
O2 FLOW 0.0L 0.0L				WASTE H2O			
REG P 100 100				QTY 1 15 PRESS 17			
N2 FLOW 0.0L 0.0L				DMP LN T 58			
REG P 202 202				NOZ T A 82			
O2/N2 CNTL VLV N2 02				B 82			
H2O TK N2 P 17 17				VAC VT NOZ T 224			
N2 QTY 131 131				CO2 CNTLR 1 2			
EMER O2 QTY 1				FILTER P 0.00L			
REG P 4L				PPC02 - 0.0L			
				TEMP 32.0L			
IMU FAN A B C ΔP				BED A PRESS 0.0L 0.0L			
HUMID SEP *				B PRESS 0.0L 0.0L			
				ΔP 0.00L 0.00L			
				VAC PRESS 0.0L			

093

ENVIRONMENT (DISP 66)

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

078

APU/ENVIRON THERM (DISP 88)

2011/ /078 SM SYS SUMM 1				4 000/14:44:12			
				000/00:00:00			
SMOKE 1/A 2/B				DC VOLTS 1/A 2/B 3/C			
CABIN 0.0				FC 30.6 30.1 31.0			
L/R FD 0.0 0.0				MAIN 30.6 30.1 31.0			
AV BAY 1 0.3 0.3				ESS 29.6 29.6 29.3			
2 0.3 0.4				A B C A			
3 0.3 0.3				CNTL 1 29.4 29.4 29.6			
CABIN				2 29.4 29.4 29.4			
PRESS 14.0				3 29.4 29.4 29.4			
dP/dT-EQ +.00 +.000				AC			
O2 CONC				VOLT φA 118 118 117			
PP02 3.00 3.00				φB 117 117 118			
FAN ΔP 5.00				φC 117 117 118			
HX OUT T 46				AMPS φA 4.3 6.3 2.1			
O2 FLOW 0.0 0.0				φB 5.5 6.6 2.2			
N2 FLOW 0.0 0.0				φC 3.1 5.0 3.2			
IMU FAN A B C				FUEL CEL			
ΔV FC1 FC2 FC3				AMPS 180 232 146			
SS1 22 21 22				REAC VLV OP OP OP			
SS2 22 22 23				STACK T +202 +206 +200			
SS3 23 21 21				EXIT T 150 152 149			
TOTAL AMPS 557				COOL P 61 60 61			
KW 17				PUMP			

243

SM SYS SUMM 1

0001/ THERMAL				5 000/00:00:00			
				BFS 000/00:00:00			
HYD SYS TEMP BDYFLP RD/SB				L OB L IB R IB R OB			
PRIME + 99 + 79 + 76 + 79 + 76 + 79							
STBY 1 + 89 + 79 + 79 + 79 + 79 + 79							
BRAKE PRESS							
HYD SYS 1/3				92 92 92 92			
2/3				92 92 92 92			
HTR TEMP				L/A R/B FREON LOOP 1 2			
PRPLT				ACCUM QTY 34 34			
POD				RAD OUT T 109 109			
OMS CRSFD				H2O SUP P 0			
EVAP				TIRE PRESS			
HI LOAD				MG LEFT RIGHT			
TOP DUCT				IB 429 420 418 418			
NOZ				OB 421 421 416 416			
FDLN				NG 397 397 381 381			
HYD BLR/HTR				1 2 3			
APU							
GG/FU PMP HTR H				H H H			
TK/FU LN HTR							
PUMP/VLV							

255

BFS THERMAL

0001/ /079 SM SYS SUMM 2				5 008/23:29:22			
				BFS 000/00:00:00			
CRYO TK 1 2 3 4 5				MANF1 MANF2			
H2 PRESS 208 208 206 206 206				208 207			
O2 PRESS 816 815 814 814 814				815 815			
HTR T1 -248 -248 -248 -248 -248							
T2 -248 -248 -248 -248 -248							
APU 1 2 3				HYD 1 2 3			
TEMP EGT 942 942 942				PRESS 3064 3064 3064			
B/U EGT 942 942 942				ACUM P 3080 3080 3080			
OIL IN 250 250 250				RSVR T 116 153 142			
OUT 264 264 264							
GG BED 511H 511H 511H				QTY 72 74 71			
INJ 1271 1271 1271							
SPEED % 99 102 101				W/B			
FUEL QTY 59 60 62				H2O QTY 78 73 78			
PMP LK P 14 14 14				BYP VLV BYP BYP BYP			
OIL OUT P 42 42 41							
FU TK VLV				THERM CNTL 1 28			
A T 63 65 62				H2O PUMP P 23 63			
B T 63 65 62				FREON FLOW 2384 2384			
AV BAY 1 2 3				EVAP OUT T 38 38			
TEMP 97 97 83							
A4 14 27.439 27.435				26.324 31.873 18.48			

051

SM SYS SUMM 2

ECLSS Rules of Thumb

NOTE

Numbers presented here are for typical orbit power and heat loads and may vary significantly depending on attitude and power loading.

- Supply water tanks fill at about 1.5 percent per hour depending on fuel cell load (.8 lb/kW hr ÷ 16 lb over 1%; 14 kW typical orbit power load).
- Water tanks empty at about 100 percent per hour for a water dump, about 50 percent per hour when using the FES high load evaporator for cooling with payload bay doors closed, and about 16 percent per hour when using the FES topping evaporator for supply water dumps on orbit with the doors open.
- On-orbit cold soak is good for 20 to 30 minutes of cooling. Prelaunch Freon conditioning is good for 2 to 3 minutes of cooling.
- NH₃ boiler supply is good for 25 minutes of ground cooling.
- A single cryo O₂ tank is good for about 2 to 3 days of orbit usage depending on crew size and power level. H₂ tanks are sized to match O₂ usage.
- A single LiOH canister is usable for about 48 man-hours.

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2.10 ESCAPE SYSTEMS

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Description

Escape systems refer to equipment and systems intended to facilitate emergency and contingency egress of the flight crew. Escape systems include equipment worn by the crewmembers, hardware built into the orbiter, and external systems located on the launch pad. Types of escape or emergency egress from the orbiter depend upon the mission phase (basically prelaunch, in-flight, and post-landing). The prelaunch phase implies the crew must perform an emergency egress while the orbiter is still positioned on the launch pad.

The in-flight phase requires that the crew can safely bail out of the orbiter during controlled gliding flight at altitudes of 30,000 feet and below. A special in-flight crew escape system is devised for this phase. It includes pressure suits, oxygen bottles, parachutes, life rafts, pyrotechnics to vent the cabin and jettison the orbiter side hatch, and an escape pole to allow the crewmembers to clear the vehicle. The most likely uses of the system would be during a return-to-launch-site (RTLS) abort, transatlantic abort landing (TAL), or abort once-around (AOA) when the orbiter has insufficient energy to achieve a runway landing or after an emergency deorbit made regardless of landing site opportunities.

During the post-landing phase, the crew exits the orbiter following an emergency landing or landing at a contingency site. The orbiter will

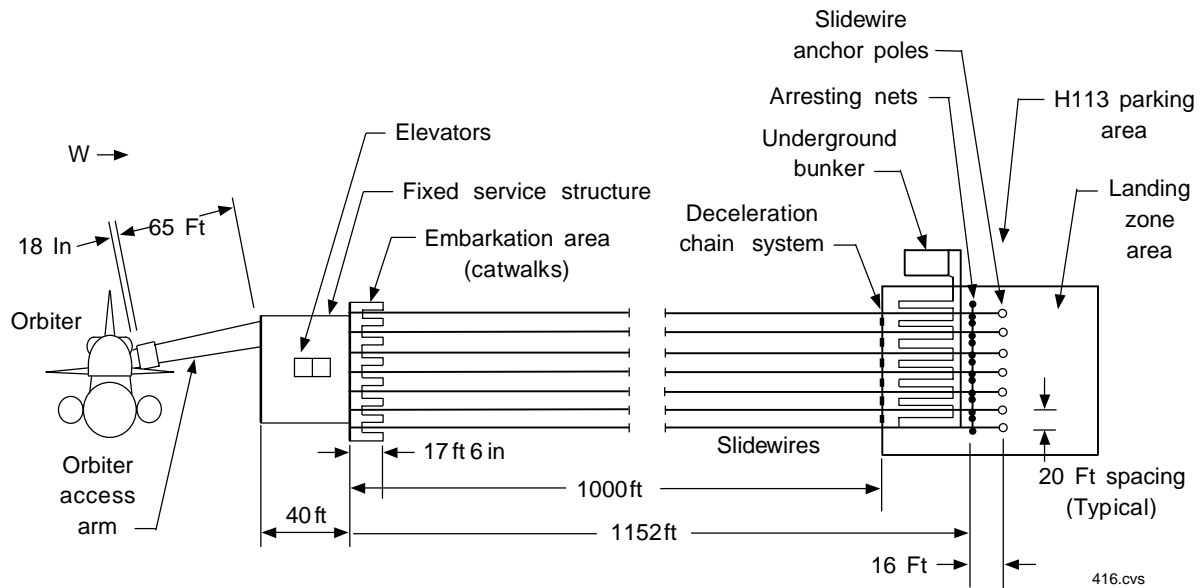
probably not survive a water ditching; therefore, bailout is the primary escape mode over water.

The orbiter-based hardware associated with the in-flight crew escape system was installed after the Challenger accident. Some orbiter modifications were required for the inclusion of the in-flight escape system. The side hatch water coolant lines for side hatch thermal conditioning were modified to accommodate the installation of the pyrotechnic separation system. The flight crewmembers' seats were also modified to accommodate the crew's altitude protection system suit. In addition, a handhold was added in the middeck next to the side hatch to permit the crewmembers to position themselves through the side hatch opening for bailout. The interdeck access ladder was widened, and a handhold was added to the commander's seat to allow easier movement through the interdeck access.

Software adjustments were also required to accommodate the in-flight escape system. Software changes applied to the primary avionics software system for OPS 3 and 6. The changes enable an automatic flight control mode of the orbiter with input by crewmembers by using the ATO abort position on the abort rotary switch in MM 603/305. The automatic mode stabilizes the orbiter by controlling the velocity and angle of attack to the desired bailout conditions, thus allowing the commander to escape.

Launch Pad Egress Systems

In the event of a potential catastrophe on the launch pad, escape by the flight crew is facilitated by descending to a safe area via slidewire baskets. The emergency egress/escape system uses seven separate slidewires and seven multi-person basket assemblies to effect rapid escape of personnel from the 195-foot level of the fixed service structure to a landing zone. The landing zone is approximately 1,200 feet west of the fixed service structure. The flight crew leaves the slidewire baskets and proceeds to the bunker, which is provided with breathing air, first aid supplies, and communications equipment. The flight crew will only leave the bunker upon instructions by the NASA Test Director.



Launch Pad Emergency Egress System

An M-113 is positioned near the slidewire termination area. The M-113 is a military personnel carrier designed to provide protected evacuation from the launch pad area.

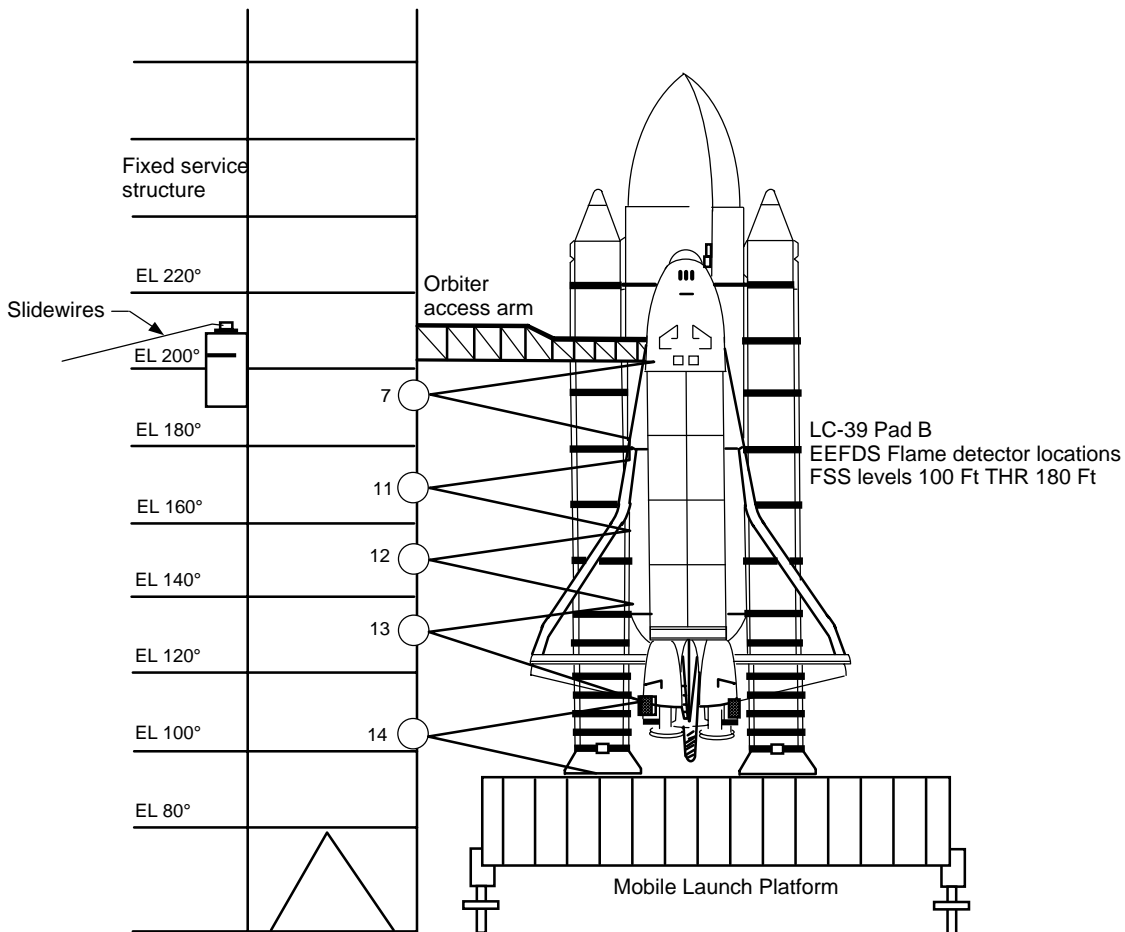
There are four modes of escape from the launch pad area, varying in degrees of egress aid to the crew by the closeout crew or pad fire/rescue crew. In the case of an aided escape, support crews are responsible for opening the side hatch using an emergency hatch opening tool.

The launch pad structure also includes an escape temperature and hydrogen fire-hazard monitoring system, consisting of 10 temperature sensors and 14 ultraviolet (UV) hydrogen fire detectors. Nine UV fire detectors are located in the area of the environmental chamber, the truss, and the fixed service structure both above and below the fire barrier. Five UV fire detectors are also spaced vertically down the fixed service structure from the 175-foot level to the 95-foot level to view a profile of the orbiter.

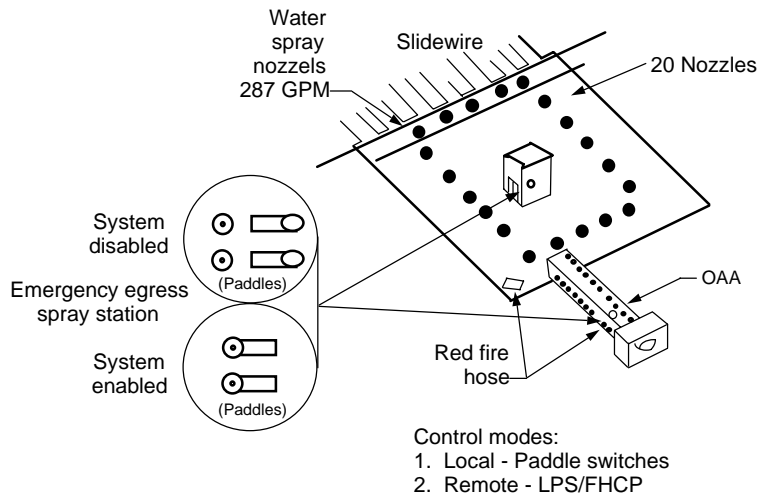
The 10 temperature sensors are located along the egress path, from the environmental chamber to the slidewire basket embarkation area. The sensors are placed both above and below the fire barrier. The signals from these sensors are displayed on firing room console C-7 in the launch control center.

The Firex spray system provides a water shower to the orbiter access arm and the fixed service structure in the event of a fire. There are 20 water spray nozzles located on the orbiter access arm, approximately 4 feet above the walkway, and 20 on the fixed service structure, 7 to 10 feet overhead. Each nozzle emits 287 gallons of water per minute. Two control modes, local and remote, operate the Firex spray system. The local mode consists of paddle switches located either outside the white room on the orbiter access arm or on the east side of the elevators directly facing the orbiter access arm. The remote mode is a hard-wire backup control panel located in the launch control center.

FLAME DETECTION (EEFDS)



417.cvs



418.cvs

Emergency Egress Water Spray Control Panels

Launch and Entry Suits

The launch entry suit (LES) and the advanced crew escape suit (ACES) are the two types of suits designed to provide protection to a crewmember during ascent and entry for the following problems:

- Loss of cabin pressure
- Environmental extremes
- Effects of prolonged zero gravity
- Contaminated atmosphere
- Loss of orbiter O₂ supply

The LES is a partial pressure suit and, as such, provides protection through a series of interconnected pressure bladders that place mechanical pressure on the crewmember. The ACES is a full pressure suit that provides an atmosphere of pressure all over the crewmember's body.

Both suits have a main sealing zipper that runs down the back of the suit, around the crotch, and slightly up the front. This zipper is a water and pressure seal on the ACES, but serves only as a pressure seal on the LES.

Both suits have automatic dual pressure controllers. The suits have slightly different pressurization schedules; however, both start to pressurize when the cabin pressure altitude rises to around 40,000 feet. Both suits are "hard pressed" above 60,000 feet. The ACES can provide pressure protection indefinitely above 100,000 feet, while the LES can provide protec-

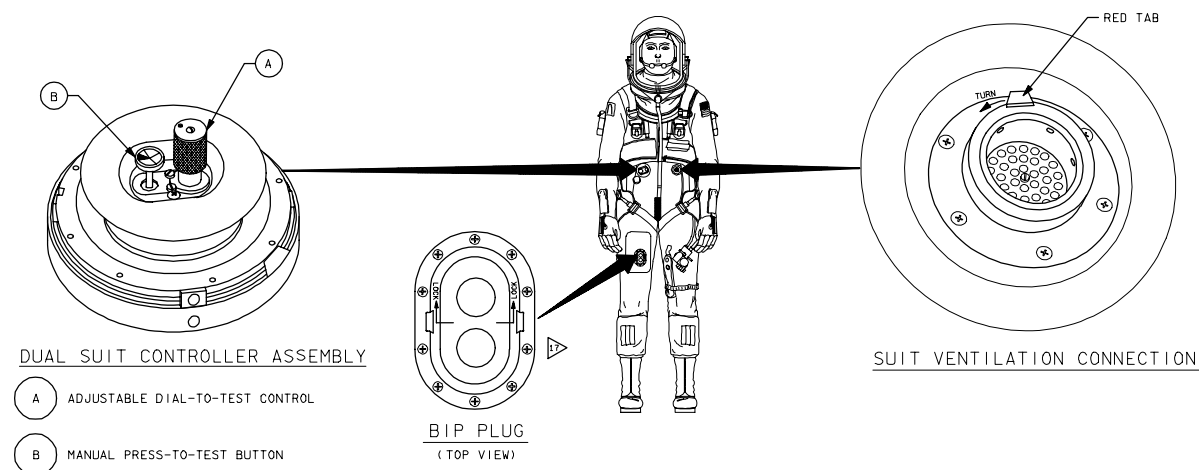
tion above 100,000 feet for 30 minutes. The suits have manual controls that are used for ground testing of the primary and secondary pressure controllers.

Both suits use a bioinstrumentation pass-thru (BIP), which allows medical lines or water cooling lines to pass into the suit for the crewmember. These lines are incorporated into a modified BIP plug that must be used to keep water out of the suits. Additionally, the ACES cannot pressurize unless this BIP plug is seated properly.

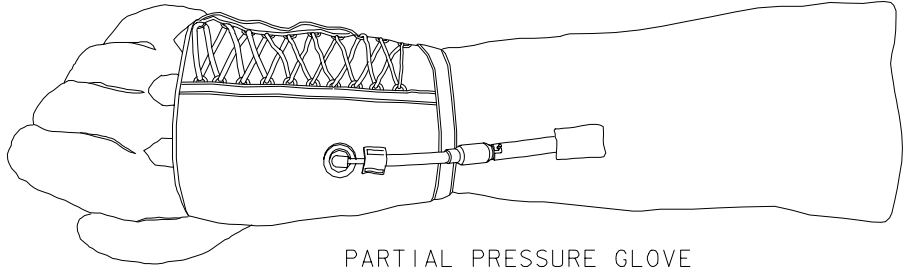
Both suits have gloves, but the gloves are used in very different ways. The ACES sleeves have metal attachment rings that mate to the end of the ACES glove. If the ACES gloves are not mated properly, the ACES suit will not provide pressure protection and water will enter the suit during survival conditions at sea.

LES gloves mate to the sleeve via a glove needle, which looks and works like the needle used to inflate a football. The LES can still provide pressure protection if the gloves are not used. The LES has wrist dams on the end of the sleeves that keep out water during a survival situation at sea.

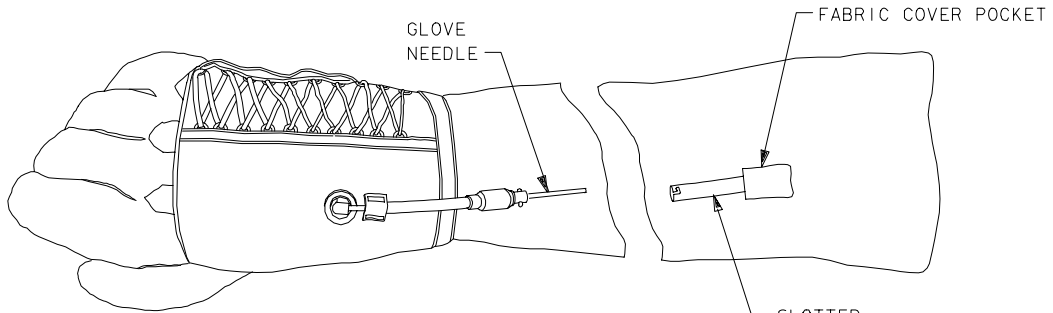
G-suits are available for both suits. The ACES g-suit can be demated and stowed prelaunch and used by the crewmember for entry and landing. The LES g-suit is integrated into the LES so the crewmember has to wear this g-suit every time the LES is used.



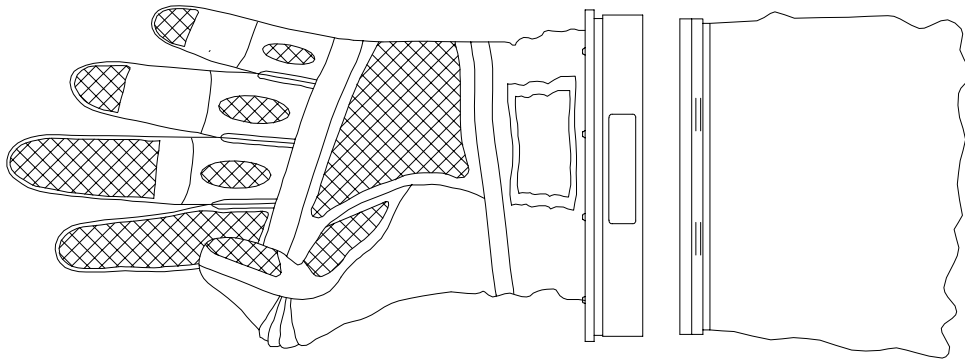
Bioinstrumentation Pass-Thru (BIP)



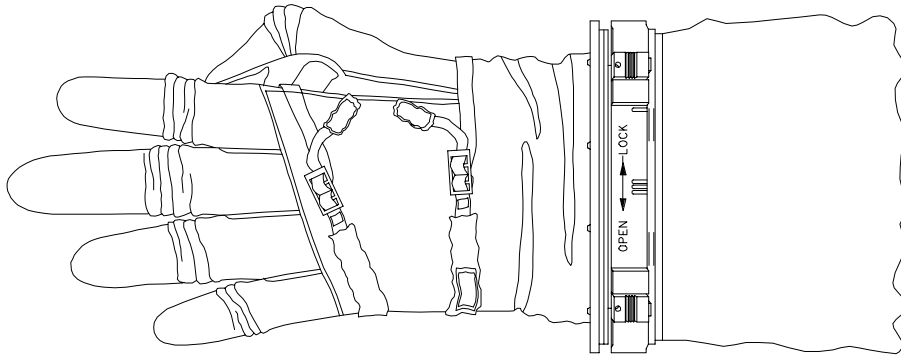
PARTIAL PRESSURE GLOVE
TWIST CONNECTOR CONNECTED



PARTIAL PRESSURE GLOVE
TWIST CONNECTOR DISCONNECTED



FULL PRESSURE GLOVE-DE-MATED



FULL PRESSURE GLOVE-MATED

Launch and Entry Suit Gloves

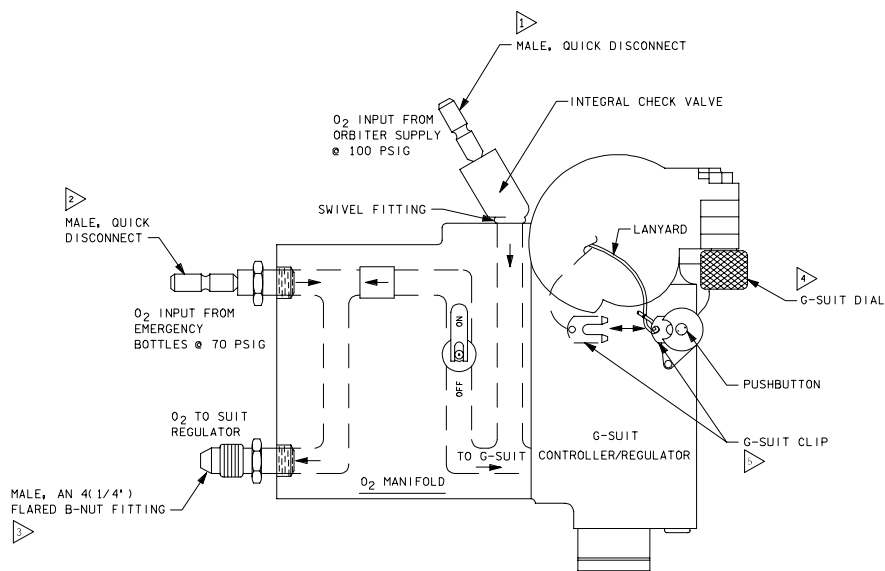
Physiological data indicate that protection should be provided for orbiter crewmembers on flights exceeding 12 hours duration to prevent fluid shifts to the lower extremities during exposure to entry g-loading. Lower extremity fluid shifts could cause degradation in crew performance during critical entry and landing mission phases. All crewmembers don the LES/ACES before entry, and, if needed, inflate the g-suit, sometimes referred to as an anti-g suit, prior to reaching a 400,000-foot altitude. The recommended setting for inflation is 1.5 psi, which is obtained by rotating the red knurled knob, found on the pressure controller, three complete turns clockwise.

The g-suit is inflated to apply pressure to the crewmember's lower body to prevent the pooling of blood and to aid in maintaining circulating blood volume. Pooling of blood can occur when high g-loads are imposed on the body and is particularly noticeable after the crewmember has had 3 days or more of zero-g.

Inflation of the g-suit is controlled at the O₂ manifold/g-suit controller (one piece), located on the upper left leg. This assembly consists of the following components, referenced to the illustration below:

- a. A male O₂ hose fitting that connects to the orbiter O₂ supply hose. It is provided with a breakaway fitting to facilitate rapid egress from the vehicle.

- b. A second male O₂ hose fitting that connects the manifold with the emergency O₂ bottles in the crewmember's parachute harness.
- c. A third (threaded) male O₂ hose fitting that connects the manifold with the demand regulator for crew-member respiration.
- d. **The g-suit controller.** When the manifold is connected to orbiter O₂, and the knurled knob is rotated clockwise (in the direction of the arrow), the controller inflates the g-suit bladders 0.5 psi per complete turn, to a maximum pressure of 2.5 psi. A one-way valve inside the manifold prevents the g-suit from inflating with emergency O₂, which is reserved for breathing. Rotation of the knob counterclockwise will deflate the g-suit bladders 0.5 psi per complete turn. Each complete revolution of the knob is indicated by a slight detent.
- e. **The g-suit controller clip.** When pulled free, the clip will trap the current volume of O₂ inside the g-suit bladders and prevent any deflation, even when the O₂ manifold is disconnected from orbiter O₂. Reinstallation of the clip will allow a normal deflation of the g-suit bladders.



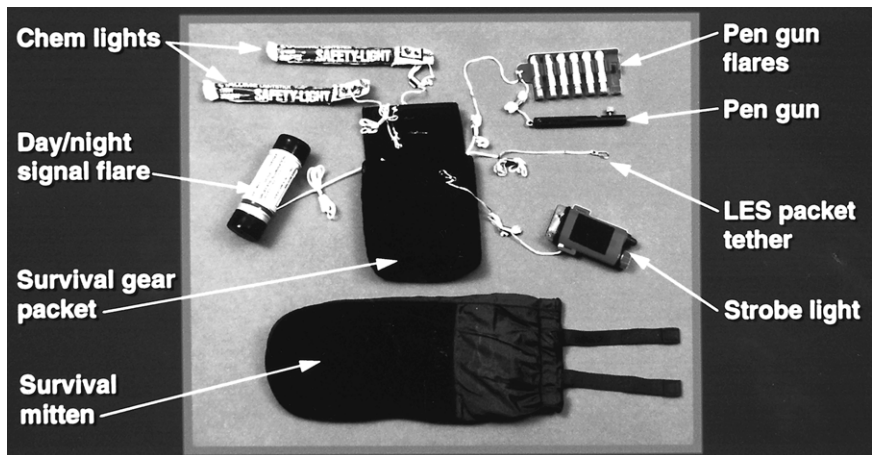
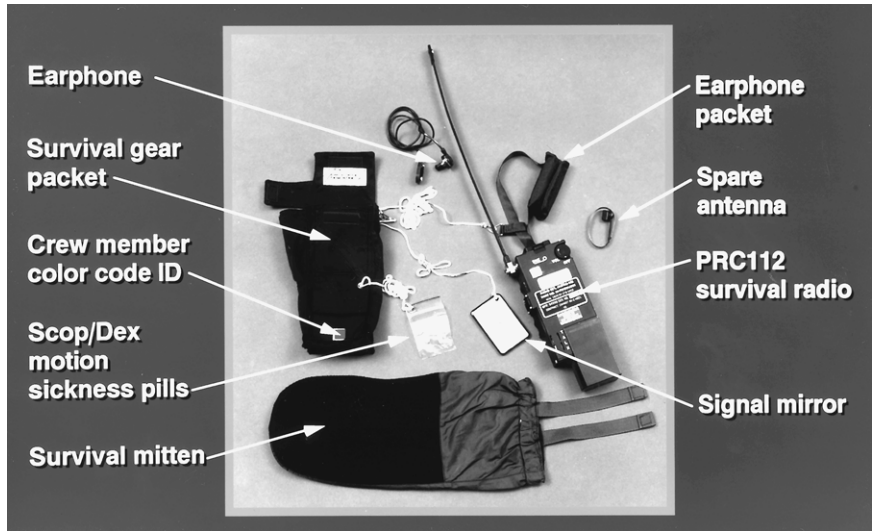
O₂ Manifold/G-Suit Controller

An internal pressure relief valve vents g-suit pressure in excess of 3.2 psi into the partial pressure bladders, where it will either be held or vented out of the suit, depending on cabin pressure.

Crewmembers can wear a liquid cooling garment (LCG) underneath either suit. The LCG mates to a thermal electric liquid cooling unit (TELCU) mounted on the crewmember's seat. The LCG and the TELCU combine to reduce heat stress during launch and entry. The TELCU replaced the suit fan for cooling crewmembers. However, spare suit fans are still available as a backup cooling option if a TELCU should fail before launch.

Survival gear is located in both of the lower leg pockets for either suit.

In addition to the suit, the crewmember wears a helmet and communications cap. The helmet attaches to a neck ring on the pressure suit. Once locked into the neck ring, the helmet swivels from side to side. Closing the pressure visor and locking it with the bailer bar seals the helmet cavity. A tinted sunshade is mounted to the outside of the helmet and can be manually raised or lowered independent of the clear visor. The helmet also contains an antisuffocation valve, located at the lower right rear of the helmet. It permits ambient air from outside the helmet to enter when the visor is closed, and breathing oxygen is not available. The valve opens when the pressure inside the helmet is 1.5 inches of water pressure less than that outside, which occurs whenever the crewmember inhales with the visor closed and there is no oxygen supply.



Survival Gear

The communications cap contains all necessary equipment for voice communication. The microphones and earphones are included in the cap. The communications cap has dual/redundant microphones and one set of dual/redundant earphones. There is a pigtail on the back of the cap that attaches to the inside of the helmet via a connector. From there, the cable passes through the helmet and connects to a standard headset interface unit, which in turn connects to the orbiter communications system via a cable. There are dual/redundant microswitches in the helmet that deactivate the microphones in the communications cap during oxygen flow to the helmet (inhalation, open visor, or leaking neck seal).

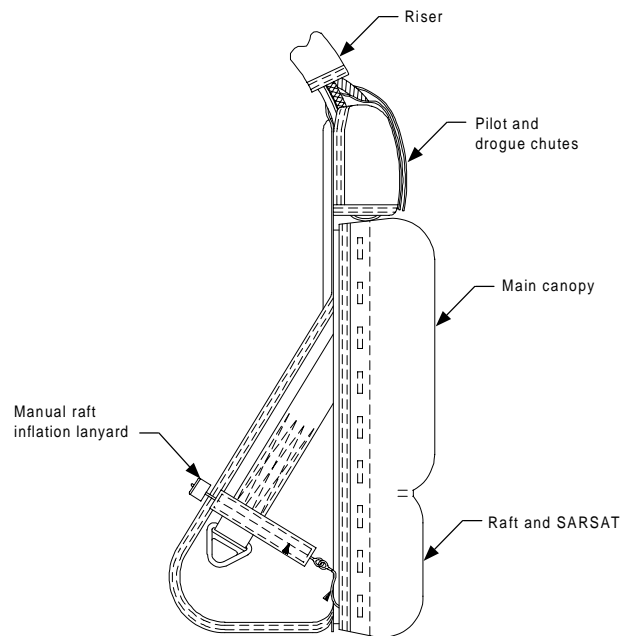
Personal Parachute Assembly

Crewmembers wear the personal parachute assembly (PPA) in the event of bailout. The PPA is designed to work automatically with the crew egress pole system or with manual backups as needed.

The parachute pack contains the parachutes, risers and associated items, a small life raft, and a radio beacon. The pack doubles as a back seat cushion and is already in the orbiter when the crew ingresses prior to launch. There are four connections between the parachute pack and the harness; two riser attach fittings and two ejector snaps. During a bailout, the crewmember needs only to rotate the lap belt connector to release the shoulder harness/lap belt to egress the seat, taking the parachute with him. Upon water landing, two standard U.S. Air Force seawater activated release system (SEAWARS) units, one for each riser, are used to release the risers and canopy from the harness. For a ground egress, the crewmember releases the four parachute attach points and leaves the parachute pack in the seat. The parachute pack contains the following items:

- Automatic and manual pilot chute deployment system
- Drogue chute release knob
- An 18-inch-diameter pilot chute
- A 4.5-foot-diameter drogue chute

- A 26-foot-diameter main canopy
- Deployment sleeve
- Automatic actuation device (AAD)
- Life raft compartment
- Life raft
- SARSAT personnel locator beacon



419.cvs

Parachute Pack (Side)

The parachute harness is a modified U.S. Navy MA-2 harness. The harness contains an interwoven system of nylon straps, providing complete body support for crewmembers during bailout, emergency egress, and rescue operations. In addition to the support straps, the harness also includes the following items that may prove necessary in an emergency:

1. Two bottles of oxygen for emergency breathing are woven into the back of the harness, and contain a total of 401 liters of oxygen at 14.7 psi. At 38 liters per minute of moderate use, the oxygen will last for 10 minutes at sea level and several times that at high altitudes.

2. A carabiner, attached to the left side of the harness, is an oval aluminum ring for attaching descent devices. The carabiner is used during emergency egress and rescue from the orbiter when it is on the ground.
3. A life preserver unit (LPU) encircles the crewmember's upper torso. It inflates automatically via a CO₂ cartridge when submersed in water. It may also be inflated manually. The unit is designed to keep an unconscious crewmember's head out of the water.
4. Sixteen individual packages contain two liters of emergency drinking water.

The primary method of deploying the pilot chute is by using the automatic bailout sequence. The extraction bridle is connected to a bailout lanyard located on the crew escape pole. As the crewmember descends the pole, the loads placed on the bridle/lanyard assembly activate two pyrotechnic systems. The first system separates the bridle/lanyard from the parachute pack, while the second system cuts the cord holding the pilot chute flap closed. As the flap opens, the spring-loaded pilot chute is allowed to deploy. The secondary system for deploying the pilot chute consists of a manual parachute ripcord handle and a single light duty pyrotechnic cutter.

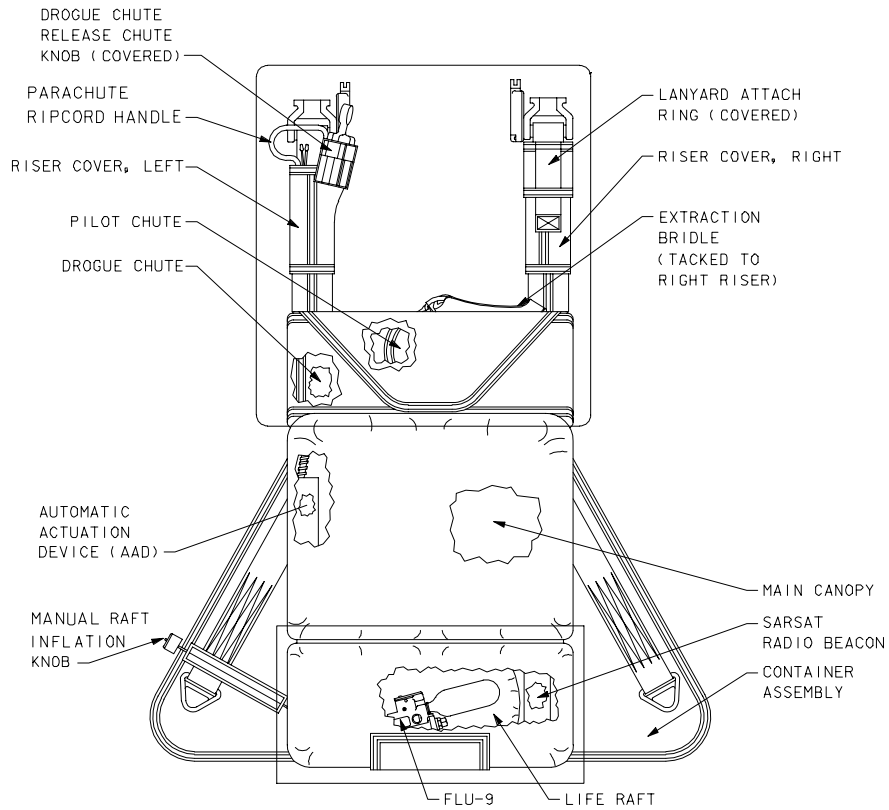
The function of the pilot parachute is to deploy the drogue parachute. The pilot parachute, located in the upper section of the pack, is a spring-loaded, internally vaned, flat circular parachute. Upon activation either through the automatic sequence or manual function, the pilot parachute is released from its closure. The pilot parachute then moves into clean air away from the crewmember providing the force for deploying the drogue chute and arming the automatic actuation device.

The drogue parachute functions as a stabilizing device to orient the crewmember in a preferred attitude in order to reduce injury during freefall, and reduce parachute opening deployment

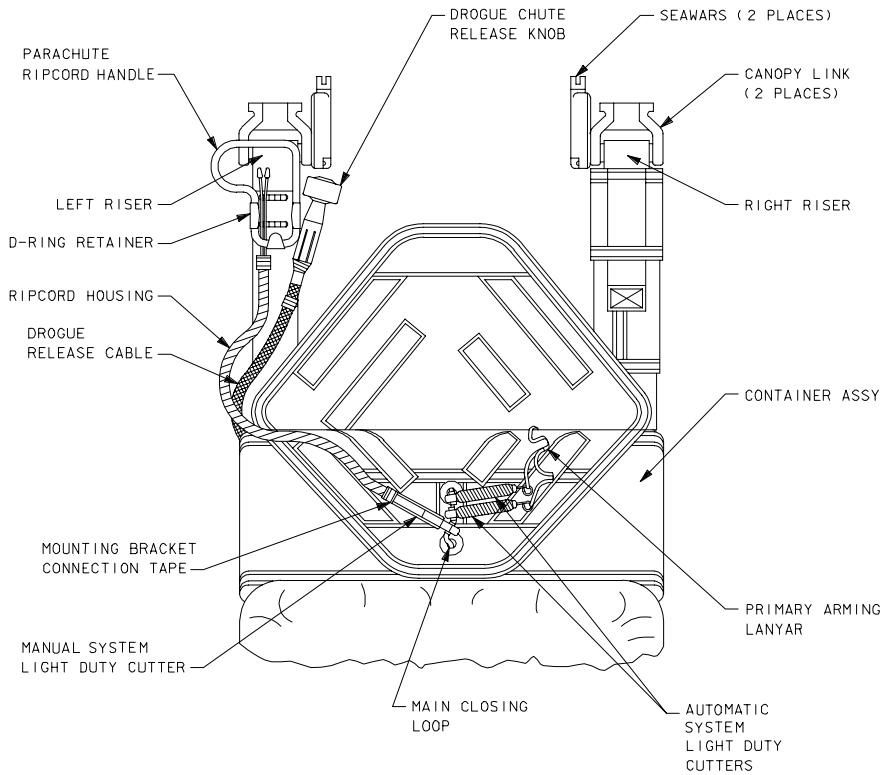
damage. The system, deployed by the pilot chute using a deployment sleeve, consists of a 4.5-foot diameter, ribless, guide-surface parachute. The drogue parachute connects to the pack through a three-ring release mechanism. The release of the first ring allows the second ring to unlock, which in turn unlocks the third ring attached to the drogue riser. Release of the first ring occurs either by the automatic actuation device at 14,000 feet altitude or by the manual drogue chute release knob. Upon release, the drogue parachute functions as a pilot chute for the main canopy, supplying the force through an extraction lanyard for deployment.

The main parachute is a modified version of the Navy, 26-foot, conical canopy with Kevlar reinforcement. A discard line reefing system is added to increase the basic strength and reduce the load to the crewmember during opening shock. Four anti-oscillation windows are added at the base of the canopy to reduce oscillation during descent. The canopy is attached to the risers by 22 suspension lines.

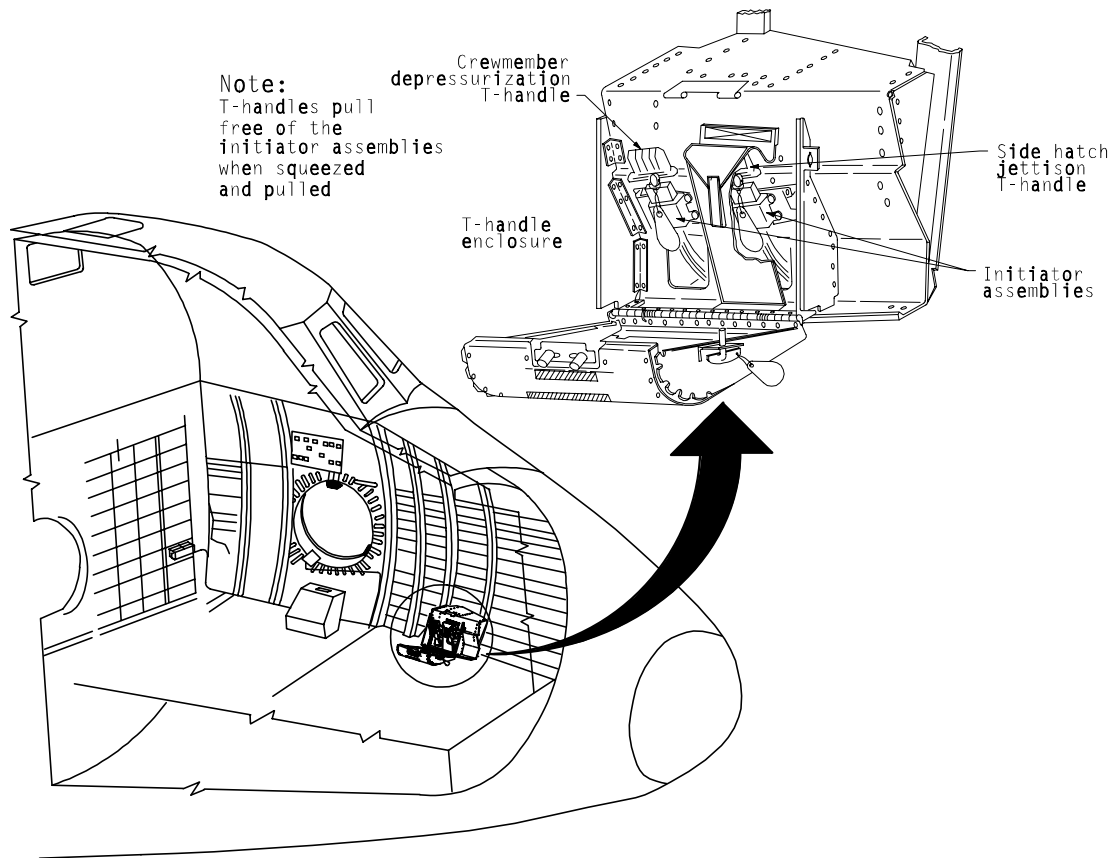
The life raft, made of polyurethane coated nylon, is contained in a separate compartment at the bottom of the parachute pack. This compartment includes the life raft and the SARSAT personnel locator beacon. Life raft inflation is accomplished using a water-activated inflation device for inflating the primary life raft chamber, and a manually activated inflation device for inflating the secondary chamber. As the main canopy pulls the parachute risers out of the pack, redundant cutters in the bottom of the life raft compartment fire, loosening the bottom of the pack. This action holds the raft in place during descent and allows the raft to inflate upon water landing. A lanyard is installed on the left side of the pack to manually open the life raft compartment and for manual inflation. Two oral inflation tubes are used for backup inflation. The SARSAT radio beacon is activated by the right parachute riser as it is pulled from the pack by the main canopy. A magnetic plug pulled by the riser activates the beacon, which transmits during crewmember descent. The beacon has a range of 60 miles to aircraft at a 10,000-foot altitude.



Parachute Pack (Back)



Parachute Pack (Back)



Emergency Crew Module Depressurization and Side Hatch Jettison T-Handles

Each crewmember is also armed with additional signalling devices, including a PRC-112 survival radio, a strobe light, a pen-gun flare kit, a hand-held flare, a signal mirror, two 12-hour stick chem-lights, and two packs of sea dye marker. Other survival gear includes drinking water, a knife, and motion-sickness pills.

Crew Escape System Pyrotechnics

The hardware associated with in-flight crew escape consists of several types of pyrotechnics plus the egress pole. The crew escape system pyrotechnics consist of a box with T-handle initiators, a pyro vent valve, and hatch pyrotechnics.

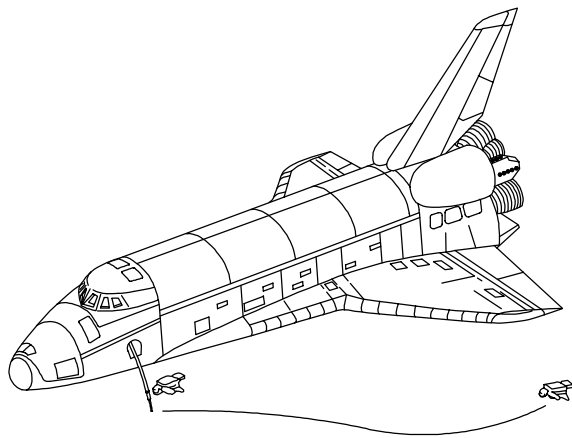
The T-handle box, containing two T-handles, is located on the port forward middeck floor. The aft T-handle activates the pyro vent valve to depressurize the cabin. The forward T-handle jettisons the side hatch. Both T-handles have safing pins through them that must be removed before the handles can be squeezed and pulled. The handles are connected to the pyro vent

valve and the side hatch pyrotechnics via dual lengths of shielded detonating cord. The handles, pyrotechnics, and detonating cord do not require orbiter power.

The pyro vent valve is located behind the waste management compartment, on the port side of the aft bulkhead of the middeck. The purpose of the valve is to depressurize the cabin at a controlled rate prior to jettisoning the side hatch in flight. This is necessary to prevent severe buckling of the middeck floor, which would occur if the side hatch were jettisoned without any attempt to equalize the inside and outside pressure. When activated by squeezing and pulling the aft T-handle, the pyro vent valve opens a 15-square-inch hole between the crew compartment and the payload bay. If it is opened at an altitude of 40,000 feet, approximately 75 seconds are required to lower the pressure in the cabin to that of the ambient air outside the orbiter. Equalization would occur at approximately 31,000 feet. The cabin vent pyros are an ignition source in the payload bay and should not be used for post landing egress.

Three separate sets of pyrotechnics are associated with the side hatch, all of which are activated simultaneously by squeezing and pulling the forward T-handle. A total of four linear-shaped charges (two per hinge for redundancy) are planted in the side hatch to sever the hinges. Two (redundant) expanding tube assemblies are included to sever the 70 frangible bolts holding the hatch adapter ring to the orbiter. Three (partially redundant) thruster packs are used to separate the hatch from the orbiter at a velocity of approximately 45 ft/sec. The hatch jettison features could be used in a landing emergency.

Egress Pole System



Crew Egress/Wing Clearance

The crew escape system orbiter-based hardware also includes the egress pole - a curved, spring-loaded, telescoping, steel and aluminum cylinder. The purpose of the egress pole is to guide escaping crewmembers on a trajectory that will clear the orbiter's left wing. The pole, extending downward 9.8 feet from the side hatch, is contained within an aluminum housing attached to the middeck ceiling (above the airlock hatch) and at the side hatch 2-o'clock position. The pole is removed from its launch position during orbit procedures and reinstalled for entry. The egress pole weighs about 240 pounds. A magazine holding eight lanyards is attached to the hatch end of the pole. The lanyards are the means by which crewmembers

are guided down the pole. Each lanyard assembly consists of a hook attached to a Kevlar strap that surrounds the escape pole. Five roller bearings on each strap surround the pole and permit the lanyard to roll freely down the pole. The Kevlar thread stitching can break away, providing the crewmember with an energy absorber. The crewmember slides down the escape pole and off the end.

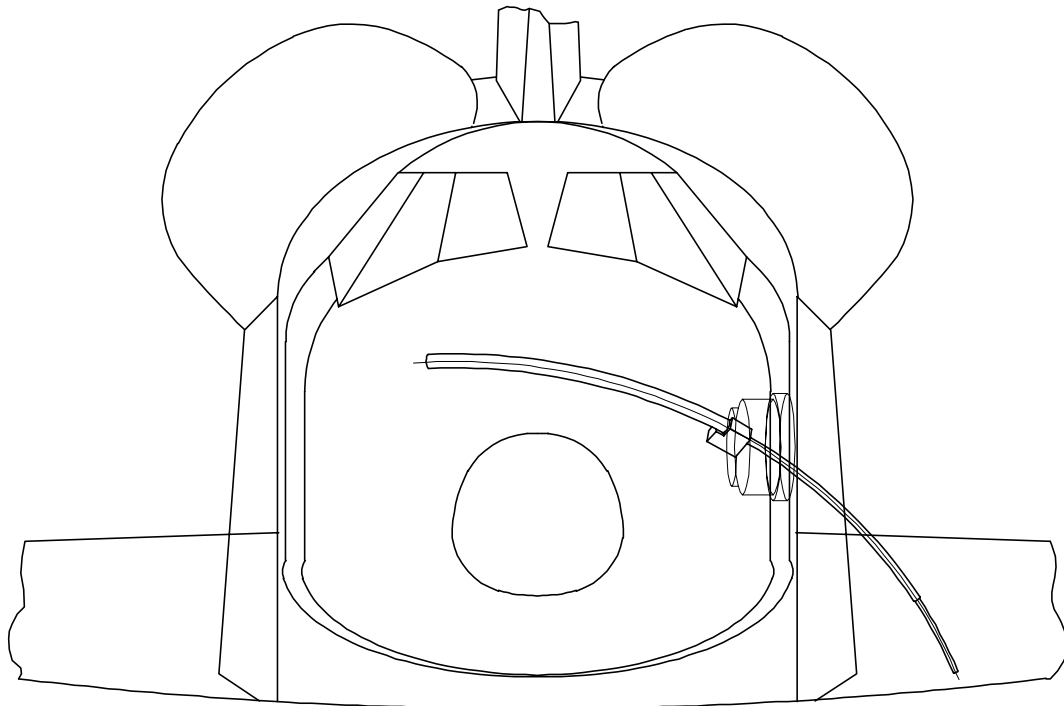
Emergency Egress Slide

The emergency egress slide provides a rapid and safe orbiter egress during post landing contingency or emergency situations. The slide allows the safe egress of the crewmembers to the ground within 60 seconds after the side hatch is fully opened or jettisoned and accommodates the egress of incapacitated crewmembers. The slide may be used after a normal opening of the middeck side hatch or after jettisoning the side hatch. Equipment consists of an inflatable slide, pressurized Argon bottle, aspirator, girt bracket, and slide cover.

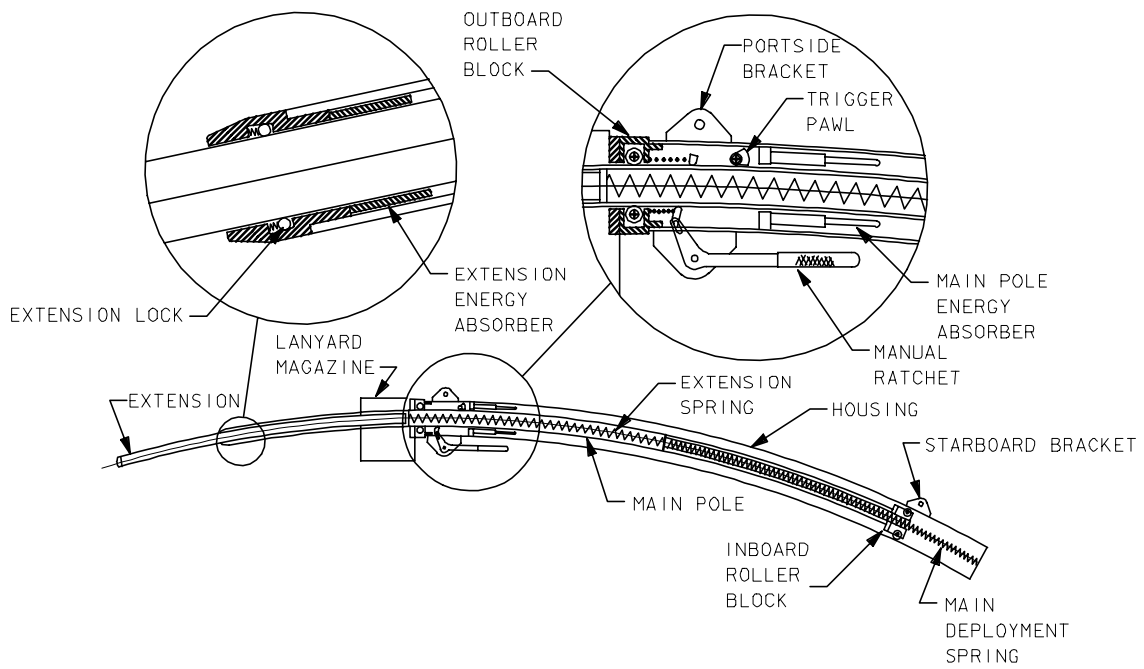
The system is configured manually by removing the slide from its stowed location below the middeck and attaching it to the side hatch if the hatch has not been jettisoned, or rotating the slide into the opening if the hatch has been jettisoned. The slide is inflated by pulling a lanyard that activates an Argon bottle pressurized to 3,000 psi. The slide inflates to approximately 2.75 psig. A relief valve bleeds off pressures greater than 3.0 psig.

The flight crewmembers egress wearing their launch entry suit. The slide remains functional in the egress environment for a minimum of 6 minutes after deployment and can be released from the side hatch to permit fire truck access.

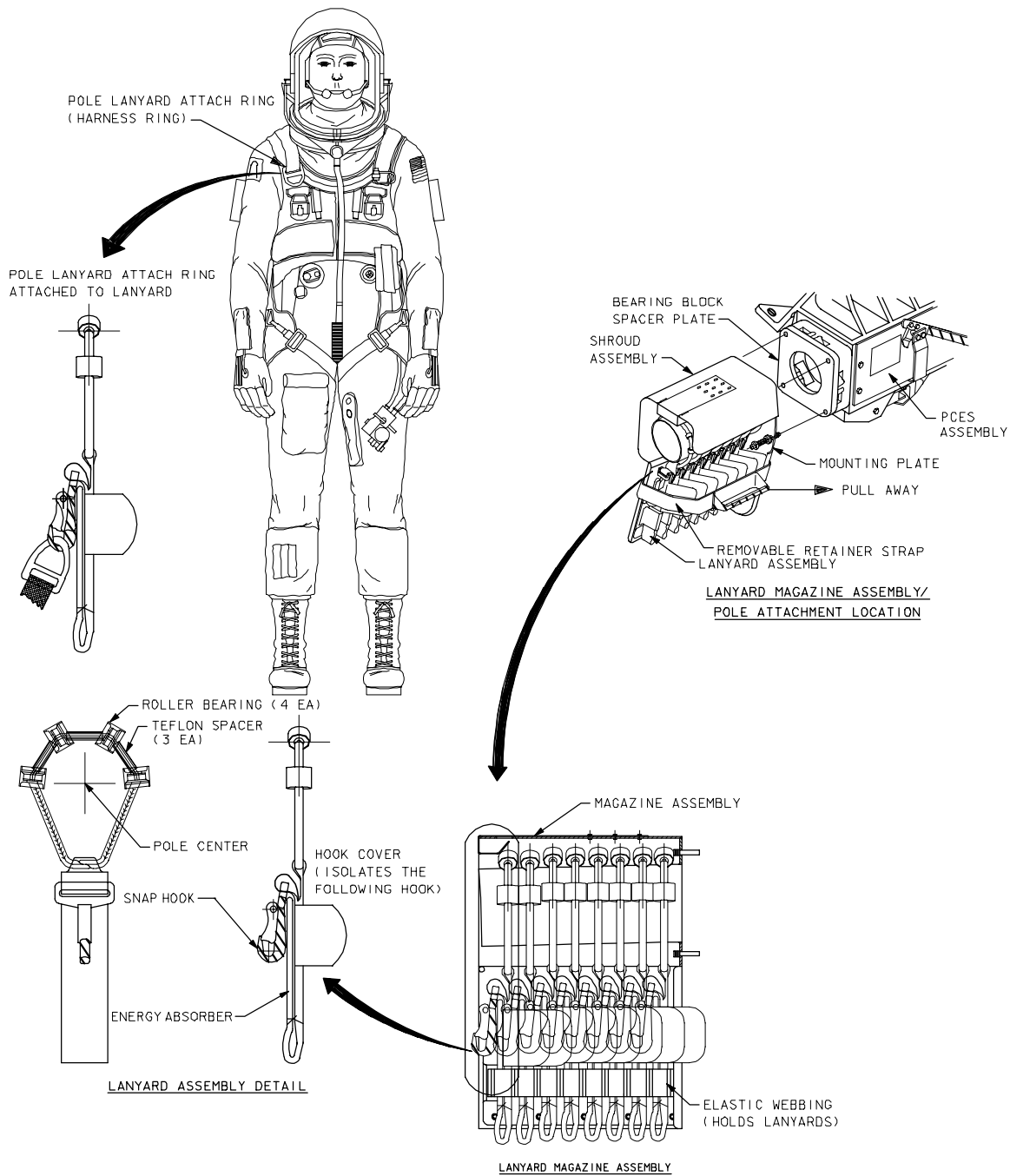
The emergency egress slide replaces the emergency egress side hatch bar, which required the flight crewmembers to drop approximately 10.5 feet to the ground. This drop could cause injury to the flight crew and prevent an injured crewmember from moving to a safe distance from the orbiter.



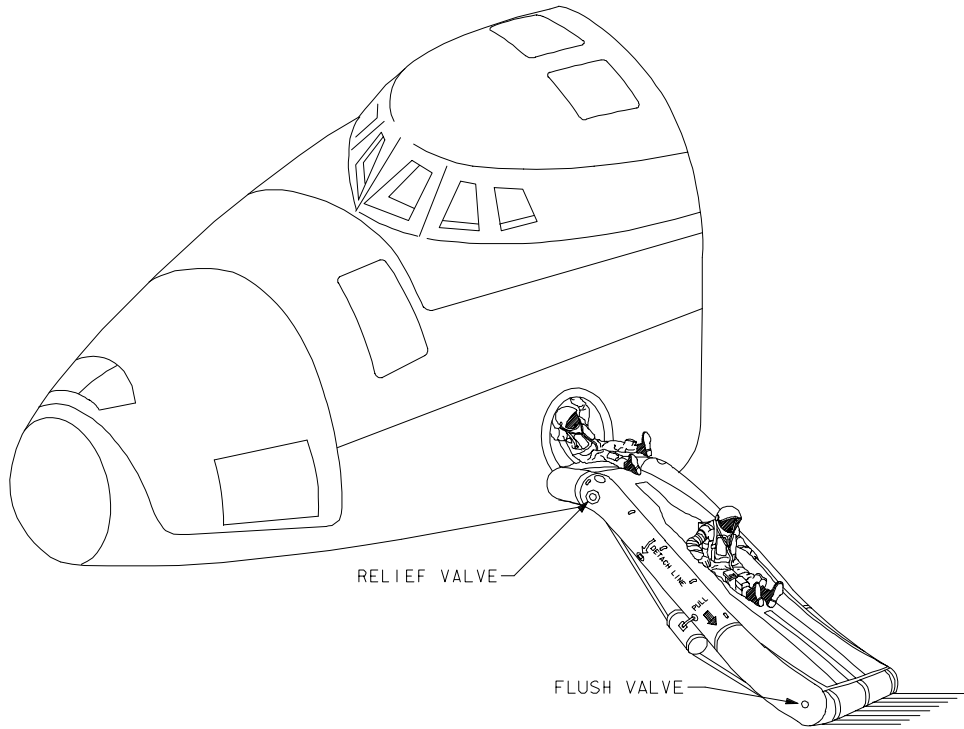
DEPLOYED POLE
(LOOKING AFT)



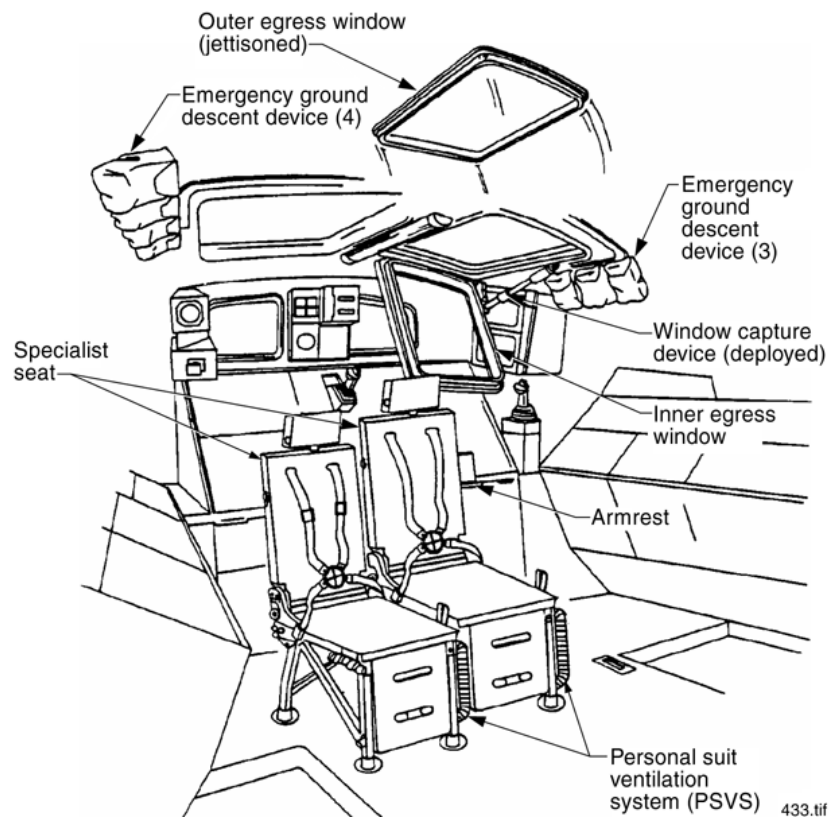
Deployed Pole Assembly



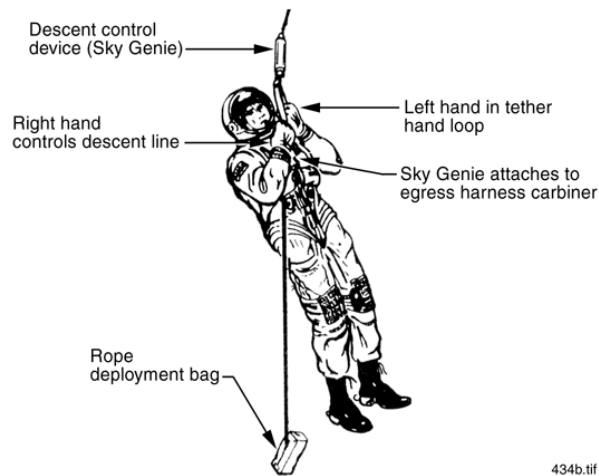
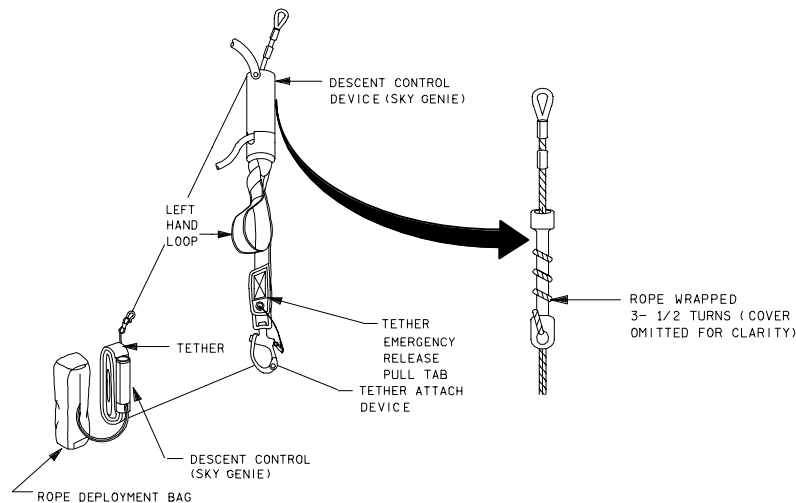
Lanyard Magazine Assembly



Emergency Egress Slide with Side Hatch Jettison



Overhead Egress Window Jettisoned



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Descent Control Device

Secondary Emergency Egress

In the event that egress through the side hatch is not possible, the port side flight deck overhead window (window 8) provides the flight crew with a secondary emergency egress route. This overhead window consists of three panes of glass, two panes attached to the crew compartment and one attached to the upper forward fuselage. The overhead window jettison system consists primarily of expanding tube assemblies, mild detonating fuses, frangible bolts, and associated initiators.

Pulling the T-handle located forward of the flight deck center console (C3) activates the overhead window jettison system. When initiated, the outer pane is jettisoned upward and aft. A time delay in the pyrotechnic firing circuit delays the initiation of the jettisoning of

the inner pane 0.3 second after the outer pane is jettisoned. The inner window pane rotates downward and aft into the crew compartment aft flight deck on hinges located at the aft portion of the window frame. A capture device attenuates the opening rate and holds the window in position. This overhead window jettison system can also be initiated from the outside of the orbiter on the starboard side of the forward fuselage by ground personnel.

Crewmembers use the MS2 seat (seat 4) to climb up through the window. Seven emergency ground descent devices (Sky Genies) are stowed on the overhead aft flight deck outboard of each overhead window, one for each flight crewmember. The emergency ground descent device enables crewmembers to lower themselves to the ground over the starboard side of the orbiter.

Procedures for Bailout, Water Survival, and Rescue

The final decision to initiate a bailout rests with the commander. When the commander determines that a bailout is necessary (normally, when the range-to-go exceeds about 50 n. mi. at an altitude of 55,000 feet), the commander places the orbiter in a minimum-sink-rate attitude and engages the autopilot. At 40,000 feet, the commander directs the crew to close their visors and activate emergency oxygen, and for MS 3 (seated in the forward left seat in the middeck) to open the pyro vent valve. At an altitude of 31,000 feet the cabin pressure is about equalized with the outside atmosphere. Shortly thereafter, the commander directs MS3 to jettison the side hatch. As soon as the hatch is jettisoned, all crewmembers unstrap from their seats and break their oxygen, cooling, and communication connections.

MS3 deploys the egress pole by pulling the safing pin and arming pin and rotating the handle counterclockwise. Should the pole fail to deploy fully, the manual ratchet is used to manually extend the pole. The exit involves each crewmember attaching the lanyard hook assembly to the parachute harness and egressing through the side hatch opening. It takes approximately 2 minutes for a maximum crew of eight to bailout. After the first crewmember bails out from the middeck, the remaining crewmembers follow until all are out.

As each crewmember exits the orbiter, the force exerted by entering the windstream activates the automatic bailout sequence. Once the crewmember is off the pole and away from the orbiter (1.5 second delay), a pyrotechnic cutter separates the bridle and lanyard. The 18-inch pilot chute is deployed 1.5 seconds later, and immediately deploys the 4.5-foot drogue chute. The drogue chute stabilizes the crewmember down to an altitude of 14,000 feet, then deploys the main canopy.

Prior to a water landing, the crewmember pulls the manual inflation tab for the life preserver unit. The unit is designed to inflate automatically upon immersion in any type of water, but should be activated manually as an additional safeguard. Upon landing in saltwater, the SEAWARS automatically releases the crewmember from the parachute risers. At the same time, the life raft automatically deploys and

inflates. The crewmember's first task is to deploy the sea anchor and get into the life raft. Next, the crewmember pulls the activation tab on the upper CO₂ cylinder to inflate the upper chamber. Raft bailing proceeds by either using the spray shield, the bailing cup, or the bailing pump.

The crewmember's next task is to unpack the signaling equipment. The SARSAT personnel locator beacon is the primary signaling device. It is located on the raft spray shield. The telescoping antenna is extended, and the flexible antenna is removed. The PRC-112 is used to monitor 282.8 MHz and establish voice contact with search and rescue forces.

The arrival time of the search and rescue forces depends on where the bailout occurred. The first rescue force to arrive will probably be a C-130 transport aircraft, specially equipped for search and rescue. Two teams are dropped, each consisting of three rescue jumpers in a motorized rescue boat. One team drops to each end of the line of orbiter crewmembers. The C-130 may also drop two 20-person rafts for the assembled crewmembers and rescue personnel to wait in until rescue helicopters arrive.

Although no formal requirements exist for crewmembers to bail out of the orbiter during uncontrolled flight, they may be able to do so under certain circumstances. The pyro vent and hatch jettison pyrotechnics do not require orbiter power to function and can be activated even if orbiter power is lost. Each crewmember is wearing his or her own emergency oxygen bottles and parachute, and if the crew cabin were not spinning rapidly, at least some crewmembers should be able to get to the side hatch and get out.

In the case involving loss of orbiter control, the crewmembers should activate their emergency oxygen as soon as possible and then evaluate the situation. If the crew module is lofting to altitudes above 40,000 feet, the crew should remain within it until it passes through 40,000 feet on the way back down. If the cabin is depressurized, the LES/ACES can be used to judge the bailout altitude of 40,000 feet.

The escape pole is intended for use only during controlled gliding flight, and its use should not be attempted during an uncontrolled bailout. Once out of the orbiter, crewmembers should pull their parachute ripcord handle to activate the automatic opening sequence for their parachutes.

Escape Systems Summary Data

- Escape systems refer to equipment and systems intended to facilitate emergency egress of the flight crew. Escape systems include equipment worn by the crewmembers, hardware built into the orbiter, and external systems located on the launch pad.
- Escape by the flight crew on the launch pad is facilitated by descending to a safe area via slidewire baskets. The launch pad structure also includes an escape temperature and hydrogen fire-hazard monitoring system and a Firex spray system for water shower .
- The LES or ACES are designed to protect crewmembers from (1) loss of cabin pressure and/or orbiter oxygen at altitudes of up to 100,000 feet, (2) cold atmospheric and/or water temperatures after bailing out, (3) pooling of blood in the lower body, and (4) contaminated atmosphere during flight or post-landing procedures.
- The personal parachute assembly is worn by the crew in the event of bailout. It is designed to work automatically with the crew egress pole system or with manual backups as needed.
- The hardware associated with the orbiter for purposes of in-flight crew escape consists of several types of pyrotechnics plus the egress pole.
- Three separate sets of pyrotechnics are associated with jettisoning the side hatch, all of which are activated simultaneously by squeezing and pulling a T-handle.
- The purpose of the egress pole is to guide escaping crewmembers on a trajectory that will clear the orbiter's left wing.
- The emergency egress slide is intended for use after a normal opening of the middeck side hatch or after jettisoning of the side hatch at the nominal end-of-mission landing site or at a remote or emergency landing site.
- In the event that egress through the side hatch is not possible, the port side flight deck overhead window (W8) provides the flight crew with a secondary emergency egress route.
- The commander may decide a bailout is necessary, if the range-to-go exceeds about 50 n. mi. at an altitude of 55,000 feet. The orbiter is placed in a minimum-sink-rate attitude on autopilot.
- Bailout includes using the escape pole to leave the orbiter, deploying the parachute for descent, and inflating the life raft for a water recovery. Special survival gear and procedures are provided in the case of a bailout.

2.11 EXTRAVEHICULAR ACTIVITY (EVA)

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Description

An EVA occurs when a crewmember leaves the protective environment of a spacecraft's pressurized cabin and ventures out into the vacuum of space wearing a space suit. An EVA is commonly referred to as a spacewalk. The current space suit, designed for a total maximum duration of 7 hours, provides environmental protection, mobility, life support, and communications. Two suits are included in each baseline

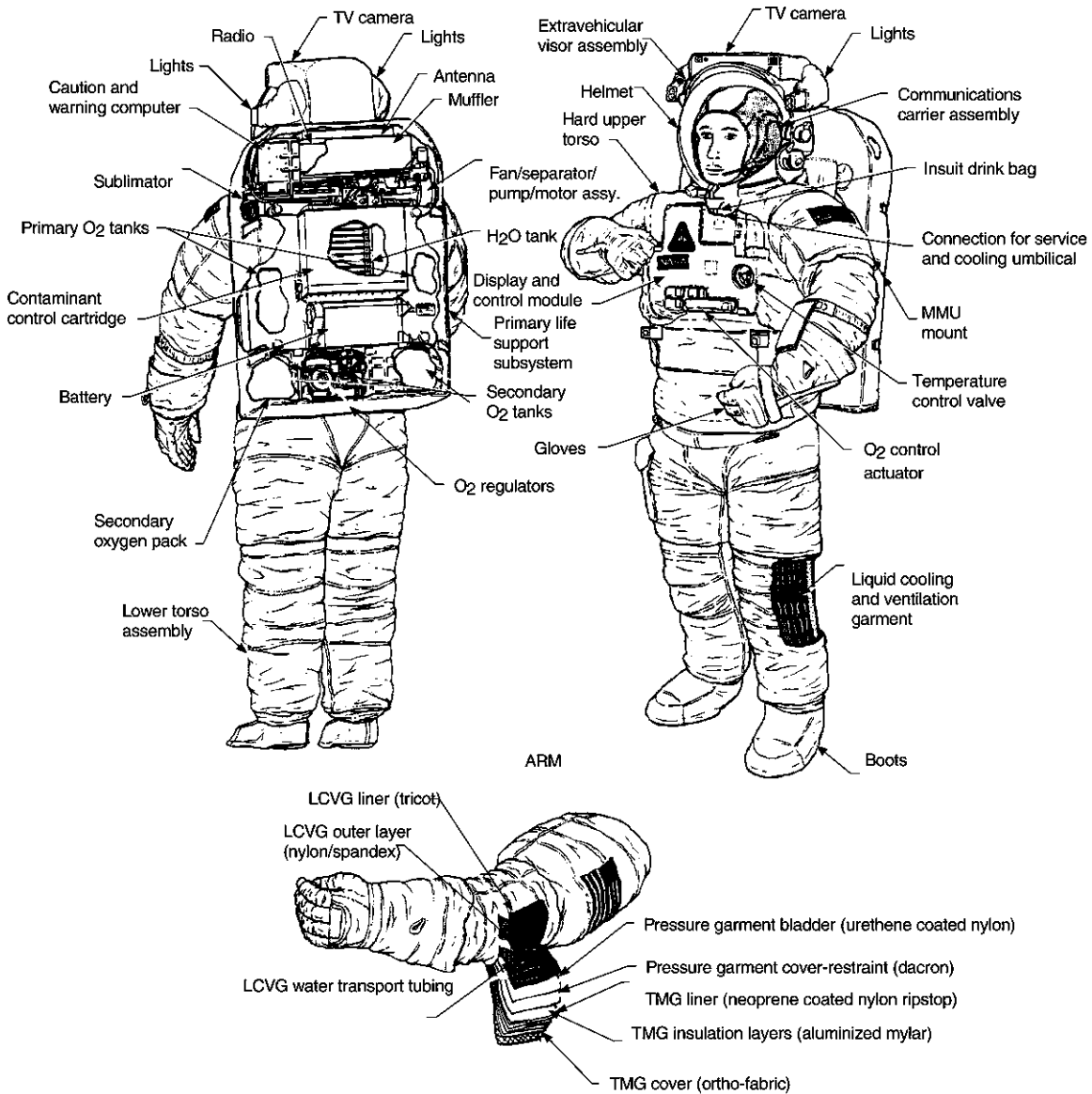
orbiter mission, and consumables are provided for three two-person, 6-hour EVAs. Two EVAs are available for payload use, with the third reserved for orbiter contingency operations. EVA has been demonstrated to be useful in satellite repair, retrieval, and refueling as well as with space station development.

There are three basic categories of EVA: scheduled, unscheduled, and contingency. A scheduled EVA is defined as any EVA incorporated into the nominal flight plan in order to complete a specific mission objective. An unscheduled EVA is not part of the flight plan; rather, it is conducted to achieve payload operation success or to advance overall mission accomplishments. A contingency EVA is also unscheduled, but is required to ensure safe return of the orbiter and flight crew.

A subcategory of scheduled EVA is the quick-response EVA. A quick-response EVA must be performed within a few hours after a problem is discovered, and it is usually associated with payload deployment. Quick-response EVAs are planned pre-flight, and the crew prepares for the EVA even though it may not be performed.

Mission	Date	Purpose of EVA	EVA crew	No. EVA/mission	Duration, man-hours
STS-6	Apr 4-9, 83	System Functional Demo	Musgrave/Peterson	1	8 hr, 34 min
STS-41B	Feb 3-11, 84	MMU Capability Demo	NcCandless/Stewart	2	23 hr, 14 min
STS-41C	Apr 6-13, 84	Solar Max Satellite Repair	Van Hoften/Nelson	2	20 hr, 12 min
STS-41G	Oct 5-13, 84	Orbiter Fuel Transfer Demo	Leestma/Sullivan	1	6 hr, 58 min
STS-51A	Nov 8-16, 84	Westar/Palapa Satellite Retrieval	Allen/Gardner	2	24 hr, 28 min
STS-51D	Apr 12-19, 85	Syncome F3 Satellite Repair	Griggs/Hoffman	1	6 hr, 20 min
STS-51I	Aug 27-Sep 3, 85	Syncome F3 Satellite Repair	Fisher/Van Hoften	2	23 hr, 42 min
STS-61B	Nov 26-Dec 3, 85	Large Structure Assembly	Spring/Ross	2	24 hr, 40 min
STS-37	Apr 5-10, 91	GRO Satellite Repair/Locomotion Studies	Ross/Apt	2	20 hr, 58 min
STS-49	May 10-14, 92	Intelsat Repair and Assembly of Station by EVA Methods (ASEM)	Thuot, Hieb, Akers, Hornton,	4	59 hr, 51 min
STS-54	Jan 17, 93	First EVA Detailed Test Objective (DTO 1210)	Harbaugh, Runco	1	8 hr, 56 min
STS-57	Jun 25, 93	EURECA Antenna Stow and Second EVA DTO (1210)	Low, Wisoff	1	11 hr, 40 min
STS-51	Sep 16, 93	Third EVA DTO (1210)	Walz, Newman	1	14 hr, 10 min
STS-61	Dec 4-8, 93	Hubble Space Telescope Repair Mission	Musgrave, Hoffman, Akers, Thornton	5	70 hr, 58 min
STS-64	Sep 16, 94	SAFER First Flight	Lee, Meade	1	13 hr, 42 min
STS-63	Feb 9, 95	First EVA Development Flight Test (EDFT) (Spartan Mass Handling)	Foale, Harris	1	13 hr, 18 min
STS-69	Sept 16, 95	Second EDFT (Task board with station EVA interfaces)	Voss, Gernhardt	1	13 hr, 32 min
STS-72	Jan 14-16, 95	Third EDFT (Station assembly and maintenance hardware)	Chiao, Barry, Scott	2	26 hr, 4 min
STS-76	Mar 27, 96	Fourth EDFT (MEEP - Mir Environmental Effects Payload)	Godwin, Clifford	1	12 hr, 4 min

Space Shuttle EVA Chronology



435.cvs

Extravehicular Mobility Unit

Extravehicular activities are classified according to level of complexity: simple, intermediate, or complex. A simple payload EVA requires minimal unique tools, mockups, or mobility aids. Existing procedures and techniques may be adapted to particular EVA needs, thus requiring minimal crew training. An intermediate payload EVA requires development of new tools and equipment. Some procedure and technique development is required, with more extensive training necessary. A complex payload EVA requires the design and development of complex or elaborate tools and equipment. The tasks require extension of basic capabilities and

may pose difficulty in access or restraint. Procedure and technique development is extensive, as are crew training requirements.

Extravehicular Mobility Unit

The extravehicular mobility unit (EMU) is an independent anthropomorphic system that provides environmental protection, mobility, life support, and communications for the crewmember to perform EVA in Earth orbit. For EMU design considerations, an EVA is defined as any time the EMU external environmental pressure is below 4.0 psia. The EMU is designed to

accommodate an EVA mission with a total maximum duration of 7 hours, consisting of 15 minutes for egress, 6 hours for useful EVA tasks, 15 minutes for ingress, and a 30-minute reserve. The EMU also accommodates specific metabolic rate limits, including (1) an average metabolic rate not exceeding 1600 Btu/hr in any given EVA hour and not exceeding 1000 Btu/hr for the entire duration, (2) a peak metabolic rate not exceeding 2000 Btu/hr for a period of 15 minutes, and (3) a minimum metabolic rate not less than 400 Btu/hr for a period of 30 minutes. The EMU is an integrated assembly, primarily composed of the space suit assembly, life support system, and numerous items of associated support and ancillary equipment.

Space Suit Assembly

The space suit assembly (SSA) is the anthropomorphic pressure vessel that encloses the crewmember's torso, limbs, and head. The SSA provides a variety of functions while the crewmember performs an EVA, including suit pressure retention, crewmember mobility, crewmember liquid cooling distribution, oxygen ventilation gas circulation, downlink of crewmember's electrocardiogram data via EMU radio, crewmember interface with EMU radio, crewmember in-suit drinking water, and urine containment. The SSA operates under specific pressure requirements and leakage criteria.

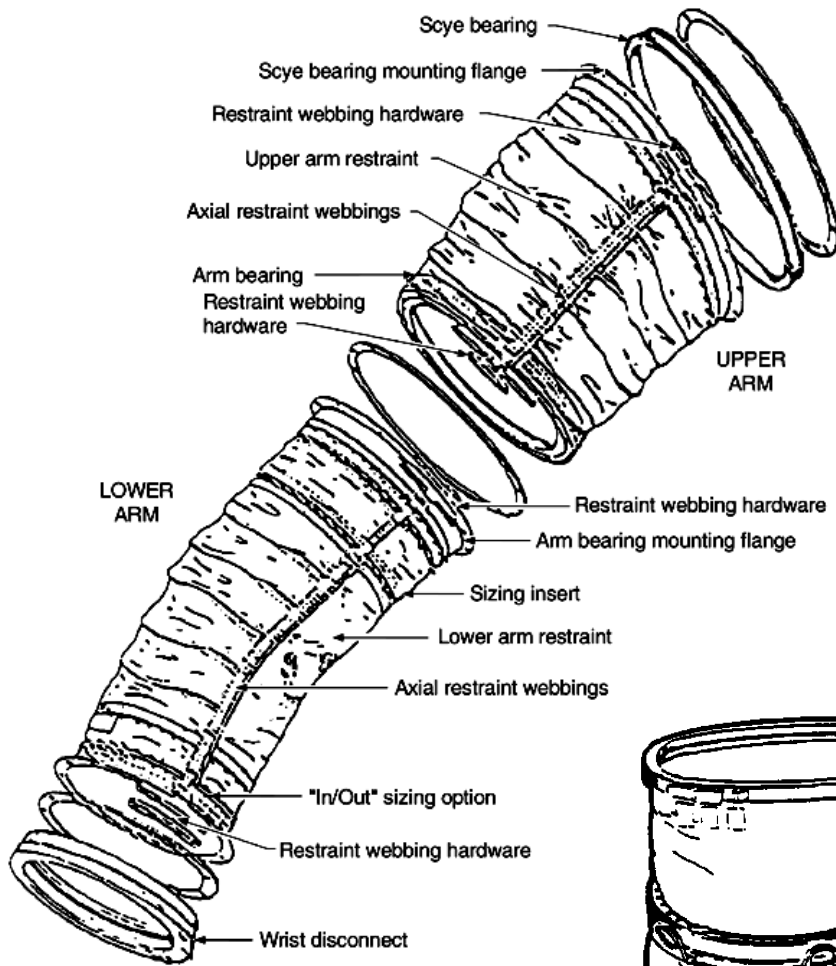
The space suit assembly consists of the following:

- Hard upper torso/arms
- Lower torso assembly
- Extravehicular gloves
- Helmet/extravehicular visor assembly
- Liquid cooling and ventilation garment
- Operational bioinstrumentation system
- Communications carrier assembly
- In-suit drink bag
- Urine collection device
- Maximum absorption garment.

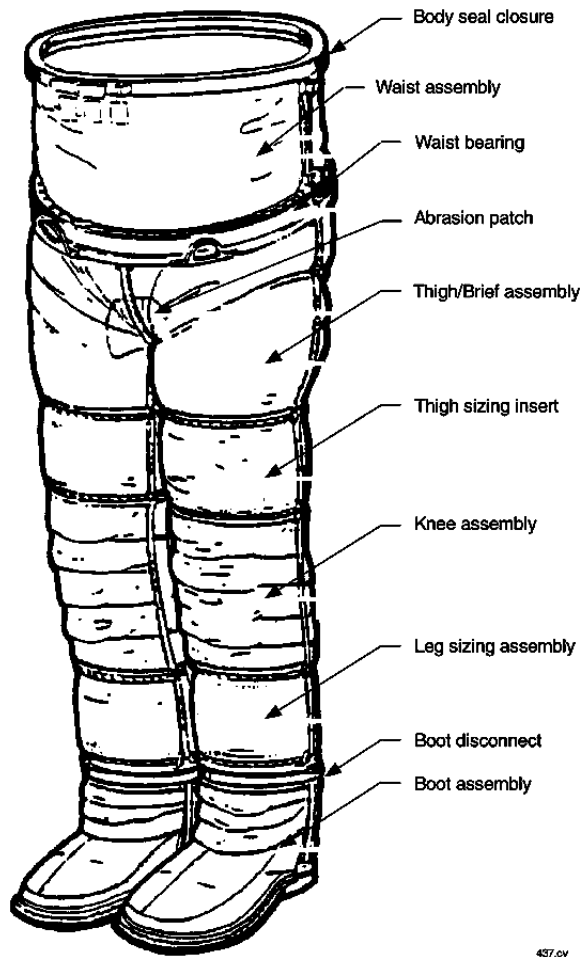
The hard upper torso (HUT) provides pressure containment for the upper torso as well as being the central component from which the mechanical, electrical, and fluid interfaces of the EMU branch. The HUT is available in four sizes to accommodate 5th through 95th percentile-sized crewmembers. The planar HUT, which deletes the arm gimbal and bellows assembly, will be available in two sizes. The HUT includes the following components: fiberglass shell (with water tubes and oxygen ducts), assorted mounting brackets, waterline and vent tube assembly, multiple water connector, EMU electrical harness, shoulder bearing assemblies, waist disconnect ring (passive half), helmet disconnect ring, and thermal micrometeoroid garment (TMG). The right and left arm assemblies are flexible, anthropomorphic pressure vessels that encompass the arms. Each arm assembly includes the following components: upper arm assembly, rotating scye bearing, lower arm assembly, rotating arm bearing, wrist disconnect ring, urethane pressure bladders, cloth restraint systems, and TMGs for the upper and lower arm assemblies.

The lower torso assembly (LTA) consists of a flexible anthropomorphic pressure vessel that encompasses the waist, lower torso, legs, and feet. The LTA includes the following components: waist assembly, waist disconnect ring, trouser assembly, rotating waist bearing between the waist and trouser assemblies, boot assembly, urethane pressure bladders, cloth restraint systems, and TMGs for the waist, trouser, and boot assemblies.

The current sizing of the arm/leg assemblies is accomplished on the ground using different sizes of each assembly for a particular crewmember. An enhanced EMU has been developed to provide an on-orbit capability of EMU resizing by using various arm/leg segments and sizing rings. The on-orbit quick-sizing capability, uses threaded quick-disconnects, softgood sizing elements, aluminum sizing rings, and adjustable-length restraint lines. This suit incorporates dual lip seal mobility bearings and low-torque fabric joints. The enhanced EMU will phase out the current space suit for future station and shuttle operations.

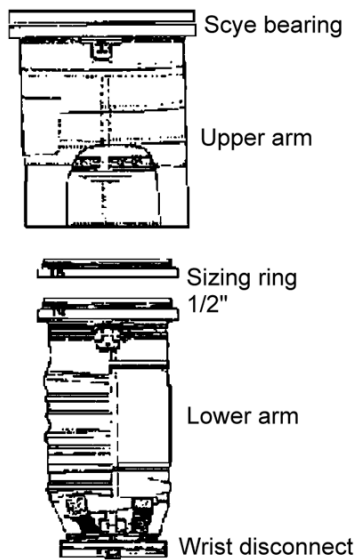


SSA Arm Assembly



Lower Torso Assembly with TMG Removed

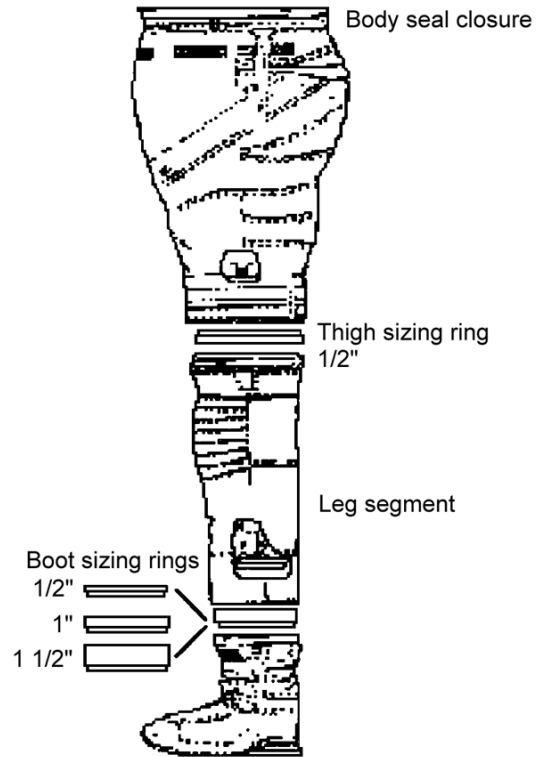
The extravehicular gloves consist of a detachable, flexible pressure vessel, encompassing each hand for use during EVA. The extravehicular gloves include the following components: urethane pressure bladder and cloth restraint system, wrist disconnect ring with rotating wrist bearing, wrist gimbal ring, adjustable palm restraint bar/strap, wrist tether strap, and TMG with palm restraint bar. The current 4000 series gloves incorporate a standard nine-size system to size the gloves for a comfortable fit. The glove fingers use a sizing feature that consists of a pair of polyester dacron cords to provide finger length adjustments. Customized gloves can be manufactured for the crewmember if a proper fit cannot be obtained from the standard size glove.



Enhanced Arm Assembly

The helmet, a "one-size-fits-all" model, consists of a detachable, transparent, hard pressure vessel encompassing the head. The helmet includes the following components: hard transparent bubble, helmet disconnect ring, helmet purge valve, and vent pad. Two crew optional items are also available for the helmet. One of these items is the Fresnel lens, which is mounted to the lower front inside of the helmet to improve display control module visibility for the crewmember. The other item is the valsalva device, attached to the inside of the bubble, which allows the crewmember to clear his or her ears during pressure changes. The extravehicular visor assembly (EVVA) attaches to the helmet to provide the crewmember with visual,

thermal, impact, and micrometeoroid protection. The EVVA includes the following components: clear protective visor, sun visor, center and side eyeshades, fiberglass shell, and latch mechanisms and supporting structure for the visor and eyeshades.



Enhanced Lower Torso Assembly

The liquid cooling and ventilation garment (LCVG) is a form-fitting elastic garment worn against the crewmember's body. The LCVG includes the following components: outer restraint fabric, inner liner assembly, crew optional comfort pads, biomed pocket, dosimeter pocket, water tubing network, paramanifold assembly, ventilation ducting network, vent plenum assembly, multiple water connector, and full torso zipper. The garment supports a network of tubing that circulates water over the body to provide cooling to the crewmember. It also supports a network of ducting that draws ventilation gas from the suit extremities and routes it back to the primary life support system to complete the suit ventilation loop. Connections to the ducting in the HUT for both cooling water and ventilation flow are made at the LCVG half of the multiple water connector. The LCVG is sized to fit the crewmember based on a sizing system with six size ranges.

The communications carrier assembly (CCA) is a cloth aviator-type cap that positions and supports the electronics for interface with the EMU radio for crewmember communications. The CCA contains the microphones and earphones necessary for the EVA crewmembers to communicate with each other or with the orbiter. The CCA also allows the EVA crewmembers to talk to Mission Control via the orbiter communications system. Six sizes allow the CCA to fit 5th through 95th percentile-sized crewmembers. The CCA includes the following components: skull cap, ear cups, ear phones, ear seals, microphone modules, microphone booms, summing module, interconnect wiring, interface cable, neck strap, crew-optional chin strap, and perspiration absorption strap.

The in-suit drink bag is a dielectrically sealed bag assembly attached to the interior of the HUT that supplies drinking water to the crewmember during EVA. The drink bag is available in two sizes with the capacity for 21 or 32 fluid ounces of water. The in-suit drink bag includes the following components: bladder, inlet valve, drink valve, drink tube, and velcro attachments.

The urine collection device (UCD) is a disposable, flexible container that has the capacity to hold up to 32 fluid ounces of urine. The UCD is worn under the LCVG by male crewmembers during EVA. It is designed for one-time use, then disposed of as wet trash. The UCD includes the following components: collection bag, attachment straps, one-way check valve, and disposable roll-on cuff.

The maximum absorption garment (MAG) consists of multiple layers of material designed to rapidly absorb and store urine. The MAG is designed to be worn under the LCVG by male or female crewmembers during EVA. It has the capacity to hold 32 fluid ounces of urine and is disposable after use. The MAG includes the following components, multilayer absorbent material and tape attachment straps.

Life Support System

The life support system (LSS) provides a safe living environment inside the EMU. The LSS provides a variety of functions while the crewmember performs an EVA, including provision

of breathing oxygen, suit pressurization, crewmember cooling, crewmember communications, displays and controls for crewmember operation of the EMU, and monitoring of EMU consumables and operational integrity. The life support system consists of the following:

- Primary oxygen system
- Secondary oxygen pack
- Oxygen ventilation circuit
- Liquid transport system
- Feedwater circuit
- Electrical interfaces
- Extravehicular communicator (EMU radio)
- Display and control module
- Caution and warning system.

The primary oxygen system, oxygen ventilation circuit, liquid transport system, feedwater circuit, electrical interfaces, extravehicular communicator, and the caution and warning system make up the primary life support subsystem (PLSS). The secondary oxygen pack is a separate unit that is attached to the bottom of the PLSS. Together, the PLSS and the secondary oxygen pack make up the backpack of the EMU.

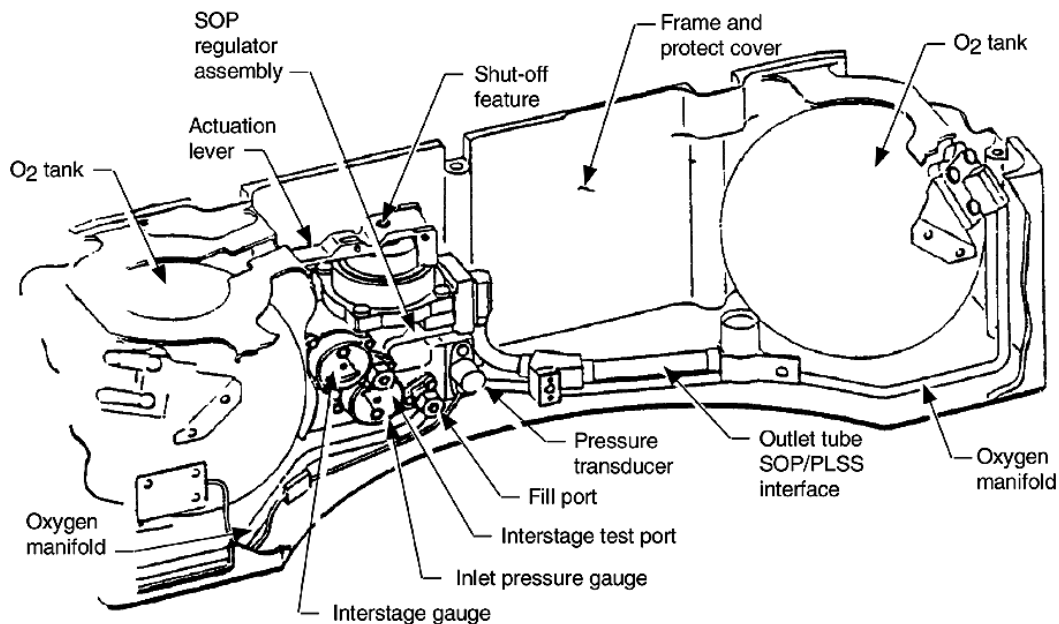
The primary oxygen system provides a crewmember with breathing oxygen and satisfies pressure requirements for EVA. The system stores 1.217 pounds of oxygen at 850 psia and 90° F. It delivers oxygen during EVA at 4.3 ± 0.1 psid, and maintains a metabolic use rate range of 0.02 to 0.33 lb/hr. The system is charged through a common multiple connection to the orbiter environmental control and life support system. Charging pressure is 850 ± 50 psig. The minimum usable pressure is 60 psi. The system performs various functions, including suit pressurization, provision of breathing oxygen, and water pressurization. The primary oxygen system includes the following components: oxygen tanks, oxygen tank pressure sensor, flow limiter, oxygen shutoff valve, oxygen actuator, suit pressure regulator, water pressure regulator, high mode relief valve, and low mode relief valve.

The secondary oxygen system, also known as the secondary oxygen pack (SOP), is the backup assembly to the primary oxygen system. This backup system provides a minimum of 30 minutes of emergency oxygen in the purge mode. The SOP functions include suit pressurization, provision of breathing oxygen, and some degree of cooling in the purge mode. There is no required crewmember interface to activate the SOP; it automatically activates whenever the oxygen actuator is in the EVA position and suit pressure is less than 3.9 psid. The SOP includes two oxygen tanks, containing a total of 2.65 pounds of oxygen at 5800 psia and 70° F. The system includes the following components: oxygen tanks, SOP inlet pressure gauge, first-stage regulator, interstage gauge, second-stage regulator/shutoff valve/flow restrictor, PLSS/SOP interface connector, and oxygen tank pressure sensor.

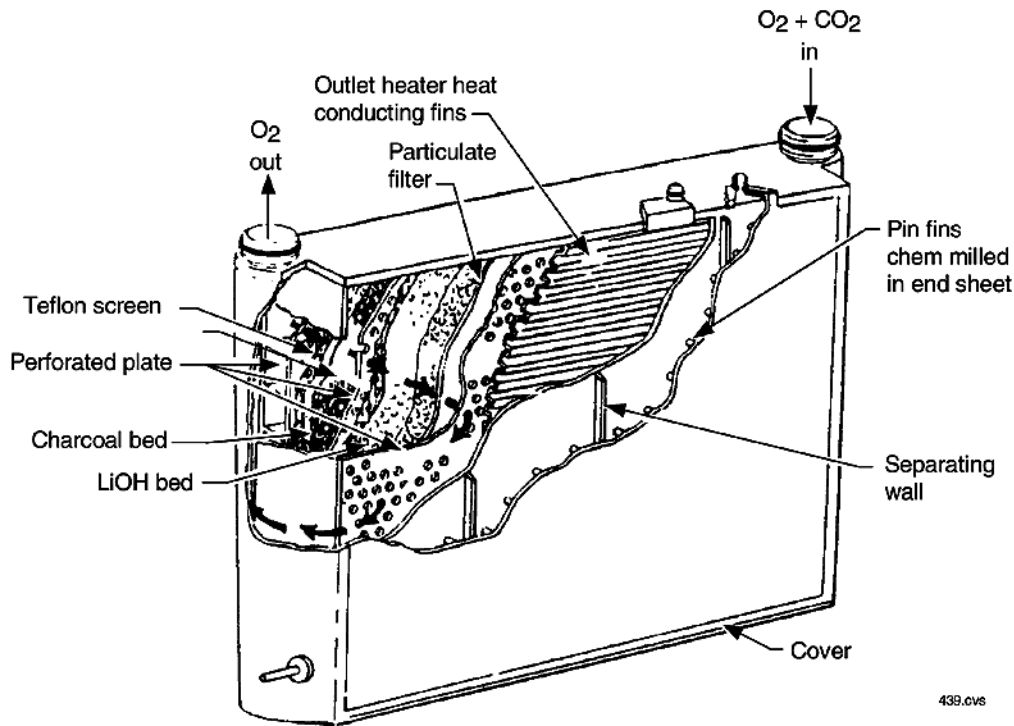
The oxygen ventilation circuit forms a closed loop with the space suit assembly. The circuit provides oxygen for breathing, suit pressurization for intravehicular activity (IVA) and EVA operation, and ventilation for cooling and elimination of exhaled gases. The oxygen flow picks up heat, humidity, carbon dioxide, and other contaminants, which are removed from the EMU by the ventilation circuit components. The system includes the following components: fan/water separator, slurper/ sublimator, vent

flow sensor/backflow check valve, suit pressure sensor, suit pressure gauge, contaminant control (lithium hydroxide) cartridge (CCC), carbon dioxide sensor, display control module purge valve, helmet purge valve, positive pressure relief valve, negative pressure relief valve, SOP checkout package, muffler, and SOP checkout fixture. Ventilation flow is picked up at the body extremities and returned to the upper torso via a vent duct manifold that is part of the LCVG. From the upper torso, the gas is routed back into the PLSS and the CCC. The CCC is sized to absorb 1.48 pounds of carbon dioxide associated with 7000 Btu of metabolic activity over a 7-hour EVA period. The cartridge is installed in the back of the PLSS and is replaceable on orbit. On the ground, the used cartridge can be recharged for future use.

The liquid transport system uses the centrifugal pump to circulate approximately 240 lb/hr of water through the LCVG. The function served by the liquid transport system is to provide cooling to the crewmember. The system includes the following components: pump, temperature control valve, LCVG, gas trap, pump priming valve, pump check valve, sublimator temperature sensor, and service and cooling umbilical bypass valve. During IVA operation, the pump circulates water not only through the EMU, but also through the service and cooling umbilical to the orbiter heat exchanger.



Secondary Oxygen Pack



LiOH Cartridge

The feedwater circuit contains the equipment and water to dissipate heat loads imposed on the system by the crewmember, the PLSS, and the environment. It also contains equipment to remove moisture from the ventilation circuit and gas from the transport circuit, to separate the water and gas, and to put them back in their respective loops. The feedwater circuit functions involve heat rejection, LCVG water makeup, and vent loop condensate separation and storage. The system includes the following components: feedwater tanks (2 primary/1 reserve), feedwater tank pressure sensors, reserve feedwater tank check valve, feedwater pressure regulator, feedwater shutoff valve, feedwater pressure sensor, sublimator, feedwater relief valve, condensate water relief valve, water separator, and coolant isolation valve. The primary and reserve tanks store approximately 10 pounds of feedwater at 15 psig. The reserve feedwater tank provides 30 minutes of water for EMU cooling in the event that primary feedwater is depleted. Potable water from the orbiter ECLSS is used to fill or recharge the tanks.

The EMU electrical system is composed of the following main components: battery, feedwater shutoff valve, coolant isolation valve, motor, instrumentation, extravehicular communicator,

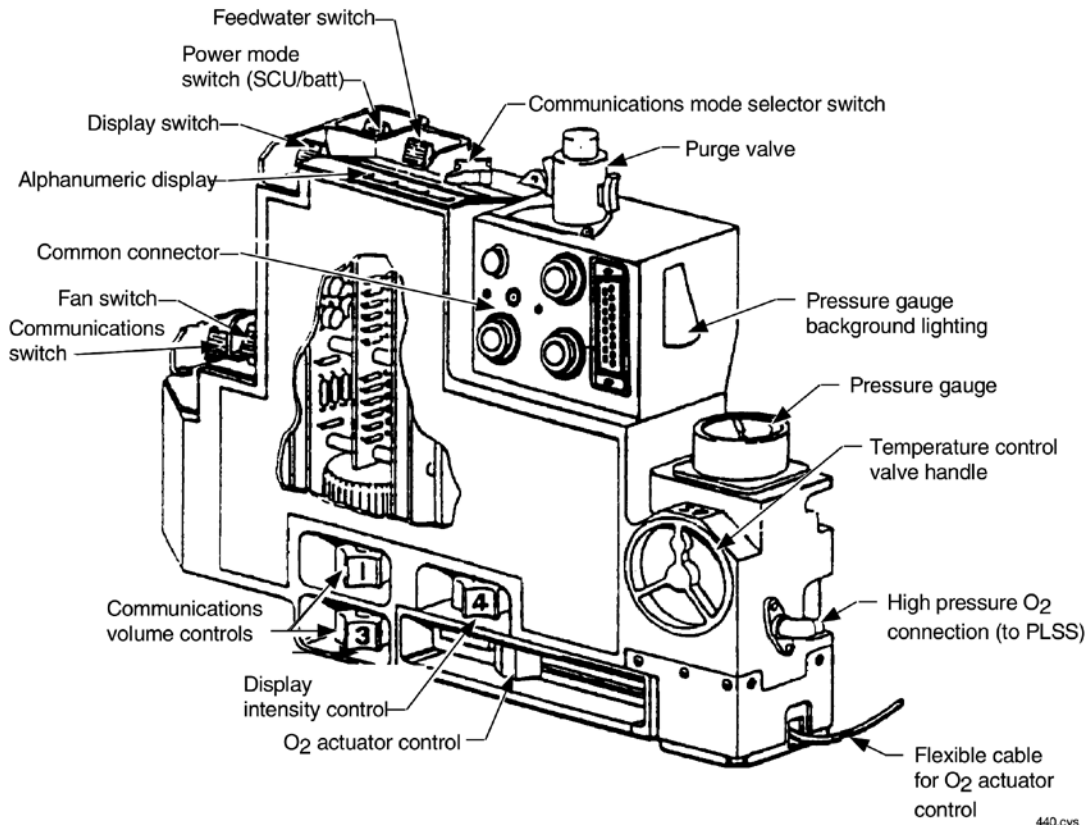
display and control module, and caution and warning system. Electrical interfaces exist between the display and control module and parts of the PLSS, SOP, and C/W. The power supply for operation of all electrical components of the EMU is a battery installed in the back of the PLSS. The EMU battery consists of eleven sealed, silver-zinc, high current density cells connected in series. The battery provides a minimum of 26.6 amp-hr of power over a 7-hour EVA mission at a nominal voltage of 16.5 V dc.

The extravehicular communicator (EVC) is composed of two parts, the orbiter-based equipment and the EMU-based equipment. The orbiter equipment consists of the EVA/air traffic control transceivers and antennas. This configuration provides communication with the EVA crewmembers and relay between EVA crewmembers and the ground (including downlink ECG and real-time data system (RTDS) telemetry). The EMU equipment consists of the EMU radio and antenna. It provides voice communications with other EVA crewmembers and the orbiter, ECG/RTDS telemetry to the orbiter for recording and/or downlink, and caution and warning tones to alert the EVA crewmember of anomalies or other significant events. The EVC includes the following compo-

nents: orbiter UHF system, EMU radio, EMU electrical harness, communications carrier assembly, biomed sensors, COMM MODE selector switch, COMM switch, volume controls, and real-time data system. Orbiter panels O6, A1R, and R10 are the crew communication interfaces. The panels control UHF operation, air-to-air or ground transmission, and biomed data down-link/recording respectively.

The display and control module (DCM) contains all controls and displays necessary for nominal operation and monitoring of EMU systems. The DCM includes the following components: POWER mode switch, DISPL switch, FAN switch, COMM switch, communications volume controls, display intensity control, oxygen actuator, temperature control valve, pressure gauge, DCM purge valve, alphanumeric display COMM mode selector, and WATER switch. The DCM is installed on the hard upper torso, with the surfaces covered with a TMG. This TMG contains the labels for the controls and displays.

The EMU caution and warning system (CWS) consists of instrumentation and a microprocessor to obtain, process, and visually display information for use by the EVA crewmember in the operation and management of the EMU. The system contains built-in test equipment (BITE), consisting of software and hardware that verify proper CWS operation. CWS serial data are also routed to the ground by the real-time data system. The CWS functions involve displaying EMU leak check procedures, monitoring and displaying EMU consumables status, monitoring EMU operational integrity, and alerting crewmembers to EMU anomalies. The system includes the following components: alphanumeric display with BITE indicator, display (DISPL) switch, alert/status/warning tones, sensors, and "black box" processor. The CWS receives inputs from EMU sensors and from the DISPL switch located on the DCM. Sensors gather information throughout the EMU system and relay it to the CWS. Information is provided on pressures, temperatures, currents, and voltages.



Display and Control Module

EMU Ancillary Equipment

The EMU ancillary equipment consists of hardware necessary to support the EMU during all phases of EVA (prep/post/operation). The following list itemizes the components with a brief description of their functions.

EMU helmet lights - attach to the helmet EVVA and provide two functionally independent sets of lights for portable lighting during an EVA task.

EMU scissors - steel cutters with one serrated edge capable of cutting anything from fabric bags and straps to lightweight steel cable and Kevlar cord.

EMU wrist mirror - attaches to the wrist of the EVA glove to allow the EVA crewmember to view the controls and displays on the front of the EMU.

EVA cuff checklist - a set of reference cards bound by an aluminum alloy bracket attached to a wrist band. The reference cards, approximately 4 inches by 5 inches in size, contain procedures and reference data for performing EVA tasks and for aiding in the diagnosis and resolution of EMU malfunctions.

Food stick - a fruit bar contained in an edible wrapper, positioned just above the neck ring adjacent to the drink valve on the in-suit drink bag.

In-suit drink bag syringe - a device used to remove gas from the water in the drink bag. The needle of the syringe is inserted in the inlet valve of the bag, and gas is suctioned out of the bag with the syringe.

Thermal mittens - an adjustable enclosure composed of several layers of thermal blankets and aluminized Mylar with a layer of Nomex felt on the palm and undersides of the fingers that fit conformally around the EV gloves to provide greater thermal hand protection at extreme high and low temperature worksites.

Lower torso assembly donning handles - left and right handles that aid in the mating of the hard upper torso and lower torso assembly halves of the waist ring.

Contingency tool - a pry bar used to disconnect the LTA and HUT halves of the waist ring in the event that the latching mechanism becomes jammed. Operation of the pry bar may damage the latching mechanism; therefore, it should be used only if the waist ring becomes jammed and the crewmember is entrapped in the space suit.

Bends treatment adapter (BTA) - an emergency device that may be used on-orbit in the event an EVA crewmember contracts decompression sickness (bends). The BTA converts the EMU into a hyperbaric treatment chamber, pressurizing the EMU to 8.0 psid over ambient cabin pressure.

SOP checkout fixture - a flight support test item installed on the HUT half of the neck ring during pre-EVA operations.

DCM plug - a cover that attaches to the multiple connector on the DCM in the event that water begins leaking from the connector after the service and cooling umbilical multiple connector is removed.

Prep kit - items necessary for preparing the EMU for EVA, such as antifog wipes, tissue-type wipes, scissors, and urine collection device clamps.

Maintenance kit - additional equipment necessary for routine EMU maintenance, including valsalva devices, stericide wipes, lubricant wipes, antifog wipes, and urine collection device roll-on cuffs.

Bio kit - equipment associated with the biomed instrumentation, including EVA cables, over-tapes, electrode placement illustration, alcohol wipes, stoma seals, and electrode paste.

Airlock stowage bag - a Nomex bag used for temporary storage and transfer of items used in prep- and post-EVA operations. When stowed in the airlock over the inner hatch, the bag and its contents are removed from the airlock prior to airlock depressurization.

EVA bag - used to stow various items (camera, thermal mittens, tool caddy) in the airlock for possible use during EVA. The EVA bag remains in the airlock during the EVA.

Airlock

An airlock on the orbiter accommodates astronaut EVA operations. The airlock permits EVA crewmembers to transfer from the mid-deck crew compartment into the payload bay in EMUs, without depressuring the orbiter crew cabin. The internal airlock provides launch and entry stowage of up to four EMUs, while the external airlock can stow two EMUs. Both types of airlock contain the interfaces and associated displays and controls for the orbiter systems that support EMU operation and servicing. Sized to accommodate a two-person EVA, the internal airlock dimensions have a diameter of 63 inches, a length of 83 inches, and two D-shaped 40-inch-diameter openings (three for external airlock). The internal airlock's volume measures 150 cubic feet, while the external airlock has a volume of 185 cubic feet. Support functions performed in the airlock include depressurization and repressurization, EVA equipment recharge, LCVG water cooling, and EVA equipment checkout, donning, and communications. All EVA gear, checkout panel, and recharge stations are located against the internal walls of the airlock.

Airlock Hatches

Two pressure-sealing hatches are mounted on the internal airlock, while the external airlock contains three of these hatches. The inner hatch is located on the exterior of the airlock opening into the middeck. The inner hatch isolates the airlock from the crew cabin. The outer hatch isolates the airlock from the unpressurized payload bay when closed and permits the EVA crewmembers to exit from the airlock to the payload bay when open. The external airlock's third hatch is an additional upper, outer hatch that will be used for docking operations. Each hatch has six interconnected latches with gearbox and actuator, a window, a hinge mechanism with hold-open device, a differential pressure gauge on each side, and two equalization valves.

Airlock repressurization is controlled from the middeck or inside the airlock. It is performed by equalizing the airlock and cabin pressure with airlock-hatch-mounted equalization valves on the inner hatch. Depressurization of the airlock is controlled from inside the airlock. The airlock is depressurized by venting the airlock

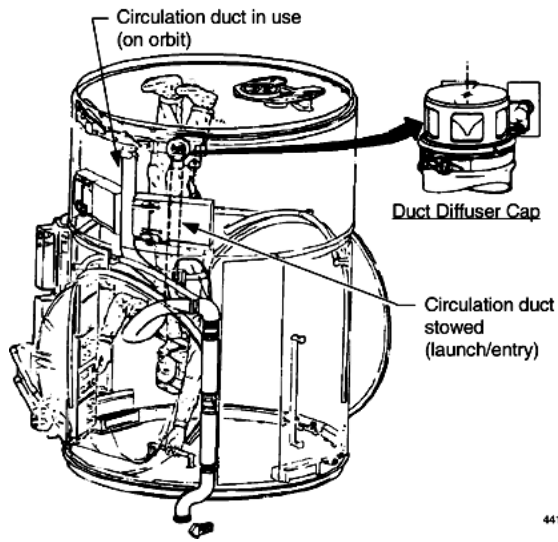
pressure overboard. The two D-shaped airlock hatches are installed to open toward the primary pressure source, the orbiter crew cabin, to achieve pressure-assist sealing when closed. Each hatch opening is 40 inches in diameter, yet with one side being flat, the minimum dimension is 36 inches.

The 4-inch-diameter window in each airlock hatch is used for crew observation from the cabin to the airlock and the airlock to the payload bay. The dual window panes are made of polycarbonate plastic and are mounted directly to the hatch using bolts fastened through the panes. Each airlock hatch has dual pressure seals to maintain the airlock's pressure integrity. One seal is mounted on the airlock hatch and the other on the airlock structure. A leak check quick disconnect is installed between the hatch and the airlock pressure seals to verify hatch pressure integrity before flight.

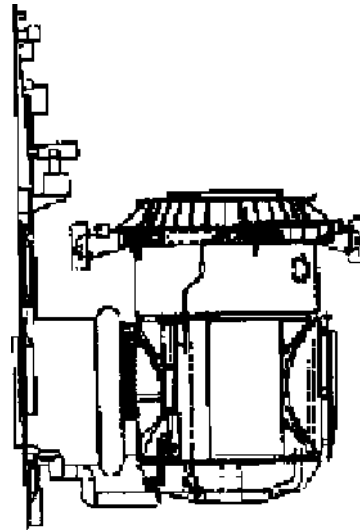
Each airlock hatch has the following design characteristics: (1) capable of being fully locked/unlocked from either side, (2) designed for 2000 open/close cycles, (3) one-handed operation by astronaut in pressure suit, (4) capable of opening against 0.2 psid maximum, (5) latches capable of withstanding 20 g's in the +X direction, and (6) actuator handle load of 30 pounds maximum.

The gearbox with latch mechanisms on each hatch allows the flight crew to open or close the hatch during transfers and EVA operations. The gearbox and the latches are mounted on the low-pressure side of each hatch, with a gearbox handle installed on both sides to permit operation from either side of the hatch. Three of the six latches on each hatch are double-acting with cam surfaces that force the sealing surfaces apart when the latches are opened, thereby acting as crew-assist devices. To latch or unlatch the hatch, the gearbox handle must be rotated 440°.

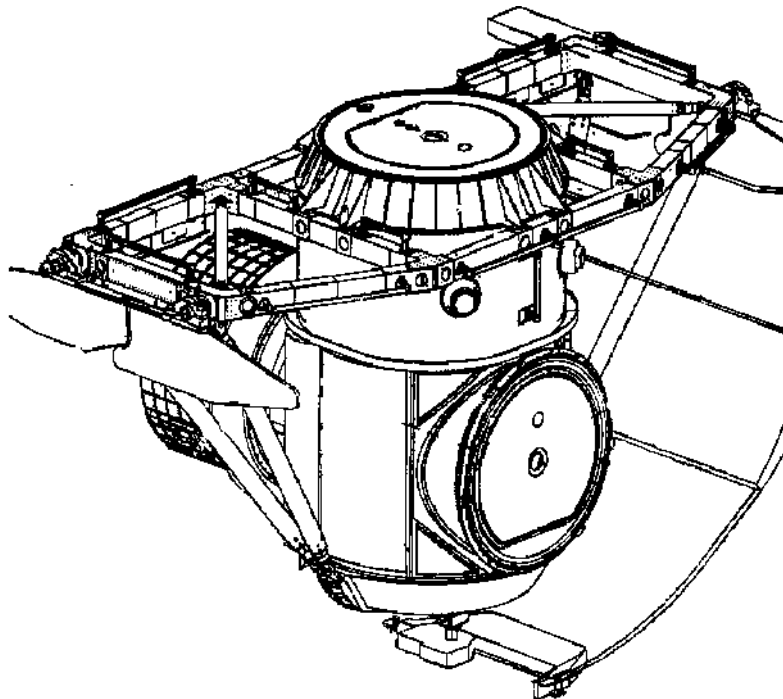
The hatch actuator/gearbox is used to provide the mechanical advantage to open and close the latches. The hatch actuator lock lever requires a force of 8 to 10 pounds through an angle of 180° to unlatch the actuator. A minimum rotation of 440° with a maximum force of 30 pounds applied to the actuator handle is required to operate the latches to their fully unlatched positions.



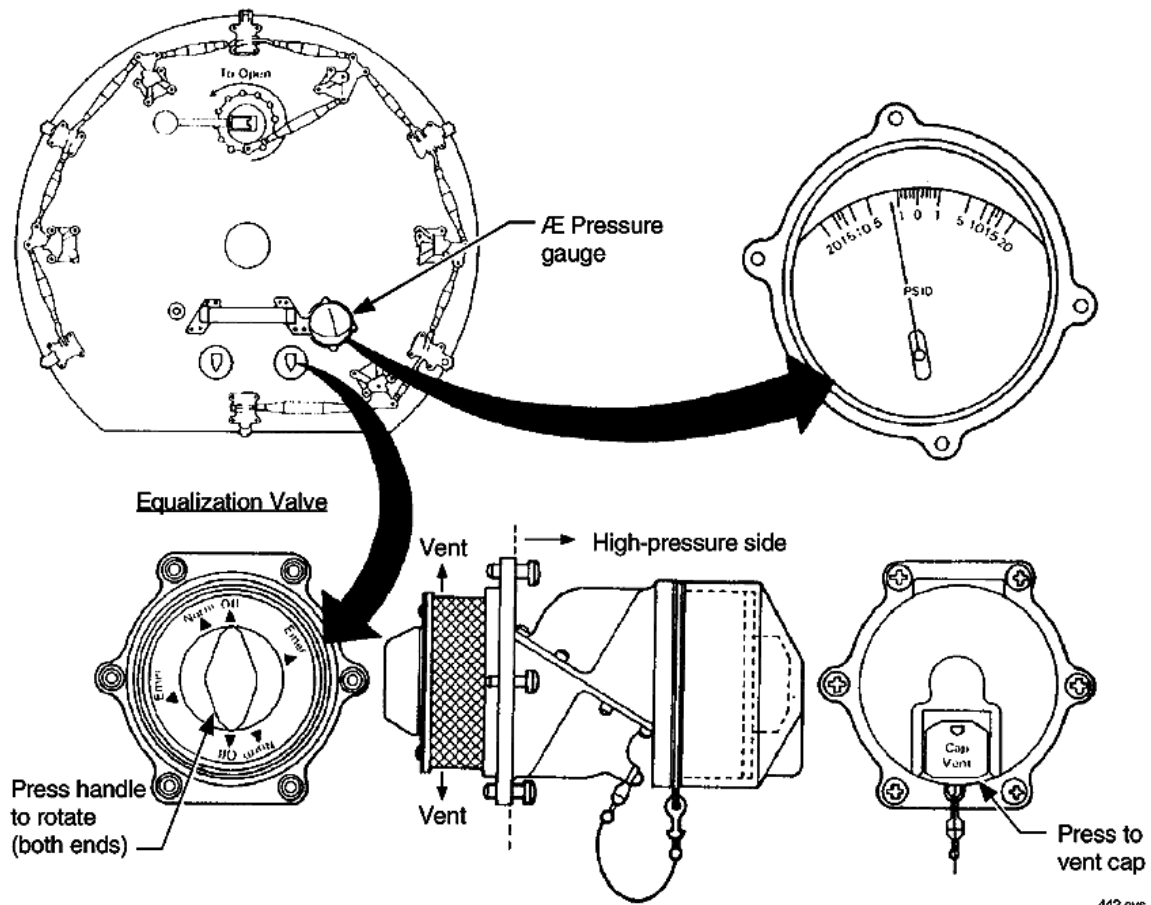
Airlock in Middeck



External Airlock
(port side view)



External Airlock ISS Configuration
(planned for OV-103, OV-104, OV-105)



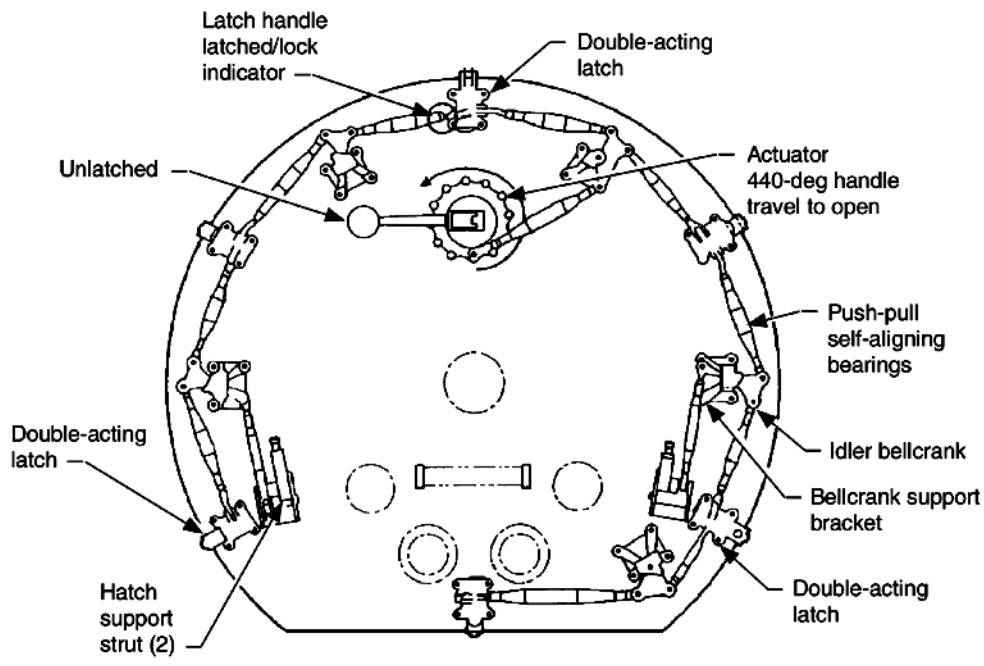
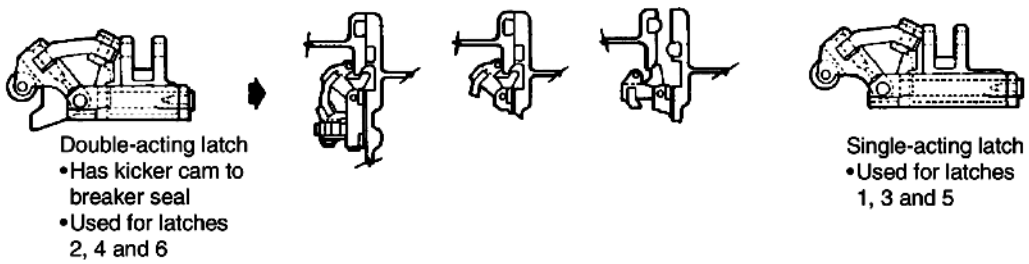
442.cvs

Airlock Repressurization, Schematic Diagram

The hinge mechanism for each hatch permits a minimum opening sweep into the airlock or the crew cabin middeck.

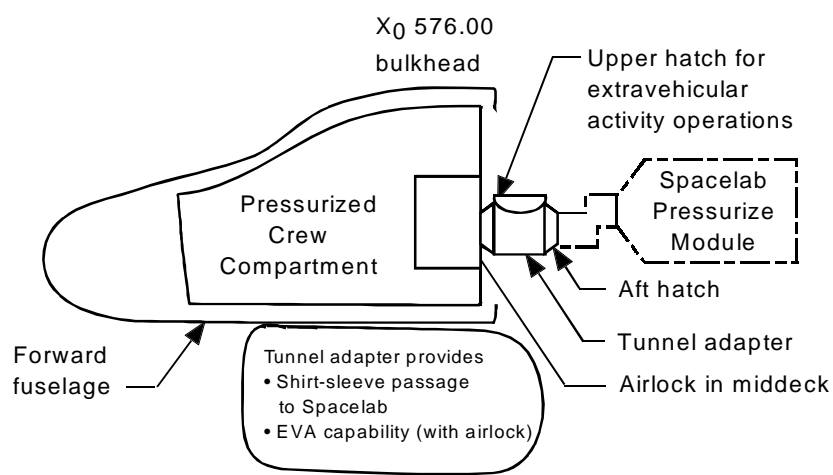
The inner hatch of the internal airlock (airlock to crew cabin) is pulled or pushed forward to the crew cabin approximately 6 inches. The hatch pivots up and to the right side. Positive locks are provided to hold the hatch in both an intermediate and a full-open position. The outer hatch of the internal airlock (airlock to payload bay) opens and closes to the contour of the airlock wall. The hatch is hinged to be pulled first into the airlock and then forward at the bottom and rotated down until it rests with the low-pressure (outer) side facing the airlock ceiling (middeck floor). The hatch has a hold-open hook that snaps into place over a flange when the hatch is fully open. To support and protect the hatch against the airlock ceiling, the hatch incorporates two deployable struts.

The configuration of the external airlock, planned for International Space Station (ISS) operations, contains an inner hatch, an EV hatch, and a docking hatch. The inner hatch of the external airlock (airlock to crew cabin middeck) has the same opening mechanism as the outer hatch of the internal airlock. The hatch is hinged so that it can be pulled into the middeck and rotated down until it rests on the middeck floor. The EV hatch of the external airlock (airlock to payload bay) also opens in the same manner. The docking hatch, located on the floor of the external airlock (toward the payload bay doors), is hinged to be pulled into the airlock and then rotated until the low pressure side rests against the airlock wall facing toward the nose of the orbiter. The external airlock hatches also have hold-open protection and deployable struts for support against the airlock structure.



443.cvs

Airlock Hatch Latches, Schematic Diagram



444.cvs

Airlock/Tunnel Adapter

Airlock Subsystems

The airlock air circulation system provides conditioned air to the airlock during non-EVA periods. The airlock revitalization system duct is attached to the outside airlock wall at launch. Upon airlock hatch opening in flight, the duct is rotated by the flight crew through the cabin/airlock hatch and installed in the airlock. The duct has a removable air diffuser cap, installed on the end of the flexible duct, which can adjust the air flow from 216 pounds per hour. The duct must be rotated out of the airlock before the cabin/airlock hatch is closed for chamber depressurization. During the EVA preparation period, the duct is rotated out of the airlock and can be used for supplemental air circulation in the middeck.

To assist the crewmember before and after EVA operations, the airlock incorporates handrails and foot restraints. Handrails are located alongside the avionics and ECLSS panels, with aluminum alloy handholds mounted on each side of the hatches. Each handrail has a clearance of 2.25 inches between the airlock wall and the handrail to allow crewmembers to grip it while wearing a pressurized glove. Foot restraints, sized for the EMU boot, can be installed on the airlock floor nearer the payload bay side. The ceiling handhold is installed nearer the cabin side of the airlock. A rotation release knob on the foot restraint is designed for shirt-sleeve operation and, therefore, must be positioned before the suit is donned. The foot restraint is bolted to the floor and cannot be removed in flight.

Airlock-based EMU support components provide for EMU stowage, EMU operational support, and EMU recharge during intravehicular activity operations. These components include the EMU mount, the service and cooling umbilical, and the lower torso restraint bag. The EMU mount provides a mechanical interface between the EMU and airlock wall for EMU stowage. The mount attaches to the back side of the EMU and engages with three fixtures on the wall of the airlock. The mount is also used to maintain the EMU in a fixed position on orbit for EMU donning and doffing operations. If necessary, the EMU mount can be removed from the airlock wall while on orbit.

The service and cooling umbilical consists of three water hoses, a high pressure oxygen hose, electrical wiring, water pressure regulators, and a strain relief tether. The system is used to interconnect the EMU and the orbiter airlock for two major functions: electrical power, hardline communications, oxygen supply, wastewater drainage, and water cooling capability from the orbiter during IVA operation; and recharge capability for the PLSS oxygen tanks, water reservoir, and battery.

The lower torso restraint bag is attached to the bottom of the EMU mount and covers the lower torso of the EMU to restrain it during launch and entry. Straps on either side of the bag are attached to points on the upper part of the EMU mount and are tightened to ensure that the EMU is fully restrained.

For Spacelab/Spacehab module missions, the internal airlock is used along with a tunnel adapter that mates with the airlock and a Spacelab/Spacehab tunnel that is installed in the payload bay. The airlock tunnel adapter, hatches, tunnel extension, and tunnel permit the flightcrew to transfer from the orbiter's pressurized middeck compartment to the Spacelab/Spacehab pressurized shirt-sleeve environment. An upper hatch in the tunnel adapter provides egress/ingress for EVA operations. The external airlock is used in conjunction with the tunnel adapter during Spacelab/Spacehab missions when the orbiter is docked to Mir or the ISS. In the event of an EVA, the flightcrew is not present in the Spacelab/Spacehab.

EVA Support Equipment

A variety of equipment is available to support the EVA crewmember. Depending on the task to be performed, the proper tool is available outside the airlock. The general equipment functions include securing the crewmember to the orbiter/RMS, providing the crewmember with mechanical assistance, and assisting the crewmember in mobility. The following list itemizes the EVA support components with a brief description of their functions.

Crewmember safety tether - ensures the crewmember is positively tethered to the orbiter while providing access to all areas of the payload bay.

Before airlock egress, this 55-foot safety tether is attached to a waist tether and remains attached at all times during EVA, while the crewmember translates from one area of the payload bay to another.

Slidewires - facilitate the translation of a crewmember and equipment in the forward and aft directions of the payload bay. Two slide-wires are installed for all STS flights on either side of the payload bay for a length of approximately 46 feet.

Tethers - include waist and wrist tethers. Waist tethers are used to attach the crewmember to the orbiter safety tether system and to provide additional crewmember restraint at a worksite when required. Waist tethers use a large hook to be attached to various tether points (including the crewmember safety tether) and a small hook that attaches to an EMU waist tether ring. Wrist tethers are used to secure tools and hardware to the EVA crewmember and to tether points. Wrist tethers are both fixed and adjustable, attaching to loops on the EMU glove.

Handrails - aluminum tubing strategically located to aid in crewmember translation or restraint to accomplish a specific task. Handrails are located on the forward and aft bulkheads, the hingeline of the payload bay doors, and the RMS end effector. Handrails are designed with tether attach points.

Portable foot restraint - a working platform designed to restrain the EVA crewmember while performing contingency operations on various components of the payload bay systems. The portable foot restraint stabilizes the crewmember by using a system of toe guides and heel clips designed to interface with the EMU boots.

EVA Winch - allows the EVA crewmember to close the payload bay doors in the event of a payload bay door drive system failure. Prior to launch, the winch is mounted on both the forward and aft payload bay bulkheads. The winch consists of a reel, assisted by spring energy, housing 24 feet of 3/8-inch-diameter Kevlar rope with a hook attached to the free end.

Provisions stowage assembly (PSA) - an aluminum tool stowage container mounted under the cargo bay liner, flush with the bottom of the payload bay. Tool box tether protocol: when stowing the tools in the PSA, the tools/tool caddies are tethered before they are removed from the mini-workstation and untethered only after they are securely placed in their corresponding storage cavity. The tools listed below are contained within the PSA.

Mini-workstation - a mechanical device that mounts on the front of the EMU to stow tools and to provide a means of tether restraint for an EVA crewmember at a worksite.

Tube cutter - used for a contingency door-closing operation. The tool consists of spring-loaded retention rollers, a cutter wheel mounted on a slide, a blade ratchet handle, a rotating body, a control lever, and a tube-cutter ratchet handle. It is designed to cut drive door linkages.

Payload bay doors disconnect tools - used to disengage the payload bay doors power drive unit(s) (two) from the power-drive-unit torque shaft, allowing manual closing of the doors. The tool is approximately 6-3/4 inches long from the tip of the tether ring to the end of the 3/8-inch steel square drive extension. Additional tools for disconnecting the door drive linkage system include vise-grip, ratcheting box-end wrench, adjustable wrench, loop pin extractor, Velcro/tape caddy, bolt puller, and trash bag.

Three-point latch tool - used to compensate for failed bulkhead latches. The tool consists of a stowable ratchet handle, two interchangeable tool handles, a ratchet control selection lever, a spring-loaded compensator, and two fixed-load pickup points.

Centerline latch tool - used to compensate for a failed payload bay door centerline latch. The tool consists of a fixed-load and a spring-loaded pickup point, plus a reversible ratchet with a stowable handle and a pair of trigger release buttons with a safety that prevents an accidental release.

Airlock latch disconnect tool - a common, EVA-modified, crescent wrench used to force open a jammed latch and/or latches disconnected from the rotary actuator. The other contingency airlock disconnect tool is a drive ratchet with a 7/16-inch hex socket and 4-inch extension.

RMS rope reel - used in conjunction with the snatch blocks in the event of an RMS joint failure. The reel consists of a rope spool, spool bracket, rope guide, and cam cleats. The rope reel contains approximately 80 feet of 5/16-inch-diameter Kexlon rope.

Snatch block - a common marine device used, in the event of an RMS failure, in conjunction with the RMS rope reel and EVA winch to backdrive the RMS to a stowed position.

Payload retention device (PRD) - used as an on-orbit temporary tiedown tool so that the article or payload being secured can be repositioned as necessary to prevent damage. It consists of a housing that encloses a 15-foot Kevlar webbing strap on a spring-loaded reel.

RMS manipulator positioning mechanism wrench (RMS MPM wrench) - a double-ended, open-end steel wrench used to deploy or stow the MPMs (in the event the MPM motors fail) by manually turning the drive shaft in the appropriate direction, thus allowing for payload deployment and/or payload bay door closing.

RMS shoulder brace release - a flat steel bar with an angled foot used to disengage the RMS shoulder brace locking mechanism, thus releasing the shoulder brace. If the lock is not released, the RMS is inoperative.

Grapple fixture release tools - used to remove a grapple fixture shaft should an end effector malfunction, failing to release a payload. The tools include a probe and 1/2-inch ratcheting box-end wrench.

Radiator actuator disconnect tools - A 3/8-inch drive ratchet and 1/4-inch allen wrench extension used to disconnect a failed radiator actuator and support stowage of the radiators.

External tank umbilical door tool - used to override a failed external tank door centerline latch and support ET door closure.

Generic jam removal tools - diagonal cutter, cable cutter, needle nose pliers, probe, hammer, pry-bar, forceps, trash bag. For use in disconnecting or dislodging jams in various orbiter mechanisms, such as PLBD hinges, latches, etc.

Portable foot restraint (PFR) bridge clamp - provides a PFR socket that mounts on the sill of the PLB in available locations on existing bridge rails.

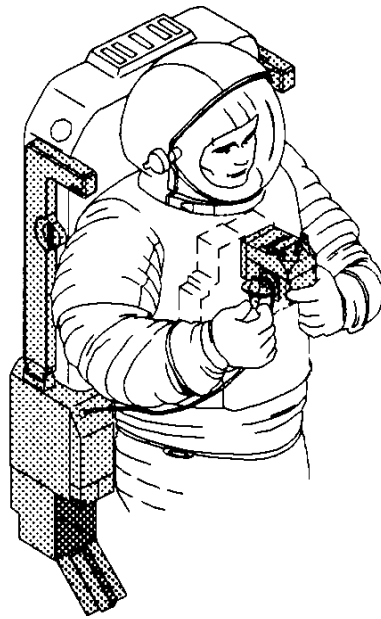
Simplified Aid for EVA Rescue

The simplified aid for EVA rescue (SAFER) is a small, self-contained, propulsive backpack system used to provide a free-flying rescue capability for an EVA crewmember. SAFER is a "simplified," single-string system that fits on the bottom of the EMU PLSS and attaches to existing mounts on the sides of the PLSS. In essence, SAFER is a small simplified version of the manned maneuvering unit (MMU). Because it is intended for self rescue use only, SAFER does not have the propellant capacity and systems redundancy that was provided with the MMU.

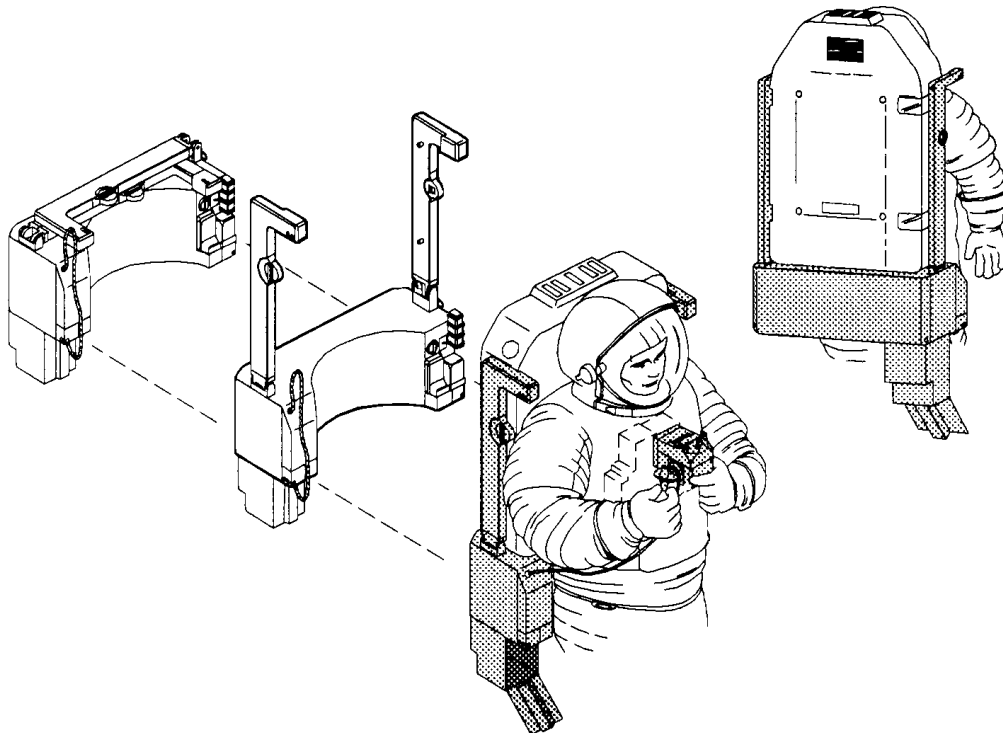
SAFER is designed to be used as a self-rescue device for a separated EVA crewmember in situations where the orbiter is unavailable to provide rescue capability. Such situations would include when the orbiter is docked to a large payload or structure, such as the Russian Mir Space Station or ISS. The SAFER will also be used during all future ISS EVA operations where the orbiter might not be present at the ISS during an EVA.

To provide self-rescue capability, the SAFER offers 13 minutes of propellant and control authority to stabilize and return a tumbling/separating EVA crewmember. The SAFER has 24 gaseous-nitrogen (GN₂) thrusters to provide 6 degrees-of-freedom maneuvering control. The SAFER is controlled by a single hand controller housed in a hand controller module box located on the bottom of the unit. The SAFER propulsion subsystem provides a total delta velocity of at least 10 ft/sec with an initial charge. The flight unit weighs approximately 85 pounds and folds for launch, landing, and on-orbit stowage.

The SAFER is the product of a Johnson Space Center (JSC) in-house project to develop, build, and produce a rescue device for the instances when the orbiter cannot provide rescue capability and for ISS EVA operations. An on-orbit SAFER detailed test objective (DTO) conducted on space shuttle mission STS-64 was very successful. This DTO demonstrated SAFER's operational capabilities and collected performance data to augment the design and development of the final operational SAFER. The STS-76 SAFER was a transitional unit between the DTO unit flown on STS-64 and the final production unit that will be manifested for ISS. The operational unit will be capable of being stationed on-orbit for 1 year; however, after use on orbit, the unit will be returned to Earth for refurbishing.



**Simplified Aid for EVA
Rescue (SAFER)**



Attachment of SAFER Unit to EMU

Operations

As previously discussed, there are three types of EVA: scheduled, unscheduled, and contingency. A scheduled EVA is defined as any EVA incorporated into the normal flight plan in order to complete a specific mission objective. An unscheduled EVA is not part of the flight plan; rather, it is conducted to achieve payload operation success or to advance overall mission accomplishments. A contingency EVA is also unscheduled, but is required to ensure safe return of the orbiter and flight crew.

Regardless of the EVA type, a series of procedures are required to initiate and terminate an EVA. These procedures cover an integrated timeline sequence from the EVA checklist. The detailed procedures are summarized for reference in the following steps:

1. **Quick don mask prebreathe** - Donning of the mask for prebreathe and cabin depressurization.
2. **Cabin depressurization to 10.2 psi** - Reducing the cabin pressure from 14.7 psi to 10.2 psi.
3. **EMU checkout** - Preliminary checkout of the EMU systems prior to EMU donning.
4. **Middeck preparation and preparation for donning** - Configuration of the EMU and its ancillary components for crewmember donning.
5. **Suit donning** - Crewmember donning of the EMU and ancillary components, approximately 40 minutes duration.
6. **EMU check** - Configuration and checkout of the EMU prior to EMU purge.
7. **EMU purge** - Nitrogen purge of the EMU prior to prebreathe.
8. **Prebreathe** - Crewmember acclimation to lower chamber pressure, over a period of 40 to 70 minutes.
9. **Preparation for depressurization** - Configuration of the airlock and

closing the inner hatch prior to airlock depressurization.

10. **Airlock depressurization** - Configuration and checkout of the EMU, airlock depressurization to vacuum, and opening of the outer hatch.
11. **Airlock repressurization** - Airlock repressurization and opening of the inner hatch.
12. **Post-EVA** - Shutdown of the EMU systems and doffing of the EMU and ancillary components.
13. **EMU maintenance/recharge** - Change-out or recharge of the EMU battery and lithium hydroxide cartridge and general cleaning of the EMU for subsequent EVA; recharge of the EMU water system.
14. **Post-EVA entry preparation** - Reconfiguration and restowage of the EMU and airlock equipment.

A set of procedures are followed when a crewmember has contracted the bends during an EVA. The crewmember discontinues the EVA and returns to the airlock to connect to the service and cooling umbilical. The airlock is repressed to 10.2 psia, and the cabin is repressed to 14.7 psia. The helmet is doffed, and the crewmember drinks a minimum of 32 ounces of fluids. After proper EMU reconfiguration, the bends treatment adapter is installed for bends recovery.

Scheduling an EVA is a very complex and involved task. The following list outlines the general mission constraints regarding EVA, but does not attempt to define the detailed specific activities.

- The maximum scheduled duration for an EVA is 6 hours.
- All scheduled and unscheduled EVAs require two crewmembers.
- No scheduled or unscheduled EVA shall occur on flight day 1 (~24 hours MET).

- No scheduled EVA shall be planned to occur prior to flight day 4 (~72 hours MET) unless:
 - i) A specific flight is dedicated to scheduled EVA activity, and
 - ii) That payload customer has specifically negotiated with NASA for the early scheduled EVA capability, and an exemption is processed.
- The latest an EVA may be scheduled in preflight planning is EOM-2.
- No unscheduled EVA shall be planned to occur prior to flight day 3 (~48 hours MET) unless:
 - i) A specific payload has no alternative but to utilize an EVA as its third level of redundancy for the purpose of a critical backup to deploy/operations that would prevent loss of the payload, and
 - ii) That payload customer has been made aware of the inherent risk that the EVA may not be able to be performed due to crew status, and the customer has agreed to accept the risk, and
 - iii) That payload customer has specifically negotiated with NASA for the early unscheduled EVA capability, and an exemption is processed.
- The following are required response times prior to an unscheduled payload EVA:
 - i) Upon the discovery of a failure leading to an EVA, approximately 24 hours are allotted for EVA preparation prior to starting actual EVA maintenance on a failed component.
 - ii) If the case above occurs on launch day, then approximately 44 hours are allotted prior to starting EVA maintenance.
 - iii) If a payload requires a shorter EVA response time, then the requirement for that EVA must be negotiated with NASA, and an exemption must be processed.
- Payload activities that could require an unscheduled EVA at the end of a mission may only be scheduled if there are sufficient consumables and landing opportunities to extend the mission to perform the EVA and preserve 2 wave-off days.
- A minimum of 1 flight day must separate two scheduled EVAs, for any given EVA crewmember.
- A contingency EVA will be scheduled in real time whenever it is necessary to restore the orbiter to a configuration for safe return.

Contingency EVAs occur if orbiter hardware sustains a malfunction. Procedures, tools, and specified work locations are identified for practice on any STS mission. The recognized failures pertain to the following orbiter systems: radiator actuator, payload bay doors, bulkhead latches, centerline latches, airlock hatch, remote manipulator system (RMS), bulkhead camera, Ku-band antenna, and external tank doors. The corrective actions for each system failure are itemized in the following table.

FAILURE	CORRECTIVE ACTION
Radiator actuator	Radiator actuator disconnect
Payload bay door system	PDU Winch operations PLBD drive system linkage cut PLBD drive system disconnect Electrical crossover disconnect Jam removal
Bulkhead latch	3-point latch tool installation Jam removal
Centerline latch	Centerline latch tool installation Jam removal
Airlock hatch	Airlock latch disconnect Hinge disconnect
RMS	RMS joint alignment RMS tiedown MPM stow/deploy RMS shoulder brace release Grapple fixture release
Bulkhead camera	Disconnect and remove camera
Ku-band antenna fails to align for stowing	Ku-band antenna gimbal alignment
External tank door	ET door centerline latch release

System Failure Corrective Actions Table

EVA Summary Data

- EVA refers to operations performed outside the spacecraft crew compartment.
- For generic orbiter missions, two suits are included with consumables provided for three, two-person, 6-hour EVAs.
- There are three basic categories of EVA: scheduled, unscheduled, and contingency.
- The extravehicular mobility unit (EMU) is an independent anthropomorphic system that provides environmental protection, mobility, life support, and communications for the crewmember to perform EVA in Earth orbit. An EVA is defined, for EMU design considerations, as any time the EMU external environmental pressure is below 4.0.
- The EMU is an integrated assembly, primarily composed of the space suit assembly, life support system, and numerous items of associated support and ancillary equipment.
- The orbiter's airlock permits EVA flight crew members to transfer from the middeck crew compartment into the payload bay in EMUs without depressurizing the orbiter crew cabin. The airlock also provides launch and entry stowage of up to three EMUs.
- The airlock's support functions include airlock depressurization and repressurization, EVA equipment recharge, LCVG water cooling, EVA equipment checkout, donning, and communications.
- Depending on the task to be performed, the proper tool is available outside the airlock. The general EVA-support equipment functions include securing the crewmember to the orbiter/RMS, providing the crewmember with mechanical assistance, and assisting the crewmember in mobility.
- A standard series of procedures (pre and post operations) are required to initiate and terminate an EVA, regardless of the EVA type.

EVA Rules of Thumb

- Always use "make before break" tether protocol.
- Don't use the glove as a hammer.
- EVA crewmember and equipment must remain tethered at all times.
- Slow and deliberate motion provides much greater stability than quick, jerky motions.
- Body positioning is 90 percent of the task.
- Each EVA crewmember should check out his or her own EMU.

2.12 GALLEY/FOOD

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Description

The middeck of the orbiter is equipped with facilities for food stowage, preparation, and dining. The food supply is categorized as either menu food, pantry food, or fresh food. Meals are individually tailored, based on crewmember preference. Menu food consists of three daily meals per crewmember and provides an average energy intake of approximately 2,700 calories per crewmember per day. The pantry food is a 2-day contingency food supply that also contains food for snacks and beverages between meals and for individual menu changes. Pantry food provides an average energy intake of 2,100 calories per crewmember per day. Fresh food items consist of perishable items such as fruits and tortillas. The types of food include fresh, thermostabilized, rehydratable, irradiated, intermediate-moisture, and natural-form food and beverages.

Three 1-hour meal periods are scheduled for each day of the mission. This hour includes actual eating time and the time required to clean up. Breakfast, lunch, and dinner are scheduled as close to the usual hours as possible. Dinner is scheduled at least 2 to 3 hours before crewmembers begin preparations for their sleep period.

If a payload or the middeck accommodation rack is installed in the middeck, the repackaged galley will be manifested. The primary components (galley oven, rehydration station, hot water tank) are taken from the existing galley inventory, and have been repackaged to occupy less space. These operate in the same manner as on the larger galley. The repackaged galley was first manifested on STS-49, and has permanently replaced the larger galley. The menu trays are housed in a middeck locker.

Repackaged Galley

The repacked galley (hereafter referred to as the galley) is a multipurpose facility that provides a centralized location for one individual to handle all food preparation activities for a meal. The galley has facilities for heating food, rehydrating food, and stowing food system accessories. The galley consists of a rehydration station, oven, hot water tank, and associated controls.

Oven

The oven is divided into two principal compartments: an upper compartment designed for heating at least 14 rehydratable food containers inserted on tracks, and a lower compartment designed to accept up to 7 flexible packages. The *OVEN/RHS ON/OFF* switch provides power to the oven heaters and the control electronics assembly. The oven fan *ON/OFF* switch enables/disables power to three oven fans. These fans circulate warm air over a heat sink, thus providing forced convection heating for the rigid packages. The flexible packages are held against the heat sink by three spring-loaded plates, and warmed by conduction. The oven has a heating range of 160° to 185° F. The oven door is operated by "squeeze" latch requiring only 3 lb of pressure to open the door.

Rehydration Station Dispensing System

The galley rehydration station dispensing system interfaces directly with food and beverage packages to provide rehydration capability and drinking water for crewmembers.

When both *WATER HEATER* switches are turned on, 145° - 160° water is available for rehydration. The *VOLUME/OUNCES* switch selects the volume of water to be dispensed by the rehydration station in 0.5-ounce increments from 0.5 of an ounce to 8 ounces. The yellow *HOT* pushbutton indicator allows hot water to be dispensed when it is depressed and is illuminated when energized. When the selected volume of water has been dispensed, the pushbutton will begin to flash on and off. The light will be extinguished when the food package is retracted, releasing the rehydration station lever *ARM/LIMIT* switch.

The rehydration station lever ARM/LIMIT switch serves as an interlock so water can be dispensed only when a food package is connected to the needle. The food package makes contact with the rehydration station lever, which activates the LIMIT switch (note that the flight crew does not physically actuate the lever).

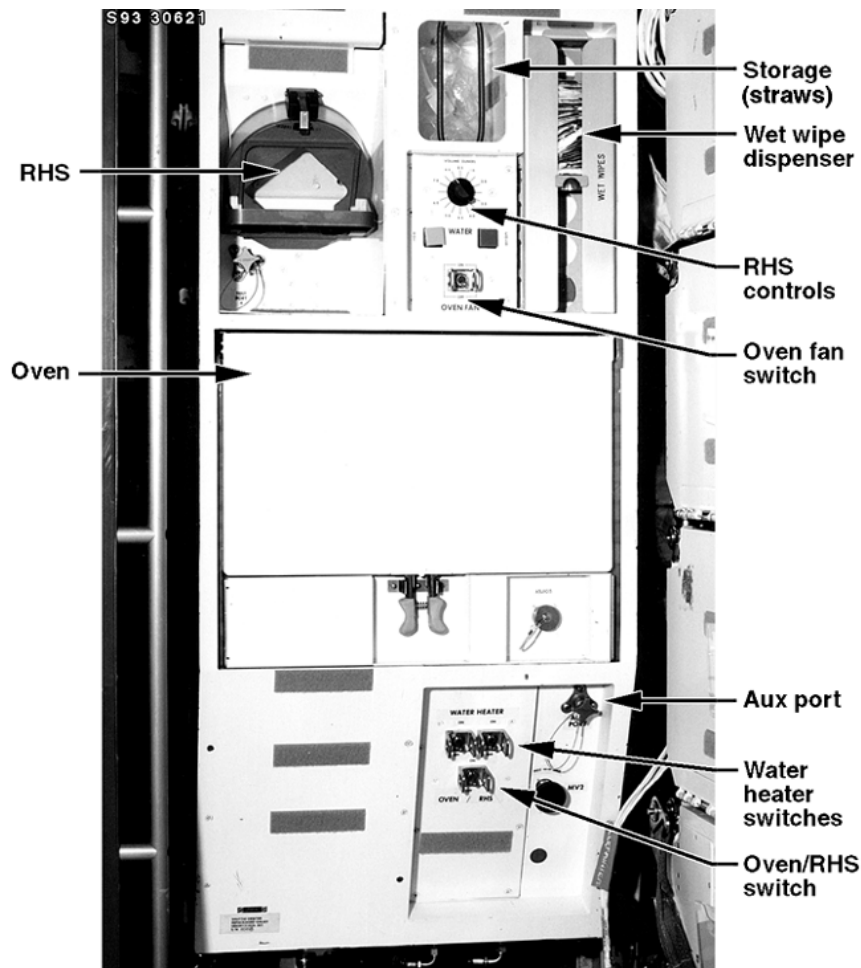
The blue COLD pushbutton indicator allows cold water to be dispensed when it is depressed and is illuminated when energized. When the selected volume of water has been dispensed, the pushbutton will begin to flash on and off. The light will be extinguished when the food package is retracted, releasing the rehydration station lever ARM/LIMIT switch.

Galley Controls

The galley controls consist of the OVEN/RHS switch, the two WATER HEATER switches, the

OVEN FAN switch, the rehydration station hot and cold pushbuttons and quantity selector dial, and the MV2 valve. Six water heater strips on the hot water tank are energized when the two WATER HEATER switches are turned on. The OVEN/RHS switch controls power to the oven heaters and rehydration pumps and associated electronics.

On the lower right-hand side of the galley (above the MV2) is an auxiliary port water quick disconnect (AUX PORT QD) that allows the crewmembers to access ambient to hot potable water when a 12-foot flex line and water dispensing valve are attached to the QD. The MV2 valve, located below the AUX PORT QD, allows the crew to control the temperature of water (hot to ambient) out of the AUX PORT. The galley also has a test port (under the rehydration station) and a canon plug (by the oven latch) that are used for ground operations.



Shuttle Repackaged Galley

Volume A - Pantry

Volume A holds a hodgepodge of items in three half trays stowed upside down. Snack foods, such as almonds, dried apricots, butter cookies, candy-coated nuts, candies, granola bars, peanut butter, and dried beef, are stowed in the right-hand tray. This "free-for-all" food is available to anyone at any time and tends to be very popular. The second tray of volume A contains all the entry day weather wave-off entrees. Unlike the menu food that is packed by meals and itemized with labels, this food is stuffed into the tray in a jumble. Crewmembers are free to swap out their planned meals during the mission with items from this tray. The third tray holds reentry kits, extra drink bags, straws, and utensils. The reentry kits, also known as fluid loading kits, contain either empty drink bags and salt tablets, chicken consommé (drink) packets, or Astroade packets (like Gatorade without sugar). Crewmembers must consume a certain amount of water and salt tablets, depending on their body weight, prior to entry

to aid in their readjustment to one-g. The extra drink bags are for drinking water. Drinking straws can be removed from this tray and temporarily stowed in the storage compartment of the galley for easy access. Each crewmember is provided with one set of utensils, which includes a knife, fork, tablespoon, and a small pair of scissors, for the entire flight.

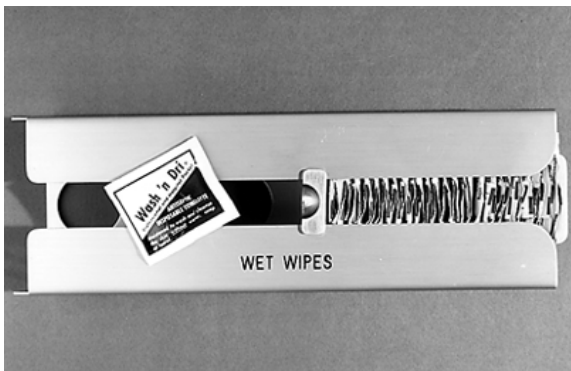
About 6 months before a flight, crewmembers attend a food tasting provided by the food systems group (SP4) to sample and rate every food and drink item, including reentry kits. Several weeks later, crewmembers individually meet with a dietitian to develop their personal menus for the flight. Choices are based on the crewmember's preferences from the tasting and on the dietitian's nutritional and caloric recommendation. Generally the food supply is more than adequate because about 30 to 50 percent of all the food manifested for flight returns unopened. The food systems people make a good effort to accommodate special requests for favorite and ethnic foods.



Utensils



Vitamins



Wet Wipes



Salt, Pepper, and Toothpicks

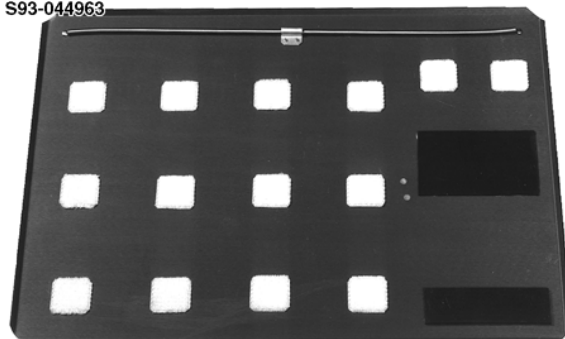
Accessories

Accessories consist of gum and candy, vitamins, wet wipes, and the galley adapter. The galley adapter is a removable piece of the galley slide/adaptor mechanism. The wet wipes dispenser is launched in place in the galley as well. This spring-loaded dispenser initially contains 100 wet wipes. As they are used up, crewmembers can use the Consumables cue card (unofficial) or the Reference Data stowage list to locate more wet wipes for the dispenser.

Trays

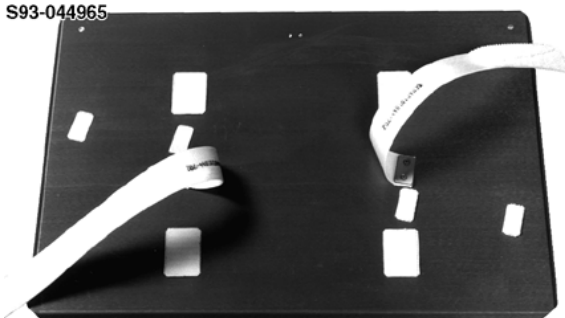
After the dehydrated foods were repackaged into nonrigid containers and after cans were demanifested, the old food trays lost their specific usefulness, and new trays were designed. The new tray consists of a flat piece of aluminum with magnets and Velcro patches for holding utensils, food, and drink packets. These trays are lighter than the old trays and generally are preferred by the crews. Crewmembers either can Velcro the trays to a wall (ceiling/floor) or can strap the trays to one of their legs for use. The strap on the underneath side has been modified so that it fits over the right or the left thigh (not both).

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Top of Tray

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Bottom of Tray

2.13 GUIDANCE, NAVIGATION, AND CONTROL (GNC)

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Description

Guidance is the computation of corrective actions to change from the navigation-determined vehicle state to a required vehicle state. The required state depends on particular mission requirements. Mission requirements usually specify a required present state (e.g., a particular orbit) or an objective (e.g., rendezvous at a point in space) from which the present required state can be computed.

Navigation is the determination of the state of motion of the vehicle; i.e., position, velocity, and attitude. This state is determined with reference to some mission-dependent coordinates suitable for defining the motion of the vehicle.

Control is the application of corrective maneuvers to obtain the changes commanded by guidance. Flight control for the orbiter converts guidance computations into effector commands to point and translate the vehicle. Control software frequently uses navigation data to determine the effectors used and the appropriate system control gains.

State Vector

The basic function of the orbiter navigation system is to maintain an accurate estimate of the inertial position and velocity of the vehicle, called its state vector, with respect to time. In addition, during a rendezvous mission, the navigation system must also maintain an estimate of a target's position and velocity. This information is then used by the onboard guidance system to compute the commands required

to transfer the vehicle from one position and velocity to another, as well as to point the vehicle at a specified target (Earth, Sun, another orbiting vehicle, etc.). The state vector data are also used by the ground controllers for monitoring the health of the onboard navigation system. Information about the orbiter and target state vectors is displayed to the crew on the dedicated displays and GNC CRT displays.

The navigation system maintains its knowledge of the orbiter's position and velocity with a group of six parameters (X, Y, Z, V_x, V_y, V_z) defining the state vector. A time tag is also associated with this state vector. The X, Y, Z components are the orbiter's position in the Mean of 1950 (M50) coordinate system measured in feet from the center of the Earth. The velocity components are measured in feet per second, and are also in the M50 coordinate system. The time at which the state vector is applicable is based on Greenwich mean time (GMT).

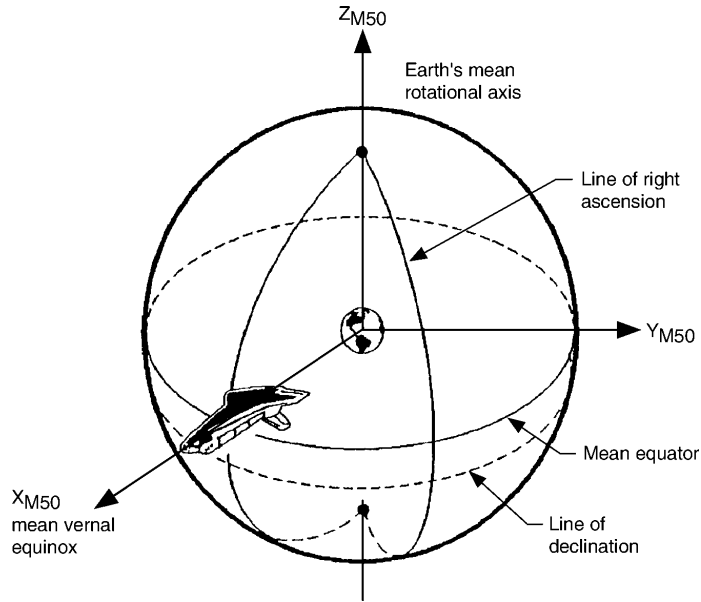
The navigation system uses the standard equations of motion along with the information received from the inertial measurement units, the navigation sensors, and the software models of the forces acting on the orbiter (gravity, drag, vents, etc.) to predict the components of the state vector at each time value. This process is called state vector propagation, a scheme in which errors are inherent. The equations of motion and the propagation technique are approximations, as are the gravity, drag, and vent models. In addition, the acceleration, position, and range rate information received from the inertial measurement units and the navigation sensors is also prone to error. To correct these errors, which increase with time, the ground controllers periodically uplink a new state vector or a delta to the current onboard state based upon the more accurate ground radar tracking data.

The release of OI-27 flight software (FSW) will begin the process of replacing the orbiter tactical air navigation (TACAN) system with a global positioning system (GPS). GPS is designed to provide the navigation system with an alternate source of orbiter state vector data throughout the orbit and entry phases of flight. GPS hardware installation onto each vehicle is determined by the orbiter maintenance down period (OMDP) schedule. As a result, a mixed

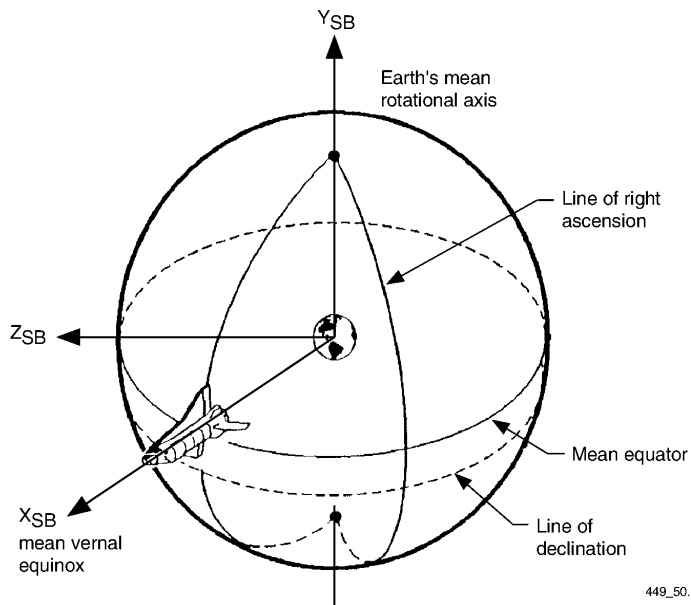
fleet operation of either triple-string TACAN or triple-string GPS will continue. Some orbiters may be equipped with a single GPS unit as part of the OI-26B development test objectives (DTOs). However, at this time there are no plans to operate the navigation software in other than a triple-string TACAN mode for these orbiters. The OI-27 FSW will support each option. This section addresses both triple-string TACAN and triple-string GPS configurations.

WARNING

Control software uses state vector information to select control effectors and set control gains, especially during entry. Large navigation errors can cause the orbiter to depart controlled flight.



M50 Coordinate System



Starball Coordinate System

Coordinate Systems

The position and velocity of the orbiter must be uniquely defined in terms of an inertial coordinate system - a reference frame that is neither rotating nor accelerating. Such a system ensures that the normal equations of motion are valid. The onboard navigation system uses the M50 inertial system. However, some computations are considerably simpler if performed in other coordinate systems. For example, when landing the orbiter, the position of the vehicle relative to the runway is more meaningful than its position in a coordinate system fixed in space. Therefore, the onboard navigation system uses a number of different coordinate systems to simplify the various inputs, outputs, and computations required. These inputs and outputs can be expressed in any coordinate system by using coordinate transformations resident in the navigation software.

All the coordinate systems referenced are right-handed Cartesian systems. These right-handed systems have three mutually perpendicular axes, sequentially ordered such that each axis satisfies the application of the right-hand rule to the other two axes (XYZ system: applying right-hand rule to the other two axes (X-Y yields Z, to Y-Z yields X, and to Z-X yields Y).

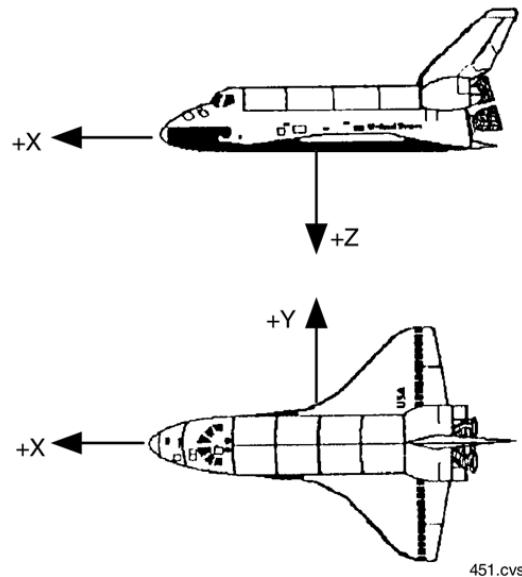
Body Axis Coordinate System

The body axis coordinate system maintains the origin at the orbiter's center of mass with the three axes stemming from that point. The X axis is parallel to the X_0 axis of the orbiter structural body (orbiter + external tank + solid rocket boosters) and lies in the orbiter plane of symmetry. The positive direction is toward the nose. The Z axis lies in the orbiter plane of symmetry and is perpendicular to the X axis. The positive direction is opposite the payload bay. The Y axis completes the right-handed orthogonal system and points out of the right wing. Note that vehicle pitch is a rotation about the Y body axis, roll is a rotation about the X body axis, and yaw is a rotation about the Z body axis.

M50 Coordinate System

The inertial coordinate system used by the onboard navigation system is the Aries Mean of 1950 Cartesian system, generally called the M50 system. The M50 system is used to establish and maintain the inertial position and velocity

of the orbiter during all flight phases. The X axis points toward the mean vernal equinox (the apparent point on the celestial sphere where the Sun crosses the Earth's equator on its northward journey) of the year 1950. The Z axis points along Earth's mean rotational axis of 1950 with the positive direction toward the North Pole. The Y axis completes the right-handed system, with the corresponding X-Y plane lying in the plane of the equator. Note that this is an inertial system and, although its origin is at the Earth's center, the M50 system is completely independent of the Earth's rotation.



Body Axis Coordinate System

Starball Coordinate System

The Starball coordinate system, a variation of the M50 system, places the origin at the orbiter's center of gravity. The Starball orientation makes the pitch angle equivalent to the right ascension and the yaw angle equivalent to declination, thus simplifying maneuvers to point at stars. This coordinate system is seldom, if ever, used.

Local Vertical/Local Horizontal Coordinate System

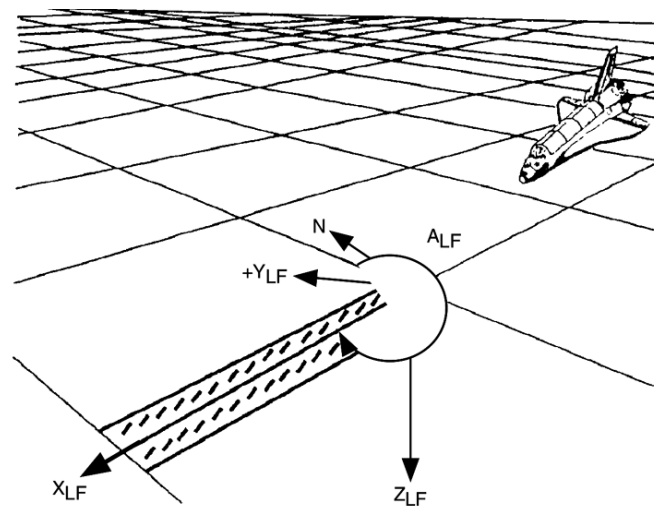
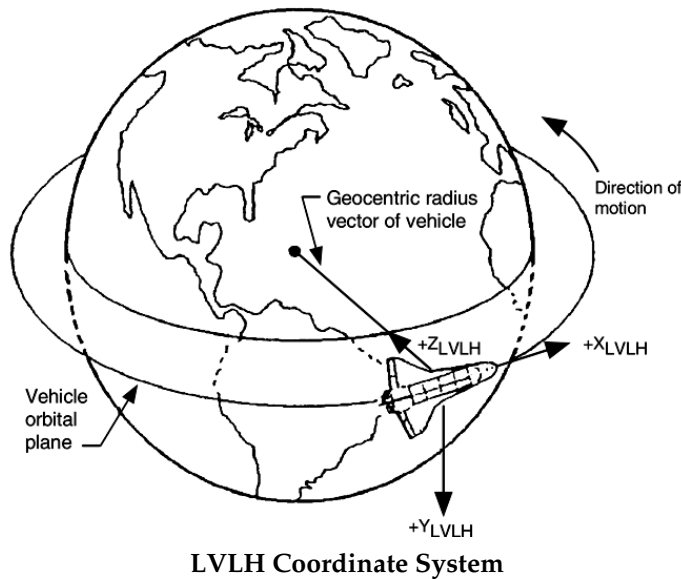
The local vertical/local horizontal (LVLH) coordinate system is an orbiter-centered system. The positive Z axis points toward the center of the Earth along the geocentric radius vector of the vehicle. The positive Y axis points toward the negative angular momentum vector of the

vehicle's orbit. The X axis completes the right-hand rule with positive X along the vehicle's direction of motion in the orbital plane. The LVLH system allows the crew to see the attitude of the orbiter in relation to the Earth's surface. It is not an inertial system, because it rotates at approximately $4^\circ/\text{minute}$ with respect to the inertial frame.

Runway Coordinate System

For launch, landing, and Earth observation, it is advantageous to know the orbiter's position and velocity in coordinate systems fixed to the Earth. These non-inertial systems are related to the M50 system by transformations that depend on time, Earth rotation rate, and the latitude and

longitude of the point of interest. The runway coordinate system is a good example of an Earth-fixed reference frame. The origin of the system is placed at the runway center at the approach threshold. The Z axis is normal to the ellipsoid model through the runway centerline and positive toward the center of the Earth. The X axis is perpendicular to the Z axis and lies in a plane containing the Z axis and the runway centerline (positive in the direction of landing). The Y axis completes the right-hand rule. Note that A is the runway azimuth measured in the X-Y plane from true north to the positive X axis (positive clockwise). The runway coordinate system is used by navigation and the crew during ascent, entry, and landing phases of flight.



Guidance, Navigation, and Control Software

Guidance, navigation, and control (GNC) software commands the GNC system to effect vehicle control and to provide sensors and controllers with the data needed to compute these commands. The process involves three steps:

1. Navigation tracks the vehicle's actual location.
2. Guidance equipment and software compute the orbiter location required to satisfy mission requirements.
3. Flight control transports the orbiter to the required location.

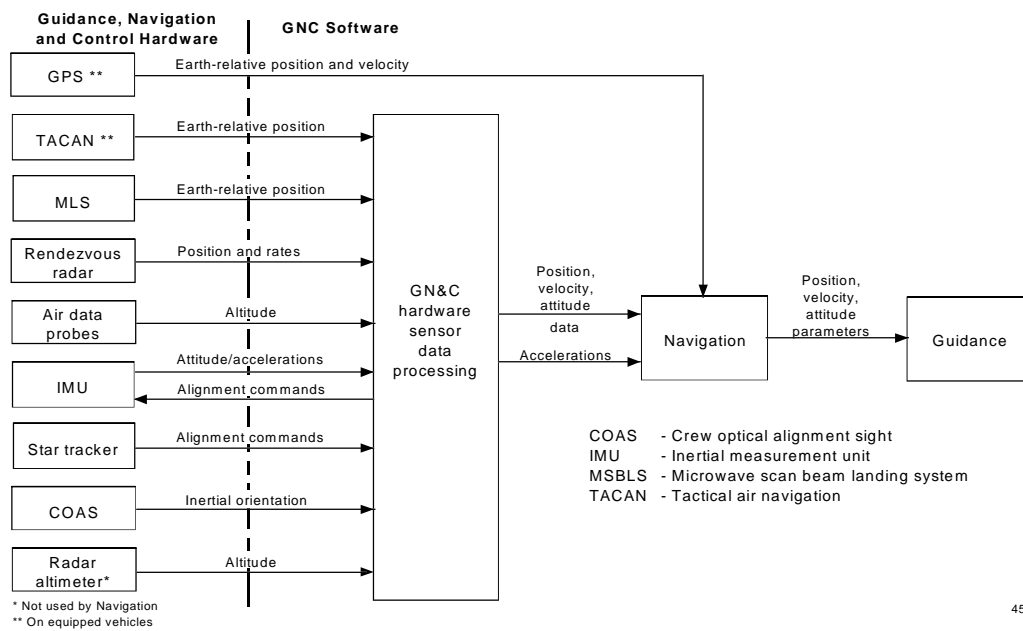
During launch and ascent, most of the GNC commands are directed to gimbal the three SSMEs and two SRBs to maintain thrust vector control. The GNC software also controls SSME burns for maximum aerodynamic loading of the vehicle during ascent, referred to as max q . To

Control Modes

The GNC system consists of two operational modes: automatic and control stick steering. In the automatic mode, the primary avionics software system (PASS) essentially allows the GPCs to fly the vehicle. The flight crew may control the vehicle in the control stick steering mode using hand controls, such as the rotational hand controller. In the control stick steering mode, flight crew commands must still pass through and be issued by the GPCs. There are no direct mechanical links between the flight crew and the orbiter's various propulsion systems or aerodynamic surfaces. The orbiter is an entirely digitally controlled, fly-by-wire vehicle.

Navigation Hardware

The navigation system uses measurements from onboard sensors to improve its estimate of the state vector. These sensors and the physical data they sense include:



Navigation Interfaces

circularize the orbit and perform on-orbit and deorbit maneuvers, the GNC software commands the orbital maneuvering system (OMS) engines. At external tank separation, on orbit, and during portions of entry, GNC controls commands to the reaction control system (RCS). In atmospheric flight, GNC controls the orbiter aerodynamic flight control surfaces.

- Inertial measurement unit (IMU) -- senses vehicle attitude in inertial space and accelerations along inertial axes.
- Star trackers -- sense vehicle line of sight vectors to stars or orbiting targets.

The communications carrier assembly (CCA) is a cloth aviator-type cap that positions and supports the electronics for interface with the EMU radio for crewmember communications. The CCA contains the microphones and earphones necessary for the EVA crewmembers to communicate with each other or with the orbiter. The CCA also allows the EVA crewmembers to talk to Mission Control via the orbiter communications system. Six sizes allow the CCA to fit 5th through 95th percentile-sized crewmembers. The CCA includes the following components: skull cap, ear cups, ear phones, ear seals, microphone modules, microphone booms, summing module, interconnect wiring, interface cable, neck strap, crew-optional chin strap, and perspiration absorption strap.

The in-suit drink bag is a dielectrically sealed bag assembly attached to the interior of the HUT that supplies drinking water to the crewmember during EVA. The drink bag is available in two sizes with the capacity for 21 or 32 fluid ounces of water. The in-suit drink bag includes the following components: bladder, inlet valve, drink valve, drink tube, and velcro attachments.

The urine collection device (UCD) is a disposable, flexible container that has the capacity to hold up to 32 fluid ounces of urine. The UCD is worn under the LCVG by male crewmembers during EVA. It is designed for one-time use, then disposed of as wet trash. The UCD includes the following components: collection bag, attachment straps, one-way check valve, and disposable roll-on cuff.

The maximum absorption garment (MAG) consists of multiple layers of material designed to rapidly absorb and store urine. The MAG is designed to be worn under the LCVG by male or female crewmembers during EVA. It has the capacity to hold 32 fluid ounces of urine and is disposable after use. The MAG includes the following components, multilayer absorbent material and tape attachment straps.

Life Support System

The life support system (LSS) provides a safe living environment inside the EMU. The LSS provides a variety of functions while the crewmember performs an EVA, including provision

of breathing oxygen, suit pressurization, crewmember cooling, crewmember communications, displays and controls for crewmember operation of the EMU, and monitoring of EMU consumables and operational integrity. The life support system consists of the following:

- Primary oxygen system
- Secondary oxygen pack
- Oxygen ventilation circuit
- Liquid transport system
- Feedwater circuit
- Electrical interfaces
- Extravehicular communicator (EMU radio)
- Display and control module
- Caution and warning system.

The primary oxygen system, oxygen ventilation circuit, liquid transport system, feedwater circuit, electrical interfaces, extravehicular communicator, and the caution and warning system make up the primary life support subsystem (PLSS). The secondary oxygen pack is a separate unit that is attached to the bottom of the PLSS. Together, the PLSS and the secondary oxygen pack make up the backpack of the EMU.

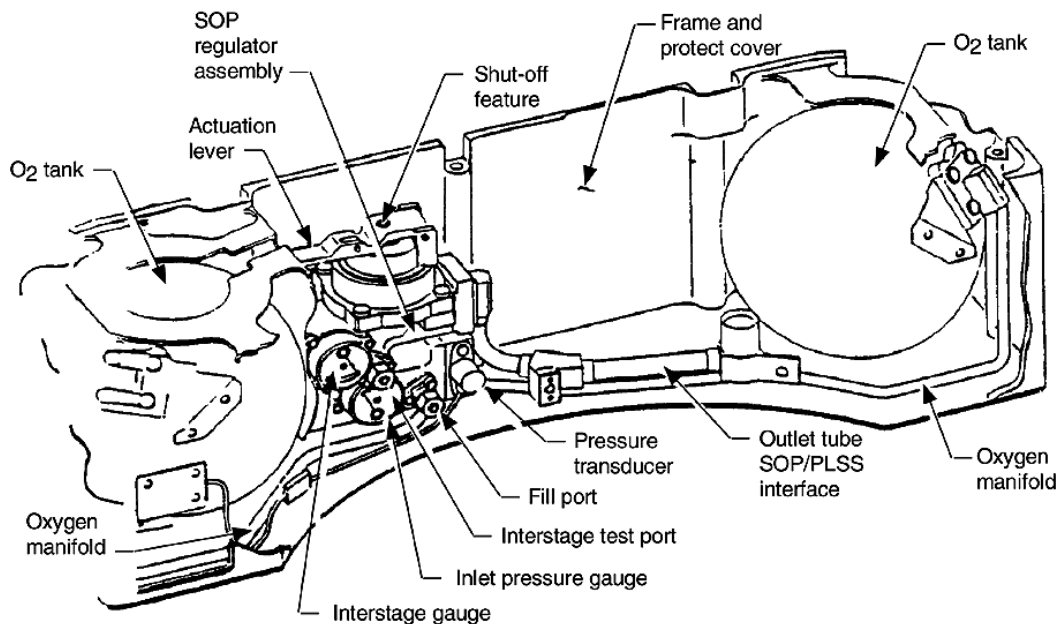
The primary oxygen system provides a crewmember with breathing oxygen and satisfies pressure requirements for EVA. The system stores 1.217 pounds of oxygen at 850 psia and 90° F. It delivers oxygen during EVA at 4.3 ± 0.1 psid, and maintains a metabolic use rate range of 0.02 to 0.33 lb/hr. The system is charged through a common multiple connection to the orbiter environmental control and life support system. Charging pressure is 850 ± 50 psig. The minimum usable pressure is 60 psi. The system performs various functions, including suit pressurization, provision of breathing oxygen, and water pressurization. The primary oxygen system includes the following components: oxygen tanks, oxygen tank pressure sensor, flow limiter, oxygen shutoff valve, oxygen actuator, suit pressure regulator, water pressure regulator, high mode relief valve, and low mode relief valve.

The secondary oxygen system, also known as the secondary oxygen pack (SOP), is the backup assembly to the primary oxygen system. This backup system provides a minimum of 30 minutes of emergency oxygen in the purge mode. The SOP functions include suit pressurization, provision of breathing oxygen, and some degree of cooling in the purge mode. There is no required crewmember interface to activate the SOP; it automatically activates whenever the oxygen actuator is in the EVA position and suit pressure is less than 3.9 psid. The SOP includes two oxygen tanks, containing a total of 2.65 pounds of oxygen at 5800 psia and 70° F. The system includes the following components: oxygen tanks, SOP inlet pressure gauge, first-stage regulator, interstage gauge, second-stage regulator/shutoff valve/flow restrictor, PLSS/SOP interface connector, and oxygen tank pressure sensor.

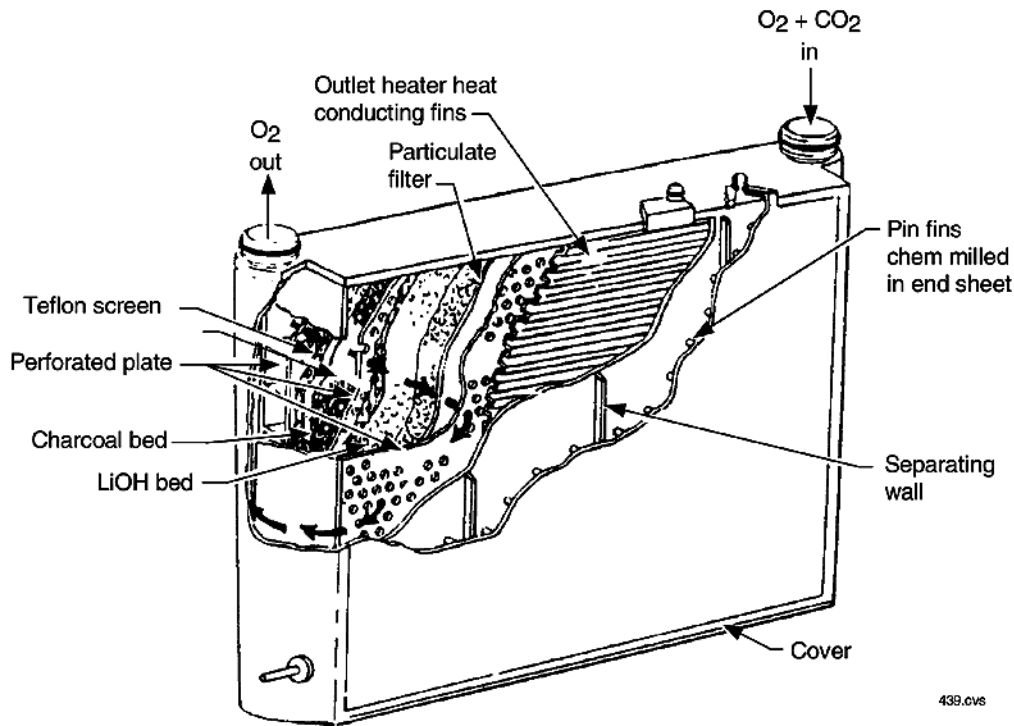
The oxygen ventilation circuit forms a closed loop with the space suit assembly. The circuit provides oxygen for breathing, suit pressurization for intravehicular activity (IVA) and EVA operation, and ventilation for cooling and elimination of exhaled gases. The oxygen flow picks up heat, humidity, carbon dioxide, and other contaminants, which are removed from the EMU by the ventilation circuit components. The system includes the following components: fan/water separator, slurper/ sublimator, vent

flow sensor/backflow check valve, suit pressure sensor, suit pressure gauge, contaminant control (lithium hydroxide) cartridge (CCC), carbon dioxide sensor, display control module purge valve, helmet purge valve, positive pressure relief valve, negative pressure relief valve, SOP checkout package, muffler, and SOP checkout fixture. Ventilation flow is picked up at the body extremities and returned to the upper torso via a vent duct manifold that is part of the LCVG. From the upper torso, the gas is routed back into the PLSS and the CCC. The CCC is sized to absorb 1.48 pounds of carbon dioxide associated with 7000 Btu of metabolic activity over a 7-hour EVA period. The cartridge is installed in the back of the PLSS and is replaceable on orbit. On the ground, the used cartridge can be recharged for future use.

The liquid transport system uses the centrifugal pump to circulate approximately 240 lb/hr of water through the LCVG. The function served by the liquid transport system is to provide cooling to the crewmember. The system includes the following components: pump, temperature control valve, LCVG, gas trap, pump priming valve, pump check valve, sublimator temperature sensor, and service and cooling umbilical bypass valve. During IVA operation, the pump circulates water not only through the EMU, but also through the service and cooling umbilical to the orbiter heat exchanger.



Secondary Oxygen Pack



LiOH Cartridge

The feedwater circuit contains the equipment and water to dissipate heat loads imposed on the system by the crewmember, the PLSS, and the environment. It also contains equipment to remove moisture from the ventilation circuit and gas from the transport circuit, to separate the water and gas, and to put them back in their respective loops. The feedwater circuit functions involve heat rejection, LCVG water makeup, and vent loop condensate separation and storage. The system includes the following components: feedwater tanks (2 primary/1 reserve), feedwater tank pressure sensors, reserve feedwater tank check valve, feedwater pressure regulator, feedwater shutoff valve, feedwater pressure sensor, sublimator, feedwater relief valve, condensate water relief valve, water separator, and coolant isolation valve. The primary and reserve tanks store approximately 10 pounds of feedwater at 15 psig. The reserve feedwater tank provides 30 minutes of water for EMU cooling in the event that primary feedwater is depleted. Potable water from the orbiter ECLSS is used to fill or recharge the tanks.

The EMU electrical system is composed of the following main components: battery, feedwater shutoff valve, coolant isolation valve, motor, instrumentation, extravehicular communicator,

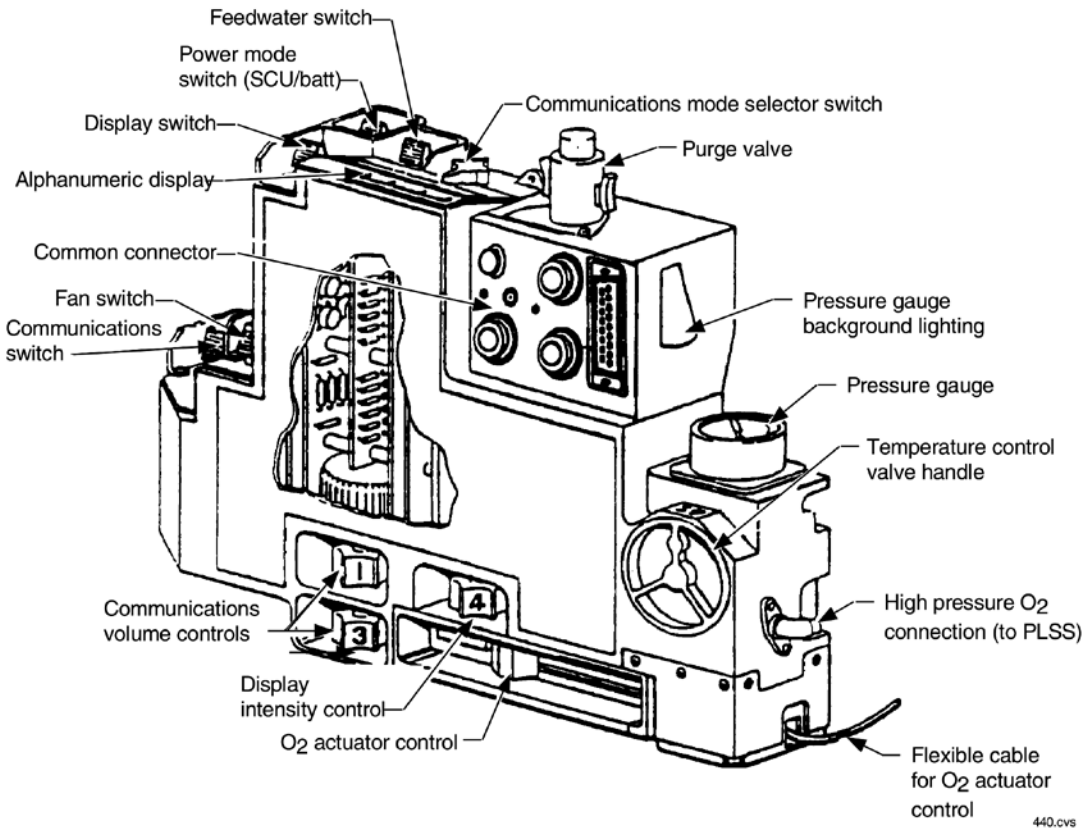
display and control module, and caution and warning system. Electrical interfaces exist between the display and control module and parts of the PLSS, SOP, and C/W. The power supply for operation of all electrical components of the EMU is a battery installed in the back of the PLSS. The EMU battery consists of eleven sealed, silver-zinc, high current density cells connected in series. The battery provides a minimum of 26.6 amp-hr of power over a 7-hour EVA mission at a nominal voltage of 16.5 V dc.

The extravehicular communicator (EVC) is composed of two parts, the orbiter-based equipment and the EMU-based equipment. The orbiter equipment consists of the EVA/air traffic control transceivers and antennas. This configuration provides communication with the EVA crewmembers and relay between EVA crewmembers and the ground (including downlink ECG and real-time data system (RTDS) telemetry). The EMU equipment consists of the EMU radio and antenna. It provides voice communications with other EVA crewmembers and the orbiter, ECG/RTDS telemetry to the orbiter for recording and/or downlink, and caution and warning tones to alert the EVA crewmember of anomalies or other significant events. The EVC includes the following compo-

nents: orbiter UHF system, EMU radio, EMU electrical harness, communications carrier assembly, biomed sensors, COMM MODE selector switch, COMM switch, volume controls, and real-time data system. Orbiter panels O6, A1R, and R10 are the crew communication interfaces. The panels control UHF operation, air-to-air or ground transmission, and biomed data down-link/recording respectively.

The display and control module (DCM) contains all controls and displays necessary for nominal operation and monitoring of EMU systems. The DCM includes the following components: POWER mode switch, DISPL switch, FAN switch, COMM switch, communications volume controls, display intensity control, oxygen actuator, temperature control valve, pressure gauge, DCM purge valve, alphanumeric display COMM mode selector, and WATER switch. The DCM is installed on the hard upper torso, with the surfaces covered with a TMG. This TMG contains the labels for the controls and displays.

The EMU caution and warning system (CWS) consists of instrumentation and a microprocessor to obtain, process, and visually display information for use by the EVA crewmember in the operation and management of the EMU. The system contains built-in test equipment (BITE), consisting of software and hardware that verify proper CWS operation. CWS serial data are also routed to the ground by the real-time data system. The CWS functions involve displaying EMU leak check procedures, monitoring and displaying EMU consumables status, monitoring EMU operational integrity, and alerting crewmembers to EMU anomalies. The system includes the following components: alphanumeric display with BITE indicator, display (DISPL) switch, alert/status/warning tones, sensors, and "black box" processor. The CWS receives inputs from EMU sensors and from the DISPL switch located on the DCM. Sensors gather information throughout the EMU system and relay it to the CWS. Information is provided on pressures, temperatures, currents, and voltages.



Display and Control Module

EMU Ancillary Equipment

The EMU ancillary equipment consists of hardware necessary to support the EMU during all phases of EVA (prep/post/operation). The following list itemizes the components with a brief description of their functions.

EMU helmet lights - attach to the helmet EVVA and provide two functionally independent sets of lights for portable lighting during an EVA task.

EMU scissors - steel cutters with one serrated edge capable of cutting anything from fabric bags and straps to lightweight steel cable and Kevlar cord.

EMU wrist mirror - attaches to the wrist of the EVA glove to allow the EVA crewmember to view the controls and displays on the front of the EMU.

EVA cuff checklist - a set of reference cards bound by an aluminum alloy bracket attached to a wrist band. The reference cards, approximately 4 inches by 5 inches in size, contain procedures and reference data for performing EVA tasks and for aiding in the diagnosis and resolution of EMU malfunctions.

Food stick - a fruit bar contained in an edible wrapper, positioned just above the neck ring adjacent to the drink valve on the in-suit drink bag.

In-suit drink bag syringe - a device used to remove gas from the water in the drink bag. The needle of the syringe is inserted in the inlet valve of the bag, and gas is suctioned out of the bag with the syringe.

Thermal mittens - an adjustable enclosure composed of several layers of thermal blankets and aluminized Mylar with a layer of Nomex felt on the palm and undersides of the fingers that fit conformally around the EV gloves to provide greater thermal hand protection at extreme high and low temperature worksites.

Lower torso assembly donning handles - left and right handles that aid in the mating of the hard upper torso and lower torso assembly halves of the waist ring.

Contingency tool - a pry bar used to disconnect the LTA and HUT halves of the waist ring in the event that the latching mechanism becomes jammed. Operation of the pry bar may damage the latching mechanism; therefore, it should be used only if the waist ring becomes jammed and the crewmember is entrapped in the space suit.

Bends treatment adapter (BTA) - an emergency device that may be used on-orbit in the event an EVA crewmember contracts decompression sickness (bends). The BTA converts the EMU into a hyperbaric treatment chamber, pressurizing the EMU to 8.0 psid over ambient cabin pressure.

SOP checkout fixture - a flight support test item installed on the HUT half of the neck ring during pre-EVA operations.

DCM plug - a cover that attaches to the multiple connector on the DCM in the event that water begins leaking from the connector after the service and cooling umbilical multiple connector is removed.

Prep kit - items necessary for preparing the EMU for EVA, such as antifog wipes, tissue-type wipes, scissors, and urine collection device clamps.

Maintenance kit - additional equipment necessary for routine EMU maintenance, including valsalva devices, stericide wipes, lubricant wipes, antifog wipes, and urine collection device roll-on cuffs.

Bio kit - equipment associated with the biomed instrumentation, including EVA cables, over-tapes, electrode placement illustration, alcohol wipes, stoma seals, and electrode paste.

Airlock stowage bag - a Nomex bag used for temporary storage and transfer of items used in prep- and post-EVA operations. When stowed in the airlock over the inner hatch, the bag and its contents are removed from the airlock prior to airlock depressurization.

EVA bag - used to stow various items (camera, thermal mittens, tool caddy) in the airlock for possible use during EVA. The EVA bag remains in the airlock during the EVA.

IMUs and star trackers, the star tracker line of sight is referenced to the navigation base and the orbiter coordinate system; thus, the GPC knows the star tracker's pointing direction and its orientation with respect to the IMUs.

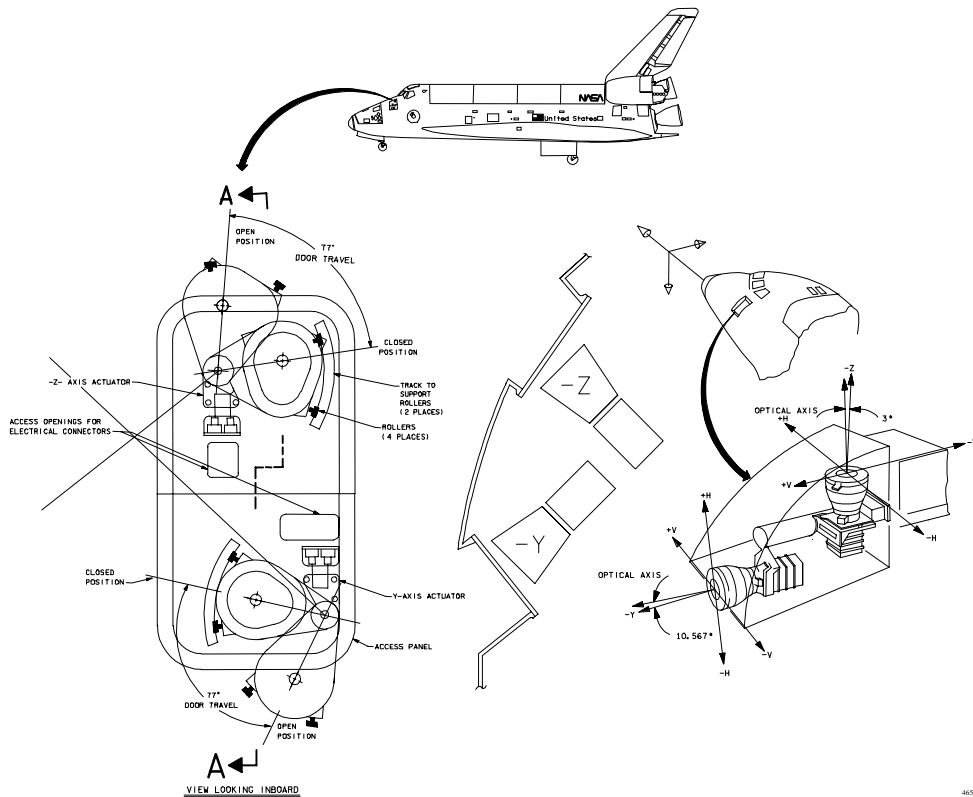
Each star tracker has a door to protect it during ascent and entry. The doors are opened on orbit to permit use of the star trackers. To enable the star tracker doors to open, the STAR TRACKER POWER -Y and -Z switches on panel O6 must be positioned to ON. The STAR TRACKER DOOR CONTROL SYS 1 and SYS 2 switches on panel O6 control two three-phase ac motors on each door. Positioning the SYS 1 switch to OPEN controls motor control logic and drives the -Y and -Z star tracker doors by electromechanical actuators to the open position. Limit switches stop the motors when the doors are open and control talkback indicators above the DOOR CONTROL switches. Setting the SYS 2 switch to OPEN controls redundant ac motors and electromechanical actuators to open both doors. Limit switches stop the motors when the doors are open and control the same two talkback indicators above the DOOR CONTROL SYS 1

and SYS 2 switches. Normally, both the SYS 1 and SYS 2 switches are used together to actuate the star tracker doors.

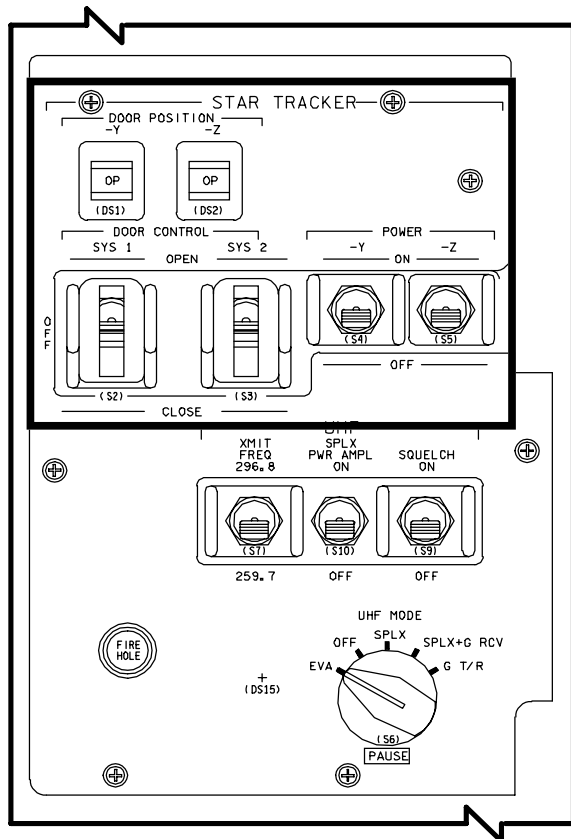
Positioning the SYS 1 switch to CLOSE drives the system 1 motors and closes the -Y and -Z doors; the talkback indicators above the switches indicate CL. Setting the SYS 2 switch to CLOSE drives the system 2 motors and closes the -Y and -Z doors; the talkback indicators above the switches indicate CL. The indicators are barberpole when a door is between open and closed. The door opening or closing time with two motors is 6 seconds; with one motor, it is 12 seconds.

The OFF position of the SYS 1 or 2 switch removes power from the corresponding motor control logic circuitry.

The star trackers are used to align the IMU inertial platforms. A star tracker searches for, acquires, and tracks stars whose approximate position is determined by the IMUs. By knowing the relationship of the star tracker to the orbiter and the location of the star in space, a line-of-sight vector from the orbiter to the star is defined. Two such vectors define the orbiter inertial attitude.



Star Trackers



STAR TRACKER Controls and Talkbacks on Panel O6

The difference between the inertial attitudes defined by the star tracker and the IMU is processed by software and results in IMU torquing angles. If either the IMU gimbals are physically torqued or the matrix defining its orientation is recomputed, the effects of the IMU gyro drift are removed, and the IMU is restored to its inertial attitude. If the IMU alignment is in error by more than 1.4°, the star tracker may be unable to acquire and track stars. In this case, the HUD must be used to realign the IMUs to within 1.4°; the star trackers can then be used to realign the IMUs more precisely.

NOTE

The star tracker cannot be used if the IMU alignment error is greater than 1.4° because the angles the star tracker is given for searching are based on current knowledge of the orbiter attitude, which is based on IMU gimbal angles. If that attitude is greatly in error, the star tracker may acquire and track the wrong star.

In addition to aligning the IMUs, the star trackers can be used to provide angular data from the orbiter to a target. This capability can be used during rendezvous or proximity operations.

The star tracker includes a light shade assembly and an electronics assembly mounted on top of the navigation base. The light shade assembly defines the tracker field of view (10° square). Its shutter mechanism may be opened manually by the crew using an entry on the S TRK/COAS CNTL display, or it can be opened and closed automatically by a bright object sensor or target suppress software. The bright object sensor reacts to close the shutter before a bright object, such as the Sun or Moon, can damage the star tracker (the sensor has a larger field of view than the star tracker shutter).

The electronics assembly contains an image dissector tube mounted on the underside of the navigation base. The star tracker itself does not move; the field of view is scanned electronically. The star tracker may be commanded to scan the entire field of view or a smaller offset field of view (1° square) about a point defined by horizontal and vertical offsets. An object is tracked when the proper intensity and the correct location are sensed. Star tracker outputs are the horizontal and vertical position within the field of view of the object being tracked and its intensity.

There is no redundancy management for the star tracker assemblies. They operate independently and can do the entire task. They can be operated either separately or concurrently.

The star tracker SOP supports the modes that are commanded manually from SPEC 22 S TRK/COAS CNTL: self-test, star track, target track, break track, and term/idle. Self-test consists of software and hardware tests. In the star track mode, the star tracker does an offset scan search for the star, acquires it, and tracks it. The star may be selected by the flight crew or GPC; in either case, a field-of-view check is made. Target track is the same as star track, but it tracks a target. Threshold is independent of target track. Break track forces the star tracker to stop tracking a star or target and to perform a search scan from the current location to track the next target it acquires. In the term/idle mode, the star tracker hardware continues

operation, but star tracker software processing ceases. In addition, the star tracker SOP maintains the star table. When a star tracker has acquired and tracked a star, and the data have passed software checks, the star identification, time tag, and line-of-sight vector are stored. The identification and time elapsed since time tag are displayed in the star table. When two or three stars are in the table, the angular difference between their line-of-sight vectors is displayed. The difference between the star tracker and star catalog angular differences is displayed as an error. The star tracker SOP selects line-of-sight vectors of two stars in the star table for IMU alignment and outputs an ALIGN ENA discrete. The software selects the star pair whose angular difference is closest to 90°.

The flight crew may manually override the SOP selection or clear the table if desired. The SOP also determines and displays star tracker status. Star tracker parameters are accessible to the crew on the S TRK/COAS CNTL display (SPEC 22).

Crew Optical Alignment Sight

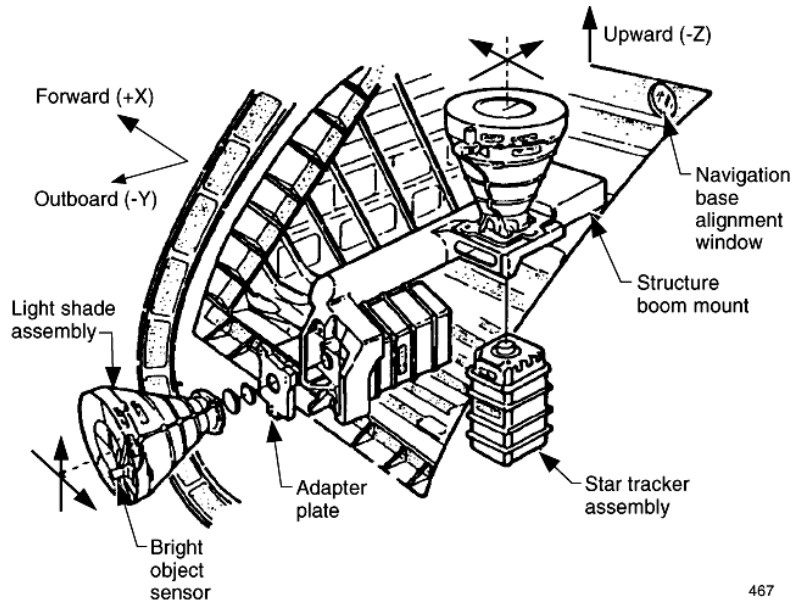
The COAS is an optical device with a reticle focused at infinity projected on a combining glass. The reticle consists of a 10°-wide circle with 1° marks. A light bulb with variable brightness illuminates the reticle. The COAS requires 115-volt ac power for reticle illumination. The COAS is 9.5 by 6 by 4.3 inches and weighs 2.5 pounds.

The COAS can be used if IMU alignment is in error by more than 1.4°, rendering the star tracker unable to acquire and track stars, but, primarily, the HUD is used.

The COAS can be mounted at either the commander's station to view along the +X axis or next to the aft flight deck overhead starboard window to view along the -Z axis. To use the COAS or HUD, the flight crewmember must manually maneuver the orbiter until the selected star is in the field of view. The crewmember then maneuvers the orbiter so that the star crosses the center of the reticle or the "P" in the HUD test pattern. At the instant of the crossing, the crewmember enters a mark by depressing the most convenient of the three

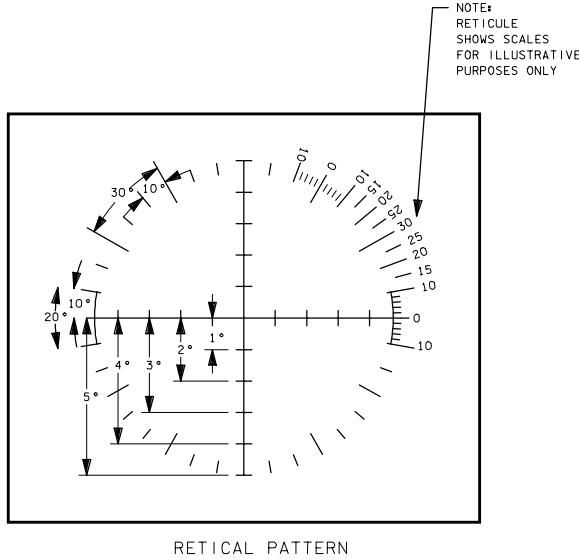
3011/022/	S TRK/COAS CNTL		1 006/09:35:06	
			000/00:00:00	
S TRK CNTL	-Y	-Z	S TABLE	1 2 3
SELF-TEST	1	2	TRK ID	15 43 0
STAR TRK	3	4	Δ MIN	1 1 0
TGT TRK	5	6	ANG DIF	84.1 0.0 0.0
BREAK TRK	7	8	ERR	0.02 0.00 0.00
TERM/IDLE	9*	10*	SEL	17* 18* 19
			S TABLE CLR	20
S TRK	-Y	-Z	COAS	
REQD ID	11 0	12 0	REQD ID	21 0
TRK ID	0	0	ΔDEG X	-0.2
S PRES			Y	+0.3
ΔANG	+0.00	+0.00	SIGHT MODE	22
THOLD	13 0	14 0	ACCEPT	23
SHUTTER	CL	CL	CAL MODE	24
MAN OP	15	16	DES	25
STATUS			POS	+X 26 -Z 27*
			ΔBIAS	0.00 0.00
			UPDATE	28 29

S TRK/COAS CNTL Display (SPEC 22)



View into Star Tracker Cavity

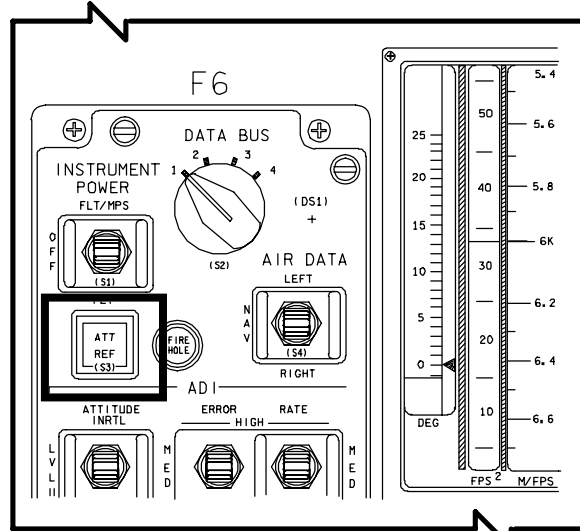
ATT REF pushbuttons located on panels F6, F8, and A6U. At the time of the mark, software stores the gimbal angles of the three IMUs. This process can be repeated if the accuracy of the star's centering is in doubt. When the crewmember feels a good mark has been taken, the software is notified to accept it. Good marks for two stars are required for an IMU alignment. The separation between the two stars should be between 60° and 120°.



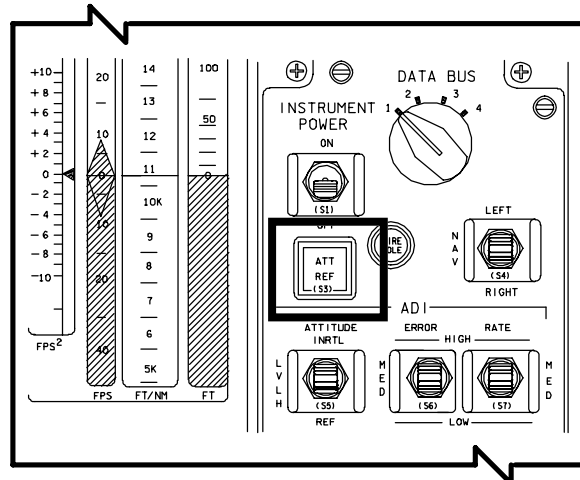
COAS Reticle Pattern

By knowing the star being sighted and the HUD or COAS's location and mounting relationship in the orbiter, software can determine a line-of-sight vector from the HUD/COAS to the star in an inertial coordinate system. Line-of-sight vectors to two stars define the attitude of the orbiter in inertial space. This attitude can be compared to the attitude defined by the IMUs; if an error exists, the IMUs can be aligned to the correct orientation.

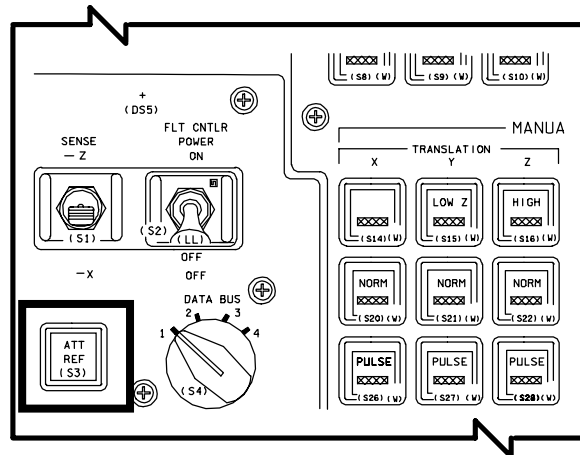
The COAS's mounting, relative to the navigation base on which the IMUs are mounted, is calibrated before launch. The constants are stored in software, and COAS line-of-sight vectors are based on known relationships between the COAS line of sight and the navigation base. These constants are usually updated by the crew on orbit using a calibration mode to mark on a star while the IMUs are known to be correctly aligned. The HUD is consistent and, generally, needs no calibration.



ATT REF Pushbutton on Panel F6



ATT REF Pushbutton on Panel F8



ATT REF Pushbutton on Panel AU6

The COAS can also be used to visually track targets during proximity operations or to visually verify tracking of the correct star by the -Z star tracker.

COAS data processing is accomplished in the star tracker SOP. This SOP accepts and stores crew inputs on COAS location, star identification, or calibration mode, accepts marks, computes and stores the line-of-sight vectors, enables IMU alignment when two marks have been accepted, and computes, updates, and provides display data. COAS parameters may be accessed using the S TRK/COAS CNTL (SPEC 22) display (lower right).

Tactical Air Navigation

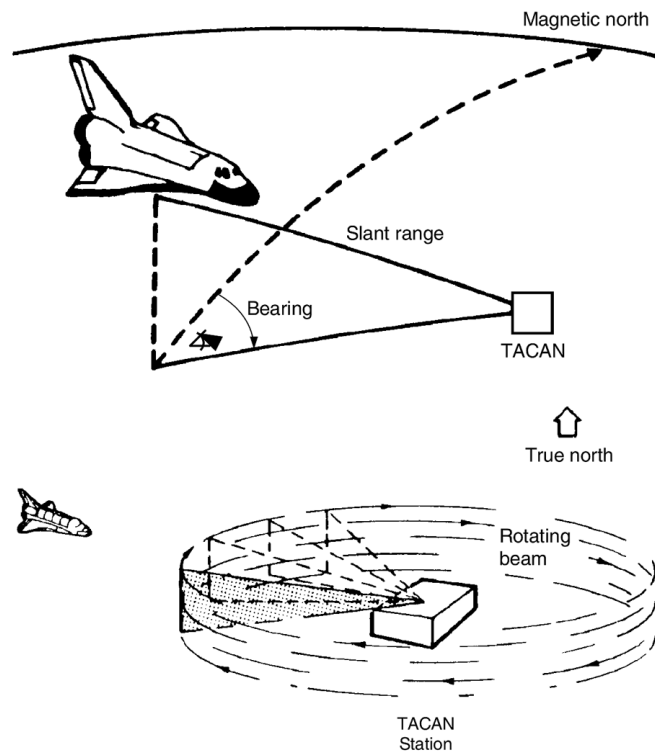
The onboard TACAN units determine slant range and magnetic bearing of the orbiter to a TACAN or VHF omnirange tactical air navigation (VORTAC) ground station.

The ground-based TACAN and VORTAC stations constitute a global navigation system for military and civilian aircraft operating at L-band frequencies (1 GHz). The TACAN unit includes a

transmitter, a receiver, and a data processor. The data processor decodes the selected channel and sends the frequency to the receiver.

Vehicles without the GPS upgrade are equipped with three TACANs that operate redundantly. Each TACAN has two antennas, one on the orbiter's lower forward fuselage and one on the orbiter's upper forward fuselage. The antennas are covered with thermal protection system tiles. The three convection-cooled TACANs are located in the orbiter crew compartment middeck avionics bays. The onboard TACANs are used to obtain orbiter position data from an external source during entry. TACAN's maximum range is 400 nautical miles (n. mi.). Each set is 7.62 inches high, 7.62 inches wide, and 12.53 inches long and weighs 30 pounds.

Each ground station has an assigned frequency (L-band) and a three-letter Morse code identification. The ground station transmits on one of 252 (126X, 126Y) preselected frequencies (channels) that correspond to the frequencies the onboard TACAN sets are capable of receiving. These frequencies are spaced at 63-MHz intervals.



- TACAN station transmits RF burst when beam points to true north.
- Aircraft receiver times interval from burst to beam impingement and derives bearing.

473_74.cvs

TACAN Operation

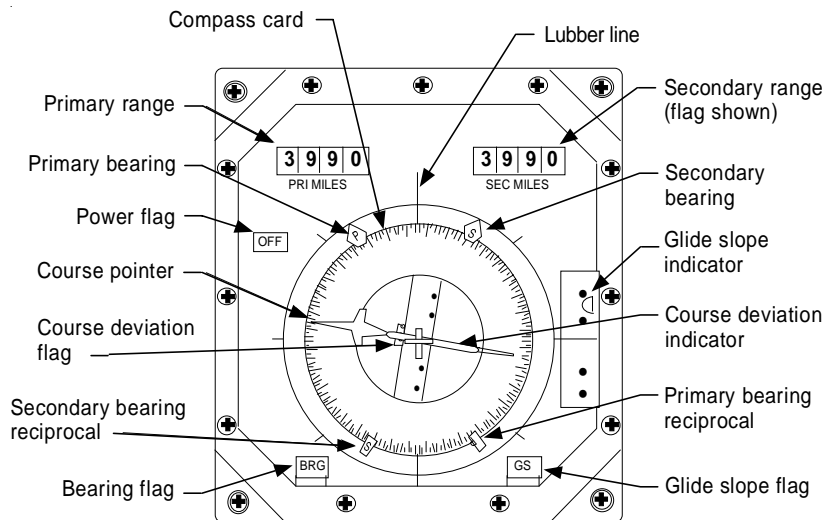
The TACAN ground station beacon continuously transmits pulse pairs on its assigned frequency. The orbiter TACAN receivers pick up these pulse pairs, and the TACAN data processors decode them to compute bearing. The onboard TACAN sets detect the phase angle between magnetic north and the position of the orbiter with respect to the ground station. The ground beacon is omnidirectional. When the orbiter is over the ground station, or nearly so, it is in a cone of confusion. Within this cone, bearing is unusable.

Periodically, the onboard TACAN sets emit an interrogation pulse that causes the selected TACAN ground station to respond with distance-measuring equipment pulses. The slant range (orbiter to ground station) is computed by the onboard TACAN sets by measuring the elapsed time from interrogation

to valid reply and subtracting known system delays. As the orbiter approaches a ground TACAN station, the range decreases. After a course has been selected, the onboard TACAN sets derive concise deviation data.

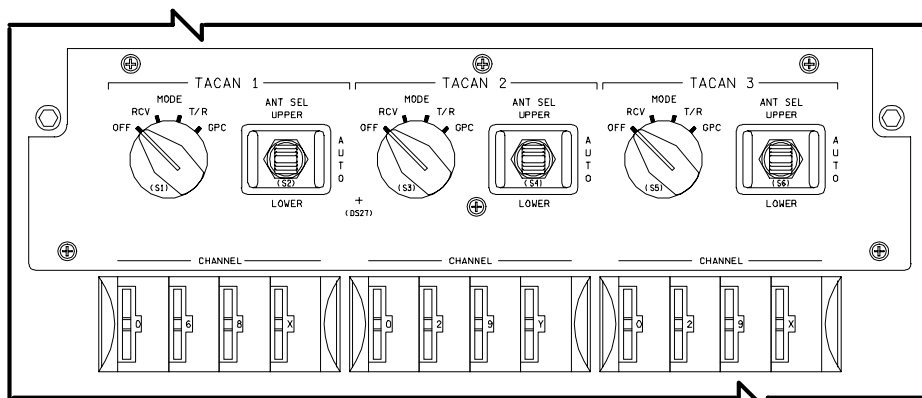
The TACAN range and bearing data are used to update the state vector position components during entry. Range and bearing data are also displayed on the horizontal situation indicators on panels F6 and F8, as well as on the CRT.

TACAN controls are located at the top of panel O7. The TACAN 1,2,3 ANT SEL switches control antenna selection. In the AUTO position, the onboard GPCs automatically select the best antenna for that TACAN. The UPPER and LOWER positions of the switches allow the flight crew to manually select the upper or lower L-band antenna.



Horizontal Situation Indicator

475.cvs



**TACAN Switches and Thumbwheels on Panel O7
(Three-string TACAN Vehicles)**

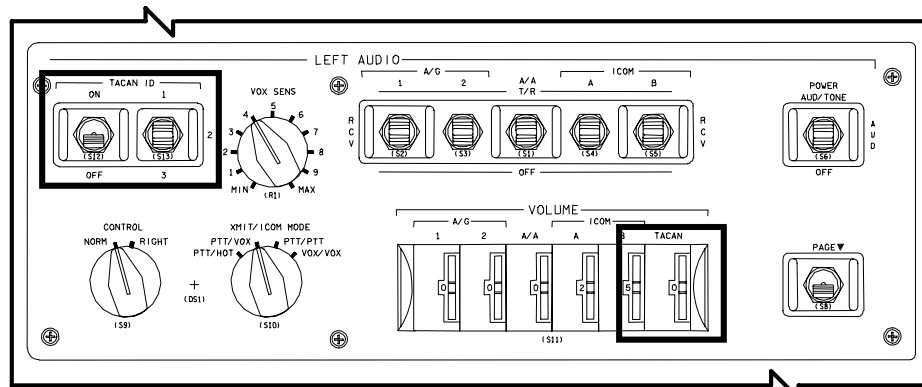
Each TACAN also has a MODE rotary switch on panel O7. The modes are OFF, receive (RCV), transmit and receive (T/R), and GPC. In the GPC mode, the onboard GPCs control TACAN ground station channel selection automatically, and both bearing and range are processed by hardware and software. In the T/R mode, both bearing and range are processed by hardware and software, but TACAN ground station channels are selected manually using the four CHANNEL thumbwheels for that TACAN on panel O7. The first three thumbwheels (left to right) select the channel (frequency), and the fourth selects the X or Y. In the RCV mode, only bearing is received and processed by the hardware; the thumbwheels for that TACAN are used to select the channel.

Approximately every 37 seconds, the selected TACAN ground station transmits its three-letter identification to the onboard TACAN. In order for the Morse code identification to be verified by the commander and pilot, TACAN ID audio controls are located on panel O5 (designated LEFT AUDIO) for the commander and panel O9

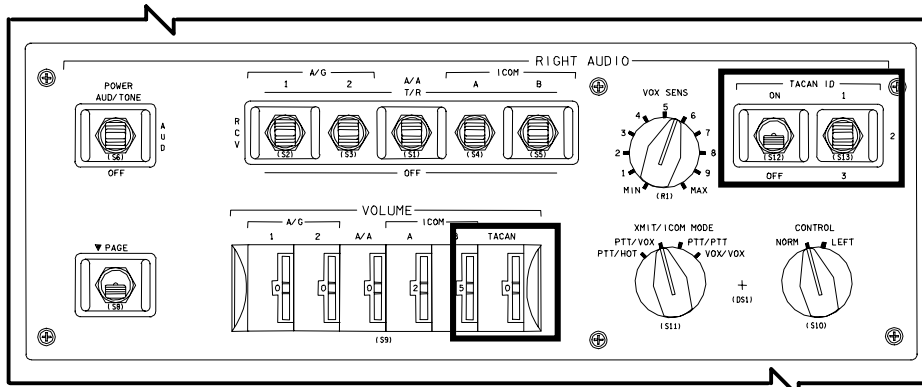
(designated RIGHT AUDIO) for the pilot. The TACAN ID ON/OFF switch is positioned to ON to receive the TACAN identification. The TACAN ID 1, 2, 3 switch selects the onboard TACAN that will transmit the TACAN identification code. VOLUME TACAN thumbwheels on panels O5 and O9 control the volume setting of the TACAN identification code to the commander and pilot.

During entry, when at least two TACANs lock on, TACAN range and bearing data are used by navigation software to update the state vector until microwave landing system (MLS) acquisition at approximately 18,000 feet.

TACAN azimuth and range (TAC AZ, RNG) are provided on the lower left side of the HORIZ SIT display (SPEC 50). TACAN range and bearing data cannot be used to produce a good estimate of the altitude position component, so navigation uses barometric altitude derived from the air data system probes, which are deployed by the flight crew at approximately Mach 5.



TACAN Controls on Panel O5



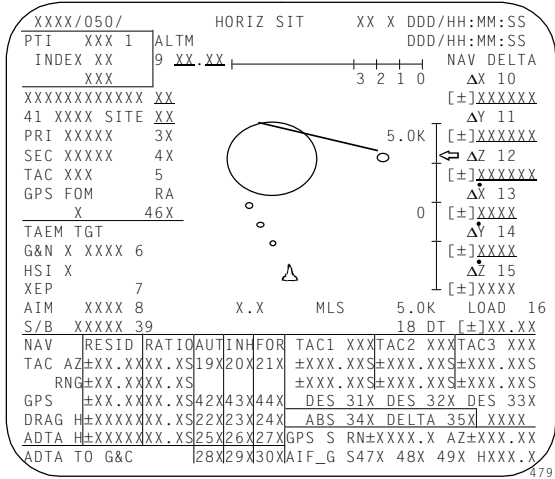
TACAN Controls on Panel O9

Global Positioning System

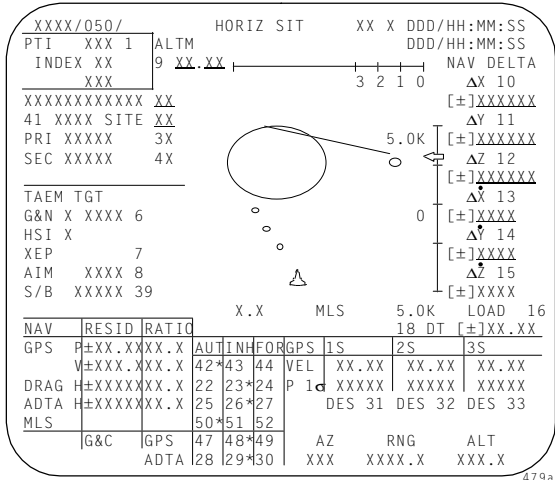
The GPS is a relatively new navigation tool to the shuttle. Because of the anticipated decommissioning of TACAN stations by the Department of Defense (DOD), shuttle program officials decided to use GPS as the replacement for TACANs, which had been a primary navigational tool for entry.

The NAVSTAR GPS is a space-based radio positioning navigation system that provides three-dimensional position, velocity, and time information to suitably equipped users anywhere on or near the surface of the Earth. The GPS constellation consists of 24 NAVSTAR satellites, including 3 active on-orbit spares. The satellites travel in 10,980 n. mi. orbits at velocities of 14,500 km/hr for periods of 12 hours. These satellites are in six planes, each at an inclination of 55° with respect to the equator. NAVSTAR satellites and their support equipment are financed by the DoD, but their navigation signals are available free of charge to anyone. The NAVSTAR satellite constellation control center facility is located at Falcon Air Force Base in Colorado Springs, CO.

The way a GPS receiver interacts with the NAVSTAR satellites to determine position and velocity is fairly straightforward. Each GPS satellite repeatedly transmits a specific sequence of codes. The receiver knows each satellite's code pattern, as well as what time a satellite is supposed to transmit specific parts of the code. After identifying a specific satellite (via code-matching techniques), the GPS receiver compares the time at which it received the specific part of the code to the time at which the satellite was supposed to have sent it. This time delta directly corresponds to how far the receiver is from the given satellite. For a receiver to determine exactly where it is near the Earth, it must make at least three such measurements from three different satellites. For the receiver to accurately measure the time delta, it must have an extremely accurate internal clock. Most receivers do not have an atomic clock; therefore, a fourth measurement is taken from another satellite to help the receiver determine its clock bias and, thus, determine an accurate state vector.



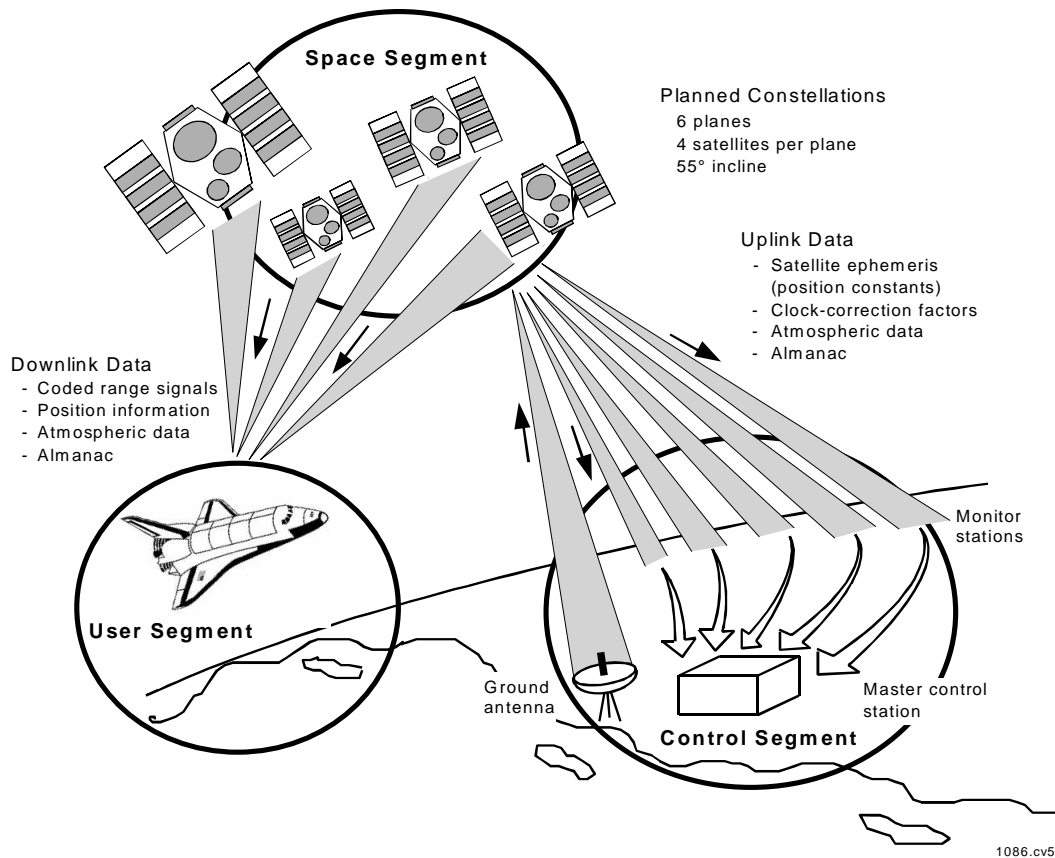
**HORIZ SIT Display (SPEC 50)
(TACAN Azimuth and Range
Three-String TACAN Vehicles)**



**HORIZ SIT Display (SPEC 50)
(Three-String GPS Vehicles)**

If MLS is not acquired, TACAN data can be used until an altitude of 1,500 feet. When runways with MLS are acquired, MLS operation is automatic. The flight crew is provided with the controls and displays necessary to evaluate MLS performance and take over manually if required.

TACAN redundancy management consists of processing and mid-value-selecting range and bearing data. The three TACANs are compared to determine if a significant difference is detected. When all three TACANs are good, redundancy management selects middle values for range and bearing. If a fault is detected, the SM ALERT light is illuminated, and a CRT fault message occurs for the applicable TACAN parameter.



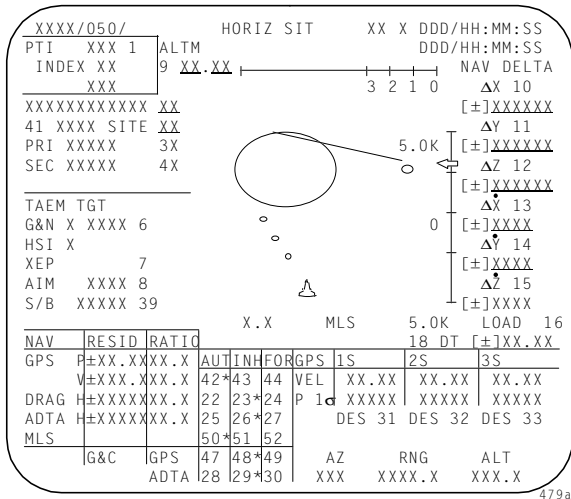
GPS Operation

The NAVSTAR satellites transmit two separate codes, one intended for U.S. military use (called Y-code) and one for civilian use (called coarse/acquisition (C/A) code). The major difference between these two codes is that the military code is encrypted and is more accurate. The encrypted code requires the military receivers to have a special "key" to decipher the transmitted messages. The accuracy of GPS using Y-code is expected to be better than 110 ft, and better than 170 ft using C/A code. The orbiter receivers contain the key necessary to use the more accurate Y-code.

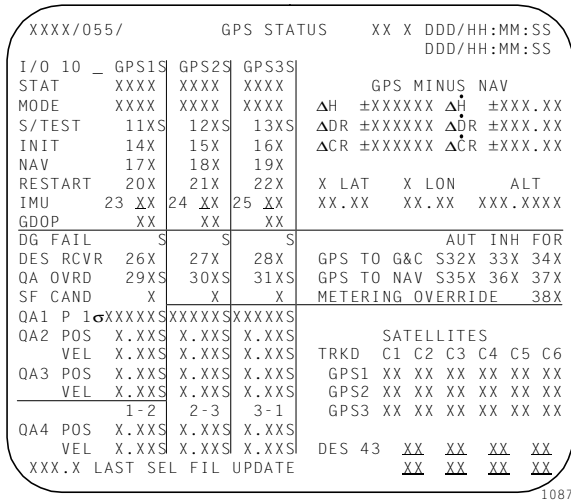
The orbiter is equipped with three GPS receivers that operate redundantly. Each receiver is equipped with two antennas, one on the orbiter's lower forward fuselage and one on the upper forward fuselage. The antennas are covered with thermal protection system tiles. The satellite signals are received by the antennas, amplified through a preamplifier, and then routed through a combiner to combine the signals from the upper and lower antenna pairs into a single stream of data. From there, the

signals are transmitted directly to the associated receiver for processing. The three convection-cooled GPS receivers are located in the orbiter forward avionics bays. Each receiver is 6.78 inches high by 3.21 inches wide by 12.0 inches long; each weighs 12.3 pounds and consumes 26 watts of power.

Unlike air data and MLS, where navigation data are used to update the onboard state vector, the selected GPS vector completely replaces the propagated vectors periodically during orbit (OPS 2 and 8) and entry (OPS 602/603 and OPS 3). For example, during orbit, the FSW will replace its propagated state vector with a selected GPS vector every 90 minutes. This vector will then be propagated forward by the FSW for the next 90 minutes, using the nominal FSW propagation techniques. GPS information is displayed on the horizontal situation indicators (HSIs) on panels F6 and F8, as well as on a CRT. Software controls and displays pertaining to GPS information can be found on the HORIZ SIT display (SPEC 50) and the GPS STATUS display (SPEC 55).



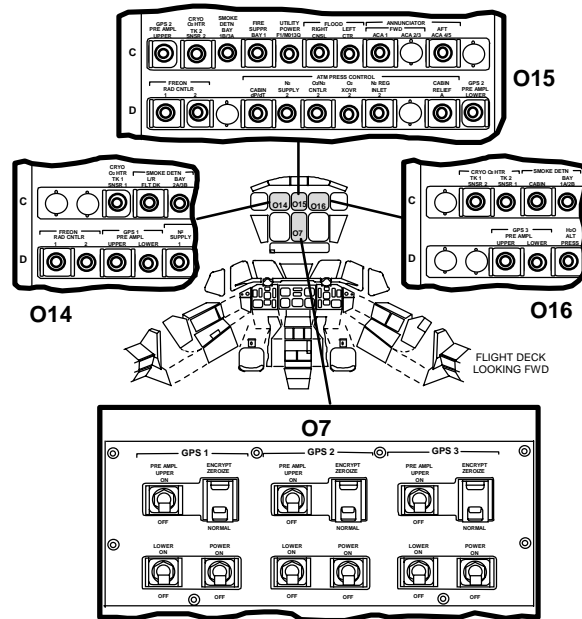
**HORIZ SIT Display (SPEC 50)
(Three-String GPS Vehicles)**



GPS STATUS Display (SPEC 55)

GPS hardware controls are located at the top of panel O7. GPS 1,2,3 PRE AMPL UPPER (LOWER) switches provide power to each of the antenna preamplifiers, with circuit breakers located on panels O14, O15, and O16. Each receiver has a POWER switch on panel O7 and is powered through a single energy storage system (ESS) bus/forward power controller (FPC) combination. The ENCRYPT switches located on panel O7 control the integrity of the Y-code key within each receiver. In NORM, the key is kept intact such that it can be used to decode the more accurate Y-code signals being sent by the NAVSTAR satellites. If this switch is moved to the ZEROIZE position, the key will be erased from the memory of the receiver and the

receiver only will be able to make measurements using the civilian codes. This is a procedure that would be used in the event of a non-U.S. landing to protect the key from being used by unauthorized users. A permanent switch guard prevents accidental movement of this switch. All of the new GPS switches on panel O7 will replace the existing TACAN switches.



**GPS Controls
(Three-String GPS Vehicles)**

Unlike the classical redundancy management (RM) schemes applied to other shuttle sensors, the GPS uses a cyclic quality assessment (QA) process that is more conducive to its performance. Because of the nature of its operation, whereby poor satellite coverage may result in short periods of invalid data, it would not be prudent to "permanently" remove a unit from availability because of these questionable periods.

There are four separate QA checks the software will perform to determine the status of the data from each receiver. These four checks include each receiver's estimate of the error in its own navigation state (QA1), the difference between each receiver's state and the FSW's computed state (QA2), the difference between each receiver's current state and its previous state (QA3), and the differences between each receiver and the other receivers (QA4). If the

FSW determines that any of these checks have failed, the associated receiver will not be considered available to the selection filter. With three candidates available (three level) to the selection filter, mid-value select (MVS) logic is used to select a unit's state vector for processing. With two candidates available (two level), the candidate data are averaged. With only one receiver available (one level), the single GPS is selected. When no eligible GPS candidates are available, the GPS selection filter will propagate the last valid data for processing. This vector will not be used to update the onboard navigation state if it has been longer than 18 seconds because the selection filter has had valid GPS data.

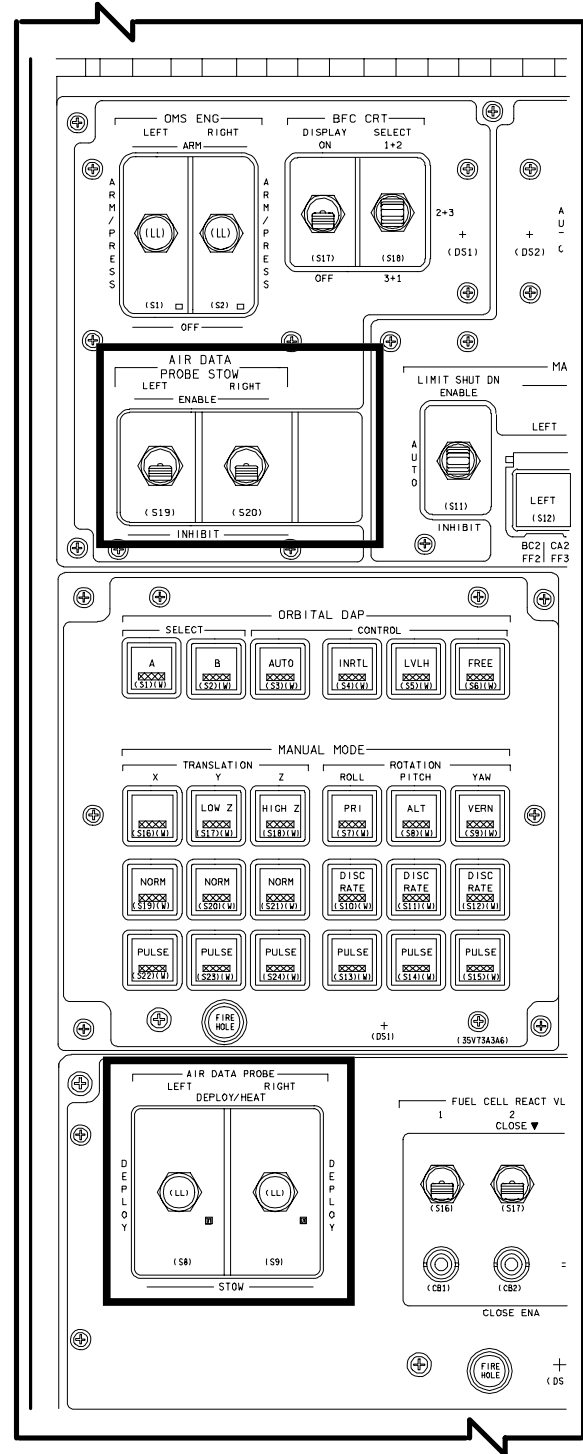
Air Data System

The air data system provides information on the movement of the orbiter in the air mass (flight environment). There are two air data probes, one on the left and one on the right side of the orbiter's forward lower fuselage. During the ascent, on orbit, deorbit, and initial entry phases, the probes are stowed inside the forward lower fuselage. The air data probe is covered by thermal protection system tiles while in the stowed position. At Mach 5, depending on mission requirements, the air data probes are deployed. Each probe is 4.87 inches high, 21.25 inches long, 4.37 inches wide, and weighs 19.2 pounds.

The air data system senses air pressures related to spacecraft movement through the atmosphere to update the navigation state vector in altitude, provide guidance in calculating steering and speed brake commands, update flight control law computations, and provide display data for the commander's and pilot's alpha/Mach indicators (AMIs), altitude/vertical velocity indicators (AVVIs), and CRTs. (The AMI and AVVI are described in detail in Section 2.7.)

Each air data probe has four pressure-port sensors and two temperature sensors. The pressures sensed include static pressure and angle-of-attack upper, center, and lower pressure. The four pressures are sensed at ports on each probe. The probe-sensed pressures are connected by a set of pneumatic lines to two air data transducer assemblies (ADTAs). The two temperature sensors are installed on each probe

and wired to an ADTA. The pressures and temperatures sensed by the left probe are connected by pneumatic tubing to ADTAs 1 and 3. Those sensed by the right probe are connected to ADTAs 2 and 4.



AIR DATA PROBE Switches on Panel C3

Within each ADTA, the pressure signals are directed to four transducers, and the temperature signal is directed to a bridge. The pressure transducer analogs are converted to digital data by digital-processor-controlled counters. The temperature signal is converted by an analog-to-digital converter. The digital processor corrects errors, linearizes the pressure data, and converts the temperature bridge data to temperatures in degrees Centigrade. These data are sent to the digital output device and then to the onboard computers to update the navigation state vector. The data are also sent to the CRTs and to the commander's and pilot's altitude/vertical velocity indicators, and alpha/Mach indicators.

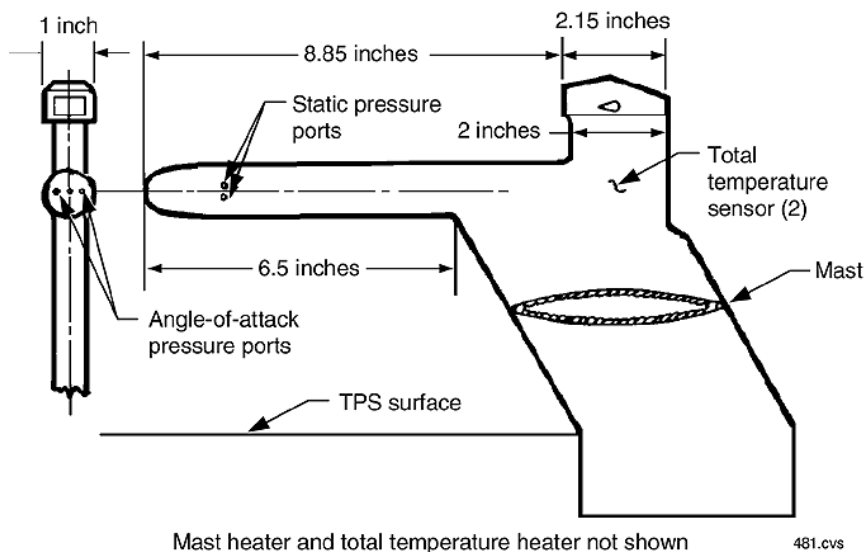
The ADTA SOP uses ADTA data to compute angle of attack, Mach number (M), equivalent airspeed (EAS), true airspeed (TAS), dynamic pressure (q-bar), and barometric altitude (h).

The GPCs compare the pressure readings from the four ADTAs. If all the pressure readings compare within a specified value, one set of pressure readings from each probe is averaged and sent to the software. If one or more pressure signals of a set of probe pressure readings fail, the failed set's data flow is interrupted, and the software receives data from the other ADTA on that probe. If both probe sets fail, the software operates on data from the two ADTAs connected to the other probe. The best total temperature from all four ADTAs is sent to the software.

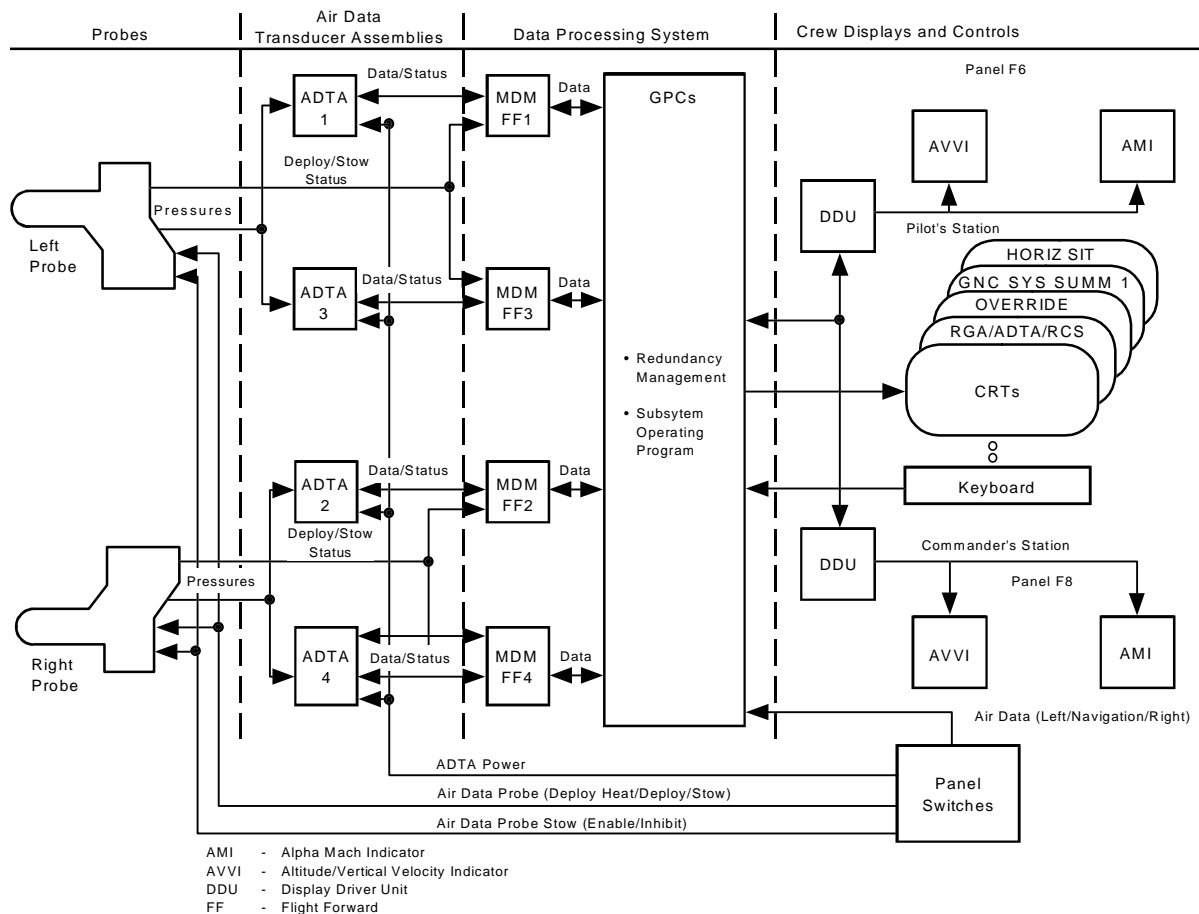
Each probe is independently deployed by an actuator consisting of two ac motors connected to a rotary electromechanical actuator. Each probe is controlled by its AIR DATA PROBE switch on panel C3. To deploy the air data probes, the LEFT and RIGHT switches are positioned to DEPLOY. The redundant motors for each probe drive the probe to the deployed position. When the probe is fully deployed, limit switches remove electrical power from the motors. Deployment time is 15 seconds for two-motor operation and 30 seconds for single-motor operation. The DEPLOY position deploys the probe without electrical heaters; the DEPLOY/HEAT position deploys the air data probes with heaters powered.

The AIR DATA PROBE STOW LEFT and RIGHT switches on panel C3 are used to stow the probes. The stow procedure includes positioning the switches to ENABLE and positioning the corresponding AIR DATA PROBE switch to STOW. The AIR DATA PROBE STOW INHIBIT position opens the ac motor circuits, disables the stow, and protects the microswitches.

The fault detection system illuminates the red AIR DATA and BACKUP C/W ALARM lights on panel F7, and illuminates the MASTER ALARM. A fault also sounds the audible tone and generates a fault message on the CRT. A communication fault illuminates the SM ALERT light.



Air Data Probe



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Air Data System Functional Block Diagram

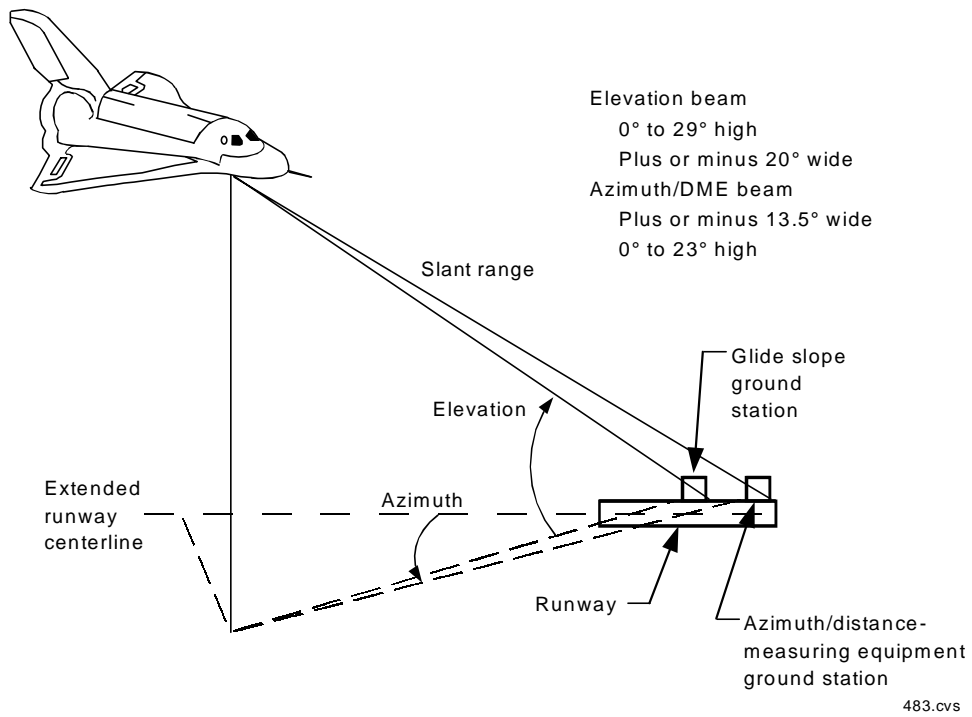
Microwave Landing System

The three onboard MLS units are airborne navigation and landing aids with decoding and computational capabilities. The MLS units determine slant range, azimuth, and elevation to the ground stations alongside the landing runway. MLS is used during the approach and landing flight phases. When the channel (specific frequency) associated with the target runway approach is selected, the orbiter's MLS units receive elevation from the glide slope ground station and azimuth and slant range from the azimuth/distance-measuring equipment ground station.

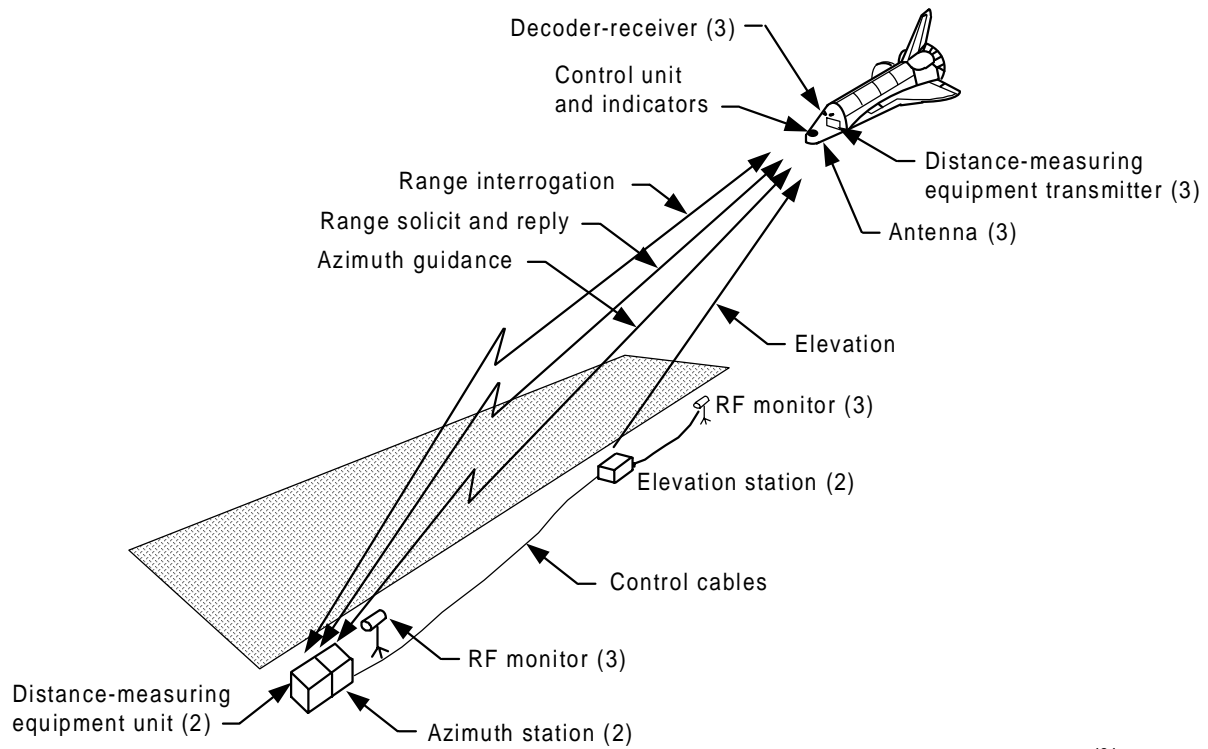
The orbiter is equipped with three independent MLS sets, each consisting of a Ku-band receiver transmitter and decoder. Data computation capabilities determine elevation angle, azimuth angle, and orbiter range with respect to the MLS

ground station. The MLS provides the orbiter highly accurate three-dimensional navigation position information to compute state vector components. The three orbiter Ku-band antennas are located on the upper forward fuselage. The three MLS and decoder assemblies are located in the crew compartment middeck avionics bays. Each MLS decoder assembly is 8.25 inches high, 5 inches wide, 16.6 inches long, and weighs 17.5 pounds. The radio frequency (RF) assembly is 7 inches high, 3.5 inches wide, 10.25 inches long, and weighs 6 pounds.

The ground portion of the MLS consists of two shelters: an elevation shelter and an azimuth/distance-measuring equipment (DME) shelter. The elevation shelter is located near the projected touchdown point, and the azimuth/DME shelter is located at the far end of the runway.



Major Microwave Landing System



Major Microwave Landing System Components and Radio Frequency Links

The MLS ground station signals are acquired when the orbiter is close to the landing site, usually at an altitude of approximately 18,000 feet. Final tracking occurs at the approach and landing interface at approximately 10,000 feet altitude and 8 n. mi. from the azimuth/DME station. (Refer to the Operations section for further information on entry procedures.)

The MLS azimuth, elevation, and range data are used to compute steering commands from acquisition through landing and rollout.

The commander's and pilot's horizontal situation indicators display the orbiter's position with respect to the runway. Elevation with respect to planned glide slope is shown on the glide slope indicator. The course deviation needle displays azimuth information, and range is displayed on a mileage indicator. Azimuth/DME data are used during the landing rollout.

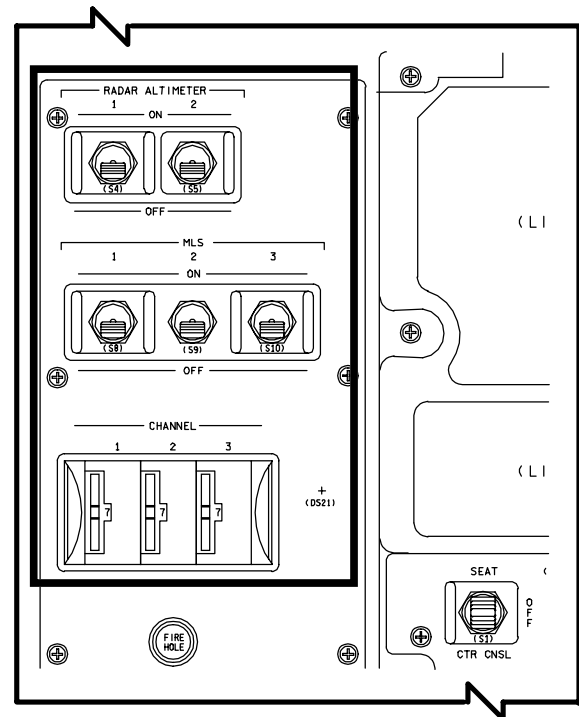
The three orbiter MLS sets operate on a common channel during the landing phase. The MLS ground station transmits a DME solicit pulse. The onboard MLS receiver responds with a DME interrogation pulse. The ground equipment responds by transmitting a return pulse. A decoder in the onboard MLS decodes the pulses to determine range, azimuth, and elevation. Range is a function of the elapsed time between interrogation pulse transmission and signal return. Azimuth pulses are returned in pairs. The spacing between the two pulses in a pair identifies the pair as azimuth and indicates on which side of the runway the orbiter is situated. Spacing between pulse pairs defines the angular position from the runway centerline. The spacing between the two pulses in a pair identifies the pair as elevation, while the spacing between pulse pairs defines the angular position of the orbiter above the runway.

Each RF assembly routes range, azimuth, and elevation information in RF form to its decoder assembly. The decoder assembly processes the information and converts it to digital data for transmission to the onboard GNC software via the MDMs.

Because the azimuth/DME shelters are at the far ends of the runway, the MLS provides useful data until the orbiter stops. Azimuth data provide position in relation to the runway

centerline; the DME gives the distance from the orbiter to the end of the runway.

Each MLS has an MLS ON/OFF power switch and a CHANNEL (frequency) selection thumbwheel on panel O8. Positioning the MLS 1, 2, or 3 switch to ON provides power to the corresponding system. MLS 1 receives power from main bus A, MLS 2 from main bus B, and MLS 3 from main bus C. Positioning the CHANNEL 1, 2, and 3 thumbwheels selects the frequency (channel) for the ground station at the selected runway for the corresponding MLS.



RADAR ALTIMETER Switches and MLS Switches and Thumbwheels on Panel O8

Redundancy management selects range, azimuth and elevation angles for processing navigation data. The three MLS sets are compared to identify any significant differences among them. When data from all three MLS sets are valid, redundancy management selects middle values from three ranges, azimuths, and elevations. In the event that only two MLS sets are valid, the two ranges, azimuths, and elevations are averaged. If only one MLS set is valid, its range, azimuth, and elevation are passed for display. During fault detection, the SM ALERT light is illuminated, and a CRT fault message is shown.

Radar Altimeters

The two RAs onboard the orbiter measure absolute altitude from the orbiter to the nearest terrain within the beam width of the orbiter's antennas. The two independent RAs consist of a transmitter and receiver antenna. The systems can operate simultaneously without affecting each other. The four C-band antennas are located on the lower forward fuselage. The two receiver/transmitters are located in the middeck forward avionics bays. Each radar altimeter receiver/transmitter measures 3.13 inches high, 7.41 inches long, 3.83 inches wide, and weighs 4.5 pounds.

Each RA transmits a C-band (4,300 MHz modulated at 8.5 kHz) pulse through its transmitting antenna. The signal is reflected by the nearest terrain, and the leading edge of the return radar echo is locked on by the RA's receiving antenna. The altitude outputs by the RA are analog voltages, proportional to the elapsed time required for the ground pulse to return. The range output of the RA is from zero to 5,000 feet. The RA may not lock on if large pitch or roll angles are present.

The GPCs process the data for display on the commander's and pilot's altitude/vertical velocity indicators and head up displays (described in more detail in Section 2.7) from 5,000 feet. Two RADAR ALTIMETER ON/OFF switches are located on panel O8. RA data is not used as input to navigation; it is for crew use only.

Flight Control System Hardware

The flight control system (FCS) ascent and entry hardware provides manual guidance commands to GNC software and responds to effector commands from GNC software in order to effect vehicle and trajectory control.

The following hardware includes sensors responsible for flight control data:

- Accelerometer assembly (AA) -- senses vehicle accelerations along two body axes.
- Rate gyro assembly (RGA) -- senses vehicle rotation rates about three body axes.

- SRB rate gyro assembly (SRB RGA) -- senses vehicle rotation rates about two body axes during first stage ascent before SRB separation.

The following hardware provides manual guidance commands:

- Rotational hand controller (RHC) -- commands acceleration about a body axis.
- Translational hand controller (THC) -- commands vehicle motion along a body axis.
- Rudder pedal transducer assembly (RPTA) -- commands an acceleration about the yaw body axis in atmospheric flight.
- Speed brake/thrust controller (SBTC) -- commands changes in vehicle aerodynamic drag or change in main engine throttle level (specific function is flight-phase dependent).
- Switches (body flap and trim) -- command the flight control system or aerosurface trim.

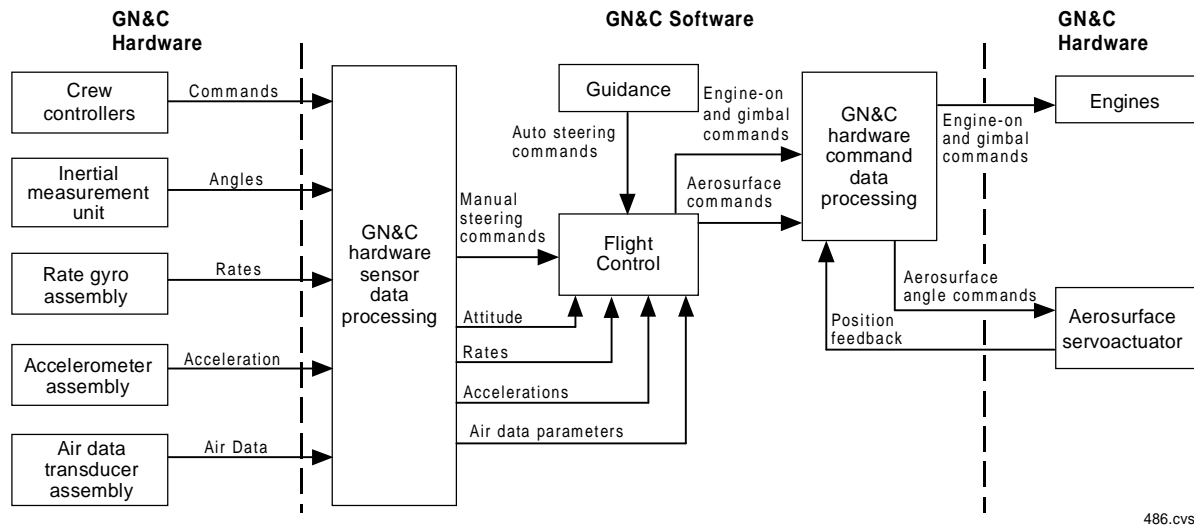
The following hardware responds to software commands:

- Aerosurface servoamplifier (ASA) -- responsible for aerosurface actuator positioning.
- Ascent thrust vector control (ATVC) -- responsible for main engine and SRB actuator positioning.

Each piece of flight control system hardware is hardwired to one of eight flight-critical MDMs connected to each of the five GPCs by data buses. Each GPC is assigned to command one or more data buses.

Accelerometer Assemblies

There are four AAs onboard the orbiter, each containing two identical single-axis accelerometers. One senses vehicle acceleration along the lateral (left and right) vehicle Y axis; the other senses vehicle acceleration along the normal (vertical) Z axis. The four AAs are located in the crew compartment middeck forward avionics bays 1 and 2. The AAs are convection cooled and require a 5-minute warmup period.



Flight Control Interfaces

The AAs provide acceleration feedback to the FCS. These accelerations are used to augment stability during first-stage ascent, aborts, and entry, to relieve vehicle load during first-stage ascent, and to compute steering errors for display on the commander's and pilot's attitude director indicators.

The lateral acceleration readings enable the FCS to null side forces during both ascent and entry. The normal acceleration readings augment pitch control and indicate the need to relieve normal loads. During the latter stages of entry, the normal acceleration measurements provide feedback for guidance to control pitch. (In contrast, the accelerometers within the IMUs measure three accelerations used in navigation to calculate state vector changes.)

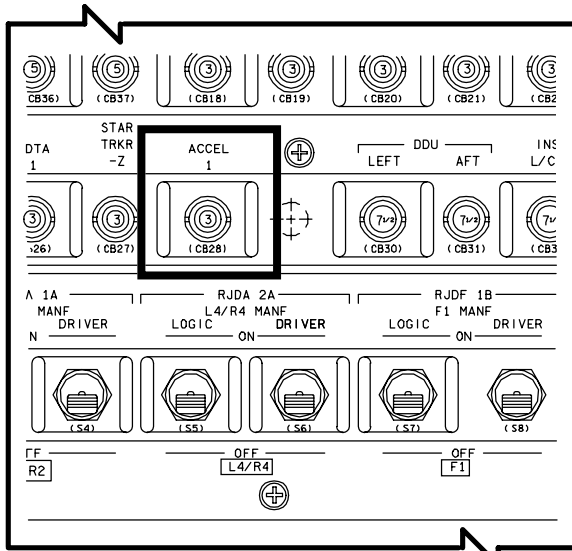
Each accelerometer consists of a pendulum suspended so that its base is in a permanent magnetic field between two torquer magnets. A light beam passes through an opening in one of the torquer magnets; photodiodes are located on both sides of the other torquer magnet. When acceleration deflects the pendulum toward one photodiode, the resulting light imbalance on the two photodiodes causes a differential voltage. This voltage increases the magnetic field on one of the torquer magnets to rebalance the pendulum at an offset position representing the sensed acceleration. The magnitude of the current required to accomplish this is

proportional to the acceleration. The polarity of the differential voltage depends on the direction of the pendulum's movement, which is opposite the direction of acceleration. The only difference between the lateral and normal accelerometers is the position in which they are mounted within the assembly. When the acceleration is removed, the pendulum returns to the null position. The maximum output for a lateral accelerometer is plus or minus 1 g; for a normal accelerometer, the maximum output is plus or minus 4 g's.

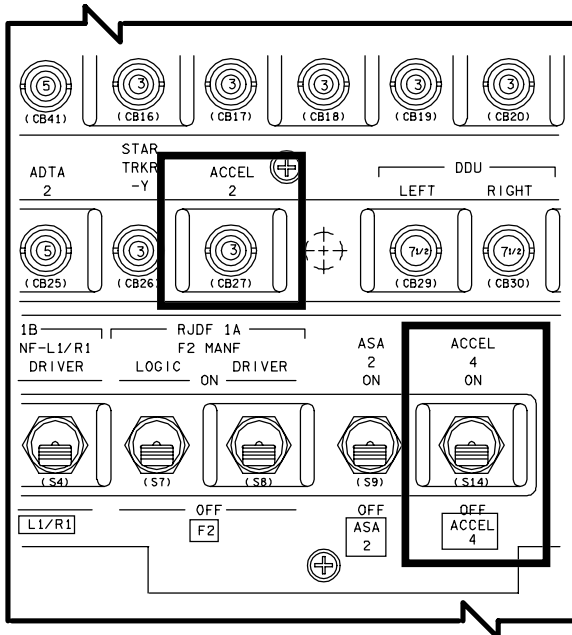
The accelerations transmitted to the forward MDMs are voltages proportional to the sensed acceleration. These accelerations are sent to the GPCs, where an accelerometer assembly subsystem operating program converts the eight accelerometer output voltages to gravitational units. These data are also sent to the CRTs and attitude director indicator during entry.

The accelerometer assemblies provide fail-operational redundancy during both ascent and entry. The four assemblies employ an interchangeable mid-value software scheme to select the best data for redundancy management and a reasonableness limit check for failure detection. Software fault detection will operate when all four AAs are operational and will then detect the first failure and deselect that accelerometer assembly. A caution and warning message "RM FAIL AA" is generated to inform the flight crew

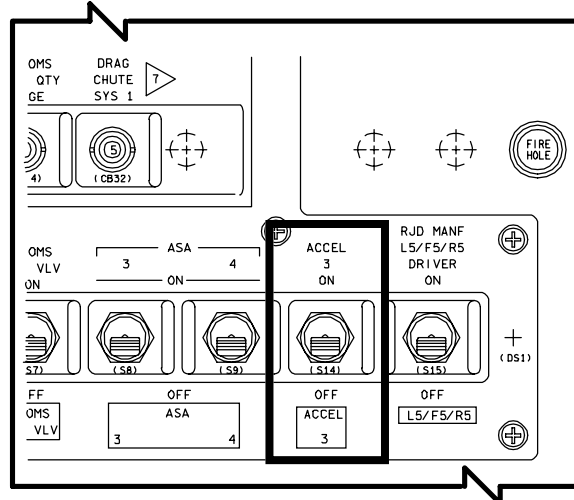
of an accelerometer failure. The RGA/ ACCEL caution and warning light on panel F7 is not supported.



Accelerometer 1 Power Control on Panel O14



Accelerometer 2 and 4 Power Controls on Panel O15

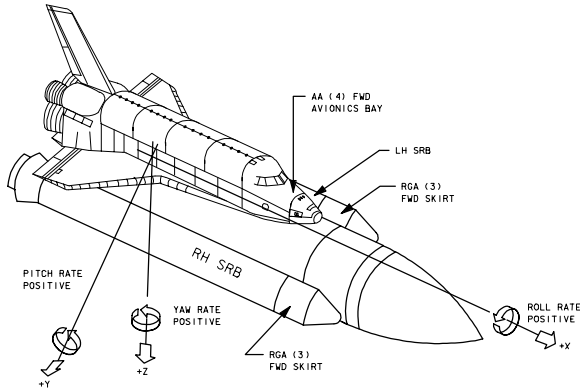


Accelerometer 3 Power Control on Panel O16

Accelerometer 1 is powered from main bus A through the ACCEL 1 circuit breaker on panel O14. Accelerometer 2 is powered from main bus B through the ACCEL 2 circuit breaker on panel O15. Accelerometer 3 is redundantly powered through the ACCEL 3 ON/OFF switch on panel O16. Accelerometer 4 is redundantly powered through the ACCEL 4 ON/OFF switch on panel O15. The accelerometers are turned off once on orbit and on again before entry.

Orbiter Rate Gyro Assemblies

The orbiter has four RGAs, referred to as RGAs 1, 2, 3, and 4. Each RGA contains three identical single-degree-of-freedom rate gyros so that each gyro senses rotation about one of the vehicle axes. Thus, each RGA includes one gyro sensing roll rate (about the X axis), one gyro sensing pitch rate (about the Y axis), and one gyro sensing yaw rate (about the Z axis). These rates are the primary feedback to the FCS during ascent, entry, insertion, and deorbit. The FCS must have good rate feedback in all three axes to maintain control.



Rate Gyro Assembly Location and Rotation Axes

The RGAs are located on the aft bulkhead below the floor of the payload bay. They are mounted on cold plates for cooling by the Freon coolant loops and require a 5-minute warm-up time.

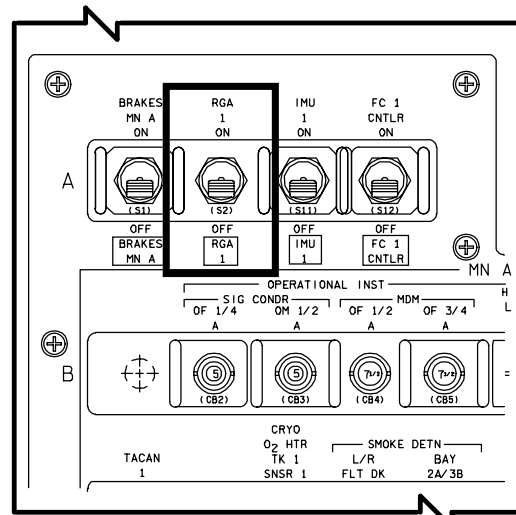
Each gyro has three axes. A motor forces the gyro to rotate about its spin axis. When the vehicle rotates about the gyro input axis, a torque results in a rotation about the output axis. An electrical voltage proportional to the angular deflection about the output axis, representing vehicle rate about the input axis, is generated and transmitted through the flight aft MDMs to the GPCs and RGA SOP. This same voltage is used within the RGA to generate a counteracting torque that prevents excessive gimbal movement about the output axis. The maximum output for roll rate gyros is plus or minus 40° per second; for the pitch and yaw gyros, the maximum output is plus or minus 20° per second.

The RGA 1, 2, 3, and 4 power switches are located on panels O14, O15, O16, and O15 respectively. The redundant power supplies for RGAs 1 and 4 prevent the loss of more than one rate gyro assembly if main bus power is lost. The RGAs are turned off on orbit, except during flight control system checkout, to conserve power. RGAs are reactivated during deorbit prep, and prior to any transition to OPS 3, when they are required for the transition DAP to control vehicle attitude.

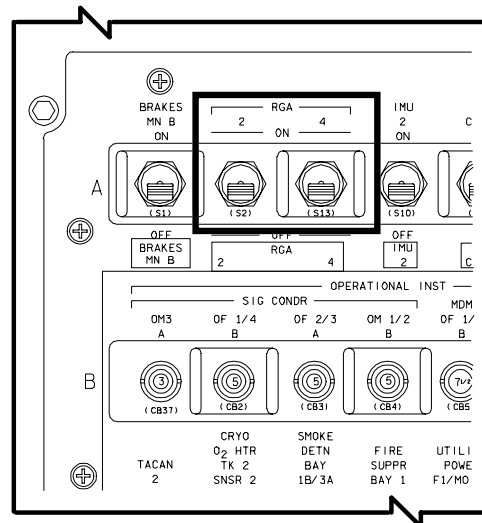
WARNING

A transition to OPS 3 with RGAs off can result in loss of control.

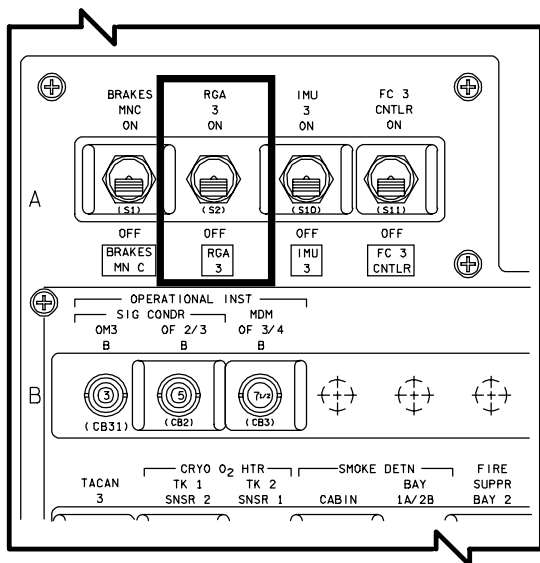
The RGAs afford fail-operational redundancy during both ascent and entry. Redundancy management software employs an interchangeable mid-value scheme to select the best data for flight control use and has two methods of failure detection. A reasonableness limit fault detection will operate when all four RGAs are operational and will then detect the first failure and deselect that rate gyro assembly. The RGAs also have power failure fault detection via a spin motor run detector (SMRD), which will deselect any RGA that has lost power up until only one RGA remains. A caution and warning message, "RM FAIL RGA," is generated to inform the flight crew of an RGA failure. The RGA/ACCEL caution and warning light on panel F7 is not supported.



RGA 1 Power Switch on Panel O14



RGA 2 and 4 Power Switches on Panel O15



RGA 3 Power Switch on Panel O16

Solid Rocket Booster Rate Gyro Assemblies

The SRB RGAs are used exclusively during first-stage ascent as feedback to find rate errors before SRB separation. There are two RGAs on each SRB, each containing two identical single-degree-of-freedom rate gyros. These gyros sense rates in the vehicle pitch and yaw axes similar in function to the orbiter RGAs. Because the SRBs are more rigid than the orbiter body, these rates are less vulnerable to errors created by structural bending. They are thus particularly useful in thrust vector control. The two RGAs in each SRB are mounted on the forward ring within the forward skirt near the SRB-external tank attach point.

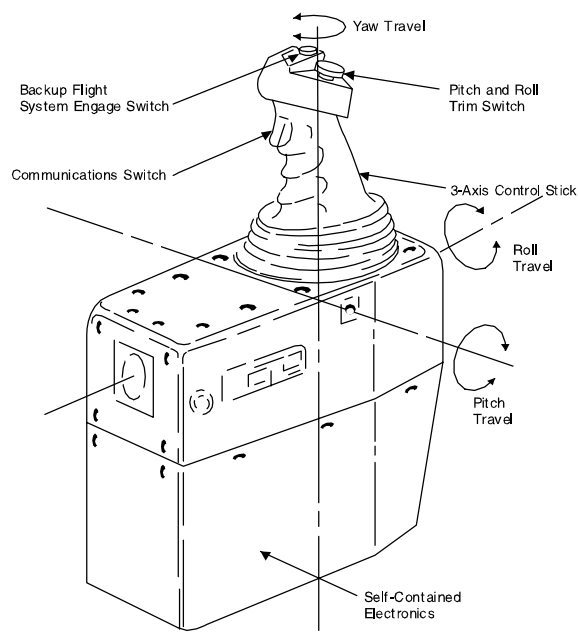
Similar to orbiter RGAs, each SRB RGA generates an electrical voltage that is transmitted through the flight aft MDMs to the GPCs and the SRB RGA SOP. The SRB RGA SOP converts the eight voltages representing a rate into units of degrees per second. The maximum outputs for the SRB RGAs are 10° per second. These rates are used by the flight control system during first-stage ascent as feedback to identify rate errors, which are used for stability augmentation. The pitch and yaw axes and a combination of rate, attitude, and acceleration signals are blended to provide a common signal to the SSMEs and SRB thrust vector control during first stage. In the roll axis, rate and attitude are summed to provide a common signal to the engines and SRB thrust vector control.

The compensated rate signals from the SRB RGA SOP are sent to redundancy management software, where the interchangeable mid-value scheme selects the best data for flight control use and a reasonableness limit check is performed for failure detection. The reasonableness limit fault detection will operate when all four SRB RGAs are operational and will then detect the first failure and deselect that rate gyro assembly. Unlike orbiter RGAs, SRB RGAs do not have fault detection for power failures. In addition, there is no crew insight into SRB RGA fault detection.

The SRB RGAs are commanded to null and released from the flight control system 2 to 3 seconds before SRB separation; SRB yaw and pitch rate data are then replaced with orbiter RGA pitch and yaw data.

Rotational Hand Controller

There are three RHCs on the orbiter flight deck: one at the commander's station, one at the pilot's station, and one at the aft flight deck station. Each RHC controls vehicle rotation about the roll, pitch, and yaw axes. During ascent, the commander's and pilot's RHCs may be used to gimbal the SSMEs and SRBs. For insertion and deorbit, the commander's and pilot's RHCs may be used to gimbal the OMS engines or to command the RCS jets.



Rotational Hand Controller

On orbit, the commander's, pilot's, and aft flight station RHCs may be used to gimbal the OMS engines and command RCS jets. In addition, the commander's and pilot's RHCs may be used to command RCS jets during the early portion of entry, as well as to command the orbiter aerosurfaces during the latter portion of entry. The aft flight station RHC is used only on orbit.

Human factors dictate that an RHC deflection produce a rotation in the same direction as the flight crewmember's line of sight. A SENSE switch on panel A6U selects the line-of-sight reference, either -Z or -X, for the aft station RHC.

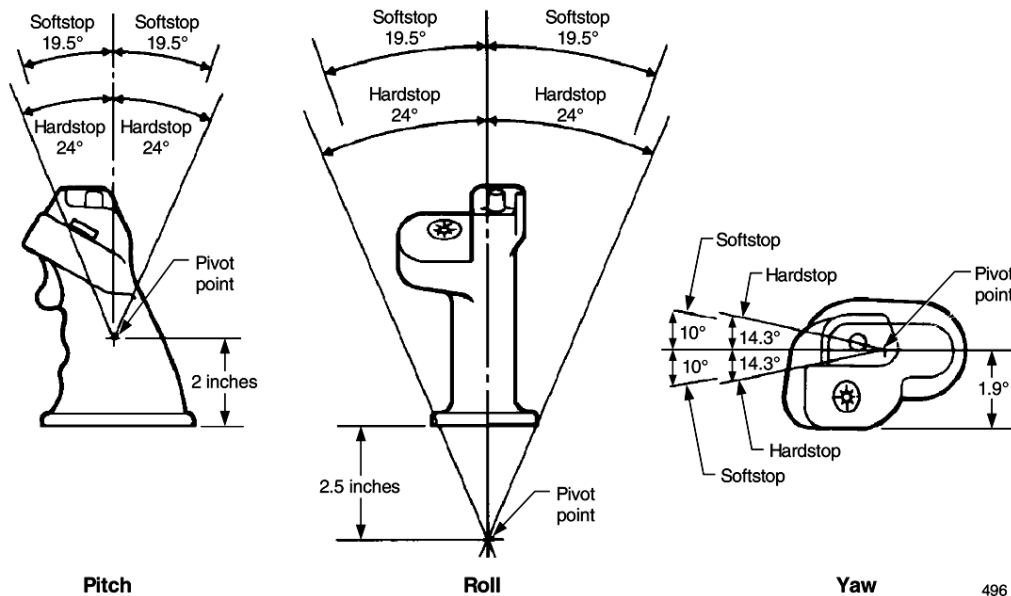
Several switches are located on the RHC. Depressing the backup flight system (BFS) mode button on the commander's and pilot's RHCs engages the BFS. The commander's, pilot's, and aft flight station RHCs have a two-contact trim switch. This switch, when pushed forward or aft, adds a trim rate to the RHC pitch command, or adds a roll trim rate when pushed left or right. The aft RHC's trim switch is inactive. The communications switch on each RHC is a push-to-talk switch that enables voice transmission.

Each RHC contains nine transducers: three transducers sense pitch deflection, three sense roll deflection, and three sense yaw deflection. The transducers produce an electrical signal proportional to the deflection of the RHC. The three transducers are called channels 1, 2, and 3.

Each channel is powered by a separate power supply in its associated display driver unit. Each controller is triply redundant; thus, only one good signal from a controller is required for the controller to operate.

Each RHC has an initial dead band of 0.25° in all three axes. To move the RHC beyond the dead band, an additional force is required. When the amount of deflection reaches a certain level, called the soft stop, a step increase in the force required for further deflection occurs. The soft stop occurs at 19.5° in the roll and pitch axes, and 9.5° to 10.5° in the yaw axis. The mechanical hard stop is 24.3° in the roll and pitch axes and 14.3° in the yaw axis.

Inputs from the RHCs to the FCS pass through a redundancy management scheme and the RHC SOP before they are passed to the aerojet digital autopilot. The RHC SOP performs four key functions. First, if an RHC is deemed bad, through redundancy management, then all commands from that RHC are set to zero. The SOP is also responsible for compensating and biasing the RHC commands, with the aft RHC commands transformed according to the SENSE switch position. Next the compensated and transformed commands are summed, by axis, to produce rotation commands for the flight control software. Finally, the SOP sets discretes to indicate if an RHC deflection is outside the software detent or beyond the software softstop.



Rotational Hand Controller Mechanical Limits

RHC Use	Forward RHC Use- Commander and Pilot	Aft Line-of-Sight Reference Aft RHC Use Sense Switch -X	Overhead Line-of-Sight Reference; Aft RHC Use Sense Switch -Z
	+ Pitch 	- Pitch 	- Pitch
	+ Roll 	- Roll 	- Yaw
	+ Yaw 	+ Yaw 	- Roll

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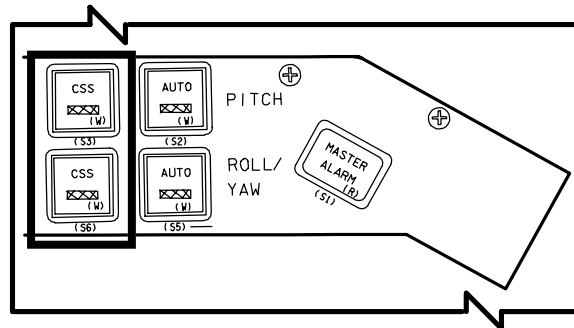
Positive Deflections of the Rotational Hand Controller by Axis

In a nominal mission, the flight crew can make manual inputs using the RHC during every major mode except terminal countdown. During all phases except ascent, when an RHC deflection exceeds the detent in an axis, the RHC SOP generates a discrete signal that converts the flight control system from the automatic mode to control stick steering (CSS), or hot stick, in the axis of deflection. During ascent, a CSS PITCH and/or ROLL/YAW pushbutton indicator on panel F2 or F4 must be depressed for manual inputs to be implemented into the flight control system from the commander's or pilot's RHC. On ascent, the CSS light for the pushbutton indicator illuminates, and control is downmoded from automatic to CSS for all axes. On entry, the CSS light on panel F2 or F4 illuminates for only the deflected axis with a hot stick downmode, or for whichever pushbutton is depressed.

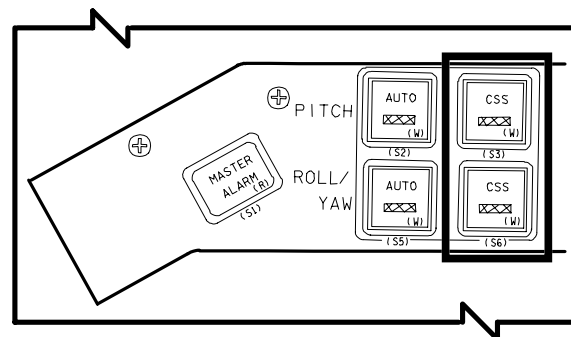
When the flight crew commands three-axis motion using the RHC, the GPCs process the RHC and motion sensor commands.

The FCS interprets the RHC motions (fore and aft, right and left, clockwise and counterclockwise) as rate commands in pitch, roll, and yaw. The flight control equations are subsequently processed to provide control

response and stability. If conflicting commands are given from more than one RHC, no commands result.



CSS Pushbuttons on Panel F2



CSS Pushbuttons on Panel F4

During orbital flight, any one of the three stations can input three-axis control commands to the flight control system. During entry and landing, the commander and pilot have two-axis (bank and pitch only) capability. Aerosurface deflection trim, in all three axes, is controlled by the panel trim switches on panels L2 and C3, while bank and pitch vehicle rate trim is controlled with the trim switches on the RHC. For a return-to-launch-site abort, both the commander's and pilot's RHC have three-axis capability during powered flight and two-axis capability during gliding flight.

The commander's RHC is powered when the FLT CNTLR POWER switch on panel F7 is positioned to ON. Similarly, the pilot's RHC and the aft RHC are powered when the FLT CNTLR POWER switches on panels F8 and A6U are positioned to ON.

RHC software redundancy management detects malfunctions in roll, pitch, or yaw axes for all three channels. The first malfunction detected will deselect all axes in that channel. For a second malfunction between the remaining two channels, the RHC is put in dilemma and the RHC SOP will no longer accept inputs from that RHC. For any detected malfunction, caution and warning generates an "RHC L," "RHC R," or "RHC A" message and illuminates the corresponding LEFT RHC or R/AFT RHC light on panel F7.

Translational Hand Controller

Signals from the THC in FCS command the RCS jets. There are two THCs, one at the commander's station and one at the aft flight deck station. The commander's THC is active during orbit insertion, on orbit, and during deorbit. The aft flight deck station THC is active only on orbit.

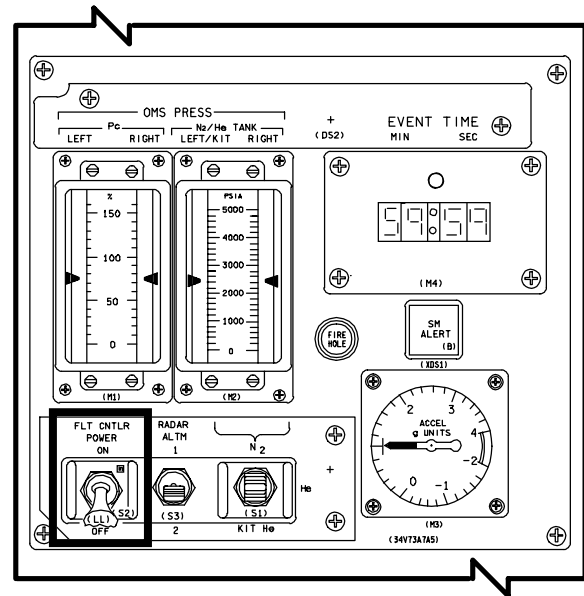
Each THC contains six three-contact switches, one in the plus and minus directions for each axis (+X, -X, +Y, -Y, +Z, -Z). Moving the forward THC to the right closes three switch contacts (referred to as channels 1, 2, and 3) and commands translation along the plus Y axis.

The aft THC is used when the crewmember is looking out the rear or overhead windows. The SENSE switch on panel A6U selects the line-of-sight reference along the -X or -Z axis of the orbiter for the aft THC. The SENSE switch must be in the -X position for aft windows and -Z for the overhead windows for the aft THC commands to be correctly transformed to give the desired orbiter movement.

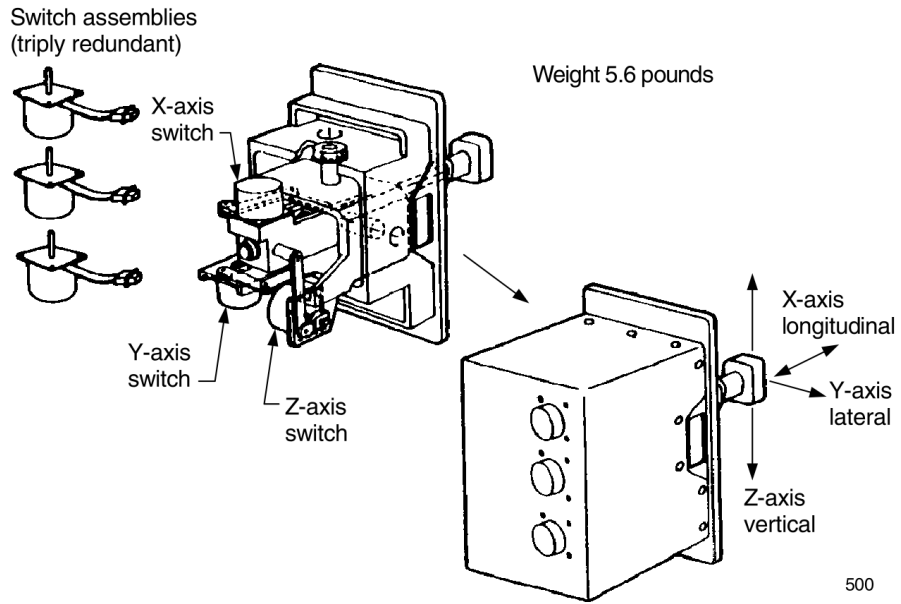
The THCs are used for manual control of translation along the longitudinal (X), lateral (Y), and vertical (Z) vehicle axes.

The normal displacement of a THC is 0.5-inch from the center null position in either direction along each of the three THC axes. A force of 2 pounds is required to deflect either THC 0.5 inch in any axis.

The redundant signals from the forward and aft THC pass through a redundancy management process and SOP before being passed to the flight control system. If the forward and aft THCs generate conflicting translation commands, no output translation command is issued.



FLT CNTLR POWER Switch on Panel F7

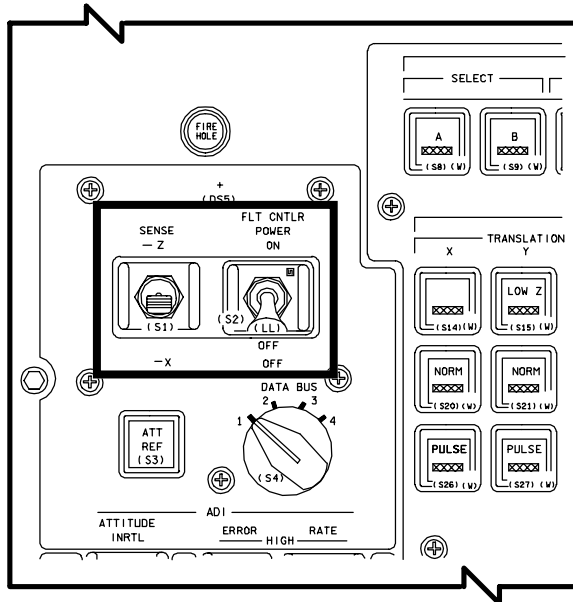


Translational Hand Controller

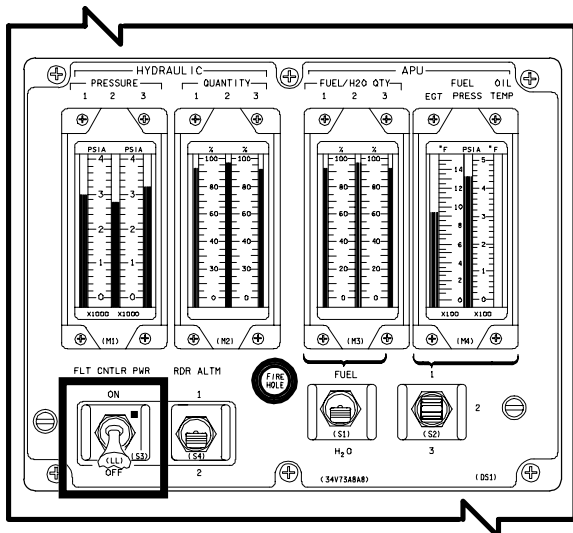
All commands to the flight control system are sent in this reference	Forward line-of-sight Reference THC use commander	Aft line-of-sight reference; Aft THC use sense switch-X	Overhead line-of-sight Reference; Aft THC use sense switch -Z
<p>Longitudinal THC movement</p>	<p>Longitudinal</p>	<p>Longitudinal</p>	<p>Vertical orbiter movement</p>
<p>Vertical THC movement</p>	<p>Vertical</p>	<p>Vertical</p>	<p>Longitudinal orbiter movement</p>
<p>Lateral THC movement</p>	<p>Lateral</p>	<p>Lateral</p>	<p>Lateral orbiter movement</p>

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Positive Deflections of the Translational Hand Controller



FLT CNTRL POWER and SENSE Switches on Panel A6U



FLT CNTRL POWER Switches on Panel F8

THC software redundancy management detects miscompares between the three channels for all six directions of movement. The first miscompare detected will deselect only that channel for that direction. A second miscompare between the remaining two channels will put that THC direction in dilemma, so its commands will no longer be noted by flight control. For any detected miscompare, caution and warning generates an "SBTC/THC L" or "SBTC THC A" message.

The commander's THC is powered when the FLT CNTRL POWER switch on panel F7 is positioned to ON. The aft THC is powered when the FLT CNTRL POWER switch on panel A6U is positioned to ON.

Rudder Pedal Transducer Assembly

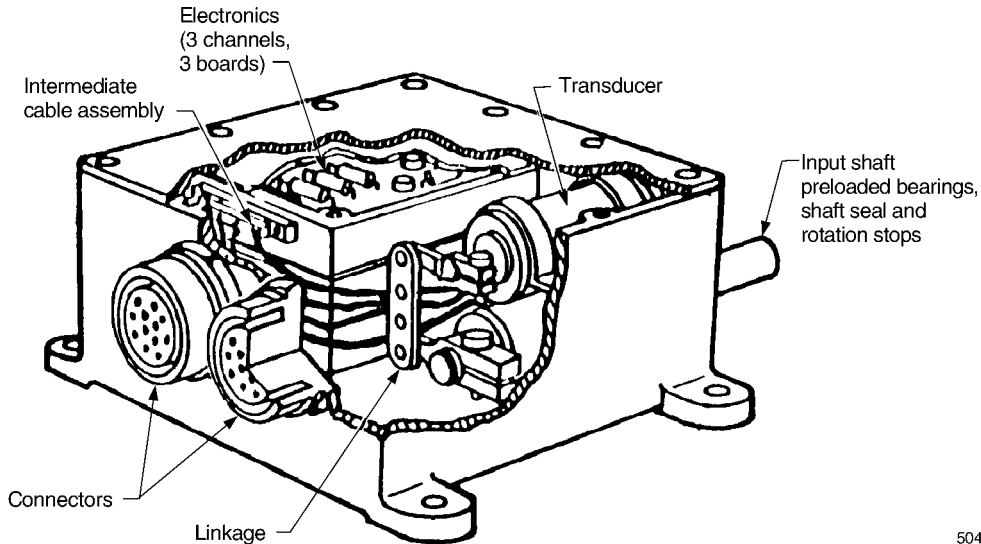
There are two pairs of rudder pedals, one pair each for the commander and pilot. The commander's and pilot's rudder pedals are mechanically linked so that movement on one side moves the other side. When depressed, the pedal moves a mechanical input arm in an RPTA. The RPTA contains three transducers (channels 1, 2, and 3), each generating an electrical signal proportional to the rudder pedal deflection.

The rudder pedals command orbiter acceleration about the yaw axis by positioning the rudder during atmospheric flight. Because the flight control software performs automatic turn coordination, the rudder pedals are not used until after touchdown for nose wheel steering.

The RPTA SOP maintains many functions in processing the RPTA data. The RPTA SOP converts the selected left and right commands from volts to degrees and selects the larger absolute value of the left and right commands for output to flight control software after applying a dead band. RPTA redundancy management software uses a reasonableness limit check to detect a malfunction among the three channels. When the first malfunction is detected, that channel will be deselected. A second malfunction between the remaining two channels puts the RPTA in dilemma and the RPTA SOP will set that RPTA output to zero. There is no crew insight into RPTA fault detection.

The rudder pedals provide two additional functions after touchdown. Rudder pedal deflections provide nose wheel steering; depressing the upper portion of the pedals provides braking. Differential braking may also be used for directional control.

The rudder pedals can be adjusted 3.25 inches forward or aft from the neutral position in 0.81-inch increments (nine positions). A pedal force of 70 pounds is required to depress a pedal to its maximum forward or aft position.



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Rudder Pedal Transducer Assembly

The commander's RPTA is powered when the FLT CNTLR POWER switch on panel F7 is positioned to ON. The pilot's RPTA is powered when the FLT CNTLR POWER switch on panel F8 is positioned to ON.

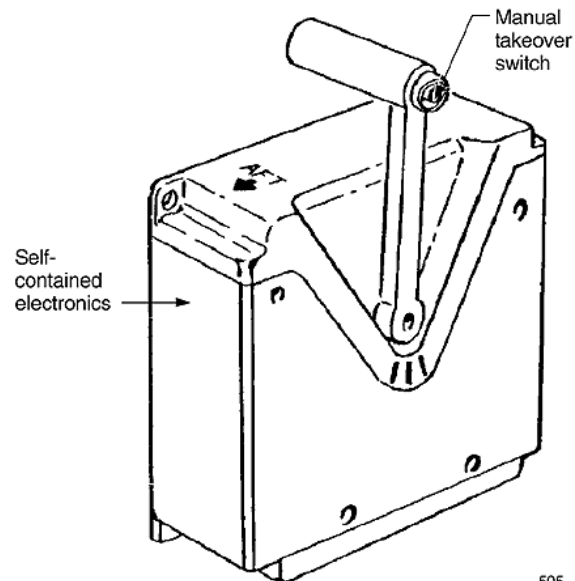
between the remaining two channels puts the SBTC in dilemma and inputs from that SBTC will no longer be accepted. For any detected malfunction, caution and warning generates an "SBTC/THC L" or "SBTC/THC R" message.

Speed Brake/Thrust Controller

There are two SBTCs, one on the commander's left-hand side of the flight deck forward on panel L2 and one on the pilot's left-hand side on the center console on panel C3. The SBTCs serve two distinct functions. During ascent, the pilot's SBTC may be used to throttle the engines. During entry, the commander's or pilot's SBTC may be used to control aerodynamic drag (hence airspeed) by opening or closing the speedbrake.

Depressing a TAKEOVER switch (with three contacts) on either SBTC changes the SSME thrust-level setting (ascent) or speed brake position (entry) to manual control. At the forward setting, the SSME thrust level is the greatest, or the speedbrake is closed. Rotating the SBTC back decreases the SSME thrust level or opens the speed brake.

Each SBTC contains three transducers (channels 1, 2, and 3) that produce a voltage proportional to the deflection. Redundancy management uses a mid-value select scheme to determine output. It also uses a reasonableness limit check between the channels to detect failures. When the first malfunction is detected, that channel will be deselected. A second malfunction



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Speed Brake/Thrust Controller

In the case of the engine thrust-level setting, the top half (AUTO) of both SPD BK/THROT pushbutton indicators on panels F2 and F4 are illuminated nominally. Only the pilot's SBTC can be enabled for manual throttle control. The pilot depresses the TAKEOVER pushbutton on the SBTC, causing the GPC throttle command to be frozen at its current value. While depressing

the TAKEOVER button, the pilot moves the SBTC to match the frozen GPC command. Manual control is established when the match is within 4 percent. When the match is achieved, the pilot's SPD BK/THROT MAN pushbutton indicator on panel F4 is illuminated, and the AUTO light is extinguished on both panels F2 and F4.

The TAKEOVER pushbutton is then released. If the TAKEOVER pushbutton is released before a match is achieved, the system reverts to GPC auto commands. Under manual throttle command, depressing either or both pushbutton indicators on panel F2 and F4 causes the system to revert to the GPC auto commands. Transferring back to auto leaves the throttle at the last-commanded manual setting until a new command is issued.

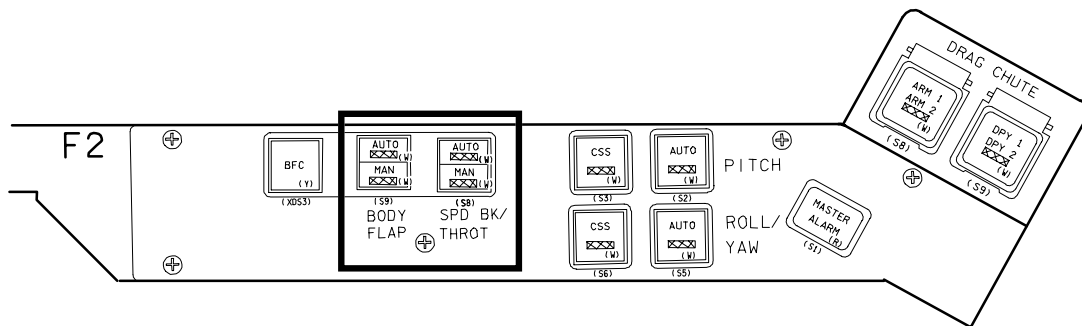
On entry, if the speed brake mode is in automatic, and the commander or pilot wishes to control the speed brake manually, momentarily depressing the TAKEOVER pushbutton takes manual control of the speed brake. The SPD BK/THROT MAN pushbutton indicator will be illuminated on the side with manual control and the AUTO lights will both be extinguished. The speed brake is driven to the position currently commanded by the SBTC. To place the speed brake under software control, either or both SPD BK/THROT pushbutton indicators on panels F2 and F4 can be depressed, thus illuminating the AUTO lights on both panels.

The SBTC SOP converts the selected SSME throttle command to a setting in percent and the selected speed brake command from volts to degrees. In addition, the SBTC SOP selects the speed brake command from the SBTC whose TAKEOVER button was depressed last. If both TAKEOVER buttons are depressed simultaneously, the commander's SBTC is given control. If redundancy management declares an SBTC bad, the command is frozen.

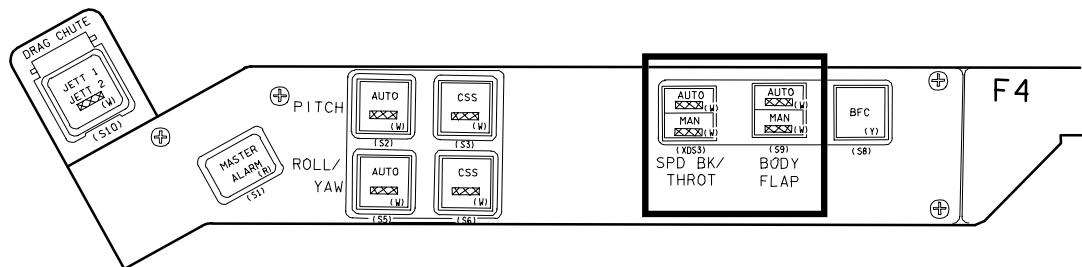
The commander's SBTC is powered by the FLT CNTLR POWER switch on panel F7 when positioned to ON. The pilot's SBTC is powered by the FLT CNTLR POWER switch on panel F8.

Body Flap Switches

There are two BODY FLAP switches, one on panel L2 for the commander and one on panel C3 for the pilot. Each switch is lever-locked and spring-loaded to the AUTO/OFF position. The UP and DOWN positions of each switch have two power supplies from separate control buses. In addition, each contact status is sent to the data processing system via an MDM. If the commander and pilot switches generate conflicting commands, a body-flap-up command is sent to flight control since the UP position has priority. The switches provide manual control for positioning the body flap for main engine thermal protection and for pitch trim to reduce elevon deflections during the entry phase.



BODY FLAP and SPD DK/THROT Pushbuttons on Panel F2



SPD BK/THROT and BODY FLAP Pushbuttons on Panel F4

Body flap control is initialized in its automatic mode with both BODY FLAP AUTO pushbutton indicators illuminated on panels F2 and F4. The body flap can be switched to its manual mode by depressing either BODY FLAP pushbutton. The white BODY FLAP MAN pushbutton indicators will then illuminate, indicating manual control of the body flap. To regain automatic control, the BODY FLAP pushbutton indicator on panel F2 or F4 is again depressed, extinguishing the MAN light and illuminating the AUTO light. The pushbutton indicator is triply redundant.

Trim Switches

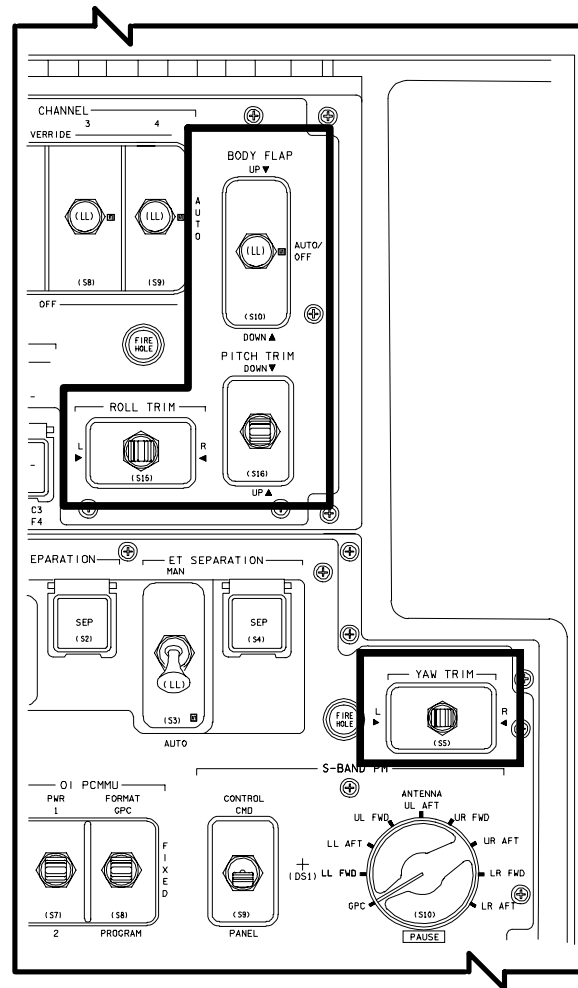
Roll and pitch panel trim switches allow the crew to actually move the aerosurfaces, whereas the RHC trim switches change the rate command. The yaw panel trim switch inputs an acceleration bias into the yaw channel.

The TRIM PANEL switches on panel F3 enable control bus power to a set of three panel trim switches. The dual-redundant TRIM RHC/PANEL switches on panel F3 provide signals to the GPCs, prohibiting software execution of the associated RHC and panel trim switch inputs while in the INHIBIT position. The ENABLE position permits the RHC and TRIM PANEL switch to be used for trimming.

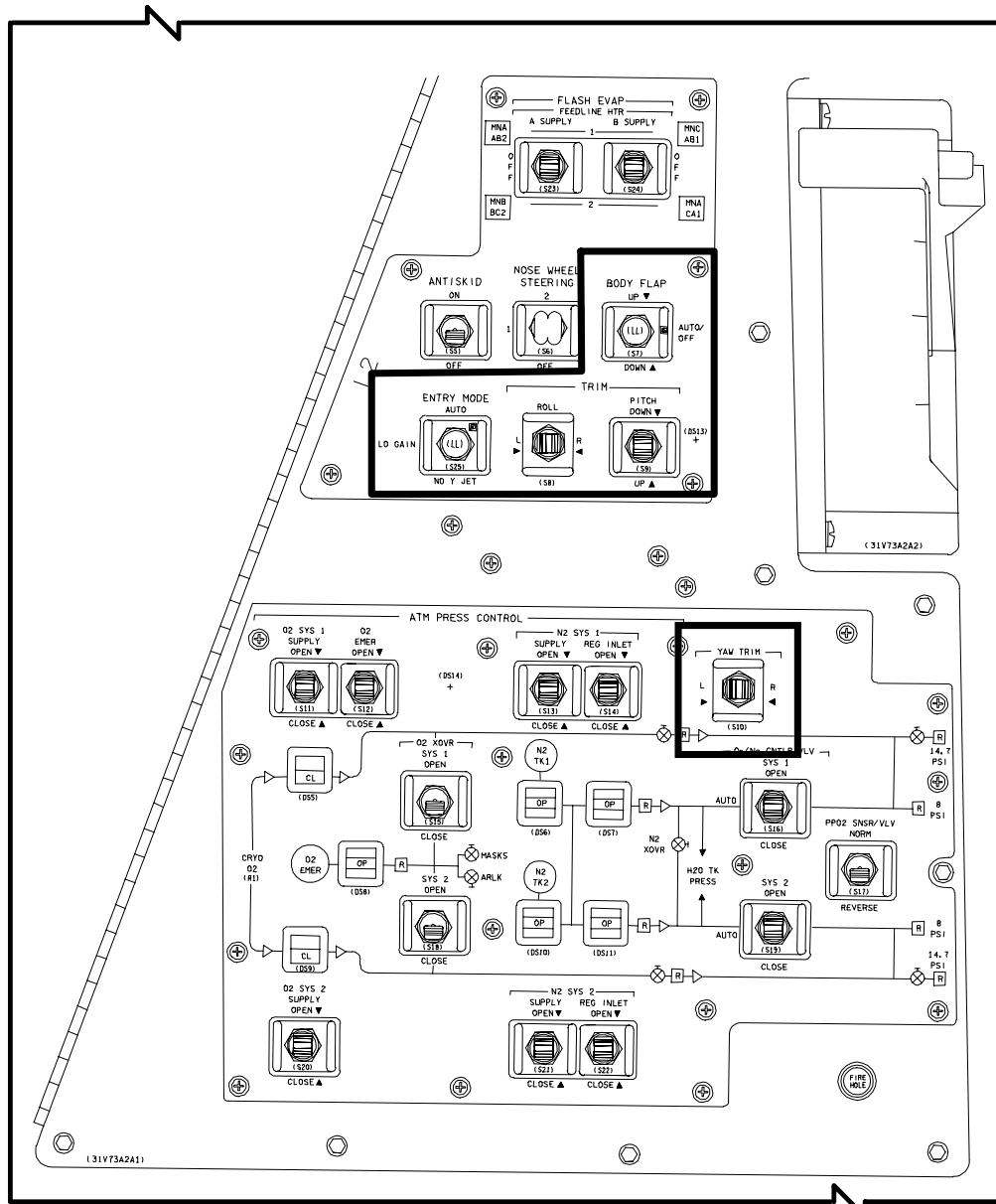
Six panel switches control roll, pitch, and yaw. The switches, labeled ROLL TRIM, PITCH TRIM, and YAW TRIM, are located on panel L2 for the commander and panel C3 for the pilot. The commander's trim switches on panel L2 are activated when the TRIM PANEL switch on the left side of panel F3 is positioned to ON. The pilot's trim switches on panel C3 are activated when the TRIM PANEL switch on the right side of panel F3 is positioned to ON. The corresponding TRIM RHC/PANEL switch must be in ENABLE for roll, pitch, and yaw trimming to take place. Likewise, the commander and

pilot RHC trim is activated when the corresponding FLT CNTRL POWER switch on panel F7 or F8 is ON and the corresponding TRIM RHC/PANEL switch on F3 is in ENABLE. All the trim switches on the RHC and on panels L2 and C3 are spring loaded to the OFF position.

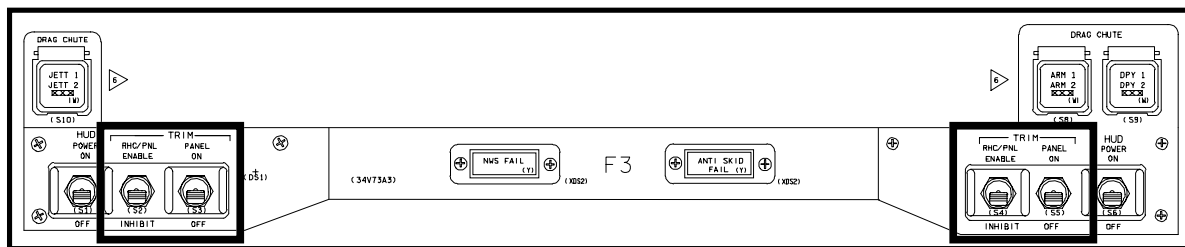
Redundancy management processes the two sets of TRIM switches. If two switches generate opposing commands, the resultant trim command in that axis is zero.



BODY FLAP and TRIM Switches on Panel C3



BODY FLAP and TRIM Switches on Panel L2



TRIM Switches on Panel F3

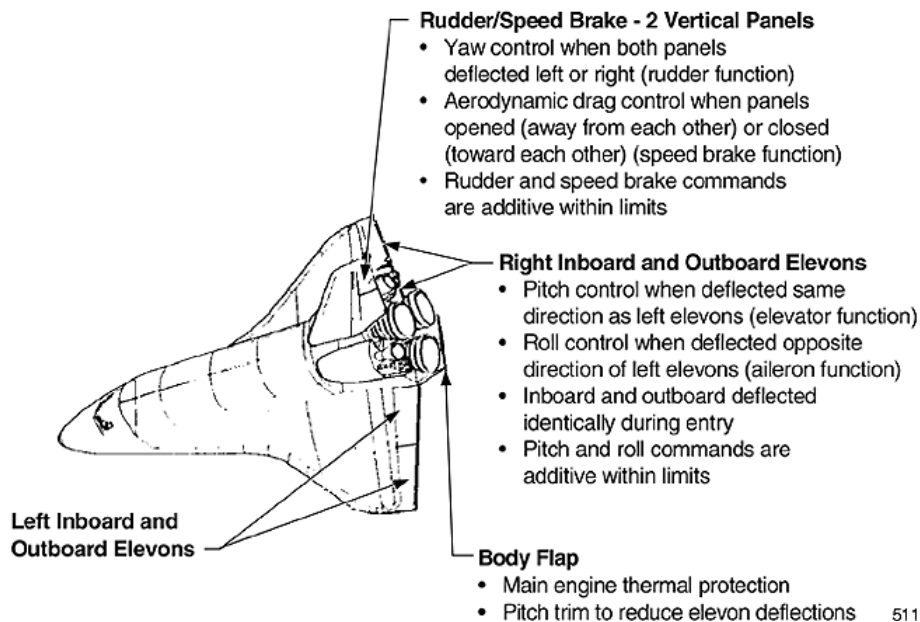
Aerosurface Servoamplifiers

Vehicle control during atmospheric flight is accomplished in the entry phase by deflecting the seven aerosurfaces on the orbiter. Each aerosurface is driven by a hydraulic device (actuator) controlled by a redundant set of electrically driven valves (ports). There are four of these valves for each aerosurface actuator, except the body flap, which has only three. These valves are controlled by electronic devices called aerosurface servoamplifiers. There are four ASAs located in aft avionics bays 4, 5, and 6. Each ASA commands one valve for each aerosurface, except the body flap. ASA 4 does not command the body flap, since the body flap has only three valves. Each ASA, weighing 30.2 pounds, is mounted on a cold plate and cooled by the Freon coolant loops. The ASA dimensions are 20 inches long, 6.4 inches high, and 9.12 inches wide. Power switches for ASA 1, 2, 3, and 4 are located on panel s O14, O15, and O16.

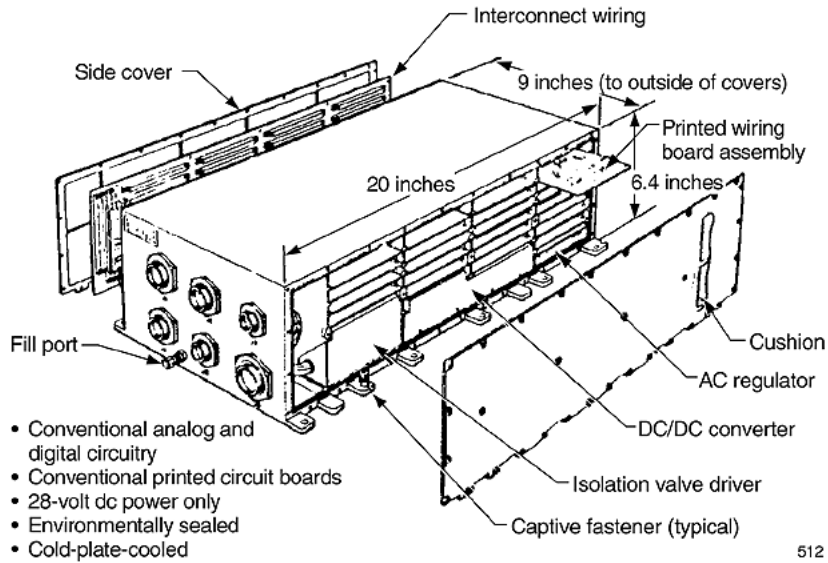
In addition to the command channels from the ASAs to the control valves, there are data feedback channels to the ASAs from the aerosurface actuators. These feedback channels include position feedback signals and pressure feedback signals. Each aerosurface has four associated position feedback transducers that provide a servoloop closure for each of the four

independent servoloops associated with the elevons, rudder, and speed brake. The path from an ASA to its associated servovalve in the actuators and from the aerosurface feedback transducers to an ASA is called a flight control channel. There are four flight control channels for each aerosurface, except for the body flap.

Each of the four elevons located on the trailing edges has an associated servoactuator for positioning. Each servoactuator is supplied with hydraulic pressure from the three orbiter hydraulic systems. A switching valve is used to control the hydraulic system that becomes the source of hydraulic pressure for that servoactuator. The valve allows a primary source of pressure (PR) to be supplied to that servoactuator. If the primary hydraulic pressure drops to around 1,200 to 1,500 psia, the switching valve allows the first standby hydraulic pressure (S1) to supply that servoactuator. If the first standby hydraulic pressure drops to around 1,200 to 1,500 psia, the secondary standby hydraulic source pressure (S2) is supplied to that servoactuator. The yellow HYD PRESS caution and warning light is illuminated on panel F7 if the hydraulic pressure of system 1, 2, or 3 is below 2,400 psia. The red BACKUP C/W ALARM light on panel F7 also illuminates.

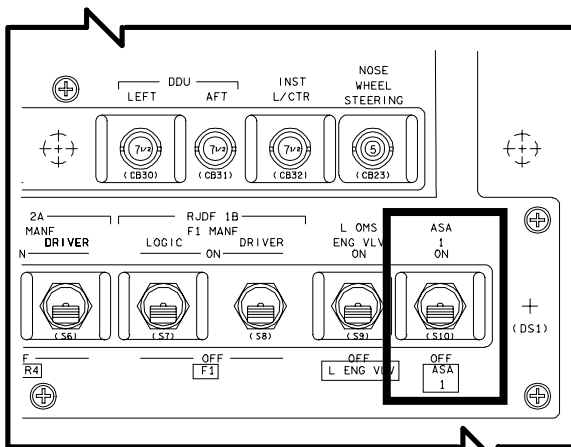


Aerodynamic Surfaces and Associated Control Axes

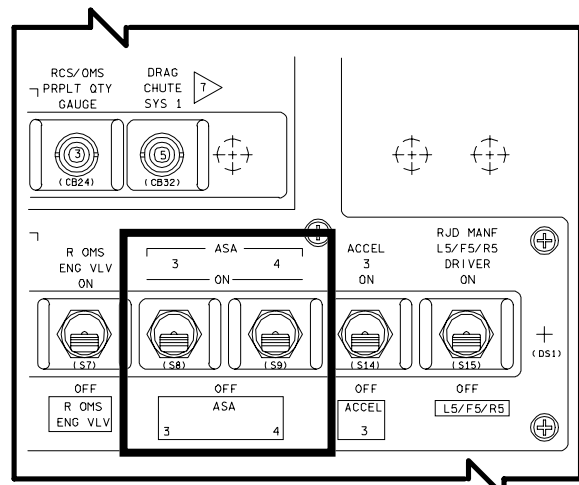


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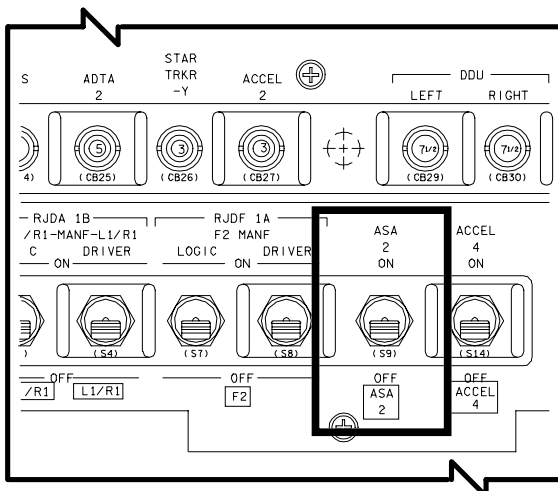
Aeosurface Servoamplifier



ASA 1 Power Switch on Panel O14



ASA 3 and 4 Power Switch on Panel O16



ASA 2 Power Switch on Panel O15

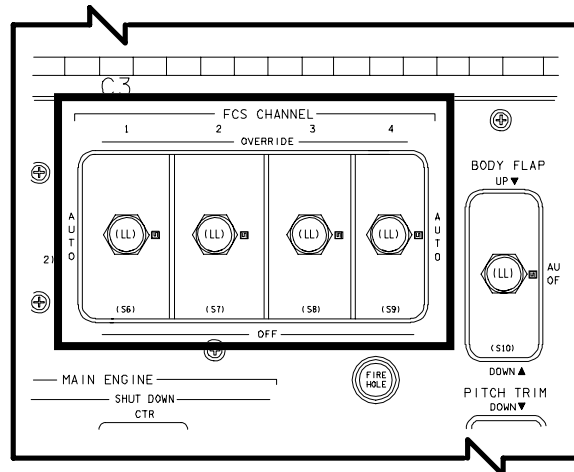
Each elevon servoactuator receives command signals from each of the four ASAs. Each actuator is composed of four two-stage servovalves that drive a modulating piston. Each piston is summed on a common mechanical shaft, referred to as the secondary force-sum actuator. The summed force positions this power spool to control the flow of hydraulic fluid to the actuator power ram, also referred to as the primary actuator. The direction of ram movement is controlled, thus driving the elevon to the desired position. When the desired position is reached, the secondary power spool moves to block the hydraulic pressure to the hydraulically operated ram, thus stopping the ram at that position.

If a problem develops within a servovalve, or it is commanded to a position different than the positions of the other three within an actuator, secondary delta pressure, measured for that servovalve off the secondary force-sum actuator, begins to rise. Once the secondary delta pressure is at or above 2,025 psi for more than 120 milliseconds, the corresponding ASA sends an isolation command to bypass that servovalve, effectively removing it from operation.

The FCS CHANNEL yellow caution and warning light on panel F7 is illuminated to inform the flight crew of a bypassed servovalve. Also, an "FCS CH X" caution and warning message is generated, corresponding to which FCS channel (1, 2, 3, or 4) had a bypassed servovalve on one of its actuators. A red FCS SATURATION caution and warning light on panel F7 is illuminated if one of the four elevons is set at more than +12° or less than -15°. This condition also generates an "FCS SAT POS" caution and warning message, informing the crew that elevon movement is becoming saturated. The FCS SATURATION light is also illuminated if any one of the four elevons has a hinge moment greater than 80 percent and an "FCS SAT MOM" message informs the crew that the elevon loading is saturated and flight control is marginal.

There are four FCS CHANNEL switches on panel C3. Each has an OVERRIDE, AUTO, and OFF position. The switch controls the channel's automatic isolation capability for high secondary delta pressure for the elevons, rudder, speed brake, and SRB and SSME actuators. When an FCS CHANNEL switch is in AUTO, the isolation capability discussed above can take place. Moving the switch to OVERRIDE and back to AUTO will reset any isolated servovalves on that channel. Leaving the switch in OVERRIDE will prevent the auto isolation from taking place. When the switch is positioned to OFF, that channel is bypassed on all actuators.

During ascent, the elevons are deflected to reduce wing loads caused by rapid acceleration through the lower atmosphere. In this scheme, the inboard and outboard elevons are deflected separately. By the time the vehicle reaches approximately Mach 2.5, the elevons have reached a null position, where they remain.



FCS CHANNEL Switches on Panel C3

The rudder/speed brake, which consists of upper and lower panels, is located on the trailing edge of the orbiter's vertical stabilizer. One servoactuator positions the panels together to act as a rudder; another opens the panels at the rudder's flared end so it functions as a speed brake.

The rudder and speed brake servoactuators receive four command signals from the four ASAs. Each servoactuator is composed of four two-stage servovalves that function like those of the elevons to drive a secondary force-sum actuator or power spool. The exception is that the rudder's power spool controls the flow of hydraulic fluid to the rudder's three reversible hydraulic motors; the speed brake's power spool controls the flow of hydraulic fluid to the speed brake's three reversible hydraulic motors. Each rudder and speed brake hydraulic motor receives hydraulic pressure from only one of the orbiter's hydraulic systems as determined by switching valves like those of the elevons.

The three rudder hydraulic motors provide output to the rudder differential gearbox, connected to a mixer gearbox that drives rotary shafts. These rotary shafts drive four rotary actuators, which position the rudder panels. The three speed brake hydraulic motors provide power output to the speed brake differential gearbox, connected to the same mixer gearbox as that of the rudder. This gearbox drives rotary shafts, which drive the same four rotary actuators involved with the rudder. Within each of the four rotary actuators, planetary gears blend the rudder positioning with the opening of the speed brake.

If a problem occurs in one of the four rudder or speed brake servoactuator channels, the corresponding secondary delta pressure transducer causes the corresponding ASA to signal an isolation valve to bypass that actuator's servovalve. The FCS CHANNEL switches control the rudder and speed brake channels the same way they control the elevons. If two of the three hydraulic motors fail in the rudder or speed brake, no servovalves are bypassed; however, about half the design speed output results from the corresponding gearbox.

Three servoactuators at the lower aft end of the fuselage are used to position the body flap. Each is separately supplied with hydraulic pressure from one of the three orbiter hydraulic system and has a solenoid-operated enable valve controlled by one of three ASAs. Note that the fourth ASA is not used for the body flap command. Each solenoid-operated enable valve supplies hydraulic pressure from one orbiter hydraulic system to two corresponding solenoid-operated up and down pilot valves, which are, in turn, controlled by one of the three ASAs.

When one of the individual pilot valves receives a command signal from its corresponding ASA, it positions a common mechanical shaft in the control valve, allowing hydraulic pressure to be supplied to the hydraulic motors. The hydraulic motors are reversible, allowing the body flap to be positioned up or down. The hydraulic brake associated with each hydraulic motor releases the hydraulic motor for rotation. When the desired body flap position is reached, the control valves block the hydraulic pressure to the hydraulic motor and apply the hydraulic brake. Each hydraulic motor provides the power output to a differential gearbox, thus driving a rotary shaft and four rotary actuators, which position the body flap. Four rotary position transducers measure the output of the differential gearbox to provide position feedback through all four ASAs to the flight control system software.

There is no channel isolation capability for the body flap. With the FCS CHANNEL switch in OFF, the corresponding ASA's body flap commands are removed from the solenoid valves. If the hydraulic system associated with the hydraulic motor fails, the remaining two

hydraulic motors position the body flap, and the HYD PRESS caution and warning light is illuminated.

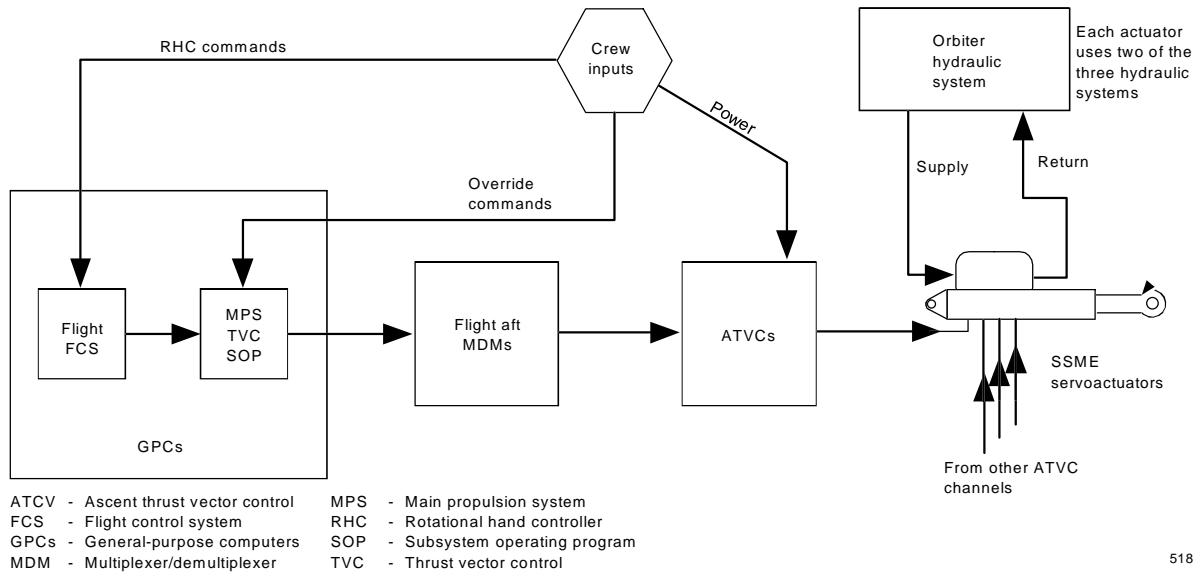
Each ASA is hardwired to a flight aft MDM. Commands originate from guidance software or from controllers. These inputs go to the flight control software, where they are routed to the ASAs. Several SOP functions associated with the ASA commands and data include:

- Converts elevon, rudder, and speed brake commands produced by flight control software from degrees to millivolts
- Sets commands to body flap valves based on an enable command from body flap redundancy management and up/down commands from flight control
- Converts position feedback to degrees for the elevons, rudder, speed brake, and body flap
- Computes body flap and speed brake deflections as percentages
- Calculates elevon and rudder positions for display on the surface position indicator
- Monitors the FCS CHANNEL switches and, if any are positioned to OVERRIDE, sets the override command for that ASA
- Monitors hydraulic system pressures for failures and limits aileron and elevator commands according to the number of failures.

Isolation status of the FCS CHANNEL servovalves is displayed on the DISP 18 GNC SYS SUMM 1 CRT display under FCS CH for all actuators, and on the SPEC 55 CONTROLS CRT display in more detail for each aerosurface and SSME actuator.

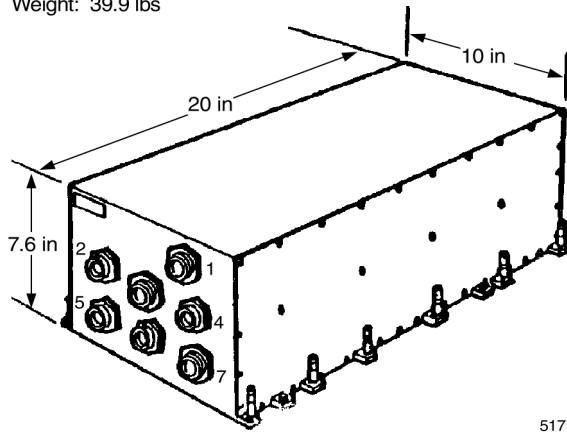
Ascent Thrust Vector Control

The orbiter ATVC portion of the FCS controls attitude and trajectory by directing the thrust of the three main engines and two solid rocket boosters during lift-off and first-stage ascent, and of the main engines only during second-stage ascent.



SSME Thrust Vector Control Interface Flow

Weight: 39.9 lbs



Ascent Thrust Vector Controller

ATVC is provided by four avionics hardware packages that supply gimbal commands and fault detection for each hydraulic gimbal actuator. The packages are located in the three aft avionics bays in the orbiter aft fuselage and are cooled by cold plates and the Freon system. The associated flight aft MDMs are also located in the aft avionics bays.

The main propulsion system (MPS) thrust vector control command flow starts in the GPCs, in which the flight control system generates the position commands, and terminates at the SSME servoactuators, where the actuators gimbal the SSMEs in response to the commands. All the position commands are issued to the MPS thrust

vector control command SOP. This program processes and transmits the commands to their corresponding flight aft MDMs. The commands are then separated and distributed to the four ascent thrust vector control channels, which generate equivalent command analog voltages for each command issued. These voltages are, in turn, sent to one of four servovalves on a servoactuator, commanding the SSME hydraulic actuators to extend or retract, thus gimbaling the main engines to which they are fastened.

Ten actuators respond to the command voltages issued by four ascent thrust vector control channels. Each FCS channel contains an ATVC that has six MPS drivers and four solid rocket booster drivers. Each actuator receives four identical command voltages from four different drivers, each located in one of the four ATVCs.

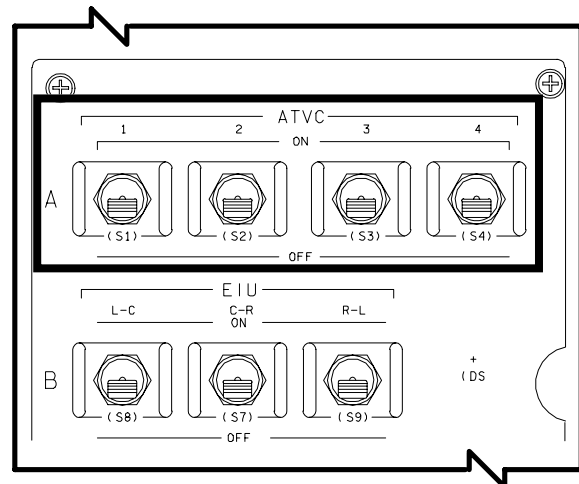
Both main engine and solid rocket booster servoactuators consist of four independent, two-stage servovalves that receive signals from the drivers. The force of these four servovalves is summed on a secondary force-sum actuator or power spool, which positions an actuator ram and thus the engine to control thrust direction.

The four servovalves in each actuator provide a force-summed majority voting arrangement to position the power spool. With four identical commands to the four servovalves, the actuator's force-sum action prevents a single

erroneous command from affecting power ram motion. If the erroneous command persists for more than a predetermined time, differential pressure measured off of the secondary force-sum actuator for that servovalve is sensed in the corresponding ATVC, which activates an isolation driver. This driver energizes an isolation valve that isolates the defective servovalve and removes hydraulic pressure, permitting the remaining channels and servovalves to control the actuator ram spool, provided the FCS CHANNEL 1, 2, 3, or 4 switch on panel C3 is in the AUTO position. A second failure would isolate the defective servovalve and remove hydraulic pressure in the same manner as the first failure, leaving only two channels remaining.

Failure monitors are provided for each channel on the GNC SYS SUMM 1 CRT display and with the yellow FCS CHANNEL and red BACKUP C/W ALARM lights on panel F7 to indicate which channel has a bypassed servovalve for any of the MPS and/or solid rocket boosters. There is more detailed crew information on precisely which MPS actuator has a bypassed servovalve on the SPEC 53 CONTROLS CRT display. If the FCS CHANNEL 1, 2, 3, or 4 switch on panel C3 is positioned to OFF, then that ATVC channel is isolated from its servovalves on all MPS and solid rocket booster actuators. The OVERRIDE position of the switch inhibits the corresponding ATVC from automatically bypassing servovalves on that channel due to high secondary delta pressure problems on the power spool and provides the capability to reset a bypassed servovalve on that channel.

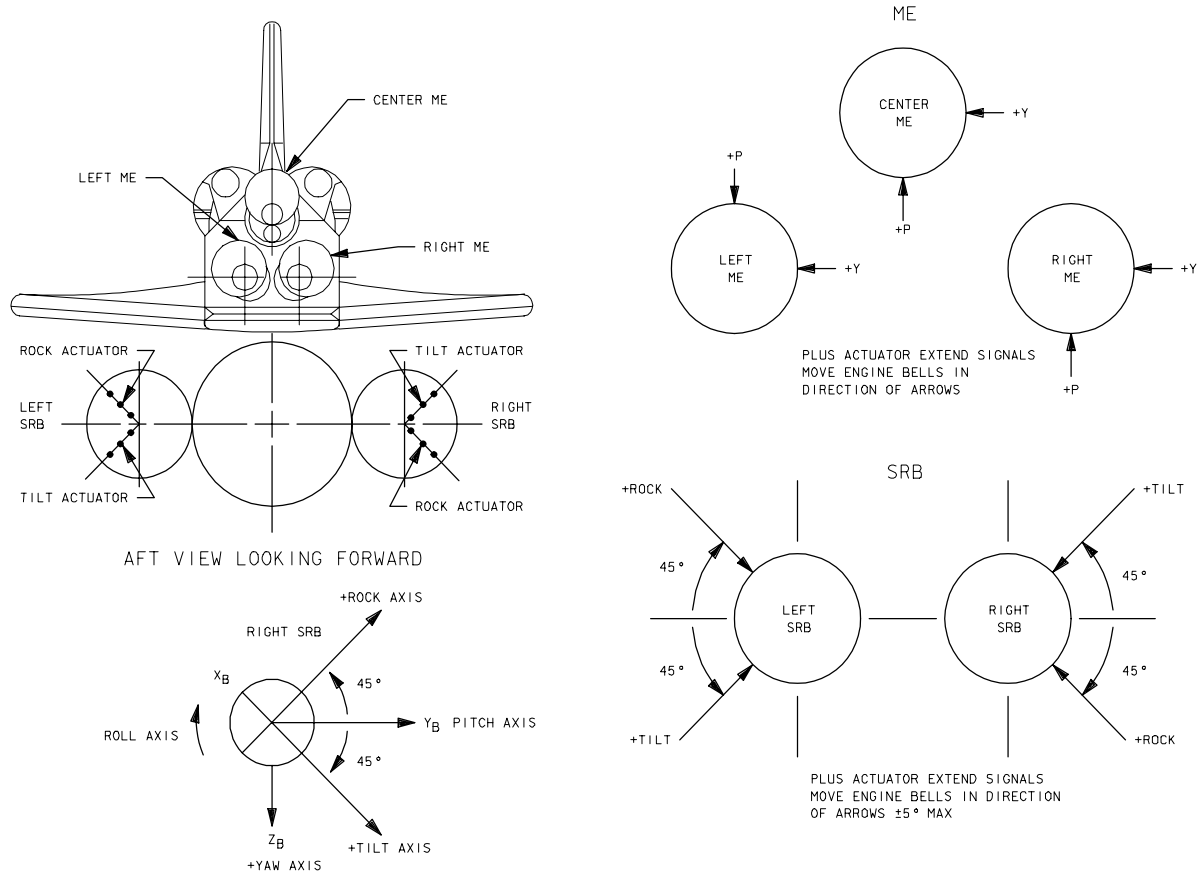
The ATVC 1, 2, 3, 4 power switches are located on panel O17. The ON position enables the ATVC channel selected; OFF disables the channel.



ATVC Power Switches on Panel O17

The SSME servoactuators change each main engine's thrust vector direction as needed during the flight sequence. Each main engine has one pitch actuator and one yaw actuator. The pitch actuator gimbals the engine up or down a maximum of 10.5° from the installed null position. The yaw actuator gimbals the engine left or right a maximum of 8.5° from the installed position. The installed null position for the left and right main engines is 10° up from the X axis and 3.5° outboard from an engine centerline parallel to the X axis. The center engine's installed null position is 16° above the X axis centerline for pitch and on the X axis centerline for yaw. When any engine is installed in the null position, the other engines cannot collide with it.

Each SRB also has two thrust vector control actuators. However, the SRB TVC coordinate axes are called "rock" and "tilt" rather than pitch and yaw. The rock and tilt axes form a 45° angle with the pitch and yaw axes. This allows an equivalent ±7° movement range in pitch and yaw with a rock/tilt gimbal range of ±5°.



SSME and SRB Thrust Vector Control

Digital Autopilot

The digital autopilot (DAP) is the heart of flight control software. It is composed of several software modules that interpret maneuver requests, compare them to what the vehicle is doing, and generate commands for the appropriate effectors. There are different DAPs for different flight phases, particularly insertion and orbit, and various modes and submodes within each.

The DAP controls the orbiter in response to automatic or manual commands during insertion and on orbit. The effectors used to produce control forces and moments on the orbiter are the two OMS engines and the 38 primary RCS jets. Six vernier RCS jets are also available on orbit for attitude control. The forward and aft RCS jets also provide attitude control and three-axis translation during external tank separation, insertion, and on-orbit maneuvers, as well as roll control for a single-OMS-engine operation. The OMS provides

propulsive control for orbit insertion, orbit circularization, orbit transfer, and rendezvous. Failure of a single OMS engine does not preclude a nominal orbit insertion.

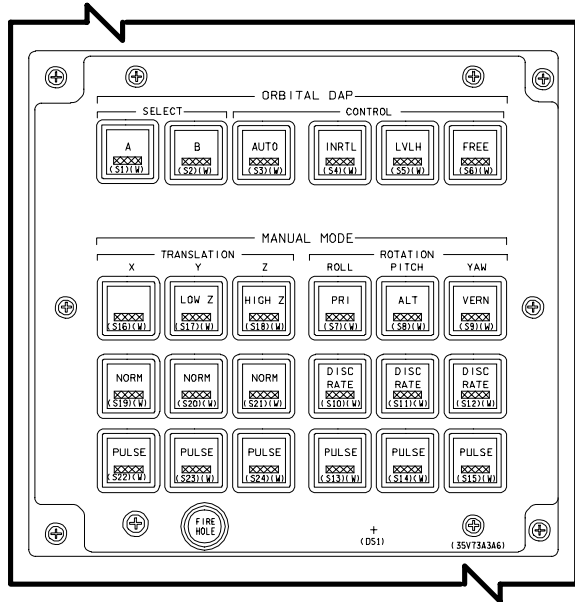
Orbital DAP Panel

There are 24 ORBITAL DAP pushbutton indicators on panels C3 and A6U. Assuming no electrical, computer, or hardware failures affect the operation of the indicators, inputs made to one panel are reflected in the configuration of the other panel. All the pushbuttons are active in the orbital DAP, whereas only a subset are operational in the transition DAP or when the backup flight system is engaged. None of the indicators are operational during ascent or entry. As with other aft flight-deck controls, aft panel A6U pushbutton indicators are only operational during the on-orbit phase.

The orbital DAP is somewhat similar to the transition DAP, but has many options and capabilities added. These added capabilities can

be best explained by a review of the ORBITAL DAP controls on panels C3 and A6U. Discussions of the various DAP modes follow.

The SELECT (A or B) pushbutton indicators toggle the DAP between one of two configurations. These configurations are changed and displayed on the DAP CONFIG CRT display (SPEC 20). The A option typically has smaller dead bands and lower rates than the B option.



**ORBITAL DAP Pushbuttons on Panel C3
(Panel A6U identical)**

2011/020/		DAP CONFIG		1 000/19:07:32	
PRI	1 DAP A08	2 DAP B08	PRI	DAP EDIT	
ROT RATE	10 0.2000	30 0.2000	50 0.2000	3 DAP A08	
ATT DB	11 1.00	31 1.00	51 1.00	4 DAP B	
RATE DB	12 0.10	32 0.10	52 0.10	5 LOAD	
ROT PLS	13 0.10	33 0.10	53 0.10		
COMP	14 .000	34 .000	54 .000		
P OPTION	15 TAIL	35 TAIL	55 TAIL		
Y OPTION	16 TAIL	36 TAIL	56 TAIL		
TRAN PLS	17 0.05	37 0.01	57 0.05		
ALT			ALT		
RATE DB	18 0.200	38 0.200	58 0.200		
JET OPT	19 ALL	39 ALL	59 ALL		
# JETS	20 2	40 2	60 2		
ON TIME	21 0.08	41 0.08	61 0.08		
DELAY	22 0.00	42 0.00	62 0.00		
VERN			VERN		
ROT RATE	23 0.2000	43 0.2000	63 0.2000	NOTCH FLTR	
ATT DB	24 1.000	44 1.000	64 1.000	ENA 6	
RATE DB	25 .020	45 .020	65 .020	INERTIAS	
ROT PLS	26 0.010	46 0.010	66 0.010	7 IX	0.938
COMP	27 .000	47 .000	67 .000	8 IY	7.129
CNTL ACC	28 0	48 0	68 0	9 IZ	7.462

DAP CONFIG Display (SPEC 20)

The CONTROL pushbutton indicators toggle the DAP between AUTO, INRTL, LVLH, and FREE. In AUTO the orbiter's attitude is

controlled by universal pointing (UNIV PTG) or orbit burn guidance. In this control mode, the DAP will rotate the orbiter about the shortest angle to the desired attitude. The rate of rotation is determined by ROT RATE items on the DAP CONFIG (SPEC 20) display. Once in attitude, the DAP will fire jets to maintain the attitude and attitude rates within the dead bands specified on the DAP CONFIG display.

In CONTROL INRTL, the orbiter is in inertial attitude hold, and in CONTROL LVLH the orbiter is in LVLH hold (LVLH hold will hold the orbiter's attitude fixed relative to the Earth). The ROTATION DISC RATE pushbutton indicators must be illuminated for INRTL or LVLH to hold attitude.

The CONTROL FREE pushbutton indicator puts the DAP into free drift. In this mode, the ROTATION PULSE pushbutton indicators will illuminate, and RCS jets will not fire if the RHC and THC remain in detent.

The first row of the MANUAL MODE TRANSLATION pushbuttons control which of the +Z (up firing) jets will fire. Nominally, none of the pushbutton indicators are illuminated, and the "normal" number of up firing jets will be commanded to fire. If the

LOW Z pushbutton indicator is depressed, DAP will never command an up firing jet to fire. This mode is used to protect a payload or crewmember that is operating close to the orbiter.

In HIGH Z, all the up firing jets will be commanded to fire if a +Z translation is commanded with the THC. All other DAP maneuvers will result in the "normal" number of up firing jets to fire. This mode is used to quickly separate the orbiter from a payload.

The second and third rows of MANUAL MODE TRANSLATION pushbuttons toggle the DAP between NORM and PULSE. In NORM, RCS jets will be continuously commanded to fire if the THC is moved out of detent. In PULSE, DAP will fire RCS jets to achieve the TRANSLATION PULSE rate specified on the DAP CONFIG display. The PULSE units are feet per second.

The first row of the MANUAL MODE ROTATION portion of the DAP panel toggles the DAP between primary (PRI), alternate (ALT), and vernier (VERN). In PRI, one or more of the primary RCS jets will be continuously commanded to fire if either the attitude or attitude rate dead bands are exceeded. This mode cannot be used for many different RMS and payload operations.

In ALT, the primary RCS jets are still used, but the number of jets, duration of firings, and time between firings can be controlled on the DAP CONFIG display. This extra control of jet firings greatly reduces the stress on a payload and the RMS. The ALT mode allows almost unrestricted payload and RMS operations if the vernier jets are not available. In ALT mode, the DAP also determines the best jet(s) to fire based on the combined orbiter/payload moments of inertias. These inertias are selected with CNTL ACCEL (item 14) on the DAP CONFIG display.

In VERN, the DAP uses the six vernier RCS jets for attitude control. Vernier control produces less stress on the RMS/payload, uses less propellant, and can achieve tighter dead bands than either PRI or ALT. Like the ALT mode, the best jet(s) to use are determined by the orbiter/payload moments of inertias.

The second and third rows of the ROTATION pushbutton indicators toggle the DAP between discrete rate (DISC RATE) and PULSE. For these rows to have any effect, the ORBITAL DAP CONTROL must not be in AUTO. In DISC RATE, if the RHC is taken out of detent, the DAP will fire RCS jets to achieve and maintain the rate specified by the ROT RATE in the DAP CONFIG display. If the RHC is in detent, the DAP will fire jets to maintain either inertial or LVLH attitude hold, depending on the selection of the ORBITAL DAP CONTROL pushbutton indicators.

In ROTATION PULSE, moving the RHC out of detent commands a pulse of jet firings to increase the rotation rate by the ROT PLS rate specified on the DAP CONFIG display. When the RHC is in detent, the DAP is in free drift for that axis. Pushing the CONTROL FREE pushbutton indicator is functionally equivalent to pushing all three ROTATION PULSE pushbutton indicators.

Continuous rotation RCS jet firings can be obtained by moving the RHC past the soft stop. This continuous firing of jets can be obtained in either DISC RATE or PULSE. Even if CONTROL is in AUTO, moving the RHC out of detent will force the DAP to INRTL, and further movement past the soft stop will cause continuous jet firings.

Transition DAP

At MECO, the transition DAP becomes active, sending attitude hold commands to the RCS. External tank separation is automatically commanded 18 seconds after MECO. The transition DAP immediately sends commands to fire the orbiter's down firing Z RCS jets, causing the orbiter to translate in the minus Z direction. When a rate of 4 feet per second is reached, RCS commands are removed. The transition DAP is used from MECO until transition to the on-orbit phase and in OPS 3 MM 301-303.

The external tank separation module compares minus Z delta velocities from the DAP attitude processor with the desired delta. Before this value is reached, the transition DAP and steering processor send commands to the RCS jet selection logic. A table-lookup technique is used for the primary RCS jets, and ten RCS down firing jets are commanded to fire. When the desired minus Z-delta velocity is reached, the translation command is set to zero. Rotation commands are also permitted during the external tank separation sequence. The RCS jet driver forward and aft assemblies provide the turn-on/turn-off jet selection logic signals to the RCS jets. There is also an RCS redundancy management program that permits only "good" RCS jets to be activated.

Insertion flight control is also accomplished with the transition DAP. The transition DAP uses commands from the guidance software for automatic maneuvers to the OMS burn attitude using RCS jets. During OMS-1 and OMS-2 (or only OMS-2 in a direct insertion), the transition DAP uses the OMS engines thrust vector control and RCS jets, as required. The transition DAP also receives commands from the commander's THC and the commander's or pilot's RHC. The transition DAP then takes these commands and converts them into appropriate RCS or OMS TVC commands. The transition DAP monitors

the resultant attitude and attitude rates and sends the necessary commands to achieve the targeted attitude and attitude rate within premission-specified dead bands.

The flight crew interfaces directly with the transition DAP through the forward RHCs and THC and indirectly through entries to the OMS MNVR EXEC CRT display and the ORBITAL DAP pushbuttons on panel C3.

In the transition DAP, the commander's THC is active and totally independent of the DAP pushbuttons or RHC position or status. Whenever the commander's THC is out of detent in either plus or minus X, Y, or Z, translation acceleration commands are sent directly to the RCS jet selection logic for continuous RCS jet firing. Rotational commands may be sent simultaneously with translation commands within the limits of the RCS jet selection logic. For example, if both plus X and minus Z translations are commanded simultaneously, plus X translation receives priority.

For rotations, the flight crew can select either automatic or manual control via the ORBITAL DAP CONTROL pushbutton indicators (AUTO, INRTL) or manual control by moving the RHC out of detent. In INRTL, the capability exists to rotate about any axis in one of two modes. When the ROTATION PULSE mode is selected, each RHC deflection results in a single burst of jet fire. In DISC RATE mode, RHC deflection results in a specified rate being commanded in that axis for the entire time the RHC is deflected. A free-drift mode (INRTL/PULSE) is also available in which no RCS jets are fired, or an attitude-hold mode, in which the DAP sends commands to maintain the current attitude with null rates within premission-specified dead bands. Also, if the RHC is deflected beyond the soft stop, continuous RCS jet firings result. In translation, movement of the THC results in continuous jet firings. Pulse translation mode is not available in the transition DAP.

The transition DAP also involves maintaining the OMS thrust vector control. The OMS processor generates OMS engine gimbal actuator thrust vector control commands to produce the desired spacecraft/engine relationship for the specified thrust direction.

For the OMS burn, the orbital state vector (position and velocity) is produced by navigation using inertial measurement unit delta velocities during powered and coasting flight. This state is sent to guidance, which uses target inputs through the CRT to compute thrust direction commands for flight control and burn parameters for CRT display. Flight control converts the commands into OMS engine gimbal angles (thrust vector control) for the OMS burn.

OMS thrust vector control for a normal two-engine burn is entered by depressing the ORBITAL DAP CONTROL AUTO pushbutton indicator with both RHCs within software detents. OMS manual thrust vector control for both OMS engines is entered by depressing the INRTL pushbutton indicator or by moving the commander's or pilot's RHC out of detent. The flight crew supplies the rate commands to the burn vector control system instead of guidance. The manual RHC rotation requests are proportional to RHC deflections and are converted into gimbal angles. OMS thrust in either case is applied through the spacecraft's center of gravity.

Orbital DAP

The orbital flight control software includes an RCS DAP, an OMS TVC DAP, and an attitude processor module to calculate vehicle attitude, as well as logic to govern the selection of a DAP. The attitudes calculated by the attitude processor are displayed on the attitude director indicator, as well as on the OPS 201 UNIV PTG CRT display, which is available whenever orbit software is active. The vehicle attitude is used by the DAP to determine attitude and rate errors.

RCS DAP

The RCS DAP is used at all times in the on-orbit phase except during an OMS burn. This DAP controls vehicle attitudes and rates through RCS jet fire commands. Either the larger primary jets or the less powerful vernier jets can be used for rotational maneuvers, depending on whether PRI, ALT, or VERN is selected on the panel C3 (or A6U) ORBITAL DAP CONTROL panel. The choice of primary or vernier thrusters depends on fuel consumption considerations, how

quickly the vehicle needs to be maneuvered to satisfy a mission objective, and interaction with payloads. ALT mode uses primary jets with fewer jet firings of a small duration and selectable delay between firings to allow attitude control when vernier jet capability is lost.

The rotation rates and dead bands, translation rate, and additional DAP options can be changed by the flight crew during the orbit phase using the DAP CONFIG CRT display. The flight crew loads the DAP with these options in two ways, one option set is accessed by depressing the A pushbutton on the ORBITAL DAP SELECT panel and the other by depressing the B pushbutton.

Each planned DAP configuration is given a reference number. Typically, the A configurations have smaller dead bands and lower rates than the B configurations. The wide dead bands are used to minimize fuel usage, while the tight dead bands allow greater precision in executing maneuvers or holding attitude.

The RCS DAP operates in an automatic or one of two (INRTL or LVLH) manual rotation modes, depending on whether the flight crew selects AUTO, INRTL, or LVLH on the ORBITAL DAP CONTROL panel. The INRTL mode is also accessed when the RHC is moved out of its detent position. In both the automatic and manual modes, the rotation rate is controlled by the selection of DAP A or B and the information loaded in the DAP CONFIG display. In addition, in automatic, the DAP determines the required attitude to be achieved from the UNIV PTG display and then computes the RCS jet-fire commands necessary to achieve these requirements within the current set of dead bands.

In the manual rotation mode, the RCS DAP converts flight crew inputs from any of the three RHCs to RCS jet-fire commands, depending on whether PULSE or DISC RATE is selected on the MANUAL MODE ROTATION ROLL, PITCH, and YAW pushbuttons on panel C3 or A6. Simply, when PULSE is selected, a single burst of jet fire is produced with each RHC deflection. The desired rotational rate is specified on the DAP CONFIG display (ROTATION). When DISC RATE is selected, jet

firings occur whenever the RHC is out of detent, but inside the soft stop, thus maintaining the rotational rate specified on the DAP CONFIG display. When the RHC is beyond the soft stop, continuous jet firings will result. When the RHC is returned to detent, the current M50 attitude will be maintained within the specified dead bands.

Another manual RCS DAP mode, local vertical/local horizontal (LVLH), is used to maintain the current attitude with respect to the rotating LVLH reference frame. It is selected through the LVLH pushbutton on panel C3 or A6U.

The RCS DAP includes only a manual translation capability, executed through the forward or aft THC. Only the primary RCS jets are used. If in VERN, DAP will automatically upmode to primary RCS (PRCS) when the THC is moved out of detent. The DAP will return to VERN or ALT when the desired rate is achieved or the THC is returned to detent. Deflections of the THC result in RCS jet firings based on the MANUAL MODE TRANSLATION pushbutton indicator selected on the ORBITAL DAP panel. PULSE mode results in a single burst of jet fire. NORM mode results in continuous jet firings as long as the THC is out of detent. Two additional submodes, HIGH Z and LOW Z, are available for special applications of +Z translations. NORM will fire three up-firing jets when a +Z translation is commanded and is the default. HIGH Z will fire all nine up-firing jets and would be used only for emergency escape from the vicinity of another orbiting body. LOW Z fires two aft-firing and two forward-firing jets for +Z maneuvers. LOW Z is used to maneuver near payloads that can be contaminated or damaged by the plume from an up-firing jet. Selection of NORM, HIGH Z, or LOW Z has no effect on choice of jets for $\pm X$, $\pm Y$, or $-Z$ translations. LOW Z will inhibit upfiring jets for rotations.

OMS TVC DAP

The OMS thrust vector control DAP is available when an OMS burn is executed through the ORBIT MNVR EXEC display. The TVC DAP uses the guidance-generated velocity requirements and converts these into the appropriate OMS gimbal commands, assuming AUTO is

selected on the ORBITAL DAP CONTROL panel. The TVC DAP also generates the OMS fire commands, the OMS shutdown commands, and, if necessary, due to OMS engine failure, the required RCS commands to maintain attitude control. Under INRTL selection, the TVC DAP takes inputs from the RHC to control attitude during the burn. When the RHC is in detent, the TVC DAP will maintain the current inertial attitude.

Before OMS ignition, the orbiter is automatically or manually maneuvered to the OMS ignition attitude using the RCS jets. Automatic TVC for one OMS engine is identical for two, except that the RCS processor is responsible for roll control. Single-OMS-engine burn is also through the orbiter's center of gravity, except when pitch or yaw rate commands are non-zero. If the left or right OMS engine fails during a burn, a red LEFT or RIGHT OMS light on panel F7 is illuminated. Since an OMS cutoff is based on time rather than velocity, a velocity residual may exist following the cutoff. The residual can be reduced to zero by the RCS through the THC.

Aerojet DAP

The aerojet DAP has the following characteristics: (1) flight adaptive (changes as a function of q-bar), (2) closed loop (compares feedback with command to generate an error signal), and (3) rate command (jets and aerosurfaces are commanded as necessary to achieve the desired rate). Once the desired rate is obtained, forward loop trim integrators maintain the desired rate. The aerojet DAP is activated by MM 304 transition, usually at EI-5, and runs through wheel stop on the runway. It slowly blends out the use of jets and blends in the use of aerosurfaces as the orbiter makes the transition from a spacecraft to hypersonic glider to subsonic glider to finally a high-speed 100-ton tricycle.

Pitch control is driven by either the auto system via alpha error (MM 304/602) or N_z error (MM 305/603), which is turned into a rate command, or by CSS via RHC input. This rate command is compared to the pitch RGA output to come up with a rate error that is turned into a jet command until q-bar 40, and/or elevator (elevons moving symmetrically) command after q-bar 2. The body flap is used as a trim device to

keep the elevons on or near schedule. This allows the elevons to be in the right position for maximum effectiveness, and to limit hinge moments and thermal effects. The speed brake is opened at $V_{REL} = 10$ k and is used supersonic as a lateral-directional stability device (speed brake opens causing a pitch-up moment that the elevons counteract by moving down, making the elevons more effective as an elevator and as ailerons). Subsonic, the speed brake is used first as an energy modulator, then as a q-bar modulator below 9,000 feet.

Other features of the pitch channel include:

- Pitch panel trim moves the elevons up or down. It requires trim be enabled and on, and either the CDR or PLT use the TRIM switches on panel L2 or C3. There is no current use for this feature, especially with the body flap in AUTO.
- RHC pitch rate trim biases the output of the RHC by inputting a rate command. It requires trim to be enabled and flight controller power on, and the CDR or PLT to use the "beep trim" switch on their RHC. Any input by the RHC rate trim will be zeroed if the pitch axis is returned to AUTO. This switch is used to perform the beep trim derotation during landing rollout.
- Nose-up turn compensation provides a pitch rate as a function of steady state turn yaw rate and bank angle during bank maneuvers in MM 305. This provides a constant flight path angle without the crew having to make a pitch adjustment during turns.
- At nose gear touchdown, the pitch axis will mode to AUTO and auto-load relief will move the elevons down to off-load the main gear. (This is the only entry phase auto flight control feature in the BFS.)

Because of the very high angles of attack (alpha) that the orbiter flies, there is a large difference in the velocity vector and the body X axis. For conventional airplanes that fly at small alpha, a body axis roll is very close to a velocity vector bank. (Bank refers to a rotation about the

velocity vector, or a stability axis rotation. Roll refers to a rotation about the X axis or a body axis rotation.) But at an alpha of 90°, a velocity vector bank is a body axis yaw. Therefore, at 40° alpha, normal alpha for the orbiter from MM 304 transition to $V_{REL} = 10.5$ k, a velocity vector bank requires a combination of a body axis roll and body axis yaw.

Another very important feature of the orbiter during early entry ($V_{REL} >$ approximately 4 k) is that the vehicle rolls and yaws due to beta or sideslip. Beta can be generated by either yaw jets or the adverse yaw caused by aileron displacement. (Adverse yaw means instead of rolling because of the increased lift caused by moving an aileron down, the vehicle will yaw because of the increased drag caused by moving an aileron down. This yaw produces beta.) Therefore, adverse yaw is purposely used during early entry to start a bank by using "reverse aileron" (left aileron up when initiating a bank to the right) along with yaw jets to develop a beta to get the vehicle banking. One of the two purposes of a gain called GALR is to determine whether the first output from the roll channel is reverse or proverse aileron, and how big the output should be. (Basically, no initial aileron is used until q-bar 10, reverse aileron is used from q-bar 10 until approximately $V_{REL} = 3.8$ k, and steadily increasing proverse aileron from $V_{REL} = 3.8$ k.) However, once a beta has been induced, it must be controlled. More precisely, beta dot must be made zero when the desired bank rate is achieved. Proverse aileron, used in the proper relationship to compensated body axis yaw and alpha, is introduced after the bank has been started to control beta and maintain the bank rate. This is called beta dot damping, and GALR controls how much aileron is used for damping and when it is terminated. Beta damping is used from q-bar 2 until Mach 0.9, although it starts ramping down at approximately $V_{REL} = 3.8$ k.

Roll channel is driven by either the auto system via bank angle error, which is turned into a bank rate command, or by CSS via RHC input. This bank rate command is multiplied by (1-GALR) to determine if the initial command should be reverse or proverse ailerons (ailerons refer to the use of elevons asymmetrically). It is converted into a roll rate command and is summed with beta dot damping (which is

multiplied by GALR to determine magnitude) and compared with the output from the roll axis RGAs after compensation for roll rates from the steady-state turn. This is the rate error that is turned into jet commands until q-bar 10 and/or aileron commands after q-bar 2.

Other features of the roll channel are:

- Roll channel trim is automatic in AUTO until rollout. Because auto trim in CSS is terminated at Mach 1.25, the CDR may experience a roll rate on final that must be compensated for by displacing the RHC slightly to the right or left. That is because the trim required on final is different from the trim required when CSS was taken. The CDR should use roll panel trim to trim the RHC back to neutral. (Roll panel trim moves the ailerons up or down.)
- RHC roll rate trim is exactly the same as pitch rate trim.
- At main gear touchdown, auto load balance keeps the wings level during rollout and prevents the downwind tire from experiencing excessive loads with crosswinds. After nose gear touchdown, load balance is faded out over 100 seconds.
- Any yaw jet firing causes the ailerons to trim in the proper direction to reduce the number of jet firings (right yaw jet firings will cause left aileron to trim up).
- No-yaw-jet (N-Y-J) entry mode eliminates all yaw jet commands. Bank maneuvers are accomplished only with reverse aileron commands. Starting with OI-25, AUTO and N-Y-J GALR gains are the same. There is no difference between PASS and BFS N-Y-J, and both can be flown from q-bar > 20 (or very soon after the end of the first non-zero bank) to landing.

Except during bank maneuvers, DAP attempts to keep beta small throughout entry. Until Mach 0.6, the yaw channel is driven by bank angle error, which is turned into a bank rate command. After Mach 0.6, the yaw channel is

driven by the roll rate compensated for steady state turn so rudder pedal inputs are not required to maintain coordinated flight. The bank rate command or the compensated roll rate is converted to a body yaw command and summed with a beta compensation term until q -bar 20. That is compared with the output from the yaw axis RGAs after compensation for yaw rates from the steady state turn. This yaw rate error is then summed with lateral acceleration (N_y), RPTA input, and yaw panel trim inputs. This is the rate that is turned into jet commands until Mach 1 and/or rudder commands after Mach 5. This causes the beta during early entry to cause the orbiter to bank, or during late entry ($M < 0.6$), coordinates the bank.

Other features of the yaw channel are:

- The RPTA does not directly control the rudder, but commands lateral acceleration, and the rudder moves as necessary to maintain that lateral acceleration. Yaw panel trim performs exactly the same function. There is no operation region to command a non-zero lateral acceleration.
- At GSENB L set (WOW set for 2 sec, $\theta < 0$ deg, WONG), if in AUTO R/Y, the yaw channel will provide nose wheel steering commands to maintain runway centerline.

Operations

Ascent

The terminal count phase extends from T-20 minutes through SRB ignition. During this timeframe, the GNC OPS 1 software is loaded into the GPCs and verified by the ground. Guidance and flight control software are not active during terminal count. Navigation software is initialized at T-8 seconds when the onboard state vector is initialized and state vector propagation begins.

First-stage guidance is active from SRB ignition through SRB separation command. In this stage, guidance uses a preflight planned ("canned") table of roll, pitch, and yaw attitudes referenced to relative velocity. In addition to sending commands to flight control to obtain

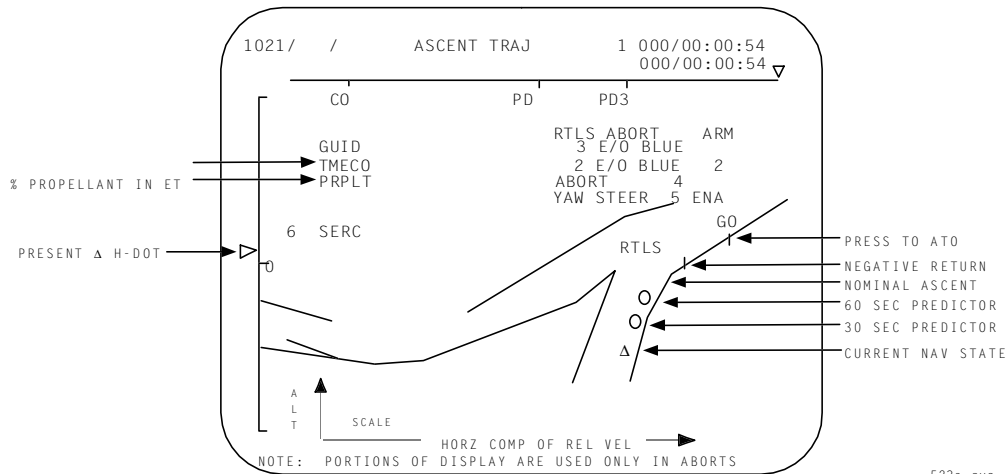
proper attitudes, the guidance software also sends commands to the MPS throttle per a preflight defined throttle schedule. Steering of the vehicle during first stage is accomplished by gimbaling the SSME bells and SRB nozzles. First-stage guidance also attempts to relieve vehicle aerodynamic loads based on sensed accelerations.

The navigation software during first stage propagates the vehicle state vector using the Super-G integration scheme using IMU data and a gravity model.

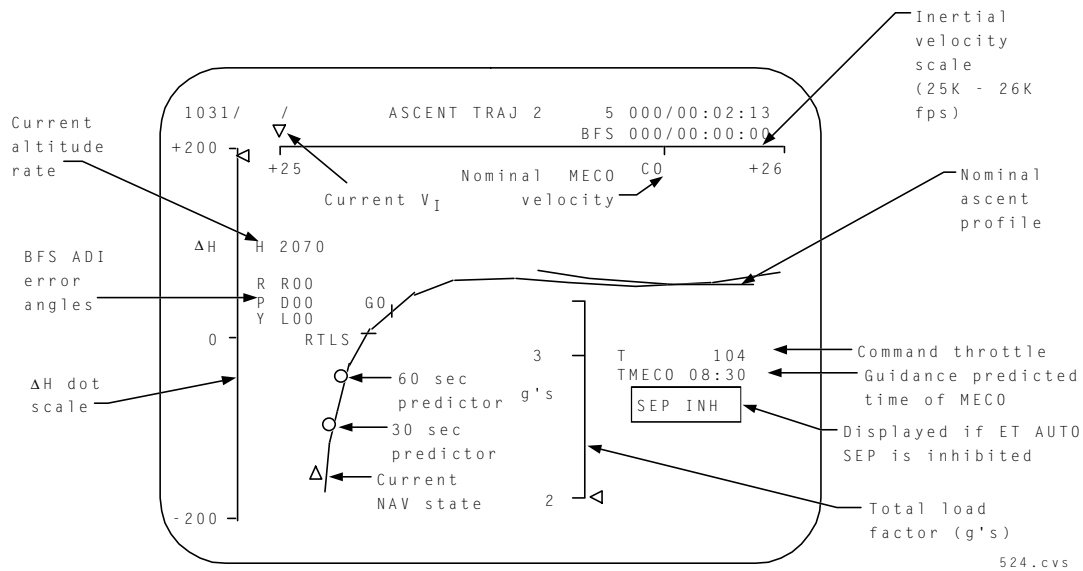
The flight control software during first stage uses commands issued by guidance. If the crew has selected CSS, commands are input through the RHC. Feedback from rate gyro assemblies and accelerometers is used to generate commands to reposition the SRB nozzles and main engine bells. The current vehicle attitude rates and the errors between current and desired attitudes are sent to the attitude director indicator for display to the crew. If the crew does CSS, the resultant control mode is discrete rate/attitude hold. In this mode, when the rotational hand controller is moved, a specified attitude rate is commanded as long as the RHC is out of its neutral position. When the RHC is in detent, attitude hold commands are generated by flight control.

During first stage, no GNC-related crew actions are planned unless a failure occurs. Following launch, the crew uses the Ascent Flip Book for general procedures. To ensure that the auto flight control system is maintaining the expected ascent profile, the crew can scan the cue cards placed next to the dedicated displays.

Second-stage ascent begins at SRB separation and extends through MECO and external tank separation. The second stage guidance software uses a cyclic, closed loop scheme to calculate the necessary commands to take the mated vehicle to a specified set of target MECO conditions. These conditions include cutoff velocity, radius from the Earth, flight path angle, orbital inclination, and longitude of the ascending node. The name of the targeting scheme is PEG (powered explicit guidance) 1. Guidance software also governs the main engine throttle commands such that 3 g's are not exceeded. The predicted time of MECO (TMECO) is calculated



PASS ASCENT TRAJ Display



BFS ASCENT TRAJ 2 Display

and displayed to the crew on the PASS ASCENT TRAJ display. Following SRB separation, it may take the PEG 1 guidance algorithm several cycles to converge and for TMECO to become stable. Forty seconds prior to MECO, guidance begins targeting only for the desired cutoff velocity.

Second-stage navigation software continues as it did during first stage; i.e., it propagates a state vector using the Super-G integration scheme. Second-stage flight control software continues through MECO as it did during first stage, with the exception of gimbaling the main engines versus the SRBs. After separation, attitude hold is commanded until guidance converges. At

MECO, the transition (or TRANS) DAP, becomes active. Initially it sends attitude hold commands. External tank separation is automatically commanded 18 seconds after MECO. The DAP immediately sets commands to fire the orbiter -Z RCS jets resulting in the orbiter translating in the -Z direction (away from the external tank). When -4 fps delta velocity is reached, the fire commands are removed.

During second stage, the crew monitors the onboard systems to ensure that the major GNC events occur correctly. These events include closed loop guidance convergence, 3-g throttling, MECO, external tank separation, and -Z translation.

The crew can monitor for guidance convergence by noting if the guidance-computed time of MECO is stabilized on the ASCENT TRAJ display. If not, the crew is required to take manual control of the vehicle. They can also ensure that 3 g's are not exceeded by monitoring the BFS ASCENT TRAJ 2 display or the accel tape AMI. The ASCENT TRAJ 2 display also can be used to monitor the MECO velocity. MECO is indicated by the illumination of three red MAIN ENGINE STATUS lights on panel F7 and the sudden decrease in acceleration. MECO confirm is also indicated by the illumination of the ORBITAL DAP pushbutton lights.

Orbit Insertion

During the orbit insertion phase, the guidance software is used to target the OMS 1 and OMS 2 burns. The primary targeting scheme used is called PEG 4. This is a cyclic, closed loop scheme that computes the required delta velocity to achieve a target specified by a time of ignition. In addition, the guidance software is constrained to optimize fuel usage. For the OMS 1 burn, it also must ensure that the burn attitude at ignition is near the MECO attitude. The PEG 4 targeting scheme can compensate for the loss of one OMS engine or an RCS downmode during the burn if it detects the OMS loss. Prior to and during the burn, guidance computes the remaining burn time and total remaining delta velocity.

Navigation during the orbit insertion phase is identical in processing to that used in the mainstage whenever the IMU-sensed acceleration is greater than the noise threshold. If the IMU-sensed acceleration drops below the threshold, navigation ignores the IMU data and propagates the state vector using an atmospheric drag model of the orbiter.

Insertion flight control is accomplished using the transition DAP. The transition DAP uses commands from guidance for automatic maneuvers to burn attitude using the RCS jets. During the OMS 1 and 2 burns, it uses the OMS engines and RCS jets as required. It can also receive commands from the crew via the forward THC and RHC. The transition DAP takes these commands and converts them into the appropriate RCS commands. It then monitors the resultant attitude and attitude

rates. The necessary commands are sent to achieve the targeted attitude and attitude rate within the pre-mission specified deadbands.

For rotations, the crew selects either AUTO or INRTL control on the ORBITAL DAP panel or by moving the RHC. In translation, movement of the THC results in continuous jet firings.

Orbit GNC

The major GNC-related orbit tasks include achieving the proper position, velocity, and attitude necessary to accomplish the mission's objectives. To do this, the GNC software maintains an accurate state vector, maneuvers to specified attitudes and positions, and points a specified orbiter body vector at a selected target. These activities are planned with several constraints in mind, including fuel consumption, vehicle thermal limits, payload requirements, and rendezvous/proximity operations considerations. The GNC displays for the majority of on-orbit operations are OPS 201 UNIV PTG and MNVR EXEC. Both are available in OPS 2, and MNVR EXEC is available for the orbit portion of OPS 1 and 3.

The navigation software has several important features. As before, it propagates the orbiter state vector using the Super-G integration scheme. During coasting flight, the software uses a model of atmospheric drag acceleration to propagate the state vector. If translational thrusts are anticipated, the crew can set a flag for navigation to use inertial measurement unit-sensed acceleration if above a noise threshold value. When this flag is set, the crew can monitor the thrust on the REL NAV display (SPEC 33) through an item called AVG G.

Another navigation option that is available on-orbit is called rendezvous navigation. When this option is enabled by a crew input on the REL NAV display, the software maintains a target state vector, as well as the orbiter state vector. In this mode, navigation can use external sensor data from the star tracker, COAS, or rendezvous radar in computing the orbiter target state vector.

For vehicles equipped with three-string GPS hardware, the navigation software will replace its propagated vector with a selected GPS vector

every 90 minutes. This will happen only if the selected GPS state vector falls within the navigation software's expected error. After the orbiter vector is updated, it will then be propagated for the next 90 minutes using the same techniques as described above (i.e., Super-G, drag model, etc.). This automatic GPS state vector update will be inhibited during rendezvous operations to avoid interfering with the current rendezvous navigation sensor processes.

Because there is no method onboard to independently compute corrections to the state vector for non-GPS orbiters, periodic updates are sent from Mission Control to correct any errors that develop with the onboard nav state.

```

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

```

MNVR Display

The on-orbit guidance software has several features. Universal pointing is used to compute attitude changes required to "point" a specified orbiter body axis at a specified target, to maneuver to a predetermined attitude, to rotate the orbiter about a specified body axis, or to maintain attitude hold. The crew interacts with this software via the UNIV PTG display.

Another guidance feature is PEG 7, or external delta-V, targeting for OMS or RCS burns. In this mode, guidance sends the commands to flight control to execute a burn specified by an ignition time (TIG) and delta velocities in the local vertical coordinate system at ignition. Commands continue to be generated until the original delta-V requirement is met. The crew monitors this option with the ORBIT MNVR EXEC display.

```

XXXX/055/ GPS STATUS XX X DDD/HH:MM:SS
DDD/HH:MM:SS
I/O 10 _ GPS1S GPS2S GPS3S
STAT XXXX XXXX XXXX GPS MINUS NAV
MODE XXXX XXXX XXXX ΔH ±XXXXXX ΔH ±XXX.XX
S/TEST 11XS 12XS 13XS ΔDR ±XXXXXX ΔDR ±XXX.XX
INIT 14X 15X 16X ΔCR ±XXXXXX ΔCR ±XXX.XX
NAV 17X 18X 19X
RESTART 20X 21X 22X X LAT X LON ALT
IMU 23 XX 24 XX 25 XX XX.XX XX.XX XXX.XXXX
GDOP XX XX XX
DG FAIL S S S AUT INH FOR
DES RCVR 26X 27X 28X GPS TO G&C S32X 33X 34X
QA OVRD 29XS 30XS 31XS GPS TO NAV S35X 36X 37X
SF CAND X X X METERING OVERRIDE 38X
QA1 P 1XXXXXXXXXXXXXXXXX
QA2 POS X.XXS X.XXS X.XXS SATELLITES
VEL X.XXS X.XXS X.XXS TRKD C1 C2 C3 C4 C5 C6
QA3 POS X.XXS X.XXS X.XXS GPS1 XX XX XX XX XX XX
VEL X.XXS X.XXS X.XXS GPS2 XX XX XX XX XX XX
1-2 2-3 3-1 GPS3 XX XX XX XX XX XX
QA4 POS X.XXS X.XXS X.XXS DES 43 XX XX XX XX
VEL X.XXS X.XXS X.XXS XX XX XX XX
XXX.X LAST SEL FIL UPDATE

```

GPS STATUS Display (SPEC 55)

```

2011/ / UNIV PTG 2 000/02:44:58
CUR MNVR COMPL 02:55:29 000/00:00:00
1 START TIME 0/000:00:00 CUR FUT
MNVR OPTION START MNVR 18
5 R 0.00 TRK 19 *
6 P 0.00 ROT 20
7 Y 0.00 CNCL 21
TRK/ROT OPTIONS ATT MON
8 TGT ID 2 22 MON AXIS 1 +X
ERR TOT 23 *
9 RA 0.000 ERR DAP 24
10 DEC [ ] 0.000
11 LAT [ ] 0.000 ROLL PITCH YAW
12 LON [ ] 0.000 CUR 163.59 40.77 338.38
13 ALT [ ] 0.0 REQD 304.04 139.80 342.99
ERR + 74.86 - 62.92 + 86.93
14 BODY VECTOR 3 RATE - 0.266 - 0.367 + 0.443
15 P 90.00
16 Y 0.00
17 OM 270.00

```

UNIV PTG Display

```

2011/033/ REL NAV 2 004/23:05:28
000/00:38:42
RNDZ NAV ENA 1* SV UPDATE
KU ANT ENA 2* POS 0.01 AVG G ON 5*
MEAS ENA 3 VEL ΔVX - 0.13
NAV ΔVY - 5.80
SV SEL 4 FLTR RR GPC ΔVZ - 0.04
RNG 97.692 RNG 97.567 ΔVTOT 72.01
R - 41.55 R - 41.30 RESET COMPNT 6
θ 11.35 EL - 0.7 TOT 7
Y - 0.04 AZ + 0.1 SV TRANSFER
Y - 0.3 ωP + 1.1 FLTR MINUS PROP
NODE 23:48:54 ωR + 0.0 POS 3.74
VEL 4.57
S TRK 12 RR 13* COAS 14 FLTR TO PROP 8
STAT OFFSET X Y PROP TO FLTR 9
ORBIT TO TGT 10
TGT TO ORB 11
SLOW RATE 15*
COVAR REINIT 16 MARK HIST EDIT OVDR
RESID RATIO ACPT REJ AUT INH FOR
RNG + 0.02 0.0 9 0 17* 18 19
R + 0.07 0.0 6 0 20* 21 22
V/EL/Y - 0.01 0.0 4 0 23* 24 25
H/AZ/X + 0.01 0.0 4 0

```

REL NAV Display (SPEC 33)

2011/034/		ORBIT TGT		2 002/13:24:45	
				000/00:55:36	
MNVR	TIG	ΔV_X	ΔV_Y	ΔV_Z	ΔV_T
10	2/14:20:21	+ 9.1	- 0.5	+ 0.8	+ 9.1
			PRED MATCH=		13
INPUTS			CONTROLS		
1	TGT NO	10	T2 TO T1	25	
2	T1 TIG	2/14:20:21	LOAD	26	
6	EL	0.00	COMPUTE T1	28	
7	$\Delta X/DNRNG$	- 49.39	COMPUTE T2	29	
8	ΔY	+ 0.00			
9	$\Delta Z/\Delta H$	- 1.39			
10	ΔX	- 14.96			
11	ΔY	+ 0.49			
12	ΔZ	- 0.50			
13	T2 TIG	2/15:42:26			
17	ΔT	+ 82.1			
18	ΔX	0.00			
19	ΔY	0.00			
20	ΔZ	0.00			
21	BASE TIME	2/14:20:21			
			ORBITER STATE		
			302/ 8:32:38.114		
			X +17213.696		
			Y - 4052.545		
			Z +13379.393		
			VX +13.793848		
			VY +16.958777		
			VZ -12.548509		

528

ORBIT TGT Display (SPEC 34)

The third guidance capability is an on-orbit targeting scheme used to compute the burn parameters required to move the orbiter to a specified target offset position in a given amount of time. This capability is used to do on-board targeting of rendezvous maneuvers. The crew monitors this feature using the SPEC 34 ORBIT TGT display.

The orbital flight control software includes the RCS DAP, OMS TVC DAP, an attitude processor, and the logic to govern DAP selection. The attitudes calculated by the attitude processor are displayed on the ADI and the UNIV PTG display screen. The vehicle attitude is used by the DAP to determine attitude and rate errors.

Options for the DAP, including the translation rate, rotation rates, and deadbands, are changeable by the crew during the orbit phase using the DAP CONFIG display. The Flight Plan specifies which DAP configurations should be loaded at each time in the mission.

Deorbit

The deorbit phase of the mission includes the deorbit burn preparations, the loading of burn targets, the execution and monitoring of the burn, post-burn reconfiguration, and a coast mode until about 400,000 feet above the Earth's surface. The deorbit and entry flight software is referred to as OPS 3.

During the deorbit phase, navigation uses the Super-G algorithm to propagate the orbiter state vector, based upon a drag model or IMU data.

Navigation maintains and propagates three orbiter state vectors, each based upon a different IMU. From these three state vectors, a single orbiter state vector is calculated using an interchangeable mid-value selection process. A single-state vector is passed on for use by guidance, flight control, dedicated display, and CRT display software. Three separate state vectors are propagated to protect the onboard software from problems due to two IMU data failures. This three-state vector system is only used during entry, since that phase is most critical with respect to navigation errors and their effects on vehicle control and an accurate landing. Another feature available during this phase is the software computational capability of a statistical estimate of the error in the state vector propagation, to be used later in flight when external sensor data are available. Also in this phase, it is possible for the crew or Mission Control to input a delta state vector to correct navigation.

Vehicles with three-string GPS hardware will be able to incorporate a selected GPS state vector every 42 seconds throughout the deorbit and entry phases of flight. This will be initialized via crew command upon entering OPS 301. Similar to orbit, the nav software will pick the best available GPS vector to replace the three IMU propagated state vectors. These three updated vectors will continue to be propagated as described above for the next 42 seconds, at which time they will be replaced with a new selected GPS vector and then the process will repeat.

Guidance during the deorbit phase is similar to that used in the orbit insertion phase. The PEG 4 scheme is used again to target the deorbit burn and guide the vehicle during the burn although the required conditions are different. The deorbit burn targets ensure the proper conditions for entry interface, including altitude, position with respect to the Earth (and landing site), and velocity/flight path angle constraints. These deorbit burn targets are specified preflight for a nominal mission, although it is also possible for the ground to uplink changes or for the crew to recompute them onboard. It is also possible to specify OMS fuel "wasted" (burned out of plane) during the deorbit burn in order to establish an acceptable orbiter center of gravity (c.g.) for entry. The crew is responsible for loading these targets on the DEORB MNVR EXEC display.

The display is used to set up and target the OMS burn, to specify fuel to be wasted, to display the required burn attitude, to initiate an automatic attitude maneuver, and to monitor the progress of the burn. The crew's task for deorbit guidance includes ensuring the correct burn targets are entered on the DEORB MNVR EXEC display, "loading" this target for PEG 4 deorbit burn guidance software, and maneuvering to calculated and displayed burn attitude either in AUTO or manually using the RHC. The burn itself is typically executed in AUTO such that the crew's task is to monitor the burn progress in terms of velocities and OMS performance.

Flight control during the deorbit phase is similar to the procedures used during orbit insertion - the transition DAP is again in effect.

Entry

The entry phase of flight is subdivided into three separate subphases because the software requirements for each are different:

- The ENTRY subphase extends from EI-5 to the point at which the vehicle is traveling at 2500 fps (83,000 ft altitude).
- The terminal area energy management (TAEM) subphase begins at 2500 fps and extends to the approach/landing capture zone, defined when the vehicle is on glide-slope, on airspeed, and on runway centerline (below 10,000 ft altitude).
- The approach/landing (A/L) subphase begins at the approach/landing capture zone and extends through the setting of the "weight on nose gear" discrete after touchdown.

The guidance software during the entry portion of flight performs different tasks during each of the ENTRY, TAEM, and A/L subphases. During the ENTRY subphase, guidance attempts to keep the vehicle on a trajectory that provides protection against excessive temperature, dynamic pressure, and normal acceleration (Nz) limits. To do this, the software sends commands to flight control to fly a drag/acceleration determined profile which guides the vehicle through a tight corridor limited on one side by altitude and velocity requirements for ranging (in order to make the

runway), and on the other side by the thermal, q-bar, and Nz constraints. Ranging is accomplished by adjusting drag acceleration to velocity such that the vehicle stays in that corridor. Drag acceleration can be adjusted by modifying the angle of attack, which changes the vehicle's cross sectional area with respect to the airstream, or by adjusting the vehicle bank angle, which affects lift and thus the vehicle's sink rate into denser atmosphere. The vehicle's angle of attack is maintained at a high value (40°) during most of this phase to protect the upper surfaces from extreme heat. It is ramped down to a lower value at the end of this phase for vehicle controllability. Using bank angle to adjust drag acceleration results in the vehicle turning off course. Therefore, at certain times, the vehicle must be rolled back toward the runway. This is called a roll reversal and is commanded as a function of azimuth error from the runway. The ground track during this phase, then, looks like a series of S-turns.

During the entry phase of flight, the crew uses CRT displays, dedicated displays, certain panel switches (such as TRIM switches), the RHC, and the SBTC to control the vehicle. Between the ENTRY interface and the TAEM interface, five ENTRY TRAJ CRT displays sequentially become available. These displays are used to monitor autoguidance and the vehicle's trajectory compared to the planned entry profile. The five displays are identical with the exception of the central plot, which shows vehicle velocity versus range or energy/weight versus range with a changing scale as the vehicle approaches the landing site. Two trajectory displays are shown on the next page as examples. This central plot also includes static background lines that allow the crew to monitor the vehicle's progression compared to planned entry profiles.

Once TAEM interface is reached, the CRT display VERT SIT 1 becomes available. This display includes a central plot of vehicle altitude with respect to range. The plot has three background lines that represent the nominal altitude versus range profile, a dynamic pressure limit profile, and a maximum lift-over-drag profile. At 30,000 feet altitude, the scale and titles on the display change to VERT SIT 2. This second display is used through landing. When the A/L interface conditions are met, a flashing A/L is displayed on the VERT SIT 2 display.

Guidance software during TAEM generates the necessary commands to enable the vehicle to achieve the proper A/L conditions by following an energy/weight versus range profile. During TAEM, as the name implies, the goal is to manage the vehicle's energy while the orbiter travels around an imaginary arc called the heading alignment cone (HAC). An HAC is an imaginary cone that when projected on the Earth, lies tangent to the extended runway centerline. The guidance software performs the TAEM function as follows:

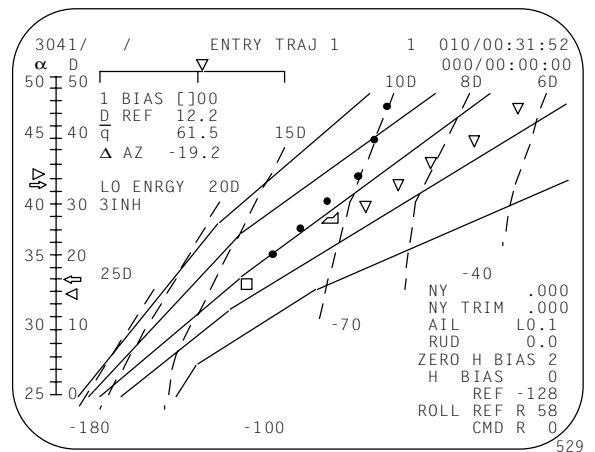
- S-Turns: If the vehicle is high on energy, it dissipates the excess by turning away from the HAC until the proper energy conditions are met.
- HAC Acquisition: Turns the vehicle toward the targeted tangent point on the HAC and flies to this point.
- Heading Alignment: Flies the vehicle around the HAC to the point at which the HAC is tangent to the runway centerline, called the nominal energy point (NEP).
- Prefinal: From the NEP, flies the vehicle down the runway centerline until the proper A/L conditions (airspeed, altitude, flight path angle, distance off centerline) are met.

Within the above steps, TAEM guidance makes the necessary adjustments to account for various energy conditions.

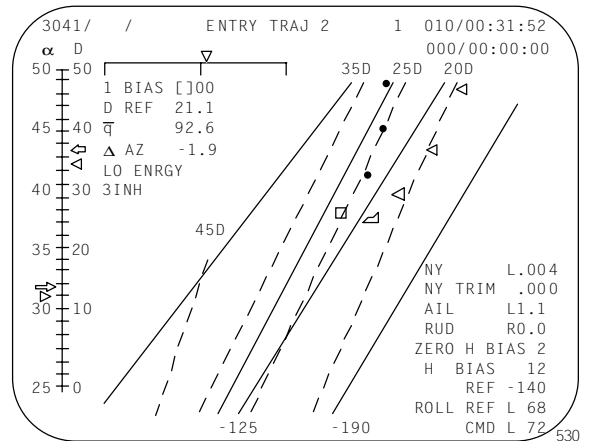
Approach/landing guidance software commences when the vehicle is about 10,000 feet altitude (at 6.0 or 6.6 n. mi. range from the runway threshold) and near the proper altitude, airspeed, and flight path angle for the outer glide slope (20° or 18°, depending on orbiter weight). The guidance software sends commands to keep the vehicle tracking the runway centerline and on the steep glide slope until approximately 2000 feet, at which point a pre-flare maneuver is performed to put the orbiter on a shallow glide slope (1.5°). Final flare is initiated between 30 and 80 feet (based on sink rate), reducing the sink rate to 3 fps for

touchdown. At this point, guidance software generates commands directing the vehicle to the runway centerline.

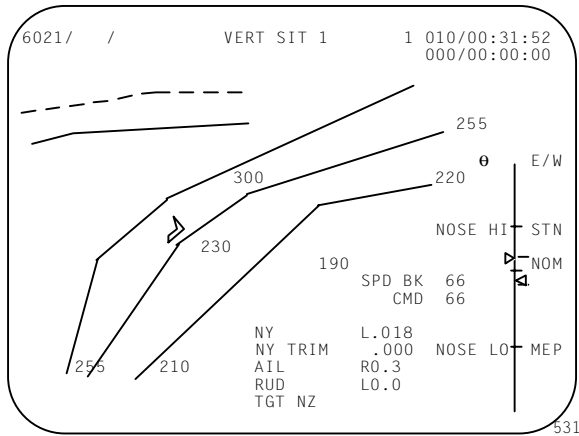
Entry flight control is accomplished using the aerojet DAP, which generates effector and RCS jet commands to control and stabilize the vehicle during its descent from orbit. During exoatmospheric flight, or flight during which certain aerosurfaces are rendered inefficient due to adverse aerodynamics, a combination of aerosurface and RCS jet commands are used. For example, at Mach > 5, the angle of attack profile flown has the vertical tail virtually blanked so that the rudder is almost useless. To compensate for this, the flight control system uses yaw jets and the yaw due to aileron movement to keep the vehicle sideslip within limits.



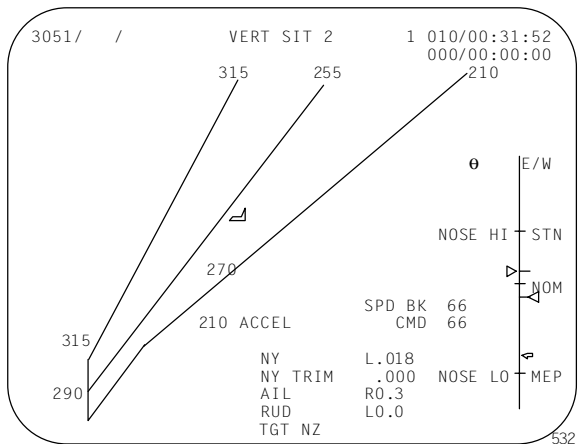
ENTRY TRAJ 1 Display



ENTRY TRAJ 2 Display



VERT SIT 1

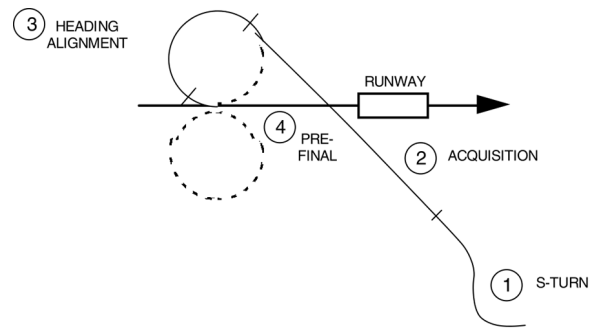


VERT SIT 2

In the entry phase, navigation software functions similarly to the deorbit phase (i.e., three-state vectors computed using the super-G algorithm corresponding to each inertial measurement unit) with the exception that additional external sensor data are sequentially incorporated. This information is used to provide the accuracy necessary to bring the orbiter to a pinpoint landing and to some extent to maintain vehicle control. The TACAN system provides slant range and magnetic bearing to various fixed stations around the landing site and becomes available at about 156,000 feet altitude until 1500 feet above ground level. The ADTA system provides pressure data to compute angle of attack, Mach number, equivalent airspeed, true airspeed, dynamic pressure, barometric altitude, and altitude rate. Only barometric altitude is used for the navigation software. The microwave landing system precisely determines slant

range, azimuth, and elevation to the ground stations located along the side of the landing runway. When landing at runways with microwave landing system ground stations, data become available at 14,000 feet for processing by navigation.

Another tool used by the navigation software is a "software sensor" called drag altitude, which uses a model of the atmosphere to correlate the drag acceleration measured by the inertial measurement units to altitude. The drag altitude data are important in keeping downrange and altitude errors bounded until TACAN data is available.

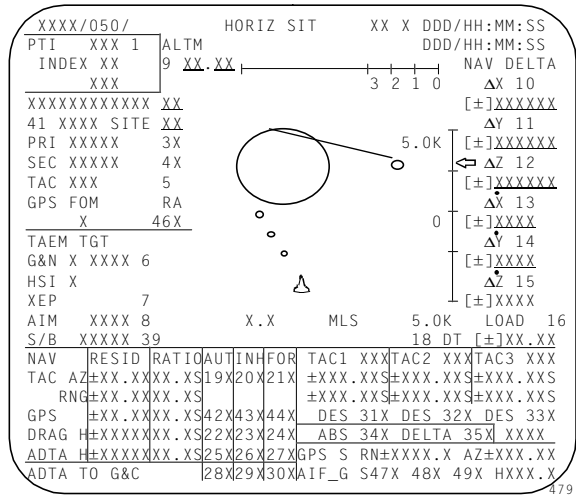


TAEM Guidance Subphases

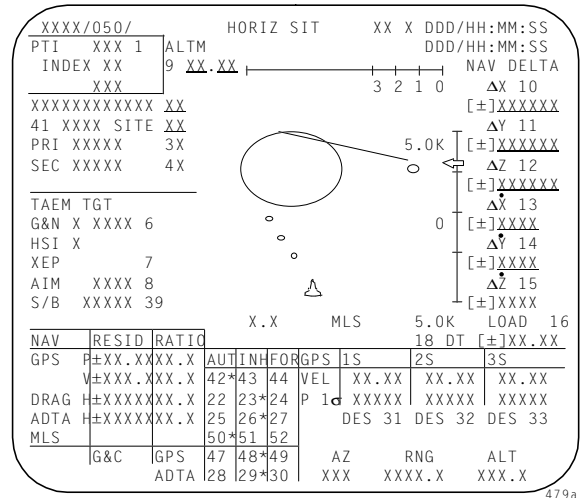
The navigation software also maintains a statistical estimate of the expected error in the state vector. When an external sensor, such as TACAN, becomes available to the navigation software, a check is made to see if the data lie within the current expected range of error. Crew controls are provided on the HORIZ SIT display to force the software to accept or inhibit the external sensor data regardless of whether they lie within this expected range. There is also a control on the display that may be selected to allow the software to use the external sensor data to update its state vector as long as the data lie within the expected range. This scheme is part of what is called Kalman filtering and is used to prevent navigation from being polluted by bad sensor data. The navigation parameters computed as a result of this filter can be seen by the crew on the dedicated displays when NAV is selected as the data source. In addition to providing insight and control over navigation parameters, the HORIZ SIT display supplies the crew with spacecraft position and heading information.

GPS-equipped vehicles will not have TACAN data to incorporate into the three-state vectors corresponding to each IMU. Similar to the other navigation sensors, GPS data are constantly checked to make sure they lie within an expected error range. Crew controls (via the HORIZ SIT display) allow the navigation software to automatically incorporate a GPS vector if the vector falls within the expected range or to force the software to accept or inhibit the data regardless of whether the

information lies within the expected range. As described in the Deorbit subsection, navigation software will select and incorporate a GPS vector every 42 seconds up to 17,000 feet and then every 9 seconds thereafter to allow for smoother updates to navigation software in the event that MLS is not available. If MLS is available, MLS will update navigation software as described above and GPS updates will automatically be inhibited by the navigation software.



**HORIZ SIT Display (SPEC 50)
(Three-String TACAN Vehicles)**



**HORIZ SIT Display (SPEC 50)
(Three-String GPS Vehicles)**

GNC Caution and Warning Summary

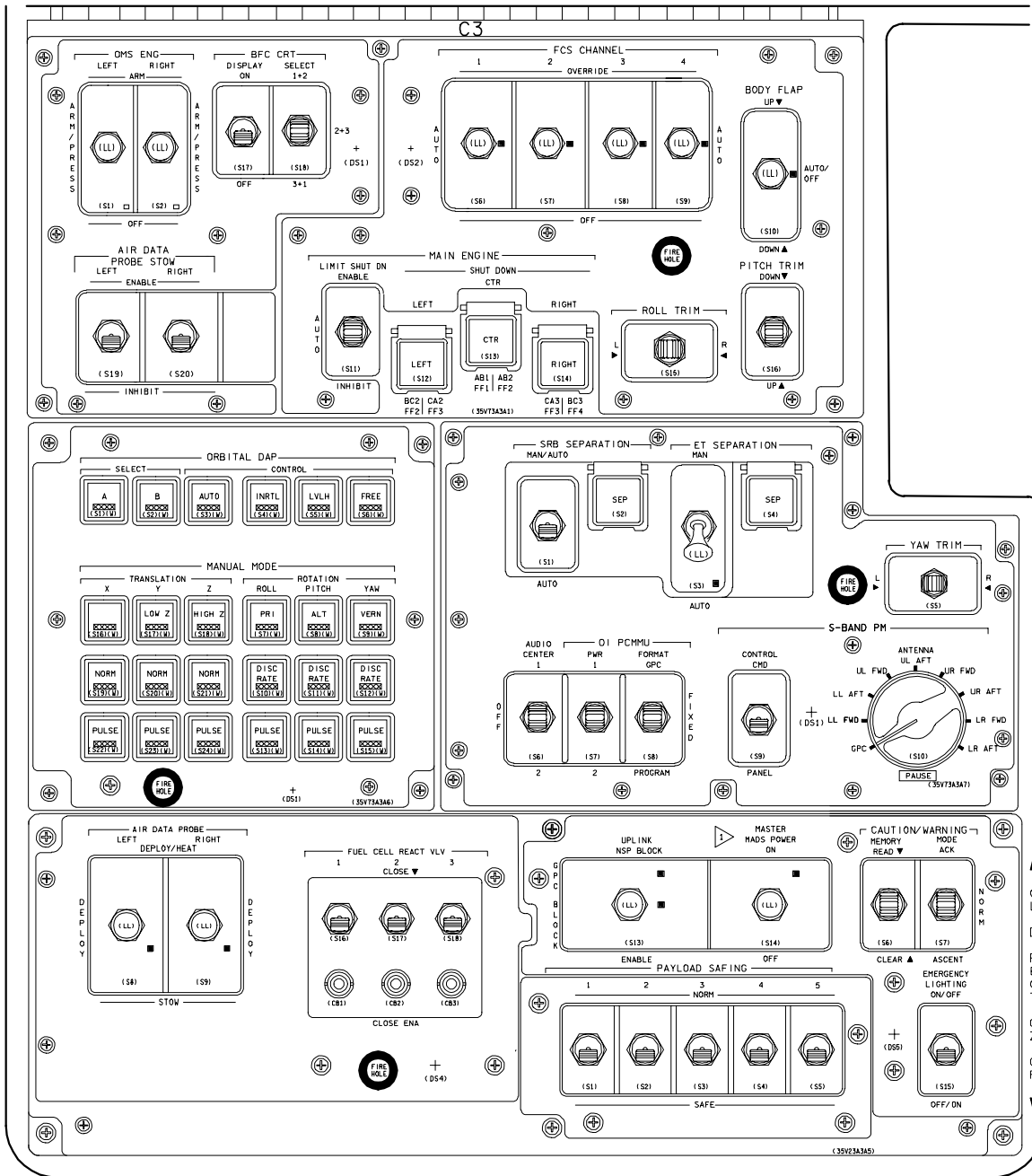
- IMU overheating or BITE-detected failures display a CRT fault message and annunciate an SM ALERT. IMU failure illuminates the IMU C/W light on panel F7.
- A TACAN, GPS, or microwave scanning beam landing system (MSBLS) fault will illuminate the SM ALERT and display a fault message.
- Fault detection in the air data system illuminates the red AIR DATA and BACKUP C/W ALARM lights on panel F7, in addition to sounding an alarm and generating a CRT fault message.
- The RGA/ACCEL light on panel F7 is not supported. RGA or AA failure will sound an alarm and generate a CRT fault message.
- A malfunction in the commander's RHC will illuminate the LEFT RHC light on panel F7; a malfunction in the pilot's RHC or the aft RHC will illuminate the RIGHT/AFT RHC light.
- If the hydraulic system pressure drops below 2,800 psi, the HYD PRESS and BACKUP C/W ALARM lights will illuminate.
- The yellow FCS CHANNEL light illuminates to indicate a failed channel; the red FCS SATURATION light is illuminated if one of the four elevons is set at more than +12° (down) or less than -15° (up).
- The OMS TVC light illuminates if the left or right OMS gimbal fails, or if software detects a TVC failure.
- The LEFT or RIGHT OMS light illuminates if the left or right OMS engine fails.

O ₂ PRESS	H ₂ PRESS	FUEL CELL REAC (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 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

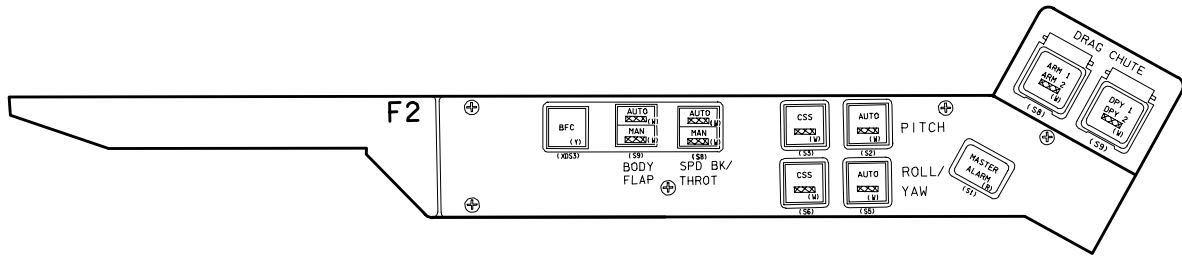
GNC Caution and Warning Lights on Panel F7

GNC Summary Data

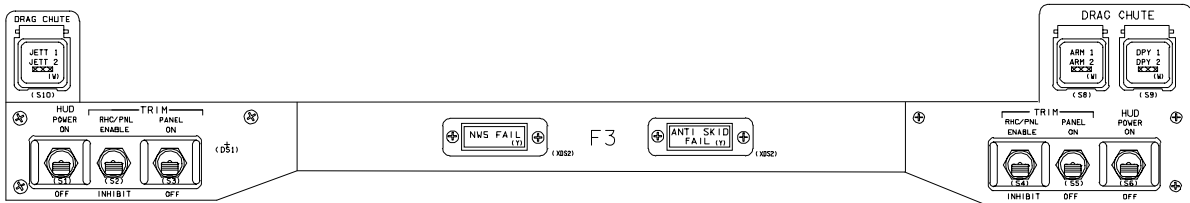
- GNC systems determine the current state of motion of the vehicle, compute actions to change its state of motion, and apply corrective maneuvers to achieve the change.
- GNC elements are navigation and flight control system hardware and digital autopilot software.
- A bad orbiter navigation state can degrade flight control, since navigation data are used to set control gains and choose control effectors.
- Navigation hardware includes: (1) IMUs, which sense vehicle orientation and accelerations; (2) star trackers, which sense vehicle line of sight vectors; (3) COAS, which allows the crew to manually determine line of sight vectors; (4) TACAN (*), which senses vehicle position with respect to a ground based station; (5) GPS (*), which senses satellite ranging signals to determine orbiter position and velocity; (6) air data system, which senses temperature and pressure; (7) MSBLS; and (8) radar altimeters.
- The flight control system hardware includes four accelerometer assemblies, four orbiter rate gyro assemblies, four SRB rate gyro assemblies, rotational and translational hand controllers, rudder pedal transducer assemblies, two speed brake/thrust controllers, two body flap switches, panel trim switches, aerosurface servoamplifiers, and ascent thrust vector control.
- DAP software interprets maneuver requests, compares them to what the vehicle is doing, and generates commands for the appropriate effectors.
- Different DAPs function during different flight phases. Transition DAP (TRANSDAP) becomes active at MECO; orbit DAP includes an RCS DAP, an OMS TVC DAP, and an attitude processor module. TRANSDAP is used again for the deorbit burn until ET-5 minutes. Aerojet DAP is used from EI-5 until wheel stop on landing.
- Primary GNC-related switches and pushbuttons are located on panels C3, A6U, F2, F3, and F4. Other switches, pushbuttons, and circuit breakers are located on the following: F6, F7, F8, O5, O6, O7, O8, O9, O14, O15, O16, O17, and L1.
- GNC-related information and crew access are provided by several displays: GNC SYS SUMM 1, IMU ALIGN, GND IMU CNTL/MON, S TRK/COAS CNTL, HORIZ SIT, MNVR, UNIV PTG, DAP CONFIG, PASS ASCENT TRAJ 1, BFS ASCENT TRAJ 2, REL NAV, ORBIT TGT, ENTRY TRAJ 1-5, VERT SIT 1, VERT SIT 2, AND GPS STATUS



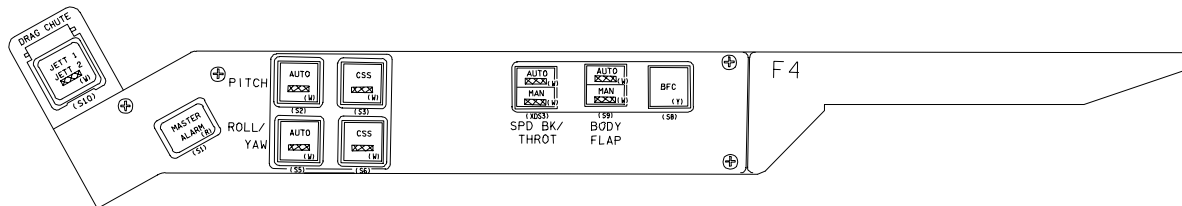
Panel C3



Panel F2



Panel F3



Panel F4

2011/ /018		GNC SYS SUMM 1		1 000/02:46:03		000/00:00:00	
RCS	JET	ISOL	SURF	POS	MOM	DPS	1 2 3 4 5
MANE	FAIL	VLV					
F1		OP	L OB			GPC	
2		OP	IB			MDM FF	
3		OP	R IB			FA	
4		OP	OB				
5		OP	AIL				
L1		OP	RUD			FCS CH 1 2 3 4	
2		OP	SPD BRK				
3		OP	BDY FLP				
4		OP					
5		OP				NAV 1 2 3 4	
R1		OP				IMU	
2		OP	CNTRLR 1 2 3			ACC	
3		OP	RHC L			RGA	
4		OP	R			TAC	
5		OP	A			MLS	
			THC L			ADTA	
			A				
			SBTC L				
			R				

GNC SYS SUMM 1 Display

9011/104/		GND IMU CNTL/MON		2 150/12:20:13		000/00:44:47	
IMU	1	2	3				
X	1	0.00	4	0.00	7	0.00	SEL IMU 1 16*
Y	2	0.00	5	0.00	8	0.00	2 17*
Z	3	0.00	6	0.00	9	0.00	3 18*
O	83.62	192.88	297.47	ATT DET	19		
M	23.65	301.81	26.65	HNGR CAL A	20		
I	99.91	42.01	351.09	B	21		
IR	0.00	0.00	0.00	C	22		
DV X	-10.72	+ 9.50	+25.73	PREFLT CAL	23		
Y	+27.14	+ 6.88	- 9.28	GYROCOMP	24		
Z	-13.24	+29.74	-16.57				
DVRSS	32.04	31.96	31.98	INERTIAL	25*		
				PLAT POS	26		
B HDW	8000	8000	8000	TERM/IDLE	27		
I S/W	00	00	00				
TSTAT	3F	3F	3F	28 MM WRITE	1		
				READ	29		
PWR ON	*	*	*	MM STATUS			
I/O							
STBY	10	11	12	30 SITE SEL	Z		
OPER	13*	14*	15*	ACTUAL	39B		

GND IMU CNTL/MON Display (SPEC 104)
(available on OPS 9 only)

3011/ /018		GNC SYS SUMM 1		1 000/02:46:03		000/00:00:00	
RCS	JET	ISOL	SURF	POS	MOM	DPS	1 2 3 4 5
MANE	FAIL	VLV					
F1		OP	L OB			GPC	
2		OP	IB			MDM FF	
3		OP	R IB			FA	
4		OP	OB				
5		OP	AIL				
L1		OP	RUD			FCS CH 1 2 3 4	
2		OP	SPD BRK				
3		OP	BDY FLP				
4		OP					
5		OP				NAV 1 2 3 4	
R1		OP				IMU	
2		OP	CNTRLR 1 2 3			ACC	
3		OP	RHC L			RGA	
4		OP	R			GPS	
5		OP	A			MLS	
			THC L			ADTA	
			A				
			SBTC L				
			R				

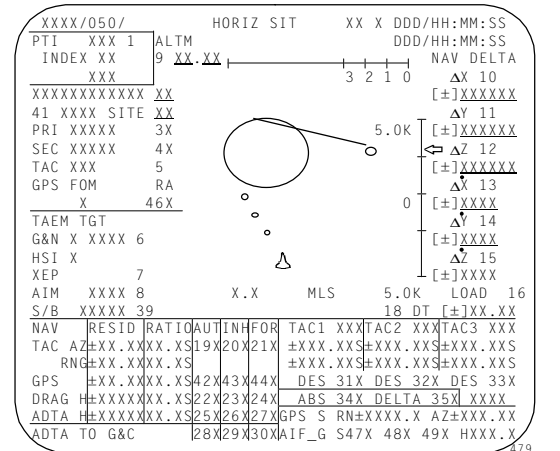
GNC SYS SUMM 1 Display
(Three-String GPS Vehicles)

3011/022/		S TRK/COAS CNTL		1 006/09:35:06		000/00:00:00	
S TRK CNTL	-Y	-Z	S TABLE	1	2	3	
SELF-TEST	1	2	TRK ID	15	43	0	
STAR TRK	3	4	Δ MIN	1	1	0	
TGT TRK	5	6	ANG DIF	84.1	0.0	0.0	
BREAK TRK	7	8	ERR	0.02	0.00	0.00	
TERM/IDLE	9*	10*	SEL	17*	18*	19	
			S TABLE CLR	20			
S TRK	-Y	-Z	COAS				
REQD ID	11	0	12	0	REQD ID	21	0
TRK ID	0	0	ΔDEG X				-0.2
S PRES			Y				+0.3
ΔANG	+0.00	+0.00	SIGHT MODE	22			
THOLD	13	0	14	0	ACCEPT	23	
SHUTTER	CL	CL	CAL MODE	24			
MAN OP	15	16	DES	25			
STATUS			POS	+X 26	-Z 27*		
			ΔBIAS	0.00	0.00		
			UPDATE	28	29		

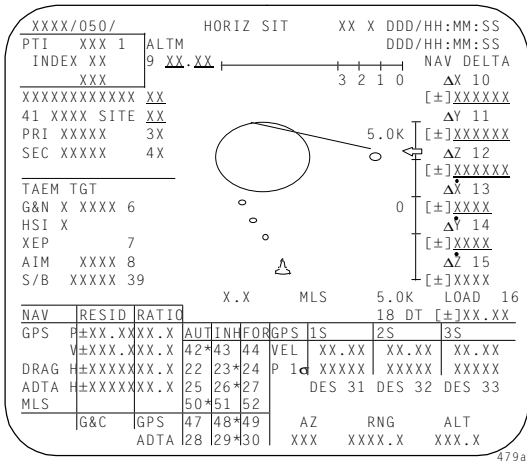
S TRK/COAS CNTL Display

3011/021/		IMU ALIGN		1 006/09:34:09		000/00:00:00	
IMU	1	2	3				
STAT				ALIGN			
TEMP	OK	OK	OK	IMU	1 10	STAR ALIGN	13*
STBY	21	22	23	2	11	14 IMU/IMU	
OPER	4*	5*	6*	3	12	MATRIX	15
DES	7	8	9				
				EXEC	16		
				TERM	17		
ACC							
X	-0.03	+0.01	-0.03	IMU BITE MASK			
Y	-0.02	-0.01	+0.03	1	0000	24	
Z	-0.01	-0.02	-0.03	2	0000	25	
				3	0000	26	
ANG							
X	299.07	299.16	299.12	NAV ΔV THRESH			
Y	339.17	339.09	339.14	18	3840		
Z	160.65	160.72	160.64	MM READ	19		
ΔX	+0.00	+0.00	+0.00				
ΔY	+0.00	+0.00	+0.00				
ΔZ	+0.00	+0.00	+0.00				

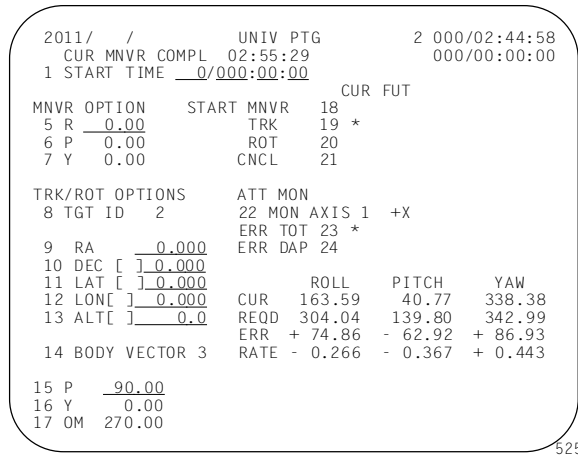
IMU ALIGN Display (SPEC 21)



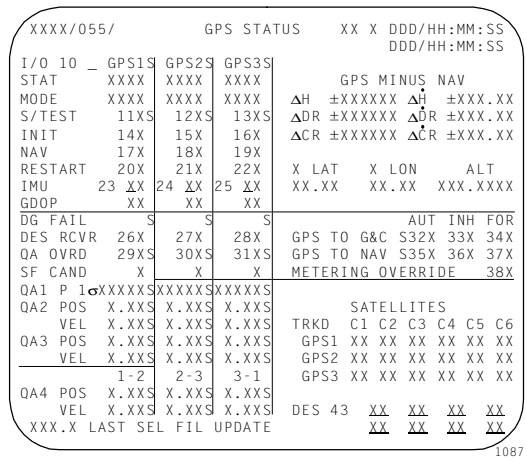
HORIZ SIT Display (SPEC 50)
(Three-String TACAN Vehicles)



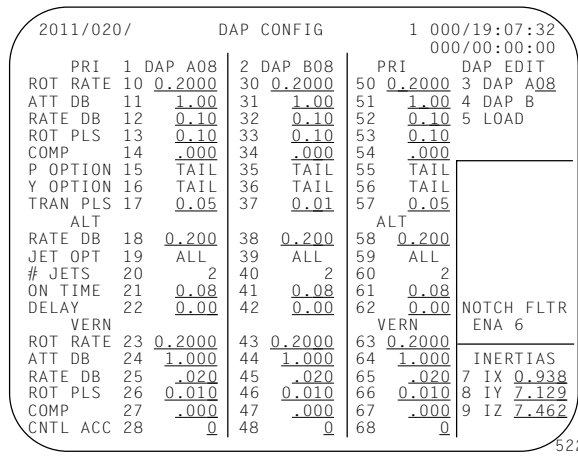
HORIZ SIT Display (SPEC 50)
(Three-string GPS Vehicles)



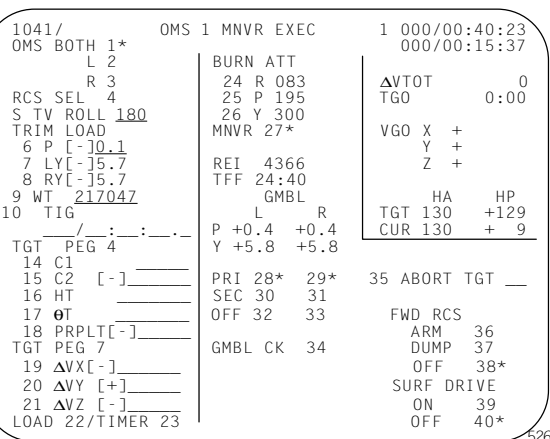
UNIV PTG Display



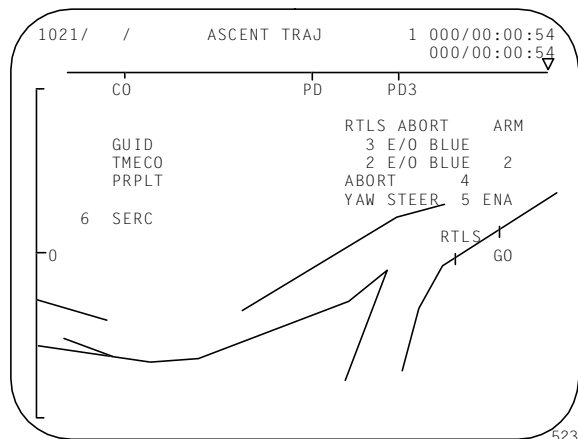
GPS STATUS Display (SPEC 55)



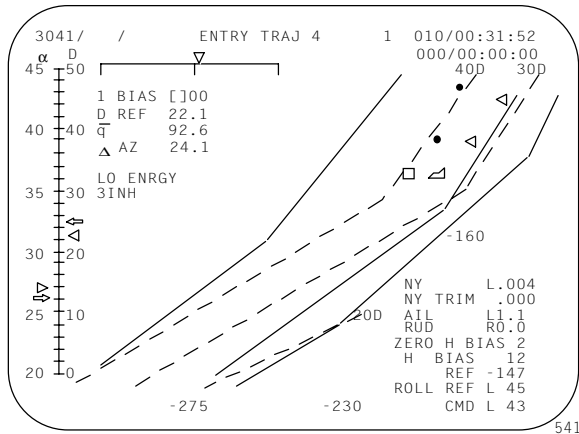
DAP CONFIG Display



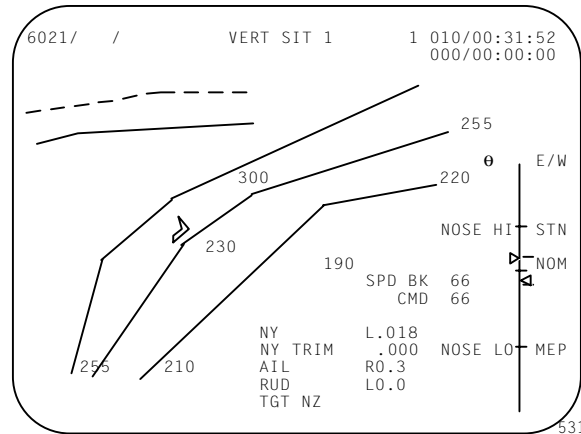
MNVR Display



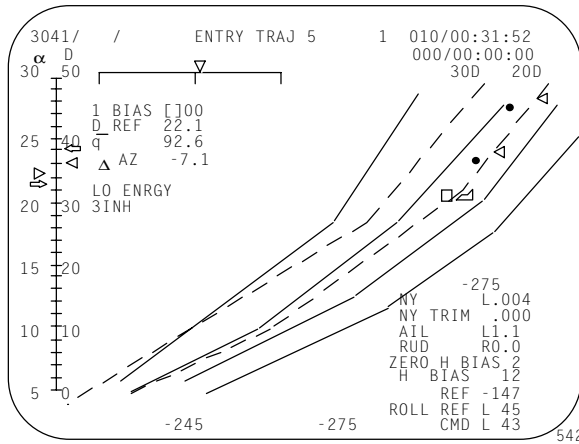
PASS ASCENT TRAJ Display



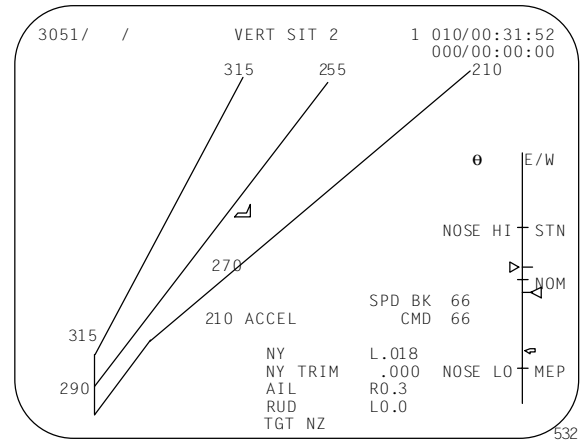
ENTRY TRAJ 4 Display



VERT SIT 1 Display



ENTRY TRAJ 5 Display



VERT SIT 2 Display

GNC Rules of Thumb

- The PASS FDIR for the RGAs, AAs, and aerosurfaces terminates after the first failure. After the first failure, crew management of the selection filter is required. However, PASS has an RGA SMRD FDIR that will continue to deselect any power failed RGAs. For the BFS selection filter, crew management is always required. Proper selection filter management is required for proper control.
- For FCS channel management:
 - Never have more active channels on one GPC than another.
 - If there are two failures on the same actuator, take the remaining FCS channels to OVERRIDE.
 - Always maintain two good commands and one good feedback on each aerosurface.
 - Delay 2 seconds between switch throws when moving FCS CHANNEL switches to OVERRIDE.
- Port bypass, or port pop, is a mechanical means to avoid force fights; feedback deselection is a software means to avoid a bad input into the selection filter.
- For ascent, only the pilot's SBTC is active. To get manual throttles, the pilot must depress the TAKEOVER button and then match the commanded throttle setting. Manual rotational control is available only in PASS and must be both pitch and roll/yaw.
- For entry, both SBTCs are active. To get manual speed brake, the CDR or pilot must depress the TAKEOVER button. Manual rotational control is available in either pitch or bank in PASS and is required in both axes in BFS.
- For TACAN and ADTA management, talk to MCC before incorporating.
- Without communication, the crew will use the NO-COMM TACAN MGMT and ADTA MGMT cue cards.

2.14 LANDING/DECELERATION SYSTEM

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Landing/Deceleration System	
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Description

The orbiter, unlike previous space vehicles, has the capability of landing on a runway using a conventional type of landing system. Once the orbiter touches down, the crew deploys the drag chute, begins braking, and starts nose wheel steering operations.

The orbiter drag chute, first used on the maiden flight of OV-105, improves the orbiter's deceleration and eases the loads on the landing gear and brakes.

Braking is accomplished by a sophisticated system that uses electrohydraulic disk brakes with an anti-skid system. Only the two main gear sets have braking capability, and each can be operated separately.

Two primary steering options are available. By applying variable pressure to the brakes, the crew can steer the vehicle by a method called differential braking. Also, by selecting nose wheel steering, the crew can use the rudder pedal assembly to operate a hydraulic steering actuator incorporated in the nose landing gear. The crew can also use the rudder to assist steering while at higher ground speeds.

Landing Gear

The landing gear system on the orbiter is a conventional aircraft tricycle configuration consisting of a nose landing gear and a left and right main landing gear. The nose landing gear is located in the lower forward fuselage, and the main landing gear is located in the lower left and right wing area adjacent to the midfuselage.

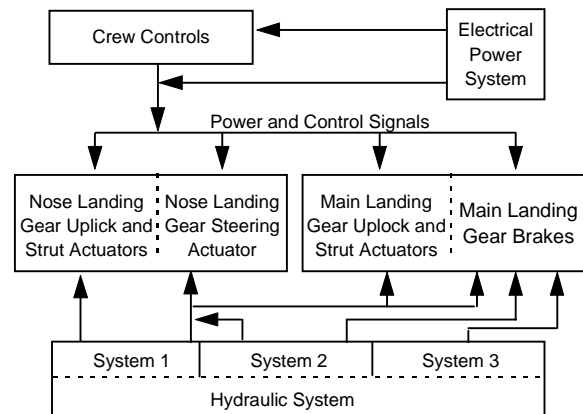
Each landing gear includes a shock strut with two wheel and tire assemblies. Each main landing gear wheel is equipped with a brake assembly with anti-skid protection.

Landing Gear Doors

The nose landing gear has two doors, and each main gear has one door. When the crew commands gear deployment, the doors open automatically as the gear is dropped. This is accomplished by the door extend/retract mechanism, which is actuated by the dropping gear. The nose landing gear doors have two door hooks that hold the doors closed, and the main gear doors have four door hooks.

In addition, the doors have door-assist bungee assemblies. These assemblies exert additional force on the inside of the doors to assist in door deployment to overcome the aerodynamic forces acting against the doors and/or in case the pressure inside the wheel wells is less than the outside pressure. The nose landing gear bungee assist assemblies exert 2,000 pounds of force on the doors; the main landing gear bungee assist assemblies exert approximately 5,000 pounds of force on the doors over the first 2 inches of travel.

The nose landing gear also contains a pyro boost system to further assure nose gear door and gear extension in case high aerodynamic forces on the nose gear door are present. This pyro system is fired each time the landing gear is deployed.



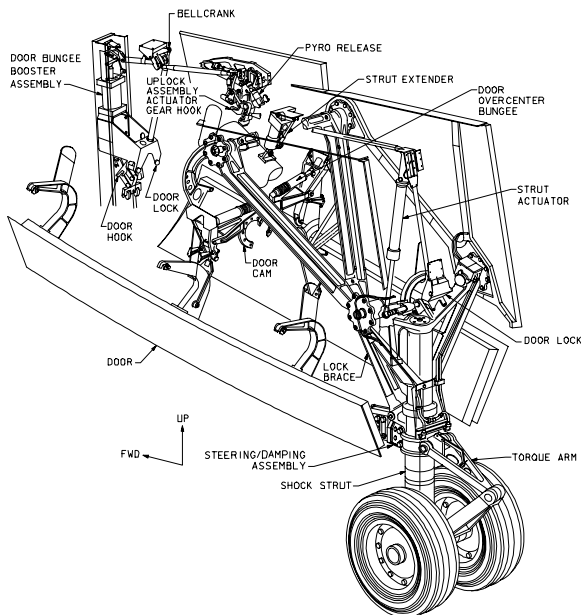
Landing/Deceleration Interfaces

Each of the landing gear doors has high-temperature reusable surface insulation tiles on the outer surface and a thermal barrier or door seal to protect the landing gear from the high temperatures encountered during reentry.

Gear Retraction

During retraction, each gear is hydraulically rotated forward and up by ground support equipment until it engages an uplock hook for each gear in its respective wheel well. The uplock hook locks onto a roller on each strut. A mechanical linkage driven by each landing gear mechanically closes each landing gear door.

The nose landing gear is retracted forward and up into the lower forward fuselage and is enclosed by two doors. The main landing gear is also retracted forward and up into the left and right lower wing area, and each is enclosed with a single door. The nose and main landing gear can be retracted only during ground operations.



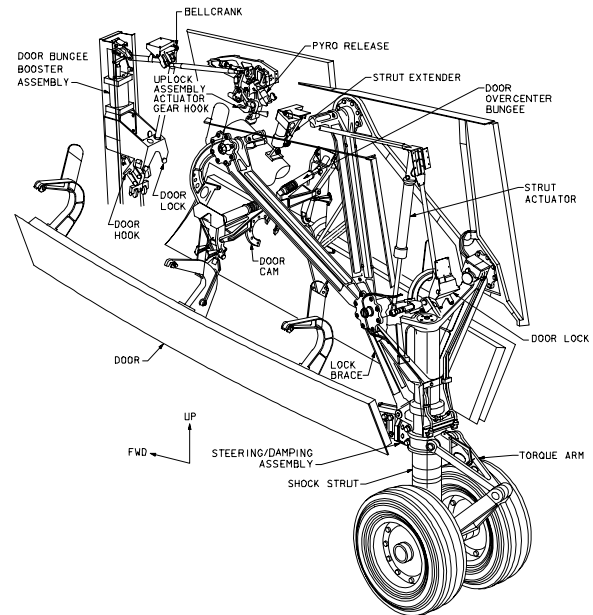
Nose Gear and Door Uplock Mechanism

Gear Deployment

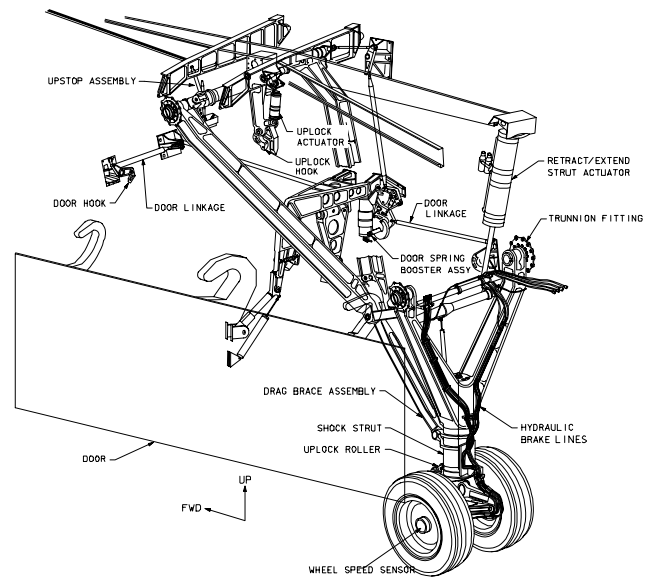
When deployment of the landing gear is commanded by the crew, the uplock hook for each gear is unlocked by hydraulic system 1 pressure. (See Section 2.1 for more information on orbiter hydraulic systems.) Once the hook is released from the roller on the strut, the gear is driven down and aft by springs, hydraulic actuators, aerodynamic forces, and gravity. A mechanical linkage released by each gear actuates the doors to the open position. The landing gear reach the full-down and extended position within 10 seconds and are locked in the

down position by spring-loaded downlock bungees. If hydraulic system 1 pressure is not available to release the uplock hook, a pyrotechnic initiator at each landing gear uplock hook automatically releases the uplock hook on each gear 1 second after the flight crew has commanded gear down.

The landing gear are deployed at 300 ± 100 feet and a maximum of 312 knots equivalent air-speed (KEAS).



Nose Landing Gear Deployed



Main Landing Gear Deployed

Shock Struts

The shock strut of each landing gear is the primary source of impact attenuation at landing. The struts have air/oil shock absorbers to control the rate of compression/extension and prevent damage to the vehicle by controlling load application rates and peak values.

Each landing gear shock strut assembly is constructed of high-strength, stress- and corrosion-resistant steel alloys, aluminum alloys, stainless steel, and aluminum bronze. The shock strut is a pneumatic-hydraulic shock absorber containing gaseous nitrogen and hydraulic fluid. Because the shock strut is subjected to zero-g conditions during space flight, a floating piston separates the gaseous nitrogen from the hydraulic fluid to maintain absorption integrity.

The nose landing gear shock strut has a 22-inch stroke. The maximum allowable derotation rate is approximately 9.4° per second or 11 feet per second, vertical sink rate.

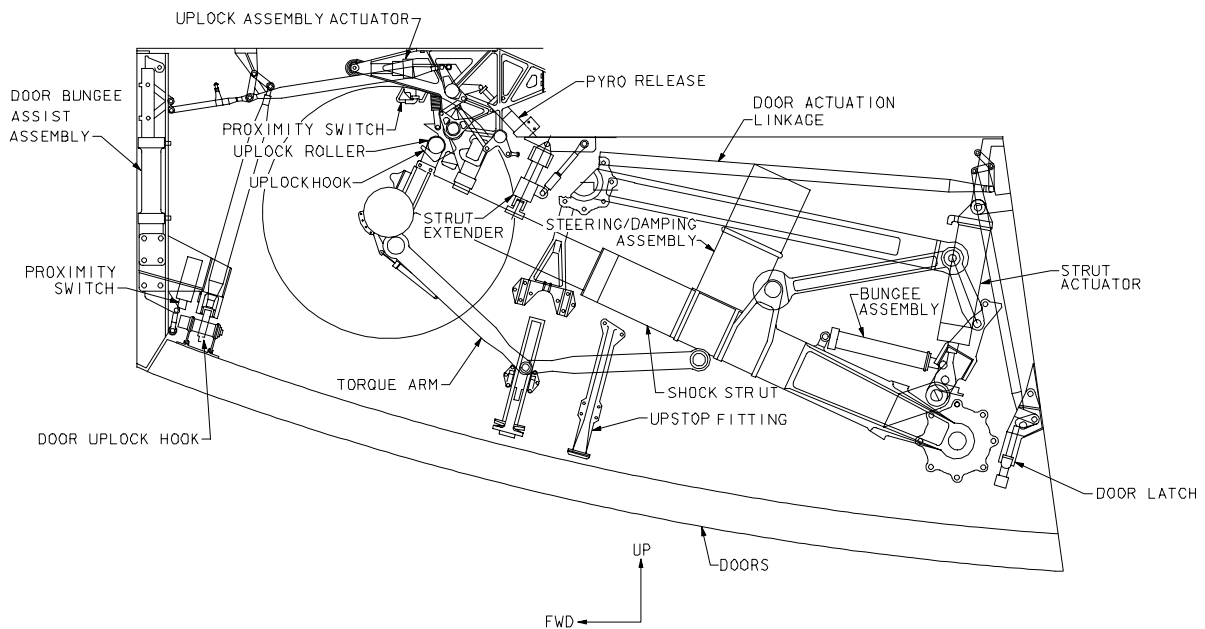
The main landing gear shock strut stroke is 16 inches. The allowable main gear sink rate for a 212,000-pound orbiter is 9.6 feet per second; for a 240,000-pound orbiter, it is 6 feet per second.

With a 20-knot crosswind, the maximum allowable gear sink rate for a 212,000-pound orbiter is 6 feet per second; for a 240,000-pound orbiter, it is approximately 5 feet per second. (Current maximum operational crosswind is limited to 15 knots.)

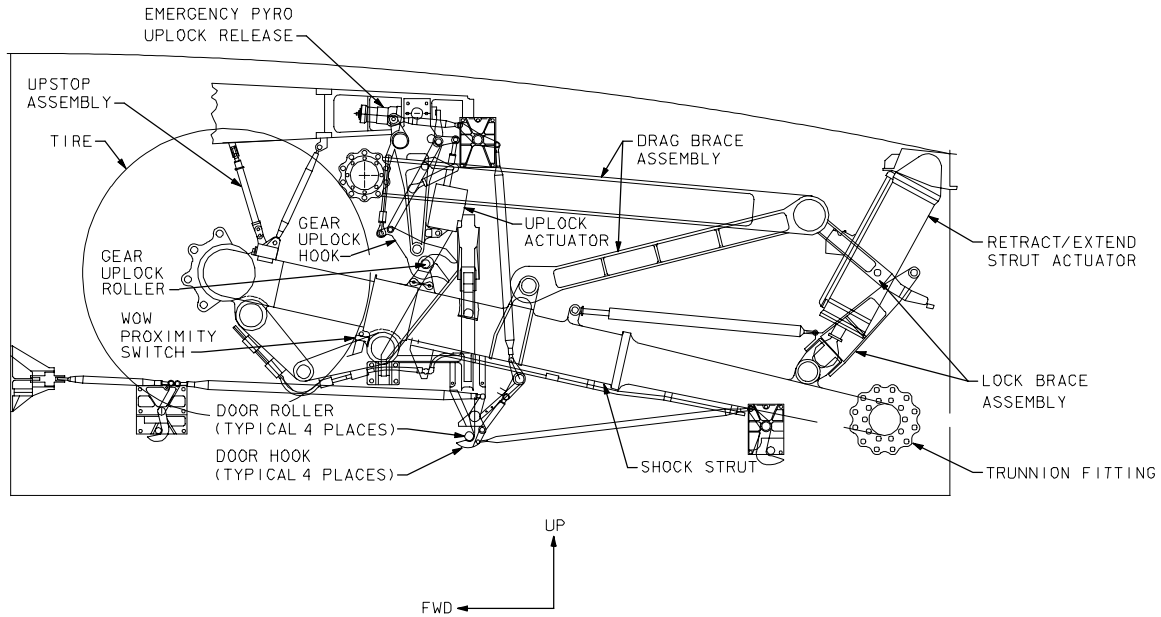
Wheels and Tires

Landing gear wheels are made in two halves from forged aluminum. The nose landing gear tires are 32 by 8.8 inches and have a normal nitrogen inflation pressure of 350 psi prior to launch. The maximum allowable load per nose landing gear tire is approximately 45,000 pounds. Nose landing gear tires are rated for 217 knots maximum landing speed. They may be reused once.

The main landing gear tires are 44.5 by 21 inches and have 16 cord layers in a bias-ply design. They are normally inflated with nitrogen to a pressure of 370 psi. The maximum allowable load per main landing gear tire is 132,000 pounds. With a 60/40 percent tire load distribution, the maximum tire load on a strut is 220,000 pounds. The main gear tires are rated at 225 knots maximum ground speed and have a life of one landing.



Nose Landing Gear Stowed

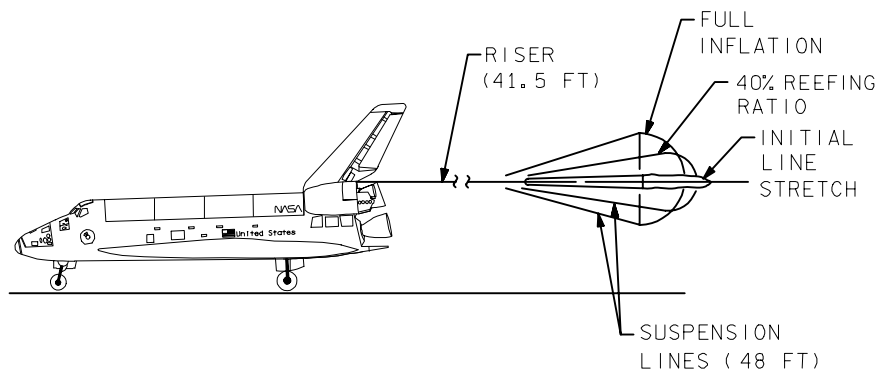


Main Landing Gear Stowed

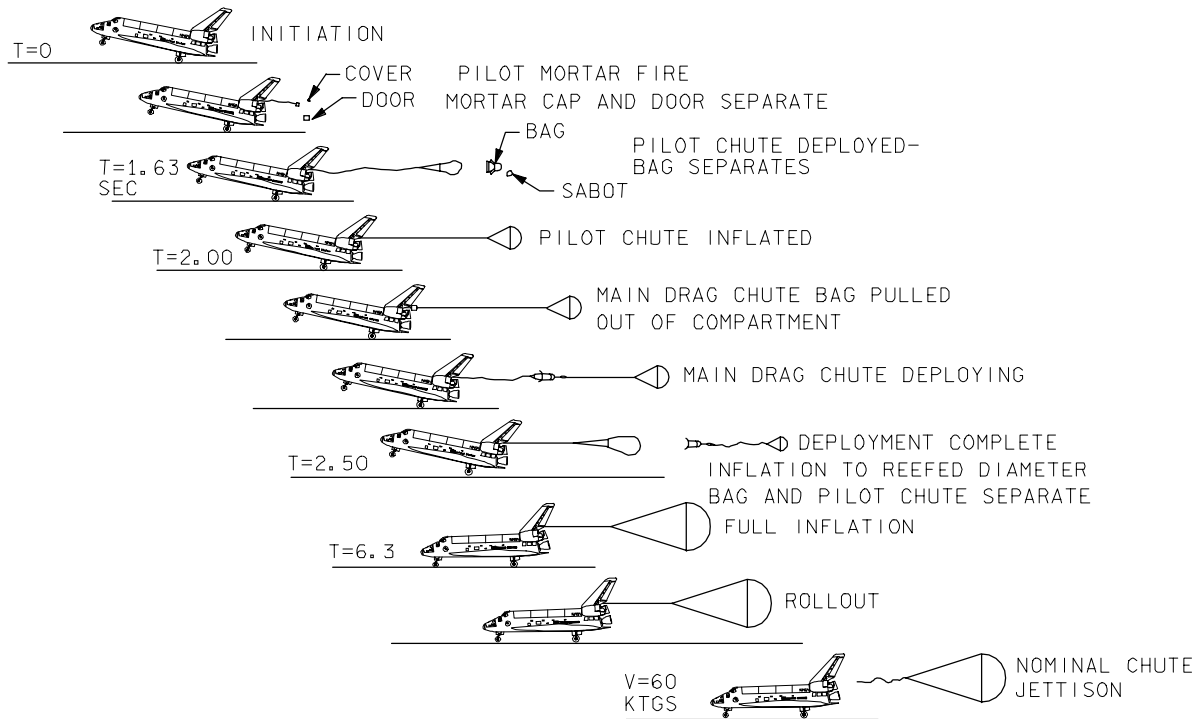
Drag Chute

The orbiter drag chute was designed to assist the deceleration system in safely stopping the vehicle on the runway at end of mission (EOM) and abort weights. Design requirements included the ability to stop a 248,000 lb TAL abort orbiter in 8,000 feet with a 10 knot tailwind on a hot (103° F) day and maximum braking at 140 knots ground speed or one half runway remaining. The drag chute, housed at the base of the vertical stabilizer, is manually deployed by redundant commands from the

CDR or PLT at derotation. Drag chute deployment may be done between main gear touchdown and derotation only for vehicle mass moments 1.53 million foot pounds. The drag chute is jettisoned at 60 (± 20) knots ground speed to prevent damage to the main engine bells. The drag chute will be used on lake bed and concrete runways except with crosswinds greater than 15 knots or in the presence of main engine bell repositioning problems. The drag chute may be deployed without engine bell repositioning if landing/rollout control problems exist.



Drag Chute Configuration



Nominal Sequence of Drag Chute Deployment, Inflation, and Jettison

Pilot and Main Chutes

When drag chute deployment is initiated, the door is blown off of the chute compartment by pyros and a mortar fires deploying a nine foot pilot chute. The pilot chute in turn extracts the 40 foot, partially reefed conical main chute. The main chute is reefed to 40 percent of its total diameter for about 3.5 seconds to lessen the initial loads on the vehicle. The main chute trails the vehicle by 89.5 feet on a 41.5 foot riser.

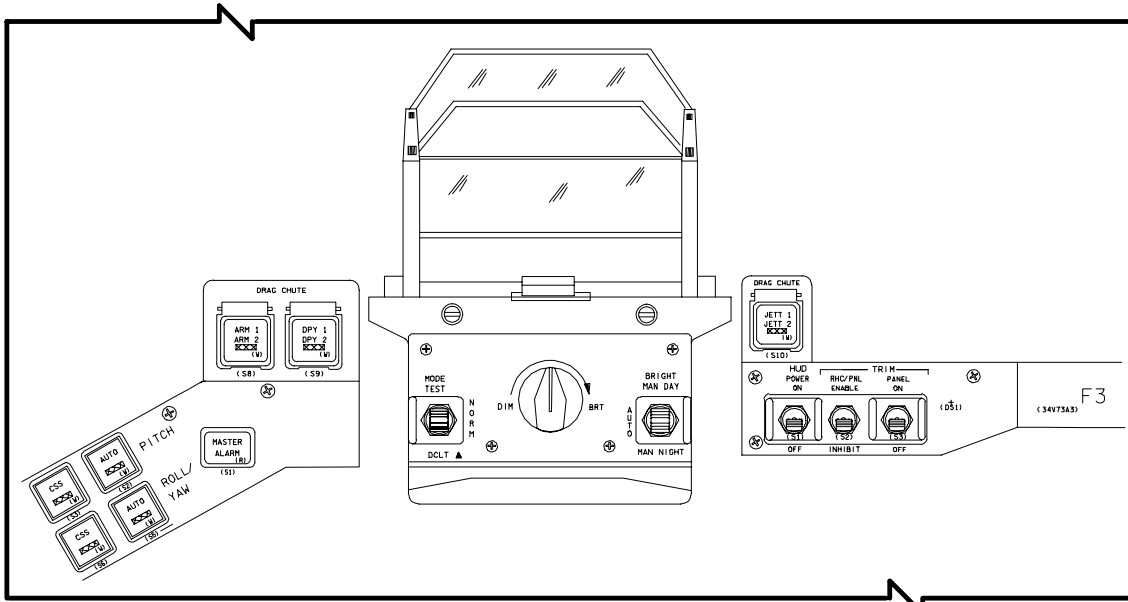
Drag Chute Controls

The drag chute deployment and jettison pushbuttons, ARM 1(2), DPY 1(2), and JETT 1(2) are installed on either side of both the CDR's and PLT's HUDs. Activation of each lighted pushbutton initiates a signal through the primary and redundant paths simultaneously. The deployment sequence requires that both the ARM and DPY pushbuttons be activated together. The JETT pushbutton signal will only be effective if the ARM command has previously been initiated. (ARM and JETT may be initiated simultaneously.) Circuit breakers for the drag chute controls are located on panels O15 and O16.

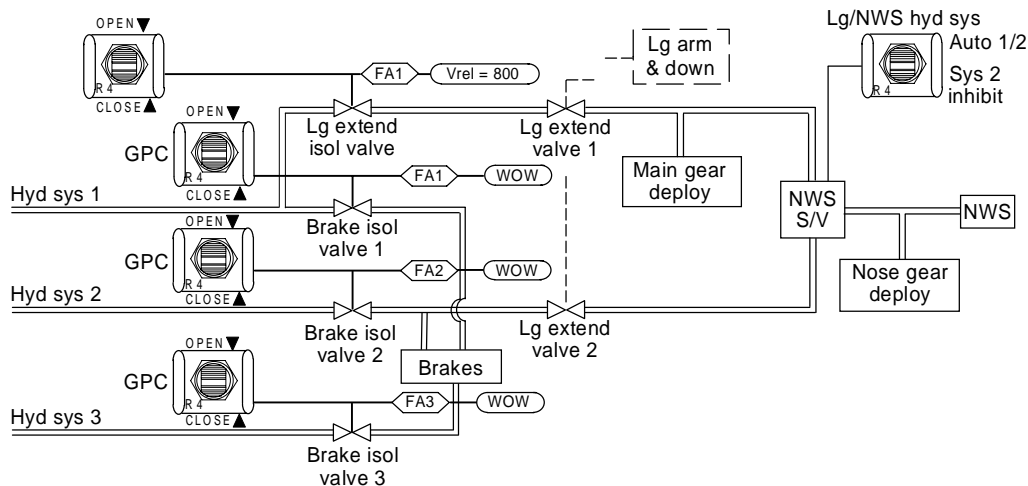
Main Landing Gear Brakes

Each of the orbiter's four main landing gear wheels has electrohydraulic disc brakes and an associated anti-skid system. The disc brake assembly consists of nine discs, five rotors, four stators, a backplate, and a pressure plate. The carbon-lined rotors are splined to the inside of the wheel and rotate with the wheel. The carbon-lined stators are splined to the outside of the axle assembly and do not rotate with the wheel.

The brakes are controlled by the commander or pilot applying toe pressure to the upper portion of the rudder pedals; electrical signals produced by rudder pedal toe pressure control hydraulic servovalves at each wheel and allow hydraulic system pressure to actuate braking. Brakes cannot be applied until about 1.9 seconds after weight on the main gear has been sensed. The anti-skid system monitors wheel velocity and controls brake pressure to prevent wheel lock and tire skidding. The braking/anti-skid system is redundant in that it utilizes system 1 and 2 hydraulic pressure as the active system with system 3 as standby, and it also utilizes all three main dc electrical systems.



Panels F2, F3



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Landing Gear Hydraulics

Brake System Hydraulic Power

Each of the four main landing gear wheel brake assemblies is supplied with pressure from two different hydraulic systems. Each brake hydraulic piston housing has two separate brake supply chambers. One chamber receives hydraulic source pressure from hydraulic system 1 and the other from hydraulic system 2. There are eight hydraulic pistons in each brake assembly. Four are manifolded together from hydraulic system 1 in a brake chamber. The remaining four pistons are manifolded together from hydraulic system 2. When the brakes are

applied, the eight hydraulic pistons press the discs together, providing brake torque.

When hydraulic system 1 or 2 source pressure drops below approximately 1,000 psi, switching valves provide automatic switching to hydraulic system 3. Loss of hydraulic system 1, 2, or both would have no effect on braking capability, because standby system 3 would automatically replace either system. Loss of hydraulic system 3 and either 1 or 2 would cause the loss of half of the braking power on each wheel, and additional braking distance would be required.

The brake valves in hydraulic systems 1, 2, and 3 must be open to allow hydraulic pressure to the brakes. All three valves are automatically commanded open after weight on the main landing gear is sensed. The 3,000 psi hydraulic pressure is reduced by a regulator in each of the brake hydraulic systems to 2,000 psig.

Anti-Skid

The anti-skid portion of the brake system provides optimum braking by preventing tire skid or wheel lock and subsequent tire damage.

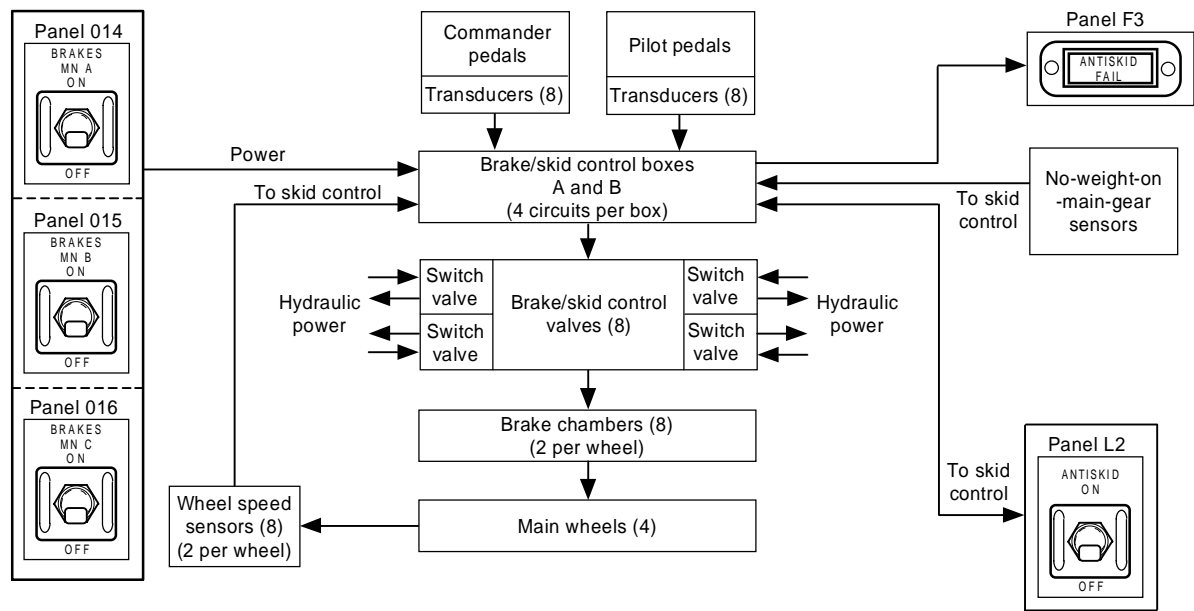
Each main landing gear wheel has two speed sensors that supply wheel rotational velocity information to the skid control circuits in the brake/skid control boxes. The velocity of each wheel is continuously compared to the average wheel velocity of all four wheels. Whenever the wheel velocity of one wheel is 60 percent below the average velocity of the four wheels, skid control removes brake pressure from the slow wheel until the velocity of that wheel increases to an acceptable range.

The brake system contains eight brake/skid control valves. Each valve controls the

hydraulic brake pressure to one of the brake chambers. The brake/skid control valves contain a brake coil and a skid coil. The brake coil allows hydraulic pressure to enter the brake chambers. The skid coil, when energized by the skid control circuit, provides reverse polarity to the brake coil, preventing the brake coil from allowing brake pressure to the brake chamber.

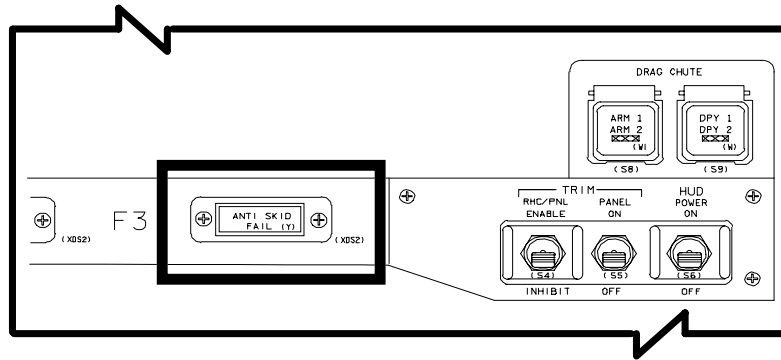
Anti-skid control is automatically disabled below approximately 10 to 15 knots to prevent loss of braking for maneuvering and/or coming to a complete stop.

The anti-skid system control circuits contain fault detection logic. The yellow ANTI SKID FAIL caution and warning light on panel F3 will be illuminated if the anti-skid fault detection circuit detects an open circuit or short in a wheel speed sensor or control valve servocoil, or a failure in an anti-skid control circuit. A failure of these items will only deactivate the failed circuit, not total anti-skid control. If the BRAKES switches on panels O14, O15, and O16 are ON, and the ANTISKID switch on panel L2 is OFF, the ANTISKID FAIL caution and warning light will also be illuminated.

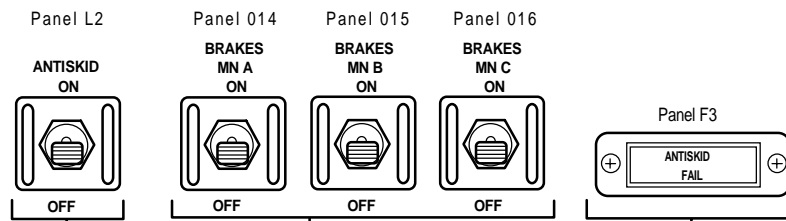


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Brake/Skid Control System Overview



ANTI SKID FAIL Caution and Warning Light on Panel F3



Anti-skid Switch		Brake Power Switch		Anti-skid Failure*		Anti-skid** Fail Light	
ON	OFF	ON	OFF	YES	NO	ON	OFF
			●				●
	●	●				●	
●		●			●	●	●
●		●		●		●	

* Anti-skid fault detection circuits detect any of the following failures:
 - Open or short in a wheel speed sensor circuit
 - Open or short in a skid control servovalve circuit
 - Failure in an anti-skid control circuit

** Applies only if brake power switches MN B, MN C or both are activated.

Note: A failure will deactivate only the failed circuit and not total anti-skid control.

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Anti-Skid Fail Light Status

Temperature Control

Insulation and electrical heaters are installed on the portions of the hydraulic systems that are not adequately thermally conditioned by the individual hydraulic circulation pump system because of stagnant hydraulic fluid areas.

Redundant electrical heaters are installed on the main landing hydraulic flexible lines located on the back side of each main landing gear strut between the brake module and brakes. These

heaters are required because the hydraulic fluid systems are dead-ended, and fluid cannot be circulated with the circulation pumps. In addition, on OV-103, OV-104, and -105, the hydraulic system 1 lines to the nose landing gear are located in a tunnel between the crew compartment and forward fuselage. The passive thermal control systems on OV-103, OV-104, and OV-105 are attached to the crew compartment, which leaves the hydraulic system 1 lines to the nose landing gear exposed to environmental temperatures, thus requiring electrical heaters on

the lines in the tunnel. Since the passive thermal control system on OV-102 is attached to the inner portion of the forward fuselage rather than the crew compartment, no heaters are required on the hydraulic system 1 lines to the nose landing gear on OV-102.

The *HYDRAULICS BRAKE HEATER* A, B, and C switches on panel R4 enable the heater circuits. On OV-103, OV-104 and -105, *HYDRAULICS BRAKE HEATER* switches A, B, and C provide electrical power from the corresponding main buses A, B, and C to the redundant heaters on the main landing gear flexible lines and the hydraulic system 1 lines in the tunnel between the crew compartment and forward fuselage leading to the nose landing gear.

The *HYDRAULICS BRAKE HEATER* A, B, and C switches on panel R4 enable the heater circuits on only the main landing gear hydraulic flexible lines on OV-102.

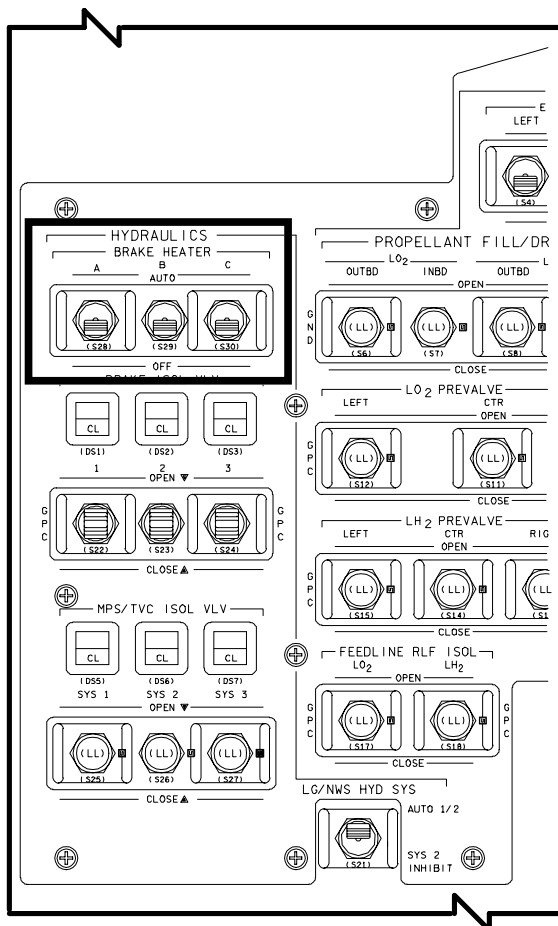
Nose Wheel Steering

The nose landing gear contains a hydraulic steering actuator that responds to electronic commands from the commander's or pilot's rudder pedals. Two types of operation are available, GPC and caster. The GPC mode is supported by hydraulic systems 1 and 2 through the selection of nose wheel steering (NWS) system 1 or 2 (*NWS 1(2)*). This provides redundant avionics modes regardless of hydraulic system support. *NWS 1* or *2* will work with either hydraulic system 1 or 2.

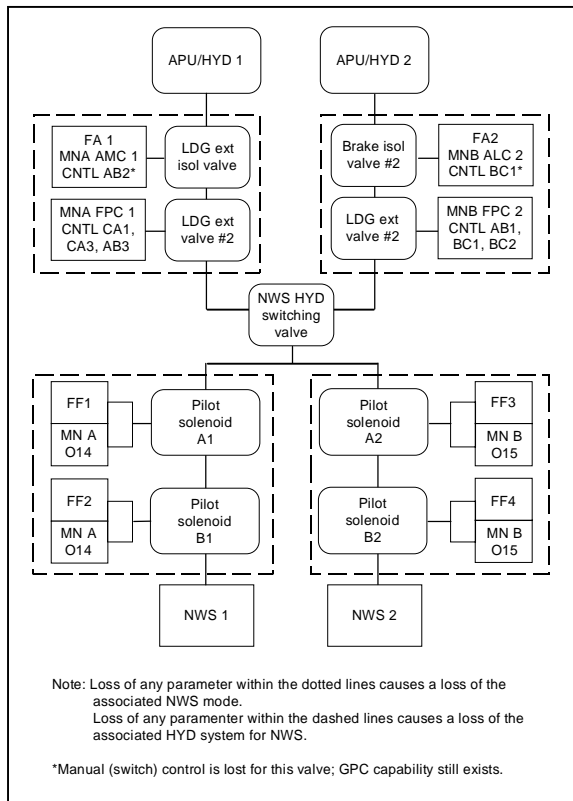
In the GPC modes (*NWS 1(2)*), the flight control software uses accelerometer assembly feedback to modify commands from the rudder pedal transducer assemblies (RPTAs) to automatically counter hardovers or large lateral accelerations due to gear or tire malfunctions. If GPC 1 or 2, or FF1 or 2 is inoperative, steering downmodes to caster if *NWS 1* is selected. Similarly, the loss of GPC 3 or 4, or FF3 or 4 will prevent the use of *NWS 2* and cause a downmode. The loss of either *NWS* system will only cause a downmode to castor. The other *NWS* system must be selected if required. In caster, no positive control over the nose wheel position is available, and differential braking and rudder are used for directional control.

A hydraulic servoactuator mounted on the nose strut permits orbiter nose wheel steering up to 9° left or right after system activation. Hydraulic systems 1 and 2 provide redundant hydraulic pressure to either *NWS 1* or *2*. If the pressure in one system is more than twice that in the other, the higher pressure system provides hydraulic power for *NWS*. If *NWS* is not activated, or if hydraulic systems 1 and 2 fail, the *NWS* actuator acts as a nose wheel shimmy damper in the caster mode.

NWS can only be enabled after certain preconditions are met. Among these preconditions are two major milestones: weight-on-wheels (WOW) and weight-on-nose-gear (WONG). There are three sensors on each main gear designed to sense when main gear touchdown (MGTD) occurs so that WOW can be set. One sensor is a proximity sensor and the other two are wheel speed sensors (one per tire). Once WOW is set, the speed brake is commanded full open, flat turn discrete is set, half gain RHC is enabled, and the HUD format downmodes. After WOW is set on one strut, brakes are also enabled.



HYDRAULICS BRAKE HEATER Switches on Panel R4



OI-21 NWS Functional Drawing

WONG can be set by either of two proximity sensors located on the nose gear. Once WONG is set (presupposing WOW is already set and the vehicle attitude (theta) is less than zero), the ground speed enable "flag" is set. This enables NWS and the I-loaded downward deflection of the elevons for tire load relief. As a backup to the WOW and WONG discrettes, the crew nominally selects

MANUAL ET or SRB SEP and presses the associated pushbutton. This will manually bypass the WOW/WONG discrettes and set the ground speed enable "flag."

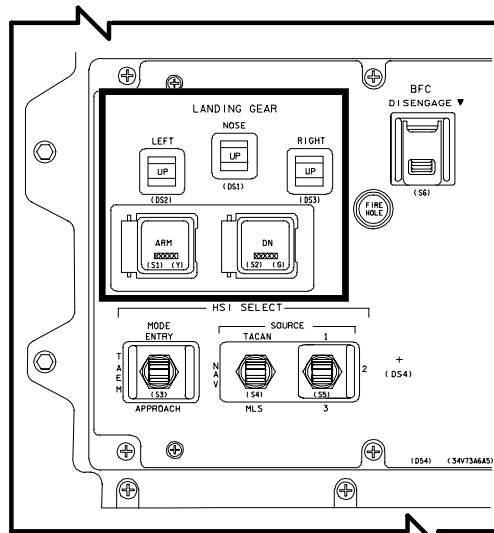
Operations

Landing Gear

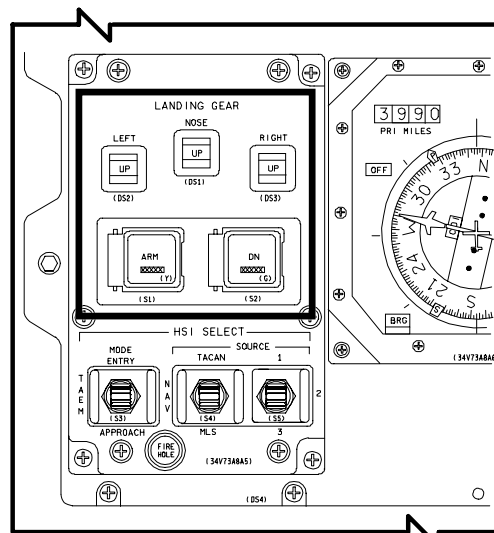
Landing gear deployment is initiated when the commander (on panel F6) or pilot (on panel F8) depresses the guarded *LANDING GEAR ARM* pushbutton and then the guarded *DN* pushbutton at least 15 seconds before predicted touchdown at a speed no greater than 312 KEAS at 300 ±100 feet above ground level (AGL).

NOTE

Deploying the landing gear at equivalent airspeeds greater than 312 knots may result in high aerodynamic loads on the doors and interference with the normal opening sequence.



Commander's LANDING GEAR Controls on Panel F6



Pilot's LANDING GEAR Controls on Panel F8

Depressing the ARM pushbutton energizes latching relays for the landing gear extend valves 1 and 2 in preparation for gear deploy. It also arms the nose and main landing gear pyrotechnic initiator controllers and illuminates the yellow light in the ARM pushbutton. This is normally performed by the pilot at approximately 2,000 feet AGL.

The DN pushbutton is then depressed. This energizes latching relays that open the hydraulic system 1 extend valve 1 and hydraulic system 2 landing gear extend valve 2. Fluid in hydraulic system 1 flows to the landing gear uplock and strut actuators and the nose wheel steering switching valve. The green light in the DN pushbutton indicator is illuminated.

The proximity switches on the nose and main landing gear doors and struts provide electrical signals to control the *LANDING GEAR NOSE*, *LEFT*, and *RIGHT* indicators on panels F6 and F8. The output signals of the landing gear and door uplock switches drive the landing gear *UP* position indicators and the backup pyrotechnic release system. The output signals of the landing gear downlock switches drive the landing gear *DN* position indicators. The landing gear indicators are barberpole when the gear is in transit.

The left and right main landing gear WOW switches produce output signals to the guidance, navigation, and control software to reconfigure the flight control system for landing and rollout gains.

The two WONG signals, along with WOW and theta (pitch angle) less than 0°, allow the GNC software to issue a nose wheel steering enable signal. This signal is then sent to the steering control box to enable nose wheel steering.

Six gear proximity switches are signal conditioned by the landing gear proximity sensor electronics box 1, located in avionics bay 1. Six additional gear proximity switches are signal conditioned by the landing gear proximity sensor electronics box 2, located in avionics bay 2. All WOW proximity switches are redundant through two signal conditioners.

Hydraulic system 1 source pressure is routed to the nose and main landing gear uplock actuators, which releases the nose and main landing gear and door uplock hooks. As the uplock hooks are released, the gear begins its deployment. During gear extension, a camming action opens the landing gear doors. The landing gear free falls into the extended position, assisted by the strut actuators and air-stream in the deployment. The hydraulic strut actuator incorporates a hydraulic fluid flow-

through orifice (snubber) to control the rate of landing gear extension and thereby prevent damage to the gear's downlock linkages.

The *BRAKE ISOL VLV 1, 2, and 3* switches on panel R4 control the corresponding landing gear isolation valve in hydraulic systems 1, 2, and 3. When the switch is positioned to *CLOSE*, hydraulic system 1 is isolated from the main landing gear brakes. The talkback indicator above the switch would indicate *CL*. The landing gear isolation valves cannot be opened or closed with hydraulic pressures less than approximately 100 psi. When the valve is open, hydraulic system 1 pressure is available to the main landing gear brake control valves. The normally closed landing gear extend valve 1, located downstream of the landing gear isolation valve, is not energized until a *LANDING GEAR DN* command is initiated by the commander or pilot on panel F6 or panel F8.

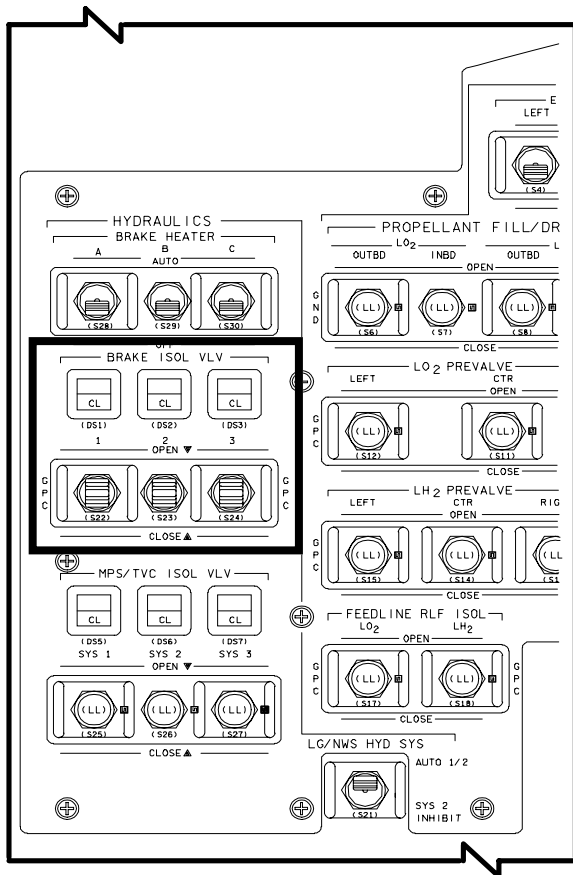
The *BRAKE ISOL VLV 2 and 3* switches on panel R4 positioned to *CLOSE* isolate the corresponding hydraulic system from the main landing gear brake control valves. The adjacent talkback indicator would indicate *CL*. When switches 2 and 3 are positioned to *OPEN*, the corresponding hydraulic system source pressure is available to the main landing gear brake control valves. The corresponding talkback indicator would indicate *OP*. Landing gear extend valve 2 is located downstream of brake isolation valve 2. This valve further isolates hydraulic system 2 supply pressure from the nose wheel steering and nose landing gear deploy actuators and is opened by a *LANDING GEAR DN* command.

When the nose and main *LANDING GEAR DN* command is initiated, hydraulic system 1 pressure is directed to the nose and main landing gear uplock hook actuators and strut actuators (provided that the *LG/NWS HYD SYS* switch is in the *AUTO 1/2* position) to actuate the mechanical uplock hook for each landing gear and allow the gear to be deployed and also provide hydraulic system 1 pressure to the nose wheel steering actuator. The landing gear/nose wheel steering hydraulic system switching valve will automatically select hydraulic system 2 supply pressure if system 1 should fail, thereby providing redundant hydraulics for NWS actuation and nose gear deploy.

NOTE

Hydraulic system 1 is the only hydraulic system for deploy of the main landing gear.

The GPC position of the BRAKE ISOL VLV 1, 2, and 3 switches on panel R4 permits the onboard computer to automatically control the valves in conjunction with computer control of the corresponding hydraulic system circulation pump.



BRAKE ISOL VLV Switches and Talkbacks on Panel R4

Two series valves, landing gear retract control valve 1 and 2, prevent hydraulic pressure from being directed to the retract side of the nose and main landing gear uplock hook actuators and strut actuators if the retract/circulation valve fails to open during nose and main landing gear deployment.

Prior to entry, the *BRAKE ISOL VLV 1, 2, and 3* switches are positioned to GPC. This allows automatic opening of the valves after weight on

main gear is sensed with *GPC* command via MDM FA1, FA2, and FA3, respectively. At 19,000 feet per second, the landing gear isolation valve automatic opening sequence begins under GNC software control. If the landing gear isolation valve is not opened automatically, the flight crew will be requested to manually open the valve by positioning the applicable *BRAKE ISOL VLV* switch to *OPEN*.

If the hydraulic system fails to release the landing gear within 1 second after the *DN* pushbutton is depressed, the nose and left and right main landing gear uplock sensors (proximity switches) will provide inputs to the pyro initiator controllers (PICs) for initiation of the redundant NASA standard initiators (pyro system 1 and 2). They release the same uplock hooks as the hydraulic system. As mentioned earlier, the nose landing gear, in addition, has a PIC and redundant NASA standard initiators that initiate a pyrotechnic power thruster 2 seconds after the *DN* pushbutton is depressed to assist gear deployment. This "nose gear pyro assist" pyro fires every time the gear are deployed.

The landing gear drag brace overcenter lock and spring-loaded bungee lock the nose and main landing gear in the down position.

Ground Reset

Landing gear reset is primarily a post landing function, which will be performed by the crew.

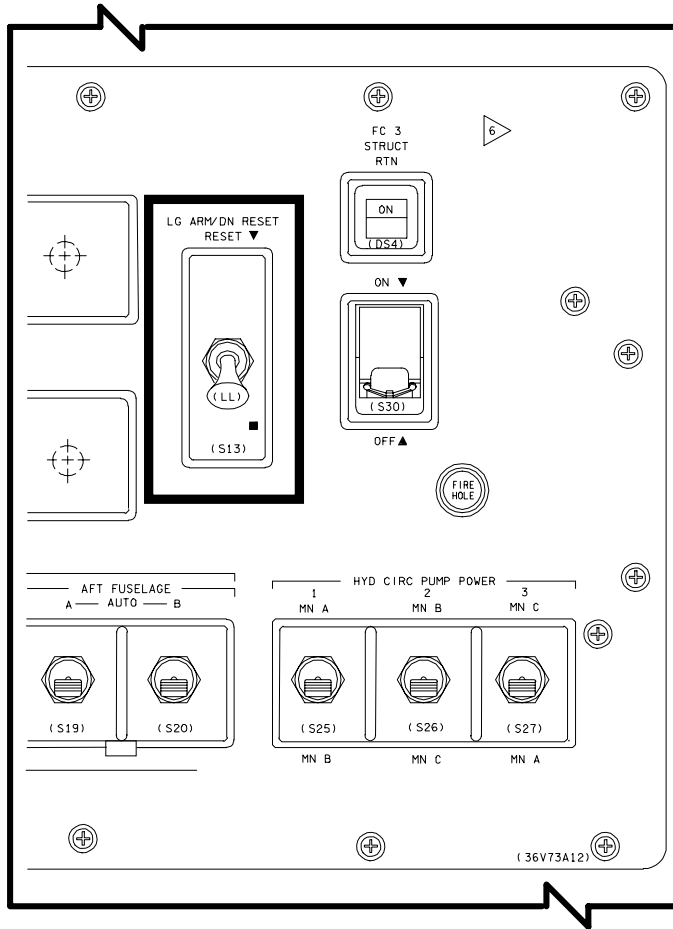
The *LG ARM/DN RESET* switch on panel A12 positioned to *RESET* unlatches the relays that were latched during landing gear deployment by the *LANDING GEAR ARM* and *DN* pushbutton indicators. The primary function of this procedure is to remove power to the PIC circuits that are still charged as a backup landing gear deploy method. The *RESET* position also will extinguish the yellow light in the *ARM* pushbutton indicator and the green light in the *DN* pushbutton.

Drag Chute

During entry, as the vehicle decelerates from 8000 to 3500 fps, the main engine bells are repositioned 10° below the nominal to preclude damage during drag chute deployment. The

crew cannot monitor the bell repositioning but can determine that the system is enabled at item 19 on the SPEC 51 OVERRIDE display. The crew can inhibit the repositioning while in MM

301-304 by toggling item 19 in SPEC 51. Nominal EOM drag chute deployment will be initiated only if main engine bell repositioning is enabled.



LG ARM/DN RESET Switch on Panel A12

Although the drag chute may be deployed at speeds up to 230 KEAS, current EOM procedures call for its deployment at 190 KEAS (195 KEAS for heavyweight vehicles) with a crosswind component no greater than 15 knots. If the drag chute is deployed above 230 KEAS, the drag chute pivot pin is designed to fail, resulting in the chute being jettisoned. Approximately one second after the CDR or PLT presses the ARM 1(2) and DPY 1(2) pushbuttons simultaneously, the pilot chute deploys. Within one second, the pilot chute extracts the main chute which deploys to its 40 percent reefed diameter. After about 3.5 seconds of reefed deployment, two cutters sever the reefing ribbon allowing the main chute to inflate to its full 40 foot diameter.

WARNING

Deployment of the drag chute between 135 and 40 ft AGL can cause loss of control of the vehicle. Drag chute jettison must be initiated immediately to prevent loss of the vehicle and crew.

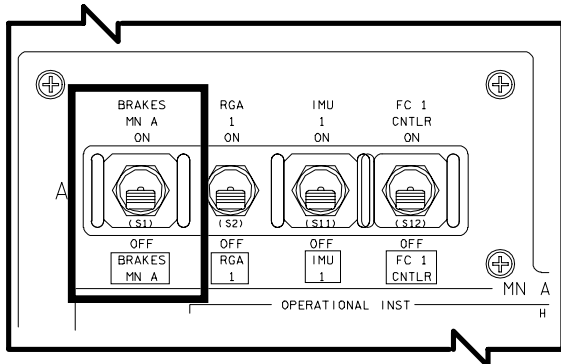
For pre-derotation deployment, an unreefed chute will produce a large nose pitch-up moment for a vehicle mass moment 1.53 million foot pounds. The large pitch-up may produce handling difficulties for the crew that could lead to loss of the vehicle and crew.

At 60 (± 20) KGS, the drag chute will be jettisoned. Below 40 KGS, if drag chute jettison has not been initiated, the chute will be retained until the orbiter has stopped to minimize damage to the main engine bells.

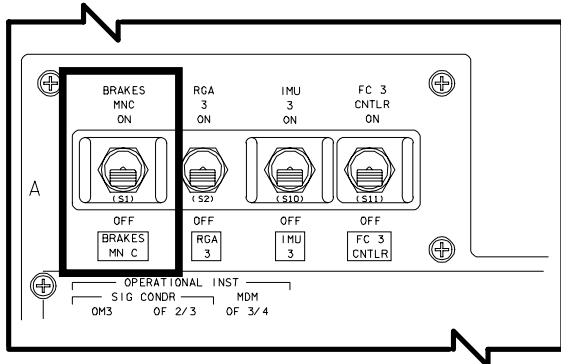
Brake Controls

The BRAKES MN A, MN B, and MN C switches are located on panels O14, O15, and O16. These switches allow electrical power to brake/anti-skid control boxes A and B. The ANTISKID switch located on panel L2 provides electrical power for enabling the anti-skid portion of the braking system boxes A and B. The BRAKES MN A, MN B, and MN C switches are positioned to ON to supply electrical power to brake boxes A and B, and to OFF to remove electrical power. The ANTISKID switch is positioned to ON to enable the anti-skid system, and OFF to disable the system.

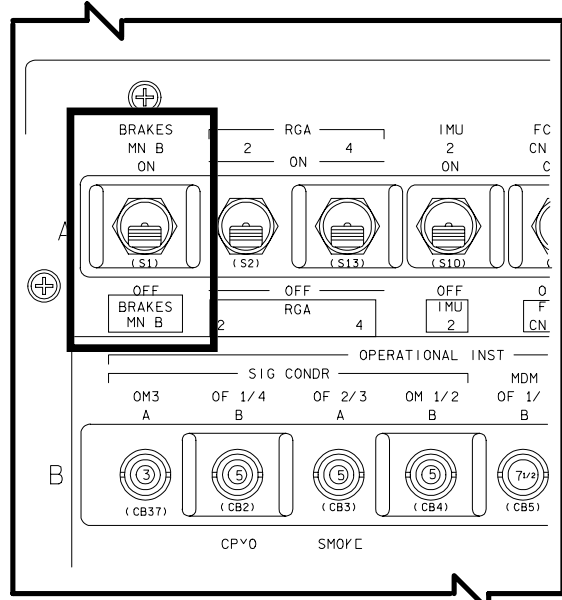
When weight is sensed on the main landing gear, the brake/anti-skid boxes A and B are enabled and brake isolation valves 1, 2, and 3 are opened permitting the main landing gear brakes to become operational.



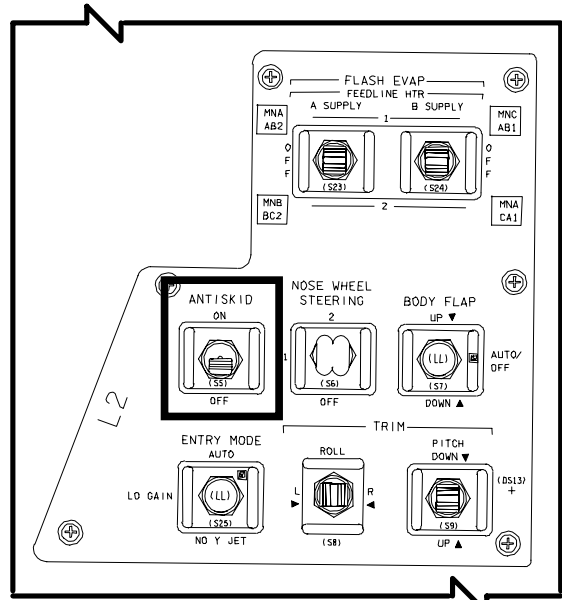
BRAKES Switch on Panel O14



BRAKES Switch on Panel O16



BRAKES Switch on Panel O15



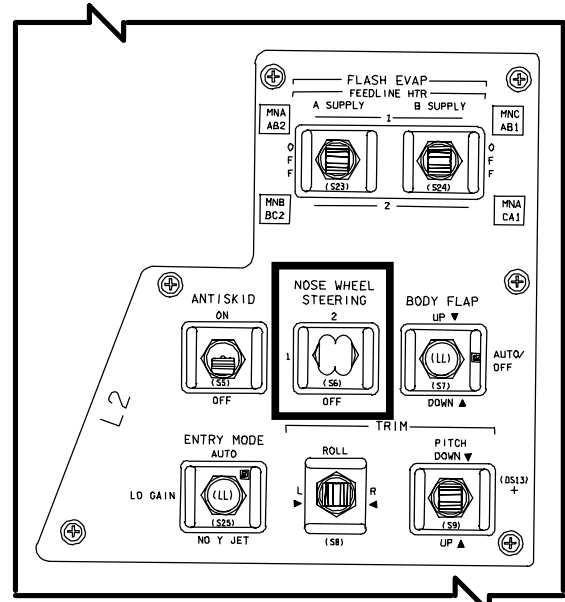
ANTISKID Switch on Panel L2

The main landing gear brakes controlled by the commander's or pilot's brake pedals are located on the rudder pedal assemblies at the commander's and pilot's stations. Pressure on the toe of the adjustable brake/rudder pedals results in a command to the wheel braking system.

Each brake pedal has four linear variable differential transducers. The left pedal transducer unit outputs four separate braking signals through the brake/skid control boxes

for braking control of the two left main wheels. The right pedal transducer unit does likewise for the two right main wheels. When the brake pedal is deflected, the transducers transmit electrical signals of 0 to 5 volts dc to the brake/anti-skid control boxes.

If both right pedals are moved, the pedal with the greatest toe pressure becomes the controlling pedal through electronic OR circuits. The electrical signal is proportional to the toe pressure. The electrical output energizes the main landing gear brake coils proportionately to brake pedal deflection, allowing the desired hydraulic pressure to be directed to the main landing gear brakes for braking action. The brake system bungee at each brake pedal provides the artificial braking feel to the crewmember.



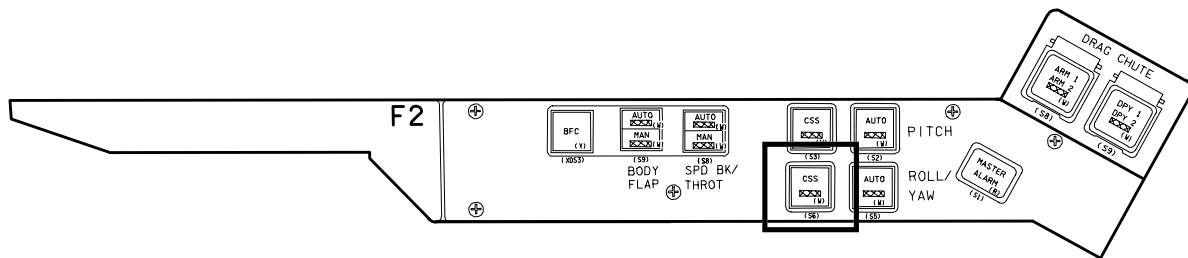
NOSE WHEEL STEERING Switch on Panel L2

Nose Wheel Steering

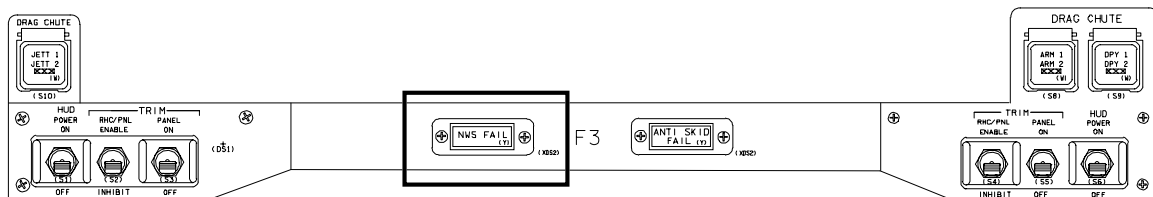
GPC Mode

The *NOSE WHEEL STEERING* switch on panel L2 positioned to *NWS 1(2)* enables the corresponding NWS (avionics) system. In addition to the NWS mode selections of the switch, the *FLIGHT CNTLR POWER* switch on panel F8 must be positioned to *ON*, and the flight control system *ROLL/YAW CSS* pushbutton on panel F2 or F4 must be depressed to enable the GPC for nose wheel steering. When either pushbutton is depressed, a white light illuminates the pushbutton.

When the commander or pilot makes an input to the rudder pedals in the NWS 1(2) mode, the rudder pedal command position is appropriately scaled within the GPC's software and transmitted to a summing network, along with lateral accelerometer inputs from within the flight control system. The accelerometer inputs are utilized to prevent any sudden orbiter lateral deviation. From this summing network, a nose wheel steering command is sent to a comparison network, as well as to the steering servo system.



ROLL/YAW CSS Pushbutton on Panel F2



NWS FAIL Light on Panel F3

Steering position transducers on the nose wheel strut receive redundant electrical excitation from the steering position amplifier, which receives redundant electrical power from data display unit 2.

Each of the three transducers transmits nose wheel position feedback to a redundancy management mid-value-select software. It then transmits a nose wheel position signal to the comparison network. The orbiter nose wheel commanded and actual positions are compared for position error and for rates to reduce any error. Absence of an error

condition will allow nose wheel steering to be enabled after WOW, WONG, and theta less than 0° are sensed in the software. The enable signal permits hydraulic system 1(2) pressure to be applied to the nose wheel steering actuator via the NWS switching valve. If hydraulic system 1 is lost, hydraulic system 2 provides the pressure for nose wheel steering. If both systems' pressures drop below approximately 1,325 psi, the actuator remains in the caster mode and a failure is annunciated to the NWS FAIL C/W yellow light on panel F3.

Landing/Deceleration System Summary Data

- The orbiter has the capability of landing on a runway using a conventional type of landing gear system. Once the orbiter touches down, the crew begins braking and steering operations.
- The landing gear consists of a nose landing gear and a left and right main landing gear. Each landing gear includes a shock strut with two wheel and tire assemblies.
- The nose wheels are co-rotating through a common axle, whereas the main gear wheels rotate independently.
- Each of the four main landing gear wheels has electrohydraulic brakes and an anti-skid system. Each gear wheel brake assembly is supplied with pressure from two different hydraulic systems. Systems 1 and 2 are the primary hydraulic systems for brake pressure; system 3 can back up either or both systems.
- Redundant electrical heaters are installed on the main landing hydraulic flexible lines located on the back side of each main landing gear strut between the brake module and brakes.
- The orbiter nose wheel is steerable after nose wheel touchdown at landing.
- ANTI SKID FAIL and NWS FAIL caution and warning lights are located on panel F3.
- Landing/deceleration controls are located on panels F6, F8, R4, L2, F2, F4, A12, O14, O15, and O16.

Landing/Deceleration System Rules of Thumb

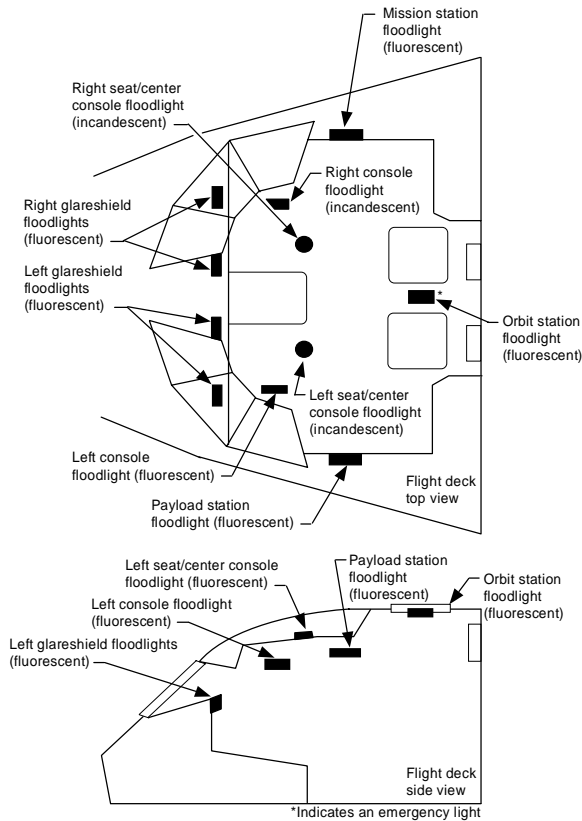
- Landing gear should not be deployed at equivalent airspeeds greater than 312 knots.
- ± 1 knot of touchdown speed corresponds to ± 90 feet of distance. This is often rounded up to 100 feet for convenience.

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2.15 LIGHTING SYSTEM

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**Floodlight Locations -
Flight Deck Forward and Aft**

Description

The orbiter lighting system provides both interior and exterior lighting. The interior lighting provides illumination for display and control visibility and for general crew station and crew equipment operations. Exterior lighting provides illumination for payload bay door operations, extravehicular activity, remote manipulator system operations, and station-keeping and docking. Interior lighting consists of floodlights, panel lights, instrument lights, numeric lights, and annunciator lights. Exterior lighting consists of floodlights and spotlights.

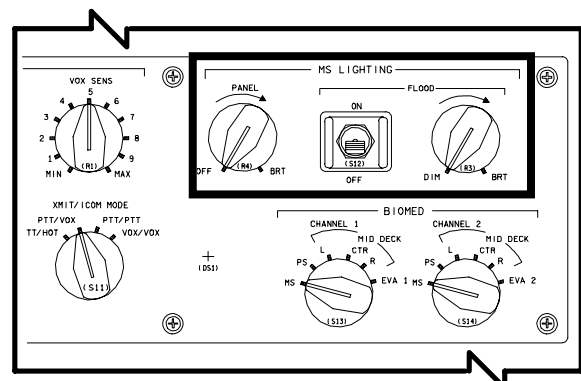
Interior Lighting

Interior floodlights provide general illumination throughout the crew cabin and allow the flight crew to function within the flight deck, middeck, airlock, tunnel adapter, Spacehab, and Spacelab (if installed). Circuit breakers, switches, and variable controls are used to operate the lights. Both fluorescent and incandescent lamps are used.

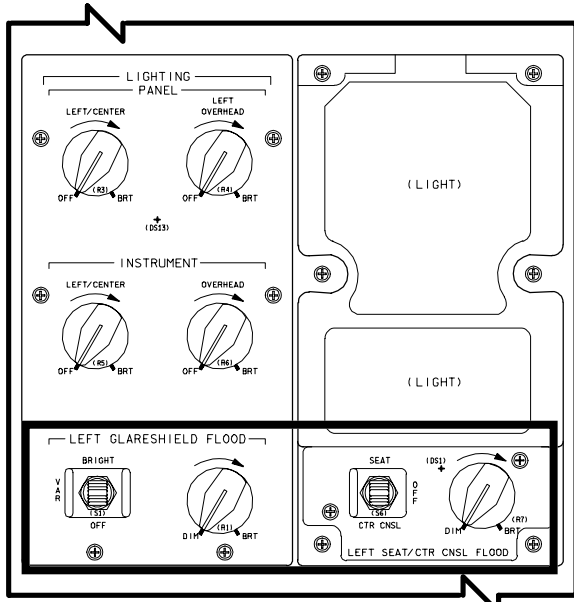
Emergency lighting is provided by selected fixtures that are powered via a separate power input from an essential bus. Existing floodlights are used, but a separate input powers the lights.

Dual fluorescent lamp fixtures provide lighting for the glareshield, mission station, and payload station floodlights. The mission station lighting is controlled by the *MS LIGHTING FLOOD ON/OFF* switch on panel R10; the adjacent rotary control *DIM/BRT* switch controls brightness. The payload station lighting is controlled by the *PS FLOOD ON/OFF* switch on panel L9, which also has an adjacent *DIM/BRT* rotary switch to control brightness.

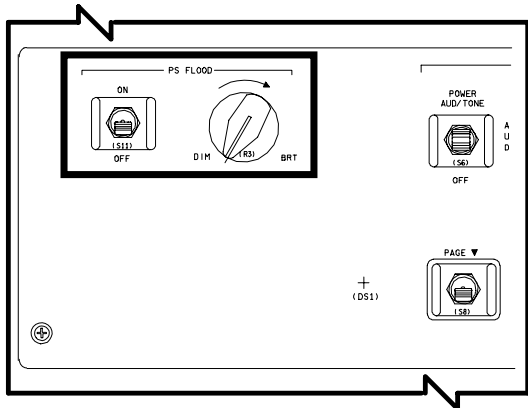
A single fluorescent lamp fixture with an integral off/variable-on is employed on each side of the commander's and pilot's side consoles and the orbit station. The commander's glareshield light, which consists of left inboard (dual lamp) and left outboard (dual lamp), is controlled by the *LIGHTING LEFT GLARESHIELD FLOOD BRIGHT, VAR, OFF* switch and a *DIM, BRT* rotary control on panel O6. (The *DIM, BRT* rotary control operates in conjunction with the *VAR* position.) The pilot's glareshield light functions the same as the commander's, except the controls (*LIGHTING RIGHT GLARESHIELD FLOOD* and *DIM, BRT*) are on panel O8.



MS LIGHTING Controls on Panel R10



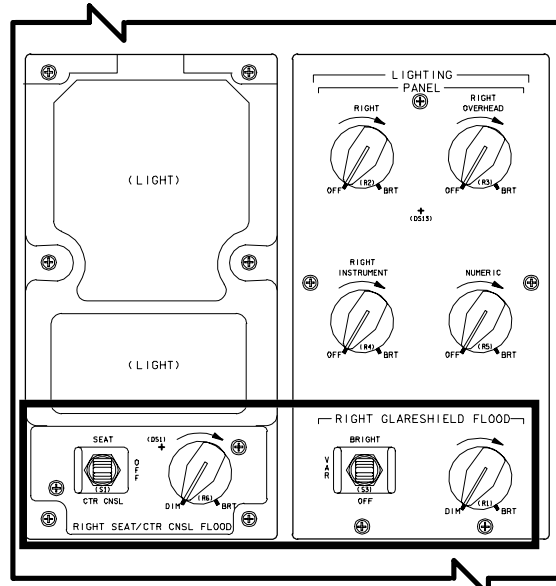
MS LIGHTING Controls on Panel R10



PS FLOOD Lighting Controls on Panel L9

The commander's side console light is controlled by an integral off/variable-on control switch on the fixture. The pilot's side console light is also controlled by an integral off/variable-on control switch on the fixture. The orbit station light is controlled by the *ORBIT STATION LIGHTING FLOOD ON/OFF* switch and *DIM, BRT* rotary control on panel A6U. There are two seat/center console floodlights: one for the commander and one for the pilot. Each light has two incandescent bulbs: the left one illuminates the commander's lap or the center console, and the other illuminates the pilot's lap or the center console. The commander or pilot can select either the lap or center console, but not both at once. The commander's seat or console light is controlled

by the *LEFT SEAT/CTR CNSL FLOOD, SEAT/OFF/CTR CNSL* switch and the *DIM, BRT* rotary control on panel O6. The pilot's seat or console light is controlled by the *RIGHT SEAT/CTR CNSL FLOOD, SEAT/OFF/CTR CNSL* switch and the *DIM, BRT* rotary control on panel O8.



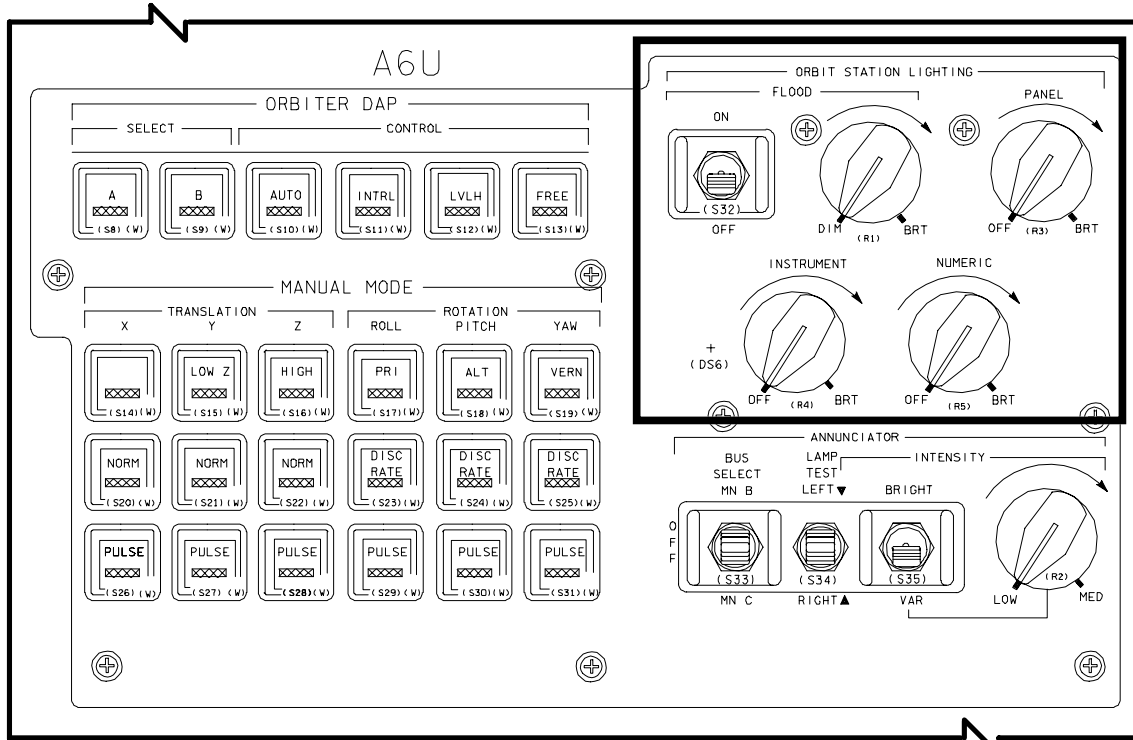
Pilot's Light Controls on Panel O8

Eight middeck ceiling floodlight fixtures are located behind a translucent polycarbonate material. They are the same fixtures as those at the orbit station and are individually controlled by *MID DECK FLOODS ON/OFF* switches on panel MO13Q. The middeck panel MO13Q is lighted by a small fluorescent lamp at each end of the recessed panel and is controlled by the *MO13Q LTG ON/OFF* switch on the panel.

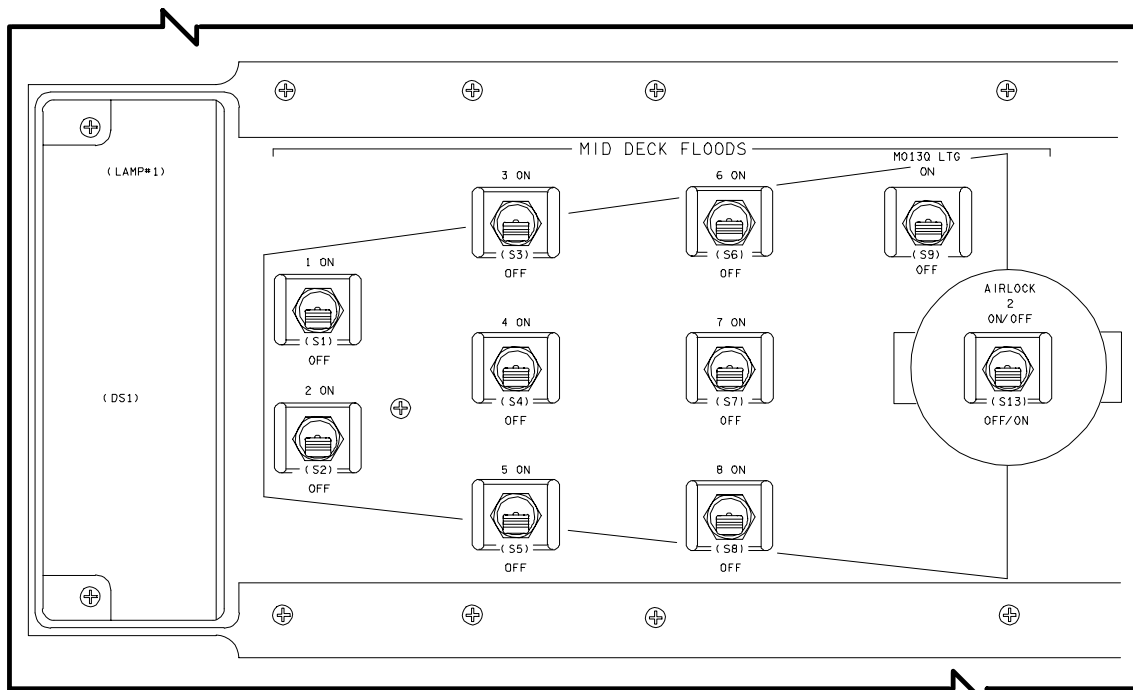
The waste management compartment floodlight is also the same as the orbit station fixture and is controlled by the *WASTE MANAGEMENT COMPARTMENT FLOOD ON/OFF* switch on panel ML18F.

The middeck sleep station bunks (if installed) use the same floodlights as the commander's and pilot's flight deck consoles and are also controlled individually.

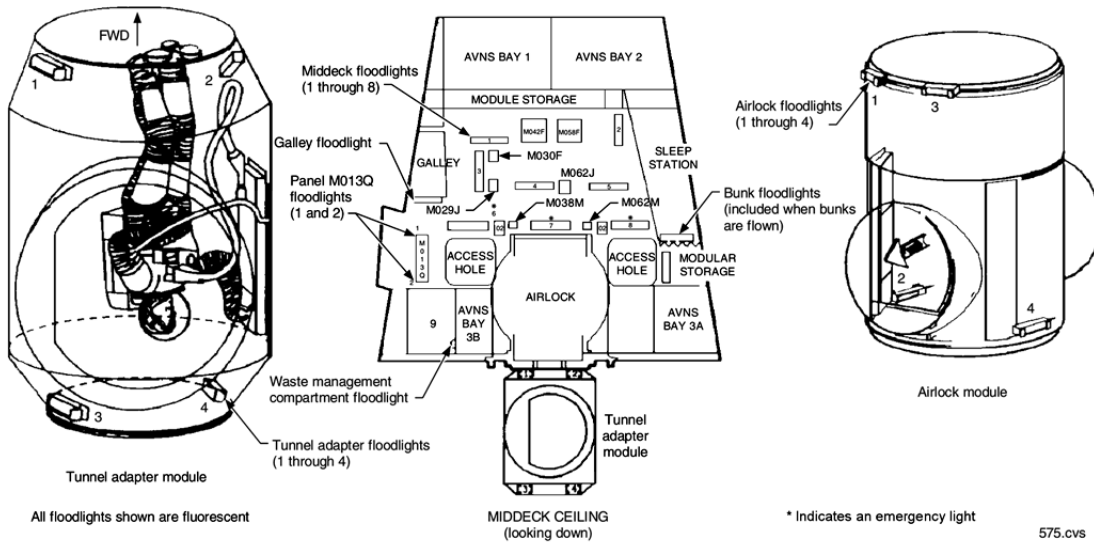
The airlock floodlights are similar to those at the commander's and pilot's flight deck side consoles, except they are controlled by *LIGHTING FLOOD* switches on panel AW18A and an *AIRLOCK 2* switch on panel MO13Q.



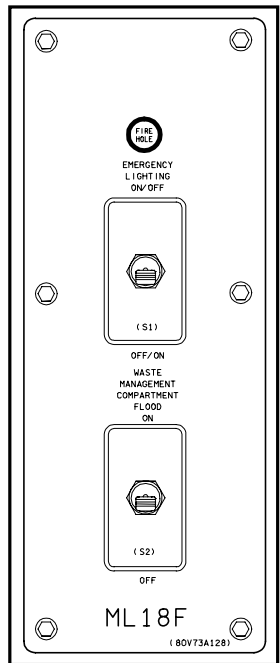
ORBIT STATION LIGHTING Controls on Panel A6U



ORBIT STATION LIGHTING Controls on Panel A6U



Floodlight Locations - Middeck and Airlock

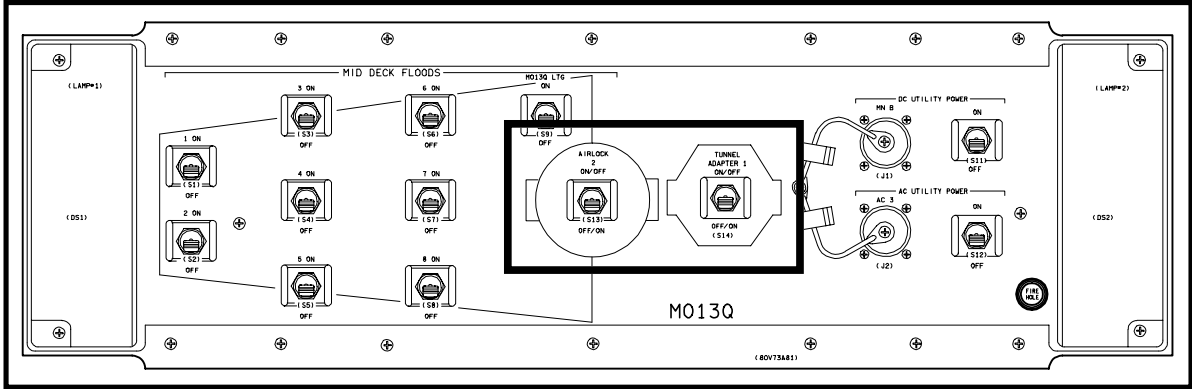


EMERGENCY LIGHTING and WASTE MANAGEMENT COMPARTMENT FLOOD Lighting Control Switches on Panel ML18F

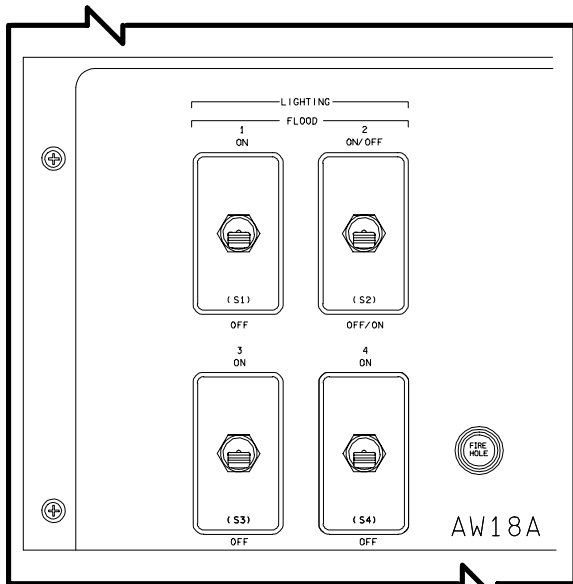
If the tunnel adapter is installed for a Spacelab or Spacehab mission, the floodlights are also similar to those at the commander's and pilot's side consoles. Tunnel adapter lights 2, 3, and 4 are controlled by individual *ON/OFF* switches on the tunnel adapter panel TW58T. Tunnel adapter light 1 is controlled by the *TUNNEL ADAPTER 1 ON/OFF* switch on panel MO13Q and the *ON/OFF 1* switch on the tunnel adapter panel.

The Spacehab (if installed) can accommodate different flight configurations, either a single module or a double module configuration. Each module has four overhead floodlights. The fixtures are single-lamp floodlights with an integral dimmer control on three. There is a main switch located on the monitor and control panel (MCP) at the entrance of the module that powers three floodlights per module. The emergency lighting system powers the remaining one floodlight per module in the event of a power failure. The Spacehab has a caution and warning (C&W) system that enables the master alarm light switch closure. The C&W luminaries are located on the MCP in the Spacehab.

The Spacelab module (if installed) has 12 overhead floodlights, a workbench floodlight, and a transfer tunnel floodlight. The overhead floodlights are single lamp with an integral on/off switch. The emergency lighting system for the Spacelab powers floodlight no. 6, located along the starboard side overhead at rack no. 6. The C&W system for the Spacelab enables the master alarm light switch closure. The C&W luminaries are located on the ECS/ECLS MCP and the C&W/FSS panel in the Spacelab. The controls for the overhead floodlights are located on the electrical power distribution system's (EPDS) MCP. The transfer tunnel floodlight has a system on/off control switch located in the forward and aft areas of the tunnel.



AIRLOCK 2 and TUNNEL ADAPTER Lighting Controls on Panel M013Q

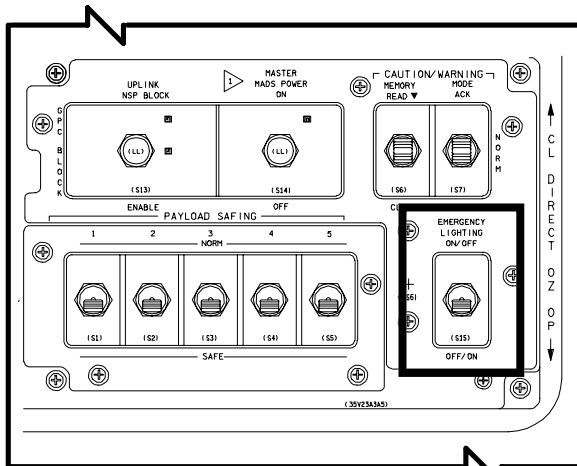


Airlock Flood LIGHTING Switches on Panel AW18A (Switches on Tunnel Adapter Panel TW58T are in Identical Configuration)

The emergency floodlights for the crew module are controlled by *EMERGENCY LIGHTING ON/OFF* switches on either panel C3 or ML18F. The emergency lighting system is powering the floodlights when both panel switches are in the same position. When the emergency system is turned on, a relay is activated that configures the lights to full bright. Chem lights are available for crewmembers during minimum floodlight operations.

Panel Lighting

Many flight deck instrument panels have integral lighting that illuminates the panel nomenclature and markings on the displays and controls. This illumination aids the flight crew in locating displays and controls while operating the orbiter. Panel lighting is transmitted from behind a panel overlay through the panel nomenclature, making it appear white-lighted. It is also transmitted to the edges of the displays and controls for general illumination. The lighting source consists of small incandescent, grain-of-wheat lamps mounted between the metal panel face and the plastic panel overlay. The overlay has a layer of white paint and a layer of gray paint on the top surface. The panel nomenclature is formed by etching the letters and symbols into the gray paint, leaving the white layer underneath.



EMERGENCY LIGHTING Switch on Panel C3

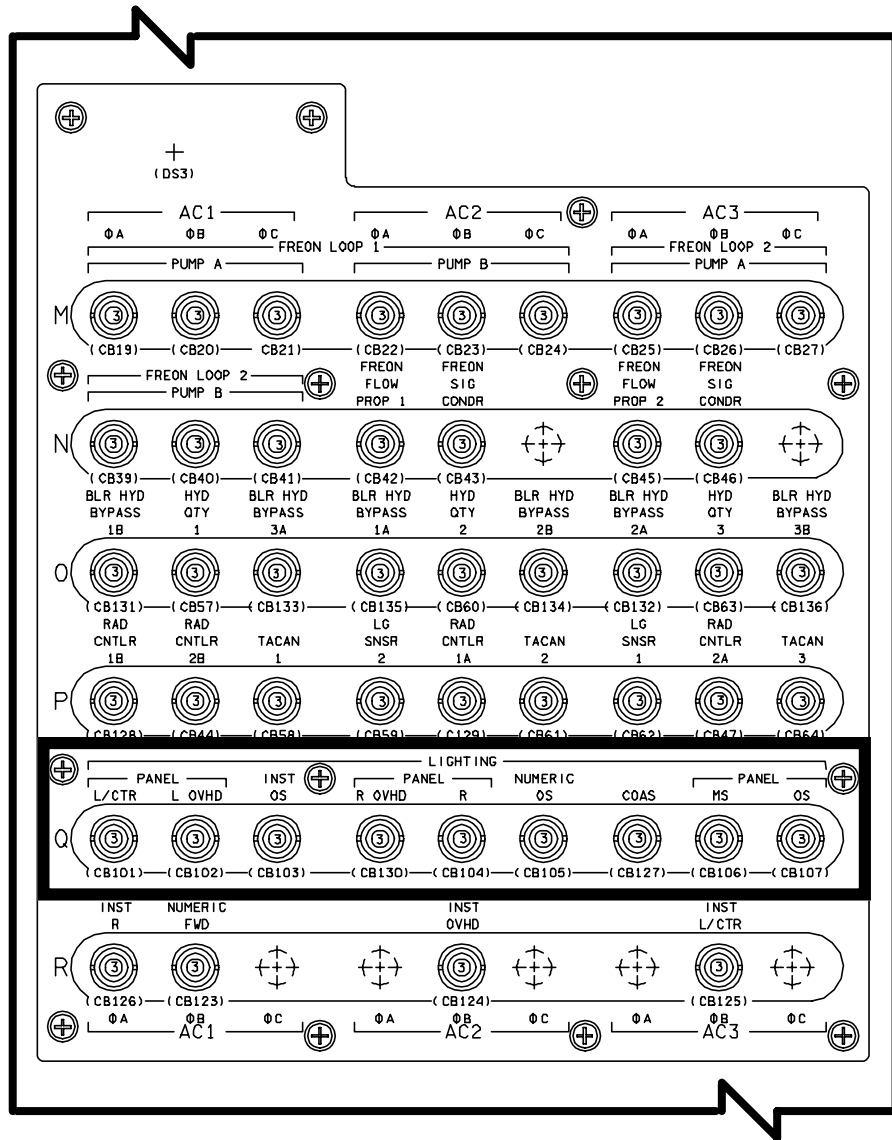
On panel L4, panel lighting circuit breakers are found in the Q row: *PANEL L/CTR*, *L OVHD*; *PANEL R OVHD*, *R*; and *PANEL MS*, *OS*. The lighting circuit breakers are generally out for day launches. *LIGHTING PANEL LEFT/CENTER* and *LEFT OVERHEAD OFF/BRT* rotary switches are found on panel O6.

LIGHTING PANEL RIGHT and RIGHT OVERHEAD OFF/BRT rotary switches are located on panel O8. A LIGHTING PANEL OFF/BRT rotary switch is located on panel R10. An ORBIT STATION LIGHTING PANEL OFF/BRT rotary switch is located on panel A6U.

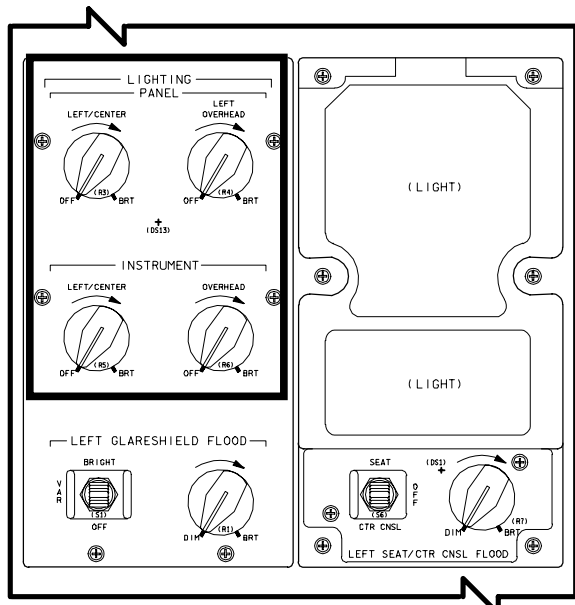
Instrument Lighting

The flight deck instruments have internal integral lighting that illuminates the face to enable the flight crew to read the displayed data. Lighting is provided by incandescent

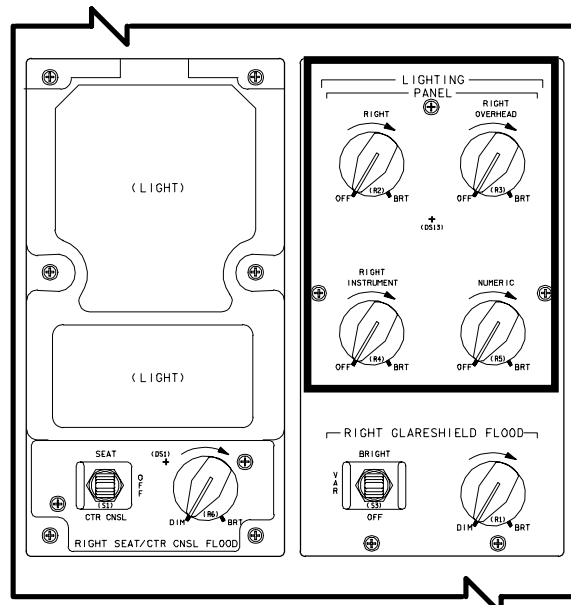
lamps located behind the face of the instruments. Prisms are used to distribute the light evenly over the face. Circuit breakers labeled INST OS, INST R, INST OVHD, and INST L/CTR are located in rows Q and R on panel L4. LIGHTING INSTRUMENT LEFT/CTR and OVERHEAD OFF/BRT rotary switches are located on panel O6. A LIGHTING PANEL RIGHT INSTRUMENT OFF/BRT rotary switch is located on panel O8. An ORBIT STATION LIGHTING INSTRUMENT OFF/BRT rotary switch is located on panel A6U.



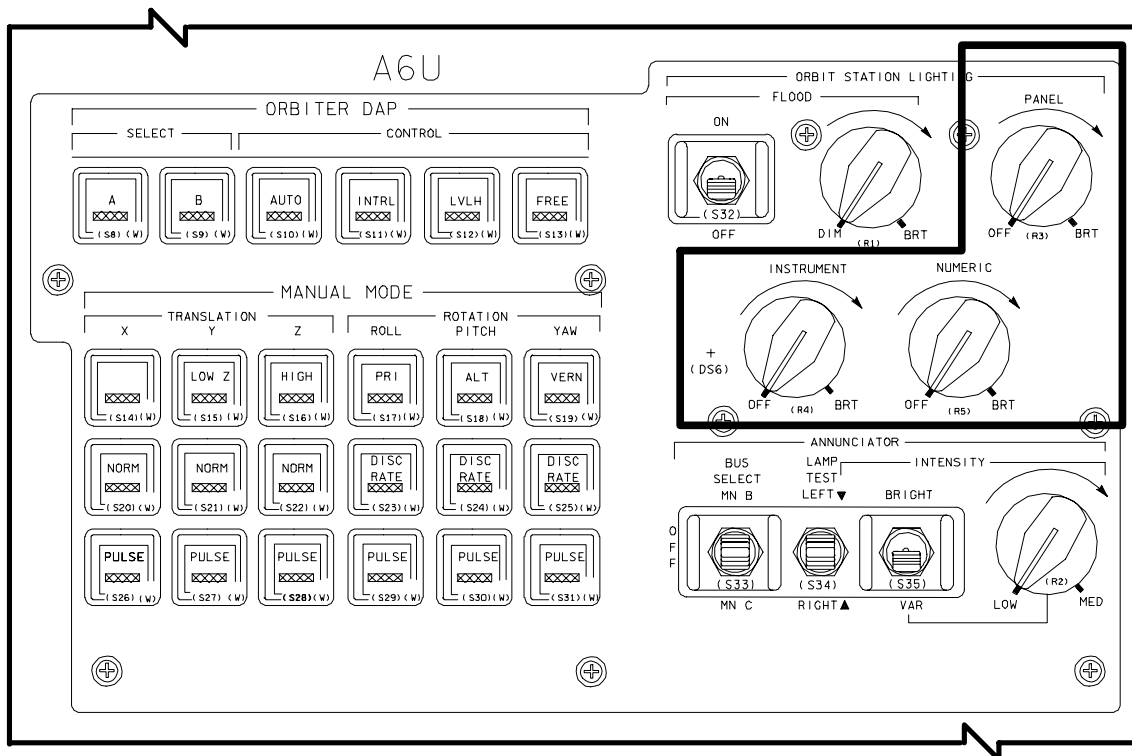
PANEL INST and NUMERIC Circuit Breakers on Panel L4



PANEL and INSTRUMENT LIGHTING Controls on Panel O6



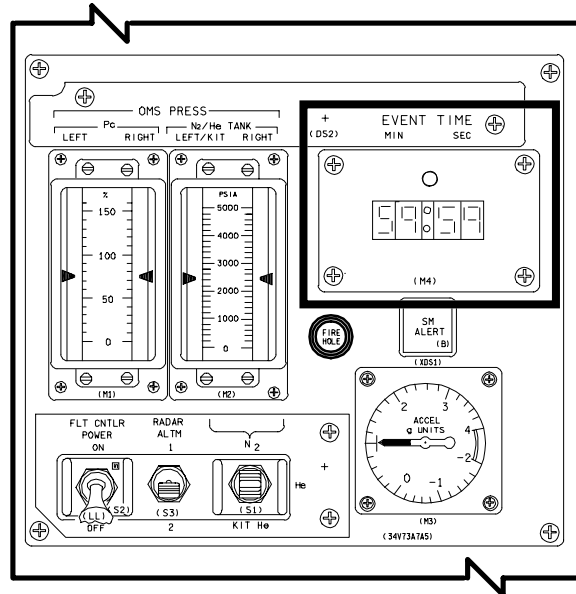
PANEL, INSTRUMENT, and NUMERIC Lighting Controls on Panel O8



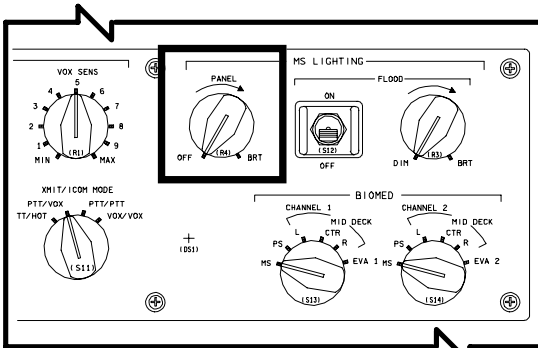
PANEL, INSTRUMENT, and NUMERIC Lighting on Panel A6U

Numeric Lighting

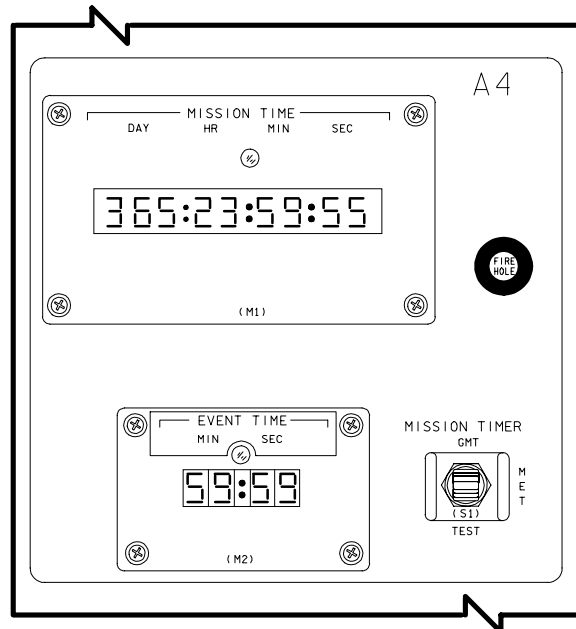
Indicators on the flight deck use illuminated numeric (digital) readouts to display data. The illumination is provided by a single incandescent lamp in each segment of a digit. Seven segments are required to generate the numbers zero through nine. Each numeric indicator has a red light to indicate failures in the indicator and will be illuminated when any lamp in the indicator fails. The numeric (digital) indicators are *EVENT TIME* (panels F7 and A4), *MISSION TIME* (panels O3 and A4), *RCS/OMS PRPLT QTY* (panel O3), and *RANGE/ELEVATION* and *RANGE RATE/AZIMUTH* (rendezvous radar) on panel A2. The *LIGHTING NUMERIC OS* circuit breaker is located in row Q on panel L4. A *LIGHTING NUMERIC OFF/BRT* rotary switch is located on panel O8, and an *ORBIT STATION LIGHTING NUMERIC OFF/BRT* rotary switch is located on panel A6U. The RMS (if installed) has numeric readouts on panel A8U.



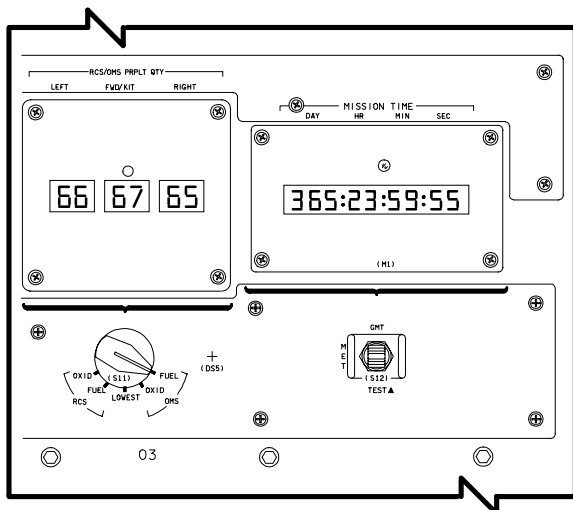
EVENT TIME Numeric (Digital) Indicator on Panel F7



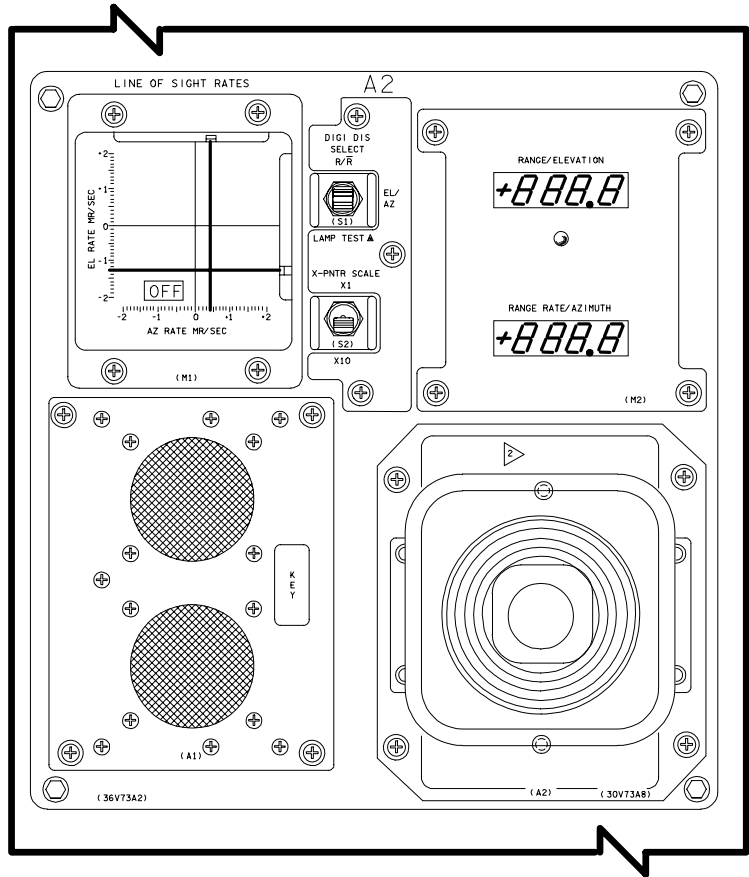
PANEL Lighting Control on Panel R10



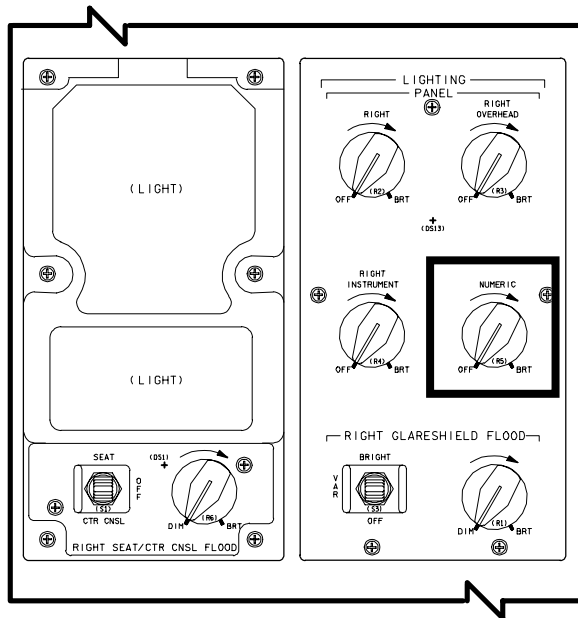
MISSION TIME and EVENT TIME Numeric (Digital) Indicators on A4



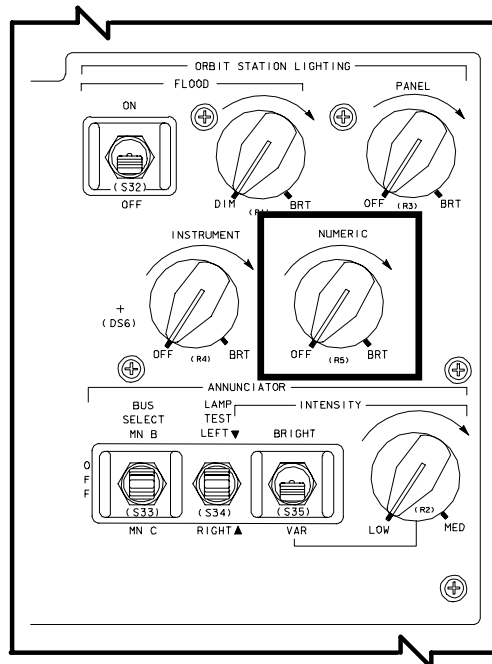
RCS/OMS PRPLT QTY and MISSION TIME Numeric (Digital) Indicators on panel O3



**RANGE/ELEVATION AND RANGE RATE/AZIMUTH
Numeric (Digital) Indicators on Panel A2**



**LIGHTING NUMERIC Rotary Switch on
Panel O8**



**ORBIT STATION LIGHTING NUMERIC
Rotary Switch on Panel A6U**

Annunciator Lights

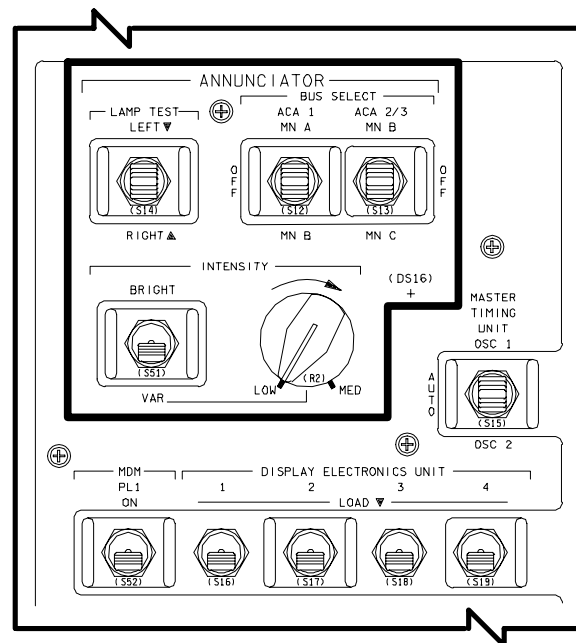
Annunciators are used to provide visual indications of vehicle and payload systems status. The annunciator lights are classified as emergency, warning, caution, and advisory. Emergency and warning annunciators are red, and cautions are yellow. Advisory annunciators may be white (status), green (normal configuration), yellow (alternate configuration), or blue (special applications).

Annunciator lighting is provided by incandescent lamps that illuminate the lens area of the annunciators. Most annunciators are driven by an annunciator control assembly, which controls the illumination of the lights during a "normal" or "test" input and also controls the brightness level. The caution and warning status lights on panel F7 and the *GPC STATUS* lights on panel O1 have separate electronic units for lighting control. Some annunciator lighting is provided by directly driven light emitting diodes (LEDs).

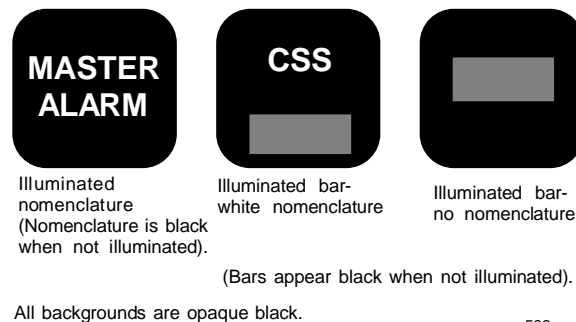
Three different lens configurations exist for the pushbutton indicators and indicator lights. One configuration has illuminated nomenclature in the appropriate color on an opaque black background. The nomenclature cannot be seen until it is illuminated. Another configuration has non-illuminated white nomenclature on an opaque black background and a bar that illuminates in the appropriate color. The nomenclature in this configuration is always visible. The third configuration has a bar that illuminates on an opaque black background and no nomenclature on the lens, but nomenclature is available as part of the panel.

The forward flight deck *ANNUNCIATOR BUS SELECT ACA 1* and *ACA 2/3* switches on panel O6 provide electrical power to enable the corresponding ac power supplies. (See Section 2.8 for details on the power system and associated terminology.) *ACA 1* is enabled by positioning *BUS SELECT ACA 1* to either the *MN A* or *MN B* position, and thus the annunciator lights associated with *ACA 1*. *BUS SELECT ACA 1* also provides electrical power to the *ANNUNCIATOR INTENSITY BRIGHT*, *VAR* switch and the *LOW*, *MED* rotary switch on panel O6, controlling the intensity of the annunciator lights associated with *ACA 1*. *ACAs 2 and 3* are enabled by positioning the

BUS SELECT ACA 2/3 switch to either the *MN B* or *MN C* position, and thus the annunciator lights associated with *ACAs 2 and 3*. *BUS SELECT ACA 2/3* also provides electrical power to the annunciator light *INTENSITY BRIGHT*, *VAR* switch on panel O6 and the *LOW*, *MED* rotary control on panel O6, thus controlling the intensity of the annunciator lights associated with *ACAs 2 and 3*. The *OFF* position of the *BUS SELECT ACA 1* switch removes power from *ACA 1*, disabling the annunciator lights associated with it. The *OFF* position of the *BUS SELECT ACA 2/3* switch removes power from *ACAs 2 and 3*, disabling the annunciator lights associated with them.



ANNUNCIATOR Lighting Controls on Panel O6



Typical Annunciator Configurations

The *ANNUNCIATOR INTENSITY* switch on panel O6 positioned to *BRIGHT* bypasses the *INTENSITY LOW, MED* rotary control. The *ANNUNCIATOR INTENSITY* switch positioned to *VAR* permits the *INTENSITY LOW, MED* rotary control to control annunciator light intensity.

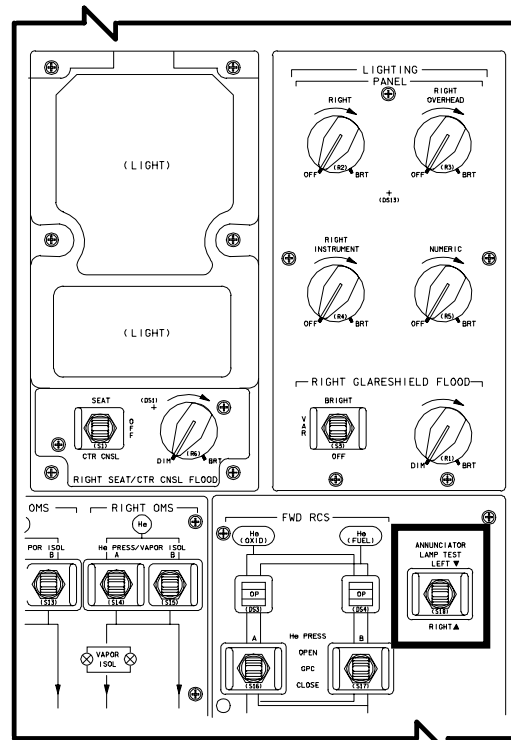
The *ANNUNCIATOR LAMP TEST* switch on panel O6 or O8 positioned to *LEFT* applies power to the ACA 1, 2, and 3 annunciator lamp test circuits, illuminating annunciator lights on panels F2 (*MASTER ALARM*), F6, L1 (*SMOKE DETECTION*), O1 (*GPC STATUS*), and M029J, the left 20 C/W lights on panel F7, and the *SM ALERT* on panel F7. Positioning the *LAMP TEST* switches to *RIGHT* applies power to the ACA 1, 2, and 3 annunciator lamp test circuits, illuminating the annunciator lights on panels C3, F4 (*MASTER ALARM*), F8, and M052J (*MASTER ALARM*), the right 20 C/W lights on panel F7, and the *MAIN ENGINE STATUS* lights on panel F7.

The aft flight deck *ANNUNCIATOR BUS SELECT* switch on panel A6U provides electrical power to enable ACAs 4 and 5. ACAs 4 and 5 are enabled by positioning *BUS SELECT* to either the *MN B* or *MN C* position, and thus the annunciator lights associated with ACAs 4 and 5. The *BUS SELECT* switch also provides electrical power to the annunciator light *INTENSITY BRIGHT, VAR* switch and the *LOW, MED* rotary control on panel A6U, thus controlling annunciator light intensity associated with ACAs 4 and 5. The *OFF* position of the *BUS SELECT* switch removes power from ACAs 4 and 5, disabling the annunciator lights associated with them.

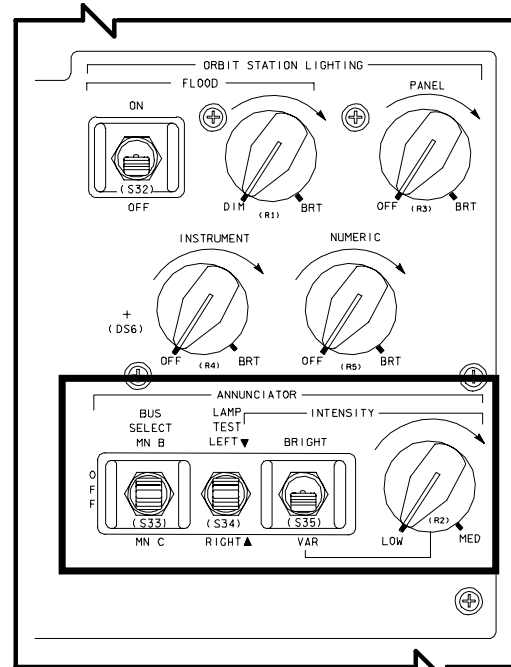
The *ANNUNCIATOR INTENSITY* switch on panel A6U, when positioned to *BRIGHT*, bypasses the *INTENSITY LOW, MED* rotary control on panel A6U. Positioned to *VAR*, it permits the *INTENSITY LOW, MED* rotary control to vary annunciator light intensity.

The *ANNUNCIATOR LAMP TEST* switch on panel A6U, when positioned to *LEFT*, applies power to the ACA 4 and 5 annunciator lamp test circuits, illuminating the annunciator lights on panels A2 and A6U, the *VIDEO INPUT* pushbuttons on panel A7U, and columns 0 through 4 on panel R13U. Positioning the switch to *RIGHT* applies power to the ACA 4 and 5 annunciator lamp test circuits, illuminating the annunciator lights (*MASTER ALARM*)

and *VIDEO OUTPUT* and *ALC/GAMMA* pushbuttons on panel A7U and columns 5 through 9 on panel R13U.



ANNUNCIATOR LAMP TEST Switch on Panel O8



ANNUNCIATOR Lighting Controls on Panel A6U

Exterior Lighting

The exterior floodlights improve visibility for the flight crew during payload bay door operations, EVA operations, RMS operations, and stationkeeping and docking.

The lights used to light the payload bay use metal halide lamps. These lamps are gas discharge arc tubes similar to mercury vapor lamps.

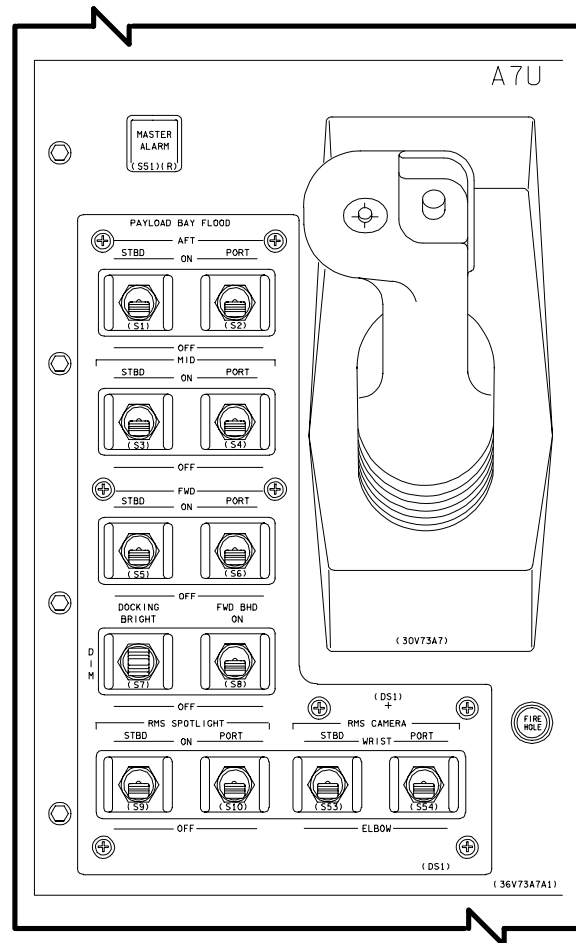
After a floodlight is turned on, it takes 2 to 3 minutes to reach full brightness. It is recommended by the manufacturer that payload bay floodlights remain powered for a minimum of 25 minutes before being turned off. The only exception to this guideline is if a floodlight fails to illuminate. If a light does not reach full brightness in 5 minutes, it should be unpowered. In addition, when a light is turned off, it should not be repowered for 10 to 16 minutes, depending on the amount of payload blocking of the light. If followed by the crewmembers, these time constraints will help to prolong floodlight life.

The premature failure of the lamps on a previous flight may have been caused by not waiting the required time before repowering the lamps. It is better to leave the lamps powered until the task is finished than to try to save power by turning them off.

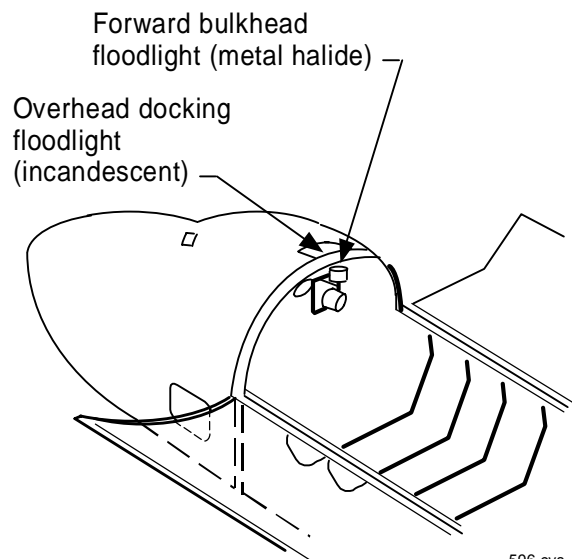
Each lamp has a separate dc/dc power supply that produces the higher voltage required to operate the lamps. Power for the lamps is supplied by the Mid Power Control assemblies, using 10 amp remote power controllers to control the lights.

The power supplies for the metal halide lamps are mounted to the floodlight electronics assemblies, which are cooled by the Freon loops. The floodlight used for docking and the forward bulkhead floodlight use a cold plate cooled by the water loops.

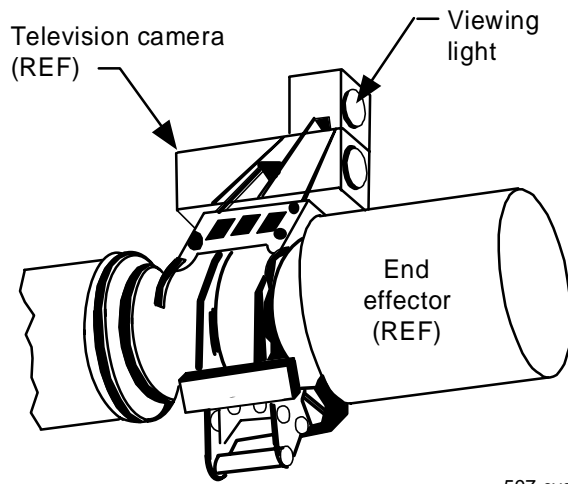
The payload bay floodlights are controlled by switches on panel A7U. The panel contains *PAYLOAD BAY FLOOD AFT*, *MID*, and *FWD* sets of switches, with a *STBD* and *PORT* switch in each set. The *DOCKING* light switch is below the payload bay flood controls on panel A7U; it has *BRIGHT*, *DIM*, and *OFF* settings. The RMS floodlight is controlled by *RMS SPOTLIGHT STBD* and *PORT* switches on panel A7U.



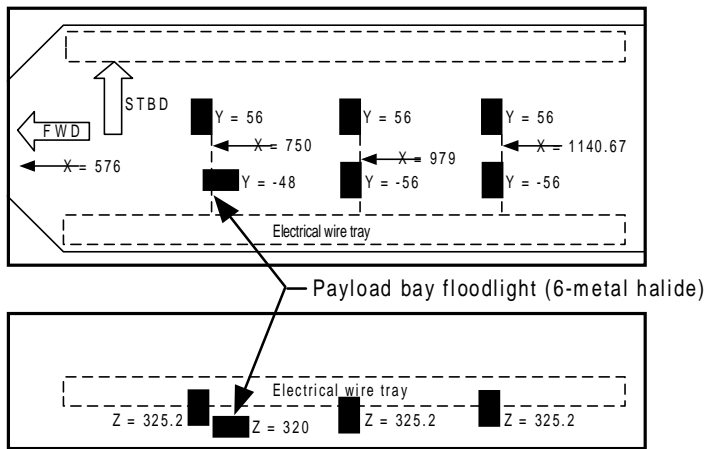
PAYLOAD BAY FLOOD, DOCKING, and RMS Lighting Controls on Panel A7U



Bulkhead Floodlights



Remote Manipulator System Wrist Floodlight



Payload Bay Forward/Mid/Aft Floodlights

Lighting System Summary Data

- Interior lighting consisting of floodlights, panel lights, instrument lights, numeric lights, and annunciator lights provides general illumination throughout the crew cabin.
- Exterior floodlights and spotlights improve visibility for the flight crew during payload bay door operations, EVA operations, RMS operations, and stationkeeping and docking.
- Emergency lighting is provided by separate fixtures powered by a separate power input from an essential bus. Emergency lighting is controlled by switches on panels C3 and ML18F.
- Switches controlling the lighting system are distributed over panels R10, L9, O8, A6U, A7U, MO13Q, ML18F, AW18A, and O6.
- Lighting system circuit breakers are located on panel L4.

Lighting System Rules of Thumb

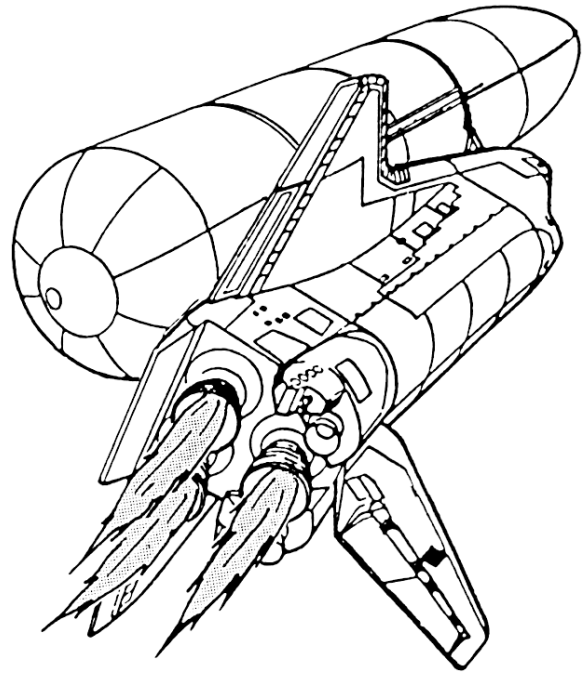
- Power consumption of cockpit lighting can be as much as 1 to 2 kW with all lights on.
- When payload bay floodlights are powered, they should be left on for a minimum of 25 minutes.
- When payload bay floodlights are turned off, they should remain unpowered for 10 to 16 minutes prior to repowering.
- If a payload bay floodlight does not reach full brightness within 5 minutes of being powered, it should be turned off.

2.16 MAIN PROPULSION SYSTEM (MPS)

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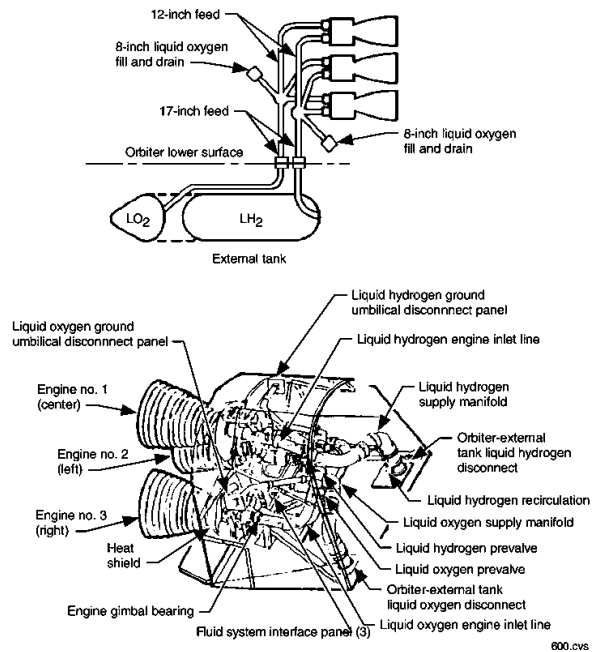
The MPS has three SSMEs, three SSME controllers, the external tank, the orbiter MPS propellant management system and helium subsystem, four ascent thrust vector control units, and six SSME hydraulic TVC servo-actuators. (The external tank is described in detail in Section 1.3.) Most of the MPS is located in the aft fuselage beneath the vertical stabilizer.



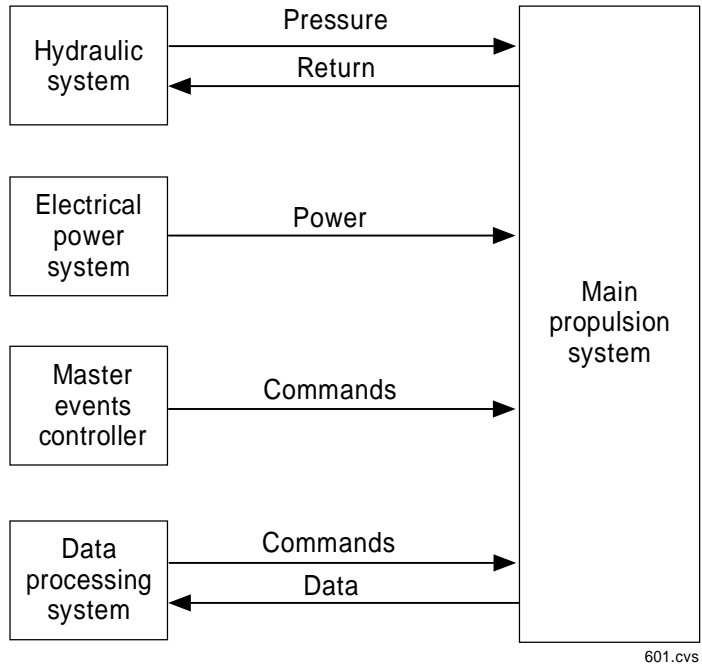
Description

The space shuttle main engines (SSMEs), assisted by two solid rocket motors during the initial phases of the ascent trajectory, provide vehicle acceleration from lift-off to main engine cutoff (MECO) at a predetermined velocity.

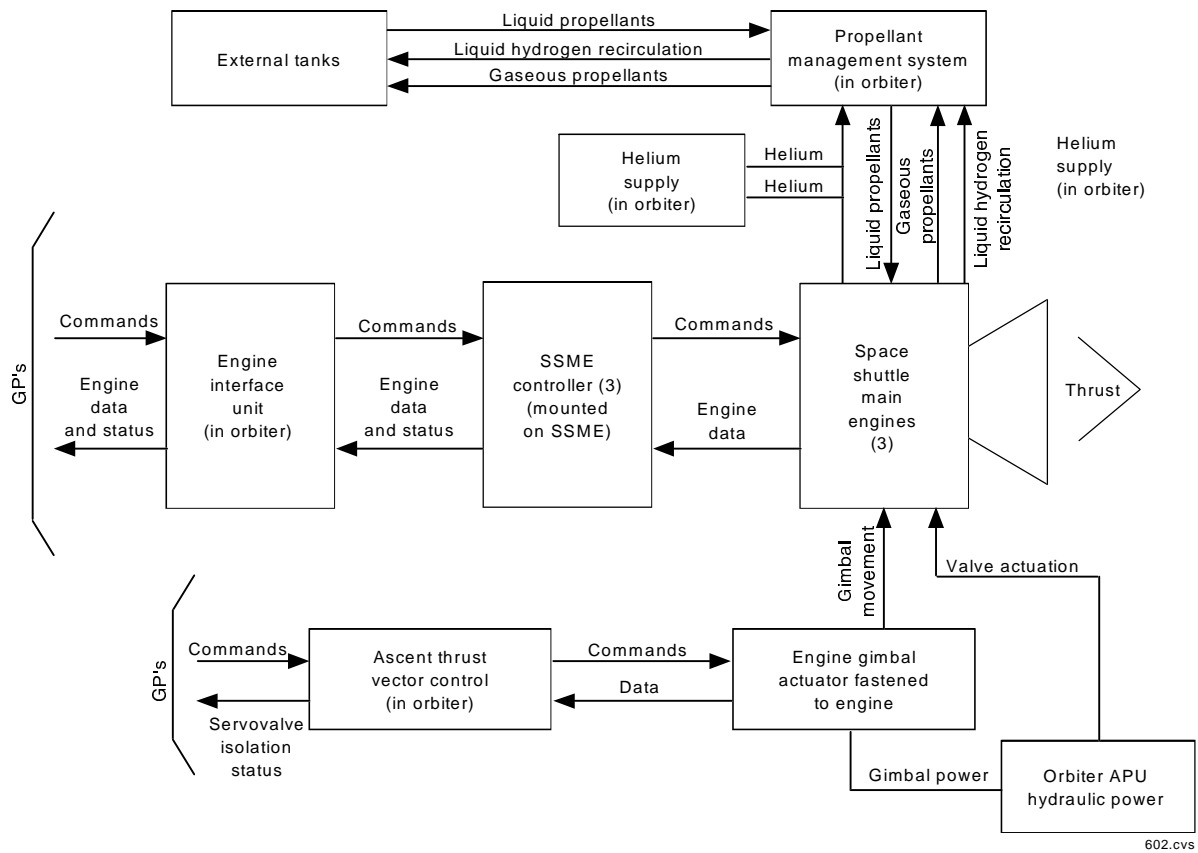
The MPS has critical interfaces with the orbiter hydraulic system, electrical power system, master events controller, and data processing system. The hydraulic system supplies hydraulic pressure to operate the main engine valves and gimbal actuators. The electrical power system furnishes ac power to operate the main engine controllers and dc power to operate the valves and transducers in the propellant management and helium systems. The master events controller initiates firings of pyrotechnic devices for separating the solid rocket boosters from the external tank and the external tank from the orbiter. The data processing system controls most of the MPS functions during ascent and entry.



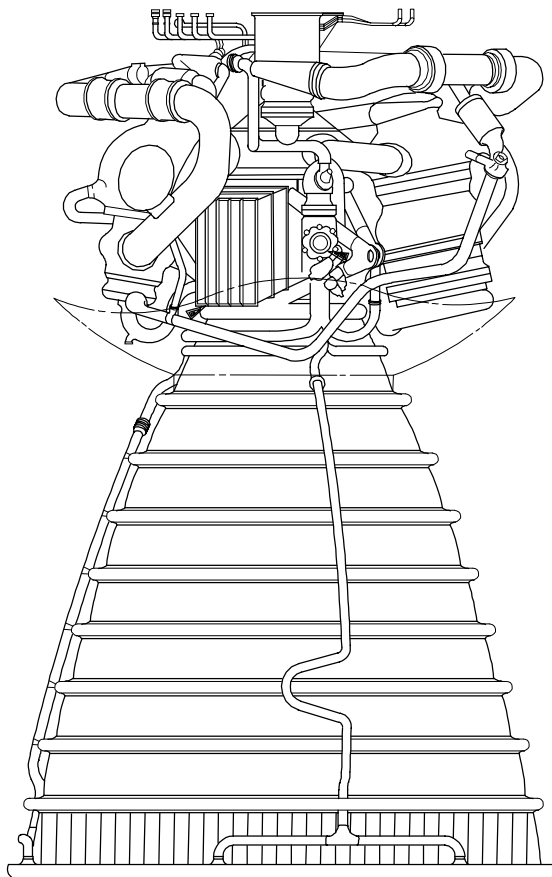
Main Propulsion System



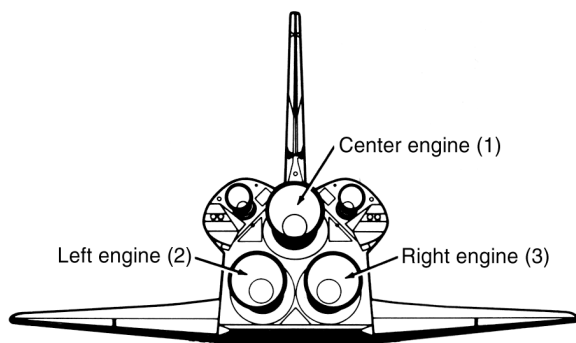
Critical Interfaces with the Main Propulsion System



Main Propulsion System Subsystem



Space Shuttle Main Engine



Main Engine Numbering System

Space Shuttle Main Engines (SSMEs)

The three SSMEs are reusable, high-performance, liquid propellant rocket engines with variable thrust. The engines use liquid hydrogen for fuel and cooling and liquid oxygen as an oxidizer. The propellant is carried in separate tanks within the external tank and is supplied to

the main engines under pressure. Using a staged combustion cycle, the propellants are partially burned at high pressure and relatively low temperature in two preburners, then completely burned at high pressure and high temperature in the main combustion chamber.

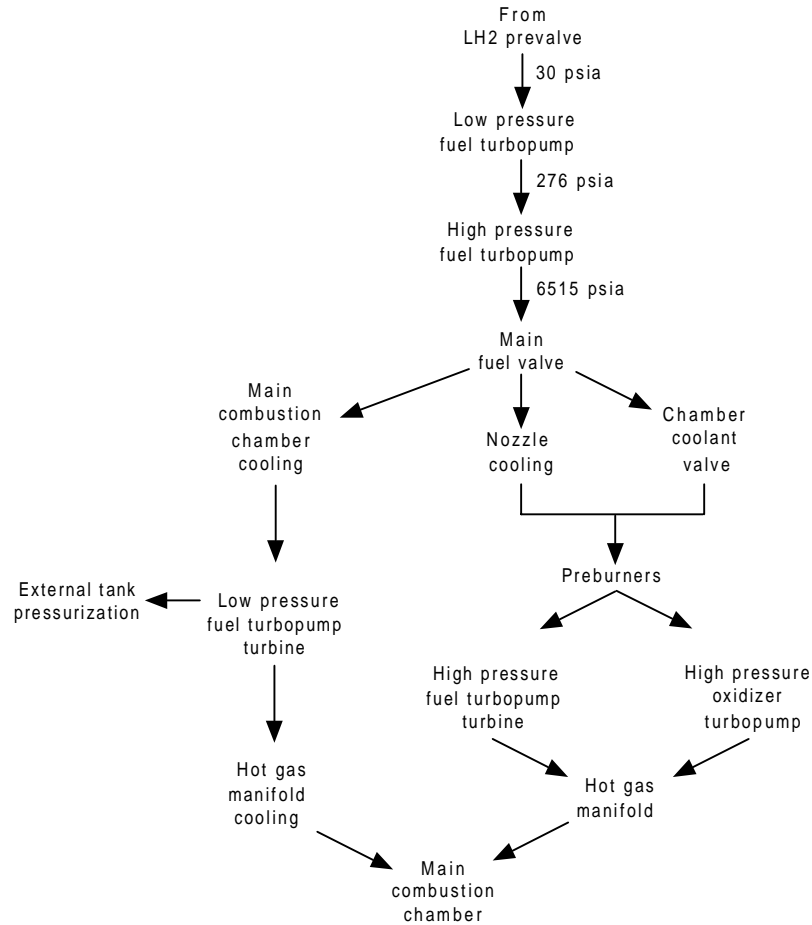
The engines are generally referred to as the center (engine 1), left (engine 2), and right (engine 3). Each engine is designed for 15,000 seconds of operation over a life span of 30 starts. Throughout the throttling range, the ratio of the liquid oxygen to liquid hydrogen mixture is 6:1. Each nozzle area ratio is 77.5:1. The engines are 14 feet long and 7.5 feet in diameter at the nozzle exit. Overall, a space shuttle main engine weighs approximately 7,000 pounds.

The main engines can be throttled over a range of 67 to 109 percent of their rated power level in 1-percent increments. A value of 100 percent corresponds to a thrust level of 375,000 pounds at sea level and 470,000 pounds in a vacuum; 104 percent corresponds to 393,800 pounds at sea level and 488,800 pounds in a vacuum; 109 percent corresponds to 417,300 pounds at sea level and 513,250 pounds in a vacuum.

At sea level, flow separation in the nozzle reduces the engine throttling range, prohibiting operation of the engine at its minimum 67-percent throttle setting. All three main engines receive the same throttle command at the same time. Normally, these come automatically from the orbiter general-purpose computers (GPCs) through the engine controllers. During certain contingency situations, engine throttling may be controlled manually through the pilot's speedbrake/thrust controller. SSME throttling reduces vehicle loads during maximum aerodynamic pressure and limits vehicle acceleration to a maximum of 3 g's during ascent.

Hydraulically powered gimbal actuators allow each engine to be gimballed in the pitch and yaw axes for thrust vector control.

The SSME major components are the fuel and oxidizer turbopumps, preburners, a hot gas manifold, main combustion chamber, nozzle, oxidizer heat exchanger, and propellant valves.



605.cvs

Main Engine Fuel Flow

Phase II, Block I, and Block II SSMEs

Currently there are two types of SSMEs in fleet, Phase II and Block I. The Phase II SSME has been flying since the STS-26 mission. The Block I SSME is a modification to the older Phase II SSME and has been flying with the Phase I SSME since the STS-70 mission.

The modifications to the Phase II SSMEs are designed to improve the safety and reliability of the engine. The modifications to the Block II SSME include a new high-pressure oxidizer turbopump (HPOT), a two-duct powerhead, and a single coil heat exchanger. The thrust and specific impulse for the Phase II and Block I SSMEs are approximately equal.

Design and testing are also underway on the Block II SSME. The Block II engine will incorporate all of the improvements of the Block I engine, plus a new high-pressure fuel

turbopump (HPFT) and a large throat main combustion chamber. The first flight of the Block II SSME is scheduled for 1997.

Fuel Turbopumps

Low-Pressure Fuel Turbopump

The low-pressure fuel turbopump is an axial-flow pump driven by a two-stage axial flow turbine powered by gaseous hydrogen. It boosts liquid hydrogen pressure from 30 psia to 276 psia and supplies the high-pressure fuel turbopump. During engine operation, this pressure increase allows the high-pressure fuel turbopump to operate at high speeds without cavitating. The low-pressure fuel turbopump operates at approximately 16,185 rpm, measures approximately 18 by 24 inches, and is flange-mounted to the SSME at the inlet to the low-pressure fuel duct.

High-Pressure Fuel Turbopump

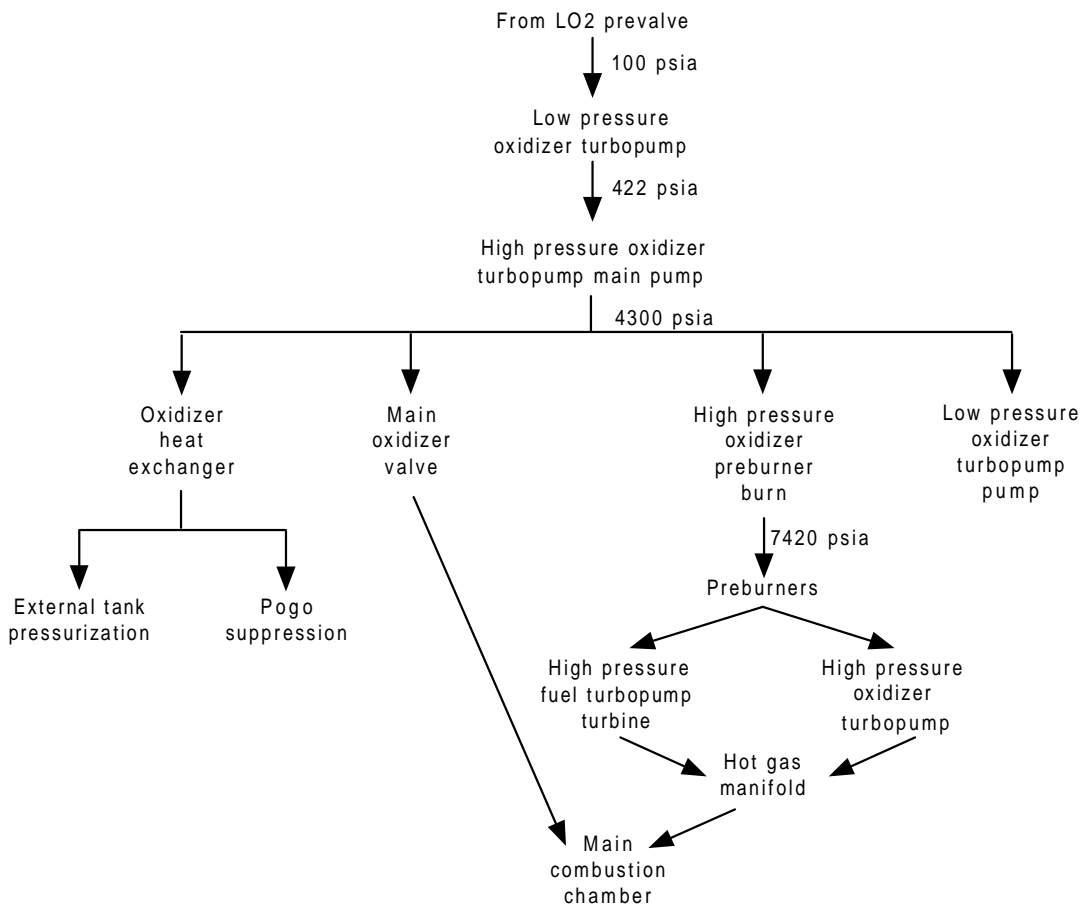
The high-pressure fuel turbopump, a three-stage centrifugal pump driven by a two-stage, hot-gas turbine, boosts liquid hydrogen pressure from 276 psia to 6,515 psia. It operates at approximately 35,360 rpm. The discharge flow from the high-pressure turbopump is routed through the main fuel valve and then splits into three flow paths. One path is through the jacket of the main combustion chamber, where the hydrogen is used to cool the chamber walls, and then to the low-pressure fuel turbopump to drive its turbine. The second flow path, through the chamber coolant valve, supplies liquid hydrogen to the preburner combustion chambers and also cools the hot gas manifold. The third hydrogen flow path is used to cool the engine nozzle. It then joins the second flow path from the chamber coolant

valve. The high-pressure fuel turbopump is approximately 22 by 44 inches and is flanged to the hot-gas manifold.

Oxidizer Turbopumps

Low-Pressure Oxidizer Turbopump

The low-pressure oxidizer turbopump is an axial-flow pump driven by a six-stage turbine powered by liquid oxygen. It boosts the liquid oxygen pressure from 100 psia to 422 psia. The flow is supplied to the high-pressure oxidizer turbopump to permit it to operate at high speeds without cavitating. The low-pressure oxidizer turbopump operates at approximately 5,150 rpm, measures approximately 18 by 18 inches, and is flange-mounted to the orbiter propellant ducting.



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Main Engine Oxidizer Flow

High-Pressure Oxidizer Turbopump

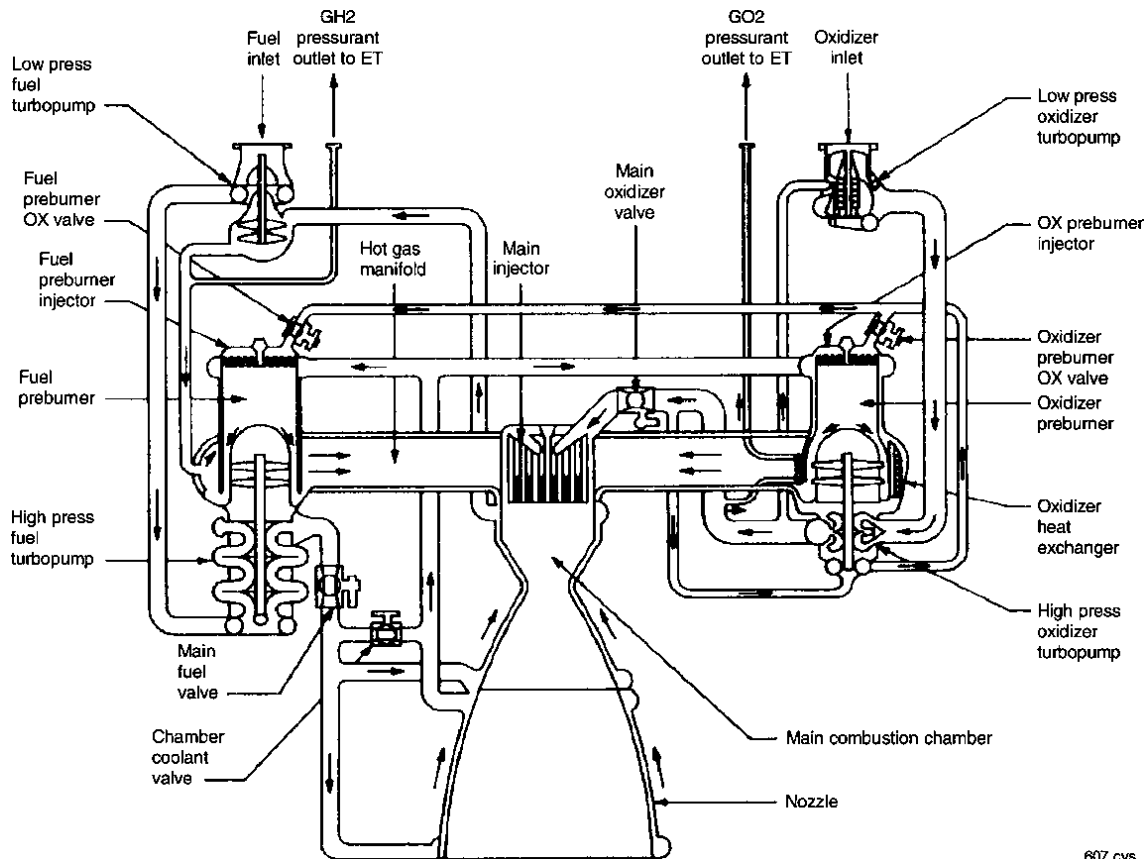
The high-pressure oxidizer turbopump consists of two single-stage centrifugal pumps (a main pump and a preburner pump) mounted on a common shaft and driven by a two-stage, hot-gas turbine. The main pump boosts liquid oxygen pressure from 422 psia to 4,300 psia while operating at approximately 28,120 rpm. The high-pressure oxidizer turbopump discharge flow splits into several paths, one of which is routed to drive the low-pressure oxidizer turbopump turbine. Another path is routed through the main oxidizer valve and enters the main combustion chamber. Another small flow path is tapped off and sent to the oxidizer heat exchanger, where it is vaporized and then used to pressurize the external tank. The final path enters the preburner boost pump to raise the liquid oxygen's pressure from 4,300 psia to 7,420 psia at the inlet to the liquid oxygen preburner. The high-pressure oxidizer turbopump measures approximately 24 by 36 inches. It is flanged to the hot-gas manifold.

Bellows

The low-pressure oxygen and low-pressure fuel turbopumps are mounted 180° apart on the engine. The lines from the low-pressure turbopumps to the high-pressure turbopumps contain flexible bellows that enable them to flex when loads are applied. This prevents them from cracking during engine operations.

Helium Purge

Because the high-pressure oxidizer turbopump turbine and pumps are mounted on a common shaft, mixing the fuel-rich hot gas in the turbine section and the liquid oxygen in the main pump could create a hazard. To prevent this, the two sections are separated by a cavity that is continuously purged by the MPS engine helium supply during engine operation. Two seals, one located between the turbine section and the cavity, and the other between the pump section and cavity, minimize leakage into the cavity.



Main Engine Schematic

WARNING

Depletion of the MPS helium supply or closure of both MPS isolation valves will cause loss of helium pressure in the cavity separating the fuel-rich hot gas and the liquid oxygen in the main pump. This condition results in an automatic engine shutdown if limits are enabled. If limits are inhibited, leakage through one or both of the seals and mixing of the propellants could result in uncontained engine damage when helium pressure is lost.

Hot Gas Manifold

The hot-gas manifold is the structural backbone of the engine. It supports the two preburners, the high-pressure turbopumps, and the main combustion chamber. Hot gas generated by the preburners, after driving the high-pressure turbopumps, passes through the hot-gas manifold on the way to the main combustion chamber.

Preburners

The oxidizer and fuel preburners are welded to the hot-gas manifold. Liquid hydrogen and liquid oxygen from the high-pressure turbopumps enter the preburners and are mixed so that efficient combustion can occur. The preburners produce the fuel-rich hot gas that passes through the turbines to generate the power to operate the high-pressure turbopumps. The oxidizer preburner's outflow drives a turbine that is connected to the high-pressure oxidizer turbopump and the oxidizer preburner boost pump. The fuel preburner's outflow drives a turbine connected to the high-pressure fuel turbopump.

Main Combustion Chamber

Each engine main combustion chamber receives fuel-rich hot gas from the fuel and oxidizer preburners. The high pressure oxidizer turbopump supplies liquid oxygen to the combustion chamber where it is mixed with fuel-rich gas by the main injector. A small augmented spark igniter chamber is located in the center of the injector. The dual-redundant igniter is used during the engine start sequence to initiate combustion. The igniters are turned off after approximately 3 seconds because the

combustion process is self-sustaining. The main injector and dome assembly are welded to the hot-gas manifold. The main combustion chamber is bolted to the hot-gas manifold. The combustion chamber, as well as the nozzle, is cooled by gaseous hydrogen flowing through coolant passages.

The nozzle assembly is bolted to the main combustion chamber. The nozzle is 113 inches long, with an exit plane of 94 inches. The physical dimension of the nozzle creates a 77.5:1 expansion ratio. A support ring welded to the forward end of the nozzle is the engine attach point to the engine heat shield. Thermal protection is provided for the nozzles to protect them from the high heating rates experienced during the launch, ascent, on-orbit, and entry phases. The insulation consists of four layers of metallic batting covered with a metallic foil and screening.

Oxidizer Heat Exchanger

The oxidizer heat exchanger converts liquid oxygen to gaseous oxygen for tank pressurization and pogo suppression. The heat exchanger receives its liquid oxygen from the high-pressure oxidizer turbopump discharge flow.

Pogo Suppression System

A pogo suppression system prevents the transmission of low-frequency flow oscillations into the high-pressure oxidizer turbopump and, ultimately, prevents main combustion chamber pressure (engine thrust) oscillation. Flow oscillations transmitted from the vehicle are suppressed by a partially filled gas accumulator, which is attached by flanges to the high-pressure oxidizer turbopump's inlet duct.

The system consists of a 0.6-cubic-foot accumulator with an internal standpipe, helium pre-charge valve package, gaseous oxygen supply valve package, and four recirculation isolation valves.

During engine start, the accumulator is charged with helium 2.4 seconds after the start command to provide pogo protection until the engine heat exchanger is operational, and gaseous oxygen is available. The accumulator is partially chilled by liquid oxygen during the engine chill-down

operation. It fills to the overflow standpipe line inlet level, which is sufficient to preclude gas ingestion at engine start. During engine operation, the accumulator is charged with a continuous gaseous oxygen flow.

The liquid level in the accumulator is controlled by an internal overflow standpipe, which is orificed to regulate the gaseous oxygen overflow at varying engine power levels. The system is sized to provide sufficient supply of gaseous oxygen at the minimum flow rate and to permit sufficient gaseous oxygen overflow at the maximum pressure transient in the low-pressure oxidizer turbopump discharge duct. Under all other conditions, excess gaseous and liquid oxygen are recirculated to the low-pressure oxidizer turbopump inlet through the engine oxidizer bleed duct. The pogo accumulator is also pressurized at engine shutdown to provide a positive pressure at the high-pressure oxidizer turbopump inlet. The post-charge prevents turbine overspeed in the zero-gravity environment.

CAUTION

Insufficient helium supply for engine shutdown could result in engine damage during shutdown. A pre-MECO manual shutdown may be required if a leak develops in the helium system.

Valves

Each engine has five propellant valves (oxidizer preburner oxidizer, fuel preburner oxidizer, main oxidizer, main fuel, and chamber coolant) that are hydraulically actuated and controlled by electrical signals from the engine controller. They can be fully closed by using the MPS engine helium supply system as a backup actuation system.

High-pressure oxidizer turbopump and high-pressure fuel turbopump turbine speed depends on the position of the oxidizer and fuel preburner oxidizer valves. The engine controller uses the preburner oxidizer valves to control engine thrust by regulating the flow of liquid oxygen to the preburners. The oxidizer and fuel preburner oxidizer valves increase or decrease the liquid oxygen flow into the preburner, thereby increasing or decreasing

preburner chamber pressure and high-pressure oxidizer turbopump and high-pressure fuel turbopump turbine speed. This directly affects liquid oxygen and gaseous hydrogen flow into the main combustion chamber, which in turn can increase or decrease engine thrust. The fuel preburner oxidizer valve is used to maintain a constant 6:1 propellant mixture ratio.

The main oxidizer valve controls liquid oxygen flow into the engine combustion chamber. The main fuel valve controls the total liquid hydrogen flow into the engine cooling circuit, the preburner supply lines, and the low-pressure fuel turbopump turbine. When the engine is operating, the main valves are fully open.

A chamber coolant valve on each engine combustion chamber coolant bypass duct regulates the amount of gaseous hydrogen allowed to bypass the nozzle coolant loop to control engine temperature. The chamber coolant valve is 100 percent open before engine start, and at power levels between 100 and 109 percent. For power levels between 67 and 100 percent, the valve's position will range from 68.3 to 100 percent open.

Propellant Dump

The main oxidizer valve is opened to allow residual liquid oxygen to be dumped overboard through the engine nozzle after engine shutdown. Both liquid hydrogen fill/drain valves, as well as the fuel bleed valve, are opened after engine shutdown to allow residual liquid hydrogen to drain overboard.

Space Shuttle Main Engine Controllers

The controller is a pressurized, thermally conditioned electronics package attached to the thrust chamber and nozzle coolant outlet manifolds on the low-pressure fuel turbopump side of the engine. Each controller contains two redundant digital computer units, referred to as units A and B. Normally, A is in control, and unit B electronics are active, but not in control. Instructions to the engine control elements are updated 50 times per second (every 20 milliseconds). Engine reliability is enhanced by a dual-redundant system that allows normal digital computer unit operation after the first

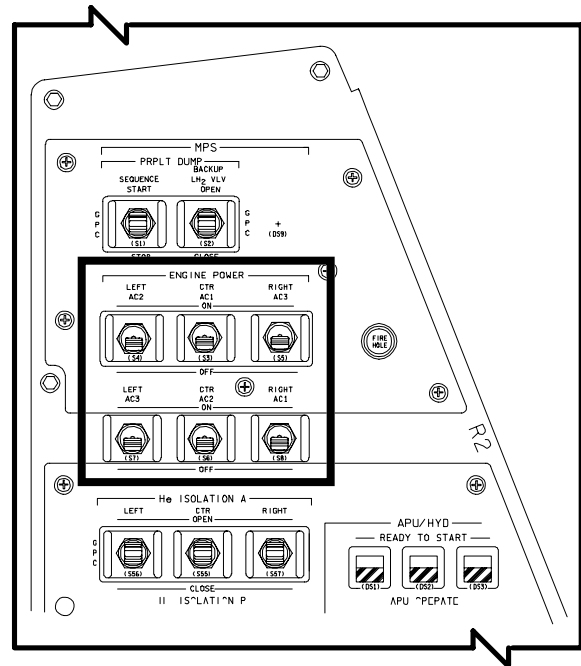
failure and a fail-safe shutdown after a second failure. High-reliability electronic parts are used throughout the controller. The digital computer is programmable, allowing engine control equations and constants to be modified by changing the software.

The controller is packaged in a sealed, pressurized chassis and is cooled by convection heat transfer through pin fins as part of the main chassis. The electronics are distributed on functional modules with special thermal and vibration protection.

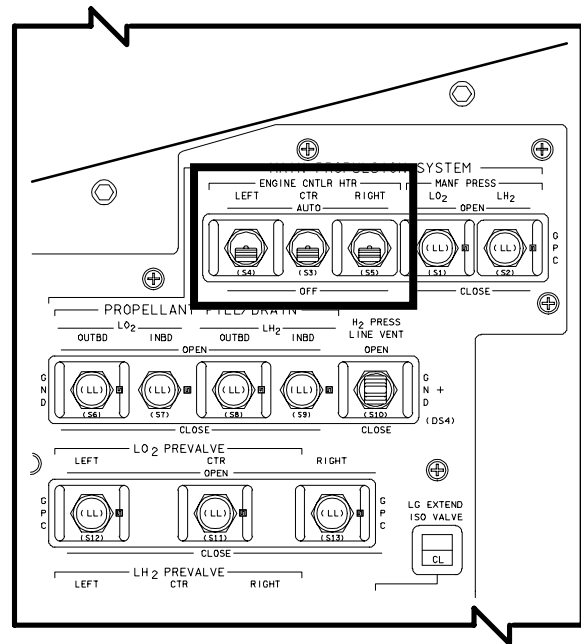
Operating in conjunction with engine sensors, valves, actuators, and spark igniters, the controllers form a self-contained system for engine control, checkout, and monitoring. The controller provides engine flight readiness verification, engine start and shutdown sequencing, closed-loop thrust and propellant mixture ratio control, sensor excitation, valve actuator and spark igniter control signals, engine performance limit monitoring, and performance and maintenance data. The controller also provides onboard engine checkout, response to vehicle commands, and transmission of engine status.

Controller power is supplied by the three ac buses in a manner that protects their redundancy. Each computer unit within a controller receives its power from a different bus. The buses are distributed among the three controllers such that the loss of any two buses will result in the loss of only one engine. The digital computer units require all three phases of an ac bus to operate. There are two MPS ENGINE POWER switches on panel R2 for each engine controller (LEFT, CTR, RIGHT); the top switch is for digital computer unit A, and the bottom switch is for digital computer unit B. Cycling an MPS ENGINE POWER switch to OFF and back to ON will cause the affected digital computer unit to stop processing.

The MAIN PROPULSION SYSTEM ENGINE CNTLR HTR LEFT, CTR, RIGHT switches on panel R4 are non-functional. The heaters were not installed in Block II controllers due to analysis that showed the Block I heaters were not required.



MPS ENGINE POWER Switches on Panel R2



MAIN PROPULSION SYSTEM ENGINE CNTLR HTR Switches on Panel R4

Command and Data Flow

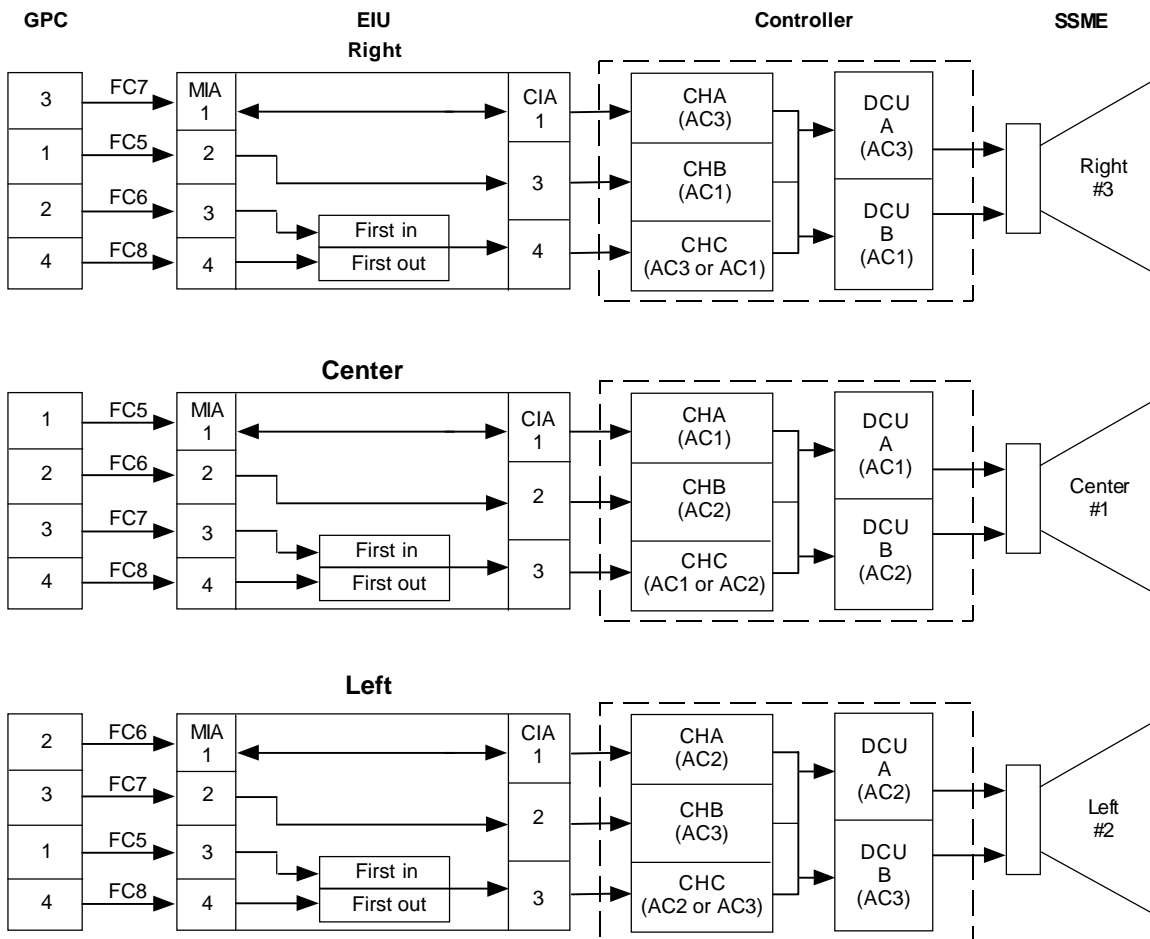
Command Flow

Each controller receives commands transmitted by the GPCs through its own engine interface unit (EIU), a specialized multiplexer/demultiplexer (MDM) that interfaces with the GPCs and with the engine controller. When engine commands are received by the unit, the data are held in a buffer until the GPCs request data; the unit then sends the data to each GPC. Each engine interface unit is dedicated to one SSME and communicates only with the engine controller that controls its SSME. The three units have no interface with each other.

The engine interface units are powered through the EIU switches on panel O17. If a unit loses power, its corresponding engine cannot receive

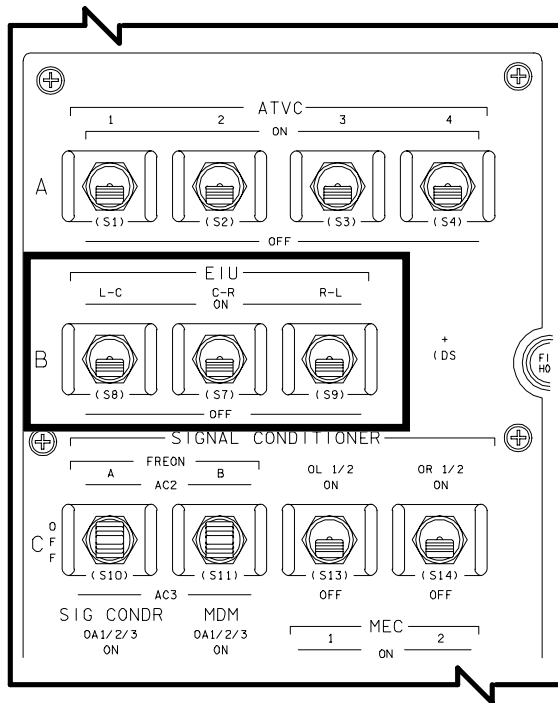
any throttle, shut down, or dump commands, and will not be able to communicate with the GPCs. As a result, the controller will maintain the last valid command until it is shut down manually via the MPS ENGINE POWER switches on panel R2.

Each orbiter GPC, operating in a redundant set, issues engine commands from resident SSME subsystem operating programs to the EIUs for transmission to their corresponding engine controllers. Engine commands are output over the GPC's assigned flight-critical data bus (a total of four GPCs outputting over four flight-critical data buses). Therefore, each EIU will receive four commands. The nominal ascent configuration has GPCs 1, 2, 3, and 4 outputting on flight-critical data buses 5, 6, 7, and 8, respectively. Each data bus is connected to one multiplexer interface adapter in each EIU.



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Main Engine Command Flow



EIU Switches on Panel O17

The EIU checks the received engine commands for transmission errors. If there are none, the EIU passes the validated engine commands on to the controller interface assemblies, which output the validated engine commands to the engine controller. An engine command that does not pass validation is not sent to the controller interface assembly. Instead, it is dead-ended in the multiplexer interface adapter. Commands that come through multiplex interface adapters 1 and 2 are sent to controller interface assemblies 1 and 2 respectively. Commands that come to multiplex interface adapters 3 and 4 pass through controller interface assembly 3 data-select logic. This logic outputs the command that arrives at the interface first. The other command is dead-ended. The selected command is output through controller interface assembly 3. In this manner, the EIU reduces the four input commands to three output commands.

The engine controller vehicle interface electronics receive the three engine commands, check for transmission errors (hardware validation), and send controller hardware-validated engine commands to the controller channel A and B electronics. Normally, channel A electronics are in control, with channel B electronics active, but not in control. If channel

A fails, channel B will assume control. If channel B subsequently fails, the engine controller will pneumatically shut the engine down. If two or three commands pass voting, the engine controller will issue its own commands to accomplish the function requested by the orbiter GPCs. If command voting fails, and two or all three commands fail, the engine controller will maintain the last command that passed voting, and the GPC will issue an MPS CMD C (L, R) fault message (PASS CRT only pre-BFS engage) and light the yellow MAIN ENGINE STATUS light on panel F7.

The backup flight system (BFS) computer, GPC 5, contains SSME hardware interface program applications software. When the four primary GPCs are in control, GPC 5 does no commanding. When GPC 5 is in control, the BFS sends commands to, and requests data from, the engine interface unit; in this configuration, the four primary GPCs neither command nor listen. The BFS, when engaged, allows GPC 5 to command flight-critical buses 5, 6, 7, and 8 for main engine control through the SSME hardware interface program, which performs the same main engine command functions as the SSME subsystem operating program. The command flow through the engine interface units and engine controllers is the same when GPC 5 is engaged as for the four-GPC redundant set.

Data Flow

The engine controller provides all the main engine data to the GPCs. Sensors in the engine supply pressures, temperatures, flow rates, turbopump speeds, valve positions, and engine servovalve actuator positions to the engine controller. The engine controller assembles these data into a vehicle data table and adds other status data. The vehicle data tables output via channels A and B to the vehicle interface electronics for transmission to the engine interface units. The vehicle interface electronics output data over both the primary and secondary data paths.

The vehicle data table is sent by the controller to the engine interface unit. There are only two data paths versus three command paths between the engine controller and the engine interface unit. The data path that interfaces

with controller interface assembly 1 is called primary data. Primary data consist of the first 32 words of the SSME vehicle data table. Secondary data is the path that interfaces with controller interface assembly 2. Secondary data consist of the first six words of the vehicle data table. Primary and secondary data are held in buffers until the GPCs send a primary and secondary data request command to the engine interface units. Primary data are output only through multiplex interface adapter 1 on each engine interface unit. Secondary data are output only through multiplex interface adapter 4 on each engine interface unit.

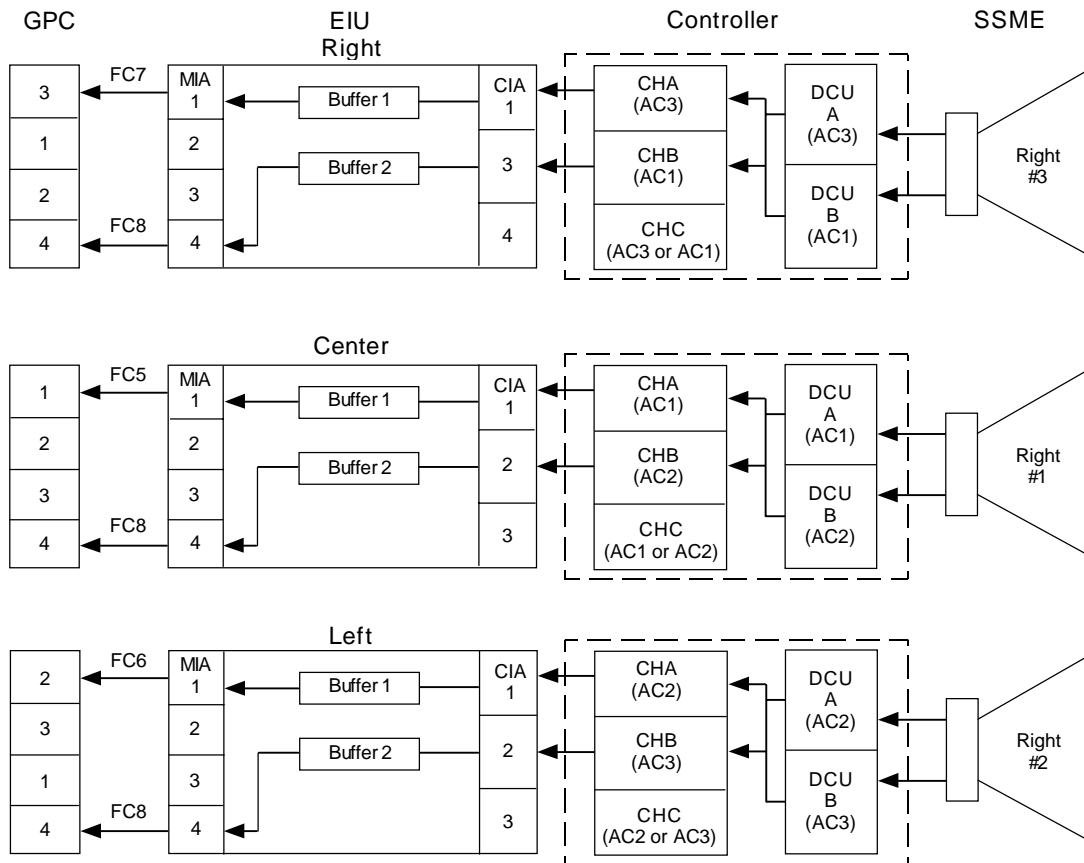
At T minus zero, the orbiter GPCs request both primary and secondary data from each engine interface unit. For no failures, only primary data are looked at. If there is a loss of primary data (which can occur between the engine controller channel A electronics and the SSME subsystem operating procedure), only the secondary data are transmitted to the GPCs.

NOTE

Prelaunch loss of either primary or secondary data will result in data path failure and either an engine ignition inhibit or a launch pad shutdown of all three main engines. Post-launch, loss of both is required for a data path failure. A data path failure will cause the GPCs to issue an MPS DATA C (L, R) fault message and light the appropriate yellow MAIN ENGINE STATUS light on panel F7.

Controller Software

The two primary engine controller programs are the flight operational program and the test operational program. The flight operational program is a real-time, process-control program that processes inputs from engine sensors, controls the operation of the engine servovalves, actuators, solenoids, and spark igniters, accepts and processes vehicle commands, provides and



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Main Engine Data Flow

transmits data to the vehicle, and provides checkout and monitoring capabilities.

The test operational program supports engine testing prior to launch. Functionally, it is similar to the flight operational program but differs in implementation. The programs are modular and are defined as computer program components. Each consists of a data base organized into tables. During application of the computer program components, the programs perform data processing for failure detection and status of the vehicle. As system operation progresses through an operating phase, combinations of control functions are operative at different times. These combinations within a phase are defined as operating modes.

The checkout phase initiates active control monitoring or checkout. The standby mode in this phase puts the controller on pause while active control sequence operations are in process. Monitoring functions that do not affect engine hardware status are continually active during this mode. Such functions include processing vehicle commands, updating engine status, and self-testing the controller. During checkout, data and instructions can be loaded into the engine controller's computer memory, permitting updates to the software and data as necessary to proceed with engine-firing or checkout operations. Component checkout is also performed during this mode.

The start preparation phase consists of system purges and propellant conditioning in preparation for engine start. Purge sequence 1 mode is the first. It includes oxidizer system and intermediate seal purge operation. Purge sequence 2 mode is the second purge sequence, including fuel system purge operation and the continuation of purges initiated during purge sequence 1. Purge sequence 3 mode includes propellant recirculation (bleed valve operation). Purge sequence 4 mode includes fuel system purges and indicates that the engine is ready to enter the start phase. The engine-ready mode occurs when proper engine thermal conditions for start have been attained, and other criteria for start have been satisfied, including a continuation of the purge sequence 4 mode.

The start phase covers engine ignition operations and scheduled open-loop operation of the

propellant valves. The start initiation mode includes all functions before ignition confirm and the closing of the thrust control loop. During thrust buildup, the main combustion chamber pressure is monitored to verify closed-loop sequencing is in progress.

Main stage is automatically entered upon successful completion of the start phase. Mixture ratio control and thrust control are active.

The shutdown phase covers operations to reduce main combustion chamber pressure and drive all valves closed to effect full engine shutdown.

The post-shutdown phase is entered upon completion of SSME shutdown. During the terminate sequence, all propellant valves are closed, and all solenoid and torque motor valves are de-energized.

Propellant Management System (PMS)

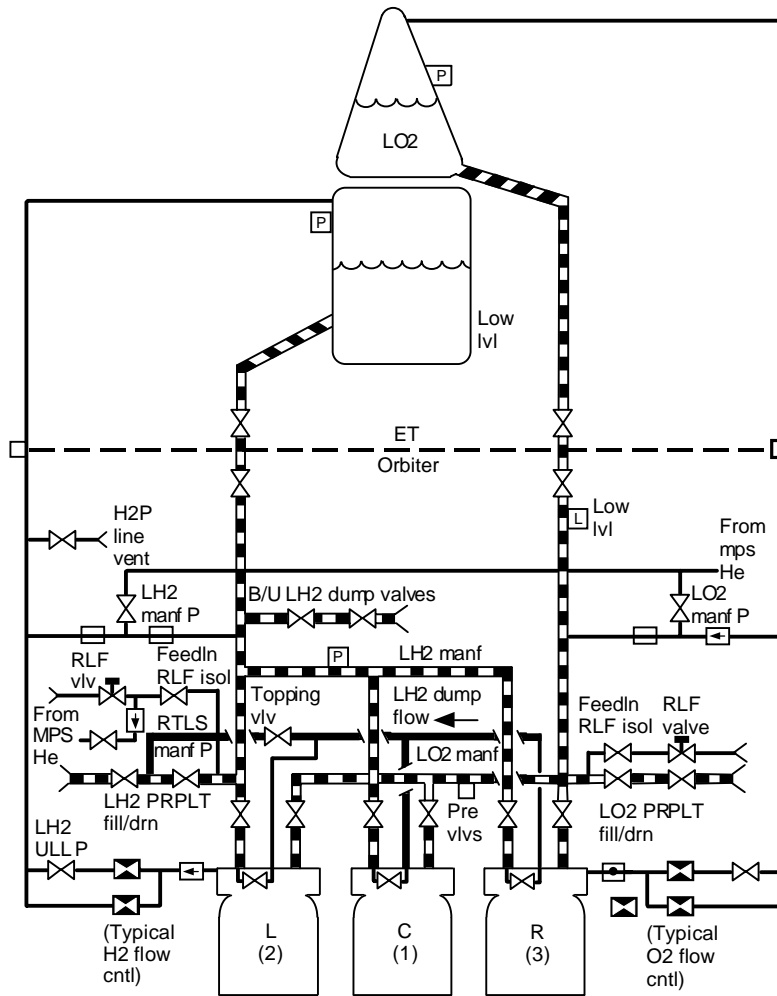
Liquid hydrogen and liquid oxygen pass from the ET to the propellant management system. The PMS consists of manifolds, distribution lines, and valves. It also contains lines needed to transport gases from the engines to the external tank for pressurization.

During prelaunch activities, this subsystem is used to load liquid oxygen and liquid hydrogen into the external tank. After MECO, the PMS is used to complete a liquid oxygen and liquid hydrogen dump and vacuum inerting. It is also used for manifold repressurization during entry.

Propellant Manifolds

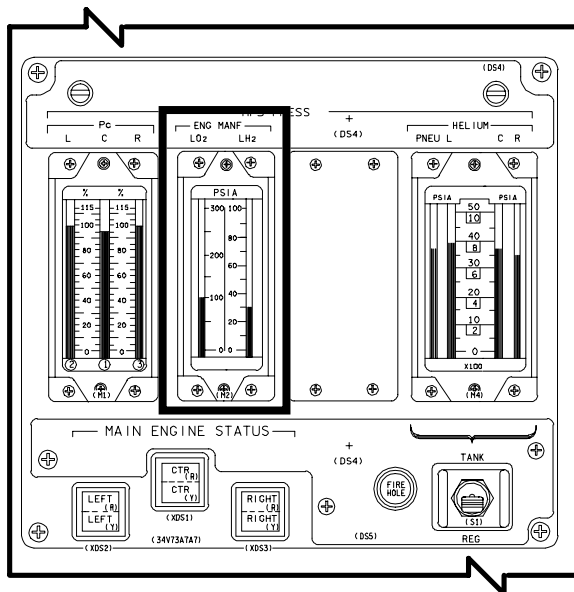
Two 17-inch-diameter MPS propellant feedline manifolds are located in the orbiter aft fuselage, one for liquid oxygen and one for liquid hydrogen. Each manifold interfaces with its respective line on the ET. Both manifolds interface with an 8-inch fill/drain line containing an inboard and outboard fill/drain valve in series. Inside the orbiter, the manifolds diverge into three 12-inch SSME feedlines, one for each engine.

Fluid pressures within the oxygen and hydrogen feedline manifolds can be monitored on the two MPS PRESS ENG MANF meters on panel F7 or on the BFS GNC SYS SUMM 1 display (MANF P LH2, LO2).



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MPS Propellant Management System Schematic from the Ascent Pocket Checklist



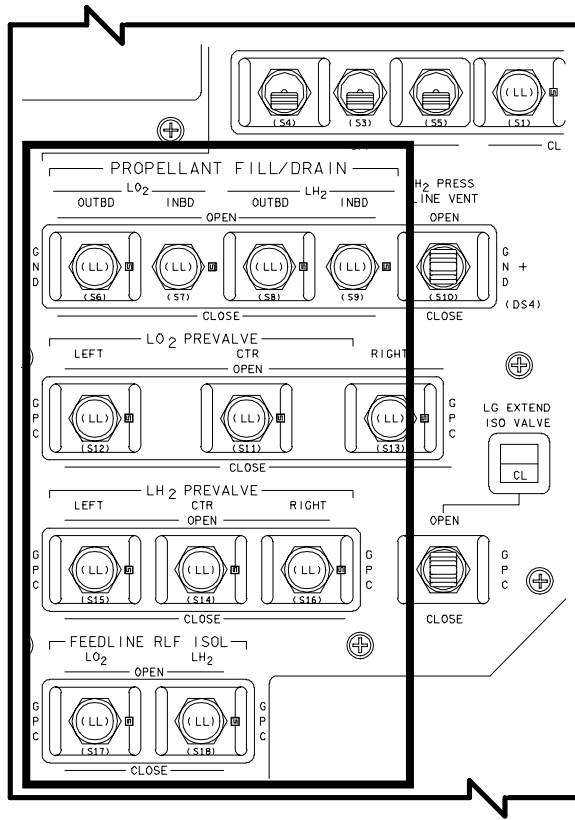
MPS PRESS ENG MANF Meters on Panel F7

Feedline Disconnect Valves

Two disconnect valves are found in each feedline where the orbiter meets the external tank. One is on the orbiter side of the manifold, and the other is on the external tank side. All four are closed automatically prior to external tank separation.

Fill/Drain Valves

Two (outboard and inboard) 8-inch-diameter liquid oxygen and liquid hydrogen fill/drain valves are connected in series. They are used to load the external tank before launch and to vacuum inert the feedline manifolds after the post-MECO MPS propellant dump. The valves can be manually controlled by the PROPELLANT FILL/DRAIN LO₂, LH₂ OUTBD, INBD switches on panel R4. Each switch has OPEN, GND, and CLOSE positions.



PROPELLANT FILL/DRAIN, REVALVE and FEEDLINE RLF ISOL Switches on Panel R4

1011/ /018		GNC SYS SUMM 1		5 000/02:46:03	
				BFS 000/00:00:00	
SURF	POS	MDM	DPS	1	2 3 4
L OB			MDM	FF	
IB				FA	
R IB				PL	
OB					
AIL					
RUD			FCS	CH	1 2 3 4
SPD BRK					
BDY FLP					
MPS	L	C	R	NAV	1 2 3 4
HE TK P	4280	4230	4240	IMU	
REG P A	784	768	768	TAC	
B	776	766	770	ADTA	
dP/dT					
ULL P LH2	42.5	42.7	42.9	MPS PNEU HE P	
L02	21.1	21.0	20.8	TK	4350
				REG	798
				ACUM	760
GH2 OUT P	70↓	50↓	40↓	MANF P LH2	46
G02 OUT T	79↓	97↓	70↓	L02	110

GNC SYSTEM SUMMARY 1

Relief Valves

Each 8-inch liquid hydrogen and liquid oxygen manifold has a 1-inch-diameter line that is routed to a feedline relief isolation valve and then to a feedline relief valve. When the feedline relief isolation valve is opened automatically after MECO, the corresponding manifold

can relieve excessive pressure overboard through its relief valve. The relief isolation valves can also be manually controlled by the MAIN PROPULSION SYSTEM FEEDLINE RLF ISOL LO₂ and LH₂ switches on panel R4. The switches have OPEN, GPC, and CLOSE positions.

Backup Liquid Hydrogen Dump Valves

The backup liquid hydrogen dump line connects the feedline manifold to an overboard port above the left wing of the orbiter. The line, designed primarily for a post-MECO liquid hydrogen dump during a return-to-launch site abort, is also used to vent the liquid hydrogen manifold after a nominal MECO. Since liquid hydrogen evaporates quickly, this vent is used to prevent pressure buildup in the hydrogen manifold from repeatedly cycling the relief valve before the propellant dump begins.

Flow through the lines is controlled by two valves in series, which are normally commanded by the GPCs. However, during OPS 1, they can be manually controlled by the MPS PRPLT DUMP BACKUP LH₂ VLV switch on panel R2, which has OPEN, GPC, and CLOSE positions. In an RTLS abort dump, liquid hydrogen is dumped overboard through a port at the outer aft fuselage's left side between the orbital maneuvering system/reaction control system pod and the upper surface of the wing. These valves are also known as the LH₂ RTLS Dump valves.

Topping Valve

This valve controls the flow of liquid hydrogen through the tank topping manifold, which is used for prelaunch liquid hydrogen tank topping and thermal conditioning. During thermal conditioning, propellants flow through the engine components to cool them for engine start.

Liquid hydrogen is loaded through the outboard fill/drain valve, circulates through the topping valve to the engines for thermal conditioning, and is pumped into the external tank for tank topping. (The part of the topping recirculation line that goes to the external tank is not shown on the pocket checklist schematic.) The topping valve can be controlled indirectly by the crew via the LH₂ inboard

FILL DRAIN switch on panel R4. When this switch is taken to OPEN, both the LH2 inboard fill drain and topping valves open.

There is no topping valve for liquid oxygen. Since liquid oxygen is harmless in the atmosphere, it is not circulated back to the external tank during thermal conditioning. Rather, it is dumped overboard through the engine liquid oxygen bleed valves and out the overboard bleed valve.

Liquid Hydrogen and Liquid Oxygen Bleed Valves

Three liquid hydrogen bleed valves, one in each engine, connect the engine internal liquid hydrogen line to the topping valve manifold. The valves are used to route liquid hydrogen through the engines during prelaunch thermal conditioning and to dump the liquid hydrogen trapped in the engines post-MECO.

There are also three liquid oxygen bleed valves that are not shown on the pocket checklist schematic. They connect the engine internal liquid oxygen lines to an overboard port and are used only during prelaunch thermal conditioning.

Prevalves

The prevalve in each of the three 12-inch feedlines to each engine isolates liquid oxygen and liquid hydrogen from each engine or permits liquid oxygen and liquid hydrogen to flow to each engine. Most of the prevalve functions are automatic, but they can also be controlled by the LO₂ and LH₂ PREVALVE, LEFT, CTR, RIGHT switches on panel R4. Each switch has OPEN, GPC, and CLOSE positions.

Ullage Pressure System

Ullage refers to the space in each tank not occupied by propellants. The ullage pressure system consists of the sensors, lines, and valves needed to route gaseous propellants from the three main engines and supply them to the external tank to maintain propellant tank pressure during engine operation.

There are two external tank pressurization manifolds, one for gaseous oxygen and one for gaseous hydrogen. During prelaunch, the manifolds are used to supply ground support pressurization of the ET using helium routed

through the T-0 umbilical. Self-sealing quick disconnects are provided at the T-0 umbilical for separation at lift-off.

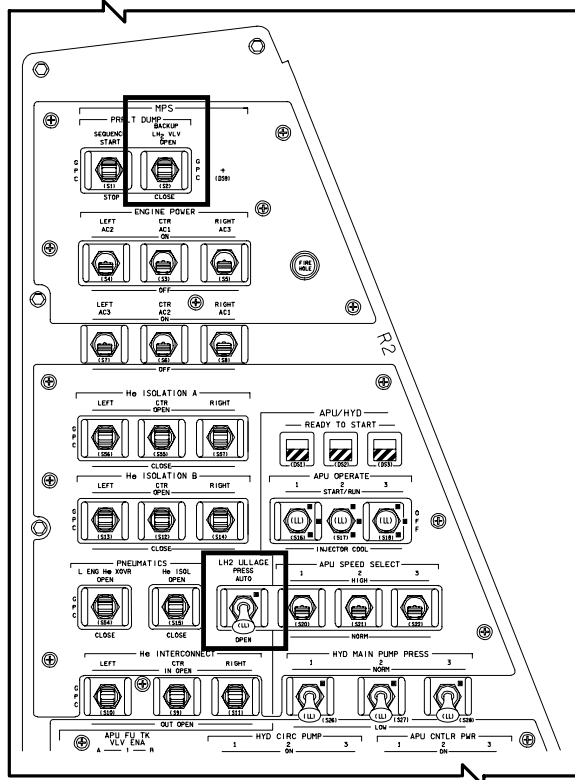
Each manifold contains three 0.63-inch-diameter pressurization lines, one from each engine. The three lines join in a common manifold prior to entering the ET.

In each SSME, a small portion of liquid oxygen from the high-pressure oxidizer turbopump main pump is diverted into the engine's oxidizer heat exchanger. The heat generated by the engine's high-pressure oxidizer turbopump converts the liquid oxygen into gaseous oxygen and directs it through a check valve to a fixed orifice and then to the ET. During ascent, the liquid oxygen tank pressure is maintained between 20 and 25 psig by the fixed orifice. If the tank pressure is greater than 30 psig, it is relieved through the liquid oxygen tank's vent and relief valve.

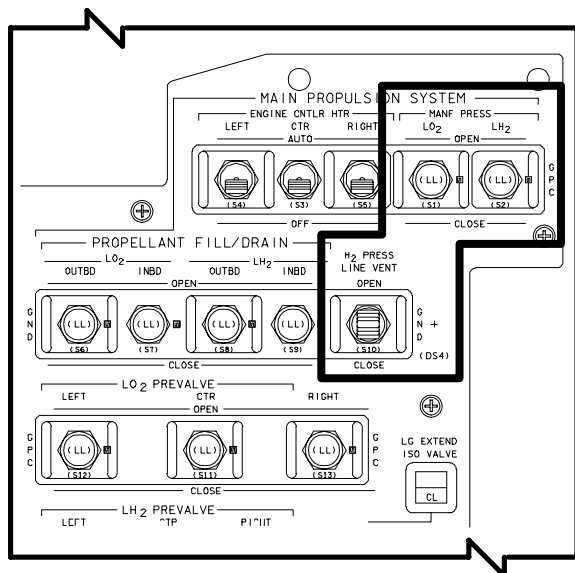
In each SSME, a small portion of gaseous hydrogen from the low-pressure fuel turbopump is directed through two check valves, two orifices, and a flow control valve before entering the ET. During ascent, the liquid hydrogen tank's pressure is maintained between 32 and 34 psia using both a variable and a fixed orifice in each SSME supply system. The active flow control valve is controlled by one of three liquid hydrogen pressure transducers. When the tank pressure decreases below 32 psia, the valve opens; when the tank pressure increases to 33 psia, the valve closes. If the tank pressure exceeds 35 psia, the pressure is relieved through the liquid hydrogen tank's vent and relief valve. If the pressure falls below 32 psia, the LH₂ ULLAGE PRESS switch on panel R2 is positioned from AUTO to OPEN, causing all three flow control valves to go to full open.

The three liquid hydrogen and three liquid oxygen ullage pressures are displayed on the BFS GNC SYS SUMM 1 display (ULL P).

The SSME/ET liquid hydrogen pressurization system also contains a line that is used to vent the liquid hydrogen pressurization manifold during inerting. It is controlled by the H₂ PRESS LINE VENT switch on panel R4. This valve is normally closed, but is positioned open during vacuum inerting for a 1-minute period. The GND position allows the launch processing system to control the valve during ground operations.



MPS PRPLT DUMP BACKUP LH₂VLV Switch and LH₂ULLAGE PRESS Switch on Panel R2



MAIN PROPULSION SYSTEM MANF PRESS and H₂ PRESS LINE VENT Switches on Panel R4

Manifold Repress Valves

The liquid hydrogen and liquid oxygen manifold repress valves route helium from the MPS helium system into the feedline manifolds. The helium pressure is used to expel propellants during the MPS propellant dump and to repressurize the propellant lines during entry. The valves can be controlled manually using the MAIN PROPULSION SYSTEM MANF PRESS switches on panel R4.

MPS Valve Types

All the valves in the MPS are either electrically or pneumatically operated. Pneumatic valves are used where large loads are encountered, such as in the control of liquid propellant flows. Electrical valves are used for lighter loads, such as the control of gaseous propellant flows.

The pneumatically actuated valves are divided into two types: type 1, which requires pneumatic pressure to open and close the valve, and type 2, which is spring-loaded to one position and requires pneumatic pressure to move to the other position.

Each type 1 valve actuator is equipped with two electrically actuated solenoid valves, which control helium pressure to an "open" or "close" port on the actuator. Energizing the solenoid valve on the open port allows helium pressure to open the pneumatic valve. Energizing the solenoid on the close port allows helium pressure to close the pneumatic valve. Removing power from a solenoid valve removes helium pressure from the corresponding port of the pneumatic actuator and allows the helium pressure trapped in that side of the actuator to vent into the aft compartment. Removing power from both solenoids allows the pneumatic valve to remain in the last commanded position. This is known as a bi-stable valve.

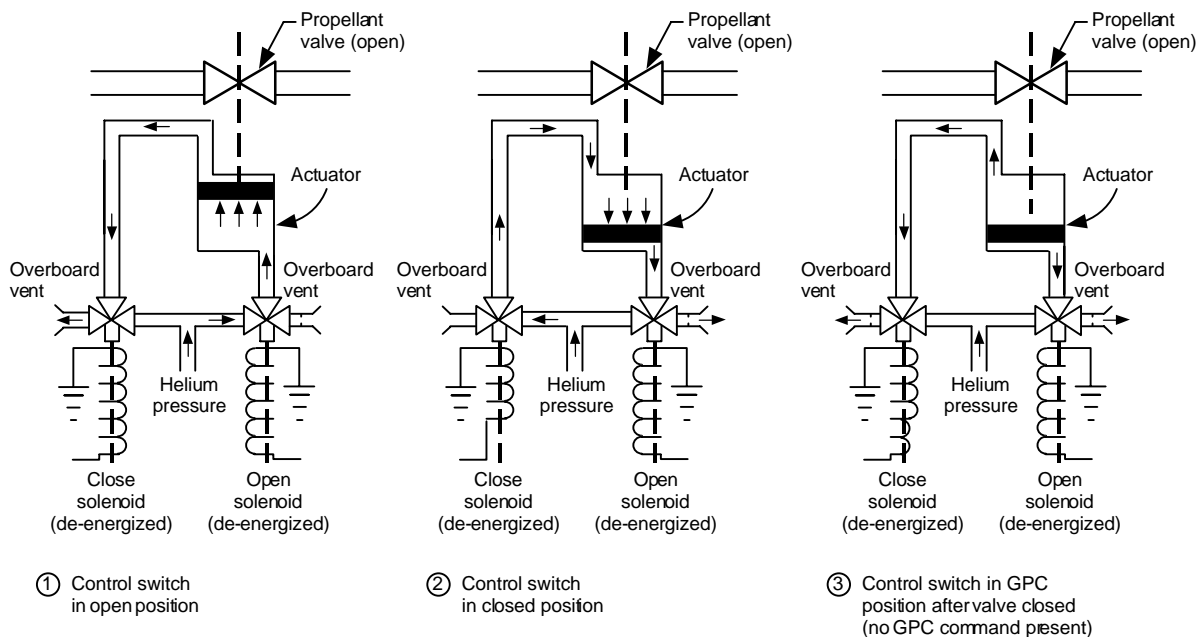
Type 1 valves are used for the liquid oxygen and liquid hydrogen feedline 17-inch umbilical disconnect valves, the liquid oxygen and liquid hydrogen prevalues, the liquid hydrogen and liquid oxygen inboard and outboard fill and drain valves, and the liquid hydrogen 4-inch recirculation disconnect valves.

Each type 2 valve is a single electrically actuated solenoid valve that controls helium pressure to either an open or a close port on the actuator. Removing power from the solenoid valve removes helium pressure from the corresponding port of the pneumatic actuator and allows helium pressure trapped in that side of the actuator to vent overboard. Spring force takes over and drives the valve to the opposite position. If the spring force drives the valve to the open position, the valve is referred to as a normally open (NO) valve. If the spring force drives the valve to a closed position, the valve is referred to as a normally closed (NC) valve.

Type 2 pneumatic valves are used for the liquid hydrogen RTLS inboard dump valve (NC), the liquid hydrogen RTLS outboard dump valve (NC), the liquid hydrogen feedline relief shutoff valve (NO), the liquid oxygen feedline relief

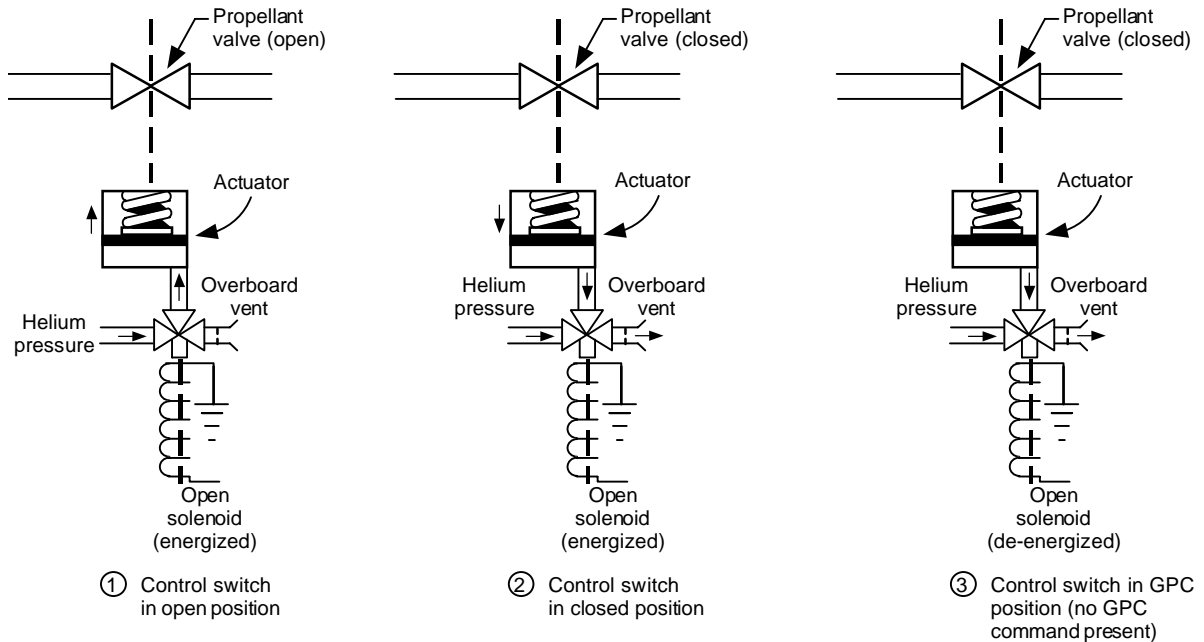
shutoff valve (NO), the three liquid hydrogen engine recirculation valves (NC), the two liquid oxygen pogo recirculation valves (NO), the liquid hydrogen topping valve (NC), the liquid hydrogen high-point bleed valve (NC), and the liquid oxygen overboard bleed valve (NO).

The electrically actuated solenoid valves are spring-loaded to one position and move to the other position when electrical power is applied. These valves also are referred to as either normally open or normally closed, depending on their position in the de-energized state. Electrically actuated solenoid valves are the gaseous hydrogen pressurization line vent valve (NC), the three gaseous hydrogen pressurization flow control valves (NO), and the three gaseous oxygen pressurization flow control valves (NO).



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Propellant Management Subsystem Typical Type 1 Pneumatically Actuated Propellant Valve



620.cvs

Propellant Management Subsystem Typical Type 2 Pneumatically Actuated Propellant Valve Helium System

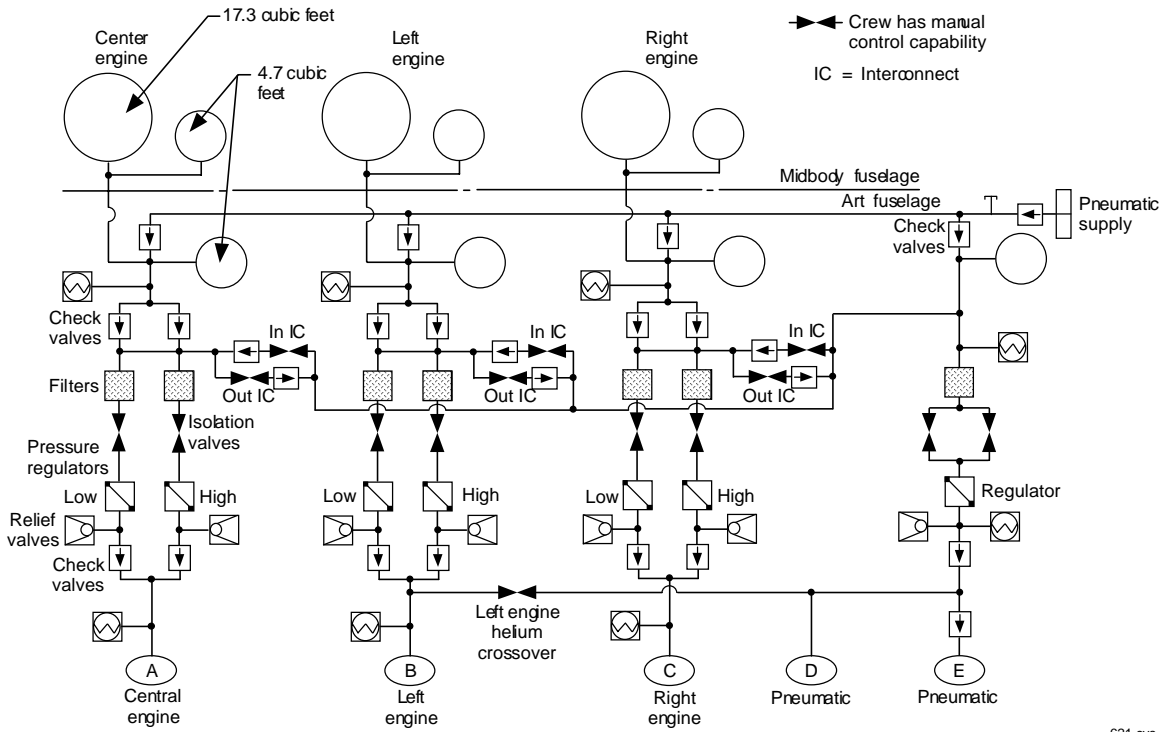
Helium System

The MPS helium system consists of seven 4.7-cubic-foot helium supply tanks, three 17.3-cubic-foot helium supply tanks, and associated regulators, check valves, distribution lines, and control valves.

The MPS helium system is used for in-flight purges within the engines, and it provides pressure for actuating engine valves during emergency pneumatic shutdowns. It also supplies pressure to actuate the pneumatically operated valves within the propellant management system. During entry, the remaining helium is used for the entry purge and repressurization. (Unlike the orbital maneuvering system and reaction control system, the MPS does not use helium to pressurize propellant tanks.)

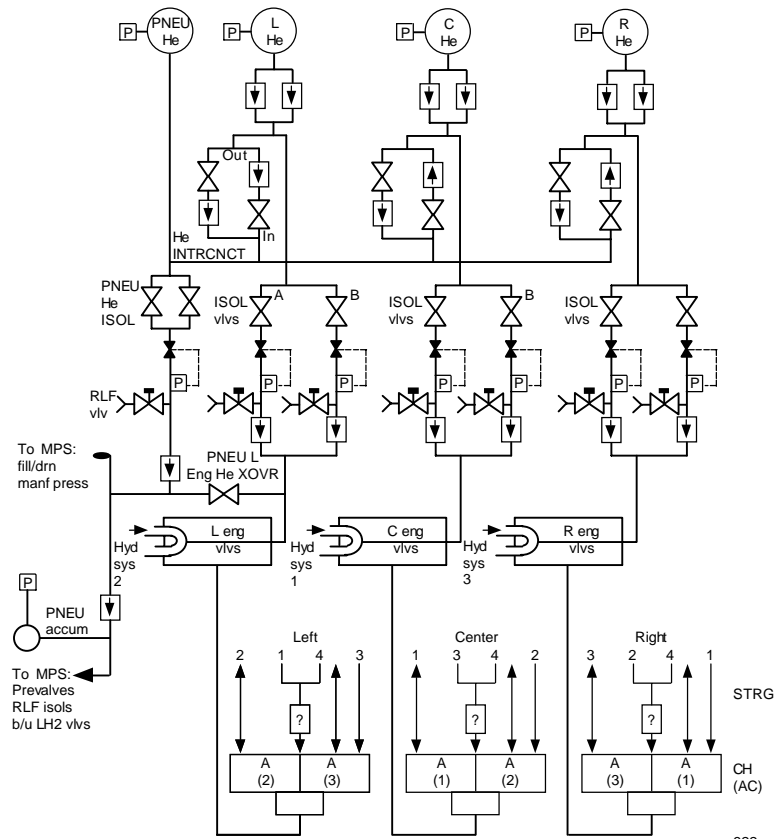
The MPS helium supply system is divided into four separate subsystems, one for each of the three main engines and a fourth pneumatic system to operate the propellant valves.

All the valves in the helium subsystem are spring-loaded to one position and electrically actuated to the other position. The supply tank isolation valves are spring-loaded to the closed position and pneumatically actuated to the open position. Valve position is controlled via electrical signals either generated by the onboard GPCs or manually by the flight crew. All the valves can be controlled automatically by the GPCs, and the flight crew can control some of the valves.



621.cvs

Helium System Storage and Supply



622.cvs

Main Propulsion System Helium Schematic from the Ascent Pocket Checklist

Helium Tanks

The tanks are composite structures consisting of a titanium liner with a fiberglass structural overwrap. The large tanks are 40.3 inches in diameter and have a dry weight of 272 pounds. The smaller tanks are 26 inches in diameter and have a dry weight of 73 pounds. The tanks are serviced before lift-off to a pressure of 4,100 to 4,500 psi.

Four of the 4.7-cubic-foot helium supply tanks are located in the aft fuselage, and the other three are located below the payload bay in the midfuselage. The three 17.3-cubic-foot helium supply tanks are also located below the payload bay in the midfuselage.

Each of the larger supply tanks is plumbed to two of the smaller supply tanks (one in the mid-body, the other in the aft body), forming three clusters of three tanks. Each set of tanks normally provides helium to only one engine and is commonly referred to as left, center, or right engine helium, depending on the engine serviced. Each set normally provides helium to its designated engine for in-flight purges and provides pressure for actuating engine valves during emergency pneumatic shutdown.

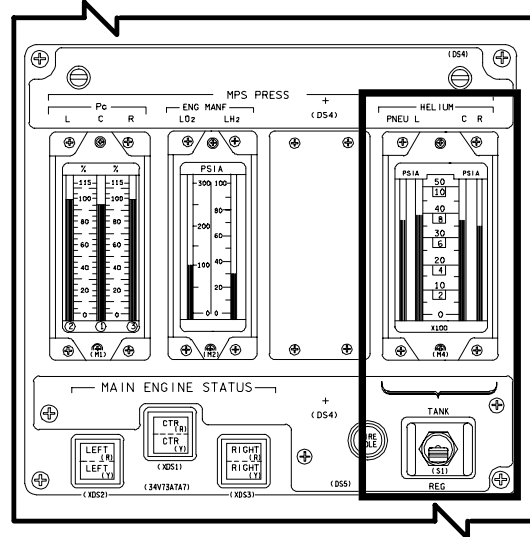
The remaining 4.7-cubic-foot helium tank is referred to as the pneumatic helium supply tank. It provides pressure to actuate all the pneumatically operated valves in the propellant management subsystem.

The helium pressure of the pneumatic, left, center, and right supply systems can be monitored on the MPS PRESS HELIUM, PNEU, L, C, R meters on panel F7 by positioning the switch below the meters to TANK. Left, center, right, and pneumatic tank pressures can be monitored on the BFS GNC SYS SUMM 1 display (MPS L, C, R HE TK P and MPS PNEU HE P TK).

Helium Isolation Valves

Eight helium supply tank isolation valves grouped in pairs control the flow of helium from the tanks. One pair of valves is connected to each of the three tank clusters, and one pair is connected to the pneumatic supply tank. In the engine helium supply tank system, each pair of isolation valves is connected in parallel, with

each valve in the pair controlling helium flow through one leg of a dual-redundant helium supply circuit. Each helium supply circuit contains two check valves, a filter, an isolation valve, a regulator, and a relief valve.



MPS PRESS HELIUM Meters and Switch on Panel F7

The two isolation valves connected to the pneumatic supply tanks are also connected in parallel. The rest of the pneumatic supply system consists of a filter, the two isolation valves, a regulator, a relief valve, and a single check valve.

Each engine helium supply isolation valve can be individually controlled by the He ISOLATION A LEFT, CTR, RIGHT, and He ISOLATION B LEFT, CTR, RIGHT switches on panel R2. The switches have OPEN, GPC, and CLOSE positions. The two pneumatic helium supply isolation valves are controlled by a single PNEUMATICS He ISOL switch on panel R2, which also has OPEN, GPC, and CLOSE positions.

Helium Pressure Regulators

Each engine helium supply tank has two pressure regulators operating in parallel. Each regulator controls pressure to within 730 to 785 psia in one leg of a dual-redundant helium supply circuit and is capable of providing all the helium needed by the main engines.

The pressure regulator for the pneumatic helium supply system is not redundant and regulates outlet pressure between 715 to 770

psig. Downstream of the pneumatic regulator are the liquid hydrogen manifold pressure regulator and the liquid oxygen manifold pressure regulator. These regulators are used only during MPS propellant dumps and manifold pressurization. Both regulators are set to provide outlet pressure between 20 and 25 psig. Flow through the regulators is controlled by the appropriate set of two normally closed manifold pressurization valves.

Downstream of each pressure regulator, with the exception of the two manifold repressurization regulators, is a relief valve. The valve protects the downstream helium distribution lines from overpressurization if the associated regulator fails fully open. The two relief valves in each engine helium supply are set to relieve at 790 to 850 psig and reseal at 785 psig.

The regulated pressure of the left, center, right, and pneumatic systems can be monitored on the BFS GNC SYS SUMM 1 display (MPS L, C, R REG P and MPS PNEU REG). They can also be displayed on the MPS PRESS HELIUM PNEU, L, C, and R meters on panel F7 by placing the switch below the meters to REG. The meters however, only display the A reg pressure. B reg pressure can only be seen on BFS GNC SYS SUMM 1.

Pneumatic Left Engine Helium Crossover Valve

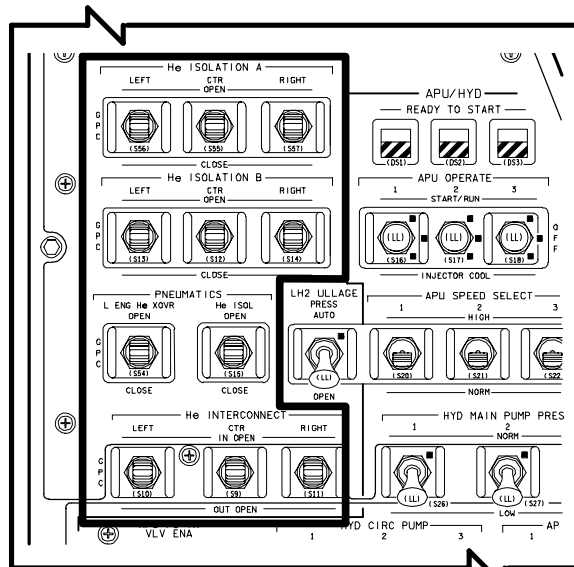
The crossover valve between the pneumatic and left engine helium systems serves as a backup for the nonredundant pneumatic pressure regulator system. In the event of a pneumatic helium regulator failure or a leak in the pneumatic helium system, the left engine helium system can provide regulated helium through the crossover valve to the pneumatic helium distribution system. The PNEUMATICS L ENG He XOVR switch is on panel R2.

Helium Interconnect Valves

Normally, each of the four helium supply systems operates independently until after MECO. Each engine helium supply has two interconnect (crossover) valves associated with it, and each valve in the pair of interconnect valves is connected in series with a check valve.

The check valves allow helium to flow through the interconnect valves in one direction only. One check valve associated with one interconnect valve controls helium flow in one direction, and the other interconnect valve and its associated check valve permit helium flow in the opposite direction. The in/open interconnect valve controls helium flow into the associated engine helium distribution system from the pneumatic distribution system. The out/open interconnect valve controls helium flow out of the associated engine helium supply system to the pneumatic distribution system.

Each pair of interconnect valves is controlled by a single switch on panel R2. Each He INTERCONNECT LEFT, CTR, RIGHT switch has three positions: IN OPEN, GPC, and OUT OPEN. With the switch in the IN OPEN position, the in/open interconnect valve is open, and the out/open interconnect valve is closed. The OUT OPEN position does the reverse. With the switch in GPC, the valves are controlled by the orbiter software.



He ISOLATION, PNEUMATICS L ENG He XOVR and He ISOL, and He INTERCONNECT Switches on Panel R2

Manifold Pressurization

Manifold pressurization valves, located downstream of the pneumatic helium pressure regulator, are used to control the flow of helium to the LO2 propellant manifold for a nominal

LO2 propellant dump and for LH2 and LO2 manifold repressurization on entry. There are four of these valves grouped in pairs. One pair controls helium pressure to the liquid oxygen propellant manifold, and the other pair controls helium pressure to the liquid hydrogen propellant manifold.

There are additional regulators just past the manifold repress valves that regulate the pneumatic helium from the normally regulated pressure of 750 psi to a lower, usable pressure. The LH2 manifolds are pressurized to 17 to 30 psig and the LO2 manifolds are pressurized to 20 to 25 psig during the MPS dump and entry manifold repressurization.

Additionally, on the LH2 propellant manifold, there are RTLS manifold pressurization valves that open on the RTLS and TAL propellant dumps to assist in removing LH2 from the manifold.

Pneumatic Control Assemblies

There is one pneumatic control assembly on each SSME. The assembly is essentially a manifold pressurized by one of the engine helium supply systems and contains solenoid valves to control and direct pressure to perform various essential functions. The valves are energized by discrete ON/OFF commands from the output electronics of the SSME controller. Functions controlled by the pneumatic control assembly include the high-pressure oxidizer turbopump intermediate seal cavity and preburner oxidizer dome purge, pogo system postcharge, and pneumatic shutdown.

MPS Hydraulic Systems

Hydraulic System Operation

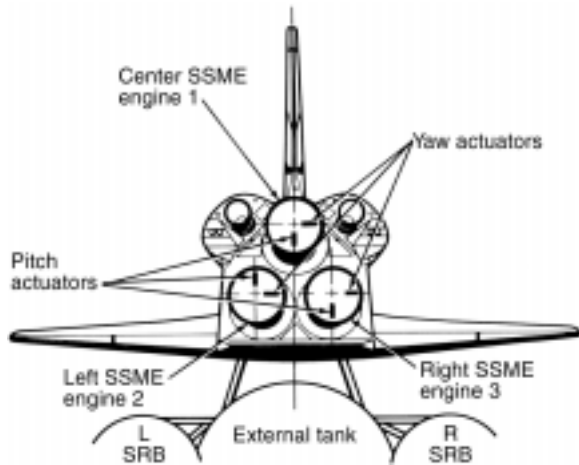
The three orbiter hydraulic systems (see Section 2.1 for details on the hydraulic system) supply hydraulic pressure to the SSME to provide thrust vector control and actuate engine valves on each SSME. The three hydraulic supply systems are distributed to the thrust vector control (TVC) valves. These valves are controlled by HYDRAULICS MPS/TVC ISOL VLV switches (one for each of the three hydraulic systems) on panel R4. A valve is opened by positioning its switch to OPEN. The

talkback indicator above each switch indicates OP when the valve is open and CL when it is closed.

When the three MPS TVC hydraulic isolation valves are opened, hydraulic pressure is applied to the five hydraulically actuated engine valves. These valves are the main fuel valve, the main oxidizer valve, the fuel preburner oxidizer valve, the oxidizer preburner oxidizer valve, and the chamber coolant valve. All hydraulically actuated engine valves on an engine receive hydraulic pressure from the same hydraulic system. The left engine valves are actuated by hydraulic system 2, the center engine valves are actuated by hydraulic system 1, and the right engine valves are actuated by hydraulic system 3. Each engine valve actuator is controlled by dual-redundant signals: channel A/engine servovalve 1 and channel B/engine servovalve 2 from that engine's controller electronics. As a backup, all the hydraulically actuated engine valves on an engine are supplied with helium pressure from the helium subsystem left, center, and right engine helium tank supply system.

Hydraulic Lockup

Hydraulic lockup is a condition in which all the propellant valves on an engine are hydraulically locked in a fixed position. This is a built-in protective response of the SSME valve actuator/control circuit. It takes effect any time low hydraulic pressure or loss of control of one or more of the five hydraulically actuated main engine valves renders closed-loop control of engine thrust or propellant mixture ratio impossible. Hydraulic lockup allows an engine to continue to burn in a safe condition. The affected engine will continue to operate at the approximate power level in effect at the time hydraulic lockup occurred. Once an engine is in a hydraulic lockup, any subsequent shutoff commands, whether nominal or premature, will cause a pneumatic engine shutdown. Hydraulic lockup does not affect the capability of the engine controller to monitor critical operating parameters or issue an automatic shutdown if an operating limit is out of tolerance, but the engine shutdown would be accomplished pneumatically.



Main Engine Gimbal Actuators

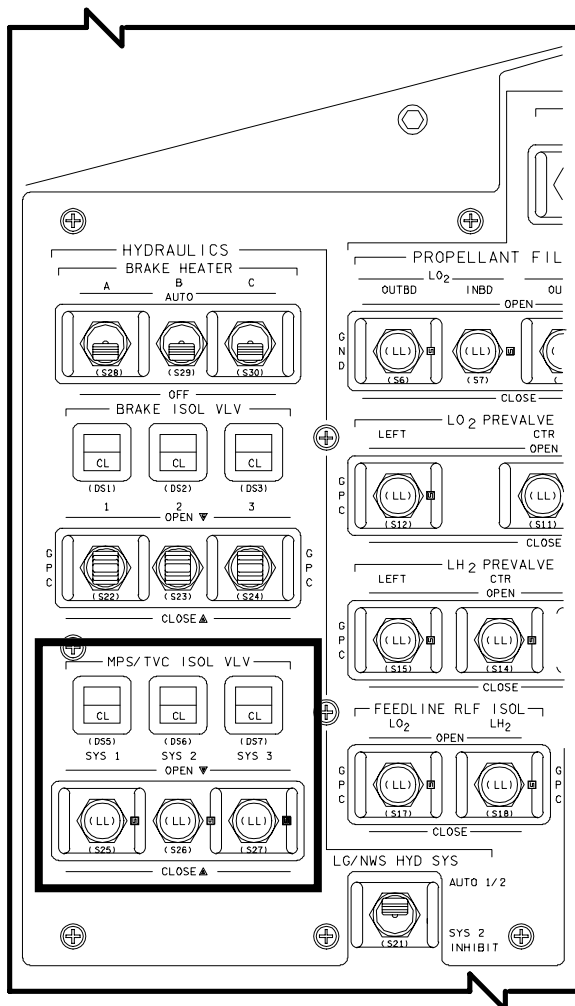
Thrust Vector Control

The three MPS thrust vector control valves must also be opened to supply hydraulic pressure to the six main engine TVC actuators. There are two servoactuators per SSME: one for yaw and one for pitch. Each actuator is fastened to the orbiter thrust structure and to the powerheads of the three SSMEs.

Two actuators per engine provide attitude control and trajectory shaping by gimbaling the SSMEs in conjunction with the solid rocket boosters during first-stage and without the solid rocket boosters during second-stage ascent. Each SSME servoactuator receives hydraulic pressure from two of the three orbiter hydraulic systems; one system is the primary system, and the other is a standby system. Each servoactuator has its own hydraulic switching valve. The switching valve receives hydraulic pressure from two of the three orbiter hydraulic systems and provides a single source to the actuator.

Normally, the primary hydraulic supply is directed to the actuator; however, if the primary system were to fail and lose hydraulic pressure, the switching valve would automatically switch over to the standby system, and the actuator would continue to function. The left engine's pitch actuator uses hydraulic system 2 as the primary and hydraulic system 1 as the standby. The engine's yaw actuator uses hydraulic system 1 as the primary and hydraulic system 2 as the standby. The center engine's pitch actuator uses hydraulic system 1 as the primary and hydraulic system 3 as the standby, and the yaw actuator uses hydraulic system 3 as the primary and hydraulic system 1 as the standby. The right engine's pitch actuator uses hydraulic system 3 as the primary and hydraulic system 2 as the standby. Its yaw actuator uses hydraulic system 2 as the primary and hydraulic system 3 as the standby.

The SSME servoactuators change each main engine's thrust vector direction as needed during the flight sequence. The three pitch actuators gimbal the engine up or down a maximum of 10.5° from the installed null position. The three yaw actuators gimbal the engine left or right a maximum of 8.5° from the installed null position. The installed null position for



MPS/TVC ISOL VLV Switches and Talkbacks on Panel R4

the left and right main engines is 10° up from the X axis in a negative Z direction and 3.5° outboard from the engine centerline parallel to the X axis. The center engine's installed null position is 16° above the X axis for pitch and on the X axis for yaw. When any engine is installed in the null position, the other engines do not come in contact with it.

There are three actuator sizes for the main engines. The piston area of the center engine upper pitch actuator is 24.8 square inches, its stroke is 10.8 inches, it has a peak flow of 50 gallons per minute, and it weighs 265 pounds. The piston area of the two lower pitch actuators is 20 square inches, their stroke is 10.8 inches, their peak flow is 45 gallons per minute, and they weigh 245 pounds. All three yaw actuators have a piston area of 20 square inches, a stroke of 8.8 inches, a peak flow of 45 gallons per minute, and weigh 240 pounds. The minimum gimbal rate is 10° per second; the maximum rate is 20° per second.

Detailed information about ascent thrust vector control is provided in Section 2.13.

Hydraulic System Isolation On Orbit

The HYDRAULICS MPS/TVC ISOL VLV SYS 1, SYS 2, and SYS 3 switches on panel R4 are positioned to CLOSE during on-orbit operations to protect against hydraulic leaks downstream of the isolation valves. In addition, there is no requirement to gimbal the main engines from the stow position. During on-orbit operations when the MPS TVC valves are closed, the hydraulic pressure supply and return lines within each MPS TVC component are interconnected to enable hydraulic fluid to circulate for thermal conditioning.

Malfunction Detection

There are three separate means of detecting malfunctions within the MPS: the engine controllers, the hardware caution and warning system, and the software C/W system.

The SSME controller, through its network of sensors, has access to numerous engine operating parameters. A group of these parameters has been designated critical operating parameters, and special limits defined

for these parameters are monitored by the main engine controller. Several MPS parameters are monitored by hardware and software. If a violation of any hardware limit is detected, the caution and warning system will illuminate the red MPS caution and warning light on panel F7. The light will be illuminated if any of the following conditions are sensed by the hardware C/W system:

- "MPS LH2/02 MANF" -MPS liquid oxygen manifold pressure is above 249 psia or the liquid hydrogen manifold pressure is above 65 psia
- "MPS HE P C(L,R)" - MPS regulated (A leg only) left, center, or right helium pressure is less than 680 or greater than 810 psia
- "MPS HE P C(L,R)" - MPS center, left, or right tank pressure is less than 1,150 psia

In addition to the MPS light, the Backup C&W light on panel F7 will also illuminate. The limits for the backup C&W system are identical to the hardware C&W. The backup C&W is what generates the applicable C&W message.

The flight crew can monitor the MPS PRESS HELIUM PNEU, L, C, R meter on panel F7 when the switch below the meter is placed in the TANK or REG position. However, the meters only display the "A" regulator pressure when in the REG position. Pressure is also shown on the BFS GNC SYS SUMM 1 display. The MPS PRESS ENG MANF LO₂, LH₂ meter can also be monitored on panel F7. A number of conditions will require crew action. For example, an ET ullage pressure low message will require the flight crew to pressurize the external liquid hydrogen tank by setting the LH₂ ULLAGE PRESS switch on panel R2 to OPEN. A low helium tank pressure may require the flight crew to interconnect the pneumatic helium tank to an engine supply using the MPS He INTERCONNECT LEFT, CTR, and RIGHT switches on panel R2.

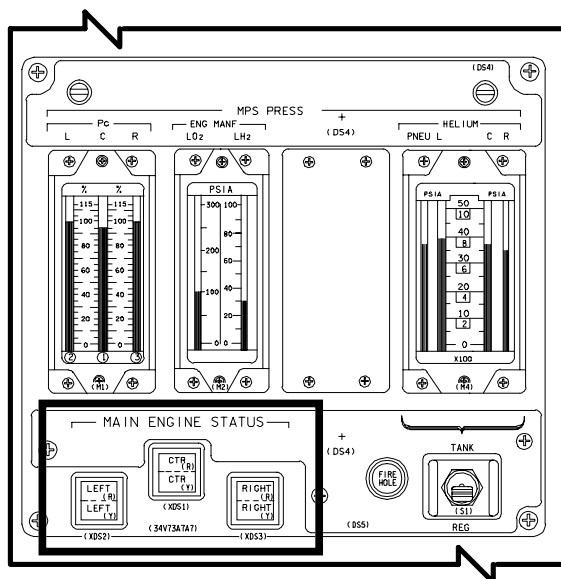
MAIN ENGINE STATUS LEFT, CTR, RIGHT lights on panel F7 are divided into two parts: the top half lights red and the bottom half lights yellow. The top half is illuminated for SSME shutdown and redline exceedances.

The yellow bottom half of the MAIN ENGINE STATUS light will be illuminated by the following failures:

- Electrical lockup
- Hydraulic lockup
- Command path failure (loss of two or more command channels or command reject between the GPCs and the SSME controller)
- Data path failure (loss of both primary and secondary data from the SSME controller)

In an electrical lockup for the affected SSME, loss of data from fuel flow rate sensors or the chamber pressure sensors will result in the propellant valve actuators being maintained electronically in the positions existing at the time the last sensor failed. For both sensors to be considered failed, it is only necessary for one sensor to actually fail. In hydraulic lockup, electrical lockup, or command path failure all engine-throttling capability for the affected engine is lost; subsequent throttling commands to that engine will not change the thrust level.

Biased sensors will affect main engine performance. During engine mainstage operation, measurements of the combustion chamber pressure and fuel flow rate are used by the controller to closely control power level and mixture ratio.



MAIN ENGINE STATUS Lights on Panel F7

There are two chamber pressure transducers on each SSME (an "A" and a "B"). Each consists of two bridges (Wheatstone-type strain gauges) for a total of four controller measurements (an A1, A2 pair and a B1, B2 pair). Each of these measurements is monitored for reasonableness before being used by the controller.

The fuel flow meter is located in the duct between the low and high pressure liquid hydrogen pumps. Four measurements (A1, A2 and B1, B2) come from the flow meter for use by the controller after each passes reasonableness checks.

Biases of either the flow meter or chamber pressure transducers can cause off-nominal engine operation. Essentially, the crew has no insight into this type of failure and must rely on Mission Control for assistance. The controller will adjust the engine valves to maintain the commanded power level as seen by the chamber pressure transducers, and this is what is displayed to the crew.

The red upper half of the MAIN ENGINE STATUS LEFT, CTR, RIGHT lights on panel F7 will be illuminated for an engine in shutdown or post-shutdown phase or for the following redline exceedances with limits inhibited:

- The high-pressure fuel turbopump's discharge temperature is above 1960° R
- The high-pressure oxidizer turbopump's discharge temperature is above 1760° R or below 720° R
- The high-pressure oxidizer turbopump's intermediate seal purge pressure is below 170 psia (Phase II SSME) or 159 psia (Block I and Block II SSMEs)
- The high-pressure oxidizer turbopump's secondary seal purge pressure is above 100 psia (Phase II SSME only)
- The high-pressure fuel turbopump's coolant liner pressure is greater than the controller-calculated limit (~3675 psig at 104%)
- The main combustion chamber's pressure is 400 psig below the reference chamber pressure

Because of the rapidity with which it is possible to exceed these limits, the engine controller has been programmed to sense the limits and automatically shut down the engine if the limits are exceeded. Although a shutdown as a result of violating operating limits is normally automatic, the flight crew can, if necessary, inhibit an automatic shutdown by using the MAIN ENGINE LIMIT SHUT DN switch on panel C3. The switch has three positions: ENABLE, AUTO, and INHIBIT. The ENABLE position allows any engine that violates operating limits to be shut down automatically. The AUTO position allows only the first engine that violates operating limits to be shut down automatically. If either of the two remaining engines subsequently violates operating limits, it would be inhibited from automatically shutting down. Should a remaining engine violate operating limits, it will not be shut down automatically unless the switch is manually taken to ENABLE and then to AUTO. The INHIBIT position inhibits all automatic shutdowns. The MAIN ENGINE SHUT DOWN LEFT, CTR, RIGHT pushbuttons on panel C3 have spring-loaded covers (guards). When the guard is raised, and the pushbutton is depressed, the corresponding engine shuts down immediately, provided the engine command is operational.

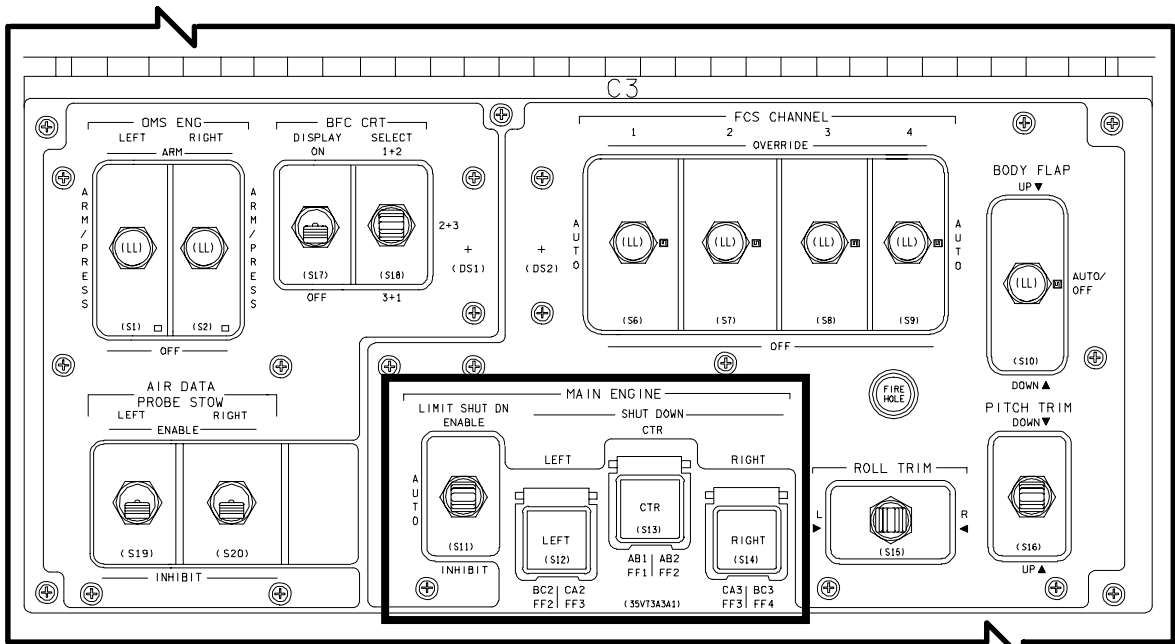
WARNING

Failure of an engine with limit shutdown inhibited will probably result in engine and controller damage, which will prevent detection of the engine failure by the GPCs.

The software caution and warning processing of the orbiter GPC's can detect certain specified out-of-limit or fault conditions of the MPS. The SM alert light on panel F7 is illuminated, a fault message appears on the PASS and/or BFS CRT displays, and an audio tone sounds if:

PASS and BFS generated fault messages

- "MPS DATA C(L,R)" - Data path failures occur due to loss of both primary and secondary data from the main engine controller
- "MPS CMD C(L,R)" - Command path failures occur due to loss or rejection of GPC commands to the main engine controller (PASS only pre-engage)
- "MPS HYD C(L,R)" - Hydraulic lockups occur due to the failure of any one of the five hydraulically actuated valves from achieving its commanded position



MAIN ENGINE LIMIT SHUT DN Switch and MAIN ENGINE SHUT DOWN Pushbuttons on Panel C3

- "MPS ELEC C(L,R)" Electric lockups occur due to the loss of all Pc data or all fuel flow rate data from the engine
- "ET SEP-INH" - ET separation inhibits occur due to feedline disconnect failures or excessive vehicle rates(>0.7 deg/sec in any axis)
- "SSME FAIL C(L,R)" - Premature main engine shutdown (backup C&W light and master alarm only, no MPS light)
- "MPS H2 OUT P C(L,R)" - SSME GH₂ outlet pressure less than 1050 psia (engine failure)
- "MPS O2 OUT T C(L,R)" - SSME GO₂ outlet temperature less than 125° F (engine failure)

PASS only generated fault messages

- "ET SEP-MAN" or "ET SEP SEP-AUT" - ET separation switch failures (PASS annunciated only) occur when the GPCs can't determine the position of the ET SEPARATION switch on panel C3
- "ME SHDN SW C(L,R)" - Main engine pushbutton failures (PASS annunciated only occur when there is a failure of one of the two contacts on an SSME shutdown pushbutton resulting in a switch dilemma)

BFS only generated fault messages

- "MPS LH2/O2 ULL" - ET liquid hydrogen ullage pressure is less than 31.6 or greater than 46.0 psia or the liquid oxygen ullage pressure is less than 0 or more than 29.0 psig
- "MPS HE P C(L,R)" - MPS regulated (A&B leg) left, center, or right helium pressure is less than 679 or more than 810 psi
- "MPS HE P C(L,R)" - Helium system pressure change over time is greater than 20 psi for 3 seconds
- "MPS PNEU P TK" - MPS pneumatic tank pressure is less than 3800 psi
- "MPS PNEU P REG" - MPS pneumatic regulator pressure is less than 700 psia or greater than 810 psia
- "MPS PNEU P ACUM" - MPS pneumatic accumulator pressure is less than 700 psia

These failures have messages that are annunciated in OPS 1 and 6. Also, the BFS does all processing of the MPS helium and ullage pressure systems. In OPS 3, the MPS parameters on the BFS SYS SUMM 1 will be blanked, except for helium REG A and B pressure. In OPS 2 there is no software caution and warning for the MPS. Therefore, if either manifold pressure (LO₂ or LH₂) violates limits while on orbit, the only indication the crew will see is hardware caution and warning (MPS light and master alarm.) There will be no message on the CRT.

Operations

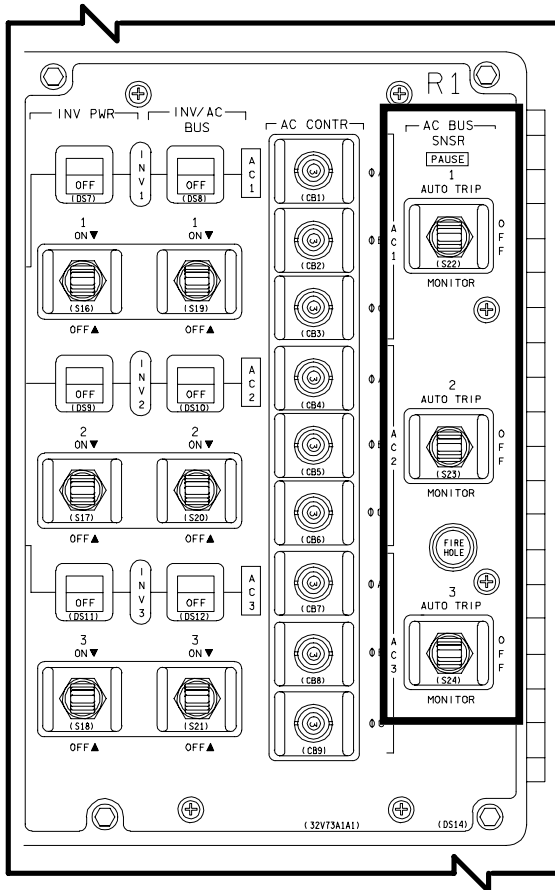
Prelaunch

At T minus 5 hours 50 minutes, the launch processing system initiates the SSME liquid hydrogen chill-down sequence in preparation for liquid hydrogen loading. At T minus 5 hours 15 minutes, the fast-fill portion of the liquid oxygen and liquid hydrogen loading sequence begins, and the liquid hydrogen recirculation pumps are started shortly thereafter. At T minus 3 hours 45 seconds, the fast fill of the liquid hydrogen tank to 98 percent is complete, and a slow topping off process that stabilizes to 100 percent begins. At T minus 3 hours 30 minutes, the liquid oxygen fast fill is complete. At T minus 3 hours 15 minutes, liquid hydrogen replenishment begins, and liquid oxygen replenishment begins at T minus 3 hours 10 minutes.

During prelaunch, the pneumatic helium supply provides pressure to operate the liquid oxygen and hydrogen prevalues and outboard and inboard fill and drain valves. The three engine helium supply systems are used to provide anti-icing purges.

The MPS helium tanks are pressurized from 2,000 psi to their full pressure at T minus 3 hours 20 minutes. This process is gradual to prevent excessive heat buildup in the supply tank. Regulated helium pressure is between 715 and 775 psi.

At this time, the MPS He ISOLATION A and B switches, the MPS PNEUMATICS L ENG He XOVR and He ISOL switches, and the MPS He INTERCONNECT LEFT, CTR, RIGHT switches on panel R2 are in the GPC position. With the switches in this position, the eight helium isolation valves are open, and the left engine crossover and the six helium interconnect valves are closed.



AC BUS SNSR Switches on Panel R1

At T minus 16 minutes, one of the first actions by the flight crew (the pilot) is to place the six MPS He ISOLATION A and B switches and the MPS PNEUMATICS He ISOL switch on panel R2 in the OPEN position. This procedure will not change the position of the helium isolation valves, which were already open, but it inhibits launch processing system control of valve position.

During prelaunch, liquid oxygen from ground support equipment is loaded through the ground support equipment liquid oxygen T-0 umbilical and passes through the liquid oxygen outboard fill and drain valve, the liquid oxygen inboard fill and drain valve, and the orbiter

liquid oxygen feedline manifold. The liquid oxygen exits the orbiter at the liquid oxygen feedline umbilical disconnect and enters the liquid oxygen tank in the external tank.

During loading, the liquid oxygen tank's vent and relief valves are open to prevent pressure buildup in the tank due to liquid oxygen loading. The MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LO₂ OUTBD and INBD switches on panel R4 are in the GND (ground) position, which allows the launch processing system to control the positions of these valves. Just prior to lift-off, the launch processing system will first command the liquid oxygen inboard fill and drain valve to close. The liquid oxygen in the line between the inboard and outboard fill and drain valves is then allowed to drain back into the ground support equipment, and the launch processing system commands the outboard fill and drain valve to close.

Also during prelaunch, liquid hydrogen supplied through the ground support equipment liquid hydrogen T-0 umbilical passes through the liquid hydrogen outboard fill and drain valve, the liquid hydrogen inboard fill and drain valve, and the liquid hydrogen feedline manifold. The liquid hydrogen then exits the orbiter at the liquid hydrogen feedline umbilical disconnect and enters the liquid hydrogen tank in the external tank. During loading, the liquid hydrogen tank's vent valve is left open to prevent pressure buildup in the tank due to boiloff. The MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LH₂ OUTBD and INBD switches on panel R4 are in the GND position, which allows the launch processing system to control the position of these valves.

During the T minus 3 hour hold the pilot positions the three AC BUS SNSR switches on panel R1 to MONITOR. These sensors are not part of the MPS, but the procedure protects the SSMEs. Each engine controller is powered by two of the three ac buses, one for each digital computer unit. Therefore, the loss of one bus will result in a loss of controller redundancy on two engines, and the loss of any two buses will cause the associated engine to shut down. With the switches positioned to MONITOR, the sensors will provide caution and warning for an over/undervoltage or overload condition, but they will not trip a bus off line.

Engine Start

At T minus 4 minutes, the fuel system purge begins. It is followed at T minus 3 minutes 25 seconds by the beginning of the engine gimbal tests, during which each gimbal actuator is operated through a canned profile of extensions and retractions. If all actuators function satisfactorily, the engines are gimballed to a predefined position at T minus 2 minutes 15 seconds. The engines remain in this position until engine ignition.

At T minus 2 minutes 55 seconds, the launch processing system closes the liquid oxygen tank vent valve, and the tank is pressurized to 21 psig with ground support equipment-supplied helium. The liquid oxygen tank's pressure can be monitored on the BFS GNC SYS SUMM 1 CRT (MANF P LO2). The 21-psig pressure corresponds to a liquid oxygen engine manifold pressure of 105 psia.

At T minus 1 minute 57 seconds, the launch processing system closes the liquid hydrogen tank's vent valve, and the tank is pressurized to 42 psig with ground support equipment-supplied helium. The pressure is monitored on the BFS GNC SYS SUMM 1 CRT display (MANF P LH2).

At T minus 31 seconds, the onboard redundant set launch sequence is enabled by the launch processing system. From this point on, all sequencing is performed by the orbiter GPCs in the redundant set, based on the onboard clock time. The GPCs still respond, however, to hold, resume count, and recycle commands from the launch processing system.

At T minus 16 seconds, the GPCs begin to issue arming commands for the solid rocket booster ignition pyro initiator controllers, the hold-down release pyro initiator controllers, and the T-0 umbilical release pyro initiator controllers.

At T minus 9.5 seconds, the engine chill-down sequence is complete, and the GPCs command the liquid hydrogen prevalues to open (the liquid oxygen prevalues are open during loading to permit engine chill-down). The MAIN PROPULSION SYSTEM LO₂ and LH₂ PREVALVE LEFT, CTR, RIGHT switches on panel R4 are in the GPC position.

At T minus 6.6 seconds, the GPCs issue the engine start command, and the main fuel valve in each engine opens. Between the opening of the main fuel valve and MECO, liquid hydrogen flows out of the external tank/orbiter liquid hydrogen disconnect valves into the liquid hydrogen feedline manifold. From this manifold, liquid hydrogen is distributed to the engines through the three engine liquid hydrogen feedlines. In each line, liquid hydrogen passes through the prevalue and enters the main engine at the inlet to the low-pressure fuel turbopump.

When the GPCs issue the engine start command, the main oxidizer valve in each engine also opens. Between the opening of the main engine oxidizer valve and MECO, liquid oxygen flows out of the external tank and through the external tank/orbiter liquid oxygen umbilical disconnect valves into the liquid oxygen feedline manifold. From this manifold, liquid oxygen is distributed to the engines through the three engine liquid oxygen feedlines. In each line, liquid oxygen passes through the prevalue and enters the main engine at the inlet to the low-pressure oxidizer turbopump.

If all three SSMEs reach 90 percent of their rated thrust by T minus 3 seconds, then at T minus 0, the GPCs will issue the commands to fire the solid rocket booster ignition pyro initiator controllers, the hold-down release pyro initiator controllers, and the T-0 umbilical release pyro initiator controllers. Lift-off occurs almost immediately because of the extremely rapid thrust buildup of the solid rocket boosters. The 3 seconds to T minus zero allow the vehicle base bending loads to return to minimum by T minus 0.

If one or more of the three main engines do not reach 90 percent of their rated thrust at T minus 3 seconds, all SSMEs are shut down, the solid rocket boosters are not ignited, and a pad abort condition exists.

Ascent

Beginning at T minus 0, the SSME gimbal actuators, which were locked in their special preignition position, are first commanded to their null positions for solid rocket booster start and then are allowed to operate as needed for thrust vector control.

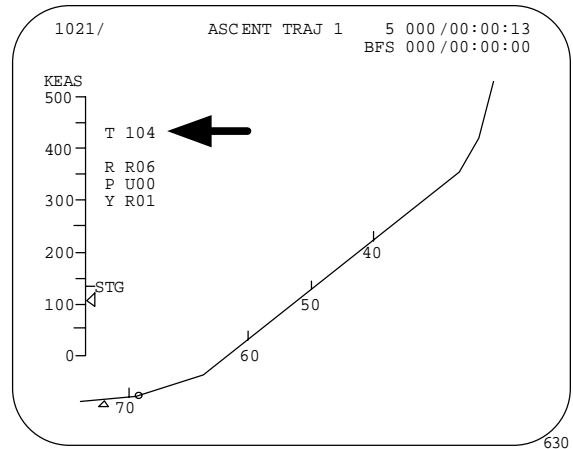
Between lift-off and MECO, as long as the SSMEs perform nominally, all MPS sequencing and control functions are executed automatically by the GPCs. During this period, the flight crew monitors MPS performance, backs up automatic functions, if required, and provides manual inputs in the event of MPS malfunctions.

During ascent, the liquid hydrogen tank's pressure is maintained between 32 and 34 psig by the orifices in the two lines and the action of the flow control valve.

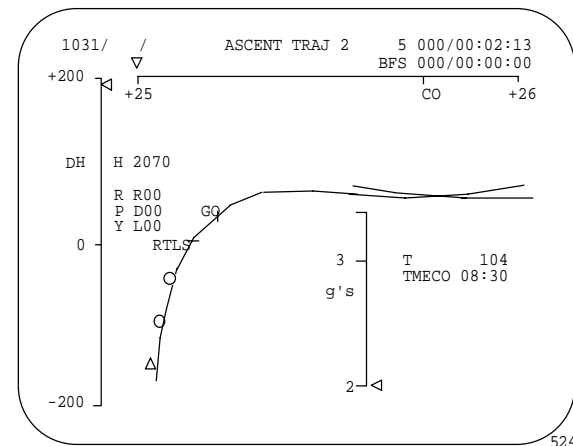
The liquid oxygen tank's pressure is maintained between 20 and 25 psig by fixed orifices in the ET to SSME pressurization lines. A pressure greater than 30 psig will cause the tank to relieve through its vent and relief valve.

The SSME thrust level depends on the flight: it is usually 104 percent, but the maximum setting of 109 percent may be required for emergency situations. This is known as max throttle. Percent of thrust that would be commanded (T) by the BFS is displayed on the BFS ASCENT TRAJ 1 and 2 displays, and actual thrust levels are read on the three MPS PRESS P_c meters on panel F7. As dynamic pressure rises, the GPCs throttle the engines to a lower power level (minimum 67 percent) to minimize structural loading while the orbiter is passing through the region of maximum aerodynamic pressure. This is called the "thrust bucket" because of the way the thrust plot appears on the graph. Although the bucket duration and thrust level vary, a typical bucket runs from about 30 to 65 seconds, mission elapsed time (MET). The solid rocket booster propellant is also shaped to reduce thrust. At approximately 65 seconds MET, the engines are once again throttled up to the appropriate power level (104 percent) and remain at that setting for a normal mission until 3-g throttling is initiated.

SRB separation is the next major event on ascent. The SRBs burn out after about two minutes of flight. Appearance of an overbright "Pc < 50" (chamber pressure in the SRBs in psi) on the trajectory display indicates to the crew that the SRB separation sequence has begun. Actual separation occurs about five seconds later to allow for SRB thrust tailoff.



BFS ASCENT TRAJ 1 DISPLAY
(percent of thrust commanded by the BFS)



BFS ASCENT TRAJ 2 DISPLAY

Liquid oxygen manifold pressure is greatly affected by acceleration from the SRBs, but because of its low density, liquid hydrogen is not. At SRB separation, the liquid oxygen manifold pressure will drop from well over 100 psia to approximately 50 psia. Pressure rises again as the vehicle approaches 3 g's. The crew can monitor the manifold pressures on the BFS GNC SYS SUMM 1 display (MANF P) and on the MPS PRESS ENG MANF meters on panel F7.

Beginning at approximately 7 minutes 40 seconds MET, the engines are throttled back to maintain vehicle acceleration at 3 g's or less. Three g's is an operational limit devised to prevent excessive physical stress on the flight crew and vehicle. Approximately 6 seconds before main engine cutoff, the engines are throttled back to 67 percent in preparation for shutdown.

Main Engine Cutoff (MECO)

Although MECO is based on the attainment of a specified velocity, the engines can also be shut down due to the depletion of liquid oxygen or liquid hydrogen before the specified velocity of MECO is reached. Liquid oxygen depletion is sensed by four sensors in the orbiter liquid oxygen feedline manifold. Liquid hydrogen depletion is sensed by four sensors in the bottom of the liquid hydrogen tank. If any two of the four sensors in either system indicate a dry condition, the GPCs will issue a MECO command to the engine controller (provided they go dry after the arming mass is reached).

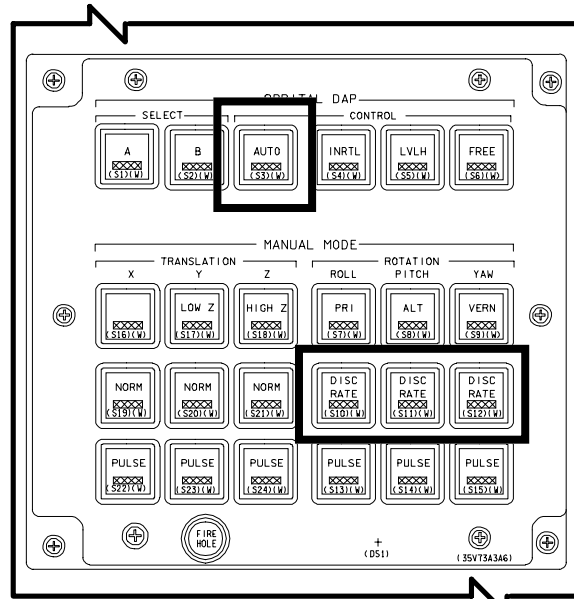
Once MECO has been confirmed at approximately 8 minutes 30 seconds MET, the GPCs execute the external tank separation sequence. The sequence takes approximately 18 seconds to complete and includes opening the feedline relief isolation valves, arming the external tank separation pyro initiator controllers, closing the liquid hydrogen and liquid oxygen feedline 17-inch disconnect valves, turning the external tank signal conditioners' power off (deadfacing), firing the umbilical unlatch pyrotechnics, retracting the umbilical plates hydraulically, and gimbaling the SSMEs to the MPS dump sequence position.

At this point, the computers check for external tank separation inhibits. If the vehicle's pitch, roll, and yaw rates are greater than 0.7 degree per second, or the feedline disconnect valves fail to close, automatic external tank separation is inhibited. If these inhibit conditions are met, the GPCs issue the commands to the external tank separation pyrotechnics. As with the SRBs, the crew has the capability to override the external tank separation with the ET SEPARATION switch located on panel C3. In crew-initiated external tank separation or RTLS aborts, the inhibits are overridden.

At orbiter/external tank separation, the gaseous oxygen and gaseous hydrogen feedlines are sealed at the umbilicals by self-sealing quick disconnects.

In the cockpit, the crew observes MECO through the illumination of the three red MAIN ENGINE STATUS lights on panel F7. In addition, the Pc meters on panel F7 drop to 0 percent. Four of the ORBITAL DAP pushbutton

lights on panel C3 illuminate when the MECO CONFIRMED software flag has been set. This flag must be set to enter the ET separation sequence. Remember, the DAP lights will not illuminate on an RTLS abort since the trans DAP is not entered at MECO as it is uphill or on a TAL abort.



ORBITAL DAP CONTROL AUTO Light on Panel C3

Post-MECO

Ten seconds after main engine cutoff, the backup liquid hydrogen dump valves are opened for 2 minutes to ensure that the liquid hydrogen manifold pressure does not result in operation of the liquid hydrogen feedline relief valve.

After MECO confirmed plus 20 seconds, the GPCs interconnect the pneumatic helium and engine helium supply system by opening the center and right out/open interconnect valves and the left in/open interconnect valve if the MPS He INTERCONNECT LEFT, CTR, RIGHT switches on panel R2 are in the GPC position. This connects all 10 helium supply tanks to a common manifold, and it ensures that sufficient helium is available to perform the liquid oxygen and liquid hydrogen propellant dumps.

After external tank separation, approximately 1,700 pounds of propellant are still trapped in the SSMEs, and an additional 3,700 pounds of

propellant remain trapped in the orbiter's MPS feedlines. This 5,400 pounds of propellant represents an overall center-of-gravity shift for the orbiter of approximately 7 inches. Non-nominal center-of-gravity locations can create major guidance problems during entry. The residual liquid oxygen, by far the heavier of the two propellants, poses the greatest impact on center-of-gravity travel.

A hazard from the trapped liquid hydrogen occurs during entry, when any liquid or gaseous hydrogen remaining in the propellant lines may combine with atmospheric oxygen to form a potentially explosive mixture. In addition, if the trapped propellants are not dumped overboard, they will sporadically outgas through the orbiter liquid oxygen and liquid hydrogen feedline relief valves, causing slight vehicle accelerations.

The MPS propellant dumps (LO2 and LH2) occur simultaneously. Both dumps are completely automatic. The helium subsystem is used during the MPS dump to help expel the liquid oxygen from the LO2 manifold. To support this, the GPCs command the center and right helium interconnects to out/open and the left interconnect to in/open at MECO plus 20 seconds. This occurs provided the helium interconnects are in the GPC position.

The MPS dump starts automatically at MECO plus 2 minutes. The MPS dump may be started manually by taking the MPS PRPLT DUMP SEQUENCE switch to START. The earliest that the manual MPS dump can be performed is MECO plus 20 seconds. The only reason that the crew may need to start the dump prior to MECO plus 2 minutes is if the LO2 or LH2 manifold pressure rises unexpectedly. The MPS dump will start automatically prior to MECO plus 2 minutes if the LH2 manifold pressure is greater than 60 psi. The dump takes 2 minutes to complete. The STOP position of the MPS PRPLT DUMP SEQUENCE switch is used to prevent the automatic dump from starting during the ET separation sequence if it is delayed by an RCS leak or feedline disconnect valve failure.

For the LO2 dump, the GPCs command the two liquid oxygen manifold repressurization valves to open (the MAIN PROPULSION SYSTEM MANF PRESS LO2 switch on panel R4 must be

in the GPC position), command each engine controller to open its SSME main oxidizer valve (MOV), and command the three liquid oxygen prevalues to open (the LO2 PREVALVE LEFT, CTR, RIGHT switches on panel R4 must be in the GPC position). The liquid oxygen trapped in the feedline manifolds is expelled under pressure from the helium subsystem through the nozzles of the SSMEs. This is propulsive and typically provides about 9-11 feet-per-second of delta V.

The pressurized liquid oxygen dump continues for 90 seconds. At the end of this period, the GPCs automatically terminate the dump by closing the two liquid oxygen manifold repressurization valves, wait 30 seconds, and then command the engine controllers to close their SSME main oxidizer valve. The three liquid oxygen prevalues remain open during the orbit phase of the flight.

Concurrent with the liquid oxygen dump, the GPCs automatically initiate the MPS liquid hydrogen dump. The GPCs command the two liquid hydrogen fill and drain valves (inboard and outboard) to open, the topping valve to open, and the three LH2 prevalues to open.

The liquid hydrogen trapped in the orbiter feedline manifold is expelled overboard without pressure from the helium subsystem. The liquid hydrogen flows overboard through the inboard and outboard fill and drain valves, and the topping valve for 2 minutes. The GPCs automatically stop the dump by closing the liquid hydrogen outboard fill and drain valve and the topping valve.

At the end of the liquid oxygen and liquid hydrogen dumps, the GPCs close the helium out/open and in/open interconnect valves, provided the He INTERCONNECT LEFT, CTR, RIGHT switches on panel R2 are in the GPC position. After the MPS dump is complete, the SSMEs are gimballed to their entry stow position with the engine nozzles moved inward (toward one another) to reduce aerodynamic heating. Although the gimbals move to an MPS dump position during the external tank separation, the I-loads are currently the same as the entry stow position. At this time, the BODY FLAP lights on panel F2 and F4 turn off. This is the crew's indication that the MPS dump is complete.

In the post OMS-1 procedures, the pilot positions all six MPS ENGINE POWER switches on panel R2 to OFF, which removes all power to the main engine controllers. Once power is removed from the controllers, the main oxidizer valves, which are necessary for the liquid oxygen portion of the dump, can no longer be operated.

The pilot also positions the six He ISOLATION switches and the PNEUMATIC He ISOLATION switch to GPC at this time. When this is done, the helium isolation valves automatically close, but the pneumatic helium isolation valve stays open to operate the pneumatic valves during the vacuum inert. The external tank gaseous hydrogen pressurization manifold is manually vacuum inerted by opening the hydrogen pressurization line vent valve by placing the MAIN PROPULSION SYSTEM H2 PRESS LINE VENT switch on panel R4 to OPEN.

After a 1 minute inert period, the switch is taken back to the GND position, which closes the valve. The hydrogen pressurization vent line valve is electrically activated; however, it is normally closed (spring-loaded to the closed position). Removing power from the valve solenoid closes the valve.

NOTE

After the helium isolation valves are closed, multiple MASTER ALARMS are annunciated as the helium pressure in the regulators bleeds down.

Vacuum Inerting

Fifteen minutes after the MPS dump stops, the GPCs initiate the sequence for vacuum inerting the orbiter's liquid oxygen and liquid hydrogen manifolds. Vacuum inerting allows traces of liquid oxygen and liquid hydrogen trapped in the propellant manifolds to be vented into space.

The LO2 vacuum inerting is accomplished by the GPCs opening the LO2 inboard and outboard fill and drain valves. The LH2 vacuum inerting is accomplished by the GPCs opening the LH2 outboard fill and drain valve and the topping valve (the inboard fill and drain valve was left open at the end of the MPS dump).

The liquid oxygen and hydrogen lines are inerted simultaneously for 1 minute. At the end of the sequence, the GPCs close the LO2 and LH2 outboard fill drain valves. The LO2 and LH2 inboard valves are left open to prevent a pressure buildup between the inboard and outboard valves.

Any GPC or FA MDM failure that will not allow the automatic vacuum inert to function properly will require the crew to perform a manual vacuum inerting procedure.

Following the OMS 2 burn, the LH2 system requires a second vacuum inerting to evacuate all of the residual liquid hydrogen. Residual hydrogen ice sublimates quickly after the OMS 2 burn (and the LH2 manifold pressure rises) due to the vibrations induced by the firing of the OMS engines.

This second vacuum inerting of the LH2 manifold is a crew procedure and is accomplished by opening the LH2 inboard and outboard fill and drain valves for 1 minute. Upon termination of the procedure, the outboard fill and drain valve is closed. The inboard fill and drain valve is left in the open position to prevent a pressure buildup between the inboard and outboard valves.

Post Insertion

In the post insertion portion of the flight, the following switches are powered off since the systems are no longer used: Ascent thrust vector control 1, 2, 3, and 4, EIUs L-C, C-R, R-L, and MECs 1 and 2, all of which are on panel O17. The hardware caution and warning system is reconfigured to inhibit caution and warning on the left, center, and right helium tank pressures and the "A" regulators since the helium system is secured and no longer used. Remember, only the "A" regulators have caution and warning. The LH2 and LO2 manifold pressure caution and warning left enabled to alert the crew to a possible high manifold pressure while on orbit. The engine controller heaters, which are not used, are located on R4 and should remain in the OFF position for the entire mission.

Orbit

All main propulsion systems have been secured by the time post insertion is complete. The MPS orbit procedures deal with off-nominal manifold pressures and are not normally performed. The concern on orbit is possible high manifold pressures due to an incomplete vacuum inert or MPS dump. If high manifold pressures were detected during orbit, the MCC would advise the crew to perform a manual vacuum inert. If the MCC were not available, the manifold pressure caution and warning parameter (left enabled during post insertion) would alert the crew of the high manifold pressure and the malfunction procedure would be performed, relieving the pressure or deducing a manifold pressure transducer failure.

Deorbit Prep

During the deorbit prep timeframe, the MPS hardware caution and warning is reconfigured in preparation for entry. Specifically, the MPS helium "A" regulators are re-enabled since helium will be provided for the entry purge and manifold repressurization. A regulator failed high would alert the crew to the problem and possible over-pressurization of the aft compartment. The manifold pressure caution and warning is inhibited at this time since the manifolds are at a vacuum state and do not need to be monitored during entry. Lastly, the ATVC switches are powered back on to allow the main engine nozzles to return to their entry stow positions, since they typically drift while on orbit.

Entry

The GPCs reconfigure the MPS helium system in preparation for the entry repressurization and purge at the MM 303 transition.

NOTE

Expect the F7 MPS light to be on until MM 303.

Once MM 303 is entered, the GPCs command the PNEUMATIC ISOLATION A and B, and the L ENG He XOVR to OPEN provided the switch is in the GPC position. At the same time, the MPS He INTERCONNECTS CTR and RIGHT

are commanded out/open, while the MPS He INTERCONNECT LEFT is commanded in/open. This feeds all the MPS helium through the left engine, through the PNEUMATICS L ENG He XOVR, and through the pneumatic isolation valves. Also at this time, the LH2 RTLS dump valves go open to insure the LH2 manifold is completely vented prior to entry.

At a ground relative velocity of 5,300 feet-per-second (between 130,000 and 110,000 feet altitude, depending on the entry trajectory), the helium blowdown valves open which allows helium to continuously purge the aft compartment, OMS pods, and the LH2 umbilical cavity area. There is no manual control of the blowdown valves. The blowdown purge continues for 650 seconds and typically ends a few minutes after touchdown. At ground relative velocity of 5,300 fps, the MAIN PROPULSION SYSTEM MANF PRESS LH2 & LO2 valves are commanded OPEN, provided the switches on panel R4 are in the GPC position. This allows the LH2 and LO2 manifolds to be pressurized, preventing contaminants from entering the manifolds during entry. Removing contamination from the manifolds or feedlines can be a long and costly process since it involves disassembly of the affected parts. The manifold repress continues until the ground crews install the throat plugs in the main engine nozzles. The LH2 backup dump valves and the LO2 prevalues go closed at the 5,300 feet-per-second velocity.

RTLS Abort Propellant Dump Sequence

For RTLS abort, immediately post-MECO, the valve sequencing is the same as for a nominal MECO. After ~25 seconds, the vehicle enters MM 602 and the RTLS dump begins. The RTLS entry dump differs only slightly from the nominal entry dump.

During the RTLS dump, liquid oxygen is initially dumped through the LO2 prevalues and through the main oxidizer valves (MOV) in the SSMEs. When the dynamic pressure is above 20 (plus an I-load) psf, there is a subsequent venting through the liquid oxygen fill and drain valves. This dump is done without helium pressurization and relies on the self-boiling properties of the liquid oxygen. In the RTLS liquid oxygen dump, the GPCs

terminate the dump whenever the ground relative velocity drops below 3,800 feet-per-second. The liquid oxygen system is repressurized when the 3,800 feet-per-second velocity is attained, and repressurization continues as in a nominal entry.

LH2 manifold is expelled in the same manner as the nominal post-MECO dump (with one exception) until a ground relative velocity of 3,800 feet per second, at which time the valves are closed. The only exception is that the RTLS LH2 dump is assisted by helium pressurization through the RTLS manifold pressurization valves for 2 minutes, beginning at RTLS dump start.

The entry repressurization and the aft compartment surge also occur during the RTLS.

The helium blowdown valves are opened at Vrel 5,300 feet-per-second, followed by the manifold repress valves opening at 3,800 feet-per-second. As with the nominal entry, the blowdown valves remain open until a few minutes after landing.

TAL Abort Propellant Dump Sequence

For a TAL abort, the entire dump sequence is the same as that for RTLS. On the TAL, the dump begins at the transition to MM 304.

The LO2 is also dumped at the MM 304 transition through the LO2 prevalves and then out the MOVs, just as in the nominal dump. To assist in removing the LO2 propellants, the LO2 inboard and outboard fill drains are opened at a Vrel of 20,000 feet per second if the LO2 manifold pressure is less than 30 psi.

MPS Caution and Warning Summary

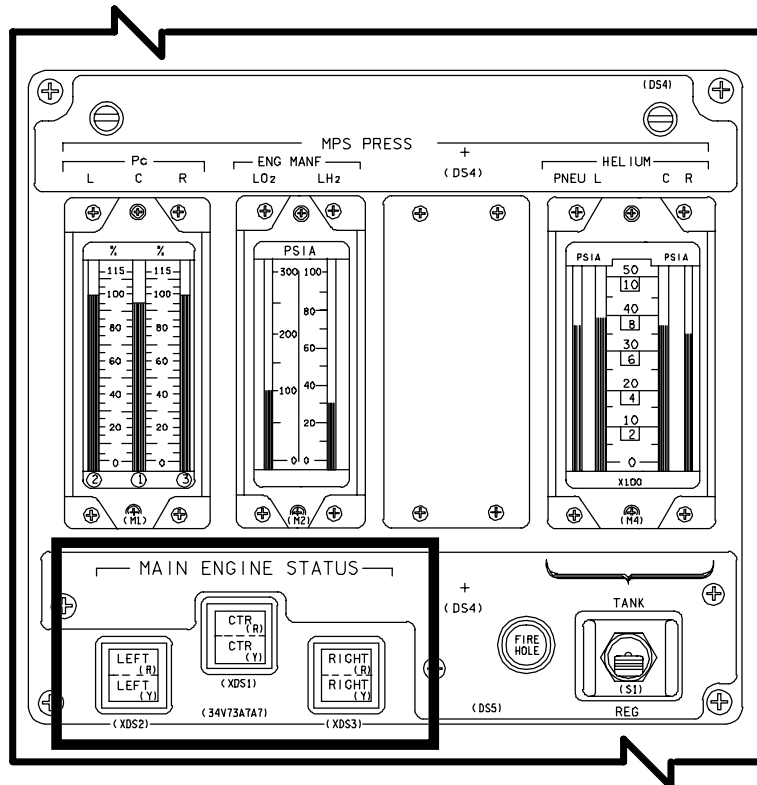
- **Data path failure** is the loss of both the primary and secondary data paths from an engine. Data path failure indications include an *SM ALERT* light and audio tone, a yellow *MAIN ENGINE STATUS* light on panel F7, the engine Pc meter on panel F7 driven to zero, and an MPS DATA L (C, R) message.
- **Command path failure** is the loss or rejection of GPC commands to the main engine controller. The engine will no longer throttle or accept commands. Indications include an *SM ALERT* light on panel F7 and audio tone, yellow *MAIN ENGINE STATUS* light on panel F7, no change in the Pc meter during throttling, and an MPS CMD L (C, R) message. This message will only annunciate on the PASS pre-BFS engage.
- **Hydraulic lockup** occurs when any of the five hydraulically actuated engine valves fails to achieve its commanded position; the engine does not throttle. Indications are an *SM ALERT* light and audio tone, a yellow *MAIN ENGINE STATUS* light on panel F7, no change in Pc meter during throttling, and an MPS HYD L (C, R) message.
- **Electrical lockup** occurs when the controller loses all Pc or all fuel flow rate data from the engine. Indications are *SM ALERT* light and audio tone, a yellow *MAIN ENGINE STATUS* light on panel F7, no change in Pc meter during throttling, and MPS ELEC L (C, R) message .
- **Engine failure** indications are a visual and audible *MASTER ALARM*, a red *MAIN ENGINE STATUS* light, engine Pc meter reading of zero, a Backup C&W Alarm light on the F7 C/W matrix and an SSME FAIL L (C, R) message on the CRT. A drop in acceleration will also occur, but may not be detectable in MM 102.
- **ET SEP** switch failures are indicated by an SM alert light and an ET SEP MAN or ET EP AUTO message. EP SEP MAN is the default software position for OPS 1 and ET SEP AUTO for OPS 6. This is annunciated by the PASS only since BFS has no switch RM.
- Main engine shutdown pushbutton failures may result in an ME SHDN SW C(L,R) message and an SM alert light and tone. This is annunciated by the PASS only since BFS has no switch RM.
- **Liquid hydrogen ullage pressure below 31.6 psia** is indicated by an *SM ALERT* light and audio tone, one or more down arrows by the LH2 pressure readings on the BFS GNC SYS SUMM 1 display, and an MPS LH2/O2 ULL message on the BFS CRT.
- **High liquid hydrogen or liquid oxygen manifold pressure** indications are: a visual and audible *MASTER ALARM*, an up arrow by the applicable MANF P reading on the BFS GNC SYS SUMM 1 display, and an MPS LH2/LO2 MANF message on the CRT. The limits are 249 psia for liquid oxygen, and 65 psia for liquid hydrogen.
- **Helium tank leaks** or regulator failure are indicated by an *SM ALERT* light and audio tone, an up arrow by the applicable dP/dT or regulator on the BFS GNC SYS SUMM 1 display, and an MPS He P C (L, R) message .
- **ET separation inhibit** is indicated by an *SM ALERT* light and audio tone and an ET SEP INH message.
- **The MPS** light on panel F7 will illuminate (red) if liquid hydrogen manifold pressure exceeds 65 psia on orbit or liquid oxygen manifold pressure exceeds 249 psia on orbit. A *MASTER ALARM* also illuminates, an audio alarm sounds, and the red *BACKUP C/W ALARM* on panel F7 illuminates as well. The light will also illuminate for helium pressure below 1,150 psia or regulated helium pressure below 680 or above 810 psia on the "A" regulators only.
- **The red upper half of the MAIN ENGINE STATUS** lights on panel F7 will be illuminated for an engine in shutdown or post-shutdown phase or exceeding redline limits with limits inhibited.
- **MPS** pneumatic system anomalies are annunciated by an SM alert light and audio tone, and an applicable message on the BFS CRT. The following pneumatic system messages will be annunciated along with an SM alert light and audio tone for the given condition. MPS PNEU TK, pneumatic tank pressure drops below 3800 psi. MPS PNEU ACUM, pneumatic accumulator pressure drops below 700 psi. MPS PNEU REG, pneumatic regulator pressure drops below 700 psi or goes above 810 psi.

MPS Caution and Warning Summary (continued)

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	LEFT RCS	RIGHT RCS (R)
_____	LEFT RHC (R)	RIGHT/AFT RHC (R)	LEFT OMS (R)	RIGHT OMS (R)
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

633.cvs

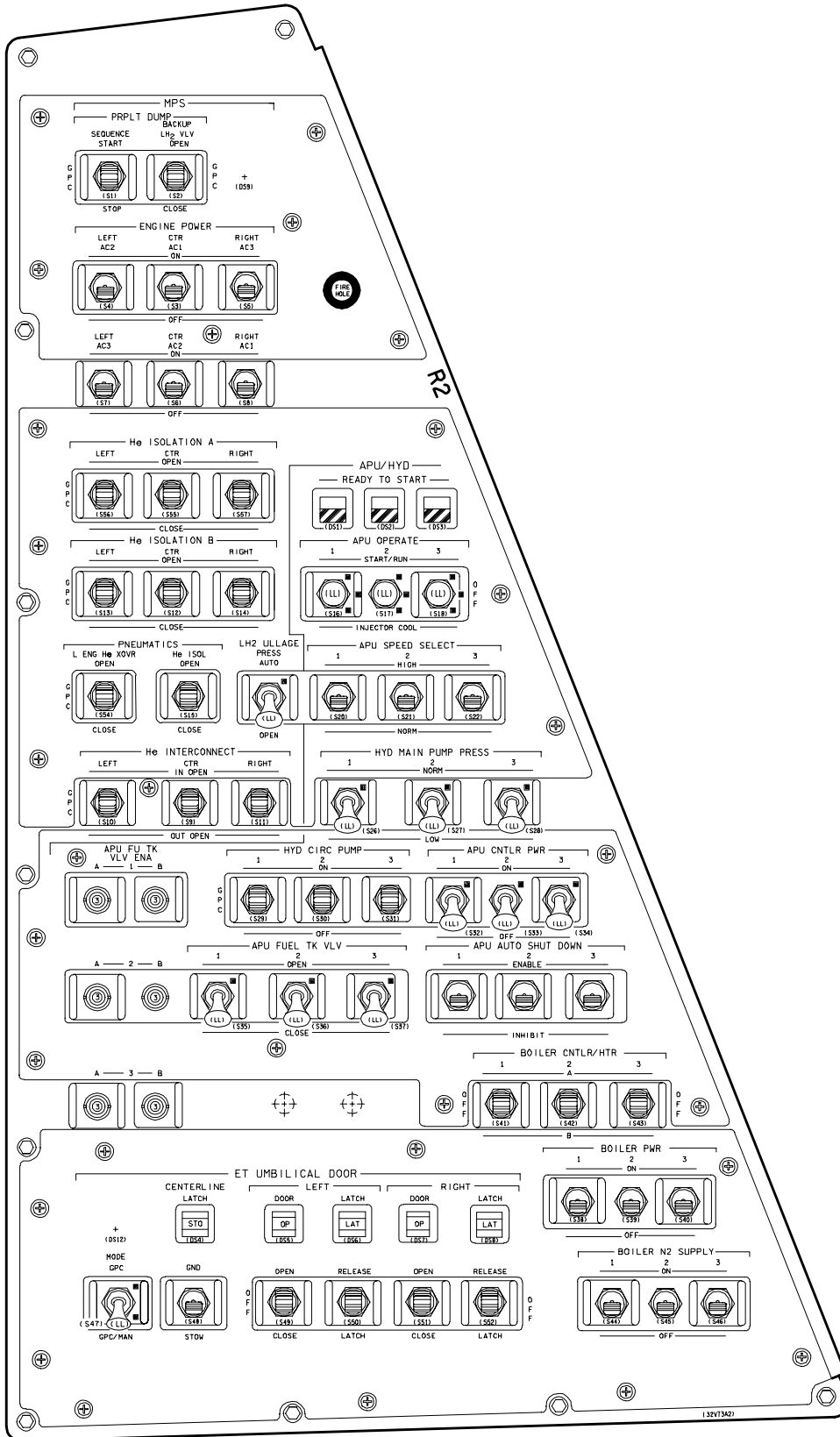
MPS Caution and Warning Lights on Panel F7



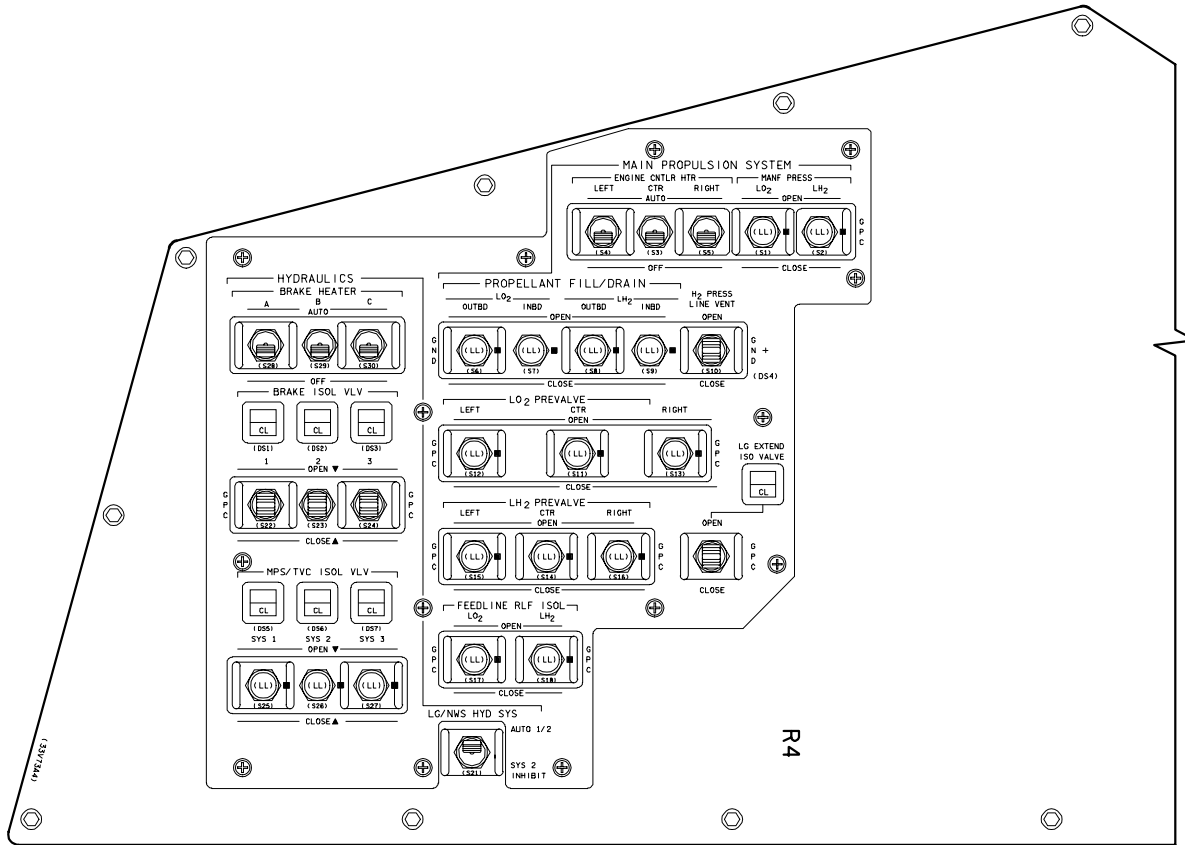
MAIN ENGINE STATUS Lights on Panel F7

MPS Summary Data

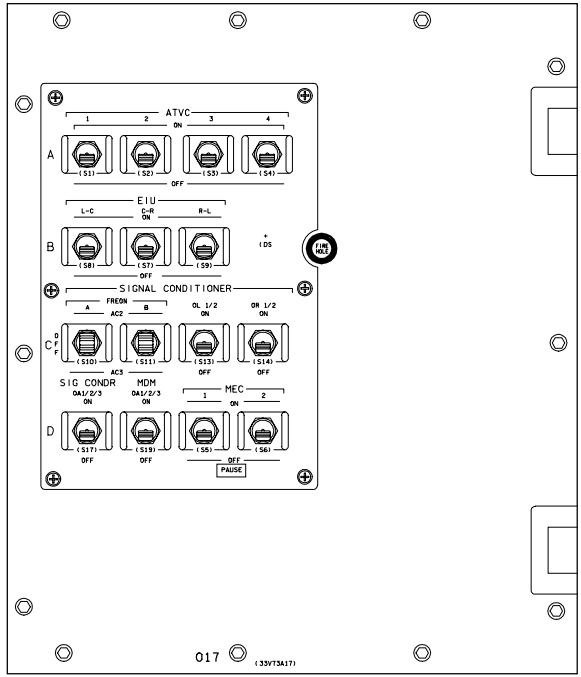
- The main engines, assisted by two solid rocket motors during the initial phases of the ascent trajectory, provide the vehicle acceleration from lift-off to MECO at a predetermined velocity.
- Most of the MPS is located at the aft end of the orbiter beneath the vertical stabilizer.
- The MPS consists of three SSMEs and controllers, the external tank, propellant management and helium systems, four ascent thrust vector control units, and six hydraulic servoactuators.
- The SSMEs are reusable, high-performance engines that use liquid hydrogen for fuel and cooling and liquid oxygen as an oxidizer.
- The SSMEs can be throttled 67 to 109 percent in 1 percent increments. Thrust level values are: 100 percent = 375,000 pounds at sea level, 470,000 pounds in a vacuum; 104 percent = 393,800 pounds at sea level, 488,000 pounds in a vacuum; 109 percent = 417,300 pounds at sea level, 513,250 pounds in a vacuum.
- Major SSME components are fuel and oxidizer turbopumps, preburners, a hot gas manifold, main combustion chamber, nozzle, oxidizer heat exchanger, and propellant valves.
- Each SSME has a controller with two redundant digital computer units. Operating in conjunction with engine sensors, valves, actuators, and spark igniters, the controllers form a self-contained system for engine control, checkout, and monitoring.
- The propellant management system consists of manifolds, distribution lines, and valves that transport propellant from the external tank to the three main engines for combustion, and gases from the engines to the external tank for pressurization.
- The helium system consists of 10 supply tanks and associated regulators, check valves, distribution lines, and control valves.
- The helium system is used for: (1) in-flight engine purges, (2) pressure for emergency closing of engine valves, (3) pressure to actuate pneumatically operated propellant valves, (4) expelling the propellants during the MPS dump and (5) entry purge and repressurization.
- There is one helium system per engine, plus a fourth pneumatic system to operate the propellant valves.
- The three orbiter hydraulic systems supply hydraulic pressure to the MPS to actuate engine valves and provide engine gimballing for thrust vector control.
- MPS controls are located primarily on panels R2 and R4, and C3 with a few on panels F7, O17, and R1.
- MPS system status indicators appear on panel F7. The BFS GNC SYS SUMM 1 CRT displays several MPS system parameters. The BFS ASCENT TRAJ 1 and 2 CRT displays engine throttling level (commanded by BFS, if engaged).



Panel R2



Panel R4



Panel O17

1011/ /018 GNC SYS SUMM 1 5 000/02:46:03
BFS 000/00:00:00

SURF	POS	MDM	DPS	1	2	3	4	
L	OB		MDM	FF				
R	IB		FA					
	OB		PL					
ALL								
RUD			FCS	CH	1	2	3	4
SPD	BRK							
BDY	FLP							

MPS	L	C	R	NAV	1	2	3	4
HE	TK	P	4280	4230	4240			
REG	P	A	784	768	768			
		B	776	766	770			

GH2	OUT	P	701	501	401	MANF	P	LH2	46
GO2	OUT	T	791	971	701			LO2	110

BFS GNC SYS SSUMM 1

MPS Rules of Thumb

- Direct insertion MECO is usually close to 8 minutes 30 seconds.
- An SSME will consume approximately 4 percent propellant per engine per minute at 104 percent. Propellant remaining is displayed on the ASCENT TRAJ display and is a guidance-calculated number.
- When an engine fails, the helium dp/dt is greater than 40 for several seconds, due to engine shutdown purges, and then it goes to zero. This is a good crosscheck to confirm engine shutdown.
- Two automatic ways to set MECO confirm are: three Pc's < 30% or two Pc's < 30% and a data path failure on the other SSME. Three manual ways to set MECO confirm are: push the three SSME PB's OPS 104 PRO, or FAST SEP.
- BFS, like the PASS, does not require all three MAIN ENGINE SHUT DOWN pushbuttons simultaneously to set MECO confirmed.
- To shut an engine down, both contacts on the MAIN ENGINE SHUT DOWN pushbutton must be good. If one contact is commfaulted, the button can be used to set the safing flag on an engine that failed under a data path failure. If a contact is power-failed, the button is inoperative to shutdown an engine but can be used to safe an engine that shuts down behind a data path if the corresponding FF is commfaulted.
- If a MAIN ENGINE SHUT DOWN pushbutton is commfaulted in BFS, or failed otherwise, it is inoperative.
- An SSME command path failure must always be shut down manually with the A/C switches and PBs.
- An SSME FAIL C (L, R) message indicates that the GNC software has recognized an engine shut down. Two of these messages will enable single engine roll control mode.
- An engine in data path failure will never display a red MAIN ENGINE STATUS light.
- There are no direct indications to the crew of limit shutdown enable/inhibit status. The status is available to the MCC, or it can be deduced by the crew.
- Limits must be enabled on an engine when the helium regulator pressure begins to decay due to a helium leak. An SSME will fail catastrophically if there is insufficient helium, and limit shutdown is inhibited.
- Manual shutdown of hydraulically or electrically locked SSME is dependent on the performance call, due to NPSP requirements.
- Actual throttle levels on the first stage throttle bucket can vary due to SRB thrust level dispersions. This is an artifact of "first stage adaptive guidance."
- Loss of an APU in powered flight will result in a hydraulic lockup.
- 23 k, 22.5 k, and 24.5 k V_i are about 30 seconds before MECO on the three-engine uphill, TAL, and two-engine uphill cases, respectively, so these numbers can be used for engine shutdown cues.
- MPS ENGINE POWER switches look very similar to He ISOLATION switches and are located close together on panel R2. **Use caution.**
- Shutdown with A/C switches will always cause a data path failure.
- Loss of ALC 1, 2, 3 (APC 4, 5, 6) will cause SSME helium isolation A to close on the C, L, R SSME with no direct indication to the pilot. Do not attempt subsequent helium leak isolations.

2.17 MECHANICAL SYSTEMS

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Description

The mechanical systems are those components that must be deployed, stowed, opened, or closed. Each of these components is physically moved by an electrical or hydraulic actuator.

The mechanical systems include the active vent system, external tank umbilical doors, payload bay doors, radiators, and landing/deceleration system. The landing/deceleration system is discussed in Section 2.14, and radiators are included in Section 2.9. The others are discussed in sequence in this section. Operations are discussed within each system description.

Certain other components that contain mechanical actuators are not included in this section, but are covered within the discussion of the system in which they are included. They are: (1)

payload retention latches, covered in Section 2.19, (2) star tracker doors and air data probes, discussed in Section 2.13, and (3) Ku-band antenna, found in Section 2.4.

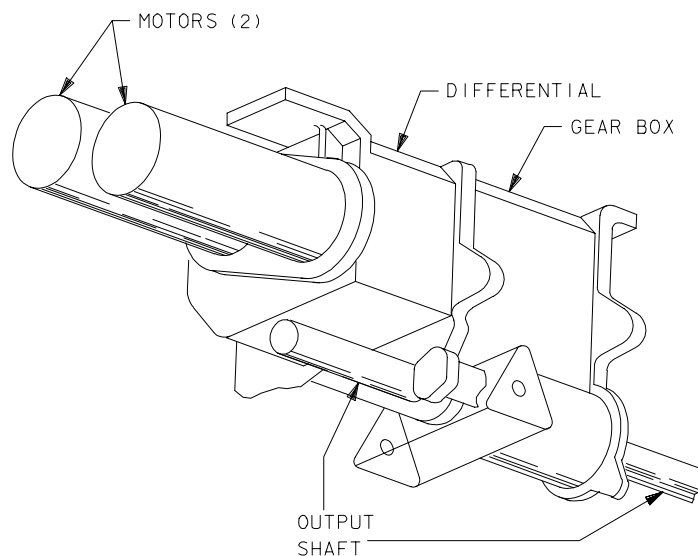
Electromechanical Actuators

The design of all orbiter electromechanical actuators is essentially the same. Each actuator assembly contains two three-phase ac motors, brakes, a differential, a gearbox, and limit switches. With the exception of the ET door centerline latches and vent doors, all actuator assemblies also contain torque limiters.

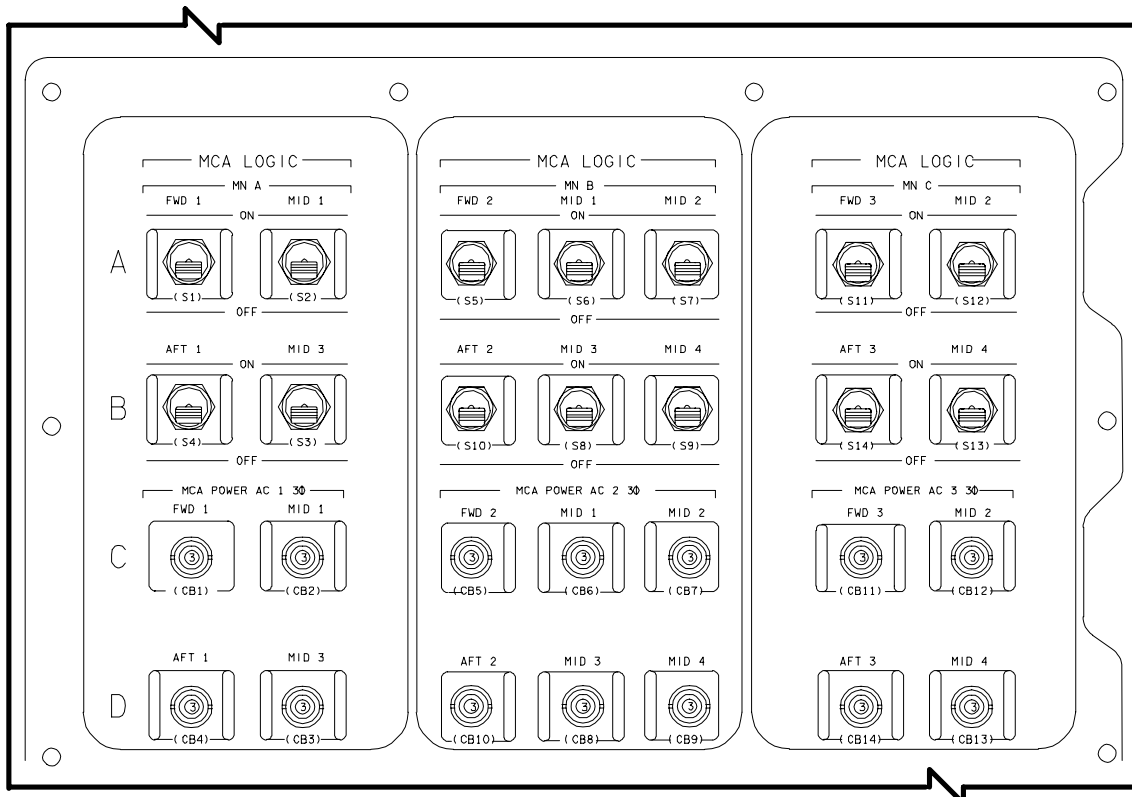
Power for the actuator motors and limit switches is provided by motor control assemblies (MCAs). Commands must be sent to the MCAs to turn the motors off and on. Commands can originate from the GPCs, CRT item entries, or hardwired switches. Multiplexer/demultiplexers (MDMs) send the commands to the MCAs. Each actuator motor is commanded by a separate MDM; the loss of one MDM will not cause the loss of an actuator.

When the actuator reaches the commanded position, the limit switches send signals back to the MCA to turn the ac power off. Signals are also sent to GPCs and talkbacks in the crew compartment.

The MCAs are controlled via the *MCA LOGIC* switches and circuit breakers on panel MA73C.



Electromechanical Actuator



MCA Controls on Panel MA73A

Active Vent System

The active vent system equalizes the unpressurized compartments of the orbiter to the ambient environment as the orbiter travels from the pressurized atmosphere of Earth to the vacuum of space.

The active vent system consists of 18 vent ports (9 on each side) in the orbiter fuselage. For identification, each door is numbered forward to aft, and each compartment has a dedicated vent on the left- and right-hand side of the orbiter. Each vent door has a pressure seal and a thermal seal, and is driven inward by an electromechanical actuator. The vent openings are sized according to the volume to be vented.

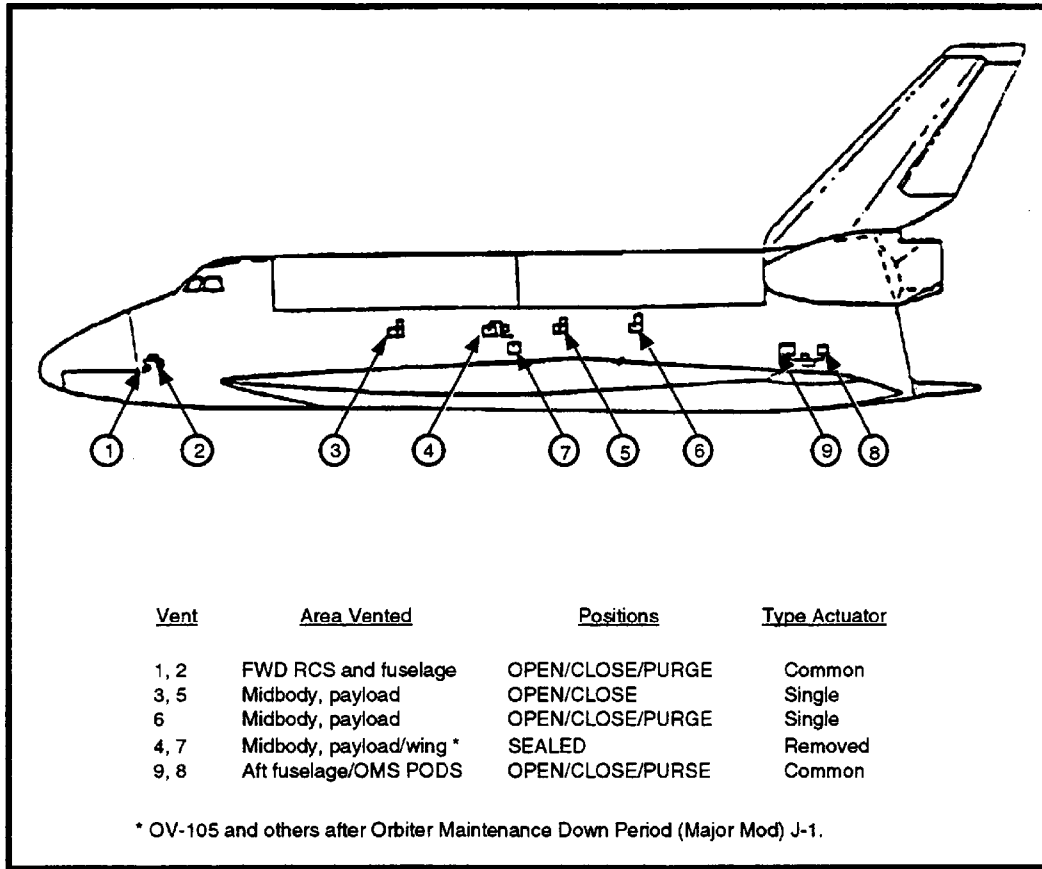
The doors for the vent ports are controlled to provide the capability to purge with dry air or nitrogen on the ground, or to exclude hazardous gases or contaminants.

Forward, mid, and aft MCAs power the vent door motors and limit switches. The crew can also use GNC OVERRIDE SPEC 51 to open or close the vent doors (VENT DOOR CNTL).

Vent Operations

The 18 doors are divided into six groups with two electromechanical actuators per group. Sequencing prelaunch is staggered with a 2.5-second delay between groups, and normal vent opening or closing time is 5 seconds. The vent doors are controlled by 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 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.



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Vent Locations

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.

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.

3051/051/	OVERRIDE	2 008/04:13:37
		000/00:29:56
ABORT MODE 1	ELEVON FILTER	ENTRY FCS
TAL 2	AUTO 17*	NOM 20*
ATO 3	FIXED 18	ALT 21
ABORT 3	SSME REPOS 19	ENA S POLE 23
MAX THROT 4		
	IMU STAT ATT DES	PRL
PRPLT DUMP	1 3 25	SYS AUT DES
	2 26	1 28* 31
INH ICNCT 5	3 27	2 29* 32
OMS DUMP		3 30* 33
ARM 6	ADTA H α M	DES
START 7	L 1 20466 + 7.0 0.58	34
STOP 8	3 20466 + 7.0 0.58	35
9 QUAN/SIDE 78	R 2 20892 + 6.9 0.58	36
OMS DUMP TTG 520	4 20892 + 6.9 0.58	37
	ET SEP	ROLL MODE AUTO
	AUTO 38	AUTO SEL 42
	SEP 39	WRAP MODE 45
AFT RCS 13	ET UMB DR	VENT DOOR CNTL
14 TIME 0	CLOSE 40	OPEN 43*
	RCS RM MANF	CLOSE 44
FWD RCS 15	CL OVRD 41	
16 TIME 0		

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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 1 st 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 1 st 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 9Mach 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

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

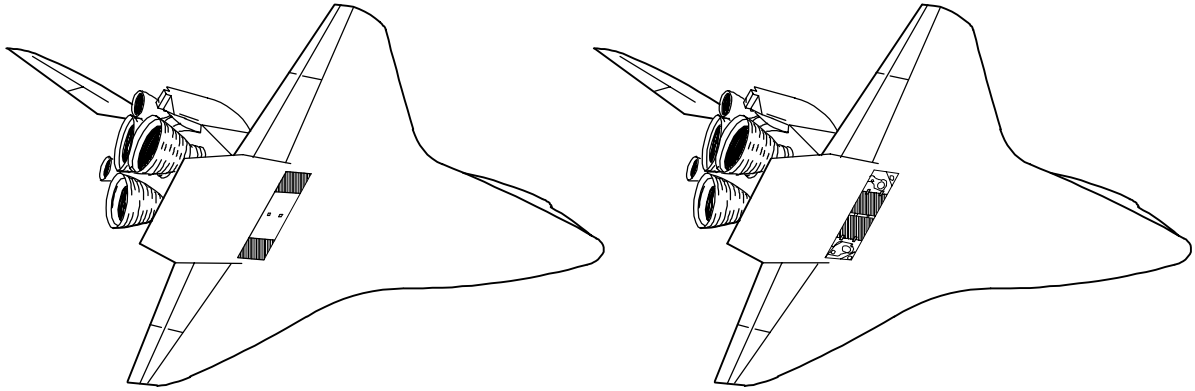
into a notch on the outer edge of the left and right doors. The centerline latches must be disengaged from the doors before both ET doors can be closed. When unlatched, the two centerline latches retract into the body of the orbiter and are then considered stowed. Nominally, 6 seconds are required to stow the centerline latches. The centerline latches are driven to the stowed position by two three-phase ac motors.

NOTE

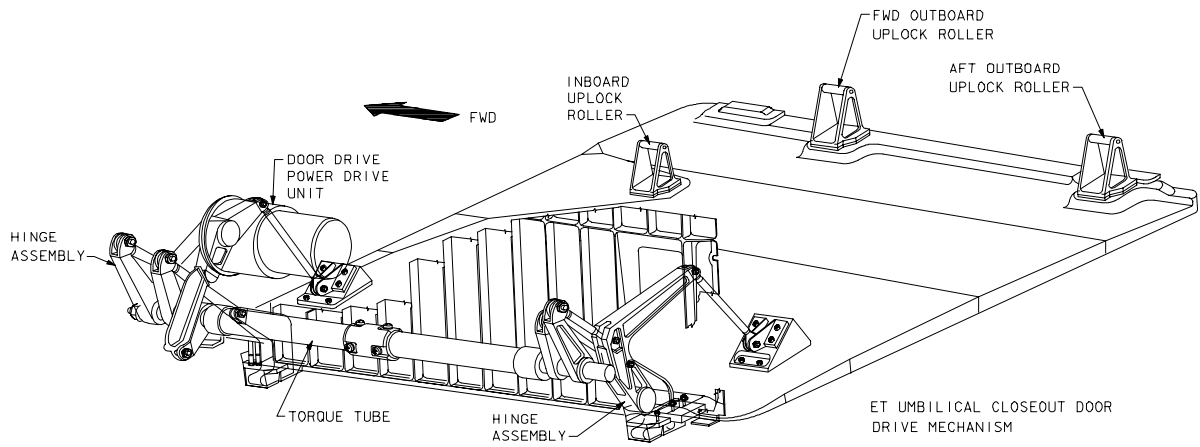
Once stowed, the centerline latches cannot be redeployed by the crew; the task must be completed by ground crews.

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.

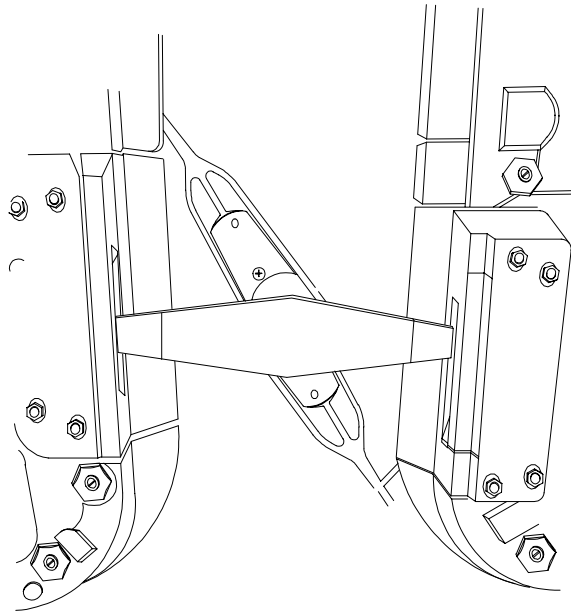
Each group of three latches is driven by two three-phase ac motors. The motors are reversible, allowing the crew to latch or unlatch the doors. Six seconds are required to latch the doors closed (dual motor time).



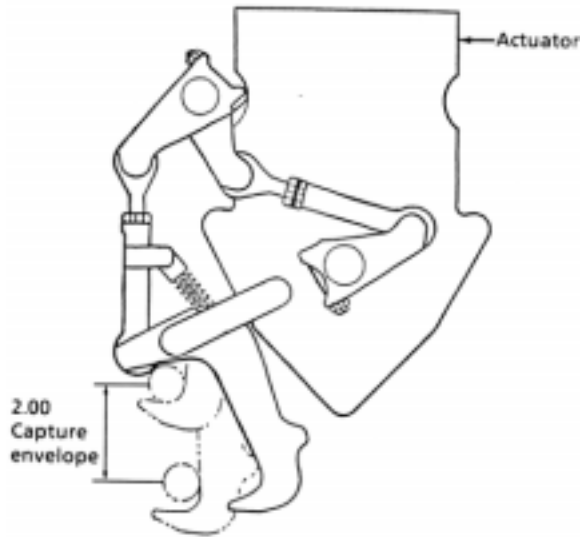
ET Door Positions



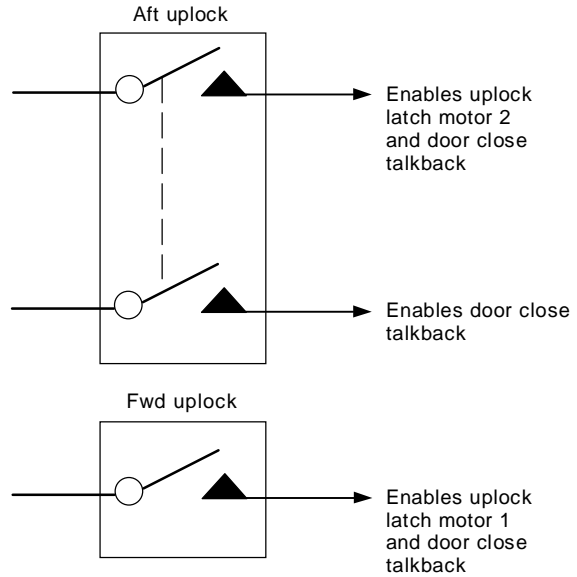
Right Side ET Umbilical Door



Centerline Latch Movement



Door Uplock Latch and Roller



Uplock Latch Limit Switches

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CAUTION

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

ET Door Operations

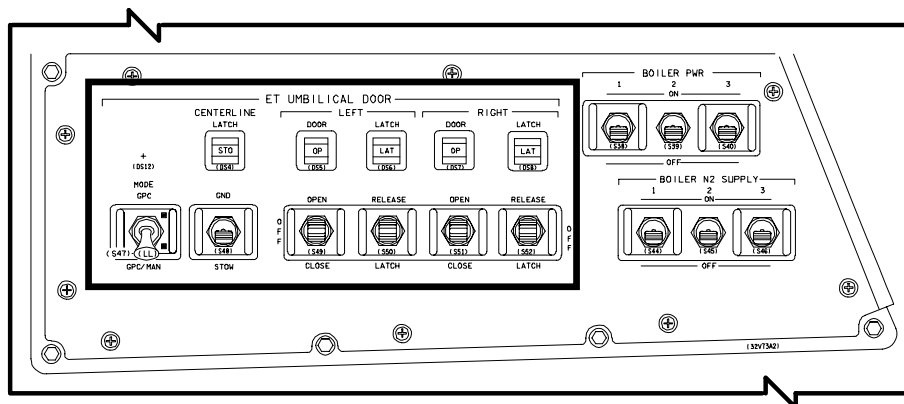
The status of the uplock latches is provided by limit switches.

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 RTLS 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.

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.

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 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 UMBILICAL DOOR Controls on Panel R2

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 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 *RTLS* and *TAL* aborts.

During these aborts, transition into MM 602 or 304 will automatically initiate the umbilical door closure sequence, providing the *RTLS* 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 X_o 1307. The curtain is designed to operate in range of -200° F to +250° F.

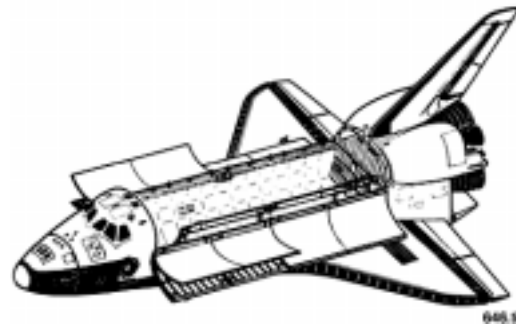
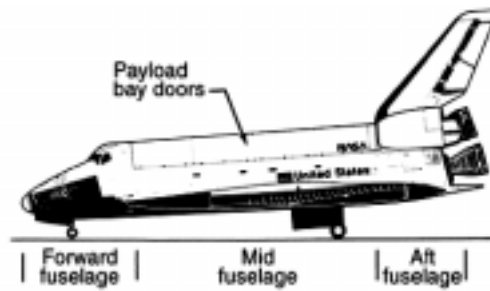
The umbilical doors are opened by the crew during postlanding activities. The crew can use only the panel R2 switches to open the ET doors.

Payload Bay Door System

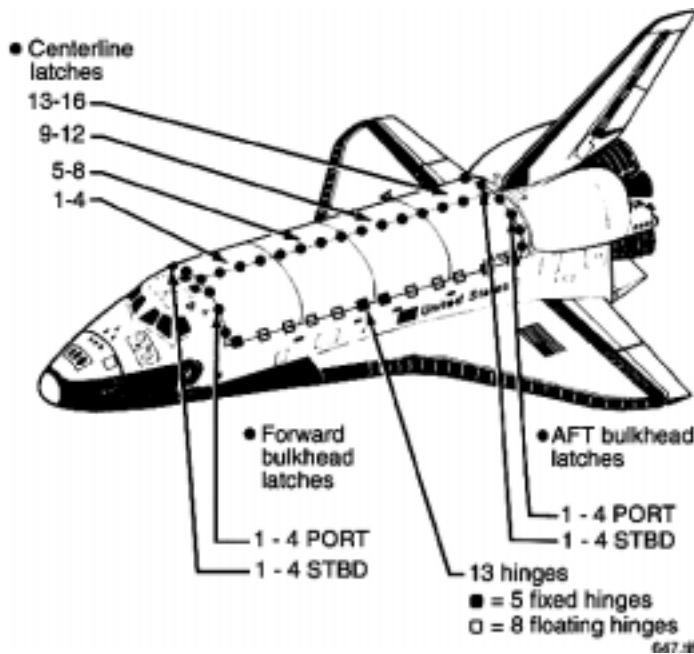
The payload bay doors provide an opening for payload deployment from and retrieval into the payload bay. The doors provide structural support for the orbiter midbody, and they house the ECLSS radiators that transfer heat from the vehicle to space.

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.

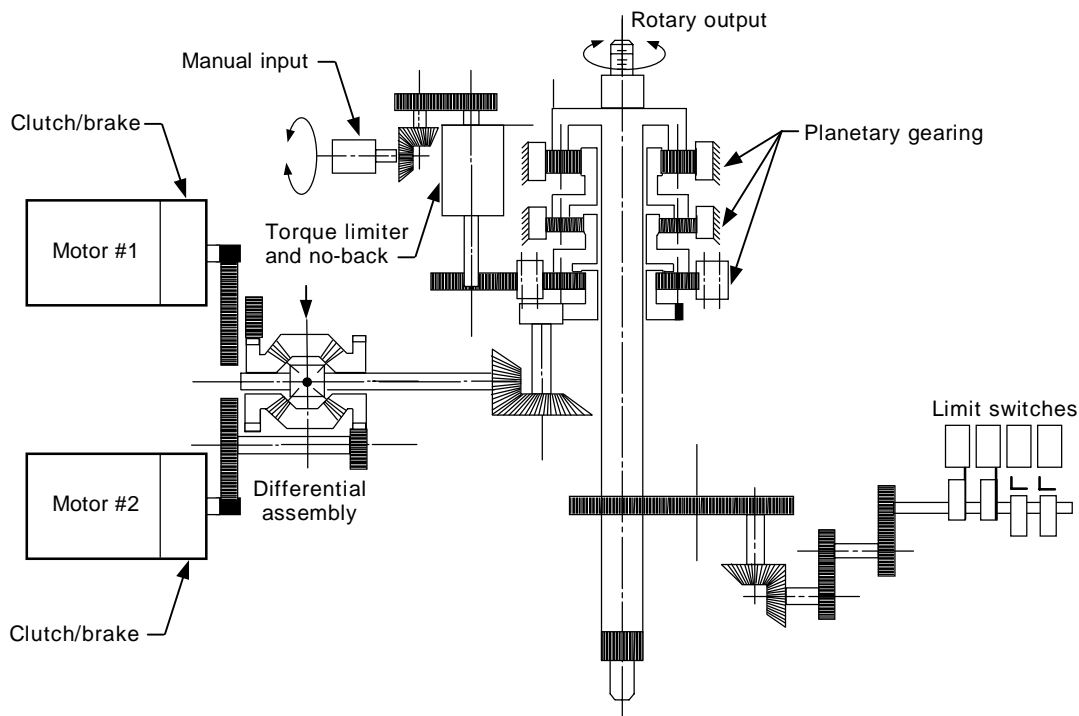
The motors are reversible, which allows the crew to latch or unlatch the doors.

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.



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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.

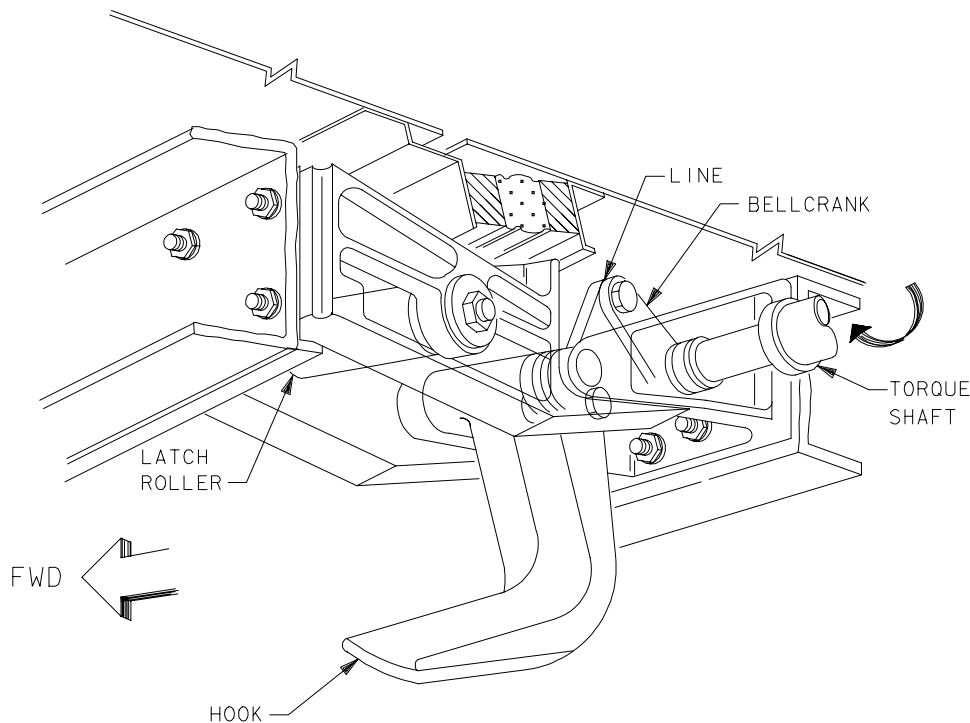
The doors are driven open or closed by a rotary actuator consisting of two three-phase ac motors per drive unit. (Each door contains its own.) Torque limiters are incorporated in the rotary

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°.

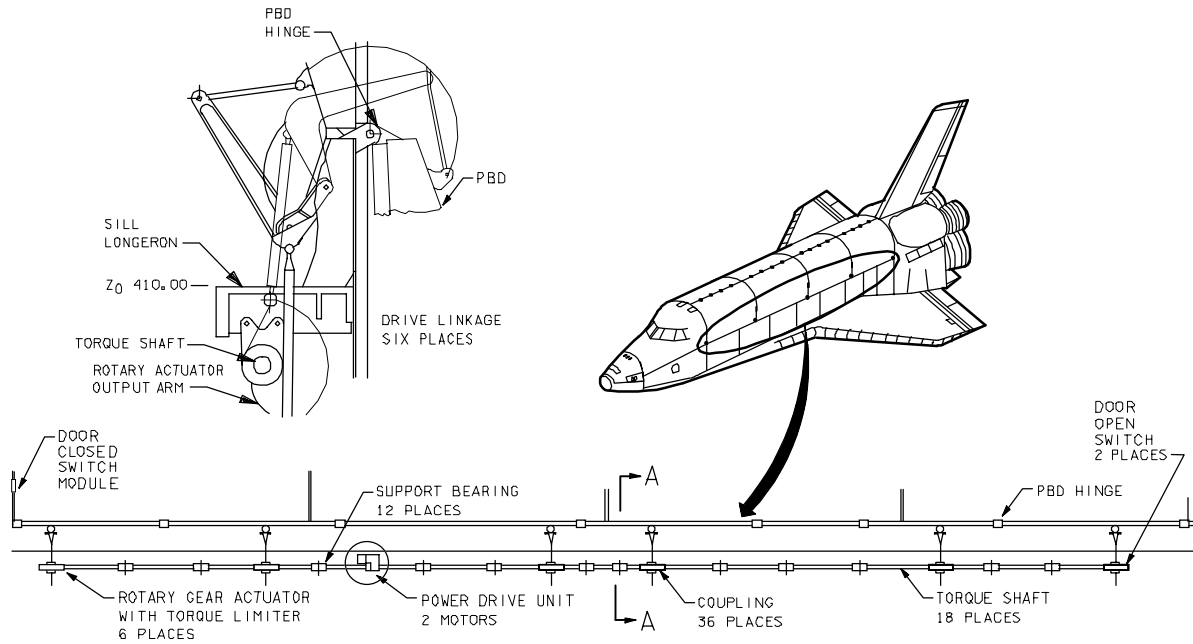
The electromechanical actuator drives a 55-foot-long torque shaft. The shaft turns the rotary actuators, causing the push rods, bellcranks, and links to push the doors open. The same arrangement pulls the doors closed.

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.

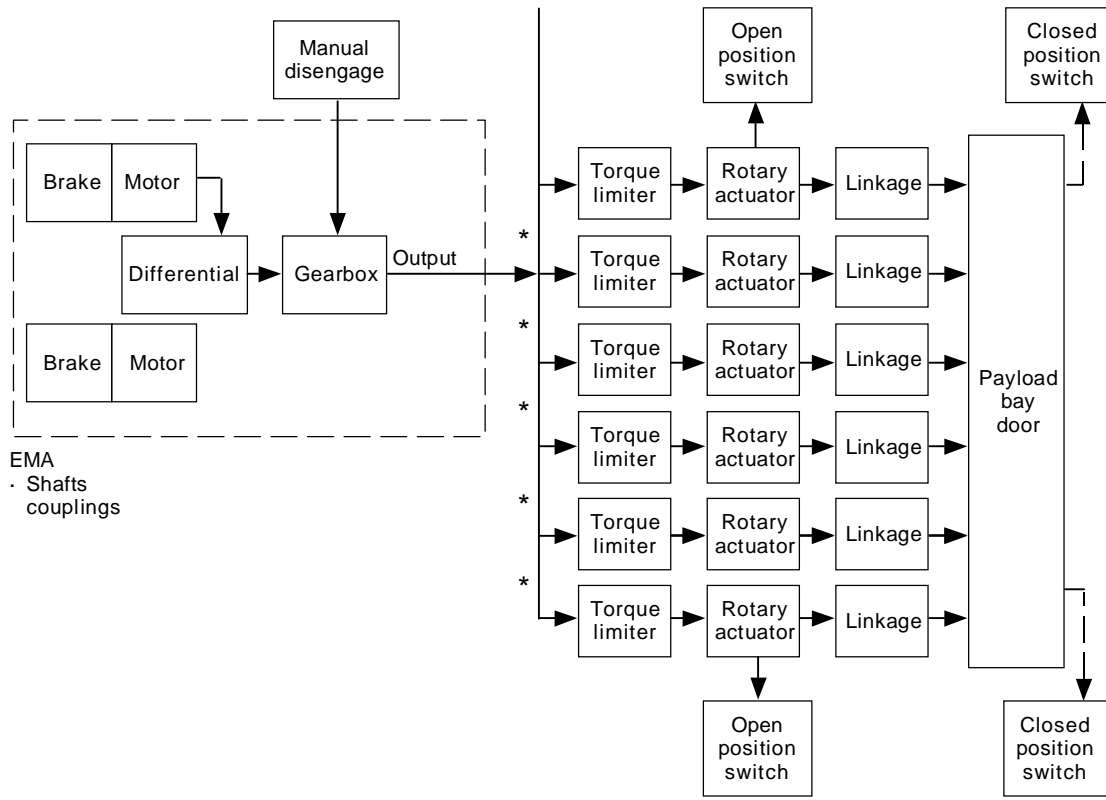
Each band, gold or silver, represents the amount the doors are open or closed in degrees of rotation.



Payload Bay Door Centerline Latch



Payload Bay Door Drive System



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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.

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. 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		4 000/02:00:00	
AC POWER ON 1*		OFF 2		000/00:00:00	
AUTO MODE SEL 3		PBD SW-CL			
				MICRO-SW STAT	
				LATS DOORS	
				CC00 CRRRO	
				ABAB ABC	
CENTER LATCHES		MAN SEL	OP/CL	AUTO SEQ	
5- 8		4	OP		0011
9-12		5	OP		0011
1- 4		6	OP		0011
13-16		7	OP		0011
STBD					
FWD LATCHES		8	OP		0011 00000
AFT LATCHES		9	OP		0011 00000
DOOR		10*			
PORT					
FWD LATCHES		11	CL		1100 11110
AFT LATCHES		12	CL		1100 11110
DOOR		13	CL		
PBD SW BYPASS 14					
					OPEN 15
					STOP 16
					CLOSE 17

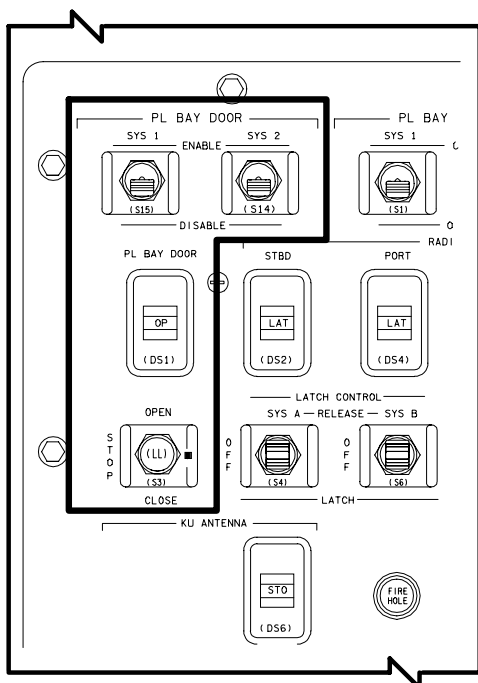
PL BAY DOORS Display

RAD/PLBD OPS NO GO FOR FOLLOWING FAILURES			
OMS/RCS	GNC	ECLS/EPS	MECH
1 OMS Engs	2 IMUs	1 H2O 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
	3 Aas	Both Cab Fans	
1 OMS Inlet line			
	3 adtaS	3 OF 6 Av Bay Fans	
OMS Prop TK Leak			DPS
	3 Elevon or 2 BF Pos	2 FCs	3 GPCs
Aft RCS He or Prop Leak	Fdbks (same surface)	Any Mn or 3 phase AC Bus	2 PL MDMs
			2 FF or FA MDMs
COMM			APU/HYD
No Voice and No CMD	2 FCS CH (same surface)	Any CNTL or MPC Bus	2 APU/HYD/WSB
		3 IMU Fans	

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.



PL BAY DOOR Controls on Panel R13L

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.

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.

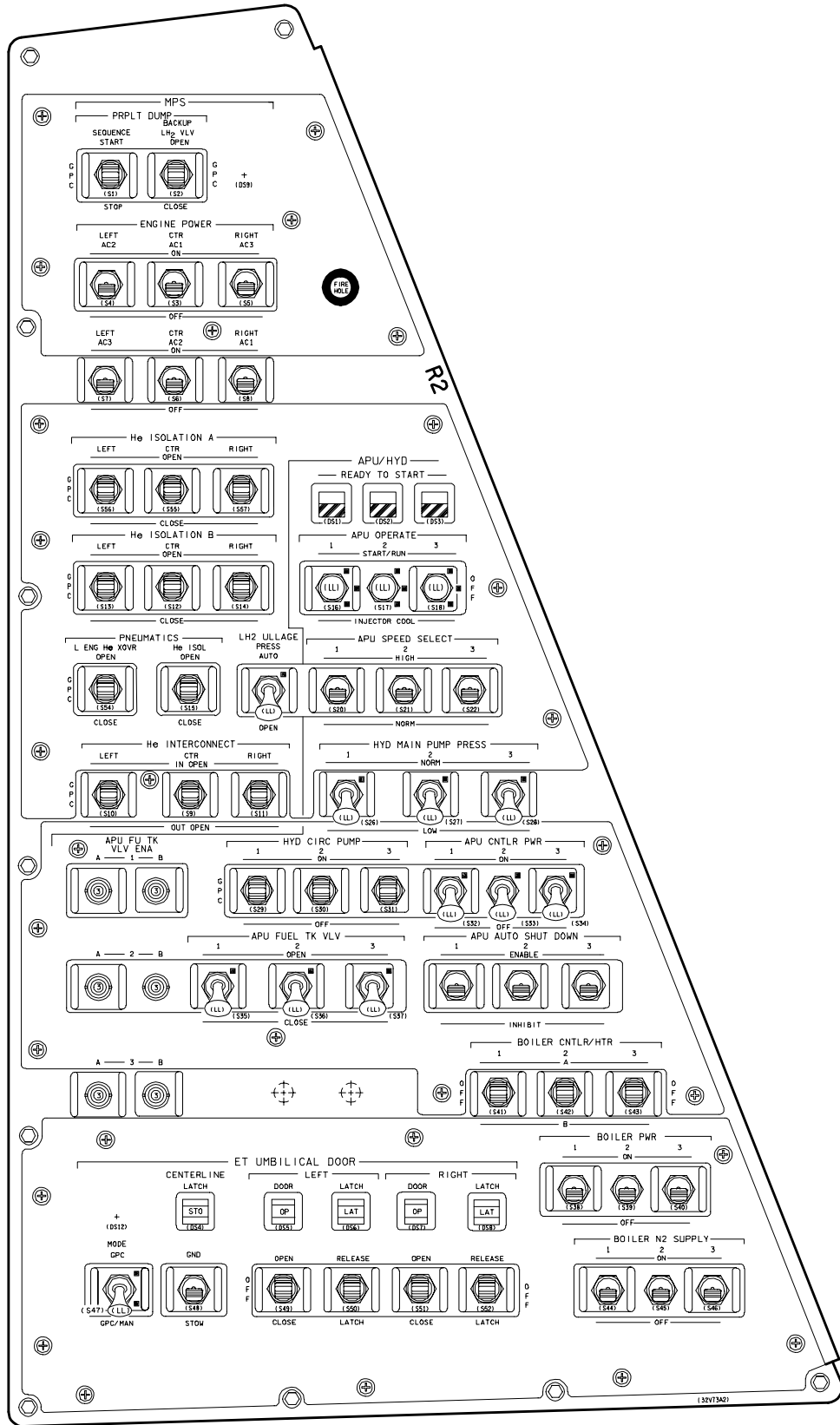
First, item 13, *PORT DOOR*, is selected. The *PL BAY DOOR* switch is set to *CLOSE*. When the port door is closed, items 11 and 12, *PORT FWD* and *AFT LATCHES*, are selected. *PL BAY DOOR* is set to *STOP*, and *PORT FWD* and *AFT LATCHES* and *DOOR* are deselected.

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.

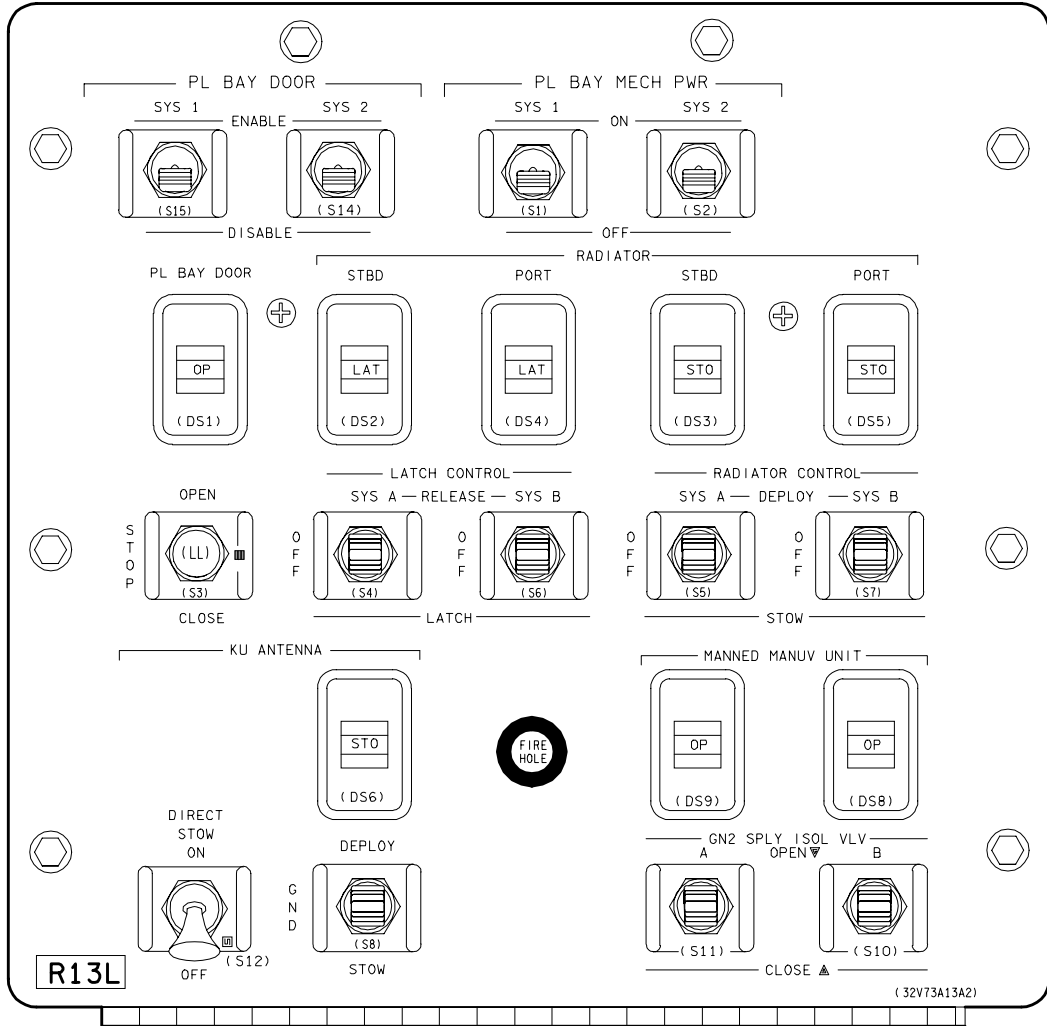
When the latches are closed, *PL BAY DOOR SYS 1* and *SYS 2* are set to *DISABLE*, and CRT item 2 is executed to turn off the power.

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

3051/051/	OVERRIDE	2 008/04:13:37
		000/00:29:56
ABORT MODE	ENTRY FCS	
TAL 1	ELEVON	FILTER
ATO 2	AUTO 17*	NOM 20*
ABORT 3	FIXED 18	ALT 21
MAX THROT 4	SSME REPOS 19	ENA S POLE 24
PRPLT DUMP	IMJ STAT	ATT DES PRL
	1 3 25	SYS AUT DES
	2 26	1 28* 31
	3 27	2 29* 32
		3 30* 33
INH ICNCT 5		
OMS DUMP	ADTA	H α M DES
ARM 6	L 1	20466 + 7.0 0.58 34
START 7	3	20466 + 7.0 0.58 35
STOP 8	R 2	20892 + 6.9 0.58 36
9 QUAN/SIDE 78	4	20892 + 6.9 0.58 37
OMS DUMP TTG 520	ET SEP	ROLL MODE AUTO
	AUTO 38	AUTO SEL 42
AFT RCS 13	SEP 39	WRAP MODE 45
14 TIME 0	ET UMB DR	VENT DOOR CNTL
	CLOSE 40	OPEN 43*
FWD RCS 15	RCS RM MANF	CLOSE 44
16 TIME 0	CL OVRD 41	

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OVERRIDE Display (SPEC 51)

2021/ /	PL BAY DOORS	4 000/02:00:00
		000/00:00:00
AC POWER	ON 1*	
	OFF 2	PBD SW-CL
AUTO MODE	SEL 3	
CENTER LATCHES	MAN SEL	OP/CL AUTO SEQ
5-8	4	OP
9-12	5	OP
1-4	6	OP
13-16	7	OP
STBD		
FWD LATCHES	8	OP
AFT LATCHES	9	OP
DOOR	10*	
PORT		
FWD LATCHES	11	CL
AFT LATCHES	12	CL
DOOR	13	CL
PBD SW BYPASS 14	OPEN 15	
	STOP 16	
	CLOSE 17	

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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)

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Description

The OMS provides propulsion for the orbiter during the orbit phase of flight. The OMS is used for orbit insertion, orbit circularization, orbit transfer, rendezvous, and deorbit. The OMS may be used to provide thrust above 70,000 feet altitude. Each OMS pod can provide more than 1,000 pounds of propellant to the RCS. Amounts available for interconnect depend on loading and number of OMS starts during the mission.

The OMS is housed in two independent pods on each side of the orbiter's aft fuselage. The pods, which also house the aft reaction control system (RCS), are referred to as the OMS/RCS pods. Each pod contains one OMS engine and the hardware needed to pressurize, store, and distribute the propellants to perform OMS

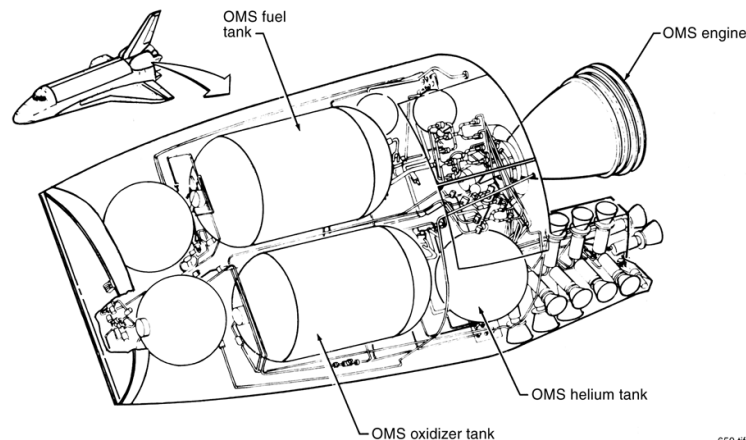
engine burns. Normally, OMS maneuvers are done using both OMS engines together; however, a burn can be performed using only one of the OMS engines. For velocity changes less than 6 fps, RCS is used. For velocity changes greater than 6 fps, a single OMS engine burn is preferred, because engine lifetime concerns make it desirable to minimize engine starts. Two OMS engines are used for large velocity changes, or for critical burns. Propellant from one pod can be fed to the engine in the other pod through crossfeed lines that connect the left and right OMS pods.

The OMS has important interfaces with the data processing system and the electrical power system. The OMS valves and gimbal actuators receive commands, and the system returns some data to the general purpose computers through multiplexer/demultiplexer units. Electrical power is supplied to the OMS through main buses, control buses, and alternating current buses for the operation of switches, valves, instrumentation, gimbal actuators, and heaters.

The OMS/RCS pods are designed to be reused for up to 100 missions with only minor repair, refurbishment, and maintenance. The pods are removable to facilitate orbiter turnaround, if required.

NOTE

At one time, there were plans to provide additional capability by including an OMS kit. It is now unlikely that OMS kits will ever be used, but OMS kit switches and gauges appear throughout the orbiter. These switches and gauges are currently inoperative and are likely to remain so.



Orbital Maneuvering System

Maneuver Display

1041/	OMS 1 MNVR EXEC	1 000/00:40:23
OMS BOTH 1*		000/00:15:37
L 2	BURN ATT	AVTOT 0
R 3	24 R 083	TGO 0:00
RCS SEL 4	25 P 195	VGO X +
S TV ROLL 180	26 Y 300	Y +
TRIM LOAD	MNVR 27*	Z +
6 P [-] 0.1	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 OT	GMBL CK 34	DUMP 37
18 PRPLT [-]		OFF 38*
TGT PEG 7		SURF DRIVE
19 AVX [-]		ON 39
20 AVY [+]		OFF 40*
21 AVZ [-]		
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°, 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 (n. mi.) of the apogee and perigee for the orbit that will result from the successful completion of the targeted OMS burn. CUR HA and HP are the current apogee and perigee altitudes. Mileages are from the Earth's surface.

Item 35 (ABORT TGT) permits entry of a stored PEG 4 target for OMS 1 or OMS 2 with a single keystroke. It is used primarily for calling up ATO and AOA targets.

Flight software is divided into operational sequences (OPS) that are subdivided into major modes (MM). Operational sequences and major modes are discussed in detail in Section 2.6; however, it should be noted that OMS burns can only be performed in MM 104, 105, 202, and 302. OMS dumps can be performed in MM 102, 103, 304, 601, and 602.

The maneuver (MNVR) display appears automatically in MM 104, 105, 106, 202, 301, 302, and 303. The title has a prefix and a suffix that vary according to major mode. The BFS version of the display is identical to the primary display.

Major mode	Title	Mission phase
MM 104	OMS 1 MNVE EXEC	OMS 1 burn
105	OMS 2 MNVE EXEC	OMS 1 burn
106	OMS 2 MNVE COAST	Post-OMS 2 coast
202	ORBIT MNVR EXEC	Orbital maneuvers
301	DEORB NMVR COAST	Pre-deorbit coast
302	DEORB NMVR EXEC	Deorbit burn
303	DEORB NMVR COAST	Pre-deorbit coast

Maneuver Display Titles Associated with Major Mode

Engines

The OMS engines are designated left and right, descriptive of location. The engines are located in gimbal mounts that allow the engine to pivot left and right 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.

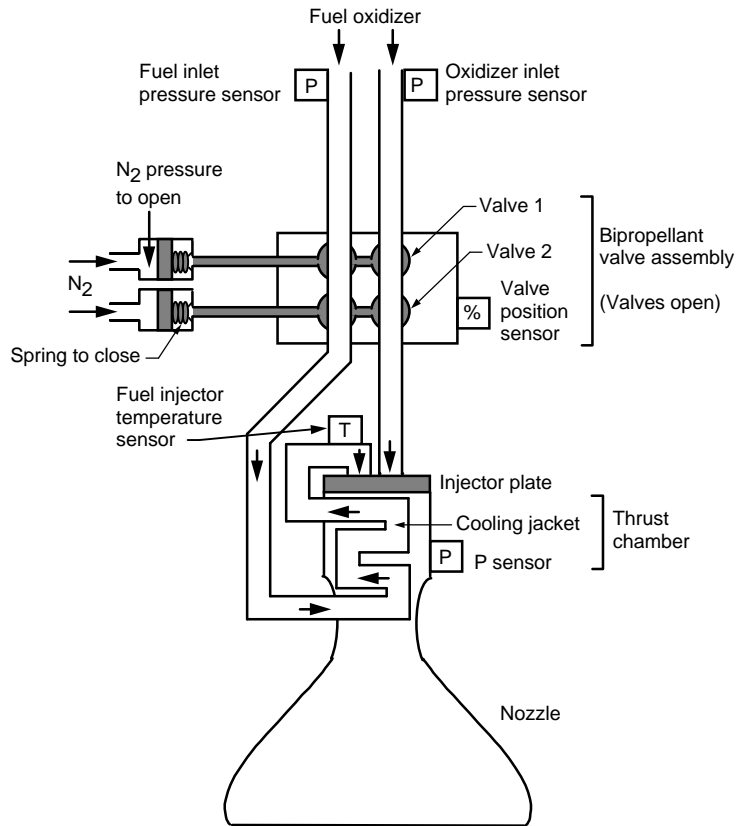
Each OMS engine has a gaseous nitrogen tank that provides pressurized nitrogen to operate the engine valves. The OMS engine does not have propellant pumps; propellant flow to the engines is maintained by pressurizing the propellant tanks with helium.

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.

Each fuel valve is mechanically linked to an oxidizer valve so that they open and close together. The name bipropellant valve comes from the fact that each linked set of valves controls the flow of both propellants.



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Orbital Maneuvering System Engine

The bipropellant valves are ball valves that rotate from fully closed (0 percent) to fully open (100 percent). The 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.

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		FU	267	258
				N2 TK	P	2220	2220
RCS				REG	P	319	319
FWD	HE P	1464	1264	P	VLV	CL	CL
	TK P	248	244	ENG	IN	P	
	QTY	0	0		OXID	257	258
MANF	1 P	248	242		FU	258	258
	2 P	248	244		VLV	1 - 2 - 2	
	3 P	250	246			2	0
	4 P	244	244				0
	5						
AFT	HE P	2800	2672	HE P	2744	2616	
L	TK P	244	249	R	TK P	247	247
	QTY	63	63		QTY	62	61
MANF	1 P	244	246		1 P	242	246
	2 P	246	250		2 P	250	246
	3 P	248	250		3 P	246	250
	4 P	246	250		4 P	246	242
	5				5		

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OMS Parameters on BFS 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
	FU	80	80	XFD	OX	68	68
ENG I/F	OX	70	70		GMBL LN	68	68
	FU	70	70	DRN	OX	65	65
	OX VLV	71	71				
	FU INJ	81	81				
WEB KEEL	1	70	70		FU	OX	
	2	70	70	BLD AFT FUS	65	66	
Y	OB	74	74	PL BAY	65	67	
	UP	74	74	OX 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
CSE SERV PNL	74	73					
TEST HE/OX	1	70	70	AFT RCS	L	R	
	2	70	70	MANF 1	OX	69	68
				DRN PNL	1	68	66
					2	68	66
				VERN PNL	1	67	67
					2	67	67

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OMS Parameters on SM SPEC 89 PRPLT THERMAL Display

Since the fuel injector temperature is the temperature of the fuel after it has passed through the chamber cooling jacket, it provides an indirect indication of the temperature of the thrust chamber walls. A high fuel injector temperature indicates that the engine may be sustaining thermal damage. The fuel normally flows to the engine at a temperature between 30° and 125° F. During engine operation, when the fuel is cooling the chamber, the fuel injector temperature should be approximately 218° F. The temperature limit for safe operation is 260° F.

Thrust Chamber

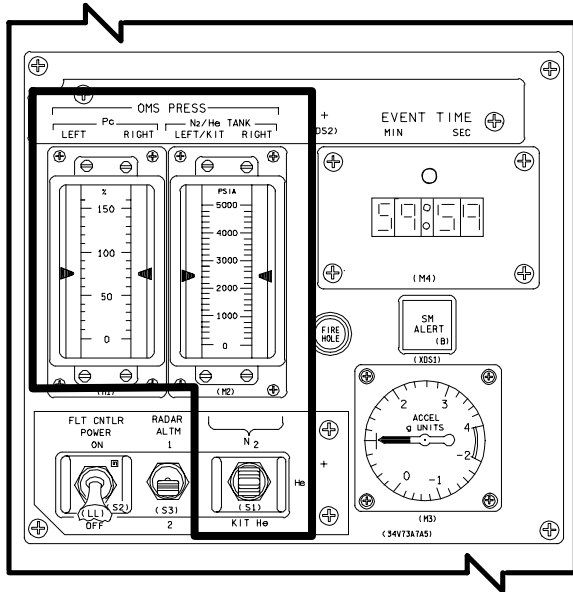
The fuel and oxidizer are mixed at the injector plate in the thrust chamber. When the fuel reaches the thrust chamber, it is directed through 120 cooling channels in the combustion

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

The fuel and oxidizer orifices are positioned so that the propellants will impinge and atomize, causing the fuel and oxidizer to ignite because of hypergolic reaction. The resulting hot gas creates thrust as it exits the chamber and expands through the engine nozzle. The contoured nozzle extension is bolted to the aft flange of the combustion chamber.

The pressure in the thrust chamber (P_c) is measured by a sensor that is wired directly to the OMS 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.



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

Pressure sensors in the fuel and oxidizer lines are located just above the bipropellant valves. These inlet pressures for each engine are shown on the GNC SYS SUMM 2 display as ENG IN P, one for oxidizer, one for fuel. When the OMS engines are not burning, the inlet pressures should match the propellant tank pressures, which are normally 254 psi. During OMS burns, propellant flow into the thrust chamber causes the inlet pressure to drop to approximately 220 to 235 psi for the fuel and to 200 to 206 psi for the oxidizer, but the propellant tank pressures remain higher. The exact inlet pressures are engine dependent.

The inlet pressures are an indirect indication of propellant flow rates. If they are abnormal, problems should be anticipated. An imbalance in the flow rates for fuel and oxidizer will result in an incorrect mixture ratio in the thrust chamber. If the mixture becomes fuel-rich, the chamber pressure and temperature will decrease, and combustion will eventually be choked off. If the mixture becomes fuel-lean, the chamber temperature will increase, and

engine damage could result. If the fuel-lean condition is the result of a low fuel flow rate, the situation is especially serious, since the fuel is used to cool the outside of the thrust chamber.

Nitrogen System

Gaseous nitrogen is used to operate the engine control valves and also to purge the fuel lines at the end of each burn. The nitrogen system consists of a storage tank, engine pressure isolation valve, regulator, relief valve, check valve, accumulator, engine purge valves, bipropellant solenoid control valves, and actuators that control the bipropellant ball valves.

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

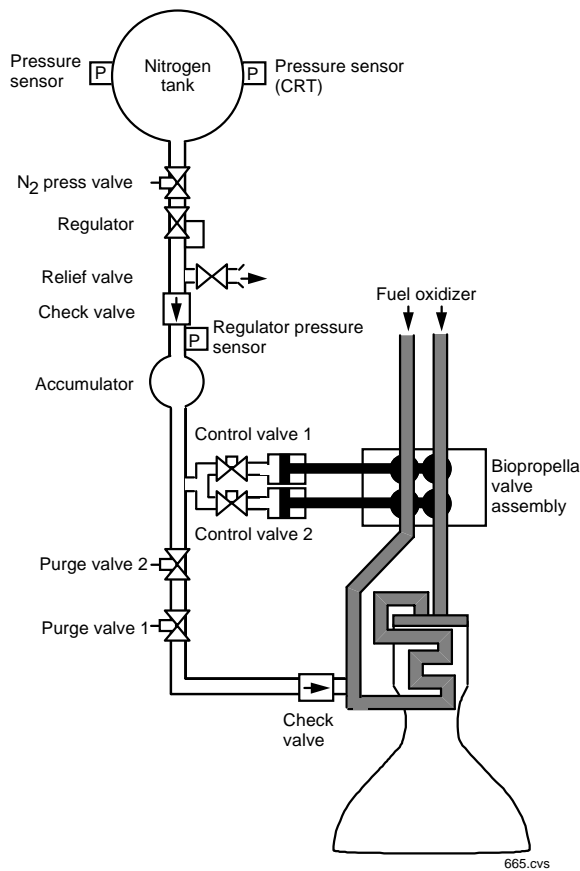
Each tank's pressure is monitored by two sensors. One is wired to directly transmit the tank pressure to the OMS PRESS N₂/He TANK LEFT/KIT, RIGHT meter on panel F7. The other sensor displays on the GNC SYS SUMM 2 display (N₂ TK P, L and R). Both pressures are downlisted by telemetry.

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

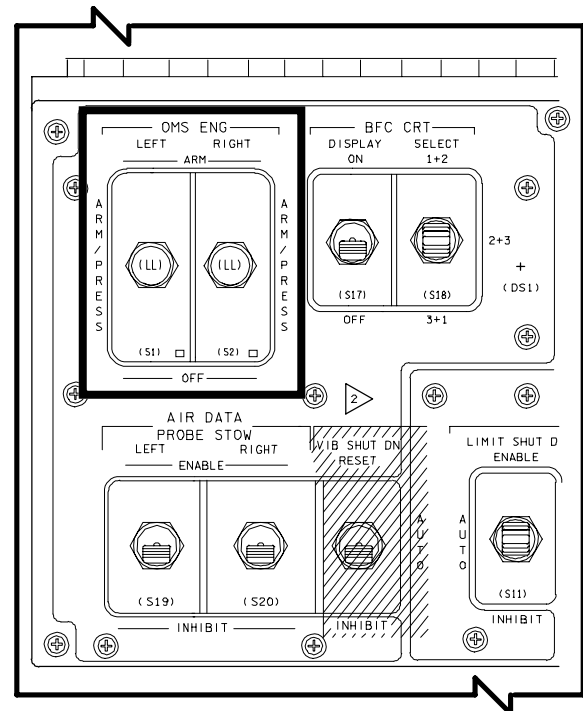
A single-stage regulator is installed in each gaseous nitrogen pneumatic control system between the gaseous nitrogen engine pressure isolation valve and the engine bipropellant control valves. The regulator reduces nitrogen pressure from its tank pressure, which can be as high as 3,000 psig, to a desired 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.

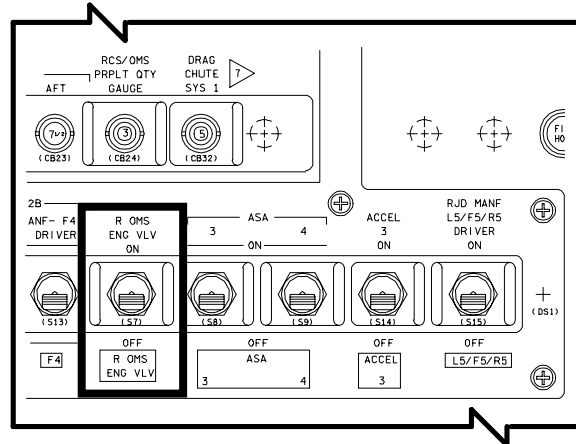
Check valves are installed in the vent port outlet of each gaseous nitrogen solenoid control valve on the spring pressure side of each actuator to protect the seal of these components from atmospheric contamination.

Ball Valve Actuation

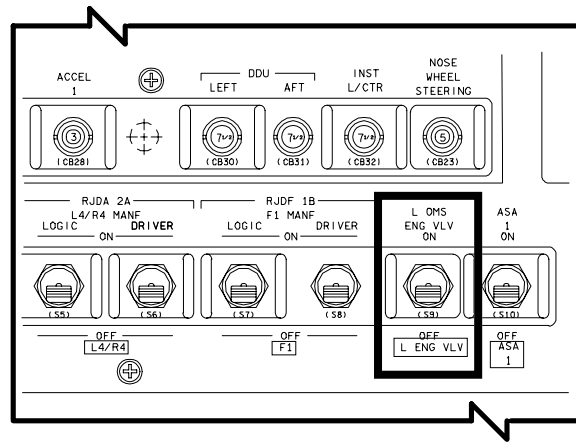
When the gaseous nitrogen solenoid control valves are energized open, pressure is directed into the two actuators in each engine. The nitrogen acts against the piston in each actuator, overcoming the spring force on the opposite side of the actuators. Each actuator has a rack-and-pinion gear; the linear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

for the first 10 minutes or so following a burn, it might be dangerous to start another burn, since forcing more fuel into already frozen lines could cause damage.

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

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

The automatic software will perform the purge only if the *OMS ENG* switch on panel C3 is in the *ARM/PRESS* position; that is, when the nitrogen pressure valve is open. For that reason, the crew should leave both *OMS ENG* switches in *ARM/PRESS* for at least 2 seconds after an OMS burn so that the purge can be completed. When the nitrogen pressure valve is open, nitrogen for the purge is supplied by the tank. If the valve were closed, the purge would deplete the accumulator, and the OMS start capability of the accumulator would be lost. This is not normally a problem since the

accumulator can be repressurized. But if the valve were closed because of an upstream leak, it would be important to save the nitrogen in the accumulator. The purge is not as important as the need to preserve the engine restart capability. With the *OMS ENG* switch in *ARM* or *OFF*, the valve is closed, and the engine purge is automatically inhibited.

Helium System

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

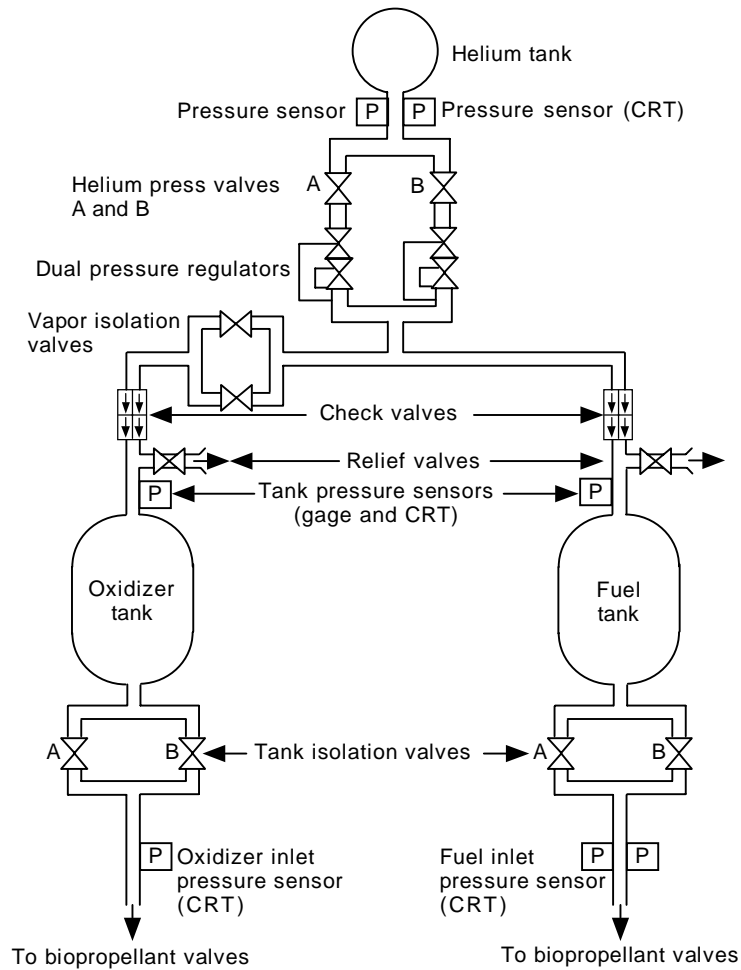
Helium Tanks

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

Two pressure sensors downstream of each helium tank in each pod monitor the helium source pressure. One 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).

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.



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Propellant and Helium Supply

Helium Pressure Valves

Two helium pressure valves in each pod isolate the helium tank from the propellant tanks. The valves are in a parallel arrangement, and are labeled A and B. This arrangement provides redundant paths for the helium to reach the propellant tanks. These valves are held closed by springs and are opened by electrical solenoids.

The valves are controlled by the *LEFT* and *RIGHT OMS He PRESS/VAPOR ISOL* switches on panel O8. The switches have manual *OPEN* and *CLOSE* positions as well as a *GPC* position that allows automatic control. These valves are normally closed at all times except during OMS burns. If the switches are in the *GPC* position, the automatic OMS burn sequence opens the helium pressure valves at the start of a burn and closes them at the end of a burn.

NOTE

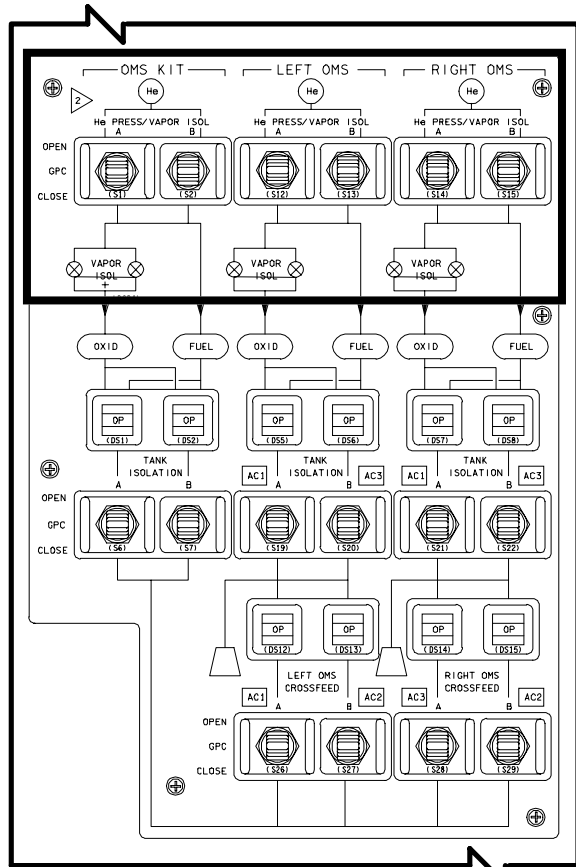
When manually opening the *He PRESS/VAPOR ISOL* switches, delay 2 seconds between opening the A and B valves. This will prevent a possible water hammer effect due to a large and sudden pressure change.

Helium Pressure Regulators

Below each helium pressure valve is a pressure regulator that reduces the helium source pressure from its value in the tank, which can be as high as 4,800 psi (at launch), to the desired working pressure of approximately 250 psig. Each pressure regulator assembly contains a flow limiter and primary and secondary regulators in series. Normally, the primary regulator is the controlling regulator. Should

the primary regulator fail, the secondary one will continue to provide pressure control.

The primary regulator pressure at normal flow is 252 to 262 psig, while the secondary regulator pressure at normal flow is 259 to 269 psig.



OMS He PRESS/VAPOR ISOL Switches on Panel O8

Vapor Isolation Valves

Over a long period of time, it is possible for small amounts of propellant vapors to diffuse through the check valves and into the helium lines. The vapor isolation valves in the helium pressurization line to the oxidizer tank prevent oxidizer vapor from migrating upstream and over into the fuel system, causing a hypergolic reaction. The vapor isolation valves are low-pressure, two-position, solenoid-operated valves that are energized open and spring-loaded closed. They can be commanded by the positioning of the *LEFT* and *RIGHT* OMS He PRESS/VAPOR ISOL switches on panel O8. When either the *A* or *B* switch is in the *OPEN*

position, both vapor isolation valves are energized open; when both switches are in the *CLOSE* position, both vapor isolation valves are closed. When the switches are in the *GPC* position, the GPC opens and closes the valves automatically.

Check Valves

The check valve assembly contains four independent check valves connected in a series-parallel configuration to provide a positive checking action against a reverse flow of propellant liquid or vapor. The parallel path permits redundant paths of helium to the propellant tanks, while the series arrangement provides redundant backflow protection. Filters are incorporated into the inlet of each check valve assembly.

Relief Valves

Below the check valves are the relief valves that protect the propellant tanks from overpressurization. Each pressure relief valve contains a burst diaphragm and filter. If excessive pressure is caused by helium or propellant vapor, the diaphragm will rupture, and the relief valve will open and vent the excessive pressure overboard. The filter prevents particulates from the non-fragmentation-type diaphragm from entering the relief valve seat. The relief valve will close and reseat after the pressure has returned to the operating level. The burst diaphragm is used to provide a more positive seal of helium and propellant vapors than the relief valve. The diaphragm ruptures between 303 and 313 psig, while the relief valve opens at 286 psig and reseats at 280 psig.

Propellant Storage and Distribution

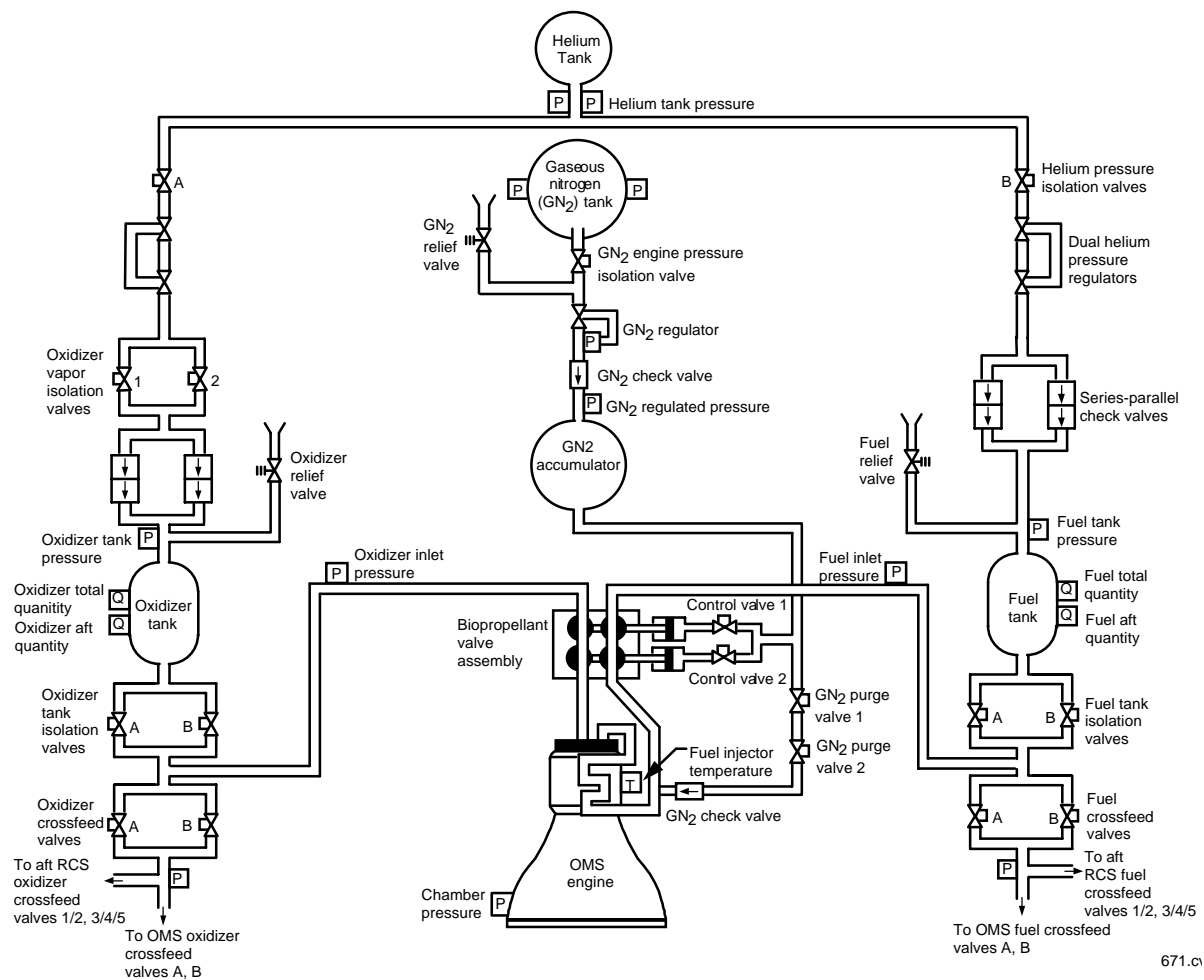
The OMS propellant storage and distribution system consists of one fuel tank and one oxidizer tank in each pod. It also contains propellant feed lines, crossfeed lines, isolation valves, and crossfeed valves. The OMS propellant in both pods enables the orbiter to perform a 1,000-foot-per-second velocity change with a 65,000-pound payload in the payload bay. The OMS pod crossfeed lines allow the propellants in the pods to be used to operate either OMS engine.

Fuel (monomethyl hydrazine) and oxidizer (nitrogen tetroxide) are stored in domed cylindrical titanium tanks within each pod. The propellant tanks, which are pressurized by the helium system, are divided into forward and aft compartments. Each tank contains a propellant acquisition and retention assembly in the aft end. This assembly consists of a mesh screen dividing the fore and aft compartments and an acquisition system. Surface tension created by the screen retains propellant in the aft compartment during zero-gravity conditions.

The acquisition assembly consists of four stub galleries and a collector manifold. The stub galleries acquire wall-bound propellant at OMS start and during RCS burns to prevent gas ingestion. The stub galleries have screens that allow propellant flow and prevent gas ingestion. The collector manifold is connected to the stub

galleries and also contains a gas arrestor screen to further prevent gas ingestion, which permits OMS engine ignition without the need of a propellant-settling maneuver employing RCS engines. The propellant tank's nominal operating pressure is 250 psi, with a maximum operating pressure limit of 313 psia.

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.



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

OMS Quantity Gauging

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

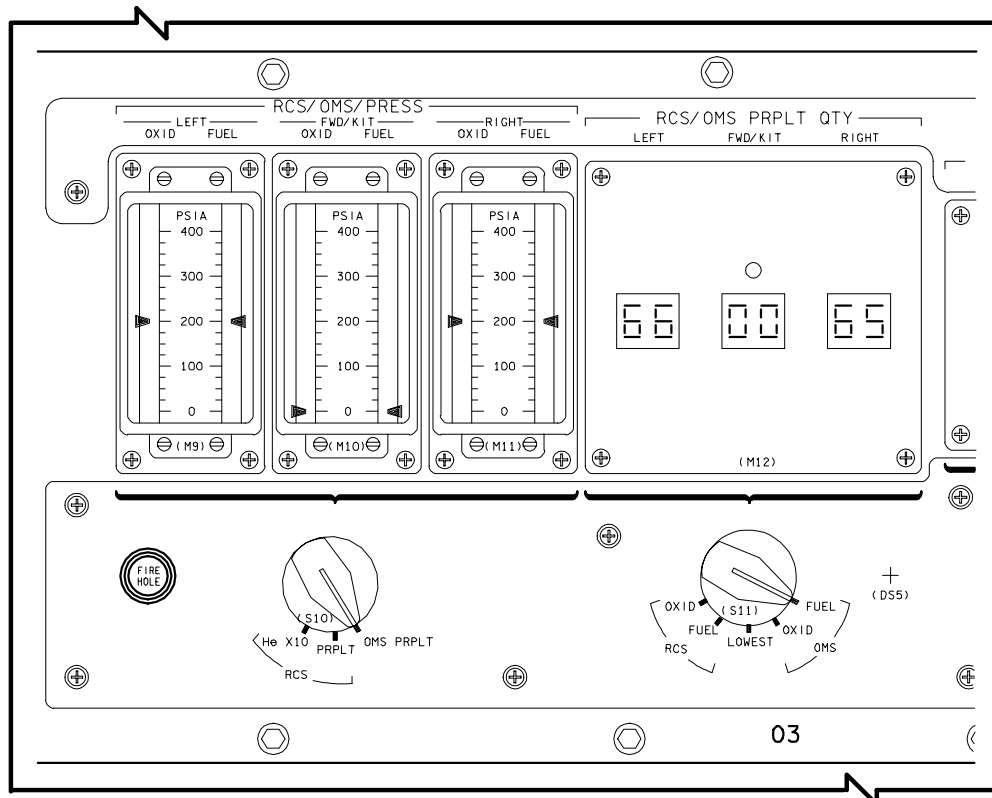
The totalizer receives OMS valve operation information and inputs from the forward and aft probes in each tank and outputs total and aft quantities and a low level quantity. The inputs from the OMS valves allow control logic in the totalizer to determine when an OMS engine is burning and which tanks are being used. The totalizer begins an engine flow rate/time integration process at the start of the OMS burn, which reduces the indicated amount of propellants by a preset estimated rate for the first 14.8 seconds. After 14.8 seconds of OMS burn, which settles the propellant surface, the probe capacitance gauging system outputs are enabled, which permits the quantity of propellant remaining to be displayed. The totalizer outputs are displayed on the

RCS/OMS PRPLT QTY LEDs on panel O3 when the rotary switch below the LEDs is positioned to the *OMS FUEL* or *OXID* position. In addition, the GNC SYS SUMM 2 display has a readout of the aft probe quantity (OMS AFT QTY). Quantity gauging is updated when at least one OMS engine is burning.

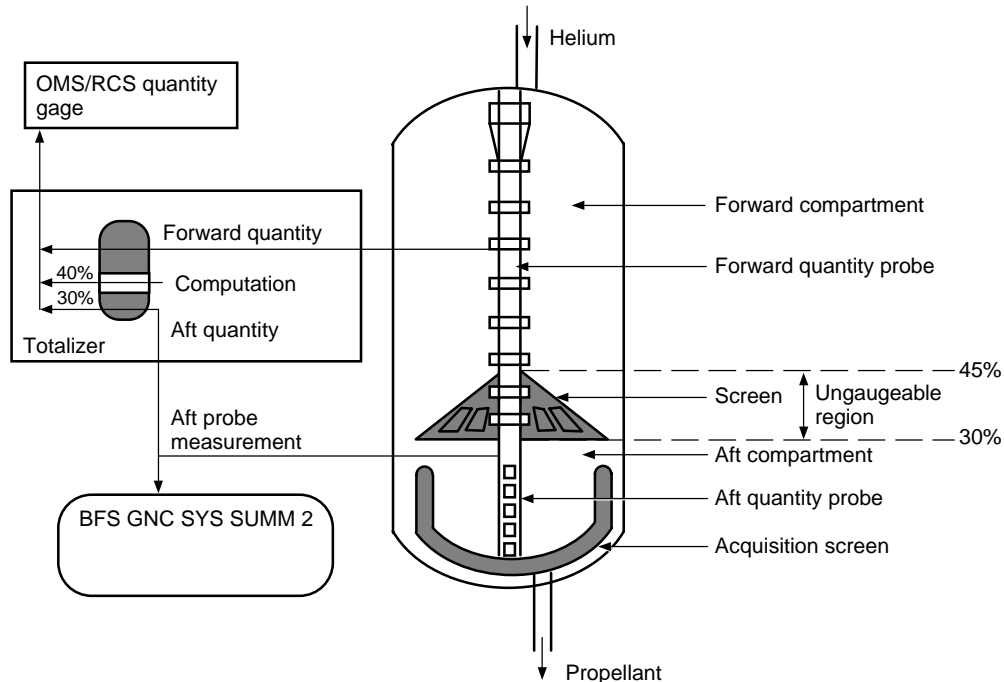
When the forward probe is dry (quantity approximately 45 percent), the unguageable propellant in the region of the intermediate bulkhead is added to the aft probe output quantity, decreasing the total quantity at a preset rate for 108 seconds, and updates from the aft probes are inhibited. After 108 seconds of burning (quantity approximately 30 percent), the aft probe output inhibit is removed, and the aft probe updates the total quantity. When the quantity decreases to 5 percent, the low-level signal is output.

NOTE

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



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



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Orbital Maneuvering System Quantity Gauging

Tank Isolation Valves

Parallel tank isolation valves (A and B) are located in each pod between the propellant tanks and the OMS engine and the OMS crossfeed valves and permit propellant to be isolated from the rest of the downstream systems. The valves are driven open and closed by ac motors that normally use 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

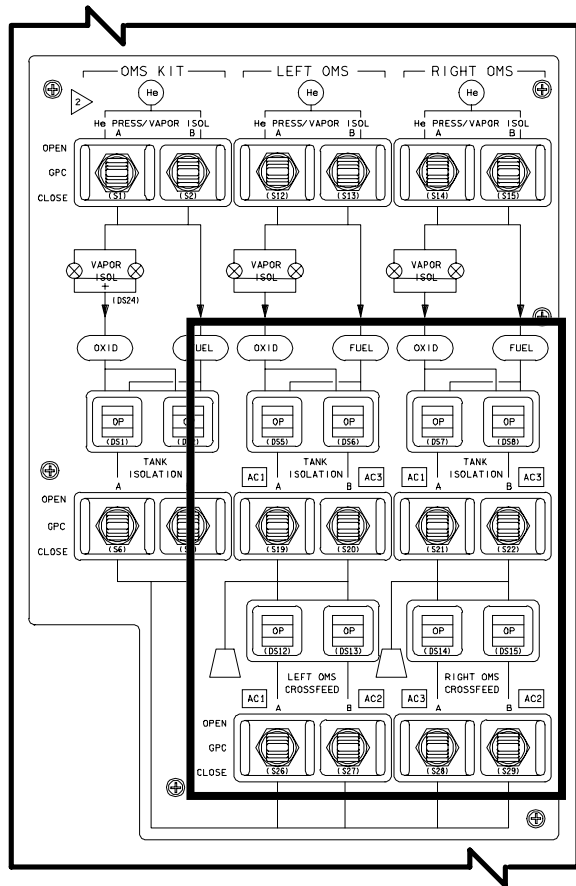
controller assembly, which supplies power to the ac-motor-operated valve actuators. Once the valve is in the commanded position, logic in the motor controller assembly removes power from the ac-motor-operated valve actuator. A talkback indicator above each *LEFT* or *RIGHT OMS TANK ISOLATION* switch 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

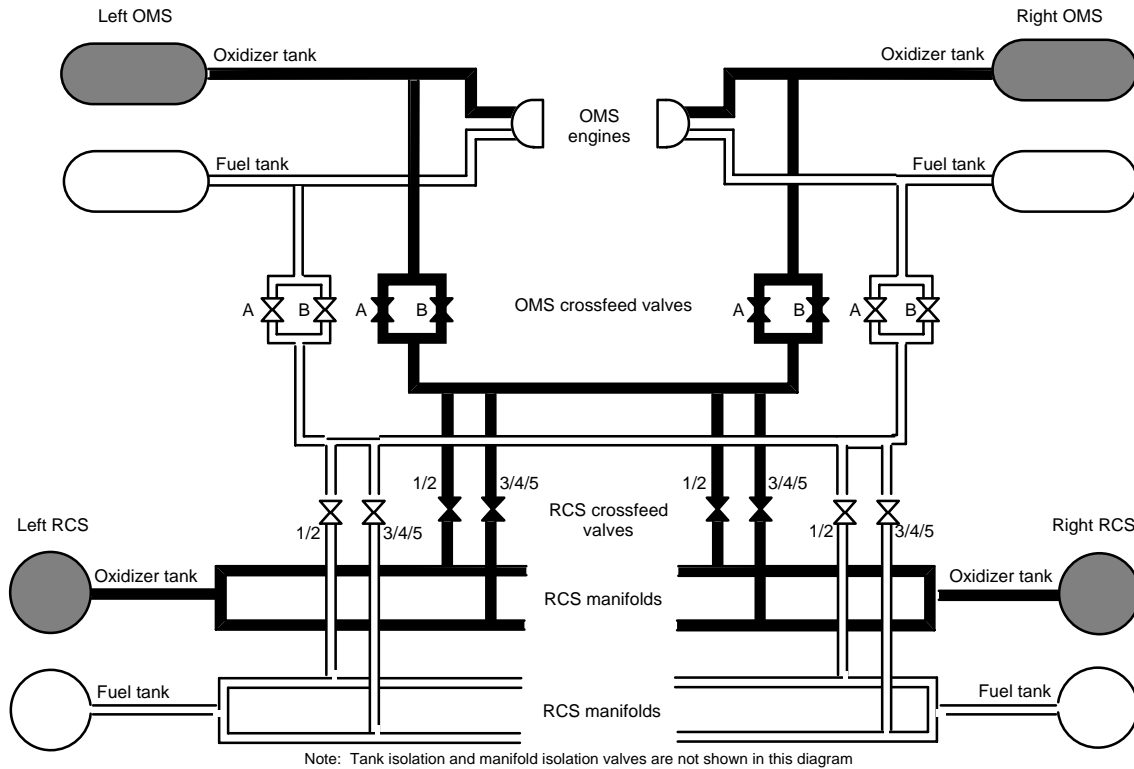
valves, that are used to connect the RCS propellant lines to the crossfeed lines. The same crossfeed lines are used for OMS crossfeeds, RCS crossfeeds, and OMS-to-RCS interconnects.

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.

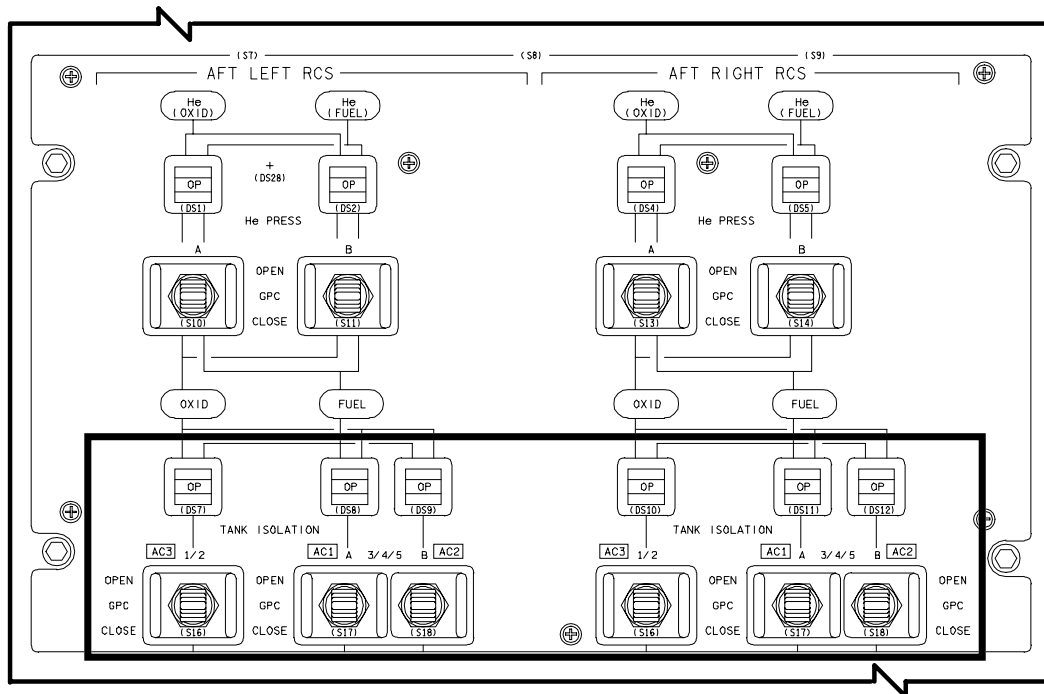
For example, when the *A* or *B* pair of crossfeed valves in the left pod is opened, fuel and oxidizer from the left pod are routed to the OMS crossfeed valves of the right pod; thus, a pair of *A* or *B* crossfeed valves in the right pod must be opened to permit the left pod fuel and oxidizer to be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

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.



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



RCS TANK ISOLATION Switches and Talkbacks on Panel O7

The *LEFT* and *RIGHT OMS CROSSFEED A* and *B* switches also provide the capability to supply OMS propellants to the left and right aft RCS engines. The left and right aft RCS will not be used to supply propellants to the OMS because the RCS tanks cannot support the flow rate required by the OMS engines.

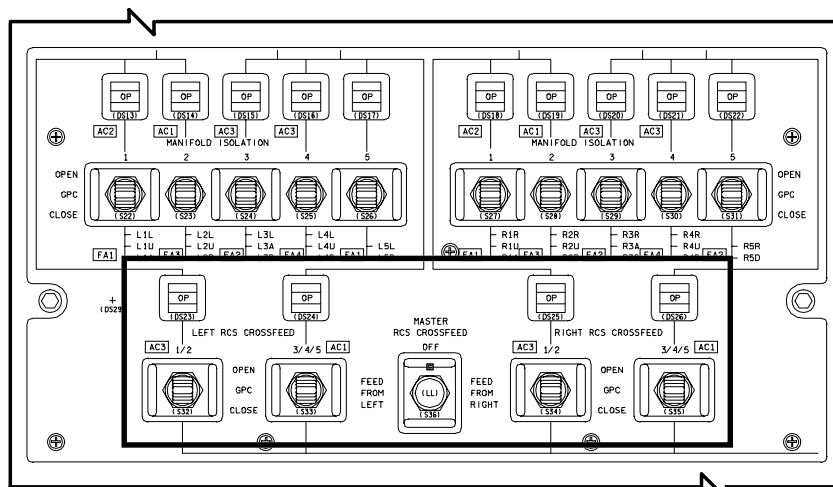
The OMS crossfeed fuel and oxidizer line pressures are monitored on telemetry and are transmitted to the RCS SPEC 23 display.

In summary, to perform an OMS to RCS interconnect on orbit, the flight crew must first select *FREE* on the *ORBITAL DAP* controls on panel C3, then configure the following switches (using a feed from the left OMS as an example):

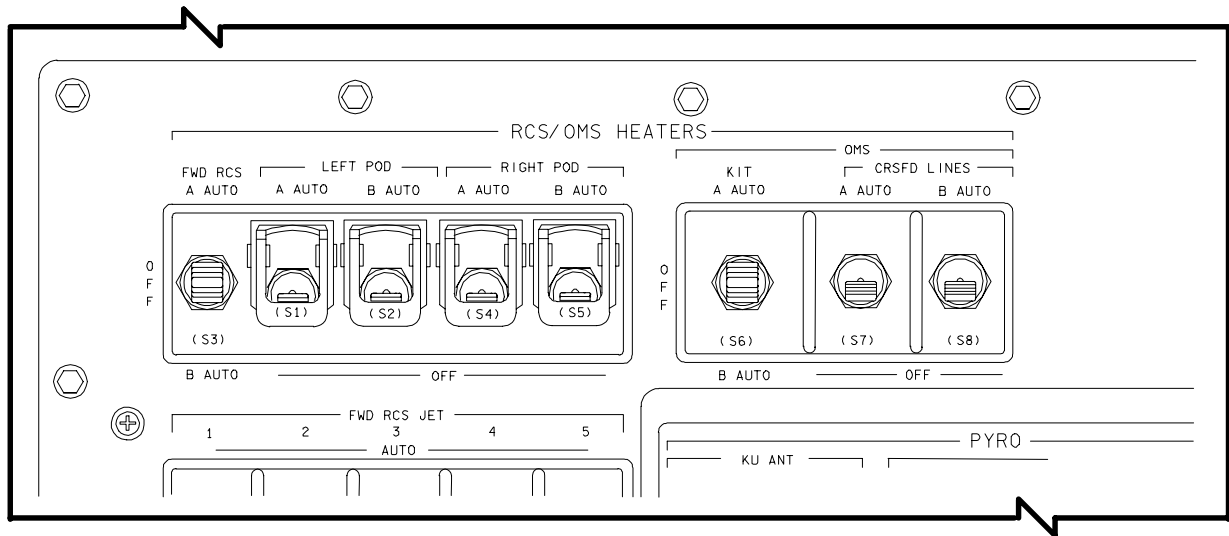
1. Position the aft *AFT LEFT RCS TANK ISOLATION 1/2, 3/4/5A* and *3/4/5B* and *AFT RIGHT RCS TANK ISOLATION 1/2, 3/4/5A* and *3/4/5B* switches on panel O7 to *CLOSE*.
2. Check that the talkback indicator above these switches indicates *CL*, and position the *AFT LEFT RCS LEFT RCS CROSSFEED 1/2, 3/4/5* and *AFT RIGHT RCS RIGHT RCS CROSSFEED 1/2, 3/4/5* switches to *OPEN*. The crew can then check for a propellant leak in the crossfeed lines.
3. Check that the left *OMS He PRESS/VAPOR ISOL VALVE A* and *B* switches on panel O8 are in the *CL* position.

4. Check that the *LEFT OMS TANK ISOLATION A* and *B* valves (panel O8) are open, and verify that the talkback indicators show *OP*.
5. Check the *RIGHT OMS CROSSFEED A* and *B* valves on panel O8 and verify that the indicators show *CL*.
6. Open the *LEFT OMS CROSSFEED B* valve on panel O8 and verify the talkback indicator shows *OP*. Check the *A* valve is closed and verify the indicator shows *CL*.
7. The left OMS-to-aft RCS interconnect quantity gauging can then be initiated by entering *OMS PRESS ENA* item entry (ITEM #5) on the RCS SPEC 23 display. The crew can then select the desired DAP.

There is software that will automatically repressurize the left OMS propellant tanks. If the *LEFT OMS He PRESS/VAPOR ISOL VALVE A* switch is in *GPC* and the *OMS PRESS ENA* item entry is done on RCS SPEC 23, the left OMS helium pressure vapor isolation valve *A* will be commanded open when the left OMS tank (ullage) pressure drops to 236 psig, and the open commands will be terminated 30 seconds later. If the left OMS tank (ullage) pressure remains below 236 psia, the sequence will set an *OMS/RCS valve miscompare flag* and will set a *Class 3 alert* and a *CRT fault message*. This feature is not used nominally, 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.



RCS CROSSFEED Switches and Talkbacks on Panel O7



RCS/OMS HEATERS Switches on Panel A14

The crossfeed line thermal control in the aft fuselage is divided into 11 heater areas. Each area is heated in parallel by heater systems A and B, and each area has a control thermostat to maintain temperature at 55° F minimum to 75° F maximum. Each circuit also has an 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 gimballed mounts that allow the engines to pivot up and down and from side to side. The OMS TVC system consists of a gimballed ring assembly, two gimballed actuator assemblies, and two gimballed actuator controllers. The engine gimballed ring assembly and gimballed actuator assemblies provide OMS TVC by gimballed the engines in pitch and yaw. Each engine has a pitch actuator and a yaw actuator. Each actuator is extended or retracted by one of a pair of dual-redundant electric motors and is actuated by general-purpose computer control signals.

The gimballed ring assembly contains two mounting pads to attach the engine to the gimballed ring

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

The pitch and yaw gimballed actuator assembly for each OMS engine provides the force to gimballed the engines. Each actuator contains a primary and secondary motor and drive gears. The primary and secondary drive systems are isolated and are not operated concurrently. Each actuator consists of two redundant brushless dc motors and gear trains, a single jackscrew and nut-tube assembly, and redundant linear position feedback transducers. A GPC position command signal from the primary electronic controller energizes the primary dc motor, which is coupled with a reduction gear and a no-back device.

The output from the primary power train drives the jackscrew of the drive assembly, causing the nut-tube to translate (with the secondary power train at idle), which causes angular engine movement. If the primary power train is inoperative, a GPC position command from the secondary electronic controller energizes the secondary dc motor, providing linear travel by applying torque to the nut-tube through the spline that extends along the nut-tube for the stroke length of the unit. Rotation of the nut-tube about the stationary jackscrew causes the nut-tube to move along the screw. A no-back device in each drive system prevents backdriving of the standby system.

The electrical interface, power, and electronic control elements for active and standby control channels are assembled in separate enclosures designated the active actuator controller and standby actuator controller. These are mounted on the OMS/RCS pod structure. The active and standby actuator controllers are electrically and mechanically interchangeable.

The gimbal assembly provides control angles of $\pm 6^\circ$ in pitch, and $\pm 7^\circ$ in yaw with clearance provided for an additional 1° for snubbing and tolerances.

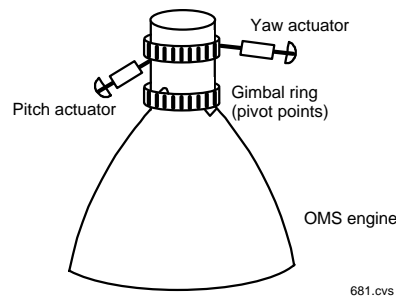
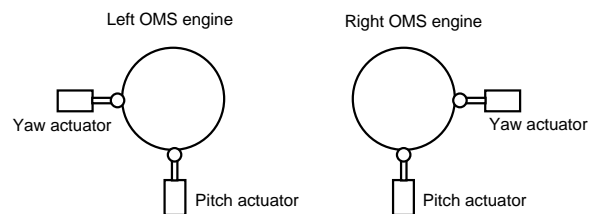
The thrust vector control command subsystem operating program (SOP) processes and outputs pitch and yaw OMS engine actuator commands and the actuator power selection discrettes. The OMS TVC command SOP is active during the following operational sequences: orbit insertion (OMS-1 and OMS-2), orbit coast, deorbit, deorbit coast, and return-to-launch-site abort (major modes 104, 105, 201, 301, 302, 303, and 601).

The flight crew can select either the primary or secondary motors of the pitch and yaw actuators by item entry (PRI 28,29 and SEC 30,31 on the MNVR display), or they can turn the actuator motors off. The actuator command outputs are selected by the TVC command SOP, depending on the flag that is present; i.e., major modes, deorbit maneuver, orbit coast, RTLS abort, center-of-gravity trim, and gimbal check. The deorbit maneuver coast flag causes the TVC command SOP to output I-loaded values to command the engines to the entry stowed position.

The presence of the RTLS abort and center-of-gravity trim flags causes the engines to be commanded to a predefined position with the thrust vector through the center of gravity. The major mode RTLS flag by itself will cause the engines to be commanded to a stowed position for return-to-launch-site entry.

The gimbal check flag causes the engines to be commanded to plus 7° yaw and 6° pitch, then to minus 7° yaw and 6° pitch, and back to zero $^\circ$ 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 discrettes from the MNVR display and performs compensation on the selected pitch and yaw actuator feedback data. These data are output to the OMS actuator fault detection and identification and to the MNVR display. The OMS TVC feedback SOP is active during orbit insertion (OMS-1 and OMS-2), orbit coast, deorbit maneuver, and deorbit maneuver coast. The present OMS gimbal positions can be monitored on the MNVR display when this SOP is active, and the primary or secondary actuator motors are selected.



Orbital Maneuvering System Gimbal Actuators

Fault Detection and Identification

OMS Engine

The OMS engine fault detection function detects and identifies off-nominal performance of the OMS engine, such as off-failures during OMS burns, on-failures after or before a burn, and high or low engine chamber pressures.

Redundancy management software performs OMS engine fault detection and identification. It is assumed that the flight crew arms only the OMS engine to be used; the OMS engine not armed cannot be used for burns. Fault detection is initialized at solid rocket booster ignition and terminated after the OMS-1 burn or, in the case

of an RTLS abort, at the transition from RTLS entry to the RTLS landing sequence program. Fault detection also is initiated 15 seconds before each OMS burn and terminated after the OMS burn is complete.

The PASS OMS engine fault detection uses both a velocity comparison and a chamber pressure comparison method to determine a failed-on or failed-off engine. The velocity comparison is used only after MECO since the OMS thrust is small compared to MPS thrust before MECO. The BFS OMS engine fault detection uses only a chamber pressure comparison method.

The measured velocity increment is compared to a predetermined one-engine and two-engine acceleration threshold value by the redundancy management software to determine the number of engines actually firing. This information, along with the assumption that an armed engine is to be used, allows the software to determine if the engine has low thrust or has shut down prematurely.

The chamber pressure comparison test compares a predetermined threshold chamber pressure level to the measured chamber pressure to determine a failed engine (on, off, or low thrust).

The engine-on command and the chamber pressure are used before MECO to determine a failed engine. The velocity indication and the chamber pressure indication are used after MECO to determine a failed engine. If the engine fails the chamber pressure test but passes the velocity test after MECO, the chamber pressure transducer will be considered failed. Such a failure would illuminate the red *RIGHT OMS* or *LEFT OMS* caution and warning light on panel F7, sound the master alarm, and produce a fault message, but the engine is still burning. If an engine fails the chamber pressure and velocity tests, the engine is considered failed, and a down arrow next to the failed engine appears on the MNVR display, in addition to illumination of the light on F7 and master alarm.

When the flight crew disarms a failed engine by turning the appropriate *ARM/PRESS* switch on panel C3 to *OFF*, a signal is sent to the OMS burn sequence to shut down the engine and to

signal guidance to reconfigure. Guidance reconfigures and downmodes from two OMS engines, to one OMS engine, to four plus X RCS jets.

OMS Gimbal Fault Detection

The OMS gimbal actuator fault detection indicator detects and identifies off-nominal performance of the pitch and yaw gimbal actuators of the OMS engines.

The OMS gimbal actuator fault detection is divided into two processes. The first determines if the actuators should move from their present position. If the actuators must move, the second part determines how much they should move and whether the desired movement has occurred.

The first part checks the actuators' gimbal deflection error (the difference between the commanded new position and the actuators' last known position) and determines whether the actuators should extend or retract or if they are being driven against a stop. If the actuators are in the desired position or being driven against a stop, the first part of the process will be repeated. If the first part determines that the actuator should move, the second part of the process is performed.

The second part of the actuator fault detection process checks the present position of each actuator against its last known position to determine whether the actuators have moved more than a threshold amount. If the actuators have not moved more than this amount, an actuator failure is incremented by one. Each time an actuator fails this test, the failure is again incremented by one. When the actuator failure counter reaches an I-loaded value of four, the actuator is declared failed, and a fault message is output. The actuator failure counter is reset to zero any time the actuator passes the threshold test.

The first and second parts of the process continue to perform in this manner. The process can detect full-off gimbal failures and full-on failures indirectly. The full-on failure determines that the gimbal has extended or retracted too far and commands reverse motion. If no motion occurs, the actuator will be

declared failed. The flight crew's response to a failed actuator is to select the secondary actuator electronics by item entry on the MNVR display. Gimbal failure on the left or right OMS will illuminate the red *OMS TVC* caution and warning light on panel F7.

Operations

The OMS burn sequence commands the OMS engines on or off and commands the engine purge function. The flight crew can select, via item entry on the MNVR display, a one or two-engine burn.

The sequence determines which engines are selected and then provides the necessary computer commands to open the appropriate helium vapor isolation valves and the engine gaseous nitrogen solenoid control valves and sets an engine-on indicator. The sequence will monitor the OMS engine fail flags and, if one or both engines have failed, issue the appropriate OMS shutdown commands as soon as the crew has confirmed the failure by placing the *OMS ENG* switch on panel C3 in the *OFF* position. This will then terminate the appropriate engine's control valve commands.

In a normal OMS burn, when the OMS cutoff flag is true, the sequence terminates commands to the helium pressurization/vapor isolation valves, and two gaseous nitrogen engine control valves. If the engine purge sequence is not inhibited, the sequence will check for the left and right engine *ARM/PRESS* signals, and open the engine gaseous nitrogen purge valves for two seconds for the engines that have the *ARM/PRESS* signals present.

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

Additional OMS burns using one or both OMS engines are performed on orbit according to the mission's requirements to modify the orbit for rendezvous, payload deployment, or transfer to another orbit.

The two OMS engines are used to deorbit. Target data for the deorbit maneuver are computed by the ground and loaded in the onboard GPCs via uplink. These data are also voiced to the flight crew for verification of loaded values. After verification of the deorbit data, the flight crew initiates an OMS gimbal test on the CRT keyboard unit.

Before the deorbit burn, the flight crew maneuvers the spacecraft to the desired deorbit burn attitude manually using the rotational hand controller, or automatically with an item entry on the MNVR display. Upon completion of the OMS burn, the RCS is used to null any residual velocities, if required.

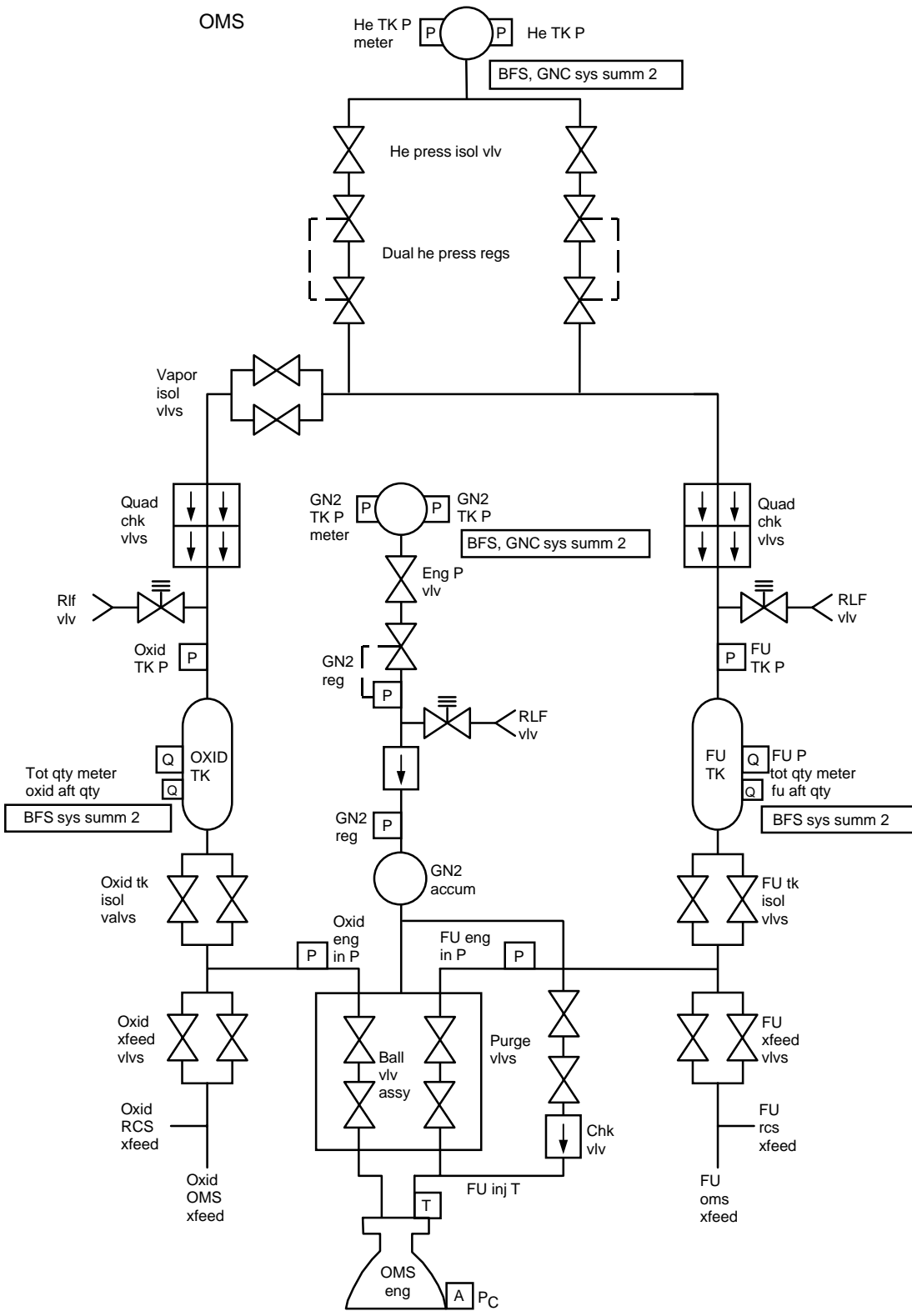
The aft RCS plus X jets can be used to complete any planned OMS burn in the event of an OMS engine failure. In this case, the OMS-to-RCS interconnect would feed OMS propellants to the aft RCS.

OMS Caution and Warning Summary

- There are class 2 and class 3 alerts for the OMS.
- Class 2 alerts can occur in all OPS and generate a *MASTER ALARM* light and tone and a light on the caution and warning matrix on panel F7.
- A class 3 alert is generated by the primary GNC or SM software in OPS 2 and 8 or by the BFS software in other OPS. Class 3 alerts include an *SM ALERT* light and tone and a fault message.
- The red *LEFT OMS* and *RIGHT OMS* lights on panel F7 will illuminate under the following conditions:
 - Left or right OMS oxidizer tank pressure is less than 232 or greater than 288 psi
 - Left or right OMS fuel tank pressure is less than 232 or greater than 288 psi
 - Left or right OMS engine P_c is less than 80 percent when the engine should be on or greater than 80 percent when the engine should be off.
- The red *OMS TVC* light will illuminate when there is gimbal failure on the left or right OMS.
- An L (R) OMS GMBL fault message will be displayed when there is a 2° 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 N₂ tank pressure is below 1,200 psi; or OMS N₂ regulator pressure is above 434 or below 299 psi.
- An L (R) OMS VLV fault message will be displayed when OMS helium pressure valve and vapor isolation valve positions do not agree.
- An L (R) OMS TEMP fault message will be displayed when OMS engine fuel injector temperature is above 260° F.
- 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.

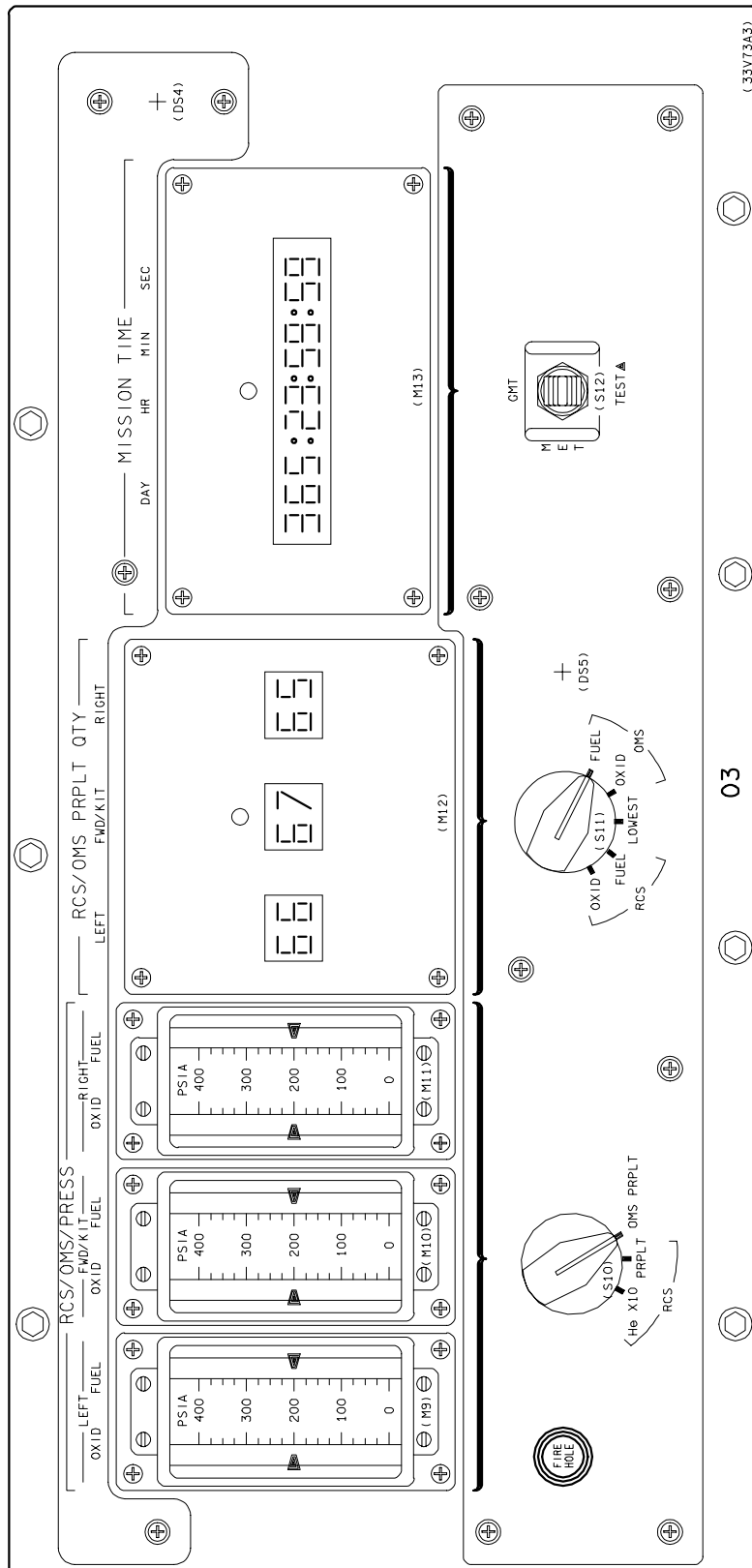
O ₂ PRESS	H ₂ PRESS	FUEL CELL REAC ^(R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM ^(R)	O ₂ HEATER TEMP	MAIN BUS UNDERVOLT	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS ^(R)	RCS JET
H ₂ O LOOP	RGA/ACCEL	AIR DATA	LEFT RCS	RIGHT RCS ^(R)
—————	LEFT RHC ^(R)	RIGHT/AFT RHC ^(R)	LEFT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

OMS Caution and Warning Lights on Panel F7

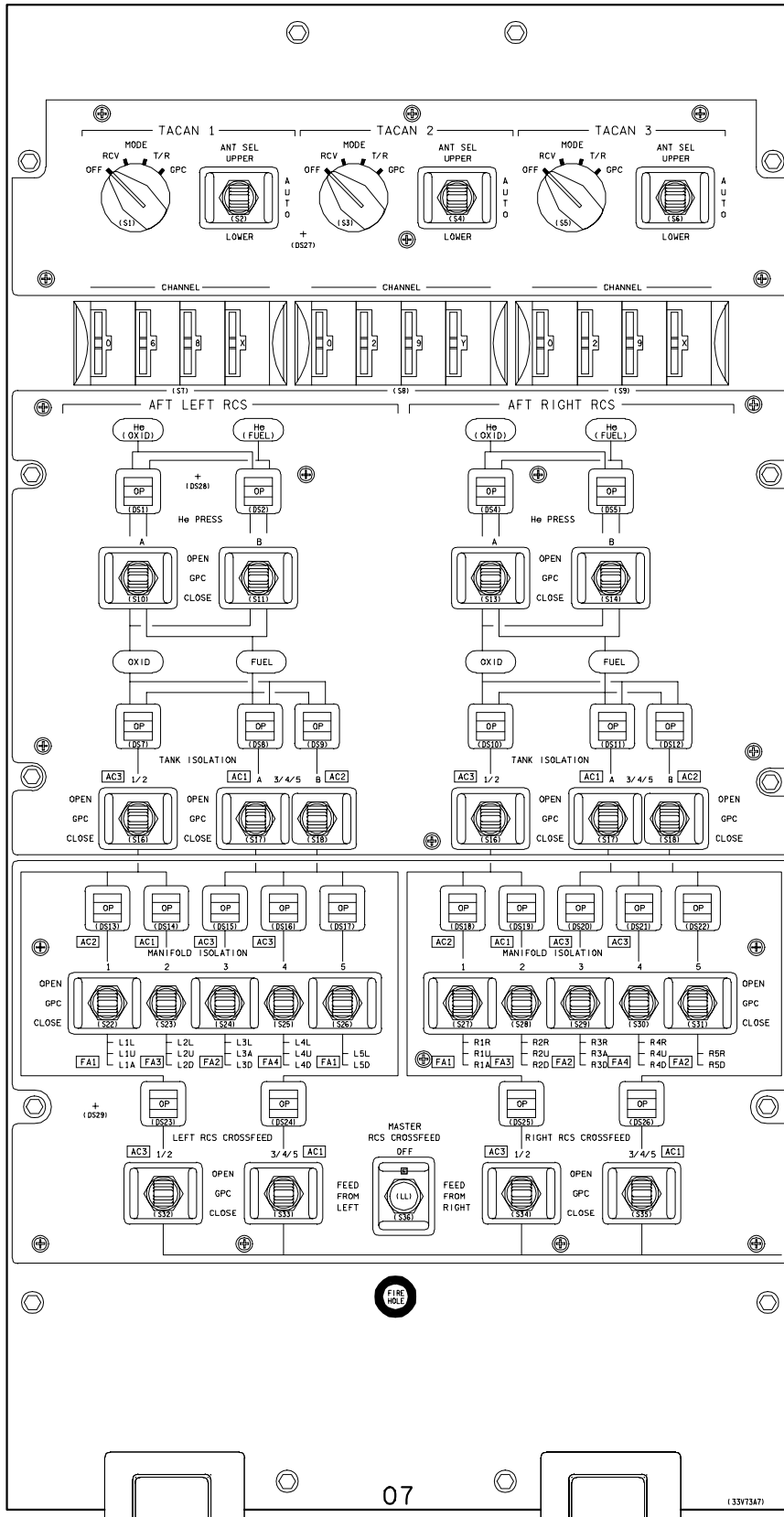


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Orbital Maneuvering System

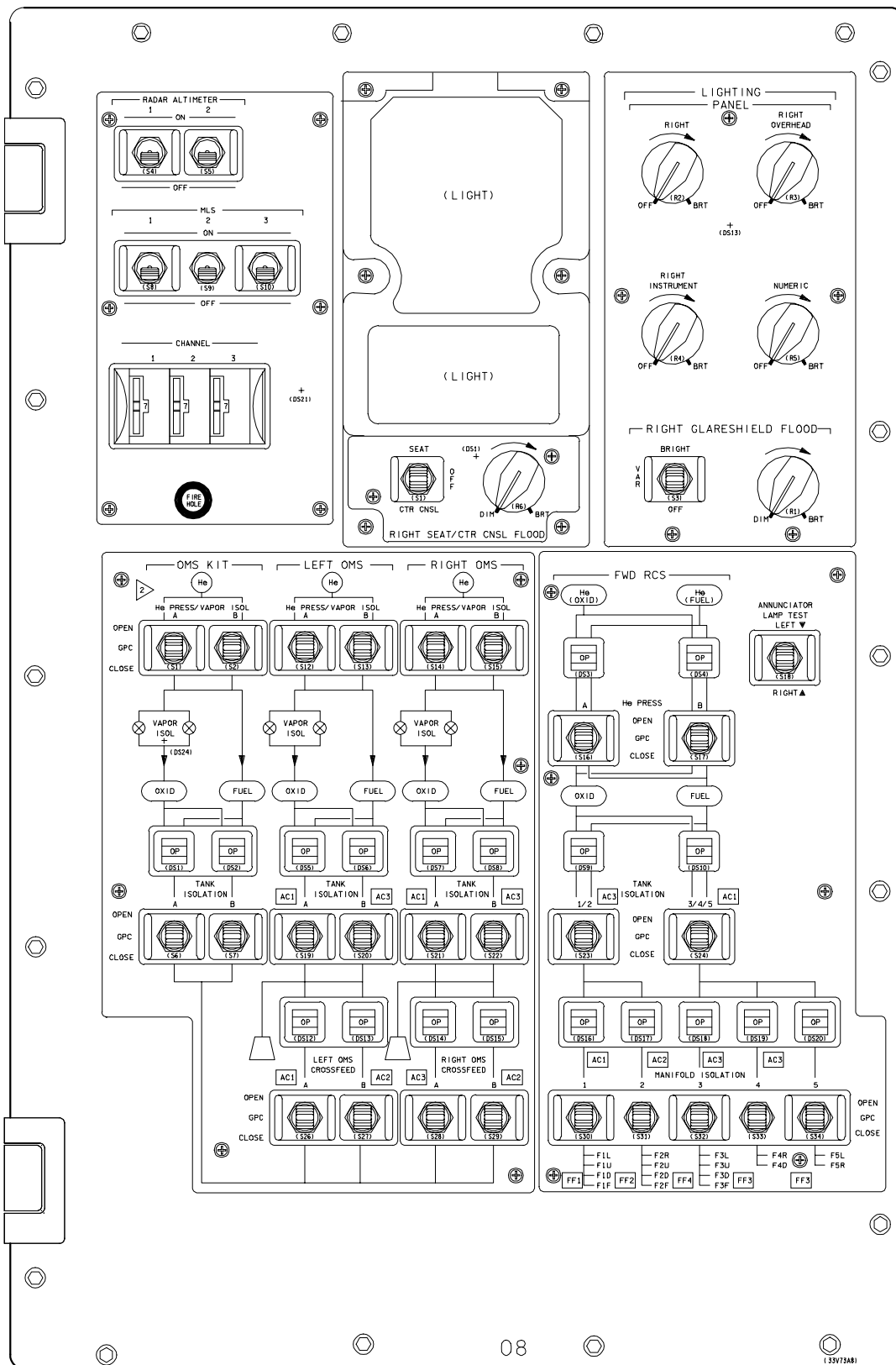


Panel O3

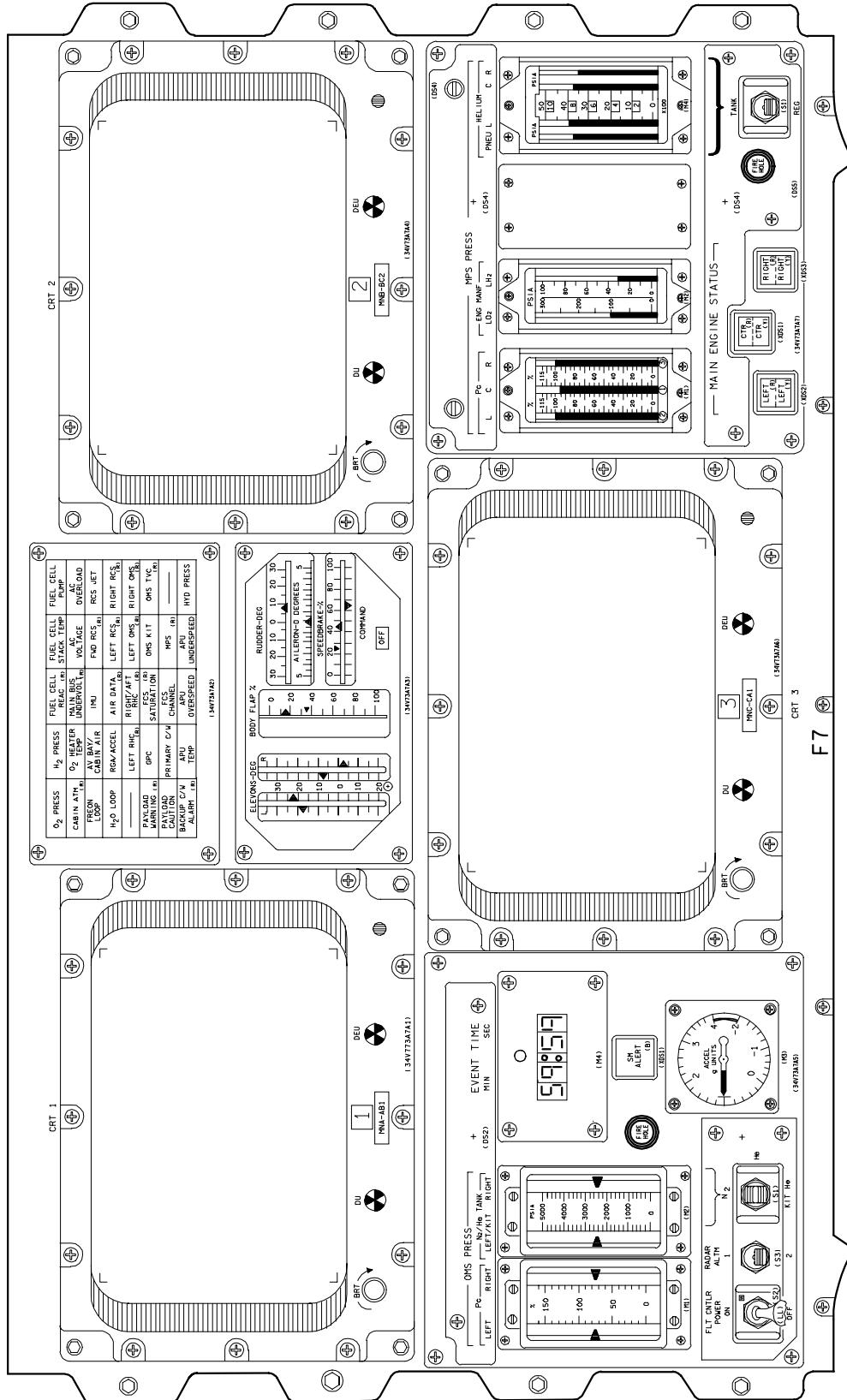


Panel O7

(3397347)



Panel O8



Panel F7

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

2011/023/ RCS FWD 1 L 2 4 FAIL LIM 2 R 3*	RCS OMS PRESS ENA L OMS 5 R OMS 6 OFF 7*	1 000/03:14:16 000/00:00:00 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	OXID FU HE P 3376 3360 PRPLT TK P 247 250 T 77 79 QTY 90 91 MANF P 1 242 246 2 250 246 3 248 248 4 246 242 MANF VLV3 STAT OVRD 1 OP 40 2 OP 41 3 OP 42 4 OP 43 5 OP 44 XFEED P 254 254 JET RESET 45

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SPEC 23 RCS Display

3011/ /019 GNC SYS SUMM 2 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 HE P 464 1264 JET ISOL FWD TK P 248 244 FAIL VLV QTY 0 0 MANF 1 P 248 242 2 P 248 244 3 P 250 246 4 P 244 244 5	N2 TK P 2220 2220 REG P 319 319 ENG IN P P VLV CL CL OXID 257 258 FU 258 258 VLV 1 - 2 - 2 2 0 0	OXID FU JET ISOL FAIL VLV
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	R HE P 2744 2616 TK P 247 247 QTY 62 61 1 P 242 246 2 P 250 246 3 P 246 250 4 P 246 242 5	

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GNC SYS SUMM 2 Display

2011/ /089 PRPLT THERMAL POD L R OMS TK OX 80 80 FU 80 80 ENG I/F OX 70 70 FU 70 70 OX VLV 71 71 FU INJ 81 81 WEB KEEL 1 70 70 2 70 70 Y OB 74 74 UP 74 74 OX DRN PNL 1 67 67 2 67 67 ENG COVER 71 73 SERV PNL 70 70 GSE SERV PNL 74 73 TEST HE/OX 1 70 70 2 70 70	THERMAL OMS CRSFD L R C XFD OX 68 68 67 GMBL LN 68 68 67 DRN OX 65 65 64 FU OX BLD AFT FUS 65 66 PL BAY 65 67 OX QD 66 67 FWD RCS FU OX LINE T1 67 66 T2 67 66 AFT RCS L R MANF 1 OX 69 68 DRN PNL 1 68 66 2 68 66 VERN PNL 1 67 67 2 67 67
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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 gimbal mounts that allow the engines to pivot up and down and from side to side ($\pm 6^\circ$ pitch, $\pm 7^\circ$ yaw).
- Switches that the crew uses to operate the OMS are located on panels C3, O14, O16, O7, O8, and A14. Panels that display OMS parameters are F7 and O3.
- The MNVR display is used by the crew to enter burn targeting parameters. Other displays on which OMS data appear are GNC SYS SUMM 2, SPEC 23 RCS, and SM SPEC 89 PRPLT THERMAL

OMS Rules of Thumb

- 1 percent of OMS propellant
 - = 6 fps
 - = 3 n. mi.
 - 130 lbs (80 lbs oxidizer, 50 lbs fuel) uses 400 psi of helium for long burns.
- One OMS engine causes approximately 1 fps² 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)

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Description

The PDRS consists of the hardware, software, and interfaces required to remotely hold and control the movements of a specified object, usually a payload, and to remotely observe or monitor objects or activities.

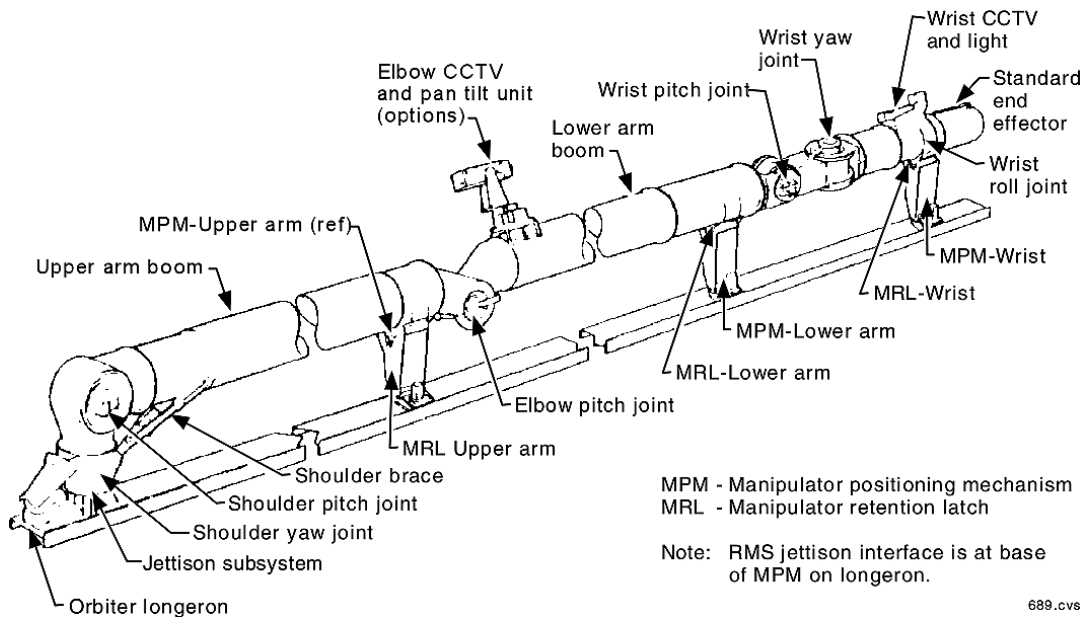
The PDRS includes the remote manipulator system (RMS), the manipulator positioning mechanisms, and the manipulator retention latches. The PDRS also interfaces with other orbiter systems, such as the SM GPC, the electrical power distribution system (EPDS), and the closed-circuit television.

Remote Manipulator System

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; 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.

The basic RMS configuration consists of a manipulator arm, an RMS display and control panel that includes 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.



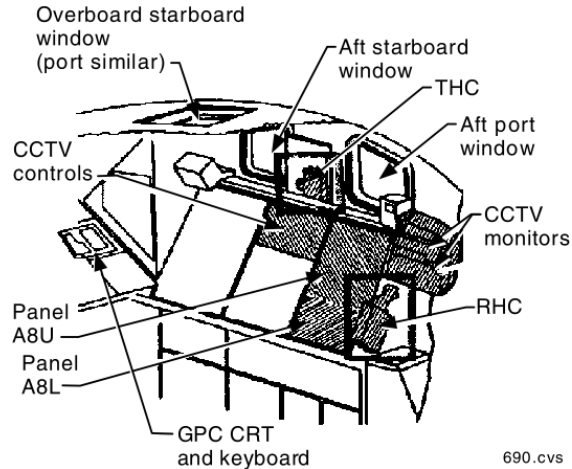
RMS-Stowed Position and General Arrangement

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 to not interfere with payload clearances.

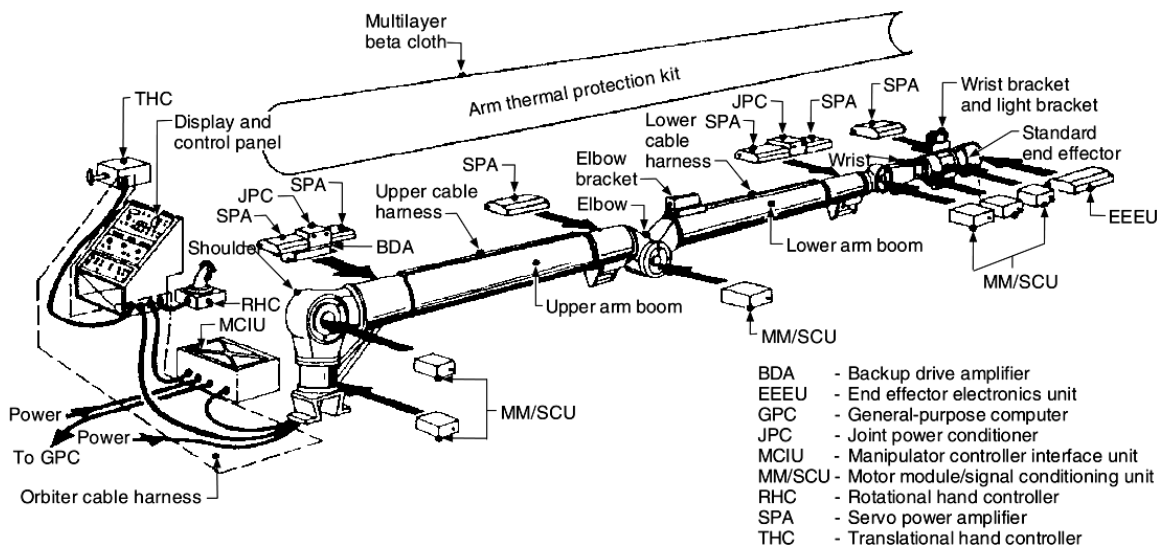
The RMS arm is 50 feet 3 inches long and 15 inches in diameter. The arm has 6 degrees of freedom: three translational (X, Y, and Z) and three rotational (P, Y, and R). They are in reference not only to the orbiter, but also to the end effector and to payloads. The arm consists of six joints connected via structural members and has a payload capturing device on the end. It weighs 905 pounds, and the total system weighs 994 pounds.



RMS Displays and Controls, Aft Station

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.

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.



- 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

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** pushbutton. This pushbutton is mounted on the top of the grip assembly and is thumb-operated. The pushbutton is used to maintain the POR translational and rotational rates at a commanded value. Rate hold is engaged when the pushbutton is depressed momentarily. Rate hold is disengaged when the pushbutton is again depressed momentarily. The rates can be biased once rate hold has been actuated, and the hand controllers have been returned to detent by deflecting a hand controller a second time.
- **RATE** switch. The **VERNIER/COARSE RATE** switch is a slide switch that produces the signal used by the RMS software to determine the POR rate limits when operating in resolved-rate modes and the joint rate limits when operating

in *SINGLE* mode. The switch is configured to produce 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.

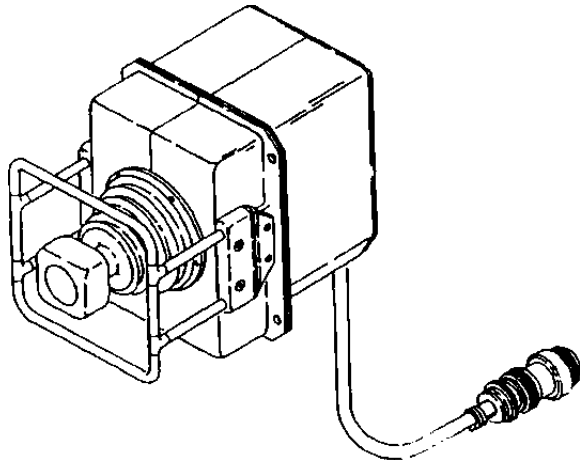
Manipulator Arm Drive System

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.

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.



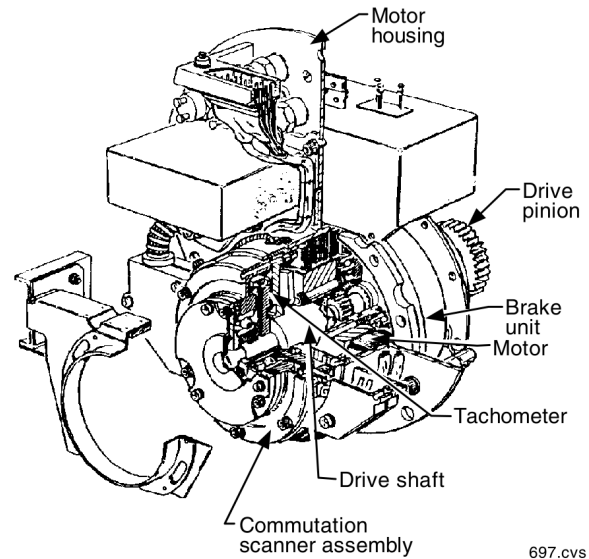
Translational Hand Controller

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 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

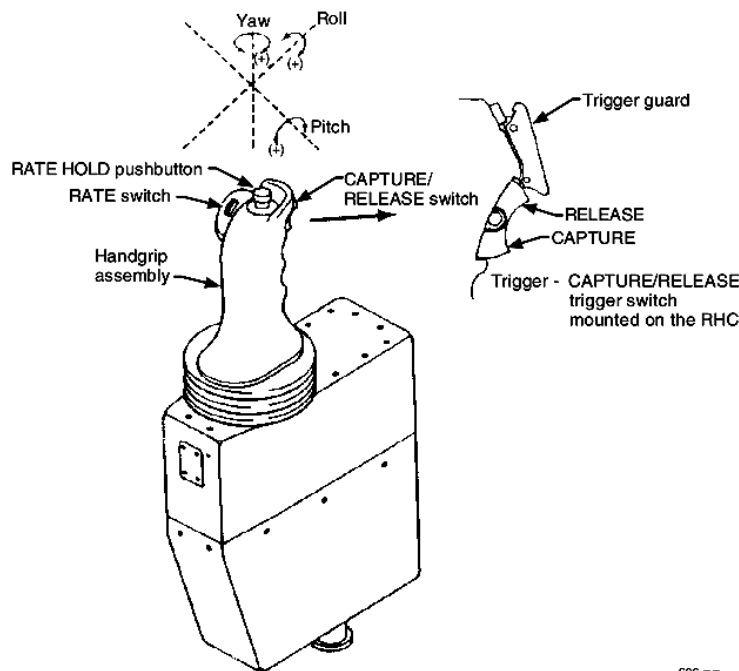
joints. The function of the conditioner is to convert the MN A +28 V dc to provide secondary regulated supply voltages at ± 15 V, +10 V, and +5.1 V dc to the SPA, motor commutators, and position encoders.

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



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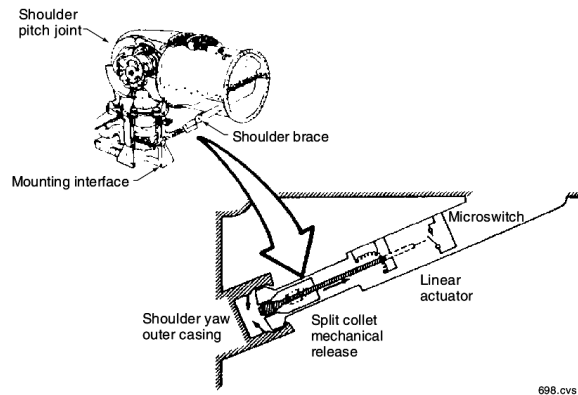
Rotational Hand Controller

Mechanical Arm Assembly

The manipulator arm drive system components, the arm cable harness, and arm structural components form the mechanical arm assembly. The structural components consist of joint housings, electronic housings, and arm booms.

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

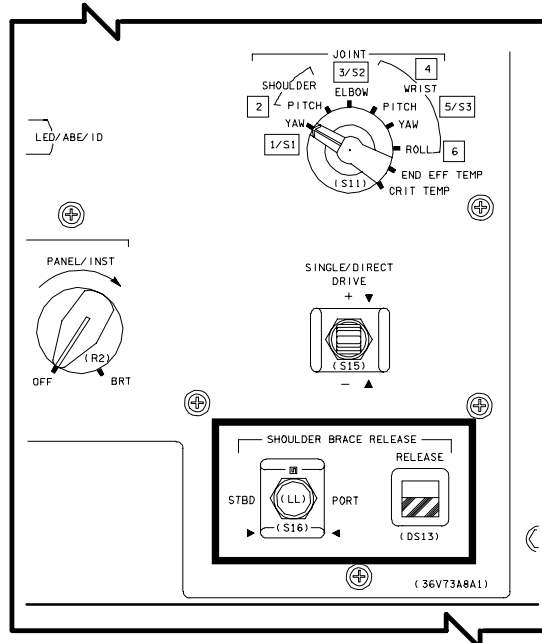
The shoulder brace is designed to minimize the high-pitch-axis moment loading on the shoulder pitch gear train during the launch environment. On orbit, the brace is released to allow RMS operations. The shoulder brace is designed to enable ground engagement of the release mechanism using an external power source. It cannot be relatched on orbit, but there is no requirement to relatch the brace before reentry and landing. A plunger is extended between two pieces of tapered metal, pushing the ends of the receptacle on the outer casing of the shoulder joint, and engaging the shoulder brace.



Shoulder Brace

Shoulder brace release is controlled by the lever-locked *SHOULDER BRACE RELEASE* switch on panel A8U. Positioning the switch to *PORT* releases the brace, which withdraws the plunger by an electrical linear actuator. This allows the tapered metal pieces to relax and move toward each other, which permits the brace to slide out of the shoulder yaw outer casing, unlatching the brace. The switch must be held 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.



SHOULDER BRACE RELEASE Switch and Talkback Indicator on Panel A8U

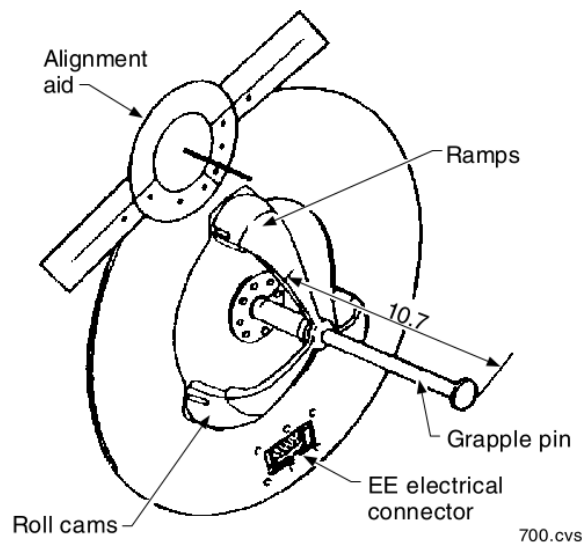
The arm boom assemblies are two thin-walled tubular sections called the upper and lower arm booms. The arm booms are structures designed to meet stiffness criteria. In order to achieve an efficient stiffness/weight design and to maintain simplicity of construction, a circular section graphite/epoxy composite 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.

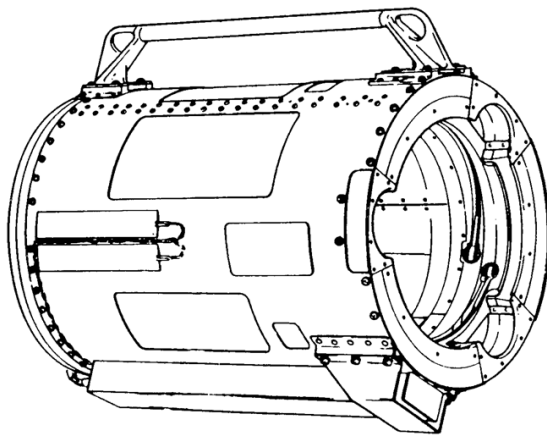
Wire arm cable harnesses are designed to minimize electrical cross-talk and electromagnetic interference. They are of a weight-efficient design and are installed on the outside of the upper and lower arm booms, utilizing a lightweight mounting technique with adhesive Kapton tape. Sufficient slack is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

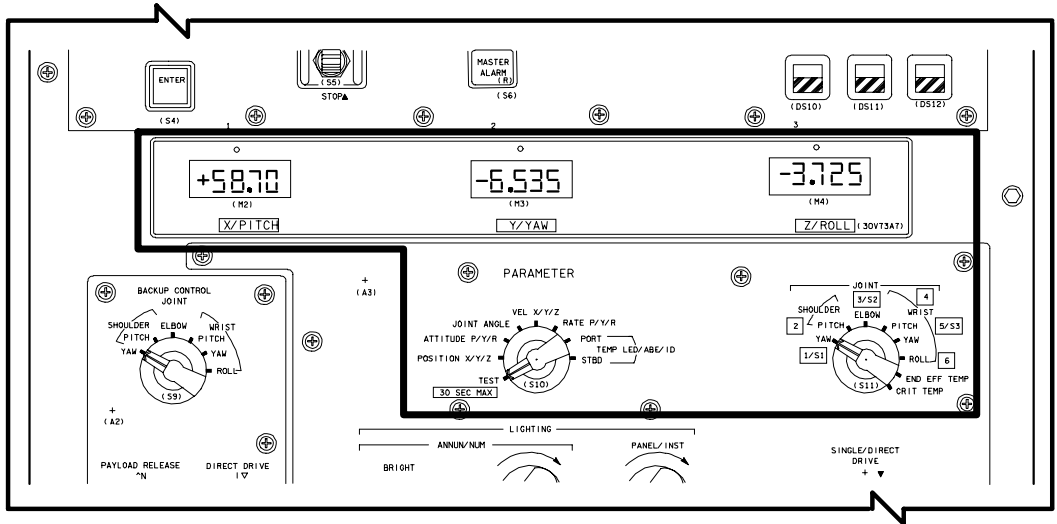
The standard end effector drive system captures or releases a payload using a rotating ring at the open end of the unit to close three wire snares around the payload-mounted grapple fixture. The entire snare ring is then pulled into the end effector until the grapple fixture base plate is flush against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

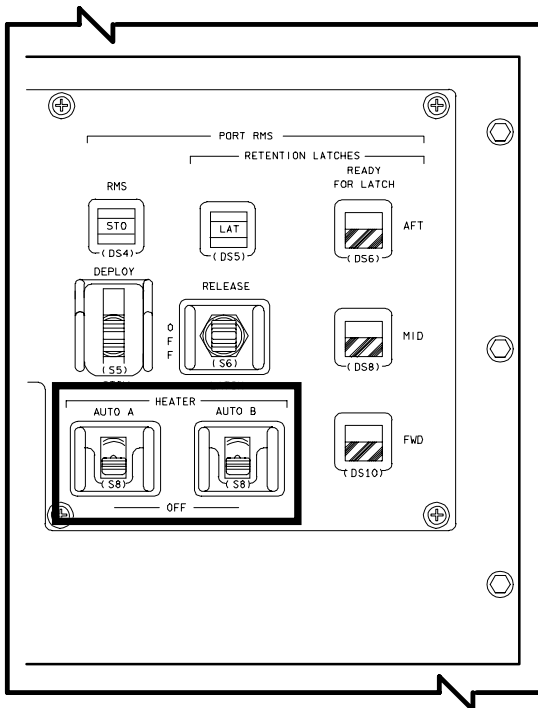
The RMS has both passive and active thermal control systems. The passive system consists of multilayer insulation blankets and thermal coatings that reflect solar energy away from the arm and aid in controlling the temperature of the hardware. The blankets are attached to the arm structure and to each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



LEDs and Rotary Switches on Panel A8U

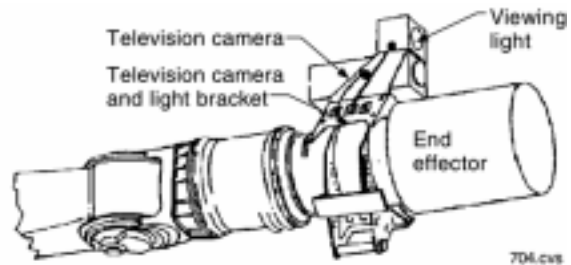


PORT TMS HEATER Switches on Panel A8L

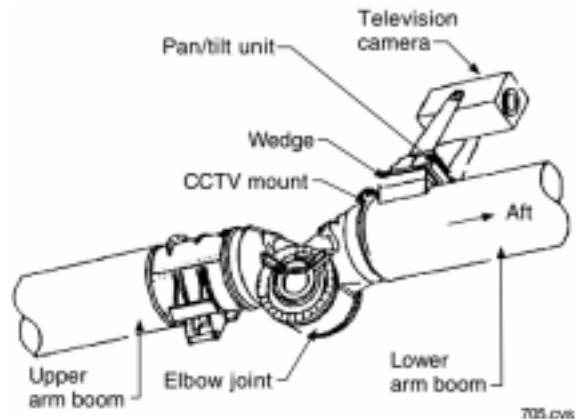
CCTV

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 payload bay can be panned, tilted, and zoomed. Keel cameras, which look up from the bottom of the payload bay, may be provided,

depending on the mission tasks. The two CCTV monitors at the aft flight deck station can each display any two of the CCTV camera views simultaneously with split screen capability. This shows two views on the same monitor, which allows crewmembers to work with four different views at once. Crewmembers can also view payload operations through the aft flight station overhead and payload bay viewing windows. (See Section 2.3 for CCTV operations.)

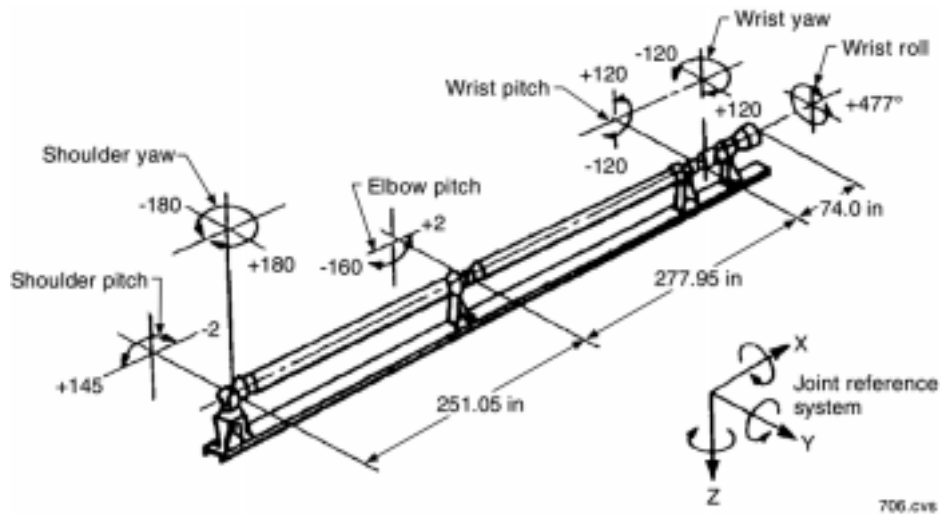


Wrist CCTV and Light Configuration



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°

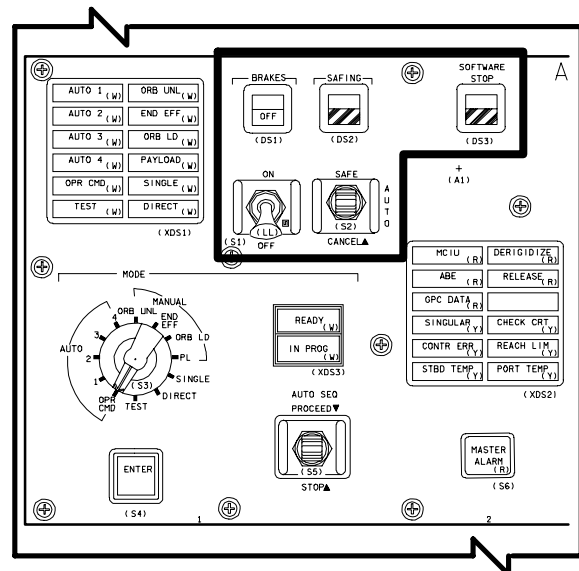


Joint Travel Limits

Reach Limits, Soft Stops, and Hard Stops

Each RMS joint has travel limits. As an example, the wrist pitch joint can be physically moved positive or negative 121.4° to the mechanical hard stop. At positive or negative 114.4°, software warns the RMS operator that the arm is approaching its end of travel by activating the yellow *REACH LIM* light and the red *MASTER ALARM* pushbutton indicator on panel A8U, sounding the master alarm, displaying a computer fault message, sounding an SM tone, and displaying a REACH LIMIT indication on the CRT.

If the operator continues driving the joint past the reach limit, the next warning is the soft stop. At this point (positive or negative 116.4° for the wrist pitch joint), the *SOFTWARE STOP* talkback on panel A8U (top center) will indicate barberpole. The arm can only be operated in *SINGLE*, *DIRECT*, or *BACKUP* modes once it reaches a soft stop. If the operator continues to drive the joint in this direction, motion will stop at positive or negative 121.4°. All joint angles equal 0° when the arm is cradled.



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

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.

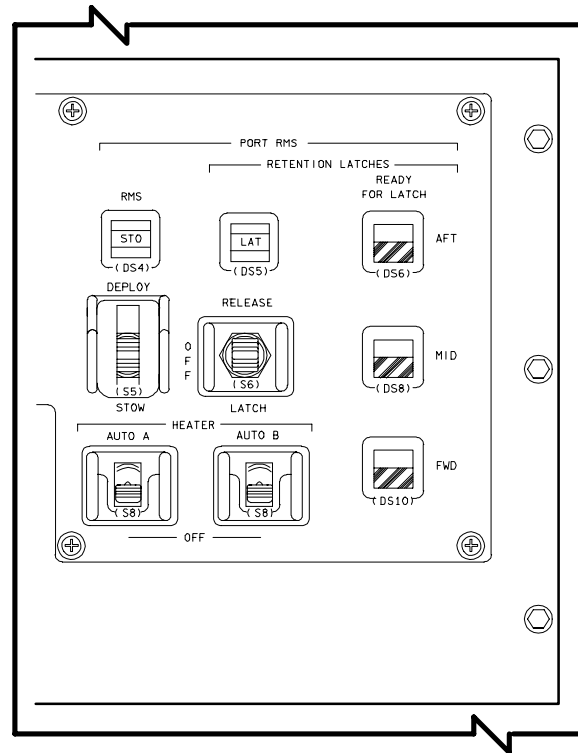
MPM Pedestals

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° saddle interfaces for cradling the arm and a retention latch to lock the arm in place. The mating hardware for the arm consists of two 45° mating plates to rest on the support saddle and a latch striker held by the retention latch.

The support assembly also contains redundant sensors or microswitches to indicate ready-to-latch and latched/release conditions.



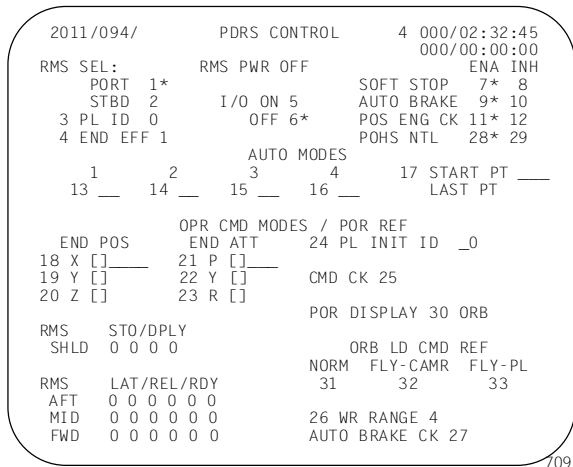
PORT RMS Controls on Panel A8L

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).



PDR CONTROL Display (SPEC 94)

Manipulator Retention Latches

The arm is latched in three locations (aft, mid, and forward) along the orbiter longeron to secure it for launch and entry loads. The retention latches are dual rotating surfaces that

are driven by redundant motors. When the three ready-to-latch indications are received, the operator positions the *PORT RMS RETENTION LATCHES* switch on panel A8L to *LATCH*, and the retention hooks catch the striker bars on the RMS and secure them firmly in place. All three latches are controlled by the switch. The MRL system contains microswitches for ready to latch, latched, and released indications. The microswitch status can be viewed via panel A8L (*AFT, MID, FWD*) talkbacks and the SPEC 94 PDRS CONTROL CRT display (RMS LAT/REL/RDY).

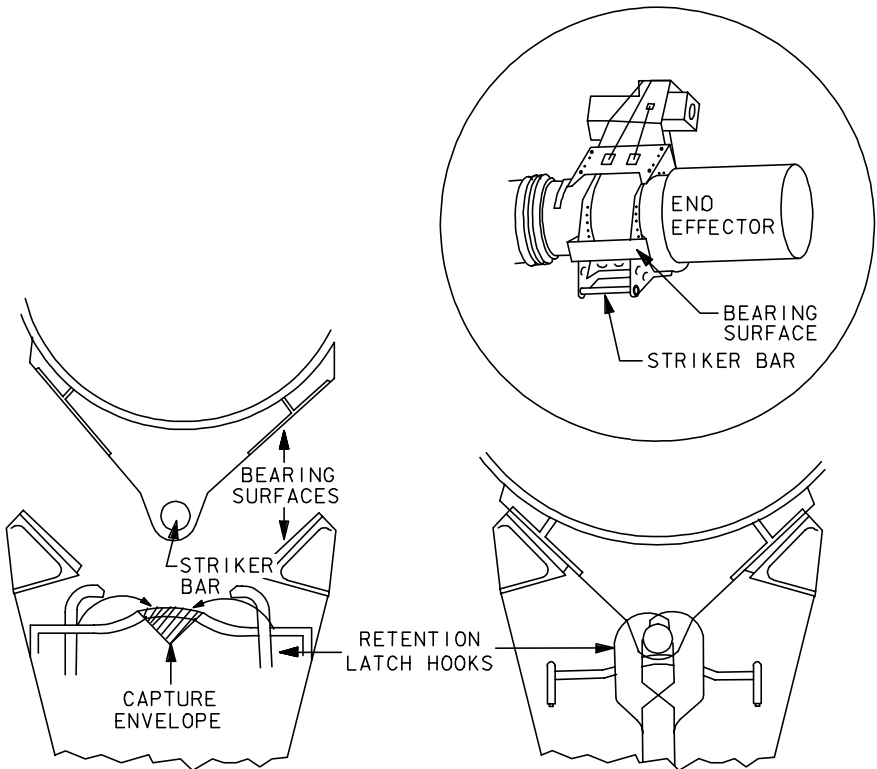
Jettison System

If for any reason the arm cannot be recradled and restowed, it can be jettisoned so that the payload bay doors can be closed. There are four separation points: one at the shoulder and one at each of the three pedestals. Each of the separation points is individually actuated. The separation system is designed to cause a non-impulsive separation.

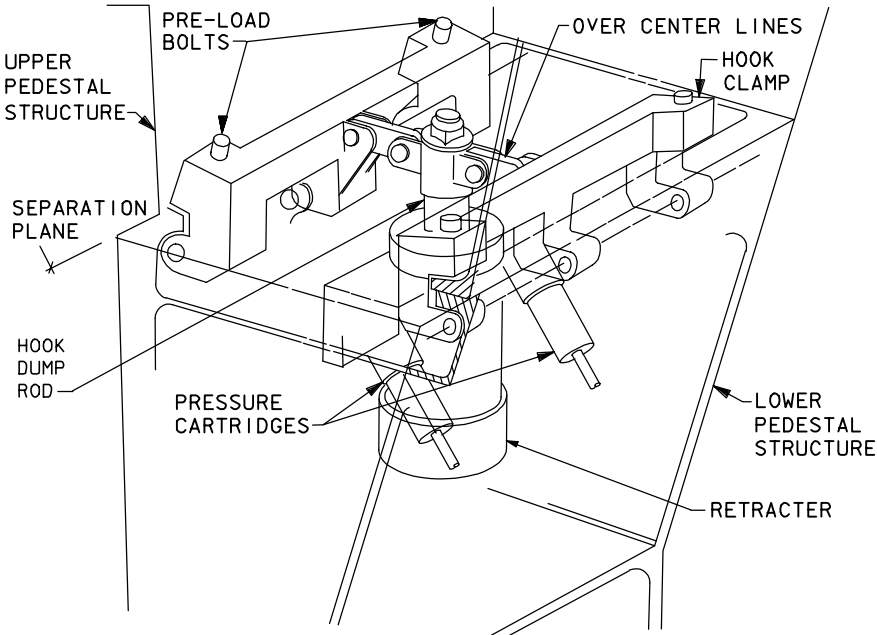
The shoulder attach point has a wire bundle that must be separated prior to shoulder support separation. The wire bundle is severed by a redundant pyro-operated guillotine prior to the activation of the support jettison system.

The jettison system works by redundant pressure cartridges firing to force down a retractor that pulls back four overcenter tie-down hooks, releasing the arm at the shoulder joint support or at one of the arm retention supports, depending upon which switch is activated.

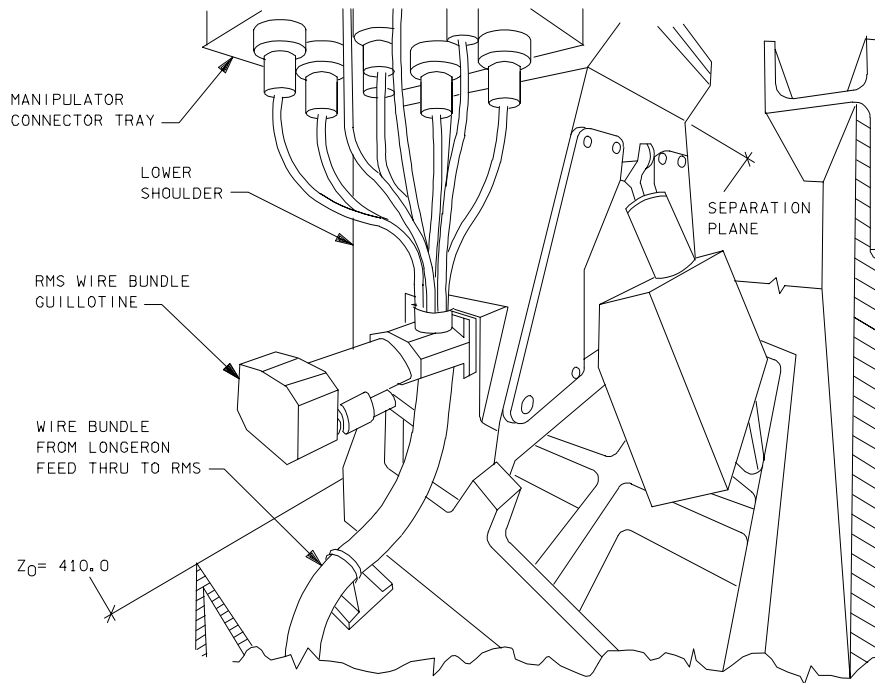
The *GUILLOTINE* switches for the RMS are located on panel A14.



RMS Retention Mechanism

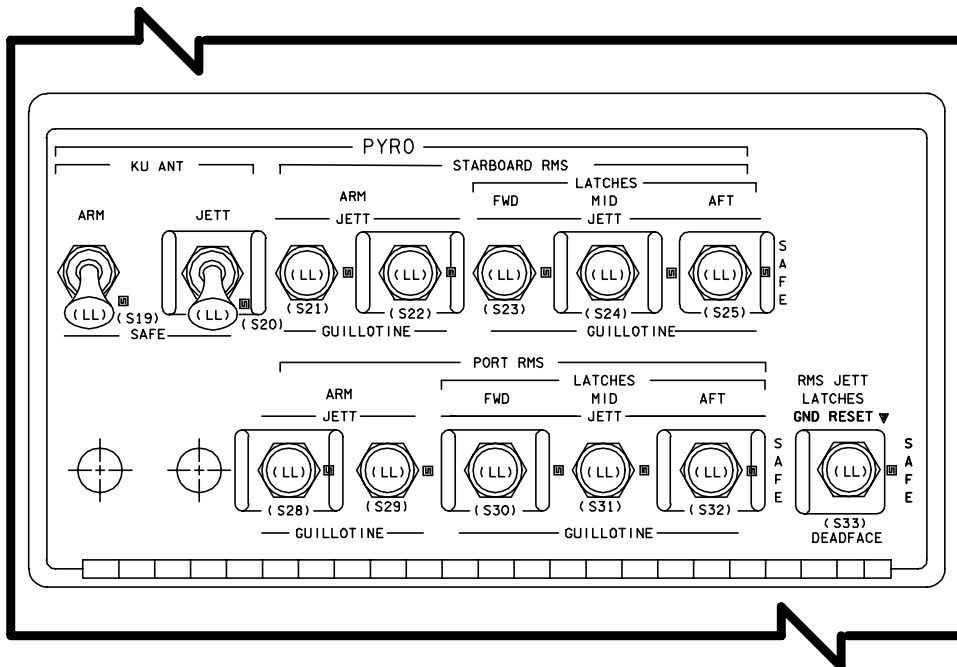


Jettison System

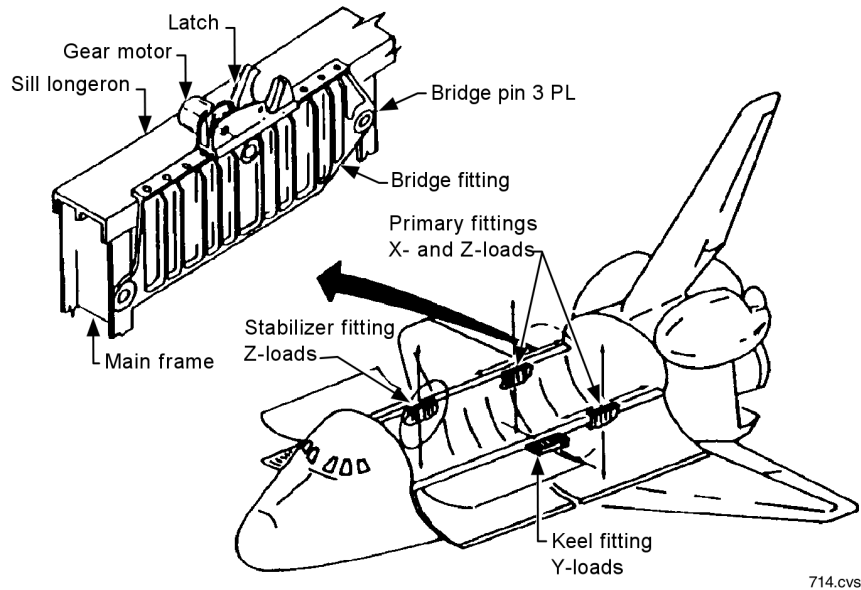


NOTE: THE MPM WIRES ARE NOT SEVERED BY GUILLOTINE

RMS Shoulder Wire Bundle



RMS Jettison Controls on Panel A14



Active Payload Retention System

Payload Retention Mechanisms

Non-deployable payloads are retained by bolted passive retention devices, and deployable payloads are secured by motor-driven, active retention devices. Payloads are secured in the orbiter payload bay with the payload retention system or are equipped with their own unique retention systems. The orbiter payload retention system provides three-axis support for up to three payloads per flight. The payload retention mechanisms secure the payloads during all mission phases and allow installation and removal of the payloads when the orbiter is either horizontal or vertical.

Attachment points in the payload bay are in 3.933-inch increments along the left- and right-side longerons and along the bottom centerline of the bay. Of the potential 172 attach points on the longerons, 48 are unavailable because of the proximity of spacecraft hardware. The remaining 124 may be used for deployable payloads. Along the centerline keel, 89 attach points are available, 75 of which may be used for deployable payloads.

Bridge Fittings

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

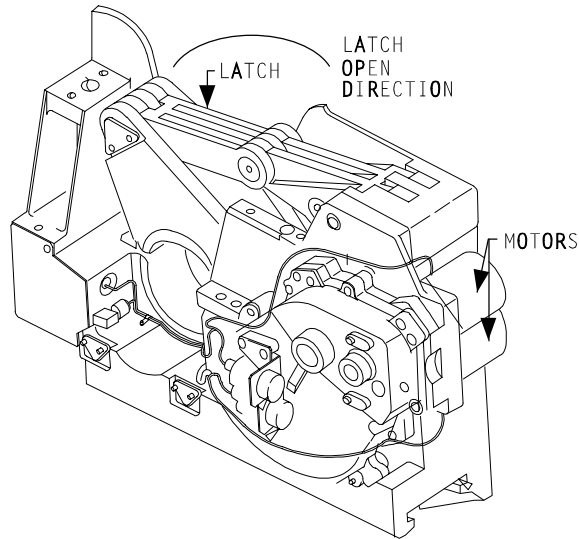
into standard and lightweight categories, just as the PRLAs and AKAs do, and of course, differ in type when used to interface longeron versus keel latches.

The keel bridge has a T-slot that accepts the T-bar fitting of the AKA; the two mated members are bolted in place. Contrastingly, the longeron bridge fitting incorporates a T-bar rail onto which the PRLA T-slot slides.

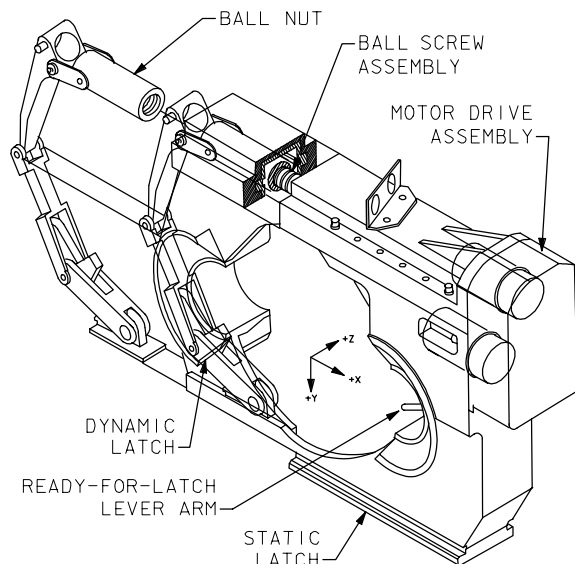
The standard and lightweight bridge fittings differ both in cross-sectional thickness and material. The standard fittings are made of titanium, and are thicker than their lightweight aluminum counterparts. Bridge fittings, whether they are standard or lightweight, longeron or keel type, are compatible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

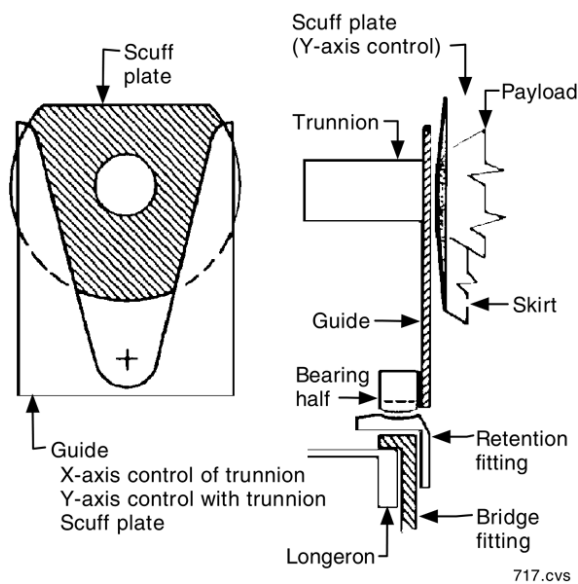
Payload Retention System Controls

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 payload, the latch status for that payload on DISP 97, and the talkback indications associated with up to five latches. In addition, two monitor settings are available (both labeled "M"). These positions allow the crewmember to monitor all the payload retention latches at once on DISP 97, but inhibit all latch control commands. Talkback indicators are also inhibited when in the monitor position and indicate barberpole.

The PAYLOAD RETENTION LATCHES 1, 2, 3, 4, and 5 switches on panel A6U are enabled by the PAYLOAD SELECT rotary switch. Positioning the PAYLOAD SELECT switch to 1 enables up to five retention latches for payload 1, and each of the five retention latches for payload 1 would be controlled by the individual 1, 2, 3, 4, and 5 switches. Positioning the PAYLOAD SELECT switch to 2 or 3 has the same effect for payloads 2 and 3.



Orbiter Payload Guide, Active Retention Fitting

NOTE

Payload retention latch wiring configurations are mission-dependent.

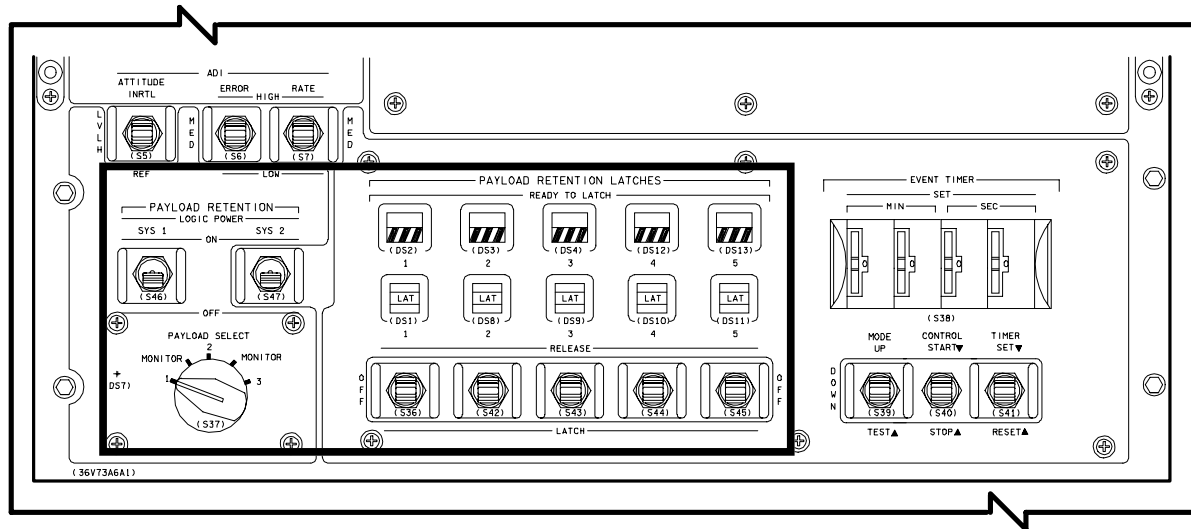
Positioning a PAYLOAD RETENTION LATCHES switch to RELEASE enables ac power to the dual electric motors associated with the retention latches designated by the position of the PAYLOAD SELECT switch, driving the retention latch open. The operating time of the latch with both motors operating is 30 seconds; with only one motor operating it is 60 seconds. The talkback indicator immediately above the switch indicates REL when the latch is fully open. There are two microswitches for the REL talkback indication; however, only one is used to control the talkback indicator (the "A" indication). The talkback is barberpole when the payload latch is between latch and release. There are two microswitches for the ready-for-latch talkback indication; however, as above, only the "A" indication is used to control the talkback indicator.

NOTE

When driving the PAYLOAD RETENTION LATCHES to RELEASE, do not continue to command a release for longer than 60 seconds if no REL indication is received. If the "A" release microswitch has failed whereby no indication is present, the latch will continue to drive against the fully open position as long as RELEASE is selected, which could quickly lead to actuator damage.

2011 / /097		PL RETENTION			4 000/02:37:49 000/00:00:00	
		LATCH 1 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	00	00	00	00	00
	LAT/REL	00/00	00/00	00/00	00/00	00/00

DISP 97 RETENTION Display



PAYLOAD RETENTION Switches and Talkbacks on Panel A6U

Positioning a *PAYLOAD RETENTION LATCHES* switch to *LATCH* provides ac power to the dual electric motor associated with the latches designated by the position of the *PAYLOAD SELECT* switch, driving the retention latch closed. The operating time of one or both motors is the same as for releasing a payload. A gray *READY* talkback indicates that latch is ready to latch. The indicator shows *LAT* when the latch is closed. There are two microswitches for the *LAT* indication; however, only system A is required to control the talkback indicator.

Operations

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

On-Orbit Initialization

Prior to any planned RMS operations, the shoulder brace must be released, and for any loaded operations, the MPM must be deployed. This procedure contains both of these activities, and checks the status of some of the panel lights, talkbacks, and switches. The PDRS CONTROL SPEC 94 display is called up, and the interface with the SM GPC is established. This operation is usually scheduled at about 2 hours MET.

RMS Powerup

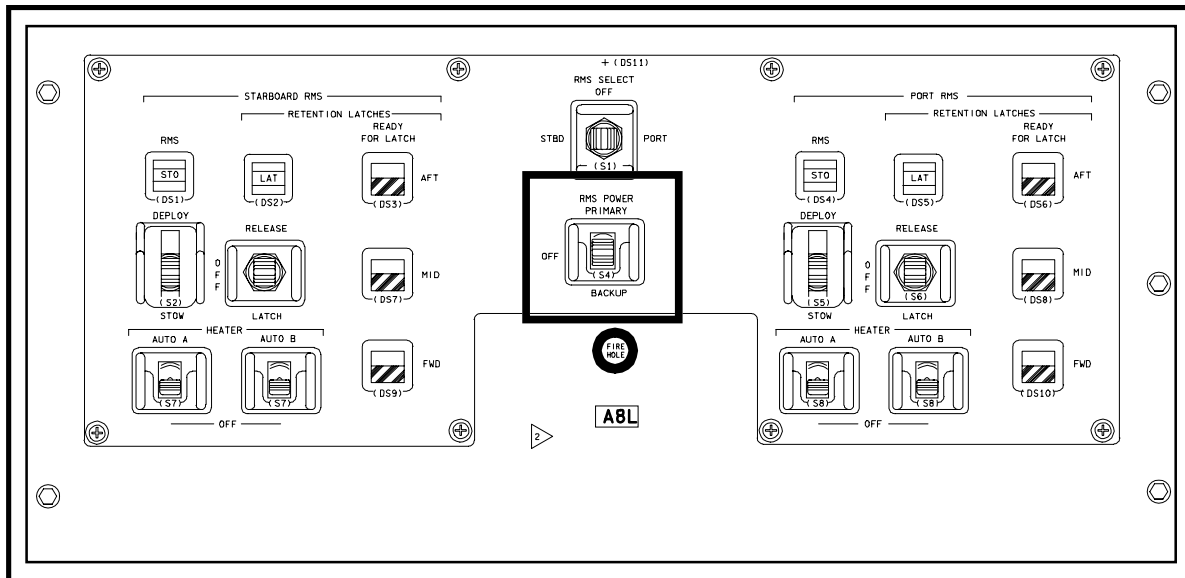
This procedure releases the MRLs and gets the arm out of the cradle to a “pre-cradle” configuration. This procedure is usually performed several times during a flight, as the arm is always powered down when not in use. The *RMS POWER* switch is on panel A8L.

NOTE

Placing the *RMS POWER* switch to *PRIMARY* generates an RMS master alarm. This alarm is generated because the panel powers up faster than the MCIU, thereby causing the *MASTER ALARM* light and tone to annunciate before the MCIU can respond with the proper master alarm flag. This is a normal condition and will occur every time the *RMS POWER* switch is cycled *OFF* and back to *PRIMARY*.

RMS Checkout

This procedure verifies in exacting detail that all the arm hardware and the panel switches and functions are in good operating condition. This is about an hour-long procedure and is done only once per flight. It is usually scheduled at about 3 or 4 hours MET on flight day 1 in order to allow plenty of time for any problems to be worked around.



RMS POWER Switches on Panel A8L

Flight-Specific Operations

The arm can perform six different types of operations. One or more may be done per flight. These operations are broken down as described below.

Contingency-Only Unloaded Operations

These unscheduled operations will only be performed if a problem arises in another orbiter system. The training for these operations is very minimal, and the tasks performed would involve surveys of some parts of the orbiter.

Unloaded Operations

These scheduled operations involve maneuvering the arm to various positions or along various trajectories. An example of this would be a payload survey. There is no payload attached to the arm during these maneuvers.

Loaded Operations

These operations involve grappling a payload that is berthed in the payload bay, releasing the payload latches, unberthing the payload, maneuvering the payload, reberthing and relatching the payload, and ungrappling the payload.

Deploy Operations

These operations involve grappling a payload that is berthed in the payload bay, releasing the payload latches, unberthing the payload, maneuvering the payload to the release position and orientation, and releasing the payload.

Retrieve Operations

These operations involve capturing a free-flying payload, maneuvering the payload to a hover position (aligned with the berthed position, but about 10 feet over the bay), berthing and latching the payload, and ungrappling it.

Deploy and Retrieve Operations

These operations apply to one payload that is both deployed and retrieved as in the steps listed above. The order of deploy and retrieve operations is flight-specific.

RMS Powerdown

This procedure returns the arm to the cradled configuration and relatches the MRLs. This is done any time arm operations are not required. The power to the ABE is deactivated, but the MCIU remains powered up and in contact with the SM GPC. For the final flight powerdown, the MPM will be stowed as part of this procedure.

RMS Deactivation

This procedure removes power from the RMS heaters and turns off the MCIU. This will only be done after all arm operations scheduled for the flight have been completed.

RMS Jettison

This is a contingency procedure that is used to jettison the arm only, the arm plus MPM pedestals, or the arm/payload combination. Jettison causes a non-impulsive separation of the arm, and then the orbiter pilot performs an orbiter separation from the jettisoned unit. Should the jettison have to be done in an expedited manner, a QUICK RESPONSE JETTISON procedure has been created and is located in the contingency deorbit checklist.

Operating Modes

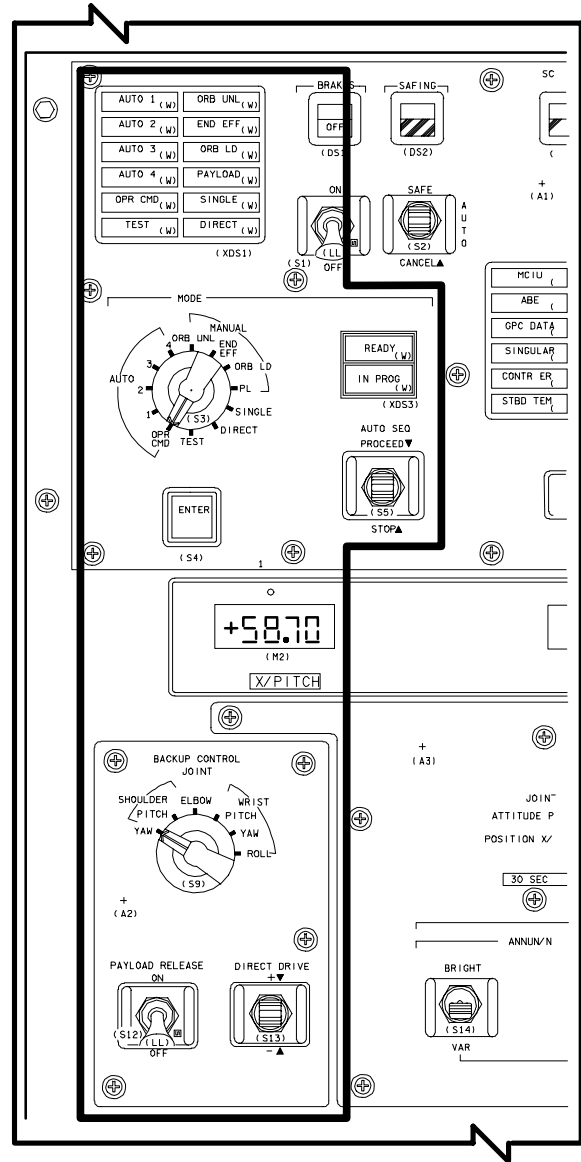
The RMS can be operated in a variety of modes. These modes are detailed below.

Single Joint Modes

Operating the arm in a single joint mode allows only one joint at a time to be driven. Single joint operations are very painstaking and time consuming, and so are only used when absolutely necessary. Uncraddling and cradling must be done via a single joint mode, since the arm is in the soft stop region for several joints. The single joint modes, selected by two rotary switches on panel A8U, are *SINGLE*, which is a computer-supported mode, *DIRECT*, which commands the joints via hardwired signals and uses MN A (primary) power, and *BACKUP*, which commands the joints via hardwired signals and uses MN B (backup) power.

Manual Augmented Modes

The manual augmented modes are computer-supported modes that use the RMS hand controllers (HCs) to control the arm trajectories. The modes that fall into these categories are orbiter unloaded, orbiter loaded, end effector, and payload modes. They are selected by corresponding positions of the *MODE* rotary switch on panel A8U: *ORB UNL*, *ORB LD*, *END EFF*, *PL*.



Mode Selection Rotary Switches and Lights on Panel A8U

In standard RMS operations, the manual augmented modes are supplemented with the position/orientation hold select (POHS) mode. POHS mode is a software improvement that has greatly increased the ability of the RMS operator to control the arm trajectory. The POHS mode is used to improve RMS performance in the manual augmented modes by correcting unwanted motion of the point of resolution. POHS mode can be selected on SPEC 94. When POHS is enabled (SPEC 94, ITEM 28), POR position hold is used to prevent POHS reference drift. When

POHS is disabled (SPEC 94, ITEM 29), joint position hold is used. The POHS reference position and attitude are displayed on SPEC 169.

ORB UNL. Orbiter unloaded mode uses the unloaded POR and defines the HC inputs to coincide with the desired arm trajectory as viewed out the aft windows. For example, to translate the arm to the left as you are looking out the aft window (toward the starboard side of the vehicle), the THC would be deflected to the left. To move the arm out of the payload bay (up), the THC would be deflected up. To bring the arm toward you, the THC would be pulled out. RHC inputs are similar. To pitch the arm or payload up with respect to you as you are looking out the aft window, the RHC would be tilted back toward you. To yaw the arm/payload as you are viewing it, the RHC would be twisted left or right about its long axis. To roll with respect to your view, the RHC would be deflected left and right.

ORB LD. Orbiter loaded mode is usually used for a loaded arm. The HC inputs in orbiter loaded mode are identical to those in *ORB UNL*; however, the POR is defined to be at a point within the grappled payload.

In the orbiter loaded mode, there are three types of HC references: normal, fly-to (also referred to as fly-camera), and fly-from (also referred to as fly-payload). These command references are mutually exclusive and can be enabled or disabled via SPEC 94. Fly-payload is used the same way orbiter loaded mode is used; however, any orbiter-based camera or window view can be used. Fly-camera is the same as fly-from with all commands reversed.

END EFF. End effector mode allows the HC inputs to reflect motion desired when viewed through the end effector camera. The sense the operator has is that he or she is “sitting” on the end of the end effector. When the arm is aligned parallel to the longeron, and the wrist joint angles are all zero, HC inputs in *END EFF* coincide with those in *ORB UNL/LD*. If the wrist is then pitched down in that configuration, the motion to take the arm down into the payload bay would be a THC downward deflection in *ORB UNL/LD*, but would be a push inward on the THC in *END EFF* mode.

PL. Payload mode uses the software-predefined POR and coordinate system and applies the HC inputs as follows: THC-in will cause motion in the +X axis of the software-defined PL coordinate system; THC-out corresponds to motion along the -X axis of the PL coordinate system. THC-right will cause motion along the PL +Y axis, while THC-left will cause motion along the PL -Y axis. THC-down will cause motion along the PL +Z axis, and THC-up will cause motion in the PL -Z axis. RHC P will cause motion about the PL Y axis, RHC Y will cause rotation about the PL Z axis, and RHC R will cause rotation about the PL X axis.

TEST. Test mode, while not strictly speaking a manual-augmented mode, uses the same POR and coordinate system definition as *ORB UNL*. Test mode allows the arm operator to monitor and verify the HC commands without causing any arm motion. This is done by cutting off the joint drive current at each joint.

AUTO Modes

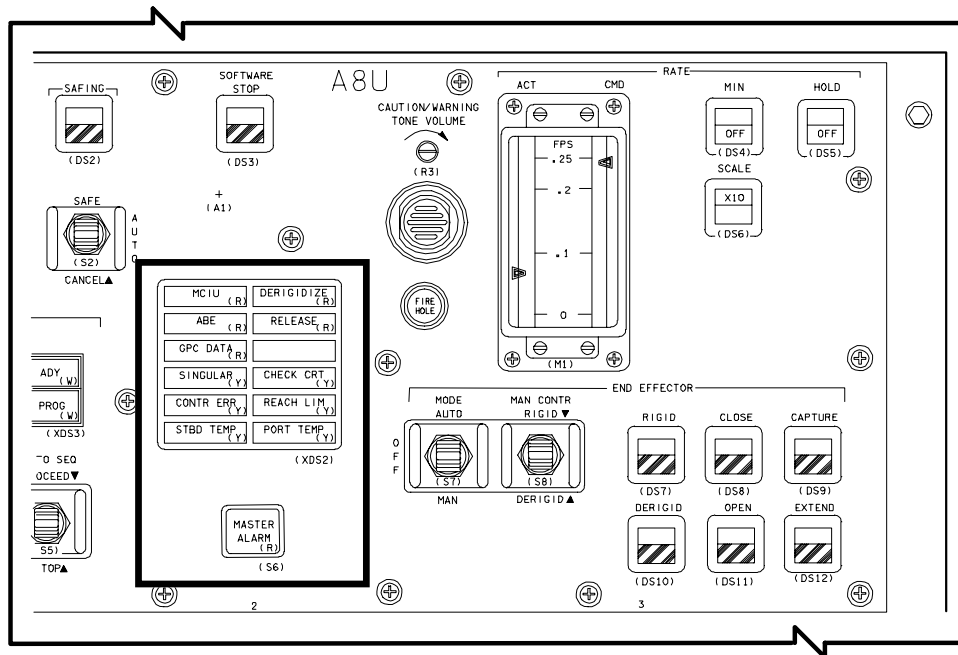
There are two types of auto modes: auto-commanded auto sequences and operator-commanded auto sequences. In either case, the SM GPC controls the arm trajectory.

Auto-Commanded Auto Sequences. These sequences consist of up to 200 pre-defined points that can be grouped in up to 20 sets, or sequences. To use an auto-commanded auto sequence, the operator enters the desired sequence number on the PDRS CONTROL SPEC for one of AUTO 1, 2, 3, or 4 slots, then selects *AUTO 1, 2, 3, or 4* via the *MODE* rotary switch on panel A8U. The arm is then commanded to start via the *AUTO SEQ* switch, and will fly through that 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

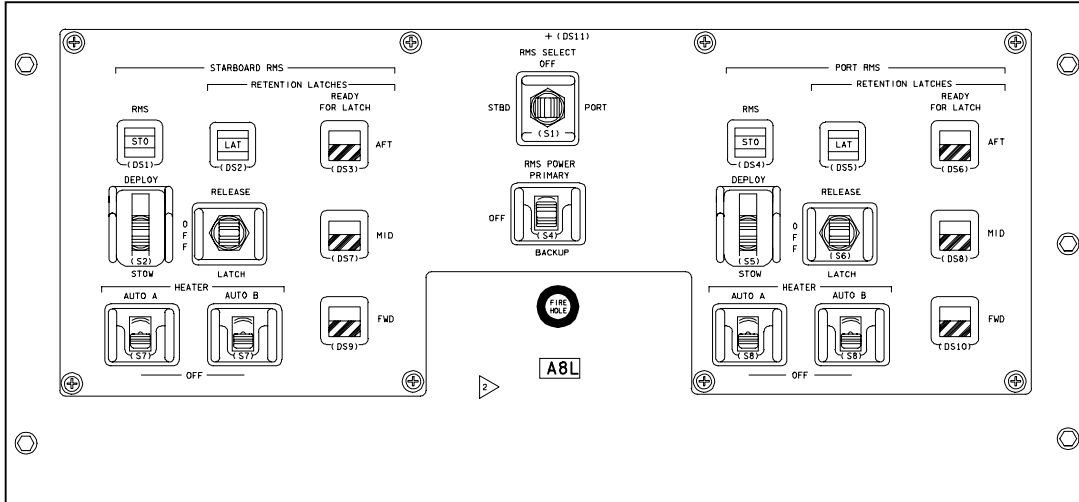
- The RMS has a separate C/W matrix on panel A8U. This system is not associated with the orbiter's C/W system.
- The red *MCIU* light indicates that the MCIU has failed a self-test.
- The red *DERIGIDIZE* light indicates that the end effector has derigidized without command.
- The red *ABE* light indicates 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 canceled by depressing the pushbutton.
- The RMS C/W tone volume may be adjusted by the *CAUTION/WARNING TONE VOLUME* knob.



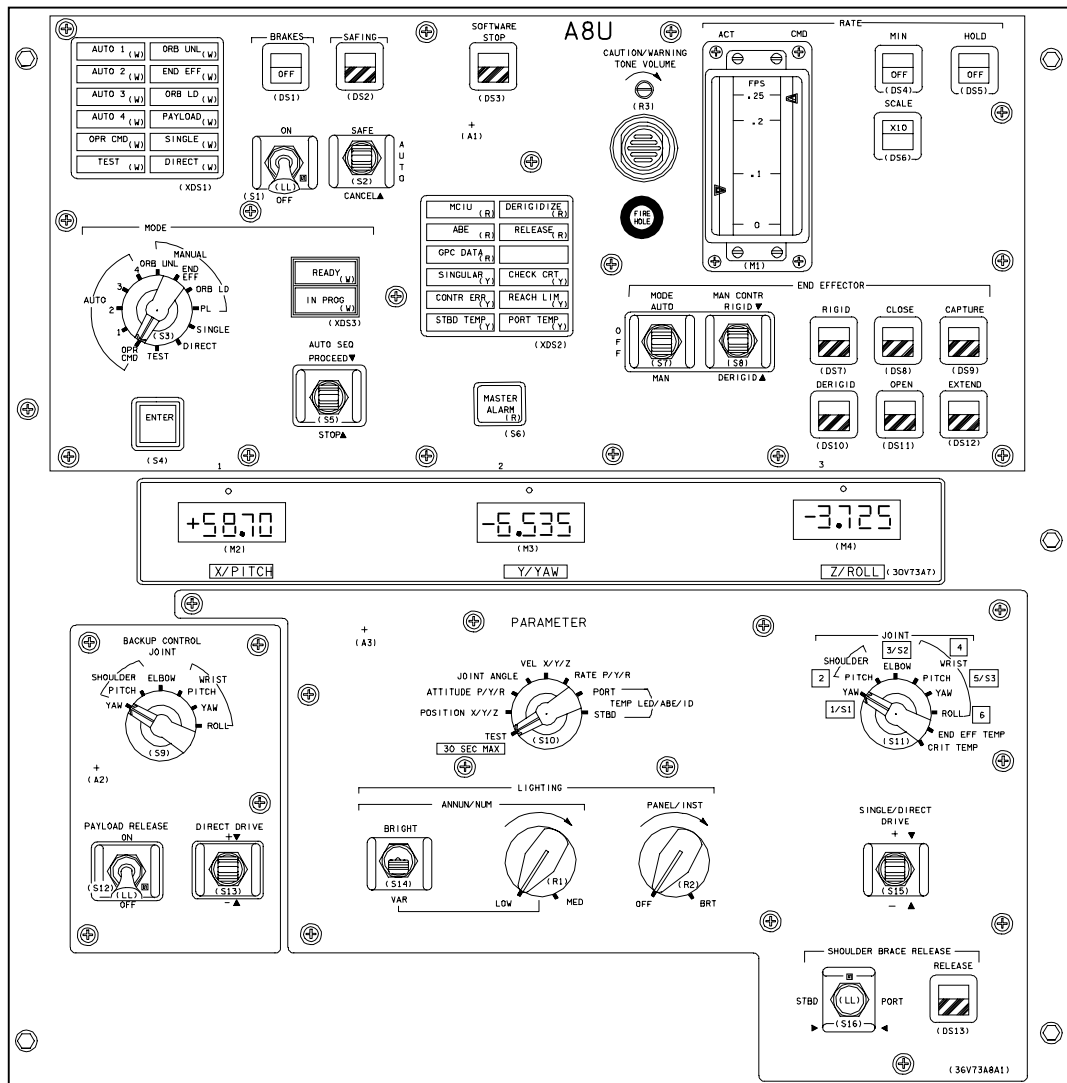
RMS Caution and Warning Lights on Panel A8U

PDRS Summary Data

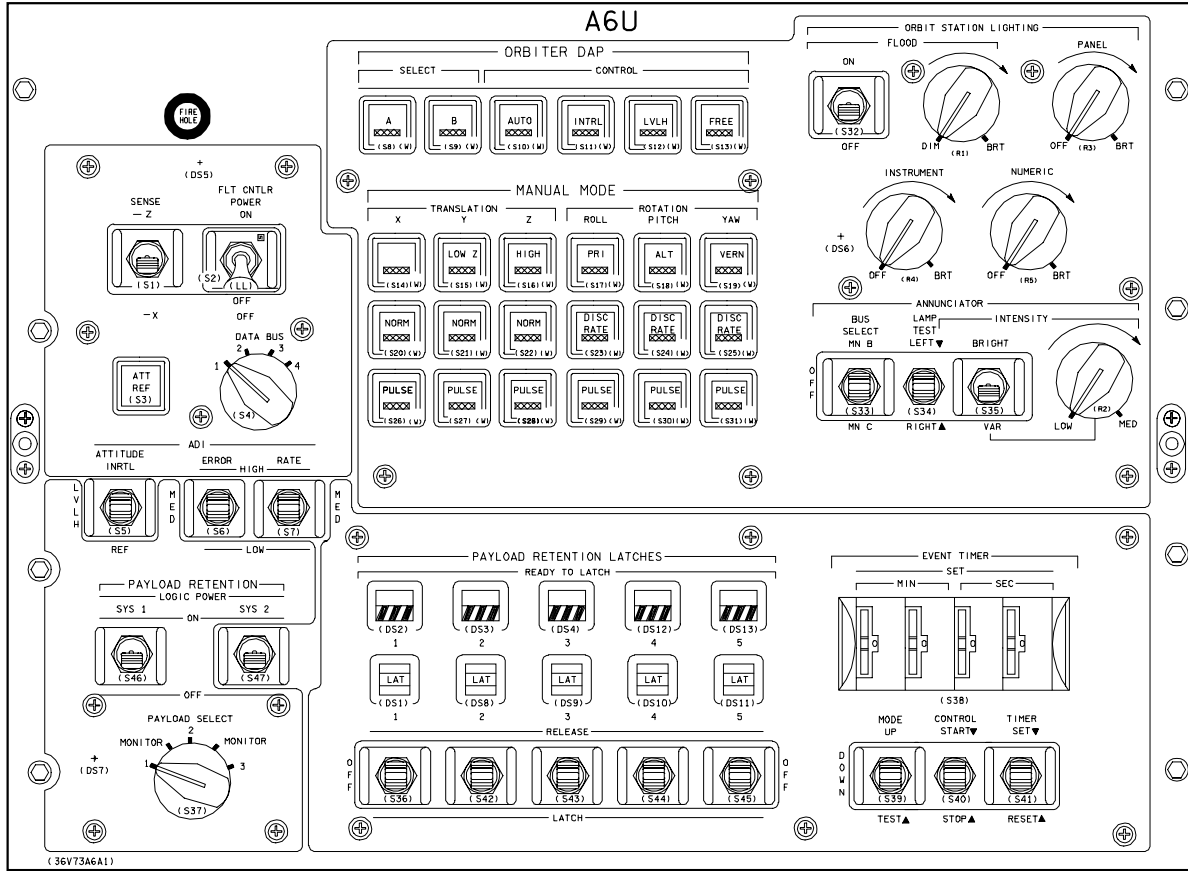
- The PDRS is used to maneuver itself or an attached payload in orbit. It consists of the RMS, MPM, AND mrls, and interfaces with other orbiter systems such as the SM GPC, the EPDS, and the CCTV.
- The RMS consists of the arm itself and the controls and interfaces needed to maneuver it. It is located on the port longeron.
- The MPM consists of the torque tube, the pedestals, the MRLs, and the jettison system. The MPM must be stowed whenever the payload bay doors are closed and must be deployed for any loaded operations.
- The pedestals contain the MRLs and the jettison electronics and mechanics and are the supports on which the RMS rests while it is cradled.
- The MRLs latch the arm to the MPM and restrain it during periods of RMS inactivity.
- The jettison allows the arm, the arm and pedestals, or the arm/payload combination to be non-impulsively separated from the orbiter if the arm cannot be cradled and stowed prior to payload door closure.
- The on-orbit arm operations fall into six categories: contingency-only unloaded operations, unloaded operations, loaded operations, deploy operations, retrieve operations, and deploy and retrieve operations.
- The arm has three basic modes of operation: single joint modes, manual-augmented modes, and auto modes.
- All RMS operations involve a two-person operator team. Each member is vital to the success of the mission.
- The PDRS controls are located primarily on panels A8L, MA73C, and A8U. Other panels that affect the RMS are ML86B, A14, A7U, A6, and R13.
- The major PDRS CRT display is SPEC 94 PDRS CONTROL. PDRS OVERRIDE SPEC 95, PDRS STATUS DISP 169, and PDRS FAULTS SPEC 96 also control and monitor the RMS. DISP 97 PL RETENTION monitors payload retention device status.



Panel A8L



Panel A8U



Panel A6U

```

2011/094/      PDRS CONTROL      4 000/02:32:45
                                000/00:00:00
RMS SEL:      RMS PWR OFF      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 [ ]      END ATT 24 PL INIT ID _0
19 Y [ ]      21 P [ ]
20 Z [ ]      22 Y [ ]      CMD CK 25
                23 R [ ]      POR DISPLAY 30 ORB

RMS  STO/DPLY
SHLD 0 0 0 0

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

```

709

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

ROT RATES    ACT      M      M      M
              CMD

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

```

727

DISP 169 PDRS STATUS Display

```

2011/095/      PDRS OVERRIDE      4 000/02:33:08
                                000/00:00:00
MODE SW OVRD 1
MODE SEL IND JNT SW OVRD 17 | RATE SW OVRD 26
ORB UNL 2    | JOINT SEL VERNIER 27*
SINGLE 3      | SH YAW 18 | COURSE 28
END EFF 4    | SH PITCH 19
ORB LD 5     | EL PITCH 20 | AUTO SW OVRD 29
PL 6         | WR PITCH 21 | PROCEED 30
OPR CMD 7    | WR YAW 22 | STOP 31
AUTO 1 8     | WR ROLL 23 |
AUTO 2 9     | EE TEMP 24 | HC AXIS CHG 32
AUTO 3 10    | CRIT TEMP 25 | THC 33
AUTO 4 11    |           | RHC 34
TEST 12      | MCIU OVERRIDE
ENTER 13     | SAFING CAN 35
                ABE OVRD A 36
                ABE OVRD B 37
                ABE OVRD C 38
LOADED RATE 14
STOWED OPS 15
SIN/DIR SW
REASSIGN 16

```

726

SPEC 95 PDRS OVERRIDE Display

```

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

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

PL SEL 3
RDY-FOR-LAT 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
SPA CMTR / SPA CMTR
TACH / TACH PLL
/ TACH TCO
/ CPU
/ MDA DMND
/ A/D CONV
/ BRAKE
/ POS ENG
/ DIR DRV
/ B/U RELAY
SPA +28V /
CONTR ERROR
CKCRT - POS
REACK LIMIT
                MCIU:
                MADC
                MCPC
                ICF
                ABE:
                COMM
                CHECK CRT:
                DC/MCIU
                EXT FS
                EE FLAG
                EEEU
                EE CMDS
                HC
                MCIU HC
                TMP CKT
                CKCRT - SPA: SY SP EP WP WY WR
                BITE TEST  LOSS  LOSS  LOSS  LOSS  LOSS  LOSS

```

1070

SPEC 96 PDRS FAULTS Display

PDRS Rules of Thumb

- Whenever there are both talkbacks and CRT displays that reflect microswitch status, they should ALWAYS both be checked during any operation affecting them.
- Whenever troubleshooting RMS malfunctions in the long-form MAL book, always READ AHEAD. The MALs have a knack for having page breaks in extremely bad locations, and if you don't know what you're supposed to look for before you turn the page, you could be in trouble.
- The hand controllers are rate-proportional and are extremely sensitive. They should be held in such a way that you can control the full range of inputs without ever stopping to rearrange your hand. Care must be taken to not overcontrol the inputs. A good practice is to slowly and steadily input a desired command, wait patiently until you see the reactions of that command on the arm, and as the desired motion is achieved, slowly back off the input. Ideally, you should reach the axis detent at the same time the arm achieves the desired position and attitude.
- MPM motion may cease during deployment or stowage before the expected microswitches are made. This is 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)

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Description

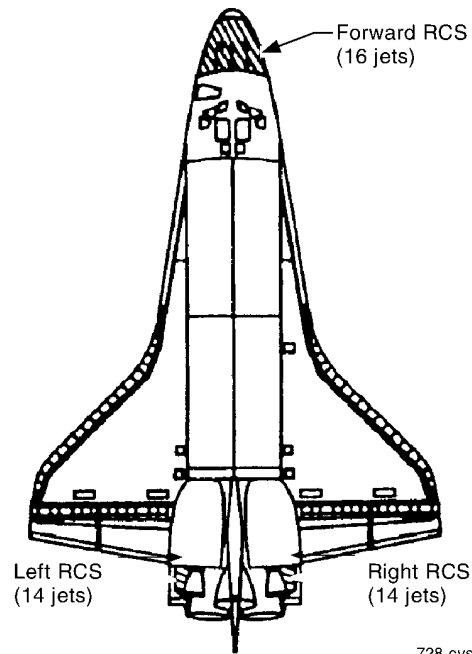
The orbiter's RCS consists of forward and aft control jets, propellant storage tanks, and distribution networks located in three vehicle modules: forward, left, and right. The forward module is contained in the nose area, forward of the cockpit windows. The left and right (aft) modules are collocated with the orbital maneuvering system (OMS) in the left and right OMS/RCS pods near the tail of the vehicle. Each RCS consists of high-pressure gaseous helium storage tanks, pressure regulation and relief systems, a fuel and oxidizer tank, a propellant distribution system, reaction control jets, and electrical jet and pod heaters.

The RCS units provide propulsive forces from a collection of jet thrusters to control the 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, roll)
- Small velocity changes along the orbiter axes (translational maneuvers)

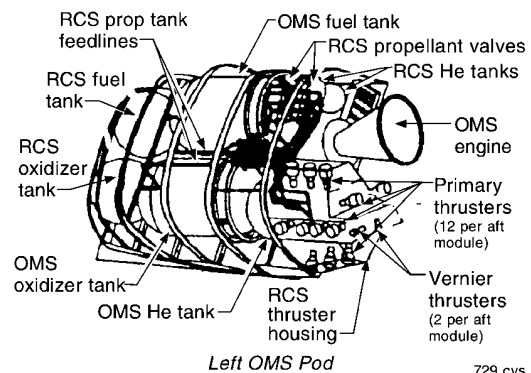
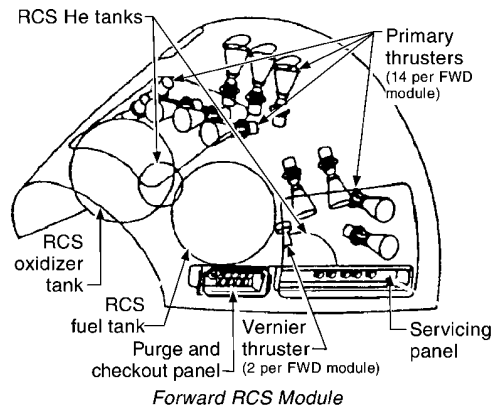
Each RCS jet is identified by the propellant manifold that supplies the jet and by the direction of the jet plume. The first identifier designates a jet as forward (F), left aft (L), or right aft (R) RCS. The second identifier, number 1 through 5, designates the propellant manifold. The third identifier designates the direction of the jet plume: A (aft), F (forward), L (left), R (right), U

(up), D (down). For example, jets F2U, F3U, and F1U are forward RCS jets receiving propellants from forward RCS manifolds 2, 3, and 1, respectively; the jet plume direction is up.



728.cvs

Forward, Left, and Right RCS Modules



729.cvs

Left and Forward RCS Modules

Manual RCS use is accomplished through the rotational and translational hand controllers, and automatic use is handled by the digital autopilot (DAP) and the general purpose computers (GPCs).

Nominal uses of the RCS occur during ascent, orbit, and entry. During ascent, the RCS is used for rotational control during mated coast with the external tank. It is also used to provide -Z translation at external tank separation, using all 10 down (-Z) primary jets. This is the only RCS translational maneuver done automatically. The RCS is also used during ascent to maneuver to OMS burn attitude and to trim residuals post-burn, if required.

During orbit, the RCS provides attitude control, including pointing and attitude hold, and rendezvous maneuvers.

During entry, the RCS provides for center of gravity (c.g.) management through the forward propellant dump. Also during entry, yaw, roll, and pitch control is provided by the aft left/right (Y) and up/down (Z) jets.

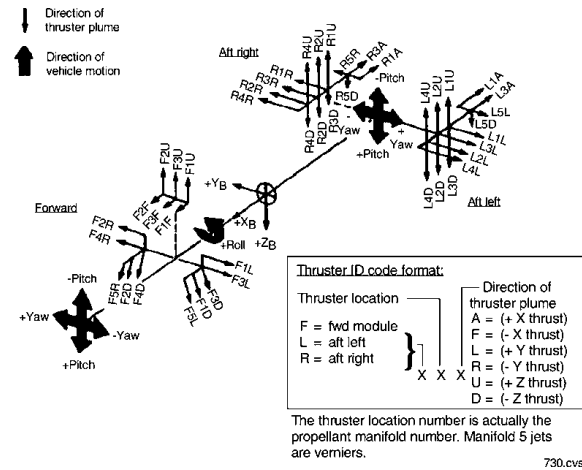
The RCS is also used during off-nominal situations. In the case of loss of two SSMEs on ascent, the OMS-to-RCS interconnect is automatically commanded, and the RCS provides single-engine roll control. If the OMS gimbaling system is not performing adequately to control vehicle attitude during an OMS burn, RCS jets are used to help maintain attitude. This is also known as "RCS wraparound." The RCS is also used to adjust an orbit if the OMS fails prematurely. During aborts, the RCS may be used to assist with ascent propellant dumps to decrease vehicle weight, improve performance, and control center of gravity.

NOTE

RCS jets assist in OMS and/or RCS dumps by burning propellant in either propulsive or non-propulsive (null) burns.

There are a total of 44 RCS jets; 38 primary and 6 vernier. The vernier jets are only used on orbit for fine attitude control. The forward RCS has 14 primary and 2 side-firing vernier jets. The aft RCS has 12 primary and 2 vernier jets in each

pod for a total of 28. One set of aft vernier jets is side-firing, and the other set is down-firing. The primary RCS jets provide 870 pounds of vacuum thrust each, and the vernier RCS jets provide 24 pounds of vacuum thrust each for precise maneuvering. The vernier jets are used for tight attitude dead bands and fuel conservation.



RCS Jet Identification

NOTE

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

Two helium tanks supply gaseous helium pressure to the oxidizer and fuel tanks. The oxidizer and fuel are then supplied under pressure to the RCS jets. Nitrogen tetroxide (N₂O₄) 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 discretely and sends them to redundancy management as an indication of actual jet firings.

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

The injector assembly directs the flow of propellants to the combustion chamber. The primary thrusters have injector hole pairs (one fuel, one oxidizer), called doublets, canted

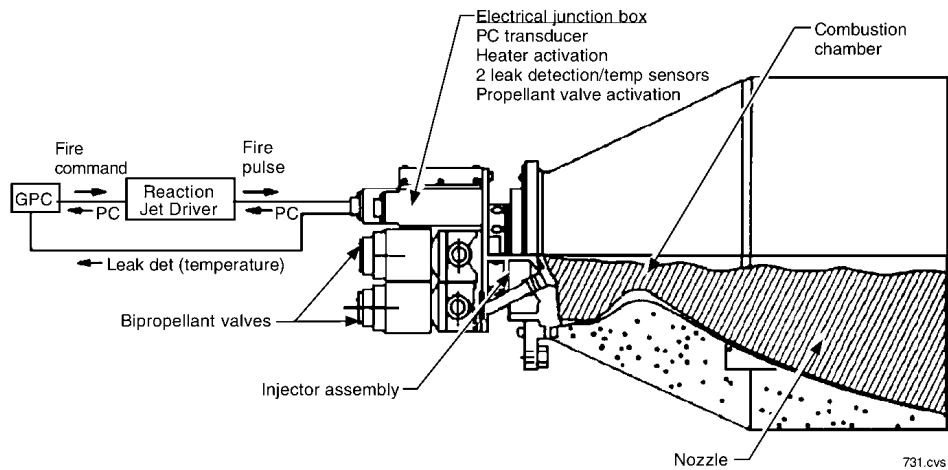
toward each other for stream impingement of the propellants in the combustion chamber. Each primary jet has 84 doublets arranged in a "showerhead" circular pattern in the combustion chamber. Additional fuel holes are provided near the outer edge of the injector assembly for cooling the combustion chamber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

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

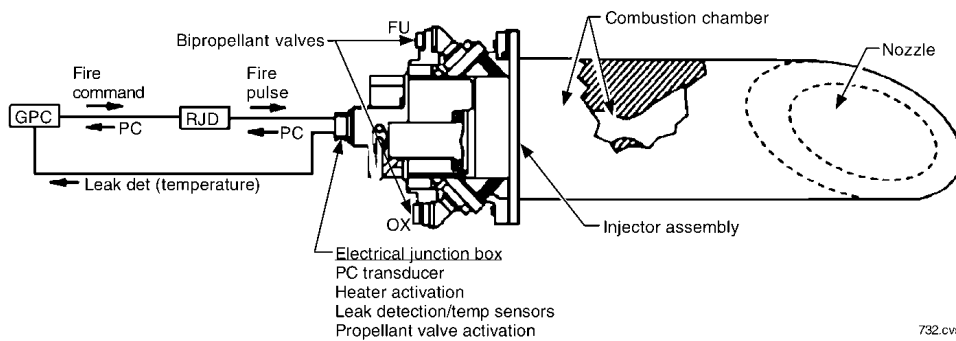
The combustion chamber of each RCS jet is constructed of columbium with a columbium disilicide coating to prevent oxidation. The nozzle of each RCS jet is tailored to match the external contour of the forward RCS module or the left and right aft RCS pods. The nozzle is radiation-cooled, and insulation around the combustion chamber and nozzle prevents the excessive heat of 2,000° to 2,400° F from radiating into the orbiter's structure.

The electrical junction box for each RCS jet has electrical connections for an electrical heater, a chamber pressure transducer, oxidizer and fuel injector temperature transducers (to detect propellant leaks) for each valve, and the propellant valves.

There is a small possibility of random but infrequent combustion instability of the primary RCS jets, causing a burnthrough in the combustion chamber wall of an RCS primary jet in a very few seconds. An instability protection system is incorporated into each of the 38 primary RCS jets. The electrical power wire of each primary RCS jet fuel and oxidizer valve is wrapped around the outside of each primary RCS jet combustion chamber wall. If instability occurs within a primary RCS jet, the burnthrough would cut the electrical power wire to that primary RCS jet's valves, remove electrical power to the valves, close the valves, and render the jet inoperative for the remainder of the mission.



Primary Jet



Vernier Jet

Propellant System

The system that distributes the propellants to the RCS jets consists of fuel and oxidizer tanks, tank isolation valves, manifold isolation valves, crossfeed valves, distribution lines, and filling and draining service connections.

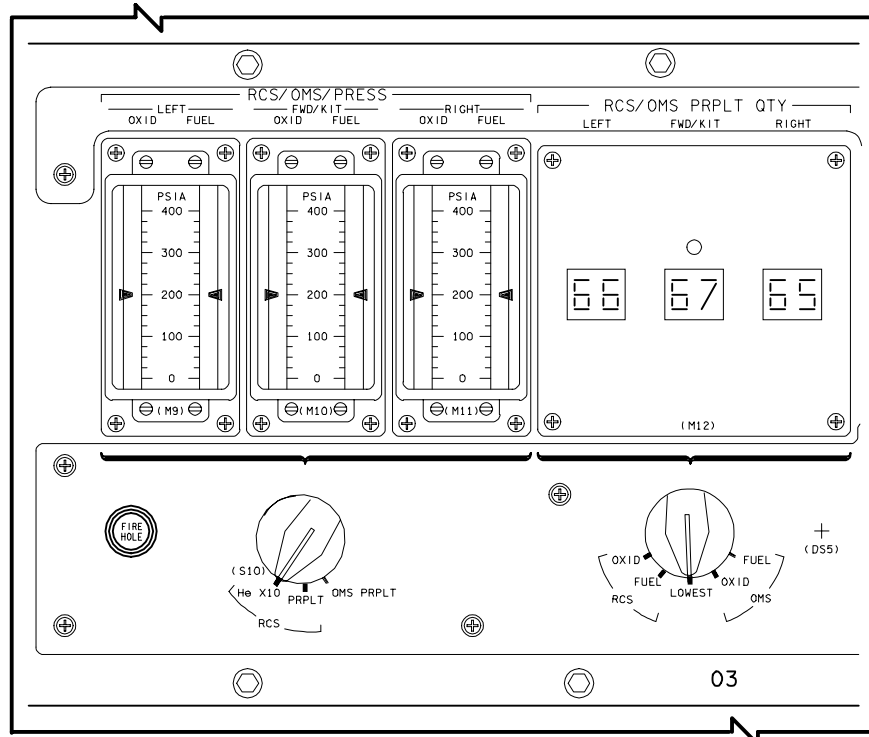
Propellant Tanks

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

Each tank is pressurized with helium, which expels the propellant into an internally mounted, surface-tension, propellant acquisition device that acquires and delivers the propellant to the RCS jets. The propellant acquisition device is required because of the orbiter's

orientation during ascent, on orbit, and during entry. The device is also needed to deal with the various accelerations, which range from very high during ascent, entry, or abort to very low during orbital operation. The forward RCS propellant tanks have propellant acquisition devices designed to operate primarily in a low-gravity environment, whereas the aft RCS propellant tanks are designed to operate in both high and low gravity, ensuring adequate propellant flow during all phases of flight. A compartmental tank with individual wire mesh screen devices in both the upper and lower compartments supplies propellant independent of tank load or orientation. A barrier separates the upper and lower compartments in each tank.

The aft RCS propellant tanks incorporate an entry collector, sumps, and gas traps to ensure proper operation during abort and entry mission phases.



**RCS/OMS/PRESS Meters and Rotary Switch and
RCS/OMS PRPLT 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)

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

RCS Propellant Quantity

The RCS quantity monitor uses the GPC to calculate the usable percent of fuel and oxidizer in each RCS module. The quantities are computed based on the pressure, volume, and temperature method, which requires that pressure and temperature measurements be combined with a unique set of constants to calculate the percent remaining in each of the six propellant tanks. Correction factors are included for residual tank propellant at

depletion, gauging inaccuracy, and trapped line propellant. The computed quantity represents the usable (rather than total) quantity for each module and makes it possible to determine if the difference between each pair of tanks exceeds a preset tolerance (leak detection).

The sequence assumes that helium flows to the propellant tanks to replace propellant leaving. As a result, the computed quantity remaining in a propellant tank will be decreased by normal usage, propellant leaks, or helium leaks.

NOTE

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

The left, right, and forward RCS fuel and oxidizer quantities are displayed to the flight crew by the RCS/OMS PRPLT QTY LEDs on panel O3. When the rotary switch on panel O3 below the LEDs is positioned to the *RCS FUEL* or *OXID* position, the LEDs will indicate, in

ISOLATION 1/2 and 3/4/5 A and B switches on panel O7 are the same type as those of the forward RCS tank isolation switches and are controlled electrically in the same manner. A talkback indicator above each switch indicates the position of the pair of valves as in the forward RCS. The 3/4/5 A and B switches control parallel fuel and oxidizer tank isolation valves to permit or isolate propellants to the respective aft left and aft right RCS manifold isolation valves 3, 4, and 5.

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

Manifold Isolation Valves

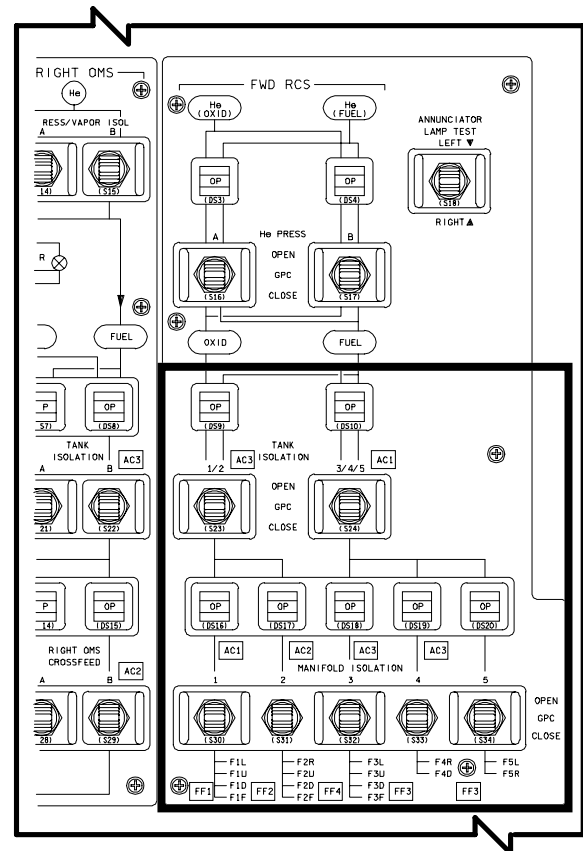
The forward RCS manifold isolation valves are between the tank isolation valves and the forward RCS jets. The valves for manifolds 1, 2, 3, and 4 are the same type of ac-motor-operated valves as the propellant tank isolation valves and are controlled by the same type of motor-switching logic. The forward RCS manifold valve pairs are controlled by the *FWD RCS MANIFOLD ISOLATION 1, 2, 3, 4, and 5* switches on panel O8. Each *MANIFOLD ISOLATION* switch controls a pair of valves (one fuel and one oxidizer), which allow propellant to flow to the jets on the corresponding manifold. A talkback indicator above each of the five switches on panel O8 indicates the status of that pair of valves. The talkback indicator is controlled in the same manner as the tank isolation valve indication. The *OPEN* and *CLOSE* positions of the switch permit control of the corresponding oxidizer and fuel valves. The *GPC* position is not supported.

NOTE

The manifold isolation valves have a backflow capability when the manifold is closed, and the manifold pressure is 30 to 50 psi higher than the tank leg.

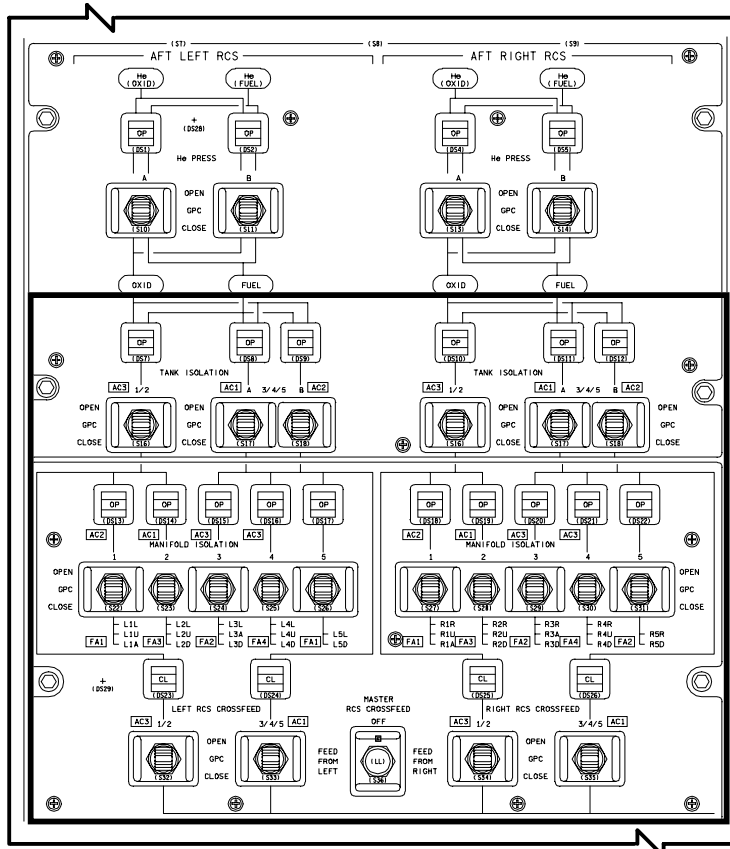
The *FWD RCS MANIFOLD ISOLATION 5* switch on panel O8 controls the manifold 5 fuel and oxidizer valves, which control propellants for the forward vernier RCS jets only. The switch is spring-loaded in the *GPC* position. When the switch is moved to the *OPEN* posi-

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



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

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



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

same manner. The *AFT LEFT* and *AFT RIGHT RCS MANIFOLD 1, 2, 3, and 4* switches provide corresponding tank propellants to the applicable primary RCS jets or isolate the propellants from the jets. The *AFT LEFT* and *AFT RIGHT RCS MANIFOLD 5* switches provide corresponding tank propellants to the applicable vernier RCS jets or isolate the propellants from the jets.

RCS Crossfeed Valves

If either aft RCS pod's propellant system must be isolated from its jets, the other aft RCS propellant system can be configured to crossfeed propellant. The aft RCS crossfeed valves that tie the crossfeed manifold into the propellant distribution lines below the tank isolation valves can be configured so that one aft RCS propellant system can feed both left and right RCS jets. The aft RCS crossfeed valves are ac-motor-operated valve actuators and identical in design and operation to the propellant tank isolation valves. The aft RCS crossfeed valves are controlled by the *AFT LEFT* and *AFT RIGHT RCS CROSSFEED 1/2 and 3/4/5*

switches on panel O7. The positions of the four switches are *OPEN*, *GPC*, and *CLOSE*. The *GPC* position allows the orbiter computer to automatically control the crossfeed valves, and the *OPEN* and *CLOSE* positions enable manual control. The *OPEN* position of the *AFT LEFT RCS CROSSFEED 1/2 and 3/4/5* switches permits the aft left RCS to supply propellants to the aft right RCS crossfeed valves, which must be opened by placing the *AFT RIGHT RCS CROSSFEED 1/2 and 3/4/5* switches to the *OPEN* position for propellant flow to the aft right RCS jets. (Note that the *AFT RIGHT* receiving *RCS TANK ISOLATION 1/2 and 3/4/5 A and B* valves must be closed.) The *CLOSE* position of the *AFT LEFT* and *AFT RIGHT RCS CROSSFEED 1/2 and 3/4/5* switches isolates the crossfeed capability. The crossfeed of the aft right RCS to the left RCS would be accomplished by positioning the *AFT RIGHT* and *LEFT RCS CROSSFEED* switches to *OPEN* and positioning the *AFT LEFT RCS TANK ISOLATION 1/2 and 3/4/5 A, B* switches to *CLOSE*.

Helium System

Each RCS has two helium storage tanks, four helium isolation valves, four pressure regulators, two check valves, two relief valves, and servicing connections for draining and filling.

Helium Tanks

The two helium tanks in each RCS supply gaseous helium individually, one to the fuel tank and one to the oxidizer tank.

NOTE

The helium tanks provide ullage pressure for the propellant tanks. Each propellant tank has a specific quantity where, should the helium tank fail, the nominal ullage pressure would result in the maximum delta V. This quantity is referred to as max blowdown. Max blowdown for the forward RCS is 22 percent; for the aft RCS, it is 24 percent propellant quantity remaining.

Helium Isolation Valves

Two parallel helium isolation valves are located between the helium tanks and the pressure regulators in each RCS. When open, the helium isolation valves permit the helium source pressure to flow to the propellant tank. The helium isolation valves are controlled by the *FWD RCS He PRESS A* and *B* switches on panel O8 and the *AFT LEFT RCS He PRESS A* and *B* and *AFT RIGHT RCS He PRESS A* and *B* switches on panel O7. Each switch controls two helium isolation valves, one in the oxidizer helium line and one in the fuel helium line. The switch positions are *OPEN*, *GPC*, and *CLOSE*. When the switch is positioned to *GPC*, the pair of valves can be closed automatically upon

command from the orbiter computer. The *OPEN/CLOSE* positions permit manual control of that pair of valves.

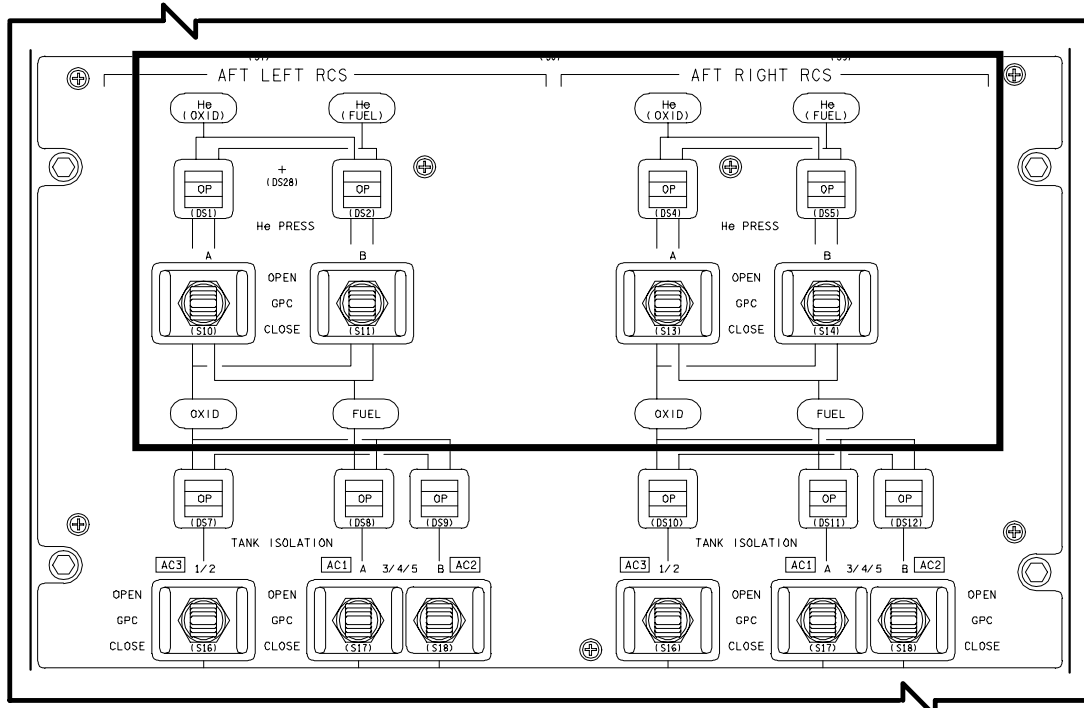
Electrical power is momentarily applied through logic in an electrical load controller assembly to energize the two helium isolation solenoid valves open and to magnetically latch the valves open. To close the two helium isolation valves, electrical power is momentarily applied through the load controller to energize a solenoid surrounding the magnetic latch of the two helium isolation valves, which allows spring and helium pressure to force the valve closed.

A position microswitch in each valve indicates valve position to an electrical controller assembly and controls a position indicator (talkback) above each switch on panels O7 and O8. When both valves (helium fuel and helium oxidizer) are open, the talkback indicates *OP*; when both valves are closed, the talkback indicates *CL*. If one valve is open, and the other is closed, the talkback indicates barberpole.

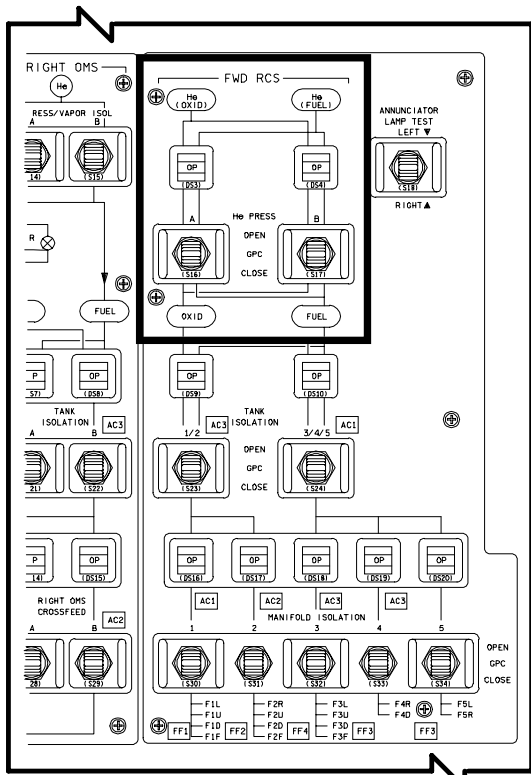
The RCS helium supply pressure is monitored on panel O3. When the rotary switch on panel O3 is positioned to *RCS He X10*, the forward and aft RCS helium pressures are displayed on the *RCS/OMS/PRESS OXID* and *FUEL* meters on panel O3.

Helium Pressure Regulators

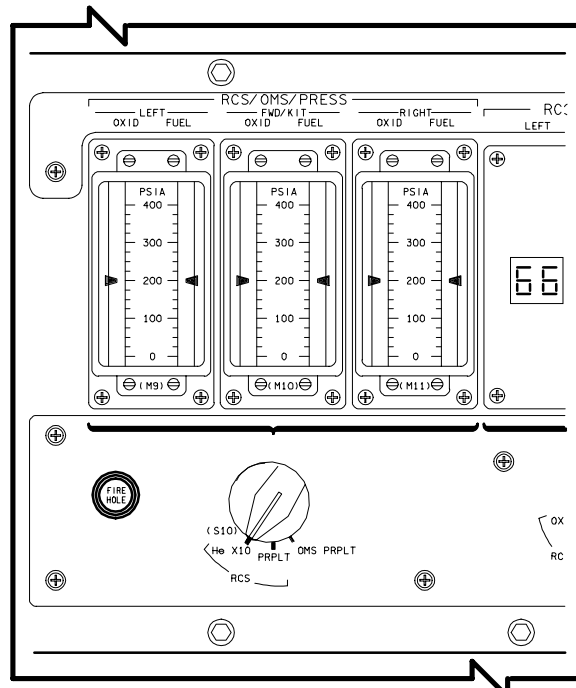
Helium pressure is regulated by two regulator assemblies, connected in parallel, downstream of the helium isolation valves. Each assembly contains two stages, a primary and a secondary, connected in series. If the primary stage fails open, the secondary stage regulates the pressure. The primary regulates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



AFT RCS He PRESS Switches and Talkbacks on Panel O7



FWD RCS He PRESS Switches and Talkbacks on Panel O8



RCS/OMS Meters and Rotary Switch on Panel O3 (Note: Information on these meters is the same as the information on SPEC 23 and BFS GNC SYS SUMM 2.)

Check Valves

The check valve assembly, which consists of four poppets in a series-parallel arrangement, is located between the pressure regulator assemblies and the propellant tank. The series arrangement limits the backflow of propellant vapor and maintains propellant tank pressure integrity in the event of an upstream helium leak. The parallel arrangement ensures the flow of helium pressure to the propellant tank if a series check valve fails in the closed position.

Pressure Relief Valve

A helium pressure relief valve assembly located between the check valve assemblies and propellant tank will vent excessive pressure overboard before it reaches the propellant tank. Each valve consists of a burst diaphragm, filter, and relief valve. The non-fragmentation diaphragm, which provides a positive seal against helium leakage, will rupture between 324 and 340 psig. The filter prevents any particles of the burst diaphragm from reaching the relief valve seat. The relief valve relieves at 315 psig minimum and reseats at 310 psig. The relief valve is sized to handle, without damaging the propellant tank, helium pressure flow volume if a regulator malfunctions to a full-open position.

Thermal Control

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

Each primary RCS jet has a 20-watt heater, except the four aft-firing jets, which have 30-watt heaters. Each vernier RCS jet has a 10-watt heater.

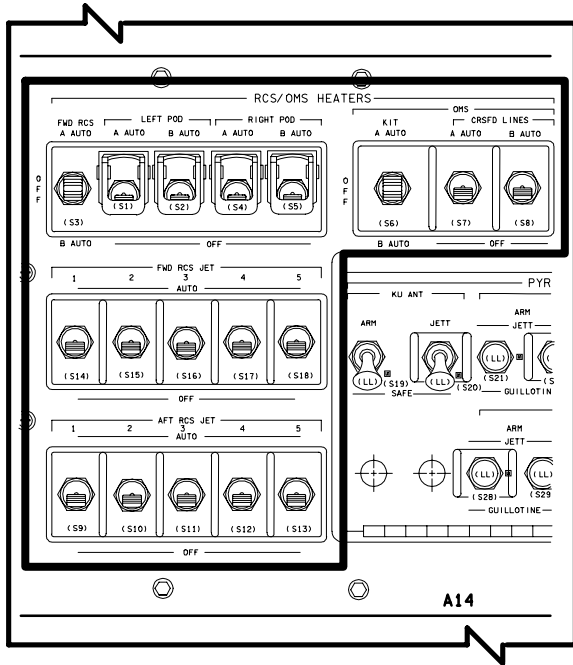
The forward RCS has six heaters mounted on radiation panels in six locations. Each OMS/RCS pod is divided into nine heater zones. Each zone is controlled in parallel by an

A and B heater system. The aft RCS jet housing contains heaters for the yaw, pitch up, pitch down, and vernier jets in addition to the aft OMS/RCS drain and purge panels.

The forward RCS panel heaters are controlled by the *FWD RCS* switch on panel A14. When the switch is positioned to *A AUTO* or *B AUTO*, thermostats on the forward left-side panel and right-side panel automatically control the respective forward RCS heaters. When the respective forward RCS panel temperature reaches a minimum of approximately 55° F, the respective panel heaters are turned on. When the temperature reaches a maximum of approximately 75° F, the heaters are turned off. The *OFF* position of the switch removes all electrical power from the forward RCS heaters.

The aft RCS heaters are controlled by the *LEFT POD A AUTO* and *B AUTO* and *RIGHT POD A AUTO* and *B AUTO* switches on panel A14. When the switches are positioned to either *A AUTO* or *B AUTO*, thermostats automatically control the nine individual heater zones in each pod. Each heater zone is different, but generally the thermostats control the temperature between approximately 55° F minimum to approximately 75° F maximum. The *OFF* position of the respective switch removes all electrical power from that pod heater system.

The forward and aft RCS primary and vernier jet heaters are controlled by the *FWD* and *AFT RCS JET 1, 2, 3, 4, and 5* switches on panel A14. When the switches are positioned to *AUTO*, individual thermostats on each jet automatically control the individual heaters on each jet. The primary RCS jet heaters turn on between approximately 66° to 76° F, and they turn off between approximately 94° to 109° F. The vernier RCS jet heaters turn on between approximately 140° to 150° F and off between approximately 184° to 194° F. The *OFF* position of the switches removes all electrical power from the jet heaters. The 1, 2, 3, 4 and 5 designations refer to propellant manifolds. There are two to four jets per manifold.



RCS/OMS HEATERS Switches on Panel A14

RCS Redundancy Management

RCS redundancy management (RM) software includes RCS jet failure detection and annunciation, jet availability, SPEC 23 RCS, SPEC 51 BFS OVERRIDE, and manifold status processing.

Jet failure modes detected and annunciated are fail-off, fail-on, and fail-leak. Fault annunciation is a class 2 alarm consisting of a master alarm, illumination of the yellow *RCS JET* and red *BACKUP C/W ALARM* lights on panel F7, and a fault summary message (F (L,R) RCS A (D, R, U) JET).

All statuses, flags, counters, and related RCS RM data are carried across OPS transitions. However, when BFS is engaged, all flags, statuses, and counters are cleared and reinitialized.

The jet parameters used in RM are the Pc discrete, CMD B, driver out discrete, and the oxidizer and fuel injector temperatures. Pc discrete is turned on when the jet chamber pressure reaches 36 psi and remains on until the chamber pressure falls below 26 psi. Individual fail detection and response parameters are as follows.

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

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

JET	FAIL	DES INH	JET DES	PTY
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
HE	P 3376	3360
PRPLT TK	P 247	250
	T 77	79
	QTY 90	91
MANF P	1 242	246
	2 250	246
	3 248	248
	4 246	242
MANF VLV	STAT	OVRO
	1 OP	40
	2 OP	41
	3 OP	42
	4 OP	43
	5 OP	44
XFEED	P 254	254
JET RESET	45	

SPEC 23 RCS Display

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

ABORT MODE	1	ELEVON	17*	ENTRY FCS	1	ATMOSPHERE	22*
ATO	2	AUTO	18	FILTER	20*	NOM	23
ABORT	3	FIXED	19	NOM	21	N POLE	24
MAX THROT	4	SSME REPOS	19	ENA	22	S POLE	24
PROPLT DUMP		IMU DES ATT		AA	1	RGA SURF	
		1 25	2	LRU DES	DES	DES	
INH ICNCT	5	2 26	1	31	35	39	
OMS DUMP		3 27	2	32	36	40	
ARM	6		3	33	37	41	
START	7		4	34	38	42	
STOP	8						
9 QUAN/SIDE	041						
OMS DUMP TTG	227						
AFT RCS	13	INH	AUTO	28	ROLL MODE		
14 TIME	000		SEP	29	WRAP MODE	45	
FWD RCS	15	INH	ET UMB DR		VENT DOOR CNTL		
16 TIME	000		CLOSE	30	OPEN	43	
					CLOSE	44	

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.

678

741b

Jet Fail-On

Detection:

- Driver out discrete is present when a CMD B is not issued for three consecutive cycles.
- RM is suspended for an MDM or LRU commfault.
- RM is unable to detect a fail-on jet when the driver out discrete is failed low.

RM Response:

- Fail-on flag is set.
- Message is annunciated.

temperature limit for three consecutive cycles.

- RM is suspended for an MDM or LRU commfault.
- RM is unable to detect a fail-leak jet for a failed-high temperature transducer.
- A failed-low injector temperature transducer will trip RM.

RM Response:

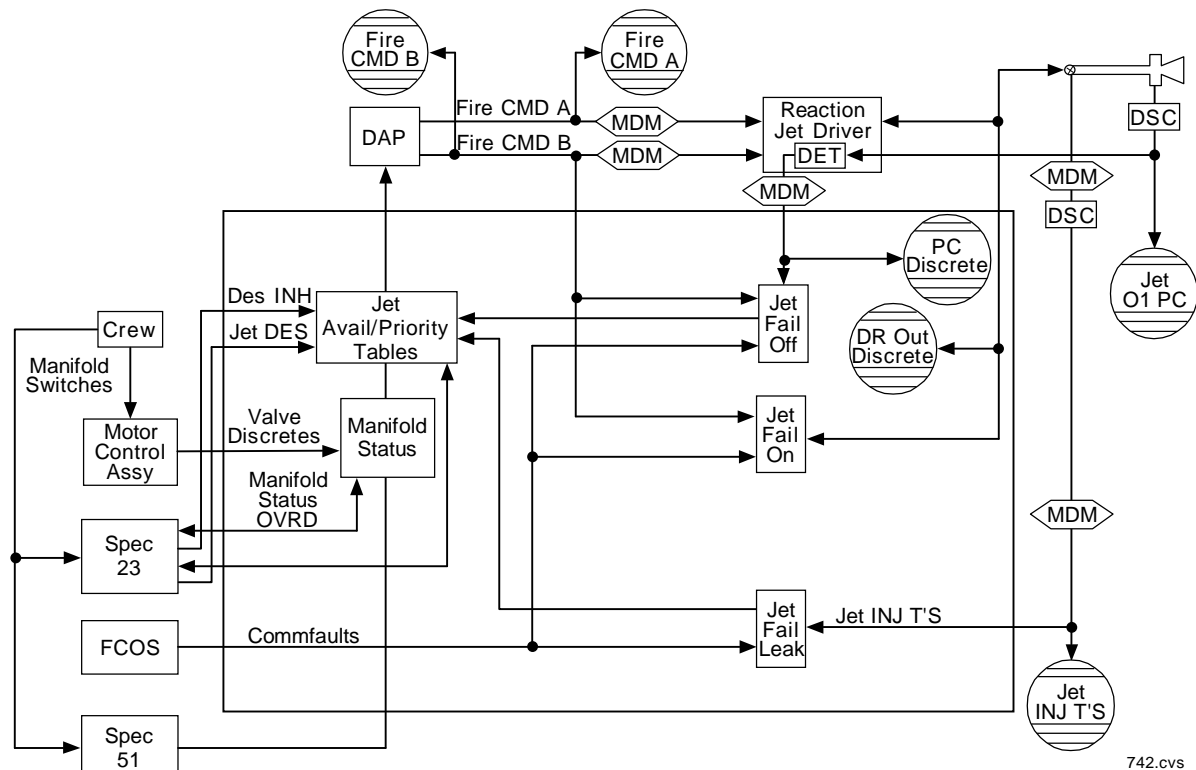
- Fail-leak flag is set.
- Message is annunciated.
- Jet is deselected unless the pod limit has been reached.

Jet Fail-Leak

Detection:

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

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



RCS Redundancy Management Schematic

Nomenclature

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

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

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

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

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

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

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

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

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

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

Deselection Candidate — Any jet that is annunciated fail-off or fail-leak by RCS RM becomes a deselection candidate, unless the jet has been deselect inhibited.

Jet Availability Table — An array that contains a bit for each jet. The bit is on if the associated jet is available and may be commanded to fire

by DAP. The bit is off when the jet is not available as determined by RCS RM. Unavailable jets will not be commanded to fire.

Jet Pod Counter and Pod Limit

RCS SPEC 23 displays the PRI JET FAIL LIM. This limit is the number of primary jets that RCS RM will deselect for the pod (forward, left, or right) currently displayed on SPEC 23. This number is I-loaded to 2 and can be changed via SPEC 23.

RCS RM will auto-deselect primary jets until the pod counter equals the pod limit. RM will continue to annunciate all jet failures not previously annunciated when the pod counter is full; however, no new jets will be auto-deselected.

Manually reselecting an auto-deselected jet will reduce the pod counter by one. Manually reselecting a jet that was manually deselected via SPEC 23 will not have an impact on the pod counter.

The pod counter is not affected by subsequent jet failures on a previously deselected jet. Decreasing the pod limit does not reselect jets. If the pod limit is at two, and two jets are currently auto-deselected, changing the limit to one will not reselect one of the auto-deselected jets.

Once a jet is annunciated fail-off or fail-leak, that jet is a deselection candidate. Assume the pod limit is two. If the pod counter is full, and a third (or more) jet becomes a deselect candidate, this jet will not be auto-deselected, as expected. If one of the jets on the same pod is then manually reselected, the pod counter is decremented to one, also as expected. However, the deselection candidate that could not previously be auto-deselected since the pod counter was at the limit will now be auto-deselected, and the pod counter will be incremented to two again. All deselect candidates remain “deselectable” until their fail-flags are cleared.

RCS Manifold RM

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

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

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

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

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

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

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

RCS RM Manifold Dilemma

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

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

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

RM Response — Issue “RCS RM DLMA” message.

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

RCS Manifold Power Fail

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

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

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

Forward manifold 3 microswitches are redundantly powered by MN A FPC1 and MN C FMC3. Forward manifold 4 microswitches are powered only by MN C FMC3. Both MN A FPC1 and MNC FMC3 must be lost for RCS RM to issue a power fail for this manifold pair. Because of the low probability of this case, forward manifold 3/4 power fails are rarely detected. However, for the loss of MN C FMC3, an “RCS RM DLMA” message is annunciated, FRCS manifold 4 is declared closed, and the associated jets are declared unavailable.

Jet Selection

The DAP jet-select module contains default logic in certain instances. When the orbiter is mated to the ET, roll rate default logic inhibits roll rotation, and yaw commands are normally in the direction of favorable yaw-roll coupling. During insertion, a limit of seven aft RCS jets per tank set applies for ET separation and for return-to-launch-site aborts. If negative Z and plus X translation commands are commanded simultaneously, both will be degraded. A limit of four aft RCS jets per tank set normally applies. If plus X and negative Z translations are commanded simultaneously, plus X is given priority. Multi-axis translation and rotation commands may require more jets than allowed and result in degraded control and excessive propellant usage.

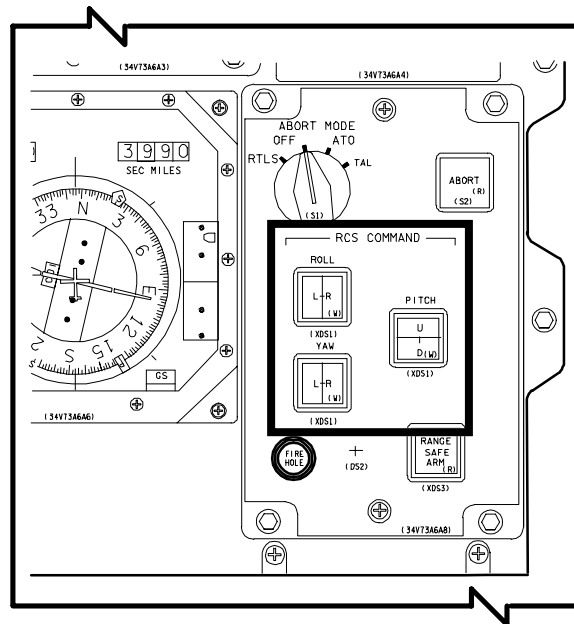
The DAP jet-select module determines which aft RCS jets (right, left, or both) must be turned on in response to the pitch, roll, and yaw jet commands from the entry flight control system. The forward RCS jets are not used during entry. After entry interface, only the four Y-axis and six Z-axis RCS jets on each aft RCS pod are used. No X-axis or vernier jets are used. The DAP sends the discretes that designate which aft RCS jets are available for firing (a maximum of four RCS jets per pod may be fired). During reconfiguration, or when the RCS crossfeed valves are open, the DAP determines the maximum combined total number of yaw jets available during certain pitch and roll maneuvers.

During ascent or entry, the DAP jet-select logic module in the flight control system receives both RCS rotation and translation commands. By using a table lookup technique, the module outputs 38 jet on/off commands to the RCS command subsystem operating program, which then generates dual fire commands A and B to the individual RCS reaction jet drivers to turn each of the 38 primary RCS jets on or off. The fire commands A and B for each of the 38 primary RCS jets are set equal to the digital autopilot RCS commands. Commands are issued to the six RCS vernier jets similarly on orbit.

Jet Fire Indications

ROLL, *PITCH*, and *YAW* white indicator lights on panel F6 indicate the presence of an RCS command during orbit and early entry. The indicators are *L* and *R* for roll and yaw left or right and *U* and *D* for pitch up and down.

From entry interface until the dynamic pressure is greater than 10 pounds per square foot, the *ROLL L* and *ROLL R* lights indicate that left or right roll commands have been issued by the digital autopilot. The minimum light-on duration is extended to allow the light to be seen even for a minimum impulse firing. When a dynamic pressure of 10 pounds per square foot has been sensed, neither *ROLL* light will be illuminated until 50 pounds per square foot has been sensed, and more than two RCS yaw jets are commanded on.



Jet Fire Indicator Lights on Panel F6

The *PITCH* lights indicate up and down pitch jet commands until a dynamic pressure of 20 pounds per square foot is sensed, after which the pitch jets are no longer used. When 50 pounds per square foot is sensed, the *PITCH* lights assume a new function. Both *PITCH* lights will be illuminated whenever the elevon surface drive rate exceeds 20° per second (14° per second if only one hydraulic system is remaining).

The *YAW* lights function as yaw jet command indicators throughout entry until the yaw jets are disabled at Mach 1 (approximately 45,000 feet). The *YAW* lights have no other function.

Operations

After main engine cutoff, the forward and aft jets are used to maintain attitude hold until external tank separation. Then the RCS provides a negative Z translation maneuver of about 4 feet per second to move the orbiter away from the external tank. Upon completion of the maneuver, the RCS holds the orbiter attitude until it is time to maneuver to the OMS-2 burn attitude. Although the targeting data for the OMS-2 burn are selected before launch, the target data in the onboard general-purpose computers can be modified by the flight crew via the CRT and keyboard, if necessary, before the OMS burn.

The OMS-2 burn uses both OMS engines to raise the orbiter to a predetermined circular orbit. (OMS-1 burns are only planned for standard insertions.) During the OMS-2 burn, vehicle attitude is maintained by gimbaling (swiveling) the OMS engines. The RCS normally does not operate during an OMS burn. If, during an OMS burn, the gimbal rate or gimbal limits are exceeded, RCS roll control would be required; or if only one OMS engine is used during a burn, RCS roll control may be required.

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

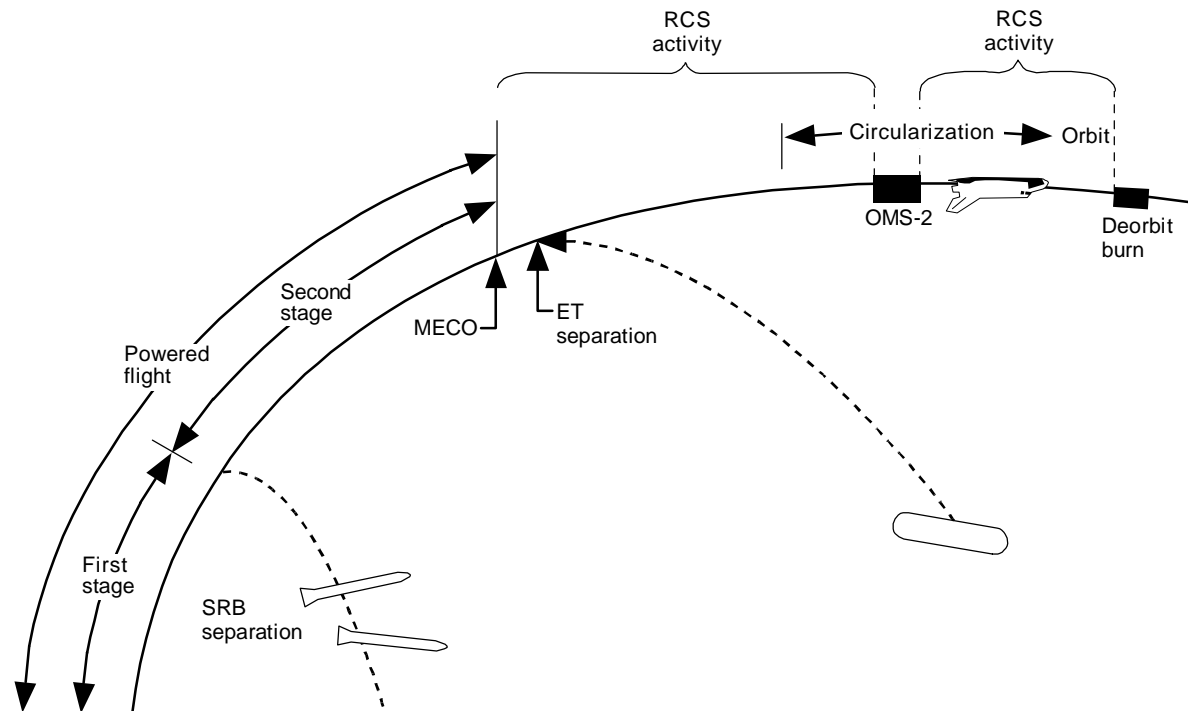
On orbit, the vernier jets are used for fine attitude control, and the primary jets are used for coarse attitude control and minor translations.

Before the deorbit burn, the flight crew maneuvers the spacecraft to the desired attitude

using RCS jets. After the OMS burn, the RCS is used to null any residual velocities, if required. The spacecraft is then maneuvered to the proper entry interface attitude using the RCS. The remaining propellants aboard the forward RCS may be dumped by burning the propellants through the forward RCS yaw jets before entry interface if orbiter center-of-gravity control is necessary.

The RCS aft (+ X) jets can be used to complete any OMS deorbit burn if an OMS engine fails. In this case, the OMS-to-aft-RCS interconnect can be used to feed OMS propellant to the aft RCS.

From an entry interface of 400,000 feet, the orbiter is controlled in roll, pitch, and yaw with the aft RCS jets. The orbiter's ailerons are used starting at a dynamic pressure (q -bar) of 2 pounds per square foot (psf), and the aft RCS roll jets are deactivated at a q -bar of 10 psf. At a q -bar of 2 psf, the orbiter's elevons are active, and the aft RCS pitch jets are deactivated at a q -bar of 40 psf. The rudder is activated at Mach 5.0, and the aft RCS yaw jets are deactivated at Mach 1 (approximately 45,000 feet).



744.cvs

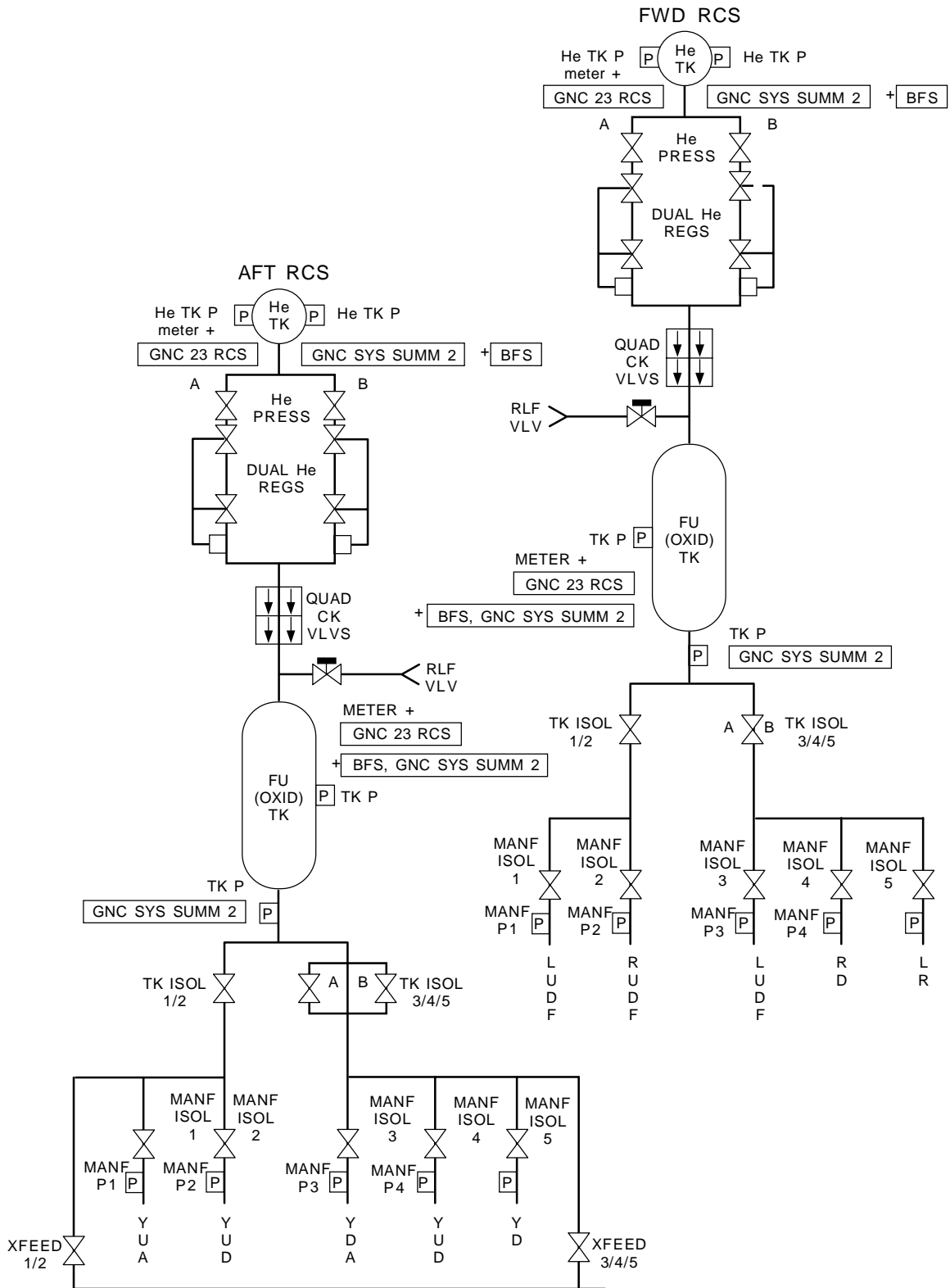
Nominal Ascent Profiles

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	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

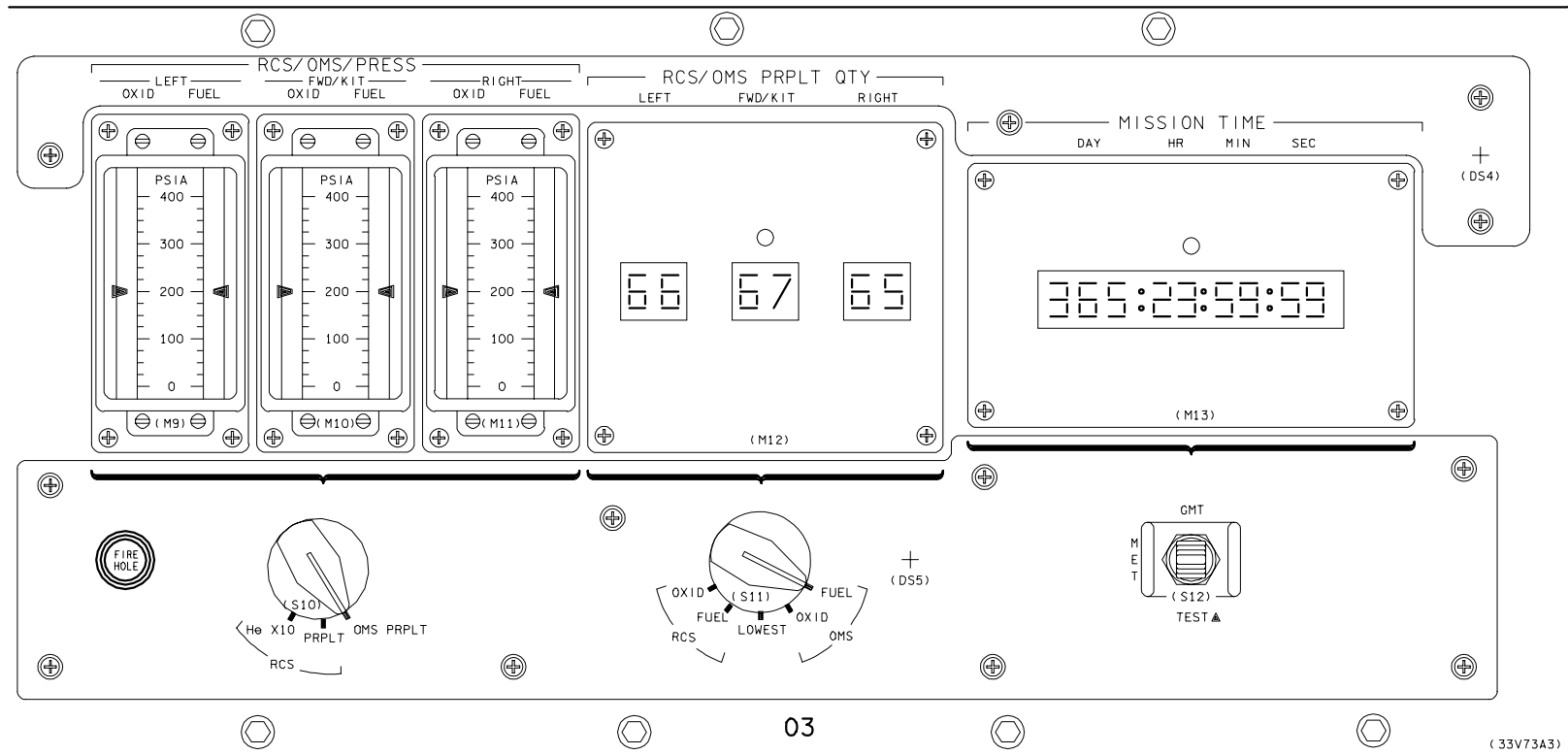
RCS Caution and Warning Lights on Panel



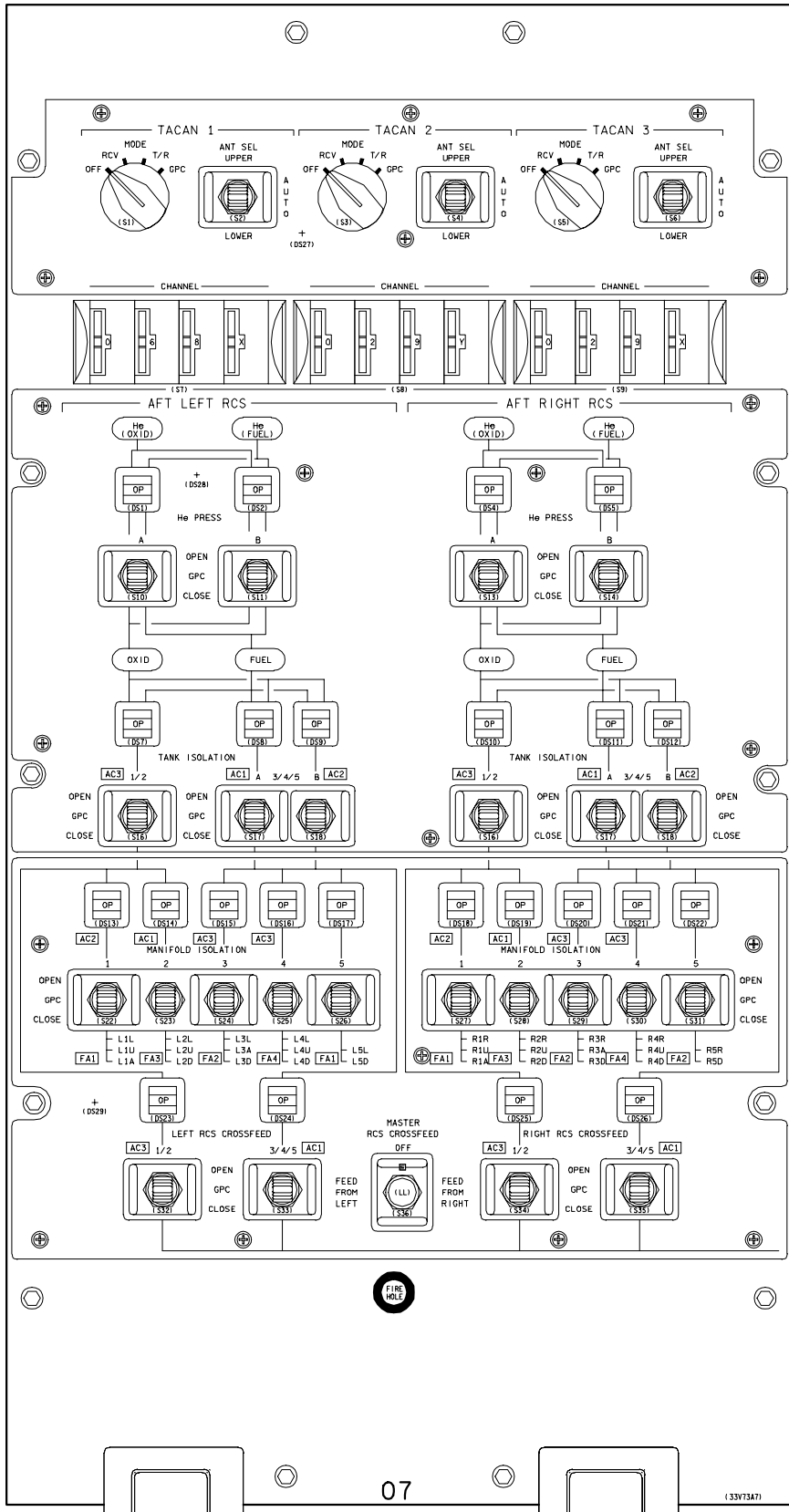
F7

746.cvs

Reaction Control System

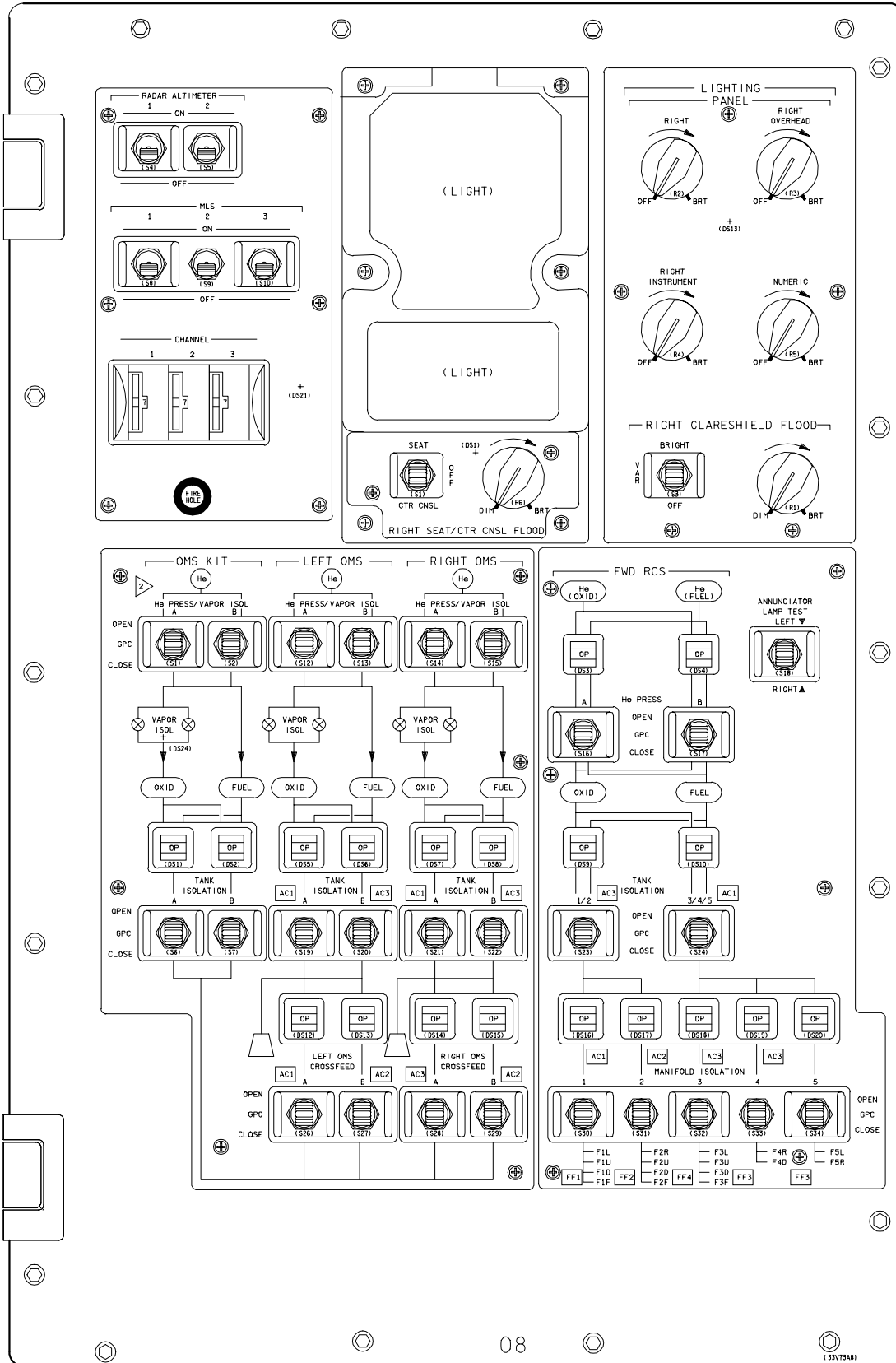


Panel O3

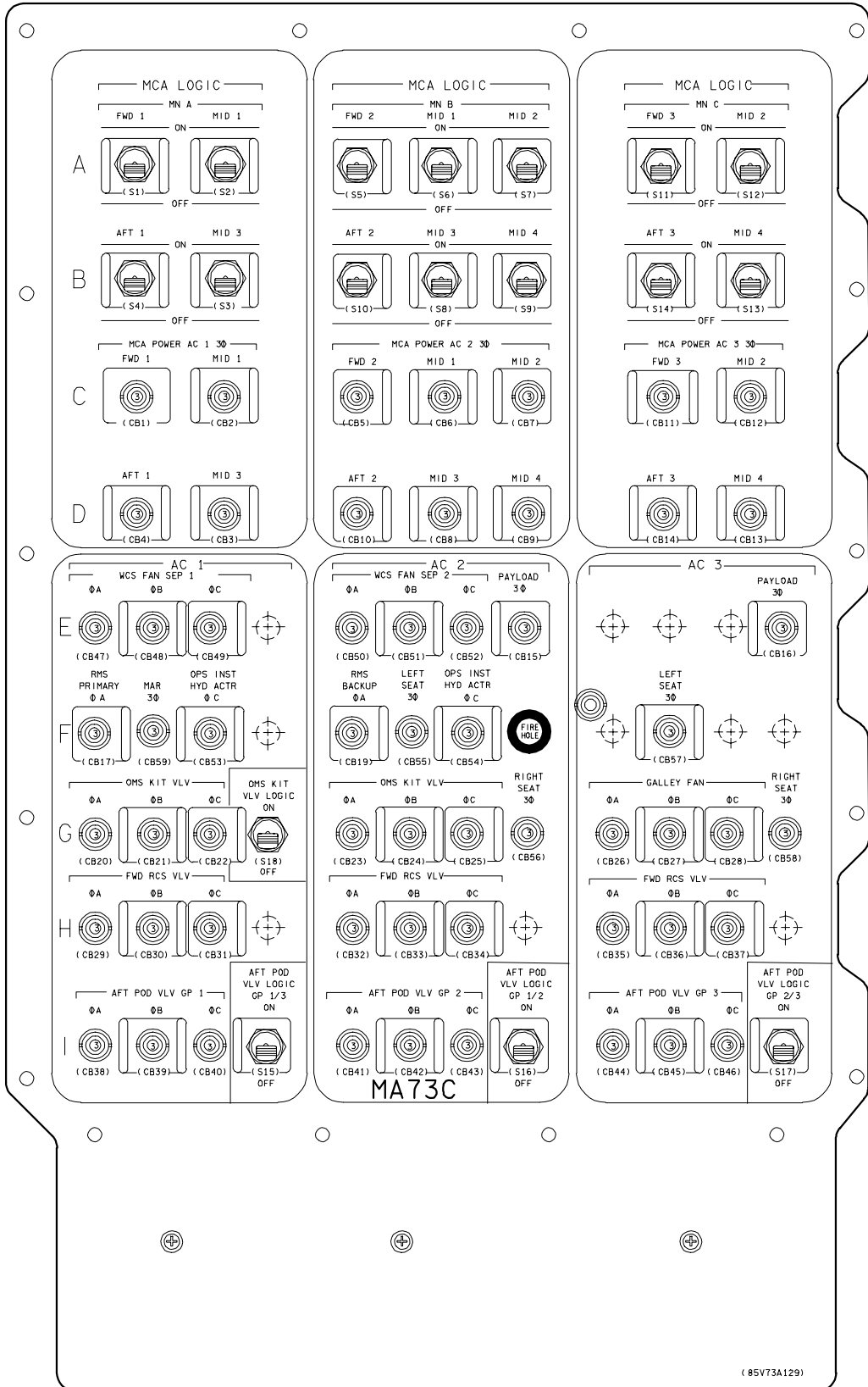


Panel O7

(33V7347)

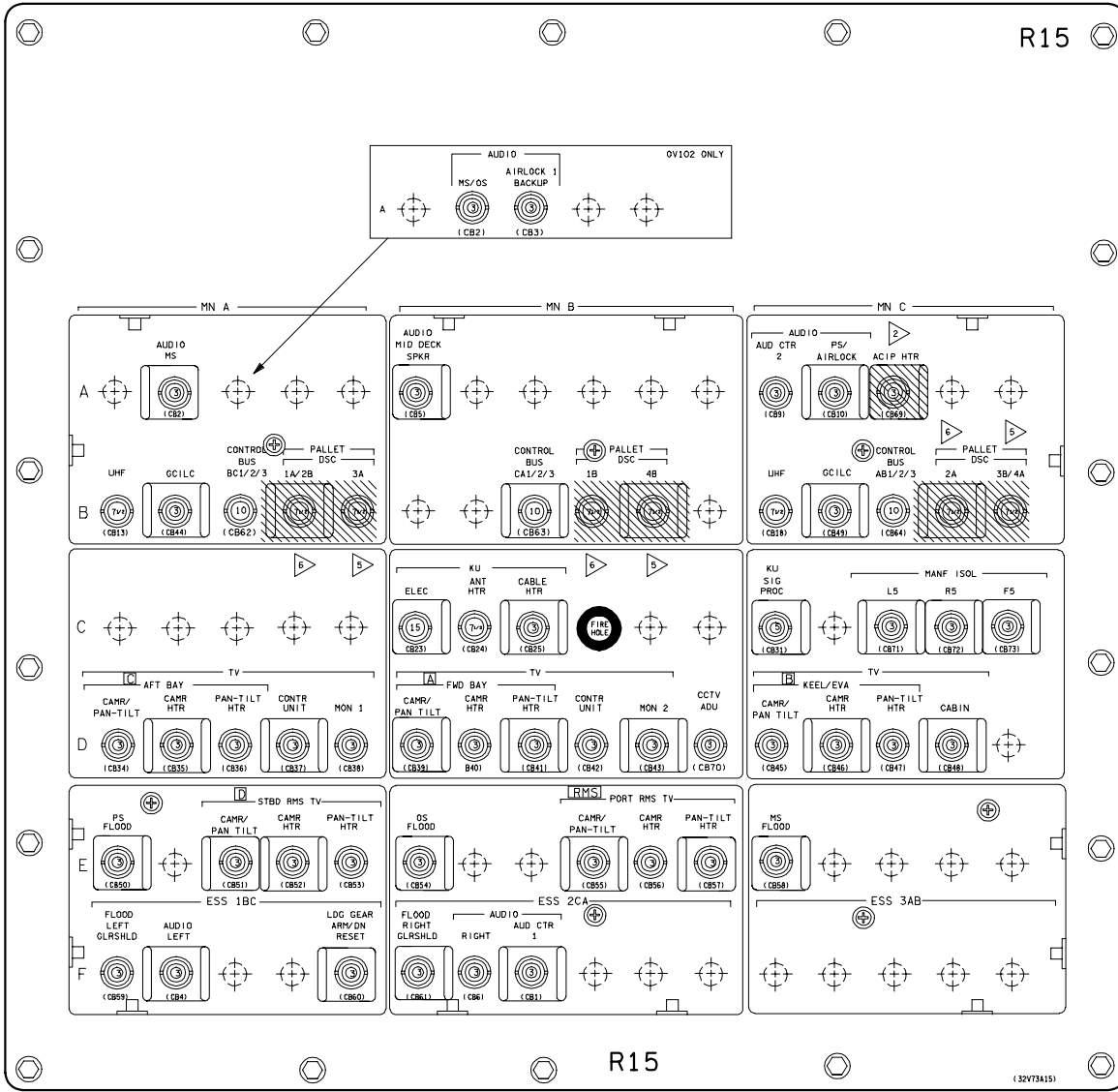


Panel O8



Panel MA73C

(85V73A129)



Panel R15

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 OXID 258 258
FU 30.2 30.2 FU 260 260

RCS	OXID	FU	JET	ISOL	FAIL	VLV
FWD HE	P3048	2968				
TK P	247	248				
QTY	67	67				
MANF	1 P	248	242			
	2 P	248	246			
	3 P	250	246			
	4 P	246	246			
	5					
AFT HE	P3200	3144				
L TK P	245	249				
QTY	82	83				
MANF	1 P	246	246			
	2 P	246	250			
	3 P	250	250			
	4 P	246	250			
	5					

N2 TK P 2260 2260
REG P 324 324
P VLV CL CL
ENG IN P
OXID 258 258
FU 260 260
VLV 1 - 3 0
2 0 - 2

HE	P	OXID	FU	JET	ISOL	FAIL	VLV
R TK P	251	249					
QTY	84	84					
1 P	242	246					
2 P	250	246					
3 P	246	258					
4 P	246	242					
5							

734

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 OMS=RCS QTY
R 3* R OMS 6 L 0.00
OFF 7* R 0.00

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

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

678

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 form the operating valve.

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2.21 SPACELAB

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Description

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

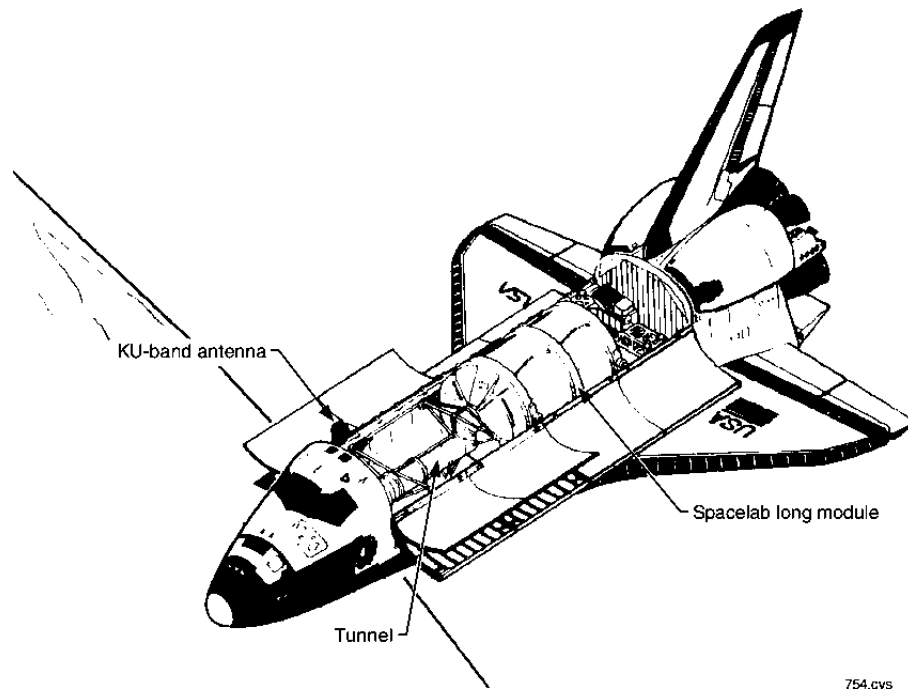
Several terms that delineate crew roles and responsibilities on Spacelab flights are described below.

Payload Commander

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

Mission Specialist

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



Spacelab On Orbit

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

Science Mission Specialist

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

Payload Specialist

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

Space Flight Participant

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

Crew

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

Flight Crew

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

Payload Crew

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

Spacelab Mission Summary

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

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

Spacelab Flights to Date

NOTE

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

Module

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

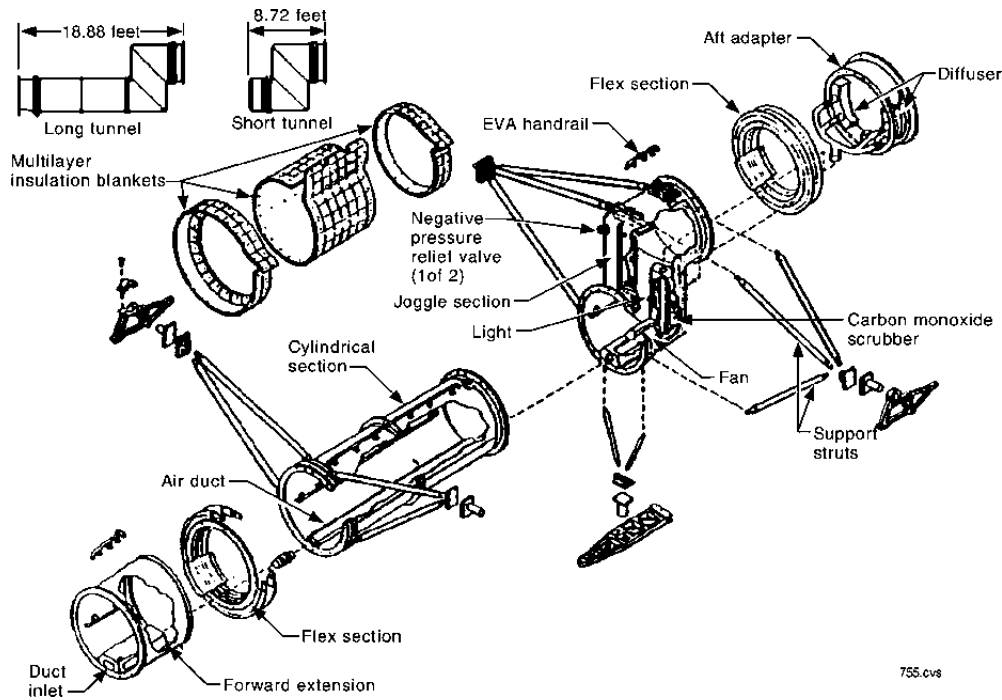
The module is structurally attached to the orbiter payload bay by four attach fittings consisting of three longeron fitting sets (two primary and one stabilizing) and one keel fitting. Because of the orbiter's center-of-gravity requirements, the module cannot be installed at the forward end of the payload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

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

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

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

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



Spacelab Transfer Tunnel

Pallet

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

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

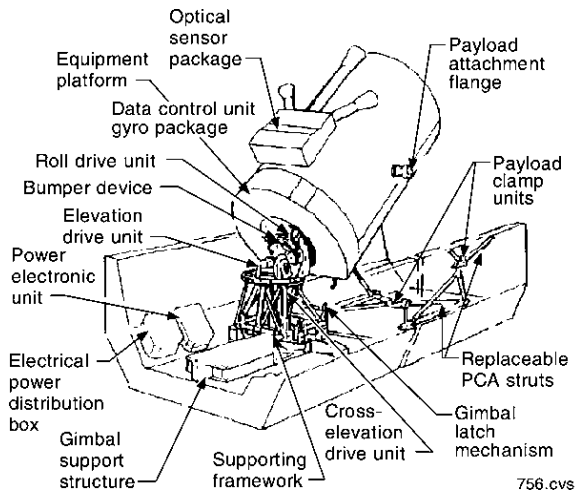
joints are used to connect the pallets to form a single rigid structure called a pallet train. Twelve joints are used to connect two pallets.

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

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

Instrument Pointing Subsystem (IPS)

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



Instrument Pointing System

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

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

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

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

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

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

Flight Deck Interfaces

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

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

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

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

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

Electrical Power

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

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

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

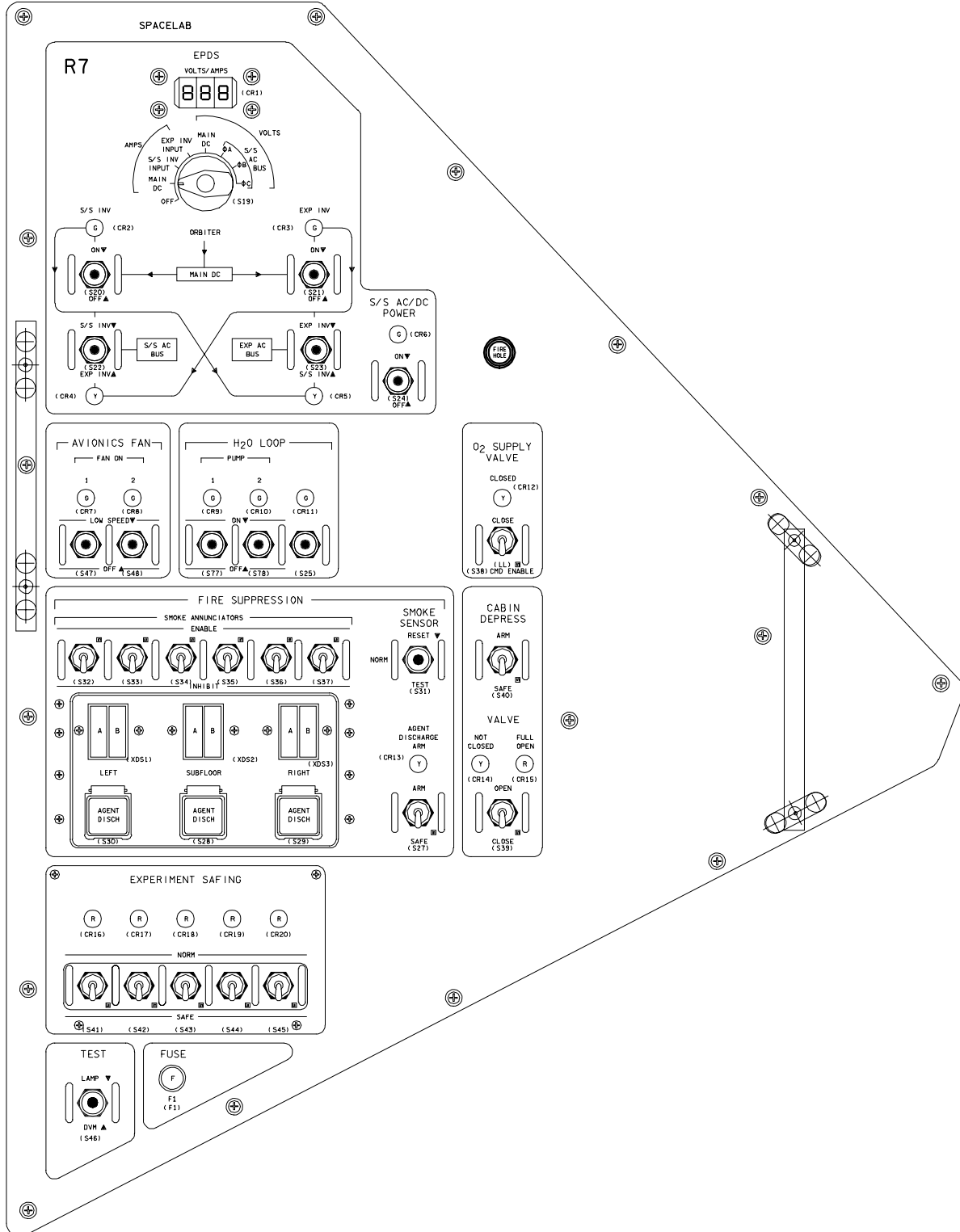
rotary switch to the MAIN DC position, and the amperage reading is obtained by setting the AMPS segment to the MAIN DC position. The R2D meter has only colored zones to indicate nominal (green) or off-nominal (red) readings. The AMP readout for main dc power has an additional color field (yellow) to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

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

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

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

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



Panel R7

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

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

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

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

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

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

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

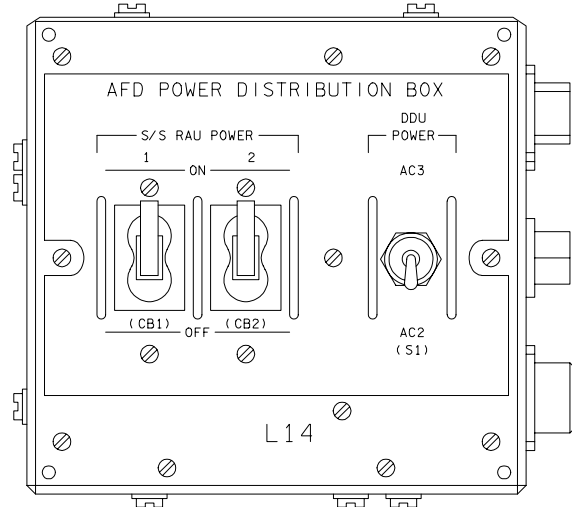
Emergency and essential dc power for the module configuration is provided by the orbiter auxiliary payload buses A and B to the Spacelab emergency box. The Spacelab emergency box supplies emergency and essential power for Spacelab critical environmental control subsystem sensors and valves, fire and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

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

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

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

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



Panel L14

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

Command and Data Management System

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

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

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

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

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

Mass Memory Unit (MMU)

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

Data Display Systems

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

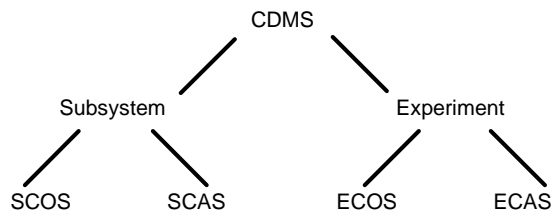
and the crew. Each DDS consists of a PGSC, an interface unit, and DDS emulation software. In a module configuration, one DDS is located in the orbiter aft flight deck station (L11), one in the control center rack in the module, and, possibly, one in an experiment rack in the module. In the pallet-only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

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

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

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

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



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

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

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

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

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

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

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

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

Closed-Circuit Television (CCTV)

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

Module Intercom

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

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

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

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

Module Environmental Control and Life Support (ECLS)

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

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

Gaseous oxygen enters the module through the lower feedthrough plate in the Spacelab forward end cone at 100 psi and a maximum flow rate of 7 pounds per hour (nominal 0.5 lbs/hr). A motor-controlled valve in the module controls the flow of gaseous oxygen. This valve, operated by Spacelab RAU commands, opens when the O₂ 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 GN₂ tank is pressurized to approximately 2300 psi. The GN₂ 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 O₂/N₂ control panel regulate the air pressure in the cabin to 14.7 psi. This system also utilizes PPO₂ measurements to maintain the proper balance of O₂ and N₂ 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 the orbiter payload MDMs are available for

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 (R)	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 (R)	LEFT OMS (R)	RIGHT OMS (R)
[REDACTED]	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
	PRIMARY C/W	FCS CHANNEL	MPS (R)	—
	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

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Payload Caution and Warning Lights on Panel F7

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.

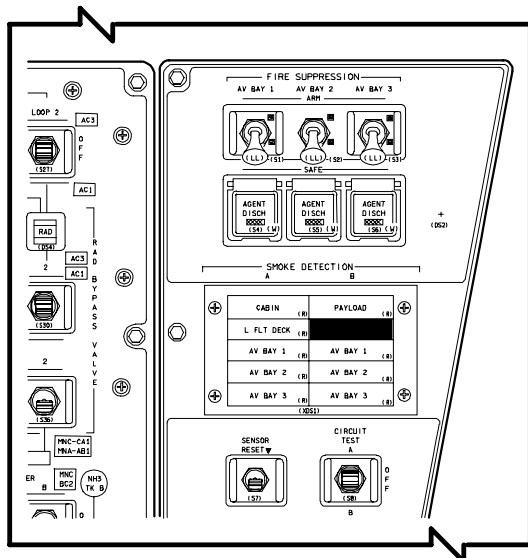
Emergency Conditions

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



Payload Fire/Smoke Detection Light on Panel L1

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.

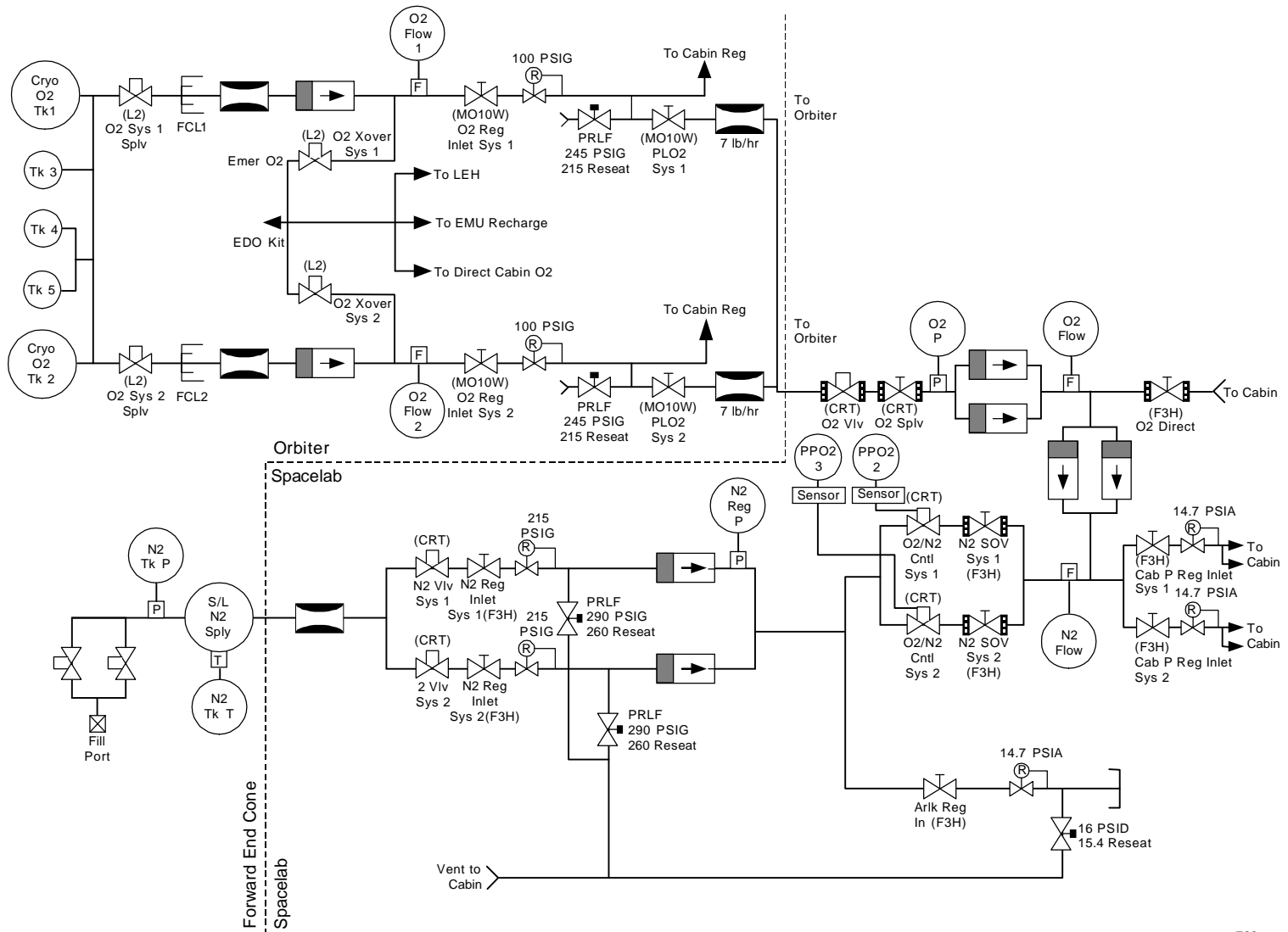
Pallet-Only Environmental Control Subsystem

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.

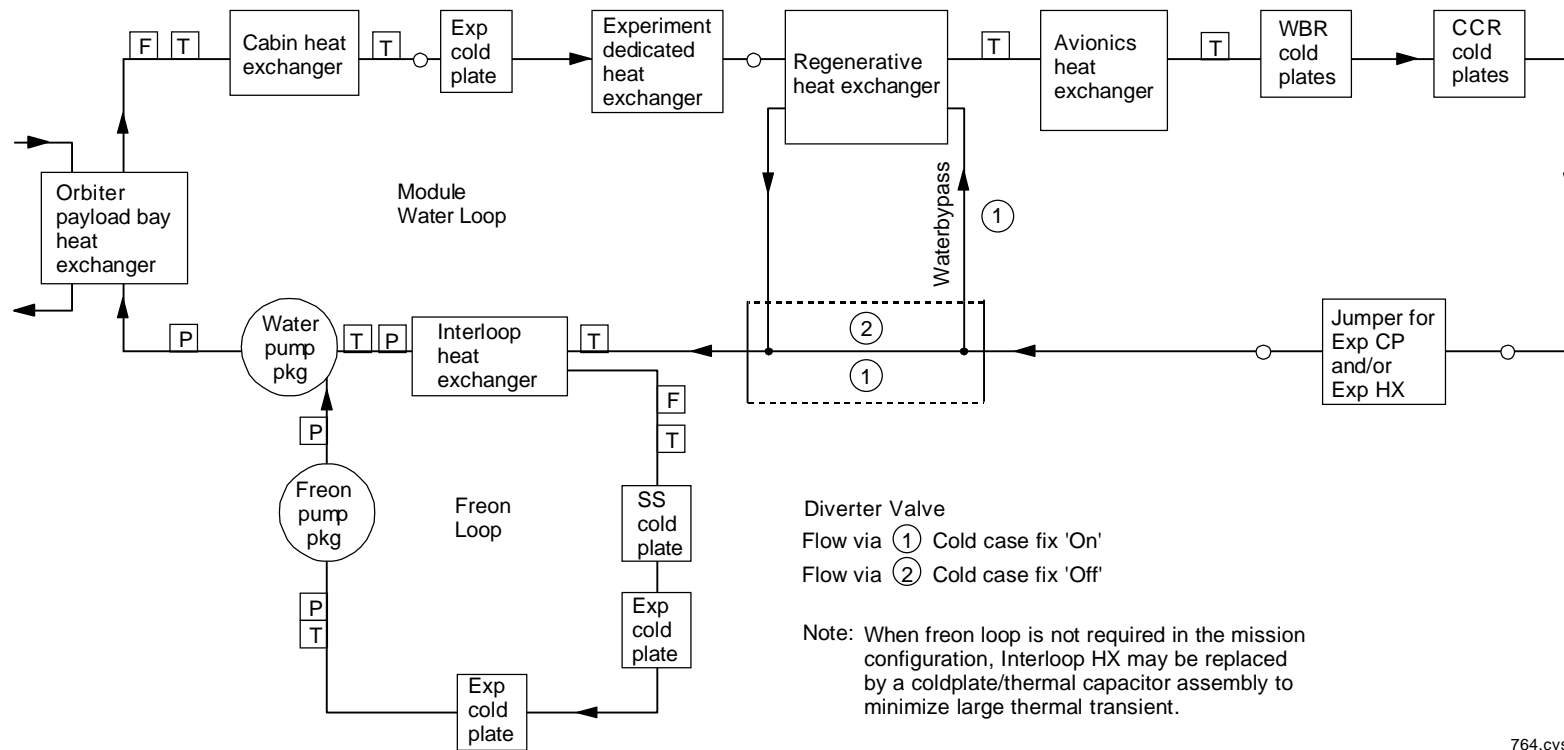
The subsystem equipment mounted in the igloo is also serviced by the Freon loop, which interfaces directly with the orbiter's payload heat exchanger. The Freon pump package is mounted on the front frame of the first pallet (forward) in the orbiter payload bay. Thermal coatings are applied to minimize 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.

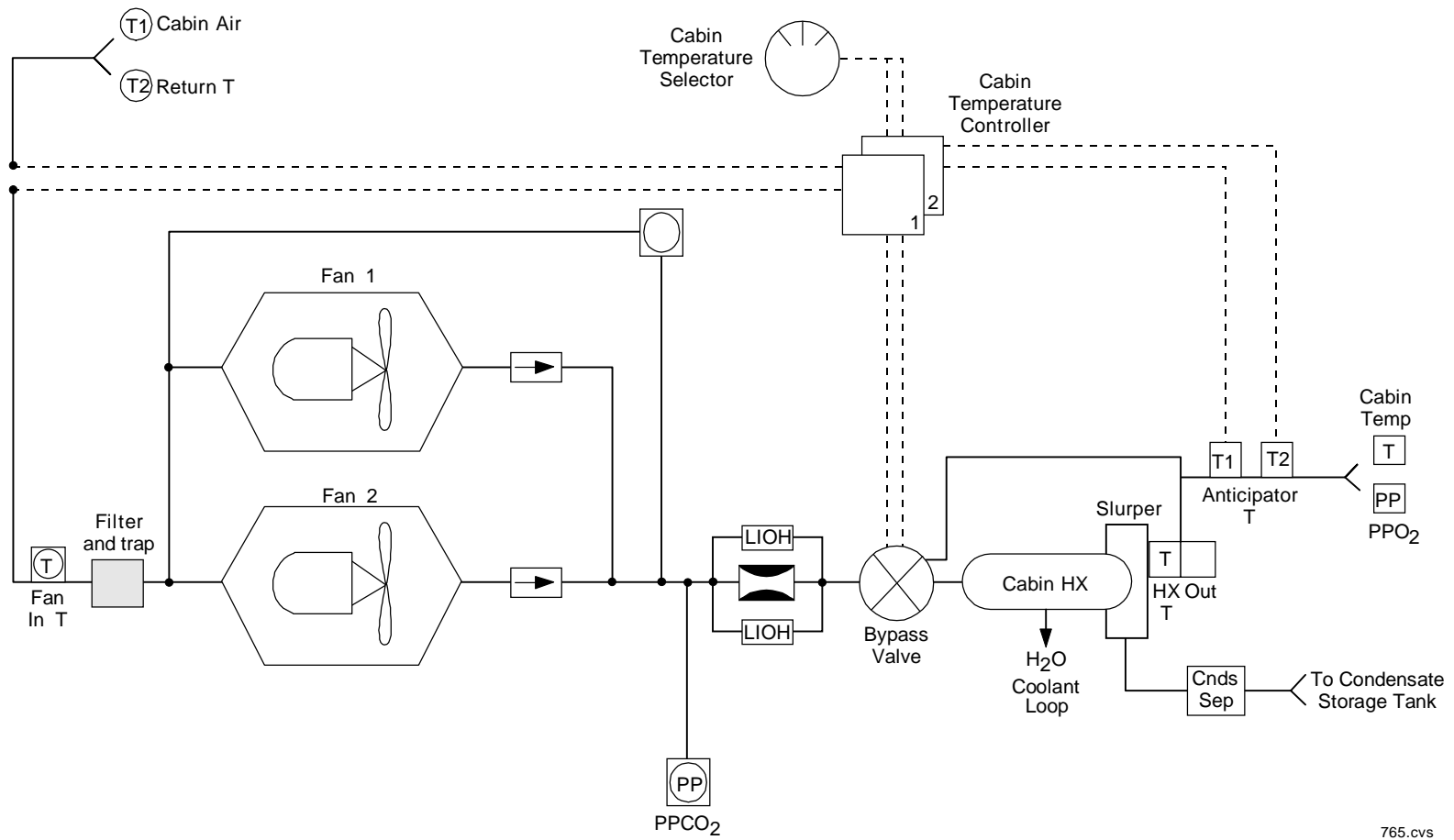


ECLS Spacelab/Orbiter Interface

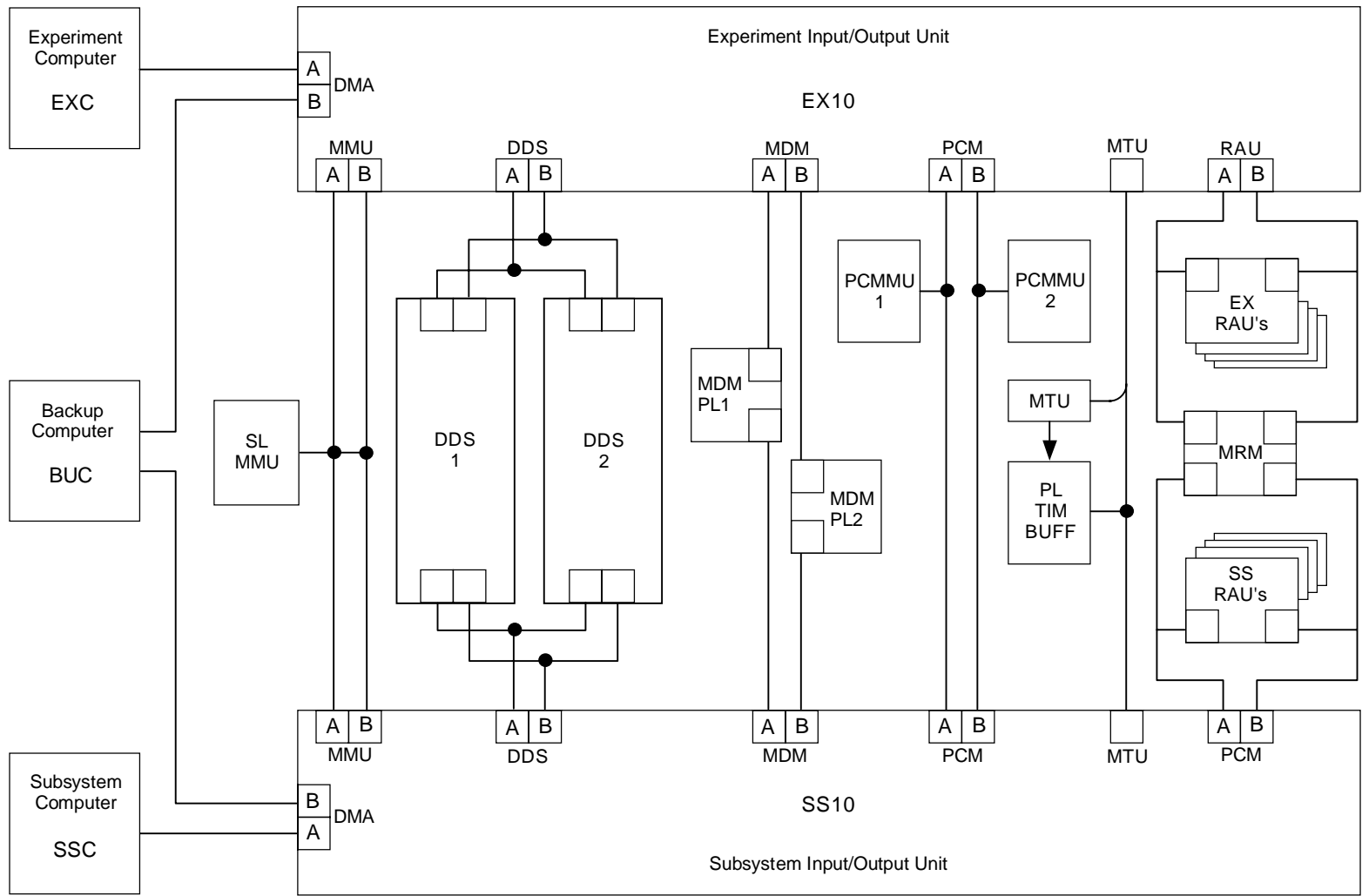


764.cvs

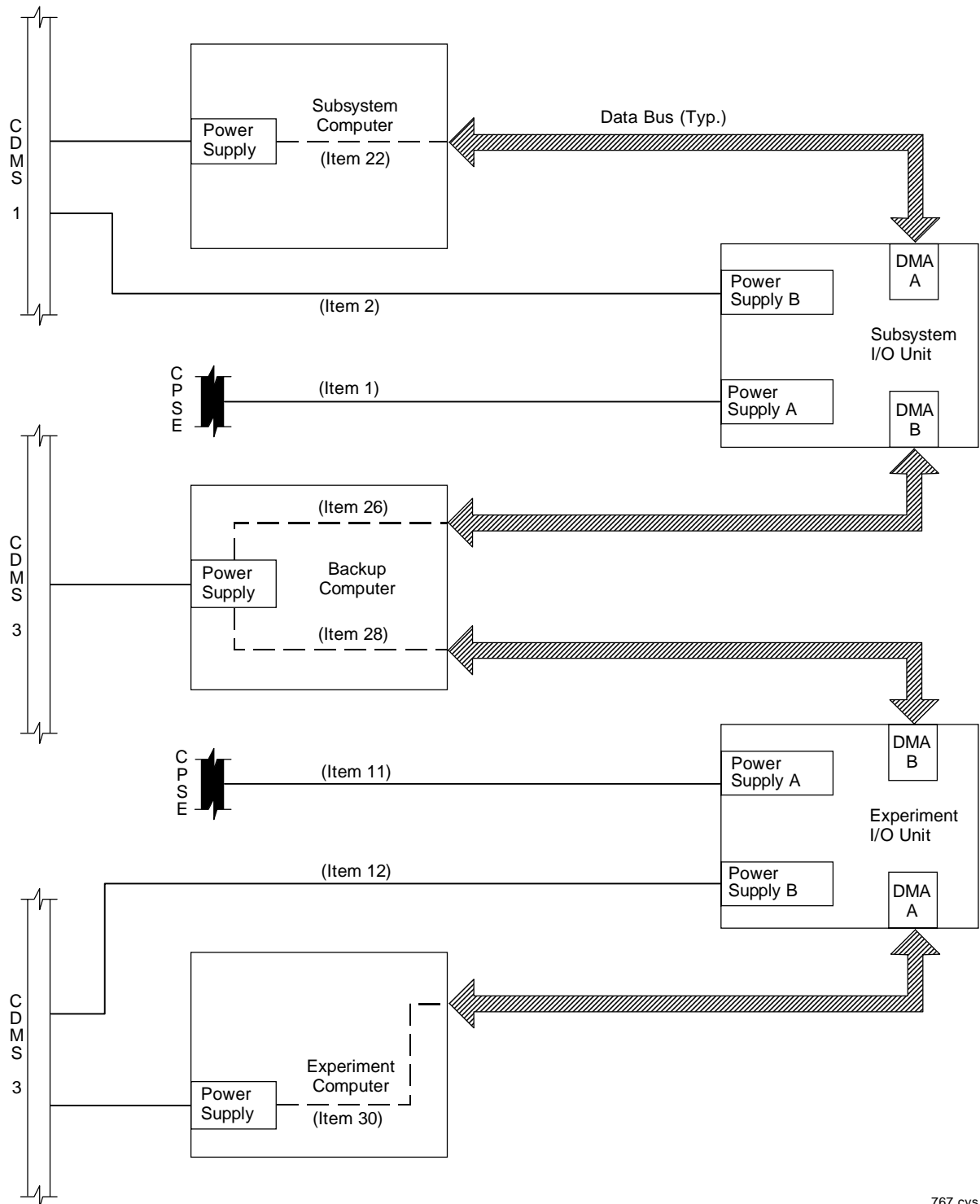
Spacelab Coolant Loops



S/L Cabin Air Loop

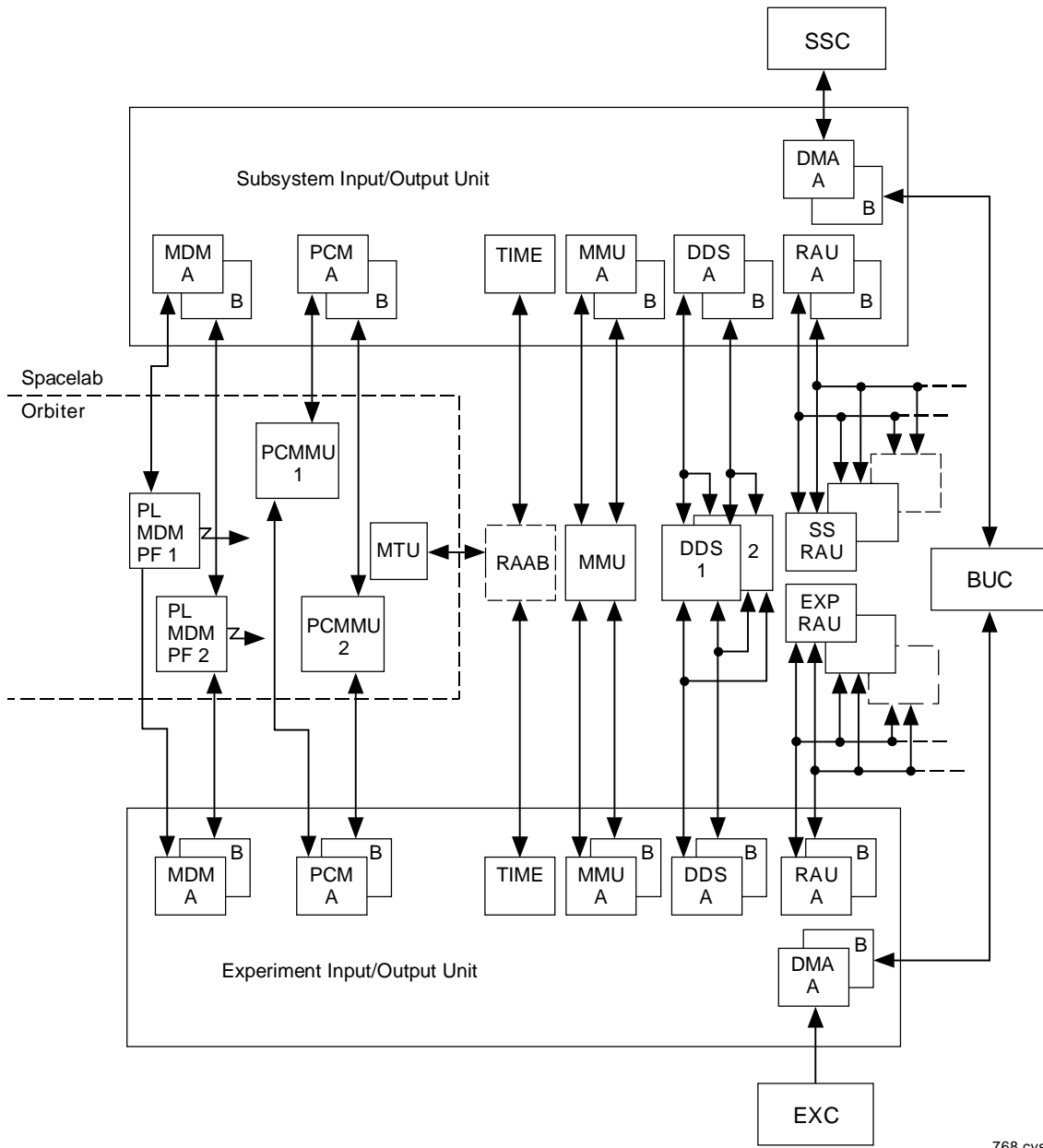


CDMS Redundancy



767.cvs

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



768.cvs

IOU Couplers and Data Buses

XXXX/XXX/206 S/L LAUNCH/ENTRY XX X DDD/HH:MM:SS BFS DDD/HH:MM:SS			
MAIN BUS VOLTS	XX.XS	CABIN PRESS	XX.XS
AUX BUS A/B U/V	S	PP02	X.XXS
SS INV IN AMPS	XXXS	AVIONICS FAN ΔP	.XXXS
TEMP	XXXS	H2O PUMP IN P	XXXS
EXP INV IN AMPS	XXXS	OUT P	XXXS
TEMP	XXXS	ΔP STAT	S
SS AC BUS VφA	XXXS		
φB	XXXS		
φC	XXXS		
EPDB STATUS 1	XXXS		
2	XXXS		
3	XXXS		

(XX) 769

S/L LAUNCH/ENTRY Display

XXXX/223/XXX S/L ATMOSPHERE XX X DDD/HH:MM:SS DDD/HH:MM:SS			
CABIN PRESS 1	XX.XS	ASCS 02/N2 CNTL 1	VLV 2
2	XX.XS	ENH 5XS	7XS
PP02 1	X.XXS	INH 6XS	8XS
2	X.XXS	STAT XXS	XXS
3	X.XXS		
PPC02	XX.XS	N2 VLV 1	2
TEMP	XXXS	OP 9XS	11XS
DEPRESS VLV	XXS	CL 10XS	12XS
STAT	XXS	FLOW X.XXS	
POS RLF VLV		REG P XXXS	
1	2	TK P XXXS	
ENA 1XS	3XS	T XXXS	
CL 2XS	4XS		
		02 VLV OP 13XS	
		CL 14XS	
		FLOW X.XXS	
		PRESS XXXS	
		CNDS SEPARATOR 1	2
		CB XXXS	XXXS
		ON 15XS	17XS
		OFF 16XS	18XS
		RPM STAT S	S
		TANK P	XX.XS
		DUMP	
		1	2
		CB XXXS	XXXS
		HTR CNTRL XXXS	XXXS
		NOZ T XXXS	XXXS
		VLV COIL 1	2
		CMD XXS	XXS
		CL 19XS	20XS
		STAT	XXS

(XX) 772

S/L ATMOSPHERE Display

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

(XX) 770

S/L COOLING LOOPS Display

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

(XX) 773

S/L SS DC POWER Display

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

(XX) 771

S/L AIR LOOPS Display

XXXX/222/XXX S/L AC POWER XX X DDD/HH:MM:SS DDD/HH:MM:SS			
INVERTERS	SS	EXP	SS POWER ON 1XS
ON	2XS	4XS	SPDB SW PWR XXXXS
OFF	3XS	5XS	
			SS EXP
V IN	XX.XS	XX.XS	BUS SS XS EXP XS
A IN	XXXS	XXXS	7XS XS
V φA	XXX.XS	XXX.XS	SS BUS VOLTS
φB	XXX.XS	XXX.XS	AMPS
φC	XXX.XS	XXX.XS	φA XXXS
A φA	XX.XS	XX.XS	φB XXXS
φB	XX.XS	XX.XS	φC XXXS
φC	XX.XS	XX.XS	φAB XXXS
TEMP	XXXS	XXXS	φBC XXXS
O/V SHDN	S	S	φCA XXXS
			EXP BUS VOLTS
			φAB XXXS
			φBC XXXS
			φCA XXXS
			CDMS φA X.XS
			φB X.XS
			φC X.XS
			ECS2 φA X.XS
			φB X.XS
			φC X.XS
			ECS3 φA X.XS
			φB X.XS
			φC X.XS
			CDMS φA X.XS
			φB X.XS
			φC X.XS

(XX) 774

S/L AC POWER Display

```

XXXX/210/XXX S/L DPA XX X DDD/HH:MM:SS
I/O UNIT SS EXP DDD/HH:MM:SS
PWR ON A 1XS 11XS 33 CDMS MSTR OFF X
B 2XS 12XS
OFF 3XS 13XS
AMPS XX.XS
TEMP XXXS
5V X.XS
O/A S
U/V S
COUPLER
ALL A ON 4 14
PMU B ON 5XS 15XS
RAU B ON 6XS 16XS
MDM B ON 7XS 17XS
MMU B ON 8XS 18XS
DDU B ON 9XS 19XS
TIME OFF 10XS 20XS
DMA S S
RAU S S
MDM S S
MMU S S
DDU S S
TIME S S
PROGRAM LOAD SS EXP
MMU BITE XS XS
LOAD COUNTER XXXS XXXS
PIOL COUNTER XXXS XXXS
TIME SOURCE XXXS XXXS
SYS STOP ERR XXXXS XXXXS
IT LEVEL XXS XXS
(XX)

```

S/L DPA Display

```

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

```

S/L EXP RAUS Display

```

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

```

S/L DPS PERIPHERAL Display

```

XXXX/214/XXX S/L COMM XX X DDD/HH:MM:SS
VOICE DIGIT ENA INH HDRR ON
CHAN 1 1XS 4XS PWR 19XS
2 2XS 5XS OFF 20XS
3 3XS 6XS STAT EU XS
HRM TU XS
PWR ON 7XS INP OVFL MTR A X.XS
OFF 8XS 1XS 12XS TEMP ±XXXS
STAT XS 2XS 13XS RATE MHZ 2 21XS
TEMP ±XXXS 3XS 14XS 4 22XS
PS0 9XS 4XS 15XS 8 23XS
PS1 10XS 5XS 16XS 16 24XS
PS2 11XS 6XS VOXS 32 25XS
OP SSC 12XS 7XS PRXS MODE STOP 26XS
NOP SSC 13XS 8XS HRXS RCD 27XS
OP EXC 14XS 9XS SSXS PB 28XS
NOP EXC 15XS 10XS EXXS FWD 29XS
SLF TEST 16XS 11XS RWD 30XS
STATUS XXXXS MOTION XXXXS
CUR FMT XXS %TAPE XXX.XS
17 LOAD FMT XXS EOT XS
EXEC 18 SELF TEST 31XS
STATUS XXXS (XX)

```

S/L COMM Display

```

XXXX/212/XXX S/L LINE MGMT XX X DDD/HH:MM:SS
MDM SEL SSC EXC GPC/SL LINK ERROR
CHANNEL A B A B SSC EXC
ENA 1X 2X 4X 5X NOP IND X X
DSBL 3X 6X CDMM X X
LINK INTRPT X X
MDM TEST SSC EXC NO SL RESP X X
RTRN CHW 7XXXX 8XXXX GPC NO MATCH X X
MSG 9XXXXX10XXXX SL LENGTH X X
SV SEL SSC EXC AR NO MATCH X X
ENA GTOD 11X 12X SR NO MATCH X X
M50 13X 14X RIW ERROR STATUS
XMIT RI XXX XXX
GPC RCVD RI XXX XXX
SL RCVD RI XXX XXX
LENGTH XXX XXX
MSG REJECT SSC EXC LINK BUSY X X
ITEM X X DSBL X X
GNC X X
U/L X X
PCS X X
TEC X X ERROR RESET 15
(XX)

```

S/L LINK MGMT Display

```

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

```

S/L EXP POWER Display

2.22 SPACEHAB

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Environmental Control	
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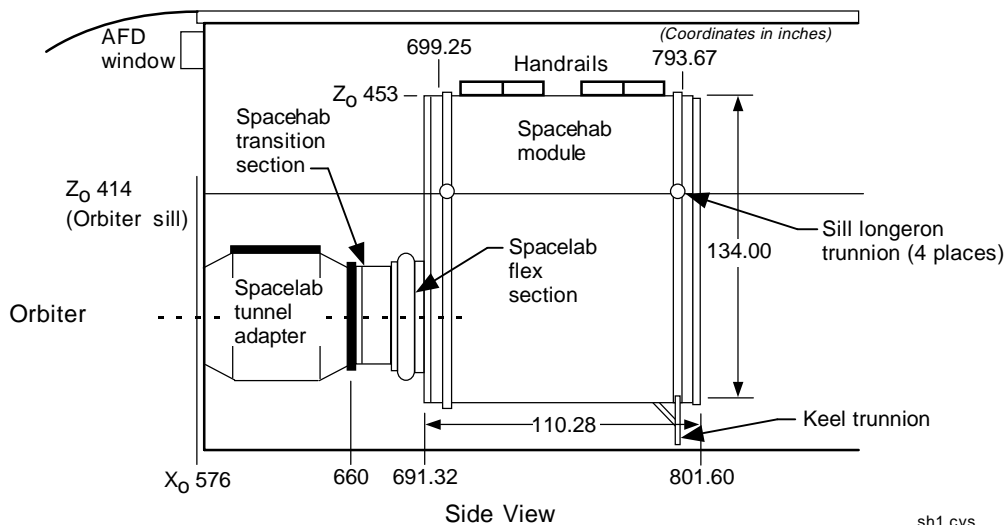
Description

The Spacehab module is a pressurized experiment carrier designed to augment space shuttle middeck experiment accommodations. The Spacehab system consists of a module flown in the orbiter payload bay that is configured with middeck-type lockers, racks, and/or the logistics transportation system (LTS) to accommodate a variety of experiments and equipment. The Spacehab module provides space for crewmembers to work on experiments in a shirt-sleeve environment. Spacehab offers the Space Shuttle Program three module configurations to accommodate mission-specific requirements.

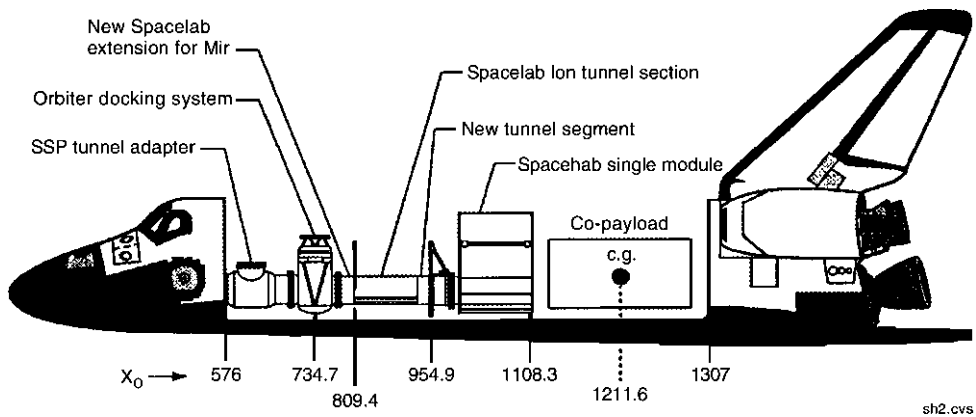
Configurations

Spacehab configuration 1 is connected to the orbiter using a modified Spacelab tunnel adapter and standard orbiter payload support resources from the cabin and payload bay. The Spacehab single module to orbiter tunnel adapter connection is accomplished using the Spacehab tunnel adapter, the Spacehab transition section, and the Spacelab flex section. The Spacehab module provides crewmembers with a place to carry out their experiments and contains cooling, power, and command and data provisions, in addition to Spacehab housekeeping systems (i.e., power distribution and control, lighting, fire and smoke detection, fire suppression, atmosphere control, status monitoring and control, and thermal control).

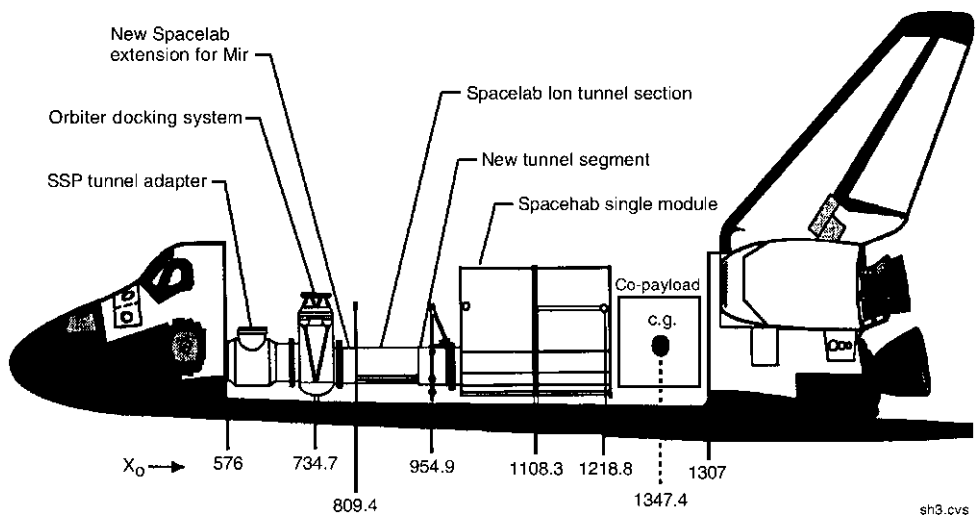
Spacehab configuration 2 allows the Spacehab single module to be mounted in a new trunnion location to accommodate the orbiter docking system (ODS). The module is connected to the ODS using a Spacelab flex section, the new Spacelab extension for Mir, the Spacehab long tunnel segment, the Spacelab tunnel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



Spacehab Configuration 1



Spacehab Configuration 2



Spacehab Configuration 3

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

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 subsystem (CDS) receives hardwired commands from the orbiter SSP and Spacehab monitor and control panel. The CDS can receive commands for Spacehab subsystem and experiment activation and deactivation from either ground uplink or the orbiter CRT via the payload signal processor (PSP) link. The Spacehab can also receive commands from an orbiter-provided microcomputer, the payload general support computer (PGSC). The PGSC commanding capability can be used only to command the Spacehab video switching unit (VSU).

The data management unit (DMU) is the major element of the Spacehab CDS. The DMU provides data acquisition and command functions for the Spacehab module. The DMU also provides all serial interfaces required for data transmission between the Spacehab module and the orbiter.

The payload data interleaver (PDI) interface to the DMU gives ground controllers the capability to monitor Spacehab subsystem and experiment telemetry.

Caution and Warning

The orbiter caution and warning (C&W) system and Spacehab subsystems work together to alert

the crew if Spacehab subsystem equipment is failing. When an alarm condition is detected, the orbiter provides a signal that activates the master alarm light in the Spacehab module.

The Spacehab C&W subsystem is defined in three groups:

- Class 1, Emergency C&W
- Class 2, Hardware C&W/software C&W
- Class 3, Fault detection annunciation

Electrical Power Subsystem

The Spacehab electrical power subsystem (EPS) distributes direct current, alternating current, and emergency current sources to subsystems and experiment equipment. Main power is distributed via the power distribution unit (PDU).

The PDU is the major component of the Spacehab EPS. The PDU receives and distributes main dc, secondary dc, and 3-phase 115-volt ac power from the orbiter. Also, the PDU distributes Spacehab inverter-generated, 3-phase 115-volt ac power to subsystem and experiment equipment.

The emergency power received from both the orbiter auxiliary A and aft payload B buses is routed to the Spacehab fire suppression control unit (FSCU) and the monitoring and control panel (MCP).

Control and monitoring of the Spacehab EPS is provided by hardwired interfaces to the SSP, payload multiplexer/demultiplexer (PL MDM), and by discrete inputs and outputs to the DMU.

Environmental Control Subsystem

The Spacehab environmental control subsystem (ECS) controls the habitable environment and provides heat rejection for subsystem and experiment thermal control. The ECS provides this capability during prelaunch, launch, on orbit, entry, and postlanding mission phases. The ECS controls atmospheric temperature control and pressure limitation, contingency depressurization, equipment thermal control, smoke detection, fire suppression, experiment vacuum venting, atmospheric monitoring, trace contaminate removal, and emergency egress breathing capability.

Audio Communication Subsystem

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

Each communication station has the following audio channels:

- Air-to-ground 1 (A/G1)
- Air-to-ground 2 (A/G2)
- Intercommunication A (ICOM A)
- Intercommunication B (ICOM B)
- Page
- Alarm tone

The channels can be configured independently to talk/listen, listen only, or off.

Fire Suppression Subsystem

The FSS includes both smoke sensors and fire suppression equipment. Detection of fire/

smoke is annunciated through the orbiter C&W electronics unit (CWEU) to crewmembers in both the orbiter and Spacehab module. The fire suppression bottles can be discharged using controls located on the SSP, on the payload safing panel (C3A5), on the Spacehab MCP, or by Spacehab SPEC commanding via the orbiter CRT. Fire suppression firing circuits, smoke detector data circuits, and test/checkout provisions are provided by the FSCU and the MCP.

Activation of the FSS is single fault tolerant during all mission phases. A handheld fire extinguisher is provided for extinguishing localized fires.

Closed Circuit Television Subsystem

The closed circuit television (CCTV) cameras or orbiter-provided camcorders may be located in the Spacehab module for video downlink of Spacehab experiment operations. In the standard configuration, orbiter-provided camcorders are used to provide video recording of Spacehab experiment operations.

2.23 ORBITER DOCKING SYSTEM

CONTENTS

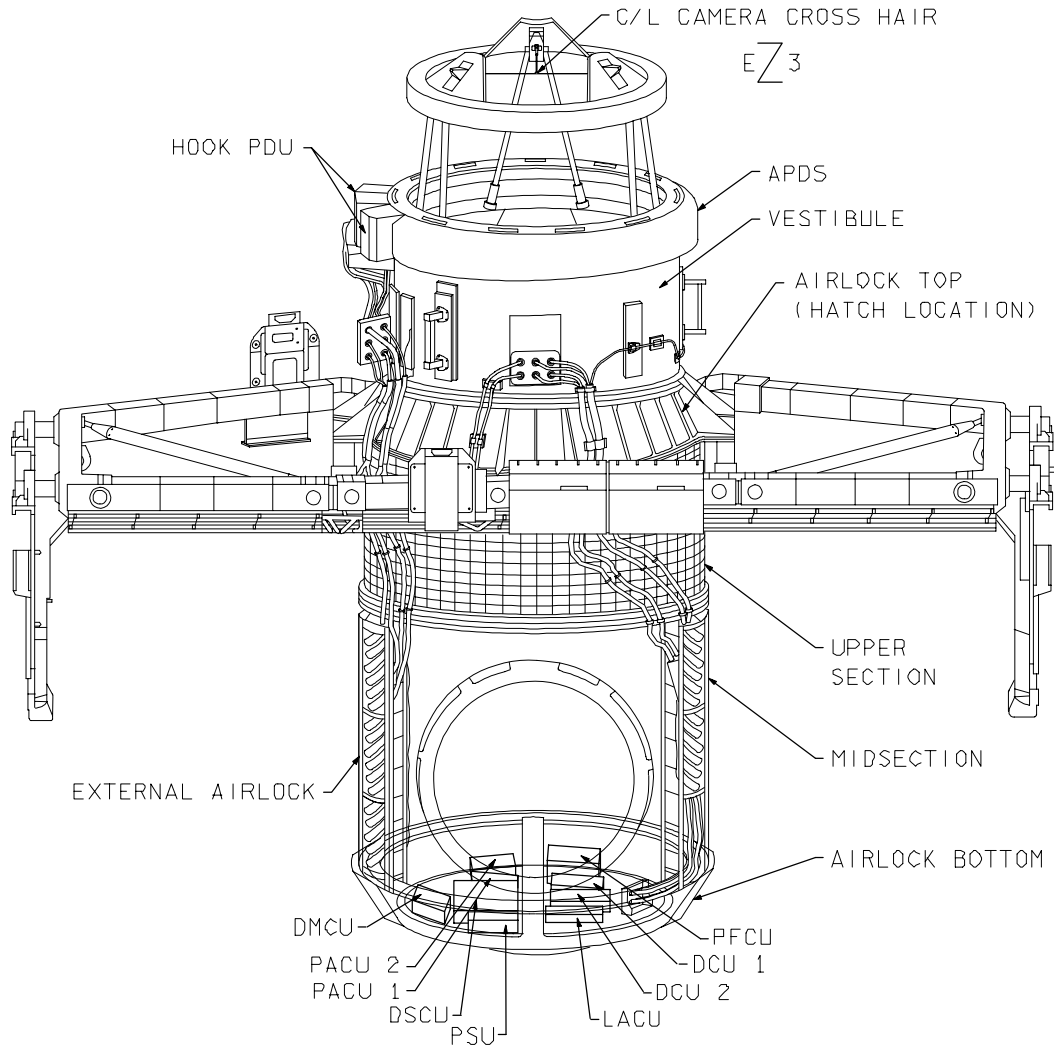
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Description

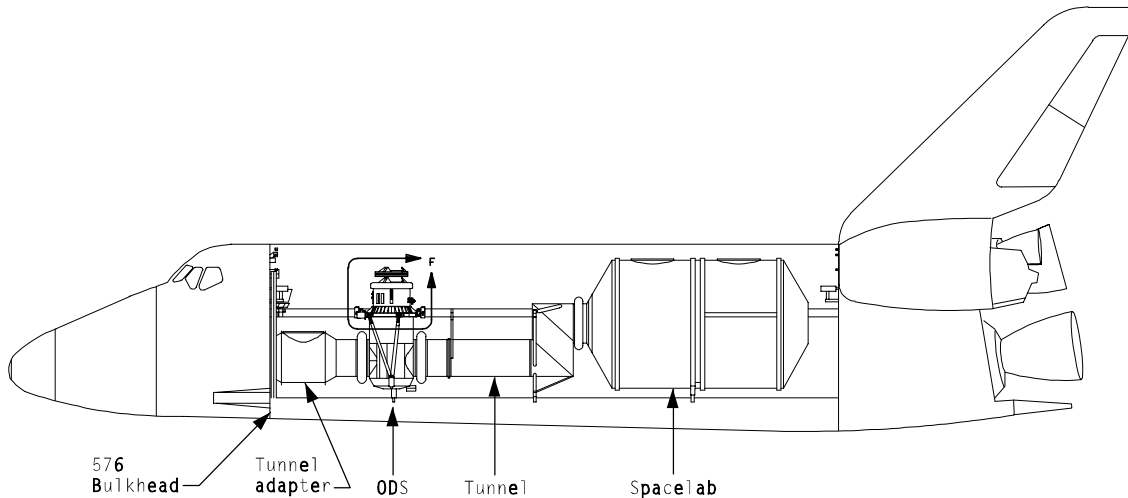
The orbiter docking system (ODS) will be used to dock the shuttle to Mir as well as to the International Space Station. The ODS has three major components

- External airlock
- Truss assembly
- Androgynous peripheral docking system

The ODS is located in the payload bay aft of the 576 bulkhead, behind the tunnel adapter.



Orbiter Docking System View Looking Aft



ODS Configuration in the Payload Bay on STS-71

External Airlock

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

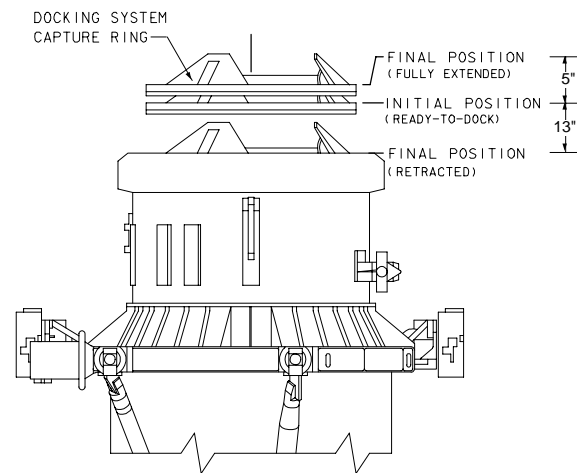
Truss Assembly

The truss assembly provides a sound structural base within which the components of the docking system are housed. The truss assembly is physically attached to the payload bay and houses rendezvous and docking aids, such as camera/light assemblies and trajectory control systems.

Androgynous Peripheral Docking System

The androgynous peripheral docking system (APDS), manufactured by RSC-Energia in Kaliningrad, Russia, is designed to achieve the capture, dynamic attenuation, alignment, and hard docking of spacecraft through the use of essentially identical docking mechanisms attached to each vehicle. The primary components of each docking mechanism are a structural base ring housing 12 pairs of structural hooks (1 active, 1 passive per pair), an extendable guide ring with 3 petals, a motor-driven capture latch within each guide petal, 3 ball screw/nut mechanism pairs connected via a common linkage, 3 electromagnetic brakes (dampers), and 5 fixer mechanisms (that allow for only z-axis movement of the guide ring). Two control panels in the aft flight deck and nine avionics boxes in the subfloor of the external airlock provide power and logic control

of the mechanical components. The docking mechanism on the rendezvousing spacecraft (orbiter) is intended to be active, while the corresponding mechanism on the target spacecraft (Mir) is typically passive.



Extendable Guide Ring Positions

APDS Avionics Overview

Aft Flight Deck Panels

The docking system power panel is a Rockwell-built panel that provides power for the various components of the ODS. This panel includes circuit breaker protection for all the ODS-related bus sources, as well as switches for application of logic and drive power to the APDS control panel, the APDS avionics boxes, the docking lights, and the vestibule depress valves.

The APDS control panel is supplied by RSC-Energia and is used to control the docking mechanism operation. On the left of the panel are nine circuit breakers (cb's) that are operated as switches. The three control panel power switches supply logic bus power to the control panel functions. The heater/data collection units (DCUs) switches provide power to heaters located around the docking ring. The H2/DCU and H3/DCU switches also provide redundant power to each of the two DCUs. The APDS power switches supply logic power to the power switching unit (PSU). Activating these switches also illuminates indicator lights below each switch. Eighteen status lights are located in the middle of the panel and provide the prime feedback on the operation of the docking mechanism. The right side of the panel includes the functional controls of the mechanism that allow for manual operation of the various motor-driven components. Also on the right are the controls of the backup pyro separation system.

Power Switching Unit

The PSU contains several relays with the sole purpose of distributing power, both logic and drive, to the other avionics boxes operating in the nominal docking sequence. These boxes include the docking system control unit (DSCU), docking mechanism control unit (DMCU), pressure actuation control units (PACUs), and latch actuation control unit (LACU). The DCUs are powered through the heater/DCU switches on panel A8. The pyro firing control unit (PFCU) is powered through several other switches on both A7 and A8 panels.

When the POWER ON pushbutton is depressed, it activates a momentary relay in the PSU and begins a chain reaction of relay operations. The result is that several latching relays are set, providing the circuit flow paths for logic and drive power to be distributed to the other avionics boxes.

Docking System Control Unit

The DSCU contains extensive logic control circuits that interface with each of the remaining avionics boxes, except the PFCU. These circuits control the timing and sequencing of the automatic docking sequence. The DSCU also receives the inputs from any manual pushbutton command from the APDS control system panel and routes the inputs to the appropriate

control box for execution. The DSCU is responsible for providing all feedback to the STATUS lights on the control panel as well.

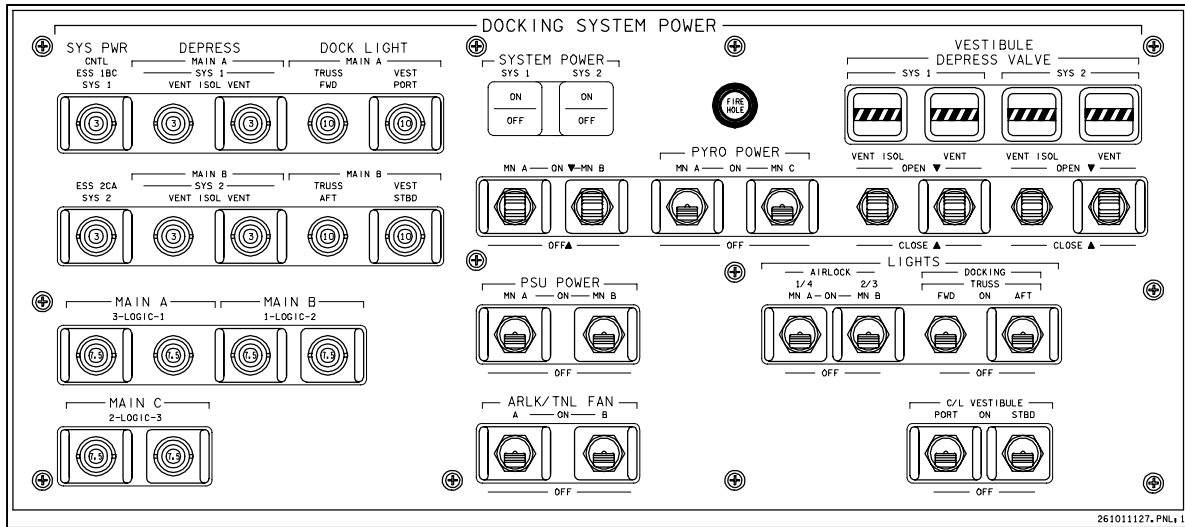
During docking, the initial contact and capture indications are routed into the DSCU. To receive a capture indication, one of two "short" capture contacts from each of the three sensors must be made, in addition to one of the six "long" capture contacts. When this condition is met, a latched logic loop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

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

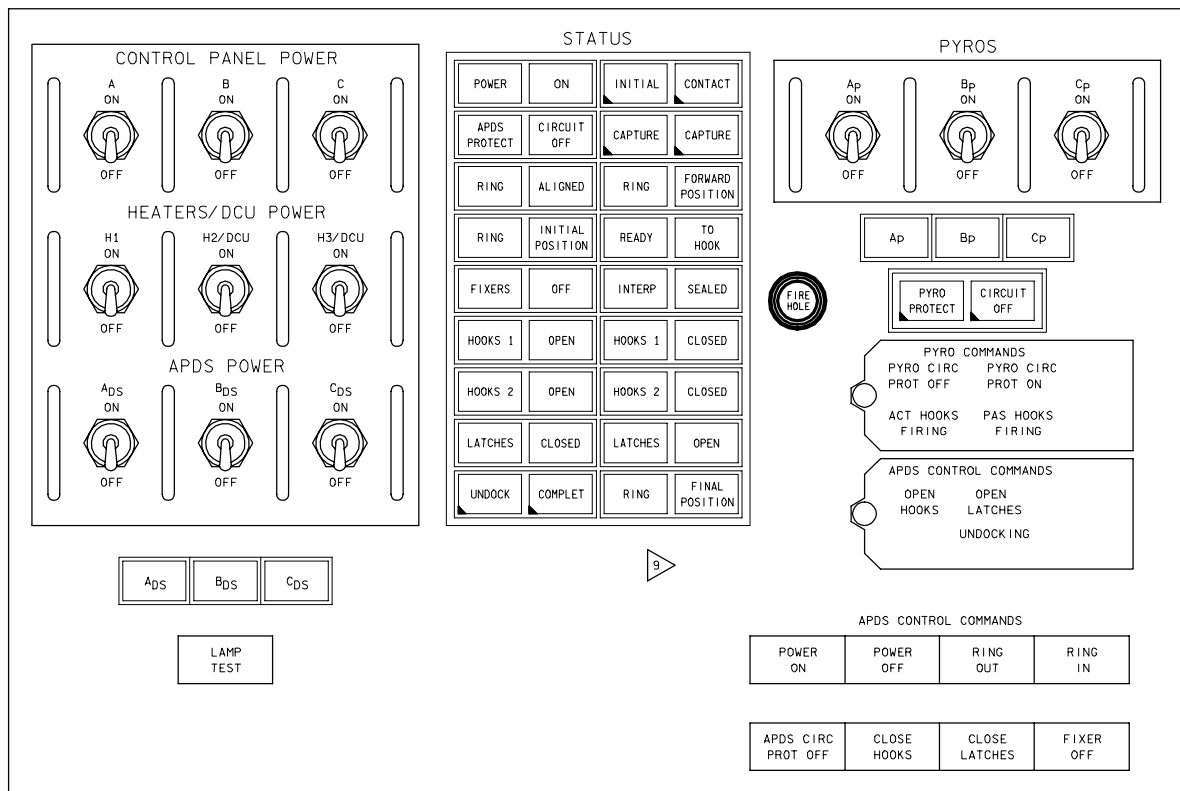
The DSCU also directly powers the fixers and the electromagnetic brakes (dampers). The fixers are energized whenever the ring is retracted during the auto sequence, and whenever the ring is manually driven in either direction. (An unwanted fixers ON command can be avoided with the fixers OFF pushbutton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

Docking Mechanism Control Unit

The DMCU provides power to each of the two extend/retract actuator motors when commanded from the DSCU. The motors are single winding dc motors. The DMCU essentially has two similar halves, one to drive the ring in, and the other to drive the ring out. Instead of using latching logic, the DMCU uses mechanically latching relays to provide power to the motors. Therefore, the relays must be energized to the reset position to stop the ring drive. To accomplish this, the DSCU issues both ring drive and ring drive stop commands at the appropriate times. A ring drive stop command must be issued before a drive command in the opposite direction will be accepted because of inhibits built into the logic.



Docking System Power Panel, Panel A7A3



APDS Control Panel, Panel A8A3

Pressure Actuation Control Units

PACUs 1 and 2 control the operation of hook gangs 1 and 2, respectively. Again, the DSCU issues the hooks open and close commands to the PACUs, based on the appropriate signals it receives. Each PACU uses latching logic to supply power to the two dc motors per actuator. The hook gangs are commanded simultaneously with one set of commands from the DSCU; i.e., they cannot be operated separately. However, if the hooks are driving in one direction, the opposing command can be issued, and the motors will reverse direction.

Latch Actuation Control Unit

The capture latch motors, one motor per latch, are continuous drive motors controlled by the LACU. The motors are dc motors, but they drive in one direction only, rotating an eccentric cam inside the capture latch. There are 10 sensor contacts per latch that provide feedback. There are two redundant open/close contacts for motor control, two redundant open/close contacts for panel feedback, and one open/close contact for telemetry per latch. For the motor to operate; for example, in the close direction, one of the two open contacts must be mated, which provides a ground path for the motor current. When the closed position is reached, the closed contacts mate, but it is the loss of the open contact shortly thereafter that causes the motor to stop driving. With the closed contacts mated, it is now ready to drive in the open direction when the proper relays in the LACU are energized. All the relays in the LACU serve to provide power and a ground path to each latch motor.

Pyro Firing Control Unit

The pyro power switches on the docking system panel, and the pyro A, B, C switches on the APDS control panel provide the main bus and logic power to the PFCU. With these switches powered, the PYRO CIRC PROT OFF pushbutton will remove one inhibit from the logic by energizing several relays within the PFCU. This will allow the ACTIVE or PASSIVE HOOKS FIRING command from the control panel to be transmitted to each pyrobolt in the hook mechanisms. There is only one pyrobolt per hook, but there are two redundant initiators per charge.

APDS Operational Sequences (OPS)

Docking System Initialization

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

Docking Mechanism Powerup

First, the PSU power switches on panel A7 are turned on to feed MNA and MNB bus power to the PSU avionics box. Now, on A8, the three control panel power cb switches are activated to provide logic power to the control panel pushbuttons and status lights. The three APDS power cb switches provide logic power from the control panel to the PSU box. The power on momentary pushbutton activates numerous relays within the PSU to distribute logic power to the following avionics boxes: the DSCU, the DMCU, the LACU, and both PACUs. This also enables the feedback circuitry from the various mechanism microswitches, which illuminate their respective status lights on the A8 panel. The control panel also has a lamp test pushbutton that is used to test all 36 status lights and the 2 pyro circuit protect off lights.

Docking Ring Extension

The docking system is launched with the active docking ring fully retracted and aligned in its final position, the structural hooks open, and the capture latches closed. In preparation for docking, the ring must be extended to its ready-to-dock or ring initial position. To do this, it is necessary to remove the inhibit that exists for manual operation of the mechanism. This is accomplished by depressing the APDS

CIRC PROT OFF pushbutton. This pushbutton activates several relays that enable the logic for the manual ring out, open hooks, open latches, and undocking pushbuttons. Without this step, these four pushbuttons will not send commands.

With the inhibit removed, the RING OUT command is sent to the DMCU avionics box. This command activates two dc motors to drive the ring out to its initial position (13 inches from final position) at a rate of approximately 4.3 in/min. As the ring is driving, the fixers are also activated to keep the ring rigidized while it drives. One second after the ring reaches its initial position, the ring motors and the fixers are commanded off. The system is then powered down.

Docking

Once the orbiter is on the Vbar (or Rbar) for final approach, the docking system is powered back on. When the POWER ON pushbutton is depressed, the docking system will be ready for docking. In this timeframe, it is also necessary to close the inner airlock hatch, check the function of the airlock fan, and turn on the docking lights and cameras.

At initial contact, the initial contact light on A8 will illuminate and the ring aligned light will go off. This will cue the crew to activate the preset postcontact thrusting (PCT) sequence, using the spare digital autopilot (DAP) pbi. The PCT is designed to provide the force required to attain capture with the APDS while not exceeding dynamic loads. To enhance the probability of success, the PCT should be initiated within 2 seconds of initial contact. To prevent exceeding loads, it should not be initiated once capture is achieved.

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

Failed Capture

For failed capture cases that result in a bounce off, it is necessary to check out the mechanism before conducting another attempt. This can be simply accomplished by fully extending the ring to verify function and realign it, and either retracting it to the initial position or fully retracting it and then reextending it to the initial position. If the mechanism appears good, and the cause of the failed capture is apparent, it is not necessary to delay a second attempt (from the mechanism perspective only).

For cases where the mechanism captures, but either the orbiter or the Mir does not get the signal (i.e., the orbiter does not get active damping or the Mir does not go to free drift), the response can be more complicated. If the crew can determine that the relative motion appears stable and will not bottom out the mechanism, the preferred approach is to hang on and wait it out. If motion ever appears unstable or excessive, the crew is to open the capture latches and back away.

Automatic Docking Sequence

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

After ≈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

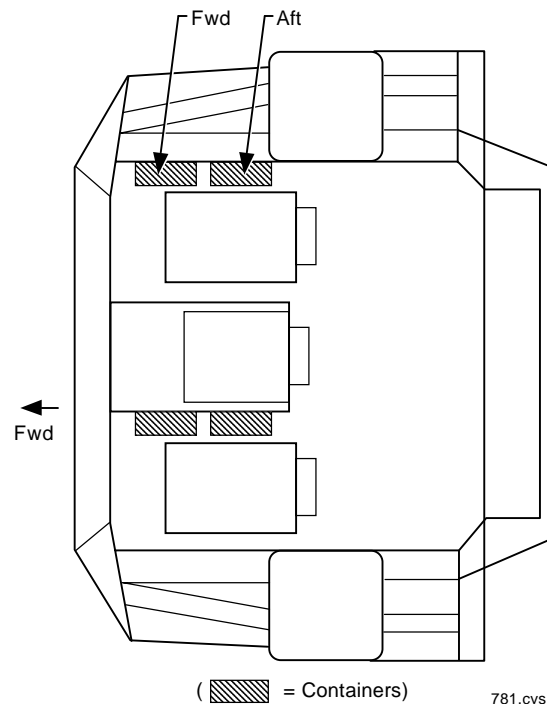
FDF Containers

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

Modular Lockers

Some equipment onboard the orbiter is stowed in lockers with insertable trays. The trays can be adapted to accommodate a wide variety of soft goods, loose equipment, and food. The lockers are interchangeable and attach to the orbiter with spring-loaded captive bolts. The lockers can be removed or installed in flight by the crewmembers. There are four sizes of trays: a single tray (two of which fit inside a locker), a double tray, a half-length single tray (four of which fit inside a locker), and a half-length double tray. Approximately 150 cubic feet of stowage space is available, almost 95 percent of it on the middeck.

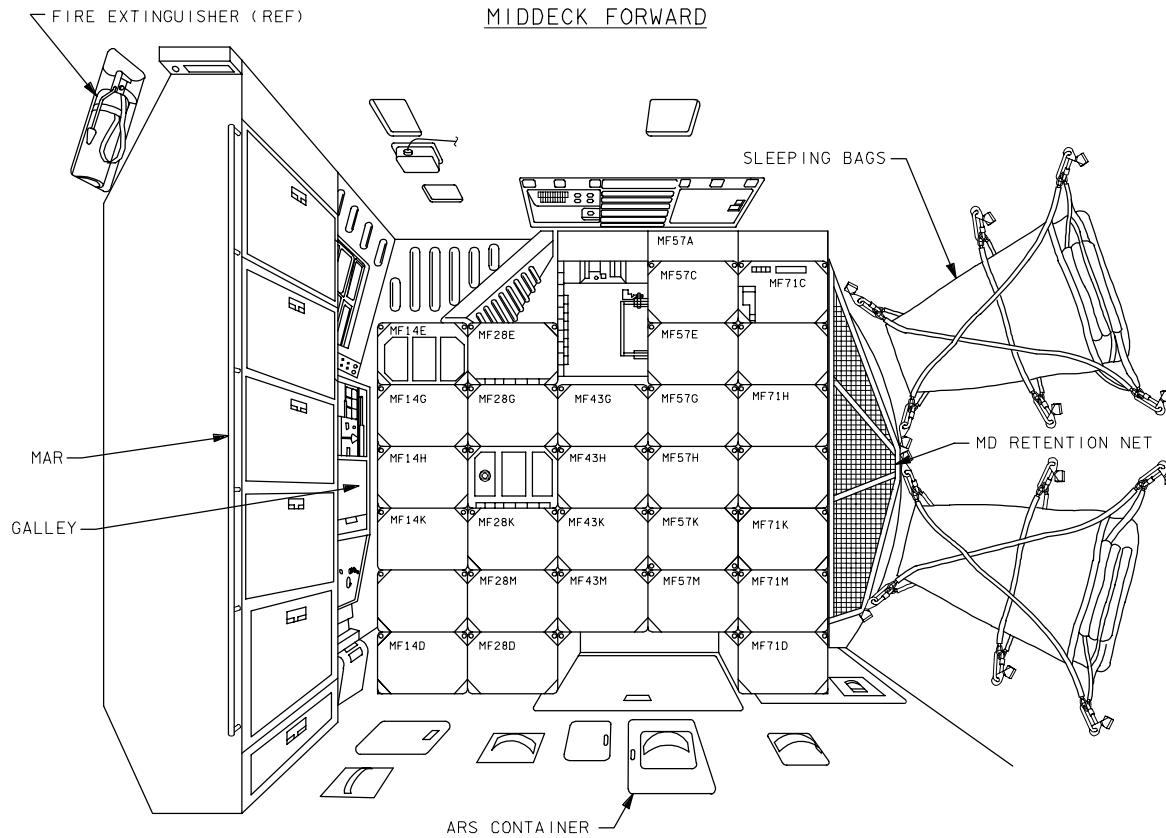


Flight Deck DFD Containers

The lockers are made of either epoxy- or polyimide-coated Kevlar honeycomb material joined at the corners with aluminum channels. Inside dimensions are approximately 11 by 18 by 21 inches. The honeycomb material is approximately 0.25-inch-thick, and was chosen for its strength and light weight. The lockers contain about 2 cubic feet of space and can hold up to 66 pounds.

Foam inserts are used in the trays to provide a friction fit for zero-g retention. In addition, straps, snaps, and mesh retention nets are used in some trays. Soft containers are used in orbiter spaces too small for the fixed lockers.

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

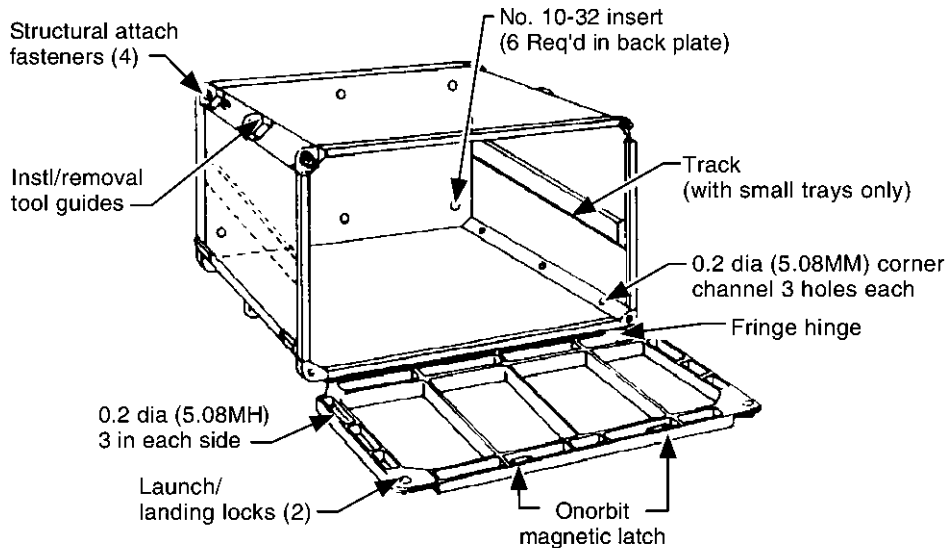
In the aft flight deck, stowage lockers are located below the rear payload control panels in the center of the deck. A trash container is nominally mounted on the port side of the flight deck, near the interdeck access opening. A temporary stowage bag is nominally located on the starboard side in approximately the same location. These side containers are interchangeable.

The crewmember can open the door a full 180°. By using the standard hole pattern of the locker, straps and brackets can be attached to the locker faces via pip pins for restraining equipment.

In 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.

In addition, a crewmember can remove lockers in flight in order to gain access to the floor compartments or the avionics bays.

In the event the locker door cannot be closed or latched because of misalignment problems, the crewmembers can remove the locker and use turnbuckles to provide structural support.



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

783.cvs

Schematic of Modular Lockers

Floor Compartments

Six floor compartments are available. Volume F (MD76M), the wet trash compartment, provides 8 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.

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

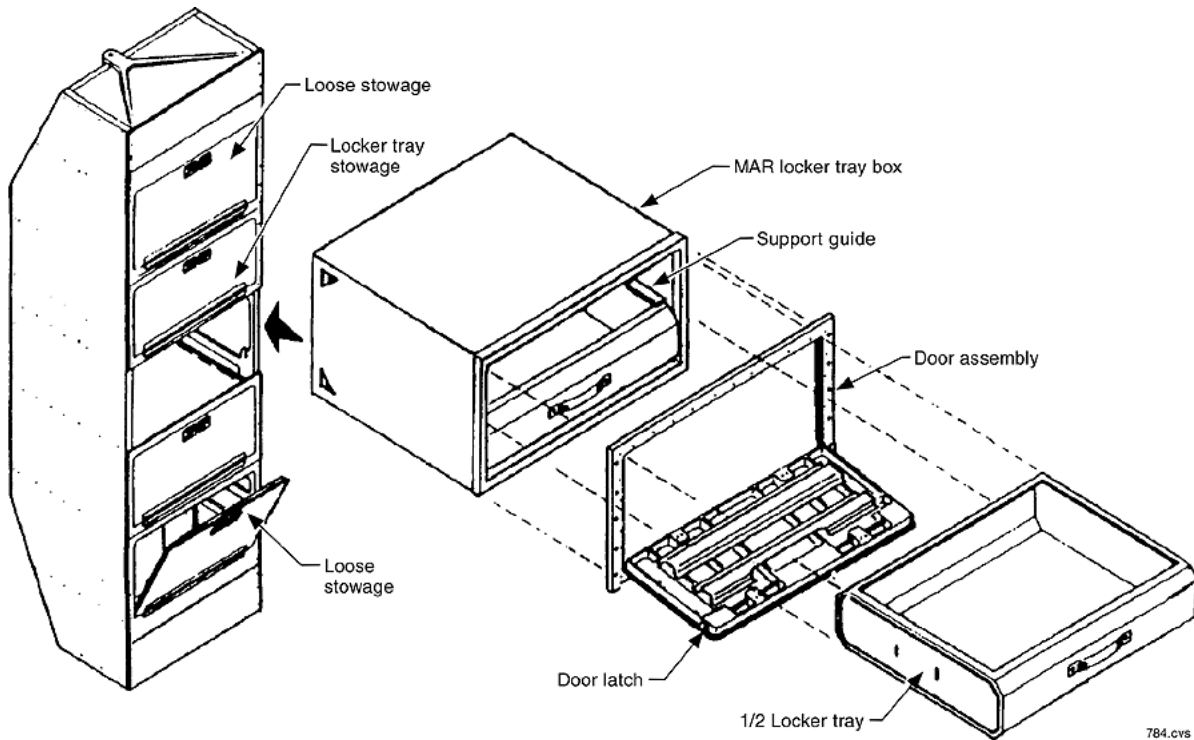
The airlock retention net is used to restrain equipment in the airlock. It is a brown polybenzine imidazole mesh net that resembles two triangles joined at their apexes.

Middeck Accommodations Rack

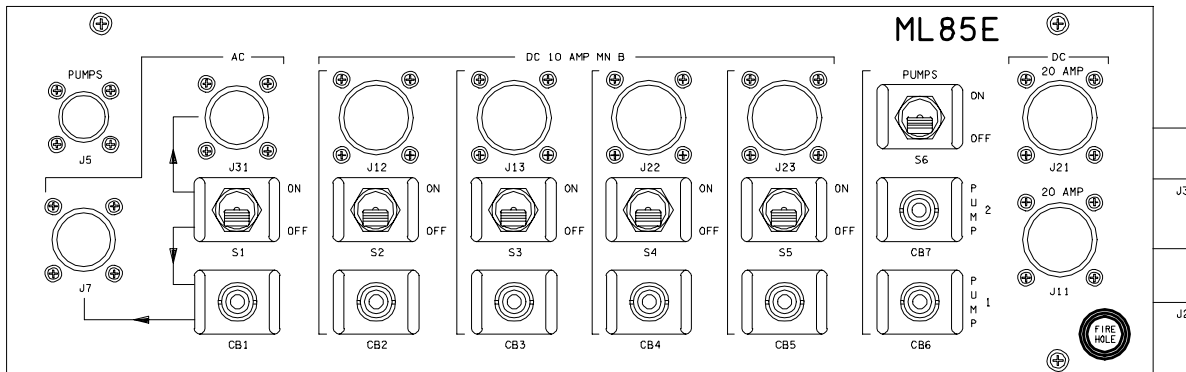
The middeck accommodations rack (MAR) permits the integration of supplemental small payloads and experiments into the middeck of the orbiter. The MAR is installed just forward of the side hatch in the area previously occupied by the galley. The blue anodized structure provides approximately 15 cubic 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 cold-plates. These NASA provided designs can dissipate heat loads of up to 1000 watts. An approved payload-unique system, located in the MAR, that connects to the orbiter heat exchange loop may also be used.



Middeck Accommodations Rack (MAR) Locker Tray Assembly



NOTES:

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

ML85E Middeck Utility Panel (MUP)

2.25 WASTE MANAGEMENT SYSTEM (WMS)

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Description

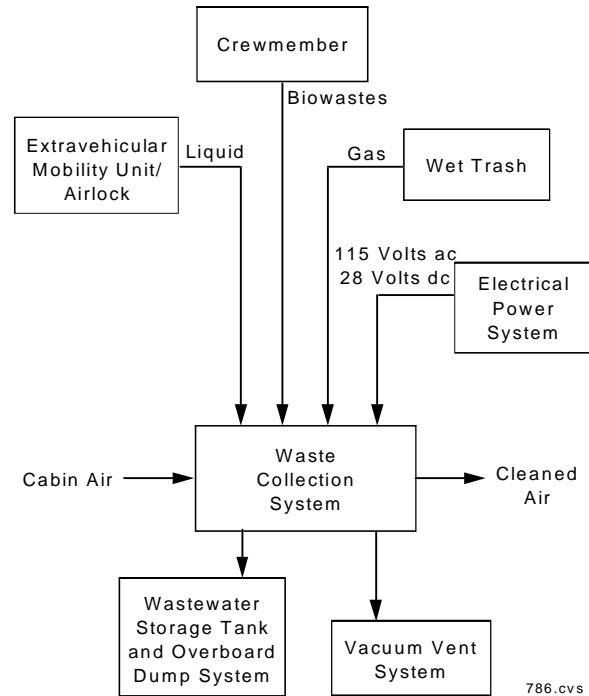
The waste management system is an integrated, multifunctional system used primarily to collect and process crew biological wastes. The WMS is located in the middeck of the orbiter crew compartment in a 29-inch-wide area immediately aft of the crew ingress and egress side hatch.

The system collects, stores, and dries fecal wastes and associated paper tissues. It processes urine and transfers it to the wastewater tank and processes EMU condensate water from the airlock and transfers it to the wastewater tank if an EVA is required on a mission. The system also provides an interface for venting trash container gases overboard and dumping atmospheric revitalization wastewater overboard in a contingency situation, and it transfers atmospheric revitalization system wastewater to the wastewater tank.

A waste management compartment door and two privacy curtains attached to the inside of the door provide privacy. One curtain is attached to the top of the door and interfaces with the edge of the interdeck access, and the other is attached to the door and interfaces with the galley, if installed. The door also serves as an ingress platform during prelaunch (vertical) operations since the flight crew must enter the flight deck over the waste management compartment. The door has a friction hinge and must be open to gain access to the waste management compartment.

The WMS consists of a commode, urinal, fan separators, odor and bacteria filter, vacuum vent quick disconnect, and controls. The commode is 27 by 27 by 29 inches, and it is used like a standard toilet. The commode contains a single multilayer hydrophobic porous bag liner

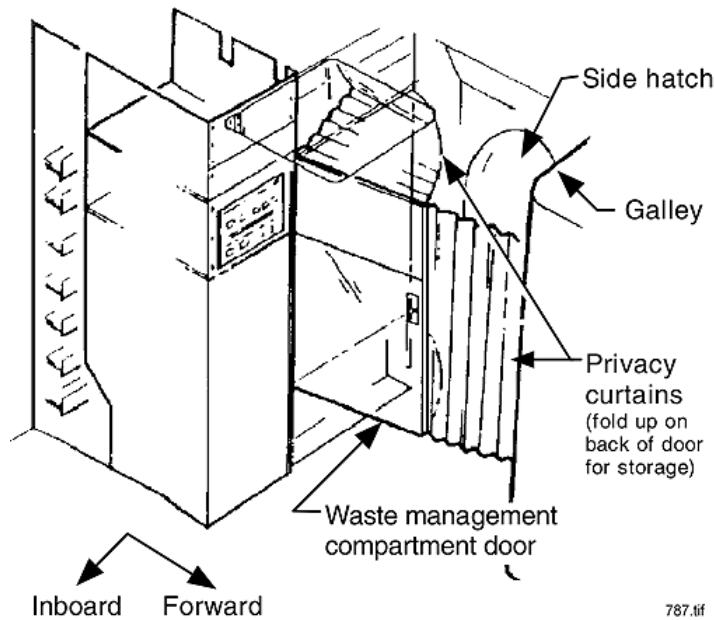
for collecting and storing solid waste. When the commode is in use, it is pressurized, and transport air flow is provided by the fan separator. When the commode is not in use, it is depressurized for solid waste drying and deactivation.



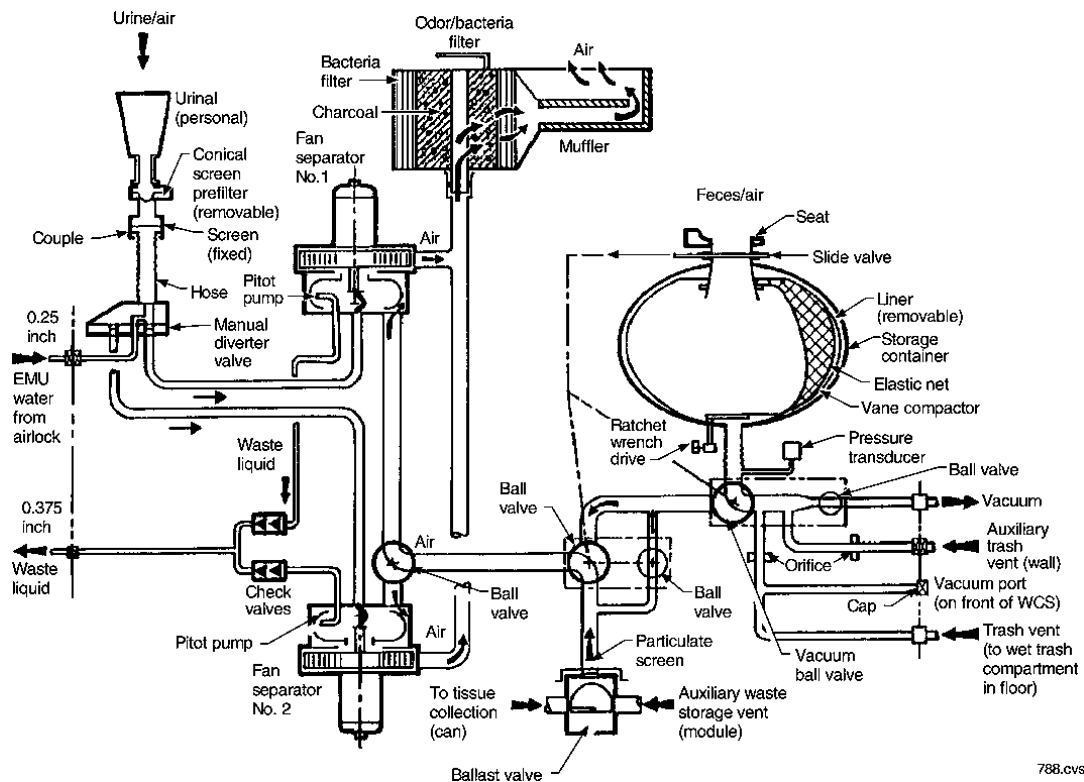
Waste Management System

The urinal is essentially a funnel attached to a hose and provides the capability to collect and transport liquid waste to the wastewater tank. The fan separator provides transport air flow for the liquid. The fan separators separate the waste liquid from the air flow. The liquid is drawn off to the wastewater tank, and the air returns to the crew cabin through the odor and bacteria filter. The filter removes odors and bacteria from the air that returns to the cabin. The vacuum quick disconnect is used to vent liquid directly overboard from equipment connected to the quick disconnect through the vacuum line.

The urinal assembly is a flexible hose with attachable funnels that can accommodate both men and women. The assembly can be used in a standing position, or it can be attached to the commode by a pivoting mounting bracket for use in a sitting position.



Waste Management System Privacy Curtains

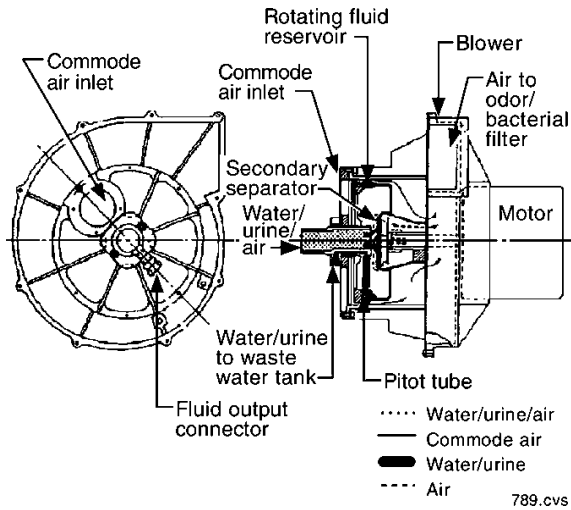


Waste Management System

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

Various restraints and adjustments enable the crew to achieve the proper body positioning to urinate or defecate in a zero-gravity environment. Two foot restraints are provided.

A toe bar is located at the commode base and is used for standing urination. It consists of two flexible cylindrical pads on a shaft that can be adjusted to various heights by releasing two locking levers that are turned 90° counterclockwise. The crewmember is restrained by slipping his or her feet under the toe bar restraint.



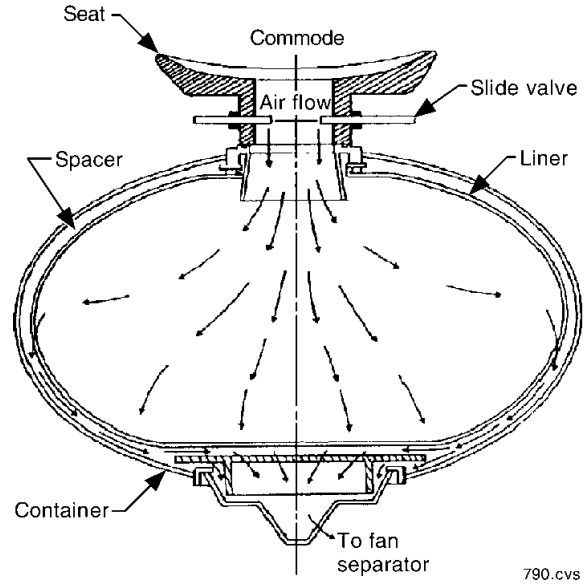
Waste Management System Fan Separator

A footrest restrains the feet of a crewmember sitting on the commode. The footrest consists of an adjustable platform with detachable Velcro straps for securing the feet. The Velcro straps are wrapped crosswise over each foot and secured around the back. The footrest can be adjusted to various angles and heights. Two locking handles pulled outward adjust the angle; two other locking levers adjust the height of the footrest.

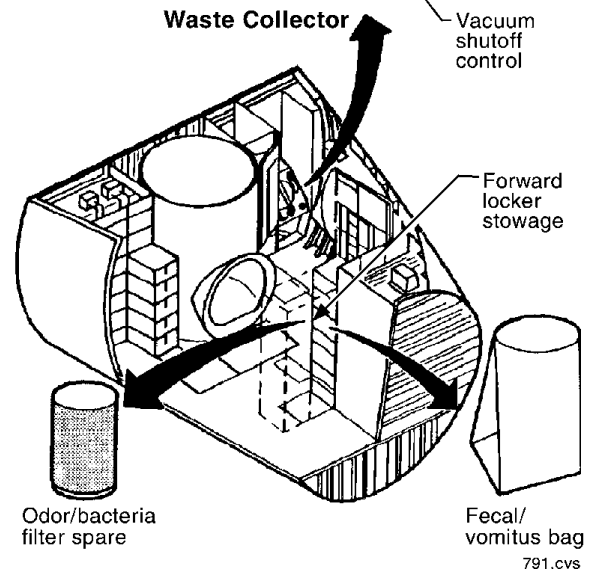
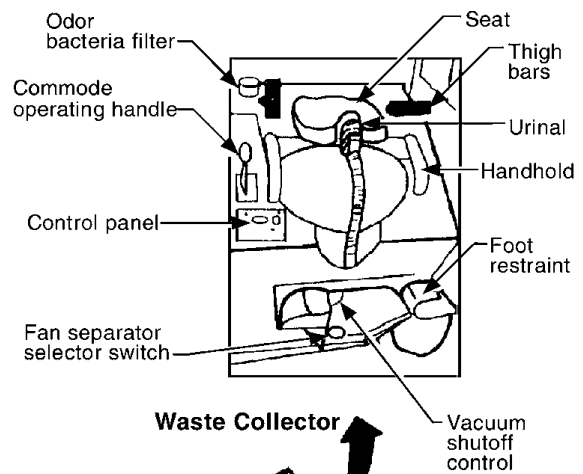
One body restraint is provided for use when crewmembers are seated on the commode. This restraint is a thigh bar that the crewmember lifts up out of the detent position, rotates over the thigh, and releases. The thigh bar exerts a preloaded force of approximately 10 pounds on each thigh.

Handholds are used for positioning or stabilizing the crewmember and form an integral part of the top cover of the waste management collection system assembly.

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



Waste Management System Container Liner



Waste Management System - Middeck

Operations

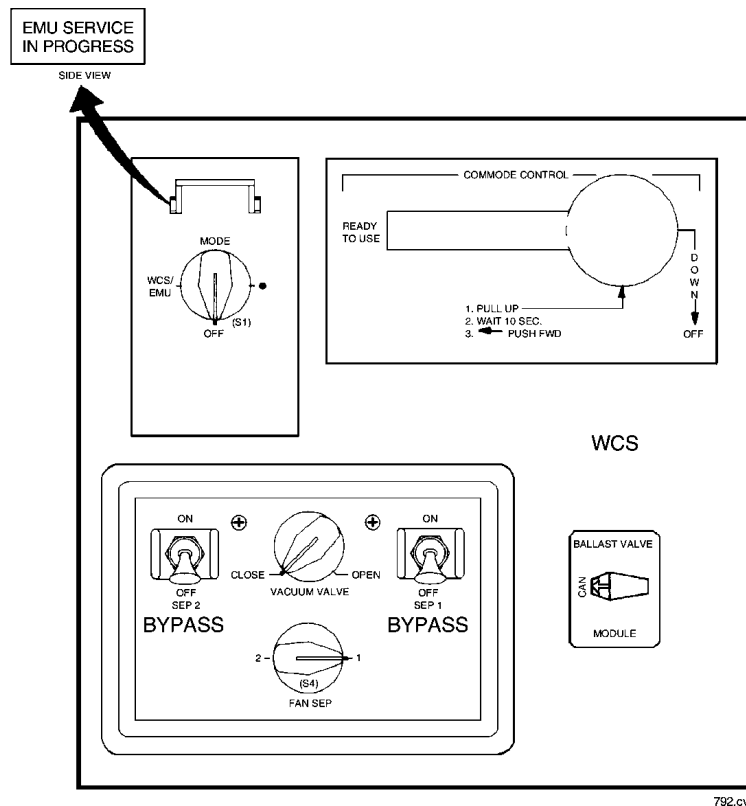
The controls on the waste management system are the VACUUM VALVE, FAN SEP select switch, MODE switch, fan separator bypass switches, and COMMODE CONTROL handle. The system uses dc power to control the fan separators and ac power for fan separator operations. The MODE switch and the COMMODE CONTROL handle are mechanically interlocked to prevent undesirable system configurations. The remaining controls operate independently. The fan separator bypass switches allow the crewmember to manually override a fan separator limit switch failure.

For launch and entry, the VACUUM VALVE switch is set to CLOSE. During on-orbit operations when the WMS is not in use, the vacuum valve is set to OPEN. This exposes the commode (overboard) via the vacuum vent system, and any solid wastes in the commode are dried. This also allows venting of the auxiliary wet trash and the volume F wet trash compartment. The hydrophobic bag liner in the

commode allows gas from the commode to vent overboard, but does not allow the passage of free liquid.

In the urine collection mode, the VACUUM VALVE remains in OPEN. The FAN SEP switch is positioned to 1 or 2. When the switch is positioned to 1, main bus A dc power is supplied to the MODE switch; when it is positioned to 2, main bus B dc power is supplied to the MODE switch. The MODE switch positioned to WCS/EMU energizes a relay for a fan separator (dependent on FAN SEP position). The active fan separator pulls cabin air flow through the urinal at a minimum of 10 cubic feet per minute and cabin air through the coffee can at 30 cubic feet per minute.

The coffee can air mixes with the urine transport air flow in the fan separator. Liquid check valves at the wastewater outlet from each fan separator prevent backflow through the non-operating separator during separator operation and prevent backflow to the urinal and air outlet when the separators are off. The liquid



Waste Management System Controls

and air mixture from the urinal line enters the fan separator axially and is carried to a rotating chamber. The mixture first contacts a rotating impact separator that throws the liquid to the outer walls of the rotating fluid reservoir. This centrifugal force causes the liquid to separate and draws it into a stationary pitot tube in a reservoir and directs the liquid through the dual check valves and into the wastewater tank. Air is drawn out of the rotating chamber and passes through the odor and bacteria filter, where it mixes with cabin air and re-enters the crew cabin.

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

In the EMU water drain mode, a guard is rotated over the *MODE* switch to preclude deactivation during the EMU and airlock water collection mode. A protective screen cap is installed on the urinal because it cannot be used during the EMU dump because of possible separator flooding. The WCS commode is still available for use during this mode. EMU condensate water is drained only if an EVA is required on a mission. The EMU wastewater is dumped through wastewater valves in the airlock. Other than these requirements, EMU dump is the same as the urine collection mode.

In the urine and feces collection mode, the *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 to the switch indicates *OP* when the valve is open, barberpole when the valve is in transit, and *CL* when the valve is closed. The *OFF* position closes the valve.

Even if the vacuum vent isolation valve could not be opened, vacuum vent functions would not be lost. A small hole in the valve plate allows proper venting overboard in such a contingency.

Alternate Vacuum Venting

Between the WCS ball valve and the vacuum vent valve is a vacuum vent quick disconnect (QD). For a failure of the vacuum vent system, vacuum venting can be regained by connecting a transfer hose from this QD to the contingency wastewater crossite QD, which allows venting through the wastewater dump line.

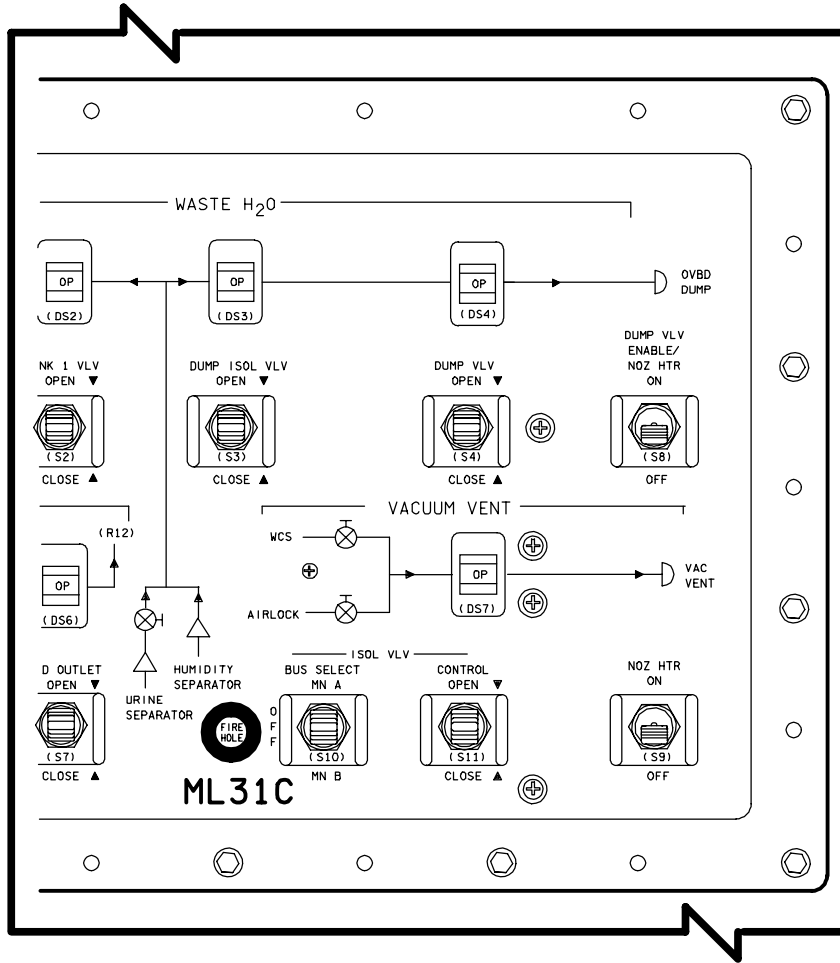
Heaters

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

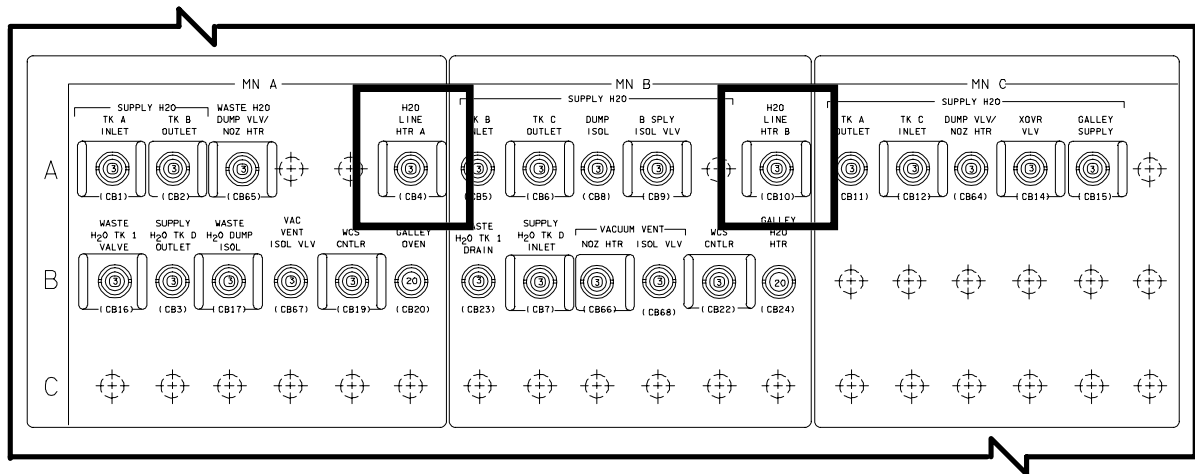
Heaters are also installed on the vacuum vent nozzle and are controlled by the *WASTE H₂O VACUUM VENT NOZ HTR* switch on panel ML31C. Electrical power is supplied to the vacuum vent nozzle heaters when the switch is positioned to *ON*. The *OFF* position removes electrical power from the vacuum vent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

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2.26 PAYLOAD AND GENERAL SUPPORT COMPUTER

CONTENTS

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Description

The payload and general support computer (PGSC) is a laptop portable computer used either as a standalone computer or as a terminal device for communicating with other electronic systems. The PGSC is one element of the command and data services provided by the Space Shuttle Program (SSP). These computers are used in many different activities.

Experiments

PGSCs are used in the middeck or flight deck to interface with flight-specific experiments that may be located in the cabin or payload bay. The PGSCs are used to monitor experiment data and/or issue commands to payloads or experiments in the payload bay.

Orbiter Communications Adapter

The orbiter communications adapter (OCA) is a card that is installed in the expansion tray to provide an interface to either the orbiter S-band PM system or the Ku-band system. While in the S-band mode, the OCA acts as a modem and allows electronic file transfers via one of the air-to-ground (A/G) audio loops, usually A/G 2 through the payload specialist (PS) audio panel. The A/G 2 loop provides a bandwidth of 32 kbps. The Ku-band system is capable of using a bandwidth of 128 kbps, in addition to one A/G loop for uplinks, thus enabling a higher data rate transfer. In the Ku mode, the downlink bandwidth could be in either 2 or 4 Mbps. Electronic file transfers include personal mail to individual crewmembers; Flight Data File (FDF) procedures; drawings; whiteboard, which is a real-time system of displaying what a person in MCC is sketching on a board; and video conferencing, which provides real-time video to and from MCC and displays the video on the PGSC screen.

Spacelab

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

Spacehab

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

Rendezvous

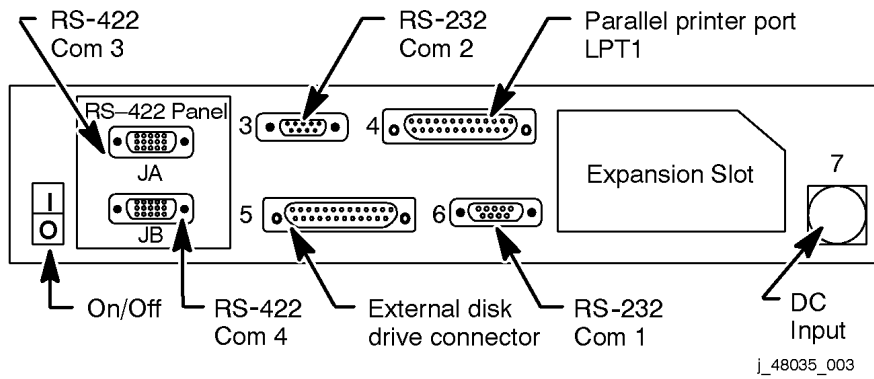
During missions that deploy or rendezvous with a payload or dock with Space Station, PGSCs are used as a tool to facilitate the orbiter's approach to its targets. Other tools used in conjunction with the PGSCs include:

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

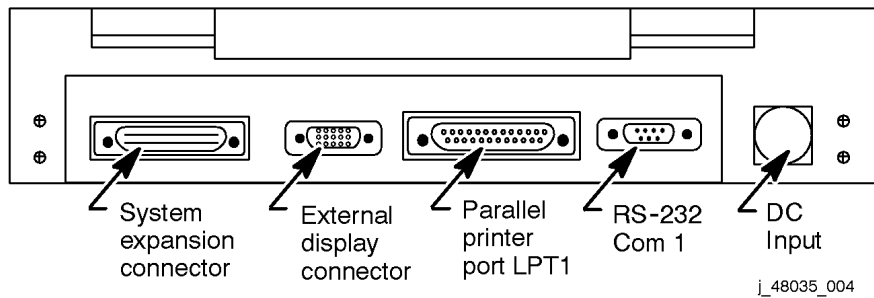
Equipment

Equipment flown to support PGSC activities includes:

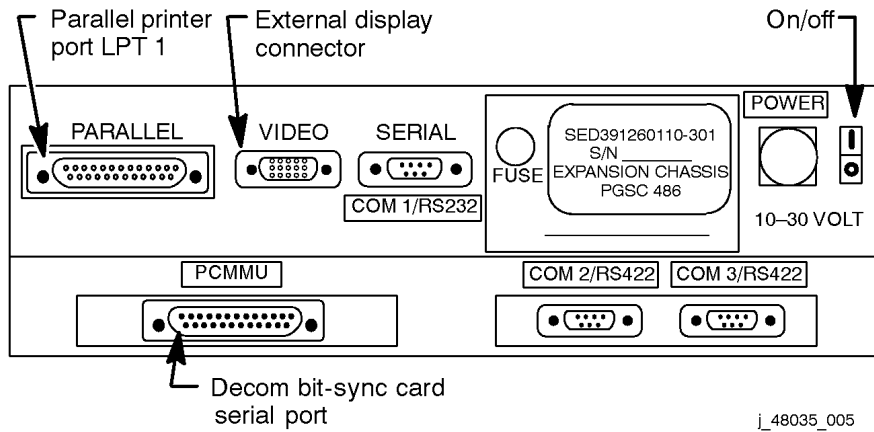
- IBM 755c laptop
- RS-422 and RS-232 Y - cables to interface multiple PGSCs
- PCDECOM cable to interface the orbiter PCMMU data to the PGSC
- RS-422 PDIP cables to interface PGSC with equipment located in the payload bay
- Cables to interface an HHL or TCS to a PGSC
- Expansion tray to provide additional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



PGSC (386) – 715; GRID



PGSC (486) – Thinkpad



PGSC (486) – Thinkpad Expansion Chassis

Back of PGSC and Expansion Chassis