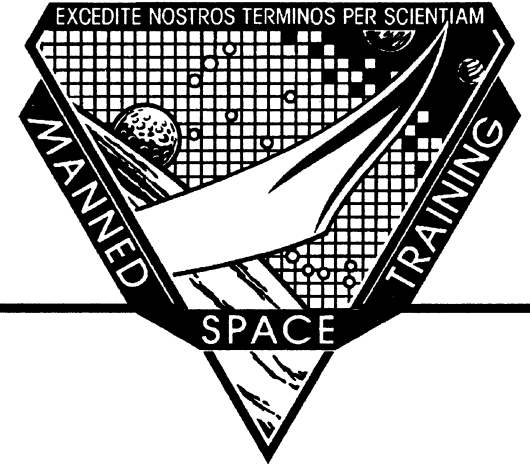


Reaction Control System Training Manual

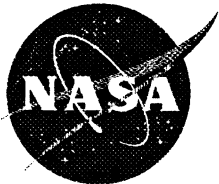
RCS 2102A



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Space Flight Training Division**

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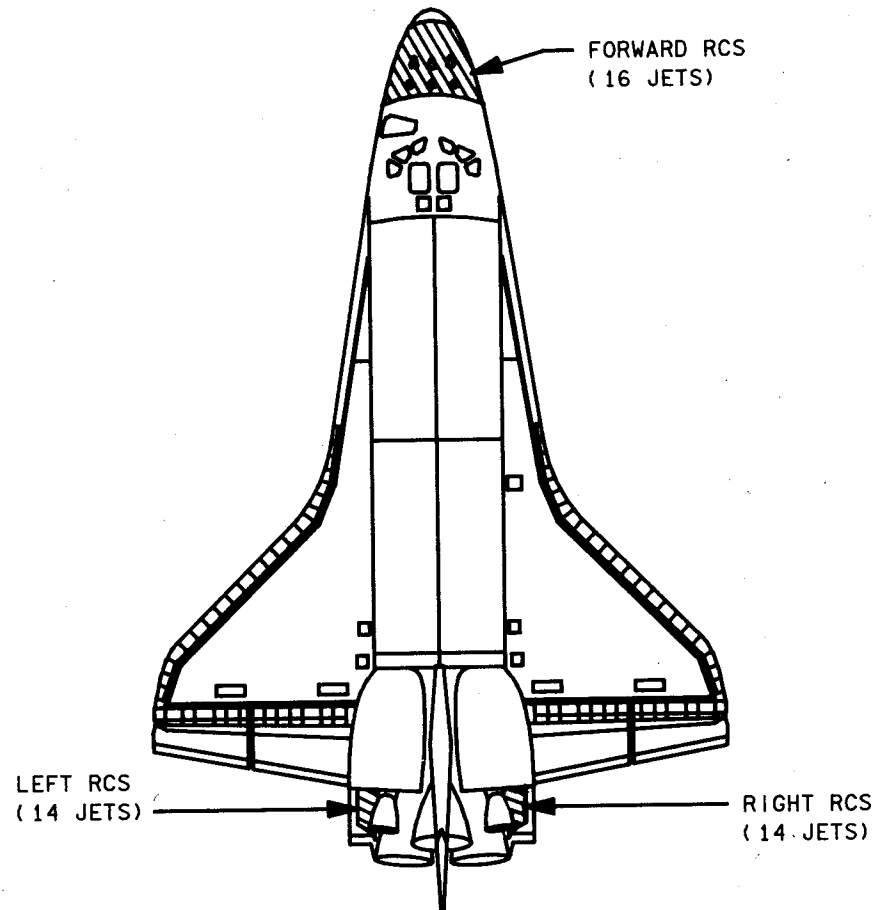
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Houston, Texas

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Section 1: Introduction

The reaction control system (RCS) is located in three separate modules in the vehicle: forward, left, and right, as illustrated in figure 1-1. The forward module is contained in the nose area, forward of the cockpit windows. The left and right modules are collocated with the orbital maneuvering system (OMS) in the left and right OMS pods, near the tail of the vehicle.



TD3400101. ART. 2

Figure 1-1.— Forward, left, and right RCS modules.

The RCS provides propulsive forces from a collection of jet thrusters in order to control the motion of the Space Shuttle vehicle. Each jet is permanently fixed to fire in a particular direction, either up, down, left, right, forward, or aft. The selective firing of individual jets (or specific combinations of jets) will provide the Orbiter with rotational movement (about an axis) or translational movement (along an axis). Refer to figure 1-2 for jet fire directions.

Rotational movement is primarily utilized for attitude control. RCS attitude control is used during orbital conditions, except during OMS burns when OMS gimbaling provides attitude control. (The RCS can assist the OMS with attitude control if OMS gimbaling is inadequate due to failures). During ascent, the RCS can assist the main propulsion system (MPS) during off-nominal situations with additional roll control. During entry, the RCS provides attitude control until the flight control surfaces become effective.

Translational movement is primarily utilized for velocity changes. Rendezvous and proximity operations on orbit may require a combination of both rotation and translation.

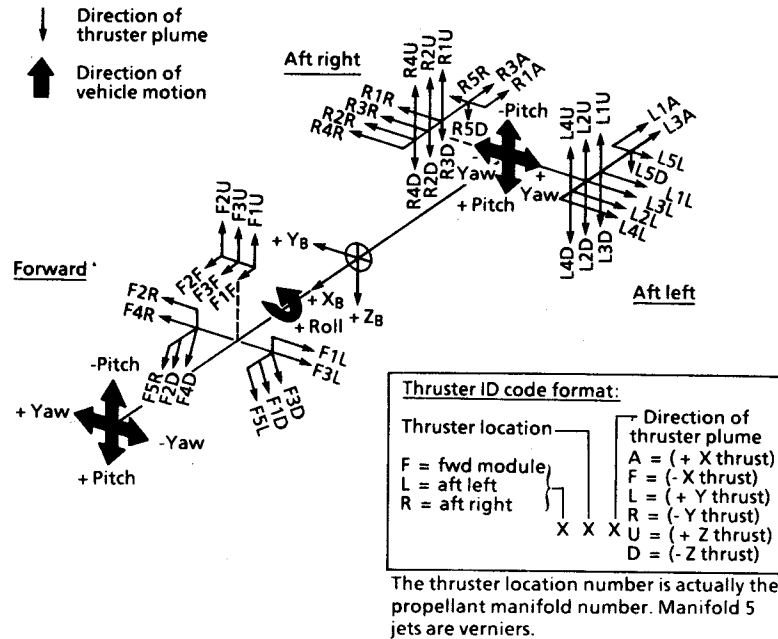


Figure 1-2.- RCS thruster identification.

The RCS has a total of 44 jets. There are 38 primary jets and 6 vernier jets. Each primary jet is rated at 870 lb of thrust and each vernier jet is rated at 24 lb of thrust. The vernier jets are only used onorbit for fine attitude control. The forward RCS has 14 primary jets and 2 verniers while each aft module has 12 primary jets and 2 verniers.

The RCS jets use monomethylhydrazine (MMH) as the fuel and nitrogen tetroxide (N_2O_4) as the oxidizer. (Note: the OMS uses the same type of propellants.) These propellants are hypergolic, which means that ignition occurs spontaneously upon fuel-oxidizer contact, thus eliminating the need for an ignition device. Although this adds reliability to the system, the volatile, corrosive, and poisonous nature of these propellants adds an operational risk, should any leakage occur.

Both propellants remain liquid at the temperatures normally experienced during a mission. However, there is a possibility of propellant freezing onorbit during long periods of RCS inactivity. Electrical heaters are utilized during these low activity periods to prevent the freezing of any propellant.

Each RCS module contains a collection of jets, a fuel tank, an oxidizer tank, and two helium tanks, along with associated feedlines, manifolds, and other supporting equipment. Propellant flow (fuel and oxidizer) to the jets is normally maintained by pressurizing the propellant tanks with helium. Refer to figure 1-3 for equipment location.

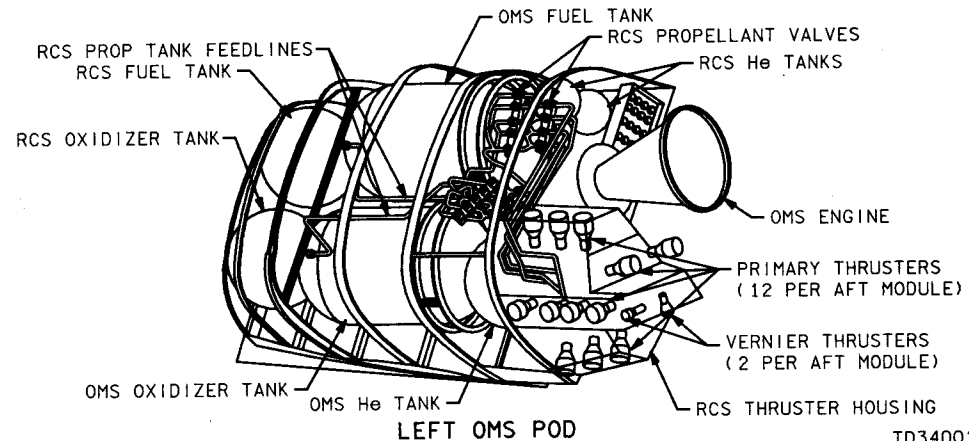
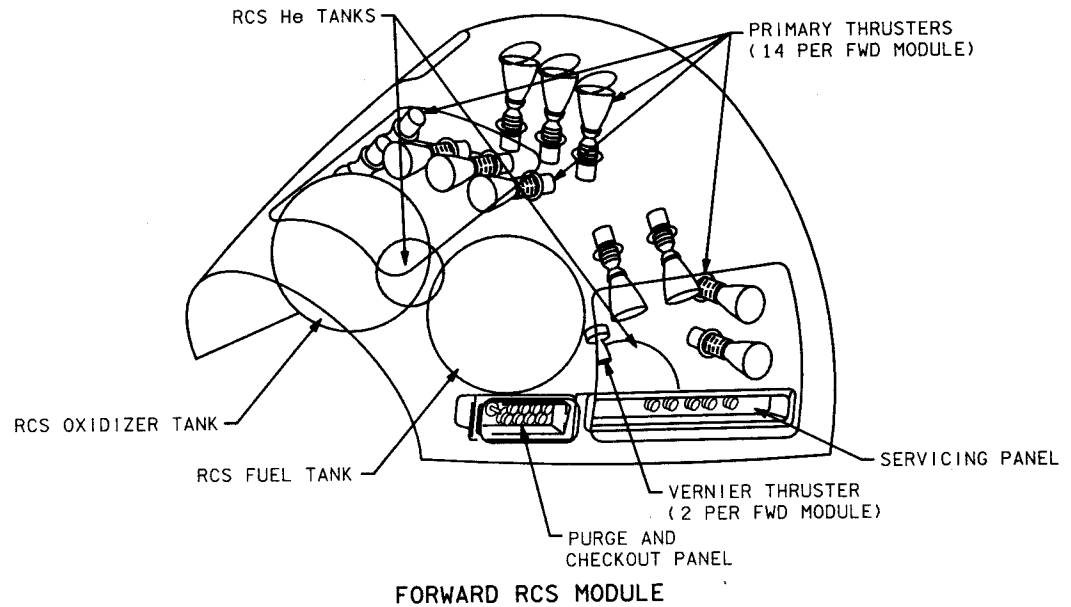
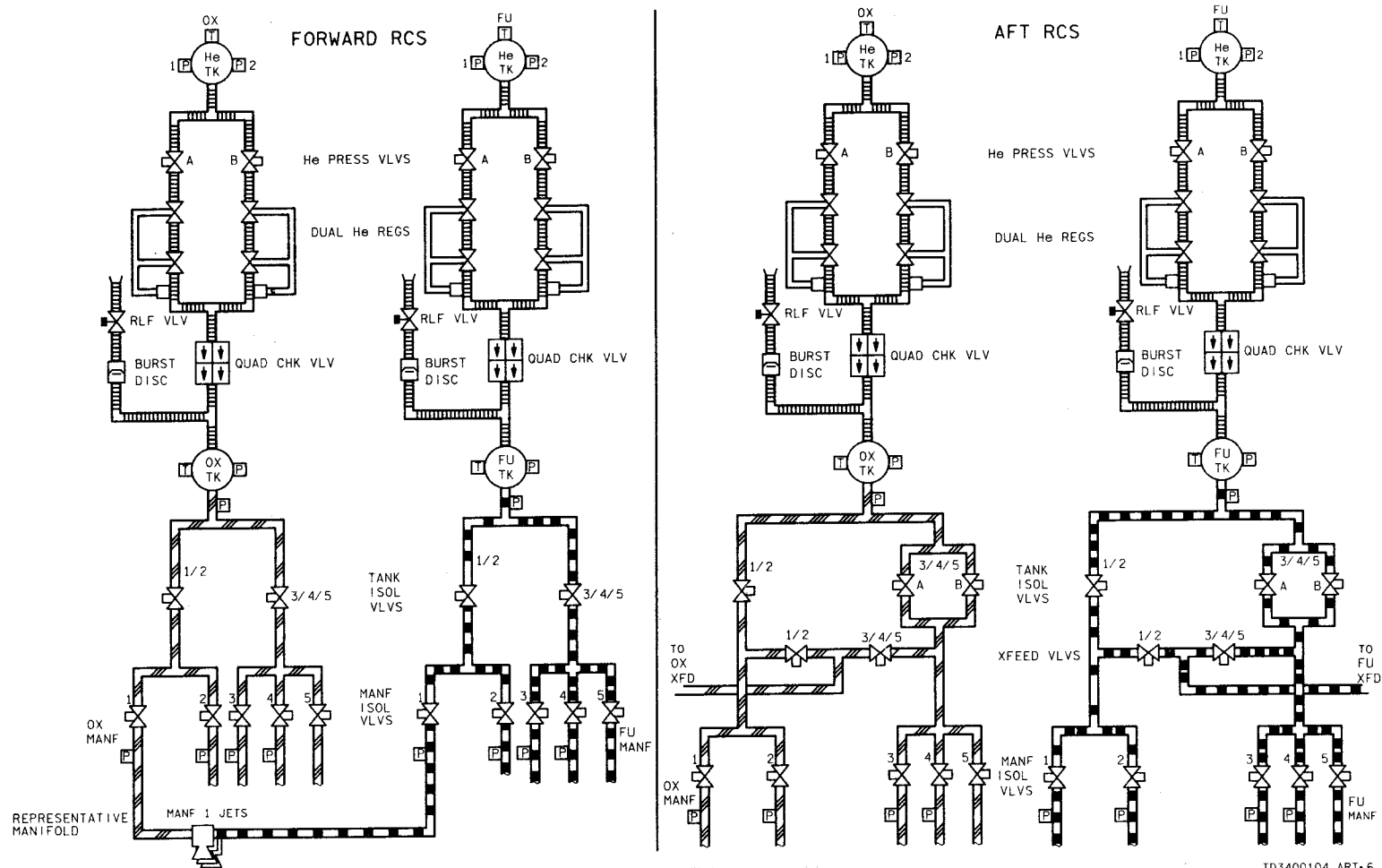


Figure 1-3.— Left and forward RCS modules.

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There are two major plumbing differences between the forward and aft RCS modules, as noted in figure 1-4. One difference is the redundancy in the aft RCS 3/4/5 tank isolation valves and the lack of the same redundancy in the forward.



TD3400104, ART. 6

Figure 1-4.- Forward and aft propellant schematics.

The other difference is the crossfeed lines between the left and right OMS pods and the lack of crossfeed lines in the forward RCS. The two crossfeed lines (one fuel and one oxidizer) are common to both OMS and RCS (figure 1-5). Depending upon the configuration of the OMS and RCS crossfeed valves, RCS propellant from one pod can be used to feed jets in the other pod (RCS to RCS crossfeed), or OMS propellant can be used to feed jets in either or both, aft modules (OMS to RCS interconnect).

RCS propellant should never be interconnected to the OMS engines because the RCS tanks are too small to support the increased propellant flow of the larger OMS engines. Subsequent propellant tank damage would occur.

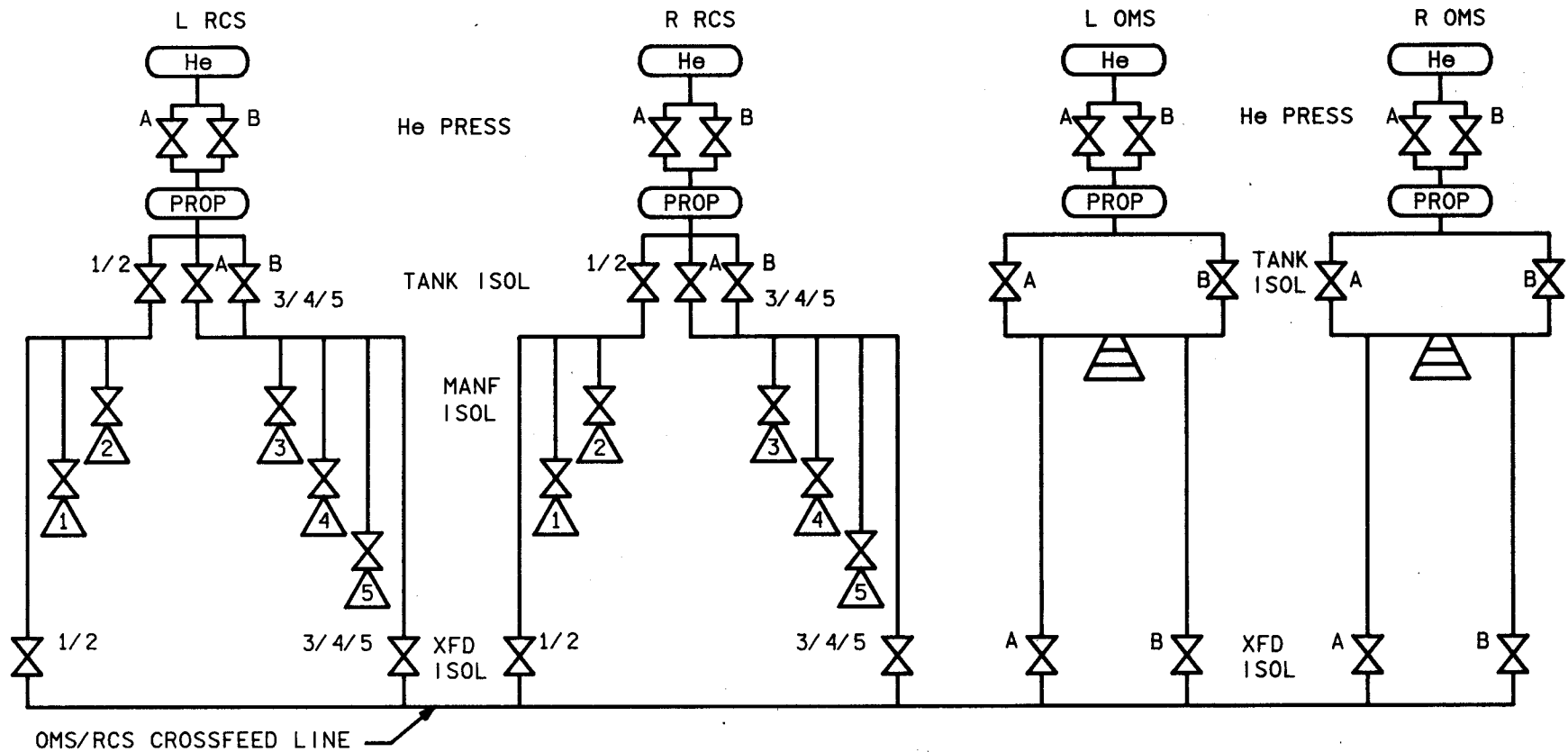


Figure 1-5.- OMS/RCS propellant schematic (FU or OX).

TD3400105. ART, 4

Nominal usage of the RCS is depicted in figures 1-6, 1-7, and 1-8 and includes control during the following time periods:

- Between main engine cutoff (MECO) and the OMS 1 (orbital insertion) burn which includes the external tank (ET) separation maneuver.
- Between the OMS 1 and OMS 2 (orbital circularization) burn.
- Onorbit (post-OMS 2 but before deorbit burn) when not in free drift or executing OMS burns.

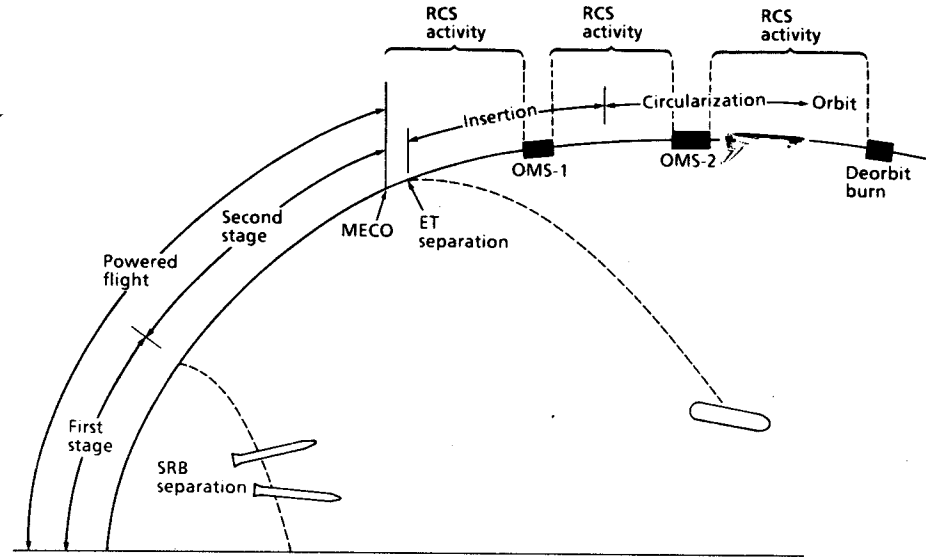


Figure 1-6.- Nominal ascent profiles.

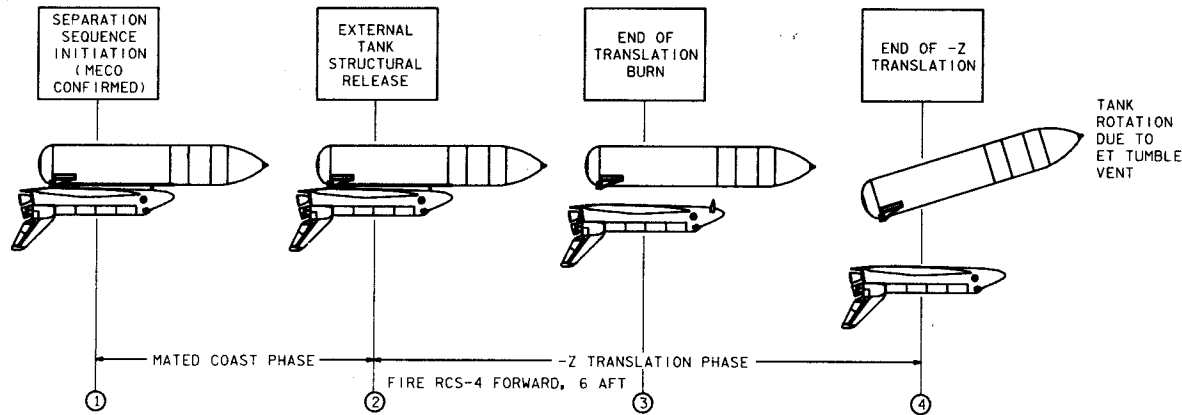
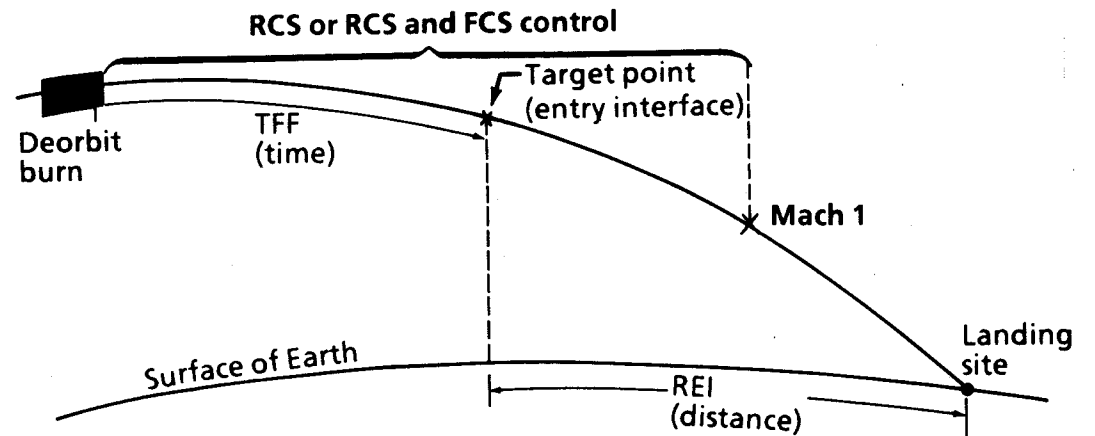
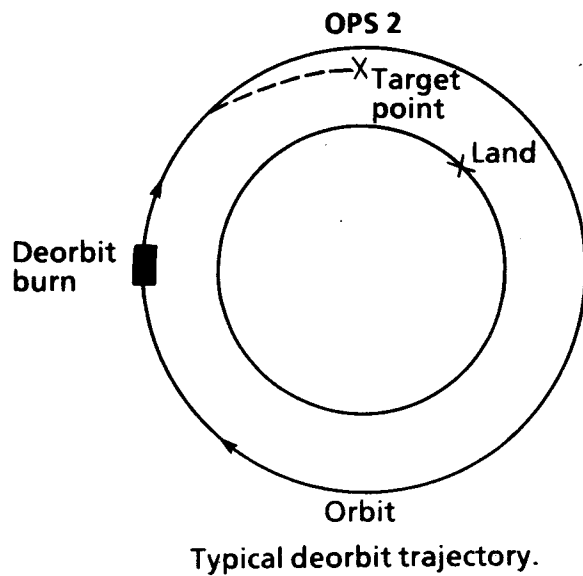


Figure 1-7.- External tank separation.

TD34001DT, ART. 3

- Post-deorbit burn until the flight control surfaces become effective. The RCS jets are used simultaneously with the flight control system (FCS) until the flight control surfaces are fully effective. When a flight control surface becomes effective, the associated RCS jets are deactivated. All RCS jets are deactivated by Mach 1.



TD340-108

Figure 1-8.- Deorbit trajectory.

The RCS is also used in the following off-nominal cases:

- Single engine roll control (figure 1-9).

In the event two main engines fail, the remaining main engine does not have sufficient gimbaling authority to control the rolling moment of the Orbiter/ET stack. The RCS is commanded to assist the single main engine with roll control. An OMS to RCS interconnect is automatically provided in order to conserve RCS propellant during this period of high RCS activity.

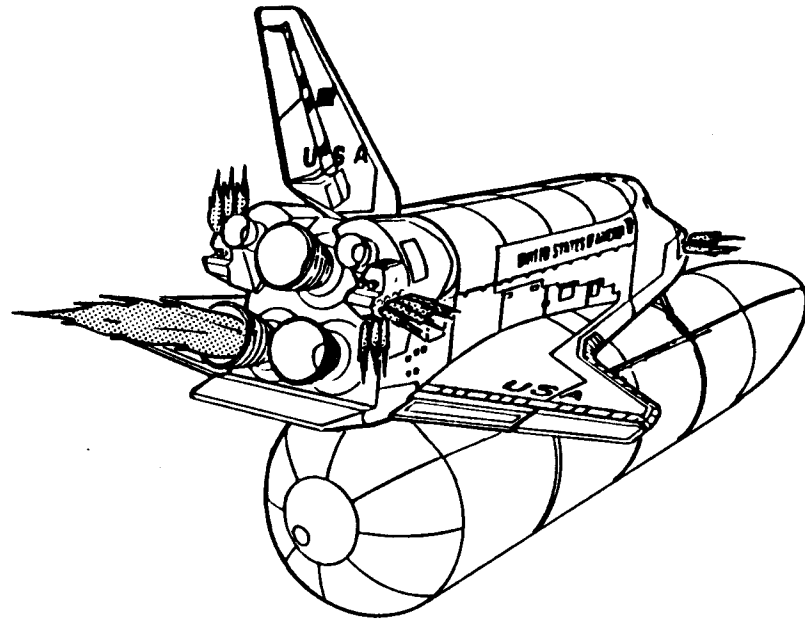


Figure 1-9.- Single engine roll control.

- Gimbal failures during OMS burns (figure 1-10).

If failures cause the lack of gimbal authority, the OMS engine(s) may not adequately control vehicle roll. The RCS can be commanded to assist the OMS (RCS wraparound). Although an interconnect is possible, it is not a requirement for RCS wraparound.

Note: Some onorbit burns are nominally planned for a single engine burn. Single engine OMS burns usually require RCS wraparound to provide roll control.

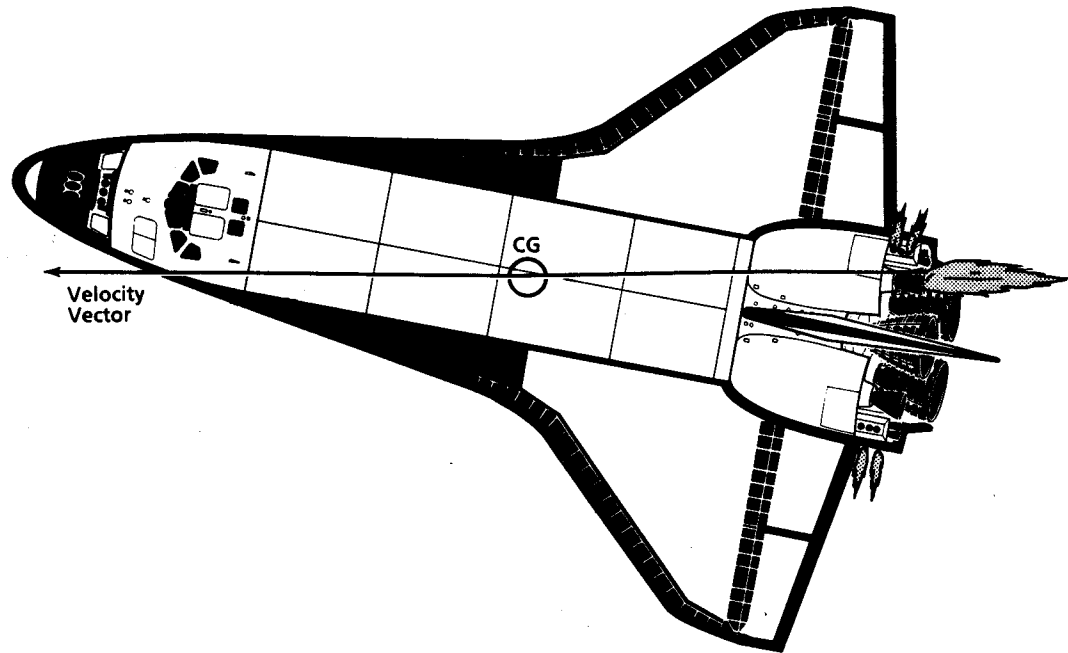


Figure 1-10.— Single engine OMS burn with RCS wraparound.

- OMS burn completion (figure 1-11).

In the event that both OMS engines fail during a burn, the RCS (forward and/or aft) can be used in the translational mode to complete the burn. The figure shows the use of the four aft firing jets for a +X completion. Use of jets in other directions (-X, +Y, etc.) would require significant attitude changes before starting the translational burn. The RCS may be interconnected to the OMS if adequate OMS propellant is available; otherwise, RCS propellant can be used to complete the burn.

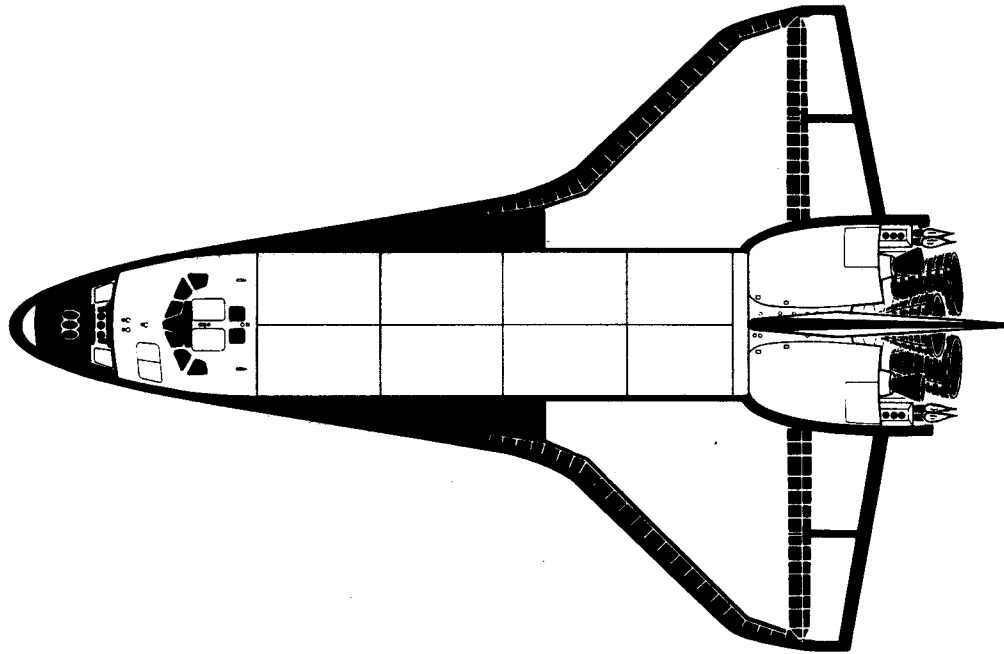


Figure 1-11. – RCS completion of an OMS burn.

- Abort dumps (figure 1-12).

In the event of an abort [return to launch site (RTL), transoceanic abort landing (TAL), etc.], a dump of excess propellant may be required to reduce the weight of the vehicle and bring the center of gravity (c.g.) within acceptable limits. The dump is not a venting of propellants but rather the simultaneous firing of up to 24 RCS jets (while interconnected to the OMS) and 2 OMS engines for propellant-wasting purposes. The abort dumps start with both OMS engines firing and an automatic interconnect. In order to rapidly deplete OMS propellants, the RCS jets fire shortly after the interconnect is complete. When the OMS dump is complete, the interconnect is reconfigured to straight feed and RCS propellant may be dumped through the aft firing jets.

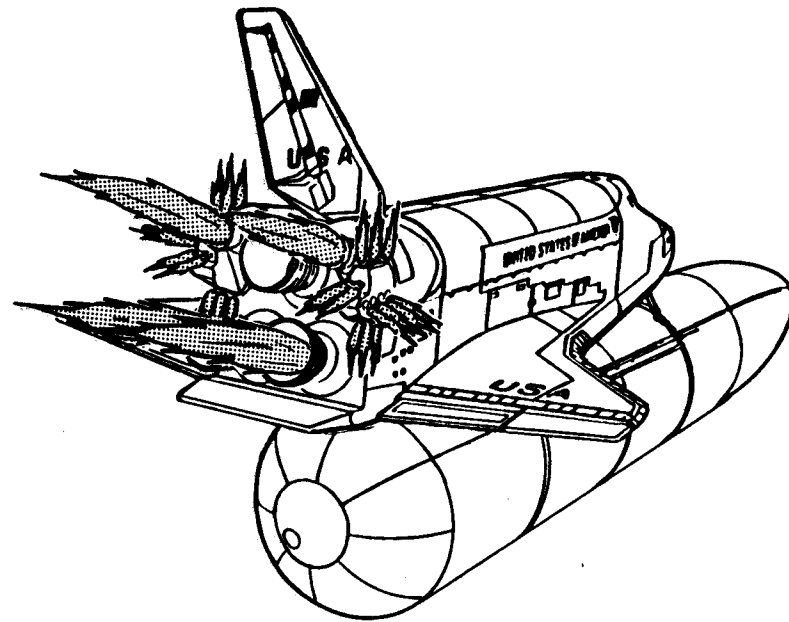


Figure 1-12. – RTL/TAL abort dump (2 OMS + 24 RCS jets).

The flight software is divided into operational sequences (OPS) that are subdivided into major modes (MMs), which correspond to mission phases (figure 1-14). It will be helpful to be familiar with the OPS and major mode numbers before continuing to the next section.

The remainder of this manual will cover the RCS in more detail. First, there will be a description of the various components of the system, followed by a description of systems operation. The next part of the manual provides the background information needed to understand and respond to system malfunctions. The last section covers differences

between the PASS and the BFS. The guidance and flight control aspects of RCS operations are discussed very briefly in this manual; if more information in this field is desired, please refer to the training manual concerning guidance and control for insertion/orbit/deorbit (G&C I/O/D 2102).

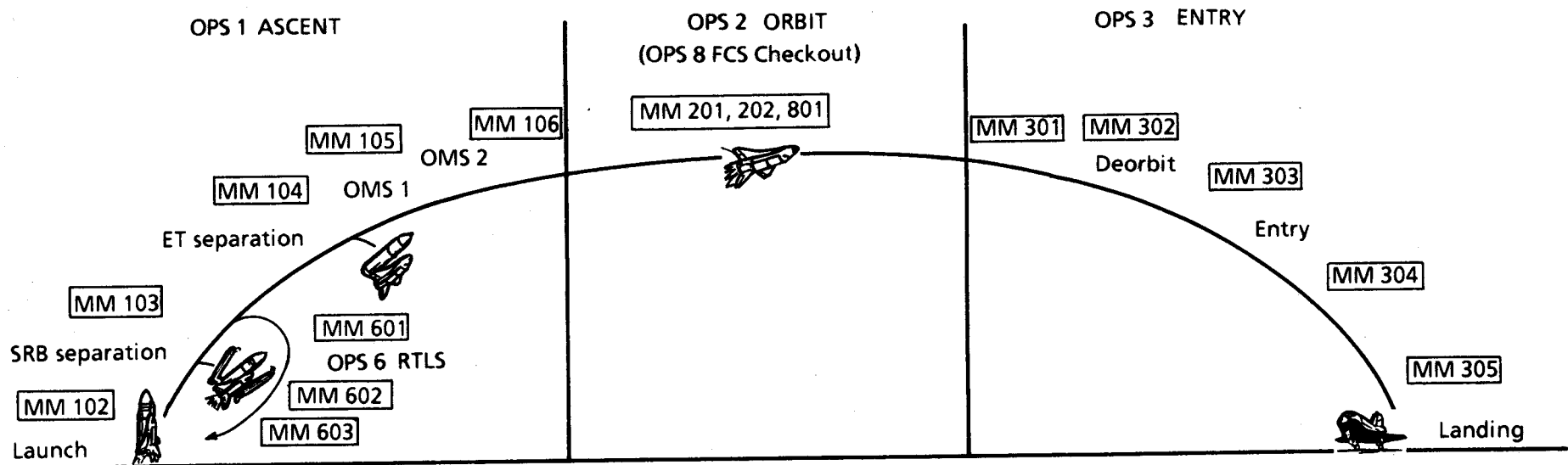


Figure 1-14.- Major modes.

Section 2: System Description

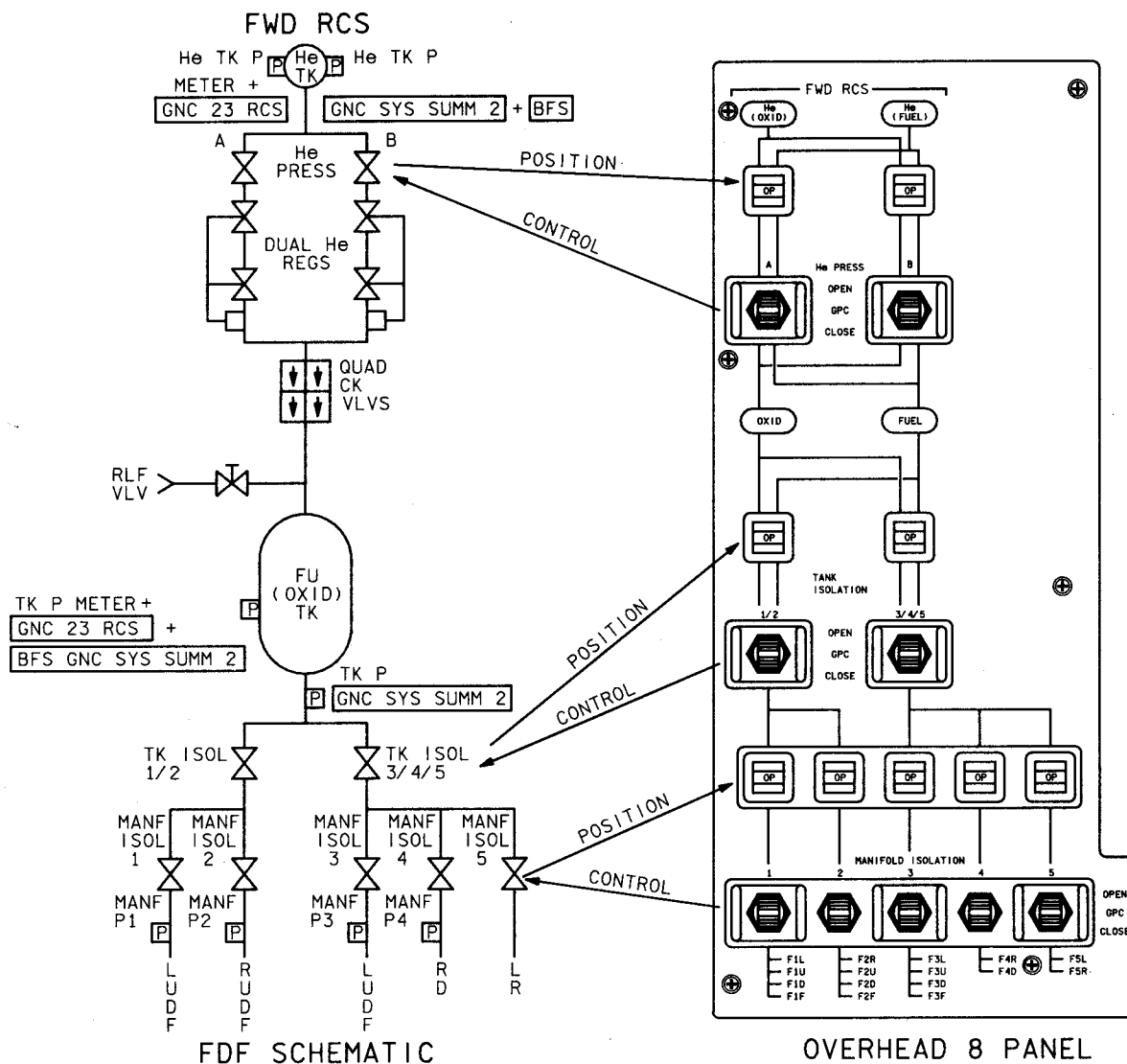
This section will cover the following components of the RCS:

- Helium and propellant supply
- Jet thruster system
- Quantity gauging
- Displays and controls
- Redundancy management (RM)
- Thermal control.

Helium and Propellant Supply

The fuel and oxidizer schematics in Section 1 showed that the propellant systems are schematically identical. Therefore, for the sake of simplicity, subsequent discussions and schematics will refer to propellants in a generic sense and will apply to both propellants (fuel and oxidizer) unless specifically mentioned otherwise.

Figure 2-1 shows a comparison between the Flight Data File (FDF) propellant schematic and the controlling panel for the forward RCS. Figure 2-2 shows the same comparison for the aft RCS. The position/control arrows refer to valve groups (TK ISOL, XFD, etc.) not to specific valves.



TD3400201, ART. 6

Figure 2-1.— Forward RCS schematic and forward RCS control panel.

Propellant is fed to the RCS jets from separate propellant tanks. The jet thrusters do not have propellant pumps; instead, propellant flow is maintained by keeping the propellant tanks pressurized with helium. Each propellant tank has a dedicated helium supply tank for pressurization.

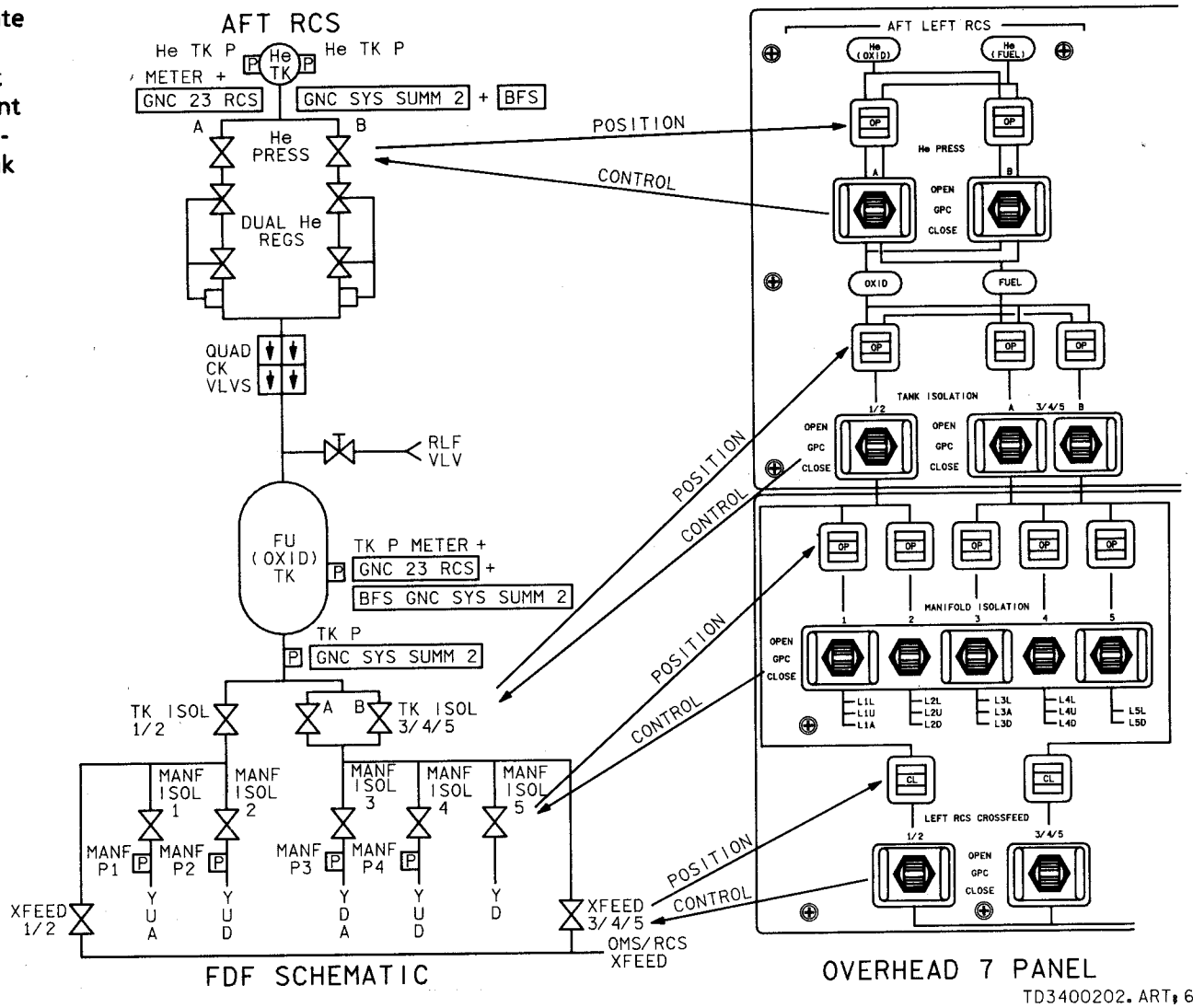


Figure 2-2.- Aft RCS schematic and aft RCS control panel.

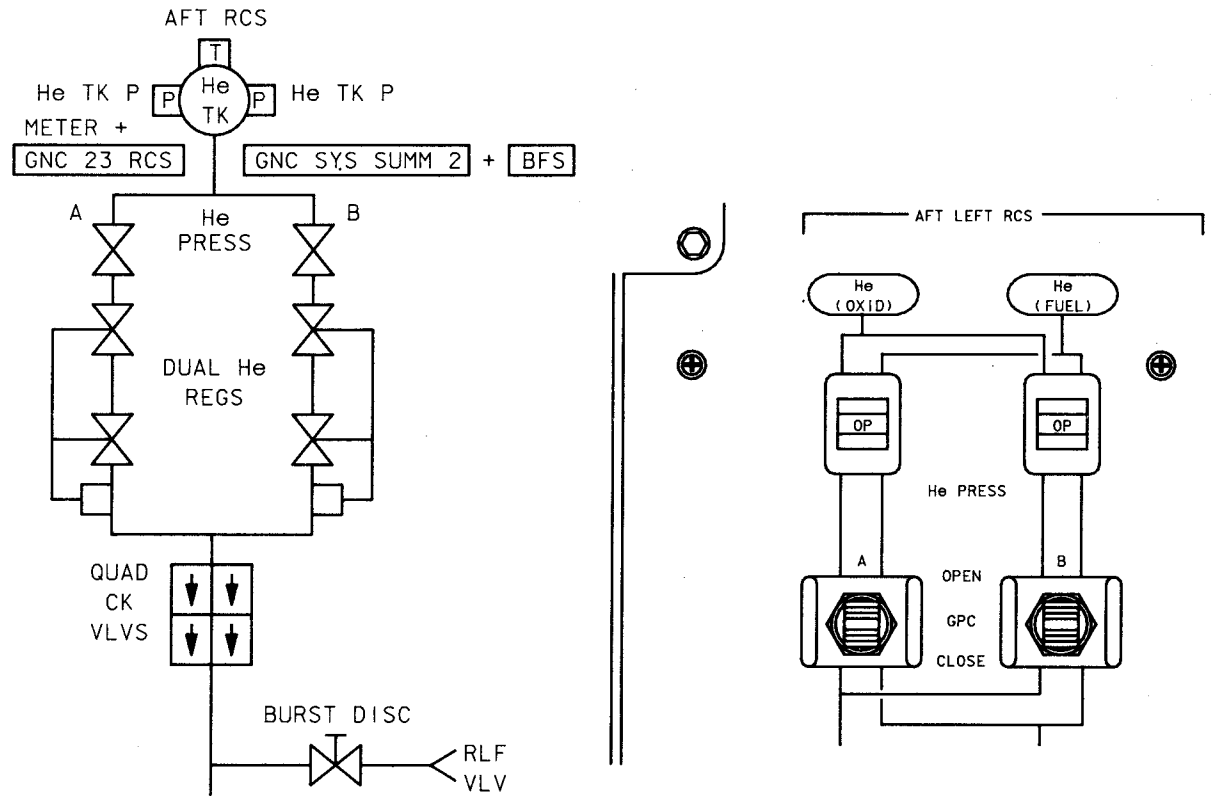
Helium System

Figure 2-3 shows the helium system of the RCS. The helium tank contains a supply of gaseous helium at a high pressure. There are two pressure sensors at the helium tank. Each sensor sends signals to independent meters (F7) and CRT displays (for redundancy and crosschecks) and to the GPCs (for quantity calculations). A temperature sensor on the helium tank also provides inputs to the GPCs for quantity calculations. Loss of temperature and/or pressure data may prevent accurate quantity displays.

The helium supply is fed to the propellant tank through two redundant lines, designated A and B. Each line has a pressurization valve to control the flow of helium to a dual pressure regulator assembly.

The helium pressurization valves are operated by two solenoids, one of which is momentarily energized to magnetically latch the valve open. The second solenoid magnetically unlatches the valve, allowing spring pressure and helium flow to force the valve closed.

These pressurization valves are activated by the associated switches on the control panels.



TD3400203. ART, 4

Figure 2-3.- Aft RCS helium system schematic and associated RCS switches.

All RCS valves are activated by an associated switch on the RCS control panels. The aft RCS switches are located on panel O7 and the switches for the forward RCS are located on panel O8. Each switch has three positions; open, close, and GPC. The open and close positions are for manual valve configurations while the GPC position allows the GPCs to perform valve configurations. The open and close positions provide continuous inputs to the valves (except for solenoid valves), until the selected configuration is attained. (Solenoid valves only receive momentary inputs upon initial switch movement.) The GPC position removes power from the valves until the GPCs are provided a command. Each switch controls two valves; one for the fuel system and one for the oxidizer system.

A position microswitch in each valve provides open and close inputs to a position indicator (talkback) on the RCS control panel. The talkback (tb) for a particular set of valves can be found just above its controlling switch on the control panel. Each talkback receives two inputs (one fuel/one oxidizer). When both inputs from the microswitches indicate open, the talkback will display OP. Likewise, if both inputs indicate closed, the talkback will display CL. If the talkback receives conflicting inputs (one open and one closed), or when the valves are in transition, the talkback will display a striped pattern (barberpole).

Downstream from each helium pressurization valve is a pressure regulator assembly that maintains the propellant tank ullage pressure at approximately 245 psi. Each assembly contains two regulators, a primary and a secondary, connected in series so that if one regulator fails open, the other can regulate the pressure within acceptable limits.

Helium supply lines A and B rejoin downstream of the regulators. The regulated flow of helium then passes through a check valve assembly. This assembly consists of four check valves arranged in two parallel sets of two, in series. The series redundancy ensures no backflow if one valve fails open. The parallel redundancy ensures adequate pressurization for the propellant tank in the event one valve fails closed.

A pressure relief valve is provided downstream of the quad check valves to prevent excessive pressure increases in the propellant system. The relief valve is a burst disc/poppet valve arrangement. If the regulated flow is within normal limits, the relief valve will be bypassed.

Propellant System

Propellant is stored in a spherical tank that is internally divided into two compartments of unequal size as illustrated in figures 2-4 and 2-5. The larger "upper" compartment has the pressurization inlet, and the smaller "lower" compartment has the propellant outlet. A pressure differential ensures the lower compartment is maintained full of propellant until the upper compartment is depleted.

Since the propellant tanks are used in a zero-gravity environment, special provisions must be made to ensure propellant flow without allowing helium ingestion into the propellant lines. This is accomplished by using the capillary action of surface tension screens (arranged in a web of channels) to capture the propellant, while the pressure differential between the compartments ensures propellant flow to the lower compartment. As long as the screen remains wet, the propellant will flow in the direction of pressure differential. If the pressure differential is zero, the surface tension of the screen will prevent any propellant backflow from the lower compartment. Negative pressure differential (propellant backflow) could destroy the surface tension of the screen and cause helium ingestion into the propellant lines.

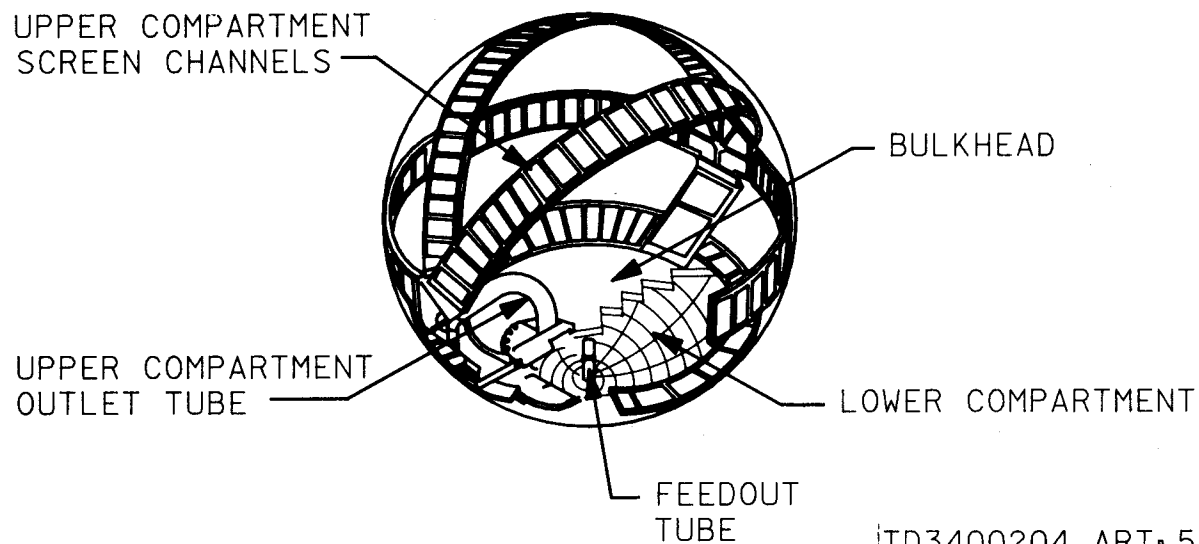


Figure 2-4.- Forward RCS propellant tank.

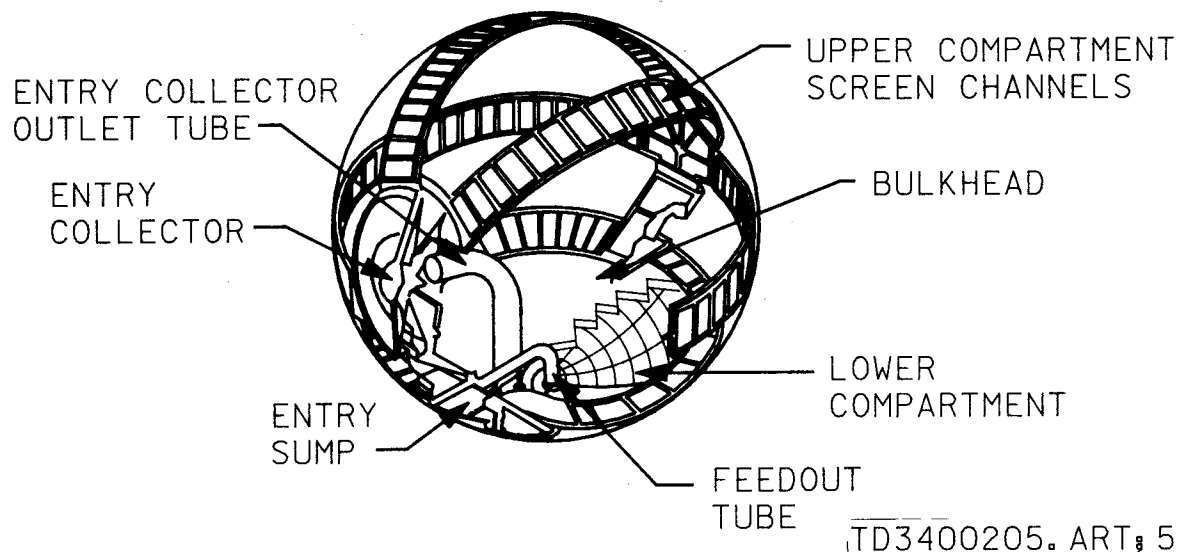
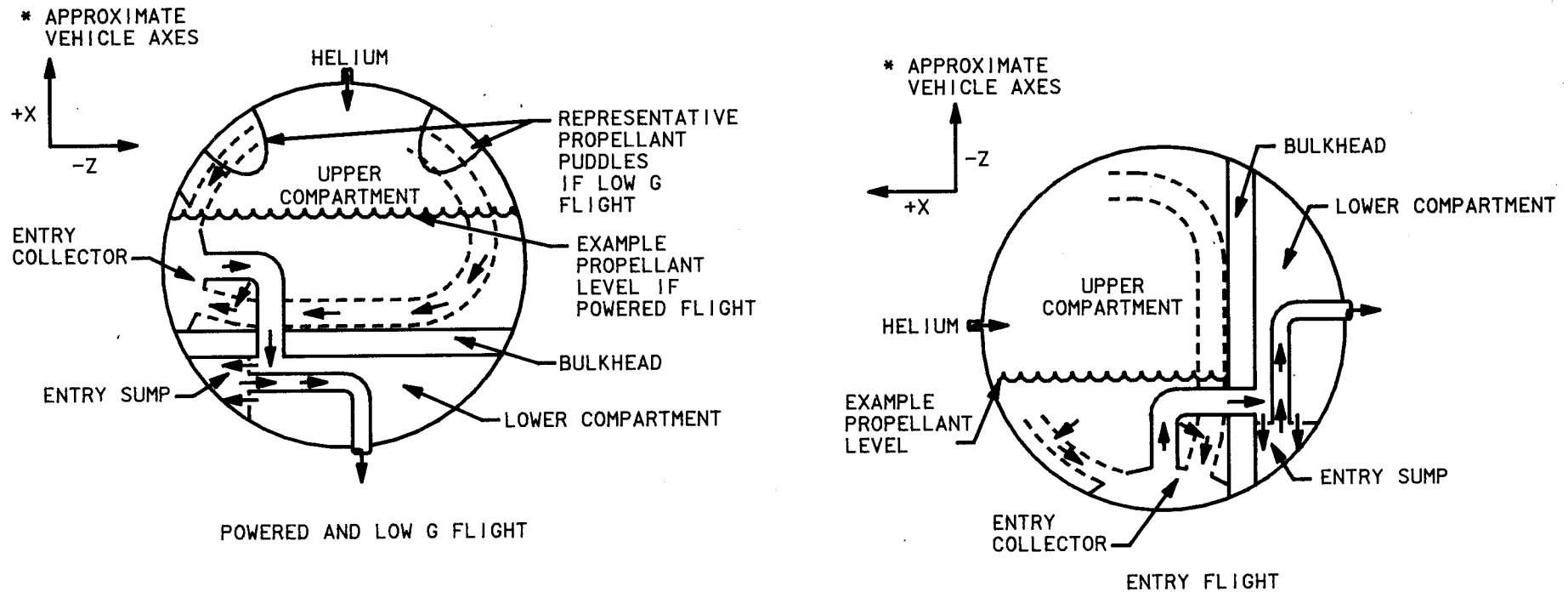


Figure 2-5.- Aft RCS propellant tank.

The forward and aft RCS propellant tanks are different in construction. Unlike the forward RCS, the aft propellant tank has an entry collector in the upper compartment and an entry sump in the lower compartment. This allows propellant acquisition to occur with the change in propellant level during the normal accelerations of entry (figure 2-6).

The forward propellant tanks are designed for low g usage only and have a limited capability during accelerated flight. Since there is no entry collector or entry sump, during accelerated flight (depending upon acceleration direction), the level of propellant could be below the level of the outflow tube. This would result in helium ingestion in the lines and subsequent jet failure.

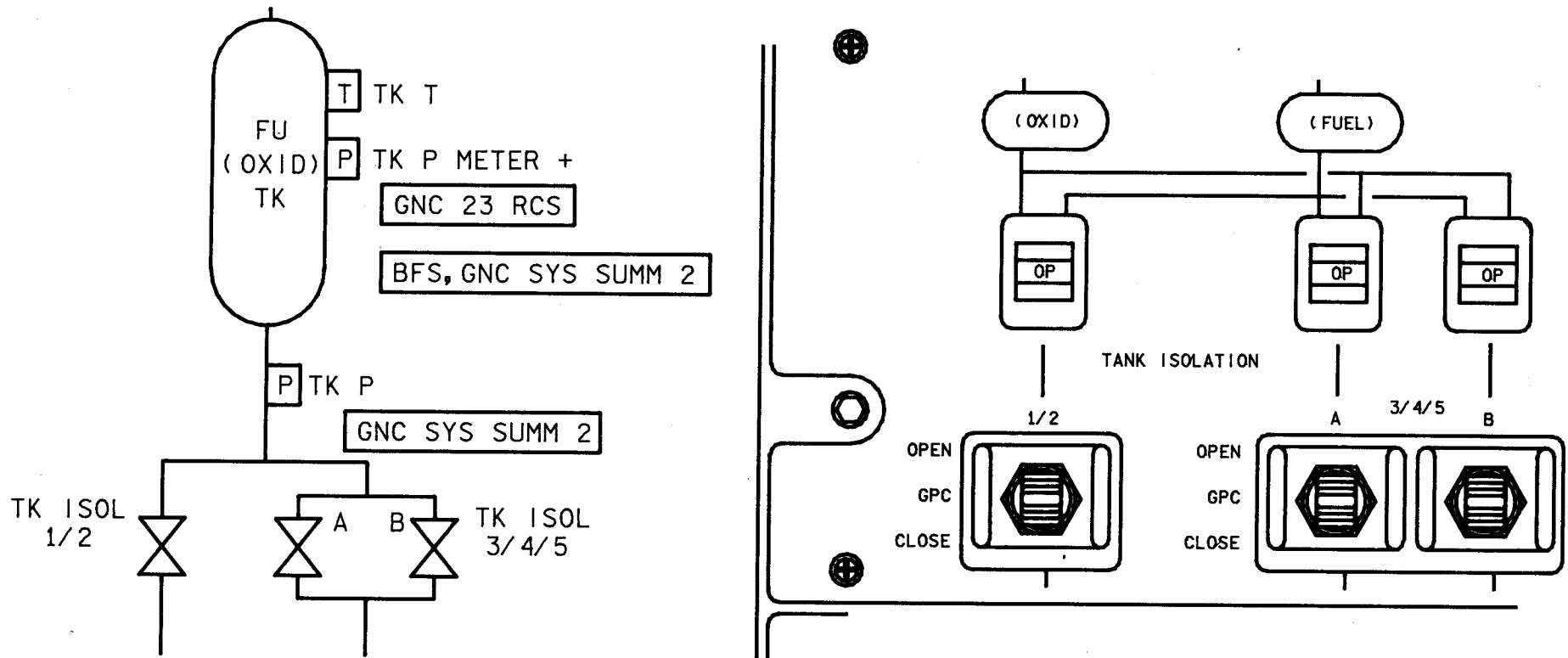


* NOTE 90° ROTATION BETWEEN FIGURES

TD3400206. ART, 8

Figure 2-6.- Propellant levels during powered flight, low g flight or entry.

Each of the propellant tanks has two pressure sensors and one temperature sensor (figure 2-7) . These sensors provide inputs to the GPCs for quantity calculations and display.



TD3400207. ART, 4

Figure 2-7.- Aft RCS propellant system schematic and associated RCS switches.

Quantity calculations are performed by using helium and propellant tank inputs to determine the gaseous volumes of the helium tanks and the gaseous volumes of the propellant tanks (ullage). The calculations are based on standard pressure-volume-temperature (PVT) relationships. The volume of the helium tank (V_H) is then compared to the volume of the associated propellant ullage (V_U). The relationship can be roughly defined as

$$Q \approx \frac{V_H}{V_U}$$

As propellant is used, V_H will decrease while V_U increases (figure 2-8). A decrease in V_H or an increase in V_U , due to a leak, will cause a decrease in displayed quantity.

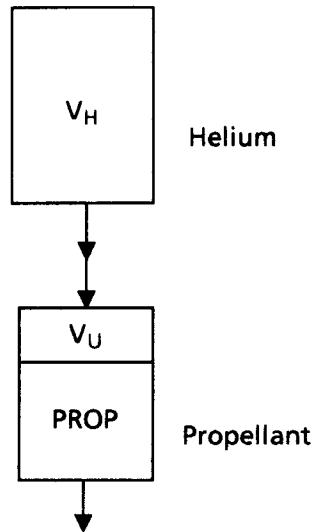


Figure 2-8.— Helium and ullage volumes.

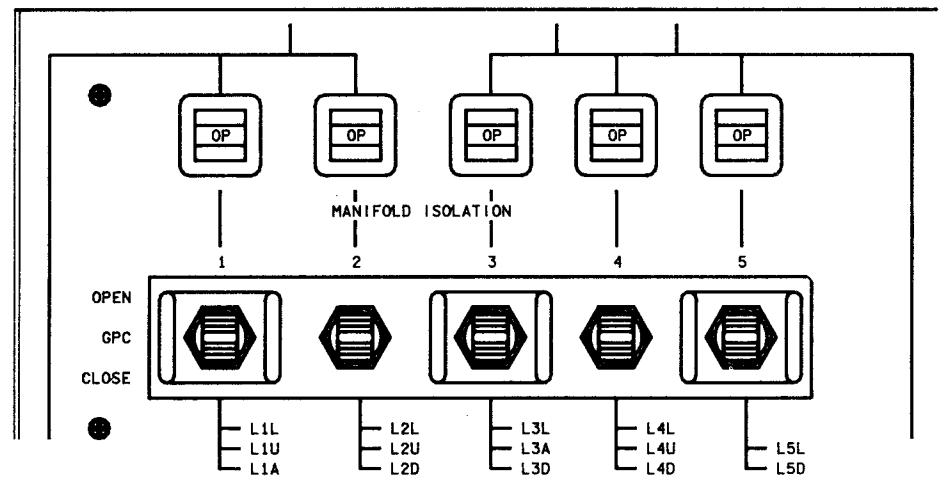
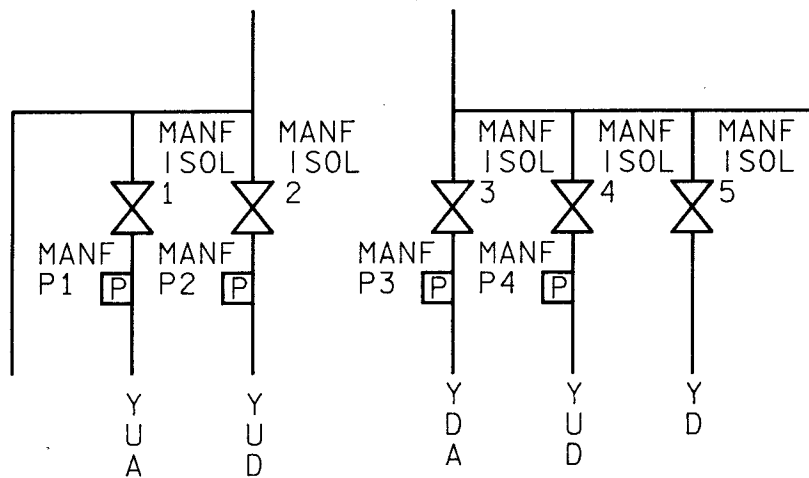
If helium pressurization is lost upstream from the helium isolation valves (helium leak, line blockage, or valves closed), then the associated propellant tank is in a "blowdown" state. The resident ullage pressure (V_U) is the only pressurization source. The amount of usable propellant is directly related to the volume of ullage. There is an optimum ullage volume that will allow total usage of the remaining propellant. This is called maximum blowdown. For the RCS, this is equivalent to about 23 percent propellant remaining.

The pressure sensor outputs are also utilized for onboard displays (CRT and meter), but each display does not use the same sensor. The lower tank pressure sensor is the TK OUT P sensor while the upper sensor is the TK P sensor. The temperature sensor signal is also used by the GPCs for display purposes on Spec 23.

Propellant supply from the tank is fed to the RCS manifolds through two separate feedline legs. Manifolds 1 and 2 are fed by one leg, and manifolds 3, 4, and 5 are fed by the other. Each leg has one tank isolation valve, except for the aft RCS. In the aft RCS, the 3/4/5 leg has two valves (labeled A and B) situated in parallel for redundancy.

The tank isolation valves are driven open and closed by ac motors that normally use three-phase ac power but have the capability of two-phase ac operation. (Single-phase capability does not exist.) These valves are activated by associated switches on the RCS control panels. Each switch controls two valves (FU and OX) and has three positions (OP/GPC/CL). Each switch has an associated talkback for valve position indication. When the valve attains its commanded position, the microswitch outputs will remove electrical power from the motor.

Downstream from each tank isolation valve, the feedlines branch off to supply individual manifolds. Each manifold has an isolation valve to control the flow of propellant. The isolation valves for manifolds 1, 2, 3, and 4 are ac motor driven while the isolation valves for manifold 5 are solenoid driven. Downstream from the manifold isolation valves each manifold feeds its associated jet thrusters (figure 2-9).



TD3400209. ART. 2

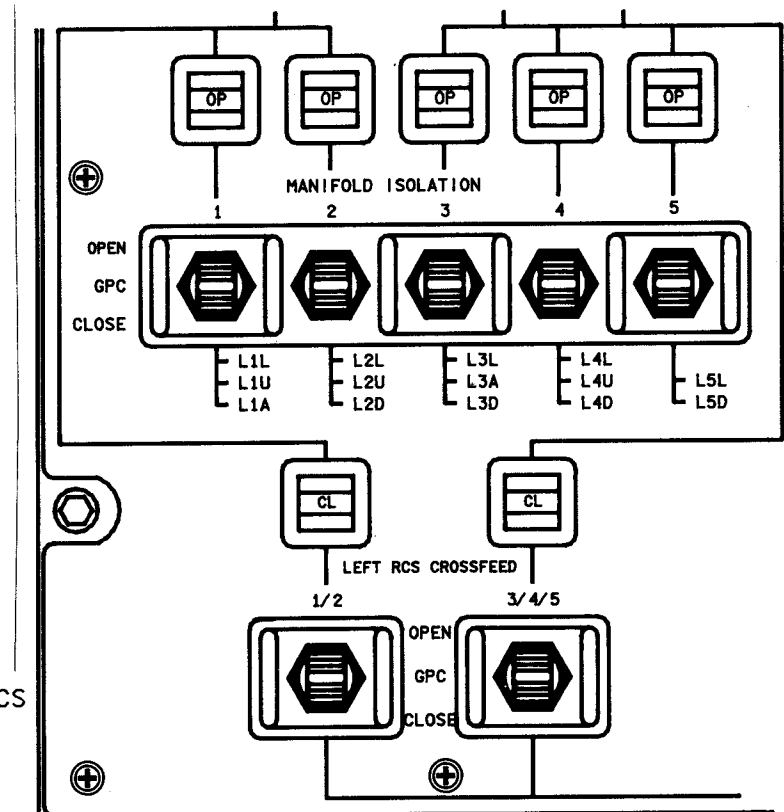
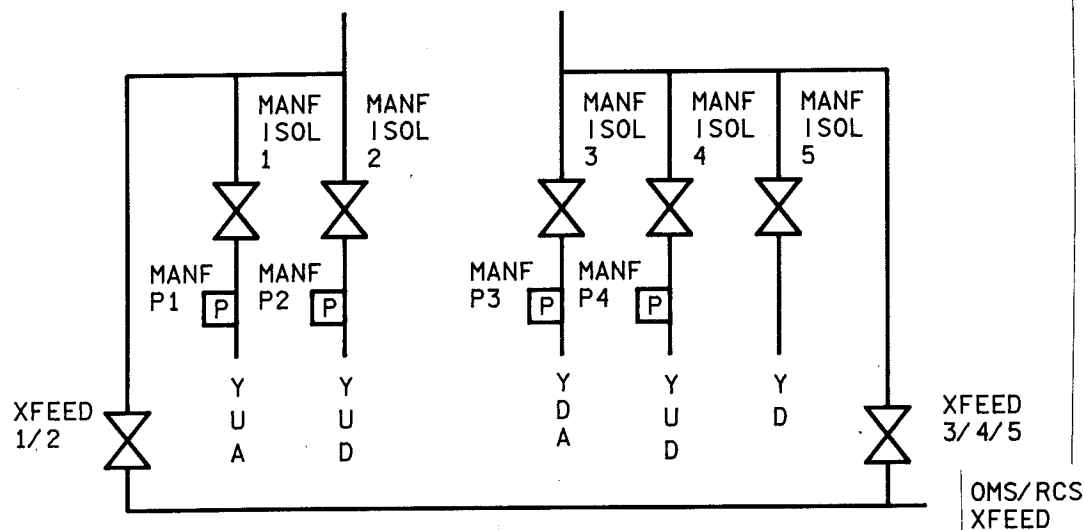
Figure 2-9.- Aft RCS MANF valves and associated RCS switches.

Crossfeed and Interconnect

In the aft RCS, it is possible to feed the RCS jets in one pod with RCS propellant from the other pod. This is called RCS to RCS crossfeed. (The forward RCS has no crossfeed capability.)

Crossfeeding is utilized primarily in cases where straight feed is impossible, impractical, or unsafe due to propellant leaks, valve failures, or line restrictions.

A crossfeed is established by opening left and right RCS crossfeed isolation valves and closing the receiving tank isolation valves. The switches controlling the left crossfeed valves can be seen in figure 2-10.



TD3400210, ART, 6

Figure 2-10.—Aft RCS/OMS crossfeed and associated RCS switches.

The crossfeed line depicted in figure 2-10 is just a portion of the crossfeed line that can also be accessed by the right RCS and both OMS. Figure 2-11 shows the relationship of the crossfeed line to both RCS and OMS during a crossfeed configuration (feed from right RCS).

Crossfeed lines connect the left and right RCS propellant tank leg lines downstream of the propellant tank isolation valves and upstream of the manifold isolation valves, feeding either the 1/2 leg or the 3/4/5 leg. Each crossfeed leg line has an associated crossfeed valve. These crossfeed valves are identical in operation to the propellant tank and primary manifold isolation valves (i.e., motor driven). Crossfeed switch and talkback operations are also identical.

Whenever propellant is introduced to a propellant leg via a crossfeed valve, the associated tank isolation valve should be closed to prevent backflow of propellant into the associated RCS tank.

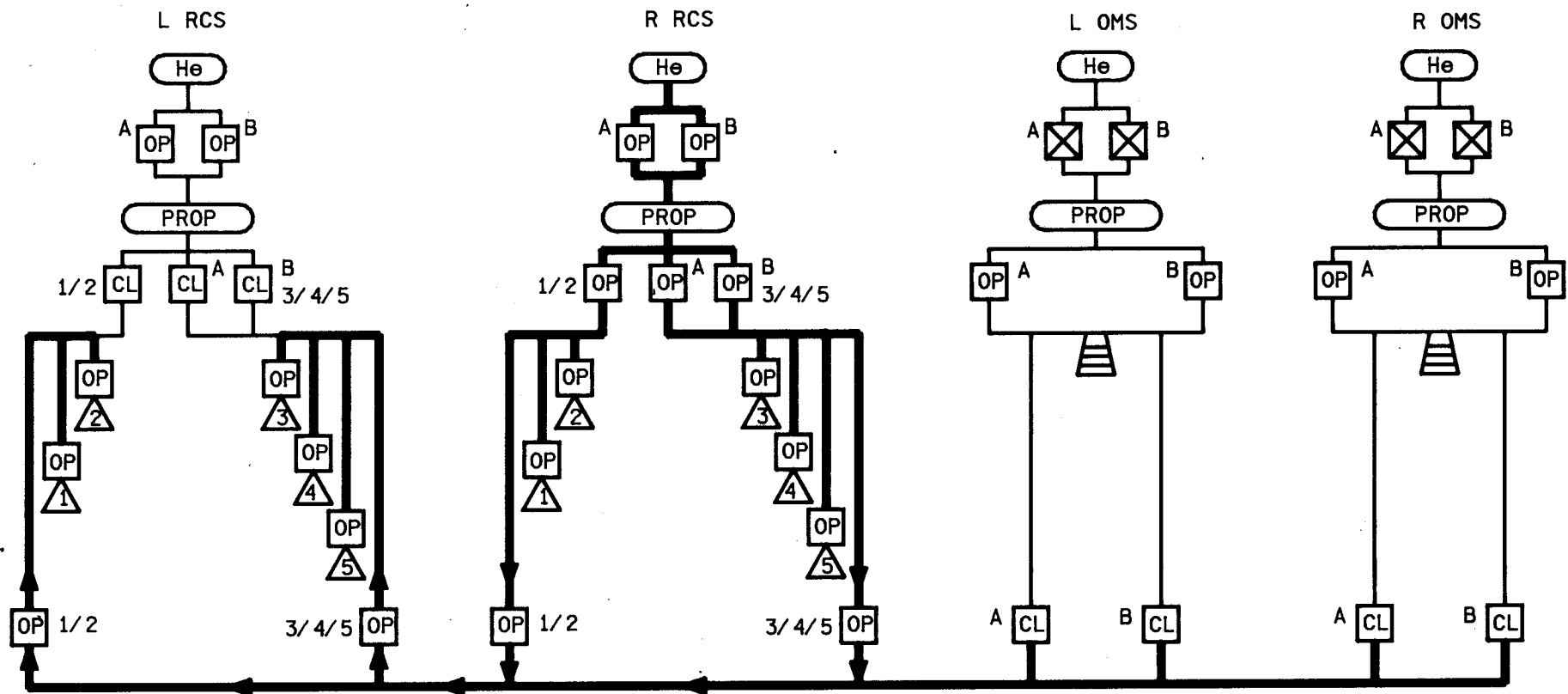


Figure 2-11.— OMS RCS schematic. RCS crossfeed - feed from right.

TD3400211. ART, 5

In order to obtain a crossfeed, the valves can be manually positioned by performing up to 10 switch movements. During ascent or entry, when reach and visibility are restricted, the crossfeed can be done automatically by moving one switch: the MASTER CROSSFEED switch on panel 07. In OPS 1, 3, and 6, when the MASTER CROSSFEED switch is moved to a FEED FROM position, the GPCs will issue appropriate commands to the RCS tank isolation and the OMS/RCS crossfeed valves in order to configure for the crossfeed. The tank isolation and crossfeed valve switches must be in GPC in order for the GPC commands to position the valves (the GPC position is nominal for ascent and entry). If any switch is mistakenly in manual open (or close), the manual command will override the GPC command for that valve.

When a crossfeed is completed, the three tank isolation talkbacks on the receiving side should indicate closed, the four RCS crossfeed talkbacks should indicate open, the four OMS crossfeed talkbacks should indicate closed, and the three tank isolation talkbacks on the feeding side should indicate open. Thus the propellant flows from the feeding tanks through the crossfeed lines to the receiving jets in the opposite pod. The jets in the feeding pod remain in a straight feed configuration.

In addition to commanding valves, the master crossfeed, when in a FEED FROM position, sets a discrete in the GPCs that indicates the RCS is in a crossfeed configuration and restricts the number of simultaneous jet firings in order to prevent tank damage. The setting of this discrete is available in all OPS and is set by the switch position not the valve configuration. Although auto crossfeed is not available in OPS 2, the setting of the crossfeed discrete is required to restrict jet firings. Note that, if the valves are manually configured for straight feed and the master crossfeed is in a FEED FROM position, the GPCs will still restrict the number of simultaneous jet firings.

It is also possible to feed OMS propellant from either (or both) pods to the aft RCS jets. This is called an OMS to RCS interconnect (Note: it is not called a crossfeed). Interconnecting OMS to RCS can be a nominal procedure if performed onorbit to save RCS propellant and use OMS propellant for maneuvering. Unlike a crossfeed, there are no restrictions to the number of simultaneous jet firings while interconnected. The RCS is interconnected to only one OMS pod for onorbit interconnects.

During aborts, the OMS propellants need to be dumped to reduce Orbiter weight and to obtain a controllable c.g. for entry. In order to accomplish this in a minimum amount of time, both OMS pods are interconnected to the RCS. Once the interconnect is achieved, OMS propellant is wasted by firing both OMS engines and up to 24 RCS jets simultaneously. Since this configuration has the RCS tank isolation valves closed, only OMS propellant is dumped.

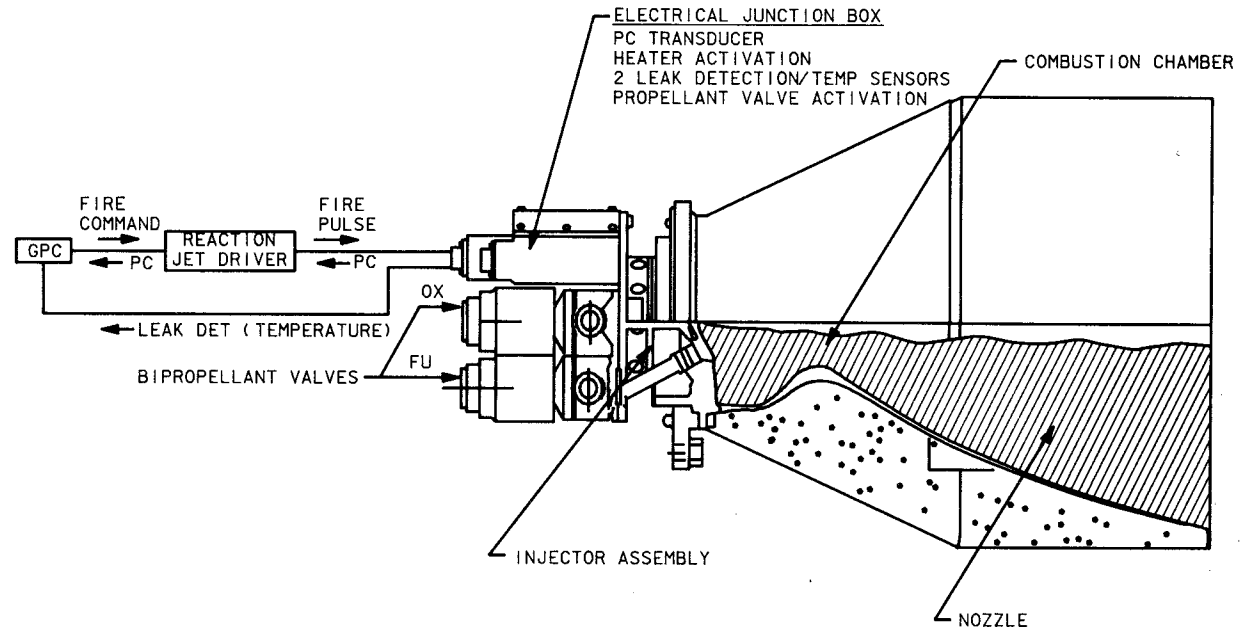
Jet Thruster System

The jet thruster system, as illustrated in figures 2-13 and 2-14, is where the fuel and oxidizer are combined to produce hypergolic combustion (hot gas thrust). The system's major components are the reaction jet driver, bipropellant valves, injector assembly, combustion chamber, and nozzle.

The reaction jet driver (RJD) is the "black box" that converts GPC fire commands into the required voltage for opening the bipropellant valves, thus initiating the combustion process. The driver also determines chamber pressure (P_c) discretely and sends them to redundancy management (RM) as an indication of actual jet firings.

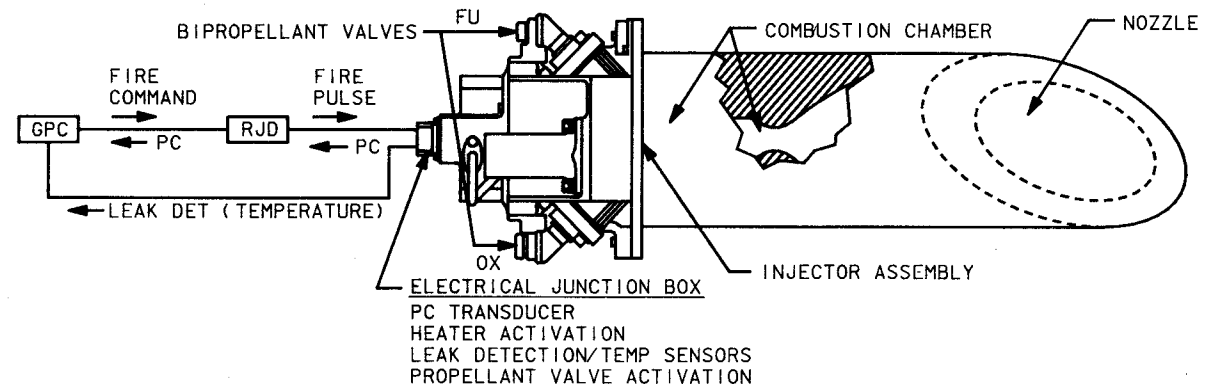
The bipropellant valves are solenoid driven and electrically activated so that both valves open and close simultaneously. The primary jet valves are hydraulically assisted by propellant pressure when opening. The vernier jet valves operate by "pure" solenoid activation (no hydraulic assist).

The valves are energized open by a jet fire pulse and are spring loaded closed when the pulse is removed. When the bipropellant valves are open, fuel and oxidizer are allowed to flow to the injector assembly.



TD3400213. ART, 2

Figure 2-13.— Primary thruster.



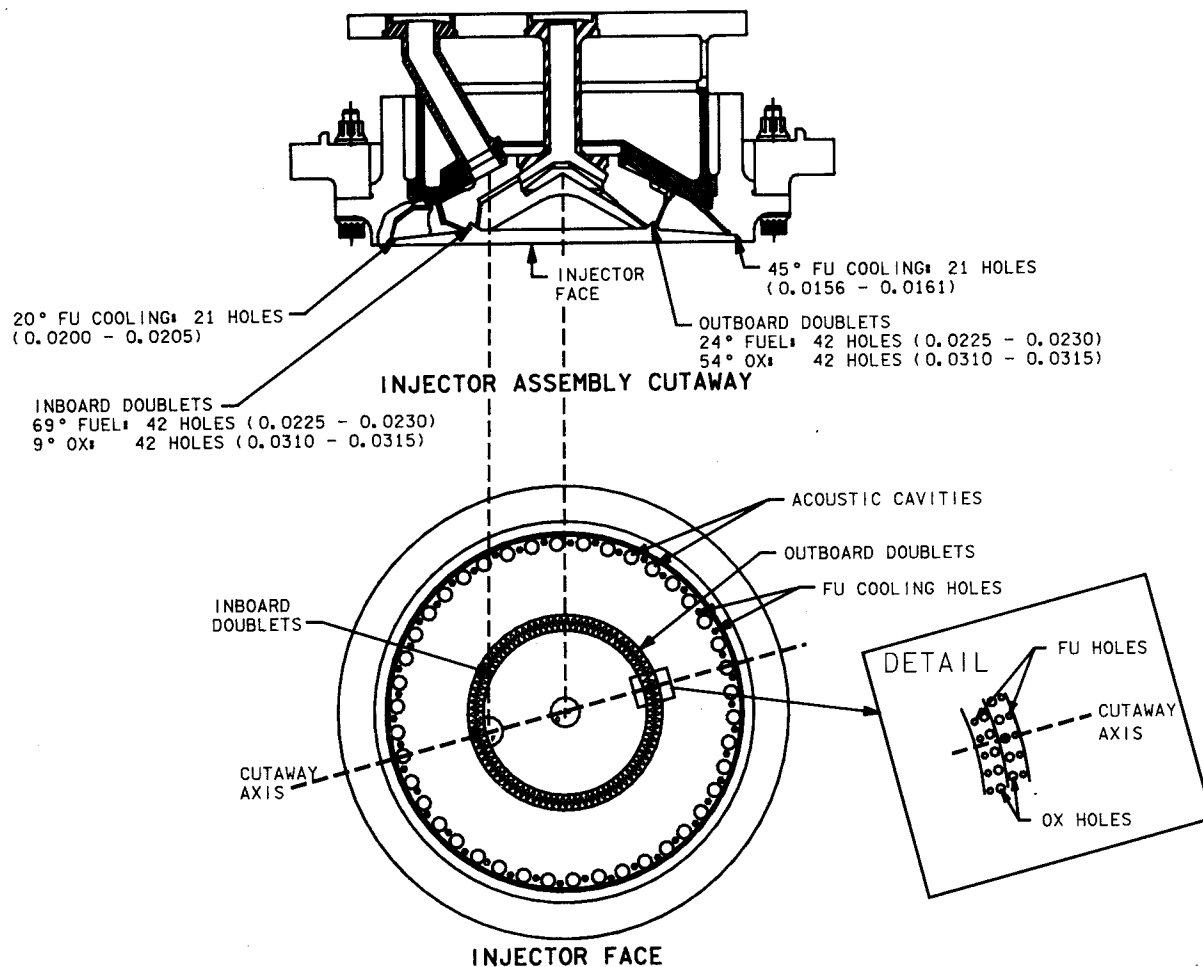
TD3400214. ART, 2

Figure 2-14.— Vernier thruster.

The injector assembly directs the flow of propellants to the combustion chamber. Figure 2-15 shows the injector assembly for a primary jet. Injector hole pairs (one fuel, one oxidizer), called doublets, are 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 at the combustion chamber. Additional fuel holes are provided near the outer edge of the injector assembly for cooling the chamber walls.

There are also acoustic cavities that provide jet stability at ignition. The smaller vernier jet (not pictured) has only one pair of injector holes. Fuel cooling of the vernier chamber walls is achieved without additional fuel holes because the fuel stream is designed to be more divergent than the oxidizer stream.

The combustion chamber area has additional supporting equipment that includes an electric heater at the injector plate to prevent propellant freezing, a P_c transducer for inputs to the RJD, and two temperature sensors for leak detection. After combustion, the hot gases are expanded through the nozzle, thus completing the thrust process



TD3400215. ART. 4

Figure 2-15.-- Primary jet injector assembly cutaway and injector face.

Quantity Gauging

The RCS quantity gauging software sequence computes the percentage of usable fuel and oxidizer remaining in each of the three RCS modules. Additionally, the sequence performs leak detection by comparing the computed fuel and oxidizer quantities in each pod. If the fuel and oxidizer quantities in any pod differ by more than 12.6 percent, then the GPCs will issue a leak alert for the affected pod.

In OPS 2, this sequence also provides automatic overpressure protection to the propellant tanks by closing the affected system's helium pressurization valves if the propellant tank pressure sensor inputs exceed the high caution and warning limit. Since this automatic closure is a GPC command, a helium pressurization valve switch must be in the GPC position for the GPC command to take effect. The software cannot reopen the valves when the pressure returns to normal limits; manual positioning is required to reopen the valves.

The BFS quantity sequence runs in OPS 1, 3, and 6. The PASS sequence runs in OPS 2, 3, and 8. The digital readout on panel O3 will display the PASS computed quantities (which will be zero in OPS 1 and 6 since there is no sequence), unless the BFS is engaged, at which time it will display BFS quantities. The BFS computations are always displayed on BFS SYS SUMM 2. In addition to BFS SYS SUMM 2, RCS quantities are displayed on SYS SUMM 2 and Spec 23. For quick review purposes, the RCS quantity display availability is summarized in table 2-1 at the bottom of the page (✓ means available).

Table 2-1.-- RCS quantity display availability.

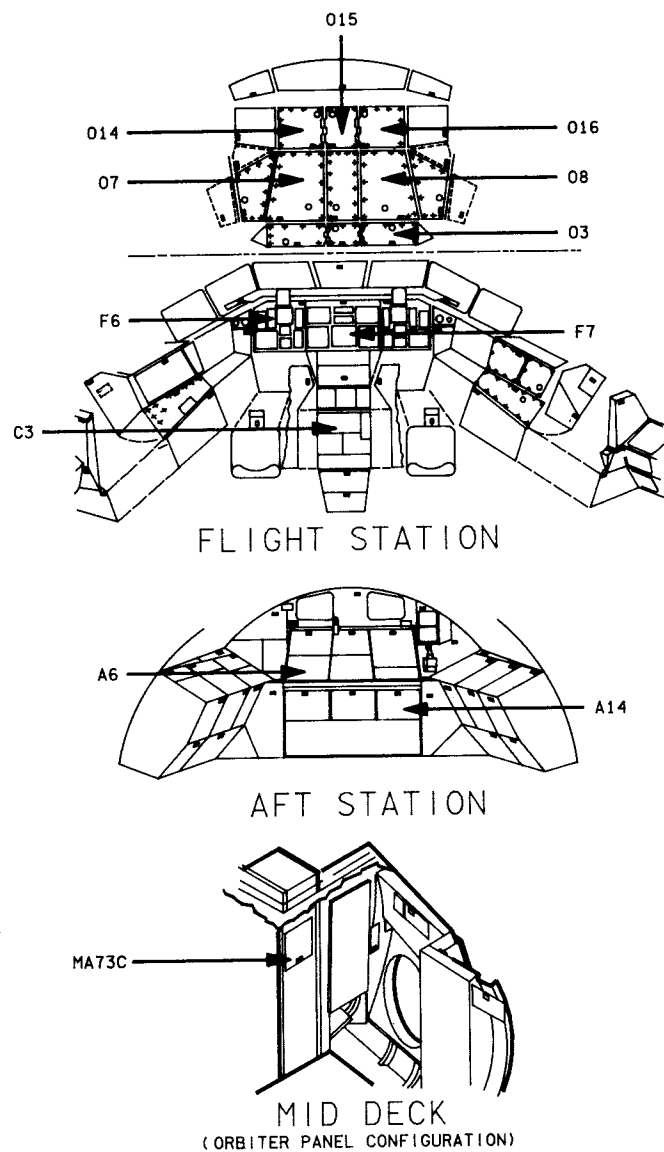
	OPS 1	OPS 2	OPS 3	OPS 6	OPS 8
O3 Digital readout	No display unless BFS is engaged then BFS calculation	PASS calculation	PASS calculation unless BFS engaged, then BFS calculation	No display unless BFS is engaged then BFS calculation	PASS calculation
BFS SYS SUMM 2	✓	Not available	✓	✓	Not available
SYS SUMM 2	Not available	✓	Not available	Not available	✓
Spec 23	Not available	✓	✓	Not available	✓

Displays and Controls

This section is a summary of the crew displays and cockpit controls that are related to RCS operation. Some have been discussed previously while others will be covered later in this manual.

Controls

There are RCS switches and/or meters in the forward station on panels C3, F6, F7, O3, O7, O8, O14, O15, and O16; in the aft station on panels A6 and A14; and in the middeck on panel MA73C (figure 2-16). The following pages show detailed views of these panels.

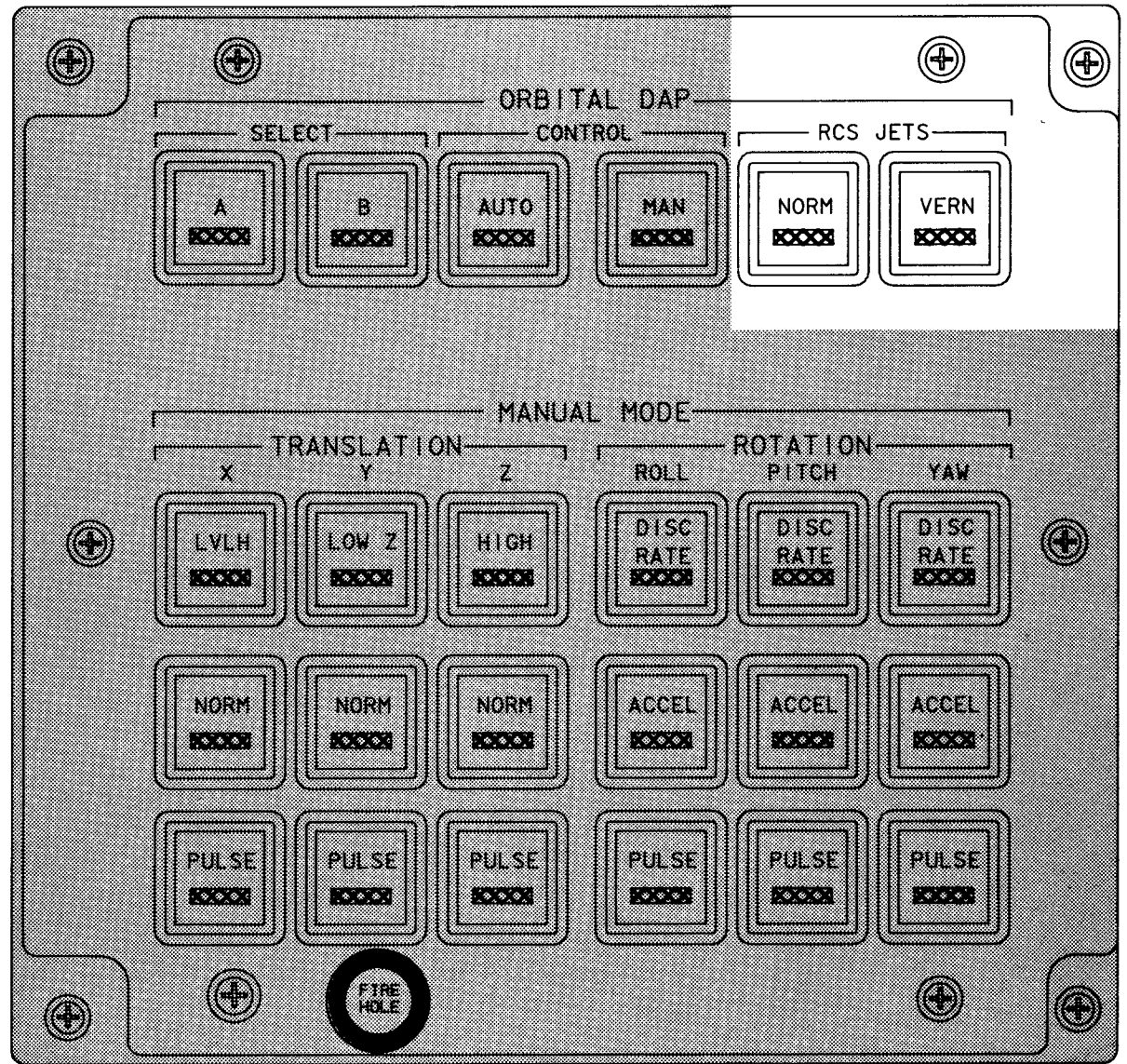


TD3400216. ART. 2

Figure 2-16.- Orbiter panel configuration.

Panel C3

The digital autopilot (DAP) panel (figure 2-17) is located on the center left side of panel C3. It includes the RCS jet selection pushbutton indicators (PBIs) in the upper right corner that are used to select either primary or vernier jets. A limited discussion of the DAP will be made in the System Operation section.

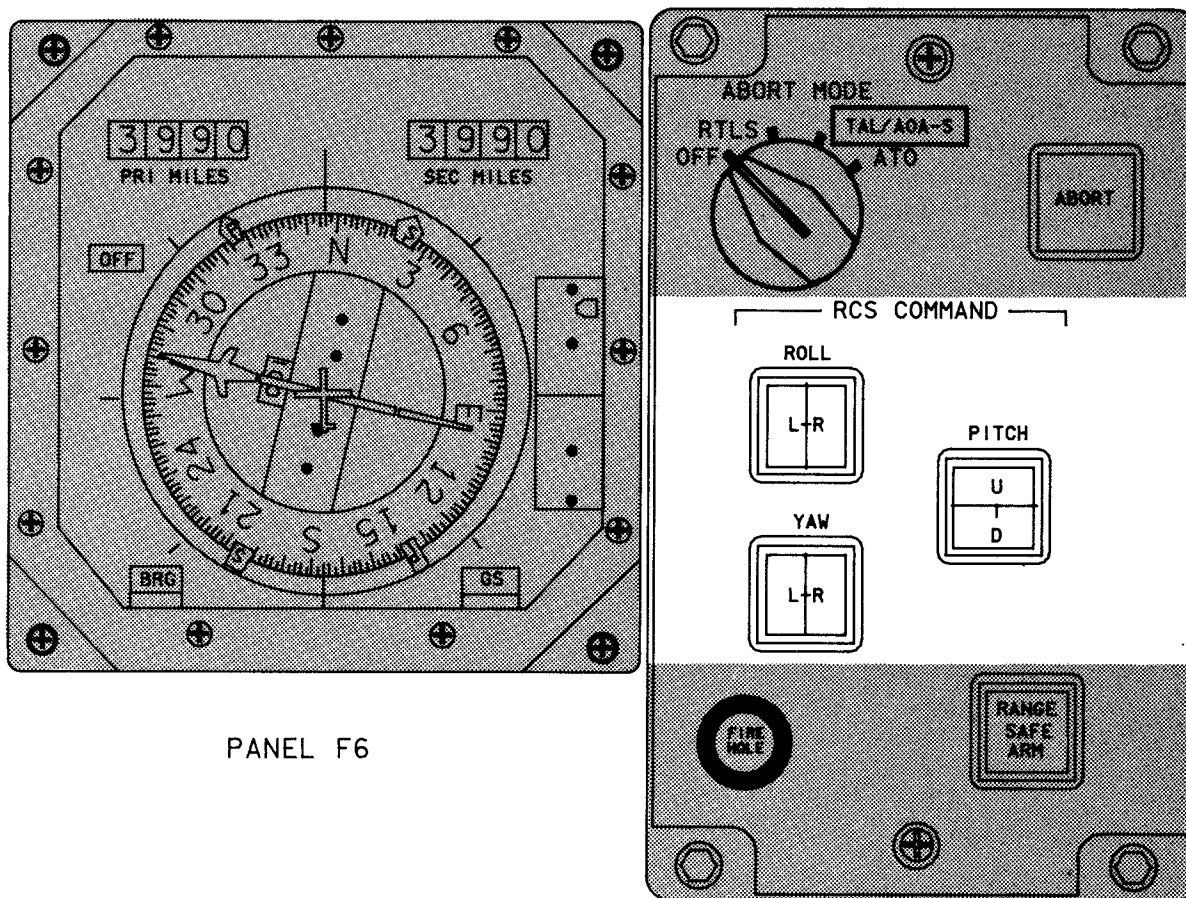


TD3400217. ART. 1

Figure 2-17.- Panel C3.

Panel F6

The RCS command lights (figure 2-18) are located in the lower right side of panel F6. The function of these lights will be described in the System Operation section.



PANEL F6

TD3400218. ART. 1

Figure 2-18.—RCS command lights.

Panel F7

The caution and warning matrix (figure 2-19) is located at the top of panel F7. The matrix includes lights for FWD RCS, LEFT RCS, RIGHT RCS, and RCS JET in the right center of the matrix. This matrix will be discussed in greater detail in the System Malfunctions section.

O ₂ PRESS	H ₂ PRESS	FUEL CELL REAC	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM	O ₂ HEATER TEMP	MAIN BUS UNDERVOLT	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	RIGHT/AFT RHC	LEFT OMS	RIGHT OMS
PAYLOAD WARNING	GPC	FCS SATURATION	OMS KIT	OMS TVC
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS	—————
BACKUP C/W ALARM	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

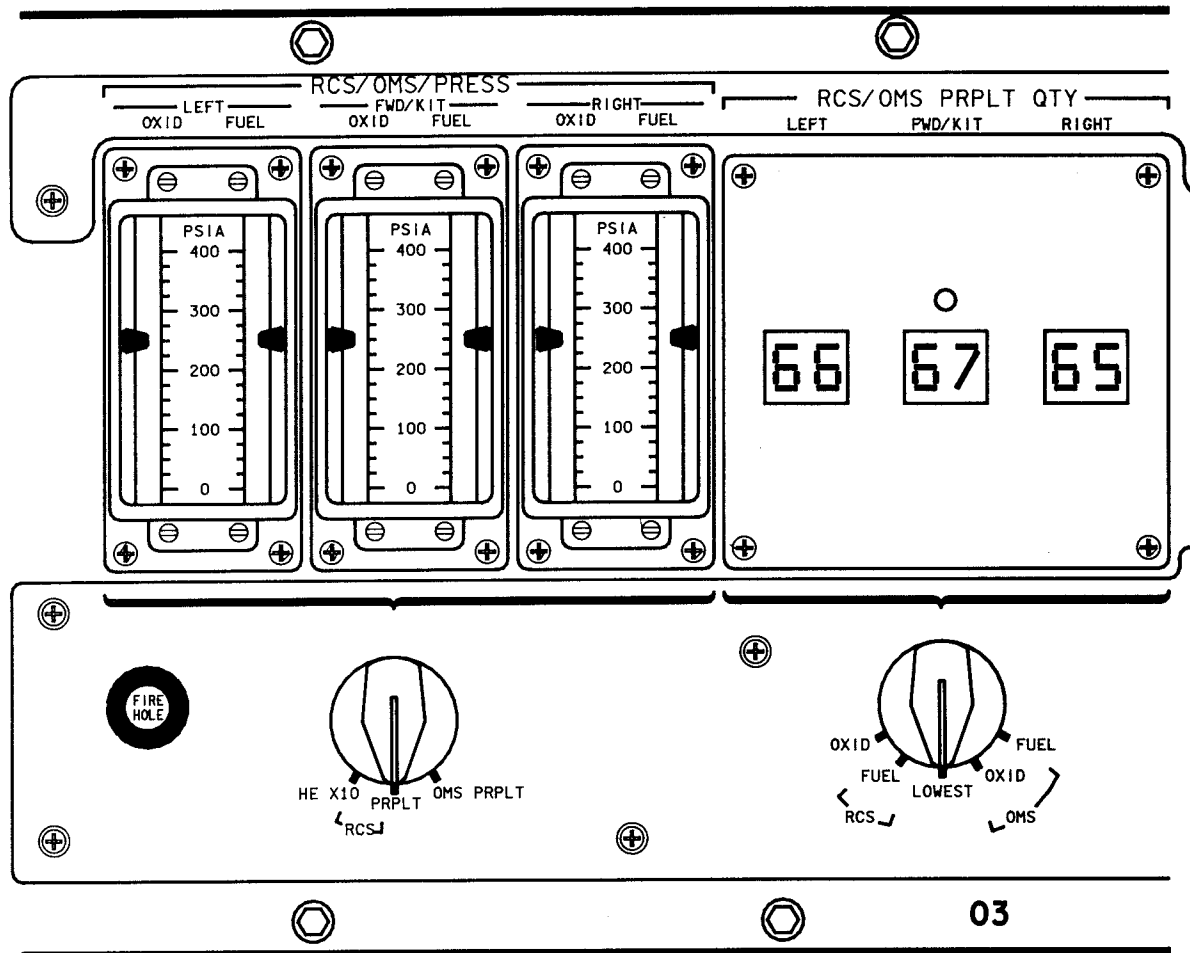
TD3400219. ART, 3

Figure 2-19.— Caution and warning matrix.

Panel O3

Panel O3, as illustrated in figure 2-20, includes RCS/OMS tank pressure gauges. Below the gauges, there is a rotary switch for selecting RCS or OMS measurement display. If RCS measurements are selected, the RCS propellant or helium tank pressures are displayed (reading left to right) for the left RCS, forward RCS, and right RCS.

Next to the pressure gauges is the RCS/OMS propellant quantity meter. The rotary switch below the digital meter is used to select either OMS or RCS quantities for display. RCS oxidizer or fuel can be selected and their respective quantities will be displayed (reading left to right) for the left RCS, forward RCS, and right RCS. There is also a position for reading the lowest quantity (which could be either fuel or oxidizer) for each pod.

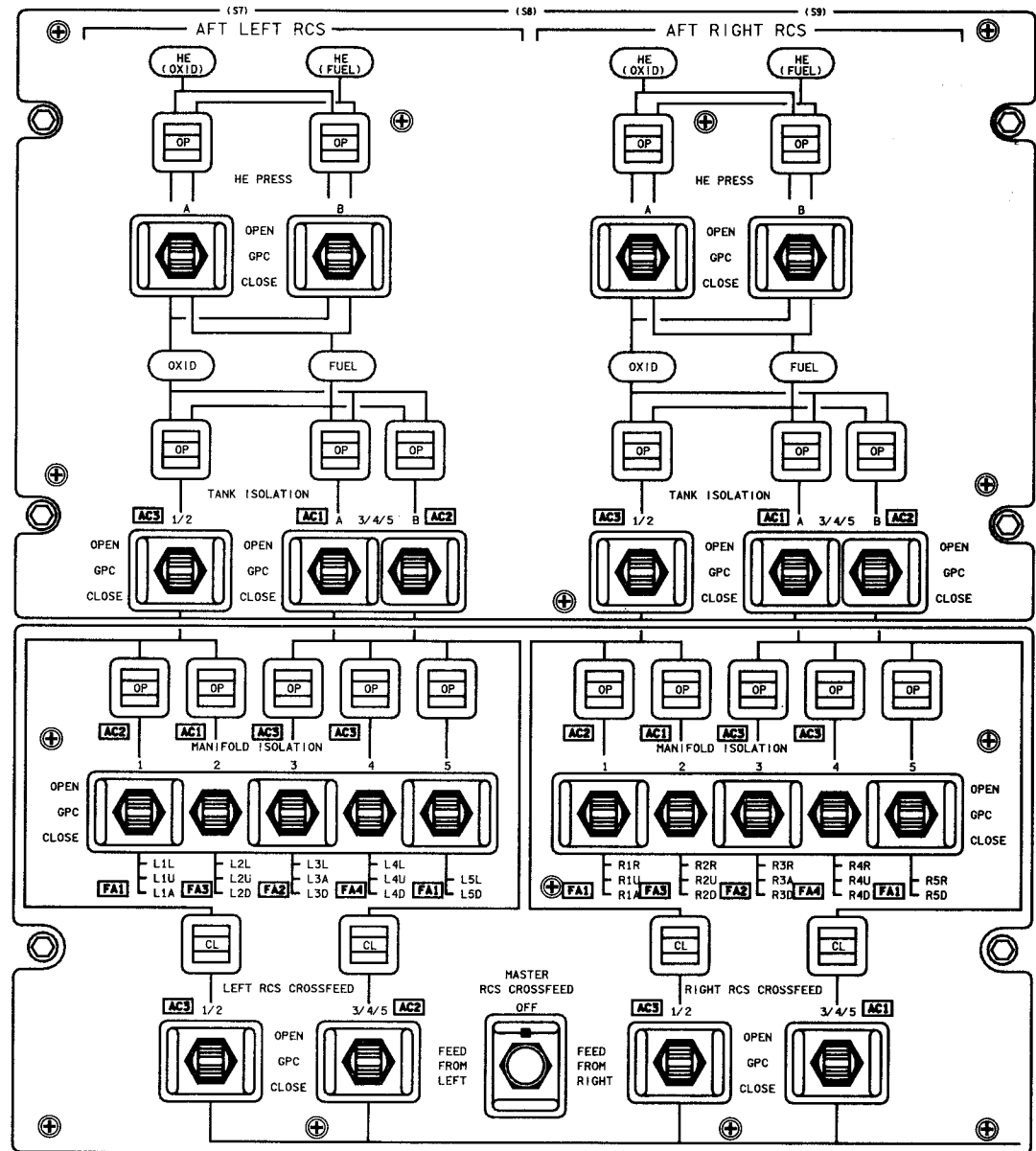


TD3400220. ART. 2

Figure 2-20.-- Panel O3.

Panel O7

Panel O7, as illustrated in figure 2-21, contains the control switches for the left and right RCS helium and propellant valves. Note that motor driven valve switches have labels indicating which ac power controls the valve. Other labels show which MDM affects each set of RCS jets. Also note the schematic in the background showing RCS plumbing. The RCS crossfeed line schematic, at the bottom of the panel, is a continuation of the same crossfeed line schematic that is at the bottom of the OMS panel on panel 08.

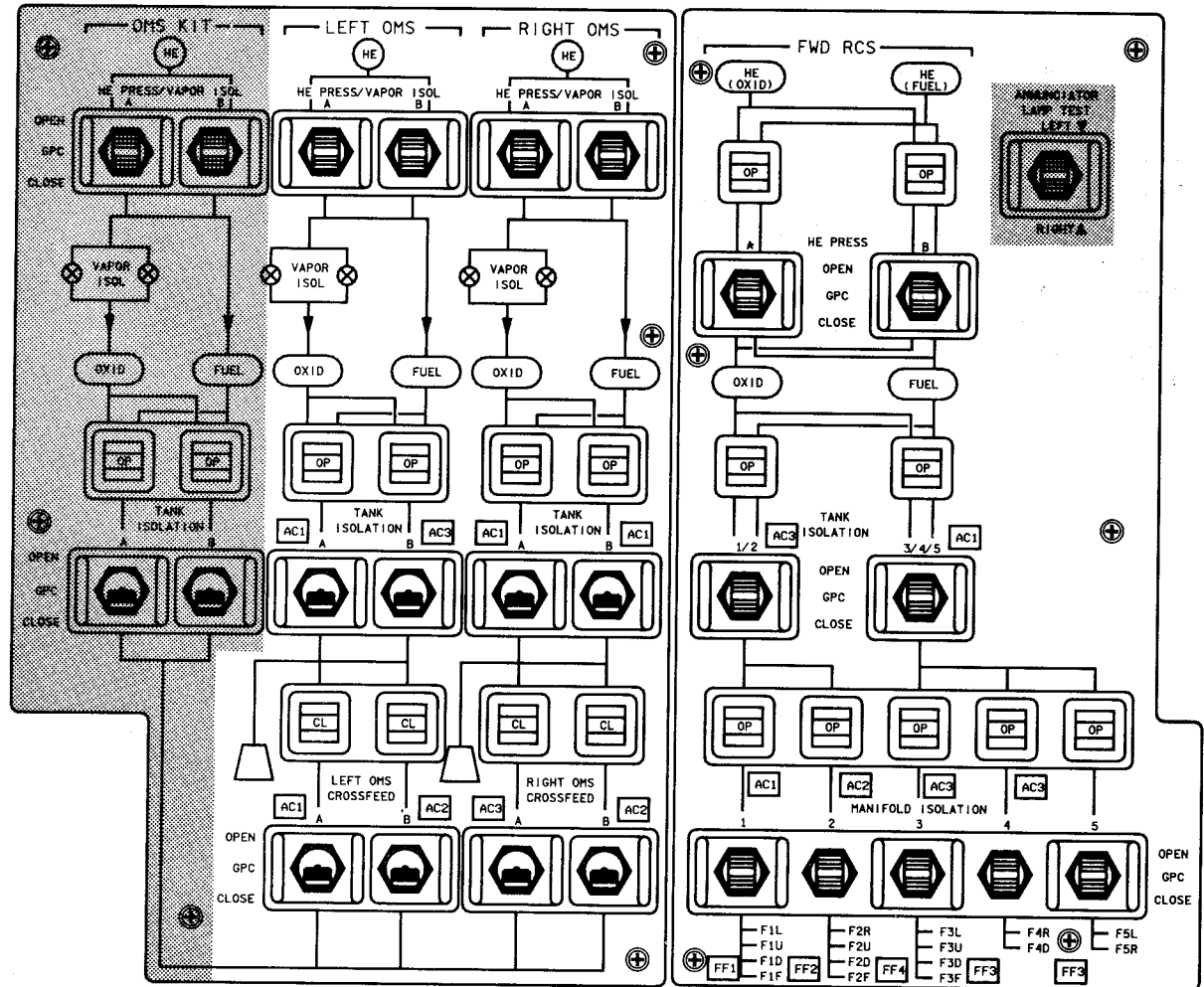


TD3400221. ART: 1

Figure 2-21.- Aft RCS switches.

Panel O8

Figure 2-22 shows the control switches for the OMS propellant tank and crossfeed valves that are on panel O8. The switches for the forward RCS valves are also located here. Note the ac and MDM labels.

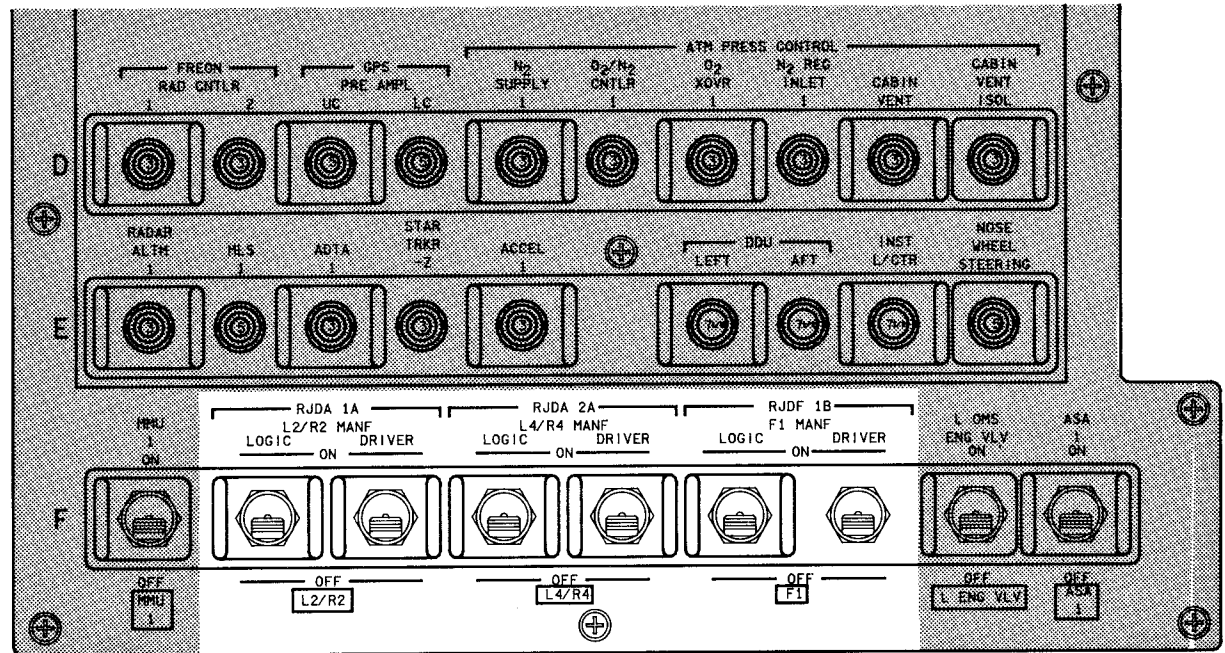


TD3400222. ART 1

Figure 2-22.- OMS and forward RCS switches.

Panels O14/O15/O16

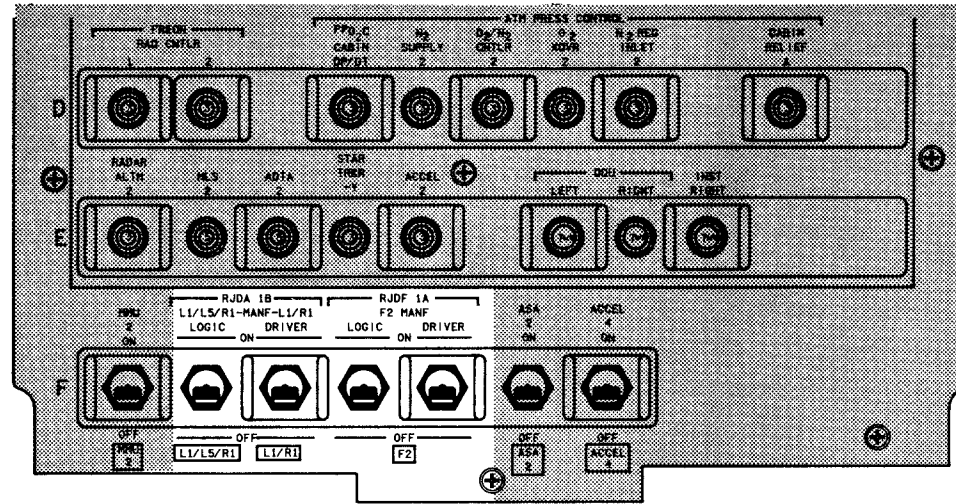
Row F of panels O14 (figure 2-23), O15 (figure 2-24), and O16 (figure 2-25) contains the power switches for each RCS jet driver. The circuit breaker for the RCS/OMS quantity gauge (panel O3) is on panel O16, in row E at the far right.



014

TD3400223. ART. 2

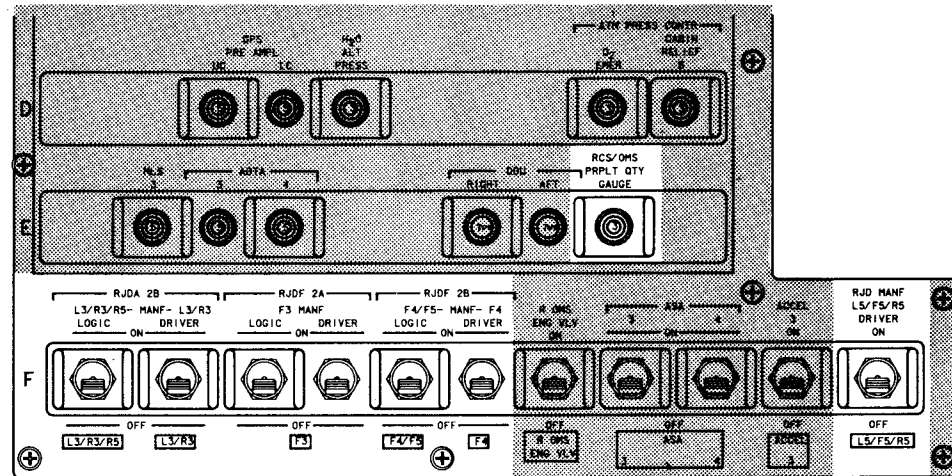
Figure 2-23.- Panel 014 detail.



015

TD3400224, ART. 3

Figure 2-24.- Panel 015 detail.



016

TD3400225, ART. 3

Figure 2-25.- Panel 016 detail.

Panel A6

The aft DAP panel (figure 2-26) is found on panel A6 and contains the DAP PBIs for RCS jet selection if controlling the vehicle from the aft station.

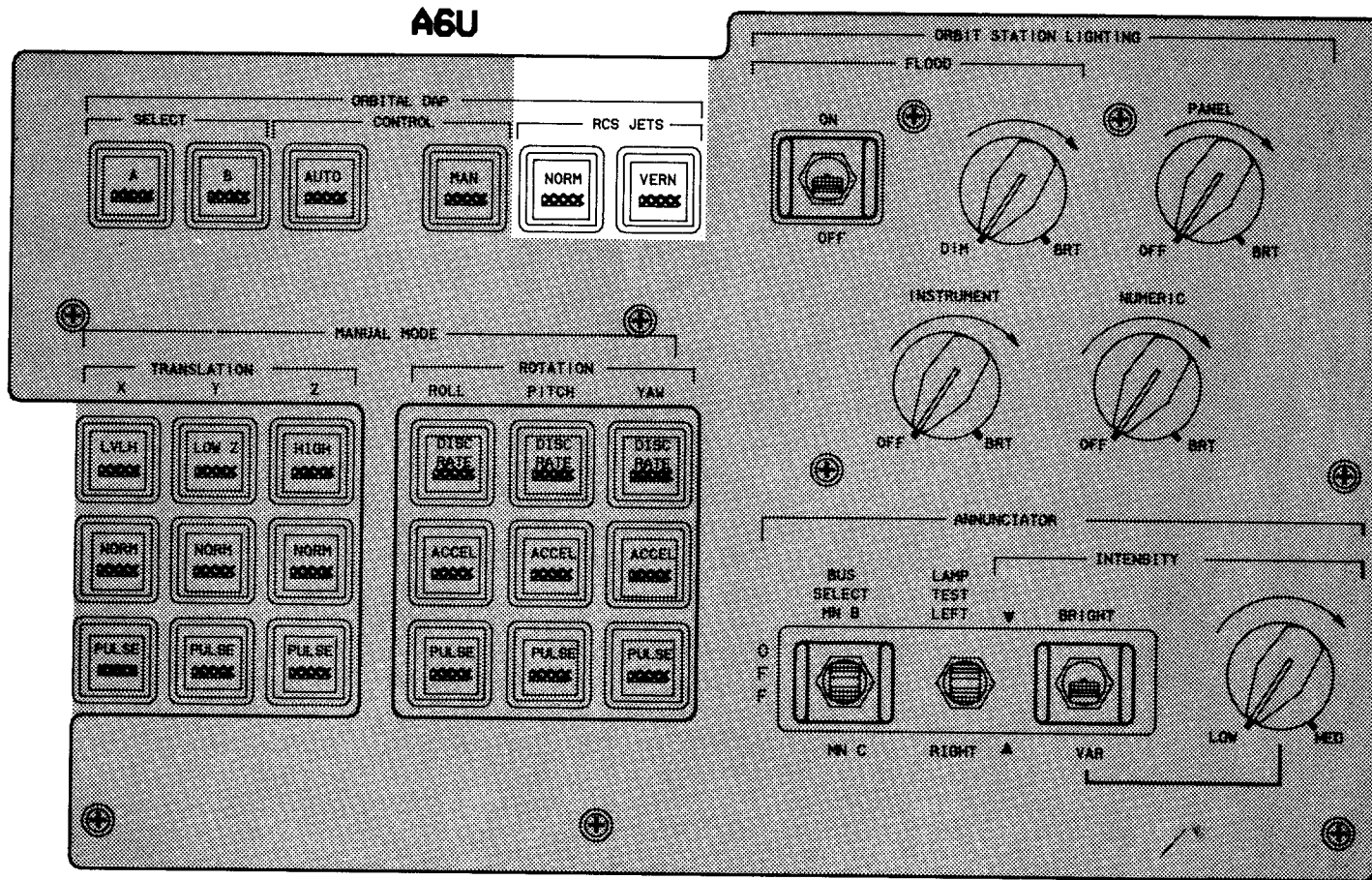


Figure 2-26.- Aft DAP panel.

Panel A14

Panel A14 contains all the OMS and RCS thermal control heater switches. The RCS heater switches (figure 2-27) are on the left side of the panel. See Thermal Control later in this section for more information on these heaters.

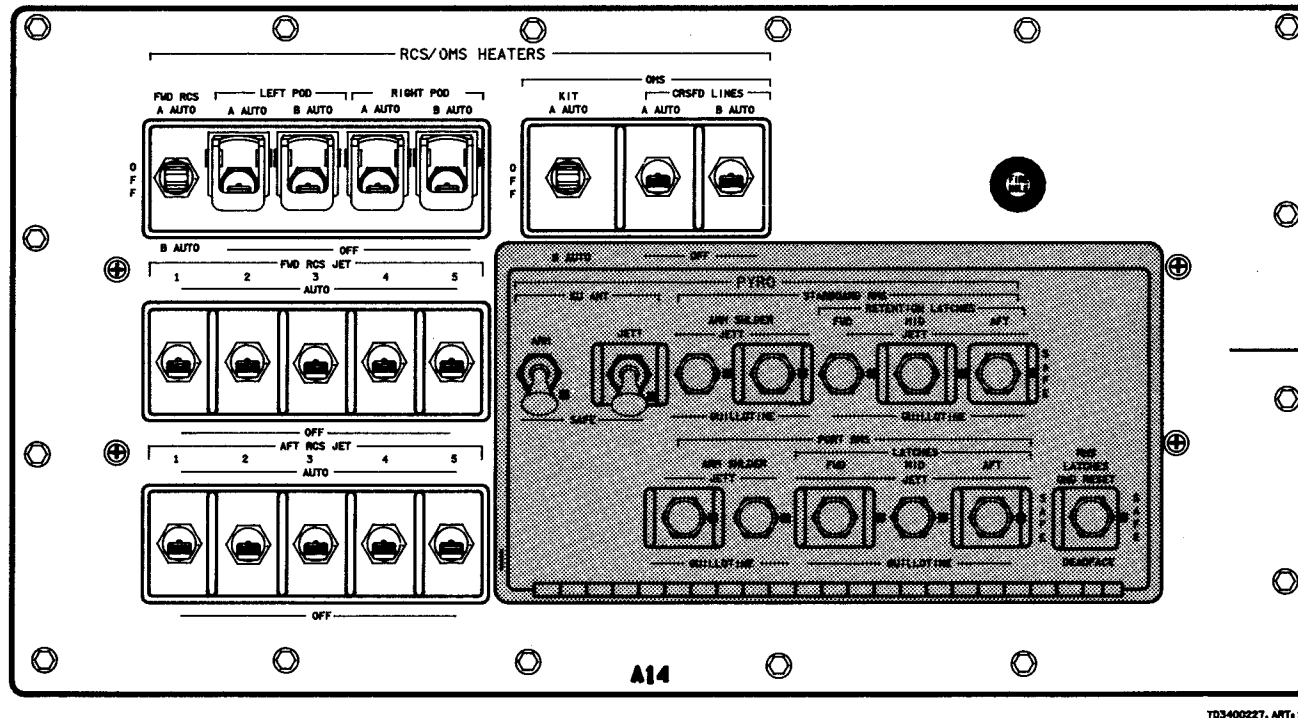
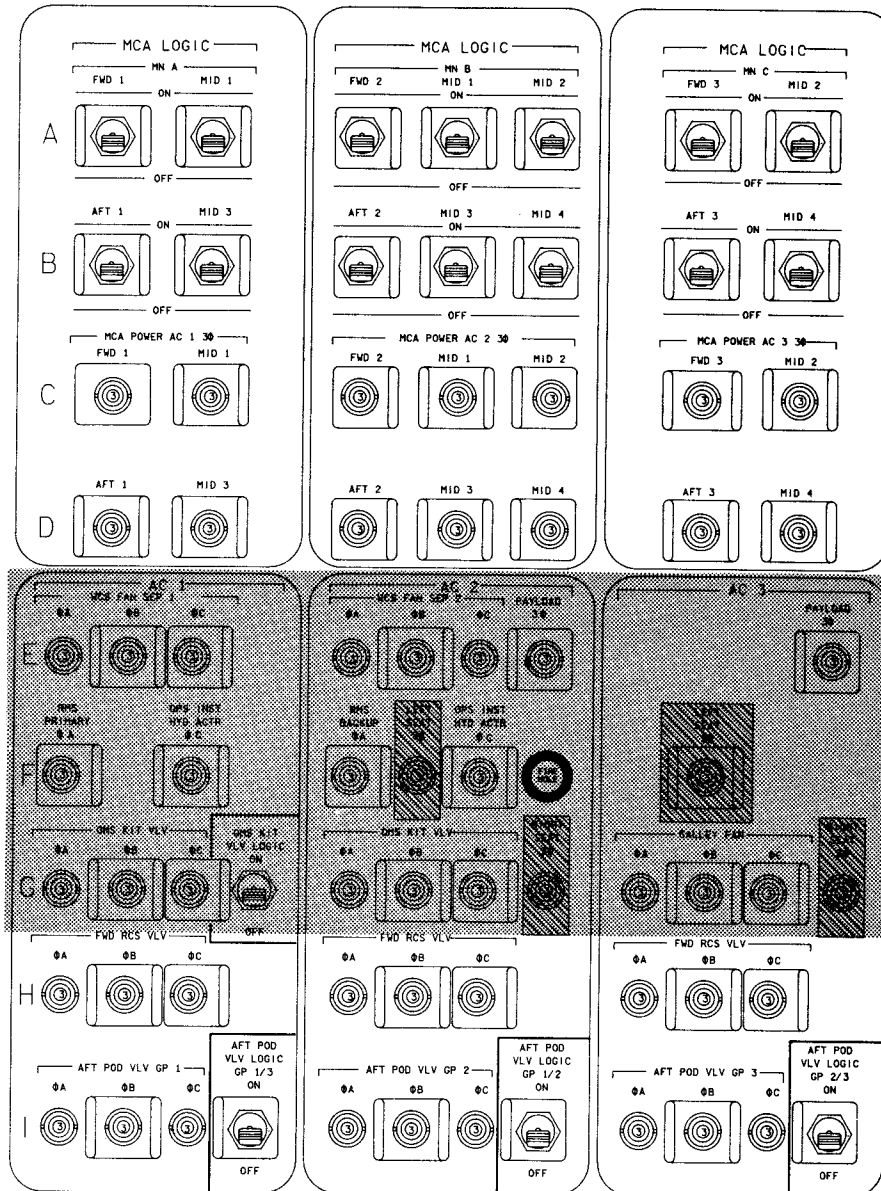


Figure 2-27.-- RCS/OMS heater switches.

Panel MA73C

Panel MA73C, as illustrated in figure 2-28, is located in the middeck and contains the switches and circuit breakers for ac motor power to the RCS valve motors (Rows A, B, C, D, H, and I). It also contains the valve logic power switches for the aft pods.



TD3400411. ART. 2

Figure 2-28.- Panel MA73C.

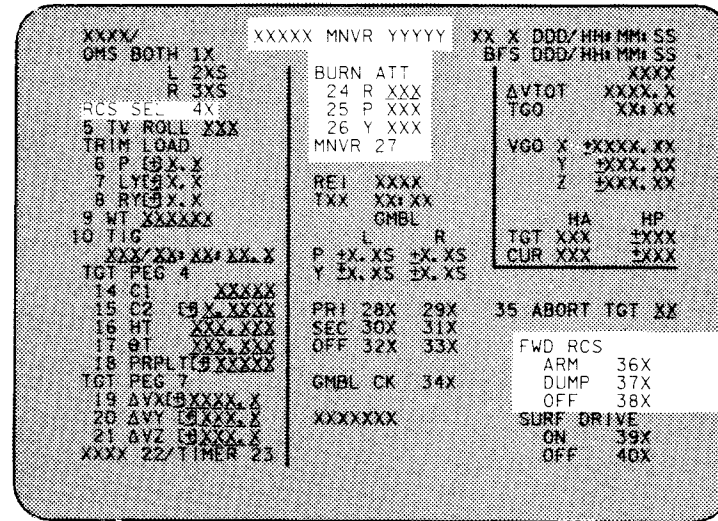
Displays

There are numerous CRT display pages that contain RCS information. Key displays are described on the following pages.

Maneuver Display

The maneuver display, as illustrated in figure 2-29, appears automatically in MM 104, 105, 106, 202, 301, 302, and 303. The title has a prefix and a suffix that vary according to the major mode, as depicted in table 2-2. The BFS version of this display is almost identical to the PASS. Three areas of the display relate to the RCS as follows:

1. RCS SEL 4 (upper left side).
Item 4 is used to select the appropriate target data if the 4 + X RCS jets are used to perform a burn maneuver instead of using the OMS engines.
2. MNVR 27 (top center) (PASS display only).
Item 27 initiates the automatic maneuver to the burn attitude (items 24, 25, and 26) which is accomplished by firing appropriate RCS jets.
3. FWD RCS (lower right) (OPS 3 only).
Item 36 arms (prepares) the forward dump sequence for execution. Item 37 starts the dump sequence. Item 38 stops the dump sequence.



4748. ART. 2

Figure 2-29.- Maneuver display.

Table 2-2.- Major mode titles.

Major mode	Title	Mission phase
MM 104	OMS 1 MNVR EXEC	OMS 1 burn
105	OMS 2 MNVR EXEC	OMS 2 burn
106	OMS 2 MNVR COAST	Post-OMS 2 coast
202	ORBIT MNVR EXEC	Orbital maneuvers
301	DEORB MNVR COAST	Pre-deorbit coast
302	DEORB MNVR EXEC	Deorbit burn
303	DEORB MNVR COAST	Post-deorbit coast

Guidance, Navigation, and Control Systems Summary 2

There is a PASS and a BFS System Summary 2, as illustrated in figure 2-31. The PASS display is available in OPS 2 and 8. The BFS display is available in OPS 1, 3, and 6. Both displays are essentially identical with regard to RCS information. The display can be called up by pressing the SYS SUMM key twice (only once if SYS SUMM 1 is presently displayed). The display may also be called up with the keyboard entry of Spec 19 PRO. RCS information is blocked off by module: forward RCS (left center), left RCS (lower left), and right RCS (lower right). Each pod section displays helium tank pressure, propellant tank pressure, propellant tank quantity, and manifold pressure for manifolds 1 through 4 (manifold 5 has no pressure measurements). The JET FAIL and ISOL VLV columns are identical to SYS SUMM 1 except that on the BFS display, these two columns will be blank unless the BFS is engaged.

XXXX/XXX/019 GNC SYS SUMM 2										XX X DDD/HH MM SS									
										BFS DDD/HH MM SS									
GMS					L					R									
AFT					HE					TK									
HE					OXID					FU									
TK					P					HE									
QTY					P					OXID									
MANF					1					2									
2					3					3									
3					4					4									
4					5					5									
5					JET					ISOL									
FAIL					VLV					VLV									
FWD					HE					TK					HE				
TK					P					OXID					FU				
QTY					P					HE					TK				
MANF					1					2					3				
2					3					4					4				
3					4					5					5				
4					JET					ISOL					VLV				
5					FAIL					VLV					VLV				
AFT					HE					TK					HE				
TK					P					OXID					FU				
QTY					P					HE					TK				
MANF					1					2					3				
2					3					4					4				
3					4					5					5				
4					JET					ISOL					VLV				
5					FAIL					VLV					VLV				

4928. ART, 4

Figure 2-31.— Systems Summary 2 display.

Digital Autopilot Configuration

This guidance, navigation, and control (GNC) display, as illustrated in figure 2-32, is called up with a keyboard entry of Spec 20 PRO. It is only available in OPS 2 and therefore is a PASS display only. It can be used to change the parameters of the digital autopilot that affect jet selection and fire duration. Detailed information related to the DAP is available in the I/O/D G&C Training Manual and the DPS dictionary.

Reaction Control System

This GNC display, as illustrated in figure 2-33, will be covered in detail in subsequent sections of this manual. It is called up with a keyboard entry of Spec 23 PRO and is only available in OPS 2, 3, and 8.

XXXX/020/		DAP CONFIG		XX X DDD/HH# MM# SS		DDD/HH# MM# SS	
TRANSLATION PULSE	1	A	15	B			
ROTATION DISC RATE	NORM 2	X.XXX	16	X.XXX			
	VERN 3	X.XXX	17	X.XXX			
PULSE	NORM 4	X.XXX	18	X.XXX			
	VERN 5	X.XXX	19	X.XXX			
COMP	NORM 6	X.XXX	20	X.XXX			
	VERN 7	X.XXX	21	X.XXX			
DEADBAND ATT	NORM 8	XX.XX	22	XX.XX			
	VERN 9	XX.XXX	23	XX.XXX			
RATE	NORM 10	X.XX	24	X.XX			
	VERN 11	X.XX	25	X.XX			
JET OPT	P 12	X	26	X			
	Y 13	X	27	X			
CNTL ACCEL	14	X	28	X			

1473. ART, 4

Figure 2-32.- Digital autopilot display.

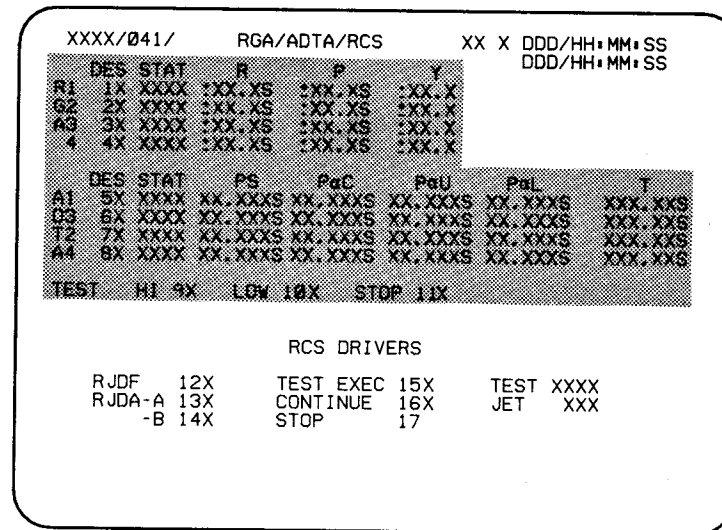
XXXX/023		RCS		XX X DDD/HH# MM# SS		DDD/HH# MM# SS	
RCS FWD	1X	PRI JET	OMS PRESS ENA	L OMS	5X	OMS-RCS	QTY
L	2X	4 FAIL LIM	X	R OMS	6X	L	XX.XXS
R	3X			OFF	7X	R	XX.XXS
JET FAIL	DES INH	JET DES	PTY	OXID	FU		
XXX	XXX	8X	9X	X			
XX	XXX	10X	11X	X			
Y	XX	12X	13X	X			
	XX	14X	15X	X			
XXU	XXX	16X	17X	X			
XU	XXX	18X	19X	X			
Z	XU	20X	21X	X			
XXX	XXX	22X	23X	X			
XD	XXX	24X	25X	X			
2D	XXX	26X	27X	X			
XD	XXX	28X	29X	X			
XXX	XXX	30X	31X	X			
X	XX	32X	33X	X			
	XX	34X	35X	X			
X5X	XXX	36X	37X	X			
V	5X	38X	39X	X			
PRPLT	TK	P	XXXXX	XXXXX			
T	XXXXX	XXXXX					
QTY	XXXXX	XXXXX					
MANF P	1	XXXXX	XXXXX				
	2	XXXXX	XXXXX				
	3	XXXXX	XXXXX				
	4	XXXXX	XXXXX				
MANF VLVS	STAT	OVRD					
1	XXS	40					
2	XXS	41					
3	XXS	42					
4	XXS	43					
5	XXS	44					
JET RESET 45							

4707. ART, 3

Figure 2-33.- Reaction control system display.

Rate Gyro Assembly/Air Data Transducer Assembly/Reaction Control System

This GNC display, as illustrated in figure 2-34, is available in OPS 8 only and is called up with a keyboard entry of Spec 41 PRO. It provides a means to perform the RCS driver test in OPS 8 to check the RCS driver command path to the RCS jets. The test can detect electrical shorts or open circuits from the GPC to the RJD. It can only detect open circuits from the RJD to the jet. It can also be used to distinguish real "fail off" jets from transducer failures. (Detailed procedures can be found in chapter 10 of the Systems Malfunction Procedures.) Item 12 checks forward RJDs. Item 13 checks RJDA-1 A and B. Item 14 checks RJDA-2 A and B.



4218.ART:4

Figure 2-34.- RGA/ADTA/RCS display.

Override

This GNC display is called up with a keyboard entry of Spec 51 PRO. There is a PASS and a BFS OVERRIDE display, as illustrated in figures 2-35 and 2-36. Keyboard entries to BFS OVERRIDE are only effective if the BFS is engaged. This display is used to

- Inhibit (INH)/enable (ENA) the OMS to RCS abort interconnect for RTLS/TAL/ATO abort dumps by using item 5. (XXX by item 5 will be ENA or INH, as appropriate.) Inhibiting the interconnect will also inhibit the RCS jet fire commands for the dump. Note: this item entry has no effect on the contingency abort interconnect that is used for the contingency abort dump and for single engine roll control. A contingency interconnect cannot be inhibited.

- Stop any OMS or RCS abort dump by using item 8.
- On PASS Spec 51 only, start a contingency abort dump in OPS 1 or 6 with an item 6 followed by an item 7. (XXX ICNCT 5 will change to CONT ICNCT ENA if the contingency interconnect is activated.)
- Start an OMS dump in OPS 3 with an item 6 and 7 that will also dump OMS propellant through RCS jets if item 5 is ENA.

XXXX/051/		OVERRIDE		XX X DDD/HH:MM:SS DDD/HH:MM:SS	
ABORT MODE		ENTRY FCS		ATMOSPHERE	
TAL/AGA 1X		ELEVON	FILTER		
ATO 2X		INH 17X	NON 20X	NON 22X	
ABORT 3X		ALT 18X	ALT 21X	N POLE 23X	
MAX THROT 4X				S POLE 24X	
PROPLT DUMP		IMJ STAT ATT DES		PRL	
OMS DUMP TTG XXX		1 XXXX X 25X		SYS AUT DES	
XXX ICNCT 5		2 XXXX XXX 26X		15 28X 31X	
		3 XXXX 27X		25 29X 32X	
				35 30X 33X	
OMS CENT		ADTA H G H DES			
ARM 6X 9X		L 15 XXXXXX 1XX X X XX 34X			
START 7X 10X		35 XXXXXX 2XX X X XX 35X			
INERT 11X		R 25 XXXXXX 3XX X X XX 36X			
STOP 8X 12X		45 XXXXXX 4XX X X XX 37X			
AFT RCS 13 XXX		ET SEP		ROLL MODE XXXXXX	
14 TIME XXX		AUTO 38X		AUTO SEL 42X	
FWD RCS 15 XXX		SEP 39X		VENT DOOR CNTL	
16 TIME XXX		ET LMB DR		OPEN 43X	
		CLOSE 40X		CLOSE 44X	
		RCS RM MANF			
		CL OVRD 41X			

TD3400235. ART, 3

Figure 2-35.- PASS OVERRIDE display.

XXXX/051/		OVERRIDE		XX X DDD/HH:MM:SS BFS DDD/HH:MM:SS	
ABORT MODE		ENTRY FCS		ATMOSPHERE	
TAL/AGA 1X		ELEVON	FILTER		
ATO 2X		INH 17X	NON 20X	NON 22X	
ABORT 3X		ALT 18X	ALT 21X	N POLE 23X	
MAX THROT 4X				S POLE 24X	
PROPLT DUMP		IMJ DES			
OMS DUMP TTG XXX		1 25X			
XXX ICNCT 5		2 26X			
		3 27X			
OMS CENT					
ARM 6X 9X		ET SEP		VENT DOOR CNTL	
START 7X 10X		AUTO 28X		OPEN 43X	
INERT 11X		SEP 29X		CLOSE 44X	
STOP 8X 12X		ET LMB DR			
AFT RCS 13 XXX		CLOSE 30X			
14 TIME XXX					
FWD RCS 15 XXX					
16 TIME XXX					

TD3400236. ART, 1

Figure 2-36.- BFS OVERRIDE display.

- Inhibit/enable the aft and forward RCS dumps with item 13 and 15, respectively. Items 14 and 16 are the displayed dump times in seconds for the respective dumps. Item 14 and 16 are initialized with I-loaded values in OPS 1 and TAL OPS 3. The OPS 6 display will use the last OPS 1 values. The OPS 3 non-TAL display will be initialized at zero. Executing an item 14 or 16 in OPS 1, 3, or 6 will change that dump time to the selected value. Items 13-16 will be blank during a contingency dump.
- Control vent door operation in the event of a propellant leak by using items 43 or 44.
- Change a closed manifold status to open for any manifold status that is closed due to a dilemma by using item 41.

XXXX/XXX/089		PRPLT	THERMAL	XX X	DDD/HH:MM:SS	SS
POD	L	R			DDD/HH:MM:SS	SS
OMS TK	OX XXXS XXXS					
	FU XXXS XXXS		OMS CRSFD	L	R	C
ENG I/F	OX XXXS XXXS		XFD	OX XXXS XXXS	XXXS	XXXS
	FU XXXS XXXS		GMBL	LN XXXS XXXS		
	OX VLV XXXS XXXS		DRN	OX XXXS XXXS		
	FU INJ XXXS XXXS					
WEB KEEL	1 XXXS XXXS					
	2 XXXS XXXS					
Y	OB XXXS XXXS		BLD AFT FUS	FU OX		
	UP XXXS XXXS		PL BAY	XXXS XXXS		
OX DRN PNL	1 XXXS XXXS					
	2 XXXS XXXS		FWD RCS	FU OX		
ENG COVER	XXXS XXXS		LINE	T1 XXXS XXXS		
SERV PNL	XXXS XXXS			T2 XXXS XXXS		
GSE SERV PNL	XXXS XXXS					
TEST HE/OX	1 XXXS XXXS		AFT RCS	L	R	
	2 XXXS XXXS		MANF 1	OX XXXS XXXS		
			DRN PNL	1 XXXS XXXS		
				2 XXXS XXXS		
			VERN PNL	1 XXXS XXXS		
				2 XXXS XXXS		

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Figure 2-37.- Propellant thermal display.

The procedural logic for these actions will be covered in later sections of this manual.

Thermal and Propellant Thermal

These displays are covered in greater detail in the section covering thermal control. The propellant thermal display (figure 2-37) systems management (SM) can be called up in OPS 2 with a keyboard entry of Spec 89 PRO. The BFS thermal display (figure 2-38) is automatically displayed when the BFS computer is in run or standby and the SM major mode is selected on the CRT select switch. These displays use inputs from numerous sensors at various locations throughout the OMS and RCS.

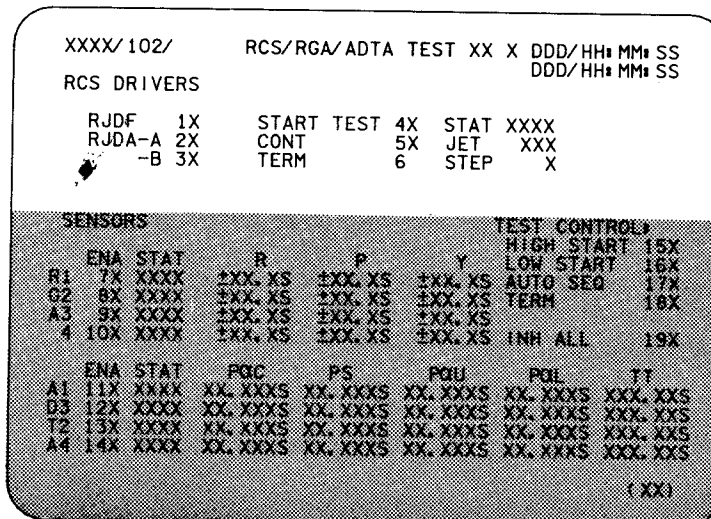
0001/ /		THERMAL				XX X DDD/HH:MM:SS	SS
						BFS DDD/HH:MM:SS	SS
HYD SYS TEMP	BDYFLP	RD/BR	L OB	L IB	R IB	R OB	
ACTR	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	
PRIME	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	
STBY 1	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	
STBY 2	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	± XXXS	
HTR TEMP	L/A	R/B	FRESH LOOP		1	2	
PRPLT			ADCLN	QTY	XXXS	XXXS	
POD	SSSSSSS	SSSSSSS	RAD IN	T	XXXS	XXXS	
OMS CRSFD	SSSSSSS		H2O				
EVAP			SUPPLY	P	XXXS		
HI LOAD	SSS						
TOP DUCT	SS						
NOZ	S	S					
FDLN	SSSS	SSSS					
HYD BLR HTR	S	S	S				
APU							
GO/FI PMP HTR	SSSS	SSSS	SSSS				
TKO/FI LN HTR	SSSSSSSSS	SSSSSSSSS	SSSSSSSSS				
PUMP/VLV COOL	SS	SS	SS				
FC END HTR A/B	XXXX/XXXXS	XXXX/XXXXS	XXXX/XXXXS				(XX)

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Figure 2-38.- BFS thermal display.

RCS/Rate Gyro Assembly/Air Data Transducer Assembly Test

This GNC display is a specialist function available in OPS 9 only (figure 2-39). It is called up with a keyboard entry of Spec 102 PRO and is used to enable testing of the RCS drivers during prelaunch activities.



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Figure 2-39.- RCS/RGA/ADTA test display.

Redundancy Management

Redundancy management (RM) for the RCS is a series of GPC processes that detect, identify, and monitor RCS performance through the use of the following GPC software modules:

- Jet fail on monitor
- Jet fail off monitor
- Jet fail leaking monitor
- Available jet status table
- Manifold valve status monitor
- Jet fail limit module.

RCS RM also has a limited capability for system reconfiguration, both automatic and manual, which will be covered later in this section.

The RCS display (Spec 23), as illustrated in figure 2-40, is the primary CRT display for monitoring and/or controlling RCS RM. Figure 2-40 should be referred to, as needed, while studying this section.

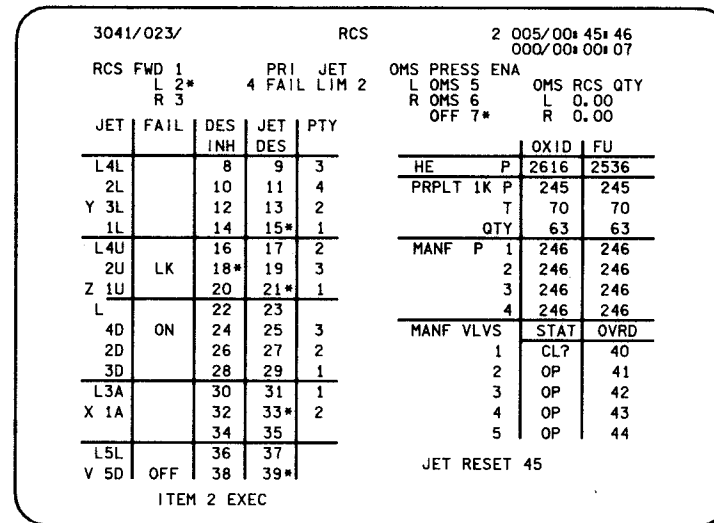


Figure 2-40.-- RCS display.

5363. ART. 2

Spec 23 has three display pages, one for each RCS module: forward, left, and right. displays the forward RCS page when called up for the first time. Subsequent requests for this Spec will show the last requested page. Items 1, 2, and 3 are used to change the pages to the desired pod. Since each page has a similar layout (and the item functions are identical), the example and discussion will be limited to the left RCS display only.

The JET column lists each jet in the pod with the primary jets grouped according to jet fire direction (Y-AXIS, Z-AXIS, and X-AXIS) and the verniers listed last.

The FAIL column is for the annunciation of any jet failures. There are three types of jet failures: fail on, fail off, and fail leaking. The annunciation will show ON, OFF, or LK, as appropriate. These failures are detected and annunciated by jet fail monitors. Only the most recent failure for any one jet will be displayed. For example, if L2L fails off, an OFF will be displayed; if a subsequent leak is detected in L2L, the OFF will change to LK. These annunciations will also appear on the fail columns of SYS SUMM 1 and SYS SUMM 2 for the appropriate manifolds. Once a jet has been annunciated as failed, that jet cannot be re-annunciated for the same type of failure (ON, OFF, LK) until the RM is reset. RM reset will be covered later in this section.

Jet fail annunciations will not appear on BFS SYS SUMM 2 unless the BFS is engaged and the failures are detected by the BFS. The BFS does not track PASS RCS RM annunciations.

Fail On Monitor

The jet fail on monitor for the PASS and the BFS use different means to detect a jet failed on. The presence of an RJD output and the absence of a jet fire command is the PASS indication of a jet failed on. The BFS uses a P_c output discrete and the absence of a jet fire command to indicate a jet failed on. The BFS uses the P_c discrete due to simplicity (i.e. fail on and fail off both use a common P_c discrete), while the PASS uses a complex, but more reliable, driver output.

The fail on monitor provides one output: a fail on indicator discrete to initiate a fail on annunciation ("ON" in the FAIL column, JET FAIL message on the CRT, RCS JET matrix light, and master alarm tone).

Fail Off Monitor

The jet fail off monitor uses jet fire command discrettes and jet P_c discrettes to determine if a jet has failed to fire when commanded. The absence of a P_c discrete when a fire command is present is an indication of a jet failed off. The monitor provides an indicator discrete for fail off annunciation.

After annunciation, the fail off discrete for that jet is sent to the jet fail limit module for auto deselection consideration.

Fail Leak Monitor

The jet fail leak monitor uses fuel and oxidizer injector temperature transducer outputs from each RCS jet to detect a propellant leak in the associated primary or vernier jet. For the primary jets, if a temperature output is less than 30° F (OX), or 20° F (FU), a jet fail leak is annunciated for that jet. The vernier jet fail leak limit is 130° for either fuel or oxidizer. The jet fail leak monitor provides an indicator discrete for jet fail leak annunciation. After annunciation, the fail leak discrete for that jet is sent to the jet fail limit module for auto deselection consideration.

Available Jet Status

The available jet status table (also called the jet availability table) provides the FCS with a collection of jets to choose from in order to get the desired vehicle motion. On Spec 23, the primary jets are grouped by fire direction (JET column) and selection priority (PTY column).

A jet is considered to be available unless there is an asterisk in the JET DES (jet deselect) column by that jet.

A JET DES asterisk indicates that the jet has been removed from the jet availability table. If the FCS requires the firing of a left yaw jet, it would select the highest priority jet available in the Y group. The RCS condition, presented on figure 2-40, shows L1L is the highest priority jet (1 in PTY column in the Y group). However, L1L is not available (asterisk by item 15). Therefore, the number 2 priority jet (L3L) would be fired to get the desired vehicle motion.

The presence of an asterisk in the JET DES column is dependent upon inputs from the following sources:

- Manifold status monitor (affects jet availability)
- Jet fail limit module (affects auto deselection)
- Keyboard entry in JET DES column (affects manual selection/deselection) or DES INH column (affects auto deselection).

A discussion of these sources will complete the redundancy management section.

Manifold Status

The manifold valve status display is in the lower right corner of Spec 23. The status can be either open (OP) or closed (CL). The display receives inputs from the manifold status monitor. The monitor uses the open and closed discretes from the valve limit micro-switches on the fuel and oxidizer manifold isolation valves in order to determine the open or closed status for each jet manifold (see table 2-3). The status output of the monitor is based on the specific combination of discretes present. Note that the manifold status is independent of the actual manifold valve position; i.e., manifold status is a software state while manifold position is a hardware condition. For example, a manifold valve could be open and the manifold status could be closed, and vice versa.

If the monitor does not have sufficient discretes to determine the manifold status, then a dilemma is annunciated. When a dilemma exists, a question mark (?) symbol will be displayed next to the appropriate manifold status symbol. Also, when a dilemma is initially declared, the manifold status is set to closed.

Table 2-3.— Manifold status.

Logical State Of Input Discretes				Manifold Status	RCS Manifold RM Dilemma
Open		Close			
Fuel	Ox.	Fuel	Ox.		
0	0	0	0	(Previous) ^a	No
0	0	0	0	Close ^b	No
0	0	0	1	Close	No
0	0	1	0	Close	No
0	0	1	1	Close	No
0	1	0	0	Close	YES
0	1	0	1	Close	YES
0	1	1	0	Close	YES
0	1	1	1	Close	No
1	0	0	0	Close	YES
1	0	0	1	Close	YES
1	0	1	0	Close	YES
1	0	1	1	Close	No
1	1	0	0	Open	No
1	1	0	1	Open	No
1	1	1	0	Open	No
1	1	1	1	Close	YES

^aThe previous manifold status is maintained if four "0" discretes are due to a power failure.

^bManifold status is closed if four "0" discretes are not due to a power failure.

The manifold status display also receives inputs from keyboard entries. An item 41, 42, 43, 44) entry will override the present status of the selected manifold to the opposite condition. If there is no further status change to that manifold, the next identical item entry would reverse the process. The manifold status is reevaluated at each change of state. Change of states are caused by microswitch failures, electrical failures, valve motion, keyboard entry, or OPS transition. For example, if a manifold status is in an overridden open status due to a dilemma override and an OPS 2 to OPS 3 transition is made, the display would change to closed (CL) to indicate the most current input (dilemma due to valve discretes). Another keyboard entry would be required to override the status back to open.

Whenever a manifold status is set closed, all available jets on that manifold are automatically removed from the availability table. An asterisk will appear in the JET DES column by each affected jet. There are only two ways to regain jets that are made unavailable due to a closed manifold status:

1. Override the affected manifold valve status to open via keyboard entry or
2. Move the affected manifold valve to open (if switch is closed – move switch to open, if switch is open – cycle switch closed to open).

Realize that step 2 will not work if a manifold status is declared closed due to a dilemma. Moving the switch will only reinitiate the dilemma and the manifold status will remain closed. In a dilemma case, the status may be overridden open by step 1 above or by a Spec 51 item entry (see next paragraph). Otherwise the status will remain closed until the dilemma is resolved.

If Spec 23 is not available for overriding manifolds that are closed due to a dilemma, then Spec 51 (override) can be used. The Spec 51, item 41 entry RCS RM MANF CL OVRD, will override the manifold status to open for all manifolds whose status is set closed due to a dilemma. It will have no effect on any manifold whose status is not in dilemma. It will also have no effect on jets that are deselected (manual or auto). The item entry cannot be used to override a manifold status to closed. Item 41 can be executed any number of times. Each time it will only affect (override) manifolds whose status is set closed by dilemma.

RCS manifold status is simultaneously annunciated on all status displays that are available (Spec 23, SYS SUMM 1, and/or SYS SUMM 2). Previously deselected jets will not be affected by changes to the manifold status. Deselected jets can only be regained by manual deselection.

Jet Fail Limit

The jet fail limit module provides the logic for jet failure annunciations and the automatic deselection of jets that have been declared failed off or failed leaking. Auto deselection will remove the affected jet from the availability table. There is no capability for the automatic deselection of a failed on jet since deselection would not stop a failed on jet from firing.

The jet fail limit module receives jet fail off and leak discretes from the jet fail monitors, after the failure is annunciated. Once a jet has been annunciated as failed, no further fail discretes of that type for that jet are sent to the jet fail limit module unless RM is reset.

When a fail off or fail leak annunciation occurs, the fail discrete is sent to the auto deselection counter. The maximum number of primary jets that can be auto deselected is controlled by the FAIL LIMIT on Spec 23 (item 4). This limit is set prelaunch at 2 per pod but can be changed for each pod by item entry to Spec 23. The FAIL LIMIT does not apply to vernier jets. There is no limit to the number of vernier auto deselections. The auto deselection counter does not count vernier auto deselections.

The auto deselect counter for each pod keeps track of the number of auto deselected primary jets, not the number of manual deselections.

Different failure annunciations can occur on the same jet, but once auto deselected, it cannot be auto deselected again unless manually reselected.

For example, if L2U is already failed off (annunciated and auto deselected) and then is declared failed leaking, the following occurs. The fail leak indicator discrete would initiate the failure annunciation since there was no previous fail leak for that jet (the OFF would change to LK in the JET FAIL column). The fail leak discrete would then be sent to the auto deselection counter. For this example, the jet fail limit is set at 2 and the L2U fail off auto deselect has been counted as one. The auto deselect counter, for the left pod, has room to count one more discrete. However, the L2U fail leak discrete would not be accepted by the auto deselect counter since L2U is already auto deselected. The capability for one more auto deselection would remain.

Auto deselection, due to a jet failure, should not be confused with auto jet removal due to a closed manifold status, even though both will cause an asterisk to appear in the JET DES column. The jet fail limit only applies to auto deselection, not to auto jet removal.

The jet fail limit can be changed by keyboard entry, but it will only change the limit of the pod being displayed. For example, on figure 2-40, the jet fail limit is set at the normal limit of 2. With this setting, the first two jets declared failed off or failed leaking will be auto deselected but only if those jets are candidates for auto deselection.

In order for a jet to be a candidate for auto deselection, no asterisks must appear in the columns for JET DES or DES INH (deselect inhibit capability will be covered later). Remember that the jet fail limit affects only the number of jets that can be auto deselected and does not limit the number of failure annunciations.

If the jet fail limit is increased while there are failure annunciations that are candidates for auto deselection, then those jets will be auto deselected (in no particular order), up to the new fail limit. If the fail limit is decreased while auto deselections are active, there will be no change since there is no auto reselection capability.

Keyboard Entries

For the PASS, there is only one way to return a jet to the availability table once it has been auto deselected. This is by manual reselection, and it is performed by item entry in the JET DES column where a deselect asterisk is already present. If the BFS is engaged (Spec 23 not available), the affected manifold switch must be cycled to open in order to reselect any auto deselected jet. The crew must check with MCC to determine which jet is auto deselected by the BFS since Spec 23 is not available.

The effect of an item entry in the JET DES column is dependent upon the availability status (asterisk presence) of the affected jet. If

there is no asterisk in the JET DES column, then a JET DES item entry will deselect that jet and an asterisk would appear. If an asterisk is present due to either a manual or auto deselection, the item entry will manually reselect that jet and the asterisk will disappear. However, if the asterisk is present due to a closed manifold status, the JET DES item entry will have no effect and the asterisk will remain, indicating the jet is still unavailable.

Manual reselection of an auto deselected jet will decrement the auto deselect counter for each auto deselected jet that is reselected. Manual reselection of a manually deselected jet has no affect to the auto deselect counter.

If a jet is auto deselected due to a fail off and is subsequently reselected, the JET DES asterisk would disappear (that jet is now available). If the jet fail limit had been set at 2 and two jets had been auto deselected, this manual reselection would decrement the auto deselect counter from 2 to 1 allowing for the auto deselection of one subsequent jet failure for that pod. Although this jet has been reselected, the failure annunciation (OFF) would remain because the RM had not been reset. (JET DES item entries do not reset RM). This reselected, but failure annunciated, jet could not be auto deselected again for a fail off. The fail off counter for that jet is full and no discretes for fail off will go to the auto deselect counter. However, a fail leak for that jet would result in auto deselection because it is a new annunciation and the reselected jet is a candidate for auto deselection.

Once a jet has been annunciated as failed, it cannot be re-annunciated for that type of failure unless the RM is reset. There are two methods to reset RM. One method uses item entries in the DES INH (deselect inhibit) column and changes jet fire priorities with resetting RM. The other method uses the JET RESET item but will not change jet fire priorities. The DES INH method will be discussed first.

The DES INH item entry is primarily used to inhibit auto deselection. Inhibiting auto deselection has no effect on manual deselection. The DES INH item entry will perform several functions depending upon the number of times it is entered for a particular jet. If no asterisk is present in the DES INH column, then auto deselect is enabled for that jet. A DES INH item entry will inhibit auto deselection and lower the jet fire priority of that jet to the lowest priority in its associated group. The other jets in that group will have their priorities increased by a count of one. An asterisk will appear by the item number in the DES INH column.

Once an asterisk is present in the DES INH column, a subsequent DES INH item entry for that jet will remove the deselect inhibit and allow for auto deselection of that jet. This DES INH item entry also resets the RM for that jet. If any jet failures are annunciated for that jet, the removal of the DES INH asterisk would remove all jet fail annunciations and reset all jet fail indicator counters for that jet to zero. This jet is now a candidate for future failure annunciations if conditions warrant.

Item entries in the DES INH column have no effect on the auto deselect counters or on JET DES asterisks. An auto deselected jet will remain auto deselected until manually reselected.

If a jet has an asterisk in the DES INH and an asterisk in the JET DES column, then a DES INH item entry would still remove all failure annunciations and reset the RM for that jet. The DES INH asterisk would disappear but the JET DES asterisk would remain. Subsequent failures could be annunciated but auto deselection would not occur since the jet is already deselected. Performing two consecutive DES INH item entries on one jet (to change its jet fire priority and then reset its RM) is called toggling RM.

The other RM reset method is performed with one item 45 entry, JET RESET. A single JET RESET item entry will reset the RM (remove the failure annunciations and reset the jet fail indicator counters to zero) for all available jets in all three pods. It cannot reset the RM of any jet with an asterisk in the JET DES column.

In summary, there are two ways to reset jet RM.

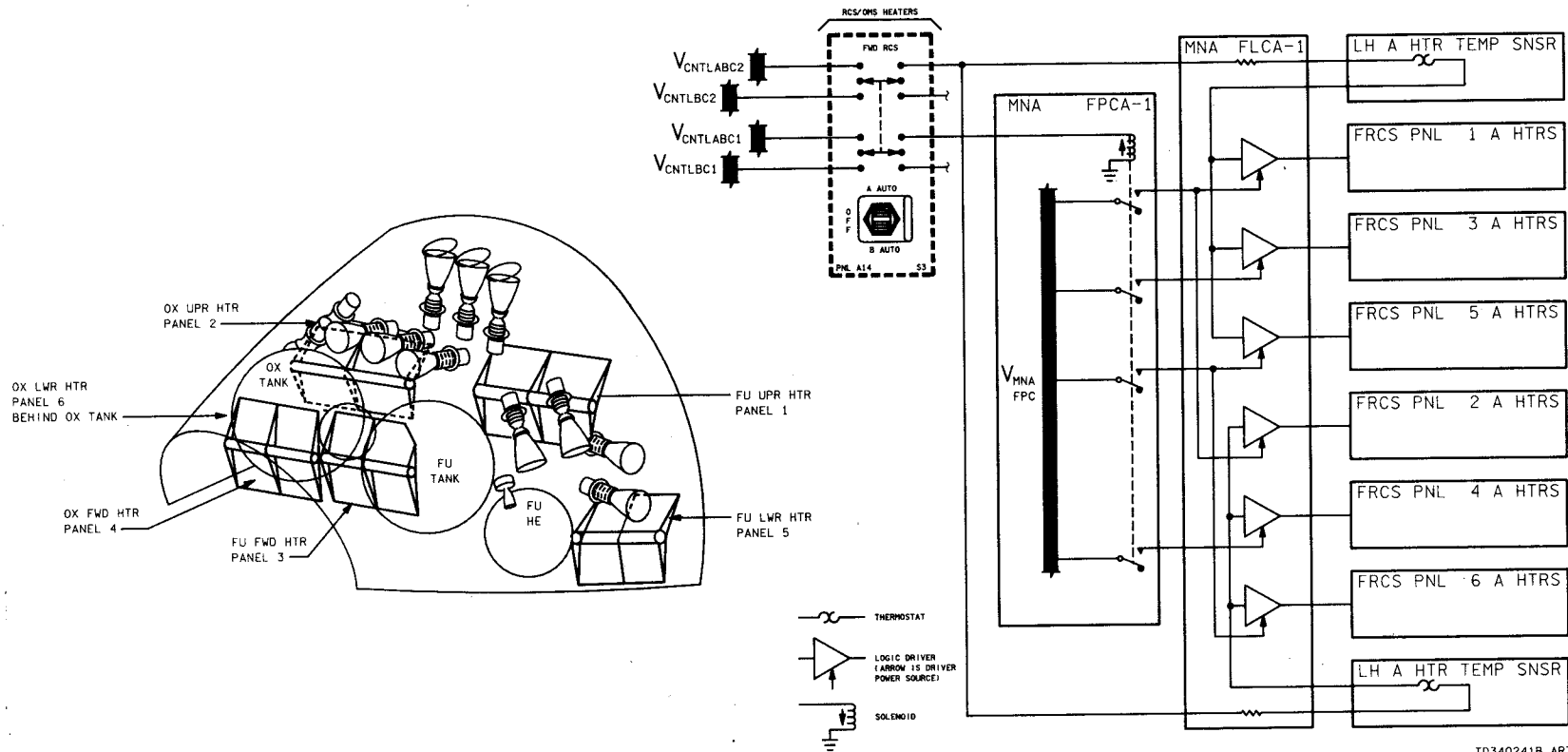
- Reset RM with an item 45. This can only reset the RM of available jets. If the jet is not available, then it must be made available by item entry or manifold status change, as applicable. This item 45 method does not affect jet priority and can affect multiple jets in multiple pods with one keystroke.
- Toggle RM (double item entry in DES INH). This method will change the jet fire priorities in the jet group and only reset RM on one jet per double keystroke. This method can reset RM on an unavailable jet.

Thermal Control

Thermal control of the RCS is achieved by insulation and electric heating. Insulation is provided for propellant lines and numerous partitions that separate and surround RCS hardware components. Electric heating is provided by four types of heaters; panel, patch, line wrap, and jet injector plate heaters. The switches controlling these heaters are found on panel A14 (figure 2-27).

The forward RCS pod uses panel type heaters to provide area heating. These heaters are installed at various locations throughout the pod (figure 2-41). There are two redundant circuits (A and B) that can activate the heater panels but only one circuit can be selected with the single switch. Figure 2-41 only shows the schematic for the A heaters for simplicity.

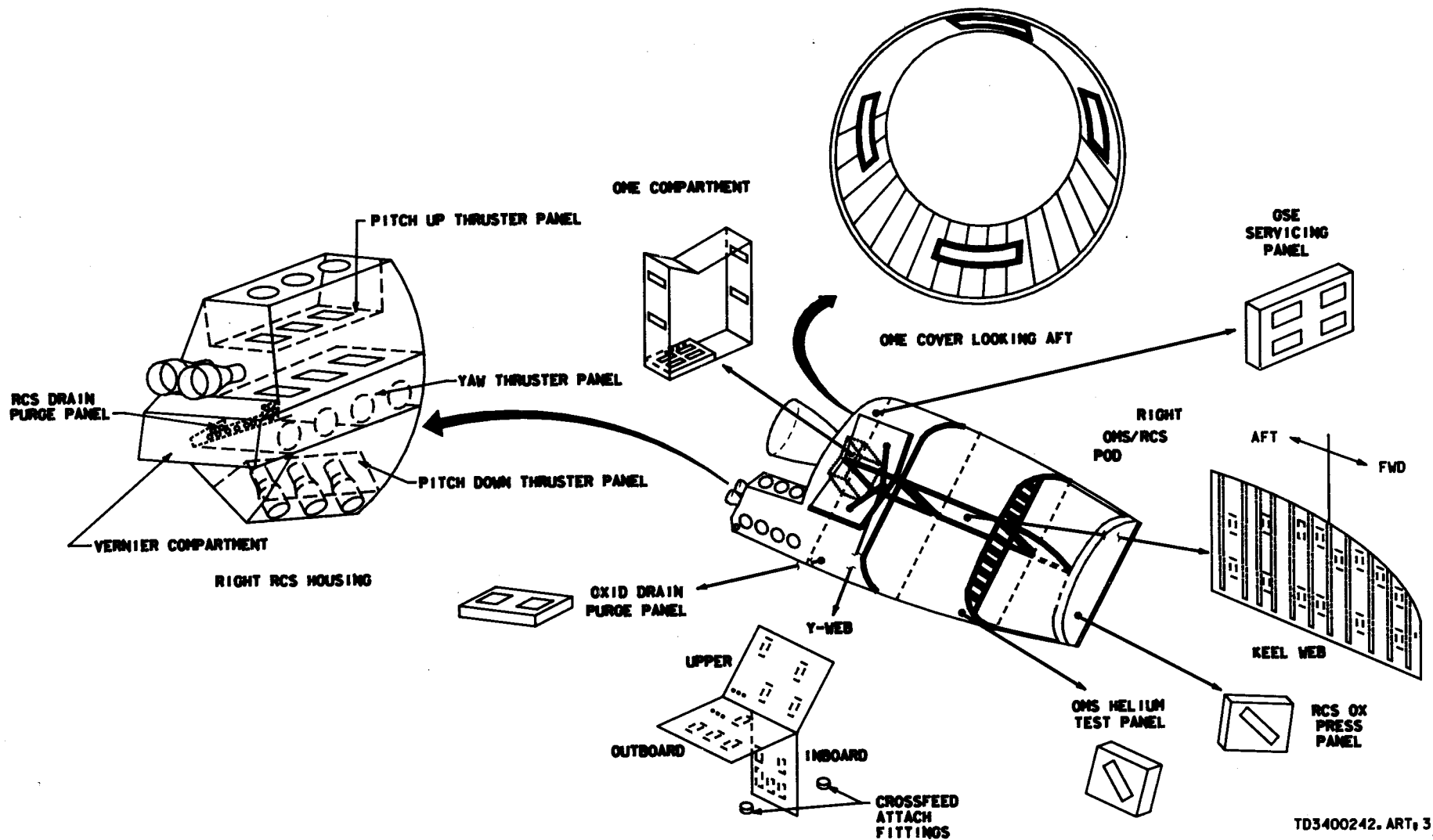
When a circuit is selected, dual control bus power is provided to the circuitry. One control bus activates the thermostats that provide auto control of the heaters which maintain pod temperatures between 55° F and 90° F. The other control bus provides main bus power from the forward power control assembly (FPCA) via the forward load control assembly (FLCA) to the panel heaters. The loss of either control bus will cause the loss of the associated heaters.



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Figure 2-41.-- Forward RCS pod heaters and schematic.

The aft RCS pods utilize numerous patch heaters that are attached to partitions throughout both pods. (Figure 2-42).



TD3400242. ART. 3

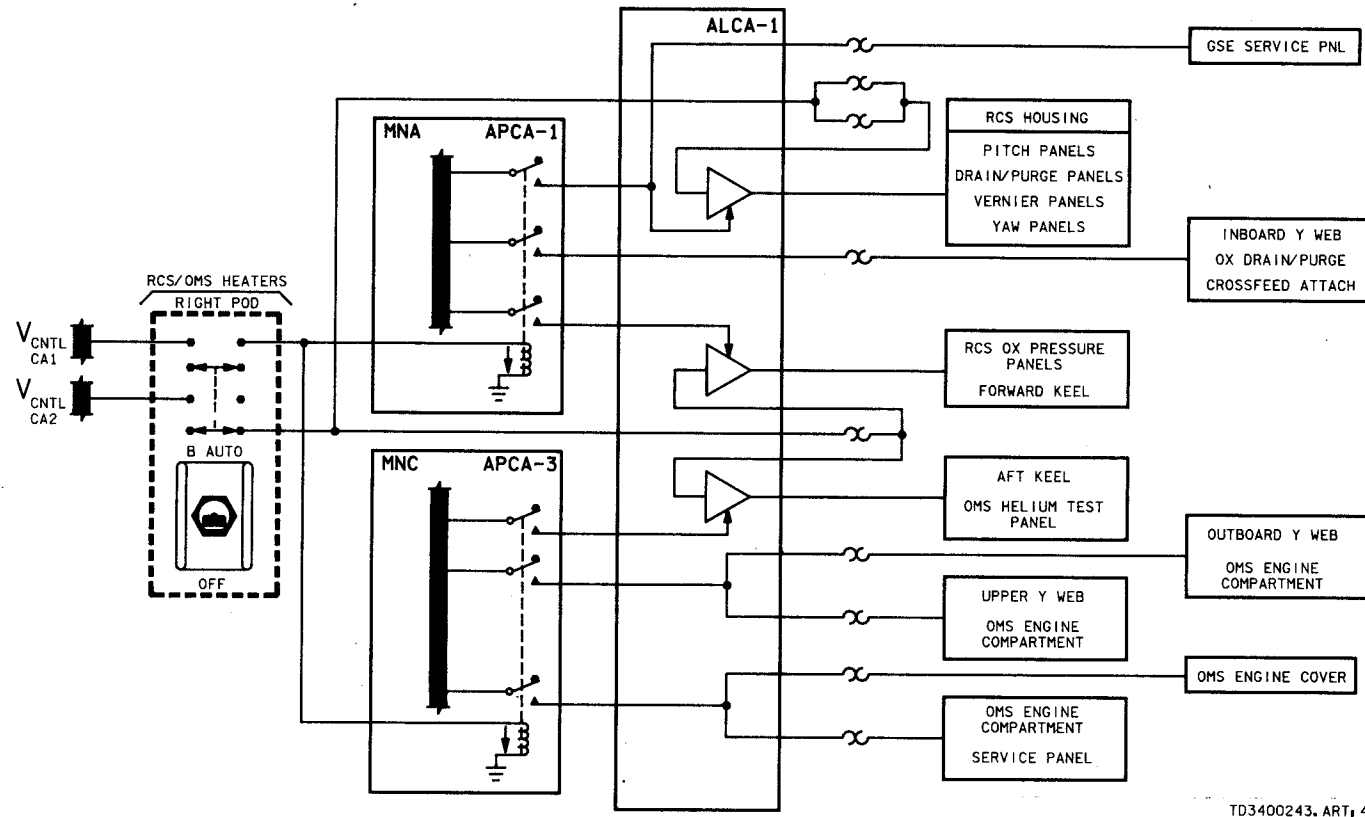
Figure 2-42.- OMS/RCS pod heater location.

There are two circuits that can activate these patch heaters and each circuit has an associated switch. Figure 2-43 only shows the B circuit schematic for simplicity reasons. Each switch provides dual control bus power to the associated circuitry. One control bus activates certain thermostats (55° F to 90° F) that provide auto cycling of a major portion of patch heaters.

The other control bus provides main bus power to all patch heaters and to main bus thermostats for the remainder of the patch heaters. The loss of the control bus for main bus voltage will cause the loss of all circuit heaters. The loss of the other control bus will cause the loss of the majority of circuit heaters (RCS housing, keel, OMS TP, and RCS PNL).

When the B circuit is activated, the A circuit should be turned off and vice versa. Simultaneous operation of the A and B pod heater circuits can cause overheat damage to the heaters on the pod. Guards are provided for these switches to preclude inadvertent switch movement.

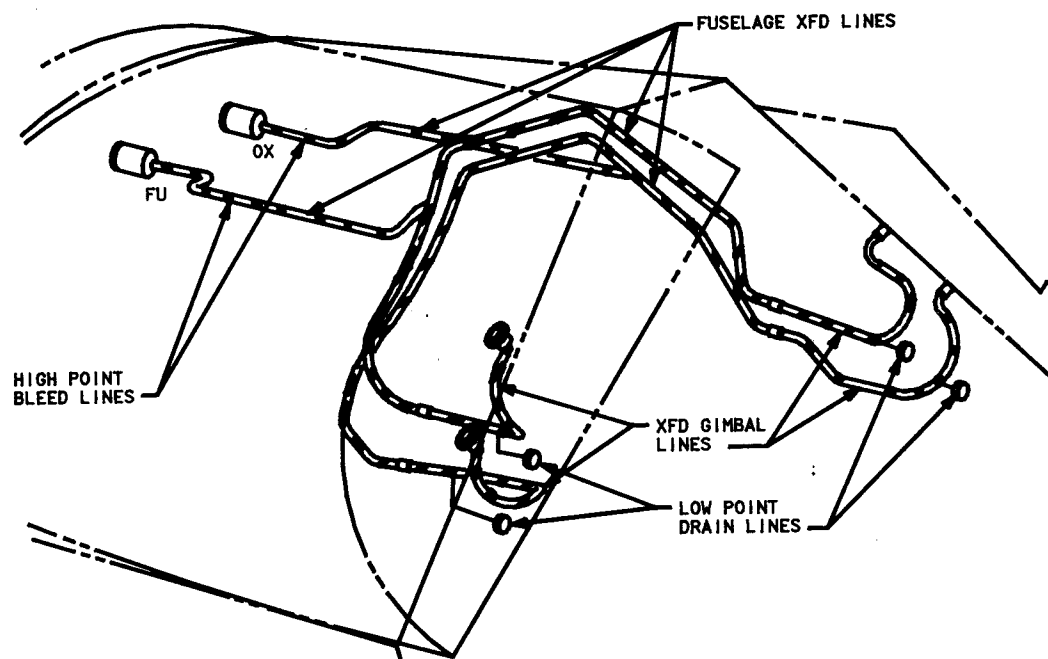
The forward and aft pod heaters are turned on during postinsertion activities and turned off during entry preparations.



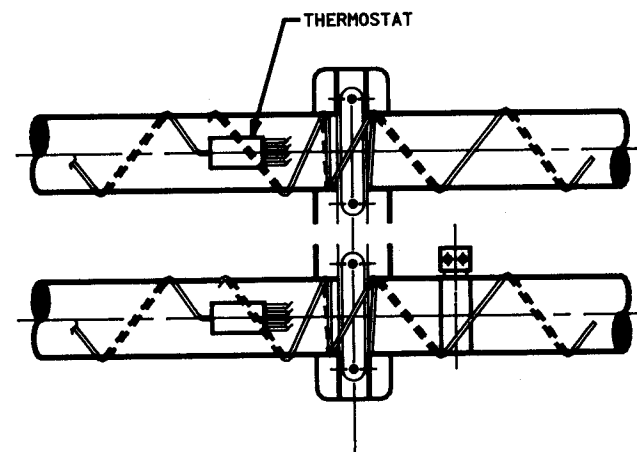
TD3400243. ART. 4

Figure 2-43. - OMS/RCS pod heater schematic.

The OMS/RCS crossfeed lines use line wrap heaters that spiral around the length of the lines underneath the line insulation (figure 2-44). There are two circuits (A and B) that can activate these line heaters and both circuits can be activated simultaneously with no harmful effects. Simultaneous operation is standard for ascent and entry.



OMS/RCS CROSSFEED LINES WITH LINE WRAP HEATERS



TYPICAL XFD LINE HEATERS AND THERMOSTATS

TD3400244. ART, 3

Figure 2-44.- OMS/RCS crossfeed line heaters.

Figure 2-45 shows a schematic for the crossfeed line A heaters. Note there is only one control bus providing activation of the heaters and the thermostats (55° F to 90° F range of operation). Dual heater operations are not required on orbit so either the A or the B circuit is used at that time.

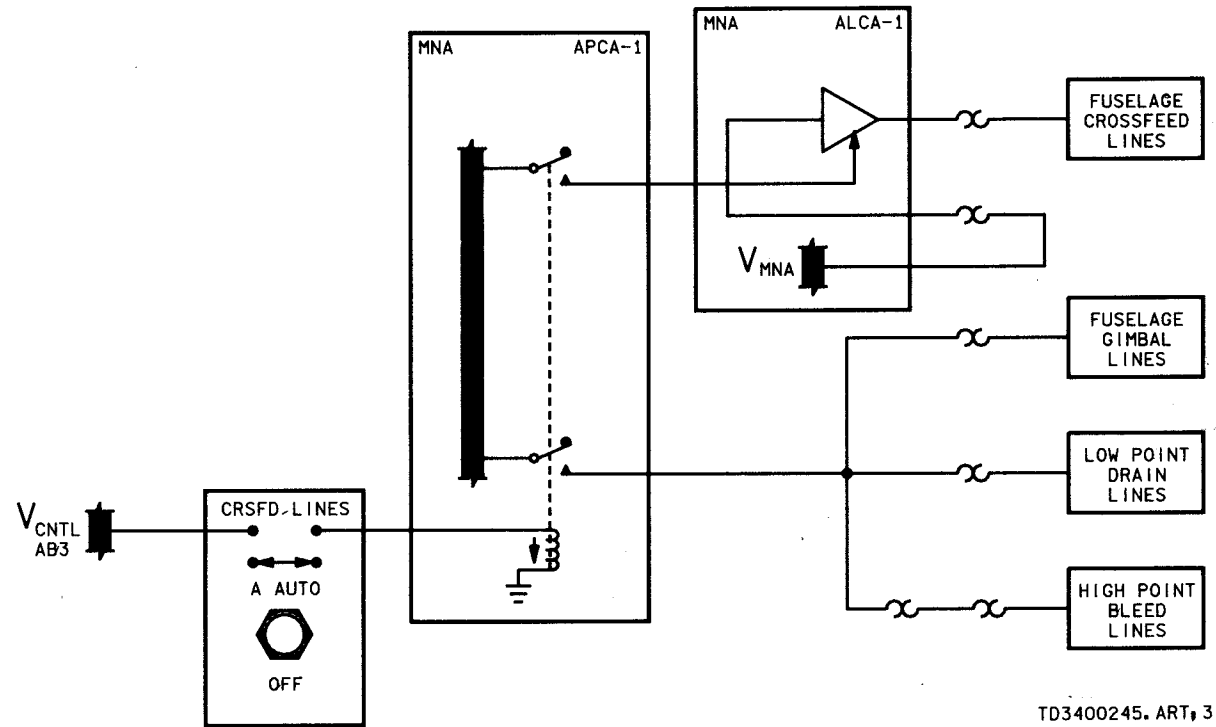


Figure 2-45.-- OMS/RCS crossfeed line heater schematic.

Each RCS jet has a heater for its injector plate to provide a proper thermal environment for jet operation.

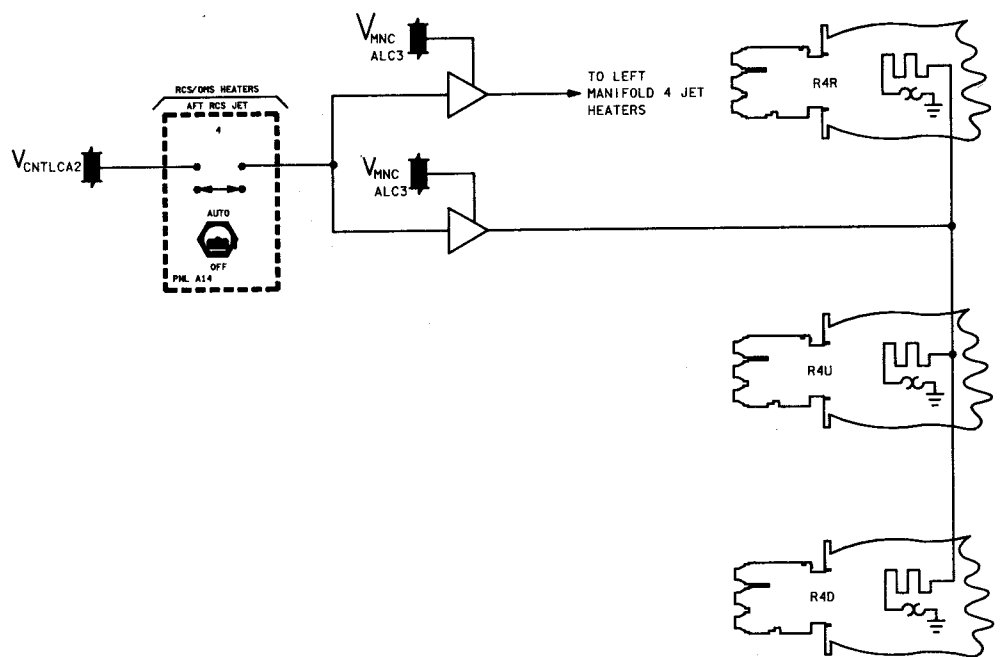
Figure 2-46 shows a representative schematic for three RCS jets. Each switch for the forward RCS jets affects a single manifold while each switch for the aft RCS jets affects two manifolds (one left and one right). Each forward RCS jet heater is activated from a single main bus power source while each aft RCS jet heater is activated by a single control bus source. The jet heaters do not have redundant A and B circuits.

The jet heaters for the primary jets (manifolds 1 through 4) are turned off for ascent since ambient pod temperatures during powered flight and post-MECO jet firings, are adequate for maintaining temperatures within limits. This also conserves electricity necessary for other systems during ascent. The vernier jets (manifold 5) are not used during ascent and must be heated in preparation for orbit operations. Subsequent onorbit jet firings maintain operational temperatures.

Primary and vernier jets cannot be used simultaneously. Whenever one set of jets is being used (primary or vernier), the other set must rely on electrical heating or solar attitudes to maintain temperatures within operational limits.

During entry, the vernier jet heaters are turned off since the verniers are not operational in OPS 3. The primary jet heaters are left in auto to provide a proper thermal environment.

The entire RCS thermal control system normally does not require much attention from the crew. Temperatures are monitored by the GPCs, and if a temperature exceeds the preset caution and warning limits, an alarm sounds and a fault message appears on a CRT display. During orbit operations, these alarms are generated by the GPC containing OPS 2 SM software. During ascent and entry, the BFS software generates these alarms. When the crew observes an alert, they can use a CRT display (or information from the ground) to determine the location of the thermal problem.



TD3400246. ART, 3

Figure 2-46. - AFT MANF 4 jet heaters.

During orbit operations, the crew uses the propellant thermal display (SM Spec 89) for troubleshooting thermal message annunciations. This display lists the temperature measurements at specific locations throughout the OMS/RCS modules (figure 2-37 is reprinted on this page for your convenience). If there is a thermal alert, one or more of these temperature measurements will have exceeded the GPC software limit. Next to each temperature indication is a space for a status indicator. The space will be blank if the temperature is within normal limits and the sensor data is seen by the GPCs. Otherwise, the space could be filled with any of the following symbols: M, †, ‡, H, or L.

The M stands for missing data and indicates that the temperature data is not being received by the GPC. The † and ‡ symbols indicate that the temperature displayed has exceeded the normal limits (†-upper/‡-lower). The H and L symbols indicate the temperature has reached the highest (H) or lowest (L) value that can be measured by the sensor. The temperature data in the left half and lower right corner of the display applies to areas affected by the left and right pod heaters. The data in the upper right corner applies to the areas served by the crossfeed line heater segment. The data in the right center of the display applies to the forward RCS module.

The BFS thermal display (BFS SM OPS 0) is available any time the BFS computer is in run or standby, which includes the ascent and entry phases. This display (figure 2-38 which is reprinted on this page) includes thermal data for several different systems and the OMS/RCS thermal information is limited. The display does not provide numerical temperature data, instead it provides status indicators that correspond to a selected set of temperature sensors. The status field for each sensor will either be blank (for normal operation) or display one of the indicators as described previously (M, †, ‡, L, H).

XXXX/XXX/089	PRPLT	THERMAL	XX X	DDD/HH# MM# SS
POD	L	R		DDD/HH# MM# SS
OMS TK	OX XXXS	XXXS		
	FU XXXS	XXXS		
ENG I/F	OX XXXS	XXXS	OMC CRSFD	L R C
	FU XXXS	XXXS	XFU	OX XXXS XXXS XXXS
	OX VLV	XXXS XXXS	DRN	OX XXXS XXXS
	FU INJ	XXXS XXXS		
WEB KEEL	1 XXXS	XXXS		
	2 XXXS	XXXS		
Y	OB XXXS	XXXS	BLD AFT FUS	FU OX XXXS XXXS
	UP XXXS	XXXS	PL BAY	XXXS XXXS
OX DRN PNL	1 XXXS	XXXS	FWD RCS	FU OX
	2 XXXS	XXXS	LINE	T1 XXXS XXXS
ENG COVER	XXXS	XXXS	T2	XXXS XXXS
SERV PNL	XXXS	XXXS		
GSE SERV PNL	XXXS	XXXS	AFT RCS	L R
TEST HE/OX	1 XXXS	XXXS	MANF 1	OX XXXS XXXS
	2 XXXS	XXXS	DRN PNL	1 XXXS XXXS
				2 XXXS XXXS
			VERN PNL	1 XXXS XXXS
				2 XXXS XXXS

TD3400237. ART, 1

Figure 2-37.- Propellant thermal display.

0001/ /	THERMAL	XX X	DDD/HH# MM# SS
			BFS DDD/HH# MM# SS
HYD SYS TEMP	BDYFLP	RD/SB	L OB L IB R IB R OB
ACTR	± XXXS	± XXXS	± XXXS ± XXXS ± XXXS ± XXXS
PRIME	± XXXS	± XXXS	± XXXS ± XXXS ± XXXS ± XXXS
STBY 1	± XXXS	± XXXS	± XXXS ± XXXS ± XXXS ± XXXS
STBY 2	± XXXS	± XXXS	± XXXS ± XXXS ± XXXS ± XXXS
HTR TEMP	L/A	R/B	FREON LOOP 1 2
PRPLT	SSSSSSS	SSSSSSS	ACCUH DTY XXXS XXXS
POD	SSSSSSS		RAD IN T XXXS XXXS
OMS CRSFD	SSSSSSS		
EVAP			H2O SUPPLY P XXXS
HI LOAD	SSS		
TOP DUCT	SS		
NOZ	S	S	
FDLN	SSSS	SSSS	
HYD BLR HTR	S	S	S
APU			
GO/FU PMP HTR	SSSS	SSSS	SSSS
TK/FU LN HTR	SSSSSSSSS	SSSSSSSSS	SSSSSSSSS
PUMP/VLV COOL	SS	SS	SS
FC END HTR A/B	XXXX/XXXX	XXXX/XXXX	XXXX/XXXX

FIGURE 2-38.

TD3400238. ART, 3

Figure 2-38.- BFS thermal display.

Section 2 Questions

1. Categorize the valves listed below according to the means of activation; S for solenoid only operation and M for motor driven operation.

 Helium isolation
 Propellant tank isolation
 Primary manifold isolation
 Vernier manifold isolation
 Crossfeed isolation
2. During accelerated flight, which propellant tanks are not capable of providing adequate propellant flow.
3. What is the difference between a crossfeed and an interconnect.
4. Assume there is an asterisk in the JET DES column of Spec 23 for LIL due to a closed manifold status. How can the asterisk be removed so that LIL is available to fire?
5. When resetting RM on Spec 23, what is the difference between a single item 45 JET RESET item entry and two identical DES INH item entries?
6. How does a jet P_c discrete failed low (false fail off) affect jet fail on RM?

Section 2 Answers

1. Categorize the valves listed below according to the means of activation; S for solenoid only operation and M for motor driven operation.

S Helium isolation
M Propellant tank isolation
M Primary manifold isolation
S Vernier manifold isolation
M Crossfeed isolation

2. During accelerated flight, which propellant tanks are not capable of providing adequate propellant flow.

A: The forward RCS propellant tanks. These tanks are designed for use in a low g environment only. During accelerated flight, a significant amount of propellant in the forward RCS could be unusable due to the level of the propellant with respect to the feedout tube. This is not a factor with the aft RCS due to its different design.

3. What is the difference between a crossfeed and an interconnect.

A: A crossfeed is the transfer of propellant from one pod to another within the same system (RCS to RCS or OMS to OMS). An interconnect is the transfer of propellant from one system to a different system (OMS to RCS).

4. Assume there is an asterisk in the JET DES column of Spec 23 for LIL due to a closed manifold status. How can the asterisk be removed so that LIL is available to fire?

A: Change the manifold status to open by one of the following methods, as applicable.

1. Move the manifold 1 switch to open, if the switch and talkback are closed.

or

2. Execute an item 40 to override the manifold status to open, if the switch and talkback are open.

or

3. If the closed manifold status is due to a dilemma and the valves are open, an item 41 entry to Spec 51 (OVERRIDE) will override the status to open.

Note: a JET DES item entry will have no effect on closed manifold status asterisks.

5. When resetting RM on Spec 23, what is the difference between a single item 45 JET RESET item entry and two identical DES INH item entries?

A: A single item 45 will reset the RM of all available jets in all three pods. If any jet is not available (asterisk in JET DES column), then item 45 will not reset the RM of that jet. Also an item 45 reset does not change the jet priorities.

A dual DES INH entry will only reset the RM of an individual jet. It also changes the jet fire priority to last priority. This method can be used to reset the RM of a nonavailable jet. If multiple jet resets are to be made, then the item 45 method may use less keystrokes.

6. How does a jet P_c discrete failed low (false fail off) affect jet fail on RM?

A: There is no effect to jet fail on RM as long as the BFS is not engaged. The PASS requires a driver discrete and no jet fire command to annunciate a jet fail on. The BFS, on the other hand, uses a P_c discrete and no jet fire command for annunciation. Since the P_c discrete is failed low, the BFS cannot annunciate a failed on jet.

Section 3: System Operation

In order to effectively describe RCS operations, it will be necessary to separate the overall operations into four general areas: ascent, orbit, entry, and aborts.

Ascent

As stated earlier, the RCS is not normally utilized until post-MECO when the Orbiter is maneuvered away from the ET. Before MECO (MM102-103), the RCS is essentially a backup system to be used only for off-nominal situations (loss of two SSMEs, propellant dump, etc.).

During prelaunch activities, the RCS switches are configured for ascent operation. When completed, the prelaunch switch configuration for the RCS will be

- Helium pressurization switches (6) – open. This provides redundant pressurization for the RCS propellant tanks and protects against valve movement due to ascent vibration.
- Aft propellant tank isolation switches (6) – GPC with the talkbacks open. This provides straight feed of RCS propellant to the manifolds under normal conditions. Since the switches are in GPC, the propellant tanks can be isolated if commanded by the GPCs for auto crossfeeds or abort interconnects.
- Forward propellant tank isolation switches (2) – open. This provides straight feed of propellant to the forward manifolds. The GPC position is not used because there is no crossfeed or interconnect capability for the forward RCS.
- Manifold isolation switches (15) – open. This provides propellant flow to the RCS jets.
- RCS crossfeed switches (4) – GPC with talkbacks closed. This allows straight feed of RCS propellant unless the GPCs command a crossfeed or interconnect configuration.
- Master crossfeed switch – OFF. This keeps the GPC controlled valves in straight feed unless the switch is moved to a “FEED FROM” position.
- OMS crossfeed A switches (2) – close. This protects the Orbiter from a single-point electrical failure that could cause the OMS crossfeed A valves to fail open, if the switches are in GPC and a return to straight feed is commanded after an abort interconnect. The B valves do not have this problem.
- OMS crossfeed B switches (2) – GPC with talkbacks closed. This allows straight feed of OMS and RCS unless an interconnect is commanded by the GPCs. It allows the closure of OMS crossfeed valves if an auto RCS to RCS crossfeed is commanded.

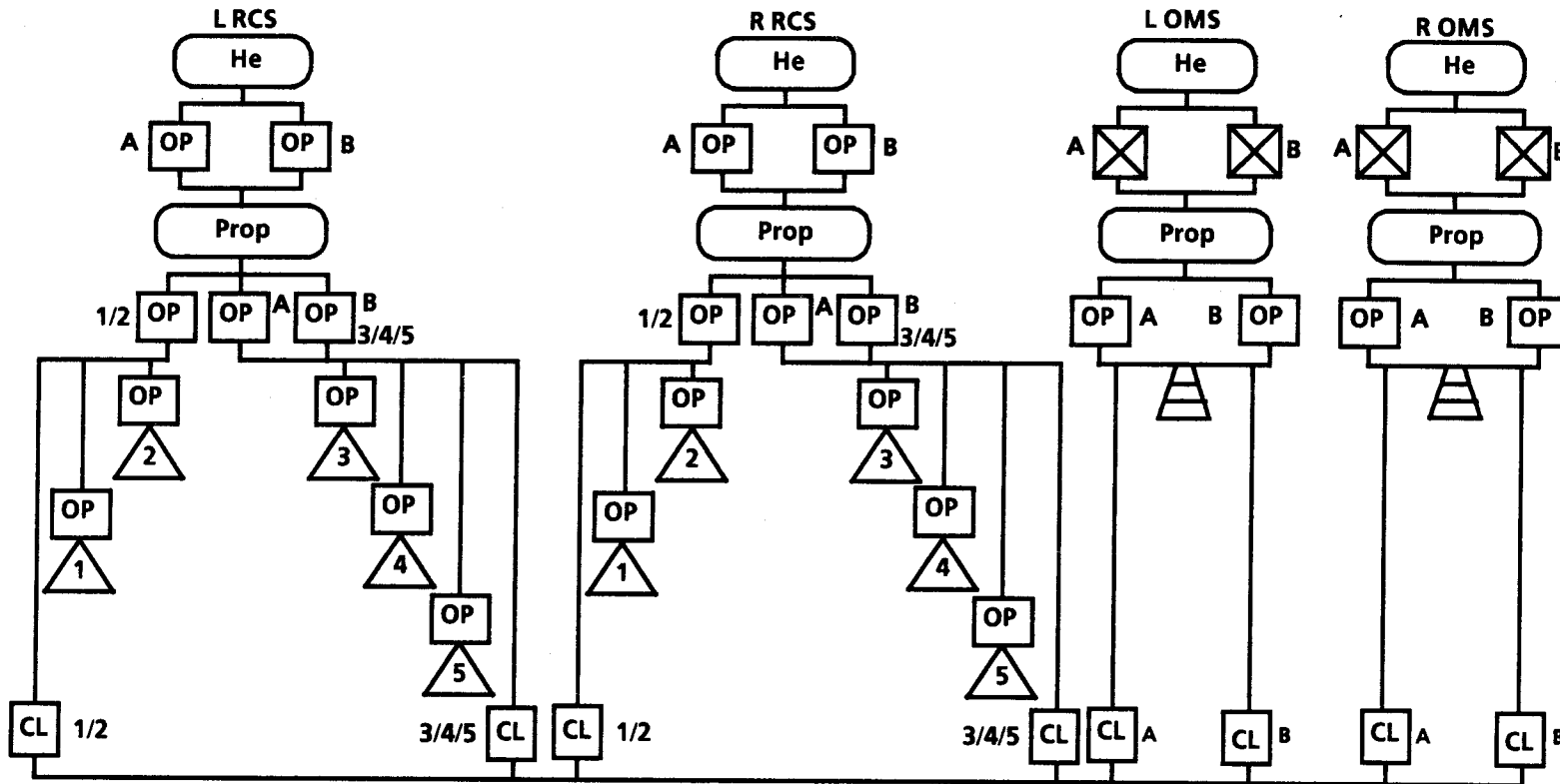
The talkback valve configuration for nominal straight feed can be seen in figure 3-1. The RCS switches would not be moved until after the OMS 2 burn, unless an abort or malfunction occurs prior to this OMS burn.

The digital autopilot (DAP) that resides in the GPCs, generates dual fire commands (A and B) to the reaction jet drivers in response to inputs from the flight control system (FCS), the abort control sequence, or both. The abort control sequence will be covered in the Aborts section.

The inputs from the FCS can be either automatic inputs from guidance or manual inputs by the crew with the rotational hand controller (RHC) or translational hand controller (THC). The fire commands during ascent and entry are directed only to the primary jets since vernier jet operations are not supported until OPS 2. When a dual fire command is generated, the B command is also sent to RM to determine jet failures.

Flight control fire commands usually result in short duration jet firing pulses.

The first nominal jet fire commands occur after ET separation when RCS jets fire to maintain attitude and maneuver the Orbiter away from the ET.



TD340*301

Figure 3-1.- Talkback configuration for straight feed.

System Monitoring

During MM 102-103, there is limited RCS operations. During these early stages, SYS SUMM 1 would be monitored to check for jet failures.

The tank pressures would be checked occasionally on the overhead meters. BFS SYS SUMM 2 can be called up to check pressures and quantities, but this will take away insight to main engine data on BFS SYS SUMM 1.

During a nominal ascent, the crew should not use the RCS digital quantity readout on panel O3 since it would indicate zeroes (unless the BFS was engaged). Additionally, the RCS command lights on panel F6 are inoperative in OPS 1 and should also be ignored.

In MM 104, after the OMS 1 targets are checked and the Orbiter is being maneuvered to the OMS 1 burn attitude, the crew would likely be using BFS SYS SUMM 2 to monitor RCS operation since insight to the main engines on BFS SYS SUMM 1 is no longer required.

Procedures

The ascent checklist contains the procedures that utilize the RCS.

The first mention of RCS procedures occurs for the OMS 2 burn setup when the RCS can be used for the OMS 2 burn, if both OMS engines have failed.

OMS 2 BURN SETUP

✓OMS 2 TARGETING, Flip Book

```
CRT1  TRIM LOAD - ITEM 6 +0.4 -5.7
      +5.7 EXEC
* For single eng burn (good eng): *
* TRIM LOAD LY - ITEM 7 + 5.2 EXEC *
* RY - ITEM 8 - 5.2 EXEC *
* OMS L - ITEM 2 EXEC *
* R - ITEM 3 EXEC *
* For RCS burn: *
* RCS SEL - ITEM 4 EXEC *
```

Certain off-nominal situations may require the use of the forward RCS for the OMS 2 burn. Dummy targets are loaded to compensate for the 180° shift in thrust direction relative to the vehicle.

OMS BURN PREP

```
L,R OMS
✓He PRESS/VAP ISOL A (two) - GPC
B (two) - CL
✓TK ISOL (four) - OP (tb-OP)
XFEED (four) - CL (tb-CL)
```

```
.....FRCS BURN PREP.....
. Load DUMMY target for FRCS .
. attitude .
. RCS SEL - ITEM 4 EXEC .
. TIG = TTA -1:00 .
. ΔVX = -2.1 (ITEM 19) .
. ΔVY = 0 (ITEM 20) .
. ΔVZ = -1.0 (ITEM 21) .
. LOAD - ITEM 22 EXEC .
. Mnvr to ATT (error needles) .
. When in attitude: .
. ADI ATT - REF (push) .
. Load External ΔV Burn Target .
. ΔVX = +80 .
. ΔVY = 0 .
. ΔVZ = 0 .
. LOAD - ITEM 22 EXEC .
. TIMER - ITEM 23 EXEC .
. ✓VGOX = negative .
. ✓VGOY = 0 .
. ✓VGOZ = +21 + 2 .
. ✓REF ball - 0,0,0 .
.....
```

After the OMS 2 burn prep, the RCS is used to maneuver to the burn attitude.

OMS 2 BURN ATTITUDE MNVR

F6/F8 /ADI ATT (two) - INTL
ADI RATE - 1

Mnvr to OMS 2 Burn Attitude

At the completion of the OMS 2 burn, the OMS and RCS switches are reconfigured in preparation for orbit operations.

OMS/RCS POST BURN RECONFIGURATION

AFT L,R RCS

He PRESS A (two) - GPC (tb-OP)
B (two) - CL (tb-CL)
TK ISOL (six) - OP (tb-OP)
XFEED (four) - CL (tb-CL)

FWD RCS

He PRESS A - GPC (tb-OP)
B - CL (tb-CL)

L,R OMS

He PRESS/VAP ISOL (four) - CL
/TK ISOL (four) - OP (tb-OP)
/XFEED (four) - CL (tb-CL)

The RCS helium isolation A valves are placed in GPC (with talkbacks open) since there is RCS propellant tank overpressure protection in OPS 2. The B valves are closed since only one set of valves is necessary for overpressure protection. Halfway through the mission, there will be a switch to the B regulators.

In OPS 2, if an overpressure is detected in the RCS propellant tanks, the GPCs will close the GPC selected helium valves to stop the overpressure. Software does not exist to automatically open the helium isolation valves when the pressure returns within normal limits. When repressurization becomes necessary after an auto closure, it must be performed with manual switch positioning.

The RCS tank isolation and crossfeed are placed in manual positions because there is no OPS 2 software for automatic crossfeeding.

Orbit

Orbit operation procedures are initiated in the Postinsertion Procedure. RCS procedures start at a mission elapsed time approximately 1 hour after lift-off. At this time, the RCS heaters are configured for orbit operations. The A heaters are used for the first half of the mission.

```

00:55  C,P  CONEIG EPCs FOR OPS 2/LOAD PAX [1] (USE DUAL G2 CONFIG, SA OPS 2)
        If two PASS EPCs failed, go to MAL, DES, CPC FRP-2
        If OPS engaged go to MAL, DES, CPC FRP-4

A1(B1)  MS  UNSION/CONEIG COMM, EDE  MID Cue Card [2]
AUTO
NORM
RT 0.2
DB 5.0

01:00  MS  AFT STATION CONFIG  AFT Cue Card [3]
  
```

AFT STATION CONFIG [3]

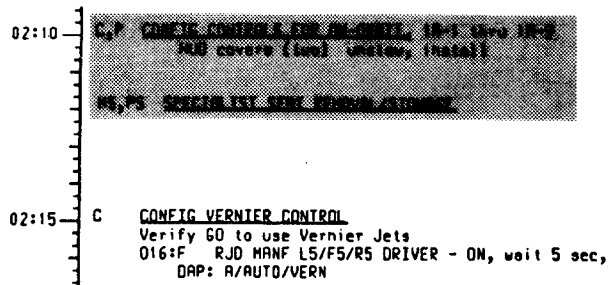
POST SEAT EGRESS

014:D cb MHA CAB VENT (two) - op

```

A14   RCS/OMS HTR FWD RCS           - A AUTO
      L POD (two)           - A AUTO, B OFF
      R POD (two)           - A AUTO, B OFF
      OMS CRS-D LINES (two) - A AUTO, B OFF
      FWD, AFT RCS JET (ten) - AUTO
  
```

At an elapsed time of about 2 hours 15 minutes, the crew should contact Mission Control to get a "GO" for vernier operations. Mission Control will verify the vernier jets are within normal thermal limits before giving the "GO". Once the "GO" is given, the crew will turn on the vernier driver. The DAP is not configured for vernier operations until the driver is warmed up for 5 seconds, otherwise jets could fail off.



The RCS will be used continuously onorbit to maintain attitude or to maneuver to a new attitude. In addition, there are several sets of procedures in the orbit operations checklist that relate specifically to RCS. These procedures include:

- RCS hot fire test. This test is used to ensure all entry critical jets are functioning properly prior to entry.

- Gravity gradient (GG) free drift. This procedure provides the most stable free drift attitude (no jets fire during free drift) by using gravity gradients. Certain payloads may require gravity gradient.
- Passive thermal control (PTC). Passive thermal control provides rotation of the Orbiter about the longitudinal axis perpendicular to the Sun to provide regular periods of solar heating to the payload bay.
- Onorbit RCS burn. This procedure is used to make small orbital adjustment burns or rendezvous maneuvers. Larger maneuvers are performed with OMS burns.
- Loss of verniers. To be used if total loss of vernier control occurs.
- Recovery of verniers. To be used if vernier jet control is regained after a loss of verniers.

Approximately halfway through the mission, the crew activity plan (CAP) will direct the crew to change to the B helium regulators and the B heaters for checkout and equal usage.

FD03 EZ CAP ACTIVITIES:

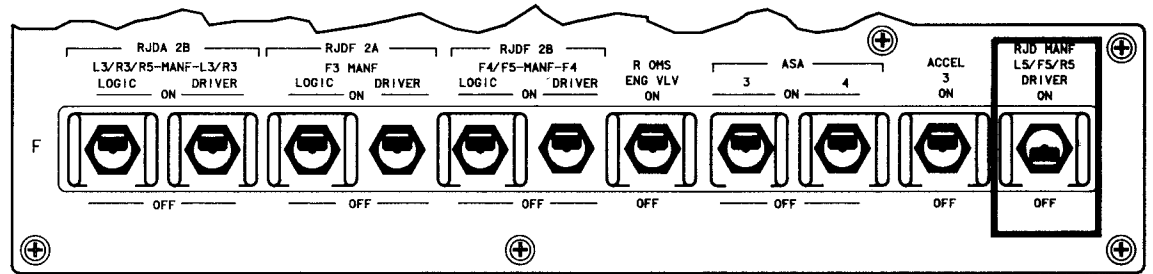
EXERCISE (1 Hr/All)
FOOD PREP/POST (One each) (30 Min)
RCS REGULATOR RECONFIGURE
 07.08 He PRESS A (three)-CL (1b-CL)
 B (three)-GPC (1b-OP)
 Perform midflight/A.M. (5 Min)
HEATER RECONFIG - B (OPB OPS, EPS)
 Perform midflight/A.M. (5 Min)
RCS REUNDANT COMPONENT C.A.
 (OPB OPS, EPS) (10 Min)

HEATER RECONFIG - Config B

A14 RCS/OMS HTR FWD RCS - B AUTO
 L POD - A OFF
 - B AUTO
 R POD - A OFF
 - B AUTO
 OMS CRSFD LINES - OFF
 - B AUTO

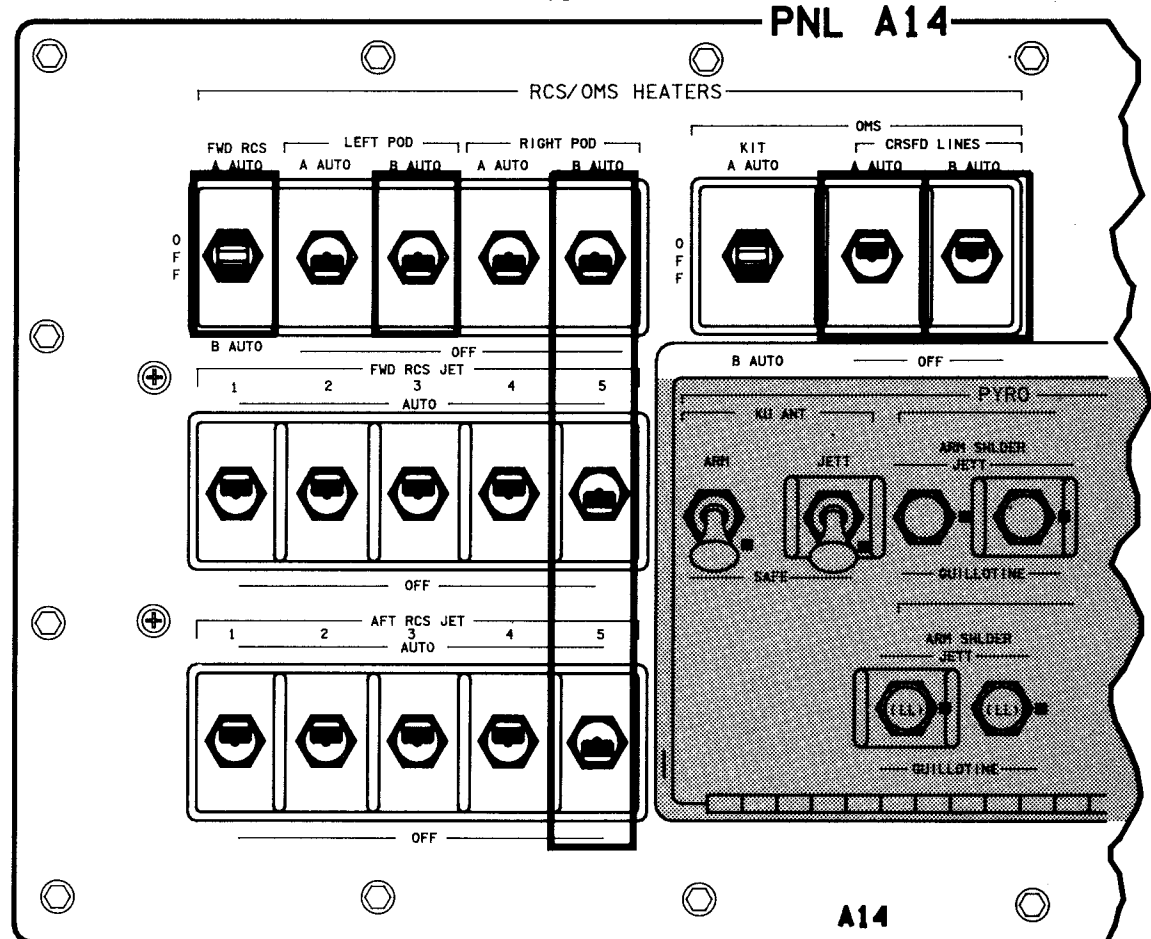
When ready for deorbit, the crew will follow the procedures in the deorbit prep checklist. These procedures start about 4 hours prior to the deorbit burn.

During deorbit preparation, the RCS is being used to maneuver and maintain various attitudes. About 1 hour 30 minutes prior to deorbit burn, the vernier drivers are turned off and the RCS heaters are configured for entry by switching all pod heaters off, both crossfeed heaters to auto, and vernier jet heaters off. See figure 3-2.



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4499. ART 4



A14

TD340302A. ART 3

The vernier drivers and heaters are turned off because the vernier jets are not supported in OPS 3. The OMS pod will retain sufficient thermal properties until entry heating occurs. Redundant OMS crossfeed heaters are required due to the line locations in the aft fuselage between the OMS pods.

About 50 minutes prior to the deorbit burn, the crew will exit the deorbit prep checklist and start using the procedures in the entry checklist.

Figure 3-2.- Entry panel configuration.

Entry

The first entry RCS configuration occurs about 30 minutes prior to the deorbit burn. The RCS tank isolation and crossfeed valves are positioned to GPC to provide for an auto crossfeed.

OMS BURN PREP

07 AFT L,R RCS
 He PRESS (four) - OP (tb-OP)
 TK ISOL (six) - GPC (tb-OP)
 XFEED (four) - GPC (tb-CL)
 ✓MSTR RCS XFEED - OFF

If the deorbit burn is to be delayed for 1 day, then Mission Control would give a go for a 24-hour extension. The crew would back out of the entry procedures and reconfigure the RCS for orbit operations.

.....
 If 24 HR EXTENSION:
 P 07 AFT L,R RCS
 He PRESS A (two) - GPC (tb-OP)
 B (two) - CL (tb-CL)
 TK ISOL (six) - OP (tb-OP)
 XFEED (four) - CL (tb-CL)
 08 FWD RCS
 He PRESS A - GPC (tb-OP)
 B - CL (tb-CL)
 C6 Stow ENT PKT C/L
 Unstow ORB PKT C/L
 Terminate Deorbit Procedures,
 go to DEORB PREP, D/O PREP
 BACKOUT, 2-1

Once these switches are configured, the crew would execute the deorbit prep back out procedures. These procedures call for reactivation of the vernier drivers, vernier jet heaters, and all RCS B (or A) heaters for orbit operations.

If the burn is not delayed, the crew will maneuver the Orbiter to the deorbit burn attitude at 15 minutes prior to the burn.

TIG-15 ► MNVR to DEORBIT BURN ATT

C F6 FLT CNTLR PWR - ON
 B F6/FB /ADI ATT (two) - INRTL
 ✓ERR (two) - MED
 ✓RATE (two) - MED
 C MNVR to BURN ATT
 (✓ADI ATT with CRT BURN ATT)

If the RCS is to be used for the deorbit burn, there are procedures which assume left OMS propellant is used first.

.....
 RCS BURN PREP
 P 08 L,R OMS
 ✓He PRESS/VAP ISOL (four) - CL
 ✓TK ISOL (four) - OP (tb-OP)
 L OMS XFEED (two) - OP (tb-OP)
 ✓R OMS XFEED (two) - CL (tb-CL)
 07 AFT L,R RCS
 XFEED (four) - OP (tb-OP)
 TK ISOL (six) - CL (tb-CL)

Interconnected OMS propellant is used by RCS jets in a translational mode (usually 4 + X jets). Specific deorbit procedures using RCS are covered in detail in the OMS 2102 training manual.

When the OMS engines are used for the deorbit burn, the RCS should be in straight feed. This will prevent RCS tank damage if an OMS/OMS crossfeed is performed. Remember the OMS and RCS use the same crossfeed line.

.....
 P 07/08 Terminate RCS/RCS XFEED or
 terminate OMS/RCS Interconnect
 unless RCS deorbit

If the burn should be terminated above a safe perigee altitude (HP), the RCS will be configured for orbit operation and the crew would back out of the entry checklist, awaiting a Mission Control call on the length of the delay.

* If burn terminated with HP > SAFE HP: *
 * ✓OMS ENG (two) - OFF *
 * ✓APU - SHUT ON *
 *C3 MSTR MADS PWR - OFF *
 * L,R OMS *
 * He PRESS/VAP ISOL (four) - CL *
 * ✓XFEED (four) - CL *
 * GNC, OPS 301 PRO *
 *07 AFT L,R RCS *
 * He PRESS A (two) - GPC (tb-OP) *
 * B (two) - CL (tb-CL) *
 * TK ISOL (six) - OP (tb-OP) *
 * XFEED (four) - CL (tb-CL) *
 *08 FWD RCS *
 * He PRESS A - GPC (tb-OP) *
 * B - CL (tb-CL) *
 * Consult with MCC at next STDN on *
 * DEORBIT DELAY of 24 HR *

Once the deorbit burn is completed, the RCS switches are checked for proper configuration and the OMS crossfeed valves are closed to allow for auto RCS crossfeed capability. Digital display rotary switches are switched from OMS to RCS.

OMS/RCS POST BURN RECONFIGURATION

- P 07 AFT L,R RCS
 - ✓He PRESS (four) - OP (tb-OP)
 - ✓TK ISOL (six) - GPC (tb-OP)
 - ✓XFEED (four) - GPC (tb-CL)

- 08 L,R OMS
 - He PRESS/VAP ISOL (four) - CL
 - ✓TK ISOL (four) --OP (tb-OP)
 - * IF OMS PRPLT FAIL,
 - * /affected TK ISOL (two) - CL *

- XFEED (four) - CL (tb-CL)

- 03 RCS/OMS PRESS sel - RCS as reqd
PRPLT QTY sel - RCS as reqd

If an interconnect is required after the burn, it should be terminated above entry interface (EI, about 400,000 ft of altitude) to prevent possible helium ingestion in the RCS due to acceleration forces and tank design.

Prior to EI, a forward RCS dump may be executed to move the Orbiter's c.g. to a more acceptable position. This dump is normally executed by simultaneously firing the four forward yaw jets (F1L, F3L, F2R, F4R). See figure 3-3.

EI-18 P FORWARD RCS DUMP
(Use for off-nominal X cg entry)

Determine FWD RCS 'DUMP TO %' using lowest of Ox or Fu qty (calculator, cg wheel, or DEL PAD)

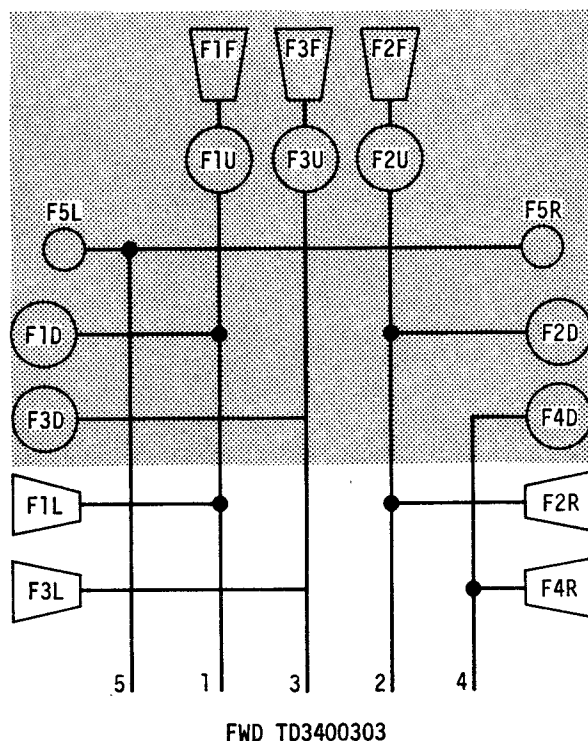
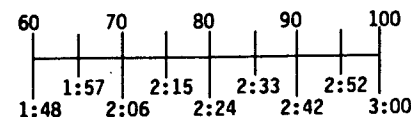
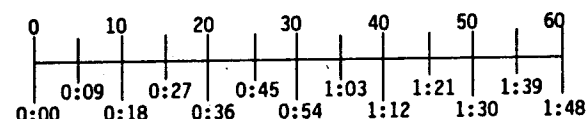


Figure 3-3.- Forward RCS yaw jets.

The crew is usually advised by the ground to dump down to a particular forward quantity indication. The PVT measurements used by the GPCs to calculate and display RCS quantity are not accurate during a dump due to the rapid drop in pressures and temperatures. Therefore, a dump time must be used to determine when to stop the dump. The crew would use the published nomograph to determine the dump time.

FOUR JET DUMP:

F RCS PRPLT TO BE DUMPED (%)



TIME FROM DUMP INITIATION (M:S)

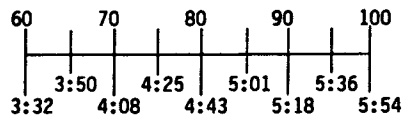
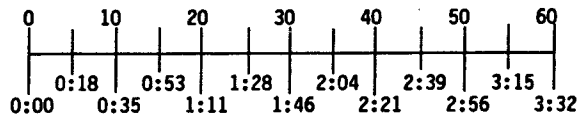
NOTE
During dump disregard RCS qty

Note that the dump time is based on the amount of propellant to be dumped not the "dump to" quantity. As an example, if the crew had 57 percent of propellant and had to dump to 10 percent, then 47 percent of propellant would have to be dumped to achieve the desired c.g. In this case, the dump should be stopped after a dump time of 1 minute 24 seconds for a four-jet dump. There is a note advising the crew to ignore quantity indications during the dump because of RCS gauging errors.

There are also nomographs for two-jet dump times. A two-jet dump (one per side) would be used if any forward yaw jet is known to be failed or otherwise unavailable prior to the dump.

TWO JET DUMP:

F RCS PRPLT TO BE DUMPED (%)



TIME FROM DUMP INITIATION (M:S)

NOTE
During dump disregard
RCS qty

The forward dump is started by two item entries (36 followed by 37). Item 38 is executed when the dump time is achieved.

CRT2 FWD RCS ARM - ITEM 36 EXEC
DUMP - ITEM 37 EXEC
(Start watch)
When dump time achieved:
OFF - ITEM 38 EXEC

When dump complete (if no FWD RCS PTIs
scheduled):
08 FWD RCS
MANF ISOL 1,2,3,4 - CL (tb-CL)

If a yaw jet failure occurs during a four-jet dump, the DAP automatically downmodes to a two-jet dump by not firing one of the opposing jets. This prevents excessive yaw excursions during the dump. The crew must recalculate the duration time of the dump depending upon when the jet failure occurred. As an example, if F1L failed off, then the DAP would stop firing F2R. If F4R subsequently failed off, the DAP would reactivate F2R and continue the two-jet dump. A forward RCS dump is not possible if both yaw jets on one side are failed or unavailable.

When a forward RCS dump is active, attitude control is maintained by firing only the aft jets (auto or RHC inputs). Translational control is not available during the forward RCS dump.

After the dump is completed, all the primary manifolds are closed, unless program test inputs (PTI) are scheduled that require forward RCS jet firings. The vernier manifolds are left open since vernier jets are not capable of being fired during entry and the vernier drivers are turned off. Closing the vernier manifolds at this time would only accomplish additional wear to the valves.

The RCS is used to maneuver to the EI-5 attitude which may require a prebank to compensate for an underburn or propellant shortage. If there is a minimum RCS quantity required to complete a particular maneuver, that number will appear in the "% RCS EACH SIDE" block.

FLIGHT CONDITIONS	% RCS EACH SIDE	MANEUVER
EI-5		✓LVLH ATT GNC, OPS 304 PRO ** * PREBANK <input type="text"/> <input type="text"/> <input type="text"/> (90° 1f AOA-S) *
EI-3		✓FWD RCS MANF ISOL 1,2,3,4 - CLOSE (OPEN 1f FWD RCS PTIs SCHED)

During entry, the utilization of the RCS is gradually phased out. Certain RCS jets are made inactive as associated flight control surfaces become effective.

During entry, when the dynamic pressure (\bar{q}) becomes greater than 10 pounds per square foot [(54 knots (KTS) equivalent air speed (EAS)], the ailerons become effective and the roll jets are deactivated. When \bar{q} reaches 40 psf (109 KTS EAS) the elevons become effective and the pitch jets are deactivated. The rudder is not fully effective until below Mach 1, so the yaw jets stay active until that time.

When the roll jets are deactivated (\bar{q} reaches 10 psf), the roll command lights are also deactivated. The same is true of the pitch command lights except that deactivation occurs when \bar{q} reaches 40 psf. When the \bar{q} becomes greater than 50 psf (121 KTS EAS), the roll and pitch command lights are reactivated but are no longer indicating roll and pitch commands. Instead, the illumination of the roll light occurs when three or four yaw jets, on one side, are firing simultaneously. The illumination of the pitch light occurs when the elevon drive rate is greater than 20 deg/sec (10 deg/sec if operating on only one hydraulic system). At this time, the yaw light is still indicating yaw fire commands.

The RCS command lights on F6 are not active in OPS 1. In OPS 3, when \bar{q} is less than 10 psf, the RCS command lights indicate if/when any roll, pitch, or yaw jets are commanded to fire. Short duration jet commands (less than 1 second) are not long enough to provide visible illumination of the command lights. Therefore, the commands are "stretched" by the command light processing software to allow for longer, thus more visible, illumination.

The roll command lights are deactivated again below Mach 1 since the yaw jets are deactivated at that time. Likewise, the yaw jet command light is deactivated below Mach 1. The pitch command light remains active until landing.

RCS command light processing is summarized on table 3-1.

Table 3-1.- RCS command light processing.

	RCS Command Light Illumination		
	Roll L/R	Pitch U/D	Yaw L/R
$\bar{q} < 10$ psf	If roll JET commanded	If pitch JET commanded	If yaw JET commanded
$\bar{q} \geq 10$ psf	Inoperative	If pitch JET commanded	If yaw JET commanded
$\bar{q} \geq 40$ psf	Inoperative	Inoperative	If yaw JET commanded
$\bar{q} \geq 50$ psf	If three or more yaw JETS commanded	If elevon drive rate > 20 deg/sec	If yaw JET commanded
Mach ≤ 1	Inoperative	If elevon drive rate > 20 deg/sec	Inoperative

During entry, the crew will monitor RCS quantities and refer to the RCS critical entry cue card (figure 3-4) to determine entry flight techniques.

The RCS critical entry cue card has two areas of significance. The lower left area shows RCS usage and techniques. The upper solid line gives an historical summary of RCS quantity versus \bar{q} and Mach during a previous mission. The lower solid line gives a worst case quantity limit that allows for nominal RCS usage. Note that the RCS percent axis is a total (left and right) aft quantity.

Boxed procedures call for various entry techniques if RCS quantity gets below recommended levels. Configuring the DAP for automatic pitch control and manual roll/yaw control reduces the amount of RCS jet activity. Control is more difficult/less accurate but RCS usage is reduced.

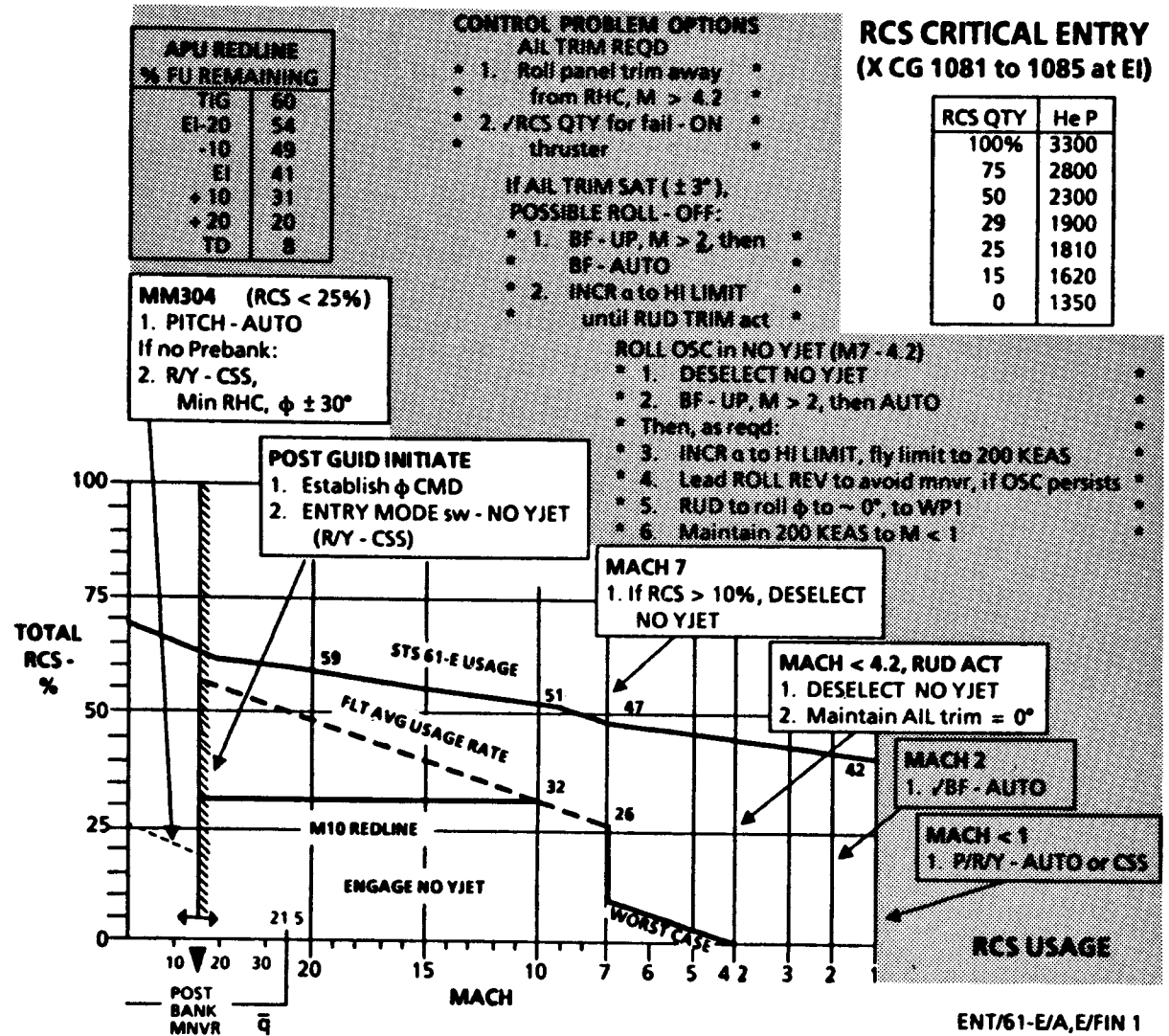
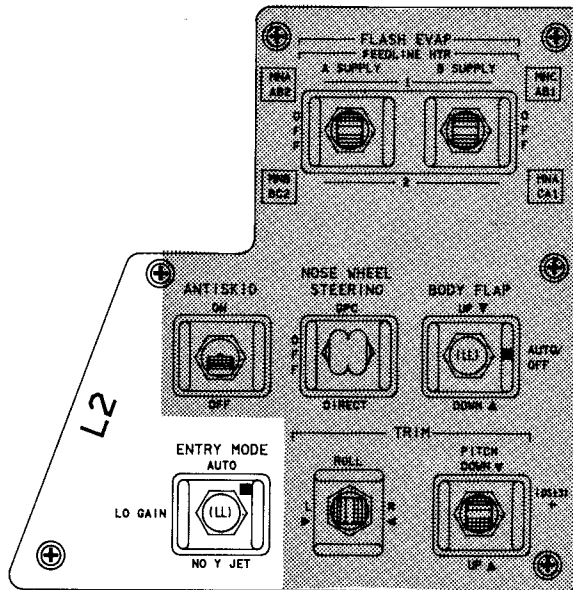


Figure 3-4.- RCS critical entry cue card.

If above Mach 10 and the total quantity is below the Mach 10 redline, then the RCS activity must be terminated to save propellant for the critical Mach 7 regime. This termination is achieved by selecting the no yaw jet entry mode for the DAP with the switch on panel L2, figure 3-5. This will prevent yaw jets from firing until the switch is moved from NO Y JET (no yaw jet). Since the pitch jets and roll jets are deactivated at a \bar{q} of 10 psf and 40 psf, respectively, RCS activity is reduced to zero.



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Figure 3-5.- Panel L2.

At Mach 10, if the RCS quantity is greater than the published quantity (32 on figure 3-4) then, no yaw jet should be deselected; otherwise, the crew would stay in no yaw jet until Mach 7. As indicated on figure 3-4, if RCS quantity is greater than 10 percent at Mach 7, no yaw jet can be deselected. Below Mach 4.2, the rudder is adequately effective and no yaw jet can be deselected regardless of RCS quantity.

The other significant area of the cue card (upper right of figure 3-4) shows an estimate of RCS quantity which is based on helium pressure. If RCS quantity calculations are invalid, these estimates can be used. Realize these estimates are based on the assumption of stable helium pressures (i.e., no leaks or excessive RCS usage).

If more information is required for entry flight controls, refer to the Controllers 2102, Effectors 2102, and Entry Flight Training for Commander and Pilot.

After landing, the RCS is safed for egress and vehicle turnaround.

RCS, OMS SAFING (RJDs)

03	✓OMS ENG (two)	- OFF
014	RJD DRIVER (nine)	- OFF
015	LOGIC (eight)	- OFF
016	OMS ENG VLY (two)	- OFF

FLT REPORT TO CONVOY 1 'RJDs OFF'

RCS, OMS SAFING (VALVES)

07	AFT L,R RCS
	✓MANF ISOL (ten) - OP (tb-OP)
	TK ISOL (six) - OP (tb-OP)
	✓He PRESS (four) - OP (tb-OP)
	XFEED (four) - CL (tb-CL)
	✓MSTR RCS XFEED - OFF

08	L,R OMS
	✓He PRESS/VAP ISOL (four) - CL
	✓TK ISOL (four) - OP (tb-OP)
	✓R OMS XFEED (two) - CL (tb-CL)
	L OMS XFEED (two) - OP (tb-OP)

FWD RCS

If RTLS (MANFs OP): No Action

If MANFs CL:

✓He PRESS (two) - OP (tb-OP)

✓TK ISOL (two) - OP (tb-OP)

✓FWD FU & OX MANF PRESS

If all FWD MANF PRESS > 130:

MANF ISOL 1,2,3,4 - OP (tb-OP)

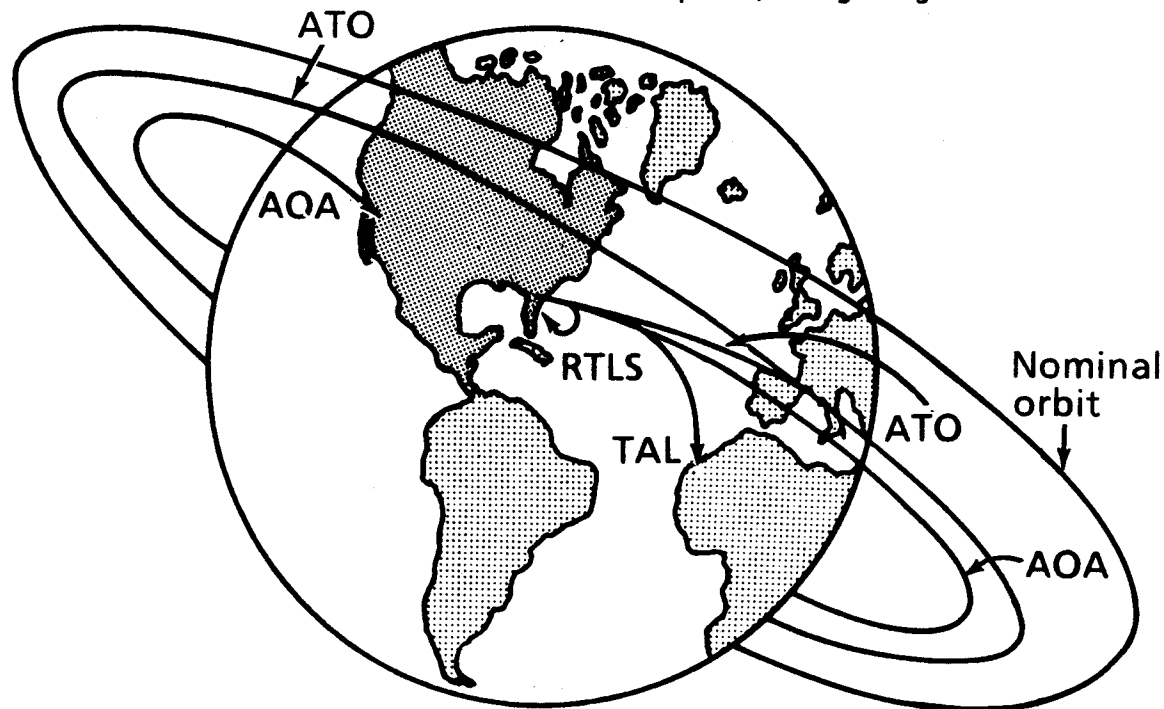
If any FWD MANF PRESS < 130:

Affected MANFs - CL (tb-CL)

Good MANFs - OP

Aborts

There are four types of intact ascent aborts: return to launch site (RTL), transoceanic abort landing (TAL), abort to orbit (ATO), and abort once around (AOA) as illustrated in figure 3-6. The RCS is more active in these scenarios than during nominal ascents, due to propellant dumping through the RCS jets and increased jet firings to maintain vehicle control.



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The intact abort modes are abort to orbit (ATO), abort once around (AOA), transatlantic abort landing (TAL), and return to launch site (RTL).

Figure 3-6.— Intact abort modes.

Generic Switch and Valve Abort Configurations

Before specific abort procedures are covered, a generic discussion of abort procedures is necessary.

The OMS and RCS switches are positioned prelaunch to provide for an automatic interconnect in the event of an abort select, a dump start, or single-engine roll control.

An abort can be selected and executed by either of two methods. One method is to use the abort rotary switch and PBI on F6 to select and execute the desired abort. The other method is to make an appropriate keyboard entry (OPS 601 PRO for RTL or item entry on Spec 51 for other type aborts). Either method can initiate an abort interconnect and a subsequent propellant dump, as required by software. The abort interconnect valve sequencing for RTL, TAL, and ATO will be performed in the following order (single-engine roll control and contingency interconnect sequencing will be covered later):

- Left and right RCS tank isolation valves are closed to prevent backflow of propellant into the tanks when the OMS and RCS crossfeeds are opened.
- Left and right OMS crossfeed B valves open to feed pressurized OMS propellant into the crossfeed lines.
- Left and right RCS crossfeed valves open to feed pressurized OMS propellant to the RCS manifolds.

When an intact abort dump is completed or MECO is about to occur, the GPCs will command a "return to normal configuration". The return to normal feed valve sequencing will occur in the reverse order of an abort interconnect: RCS crossfeeds close, OMS crossfeeds close, and RCS tank isolations open.

Since each set of valves requires about 1.5 seconds to reach a commanded position, there is a short period (less than 3 seconds) when the RCS jets are isolated from all propellant tanks. This is not a hazardous situation since jet activity is nominally not required during powered flight.

However, there are several off-nominal situations that may require high RCS jet activity. During these scenarios, the sequence of valve movements for an interconnect or return to straight feed must be altered to ensure sufficient propellant is available at the jets for control.

These high jet activity scenarios are set by the "mode 2" flag in the abort control software and include:

- Single engine roll control when multiple RCS jet firings are required to assist the remaining main engine.
- Starting a contingency dump or stopping any dump with an item entry to Spec 51 (DUMP ARM, START, or DUMP STOP). The GPCs are programmed to associate these item entries with scenarios that might require increased jet firings.
- Manually flying an intact abort and MECO occurs while a dump is underway. All abort dumps are stopped at MECO and a return to normal feed is commanded.

Standard abort control valve sequencing could starve jets needed for control. If the standard sequence is not altered, jet activity could occur during a period of tank isolation. Numerous jets would fail off and a loss of control could occur. In order to prevent this, the GPCs are programmed for mode 2 scenarios and will change the sequence of valve movements. This valve sequence will ensure that pressurized propellant is provided to the manifolds at all times. The mode 2 interconnect sequence is

- Right OMS crossfeed B valves open
- Left and right RCS crossfeed valves open
- Left and right RCS tank isolation valves close
- Left OMS crossfeed B valves open.

A return to normal configuration, during mode 2 scenarios, is performed in the following order:

- Left and right RCS tank isolation valves open
- Left and right RCS crossfeed valves close
- Left and right OMS crossfeed B valves close.

Note that these sequences create a short period when the OMS and RCS propellant tanks are tied together. Although this configuration increases the possibility of backflow, it is considered acceptable in order to maintain vehicle control.

General Abort Notes

It should be realized that an abort interconnect can be commanded when not in an abort situation. For example, if two main engines should fail late in ascent, past the single-engine press-to-MECO boundary (see Flight Rules, All Vehicle for the specific definition), an abort interconnect would be commanded to provide single-engine roll control. In this situation, a nominal MECO and a nominal orbit could be achieved, thus not an abort.

Talkback monitoring may be essential to successfully completing an abort. Although it is not specifically mentioned in the procedures, it is a good idea for the crew to observe the OMS and RCS talkbacks immediately after abort select (or after a second main engine failure) to ensure that all valves are configured properly for the interconnect. An improper configuration could result in the wasting of valuable RCS propellant or jet starvations.

It is understood that talkback observation is a difficult, if not impossible, task for the commander (CDR) and pilot (PLT) due to vision constraints (helmets), high g forces, and increased piloting workloads. The position of the mission specialist (MS), in the center seat, might allow for observation of the talkbacks and probably not without considerable effort.

When MECO occurs (expected or unexpected), all abort dumps are automatically stopped and a return to normal feed is commanded.

Abort Dump Jet Activity

As previously mentioned, FCS outputs fire commands to selected jets for short duration burns. The abort control sequence, on the other hand, outputs continuous jet fire commands to selected sets of thrusters in order to obtain specific dump rates.

There are four basic groups of abort dump jet firings:

1. **Abort + X jets (figure 3-7).** All aft firing jets (L1A, L3A, R1A, and R3A) are commanded to fire simultaneously.
2. **8 RCS null jets (figure 3-8).** All aft yaw jets (L1L, L2L, L3L, L4L, R1R, R2R, R3R, and R4R) are commanded to fire simultaneously. A null jet is assumed to be firing perpendicular to the velocity vector so that there is a null effect to vehicle performance.

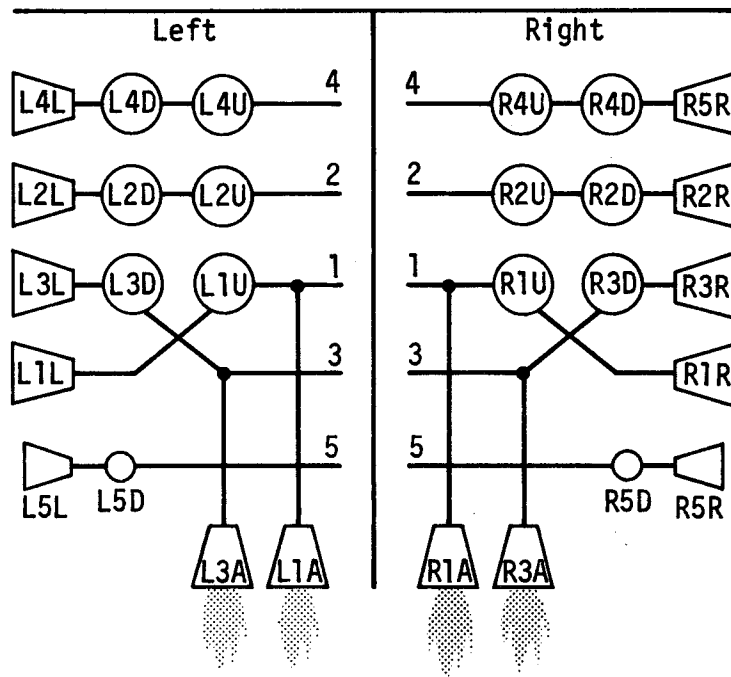


Figure 3-7.- Abort + X jets.

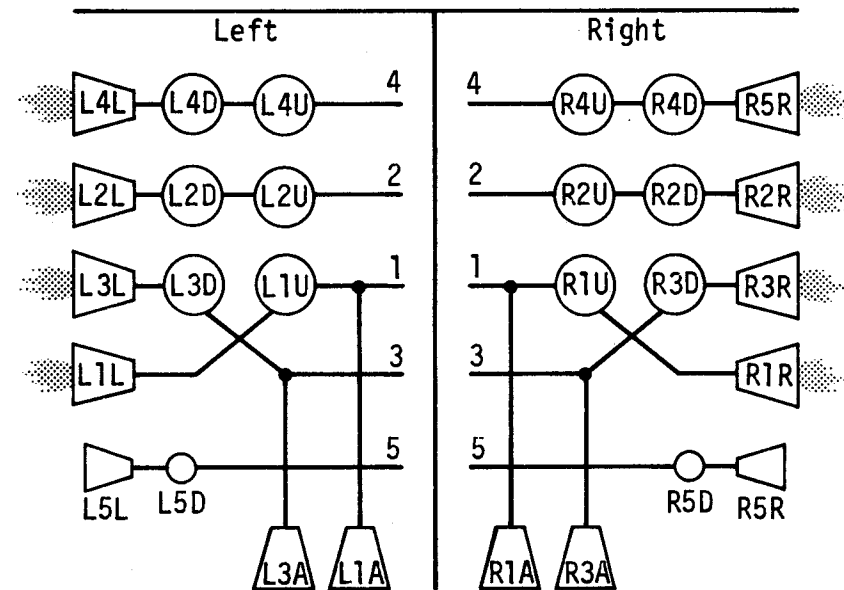


Figure 3-8.- 8 RCS null jets.

3. 14 RCS null jets (figure 3-9). All aft yaw jets and all aft down firing jets (L2D, L3D, L4D, R2D, R3D, R4D) are commanded to fire simultaneously.

4. 20 RCS null jets (figure 3-10). All aft yaw jets, all aft down firing jets, and all aft up firing jets (L1U, L2U, L4U, R1U, R2U, and R4U) are commanded to fire simultaneously.

The selection of a particular abort group (or combination of abort groups) to provide propellant dumps will be covered in the specific abort sections.

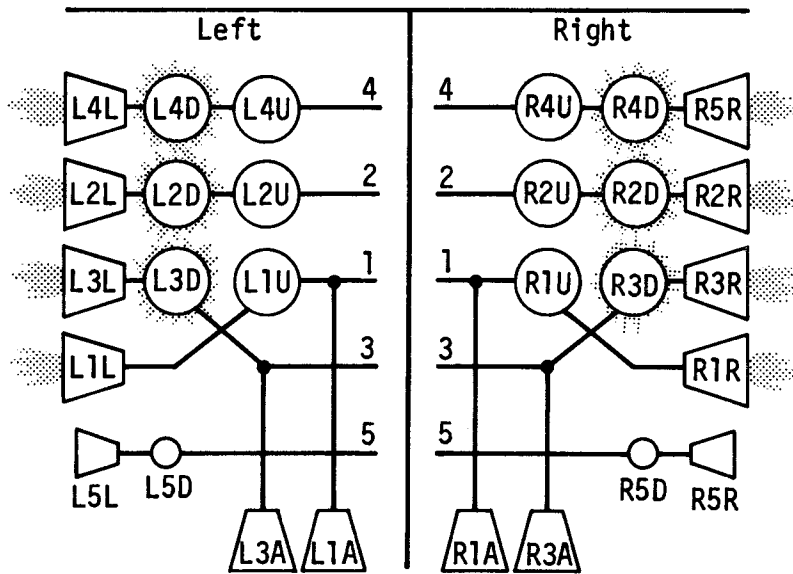


Figure 3-9.— 14 RCS null jets.

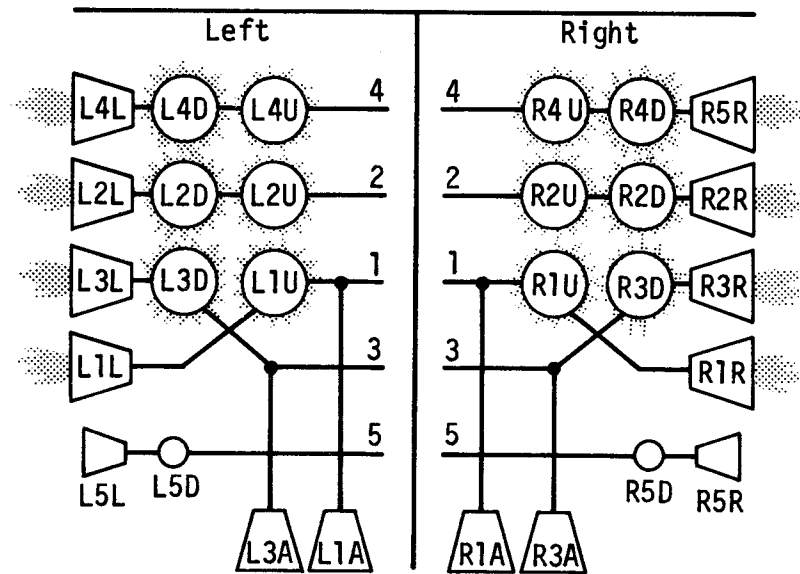


Figure 3-10.— 20 RCS null jets.

Mirror Image Logic

During single engine roll control, if a contingency abort dump is executed, the GPCs use "mirror image logic" to alter the jet fire commands in order to provide the desired motion. If a jet is commanded to fire by the FCS but it is already firing (dumping), then mirror image logic would stop firing the opposing jet to obtain the desired vehicle motion. If the desired jet is not dumping, then mirror image logic is not applied and the command is processed exactly as received.

As an example, if a right rolling moment is desired, the FCS would command L2D to fire (along with other jets). The GPCs would then generate the L2D dual fire command. If a 24-jet dump was in progress, mirror image logic would alter the L2D fire command. The L2D fire command could be changed to a cancel L2U fire command, in order to obtain the right rolling moment while continuing the dump. Once the desired vehicle motion is achieved, L2U would resume dumping until the dump sequence is completed or another FCS input is made.

Mirror image logic is only used when single engine roll control is followed by a contingency dump (Spec 51 DUMP ARM, START). Mirror image logic is not applied if single engine roll control occurs during any dump (intact or contingency). This is because all RCS jet dump firings are terminated to provide for single engine roll control when the "second main engine fail" flag is set in the abort control software. Although the RCS portion of the dump is stopped, the OMS

engines continue to fire until the dump quantity is achieved.

If a contingency dump is in progress and single engine roll control occurs, then all RCS jet dump firings are stopped. If the dump is stopped and restarted, the RCS jet dump firings would reactivate and mirror image logic would apply.

Abort Dump Stop

An abort dump may be terminated by item entry to the override display, Spec 51.

An item 8 DUMP STOP will terminate all OMS and RCS ignition commands and will maintain the interconnect until just before MECO. At that time, straight feed is commanded for MECO preparation. If the DUMP STOP is performed post-MECO, straight feed is commanded immediately after the OMS and RCS firings are commanded off.

If only the RCS portion of an intact abort dump is to be stopped, then an item 5 entry to Spec 51 will inhibit the interconnect and stop all RCS abort jet firings. If the abort interconnect was due to a Spec 51 DUMP START or single engine roll control, the item 5 entry would not be accepted. Mode 2 interconnects cannot be inhibited. (Manifolds would have to be closed to stop RCS jet firings.)

The aft and forward RCS dumps of RCS propellant can be stopped with items 13 and 15, respectively. These item entries inhibit RCS ignition commands but have no effect on abort interconnects.

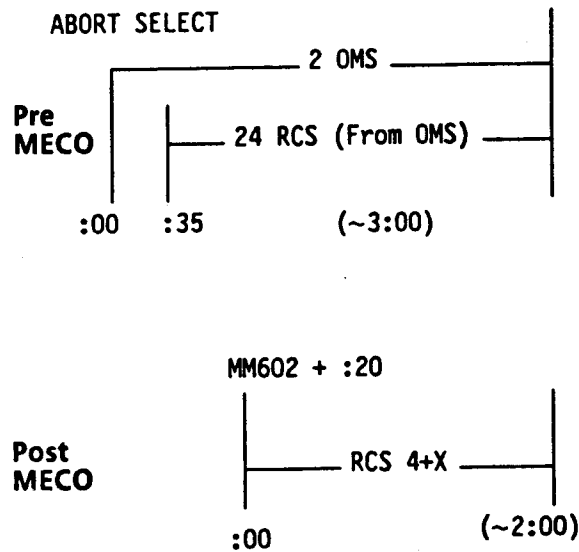
Return To Launch Site

The RTLS mode involves flying downrange to dissipate main engine propellant and then turning around under power to return to a landing near the launch site. OMS and RCS propellant will be dumped through the OMS engines and the RCS jets to improve vehicle performance and reduce landing weight. Immediately after the abort is selected (abort PBI depressed or keyboard entry), the OMS engines will ignite and the OMS/RCS valves will be configured for an OMS/RCS interconnect. The RCS jets will not be commanded to fire until approximately 35 seconds after the interconnect is completed. This will allow the crew sufficient time to ensure all valves have been correctly configured for the dump. If the valves are not in the correct configuration, the valves can be manually positioned or the interconnect can be inhibited by an item 5 entry to Spec 51. Inhibiting the interconnect will inhibit RCS jet dump commands but it will not affect RCS jet firings needed for vehicle control.

The pre-MECO dumping of OMS propellant for an RTLS is usually performed by burning both OMS engines and 24 aft RCS jets (abort + X and 20 RCS null jets) while interconnected. The pre-MECO dump is stopped automatically by a software timer. When this dump is complete, the OMS/RCS valves are automatically returned to a straight feed configuration.

A representation of the RTLS dump can be found in the Ascent/Entry Systems Procedures (OMS section). It shows estimated dump times and blanks to be filled in with mission specific numbers.

RTLS DUMP



If an RTLS dump is still in progress just before MECO, the dump will be automatically stopped for MECO preparation.

Post-MECO, the RCS jets will be used to safely maneuver the Orbiter away from the ET after separation. Since the Orbiter is much lower in the atmosphere on an RTLS ET separation, more RCS jets must be available for separation than are required for a nominal (or TAL) ET separation.

ET SEPARATION RCS REQUIREMENTS		
Jet Group	Minimum Requirements	
	Nominal	RTLS
FWD down	1	2 (sides balanced)
AFT left	1	3
AFT right	1	3
AFT up	1/side	2/side
AFT down	1/side	2/side

A dump of RCS propellant is made post-MECO through four jets (abort + X jets). This dump is required for landing weight and/or center of gravity conditions.

The length of the dump is mission specific and an estimate can be seen in the FDF representation. The precise duration can be seen on Spec 51, item 14.

Specific information about abort dump sequencing can be found in the Functional Subsystem Software Requirements (FSSR) Sequence Requirements, sections 4.3.1 and 4.3.2.

RTLS Glide

The utilization of the RCS is gradually phased out during entry.

The RCS jets are deactivated at the standard entry points:

Roll jets at 10 psf

Pitch jets at 40 psf

Yaw jets at Mach 1

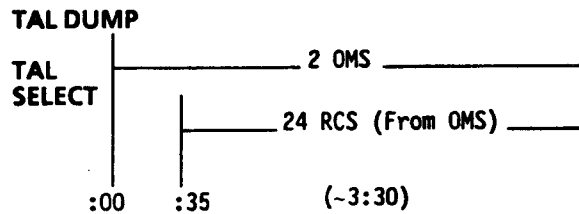
RCS command light activity is also identical to nominal entry processing.

Transoceanic Abort Landings

The TAL mode is designed to permit an intact landing downrange, across the ocean, from the launch site.

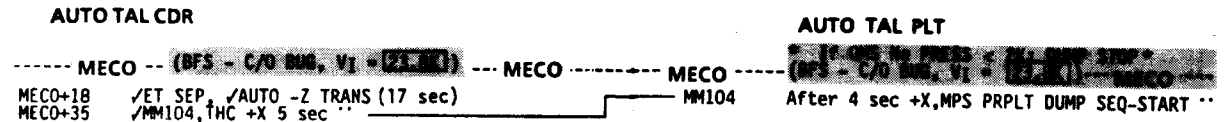
When a TAL abort is initiated, the abort interconnect and abort dump occur in the same sequence as an RTLS abort. The pre-MECO dumping of OMS propellant for a TAL is usually performed by burning both OMS engines and 24 aft RCS jets (abort + X and 20 null jets). The OMS engines ignite initially at abort select, and the RCS jets are fired approximately 35 seconds after the abort interconnect is completed.

A representation of the TAL dump can be found in the Ascent/Entry Systems Procedures and is reproduced below.



The pre-MECO OMS propellant dump will be stopped automatically by a software timer. When the OMS propellant dump is completed, the OMS and RCS valves are returned to a straight feed configuration.

After ET separation, a manual dumping of MPS propellant is required. Remember that during a nominal ascent, the OMS 1 burn and MPS dump would occur simultaneously (the OMS thrust settles the MPS propellant for dumping). Since there is no OMS 1 burn, the RCS must be used to provide the thrust for MPS propellant setting.



During entry, at about mach 8, there can be a dump of RCS propellant through the 4 + X jets. The duration of the dump can be seen on Spec 51, item 14.

If an additional dump of OMS propellant is required, it can be executed on Spec 51 with a DUMP ARM, START item entry. A 24-jet interconnected dump can be enabled/inhibited with an item 5 entry.

In OPS 304, the forward RCS will no longer be used and all primary forward manifolds are closed. Boxed quantities are guidelines for inhibiting RCS propellant dumps and are filled in with mission specific numbers.

MM304

```

FWD RCS MANF ISOL 1,2,3,4 - CL (tb-CL)
✓ET SEP, SRB SEP - AUTO
✓RCS Qty > [ ] % each side
* If RCS < [ ] %:
* [G51] Aft RCS INH, ITEM 13 EXEC *
    
```

During entry, the RCS jets are deactivated at the standard entry limits. RCS command light activity is also being processed by entry standards.

Abort To Orbit

The ATO mode is designed to achieve a temporary orbit that is lower than the nominal orbit. This mode requires less performance than a nominal orbit and allows time to evaluate the situation that caused the abort.

Depending upon the outcome of the evaluation, a decision would be made to perform an early deorbit burn, or stay at the temporary orbit and complete the mission, or raise the orbit and complete the mission.

The ATO is very similar to a nominal ascent as far as RCS procedures are concerned. The only major difference is that an ATO dump may or may not be required depending upon specific vehicle performance and the ET impact footprint. The dump, if required, is performed with both OMS engines and may be interconnected with 18 RCS jet firings (abort + X and 14 null jets) by enabling the interconnect on Spec 51.

Abort Once Around

The AOA mode is designed for making an intact landing after flying once around the Earth. This mode usually requires two OMS burns: the OMS 1 burn for orbital insertion and the OMS 2 burn for deorbit. The initial AOA RCS procedures are identical to the nominal procedures for ascent through the OMS 1 burn. If both OMS engines fail, there are dedicated steps for making an RCS deorbit burn using OMS propellant.

P OMS BURN PREP

```

08 L,R OMS
  ✓He PRESS/VAP ISOL A (two) - GPC
    B (two) - CL
  ✓TK ISOL (four) - OP (tb-OP)
  XFEED (four) - CL (tb-CL)
    
```

.....RCS BURN PREP (I'cnct OMS to RCS).....

```

. P 08 L,R OMS
.   He PRESS/VAP ISOL (four) - CL
.   ✓TK ISOL (four) - OP (tb-OP)
.   L OMS XFEED (two) - OP (tb-OP)
.   R OMS XFEED (two) - CL (tb-CL)
. 07 AFT L,R RCS
.   XFEED (four) - OP (tb-OP)
.   TK ISOL (six) - CL (tb-CL)
.
.
.
    
```

RCS is used to maneuver to the burn attitudes.

Postburn, the OMS and RCS are configured for entry (auto crossfeed prep).

OMS/RCS POST BURN RECONFIGURATION

```

07 AFT L,R RCS
  ✓He PRESS (four)- OP (tb-OP)
  ✓TK ISOL (six) - GPC (tb-OP)
  ✓XFEED (four) - GPC (tb-CL)
    
```

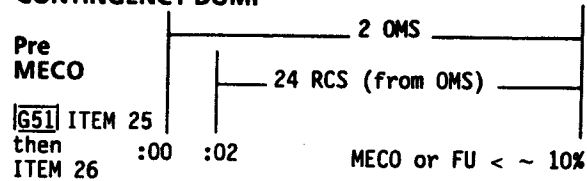
Since a complete MPS propellant dump and purge is accomplished on an AOA, the c.g. is forward of a recommended entry position. A forward RCS dump is usually required to move the c.g. aft to a more favorable (i.e., controllable) position. When the forward RCS dump is completed, the primary forward manifolds are closed. Subsequent RCS entry procedures are identical to a nominal entry.

Nonintact Aborts

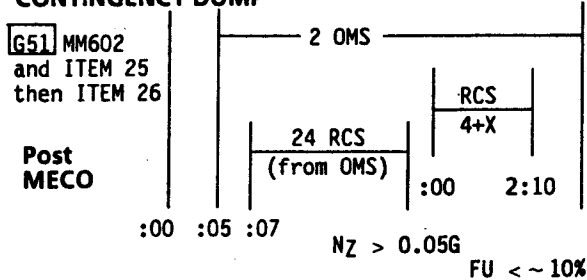
There are additional procedures for executing nonintact aborts to an oceanic or nonrunway landing. These aborts may require the execution of a contingency abort dump to reduce vehicle weight and move the vehicle c.g. This contingency dump is performed by a DUMP START item entry on Spec 51. The dump is executed by burning both OMS and interconnecting OMS propellant to 24 firing RCS jets (abort + X and 20 null jets). The post-MECO RCS portion of the interconnected dump is stopped when normal acceleration is greater than 0.05 g's. Straight feed is commanded after the RCS jets are commanded off. There is also a short dump of aft RCS propellant through the + X jets when acceleration is greater than 0.05 g.

Any time a contingency dump is executed (DUMP START on Spec 51), any other dump in progress will be terminated and the contingency dump will be substituted. The contingency dump will be stopped automatically when internally computed aft quantities for the left and right OMS tanks are obtained.

CONTINGENCY DUMP



CONTINGENCY DUMP



This concludes the section on aborts. If more detailed information is required, refer to the following sources: GNC Training Manuals for ATO/AOA/TAL and RTLS/Contingency Abort; the Functional Subsystem Software Requirements (FSSR) for Ascent/RTLS Guidance and Sequence Requirements.

Section 3 Questions

1. During an RTLS, while the post-MECO RCS dump is in progress, the crew is directed to stop the dump. How is this accomplished and how is the dump stop confirmed?
2. A TAL abort is selected and both OMS engines are ignited. If the abort interconnect is enabled on the override display (Spec 51), how many RCS jets will fire and when will RCS ignition occur?
3. During entry, the crew notices the PITCH UP jet command light illuminated on panel F6. The \bar{q} on the vehicle is 70 psf. What has caused the illumination of the RCS command light?
4. Which type of ET separation maneuver requires the most RCS jet activity?
5. During postinsertion activities, the RCS helium pressurization switches are configured so that only one set of regulators is used onorbit. How is this accomplished?
6. How can the RCS be used for OMS burns in the event of OMS engine failures?
7. Mission Control requests the crew to dump the forward RCS to 12 percent during entry. The crew elects to use a four-jet dump and the predump quantity is 48 percent. When does the crew stop the forward RCS dump? (Use FOUR-JET DUMP graph from page 3-9).
8. How does the abort interconnect sequence differ between an RTLS dump and a contingency dump?
9. During orbit operations, the GPCs closed the right RCS helium pressurization valves due to an overpressure in the right RCS oxidizer tank. At what propellant tank pressure will the GPCs reopen the right RCS helium pressurization valves.

Section 3 Answers

1. During an RTLS, while the post-MECO RCS dump is in progress, the crew is directed to stop the dump. How is this accomplished and how is the dump stop confirmed?

A: The dump can be inhibited by keyboard entry item 13 to the PASS override display, Spec 51. During the dump, the aft RCS helium tanks would be depleting at a steady rate. When the dump stops, the RCS helium pressures should stop decreasing and stabilize.

2. A TAL abort is selected and both OMS engines are ignited. If the abort interconnect is enabled on the override display (Spec 51), how many RCS jets will fire and when will RCS ignition occur?

A: A total of 24 RCS jets will be commanded to fire (20 null jets and 4 + X jets). The RCS jets will not be commanded to fire until 35 seconds after the OMS interconnect is completed. This allows the crew to check the abort interconnect configuration before the jets are fired.

3. During entry, the crew notices the PITCH UP jet command light illuminated on panel F6. The \bar{q} on the vehicle is 70 psf. What has caused the illumination of the RCS command light?

A: If two or more hydraulic systems are working, the elevon drive rate is greater than 20 deg/sec. The pitch jets were deactivated at a \bar{q} of 40, so the RCS pitch jet command lights no longer indicate RCS jet activity.

4. Which type of ET separation maneuver requires the most RCS jet activity?

A: The RTLS ET separation occurs lower in the atmosphere than other scenarios and requires more jets to achieve the required separation.

5. During postinsertion activities, the RCS helium pressurization switches are configured so that only one set of regulators is used onorbit. How is this accomplished?

A: If the A regulators are to be used during the first part of the mission, the B helium pressurization switches will be closed. The A pressurization switches will be placed in GPC with the talkbacks open in order to provide automatic overpressurization protection for the propellant tanks.

6. How can the RCS be used for OMS burns in the event of OMS engine failures?

A: The OMS and RCS crossfeed valves must be opened to provide OMS propellant to the RCS. The + X jets are then fired to provide thrust in the same direction as the failed OMS engines. The other RCS jets will be fired as necessary to maintain the correct burn attitude.

7. Mission Control requests the crew to dump the forward RCS to 12 percent during entry. The crew elects to use a four-jet dump and the predump quantity is 48 percent. When does the crew stop the forward RCS dump?

A: The crew would stop the dump at an elapsed time of 1 minute 5 seconds. The nomograph for a four-jet dump is entered at 36 percent since this is the amount of propellant to be dumped.

8. How does the abort interconnect sequence differ between an RTLS dump and a contingency dump?

A: On a contingency dump, the RCS tank isolation valves do not close until the RCS and OMS crossfeed valves open in order to provide pressurized propellants to the jets at all times. The RTLS dump interconnect closes the RCS tank isolation valves first in order to prevent the tying of propellant tanks when the RCS and OMS crossfeed valves are opened.

9. During orbit operations, the GPCs closed the right RCS helium pressurization valves due to an overpressure in the right RCS oxidizer tank. At what propellant tank pressure will the GPCs reopen the right RCS helium pressurization valves.

A: The GPCs cannot reopen helium valves when the pressures return to normal limits. The software is only capable of closing valves when the pressure exceeds the caution and warning limits. If the valves are to be opened, it must be done manually.

Section 4: System Malfunctions

Caution and Warning Overview

If a malfunction occurs in the RCS, the crew will be alerted by the caution and warning (C&W) system. There are two types of C&W alerts for the RCS. One type is the class 2 alert consisting of a master alarm light, master alarm tone, C&W matrix light, and a CRT fault message. The other type is a class 3 alert consisting of the SM alert light, SM alert tone, and a CRT fault message. See figure 4-1 for C&W annunciation locations.

Crew procedures for correcting RCS malfunctions cannot be initiated until the off-nominal situation is recognized. The crew or Mission Control may detect malfunctions before any C&W annunciations occur. However, if malfunctions are not corrected (or recognized), a CRT fault message and warning tone will be generated.

Table 4-1 lists various RCS malfunctions grouped according to the generated fault message for each off-nominal situation. Also included in the table are the OPS in which the fault messages can occur, the warning lights and tones that accompany the messages, and the supporting data displayed on CRT displays and meters.

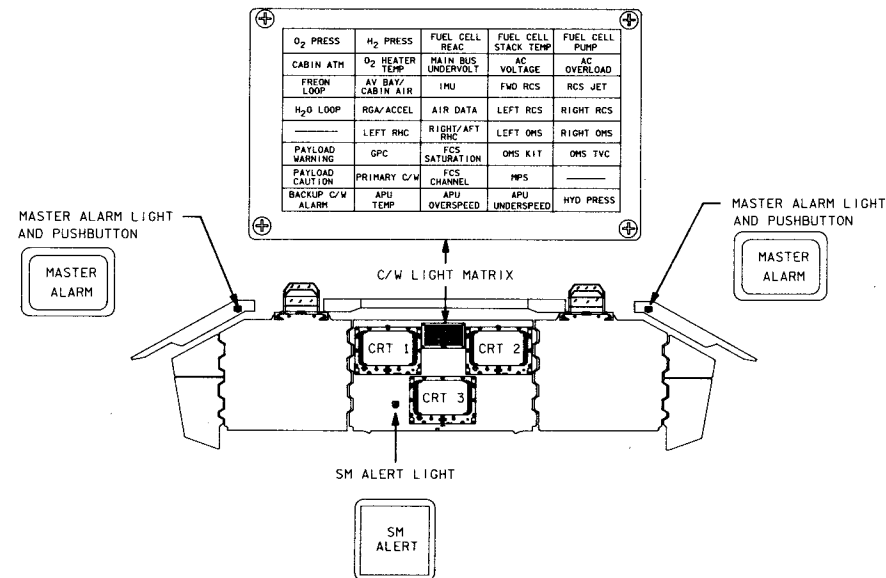


Figure 4-1.— Caution and warning annunciation locations.

Table 4-1.- RCS malfunctions.

Fault Message	OPS Available		Cause	C&W Matrix Light	Warning Light & Tone		CRT Display Symbology	Supporting Display Info
	PASS	BFS			Master Alarm	SM Alert		
F(L,R) RCS U JET -or- D JET -or- L JET -or- R JET -or- F JET -or- A JET	1,2,3, 6,8	Not Avail	Jet fail on (driver output and no fire command) -or- Jet fail off (fire command and no PC discrete) -or- Jet fail leak (jet temp less than an I-load value)	RCS Jet	Yes	No	ON, OFF, or LK by the affected manifold on SYS SUMM 1 and SYS SUMM 2 and by the affected jet on Spec 23. No fail off detection in MM 101 and 102.	Fail off – possible control problems. Fail on – abnormal quantity drop or increased jet activity Fail leak – diverging quantities and/or pressures on meters
FRCS Jet -or- LRCS Jet -or- RRCS Jet	Not Avail	1,3,6	Jet fail on (PC discrete and no fire command) -or- Jet fail off (fire command and no PC discrete)	RCS Jet	Yes	No	ON or OFF by the affected manifold on BFS SYS SUMM 2 (if BFS engaged). No fail leak detection in BFS	Fail on – abnormal quantity drop or increased jet activity Fail off - possible control problems
FRCS He P -or- LRCS He P -or- R RCS He P	2,8	1,3,6	Helium pressure (FU or OX) in the affected pod is below 500 psi.	None	No	Yes	(↓) by the affected pressure reading on SYS SUMM 2 and Spec 23	Decreasing helium pressure on meters
FRCS LEAK -or- LRCS LEAK -or- RRCS LEAK	2,3,8	1,3,6	Propellant quantities (FU and OX) in any one pod differ by more than 12.6 percent	FWD RCS -or- LEFT RCS -or- RIGHT RCS	Yes	No	(↓) by the lower quantity on SYS SUMM 2 or Spec 23	Should see decreasing helium and/or propellant pressure on meters

Table 4-1.- Continued.

Fault Message	OPS Available		Cause	C&W Matrix Light	Warning Light & Tone		CRT Display Symbology	Supporting Display Info
	PASS	BFS			Master Alarm	SM Alert		
FRCS PVT -or- LRCS PVT -or- RRCS PVT	2,3,8	Not Avail	Loss of pressure or temperature data (needed for RCS quantity calculations)	None	No	Yes	(M) by the missing data on SYS SUMM 2 and/or Spec 89. RCS quantity calculations cease for the affected pod.	Digital display quantities should match associated CRT quantities
FRCS TK P -or- LRCS TK P -or- RRCS TK P	2,8	1,3,6	Propellant tank pressure exceeds upper (312 psi) or lower (200 psi) limit	FWD RCS -or- LEFT RCS -or- RIGHT RCS	Yes	No	(+ or +) by the affected pressure reading on SYS SUMM 2 and Spec 23	Meters should match CRT display. If pressure high and venting prop overboard, a leak could be annunciated
G23 RCS system F(L,R)	2,8	Not Avail	Propellant tank outlet pressure exceeds upper (300 psi) or lower (220 psi) limit or propellant tank temperature exceeds upper (90° F) or lower (50° F) limit	None	No	Yes	Crew display on PASS SYS SUMM 2 (OPS 2 only). Ground readout at all times. Tank pressure on BFS SYS SUMM 2 and Spec 23 use different sensors	None
RCS PWR fail	1,2,3,6,8	Not Avail	Loss of valve logic power to manifold isolation valves	None	No	Yes	None	RCS talkbacks that are barberpoled indicate the valves are stuck in last position

Table 4-1.- Concluded.

Fault Message	OPS Available		Cause	C&W Matrix Light	Warning Light & Tone		CRT Display Symbology	Supporting Display Info
	PASS	BFS			Master Alarm	SM Alert		
RM DLMA MANF	1,2,3,6,8	Not Avail	A dilemma is detected in the manifold valve status (FU and OX valve positions disagree)	None	No	Yes	(?) by the affected manifold on SYS SUMM 2 and Spec 23. Manifold status will always be closed until/ unless valve status is overridden open	Affected valve talkback should be barberpoled
S89 PRPLT THRM RCS	2,4	Not Avail	Temperature in the affected structure exceeds I-loaded upper or lower limits	None	No	Yes	(↑ or ↓) by affected temperature display on Spec 89 (SM)	None

A summary of system failures will be discussed in this section. The purpose of this section is not to provide a step-by-step rationale for specific procedures but rather to develop a general background knowledge that will make the procedures more understandable. The following categories of system failures will be covered:

- Propellant leaks
- Tank pressure high
- Tank pressure low
- Jet failures
- Electrical and DPS failures
- Interconnect failures
- RM dilemmas
- RM loss
- Switch, valve, and talkback failures

Procedures for responding to RCS failures can be found in various checklists. During early ascent (MM 102-104), late entry (MM 304 and 305), and RTLS (MM 601-603), the ascent/entry systems (pilot flipbook) procedures should be utilized. Procedures to be used at other times can be found in the appropriate pocket checklists (ascent: MM 105-106; orbit: MM 201-202; entry: MM 301-303).

These checklist procedures should provide rapid fixes to the malfunctioning system but do not always provide for extensive troubleshooting. Extensive troubleshooting procedures can be found in the Systems Malfunction Procedures. These procedures are usually exercised during orbit situations when adequate troubleshooting time is available. In-depth discussion of Systems Malfunction Procedures will not be covered in this manual. These onorbit troubleshooting procedures will be covered extensively during simulator training.

Before malfunction procedures are discussed, there are three basic procedures that need to be covered. These procedures are RCS secure, RCS crossfeed, and OMS/RCS interconnect.

RCS Secure

RCS secure procedures are used to isolate the RCS if a leak is suspected. All securing procedures start by closing the manifolds and then working "upstream," closing the helium isolation valves last (figure 4-2).

RCS SECURE (FWD,AFT)

If normal config:

1. RCS MANF ISOL (five) - CL (tb-CL)
- MANF ISOL 5 - GPC
- XFEED (two) - CL (tb-CL)
- TK ISOL (all) - CL (tb-CL)
- He PRESS (two) - CL (tb-CL) >>

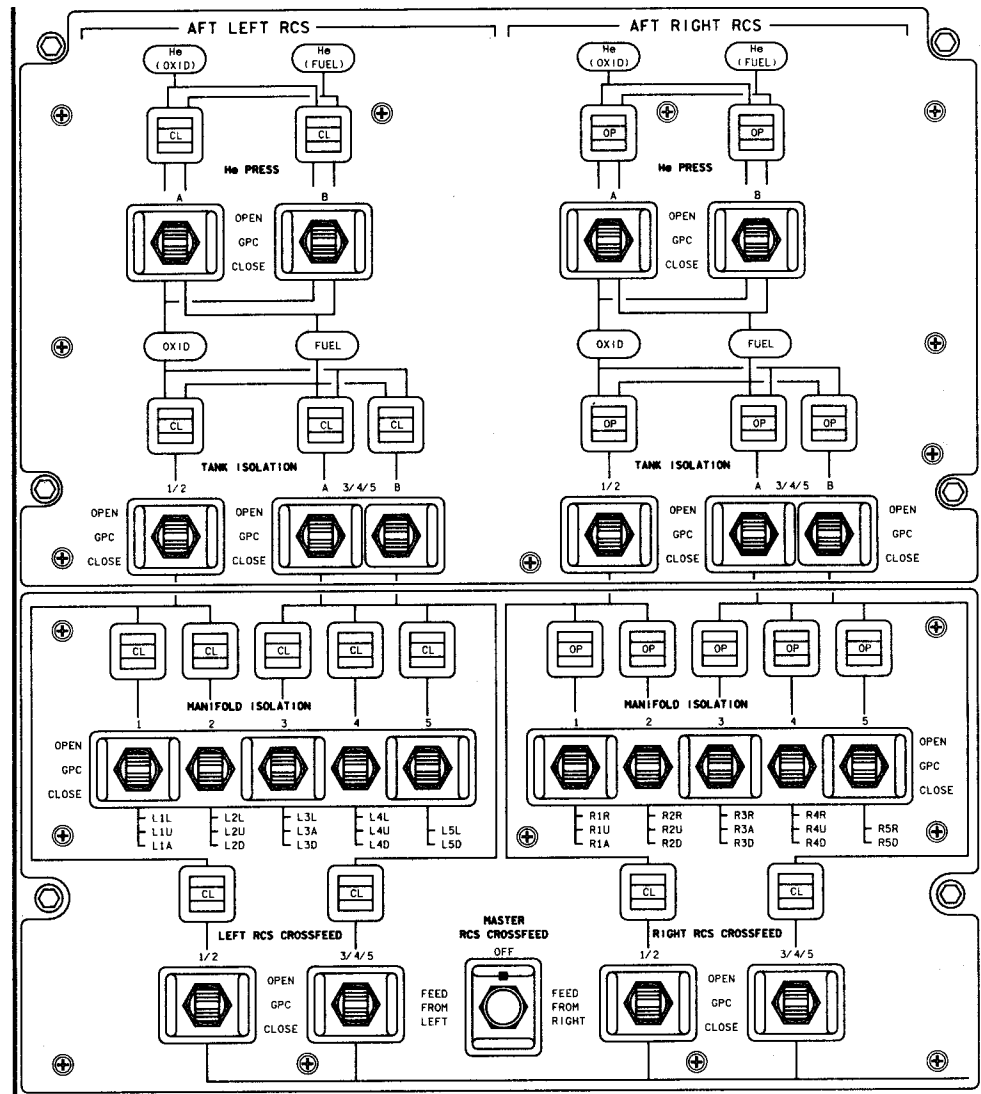
If the system is mistakenly secured in the reverse order (starting at the top and securing downstream), then jets could fail off. Propellant starvation occurs because the manifold isolation valves and statuses are still open while tank isolation valves are closed. This starvation could cause manifold evacuations, jet failures, and possible permanent jet damage. The reduced pressure readings, due to evacuated manifolds, would prevent accurate determination of leak location and would complicate any return to normal configuration. By following the proper sequence (close the manifolds first), the closed manifold statuses will remove the associated jets from the availability table, thus preventing jet firings while the RCS is secured. Any subsequent drop in pressure readings would indicate the leak location.

He PRESS ③

TK ISOL ②

MANF ①

SECURE VALVES IN THE ABOVE ORDER



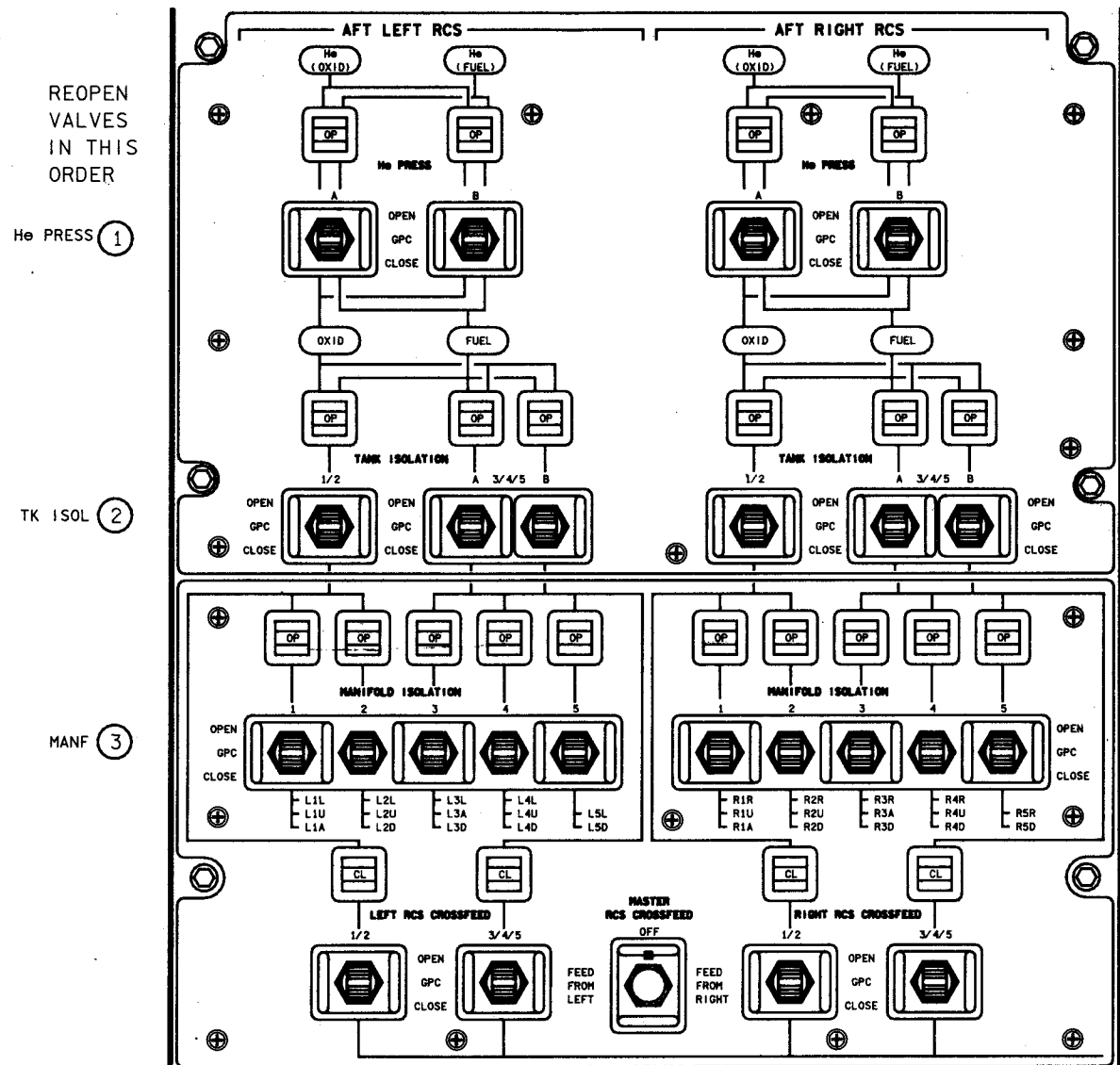
TD3400402. ART 5

Figure 4-2.- RCS secure sequence.

The vernier manifolds (manifold 5) do not have a pressure display for troubleshooting purposes. Once the RCS is secured, the vernier manifolds will not be reopened unless the leak is found elsewhere and does not affect manifold 5.

Unlike the primary manifold valves (motor driven), the vernier manifolds are solenoid powered. There is a possibility of a solenoid force fight if the switch for manifold 5 is left in the closed position. A dual-powered solenoid (both open and closed coils simultaneously powered) could result in an overheat condition. An overheated solenoid is a hazardous condition due to the thermal sensitivity of the fuel that is in contact with the heated valve. The force fight can be prevented if the manifold 5 switch is placed in GPC, after the valve is manually closed. This removes power from the solenoid and prevents the overheat situation.

When the RCS is returned to a normal feed configuration after a leak is isolated, there may not be dedicated procedures to follow. In order to achieve an acceptable normal feed configuration, the procedure that was used to secure the RCS should be followed in reverse order. As illustrated in figure 4-3, in order to return to normal feed, first open the helium isolation valves then work down, opening the manifold isolation valves last. This sequence of switch movement will prevent manifold evacuations and jet failures. Do not reopen a leg with a known leak.



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Figure 4-3.- Return to straight feed sequence.

During ascent and entry, situational awareness is required when returning to normal feed. If the crew desires to retain the auto crossfeed capability, the tank isolation and crossfeed valve switches must be placed in the GPC position after the valves are manually positioned open or closed. If some switches are mistakenly placed in manual positions while other switches are in GPC, a subsequent auto crossfeed would result in an unsatisfactory, if not hazardous, configuration.

Crossfeed

Before a crossfeed is initiated, several constraints must be observed to protect the RCS propellant tanks.

RCS CONSTRAINTS

RCS to RCS Xfeed Initiation

On-orbit, $\Delta P < 80$

Entry, $\Delta P < 55$ and $ACCEL < 48$

Evacuated Manf

No repress for jet fail ON;

Otherwise, repress one at a time

Since ascent and entry crossfeed procedures tie propellant tanks, a high pressure differential between left and right tanks could cause tank damage or helium ingestion when a crossfeed is initiated.

During ascent and orbit (also entry when the g load \approx zero), the maximum allowable pressure differential between tanks, before initiating a crossfeed, is 80 psi. During entry, when normal acceleration is greater than zero on the cockpit displays, the maximum acceptable pressure differential is reduced to 55 psi and the maximum allowable acceleration is 1.5 g (48 ft/s²) when initiating a crossfeed.

Another constraint pertains to crossfeeding into evacuated manifolds during ascent and entry. If evacuated manifolds are present (any fuel or oxidizer manifold pressure less than 130 psi), additional steps must be taken to protect evacuated jets before initiating a crossfeed. All evacuated manifolds should be isolated (manifold valves closed) before a crossfeed is initiated. After the crossfeed is completed, the evacuated manifolds may be repressed one at a time. There is one exception to this rule: if any manifold is evacuated due to an isolated failed on jet, that manifold should not be repressed.

Once these constraints are met, a crossfeed may be initiated. During ascent and entry, there are two methods of crossfeeding; auto and manual.

XFEED: RCS to RCS

If Auto:

1. L,R RCS TK ISOL (six) - GPC
XFEED (four) - GPC
2. OMS XFEED (four) - CL
3. MSTR RCS XFEED - FEED FROM L(R) >>

If Manual:

1. L,R OMS XFEED (four) - CL
2. RCS XFEED (four) - OP
3. Receiving RCS TK ISOL (three) - CL
He PRESS (two) - CL
4. MSTR RCS XFEED - FEED FROM L(R)

The procedures for executing an auto crossfeed ensure that the appropriate switches are in GPC for auto sequencing. Although the auto sequencing sends closed commands to the OMS crossfeed valves, the OMS crossfeed valves are manually closed to prevent a subsequent interconnect while crossfeeding. When the master crossfeed switch is positioned to feed, the GPC controlled valves move to the commanded configuration, thus providing single pod RCS propellants to all manifolds.

The master crossfeed switch also sets a discrete in the DAP that restricts the number of simultaneous jet firings while in a crossfeed configuration. This restriction is imposed to prevent helium ingestion into the RCS propellant tanks if too many jets fire simultaneously.

Present tank restrictions limit simultaneous jet firings to 5 per pod in straight feed; 7 total aft while crossfeeding with the ET attached; and 5 total aft while crossfeeding after ET separation.

The simultaneous jet firing restrictions are not applied for single engine roll control since OMS propellant is being used.

A manual crossfeed may be required if MDM/GPC failures have affected the auto crossfeed.

The sequence for a manual crossfeed, during ascent and entry, also ensure that all manifolds are constantly pressurized by manually positioning the appropriate valves. Although the master crossfeed does not provide any automatic valve movement, it still must be placed in a feed position to set the discrete in the DAP that will reduce the number of simultaneous jet firings. Remember that the position of the master crossfeed will limit the number of jet firings regardless of actual RCS valve position.

If a return to straight feed is required after a crossfeed, there are dedicated procedures to follow. Note that the return to normal feed is essentially a reverse sequence of the crossfeed procedure.

XFEED RETURN: RCS to RCS

If Auto:

1. L,R RCS TK ISOL (six) - GPC
XFEED (four) - GPC
2. MSTR RCS XFEED - OFF >>

If Manual:

1. L,R RCS He PRESS (four) - OP
TK ISOL (six) - OP,GPC
XFEED (four) - CL,GPC
2. MSTR RCS XFEED - OFF

The OPS 2 crossfeed procedures differ slightly from the ascent and entry procedures.

XFEED: R RCS to L RCS

1. DAP: free drift
2. ✓L,R OMS XFEED (four) - CL (tb-CL)
3. AFT L RCS TK ISOL (three) - CL (tb-CL)
XFEED (two) - OP (tb-OP)
4. AFT R RCS
✓He PRESS A(B) - GPC (tb-OP)
✓B(A) - CL (tb-CL)
✓TK ISOL (three) - OP (tb-OP)
XFEED (two) - OP (tb-OP)
5. MSTR RCS XFEED - FEED FROM R
6. DAP: as reqd

There is no auto crossfeed capability in OPS 2. Also note that this sequence of valve movement does not allow any tying of propellant tanks. The hazard of tied tanks onorbit offsets the need for constant attitude control. Since attitude control onorbit is not as critical as ascent or entry, the first step for orbit crossfeed is to place the DAP in free drift. The free drift mode prevents jets from firing while the RCS is being secured.

Free drift is usually obtained by first taking the DAP from auto to manual to prevent automatic jet firing. Next, ensure the jet firing mode is not in discrete, since the discrete mode can automatically fire jets while under manual control if the attitude exceeds the deadband (the pulse mode is preferred over acceleration mode). Finally, ensure the flight controller power is off to prevent manual jet firings if the RHC or THC is inadvertently moved.

The remaining steps in the orbit procedure configure the orbit crossfeed in a sequence that does not tie propellant tanks.

The onorbit return to straight feed is essentially a reverse of the secure procedures.

XFEED RETURN: RCS

1. DAP: free drift
2. MSTR RCS XFEED - OFF
3. AFT L,R RCS XFEED (four) - CL (tb-CL)
TK ISOL (six) - OP (tb-OP)
✓He PRESS A(B) (two) - GPC (tb-OP)
✓B(A) (two) - CL (tb-CL)
4. DAP: as reqd

Crossfeed Complications

If a leak occurs while the RCS is configured for a crossfeed, the dedicated procedures may not be pertinent to the crossfeed configuration. Leak isolation procedures for the pocket checklists are fairly comprehensive, but there are presently no procedures in the pilot flipbook to cover RCS leaks while crossfeeding. Situational awareness during early ascent, late entry, and RTLS is especially important.

It must be realized that, while crossfeeding, there is only one set of propellant tanks feeding the manifolds in both pods. A leak could be announced in either the feeding RCS or the receiving RCS as illustrated in figure 4-4. If the leak was announced on the receiving side, the leak would have to be upstream of the closed propellant tank isolation valves. In this case, only the helium isolation valves would have to be closed for leak isolation.

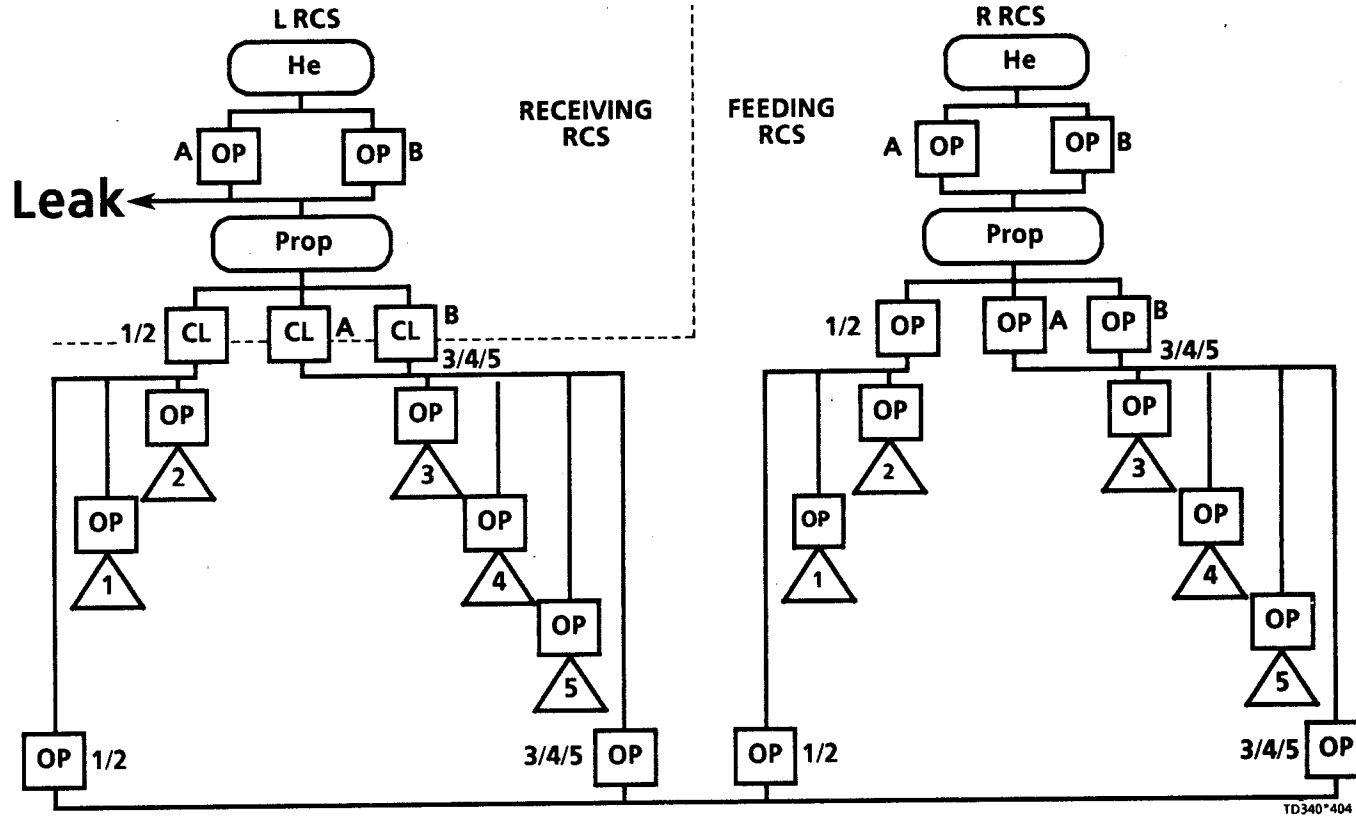
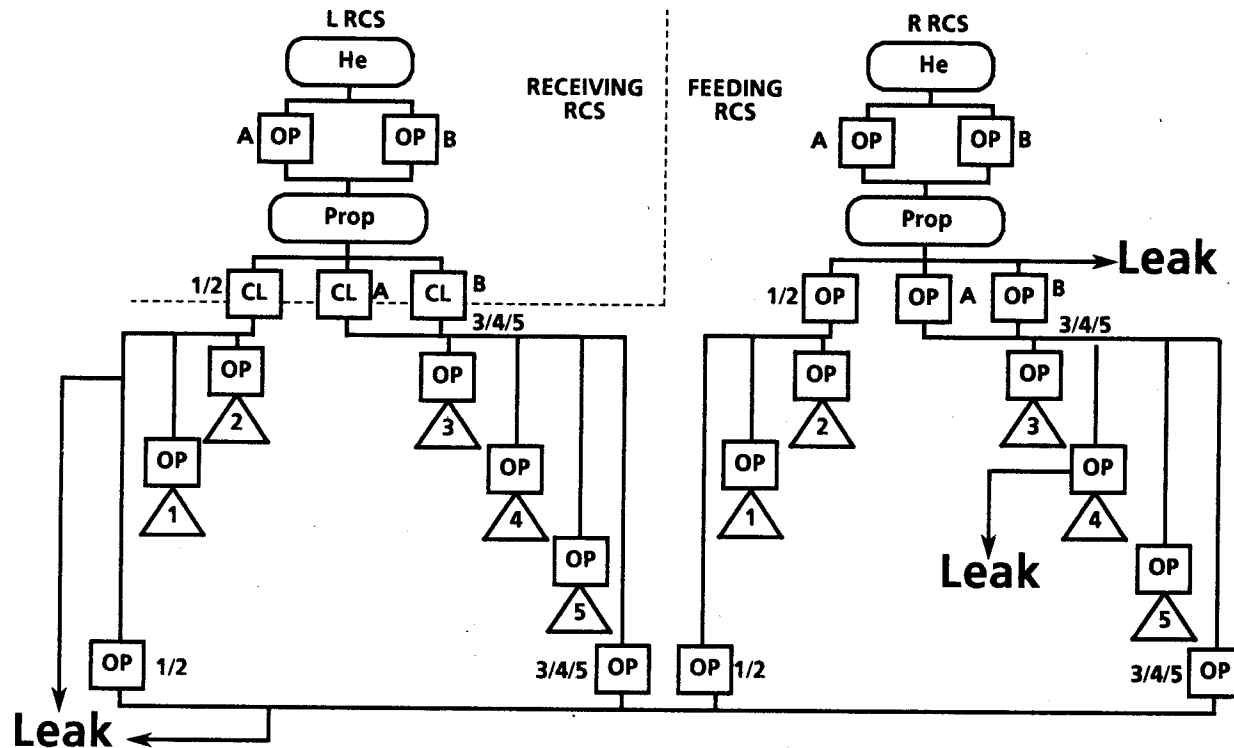


Figure 4-4.- Representative leak in receiving RCS during a crossfeed.

If a leak is annunciated in the feeding RCS the securing of the RCS is more complicated. Figure 4-5 shows example locations for leaks in the feeding RCS. When the manifolds are to be closed, the crew must remember to close all manifolds that are being fed from the leaking system. If only the feeding side manifolds and tank isolation valves are closed, the opposite manifolds would still be open. If the leak was on this side, all manifolds would evacuate and leak location would be difficult to determine. If associated jets were to fire, they would fail off due to propellant starvation.

In order to prevent inadvertent evacuations, secure the feeding RCS in the following order: all manifolds, receiving crossfeed, feeding crossfeed, feeding tank isolation, feeding helium isolation, and finally master crossfeed OFF. A return to crossfeed can be accomplished in the reverse order of the secure (except that the master crossfeed switch should be moved last). Do not open any valve that will feed a known leak unless the situation dictates otherwise (loss of control, ET SEP requirements, etc.).

Another area of concern while crossfeeding is that it can complicate subsequent scenarios. The majority of malfunction procedures are only designed for single failures with an assumed straight feed configuration. These procedures may have to be modified by the crew in real time in order to not complicate the situation.



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Figure 4-5.- Representative leak locations in feeding RCS during a crossfeed.

Interconnect

There are numerous situations that could require an interconnect. Before an interconnect is initiated, several constraints must be met.

INTERCONNECT (OPS 1 & 3): OMS to RCS I'cnect Initiation **OMS TK P > RCS TK P & $\Delta P < 50$**

During ascent and entry, the interconnect procedures ensure that, for vehicle control, the RCS manifolds are constantly pressurized from a propellant source during the transition from straight feed. Since this sequence ties the OMS propellant tanks to the RCS propellant tanks, subsequent damage could occur if the pressure in the RCS tanks was higher than the OMS tanks. If this were true, the aft bulkhead in the RCS tanks could collapse against the outlet, preventing further use of the RCS. Therefore, the pressure in the OMS propellant tanks must be greater than in the RCS propellant tanks, if the tanks are going to be tied.

Once this constraint is met, the pressure differential must not be greater than 50 psi or the rapid flow of propellant into the RCS tanks could cause tank damage. Realize that all RCS crossfeeds are opened while the RCS tank isolation valves are opened. This means that the RCS to RCS crossfeed ΔP constraints should be met in addition to the OMS to RCS ΔP constraints.

During ascent, there are two types of interconnects; auto and manual. The auto interconnect is used for abort dumps and single engine roll control. If the auto sequence fails, the manual procedures must be used. During orbit and entry, the auto sequence is not available, leaving only manual procedures.

L OMS to RCS:

L OMS XFEED	(two)	- OP
He PRESS/VAP ISOL	(two)	- OP
L,R RCS XFEED	(four)	- OP
TK ISOL	(six)	- CL

The initial steps for ascent and entry manual interconnect procedures pressurize the crossfeed lines between the OMS and RCS. Note that both A and B OMS crossfeed valves are opened (the single point electrical failure on the A valves does not offset the need for valve redundancy for a manual interconnect). The OMS helium is then introduced to repressurize the OMS propellant tanks. Next, the RCS crossfeeds are opened to provide propellant to the RCS manifolds before the RCS tank isolation valves are closed. This sequence of valve movement is essential to prevent manifold evacuations and jet failures during ascent and entry.

The onorbit interconnect procedures differ slightly in sequencing from ascent and entry in order not to tie propellant tanks. The sequencing logic is similar to the onorbit crossfeed procedures in regard to utilizing free drift before closing the RCS tank isolation valves and opening the crossfeed valves.

I'CNECT: L OMS to RCS

1. DAP: free drift
2. L,R RCS TK ISOL (six) - CL (tb-CL)
XFEED (four) - OP (tb-OP)
3. If RCS MANF P(OX and FU) > 130 continue; otherwise, check with MCC and >>
4. \sqrt{L} OMS He PRESS/VAP ISOL (two) - CL
TK ISOL (two) - OP (tb-OP)
 \sqrt{R} OMS XFEED (two) - CL (tb-CL)
L OMS XFEED A - CL (tb-CL)
B - OP (tb-OP)
5. OMS PRESS ENA, L OMS - ITEM 5 EXEC
6. DAP: as reqd

The step to check manifold pressures > 130 psi, after opening the crossfeed valves, is to check for any leaks in the crossfeed lines. (When pressure sensors are added to the crossfeed lines, these interconnect procedures will be modified.) If no leak is detected in the crossfeed lines, the OMS propellant tanks are connected to the crossfeed lines through just one set of crossfeed valves (redundancy not required since time is available for manual reconfiguration).

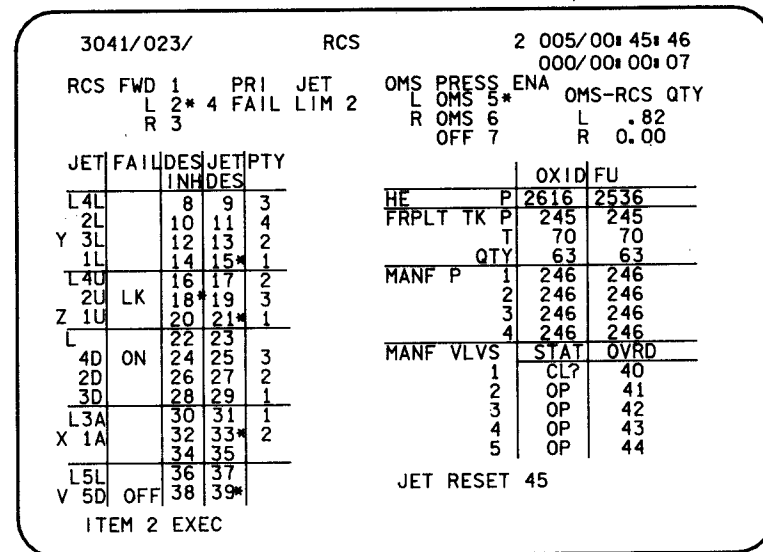
The helium isolation valves on the OMS are not opened for an onorbit interconnect in order to allow for earlier C&W annunciation of any leak. Since the OMS propellant tanks are in "blowdown", any leak in the OMS downstream of the OMS helium isolation valves would be annunciated as low tank pressure in the feeding OMS propellant tank.

Remember that during an interconnect, the RCS plumbing downstream of the RCS propellant tank isolation valves is essentially part of the OMS. A leak in the RCS, below the tank isolation valves, would be annunciated as low tank pressure in the OMS, not an RCS leak. If an RCS leak was annunciated during an interconnect, it would mean the leak is upstream of the closed RCS propellant tank isolation valves.

The need for blowdown is critical. If the OMS helium isolation valves were kept open and a leak developed, there would be no C&W annunciation of the leak until the helium tank reached its C&W limit. Most of the OMS propellant (leaking) would then be gone and the remaining propellant (nonleaking) would have a limited blowdown capability since the helium supply has been depleted. (Remember the OMS differs from the RCS by having one helium tank pressurizing both the fuel and the oxidizer tanks.) Blowdown, therefore, provides a more prudent interconnect configuration for onorbit operations. Once the onorbit interconnect is completed, an item entry on Spec 23 (OMS PRESS ENA, item 5 or 6 on figure 4-6) activates Shuttle software calculations that estimate OMS propellant usage by the RCS jets. This item entry can be made to any of the three Spec 23 pages (F, L, R). The calculations are based on the duration of jet fire commands. The calculations are displayed on Spec 23 under the heading of OMS RCS QTY in units of percent (0.82 = 0.82 percent of OMS propellant used).

This estimate of propellant usage is needed because all OMS quantity calculations cease when the OMS engines stop firing. During these periods of OMS inactivity, the displayed quantity on panel O3 is actually the quantity that remained at the end of the last OMS burn. Any OMS quantity decrease, due to interconnected RCS usage after a burn, would not be displayed until 15 seconds after the OMS engines ignited for the next OMS burn.

The activation of the OMS RCS QTY display allows the crew to make an estimate of OMS propellant remaining without executing an OMS burn. In order to make the estimate, the crew should subtract the OMS RCS QTY on Spec 23 from the appropriate OMS quantity displayed on panel O3.



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Figure 4-6.- RCS display.

There are several key points that must be made about the OMS PRESS ENA item entries. The OMS RCS QTY is a running total. There is no way to reset the counters to zero. If an onorbit OMS burn is executed, a new OMS quantity will be displayed on panel O3. The OMS RCS QTY displays, if reading other than zero, are now superfluous. The crew should record the OMS RCS QTY display at the end of each onorbit burn and use this data as a zero base for future estimates if/when the OMS PRESS ENA is reactivated.

Example

1.	Preburn L OMS QTY	40%
	L OMS RCS QTY (Spec 23)	<u>- 3.32</u>
	OMS propellant remaining	36.68%
2.	New OMS burn executed	
	Postburn L OMS QTY 25%	
3.	OMS RCS interconnect continued	
	L OMS QTY	25%
	L OMS RCS QTY	- 4.32
	(preburn L OMS RCS QTY)	<u>+ 3.32</u>
	OMS propellant remaining	24%

The OMS RCS QTY calculations are not based on valve configuration. If the crew interconnects to the right OMS, but by mistake executes an item 5 on Spec 23, the software will estimate left OMS propellant usage when in fact right OMS propellant is being used.

Another keyboard mistake can be made during the tank switch procedures. Notice that the calculations must be stopped (item 7) after the tank switch.

I'CONNECT TK SWITCH: From L to R OMS FEED

1. DAP: free drift
2. L OMS XFEED B - CL (tb-CL)
R OMS XFEED B - OP (tb-OP)
3. OMS PRESS ENA, OFF - ITEM 7 EXEC
R OMS - ITEM 6 EXEC
4. DAP: as reqd

If the crew failed to stop the calculation (item 7) before executing the item 6 entry, the subsequent OMS RCS QTY indication would be incorrect. The running total would continue calculating on the "new" pod. The "old" pod quantity would be frozen at the last calculation. As an example, assume the crew is switching from a left OMS interconnect to a right OMS interconnect and the OMS RCS QTY reads L2.30 (item 5 active) R0.00 (no usage). If an item 6 is executed without executing an item 7, the OMS RCS QTY would read L2.30 R2.30 because the quantity calculations were not stopped. In this situation, a 0.1 percent usage of right OMS propellant would be displayed as L2.30 R2.40. On the other hand, if the correct procedures had been executed (item 7 followed by item 6), the old calculations would have stopped and its new calculations would have picked up at the correct indication of L2.30 R0.00. A subsequent 0.1 percent usage would then be correctly displayed as L2.30 R0.10.

The crew must realize that as long as the OMS PRESS ENA is active, calculations will continue regardless of configuration (interconnect, crossfeed, or straight feed). When stopping an interconnect for leak isolation procedures, do not forget to stop the OMS PRESS ENA.

Remember that the OMS RCS QTY calculations are based on the duration of RCS jet fire commands, not actual jet firings. If jet fire commands are given to a failed off jet, those commands would be used to calculate and display propellant usage when, in fact, there is no usage. Likewise, a failed on jet would be using up propellant, but there would be no calculations of propellant usage by that jet since there is no fire command. If other jets were firing to compensate for the failed on jet, those fire commands would be used for calculations.

In addition to providing OMS propellant usage calculations, the OMS PRESS ENA item entry provides automatic pressurization of the OMS propellant tanks if the OMS helium isolation switches are placed in GPC. However, this is not a recommended procedure since it eliminates the "blowdown protection" for early C&W annunciation of propellant leaks. For all nominal onorbit interconnects, the helium isolation valves should be manually closed.

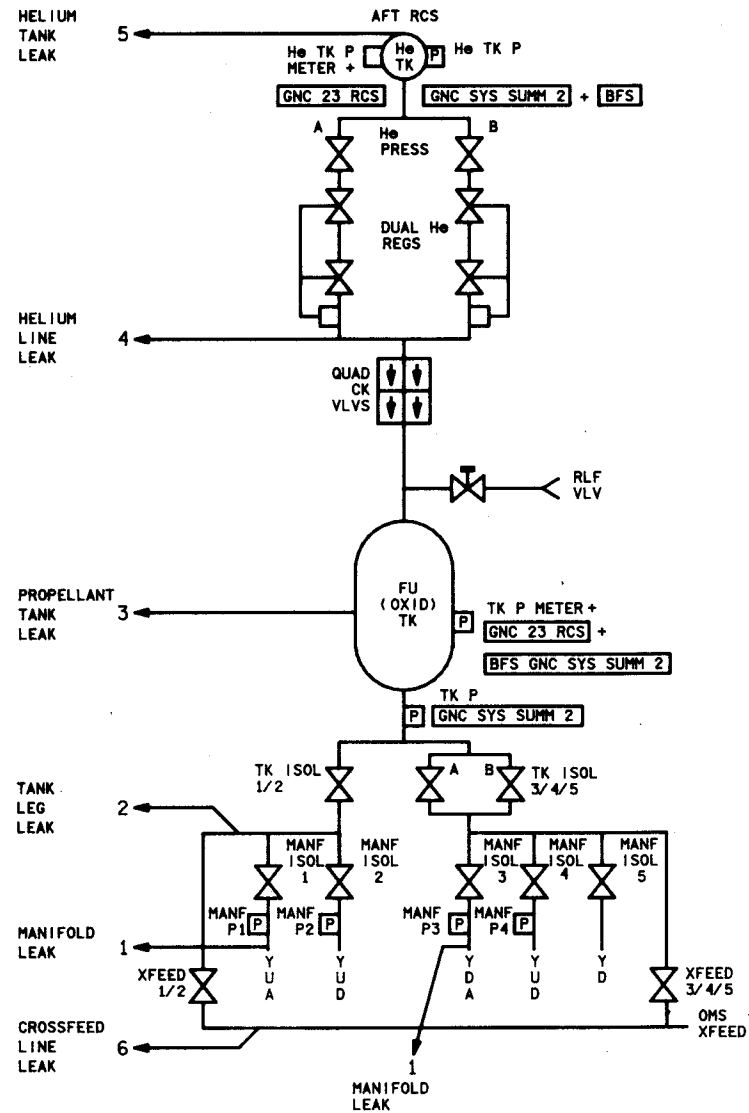
The step-by-step rationale for RCS malfunction procedures can be found in the Flight Procedures Handbook (ascent/orbit/entry pocket checklist) volume II, section 8. This section of the Flight Procedures Handbook is highly recommended for follow-up study to this manual, or it can be used in conjunction with this manual in order to provide a more complete understanding of the off-nominal situations that follow.

Leak Isolation

Propellant or helium leaks could occur anywhere in the various tanks and lines. Procedures to isolate leaks will differ slightly, dependent upon valve configuration and flight phase. These procedures were developed to provide a practical sequence of valve movement in order to determine the location of the leak, to isolate the leak, and then return the RCS to a functional configuration. The crew does not have to wait for leak annunciation to begin leak isolation procedures.

Leak annunciation will occur when the fuel and the oxidizer quantities in any one pod differ by more than 12.6 percent. The lower quantity should indicate the propellant system with the leak.

Leaks are generally typed according to the location of the leak as illustrated in figure 4-7.



TD3400407. ART. 6

Figure 4-7.- Location of leaks.

1. **Manifold leak.** Located downstream of the manifold isolation valves. Determined by a single manifold pressure decrease with the manifold valve closed. Pressure can drop to zero.
2. **Tank leg leak.** Located between the manifold isolation valves and the propellant tank isolation valves (also upstream of crossfeed valves for the aft RCS). Determined by two decreasing manifold pressures (either 1 and 2 or 3 and 4) with the manifold valves and tank isolation valves closed. Backflow through the closed manifold valves causes a pressure drop, but the pressure should not be lower than 30 psi.
3. **Propellant tank leak.** Located between the quad check valves and the propellant tank isolation valves. Determined by propellant tank pressure decreasing with the helium isolation and propellant tank isolation valves closed.
4. **Helium line leak.** Located between the quad check valves and the helium isolation valves. Determined by decreasing helium tank pressure with the helium isolation valves open, the propellant tank isolation valves closed, and confirmation of no helium tank or propellant tank leak.

5. **Helium tank leak.** Located upstream of the helium isolation valves. Determined by helium pressure decrease with the helium isolation valves closed.
6. **Crossfeed line leak.** Located between the RCS crossfeed valves and the OMS crossfeed valves. Presently determined by decreasing OMS engine inlet pressure with all RCS crossfeed valves closed, one OMS crossfeed valve open, and the associated OMS tank isolation valves closed. Realize that the evacuation of an OMS engine inlet to determine a crossfeed line leak will prevent the subsequent use of that OMS engine.

Before the discussion of leak isolation procedures is continued, the difference between helium and propellant leak annunciation should be covered. If propellant is leaking (the leak is downstream of the helium isolation valves), the helium tank will continue to maintain a normal pressure within the propellant tank. Since helium is replacing the leaking propellant, the quantity calculations based on PVT measurements will be accurate. If the propellant tank pressure should get below 190 psi, or the quantity drops below zero, then the propellant tank is considered failed and unusable.

If helium is leaking (the leak is upstream from the helium isolation valves), the displayed quantity will be inaccurate because of PVT calculation assumptions; i.e., all helium leaving the helium tank is replacing propellant leaving the propellant tanks.

If the helium pressure drops below 456 psi, the helium tank is considered failed and the associated propellant tank is in "blowdown."

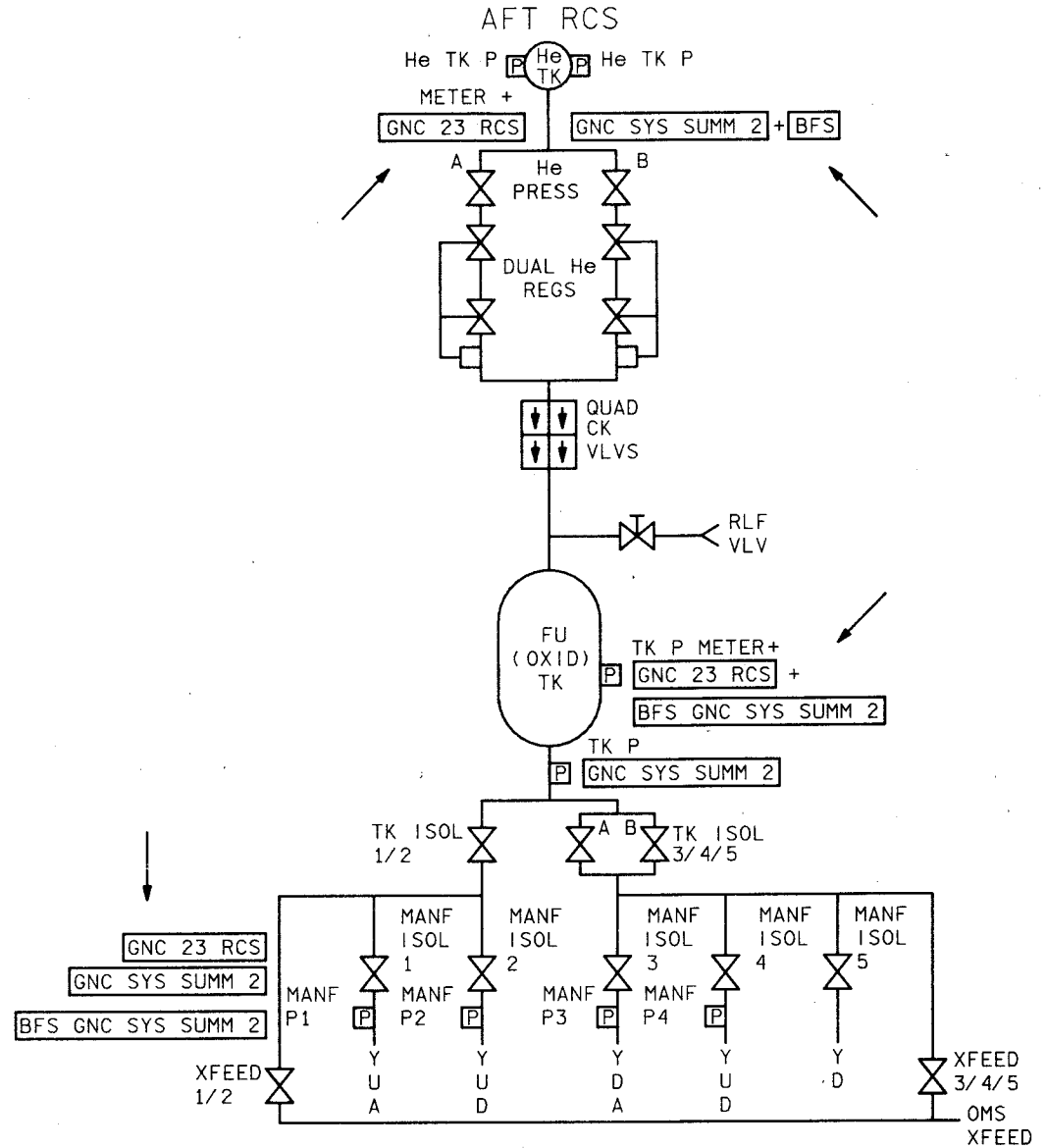
The initial goal of leak isolation is to determine the location of the leak. Before leak isolation is initiated, the crew should check propellant tank pressures and cross-check sensor indications.

Whenever RCS valves are moved, the crew should monitor the associated talkback for confirmation of valve position and switch function. This can aid in the prevention of jet failures and manifold evacuations.

A high tank pressure may vent propellant overboard which can result in a leak annunciation. Procedures for tank pressure high will correct the situation and stop the venting. Leak isolation procedures should not be followed if the tank pressure is high.

A pressure or temperature sensor could fail and give a false input to quantity calculations. This could trigger a leak annunciation. The location of these sensors can be seen on figure 4-8. There are multiple sensors in each RCS and the associated outputs can be displayed at separate locations (CRT or meter). By cross-checking these sensors, a true leak can be confirmed: pressures and quantities actively decreasing, CRT displays agree with meters, etc.

If tank pressures are normal and pressure sensors are giving true information, then leak isolation procedures should be initiated.



TD3400408. ART, 5

Figure 4-8.- Sensor output display destinations.

Leak Isolation Procedure

RCS LEAK ISOL

IGNC SYS SUMM 2

If FU or OXID TK P high, go to RCS TK P (FU or OX) HIGH.

If FU and OXID TK P low:

✓FU(OXID) He P (CRT & meter)

If decreasing, go to step 1

If not decreasing, go to RCS TK P (FU or OX) LOW, step 2

If FU or OXID TK P normal:

✓FU(OXID) He P (CRT & meter) decr:

1. DAP: free drift

Secure RCS:

2. Perform affected RCS SECURE, then:
3. If affected RCS receiving XFEED/I'CONNECT, go to step 6

✓Single MANF:

4. ✓Only one MANF P decr
If decr, return to normal config except leave leaking MANF closed >>

✓PRPLT TK Leg (✓two MANF P):

5. ✓MANF 1,2 or MANF 3,4 P decr
If two MANF P decr, return to normal config except leave affected TK ISOL (1/2 or 3/4/5), MANFs, and corresponding XFEED vlvs closed.
If 3/4/5, go to LOSS OF VERNIERS (ORB OPS, RCS) >>

✓He TK:

6. ✓He P decr
If decr, call MCC for use of LEAKING He RCS BURN When att cntl reqd:

If AFT RCS, I'CONNECT from OMS, then open all MANFs. Prior to deorbit TIG return to straight RCS feed. When He TK P < 456, perform I'CONNECT from OMS. At EI perform XFEED from good RCS. >>

If FWD RCS, return to normal config
When He P < 456, IGNC 23 RCS - override FWD MANFs STAT closed, perform LOSS OF VERNIERS (ORB OPS, RCS), then override open prior to deorbit. When PRPLT TK P < 190, perform RCS SECURE (FWD). >>

✓PRPLT TK:

7. ✓PRPLT TK P decr

If decr:

If AFT RCS, I'CONNECT from OMS, then open all MANFs. Prior to deorbit TIG, go to XFEED from good RCS. >>

If FWD RCS, return to normal config and perform FRCS DUMP

to depletion, or until PRPLT TK P < 190. Then perform RCS SECURE (FWD), then go to LOSS OF VERNIERS (ORB OPS, RCS) >>

✓He Leg:

8. Open He PRESS A and B (✓He P decr)

If decr:

If AFT RCS, close He PRESS A and B, I'CONNECT from OMS, then open all MANFs. Prior to deorbit TIG, return to straight RCS feed. Leave He PRESS A and B - CL. Cycle to maintain TK P 200-245. Repress to 245 at C/W limit (200 psia). When He TK P < 456, I'CONNECT from OMS. At EI perform XFEED from good RCS. >>

If FWD RCS, return to normal config except close He PRESS A,B; cycle to maintain PRPLT TK P 200-245. Repress to 245 at C/W limit (200 psia). When He P < 456, IGNC 23 RCS - override FWD MANFs STAT closed, perform LOSS OF VERNIERS (ORB OPS, RCS), override open prior to deorbit, then when PRPLT TK P < 190, go to RCS SECURE. >>

If XFEED, ✓XFEED lines (✓OMS ENG in P):

9. L(R) OMS TK ISOL (two) - CL. Open one OMS XFEED vlv. ✓OMS ENG IN P decr.
If decr, return to straight RCS feed.
DAP as reqd. Do not XFEED/I'CONNECT >>

MANF 5:

10. If leak not found above, assume MANF 5 leak. Leave MANF ISOL 5 (two) - GPC (tb-CL). Go to LOSS OF VERNIERS (ORB OPS, RCS)

Leak isolation generally begins with a secure of the RCS, and then a check for any pressure decrease. Since the RCS is unusable when secured, the crew must evaluate the need for RCS control before closing any manifolds. Also, anytime the RCS is reconfigured, the crew should monitor the valve talkbacks associated with each switch movement. This will help to confirm that the associated switch is operational.

If the leak is not massive, there may be time available to check pressures between switch group movements, rather than close all valves and then check all pressures. In other words, when all manifolds are closed, check the manifold pressures; when all tank isolation valves are closed, check the tank leg pressures, etc. Crew coordination can be helpful in this situation. While one crewmember is moving switches and checking talkbacks, another crewmember can be monitoring pressures and quantities.

Whenever a confirmed leak is isolated, situational awareness must be increased. This can be especially true if ET separation has not yet happened. The loss of isolated jets may be critical. Mission Flight Rules specify the minimum number of jets required for ET separation. More jets are required for the RTLS ET separation than are required for a nominal separation due to the increased maneuvering and aerodynamic loads on the vehicle.

ET SEPARATION RCS REQUIREMENTS		
Jet Group	Minimum Requirements	
	Nominal	RTLS
FWD down	1	2 (sides balanced)
AFT left	1	3
AFT right	1	3
AFT up	1/side	2/side
AFT down	1/side	2/side

If jet availability is less than the minimum required because of leak isolation, the crew might consider reopening closed manifolds just prior to ET separation in order to provide adequate control. Since manifold reopening would feed a known leak, it should not be done without the advice and consent of Mission Control.

RTLS ET separation is a critical maneuver, so the crew might consider delaying the closure of manifolds if leak annunciation occurs close to MECO. Once the Orbiter is safely separated from the tank, the crew could then initiate leak isolation procedures as long as it did not interfere with the execution of a critical OMS-1 burn.

The ET SEP switch is placed in the MANUAL position for leak isolation on nominal (non-RTLS) ascents (Pre ET SEP).

AFT RCS LK (Pre ET SEP)

N/A During Dump/SE Roll Cnt1
(/He P decr; CRT & meter)
(/TK P; if '↑', go to TK P HIGH)

1. ET SEP - MAN (N/A RTLS)
After leak isolation: ET SEP - AUTO
2. Affected RCS MANF (Five) - CL
RCS MANF ISOL 5 - GPC (tb-CL)
Affected RCS TK ISOL (three) - CL

This is done to prevent automatic ET separation while the RCS is being secured. An ET separation maneuver with no jets available on one pod could result in Orbiter/ET recontact. The ET SEP switch is kept in AUTO for RTLS because ET separation is time critical for that phase and cannot be delayed.

Caution must be exercised when returning the ET SEP switch to AUTO after the leak is isolated and propellant flow is established. If MECO has occurred during leak isolation, placing the ET SEP switch to AUTO will result in an immediate tank separation. Therefore, the crew should consider Orbiter attitude, rates, and ET ground impact before moving this switch.

The ET separation maneuver requires jets from all three pods. The loss of jets due to an unisolatable tank leak in an aft pod can be overcome by using a crossfeed. Remember the forward RCS has no crossfeed capability, so an unisolatable tank leak in that pod could prevent a normal ET separation maneuver. If a propellant tank is unusable in the forward RCS on a nominal ascent, the crew must inhibit the automatic -Z translation (by moving the THC out of detent) and perform a manual maneuver that uses only the aft jets.

FWD RCS LK

```
(/He P decr; CRT & meter)
(/TK P; if '+', go to TK P HIGH)
If RTLS: 1. RCS SECURE
          2. Post PPD - reopen RCS
          3. Post ET SEP - RCS SECURE >>
If Pre ET SEP (N/A RTLS):
4. ET SEP - MAN
5. RCS SECURE
6. If single MANF leak:
   Reopen RCS, except bad MANF
   ET SEP - AUTO >>
7. If TK leg leak: (two MANF P Low)
   Reopen RCS, except bad leg
   ET SEP - AUTO >>
8. If PRPLT TK P decr:
   Post MECO - reopen RCS
   If TK P > 200 & QTY > 0%:
     9. ET SEP - AUTO
     10. Post ET SEP - RCS SECURE >>
   If TK P < 200 or QTY = 0%:
     11. RCS SECURE
     12. DAP - MAN, PITCH - PULSE
     13. THC -X and hold
     14. ET SEP - AUTO
     15. At SEP:
         THC +Z (3 sec)
         THC -Z (2 sec) (-.2°/sec)
         COAST (15 sec)
         THC +X (10 sec) (-.5°/sec)
     16. OPS 104 PRO, DAP - AUTO >>
```

If an unisolatable forward RCS leak occurs on an RTLS, the crew's only option is to perform the powered pitch down with only the aft jets.

During ascent or aborts, if a leak occurs in the RCS, the crew must conserve the remaining propellant. In this situation, it is prudent to inhibit any RCS dump. There are numerous RCS dumps programmed in the Shuttle software. These include pre-MECO and post-MECO dumps for RTLS, TAL, and ATO. (At the present time, only the RTLS and TAL post-MECO dumps are actively programmed with a dump duration time.)

If a leak occurs pre-MECO that reduces any aft RCS quantity below 75 percent, then ET separation must be performed in a crossfeed from the good pod.

During ascent, orbit, and early entry, aft RCS leak isolation procedures call for a complete secure of the leaking pod. During late entry (MM 304-305, 603), the demand for aft RCS control is more critical and the RCS should not be completely secured. In order to maintain adequate control during leak isolation, the aft RCS is secured "one half" at a time.

AFT RCS LK (GRTLS/304/305)

```
(/He P decr; CRT & meter)
(/TK P; if '+', go to TK P HIGH)
1. Open vent doors.
   After proc complete: If not OX TK 1k And M > 3,
   Cl vent drs
2. If RTLS/TAL: 601 DUMP OFF
3. Secure 3/4/5 MANFs & TK ISOLS
   /If single MANF leak: Reopen, except bad MANF >>
4. /If TK leg leak (two MANF): Leave leak leg CL
   Aft RCS XFEED - CL >>
5. Reopen (leave MANF 5 GPC (tb-CL))
   /TK ISOL(s) - GPC, then repeat for 1/2 leg
6. He PRESS (two) - CL, /if He TK leak:
   He PRESS (two) - OP, at He P < 456 - XFEED >>
7. /If PRPLT TK leak (FU/OX TK P diverge):
   He PRESS (two) - OP, when QTY = 0 - XFEED >>
8. He PRESS (two) - OP, /if He leg leak (He P decr):
   Cycle He PRESS so 200 < TK P < 245, at
   He P < 456 - XFEED >>
9. Assume MANF 5 leak
```

This allows half the jets in the leaking pod to be available for control while the other half is being secured. If manifold pressure decreases are not observed and the leak is still active, the process is repeated for the other half until the leak is located and isolated.

A helium tank leak (a leak upstream from the quad check valves) will cause unreliable quantity calculations. The Shuttle crew will need to communicate with Mission Control to determine the actual propellant quantity. If there is no communication with the ground, the crew can only estimate how much propellant remains in the leaking system.

In order to make an estimate, the crew would use the good quantity of the opposing propellant plus any preleak difference. For example, if displayed quantities in the leaking pod, preleak, were FU 38%, OX 40%, and fuel helium was leaking, then a good estimate for fuel quantity would be oxidizer quantity minus 2% and then adjust for blowdown.

Once the quantity of propellant is estimated, it must be realized that not all of the propellant may be usable due to blowdown. If the preleak quantity is in the vicinity of 23 percent, the propellant tank is at maximum blowdown and the ullage pressure is adequate to feed the remaining propellant to the manifolds. Quantities greater than the maximum blowdown quantity will have less than 23 percent usable propellant. A completely full propellant tank with minimal ullage is essentially unusable since the small amount of ullage pressure would be rapidly depleted in blowdown.

If an unisolatable helium leak is present (and time permits), the crew would follow orbit pocket checklist procedures to dump RCS propellant until the quantity reaches the maximum blowdown quantity.

Tank Pressure Malfunctions

These malfunctions are divided into two propellant categories; high and low tank pressures. The crew must ensure the failure is real (not a sensor problem) before taking any action. The use of CRT and meter cross-checks will serve this purpose. Since the tank isolation valves are open, tank and manifold pressures should be equal.

AFT RCS TK P (FU or OX) LOW (✓MANF P)

1. If Pre ET SEP: ET SEP - MAN (N/A RTLS)
2. XFEED from good RCS
3. ET SEP - AUTO

A low tank pressure can result from four situations: (1) both regulators fail to a low setting, (2) the helium pressurization valves are closed while RCS is being used, (3) a propellant leak occurs, or (4) a line blockage exists. If the pressure drops below 190 psi, that tank is considered failed and unusable, unless it can be repressurized by changing regulators or opening helium isolation valves. RCS jets will probably fail off if fired when manifold pressures are less than 190 psi.

The crossfeed capability for the aft RCS provides a workaround for low tank pressure. The ET SEP switch is placed in manual until the crossfeed is established.

A low tank pressure can occur if the RCS is used while in an intentional blowdown. At some point, the crew could repressurize the propellant tank back to normal limits.

RCS TK PRESS (FU or OX HIGH)

✓Via associated MANF P:

1. Affected RCS He PRESS (two) - CL (tb-CL)
When good RCS TK P < 200:
2. Affected RCS He PRESS A - OP (tb-OP)
If subsequently RCS TK P > 312:
3. Affected RCS He PRESS A - CL (tb-CL)
B - OP (tb-OP)

A high tank pressure can be caused by a failed regulator and only affects propellant tanks. If the pressure exceeds 332 psi, a burst diaphragm will rupture allowing helium to flow to a pressure relief valve that vents at pressures over 315 psi. If this overpressure is not corrected and propellant venting continues, a leak would eventually be annunciated. Leak isolation procedures do not solve the overpressure problem. In order to correct the overpressure, the crew must isolate both regulators (by closing the helium isolation valves) and wait for the pressure to "bleed down" to normal limits. At that time, the regulators could be opened one at a time until the good regulator is found.

Remember that the helium isolation valve switches control pressurization for both fuel and oxidizer tanks. When an over pressurized tank bleeds down to normal limits (about 250 psi), the opposing propellant tank could have dropped near 190 psi. Jet firings below 190 psi tank pressure can result in jets failing off. The crew should base repressurization on the lowest tank pressure not on the high pressure tank returning to normal.

One additional note: if fuel tank pressure is greater than 20 psi above the associated oxidizer tank pressure, the vernier jets are no-go for operation.

Thermal Control System Failures

One or more of the following fault messages can appear when a temperature in the OMS pods is detected as out-of-limits: S89 PRPLT THERM OMS, S89 PRPLT THERM POD, or S89 PRPLT THERM RCS (PASS); SMO PRPLT THERM (BFS). These messages usually mean that a heater, thermostat, or temperature sensor has failed. In ascent, there are no crew actions because the heater switches cannot be reached easily. Once onorbit, the systems malfunction procedures call for switching to an alternate heater circuit on panel A14. Vehicle attitude may also be adjusted to utilize solar heating to compensate for a total loss of heating capability.

Jet Failures

As mentioned earlier, there are three types of jet failures; fail on, fail off, and fail leak. Procedures will differ according to the type of failure.

RCS JET FAIL ON

1. RCS MANF ISOL - CL
If MANF 5: GPC
- If MANF P > 130
2. RCS MANF ISOL - OP
3. ✓AFT RCS RM LOSS (ENTRY)

A failed on jet can create control difficulties due to excess thrusting. Propellant usage will increase if the jet is not isolated. The first procedural step calls for the closing of the associated manifold valve and then checking the manifold pressures. If the failure is a true fail on, the jet will continue to fire with the manifold closed, and both fuel and oxidizer pressures will drop below 130 psi. (If the pressures stay above 130 psi, then the fail on indication is false.)

RCS JET FAIL OFF

- If > 1 jet/pod/dir failed:
1. [G23] Resel jets
 2. DES INH * (Reprioritize)

The annunciation of a jet fail off indicates the GPCs did not detect any chamber pressure. If this is the first fail off and there are sufficient jets available for redundancy, no action is usually required. However, if the failed off jet is needed for redundancy, then steps are taken to continue to use this jet in the hopes that the failure is false; i.e., the P_c sensor has failed.

In order to regain the use of a failed off jet, Spec 23 must be available in order to reselect that jet since it has probably been auto deselected. Deselect inhibit entries are made to lower the firing priority of reselected jets. If a failure occurs onorbit, there are procedures for a hot fire test to determine if the jet is really firing. If a jet fails off during ascent/RTLS, there is no action to take since Spec 23 is not available.

RCS JET FAIL LEAK

- If Ox/Fu Qty diverging:
1. Affected RCS MANF ISOL - CL
If MANF 5: GPC

A jet declared failed leaking does not require any action unless a leak is confirmed. If the fuel and oxidizer quantities are diverging, the associated manifold is closed to isolate the leak.

RM Malfunctions

The CRT message RM DLMA MANF will be annunciated if the RM software has an insufficient number of open or closed discrettes from the valve position microswitches. If a dilemma exists, the manifold status will be declared "closed" and a "?" will appear by the manifold status. If the talkback indicates open and the crew desires to have those jets available, the manifold status can be overridden open via keyboard entry (item 41) to Spec 51.

RM DLMA MANF

If MANF tb - op
G51 MANF OVRD, ITEM 41

This item entry will override to open all manifolds that have a closed status due to a dilemma. It will not affect the closed status due to a closed manifold or software override. If Spec 23 is available, an individual manifold in dilemma may be overridden open via keyboard entry (item 40-44).

The RM loss malfunction is not annunciated with any dedicated message. Instead, RM loss must be associated with MDM failures (full or partial) or false jet failures. A full MDM failure or partial failure (BCE BYP - bus control element bypass) can cause the loss of RM to multiple jets associated with that element.

RCS RM LOSS

If vernier jets:

If loss of FAIL OFF detection:

1. Resel >>

If BCE BYP (B or D), MDM fail, or loss of LK
 or detection:

If only L5L and/or R5R affected:

2. Desel affected jet >>

If any Down Firing Vernier affected:

3. Affected MANF 5 - CL (tb-CL), then GPC
 4. Go to LOSS OF VERNIERS (ORB OPS,
RCS) >>

If primary jets:

If loss of FAIL OFF or LK detection:

5. If att control still avail, desel
 affected jet(s)

or 6. DES INH twice (reprioritize, reset RM)

7. At seat ingress, go to AFT(FWD) RCS RM LOSS
 (ENT PKT, RCS) >>

If loss of FAIL ON detection:

8. If att control still avail, override
 STAT closed for all MANFs on affected RJD
 or and affected RJD - OFF

9. DES INH twice (reprioritize, reset RM)

10. At seat ingress, go to AFT(FWD) RCS RM LOSS
 (ENT PKT, RCS) >>

If BCE BYP (B or D), or MDM fail:

11. If att control still avail, leave
 STAT closed for all MANFs on affected RJD
 and affected RJD - OFF

12. DES INH twice (reprioritize, reset RM)

13. At seat ingress, go to AFT(FWD) RCS RM LOSS
 (ENT PKT, RCS)

False jet failures cause the loss of RM for that jet only. To be specific, a false jet fail leak (injector temperature transducer failure) will cause the loss of fail leak RM but will not affect fail on or fail off RM. A jet P_c transducer failure will cause the loss of fail off RM (PASS and BFS) and fail on RM (BFS only) but will not affect fail leak RM or fail on RM for PASS.

The procedures for RM loss differ slightly depending upon the flight phase where the loss occurs. During entry, the loss of fail off, fail on, or fail leak detection usually requires reprioritizing and deselecting the affected jet. If the loss affects any + X or - X jets, those jets can be reselected for an RCS completion of a deorbit burn. There is a general caution not to take any action (jet deselection) that will result in less than fail-safe redundancy for entry.

If the RM loss occurs onorbit and only affects the vernier jets, procedures differ depending upon which jets are affected. If L5L or R5R (noncritical vernier jets) are affected, those jets can be deselected and vernier jet operations can continue, since the down firing vernier jets provide some degree of yaw motion due to the angle of jet firing. The loss of fail off detection for vernier jets is not considered a major problem, so vernier operations can continue. Any other type of RM loss to critical vernier jets will result in the total loss of vernier operations.

Onorbit RM loss to the primary jets requires placing the affected jets in last firing priority and resetting the RM. At seat ingress for deorbit, entry procedures are followed to ensure a "fail operational" mode for jet availability.

Each type of onorbit RM loss requires additional steps. Loss of fail off or fail leak detection calls for deselection of the affected jets. This allows good jets on the affected manifolds to be available for use.

Loss of fail on detection calls for overriding the affected manifold status to closed. This removes the affected jets from the availability table since the jet drivers will be turned off. This allows the manifold valves to be left open, which protects against thermally induced jet fail leaks.

Comm faults due to MDM failures and BCE bypasses will automatically cause the affected manifold statuses to go closed. All that remains is to turn the affected jet drivers off.

Electrical/Data Path Failures

The operation of the RCS is dependent on electrical power supplied through various electrical buses and to components of the data processing system (DPS). Failures in these systems can have significant effects on the RCS. There are three main buses, nine control buses, eight FA/FF MDMs, and five GPCs that are associated with the RCS.

Figure 4-9 is a simplified schematic of electrical and data path flow for solenoid driven valve operation. Switch or GPC outputs provide gate inputs to main bus powered logic circuits. The outputs of the logic circuit activate remote power controllers that provide main bus power control of selected valves.

Figure 4-10 shows the schematic for a motor driven valve. The circuitry is similar to the solenoid type valve up to the logic box. At this point, the logic output activates a solenoid. This solenoid trips a relay that provides ac power to the valve motor.

The detailed schematics of the RCS can be found in the Space Shuttle Systems Handbook, Volume I, numbers 11.4 through 11.10. Deductive analysis of these schematics will reveal the results of specific combinations of electrical and data path failures.

The following paragraphs will describe only the basic arrangement of power and data transmission and the effect of simple electrical and DPS failures on RCS valves and switches. The use of the OMS/RCS slide rule for evaluating these failures will also be discussed.

Other areas of discussion will include electrical/DPS effects to:

- OMS to RCS interconnect sequence
- RCS to RCS crossfeed sequence
- Pressure and temperature sensors
- Quantity gauging
- Jet fire commands
- Pod heaters

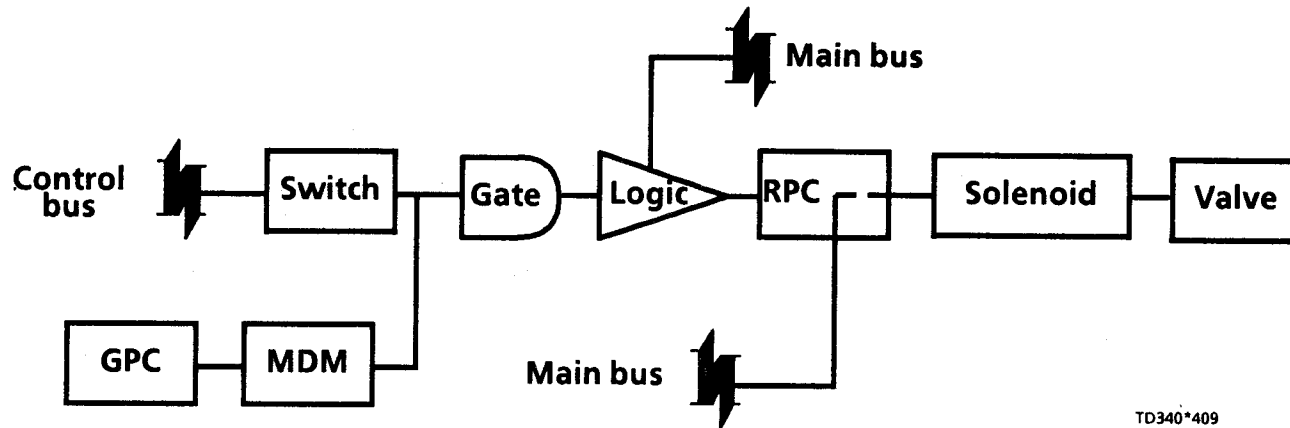


Figure 4-9.- Schematic of electrical and datapath flow for solenoid driven valve operations.

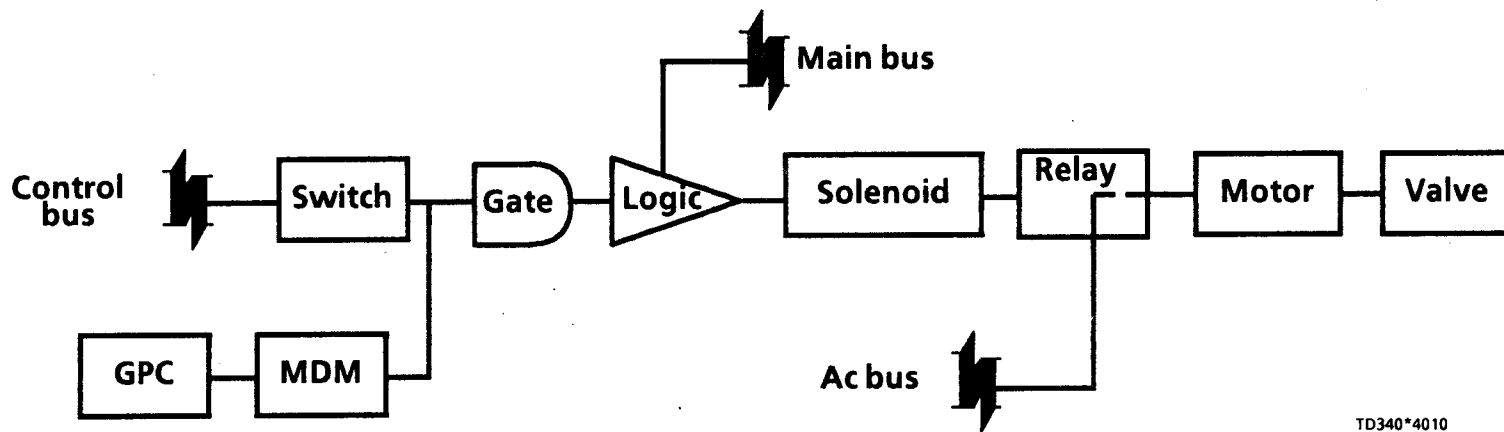


Figure 4-10- Schematic of electrical and datapath flow for motor driven valve operations.

RCS Valves and Switches

As previously mentioned, there are two types of valves in the RCS; a solenoid type and a motor-driven type.

Solenoid type valves are used for helium pressurization and vernier manifold operation. Figure 4-11 shows a schematic for the aft right helium pressurization A valves. This schematic can be considered as representative of all solenoid type valves. The vernier manifold schematic is slightly different but similar in operation. Refer to the Space Shuttle Systems Handbook (volume 1, section 11) for specific differences between the two solenoid valves.

The switch for the solenoid type valves has dual contacts for the close position but only a single functional contact for the open and the GPC position.

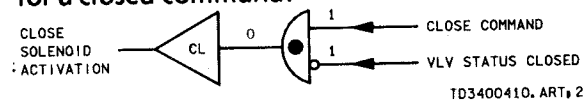
Close Operation

Placing the switch to the close position enables control bus power flow through various gates and logic circuits to remote power controllers (RPC). These RPCs allow main bus power activation of solenoids that close both the fuel and oxidizer valves. Note in figure 4-11 that the closed RPCs are in series. Both RPCs must be activated in order to close the valves.

When the valves reach a fully closed position, the close command is terminated. This can be seen in the schematic circuitry. Notice that the gates for the load control assemblies (LCA) and power control assemblies (PCA) are AND gates.



In order for an AND gate to make an output, both "one" inputs are required. Any other combination of inputs (a one and a zero/two zeroes) will give a zero output. Some of the AND gates for valve commands must also have a valve status input. Note the following figure for a closed command:



This AND gate has an inverted input (o ←) for valve status. If the valve is closed, the "one" input is inverted to a "zero" input resulting in a zero output to the valve solenoid (canceled close command). If the valve is not closed, the "zero" input is inverted to a "one" input allowing a close command to activate the valve solenoid.

Manual close control of the valves is lost if any of the following occurs:

- Loss of either control bus power to the switch contacts. (Note the close RPCs are in series).
- Loss of main bus power to the close logic circuitry.

- Loss of main bus power to the close RPCs.

Open Operation

Placing the switch to the open position energizes the solenoids that open both fuel and oxidizer valves. When the valves reach a fully open position, the open command is terminated.

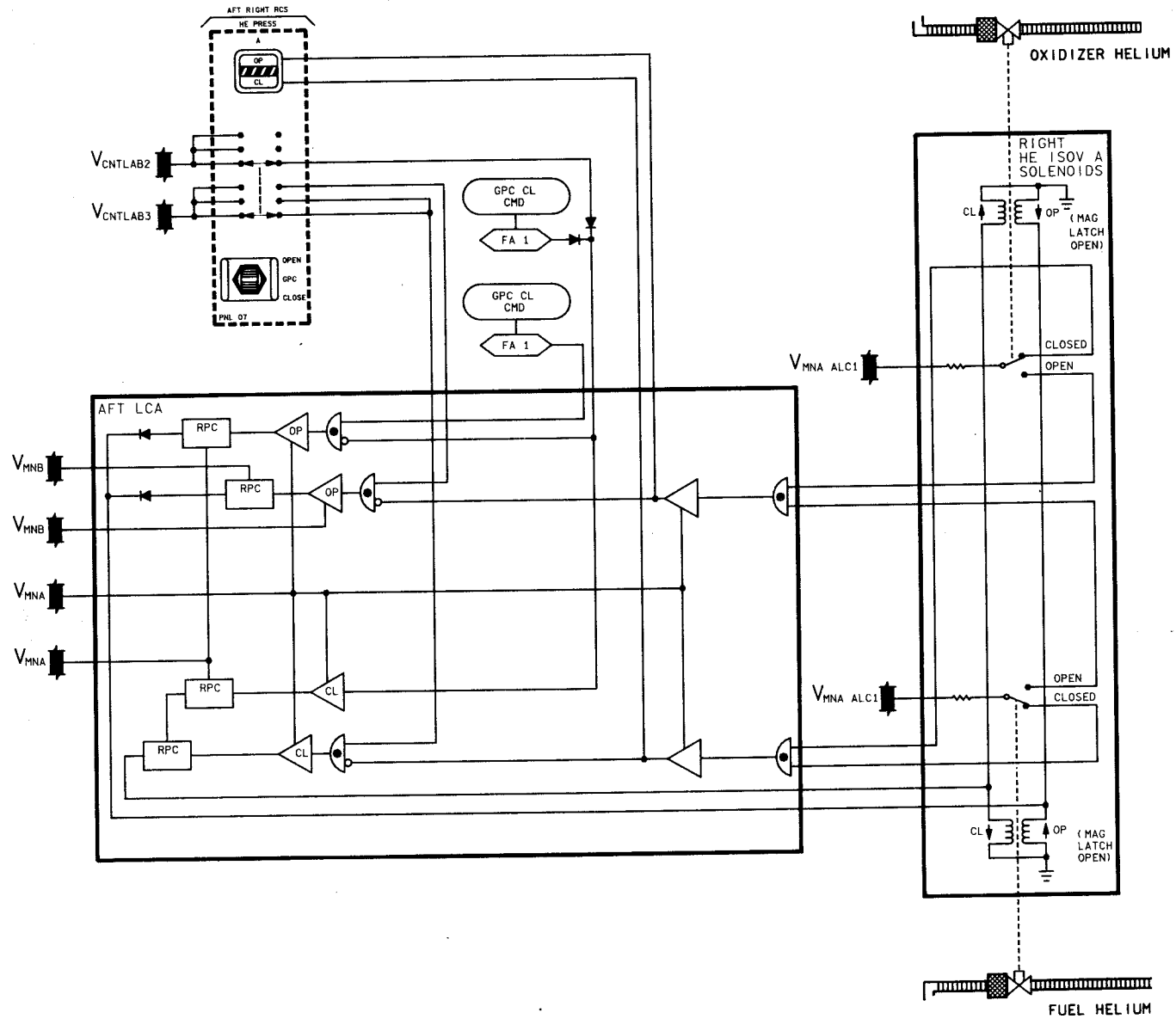
Manual open control of the valves is lost if any of the following occurs:

- Loss of control bus power to the single manual open contact.
- Loss of main bus power to the manual open logic.
- Loss of main bus power to the manual open RPC.

GPC Operation

If the switch is placed in GPC, then GPC commands can be output through dedicated MDMs to open or close the affected valves.

A GPC close command enters the LCA circuitry downstream of the "upper" switch contact for manual close control. Since this contact is open with the switch in GPC, the GPC command (not control bus power) will activate that portion of the circuitry. This enables the first close RPC, however the valve will not operate until the second close RPC is activated.



TD3400411-ART1-2

Figure 4-11.— Schematic for the aft right RCS helium pressurization A valves.

With the switch in GPC, the second close RPC is activated whenever the valves are not in a closed position. The combination of a GPC close command to the first RPC and control bus activation of the second RPC provides the main bus power to close the valves.

GPC close control is lost if any of the following occurs:

- Loss of the dedicated MDM (or its associated GPC).
- Loss of control bus power to the "lower" 3-contact bus of the switch.
- Loss of main bus power to the GPC close logic.
- Loss of main bus power to either close RPC.

A GPC open command uses separate circuitry within the LCA to open the associated valves. The gate for the GPC open command has an inverted input from close commands instead of valve position status. This is to ensure that all close commands can override any GPC open commands. Note, the GPC open circuitry is separate from the manual open circuitry (RPCs are in parallel).

GPC open control is lost if any of the following occurs:

- Loss of the dedicated MDM (or its associated GPC).

- Loss of main bus power to the GPC open logic.
- Loss of main bus power to the GPC open RPC.

Note that the loss of control bus power to the switch has no effect on GPC open commands.

Motor driven valve circuitry is slightly more complex than pure solenoid operation. Motor driven valves are used for the RCS tank isolation, manifold isolation, and crossfeed isolation valves. The flow of ac power to the motor control assemblies (MCAs) is enabled by switches and circuit breakers on panel MA73C, as illustrated in figure 4-12.

The ac circuit breakers for the forward RCS valves are on row H and provide ac power to the following fuel and oxidizer valves:

<u>AC1</u>	<u>AC2</u>	<u>AC3</u>
TK ISOL 3/4/5	MANF 2	TK ISOL 1/2
MANF 1		MANF 3
		MANF 4

Logic power to the forward RCS MCAs is enabled by switches and circuit breakers on MA73C. The switches are located on rows A and B while the circuit breakers can be found on row C. Each forward RCS MCA receives logic power from only one source; either main A, main B, or main C.

The aft RCS MCA circuitry is different from the forward RCS in that the MCAs in the aft pod also control certain OMS valves. These OMS and RCS valves are distributed among three groups: aft pod valve group 1 (powered by AC1), valve group 2 (AC2), and valve group 3 (AC3). The circuit breakers for the associated ac motor power can be found on row I of MA73C and provide power to the following fuel and oxidizer valves.

<u>AFT POD VLV GP 1</u>	
L&R	RCS TK ISOL 3/4/5A
L&R	MANF 2
L&R	RCS XFD 3/4/5
L&R	OMS TK ISOL A
L	OMS XFD A

<u>AFT POD VLV GP 2</u>	
L&R	RCS TK ISOL 3/4/5B
L&R	MANF 1
L&R	OMS XFD B

<u>AFT POD VLV GP 3</u>	
L&R	RCS TK ISOL 1/2
L&R	MANF 3
L&R	MANF 4
L&R	RCS XFD 1/2
R	OMS XFD A
L&R	OMS TK ISOL B

The logic power for the aft RCS MCAs are carried by a special bus that provides dual redundant logic power to each MCA as illustrated in figure 4-13. The switches for the logic buses are can be found on row I of MA73C. Each MCA can receive inputs due to the position of the controlling valve switch. This switch provides control bus power through various gates and logic circuits in order to activate controlling solenoids. These solenoids close the relays that provide ac power to the motors for opening or closing the propellant valves.

The controlling switch for valve operation has either single or dual control bus power sources. The single contact type switch (one control bus) is used for the aft tank isolation 3/4/5 valves and all primary jet manifold isolation valves. All other motor driven valves (forward tank isolation, aft tank isolation 1/2, and all crossfeed isolation) have dual contact type (two control buses) switches. The single contact control bus switch will be covered first.

Before a discussion of RCS switches is begun, an explanation of figure detail is required. Subsequent figures for MCA schematics are quite detailed. These schematics may be scanned quickly if desired, since the main text provides an adequate description of valve operation.

However, if an indepth understanding of MCA operation is desired, continue reading this paragraph. Figures 4-14, 4-15, and 4-16 show schematics for different types of MCAs. Since the fuel "wiring" is essentially identical to the oxidizer's for each MCA, a word description is substituted for the fuel valve input flow in each MCA schematic. This wording may be easier to follow than chasing the electron flow of the oxidizer side of the wiring diagram. A study of these figures will provide an understanding of valve operation, manual override of GPC commands, and motor stoppage when the valves reach a desired position.

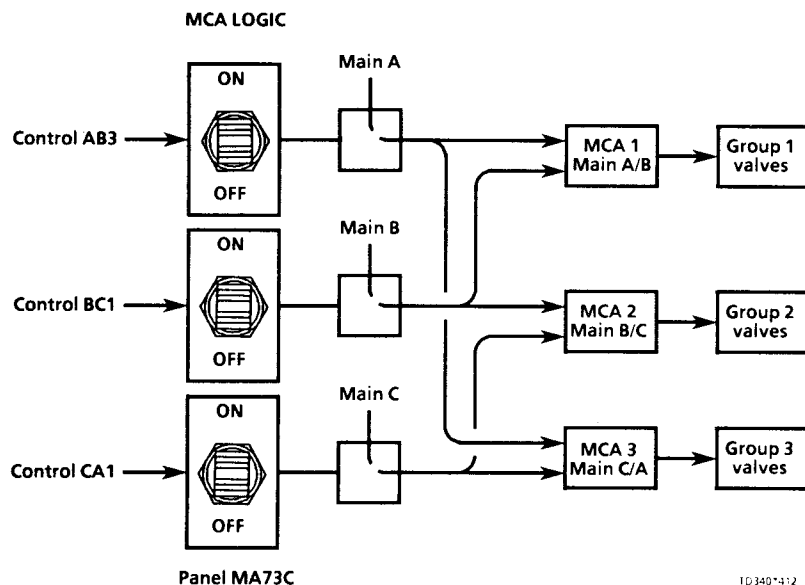


Figure 4-13.- MCA logic on Panel MA73C.

Single Control Bus Switch. Figure 4-14 shows a schematic for a single contact switch. Each valve motor has one open and one close solenoid for relay activation. The manual close and GPC close commands share the same close circuitry. Likewise, the manual open and GPC open commands share the same open circuitry.

Placing the switch in either manual open or close provides control bus activation of the selected ac motor. If the switch is in the GPC position, power is removed from the switch, allowing GPC command activation of the valve motors. (Note that a control bus failure will allow GPC activation of the affected valves regardless of switch position.) When the valves reach the selected position, the motor is stopped. Manual close commands will override any open commands.

Manual control (open and close) of these valves is lost if any of the following occurs:

- Loss of control bus power.
- Loss of main bus logic power.
- Loss of two or more phases of ac power to the motors.

The loss of control bus power will not affect GPC operation of the valves; however, the loss of dedicated MDMs (or GPCs), logic power, or ac power will cause the loss of GPC control for the affected valves.

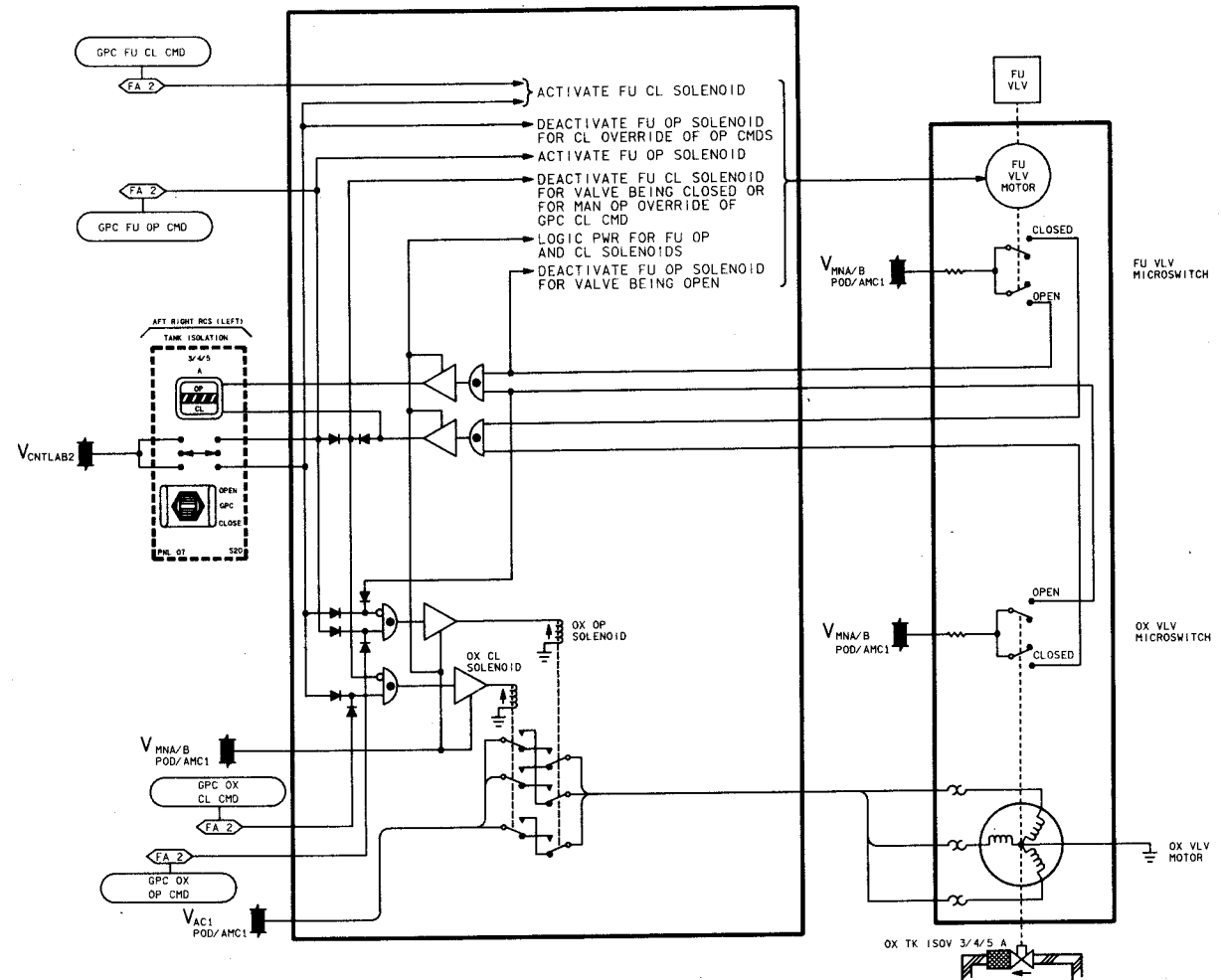


FIGURE 4-14. - SCHEMATIC FOR A SINGLE CONTACT SWITCH.

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Figure 4-14. - Schematic for a single contact switch.

Dual Control Bus Switch. There are two types of MCA circuitry for dual contact switches. One type has three solenoids (two closed and one open) per valve motor and the other type has four solenoids (two open and two closed) per valve motor.

Figure 4-15 shows a schematic for a three-solenoid MCA. The three-solenoid MCA is only used for the forward RCS propellant tank isolation valves.

Placing the switch to close allows dual control bus activation of two close solenoids. One bus controls the A solenoids while the second controls the B solenoids. Both A and B close solenoids are required for manual close operation. Manual close operation is lost if any of the following occurs:

- Loss of either control bus.
- Loss of main bus logic power.
- Loss of two or more phases of ac power to the motors.

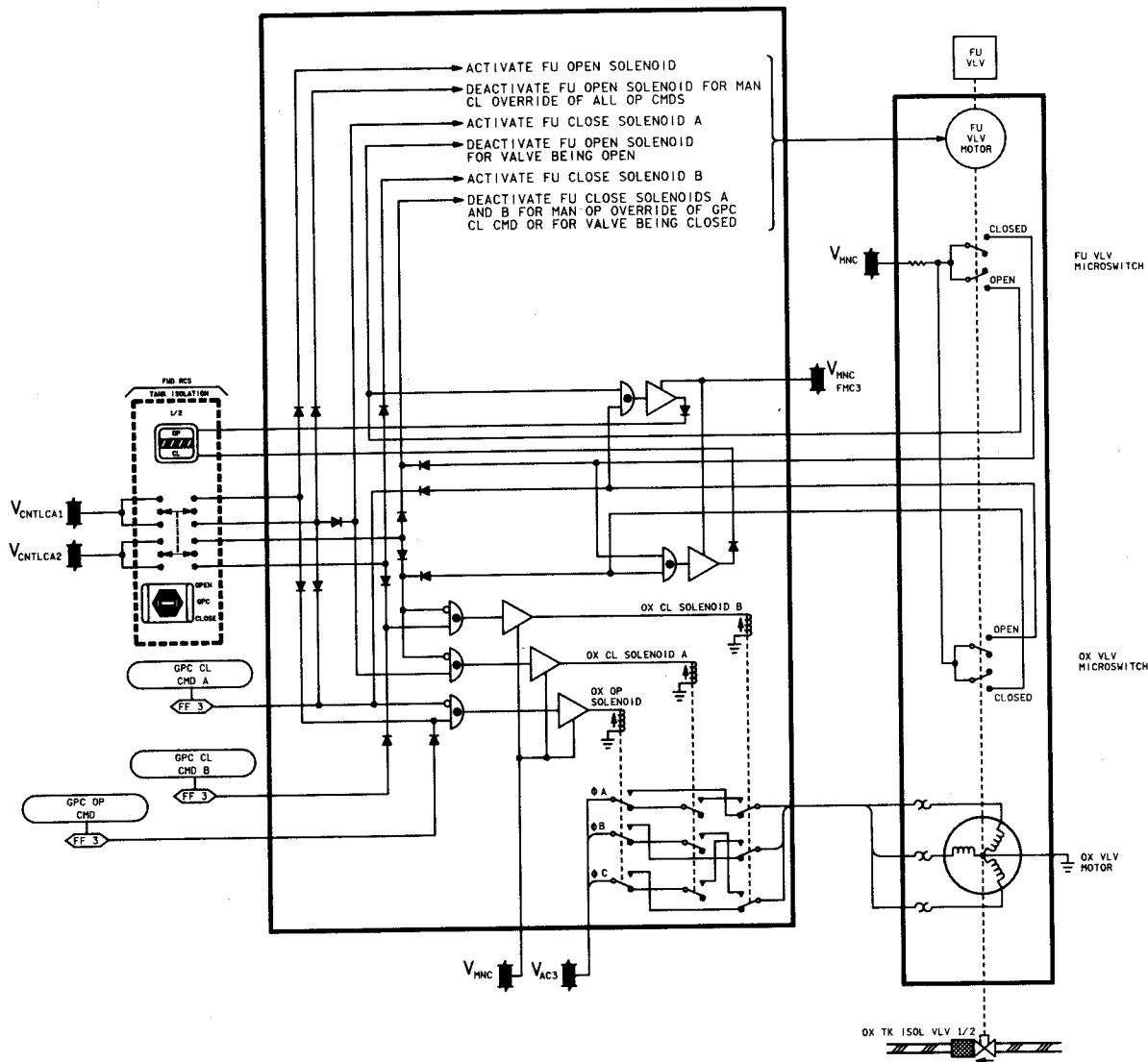


Figure 4-15.- Schematic for a three-solenoid MCA.

Placing the switch to open allows control bus power activation of the single open solenoid. Only one of the two control buses is used for open solenoid operation. The other control bus only provides manual open input to the close circuitry gates in order to override any GPC close command. The loss of this control bus will not affect open operation.

Manual open operation is lost if any of the following occurs:

- Loss of the primary control bus (solenoid operation).
- Loss of main bus logic power.
- Loss of two or more phases of ac power to the motors.

Placing the switch to GPC removes control bus power from the MCA allowing GPC command activation of appropriate open or close solenoids.

Single GPC open commands enter the MCA manual open circuitry (solenoid operation), downstream from the switch, providing activation of the single open solenoid. The other open circuitry (inputs to close solenoid gates) is not powered with the switch in GPC.

GPC open operation is lost if any of the following occurs:

- Loss of the dedicated MDM (or the controlling GPC).
- Loss of main bus logic power.
- Loss of two or more phases of ac power to the motors.

GPC close operation is controlled by A and B close commands since there are two close solenoids. A single GPC close A command goes to both fuel and oxidizer A solenoids. Dual close B commands (one for fuel and one for oxidizer) go to respective B solenoids. All three commands are required to close both the fuel and oxidizer valves.

GPC close operation is lost if any of the following occurs:

- Loss of the dedicated MDM (or the GPC).
- Loss of main bus logic power.
- Loss of two or more phases of ac power to the motors.

The four-solenoid MCAs control the aft RCS tank isolation 1/2 valves and all crossfeed isolation valves. Figure 4-16 shows a typical four-solenoid MCA. This MCA type is similar in operation to a three-solenoid MCA except for two major differences.

First difference: the four-solenoid MCA has two open solenoids not one. Manual open operation provides dual control bus power to the two open solenoids. Either solenoid is capable of providing open operation of the valves. Since there are two open solenoids, the GPC open commands are divided into A and B open commands. Either A or B open commands are adequate to provide open operation of the valves.

Second difference: the four-solenoid MCA GPC A and B commands are routed through different MDMs. The loss of one MDM will only affect GPC closed operation of the affected valves. GPC open operation is not lost with the loss of one MDM.

Manual open operation is lost if any of the following occurs to a four-solenoid MCA:

- Loss of both control buses.
- Loss of both main bus logic power sources.
- Loss of two or more phases of ac power to the motors.

GPC open operation is lost if any of the following occurs:

- Loss of both MDMs (or the respective GPCs).
- Loss of both main bus logic power sources.
- Loss of two or more phases of ac power to the motors.

Manual and GPC close operation is identical to the three-solenoid MCA, except that GPC close operation is lost if either MDM (or its GPC) fails.

The specific procedures to deal with the switch failures and talkback failures that could indicate MCA difficulties are covered in the systems malfunction procedures that will be exercised during orbit simulations.

The use of the OMS/RCS slide rule will greatly simplify the understanding of specific electrical or data path problems.

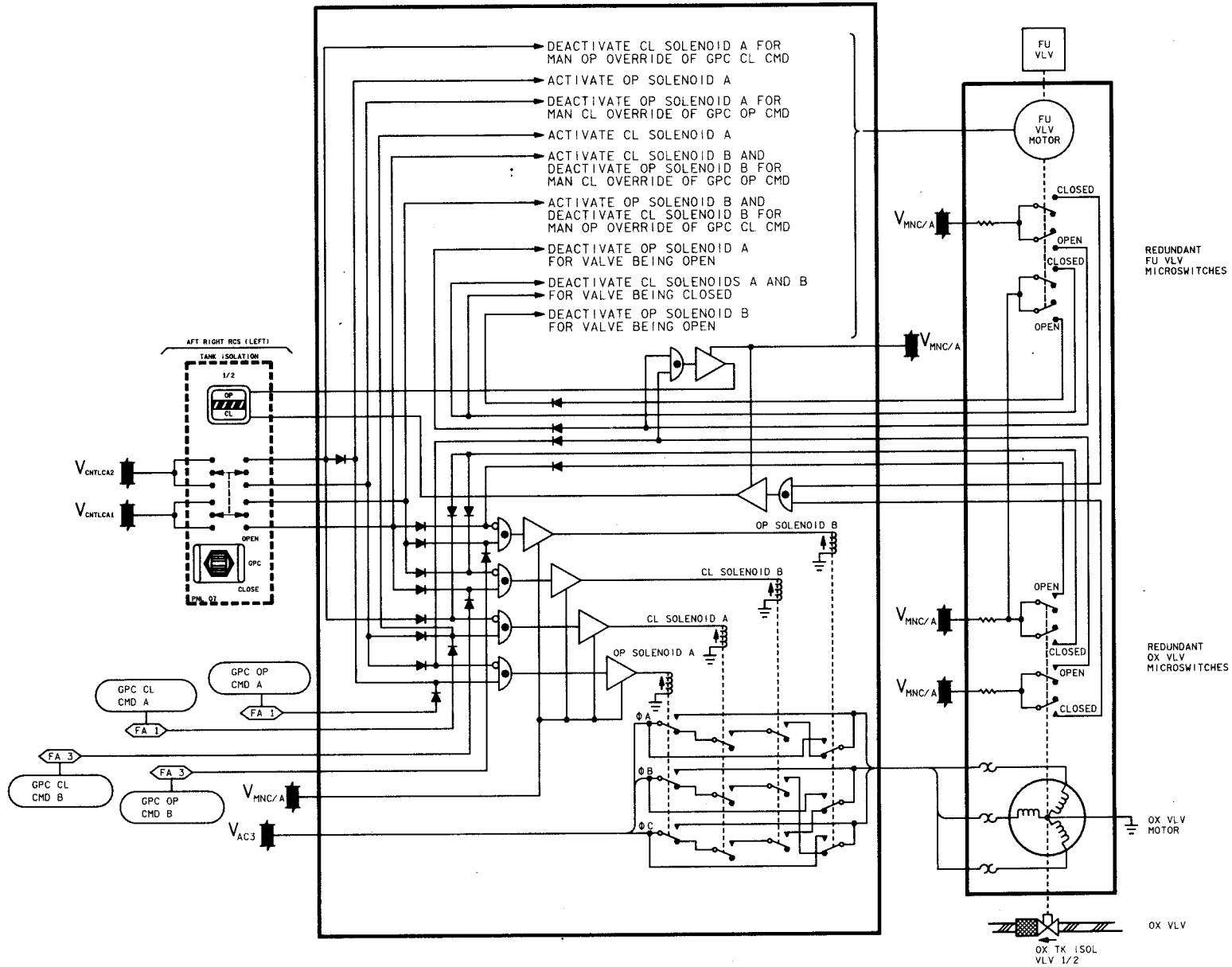


Figure 4-16.- Four-solenoid MCA.

Orbital Maneuvering System/Reaction Control System Slide Rule

The crew can determine the effects of electrical bus or MDM failures by referring to the reference data book that is carried onboard. A slide rule device is also available for use in determining OMS and RCS valve and switch capability for various single and multiple electrical and DPS failures. The slide rule has a schematic of the OMS and RCS with a window for each valve. A slide is inserted and

positioned for the appropriate failure. Any loss of capability (manual open, manual close, GPC open, GPC close) is indicated by a black window for the affected valve.

Figure 4-17 shows the effects of an FA1 MDM failure. There are transparent slides that can be inserted to show the effects of multiple failures. Figure 4-18 shows the effects of an FA1 MDM failure combined with a CNTL AB2 bus failure.

Note on figure 4-18 that there are small letters in some valve windows ("B" in the MAN OP window of L RCS 3/4/5 XFD for example). If that letter is also in the "DUAL FAILURE" window, then that capability (MAN OP, in this example) would be lost, otherwise that capability exists (in the figure, G and H are the only letters in DUAL FAILURE so MAN OP capability exists for the FA1/CNTL AB2 dual failure).

Some dual failures cause the loss of an MDM or aft motor controller (AMC). The reverse side of the slide rule lists the specific combo and the use of a third failure transparency.

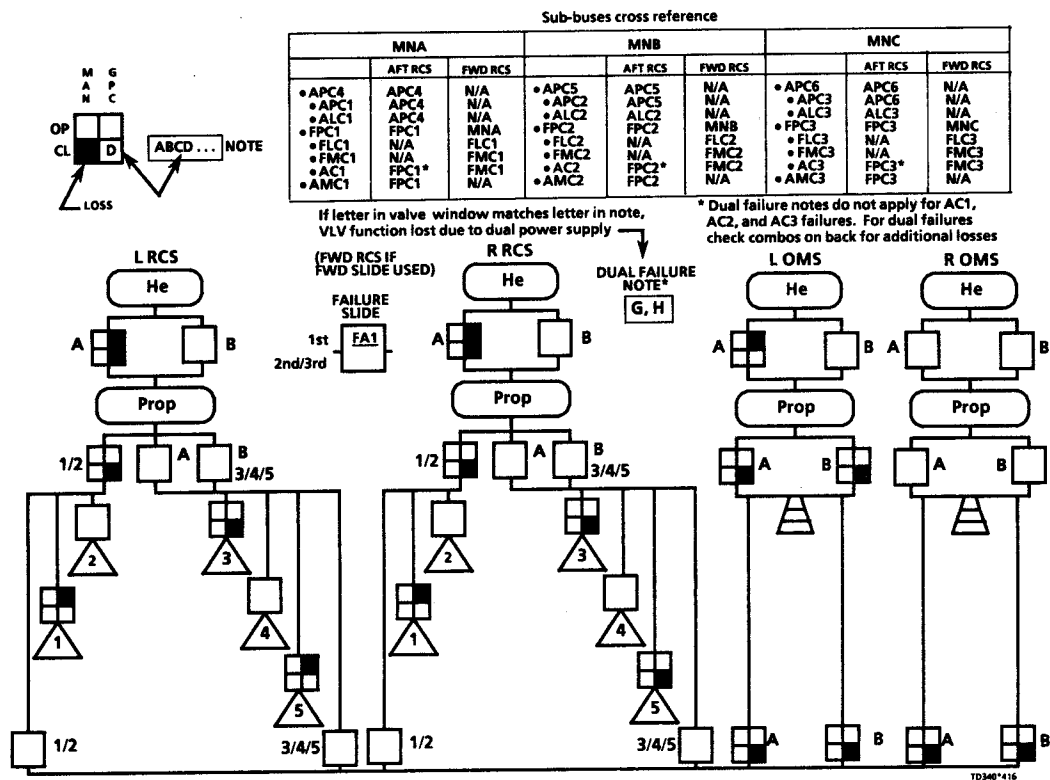
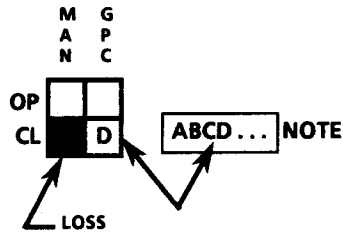


Figure 4-17.- Slide rule configured for FA1 failure.

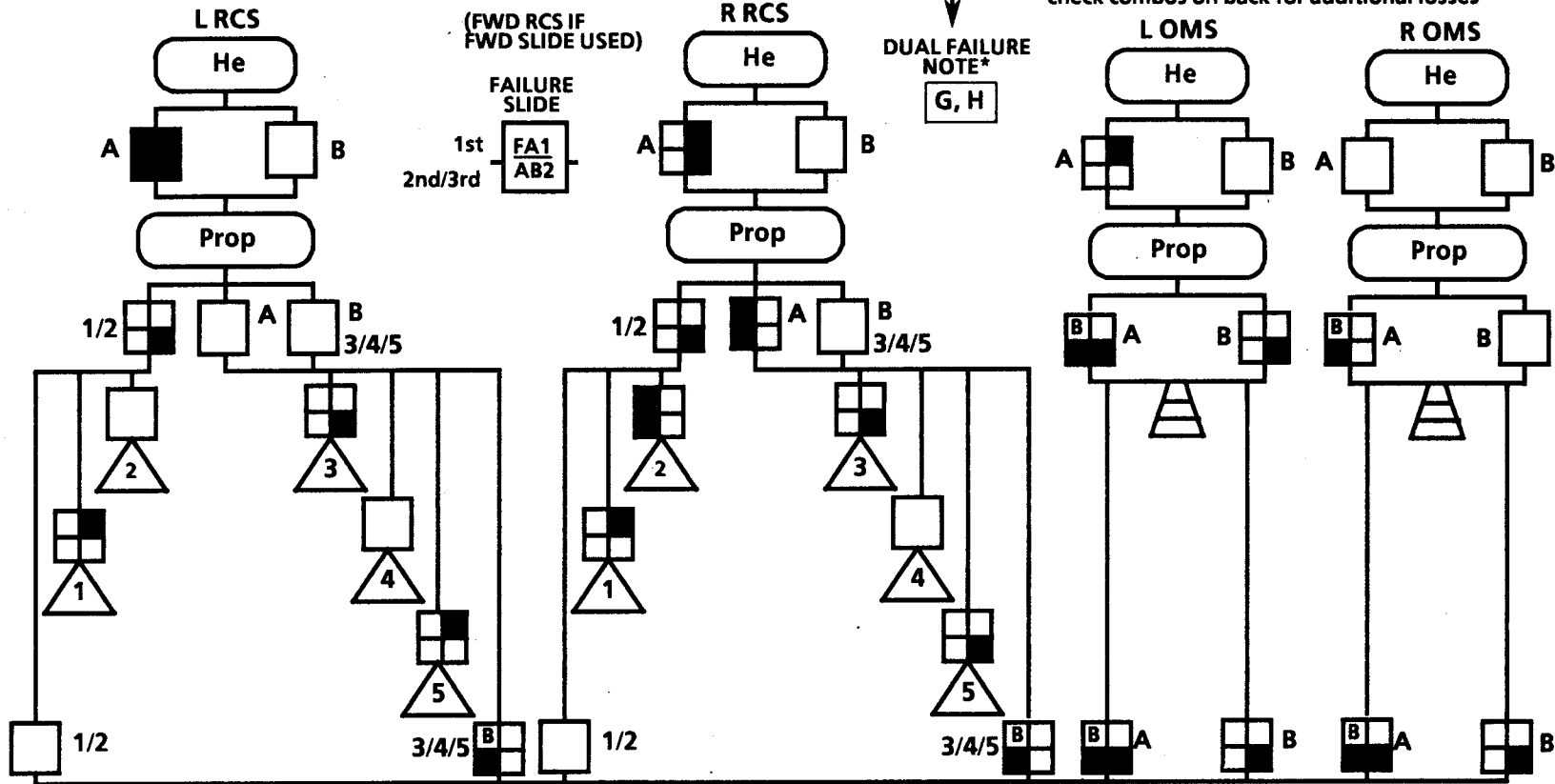
Sub buses cross reference

	MNA		MNB			MNC		
	AFT RCS	FWD RCS		AFT RCS	FWD RCS		AFT RCS	FWD RCS
• APC4	APC4	N/A	• APC5	APC5	N/A	• APC6	APC6	N/A
• APC1	APC4	N/A	• APC2	APC5	N/A	• APC3	APC6	N/A
• ALC1	APC4	N/A	• ALC2	ALC2	N/A	• ALC3	ALC3	N/A
• FPC1	FPC1	MNA	• FPC2	FPC2	MNB	• FPC3	FPC3	MNC
• FLC1	N/A	FLC1	• FLC2	N/A	FLC2	• FLC3	N/A	FLC3
• FMC1	N/A	FMC1	• FMC2	N/A	FMC2	• FMC3	N/A	FMC3
• AC1	FPC1*	FMC1	• AC2	FPC2*	FMC2	• AC3	FPC3*	FMC3
• AMC1	FPC1	N/A	• AMC2	FPC2	N/A	• AMC3	FPC3	N/A



if letter in valve window matches letter in note, VLV function lost due to dual power supply

* Dual failure notes do not apply for AC1, AC2, and AC3 failures. For dual failures check combos on back for additional losses



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Figure 4-18.- Transparent slide added to show CNTL AB2 and FA1 combined failure.

OMS/RCS Interconnect Sequence

When an OMS to RCS interconnect is required for an abort dump or for single-engine roll control during ascent, the valves are configured automatically. This means that the RCS tank isolation valves close and the OMS and RCS crossfeed valves open by GPC commands.

If an FA MDM or GPC fails before the interconnect is initiated, some valves cannot receive commands for the interconnect. If the failure occurs while interconnected, some valves cannot receive commands to reconfigure when the return to normal feed is commanded.

The main concern of an interconnect failure before an interconnect is commanded is that a dump of OMS propellant can occur with some of the RCS tank isolation valves open. This can cause a rapid drain of the RCS tanks.

If an interconnect failure occurs after the interconnect is established, some RCS tank isolation valves may remain closed after the return to normal feed configuration is commanded. Affected RCS jets might not have a propellant supply which can cause jet failures.

There are manual procedures that are designed to work around the interconnect failures. In the case of DPS failures, RCS valves are manually positioned for the interconnect. In the case of electrical failures, alternate feed or isolation configurations are required. There are OMS interconnect failure procedures which list the steps for each type of failure. These procedures are covered in detail in the Flight Procedures Handbook for ascent/orbit/entry cue cards.

Figures 4-19 through 4-22 show the effects of some failures. The effects of all main bus, ac bus, FA MDM, and GPC failures for interconnects can be seen by using the OMS/RCS slide rule. It is not necessary to memorize this information, but it is helpful to appreciate the pattern of valve failures and the possible propellant flow disruptions for each bus or MDM loss.

Figure 4-19 shows that FA1 has failed (MDM failure or GPC1 failure) prior to an interconnect. If no action is taken and an interconnect is commanded, two of the RCS tank isolation valves will remain open. This creates two major problems. The first is the tying of the OMS tanks to the RCS tanks for an extended period of time.

The second problem occurs when the jets on manifolds 1 and 2 are dumping. RCS propellant will be dumped in addition to the OMS propellant. Depending upon pressure differentials, RCS propellant could backflow through the crossfeed lines and be dumped through the manifold 3 and 4 jets. This situation must be corrected quickly or all RCS propellant will be lost. The RCS tank isolation valves can be closed manually (FDF procedures will dictate the order of closings). There may also be additional actions required after completion of the interconnect.

Procedures for interconnect failures during intact aborts call for an inhibit to the interconnect on Spec 51. If this is performed, RCS jets will not be fired and the interconnect will not be commanded. The crew will have more time to troubleshoot the situation. Contingency interconnects cannot be inhibited. The scenarios in figure 4-19 through 4-22 assume that the interconnect is enabled due to single engine roll control; i.e., Spec 51 item entry has no effect. The FA1 interconnect failure is similar to other FA or GPC failures except that a different set of valves will be affected.

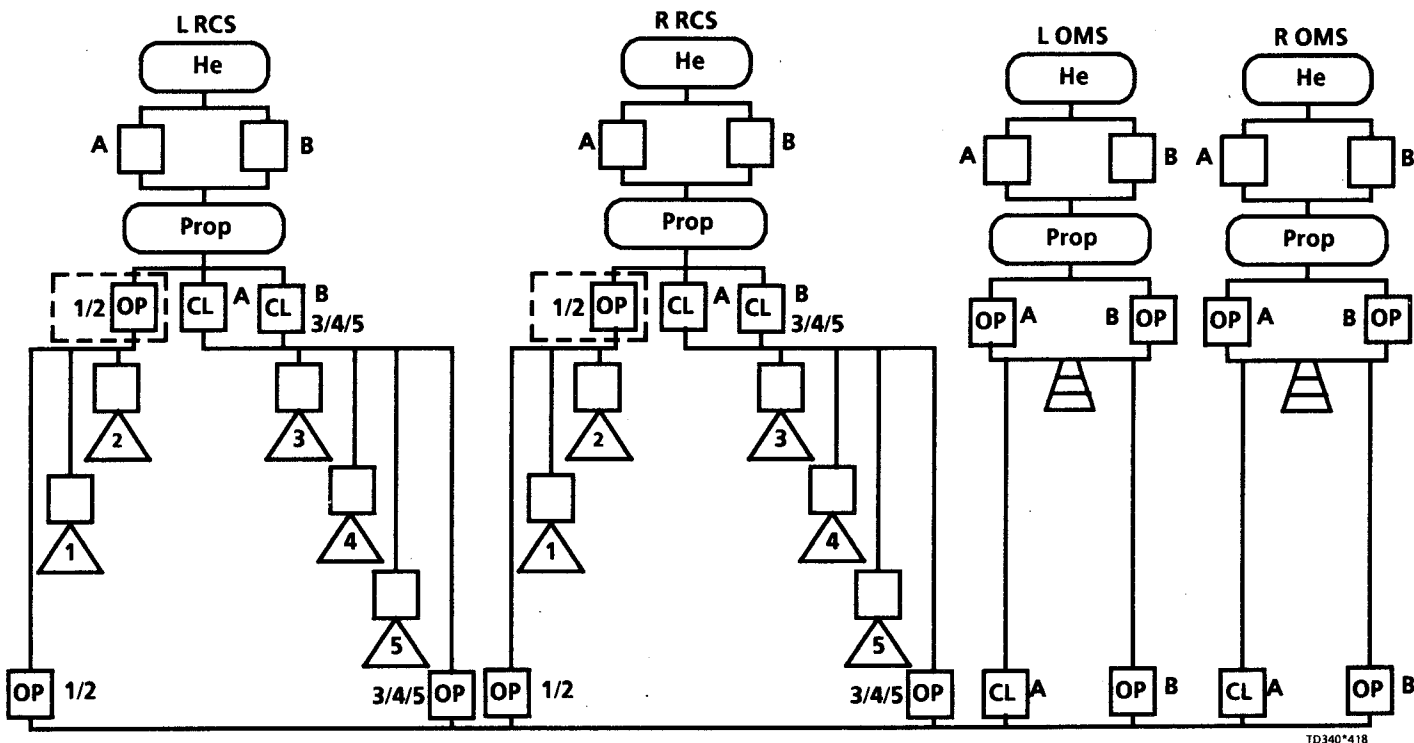


Figure 4-19.- Interconnect failed - FA1 failed before the interconnect.

Figure 4-20 shows the valve configuration if FA1 or GPC 1 failed during an abort interconnect. The OMS crossfeed B valves could not return to a closed position when straight feed is commanded. Although there are no immediate problems with this configuration, except for the tying of the OMS tanks, there is an effect on subsequent configurations. RCS to RCS crossfeed would not be effective until the OMS crossfeeds are closed. Manually positioning these valves to the proper configuration would solve the problem. A different FA MDM or GPC failure would affect a different set of valves.

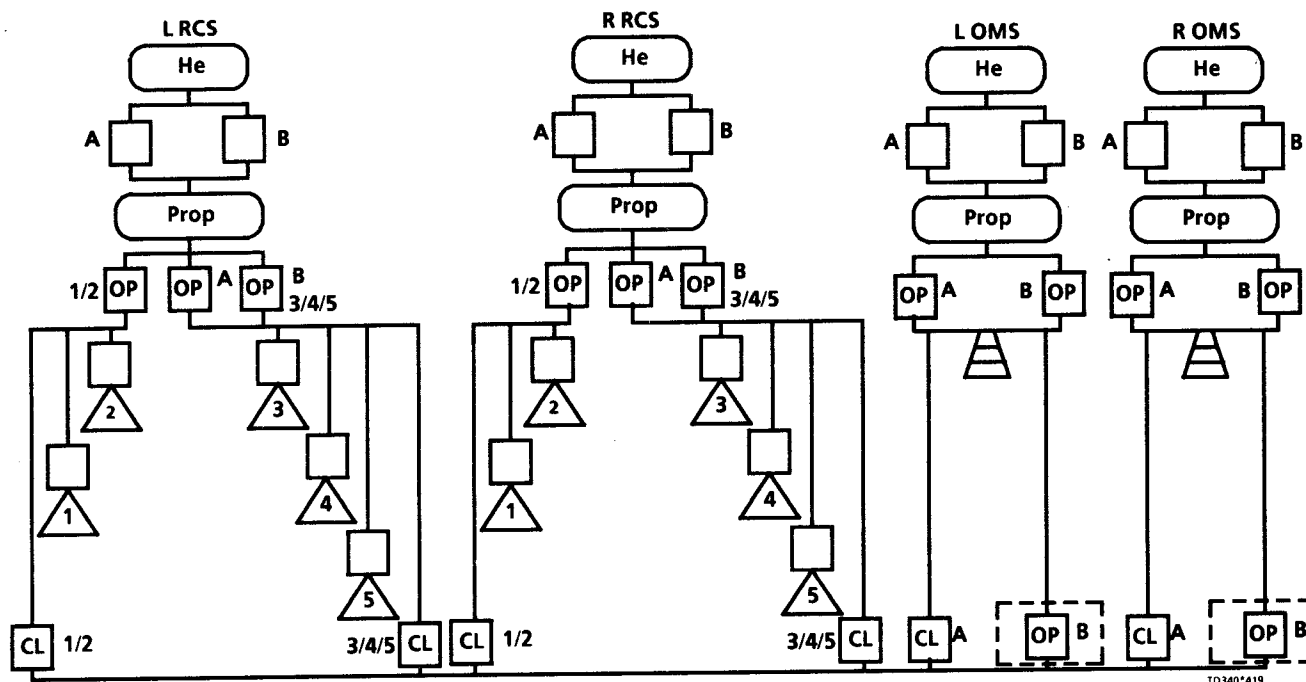


Figure 4-20.- Return from interconnect failed - FA1 failed while interconnected.

An interconnect failure due to electrical problems causes a more complicated scenario since the failed valves cannot be moved. Figure 4-21 shows main A failed before an interconnect. Two RCS tank isolation and two RCS crossfeed valves are not capable of operation. In this case, RCS propellant can be inadvertently dumped through the manifold 3 and 4 jets unless immediate action is taken.

Since the affected valves will not move, other measures are needed. Closing the manifold isolation valves on manifolds 3 and 4 (on both sides) will prevent those jets from wasting RCS propellant. When the return to straight feed is commanded, additional manual actions will be required to return to normal feed and to recover the use of manifolds 3 and 4. Other main bus or ac failures would cause similar effects to a different set of valves.

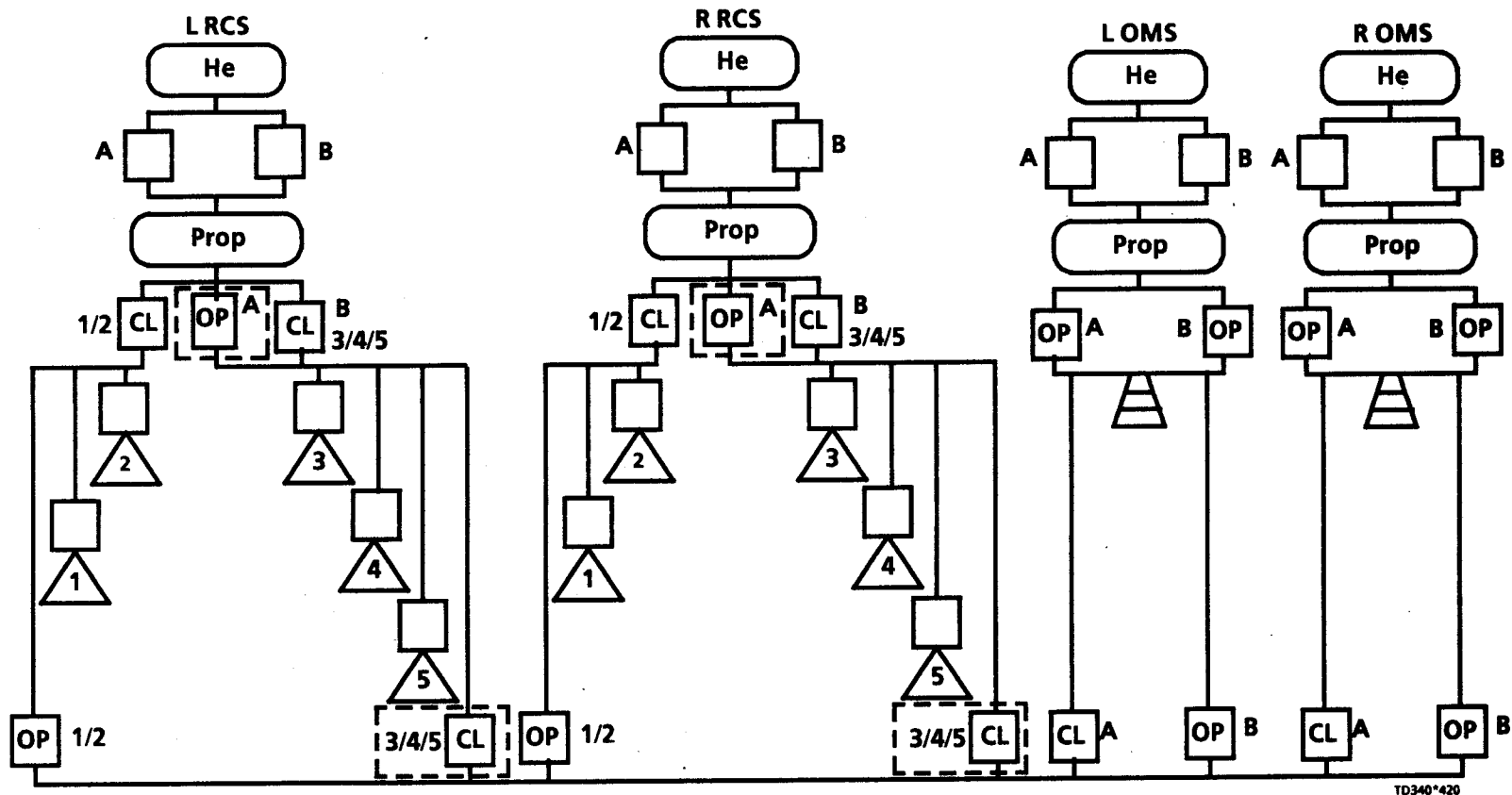


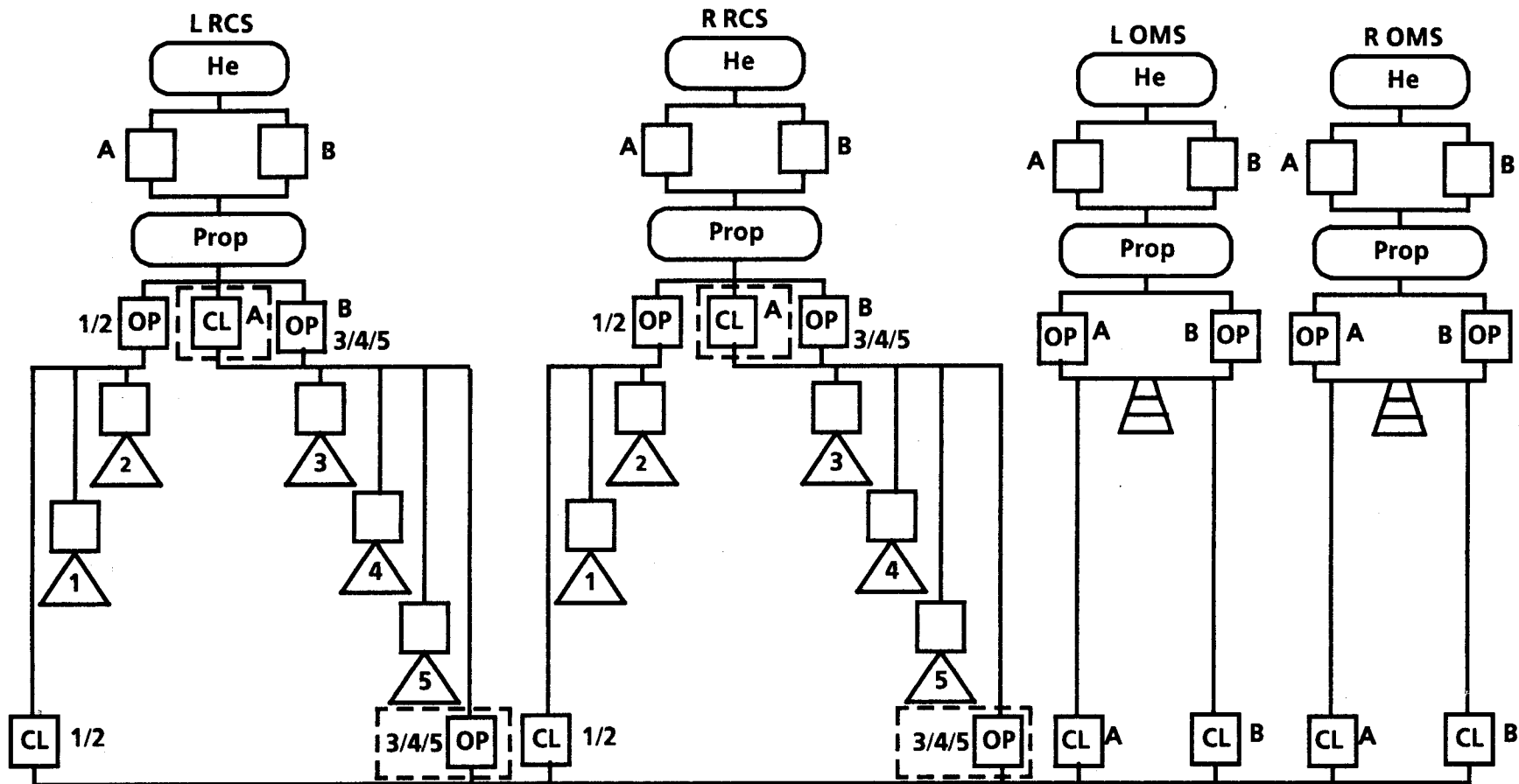
Figure 4-21.- Interconnect failed - MNA failed before the interconnect.

Figure 4-22 shows the result of main A failed during an interconnect. Two RCS tank isolation valves (3/4/5 A) would be stuck closed and two RCS crossfeed valves would be stuck open when the return to straight feed is commanded. The 1/2 sides of the RCS would be in straight feed while the 3/4/5 sides would have the RCS propellant tanks tied.

To correct the situation, the crew would configure the RCS for a crossfeed from one tank then switch tanks at a suitable halfway point, thus preventing the tying of tanks.

A subsequent leak in this configuration would call for a modified RCS secure procedure.

A different main bus or ac failure would affect a different set of valves but would require similar manual configuration.



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Figure 4-22.- Return from interconnect failed - MNA failed while interconnected.

RCS to RCS Crossfeed Sequence

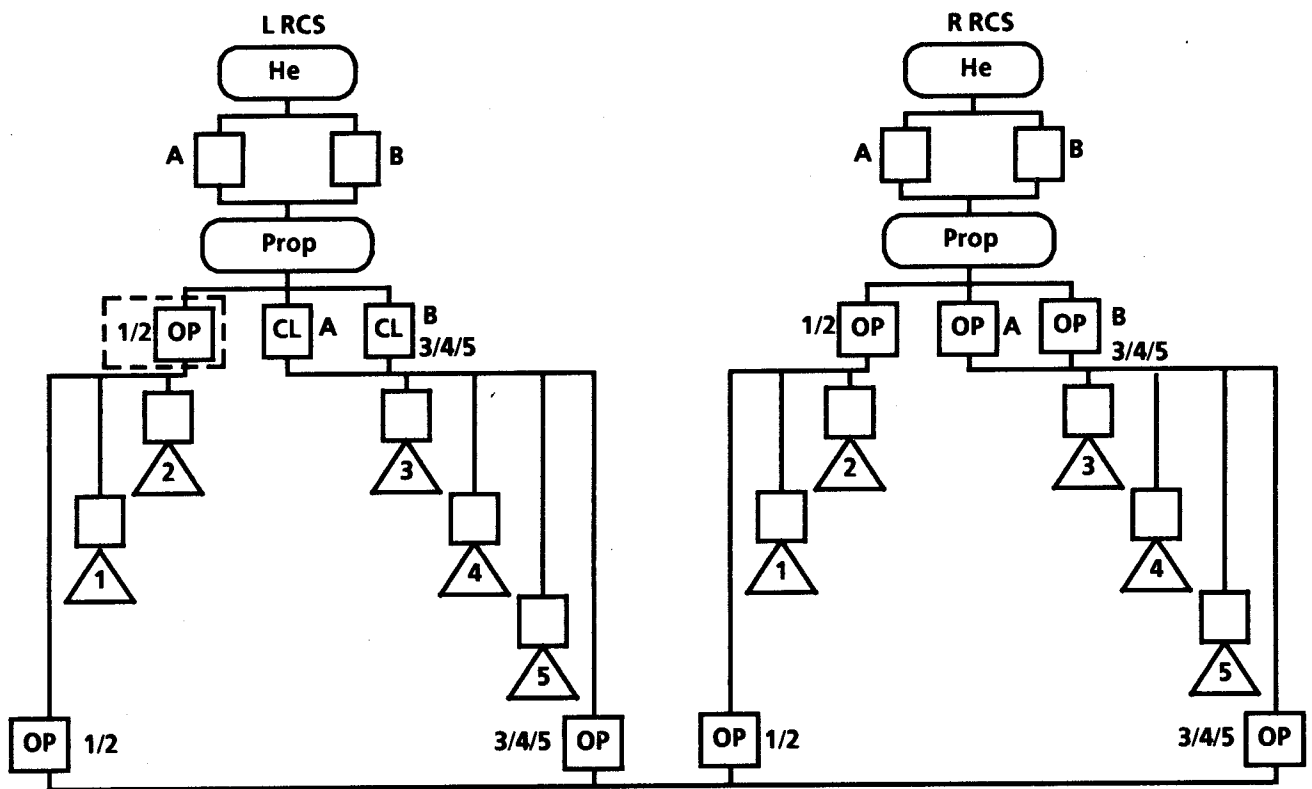
If an RCS to RCS crossfeed is required to maintain propellant flow to all RCS jets, the valves may be configured automatically during ascent and entry by moving the master crossfeed switch to a feed position. The switches for the affected valves should already be in the GPC position for ascent and entry. The RCS tank isolation valves on the receiving side will close after all the RCS crossfeed valves are automatically opened and the OMS crossfeed valves are automatically closed.

If an FA MDM or GPC fails before an auto crossfeed is initiated, some valves will not receive commands to crossfeed. Likewise, if the failure occurs while crossfeeding, some valves will not receive commands for an auto return to a normal feed configuration. Manual commands should provide a work-around for these configuration difficulties. If the failure is due to a main bus or an ac problem, the valves cannot move regardless of manual or auto inputs. These failures can prevent propellant flow to some RCS jets.

There are manual procedures designed to work-around the crossfeed failures. In the case of DPS failures, the crossfeed will probably be performed manually. In the case of electrical failures, alternate feed or isolation configurations are set up manually.

Figures 4-23 through 4-26 show the effect of some failures. The effects of all failures affecting crossfeeding can be noted through the use of the OMS/RCS slide rule. It is not necessary to memorize the failure patterns but rather to associate the pattern of valve problems for each type of DPS/electrical failure.

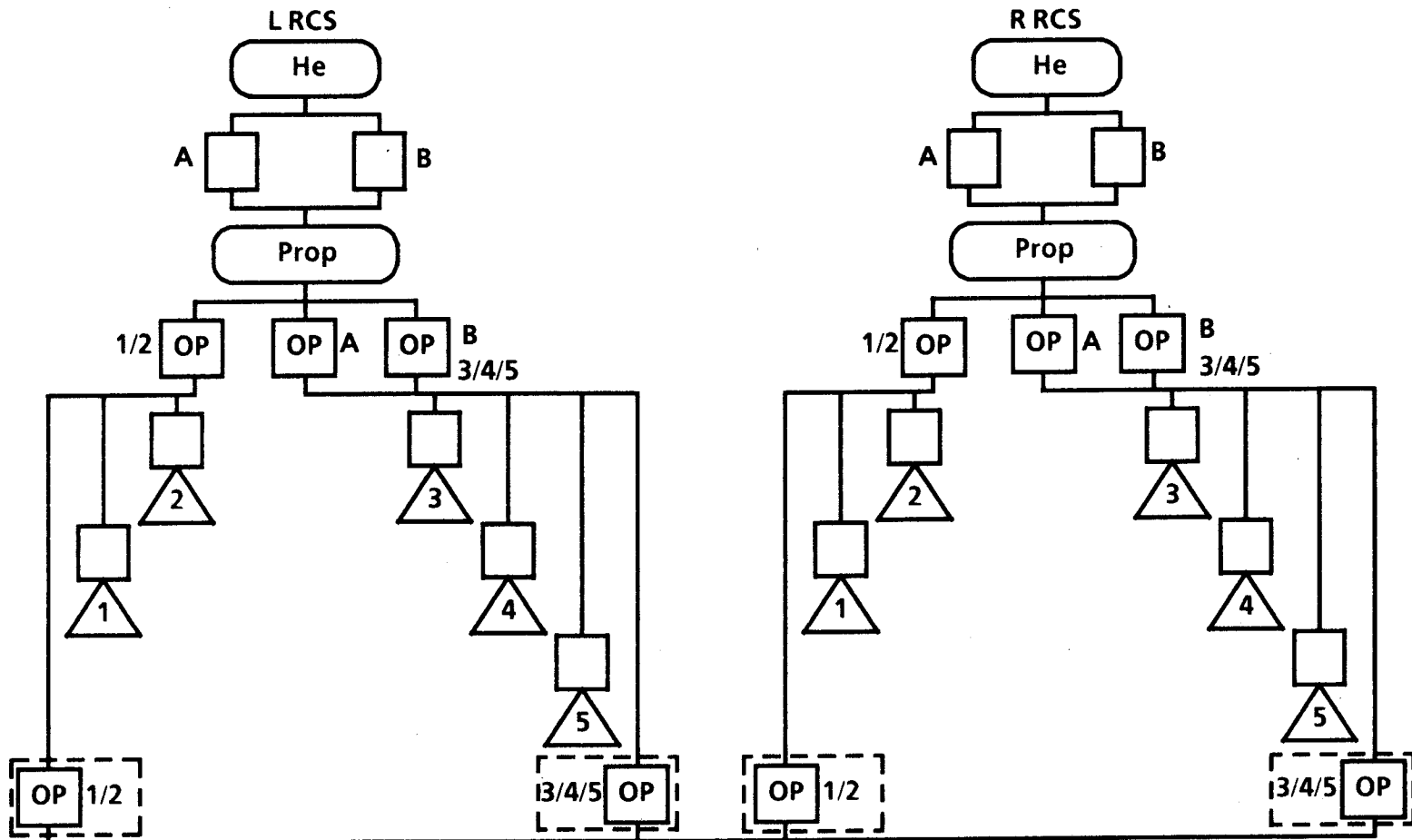
Figure 4-23 shows the effects if FA3 (or GPC 3) failed prior to an auto crossfeed. The selection of "feed from right" would configure properly except for the left RCS 1/2 tank isolation valve. The backflow of right RCS propellant into the left RCS tank would waste valuable right RCS propellant and could cause tank damage. Manually closing the valve would quickly solve the problem. A different FA MDM or GPC failure would have similar results but would affect different valves.



TD340*422

Figure 4-23.- Auto crossfeed failed - FA3 failed before the crossfeed.

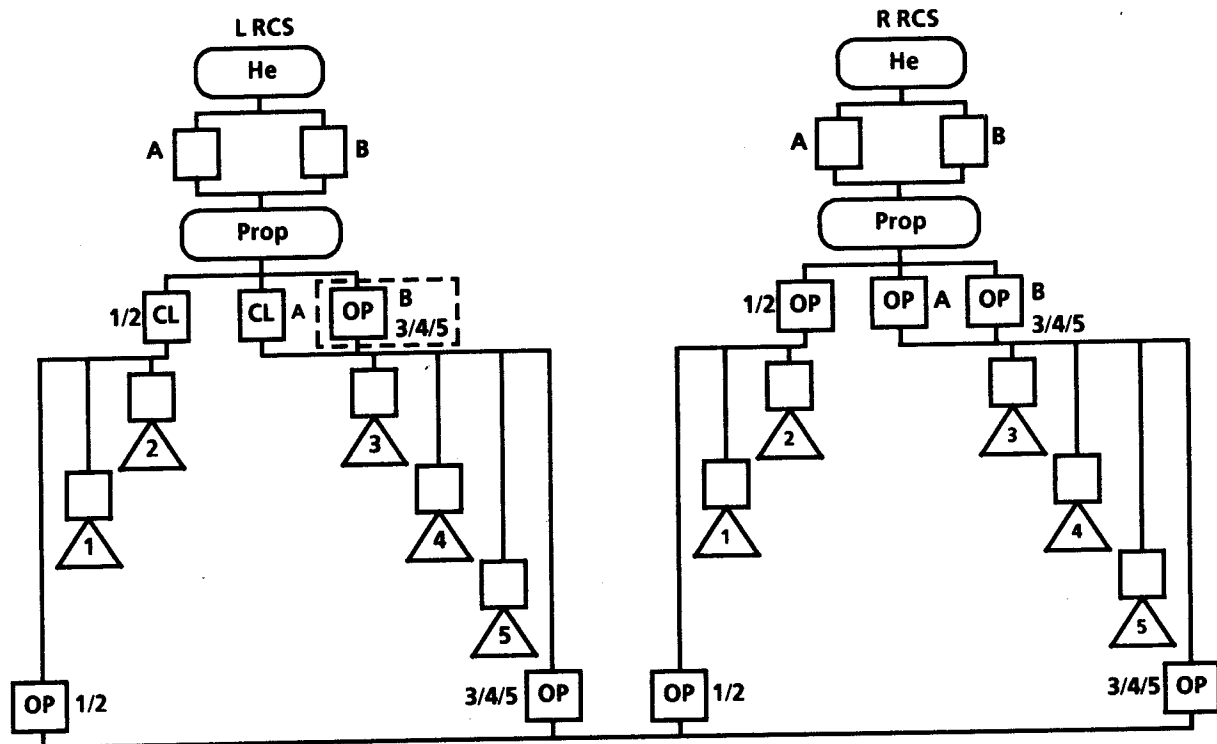
Figure 4-24 shows the effects if FA3 or GPC 3 failed during a crossfeed configuration. An auto return to normal feed would result in the tying of all RCS propellant tanks. Manual movement of the valves would preclude this difficulty.



TD340*423

Figure 4-24.- Auto return to normal feed failed - FA3 failed while crossfeeding.

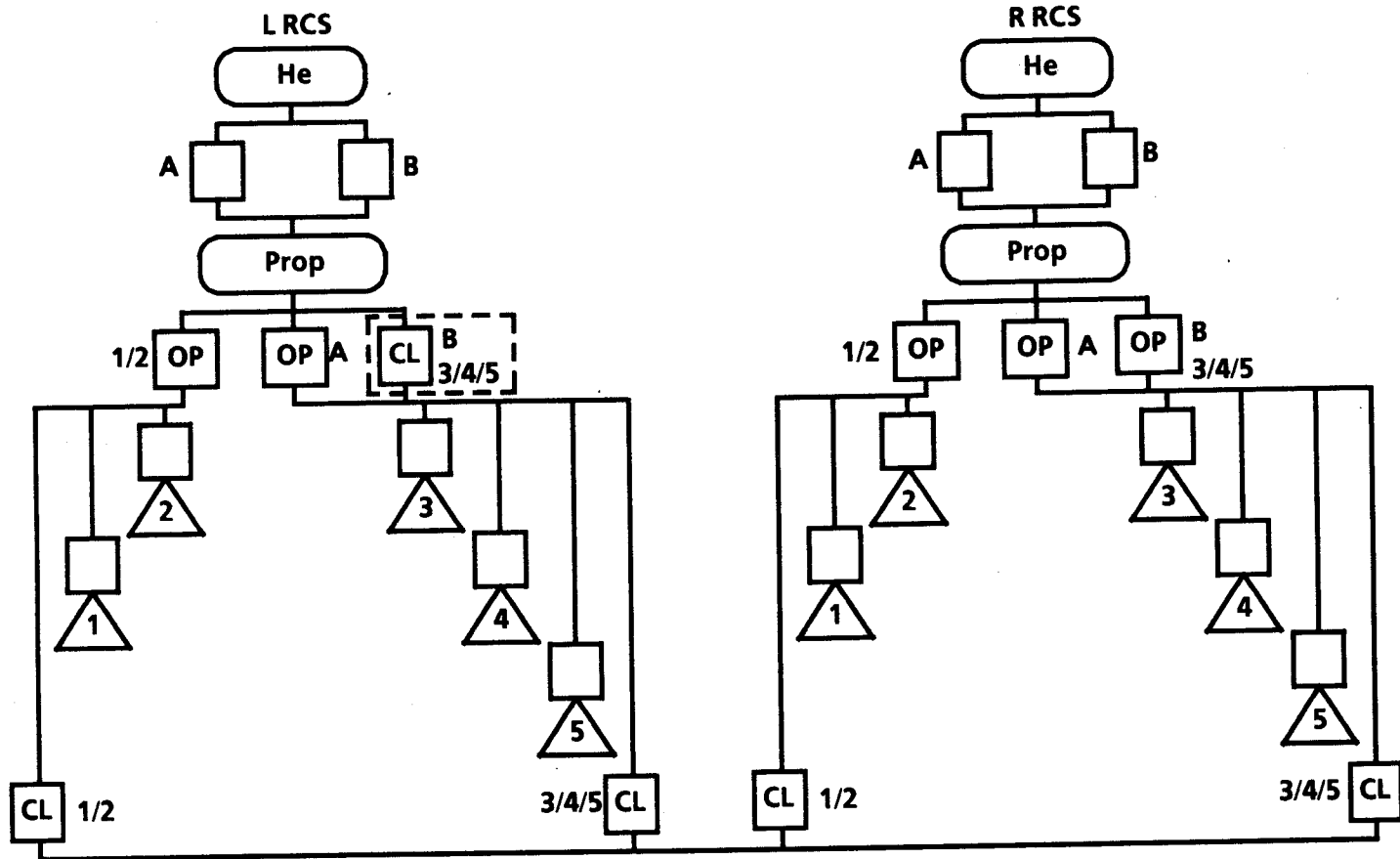
Electrical failures are more complex. Figure 4-25 shows the effects if main B is lost before a crossfeed is commanded. This seriously affects propellant flow to the left 3/4/5 manifolds. Since the tying of tanks cannot be avoided and a leak may be present in the left RCS propellant tank (the reason for the crossfeed), it may be prudent to manually close the left 3/4/5 crossfeed valve to isolate the leak and close manifolds 3, 4, and 5 to prevent jet failures due to propellant starvation.



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Figure 4-25.— Auto crossfeed failed - MNB failed before the crossfeed.

Figure 4-26 shows the effects of main B failing while crossfeeding. This would create some configuration problems if a return to normal feed is commanded. But in this case, it is only a nuisance since the A valve on the left side is providing redundant propellant flow. A different bus or ac failure could cause more serious difficulties.



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Figure 4-26.- Auto return to normal feed failed - MNB failed while crossfeeding.

Pressure and Temperature Sensors

The RCS pressure and temperature sensors receive power through signal conditioners; specifically the left RCS uses OL1 and OL2, the right RCS uses OR1 and OR2, while the forward RCS uses OF1 and OF2. Each signal conditioner is redundantly powered by two main buses. Some sensor outputs go directly to gauges while others are transmitted to the GPCs via FA or FF MDMs. Sensor data is used for CRT displays and quantity calculations.

If a particular MDM or signal conditioner fails, certain RCS data is lost. Specific losses can be checked in the reference data book. In order to provide an overview of the effects of these types of failures, examples of some displays showing single point MDM and signal conditioner assignments are provided here. MDM and signal conditioner data assignment for GNC SYS SUMM 2 is shown in figures 4-27 and 4-28. Examination of the schematics in the Space Shuttle System Handbook will provide insight into other displays.

		GNC SYS SUMM 2				5 000/00:30:00			
		/019				BFS 000/00:00:00			
		L R				L R			
RCS		OXID	FU	JET	SOL				
FWD	HE P	FF1	FF3			N2 TK P	HE	OXID	
	TK P	FF1	FF3			P VLV	FU		
	QTY					ENG IN P	OXID		
MANF	1 P	FF1	FF2			VLV 1	FU		
	2 P	FF2	FF2			2			
	3 P	FF4	FF4						
	4 P	FF3	FF3						
	5								
AFT		FA1	FA1			OXID	FU	JET	SOL
L	HE P	FA1	FA1			HE P	FA2	FA2	
	TK P	FA1	FA1			R TK P	FA2	FA2	
	QTY	FA1	FA1			1 P	FA2	FA2	
MANF	1 P	FA1	FA1			2 P	FA1	FA1	
	2 P	FA3	FA3			3 P	FA3	FA3	
	3 P	FA2	FA2			4 P	FA2	FA2	
	4 P	FA4	FA4			5	FA4	FA4	
	5								

TD3400427. ART. 1

Figure 4-27.— GNC SYS SUMM 2 display showing MDM assignments for RCS measurements.

		GNC SYS SUMM 2				1 003/02:20:45			
		/019				000/00:00:00			
		L R				L R			
RCS		OXID	FU	JET	SOL				
FWD	HE P	OF2	OF4			N2 TK P	HE	OXID	
	TK P	OF4	OF2			P VLV	FU		
	QTY					ENG IN P	OXID		
MANF	1 P	OF4	OF4			VLV 1	FU		
	2 P	OF4	OF4			2			
	3 P	OF2	OF2						
	4 P	OF2	OF2						
	5								
AFT		OL1	OL2			OXID	FU	JET	SOL
L	HE P	OL1	OL2			HE P	OR1	OR2	
	TK P	OL1	OL2			R TK P	OR1	OR2	
	QTY					1 P	OR1	OR1	
MANF	1 P	OL1	OL1			2 P	OR1	OR1	
	2 P	OL1	OL1			3 P	OR2	OR2	
	3 P	OL2	OL2			4 P	OR2	OR2	
	4 P	OL2	OL2			5	OR2	OR2	
	5								

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Figure 4-28.— GNC SYS SUMM 2 display showing signal conditioner assignments for RCS measurements.

Quantity Gauging

The RCS quantity calculations performed by onboard software require temperature and pressure inputs from the helium and propellant tanks. The temperature and pressure inputs are converted to helium volumes and propellant volumes by using PVT relationships. These volumes are then used in subsequent calculations to determine the

quantity of usable propellant. The calculations are set up so that a decrease in either propellant volume or helium volume is indicative of propellant usage and a reduction in quantity will be displayed.

The PASS PVT calculations are similar to the BFS calculations except for input substitution. The PASS can use substitute inputs in the event primary inputs are invalid or unavailable due to electrical or DPS failures.

The volume calculations are performed with one temperature input and the average of the two pressure inputs for each tank. The replacement of failed primary inputs with substitute inputs will provide reasonably accurate PASS calculations.

Since the BFS does not have the capability to substitute inputs, the loss of any input can cause invalid BFS quantity calculations.

Table 4-2 lists the primary inputs and the associated substitutes for PASS calculations along with recent MDM and signal conditioner assignments. (See the latest schematics in the Space Shuttle Systems Handbook for the most current MDM/signal conditioner assignment.)

Table 4-2.- Primary inputs and associated substitutes.

FRCS		LRCS		RRCS	
PRIMARY	SUBSTITUTE	PRIMARY	SUBSTITUTE	PRIMARY	SUBSTITUTE
F OX HE T (FF3, OF2)	F FU HE T (FF1, OF4)	L OX HE T (FA1, OL1)	L FU HE T (FA3, OL2)	R OX HE T (FA2, OR1)	R FU HE T (FA4, OR2)
F OX HE P1 (FF3, OF2)	F OX HE P2 (FF2, OF2/OF4)	L OX HE TK P1 (FA1, OL1)	L OX HE TK P2 (FA4, OL2)	R OX HE P1 (FA2, OR1)	R OX HE P2 (FA4, OR2)
F OX HE P2 (FF2, OF4)	F OX HE P1 (FF3, OF2)	L OX HE TK P2 (FA1, OL2)	L OX HE TK P1 (FA1, OL1)	R OX HE P2 (FA2, OR2)	R OX HE P1 (FA2, OR1)
F OX TK P (FF1, OF4)	F OX TK OUT P (FF3, OF2)	L OX TK P (FA1, OL1)	L OX TK OUT P (FA3, OL1)	R OX TK P (FA2, OR1)	R OX TK OUT P (FA4, OR2)
F OX TK OUT P (FF3, OF2)	F OX TK P (FF1, OF4)	L OX TK OUT P (FA1, OL1)	L OX TK P (FA1, OL1)	R OX TK OUT P (FA2, OR2)	R OX TK P (FA2, OR1)
F OX TK T (FF1, OF4)	F FU TK T (FF4, OF2)	L OX TK T (FA1, OL2)	L FU TK T (FA3, OL1/OL2)	R OX TK T (FA2, OR2)	R FU TK T (FA4, OR1/OR2)
F FU HE T (FF1, OF4)	F OX HE T (FF3, OF2)	L FU HE T (FA1, OL2)	L OX HE T (FA1, OL1)	R FU HE T (FA2, OR2)	R OX HE T (FA2, OR1)
F FU HE P1 (FF1, OF4)	F FU HE P2 (FF2, OF2)	L FU HE P1 (FA1, OL2/OA1)	L FU HE P2 (FA3, OL1)	R FU HE P1 (FA2, OR2/OA2)	R FU HE P2 (FA4, OR1)
F FU HE P2 (FF3, OF2)	F FU HE P1 (FF1, OF4)	L FU HE P2 (FA1, OL1)	L FU HE P1 (FA1, OL2/OA1)	R FU HE P2 (FA2, OR1)	R FU HE P1 (FA2, OA2/OS2)
F FU TK P (FF3, OF2)	F FU TK OUT P (FF4, OF4/OF2)	L FU TK P (FA1, OL2/OA2)	L FU TK OUT P (FA3, OL2)	R FU TK P (FA2, OR2/OA2)	R FU TK OUT P (FA4, OR2)
F FU TK OUT P (FF1, OF4)	F FU TK P (FF3, OF2)	L FU TK OUT P (FA1, OL2)	L FU TK P (FA1, OL2/OA2)	R FU TK OUT P (FA2, OR2)	R FU TK P (FA2, OR2/OA2)
F FU TK T (FF3, OF2/OF4)	F OX TK T (FF1, OF4)	L FU TK T (FA1, OL1)	L OX TK T (FA1, OL1)	R FU TK T (FA2, OR1)	R OX TK T (FA2, OR2)

Jet Fire Commands

The jet fire commands from the GPCs go to the RCS jets via the associated jet drivers and FF (or FA) MDMs as illustrated in figure 4-29.

Multiple electrical or DPS failures can interrupt jet fire commands at the GPC, the jet driver, or the driver logic. A total MDM failure can result in the loss of commands to the associated jet drivers and the loss of feedback from the thrusters/manifolds. Certain types of MDM failures (BCE BYP) can prevent the GPCs from receiving inputs from the RCS (jet RM, valve position, pressures) but can still allow GPC output to the RCS (jet fire commands, valve operation).

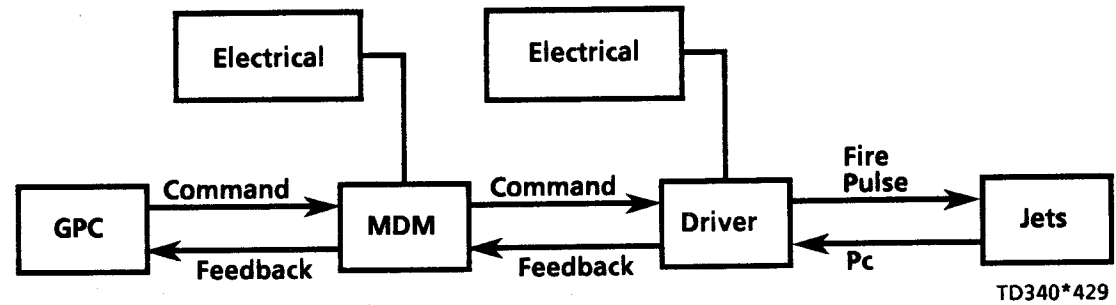


Figure 4-29.-- Jet fire commands.

Heaters

The heaters for the three RCS pods, aft RCS jets, and crossfeed lines require both control bus and main bus power. The forward RCS jet heaters require only main bus power.

The pod heaters require power from two control buses and one main bus in order to operate (except for the keel heaters in the aft OMS/RCS pods which use power from two control buses and two main buses). The aft RCS heaters and crossfeed line heaters require only one control bus and one main bus for operation.

The loss of any one bus will cause the affected heaters to be unusable. Procedures call for selecting another heater circuit, if available. Heater bus assignments are summarized in tables 4-3 and 4-4 to show the general distribution for the various circuits.

Notice the left and right pod B circuit heaters are assigned two main buses rather than the single bus assigned to other pod heaters. Not all individual heaters in these B circuits are powered by the same bus. The loss of one main bus will only affect some of the heaters on the B circuit.

The heaters are controlled by thermostats and no active interaction with the GPCs is required. However, temperature inputs go to the GPCs via MDMs for display purposes. An associated MDM loss will cause the loss of data but will not affect the operation of the heater.

Table 4-3.- Summary of pod and line heater bus assignments.

Pod and Line Heaters	A Circuit	B Circuit
Forward pod	CNTL AB1 and AB2, Main A	CNTL BC1 and BC2, Main B
Left pod	CNTL AB1 and AB2, Main A	CNTL BC1 and BC2, Main B and C
Right pod	CNTL BC1 and BC2, Main B	CNTL CA1 and CA2, Main A and C
Crossfeed line	CNTL AB3 and Main A	CNTL BC3 and Main B

Table 4-4.- Summary of jet heater bus assignment.

JET Heaters	Forward	AFT
Manifold 1	Main A	CNTL BC1 and Main B
Manifold 2	Main B	CNTL AB1 and Main A
Manifold 3	Main B	CNTL CA1 and Main C
Manifold 4	Main C	CNTL CA2 and Main C
Manifold 5	Main C	CNTL CA3 and Main C

Section 4 Questions

1. Why is it important to close the manifold isolation valves first when executing the RCS secure procedures?
2. During ascent and entry, what precaution must be taken concerning propellant tank and crossfeed isolation valve switches when returning to normal configuration after securing the RCS?
3. If the pressure in manifolds 2 and 3 dropped to less than 130 psi after the RCS is secured, would this be an indication of a tank leg leak (two manifolds decreasing)?
4. Suppose during a nominal ascent that the P_c discrete for L2L fails high. What caution and warning annunciation would the crew receive?
5. How can multiple GPC/MDM and electrical failures affect ET separation?
6. GPC 2 fails during ascent. What type of failure must be anticipated to protect the RCS?
7. An auto crossfeed, feed from the right has been executed. Subsequently, the control bus for the aft right tank isolation 3/4/5 B valve switch fails. (The switch is controlled by only one control bus CNTL BC2). This valve can no longer be manually positioned. How can this valve be closed for leak isolation in the right 3/4/5 side?

Section 4 Answers

1. Why is it important to close the manifold isolation valves first when executing the RCS secure procedures?

A: Closing the manifold creates a closed manifold status for the affected jets and removes those jets from the availability table. This prevents isolated jets from firing and evacuating the manifold.

2. During ascent and entry, what precaution must be taken concerning propellant tank and crossfeed isolation valve switches when returning to normal configuration after securing the RCS?

A: The propellant tank and crossfeed isolation valve switches must be in GPC in order to provide automatic sequencing. If the switches are placed in the manual positions, then the auto crossfeed and auto interconnect capability is lost.

3. If the pressure in manifolds 2 and 3 dropped to less than 130 psi after the RCS is secured, would this be an indication of a tank leg leak (two manifolds decreasing)?

A: No. Since manifolds 2 and 3 are on different legs, this could be an indication of two separate manifold leaks.

4. Suppose during a nominal ascent that the P_c discrete for L2L fails high. What caution and warning annunciation would the crew receive?

A: None, unless the BFS is engaged. Only Mission Control has the data via downlink to display the status of all jet P_c discrettes. If the BFS was subsequently engaged, the BFS would annunciate a jet fail on (false failure). For L2L, although there is no caution and warning, fail off RM is lost for L2L in both PASS and BFS.

5. How can multiple GPC/MDM and electrical failures affect ET separation?

A: Since each manifold per pod is assigned to a different MDM and/or electrical power source, multiple failures could prevent multiple jets from receiving fire commands. The resulting actual vehicle maneuver rates could be less than the commanded rates. This could result in ET/Orbiter contact. A configuration of valves or a BFS engage may be required to have sufficient RCS jets available for the separation maneuver.

6. GPC 2 fails during ascent. What type of failure must be anticipated to protect the RCS?

A: The OMS interconnect fail procedures. If an abort interconnect is commanded, not all valves may be configured properly. If any RCS tank

isolation valves are open, the associated RCS propellant could be dumped instead of the OMS propellant.

7. During entry an auto crossfeed (feed from the right) has been executed. Subsequently, the control bus for the aft right tank isolation 3/4/5 B valve switch fails. (The switch is controlled by only one control bus CNTL BC2.) This valve can no longer be manually positioned. How can this valve be closed for leak isolation in the right 3/4/5 side?

A: Place all aft RCS tank isolation and crossfeed valve switches in the manual positions for a feed from right configuration except for the right 3/4/5 leg. Since this leg needs to be secured, manually close the right 3/4/5 A tank isolation and the right 3/4/5 crossfeed valves to prevent feeding the leak from either the tank isolation or the crossfeed side. The right 3/4/5 B tank isolation switch should still be in GPC. Move the master crossfeed switch to feed from left and only the right 3/4/5 B valve will close (no other switches are in GPC). The leak is now isolated and the crossfeed discrete is set to restrict the number of simultaneous jet firings. (Note: this procedure does not work for all valves. The loss of a control bus can affect multiple switches and cause these switch outputs to be GPC regardless of the switch position.)

Section 5: Differences in the BFS

The operation of the RCS, with the BFS engaged, is almost identical to normal PASS operation. The software differences with the BFS engaged are summarized as follows.

During powered flight and ET separation, only auto flight control is available. After ET separation, only manual control is available, so jet firings are initiated by hand controller inputs to the BFS.

There is no BFS software to support single-engine roll control, if two main engines fail during ascent. It can provide an abort interconnect and support RTLS, TAL, and ATO dumps. A contingency dump (Spec 51, DUMP ARM, START) is not supported in the BFS. A BFS engage will stop any contingency dump in progress that had been started in PASS. All other PASS initiated abort dumps will continue and stop automatically at the I-loaded values. All abort dumps may be stopped by BFS Spec 51 DUMP STOP or dump inhibit, as appropriate. Only the OPS 3 TAL dump can be started on BFS Spec 51, with a DUMP ARM, START.

Manual flight control during a BFS engaged entry may result in higher than normal RCS propellant usage. If the entry is a TAL or RTLS, the crew should monitor the post-MECO dump of RCS propellant very closely. If RCS quantities get too low, the RCS dump should be stopped/inhibited.

The BFS will not support vernier jet operation but it will support all primary jet firings.

BFS RM does not function pre-engage. Postengage, BFS RM will detect failed off and failed on jets. There is no jet fail leak detection.

Only the first failure provides discretes to the jet fail limit module. If the first failure is a fail on, there will be no auto deselection and also no subsequent auto deselection if subsequent jets fail off. If the first failure is a fail off, there will be only one auto deselection per vehicle. An auto deselected jet may be reselected by cycling the associated manifold switch closed then open. Jet fail on annunciation is based on a P_c discrete and no fire command, as opposed to the PASS, which uses a driver on discrete and no fire command.

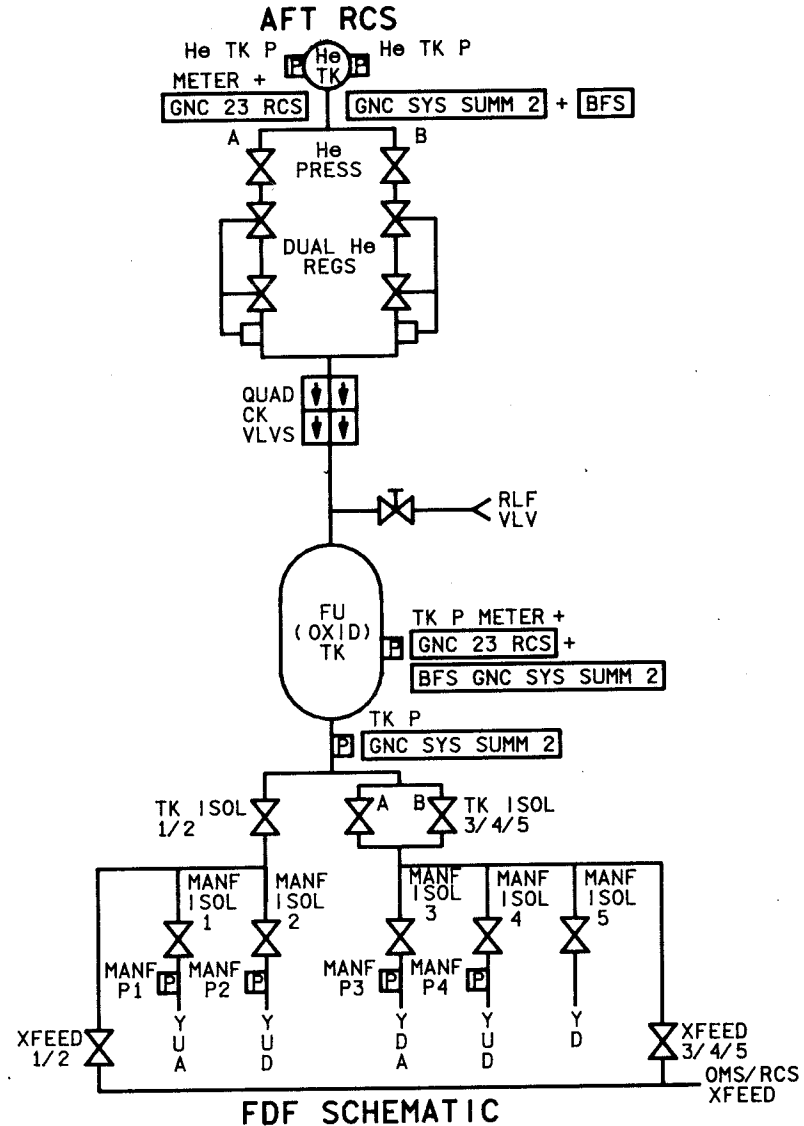
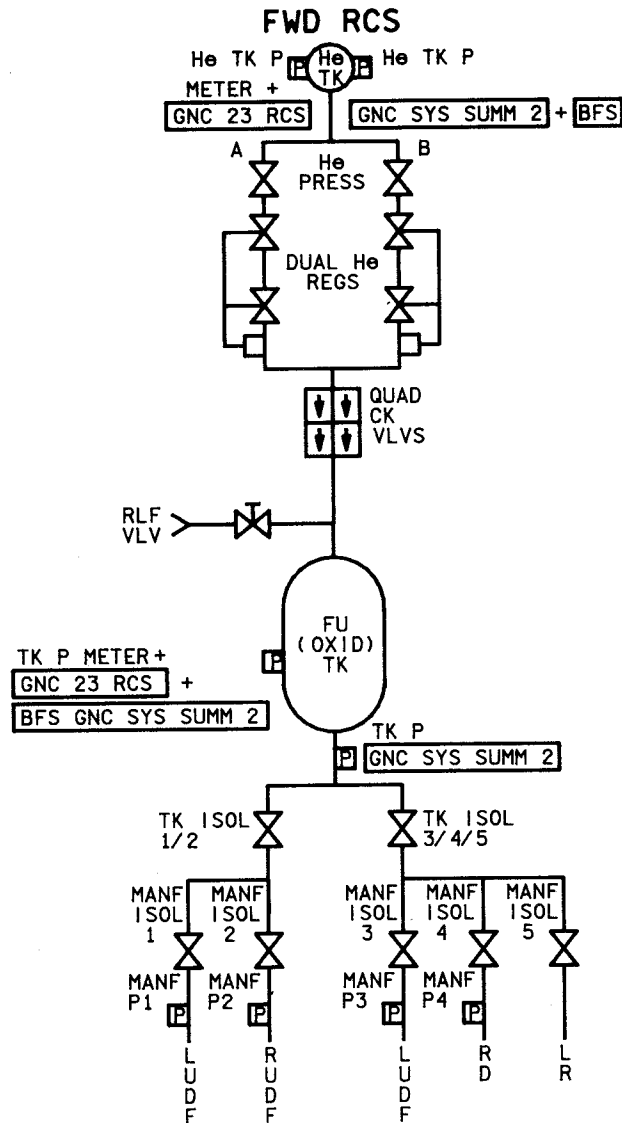
The JET FAIL and ISOL VLV columns of BFS SYS SUMM 2 display become active upon BFS engage. RCS quantity calculations are simplified since the BFS cannot use substitute parameters for missing data. The RCS digital quantity display in OPS 1 and 6 is active upon engagement.

There is no auto crossfeed sequence in the BFS. If the BFS is engaged after an auto crossfeed has been configured, the crossfeed configuration will remain. The BFS does recognize the master crossfeed switch position in order to restrict jet firings even though it will not configure valves.

Appendix A: Suggested Reference Documents

1. Referenced training manuals, currently available or in preparation, cover related Space Shuttle systems, guidance, navigation, and flight control subjects.
2. There are Flight Procedures Handbooks that provide detailed explanations of crew procedures for all phases of flight. Three handbooks that are especially relevant to RCS are:
 - Ascent/Aborts
 - Entry
 - Ascent/Orbit/Entry Pocket Checklist and Cue Cards
3. The procedures described in this book are specified in the following Flight Data File items:
 - Ascent Checklist
 - Orbit OPS Checklist
 - Entry Checklist
 - Ascent Pocket Checklist
 - Orbit Pocket Checklist
 - Entry Pocket Checklist
 - Ascent/Entry Systems Procedures Checklist
 - Systems Malfunctions Procedures book
 - Cue Cards
 - DPS Dictionary
 - Reference Data
4. The STS Operational Flight Rules document outlines preplanned decisions for failure situations.
5. The Space Shuttle Systems Handbook has detailed drawings of all systems including the RCS.
6. The Shuttle Operational Data Book (SODB) is a compilation of data on all Shuttle systems.
7. The Functional Subsystem Software Requirements (FSSR) document provides detailed descriptions of the primary flight software. It is divided into separate books on various segments of the software. The following are relevant to the RCS:
 - Redundancy Management
 - Sequencing
 - Displays and Controls
 - GNC – Flight Control Ascent
 - GNC – Flight Control Orbit DAP
 - GNC – Flight Control Entry/GRTL
8. The BFS Program Requirements Document (PRD) is the BFS equivalent to the FSSR. The two volumes of relevance to the RCS are:
 - Flight Control
 - Sequencing

Appendix C: RCS Summary

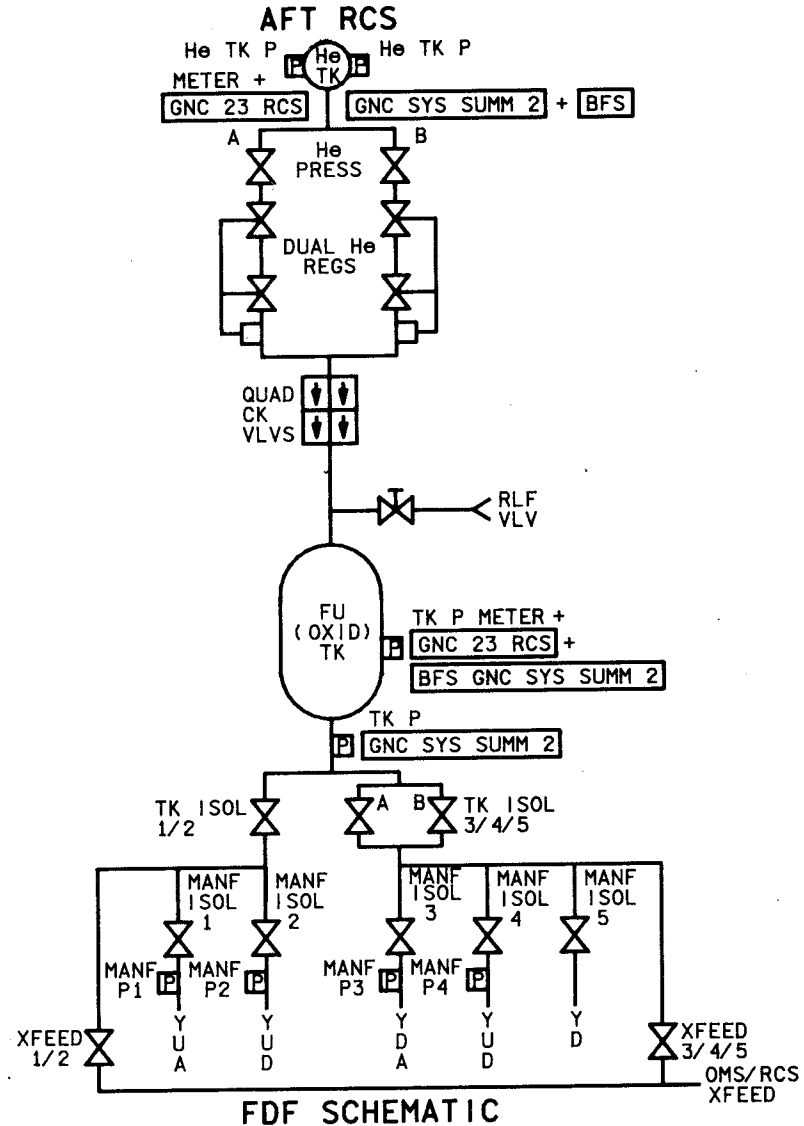
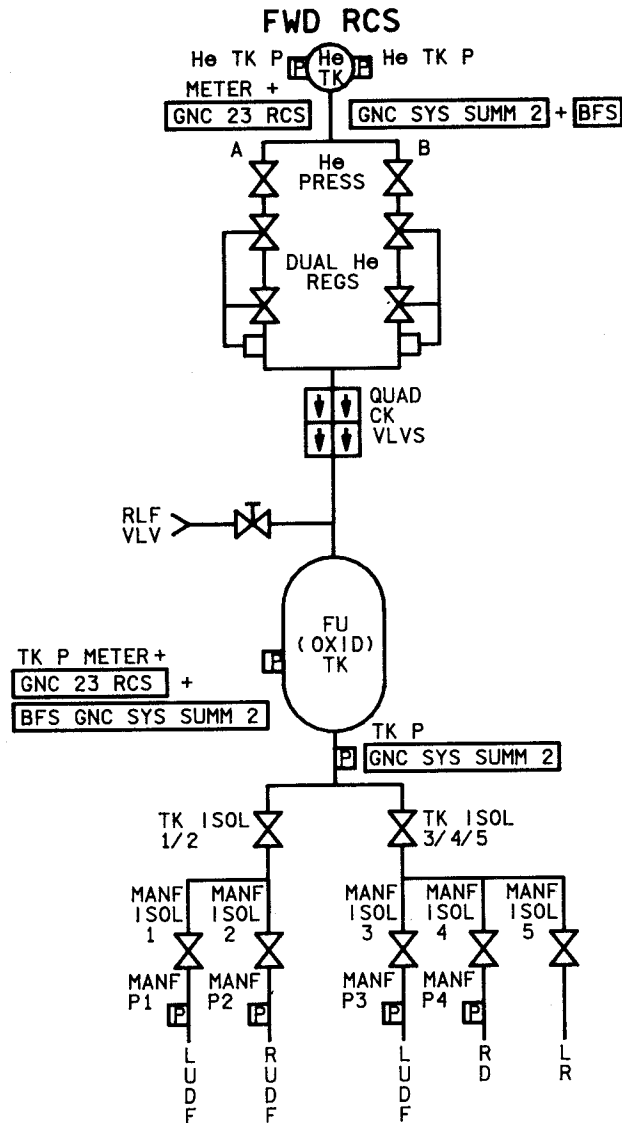


C-1.- Pocket checklist schematics.

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Thrust	Primary jets – 870 LB Vernier jets – 24 LB			
Maximum fire duration	Aft primary Fwd primary Vernier	<u>Nominal</u> 150 sec 150 sec 125 sec	<u>Contingency</u> 800 sec 300 sec 125 sec	
Jet fail leak detection	Primary Vernier	<u>Fuel</u> < 20° F < 130° F	<u>Oxidizer</u> < 30° F < 130° F	
Pressures	Helium tank sensor – Propellant tank P sensor – Propellant tank out P sensor –	<u>Normal indication</u> 4000 – 456 psi 243 ± 3 psi 243 ± 3 psi	<u>C&W low limit</u> 500 psi 200 psi 220 psi	<u>C&W high limit</u> – 312 psi 300 psi
Tank unusable	Helium tank – Propellant tank –	<u>Crew indication</u> Pressure < 456 psi Pressure < 190 psi		
Backflow through closed ISOL valves	Manifolds (primary) Tank isolation Crossfeed	<u>Differential pressure</u> 33 – 50 psi 275 – 360 psi 275 – 360 psi		
Helium relief	Burst disc Valve crack	332 ± 8 psi 315 psi		
Maximum blowdown	Fwd RCS Aft RCS	<u>Crew indication</u> 22 percent 23 percent		

Appendix C: RCS Summary



C-1.- Pocket checklist schematics.

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Appendix B: Acronyms and Abbreviations

A	aft	EAS	equivalent air speed
ac	alternating current	EI	entry interface
ADI	attitude direction indicator	ENA	enable
AMC	aft motor controller	ENG	engine
AOA	abort once around	EPS	electrical power system
ATO	abort to orbit	ET	external tank
ATT	attitude	EXEC	execute
AUTO	automatic		
		F	Fahrenheit, forward
BCE	bus control element	FA	flight critical aft MDM
BFS	backup flight system	FCS	flight control system
bp	barberpole	FDF	flight data file
		FF	flight critical forward MDM
C1, C2	velocity targets for deorbit	ft/s	feet per second
CDR	commander	FU	fuel
c.g.	center of gravity	FWD	forward
CK	check		
CL	close	GG	gravity gradient
CONT	contingency	GMBL	gimbal
CRSFD	crossfeed	GNC	guidance, navigation, and control
CRT	cathode-ray tube	GN ₂	gaseous nitrogen
CUR	current	GP	group
C&W	caution and warning	GPC	general purpose computer
D	down	H	altitude, high
DAP	digital autopilot	HA	apogee altitude
deg/sec	degrees per second	He	helium
DEORB, D/O	deorbit	HP	perigee altitude
DES	deselect	HT	target altitude
DPS	data processing system	HTR	heater

ICNCT	interconnect	P	pitch, pressure
I-load	initialization load	PAD	preliminary advisory data
IN	inlet	PASS	primary avionics software system
INH	Inhibit	pbi	pushbutton indicator
INJ	injector	Pc	chamber pressure
ISOL	isolation	PCA	power control assembly
		PEG	powered explicit guidance
KTS	knots	PEG 4	PEG targets - closed loop
		PEG 7	PEG targets - open loop
L	left, low	PLT	pilot
LCA	load control assembly	PNL	panel
LK	leak	PPA	powered pitch around
LN	line	PRESS	pressure, pressurization
		PRI	primary
M	missing	PRO	proceed
MANF	manifold	PRPLT	propellant
MCA	motor control assembly	PSF	pounds per square foot
MCC	mission control center	PSI	pounds per square inch
MDM	multiplexer/demultiplexer	PTI	program test inputs
MECO	main engine cut off	PTY	priority
MET	mission elapsed time	PVT	pressure-volume-temperature
MM	major mode		
MMH	monomethyl hydrazine	\bar{q} , QBAR	dynamic pressure
MNVR	maneuver	QTY	quantity
MPS	main propulsion system		
MS	mission specialist	R	right, roll
		RCS	reaction control system
n. mi.	nautical mile	REG	regulator
N ₂	nitrogen	REI	range to entry interface
N ₂ O ₄	nitrogen tetroxide	RHC	rotational hand controller
		RJD	reaction jet driver
O	overhead	RM	redundancy management
OMS	orbital maneuvering system	RTLS	return to launch site
OMS 1	insertion OMS burn		
OMS 2	circularization OMS burn		
OP	open		
OPS	operational sequence		
OVRD	override		
OX, OXID	oxidizer		

SE single engine
 SEC secondary
 SEL selection
 SEP separation
 SM systems management
 SPEC specialist function
 SRB solid rocket booster
 SSME space shuttle main engine
 STAT status
 STS Space Transportation System
 SUMM summary
 SYS system

T temperature, time
 TAL transoceanic abort landing
 tb talkback
 TEMP temperature
 TFF time to free fall
 TGO time-to-go
 TGT target
 THC translational hand controller
 TIG time of ignition
 TK tank
 TRANS transition
 TRANSDAP transition DAP
 TTA time to apogee
 TTC time to circularize
 TTG time to go
 TTP time to perigee
 TVC thrust vector control

U up
 VERN vernier
 VGOX,Y,Z velocity-to-go in X, Y, and Z directions
 VLV valve
 WT weight
 XFEED/XFD crossfeed
 Y yaw
 ΔV velocity change
 $\Delta VTOT$ total velocity change
 $\Delta VX,Y,Z$ velocity change in X, Y, and Z directions
 θT target angle