

Space Program Operations Contract

Reaction Control System Workbook

RCS 21002

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Final Version

This document has been reviewed and updated. No subsequent updates to this document are anticipated or required due to the approaching shuttle program closure.

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**Reaction Control System Workbook
RCS 21002**

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PREFACE

The content of this document was provided by the Control/Propulsion Department, Space Flight Training Division, Mission Operations Directorate (MOD), Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA). Technical documentation support was provided by Integrated Documentation Services (IDS), Hernandez Engineering Inc. Any questions concerning this workbook or any recommendations should be directed to any of the book managers.

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1.0 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.

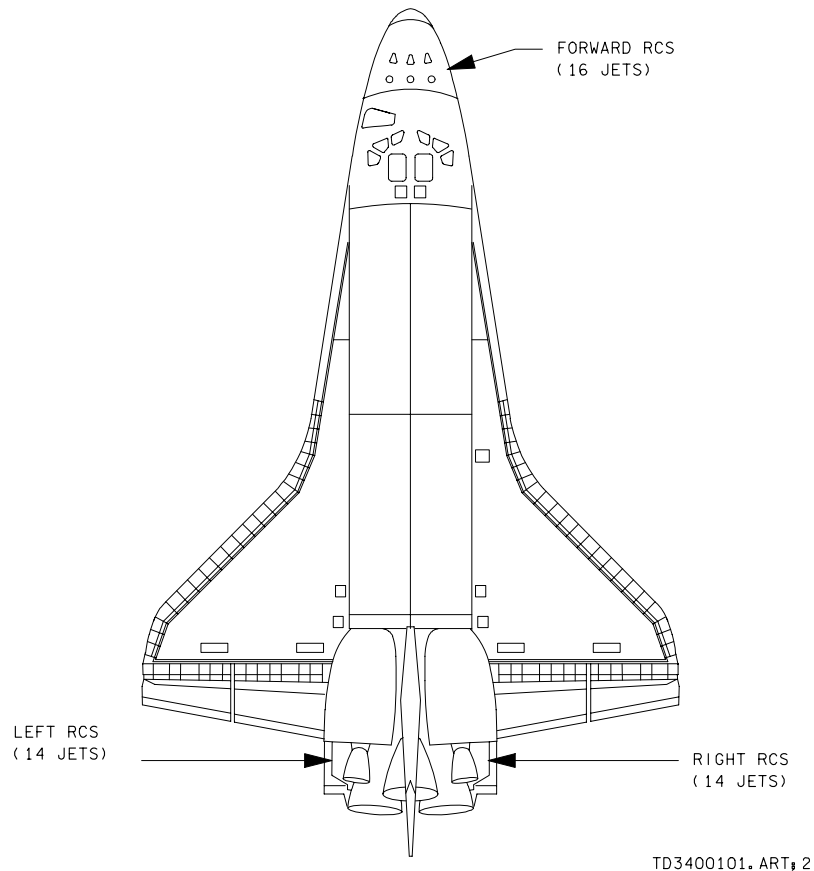


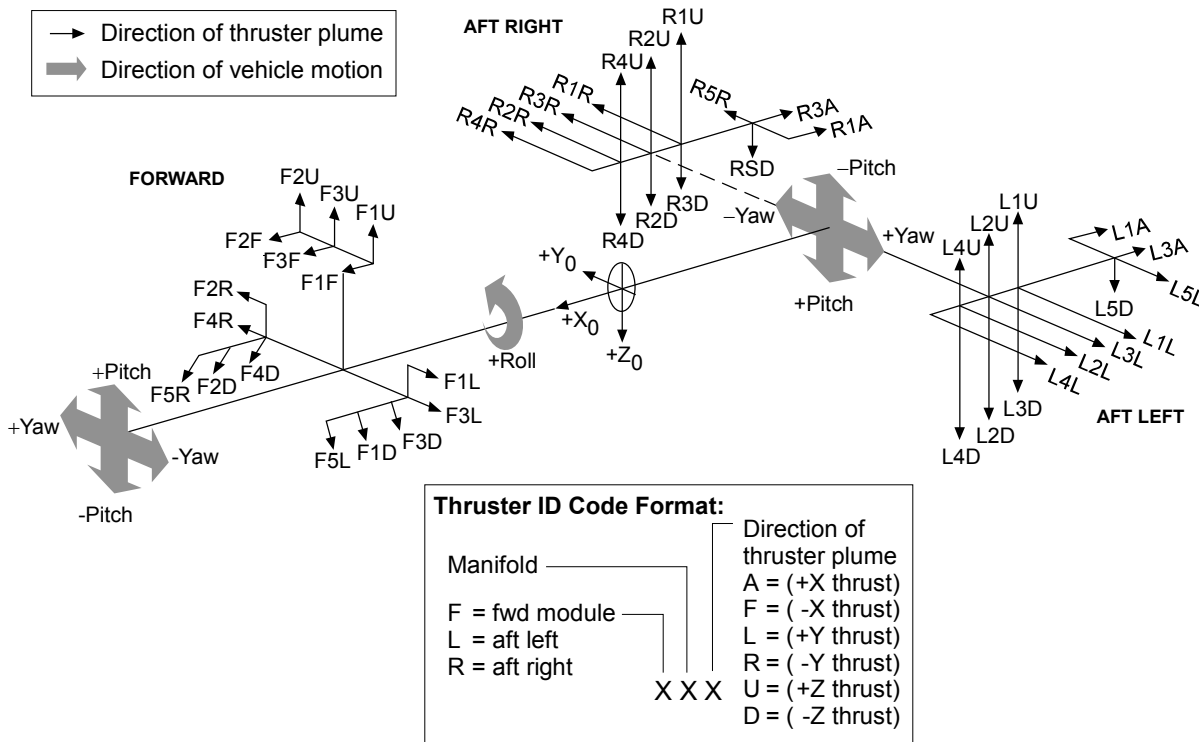
Figure 1-1. Forward, left, and right RCS modules

The RCS provides propulsive forces from a collection of jet thrusters to control the motion of the space shuttle vehicle. Each jet is permanently fixed to fire in a particular direction: Up (U), Down (D), Left (L), Right (R), Forward (F), or Aft (A). 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 used for attitude control. RCS attitude control is used during orbit, except during OMS burns when OMS gimbaling provides attitude control. (The RCS will provide backup attitude control to the OMS via RCS wraparound. RCS wraparound is programmed for single-engine OMS burns and it is used only if OMS gimbaling is providing insufficient control.) During ascent, the RCS can assist the Main Propulsion System (MPS) during off-nominal situations with additional roll control (called Single Engine Roll Control (SERC)). During entry, the RCS provides attitude control until the dynamic pressure is high enough for flight control surfaces to be effective.

Translational movement is used primarily for velocity changes. Orbital rendezvous and proximity operations may require a combination of both rotation and translation.



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Figure 1-2. RCS thruster identification

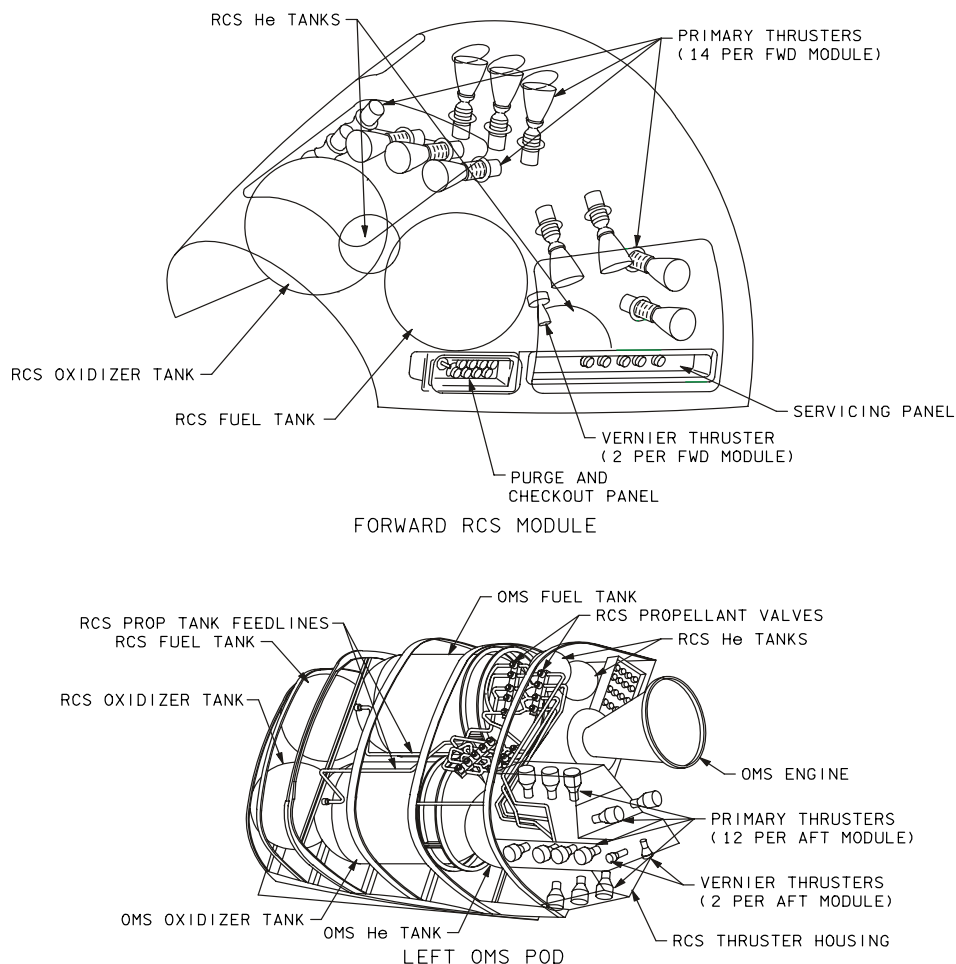
The RCS has a total of 44 jets. There are 38 primary jets and 6 vernier jets. Each primary jet is rated at 870 lb of thrust and each vernier jet is rated at 24 lb of thrust. The vernier jets are used only on orbit for fine attitude control. The forward RCS has 14 primary jets and 2 verniers, while each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

The RCS jets use monomethyl hydrazine (CH_3NHNH_2 or more commonly, MMH) as the fuel (FU) and nitrogen tetroxide (N_2O_4) as the oxidizer (OX). (Note: The OMS also uses the same type of propellants.) These two propellants are hypergolic, which means that ignition occurs spontaneously upon fuel-oxidizer contact, thus eliminating the need

for an ignition device. Although this addition increases system reliability, the volatile, corrosive, and poisonous nature of these propellants adds an operational risk if any leakage occurs.

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

Each RCS module contains a collection of jets, a fuel tank, an oxidizer tank, and two helium (He in the figures) tanks, along with associated feedlines, manifolds (MANFs), 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 locations.



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Figure 1-3. Left and forward RCS modules

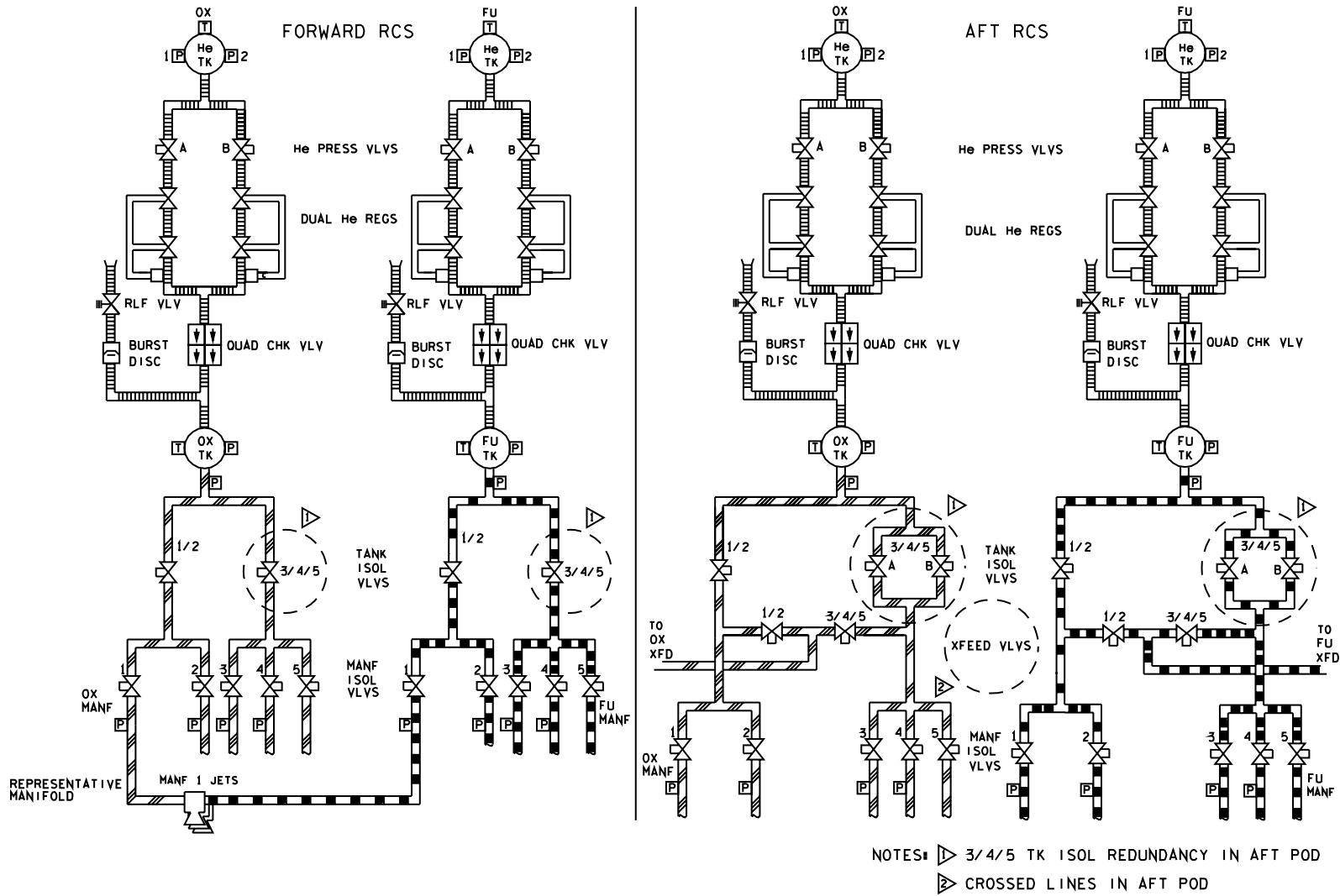


Figure 1-4. Forward and aft propellant schematics

There are two major plumbing differences between the Forward and Aft RCS modules, as noted in Figure 1-4.

One difference is the absence of redundancy in the Forward Reaction Control System (FRCS) 3/4/5 propellant leg as compared to the 3/4/5 A and B redundancy in the Aft Reaction Control System (ARCS). The redundancy in the aft RCS helps to ensure that propellant reaches at least some of the aft RCS jets, which are critical for attitude control early during entry. The forward RCS is not used for control during entry; so a redundant propellant leg is not necessary and one less valve set saves on vehicle weight.

The other difference is the system of 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, as shown in 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 fire the OMS engines because the RCS tanks have insufficient size/capacity to support the increased propellant flow of the larger OMS engines. Subsequent propellant tank damage would occur.

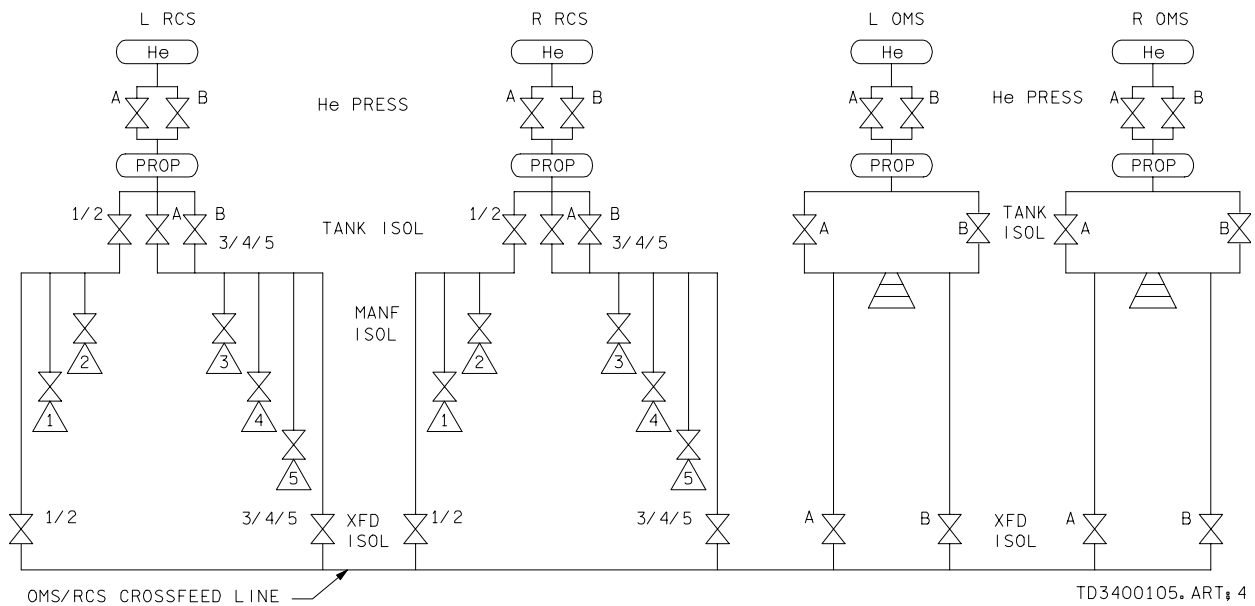


Figure 1-5. OMS/RCS propellant schematics (FU or OX)

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

- a. At Solid Rocket Booster (SRB) Separation (SEP), the firing of all three forward up-firing jets disperses SRB separation rocket particulates away from the forward windows, which minimizes the pitting on the windows that is buffed out during vehicle turnaround. (This FRCS window-protect sequence is not a flight control requirement but rather a cost/resource savings use of the RCS since window rebuffing is a significant time-consuming effort during ground turnaround.)
- b. Between Main Engine Cutoff (MECO) and the OMS 1 (orbital insertion) burn for control that includes the External Tank (ET) separation maneuver (MNVR).
- c. Between the OMS 1 and OMS 2 (orbital circularization) burn for control.
- d. On-orbit control (post-OMS 2 but before deorbit burn) when not in free drift or executing OMS burns.
- e. Post-deorbit burn until the aerosurfaces become effective. The RCS jets are exclusively used at first. However, as the dynamic pressure builds on the vehicle, the RCS jets are gradually phased out. By Mach 1, all the jets are deactivated, and attitude control is exclusively handled by the aerosurfaces.

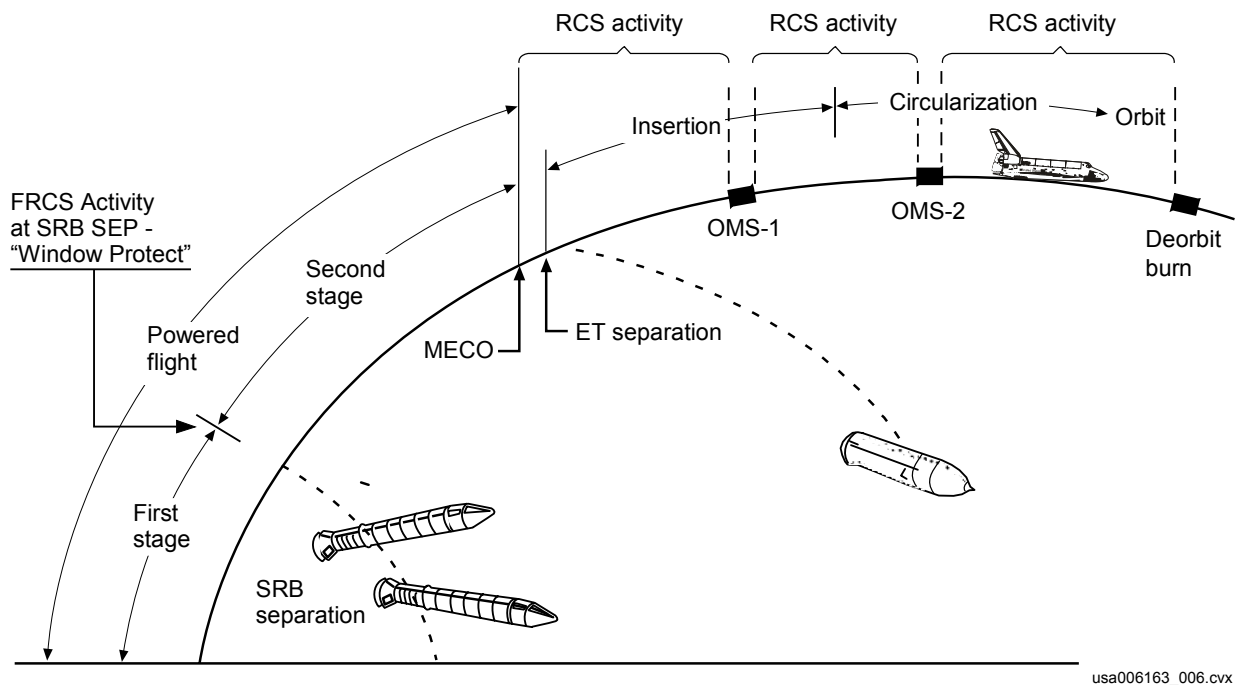
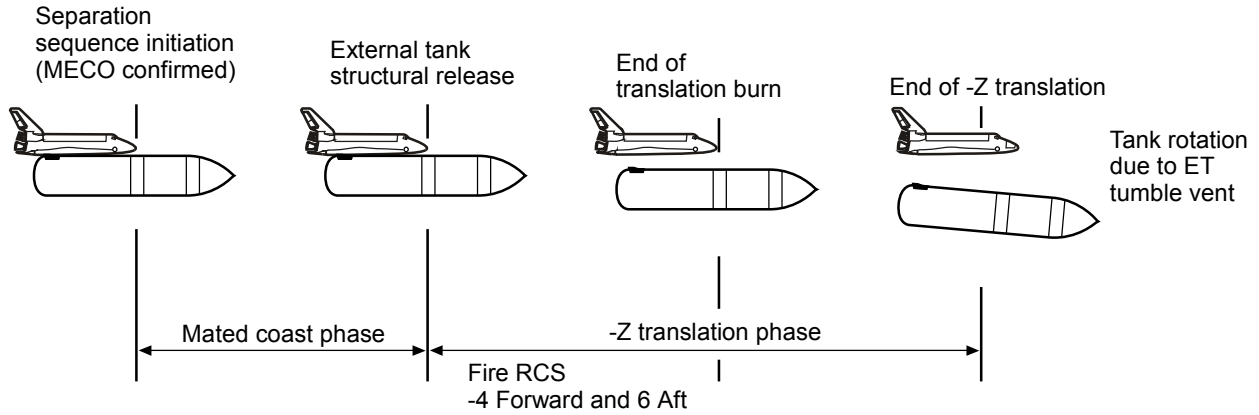


Figure 1-6. Nominal ascent profiles



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Figure 1-7. External tank separation

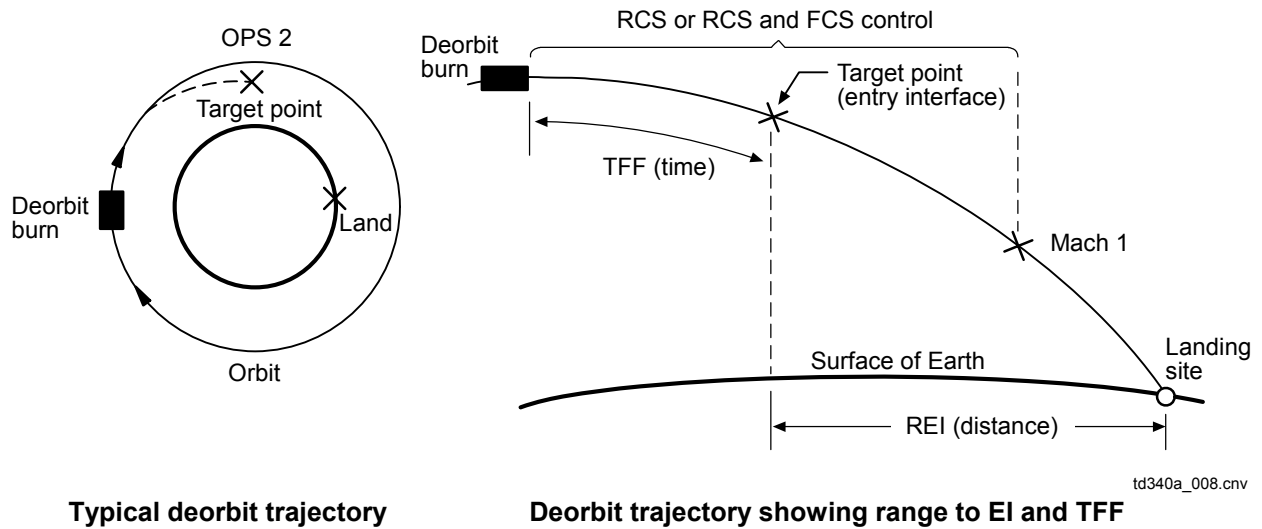
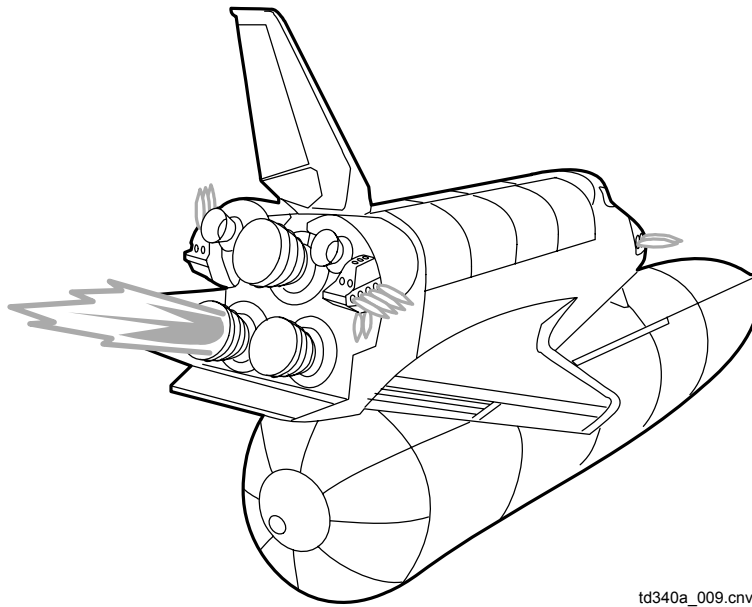


Figure 1-8. Deorbit trajectory

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

a. SERC (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 to conserve RCS propellant during this period of high RCS activity.



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Figure 1-9. Single-engine roll control

b. OMS gimbal failures during OMS burns (Figure 1-10)

If multiple failures degrade gimbal authority, the OMS engine(s) may not adequately control vehicle attitude and the RCS will be commanded to assist the OMS (this assist is called RCS wraparound). Some on-orbit burns are nominally planned for a single-engine burn. A few RCS wraparound firings during single engine OMS burns are not an unusual occurrence.

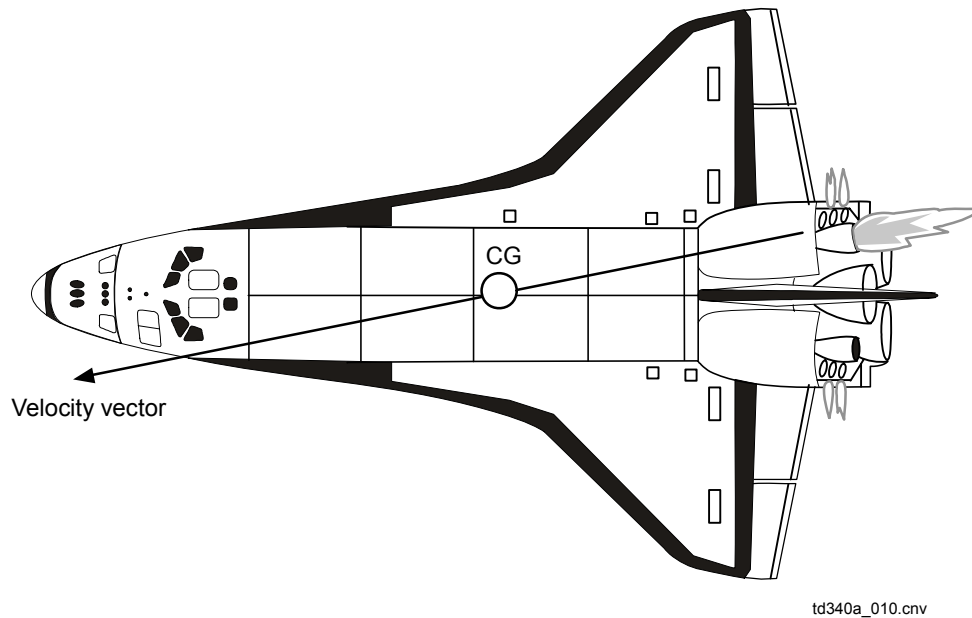
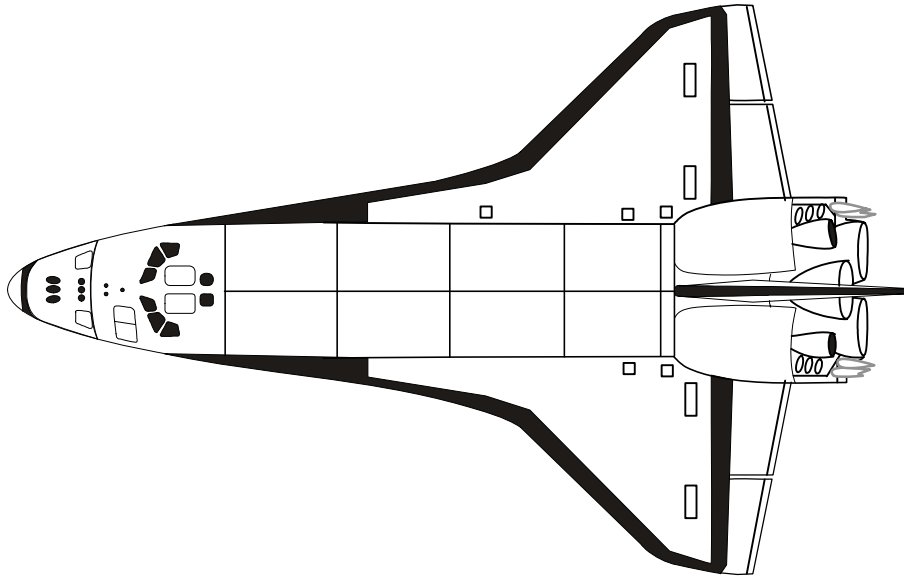


Figure 1-10. Single-engine OMS burn with RCS wraparound

c. OMS burn completion (Figure 1-11)

If both OMS engines fail during a burn, the forward and/or aft RCS 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. The aft RCS may be interconnected to the OMS if adequate OMS propellant is available; otherwise, RCS propellant can be used to complete the burn.

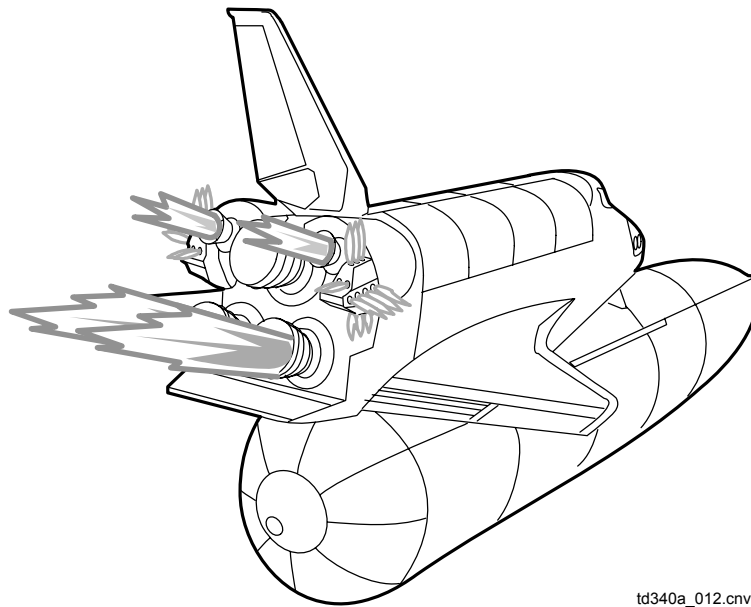


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Figure 1-11. RCS completion of an OMS burn

d. Abort dumps (Figure 1-12)

In the event of an abort (Return to Launch Site (RTLS), Transoceanic Abort Landing (TAL), intact contingency, 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. Through an OMS-to-RCS interconnect, the 24 aft RCS jets can be used to help the OMS engines burn away (“dump”) the OMS propellants. The RCS jets are also used to dump excess RCS propellant in both the forward and aft pods.

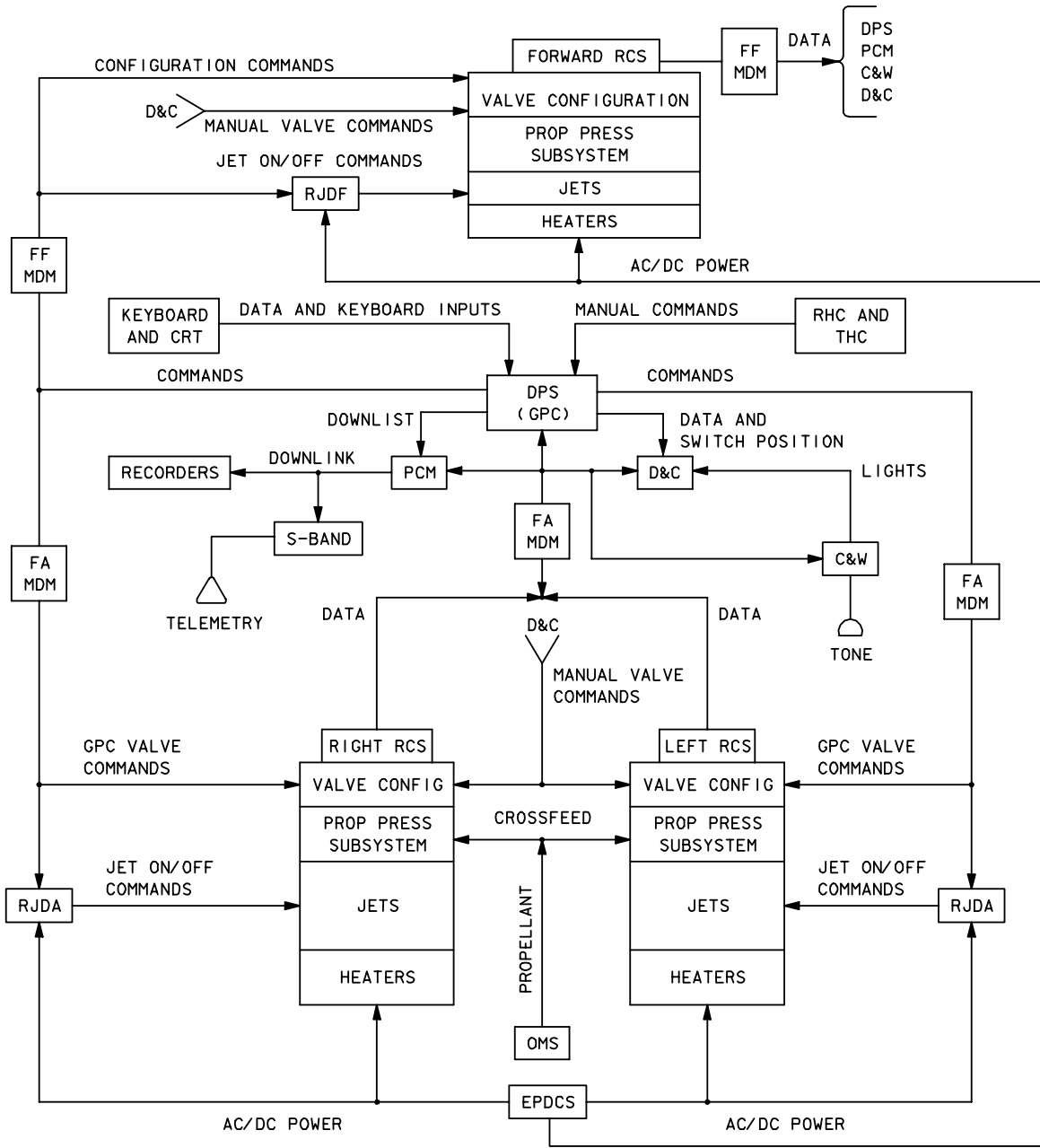


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Figure 1-12. RTLS/TAL abort dump (2 OMS + 24 RCS jets)

The RCS receives all commands (both auto and manual) via the space shuttle flight computer software. This software is contained in the five General Purpose Computers (GPCs). Up to four of these computers contain redundant sets of the Primary Avionics Software System (PASS), and the fifth GPC contains the software for the Backup Flight System (BFS). The PASS computers are in control of the vehicle unless the BFS is manually engaged. All the GPCs, including the backup, can provide information to the crew by means of Cathode-Ray Tube (CRT)/Multifunction Electronic Display System (MEDS) displays. See Figure 1-13 for an overview of RCS interfaces.

The Data Processing System (DPS) allows control of all RCS activity. The RCS sends pressure, temperature, and valve position data to the DPS for processing. These data are sent to the crew through the Displays and Controls (D&C) system and are also downlinked to Mission Control via S-band telemetry through the pulse-code modulator. Data are also provided to onboard recorders. The DPS transmits commands for valve configuration and jet firings. These commands and feedbacks are relayed through Multiplexer/Demultiplexer (MDM) units. Of primary concern to the RCS are the four Flight-Critical Aft (FA) MDMs and the four Flight-Critical Forward (FF) MDMs. Electrical power is supplied to the RCS through main buses, control buses, and alternating current (ac) buses to operate switches, valves, instrumentation, and heaters.



C&W	CAUTION AND WARNING
D&C	DISPLAYS AND CONTROLS
DPS	DATA PROCESSING SYSTEM
EPDCS	ELECTRICAL POWER DISTRIBUTION AND CONTROL SUBSYSTEM
GPC	GENERAL PURPOSE COMPUTER
OMS	ORBITAL MANUEVERING SYSTEM
PCM	PULSE CODE MODULATOR
RHC	ROTATIONAL HAND CONTROLLER
RJDA	REACTION JET DRIVER AFT
RJDf	REACTION JET DRIVER FORWARD
THC	TRANSLATIONAL HAND CONTROLLER

TD3400113. ART. 5

Figure 1-13. Reaction control system overview

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 MM numbers before continuing to the next section.

The remainder of this manual covers the RCS in more detail. Section 2 contains a description of the various components of the system, followed by a description of systems operation in Section 3. Section 4 of the manual provides the background information needed to understand and respond to system malfunctions. The fifth 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; for more information in this field, please refer to the training material concerning Guidance and Control (G&C) for insertion/orbit/deorbit (G&C I/O/D 2102).

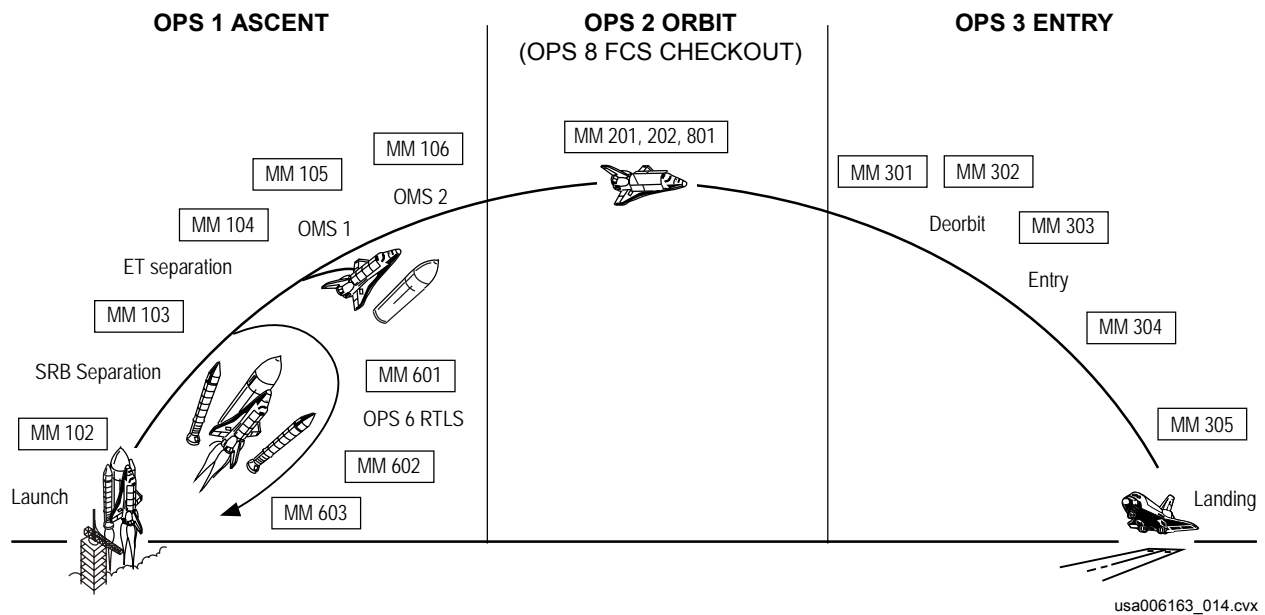


Figure 1-14. Major modes

2.0 SYSTEM DESCRIPTION

2.1 OBJECTIVES

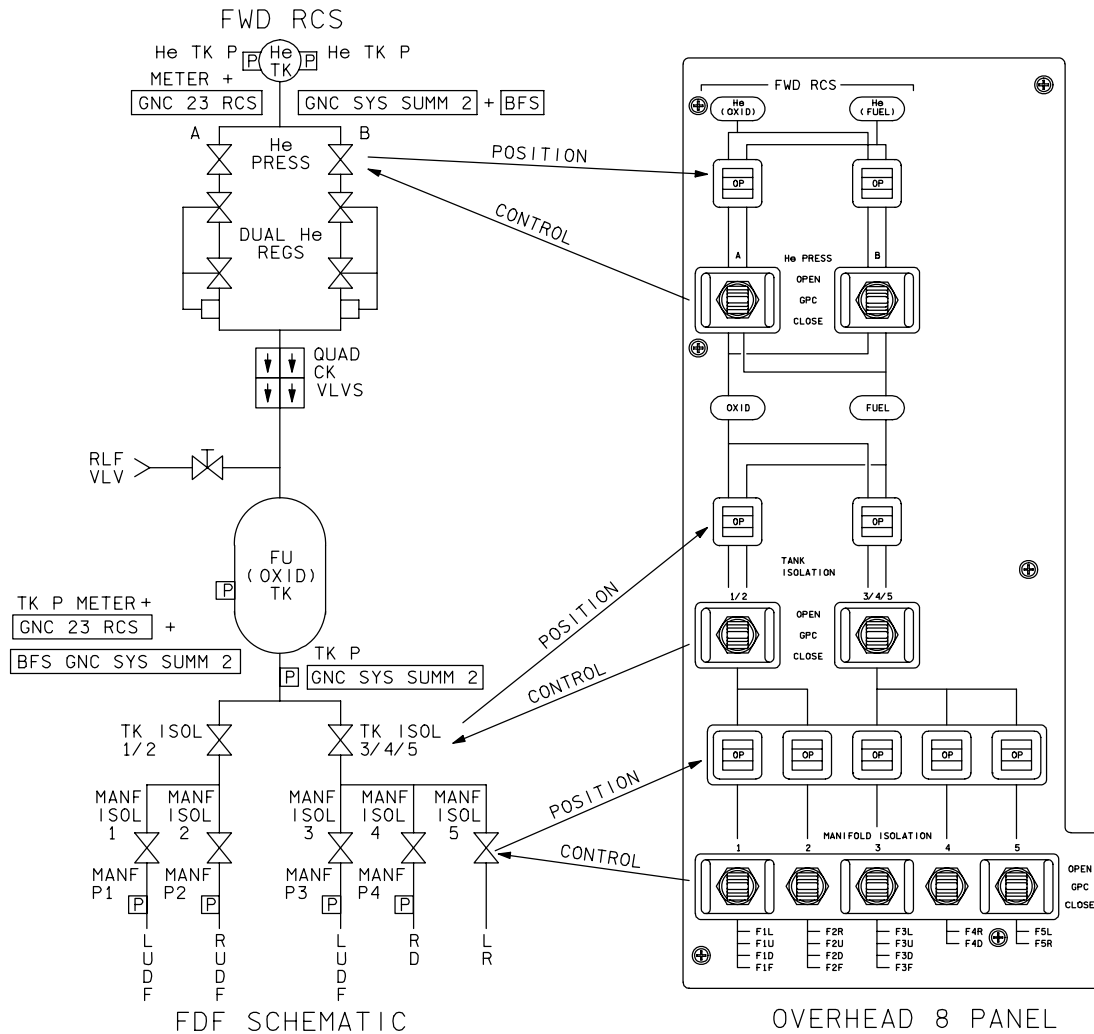
As a result of reading this section, the student should be able to identify and state the purpose of the following components of the RCS:

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

2.2 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 refer to propellants in a generic sense and apply to both propellants (fuel and oxidizer) unless specifically stated otherwise.

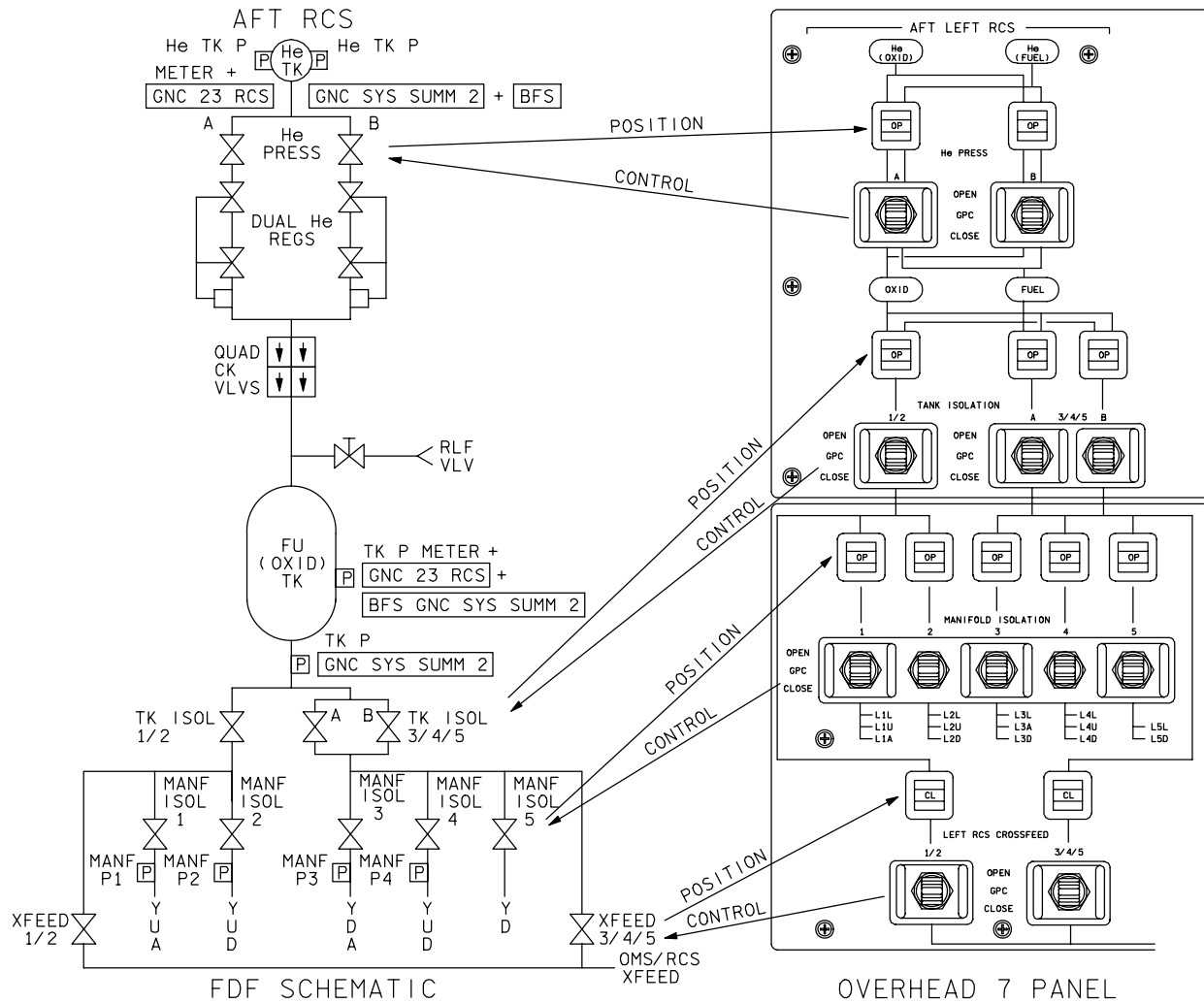
Figure 2-1 shows a comparison between the Flight Data File (FDF) propellant schematic and the controlling panel for the forward RCS. Figure 2-2 shows the same comparison for the aft RCS. The position/control arrows refer to valve groupings (TK ISOL, XFD, etc.), not to any specific valve, switch, or talkback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



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.



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

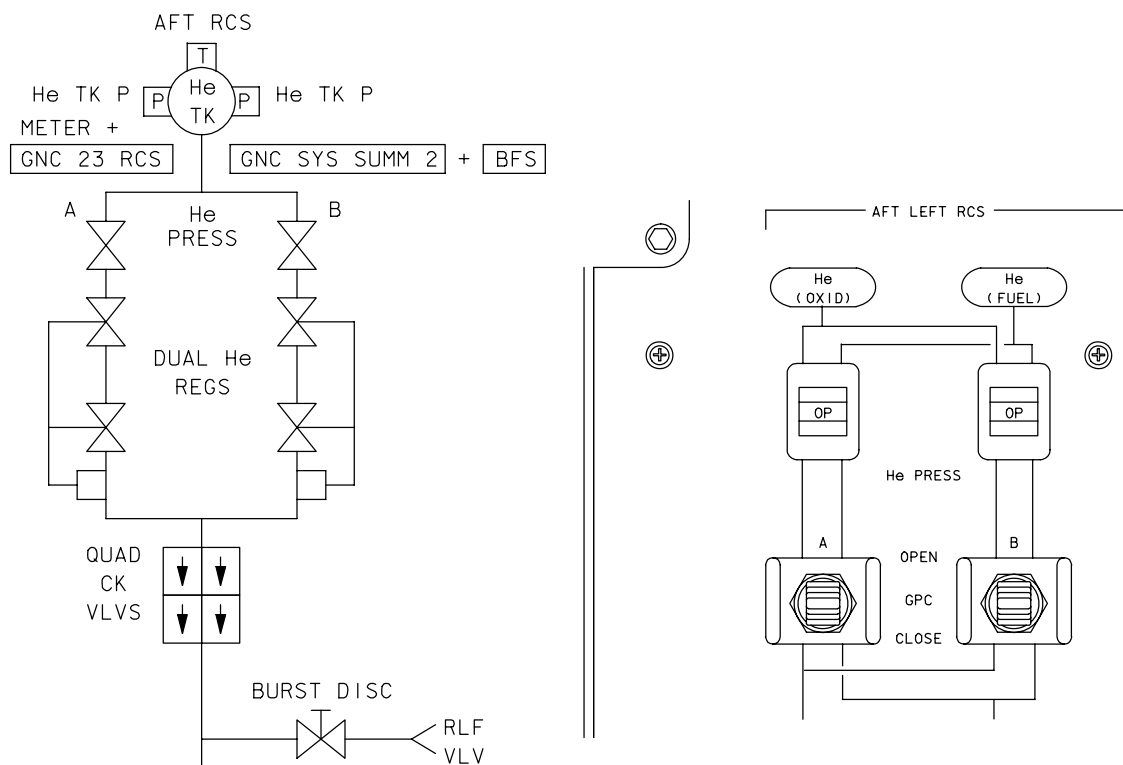
2.2.1 Helium System

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/MEDS 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. Any degradation or loss of temperature and/or pressure inputs to the GPCs will affect the accuracy of quantity displays.

The helium supply is fed to the propellant tank through two redundant lines, designated A and B, either of which is capable of fully supporting normal propellant tank pressurization. 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 other solenoid, when activated, magnetically unlatches the valve, allowing spring pressure and helium flow to drive the valve closed.

These pressurization valves are controlled per the associated switch position on the control panels.



TD3400203. ART 4

Figure 2-3. Aft 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 controls two valves, one for the fuel system and one for the oxidizer system. Each switch has three positions, Open (OP), Close (CL), and GPC. The open and close positions are for manual valve configurations, while the GPC position allows the GPCs to perform valve configurations. Unlike the “manual” switch positions, the GPC position is an “unpowered” position and provides no control power to the valve operation circuitry. When the switch is in the GPC position, all valve operation power is provided via GPC command inputs to the valve operation circuitry. A position microswitch in each valve provides open and close status inputs to a position indicator (talkback) on the RCS control panel and also to the GPCs for CRT/MEDS display and valve circuitry feedback. The talkback 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 displays OP. Likewise, if both inputs indicate closed, the talkback displays CL. If the talkback receives conflicting inputs (one open and one closed) or when the valves are in transition, the talkback displays a striped pattern (barberpole (bp)). More detail on the utilization of microswitch feedback is described in Section 2.6.5, Manifold Status.

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, one primary and one secondary, connected in series so that if one regulator fails open, the other unit regulates 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 if one valve fails closed.

A pressure relief valve is provided downstream of the quad check valves to prevent failed open regulators from overpressurizing the propellant tanks. The relief valve is a burst disc/poppet valve arrangement. If the regulated flow is within normal limits, the relief valve will be bypassed. Otherwise, the excess helium is vented overboard.

2.2.2 Propellant System

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

Because the propellant tanks are used in a zero-gravity (zero-g) 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 flows in the direction of pressure differential. If the pressure differential is zero, the surface tension of the screen prevents 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.

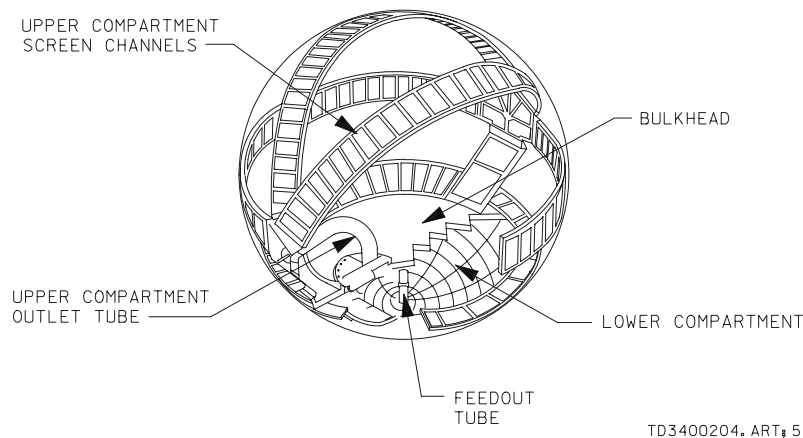


Figure 2-4. Forward RCS propellant tank

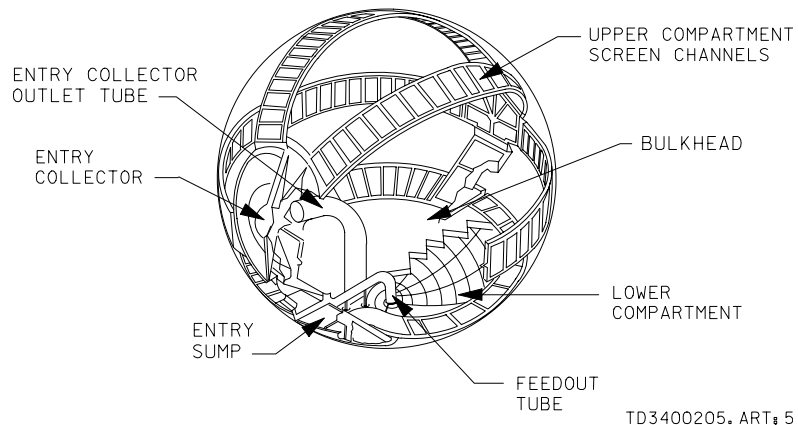
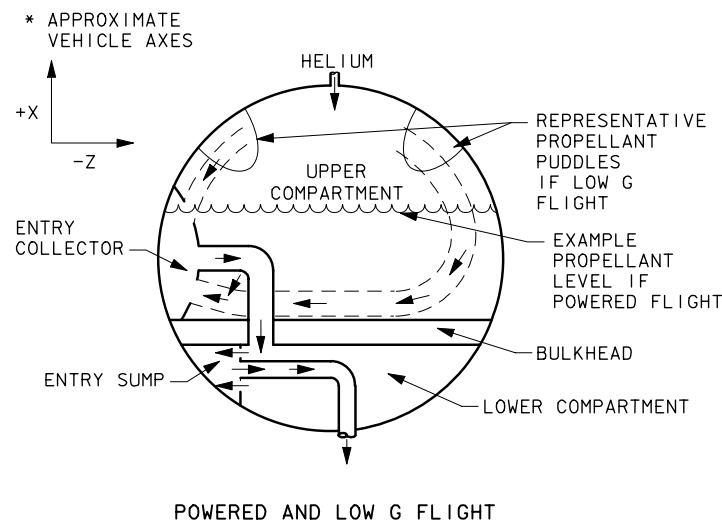


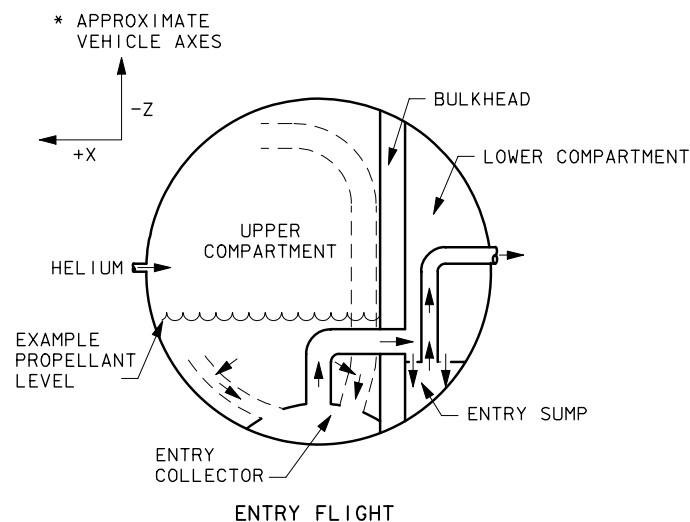
Figure 2-5. Aft RCS propellant tank

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

The Forward RCS is not used for control during entry. Forward RCS propellants are dumped prior to entering the atmosphere to help improve the vehicle's center of gravity. If the forward RCS jets were used, their plumes and exhaust could damage the vehicle and disrupt the boundary layer over the wings. Therefore, the forward RCS propellant tanks lack the entry collector and sump hardware.



* NOTE 90° ROTATION BETWEEN FIGURES

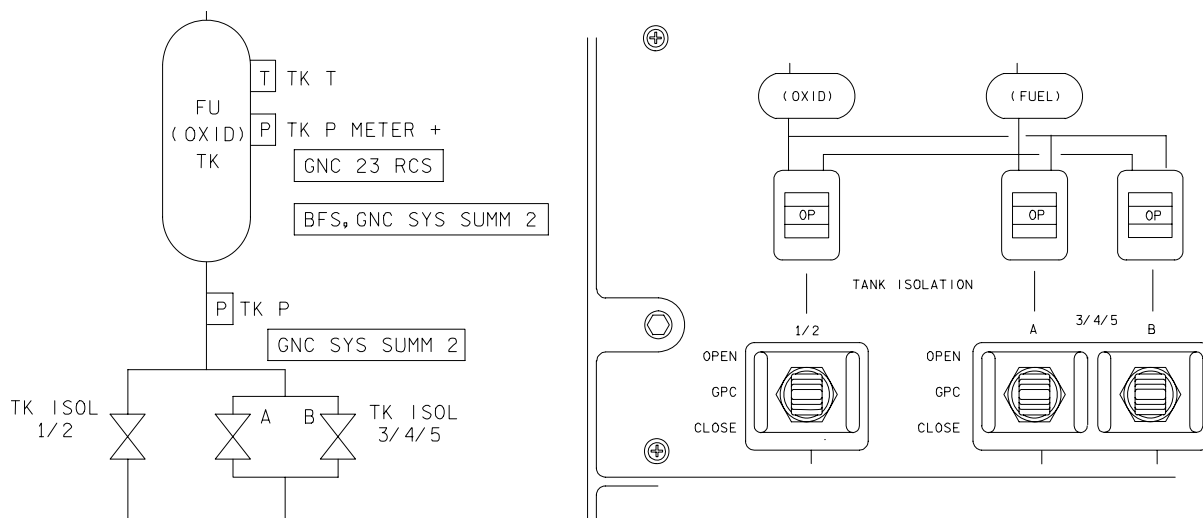


TD3400206. ART. 8

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.

In OPS 2, the GPCs provide automatic overpressure protection to the propellant tanks by closing the helium pressurization valves of the affected system if the propellant tank pressure sensor inputs exceed the upper Caution and Warning (C&W) limit. Because this automatic closure is a GPC command, the 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; so manual positioning is required to reopen the valves.



TD3400207. ART 4

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

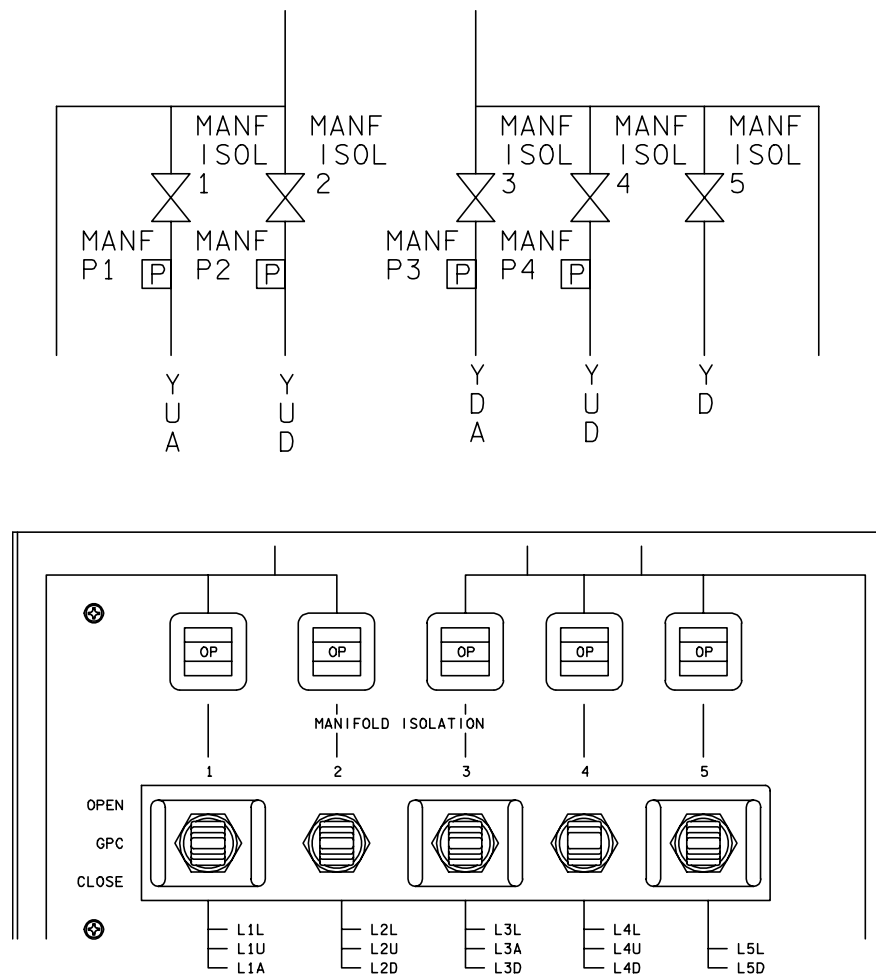
If helium pressurization is lost upstream from the helium isolation valves (helium leak, line blockage, or valves closed), the associated propellant tank is in a “blowdown” state. The resident ullage pressure (V_U) in the propellant tank is the only pressurization source. The amount of usable propellant is directly related to the volume of ullage. There is an optimum ullage pressure that allows total usage of the remaining propellant and is called maximum blowdown. For the RCS, max blowdown is approximately 23 percent propellant remaining.

The pressure sensor outputs are also utilized for onboard displays (CRT/MEDS and meter), but each display does not use the same sensor. The temperature sensor signal is also used by the GPCs for display purposes on Specialist Function (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 isolation 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 operation is not possible.) 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 relays 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 2-8).



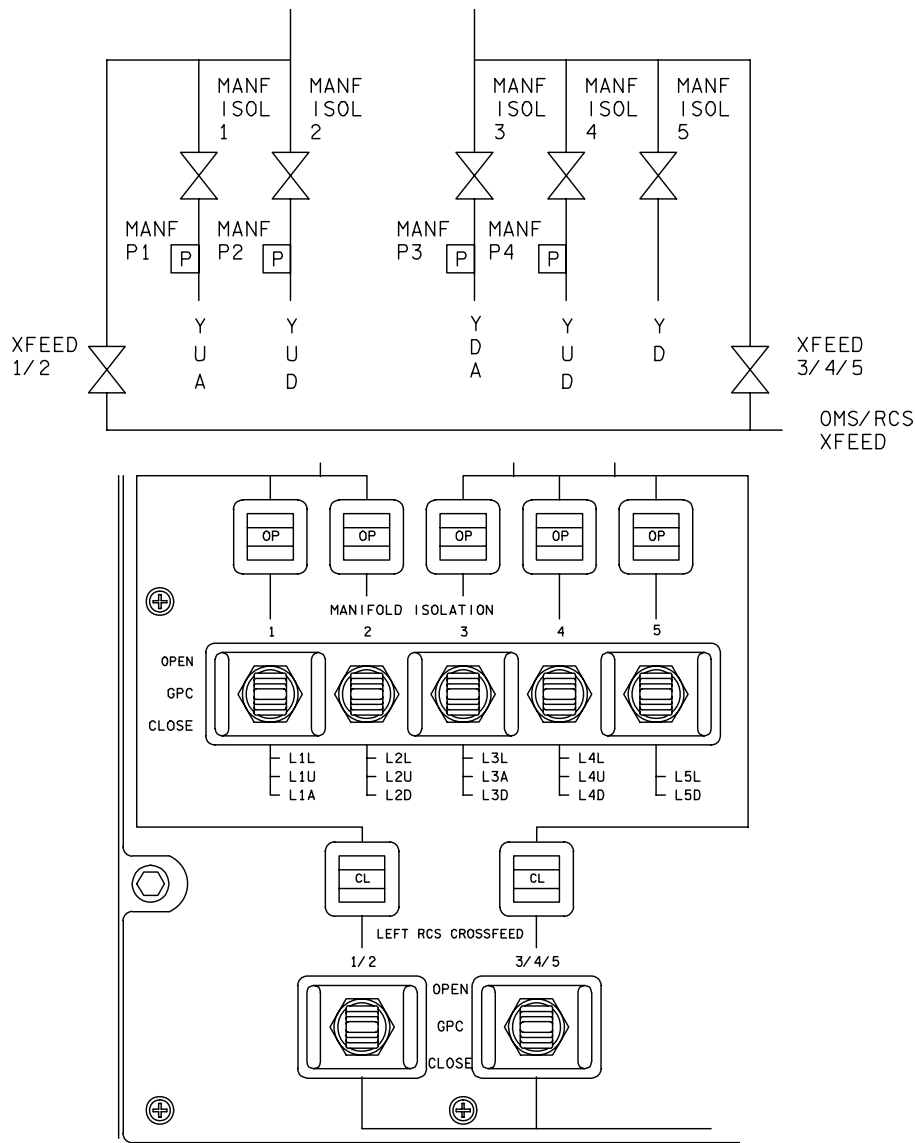
TD3400209. ART. 2

Figure 2-8. Aft RCS MANF valves and associated RCS switches

2.2.3 Crossfeed and Interconnect

In the aft RCS only, 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 because of propellant leaks, valve failures, or line restrictions.

The crossfeed line depicted in Figure 2-9 is just a portion of the crossfeed line that can also be accessed by the right RCS and both OMS.



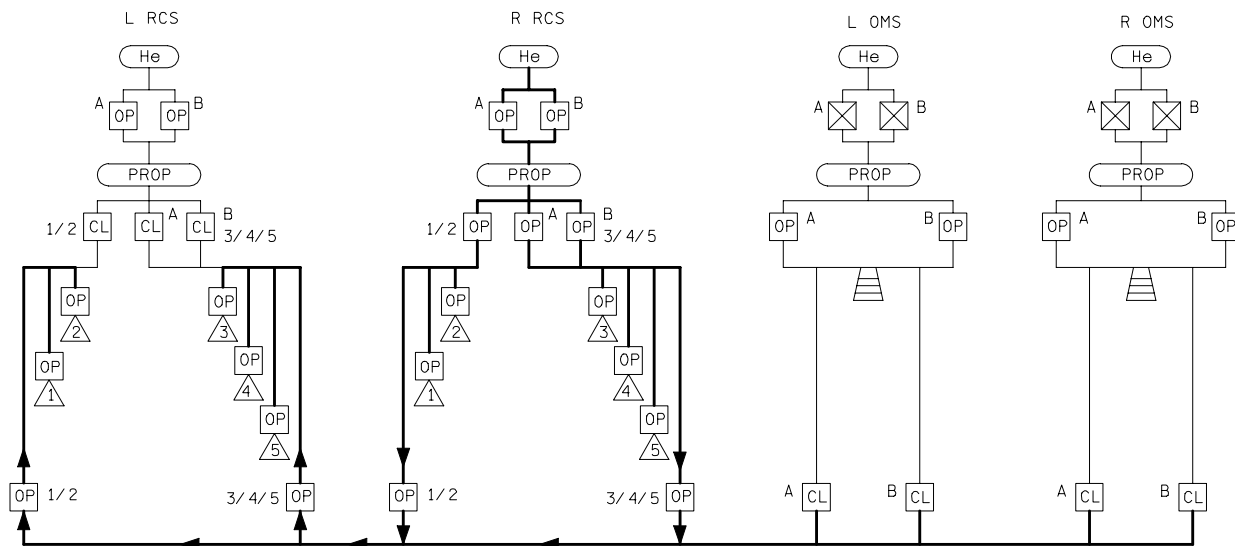
TD3400210. ART# 6

Figure 2-9. Representative aft RCS/OMS crossfeed and associated RCS switches

Figure 2-10 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., ac 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 that RCS tank.



TD3400211. ART. 5

Figure 2-10. OMS RCS schematics - RCS crossfeed - feed from right

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 sequencing can be done automatically via the movement of one switch: the MASTER CROSSFEED switch on panel O7. In OPS 1, 3, and 6, when the MASTER CROSSFEED switch is moved to a FEED FROM position, the GPCs issue appropriate commands to the RCS tank isolation and the OMS/RCS crossfeed valves to configure for the crossfeed. The tank isolation and crossfeed valve switches must be in GPC for the GPC commands to position the valves. (The GPC position is nominal for ascent and entry.) If any valve switch is in the manual open (or closed) position by mistake, the manual command overrides the GPC command for that valve.

An auto crossfeed can also be performed by the GPCs when a low tank pressure is detected and the master crossfeed switch is in the OFF position. The auto crossfeed sequence will be covered in greater detail in Section 4.3.2 of this workbook.

Placing the master crossfeed switch in a FEED FROM position also sets a discrete in the GPCs that restricts the number of simultaneous jet firings while in a crossfeed configuration. Otherwise, the propellant draw from a large number of jets on just one set of propellant tanks could damage the surface tension screens inside the tanks. The setting of this discrete is available in all OPS and is set by the master crossfeed switch position, not by any valve movements. Although auto crossfeed is not available in OPS 2, the setting of the crossfeed discrete with the master crossfeed switch is still required to restrict jet firings. Note that if the valves are manually configured for straightfeed and the master crossfeed is erroneously kept in a FEED FROM position, the GPCs 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 (called an OMS-to-RCS interconnect). Interconnecting OMS to RCS is often performed on orbit to save RCS propellant for use during entry. 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 on-orbit interconnects.

During ascent aborts, the OMS propellants need to be dumped to reduce orbiter weight and to obtain a controllable c.g. for entry. To accomplish this dump in a minimum amount of time, both OMS pods are interconnected to the RCS (Figure 2-11). Once the interconnect is achieved, OMS propellant is wasted by firing both OMS engines and simultaneously firing all 24 aft RCS jets.

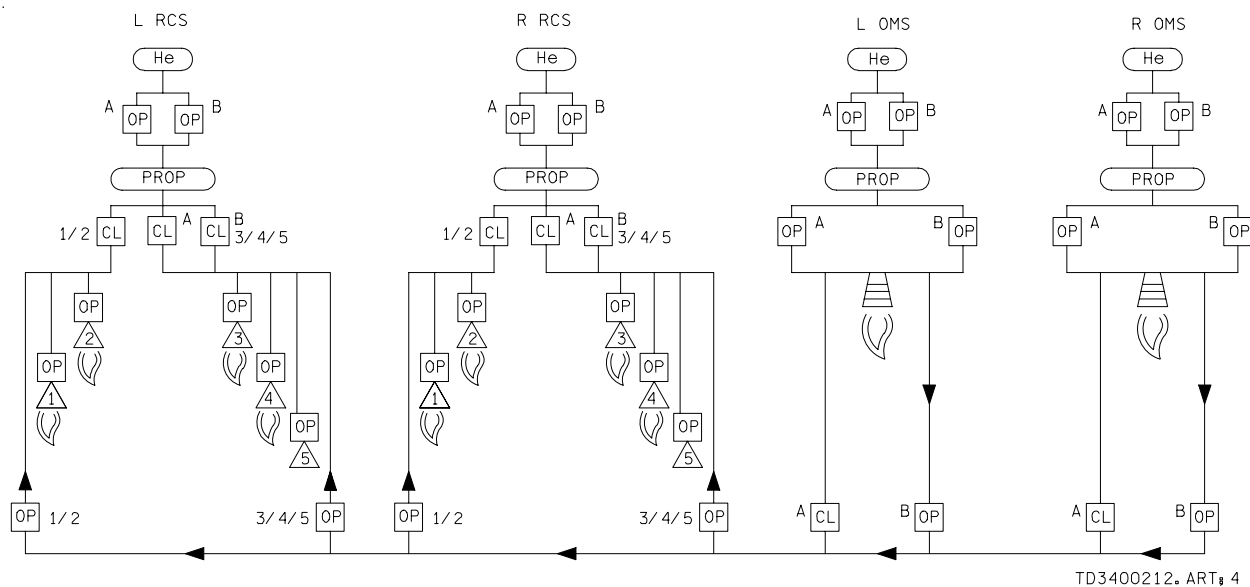


Figure 2-11. Abort interconnect

2.3 JET THRUSTER SYSTEM

In the jet thruster system, as illustrated in Figure 2-12 and Figure 2-13, the fuel and oxidizer combine to produce hypergolic combustion (hot gas thrust). The system's major components are the Reaction Jet Driver (RJD), bipropellant valves, injector assembly, combustion chamber, and nozzle.

The 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 RM as an indication of actual jet firings.

The bipropellant valves are solenoid driven and electronically activated so that both valves open and close simultaneously. 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.

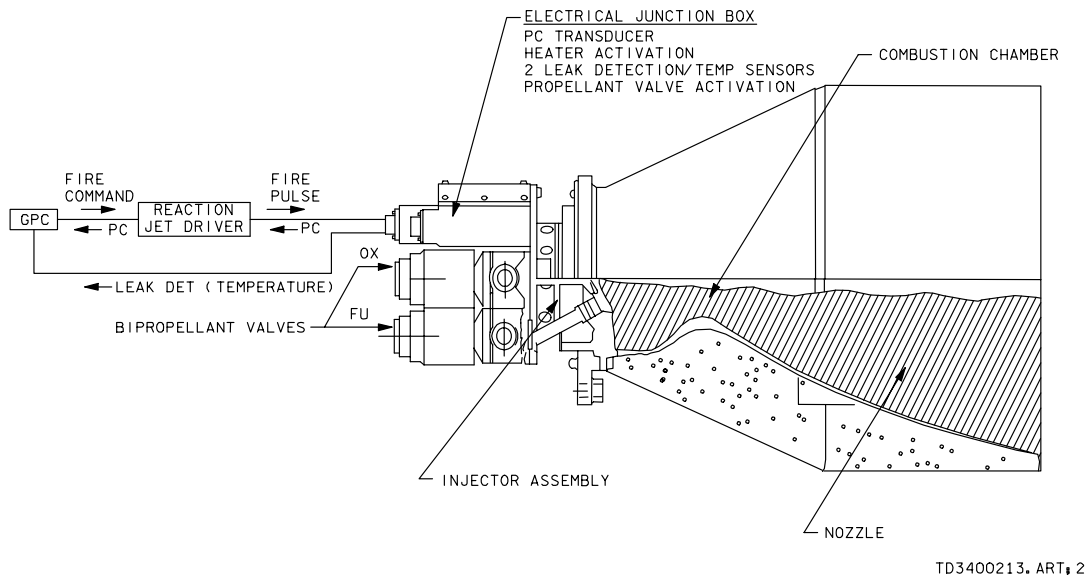


Figure 2-12. Primary thruster

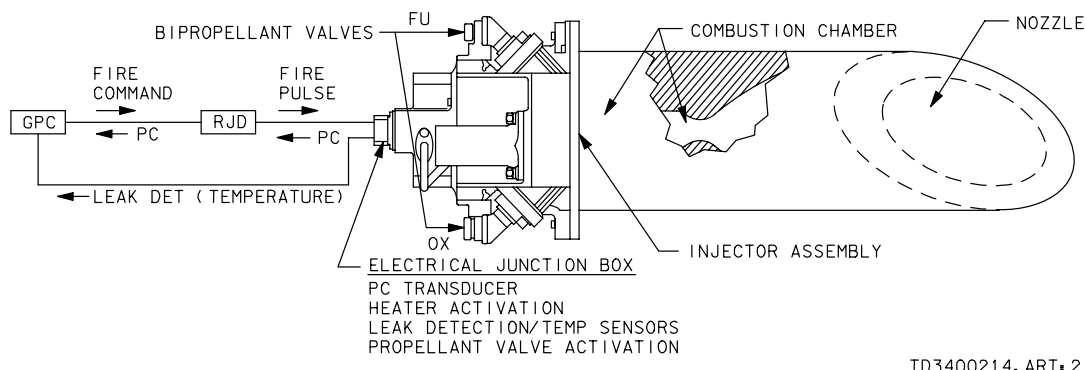
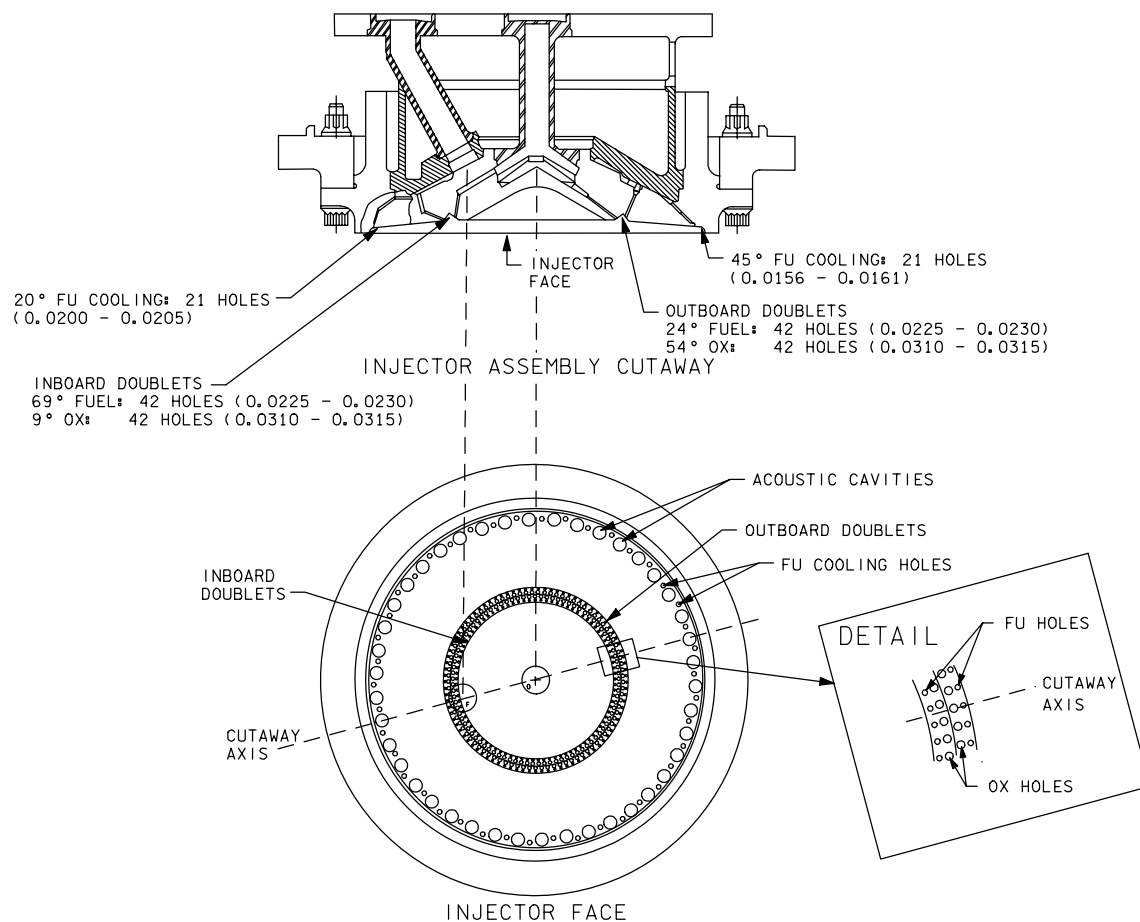


Figure 2-13. Vernier thruster

The injector assembly directs the flow of propellants to the combustion chamber. Figure 2-14 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 injector assembly for the smaller vernier jet (not pictured) has only one pair of injector holes. Fuel cooling of the vernier chamber walls is achieved by flowing slightly more fuel than oxidizer.

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 2-14. Primary jet injector assembly cutaway and injector face

2.4 QUANTITY GAUGING

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 “mass” of helium in the helium tank (M_H) is then compared to the volume of the associated propellant ullage (V_U). The relationship can be roughly defined as

$$\frac{M_H}{V_U}$$

As propellant is used, M_H will decrease while V_U increases (Figure 2-15). A decrease in M_H or an increase in V_U due to a leak causes a decrease in displayed quantity.

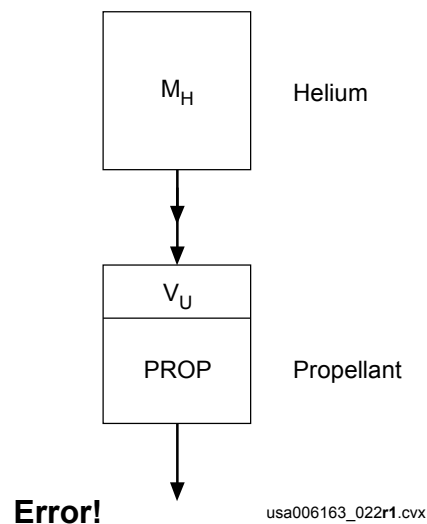


Figure 2-15. Helium mass and ullage volume

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 9.5 percent, the GPCs issue a leak alert for the affected pod.

The BFS quantity sequence runs in OPS 1, 3, and 6. The PASS sequence runs in OPS 1, 2, 3, 6, and 8. The digital readout on panel O3 displays the PASS computed quantities unless the BFS is engaged, at which time it displays 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. (The symbol √ indicates availability.)

Table 2-1. RCS quantity display availability

	OPS 1	OPS 2	OPS 3	OPS 6	OPS 8
O3 digital readout	PASS calculation unless BFS is engaged, then BFS calculation	PASS calculation	PASS calculation unless BFS is engaged, then BFS calculation	PASS calculation unless BFS is engaged, then BFS calculation	PASS calculation
BFS SYS SUMM 2	√	Not available	√	√	Not available
PASS SYS SUMM 2	Not available	√	Not available	Not available	√
SPEC 23	√	√	√	√	√

2.5 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 are covered later in this manual.

2.5.1 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.

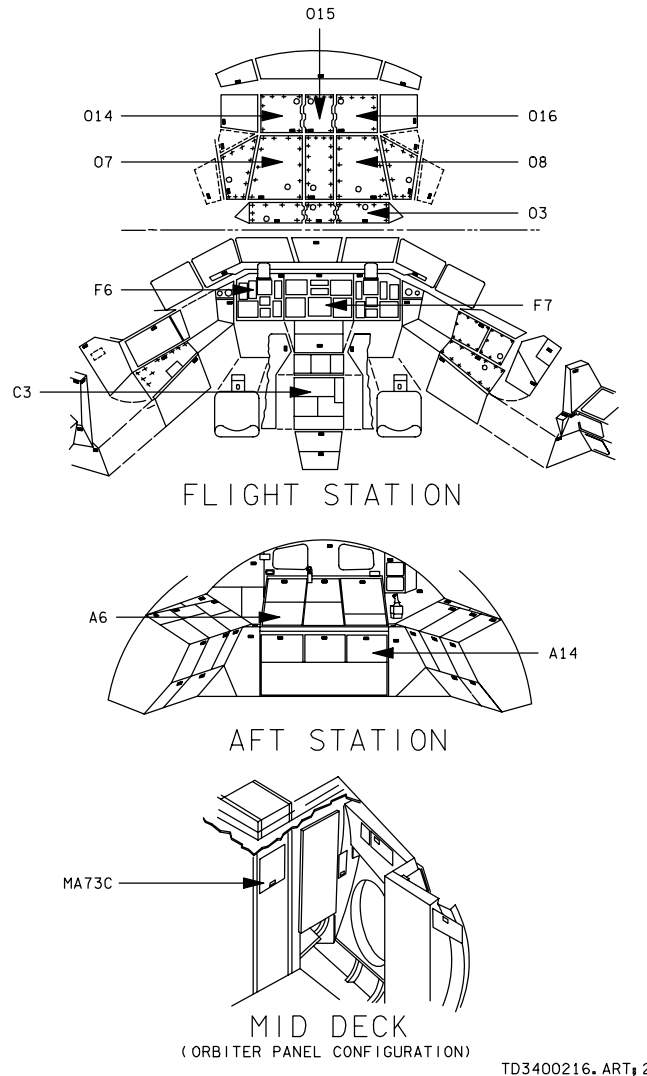
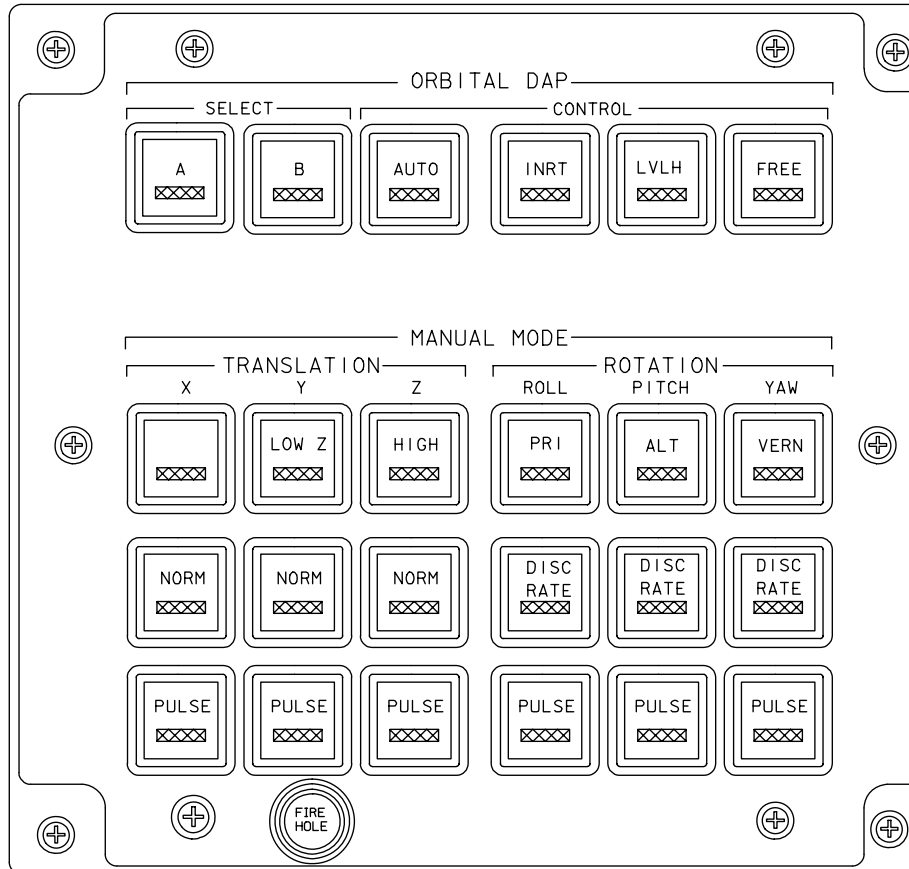


Figure 2-16. Orbiter panel configuration

2.5.1.1 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) that are used to select either primary or vernier jets. A limited discussion of the DAP will be made in the System Operation section.

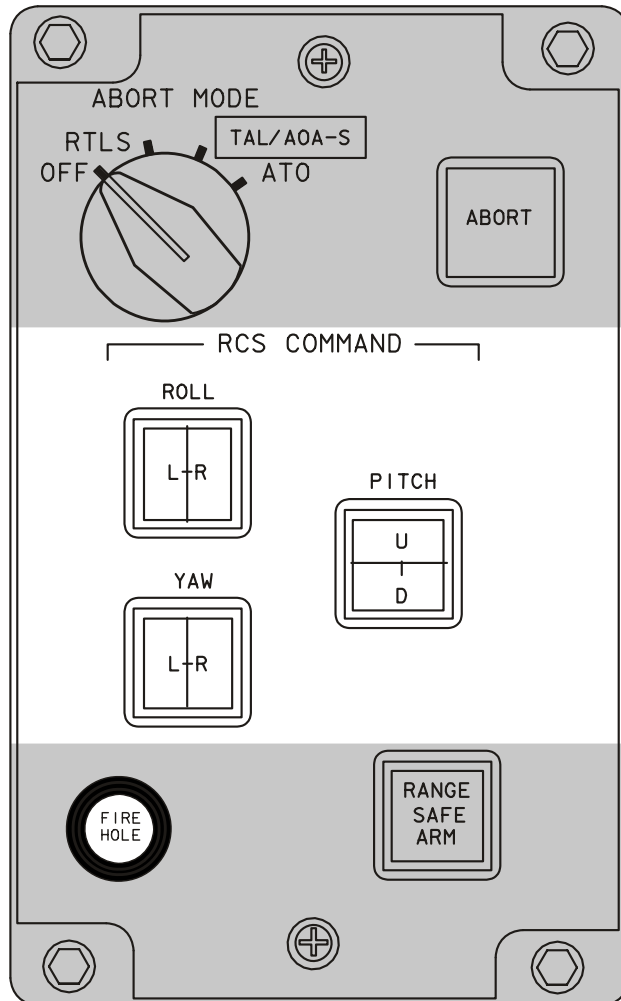


TD3400217, PNL, 3

Figure 2-17. Panel C3

2.5.1.2 Panel F6

The RCS command lights (Figure 2-18) are located in the lower right side of panel F6. The function of these lights is described in Section 3, System Operations.



00616306. ART# 1

Figure 2-18. RCS command lights

2.5.1.3 Panel F7

The C&W 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 is discussed in greater detail in Section 4, System Malfunctions.

O ₂ PRSS	H ₂ PRSS	FUEL CØLL RØAC	FUEL CØLL STACK TØMP	FUEL CELL PUMP
CABIN ATM	O ₂ HØATØR TØMP	MAIN BUS UNØØRVOLT	AC VOLTAGE	AC ØVØRLOAD
FRØØN LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS	RCS JET
H ₂ O LOOP	RGA/ADCØL	AIR DATA	LØFT RCS	RIGHT RCS
————	LØFT RHC	RIGHT/AFT RHC	LØFT ØMS	RIGHT ØMS
PAYLOAD WARNING	GPC	FCS SATURATION	ØMS KIT	ØMS TVC
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS	————
BACKUP C/W ALARM	APU TEMP	APU ØVØRSPØØD	APU UNØØRSPØØD	HYD PRSS

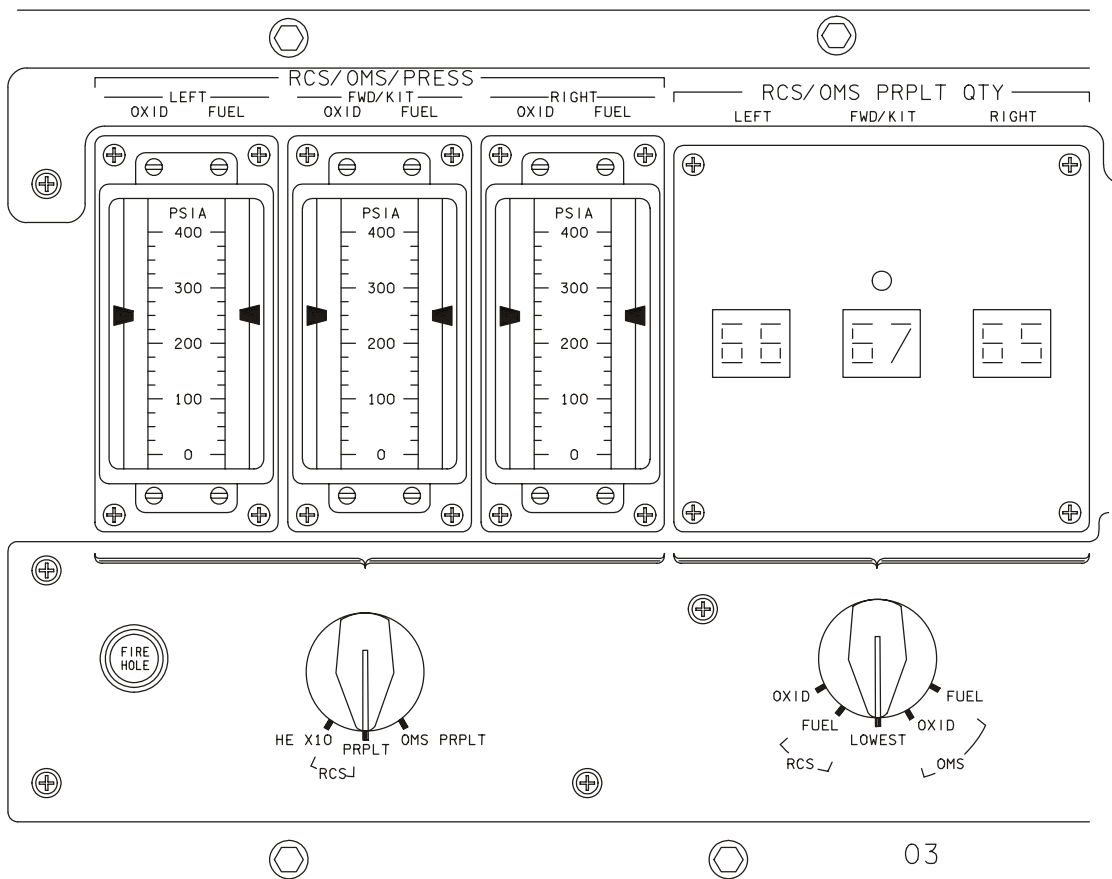
TD3400219. ART: 3

Figure 2-19. Caution and Warning matrix

2.5.1.4 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 are 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.

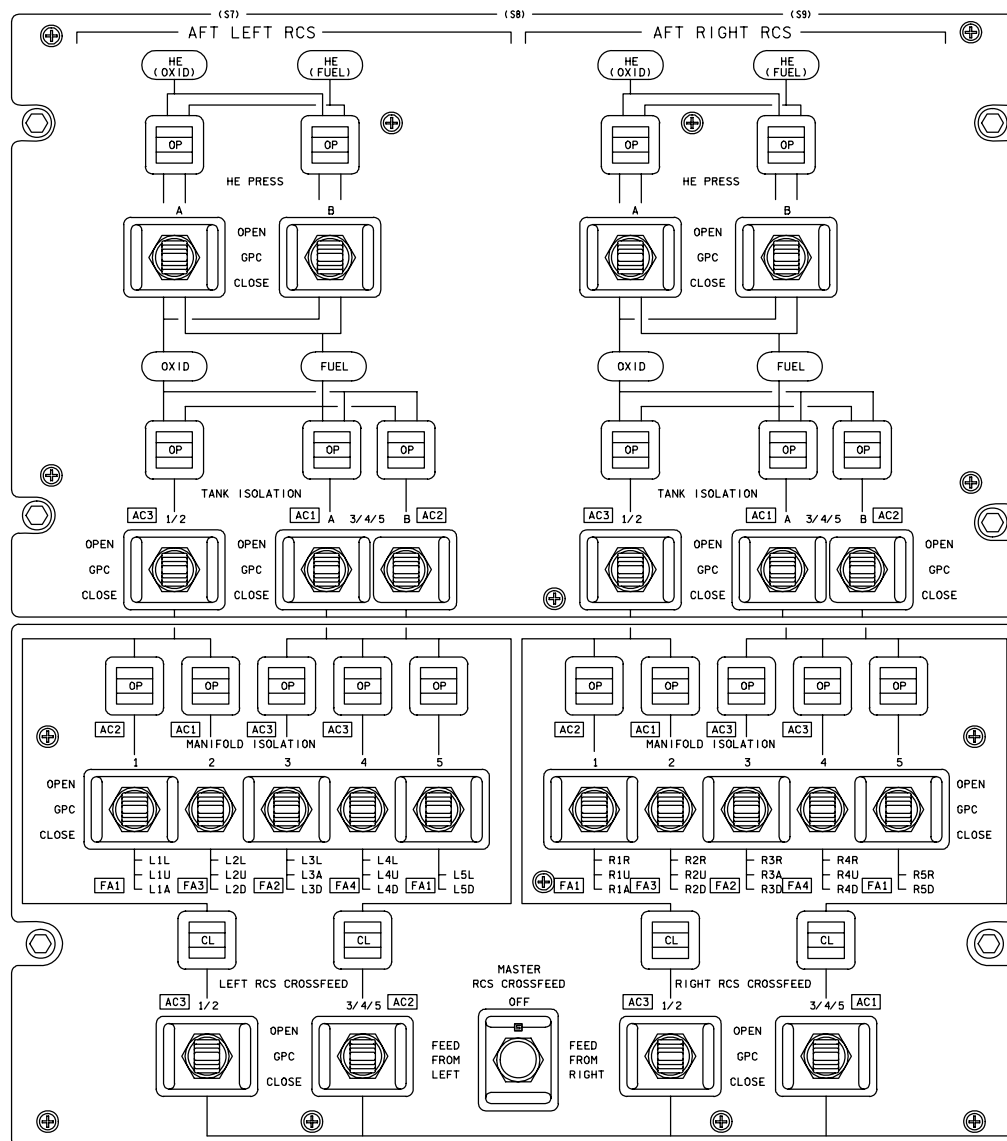


TD3400220, ART. 2

Figure 2-20. Panel O3

2.5.1.5 Panel O7

Panel O7, 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 O8.



TD3400221. ART. 3

Figure 2-21. Aft RCS switches

2.5.1.6 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.

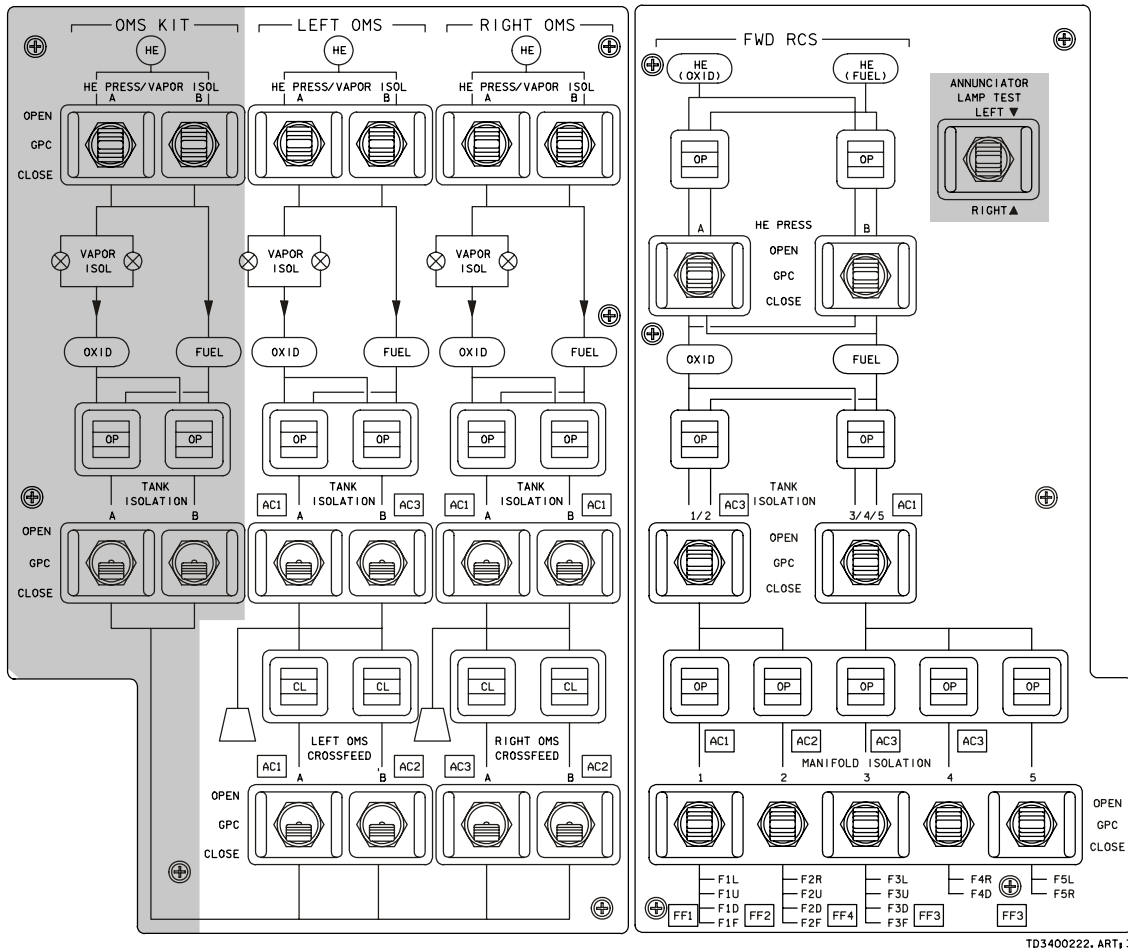
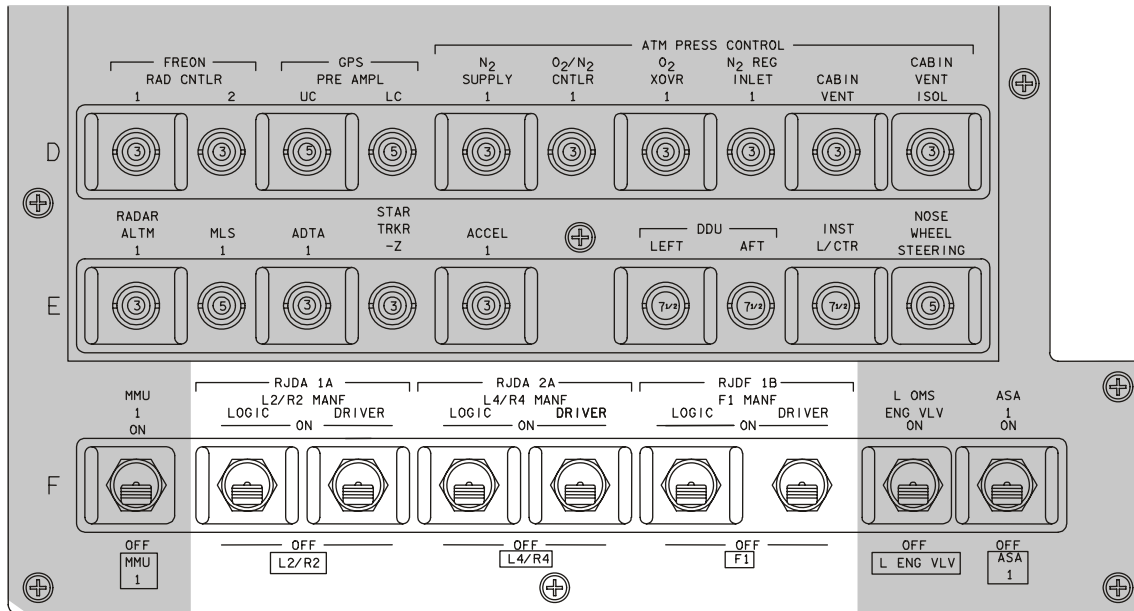


Figure 2-22. OMS and forward RCS switches

2.5.1.7 Panels O14/O15/O16

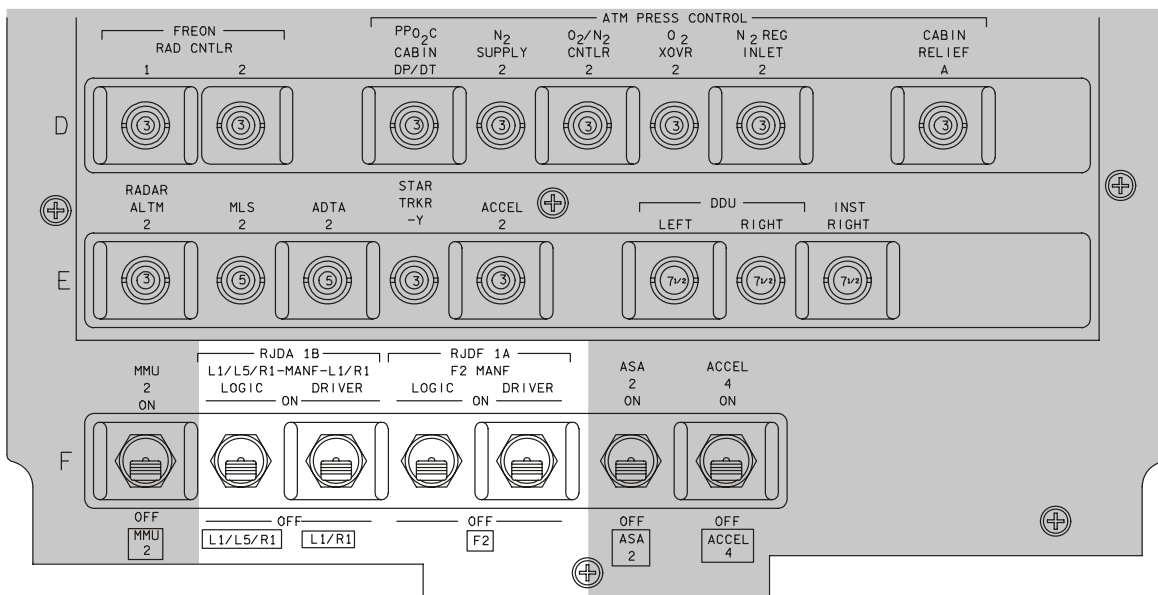
Row F of panels O14 (Figure 2-23), O15 (Figure 2-24), and O16 (Figure 2-25) contains the power switches for each RCS jet driver. The circuit breaker (cb) for the RCS/OMS quantity gauge (panel O3) is on panel O16, in row E at the far right.



014

TD3400223, ART. 2

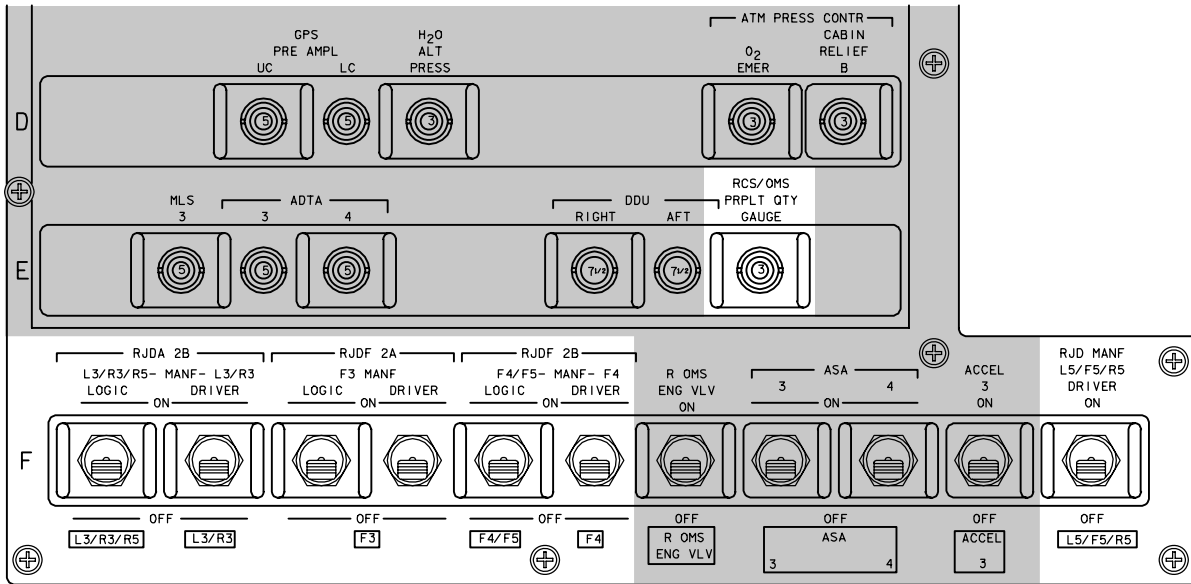
Figure 2-23. Panel O14 detail



015

TD3400224, ART. 3

Figure 2-24. Panel O15 detail



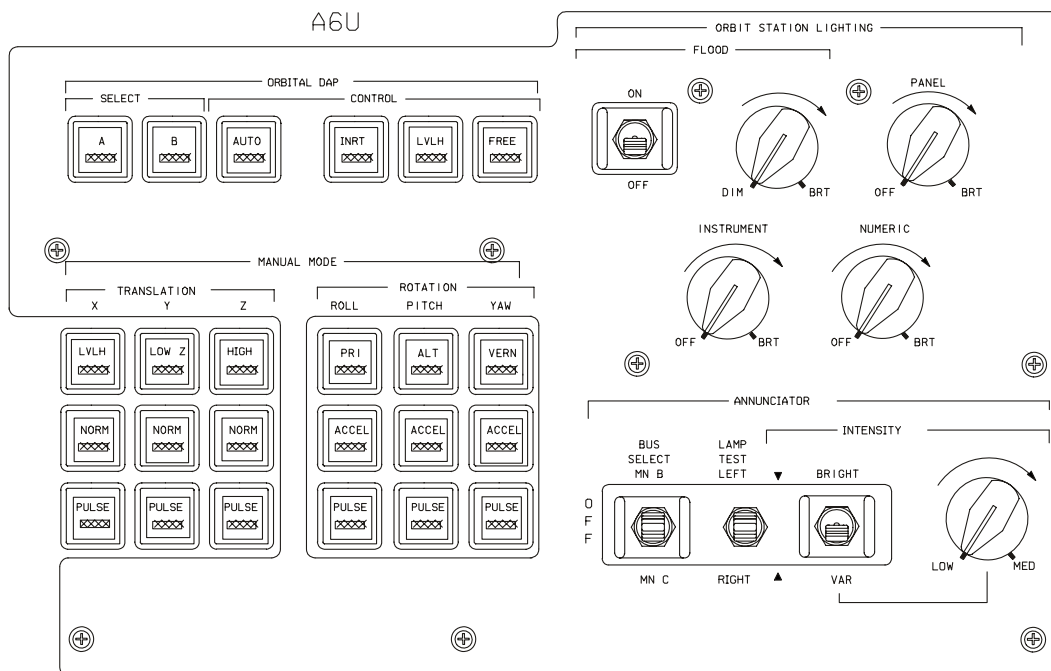
016

0061613011.PNL 1

Figure 2-25. Panel O16 detail

2.5.1.8 Panel A6

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

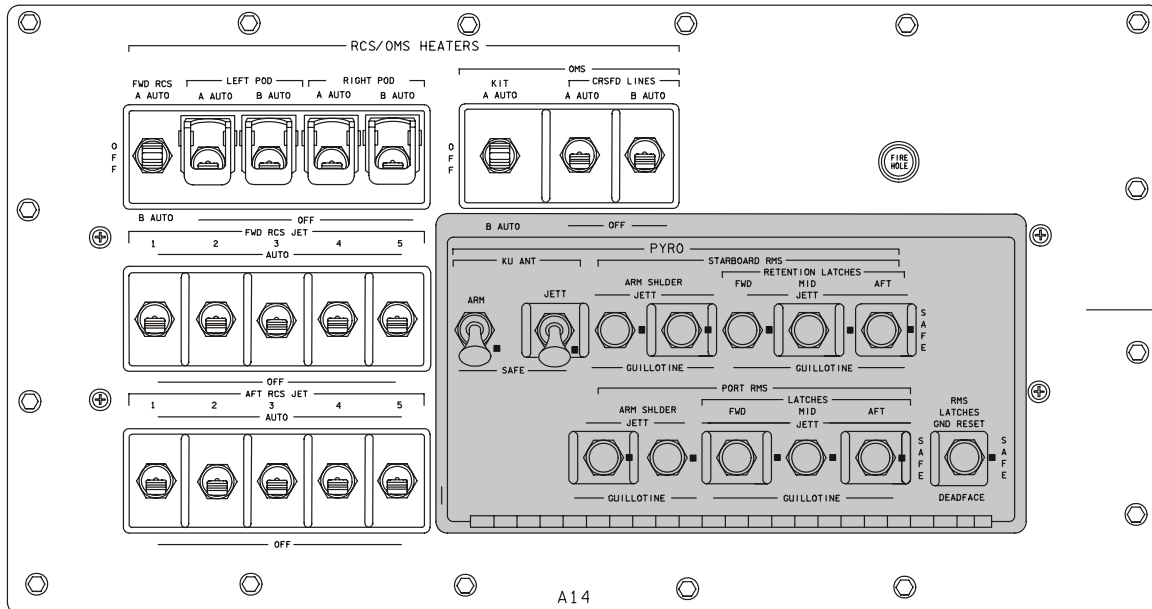


TD3400226.PNL 4

Figure 2-26. Aft DAP panel

2.5.1.9 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 in Section 2.7 for more information on these heaters.

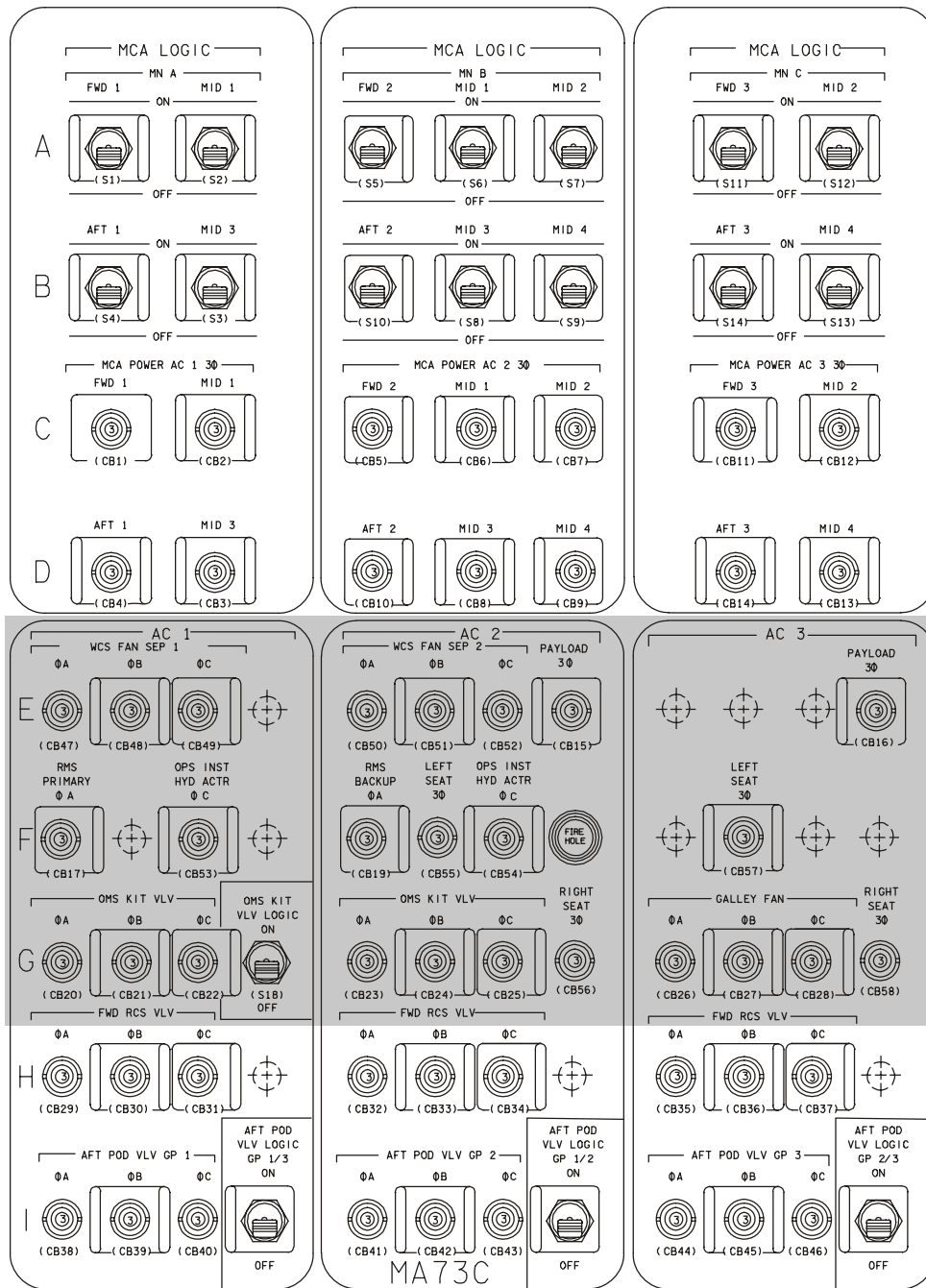


TD3400227.ART.2

Figure 2-27. RCS/Oms heater switches

2.5.1.10 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.



TD3400228. ART, 1

Figure 2-28. Panel MA73C

2.5.2 Displays

There are numerous CRT/MEDS 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 MMs 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)

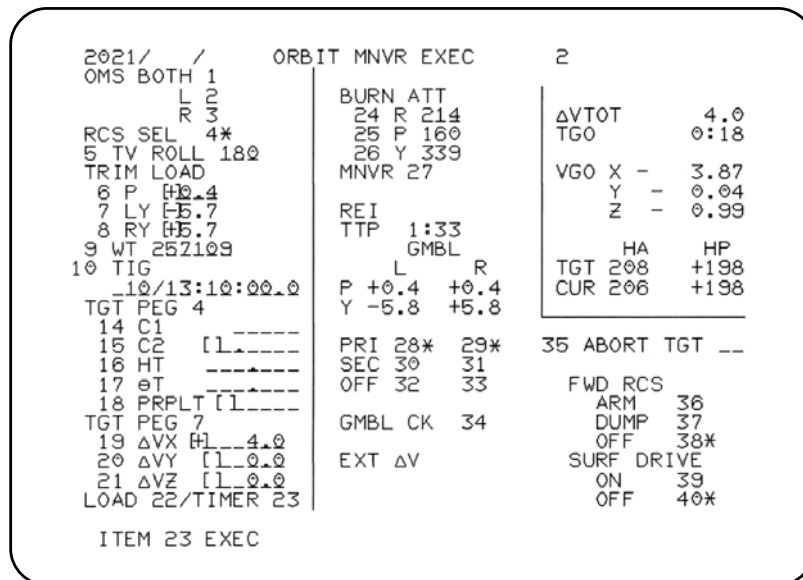
Item 4 is selected when the 4+X RCS jets are used, instead of the OMS engines, to perform a burn maneuver.

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.



usa006163_049.cvx

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
MM 105	OMS 2 MNVR EXEC	OMS 2 burn
MM 106	OMS 2 MNVR COAST	Post-OMS 2 coast
MM 202	ORBIT MNVR EXEC	Orbital maneuvers
MM 301	DEORB MNVR COAST	Pre-deorbit coast
MM 302	DEORB MNVR EXEC	Deorbit burn
MM 303	DEORB MNVR COAST	Post-deorbit coast

2.5.2.1 Guidance, Navigation, and Control System Summary 1

There is a System Summary 1 for both the PASS and the BFS; the PASS display is shown in Figure 2-30. System Summary 1 can be called up via the SYS SUMM key or with the keyboard entry SPEC 18 PRO. The BFS display has no RCS information and is not discussed further. On the PASS SYS SUMM 1 display, the RCS section is at the upper left side.

The JET FAIL column is for jet failure annunciations: jet fail Leak (LK), jet fail On (ON), and jet fail Off (OFF). The ISOL VLV column displays manifold valve status, either Open (OP) or Closed (CL). If there are no failures, the jet fail column is blank.

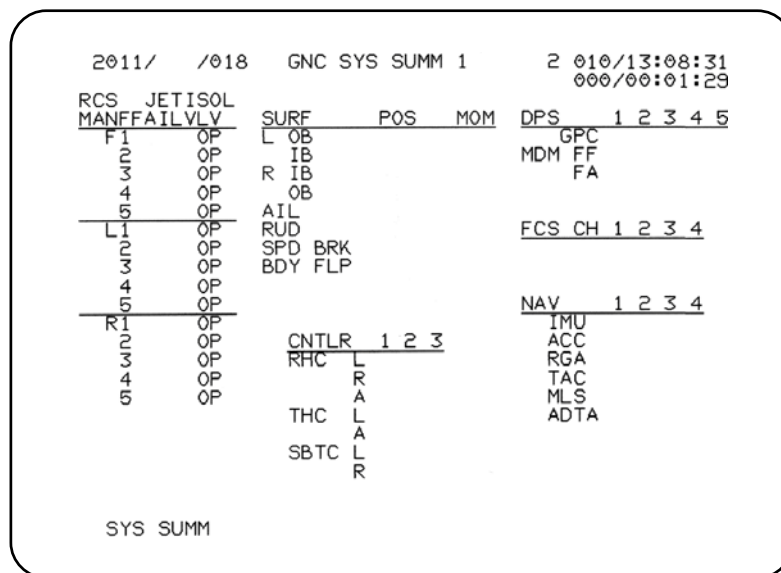


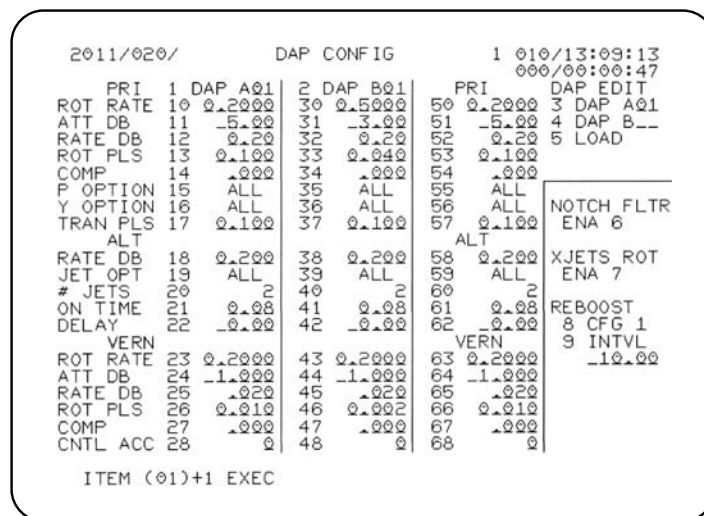
Figure 2-30. System Summary 1 display

2.5.2.3 Digital Autopilot Configuration

This DAP Configuration 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 DAP that affect jet selection and fire duration. Detailed information related to the DAP is available in the I/O/D G&C Training Document and the DPS dictionary.

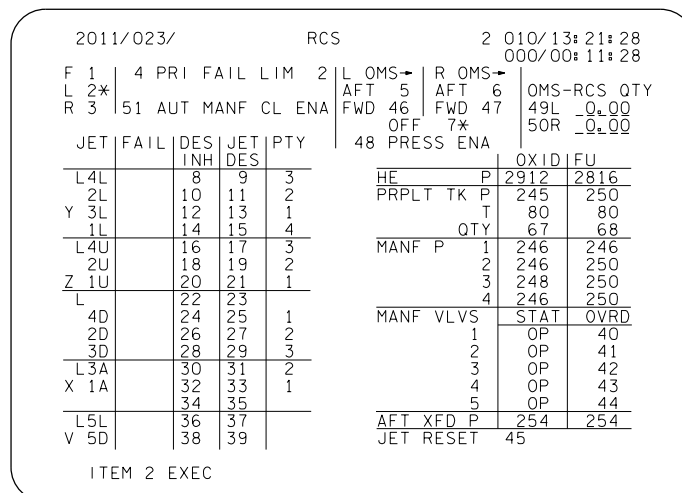
2.5.2.4 Reaction Control System

This RCS display, as illustrated in Figure 2-33, is covered in greater detail in subsequent sections of this workbook. It is called up with a keyboard entry of SPEC 23 PRO and is available in OPS 1, 2, 3, 6, and 8.



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Figure 2-32. Digital autopilot display

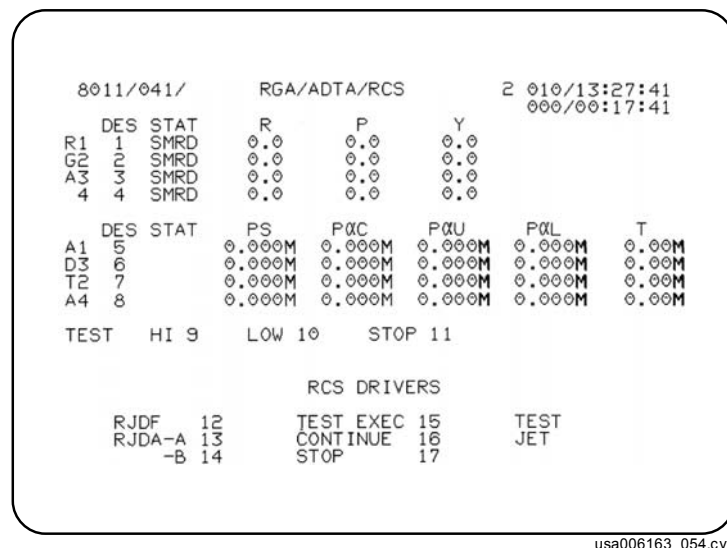


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Figure 2-33. Reaction Control System display

2.5.2.5 Rate Gyro Assembly/Air Data Transducer Assembly/RCS

This GNC display, Rate Gyro Assembly (RGA)/Air Data Transducer Assembly (ADTA)/RCS, as illustrated in Figure 2-34, is available in OPS 8 only and is called up with a keyboard entry of SPEC 41 PRO. The RCS Drivers portion of the display is not currently being utilized for nominal checkout procedures. Originally, it provided a means to perform the RCS driver test in OPS 8 to check the RCS driver command path to the RCS jets. The test detected electrical shorts or open circuits from the GPC to the RJD. Subsequently, this test was replaced with the RCS hot fire test, which actually fires jets, and thus gives a better indication of jet functionality. (The hot fire test is discussed further in Section 3.3).



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Figure 2-34. RGA/ADTA/RCS display

2.5.2.6 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 Figure 2-35 and Figure 2-36. Keyboard entries to BFS OVERRIDE are effective only if the BFS is engaged. This display is used to execute the following actions:

- a. Inhibit (INH)/Enable (ENA) the OMS-to-RCS abort interconnect (item 5) for RTLS/TAL/Abort-to-Orbit (ATO) abort dumps. (XXX by item 5 is ENA or INH, as appropriate.) Inhibiting the interconnect also inhibits 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 SERC. A SERC interconnect cannot be inhibited.

- b. Stop any OMS or RCS abort dump (item 8).


```

3031/051/          OVERRIDE          2 010/18:23:28
                                000/00:17:28
ABORT MODE          ENTRY FCS
TAL                1          ELEVON  FILTER  ATMOSPHERE
ATO                2          AUTO 17*  NOM 20   NOM    22*
ABORT              3          FIXED 18   ALT 21*  N POLE 23
THROT MAX         4          SSME REPOS 19 ENA  S POLE 24
  ABT 50
  NOM 51
PRPLT DUMP
INH ICNCT         5          IMU STAT ATT DES          PRL
OMS DUMP
ARM              6          1 25          SYS AUT DES
START           7          2 26          1↓ 28* 31
STOP            8          3 27          2↓ 29* 32
9 QUAN/SIDE     84          7 27          3↓ 30* 33
OMS DUMP TTG    456
AFT RCS 13      INH
14 TIME         0
FWD RCS 15      INH
16 TIME         0
ELEVON          FILTER  ATMOSPHERE
AUTO 17*        NOM 20   NOM    22*
FIXED 18        ALT 21*  N POLE 23
SSME REPOS 19  ENA    S POLE 24
IMU STAT ATT DES          PRL
1 25          SYS AUT DES
2 26          1↓ 28* 31
3 27          2↓ 29* 32
7 27          3↓ 30* 33
H 0 0.0 0.00 34
0 0.0 0.00 35
0 0.0 0.00 36
0 0.0 0.00 37
E
AUTO 38          ROLL MODE AUTO
SEP 39          AUTO SEL 42
ET UMB DR       WRAP MODE 45 ENA
CLOSE 40        VENT DOOR CNTL
RCS RM MANF     OPEN 43
CL OVRD 41      CLOSE 44* CL

```

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Figure 2-35. PASS OVERRIDE display

```

3031/051          OVERRIDE          5 010/18:20:34
                                BFS 000/00:20:22
ABORT MODE          ENTRY FCS
TAL                1          ELEVON  FILTER  ATMOSPHERE
ATO                2          AUTO 17*  NOM 20   NOM    22*
ABORT              3          FIXED 18   ALT 21*  N POLE 23
THROT MAX         4          SSME REPOS 19 ENA  S POLE 24
  ABT 50
  NOM 51
PRPLT DUMP
INH ICNCT         5          IMU DES ATT          AA  RGA  SURF
OMS DUMP
ARM              6          1 25  2  LRU DES  DES  DES
START           7          2 26  1  31  35  39
STOP            8          3 27  2  32  36  40
9 QUAN/SIDE     015        ET SEP          3  33  37  41
OMS DUMP TTG    000        AUTO 28          4  34  38  42
                          SEP 29
AFT RCS 13      INH
14 TIME         000        ET UMB DR          ROLL MODE
                          CLOSE 30          WRAP MODE 45 ENA
FWD RCS 15      INH
16 TIME         000        VENT DOOR CNTL          COMM  LOCK
                          OPEN 43          TDRS  46*
                          CLOSE 44* CL    STDN-HI 47
                          SGLS  49

```

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Figure 2-36. BFS OVERRIDE display

- c. Start a contingency abort dump in OPS 1 or 6 (item 6, followed by an item 7).
- d. Start an OMS dump in OPS 3 (item 6, then 7) that also dumps OMS propellant through RCS jets if item 5 is ENA.
- e. Inhibit/enable the aft and forward RCS dumps (items 13 and 15, respectively) or modify dump times (items 14 and 16, the displayed dump times in seconds for the respective dumps. Items 14 and 16 are initialized with I-loaded values in OPS 1 and TAL OPS 3. The OPS 6 display uses the last OPS 1 values. The OPS 3 non-TAL display is initialized at zero. Executing an item 14 or 16 in OPS 1, 3, or 6

changes that dump time to the selected value. Items 13-16 are blank during a contingency dump.)

- f. Control vent door operation (items 43 or 44 as appropriate) if propellant is leaking.
- g. On PASS SPEC 51 only, change a “closed” manifold status to “open” (item 41) for any manifold status that is closed because of a dilemma.
- h. On PASS SPEC 51 and in OPS 3 only, select DAP “Wrap Mode” (item 45).

Note: This Entry DAP setting provides increased efficiencies in RCS usage during nominal entry (not recommended for failure scenarios), and the “Wrap” term should not be confused with RCS wraparound firings for assisting OMS burn roll control.

The procedural logic for these actions is covered in later sections of this workbook.

2.5.2.7 Thermal and Propellant Thermal

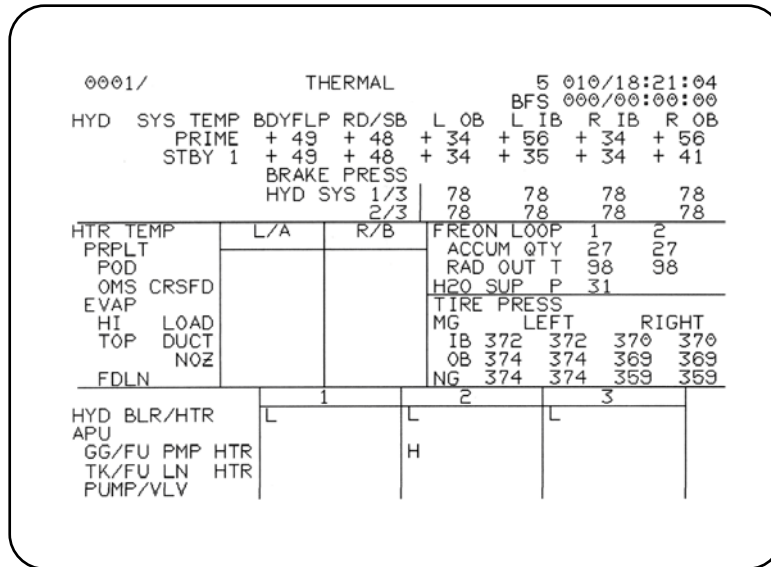
These displays are covered in greater detail in Section 2.7, Thermal Control. The propellant thermal display (Figure 2-37) Systems Management (SM) can be called up in OPS 2 with a keyboard entry of SPEC 89 PRO. The BFS thermal display (Figure 2-38) is displayed automatically when the BFS computer is 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.

2011/ /089		PRPLT		THERMAL		4 010/13:14:04	
POD		L	R			000/00:00:00	
OMS TK	OX	78	78	OMS CRSFD	L	R	C
	FU	78	78	XFD	OX	65	75
ENG I/F	OX	70	70	DRN	GMBL LN	66	70
	FU	70	70		OX	67	77
	OX VLV	70	70				
	FU INJ	81	81				
WEB KEEL	1	72	72				
	2	73	73				
Y	OB	67	67				
	UP	67	67				
OX DRN PNL	1	63	63				
	2	63	63				
ENG COVER		66	67	FWD RCS	FU	OX	
SERV PNL		67	67	LINE	T1	80	80
GSE SERV PNL		64	64		T2	80	80
TEST HE/OX	1	69	69				
	2	69	69	AFT RCS	L	R	
				MANF 1	OX	67	67
				DRN PNL	1	61	61
					2	61	61
				VERN PNL	1	86	86
					2	86	86

SPEC 89 PRO

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Figure 2-37. Propellant thermal display

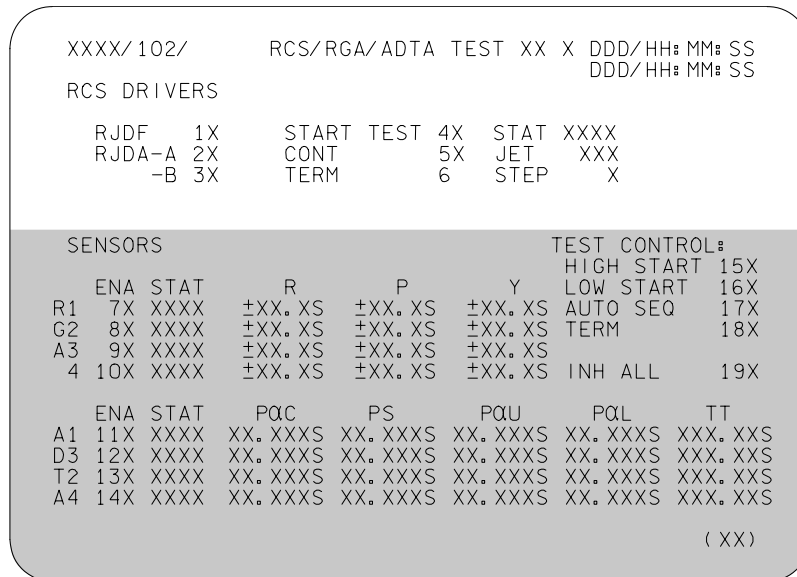


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Figure 2-38. BFS THERMAL display

2.5.2.8 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.



TD3400239. ART 1

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

2.6 REDUNDANCY MANAGEMENT

RM for the RCS is a series of GPC processes that detect, identify, and monitor RCS performance by using the following GPC software modules:

- Jet fail on monitor
- Jet fail off monitor
- Jet fail leak 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 the workbook.

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

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

MANF		VLVS	STAT	OVRD
	1		OP	40
	2		OP	41
	3		OP	42
	4		OP	43
	5		OP	44

HE		P	OXID	FU
	2912			2816
PRPLT	TK	P	245	250
		T	80	80
		QTY	67	68
MANF	P	1	246	246
		2	246	250
		3	248	250
		4	246	250
AFT	XFD	P	254	254
JET	RESET		45	

ITEM 2 EXEC

00616309. CRT; 1

Figure 2-40. RCS display

SPEC 23 has three display pages, one for each RCS module: forward, left, and right. It displays the forward RCS page when called up for the first time. Subsequent requests for this SPEC show the last requested page. Items 1, 2, and 3 are used to change the pages to the desired pod. When using SPEC 23, first ensure that the desired pod is displayed. Because each page has a similar layout (and the item functions are identical), the example and discussion is 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 particular jet failures. There are three types of jet failures: fail on, fail leak, and fail off. The annunciation shows ON, LK, or OFF, as appropriate. These failures are detected and annunciated by jet fail monitors. For SPEC 23, only the most recent failure for any one jet is displayed. For example, if L2L fails OFF, an OFF is displayed; if a subsequent leak is detected in L2L, the OFF changes to LK. The identical annunciations also appear on the fail columns of SYS SUMM 1 and SYS SUMM 2 for the appropriate manifolds, but only per the specific hierarchy where ON has priority annunciation over LK and OFF and where LK has priority over OFF. Once a particular jet failure has been annunciated, that particular failure cannot be re-annunciated until the RM is reset. RM reset will be covered in more detail later in this workbook.

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.

2.6.1 Fail On Monitor

The jet fail on monitor for the PASS and for the BFS uses different means to detect a jet failed on. Both are illustrated in Figure 2-41. The BFS uses the P_c discrete for simplicity, while the PASS uses a complex, but more reliable, driver output. 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 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/MEDS, RCS JET matrix light, and master alarm tone).

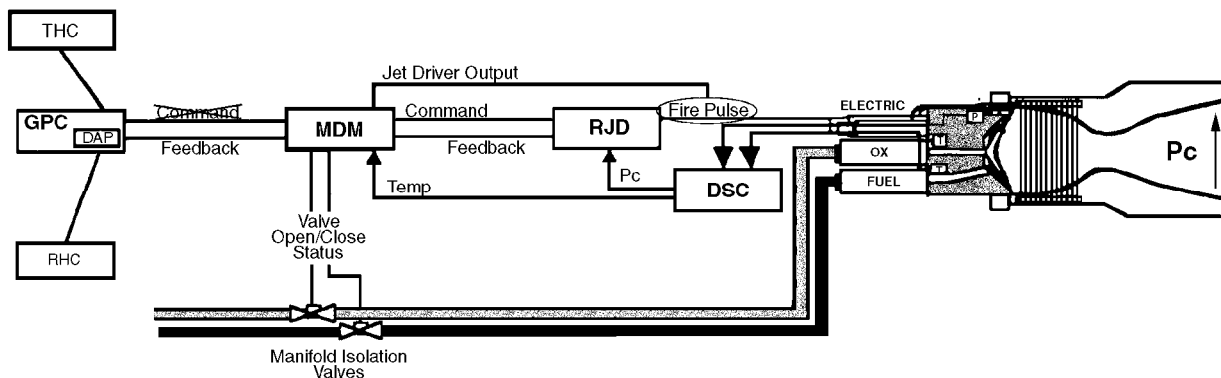


Figure 2-41. Jet fail on detection

2.6.2 Fail Off Monitor

The jet fail off monitor for both PASS and BFS uses jet fire command discretely and jet P_c discretely to determine if a jet has failed to fire when commanded. If a fire command is sent, but the P_c discrete is zero, 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. The jet fail limit module is discussed in Section 2.6.6.

2.6.3 Fail Leak Monitor

The jet fail leak monitor, in PASS, uses fuel and oxidizer injector temperature transducer outputs from each RCS jet to detect a propellant leak in the associated jet. As propellant leaks into the combustion chamber, it freezes and brings down the injector temperature. 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° F for both fuel and 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.

The BFS has no jet fail leak monitor because of the limited computing power of the BFS.

2.6.4 Available Jet Status

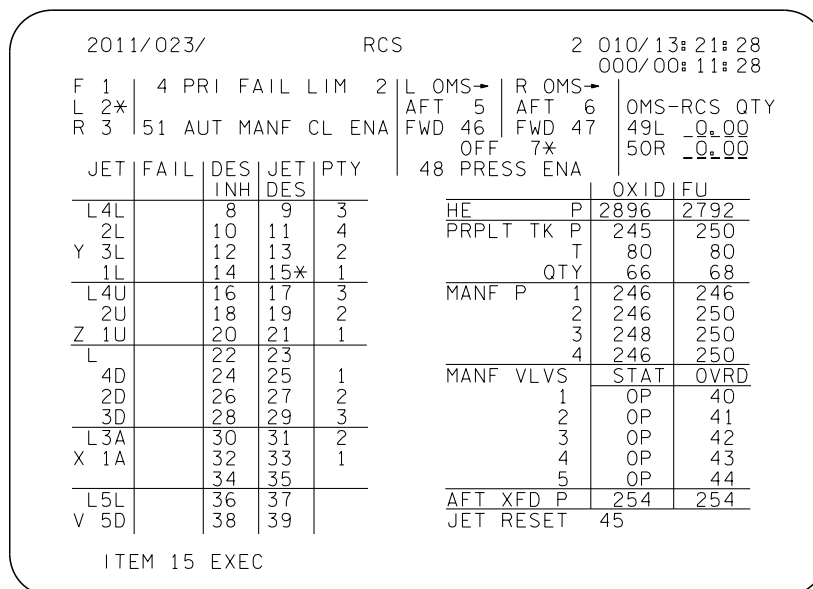
The available jet status table (also called the jet availability table) tells the DAP which jets it may use to get the desired vehicle motion. On SPEC 23, the primary jets are grouped by fire direction (JET column) and selection priority (PTY column).

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

An asterisk in the JET DES column indicates that the jet has been removed from the jet availability table. If the DAP requires the firing of a left yaw jet, it selects the highest priority jet available in the Y group. The RCS condition, presented on Figure 2-42, 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 produce 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)



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Figure 2-42. RCS display showing jet availability

2.6.5 Manifold Status

The manifold valve status display is in the lower right corner of SPEC 23. The status can be either OP or CL. The display receives inputs from the manifold status monitor. The monitor determines the open or closed status for each jet manifold by using the open and closed discretes from microswitches on the fuel and oxidizer manifold isolation valves. The status output of the monitor is based on the specific combination of discretes present. If both the FU and OX manifold isolation valves read open, that jet manifold is considered open. If both read closed, the jet manifold is considered closed. Note that the manifold status is a software state and is independent of the actual manifold valve position. Nominally, the manifold status will accurately reflect the physical status of the valves. However, a manifold valve could be open while the manifold status reads closed or, conversely, the valve could be closed while the status reads open.

The manifold valve status is affected by certain failures. If the FU and OX manifold isolation valve discretes disagree (e.g., one reads open and the other closed), this creates a manifold dilemma. A dilemma automatically changes the manifold status to closed and places a question mark (?) by the affected status. A GPC/MDM failure will also automatically change the manifold status to closed, placing a commfault indicator (M) by the affected status. Dilemmas and commfaults are discussed further in Section 4.

The manifold status display also receives inputs from keyboard entries. An item 40 (or an item 41, 42, 43, or 44) entry overrides the software status of the selected manifold to the opposite condition. The manifold status is reevaluated at each change of state. Changes of state are caused by microswitch failures, electrical failures, valve motion, keyboard entry, or OPS transition. Whenever a manifold status is set closed, all available jets on that manifold are automatically removed from the availability table. An asterisk appears in the JET DES column by each affected jet.

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

2.6.6 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 leak. Auto deselection removes the affected jet from the availability table. There is no capability for the automatic deselection of a failed on jet since deselection will not necessarily protect against a failed on command.

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 OFF (or LK), no further fail discretes of that type for that jet are sent to the jet fail limit module unless

RM is reset. For example, if jet L2U failed off, the software would annunciate this failure only once. Subsequent failed attempts to fire L2U would not be annunciated.

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 two 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, say L2U has previously failed off (annunciated and auto deselected). Then, L3D is declared failed leak. L3D is also annunciated and deselected. However, now two primary jets on the left pod have been deselected. If L1A fails off, it will annunciate, but it will not be auto deselected. Auto deselection because of a jet failure should not be confused with auto jet removal because of a closed manifold status, even though both cause an asterisk to appear in the JET DES column. The jet fail limit applies only to auto deselection, not to auto jet removal.

The jet fail limit can be changed by keyboard entry, but it changes only the limit of the pod being displayed. For example, in 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 leak are auto deselected, but only if those jets are candidates for auto deselection.

For a jet to be a candidate for auto deselection, no asterisks appear in the columns for JET DES or DES INH (deselect inhibit capability is 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, those jets are auto deselected (in no particular order) up to the new fail limit. If the fail limit is decreased while auto deselections are active, there is no change because there is no auto reselection capability.

2.6.7 Jet Availability Keyboard Entries to SPEC 23

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, where SPEC 23 is not available, the affected manifold switch must be cycled to open to reselect any auto deselected jet. The crew must check with Mission Control Center (MCC) to determine which jet is auto deselected by the BFS.)

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, a JET DES item entry deselects that jet and an asterisk appears. If an asterisk is present because of either a manual or auto deselection, the item entry manually reselects that jet and the asterisk disappears. However, if the asterisk is present because of a closed manifold status, the JET DES item entry has no effect and the asterisk remains, indicating the jet is still unavailable.

Manual reselection of an auto deselected jet decrements the jet fail limit counter, while manual reselection of a manually deselected jet has no effect on the jet fail limit counter.

If a jet is auto deselected because of a fail off and is subsequently reselected, the JET DES asterisk disappears, indicating that jet is now available. If the jet fail limit was set at 2 and two jets were auto deselected, manual reselection would decrement the jet fail limit counter from 2 to 1, allowing for the auto deselection of one subsequent jet failure for that pod. Although this jet is reselected, the failure annunciation (OFF) remains because the RM has not been reset. (JET DES item entries do not reset RM.) This reselected, but failure annunciated, jet cannot be auto deselected again for a fail off. The fail off counter for that jet is full, and no discretetes for fail off go to the auto deselect counter. However, a fail leak for that jet results 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. The other method uses the JET Reset item entry. The DES INH item entry was originally designed to inhibit auto deselection but is now more often used to change the firing priority of the jet. A DES INH item entry inhibits auto deselection and lowers the jet fire priority of that jet to the lowest priority in its associated group. The other jets in that group increase their priorities by a count of one. An asterisk appears by the item number in the DES INH column. Inhibiting auto deselection has no effect on manual deselection. If no asterisk is present in the DES INH column, then auto deselect is enabled for that jet. The DES INH item entry performs several functions depending upon the number of times it is entered for a particular jet. Once an asterisk is present in the DES INH column, a subsequent DES INH item entry for that jet removes the deselect inhibit and allows 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 removes all jet fail

annunciations and resets 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 remains auto deselected until manually reselected.

If a jet has an asterisk in the DES INH and an asterisk in the JET DES column, a DES INH item entry still removes all failure annunciations and resets the RM for that jet. The DES INH asterisk disappears, but the JET DES asterisk remains. Subsequent failures could be annunciated, but auto deselection does 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 resets the RM (removes the failure annunciations and resets 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. Generally, "resetting RM" with an item 45 is preferred, since it does not also affect jet priority.

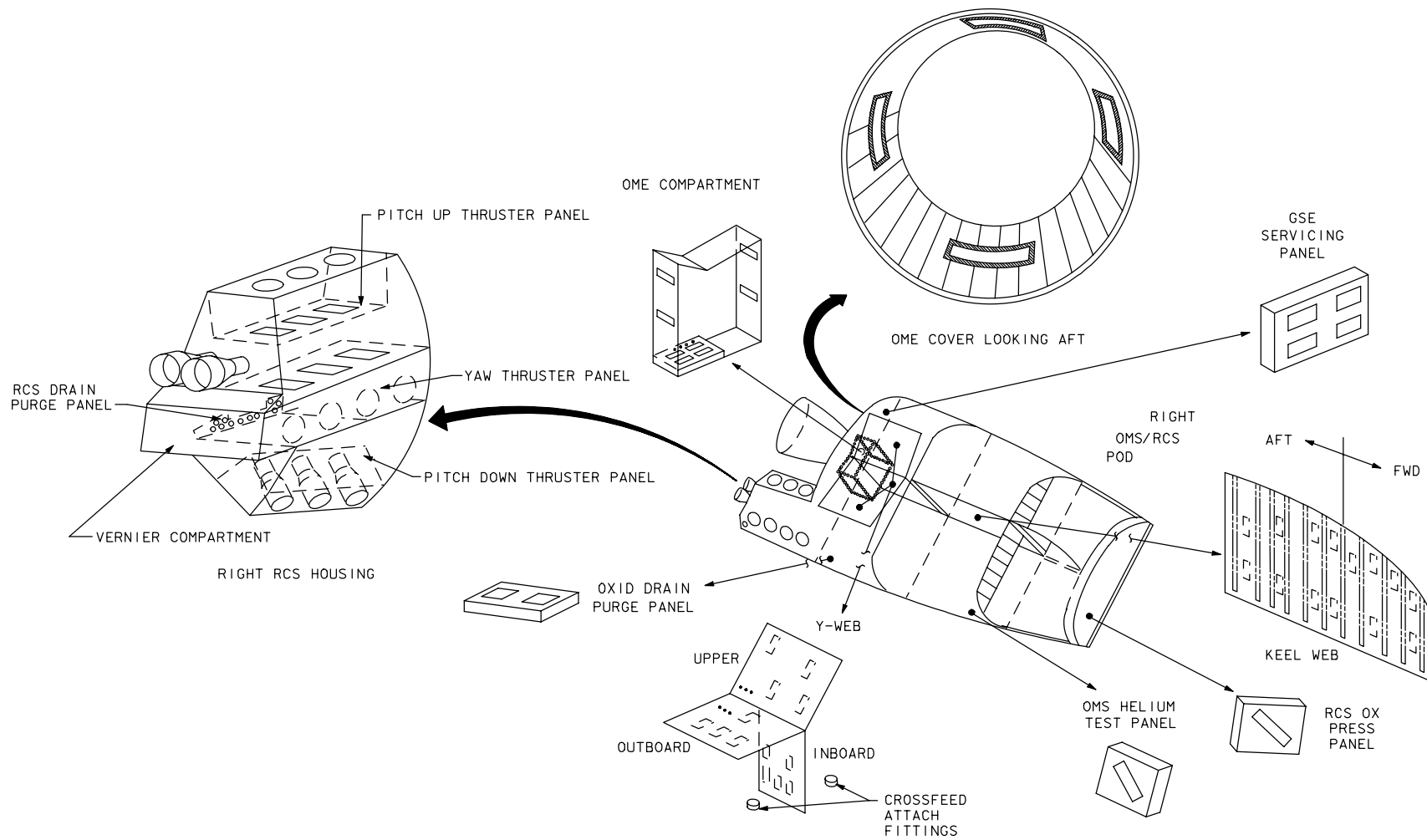
In summary, there are two ways to reset jet RM.

- a. Toggle RM (double item entry in DES INH). This method changes the jet fire priorities in the jet group and only resets RM on one jet per double keystroke. This method can reset RM on an unavailable jet.
- b. Reset RM with an item 45. This resets only the RM of available jets. If the jet is not available, 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.

2.7 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. 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 2-43). 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.

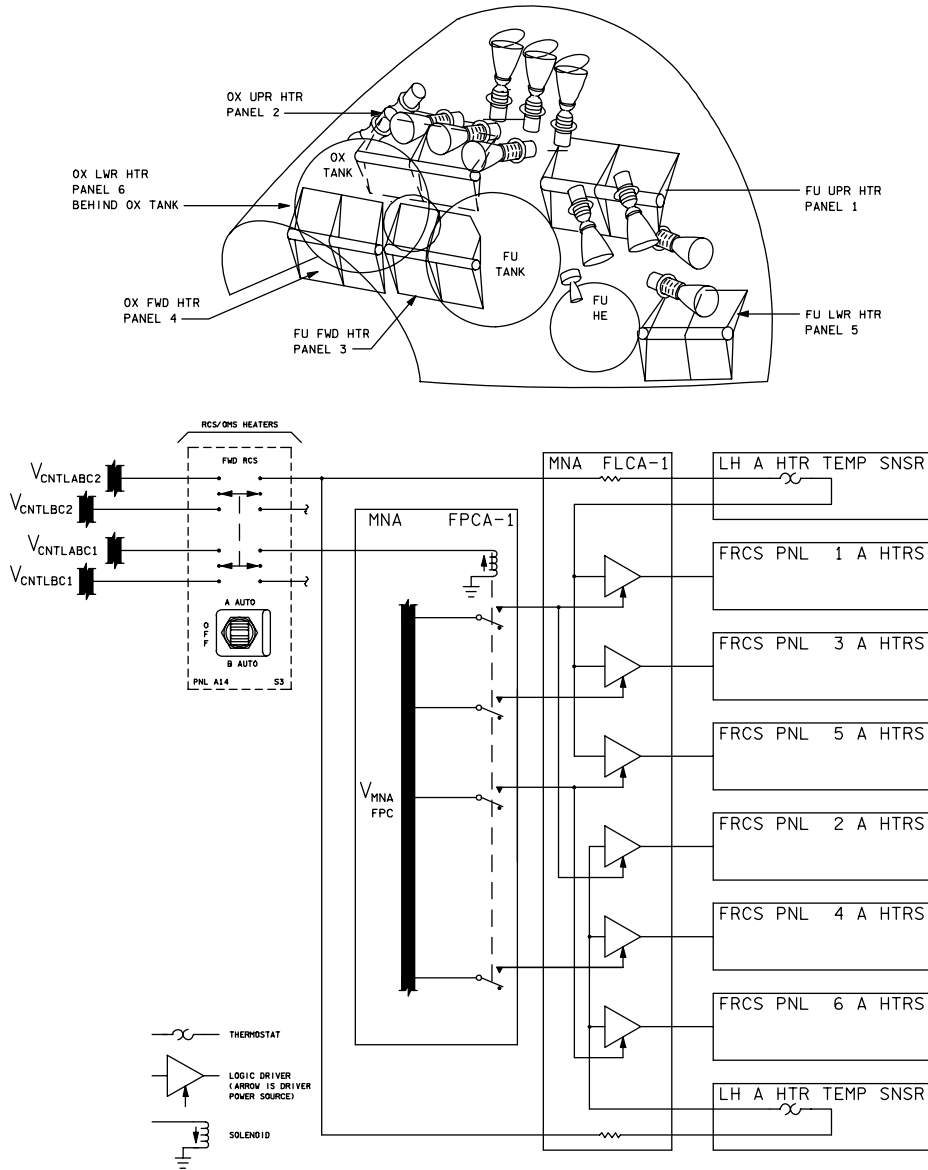


TD3400242, ART. 3

Figure 2-43. OMS/RCS pod heater location

Figure 2-44 shows the schematic for only 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 that maintain pod temperatures between 55° 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 causes the loss of the associated heaters.



TD340241B, ART: 4

Figure 2-44. Forward RCS pod heaters and schematic

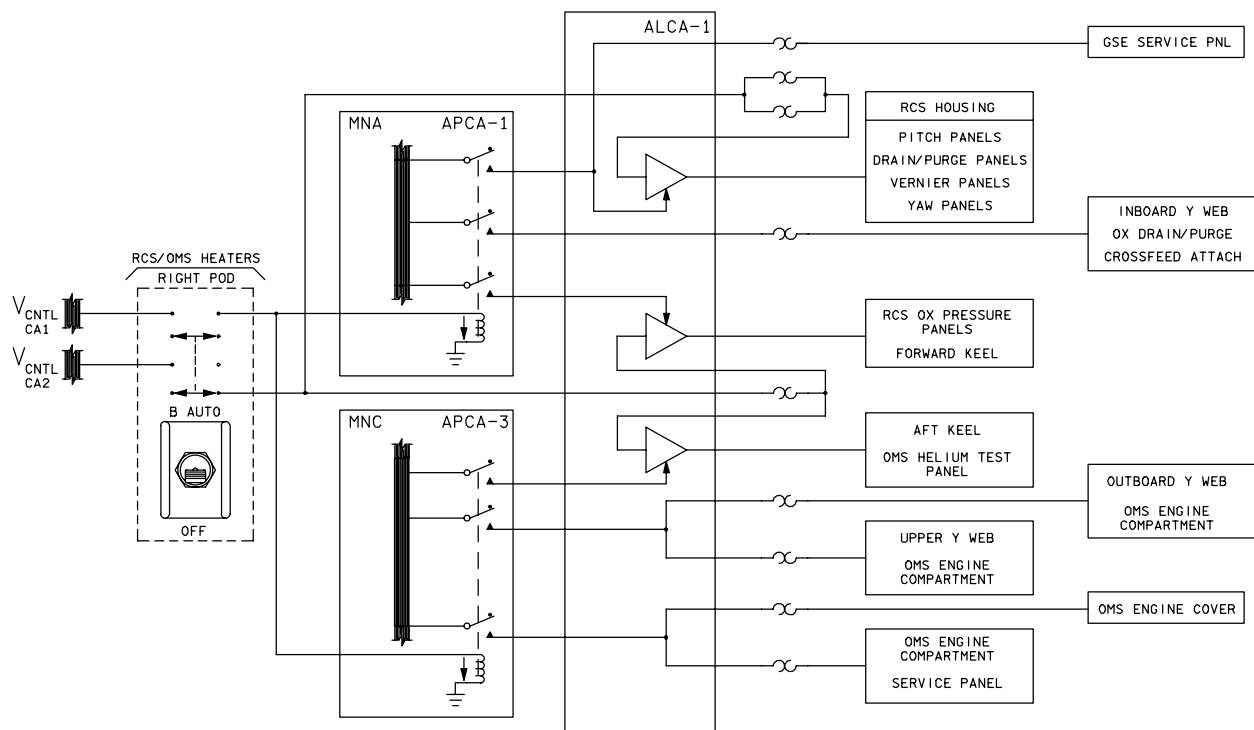
The aft RCS pods utilize numerous patch heaters attached to partitions throughout both pods.

There are two circuits that can activate these patch heaters, and each circuit has an associated switch. Figure 2-45 shows only the B circuit schematic for reasons of simplicity. Each switch provides dual control bus power to the associated circuitry. One control bus activates certain thermostats (55° to 90° F) that provide autocycling 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 causes the loss of all circuit heaters. The loss of the other control bus causes the loss of the majority of circuit heaters (RCS housing, keel, OMS TP, and RCS P 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 the patch heaters to separate from their mountings in the pod, which damages the heaters. Guards are provided for these switches to preclude inadvertent switch movement.

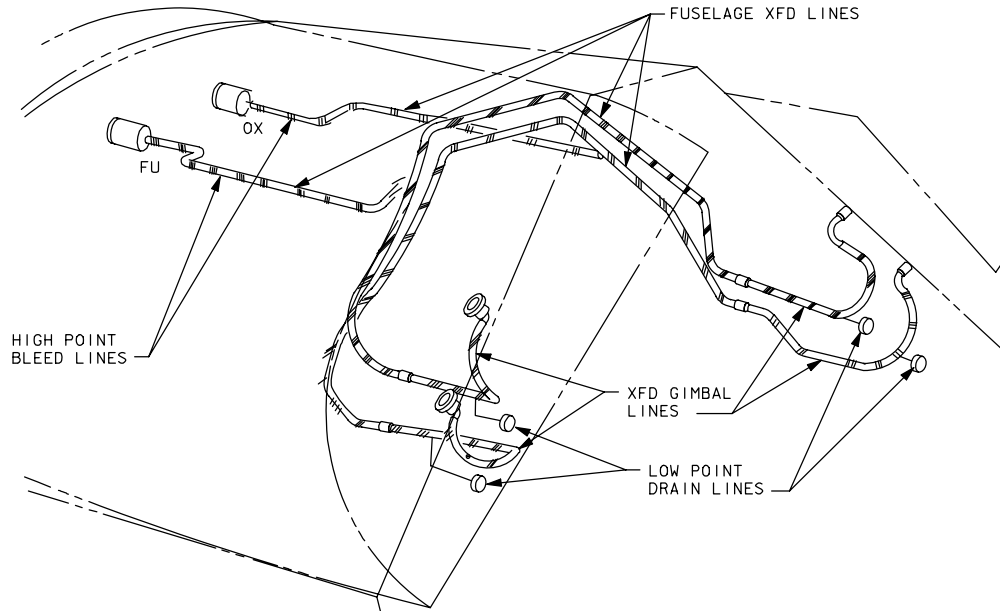
The forward and aft pod heaters are turned on during post insertion activities and turned off during entry preparations.



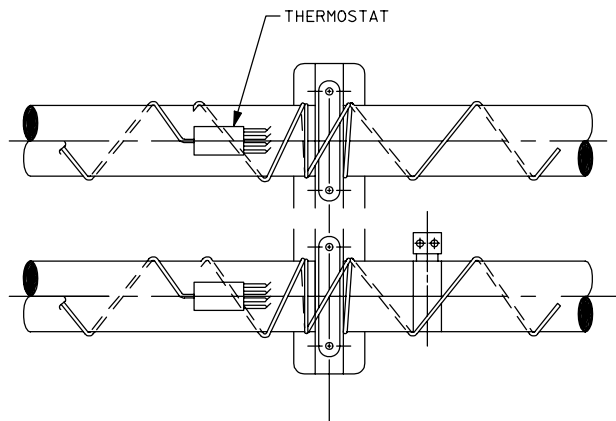
TD3400243, ART. 4

Figure 2-45. 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 2-46). There are two circuits (A and B) that can activate these line heaters. 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



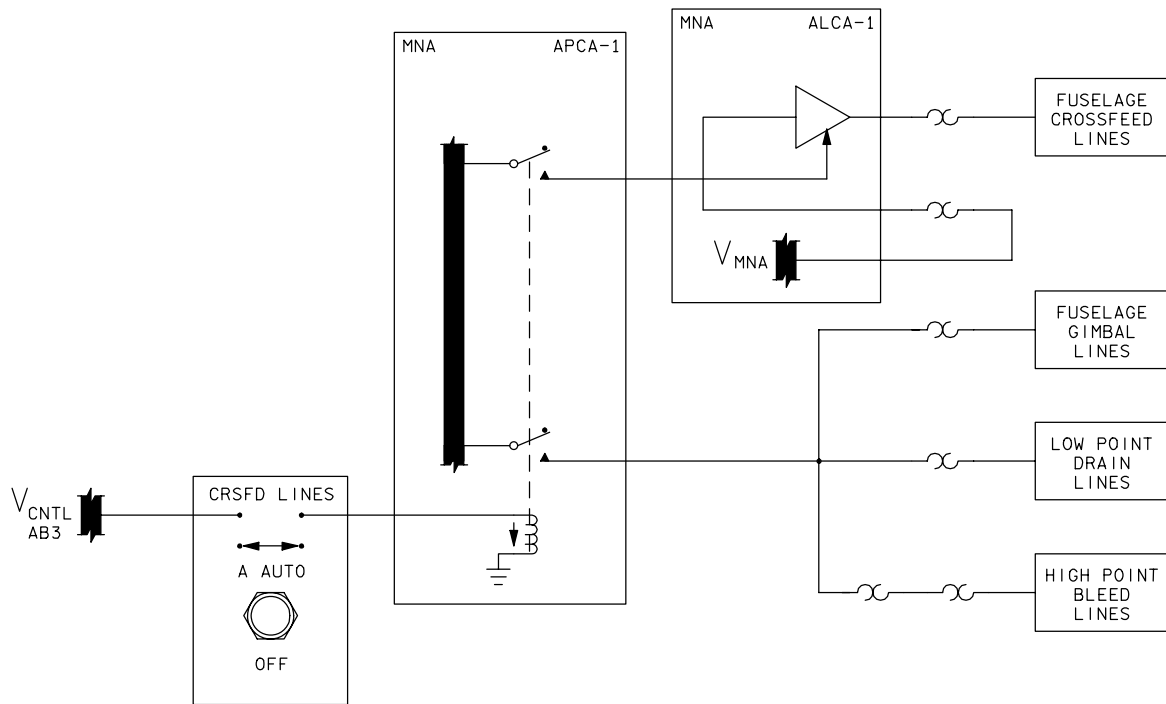
TYPICAL XFD LINE HEATERS AND THERMOSTATS

TD3400244, ART 3

Figure 2-46. OMS/RCS crossfeed heaters

Figure 2-47 shows a schematic for the crossfeed line A heaters. Note that there is only one control bus providing activation of the heaters and the thermostats (55° 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.

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



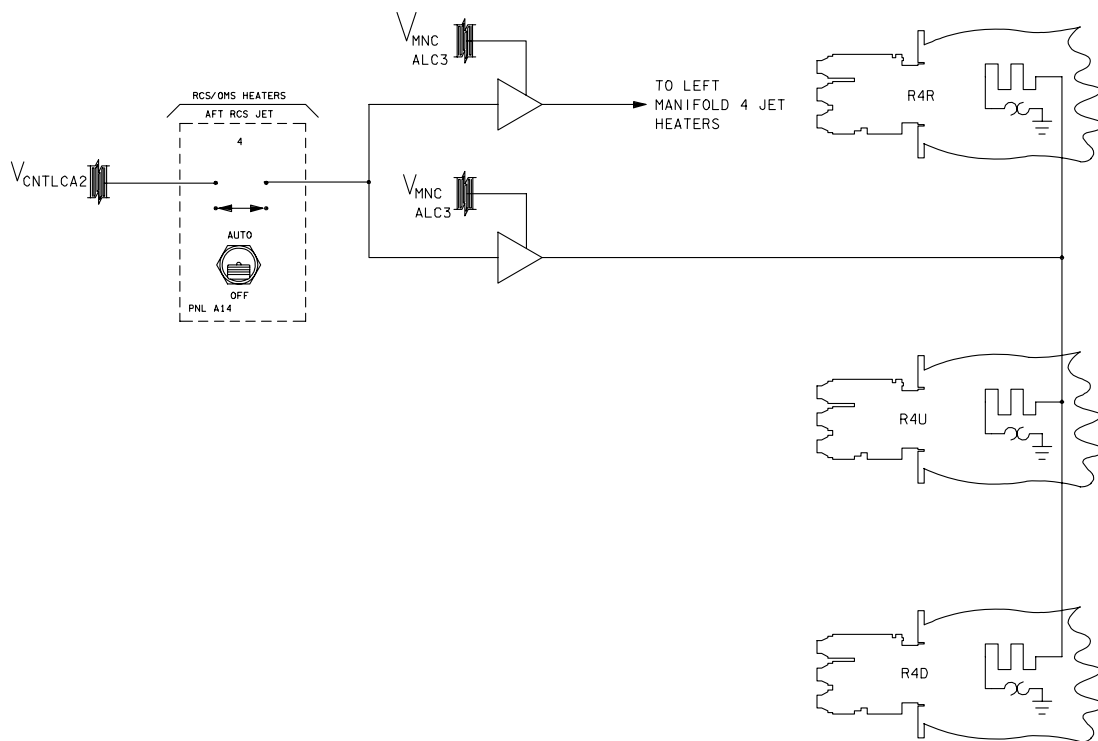
TD3400245, ART. 3

Figure 2-47. OMS/RCS crossfeed heater schematic

Figure 2-48 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.

During entry, the vernier jet heaters are turned off because 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 C&W limits, an alarm sounds and a fault message appears on a CRT/MEDS 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/MEDS display (or information from the ground) to determine the location of the thermal problem.



TD3400246. ART, 3

Figure 2-48. 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 (Figure 2-49) lists the temperature measurements at specific locations throughout the OMS/RCS modules. If there is a thermal alert, one or more of these temperature measurements has exceeded the GPC software limit. Next to each temperature indication is a space for a status indicator. The space is blank if the temperature is within normal limits and the sensor data are seen by the GPCs. Otherwise, the space is filled with one 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 established upper (↑) or lower (↓) limits. The H and L symbols indicate that 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 apply to areas affected by the left and right pod heaters. The data in the upper right corner apply to the areas served by the crossfeed line heater segment. The data in the right center of the display apply to the forward RCS module.

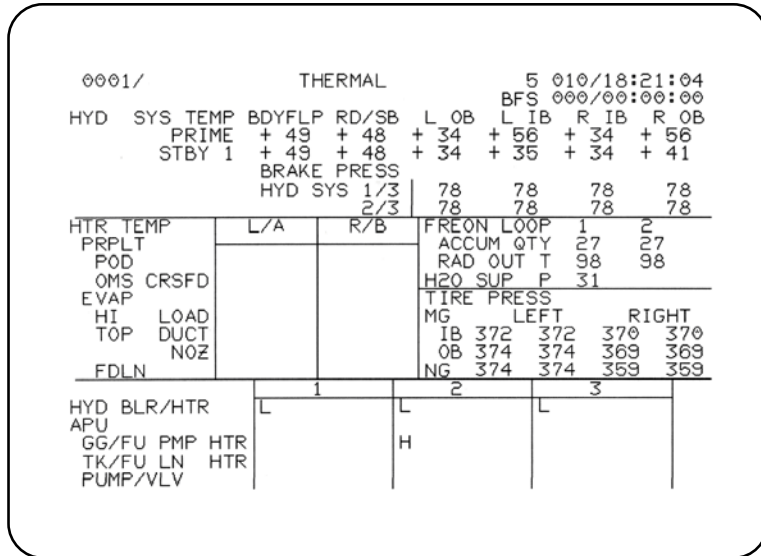
2011/ 089		PRPLT		THERMAL	4 010/13:14:04		
POD		L	R				
OMS TK	OX	78	78				
	FU	78	78	OMS CRSFD	L	R	C
ENG I/F	OX	70	70	XFD	OX	65	75
	FU	70	70	DRN	GMBL LN	66	70
	OX VLV	70	70		OX	67	77
	FU INJ	81	81				
WEB KEEL	1	72	72				
	2	73	73				
Y	OB	67	67				
	UP	67	67				
OX DRN PNL	1	63	63				
	2	63	63				
ENG COVER		66	67	FWD RCS	FU	OX	
SERV PNL		67	67	LINE	T1	80	80
GSE SERV PNL		64	64		T2	80	80
TEST HE/OX	1	69	69				
	2	69	69	AFT RCS	L	R	
				MANF 1	OX	67	67
				DRN PNL	1	61	61
					2	61	61
				VERN PNL	1	86	86
					2	86	86

SPEC 89 PRO

usa006163_057.cvx

Figure 2-49. PRPLT THERMAL display

The BFS thermal display (BFS SM OPS 0) is available anytime the BFS computer is in run or standby, which includes the ascent and entry phases. This display (Figure 2-50) 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 is either blank (for normal operation) or displays one of the indicators as described previously: M, ↑, ↓, L, H.



usa006163 058.cvx

Figure 2-50. BFS THERMAL display

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. What is the difference between a crossfeed and an interconnect?
3. Assume there is an asterisk in the JET DES column of SPEC 23 for L1L because of a closed manifold status. How can the asterisk be removed so that L1L is available to fire?
4. 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?
5. How does a jet P_c discrete failed low (false fail off) affect jet fail on RM?

Note: The answers are found in Appendix B.

3.0 SYSTEM OPERATIONS

3.1 OBJECTIVES

As a result of reading this section, the student should be able to

- State the function of the RCS system during ascent, orbit, entry, and aborts
- Identify and state the purpose of propellant dumps involving the RCS system during the abort sequence

To effectively describe RCS operations, it is necessary to separate the overall operations into four general areas: ascent, orbit, entry, and aborts.

3.2 ASCENT

The RCS is first used at SRB SEP, when the three forward up-firing jets fire to protect the forward windows from particulates from the SRB SEP motors. Before MECO (MMs 102-103), the RCS is also a backup system to be used for off-nominal situations (loss of two Space Shuttle Main Engines (SSMEs), propellant dump, etc.). Post-MECO, the RCS is used to hold attitude during the mated coast phase. Post-ET Sep, the 10 down-firing jets are used to maneuver the orbiter away from the ET. The RCS is also used in the two manual ET Photo Maneuvers, +X translation and rotation about the Y body-axis.

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

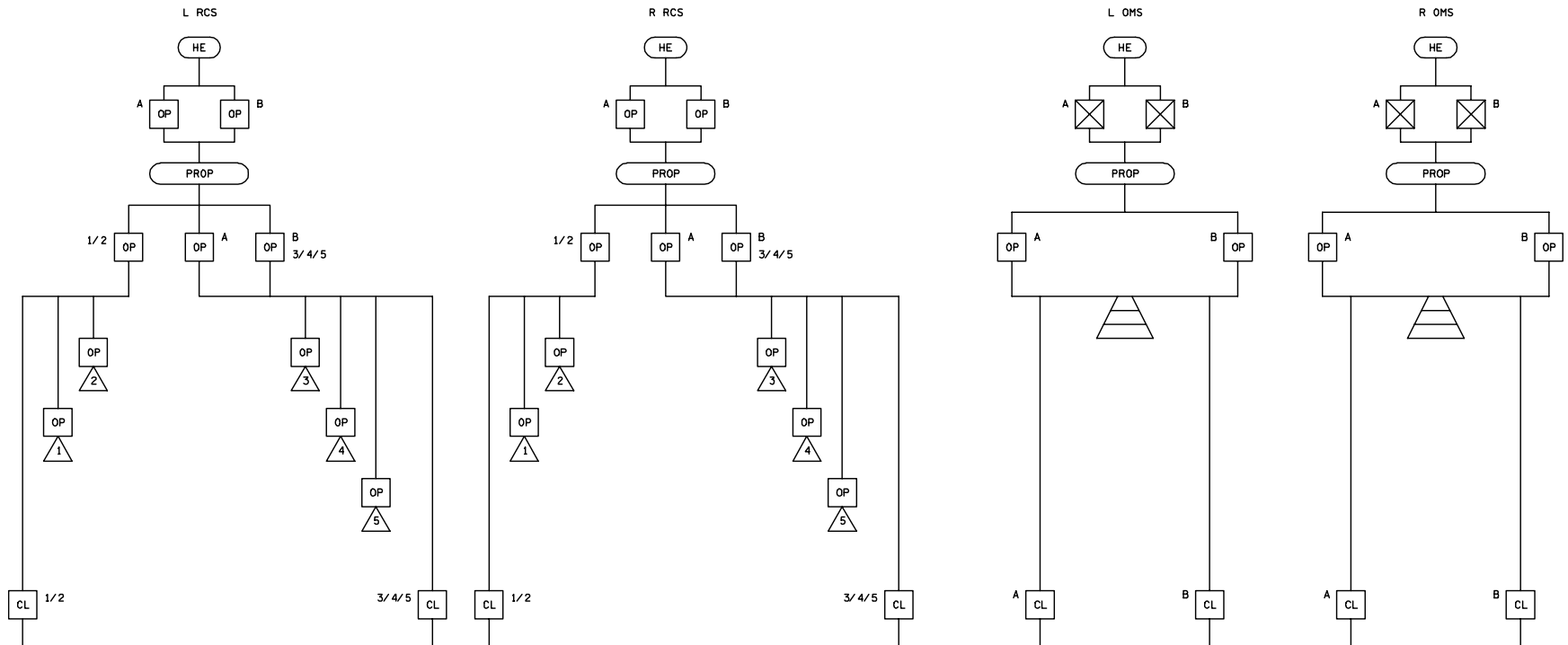
- a. Helium pressurization switches (6) – Open with talkbacks open. This position provides redundant pressurization for the RCS propellant tanks and protects against valve movement caused by ascent vibration.
- b. Propellant tank isolation switches (8) – GPC with the talkbacks open. This provides straightfeed of RCS propellant to the manifolds under normal conditions. Because the switches are in GPC, the propellant tanks can be isolated if commanded by the GPCs for auto crossfeeds or abort interconnects. The forward RCS does not have crossfeed or interconnect capability, but uses the same switch position for consistency.
- c. Manifold isolation switches (15) – GPC with talkbacks open. This provides propellant flow to the RCS jets. During nominal flight ops, there is no GPC function for the manifold isolation switches. The GPC position is used for off-nominal situations where repositioning is performed by the GPCs via onboard software, MCC uplinks, and during ground ops. Having these switches in GPC during ascent simply unpowers the ac motors for the valves. This protects against microswitch failures during ascent that would cause the motors to constantly drive and eventually burn out.

- d. RCS crossfeed switches (4) – GPC with talkbacks closed. This allows straightfeed of RCS propellant unless the GPCs command a crossfeed or interconnect configuration or the master crossfeed switch is used by the crew.
- e. Master crossfeed switch – OFF. This keeps the GPC controlled valves in straight-feed unless/until the switch is moved to a FEED FROM position.
- f. OMS crossfeed switches (4) – GPC with talkbacks closed. This allows straightfeed of OMS and RCS unless an interconnect is commanded by the GPCs. The OMS crossfeed valves are commanded closed if a subsequent auto RCS-to-RCS crossfeed is commanded.

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

The DAP that resides in the GPCs generates dual fire commands (A and B) to the RJDs 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 Section 3.5, Aborts.

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 because vernier jet operations are not supported until OPS 2. When a fire command is generated, it is also sent to RM to determine jet failures.



TD3400301. ART 1

Figure 3-1. Talkback configuration for straightfeed

3.2.1 System Monitoring

During MMs 102-103, there are limited RCS operations. During these early stages, PASS SYS SUMM 1 or SPEC 23 is monitored to check for jet failures. Tank pressures and quantities may be checked on the overhead meters (panel O3), SPEC 23, or BFS SYS SUMM 2. Also note that the RCS command lights on panel F6 are inoperative in OPS 1.

Procedures

The ascent checklist contains the procedures that utilize the RCS.

Post-OMS 1, MCC may call for the ET photo maneuver. The Commander (CDR) will manually pitch up, using the RCS jets to obtain an attitude from which pictures of the ET can be taken from the overhead window.

ET PHOTO MANEUVER

✓MCC, ADI – REF, Pitch up 2°/sec until ET in
O/H WINDOW θ ~100°

For some missions, MCC may call for Tail Only Control. This procedure preserves FRCS propellant by overriding the manifold status of the forward primary RCS manifolds to close, thereby causing them to be auto deselected.

TAIL ONLY CONTROL (✓MCC)

CRT2 OVRD FWD RCS MANF STATs 1,2,3,4 – CL

2: GNC 23 RCS

Another RCS procedural step is in 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 using the forward RCS for the OMS 2 burn.

OMS BURN PREP

* For single eng burn/No PROP *
* failures: *
* XFEED failed eng PROP to *
* good eng *

O8 L,R OMS
✓He PRESS/VAP ISOL A (two) – GPC
 B (two) – CL
✓TK ISOL (four) – GPC (tb–OP)
✓XFEED (four) – GPC (tb–CL)

Wedge Install OMS 2/ORBIT OMS BURN and
OMS 2 BURN MONITOR Cue Cards
(F6,F8)

If FRCS reqd,
Go to OPS 1 RCS BURN (Cue Card)

The OPS 1 RCS burn cue card provides procedures for an RCS burn.

OPS 1 RCS BURN

AFT RCS

✓RCS BURN CONFIG:
 OMS TK ISOL (all) – OP OMS TK
 L(R) OMS XFEED (two) – OP switch at
 R(L) OMS XFEED (two) – CL 1/2 ΔVTOT
 AFT L,R RCS XFEED (four) – OP (If reqd)
 TK ISOL (six) – CL

TIG-2 L,R OMS He PRESS/VAP ISOL A – OP
 . . . Wait 2 sec . . .
 L,R OMS He PRESS/VAP ISOL B – OP

✓MM105
 CNTLR PWR (two) – ON
 ✓BURN ATT (INRTL) then REF, pb – push
 ✓RCS SEL
 DAP: INRTL/DISC
 :00 + X
 Maintain PITCH ATT ERR ± 3°
 Monitor OMS data
 Monitor ΔVTOT
 CUTOFF Release THC
 CNTLR PWR (two) – OFF

FWD RCS

FRCS BURN PREP
 Load DUMMY target for FRCS attitude
 RCS SEL – ITEM 4 EXEC
 TIG @ TTA = 2:00 or as reqd
 ΔVX = -2.1 (ITEM 19)
 ΔVY = 0 (ITEM 20)
 ΔVZ = +1.0 (ITEM 21)
 LOAD – ITEM 22 EXEC
 TIG-10 Auto Mnvr to ATT
 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

NOTE
 Error needles invalid during burn
 Burn time = ~2X TGO
 TGT Hp = for ASCENT

--:30 CNTLR PWR (two) – ON
 DAP: INRTL/DISC
 :00 -X
 CUTOFF CUR HP = TGT HP , release THC
 CNTLR PWR (two) – OFF

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) – INRTL
 RATE (two) – 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.

- a. The RCS helium isolation A valves are placed in GPC (with talkbacks open). The B valves are closed because only one leg of helium is required to pressurize the propellant tanks. Halfway through the mission, a switch to the B regulators occurs. The GPC position accommodates the overpress protection software in OPS 2. If a set of helium regulators fail open and start to overpress the propellant tanks, the GPCs close the GPC-selected helium valves to stop the overpressure. There is no software to automatically open the helium isolation valves when the pressure returns to normal limits. When necessary, the crew must manually reopen the helium valves, OP (with talkbacks open).
- b. The RCS tank isolation switches are placed in OP (with talkbacks open) because there is no OPS 2 software for automatic crossfeeding and interconnecting.
- c. Manifold isolation switches are placed in GPC (with talkbacks open) to allow propellant to flow to the jets and automatic valve closure for a failed on jet in OPS 2.
- d. Crossfeed switches are placed in close (with talkbacks closed) because there is no automatic crossfeed or interconnect capability in OPS 2.

3.3 ORBIT

Orbit operation procedures are initiated in the post insertion procedure. RCS procedures start at an approximate Mission Elapsed Time (MET) of 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.

AFT STATION CONFIG 3

		<u>POST SEAT EGRESS</u>	
O14:D	cb MNA CAB VENT	- op	
	ISOL	- op	
A14	RCS/OMS HTR FWD RCS	- A AUTO	
	L POD (two)	- A AUTO, B OFF	
	R POD (two)	- A AUTO, B OFF	
	OMS CRSFD LINES (two)	- A AUTO, B OFF	
	√FWD,AFT RCS JET (ten)	- AUTO	

Approximately halfway through the mission, the Flight Plan directs the crew to change to the B helium regulators and the B heaters for checkout and equal usage.

HEATER RECONFIG – CONFIG B(CONFIG A)

A14	RCS/OMS HTR FWD RCS	– B AUTO(A AUTO)
	L POD	– A OFF(A AUTO)
		– B AUTO(B OFF)
	R POD	– A OFF(A AUTO)
		– B AUTO(B OFF)
	RCS/OMS HTR OMS	
	CRSFD LINES	– OFF(A AUTO)
	CRSFD LINES	– B AUTO(OFF)

At an MET of about 2 hours 15 minutes, the crew should contact Mission Control to get a GO for vernier operations. Mission Control verifies that the vernier jets are within normal thermal limit and that the Flash Evaporator System (FES) dump is complete before giving the GO. The FES dump is propulsive and produces rates that would cause the vernier jets to continuously fire and overheat. Once the GO is given, the crew turns on the vernier driver. The DAP is not configured for vernier operations until the driver is warmed up for 5 seconds; otherwise, the jets could fail off.

02:05	C	
A6(B1)		
AUTO		
VERN		
RT 0.2		
DB 1.0		
		CONFIG VERNIER CONTROL
		√MCC, GO for vernier control
O16:F		RJD MANF L5/F5/R5 DRIVER – ON, wait 5 sec
		DAP: A/AUTO/VERN

The RCS is used continuously on orbit to maintain attitude or to maneuver to a new attitude. In addition, several sets of procedures in the Orbit Operations Checklist relate specifically to RCS. These procedures include

- RCS hot fire test – This test is typically performed the day before the deorbit burn and fires each of the primary jets. This ensures that 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 fired during free drift) by using GGs. Certain payloads may require GG.
- Passive Thermal Control (PTC) – PTC provides rotation of the orbiter about the longitudinal axis perpendicular to the Sun to provide regular periods of solar heating to the payload bay.
- On-orbit RCS burn – This procedure makes small orbital adjustment burns or rendezvous maneuvers when the required delta V is less than 6 feet per second. Larger maneuvers are performed with OMS burns.
- Loss of verniers – To be used if total loss of vernier control occurs.

- f. Recovery of verniers – To be used if vernier jet control is regained after a loss of verniers.

When ready for deorbit, the crew follows the procedures in the Deorbit Prep All throughout orbit; the RCS is used to maneuver and maintain various attitudes. About 1 hour 30 minutes prior to deorbit burn, the vernier drivers are turned off.

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

About 50 minutes prior to the deorbit burn, the crew exits the Deorbit Prep Checklist and starts the procedures in the Entry Checklist.

3.4 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

```
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, Mission Control gives a GO for a 24-hour extension. The crew backs out of the entry procedures and reconfigures the RCS for orbit operations.

```

. . . . .
. IF 24-HR EXTENSION
. P  O7  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)
. O8  FWD RCS
.           He PRESS A - GPC (tb-OP)
.           B - CL (tb-CL)
. C6  Unstow ORB PKT C/L
.       Terminate Deorbit Procedures,
.       go to DEORB PREP, D/O PREP
.       BACKOUT
. . . . .
```

Once these switches are configured, the crew executes the deorbit prep backout 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 maneuvers the orbiter to the deorbit burn attitude 15 minutes prior to the burn. At this time, the RCS heaters are configured for entry: the pod heaters are turned off, both crossfeed line heaters are placed in auto, and the vernier jet heaters are turned off. See Figure 3-2.

TIG-20> **MNVR TO DEORBIT BURN ATT**

- C C3 ✓DAP: AUTO
- B F6/F8 ✓ADI ATT (two) - INRTL
 ✓ERR (two) - MED
 ✓RATE (two) - MED
- C MNVR to BURN ATT
 (✓ADI ATT with CRT BURN ATT)
- B Copy last DEL PAD and OMS PRPLT PAD
 data on DEORBIT BURN Cue Cards
- F6/F8 ✓DEORBIT BURN and DEORBIT BURN
 MONITOR Cue Cards installed
- A14 RCS/OMS HTR
 FWD RCS - OFF
 L POD (two) - A OFF, B OFF
 R POD (two) - A OFF, B OFF
 OMS CRSFD LINES (two) -
 A AUTO, B AUTO
 FWD RCS JET 5 (one) - OFF
 AFT RCS JET 5 (one) - OFF

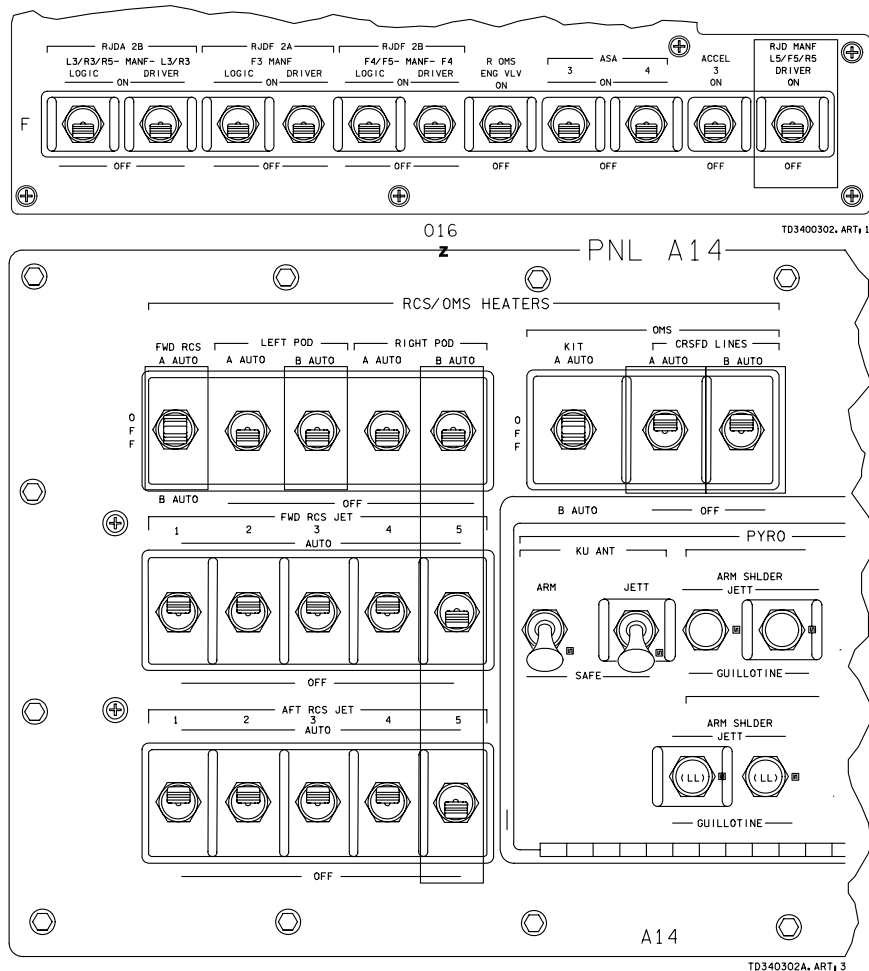


Figure 3-2. Entry panel configuration

If the RCS is to be used for the deorbit burn, the procedures assume that left OMS propellant is consumed first. However, depending on the circumstances, the burn could start with the right OMS propellant just as well.

```

RCS BURN PREP
P O8 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)
O7 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 four +X jets). Specific deorbit procedures using RCS are covered in detail in the OMS training materials.

When the OMS engines are used for the deorbit burn, the RCS should be in straightfeed. This prevents RCS tank damage if an OMS/OMS crossfeed is performed, since the OMS and RCS share the crossfeed line. The exception would be if an RCS helium or propellant tank has been lost. If either aft RCS system has lost a helium or propellant tank, an interconnect is required to maintain propellant flow to the RCS jets. These jets are needed for a maneuver to deorbit burn attitude.

```

RCS DEORBIT OR RCS
He/PRPLT TK FAIL
Do not terminate OMS/RCS
Interconnect

```

If the burn is terminated above a safe Height of Perigee (HP), the RCS is configured for orbit operation and the crew backs out of the Entry Checklist, awaiting an MCC call on the length of the delay.

```

*           If burn terminated with HP > SAFE HP: *
*           ✓OMS ENG (two) - OFF *
*           ✓APU - SHUT DN *
* C3        MSTR MADS PWR - OFF *
*           OPS 301 PRO *
*           If I'CNCT: *
*           DAP: INRTL/PULSE *
* O8        L,R OMS *
*           He PRESS/VAP ISOL (four) - CL *
*           ✓XFEED (four) - CL *
* O7        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) *
* O8        FWD RCS *
*           He PRESS A - GPC (tb-OP) *
*           B - CL (tb-CL) *
* F6,F8     FLT CNTLR PWR (two) - OFF *
* C3        ✓DAP: AUTO *
*           ✓MCC at next AOS on DEORBIT DELAY *
*           of 24 hr *

```


Once the deorbit burn is completed, the RCS switches are checked for proper entry. Digital display rotary switches are switched from OMS to RCS.

OMS/RCS POST BURN RECONFIG

- O7 AFT L,R RCS
 ✓He PRESS (four) – OP (tb–OP)
 ✓TK ISOL (six) – GPC (tb–OP)
 ✓XFEED (four) – GPC (tb–CL)
- O8 L,R OMS
 He PRESS/VAP ISOL (four) – CL
 ✓TK ISOL (four) – OP (tb–OP)
- * If OMS PRPLT FAIL, *
- * ✓Aff TK ISOL (two) – CL *
- XFEED (four) – CL (tb–CL)
- O3 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 caused by acceleration forces and tank design.

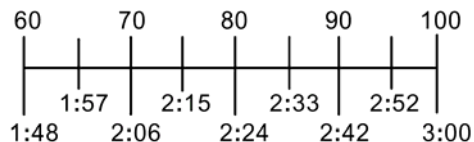
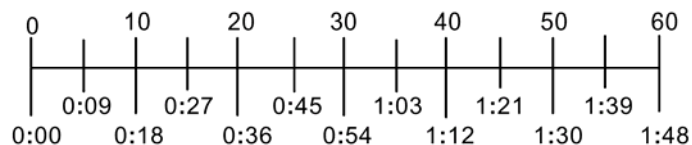
Prior to EI, a forward RCS dump may be executed to move the orbiter c.g. to a more acceptable position. This dump is normally executed by simultaneously firing the four forward yaw jets (F1L, F3L, F2R, F4R).

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 or DEL PAD)

FOUR JET DUMP:

F RCS PRPLT TO BE DUMPED (%)



TIME FROM DUMP INITIATION (M:S)

NOTE
 During dump disregard FRCS qty

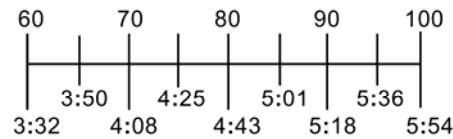
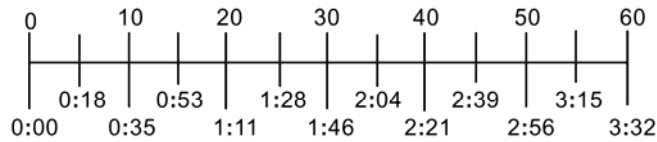
The crew is usually advised by MCC to dump down to a particular forward quantity indication. The PVT measurements used by the GPCs to calculate and display RCS quantity are not accurate during a dump because of the rapid drop in pressures and temperatures. Therefore, a dump time must be used to determine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

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) is 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)

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

```

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

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. For example, if F1L fails off, the DAP stops firing F2R. If F4R subsequently fails off, the DAP reactivates F2R and continues 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.

The RCS is used to maneuver to the EI-5 attitude, which may require a prebank to compensate for an underburn or propellant shortage.

FLIGHT CONDITIONS	MANEUVER
EI-5	✓LVLH ATT GNC, OPS 304 PRO * If PREBANK, R/Y – CSS * * Roll at 1°/sec to <input type="text"/> * * Maintain PREBANK ± 5° * If previous OMS OX TK or He TK or RCS OX TK leak: <input type="text"/> VENT DOORS – OP PTI – ENA at EI-5 when applicable

During entry, use 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 (q) becomes greater than 10 pounds per square foot (psf) (54 Knots Equivalent Air Speed {KEAS}), the ailerons become effective and the roll jets are deactivated. When q reaches 40 psf (109 KEAS), 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 point.

The RCS command lights on F6 are active post-MECO during MM104-106, OPS 2, 8, 3, and MM 602-603. In OPS 3, when 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, more visible illumination. RCS command light processing is summarized in Table 3-1.

Table 3-1. RCS command light processing

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

During entry, the crew monitors RCS quantities and refers to the Entry Control cue card if the total aft quantity gets below 10 percent.

ENTRY CONTROL

ARCS QTY (L + R) < 10%	
ARCS QTY = 0 & JETS FAIL OFF	1. ENTRY MODE – NO Y JET (R/Y CSS; expect sluggish control)
$\bar{q} \geq 20$ & $M > 6$	2. [G51] ELEVON FIXED – ITEM 18 EXEC (*)
CONTROL PROBLEMS* & ARCS QTY > 0	3. ENTRY MODE – AUTO When control regained:
	4. ENTRY MODE – NO Y JET
	5. ✓AIL trim
$M < 6$ & ARCS QTY > 0	6. ENTRY MODE – AUTO
$M < 5$	7. TRIM/RHC PNL – ENA
	8. TRIM ROLL – away from AIL trim (to < 1)

*Region of least margin: M 12-8

Note: The RCS percent is a total (left and right) aft quantity.

In cases of low or zero RCS quantity, RCS yaw jet activity is terminated to save whatever propellant remains for times of severe control problems. This termination is achieved by selecting the no yaw jet mode for the DAP with the entry mode switch on panel L2, Figure 3-3. This prevents yaw jets from firing until the switch is moved from NO Y JET (no yaw jet). Also note that roll jet activity was terminated at q of 10 psf, so only jets commanded for pitch will fire, until q of 40 psf. In place of RCS jets, the DAP relies on the aerosurfaces with increased gains.

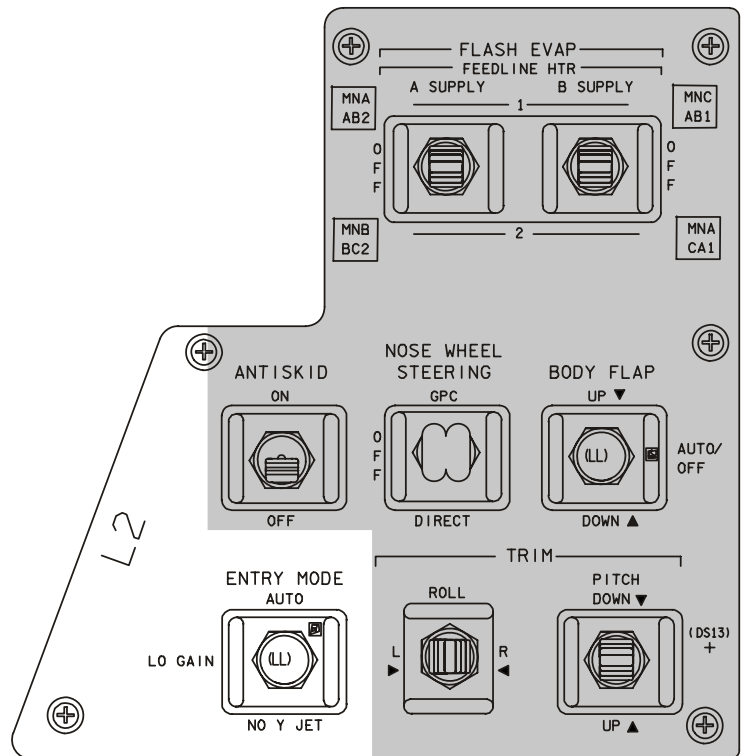


Figure 3-3. Panel L2

For more information on the Entry Control Cue Card, refer to the Entry Flight Procedures Handbook.

After landing, the RCS RJDs are safed and the valves are tested, then safed, for egress and vehicle turnaround. The valve test is performed to confirm that switch throws command the corresponding valves properly.

RCS, OMS SAFING (RJDs)

C3	✓OMS ENG (two)	- OFF
O14:F	RJD DRIVER (nine)	- OFF
O15:F	LOGIC (eight)	- OFF
O16:F	OMS ENG VLV (two)	- OFF

RCS, OMS VALVE TEST

Pause 1 sec between each line

O7	✓MSTR RCS XFEED	- OFF
O8	L,R OMS He PRESS/VAP ISOL (four)	- CL, GPC
	L OMS XFEED (two)	- OP (tb-OP),
	then	- CL (tb-CL)
	R OMS XFEED (two)	- OP (tb-OP),
	then	- CL (tb-CL), GPC
	L,R OMS TK ISOL (four)	- CL (tb-CL),
	then	- OP (tb-OP), GPC
	L OMS XFEED (two)	- OP (tb-OP), GPC
	FWD RCS	
	He PRESS (two)	- CL (tb-CL), GPC
	TK ISOL (two)	- CL (tb-CL),
	then	- OP (tb-OP), GPC
	MANF ISOL (five)	- CL (tb-CL)
	then	- OP (tb-OP), GPC
O7	L,R RCS	
	He PRESS (four)	- CL (tb-CL), GPC
	MANF ISOL (ten)	- CL (tb-CL),
	then	- OP (tb-OP), GPC
	TK ISOL (six)	- CL (tb-CL)
	XFEED (four)	- OP (tb-OP),
	then	- CL (tb-CL), GPC
	TK ISOL (six)	- OP (tb-OP), GPC

3.5 ABORTS

There are four types of intact ascent aborts as illustrated in Figure 3-4:

- RTLS – Return to Launch Site
- TAL – Transoceanic Abort Landing
- ATO – Abort to Orbit
- AOA – Abort Once Around

The RCS is more active in aborts than during nominal ascents because of propellant dumping through the RCS jets and increased jet firings to maintain vehicle control.

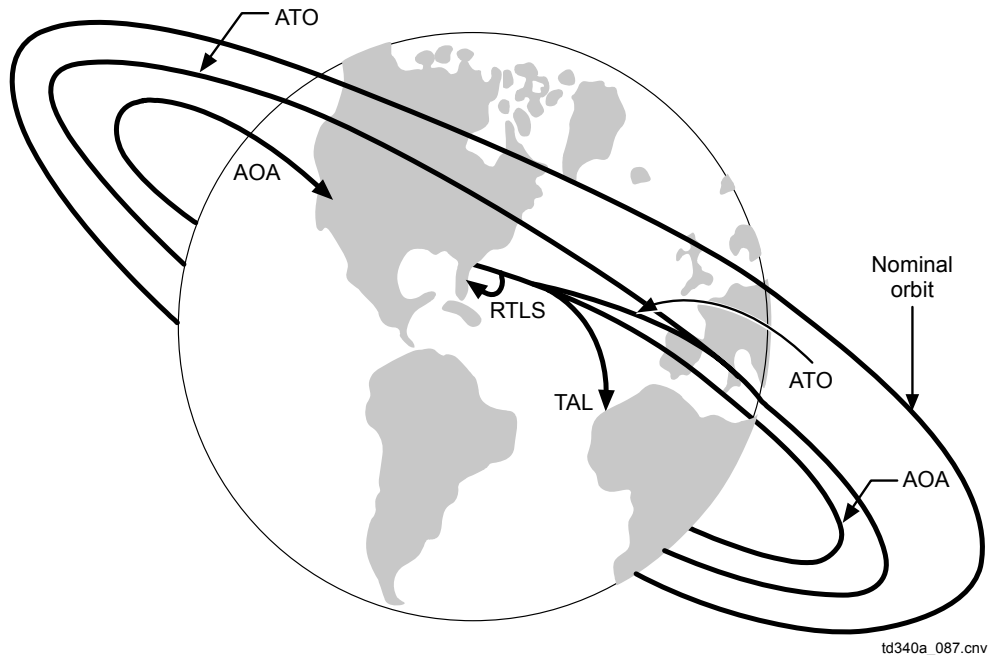


Figure 3-4. Intact abort modes

3.5.1 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 for SERC.

Pre-MECO aborts can be selected and executed by either of two methods. One method uses the abort rotary switch and PBI on F6 to select and execute the desired abort. The other method makes an appropriate keyboard entry (OPS 601 PRO for RTL or item entry on SPEC 51 for TAL and ATO aborts). Either method can initiate an abort interconnect and a subsequent propellant dump, as required by software. The abort interconnect valve sequencing is performed in the following order:

1. 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.
2. Left and right RCS crossfeed valves are opened to feed pressurized OMS propellant to the RCS manifolds.
3. Left and right OMS crossfeed B valves are opened to feed pressurized OMS propellant into the crossfeed lines and to the RCS manifolds.

When an intact abort dump is completed or MECO is imminent, the GPCs command a “return to normal configuration.” The return to normal feed valve sequencing occurs in the following order: OMS crossfeeds close, RCS tank isolations open, and RCS crossfeeds close.

Because each set of valves requires about 1.5 seconds to reach a commanded position, for a short period (less than 3 seconds), the RCS jets are isolated from all propellant tanks. This situation is not hazardous because 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 remains the same, but return to straightfeed must be altered to ensure that sufficient propellant is available to the jets for control.

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

- SERC when multiple RCS jet firings are required to assist the remaining main engine in its Thrust Vector Control (TVC) task.
- MECO when flying an intact abort at the time of a dump. All abort dumps are stopped at MECO, and a return to normal feed is commanded.

Standard abort control return to normal valve sequencing starves 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 would occur. To prevent this, the GPCs are programmed for mode 2 situations and change the sequence of these valve movements. This valve sequence ensures that pressurized propellant is provided to the manifolds at all times.

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

1. Left and right RCS tank isolation valves open
2. Left and right RCS crossfeed valves close
3. Left and right OMS crossfeed 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.

3.5.2 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 failed late in ascent, past the single-engine press-to-MECO boundary (see Flight Rules, All Vehicle, for the specific definition), an abort interconnect is commanded to provide SERC. In this situation, a nominal MECO and a nominal orbit could be achieved, thus preventing an abort.

Talkback monitoring may be essential to the successful completion of an abort interconnect. Although it is not specifically mentioned in the procedures, the crew should 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 may result in the wasting of valuable RCS propellant (rather than burning OMS propellant) or may lead to control problems due to an off-nominal center of gravity.

It is understood that talkback observation is a difficult, if not impossible, task for the CDR and Pilot (PLT) because of 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 but probably not without considerable effort.

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

3.5.2.1 Smart Interconnect

The OMS/RCS "smart interconnect" function provides the capability for feeding OMS propellant to the RCS while checking to see that certain valves have moved to the proper position. If the valves have not moved because of a valve failure, an MDM failure/commfault, or an Electrical Power System (EPS)/DPS failure, then the abort dump is reconfigured so that RCS propellant required for entry is not consumed. Depending on the failures, the valves could be configured for a dump with 2 OMS and 24 RCS jets (2 + 24), 2 OMS and 10 RCS jets (2 + 10), or 2 OMS engines only.

Prior to opening the RCS crossfeed valves, the status of the RCS tank isolation valves is monitored. If any of the tank isolation valves do not indicate closed or are commfaulted, the smart interconnect software inhibits the use of jets on those manifolds for dumping OMS propellants. The RCS crossfeed valves are commanded closed and a set of RCS tank isolation valves are commanded open for those manifolds with inhibited jets.

If all of the jets have been inhibited in the above process, the RCS tank isolation valves are opened, and the interconnect is terminated. The dump continues with the OMS engines only. The smart interconnect software module monitors the status of the RCS valves only during the initial reconfiguration for the dump. Once the interconnect

reconfiguration is complete, it will not upmode or downmode if valve capability changes during the dump.

3.5.2.2 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 to obtain specific dump rates.

There are two basic groups of abort dump jet firings.

- Abort +X jets (Figure 3-5). All aft firing jets (L1A, L3A, R1A, and R3A) are commanded to fire simultaneously.
- Twenty RCS null jets (Figure 3-6). 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 is covered in the specific abort sections.

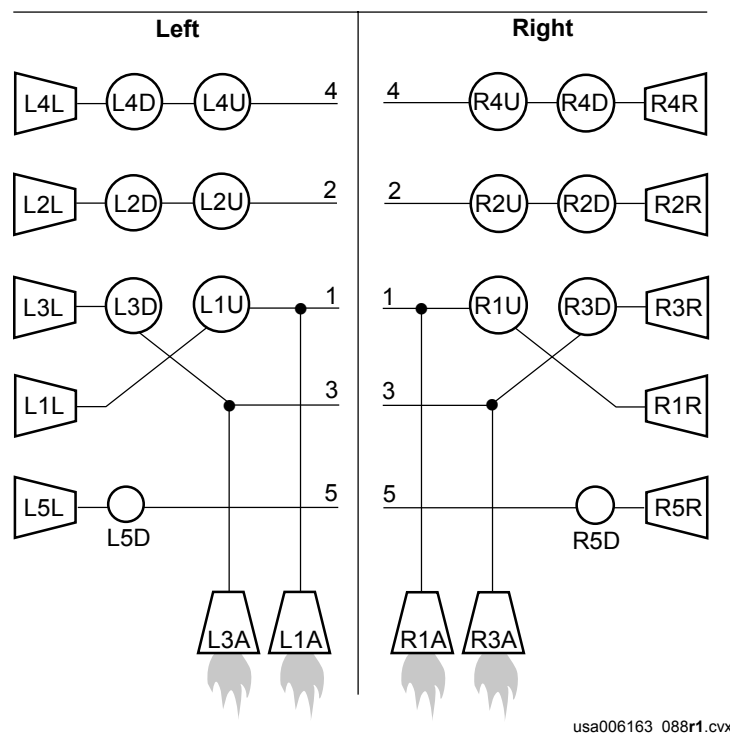


Figure 3-5. Abort +X jets

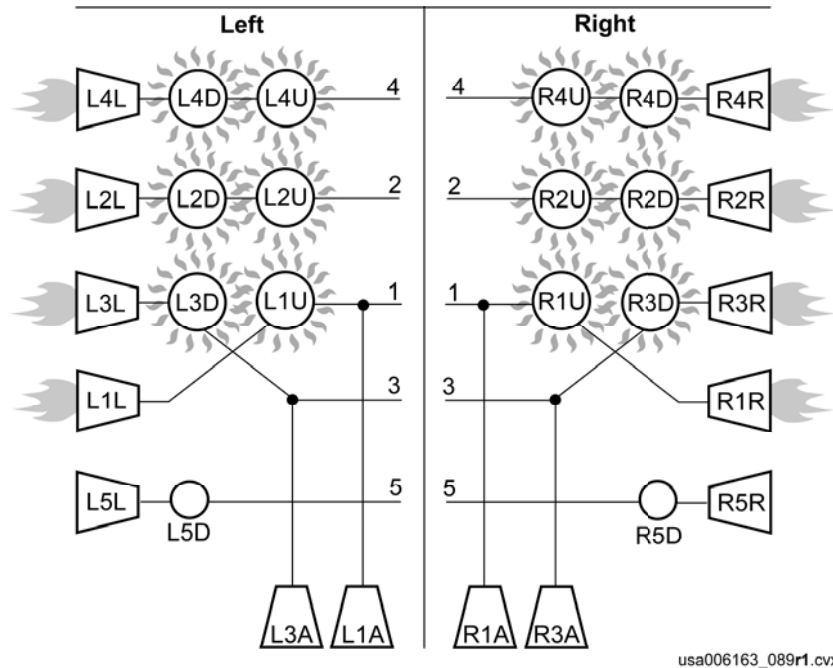


Figure 3-6. Twenty RCS null jets

3.5.2.3 Mirror Image Logic

If a contingency abort dump is executed during SERC, the GPCs use “mirror image logic” to alter the jet fire commands to provide the desired motion. If FCS commands a jet to fire, but it is already firing (dumping), mirror image logic stops firing the opposing jet to obtain the desired vehicle motion. If the desired jet is not dumping, 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 commands L2D to fire (along with other jets). The GPCs 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 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 used only when SERC is followed by a contingency dump (SPEC 51 DUMP ARM, START). Mirror image logic is not applied if SERC occurs during any dump (intact or contingency). This is because all RCS jet dump firings are terminated to provide for SERC 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 SERC occurs, then all RCS jet dump firings are stopped. If the dump is stopped and restarted, the RCS jet dump firings reactivate and mirror image logic applies.

3.5.2.4 Abort Dump Stop

An abort dump may be terminated by item entry to the override display, SPEC 51 (Figure 3-7).

An item 8 DUMP STOP terminates all OMS and RCS ignition commands and maintains the interconnect until just before MECO. At that time, straightfeed is commanded for MECO preparation. If the DUMP STOP is performed post-MECO, straightfeed 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, an item 5 entry to SPEC 51 inhibits the interconnect and stops all RCS abort 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.

1031/051/		OVERRIDE		1 000/00:03:12	
				000/00:03:12	
ABORT MODE		ENTRY FCS			
TAL	1	ELEVON	FILTER	ATMOSPHERE	
ATO	2	AUTO 17*	NOM 20*	NOM 22*	
ABORT	3	FIXED 18	ALT 21	N POLE 23	
THROT MAX	4*	SSME REPOS	19	S POLE 24	
ABT	50	IMU STAT ATT DES		PRL	
NOM	51	1	1 25	SYS AUT DES	
PRPLT DUMP		2	26	1 28*	31
ENA ICNCT	5	3	27	2 29*	32
OMS DUMP				3 30*	33
ARM	6	ADTA	H	a	M DES
START	7	L	1		34
STOP	8		3		35
9 QUAN/SIDE	63	R	2		36
OMS DUMP TTG	423		4		37
		ET SEP		ROLL MODE AUTO	
		AUTO	38	AUTO SEL 42	
AFT RCS 13	ENA	SEP	39	WRAP MODE 45 INH	
14 TIME	---	ET UMB DR		VENT DOOR CNTL	
		CLOSE	40	OPEN	43
FWD RCS 15	INH	RCS RM MANF		CLOSE	44
16 TIME	---	CL OVRD	41		
ITEM 4 EXEC					

Figure 3-7. SPEC 51 Override

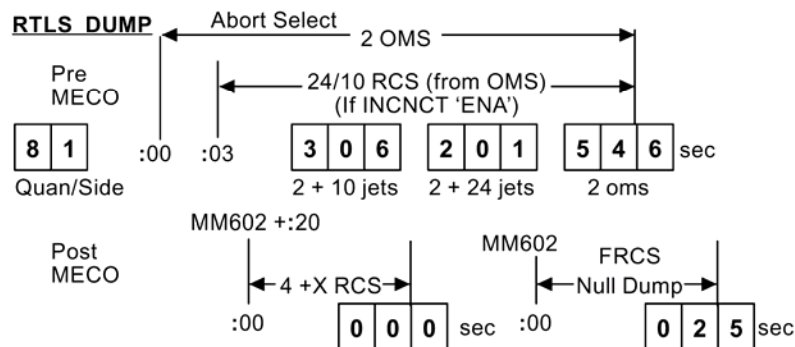
3.5.3 Return to Launch Site

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 are dumped through the OMS engines and the RCS jets to improve vehicle performance, maintain c.g., 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 may be configured for an OMS/RCS interconnect. The necessity of an interconnect is determined based on the flight-specific OMS propellant loading. This loading is determined by many factors, including vehicle mass (orbiter, payload, consumables), mission attitude, and trajectory. However, a good rule of thumb holds that the interconnect is enabled if the OMS load is 65 percent or greater. If the interconnect is enabled, the RCS jets are not commanded to fire until approximately 3 seconds after the interconnect is completed. Inhibiting the interconnect inhibits RCS jet dump commands, but it does 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 or 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 straightfeed configuration.

A representation of the RTLS dump can be found in the Ascent Checklist (Abort Dumps section). It shows mission-specific times for each type of dump.



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

Post-MECO, the RCS jets are used to safely maneuver the orbiter away from the ET after separation. Because 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	3
AFT LEFT	1	3
AFT RIGHT	1	3
AFT UP	1 / SIDE	2 / SIDE
AFT DN	1 / SIDE	2 / SIDE
FWD YAW	-	1 / 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 c.g. 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 (Abort Control Sequence) and 4.3.2 (Abort OMS/RCS Interconnect).

RTLS Glide

The RCS is gradually phased out during entry.

The RCS jets are deactivated at the standard entry points.

- a. Roll jets at 10 psf
- b. Pitch jets at 40 psf
- c. Yaw jets at Mach 1

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

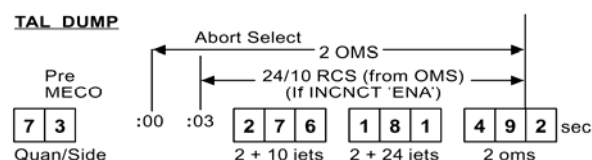
3.5.4 Transoceanic Abort Landings

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

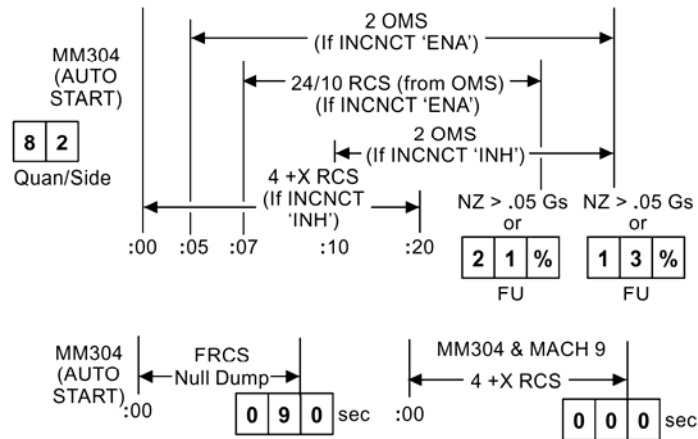
When a TAL abort is initiated, the abort interconnect, if necessary, and abort dump occur in the same sequence as for an RTLS abort. The pre-MECO dumping of OMS propellant for a TAL is usually performed by burning both OMS engines or both OMS engines and 24 aft RCS jets (abort +X and 20 null jets). The OMS engines ignite initially at abort select, and the RCS jets are fired approximately 3 seconds after the abort interconnect is completed.

A representation of the TAL dump is found in the Ascent Checklist (Abort Dumps section).

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



Post-MECO, an additional OMS dump is started automatically at the transition to MM 304. This additional dump provides the thrust needed to move the vehicle away from the ET. This dump is usually performed by burning both OMS engines or both OMS engines and 24 aft RCS jets (abort +4x and 20 null jets). If the interconnect is enabled, the OMS engines ignite about 5 seconds after the start of the sequence to allow the engines to move into position and the interconnect sequence to complete. The RCS jets begin to fire approximately 2 seconds later. If the dump is through the OMS engines only, an RCS four +X settling burn occurs prior to OMS ignition to ensure the OMS propellant is in the aft part of the tank. A representation of the OPS 304 dump can be found in the Ascent Checklist.



At OPS 304, an auto FRCS dump occurs. At Mach 9, a specific flight may or may not have a dump of aft RCS propellant through the four +X jets, depending on c.g. concerns and performance requirements. The duration of the dump can be seen via SPEC 51, item 14. The “boxed” quantity in the TAL procedure is a guideline for inhibiting any aft RCS dump to allow sufficient propellant for vehicle control. (Note: This is a flight-specific number.)

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

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

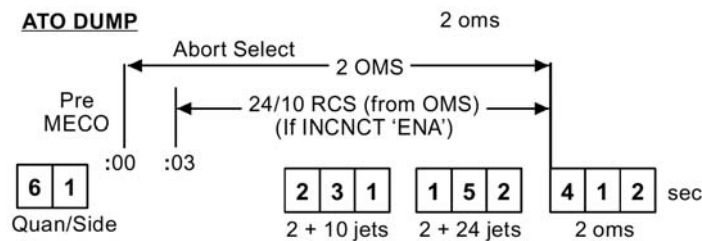
3.5.5 Abort to Orbit

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 is made to perform an early deorbit burn, 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 24 RCS jet firings (abort +X and 20 null jets) by enabling the interconnect on SPEC 51.

A representation of the ATO dump can be found in the Ascent Checklist.



3.5.6 Abort Once Around

The AOA mode is designed for making an intact landing after flying once around the Earth. If both OMS engines fail, there are dedicated steps for making an RCS deorbit burn using OMS propellant.

OMS BURN PREP

- * For single eng burn/No PROP failures: *
- * XFEED failed eng PROP to good eng *

- O8 L,R OMS
- ✓He PRESS/VAP ISOL A (two) – GPC
 - B (two) – CL
 - ✓TK ISOL (four) – OP (tb-OP)
 - ✓XFEED (four) – GPC (tb-CL)

RCS BURN PREP (I'CNCT OMS to RCS)

- P O8 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)
- O7 AFT L,R RCS
- XFEED (four) – OP (tb-OP)
 - TK ISOL (six) – CL (tb-CL)

RCS is used to maneuver to the burn attitudes.

Post-burn, the OMS and RCS are configured for entry (auto crossfeed prep).

OMS/RCS POST BURN RECONFIG

```

:-----:
: IF I'CNCT :
: Perform I'CNCT RETURN :
: (ENT PKT, RCS) :
:-----:
  
```

- O7 AFT L,R RCS
 - ✓He PRESS (four) - OP (tb-OP)
 - ✓TK ISOL (six) - GPC (tb-OP)
 - MANF ISOL 1,2,3,4 (eight) - OP (tb-OP)
 - ✓XFEED (four) - GPC (tb-CL)

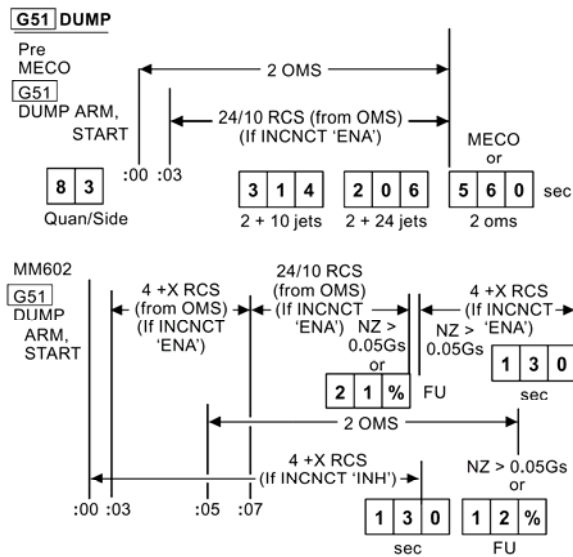
- O8 FWD RCS
 - TK ISOL (two) - OP (tb-OP)
 L,R OMS
 - He PRESS/VAP ISOL (four) - CL
 - TK ISOL (four) - OP (tb-OP)

Because a complete MPS propellant dump and purge are 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. Subsequent RCS entry procedures are identical to a nominal entry.

3.5.7 Non-Intact Aborts

There are additional procedures for executing non-intact aborts when a safe landing cannot be assured and a bailout may be required. These non-intact aborts may require the execution of a manual dump to reduce vehicle weight and move the vehicle c.g. This dump is performed by a DUMP ARM, START item entry on SPEC 51. The dump is executed by burning both OMS or both OMS and 24 aft RCS jets (abort +X and 20 null jets). The post-MECO portion of the manual dump may be OMS engines only or OMS engines plus 24 aft RCS jets. There is also a dump of RCS propellant through the four +X jets.

Manual dump software takes priority over any dump in progress. A representation of the manual dump can be found in the Ascent Checklist.



For more detailed information on aborts, refer to the following sources:

1. GNC Training materials for ATO/AOA/TAL and RTLS/Contingency Abort
2. FSSR for Ascent/RTLS Guidance and Sequence Requirements

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 qbar 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 post insertion activities, the RCS helium pressurization switches are placed in the GPC position (starting with the A regs, then later switching to the B regs). Why?
6. How can the RCS be used for OMS burns if OMS engine failures occur?
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 chart from Section 3.4, page 3-12.)
8. During orbit operations, the GPCs closed the right RCS helium pressurization valves because of an overpressure in the right RCS oxidizer tank. At what propellant tank pressure will the GPCs reopen the right RCS helium pressurization valves?

Note: Answers found in Appendix B.

4.0 SYSTEM MALFUNCTIONS: IDENTIFICATION AND MITIGATION

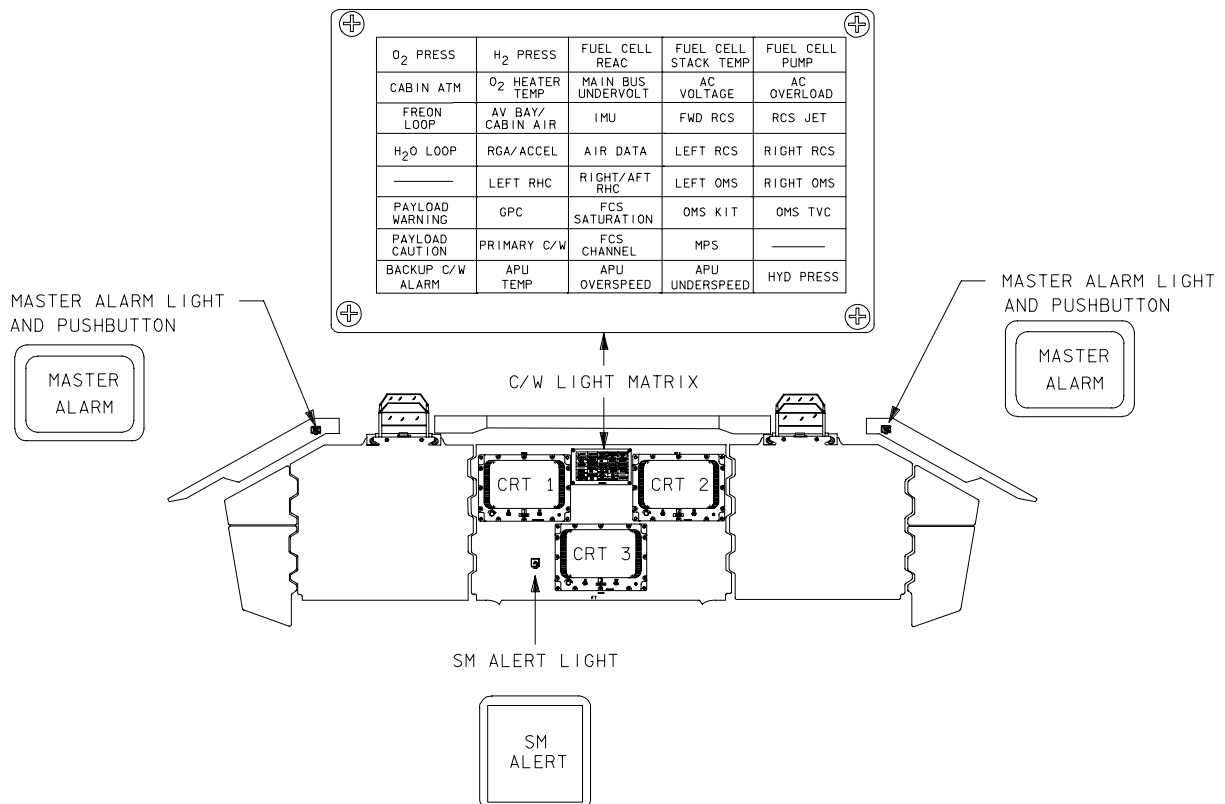
4.1 OBJECTIVES

As a result of reading this section, the student should be able to

- State the steps of the RCS Secure procedure and their rationale
- Explain the difference between a crossfeed and an interconnect and conditions when each should be used
- Identify the location of a leak in the RCS system using the leak isolation procedure
- Identify the three different types of RCS jet failures and their causes

4.2 CAUTION AND WARNING OVERVIEW

If a malfunction occurs in the RCS, the crew is alerted by the 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/MEDS fault message. The other type is a class 3 alert consisting of the SM alert light, SM alert tone, and a CRT/MEDS fault message. See Figure 4-1 for C&W annunciation locations.



TD3400401. ART. 3

Figure 4-1. Caution and warning annunciation locations

Crew procedures for correcting RCS malfunctions can be initiated when the off-nominal situation is recognized. The crew or Mission Control may detect malfunctions via off nominal trending of temperatures, pressures, and/or quantities long before any C&W annunciators occur. If the degrading signatures are not mitigated in time, a CRT/MEDS fault message and warning tone are generated when the degradation reaches the pre-set software limits.

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/MEDS displays and meters.

Table 4-1. RCS malfunctions

Fault message	OPS available		Cause	C&W matrix light	Warning light and tone		CRT/MEDS display symbology	Supporting display info
	PASS	BFS			Master alarm	SM alert		
F(L,R) RCS UJET -or- DJET -or- LJET -or- RJET -or- FJET -or- AJET		Not avail	Jet fail on (driver output and no fire cmd) -or- Jet fail off (fire cmd 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 MMs 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
F RCS JET -or- L RCS JET -or- R RCS JET	Not avail	1,3,6	Jet fail on (PC discrete and no fire cmd) -or- Jet fail off (fire cmd 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
F RCS He P -or- L RCS He P -or- R RCS He P	2,8	1,3,6	Helium pressure (FU or OX) in 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

Table 4-1. RCS malfunctions (continued)

Fault message	OPS available		Cause	C&W matrix light	Warning light and tone		CRT/MEDS display symbology	Supporting display info
	PASS	BFS			Master alarm	SM alert		
F RCS LEAK -or- L RCS LEAK -or- R RCS LEAK	2,3,8	1,3,6	Propellant quantities (FU and OX) in any one pod differ by more than 9.5 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
F RCS PVT -or- L RCS PVT -or- R RCS 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/MEDS quantities
F RCS TK P -or- L RCS TK P -or- R RCS 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/MEDS 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 talk-backs that are barber-poled indicate the valves are stuck in last position

Table 4-1. RCS malfunctions (concluded)

Fault message	OPS available		Cause	C&W matrix light	Warning light and tone		CRT/MEDS 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

4.3 SYSTEM FAILURES

A summary of system failures is 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 makes the procedures more understandable. The following categories of system failures are covered:

- a. Propellant leaks
- b. Tank pressure high
- c. Tank pressure low
- d. Jet failures
- e. Electrical and DPS failures
- f. RM dilemmas
- g. RM loss
- h. Switch, valve, and talkback failures

Procedures for responding to RCS failures can be found in various checklists. During early ascent (MMs 102-104), late entry (MMs 304 and 305), and RTLS (MMs 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: MMs 105-106; orbit: MMs 201-202; entry: MMs 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 “long form” malfunction procedures are usually exercised during orbit situations when adequate troubleshooting time is available. In-depth details of Systems Malfunction Procedures are not provided in this manual but are covered extensively during simulator training.

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

4.3.1 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)

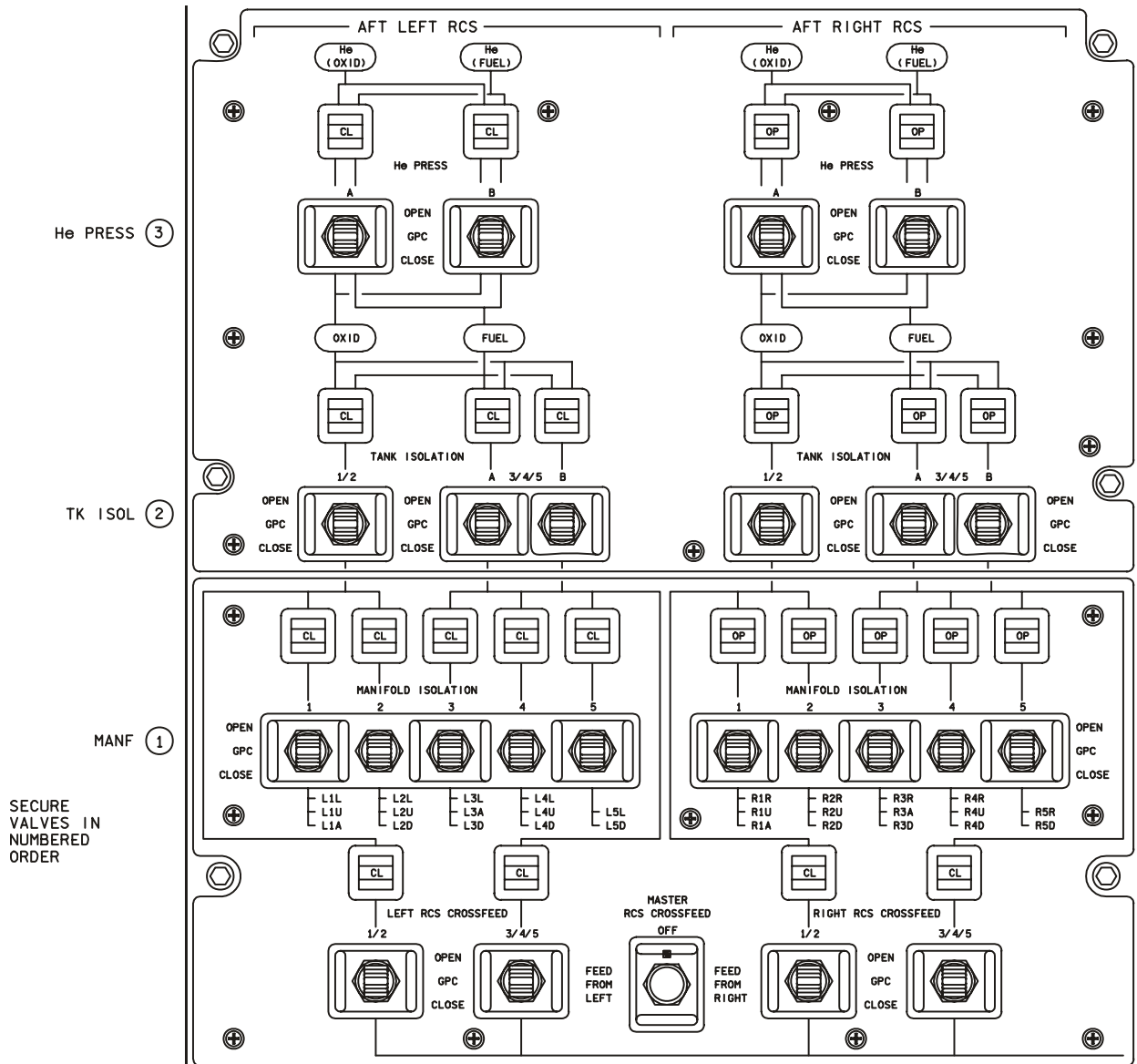
If normal config:

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

If the system is incorrectly secured in the reverse order (i.e., starting at the top and securing downstream), prop-isolated jets could fail off. Propellant starvation occurs because the manifold valves and statuses are still open (jets available) while tank isolation valves are closed (trapped propellant in the lines cannot support jet firings). This starvation causes manifold evacuations, jet failures, and possible permanent jet damage. The reduced pressure readings, caused by evacuated manifolds, prevent accurate determination of leak location and complicate any return to normal configuration.

By following the proper sequence (close the manifolds first), the closed manifold statuses remove the associated jets from the availability table, thus preventing jet firings while the RCS is secured. Any subsequent drop in pressure readings downstream of a closed/isolated valve indicates the location of a leak.

Error!

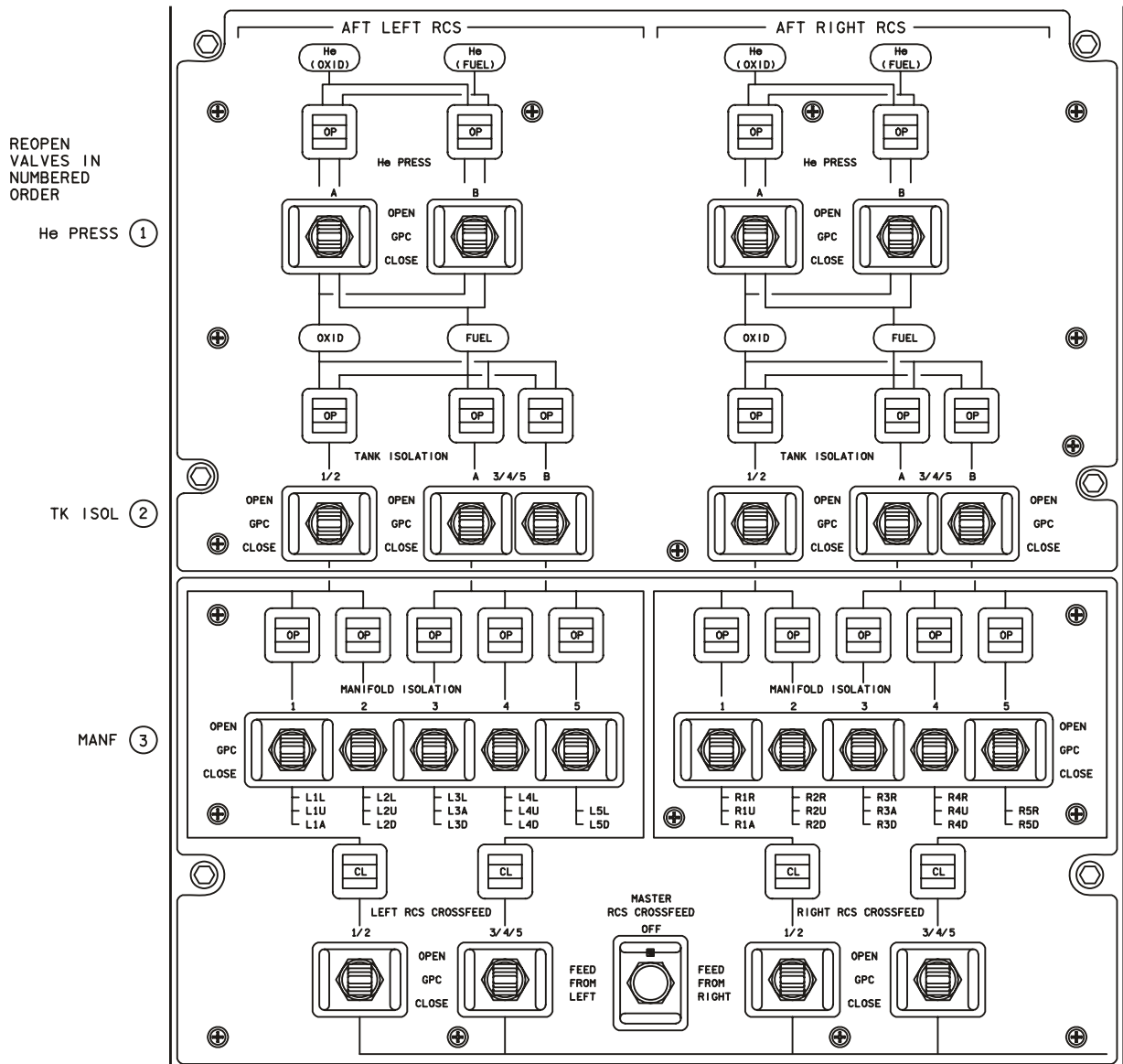


00616304. ART 1

Figure 4-2. RCS secure sequence (L RCS)

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.

When the RCS is returned to a normal feed configuration after a leak is isolated, there may not be dedicated procedures to follow. To achieve an acceptable normal feed configuration, the procedure used to secure the RCS should be reversed. As illustrated in Figure 4-3, 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 prevents manifold evacuations and jet failures. Lines with known leaks should not be opened unless the associated jets are needed for vehicle control.



00616303. ART. 1

Figure 4-3. Return to straightfeed 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 results in an unsatisfactory, if not hazardous, configuration.

4.3.2 Crossfeed

Before a crossfeed is initiated, some constraints must be considered that protect the RCS propellant tanks. These constraints are documented in the Shuttle Operational Data Book (SODB). Because ascent and entry crossfeed procedures tie propellant tanks, a high pressure differential between left and right tanks could cause tank damage or helium ingestion if a crossfeed is initiated.

During ascent, orbit, and early entry when the normal gravity load is at or about 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 1.5g (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 should be considered to protect evacuated jets before initiating a crossfeed, time permitting. 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 because of an isolated failed on jet, that manifold should not be repressed.

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

XFEED: RCS to RCS
 If AUTO XFEED:
 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 XFEED:
 4. L,R OMS XFEED (four) – CL
 5. RCS XFEED (four) – OP
 6. Receiving RCS TK ISOL (three) – CL
 He PRESS (two) – CL
 7. MSTR RCS XFEED – FEED FROM L(R)

The procedures for executing an auto crossfeed ensure that the appropriate switches are in GPC to enable auto sequencing through the use of the master crossfeed switch. 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 and the

GPC-sensed parameters are met, the GPC-controlled valves can 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.

With the master crossfeed switch set in a FEED FROM position, simultaneous aft jet firings are limited as follows in Table 4-2:

Table 4-2. Crossfeed simultaneous jet fire limits

	MECO through ET SEP	TRANS DAP	ORBIT DAP	ENTRY DAP
No. of jets	7	5	4	4

The simultaneous jet firing restrictions are not applicable to SERC since OMS propellant is used.

Some manual switch movements may be required if/ when MDM/GPC failures have affected the auto crossfeed.

The sequence for a manual crossfeed during ascent and entry also ensures 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 reduces the number of simultaneous jet firings. Remember that only the FEED FROM positions of the master crossfeed limit the number of jet firings independently from the actual RCS valve position.

If a return to straightfeed 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 XFEED:

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

If MANUAL XFEED:

3. L,R RCS He PRESS (four) – OP (tb–OP)
TK ISOL (six) – OP (tb–OP), GPC
XFEED (four) – CL (tb–CL), GPC
4. 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
2. ✓L,R OMS XFEED (four) – CL (tb-CL)
3. RCS TK ISOL (six) – CL (tb-CL)
XFEED (four) – OP (tb-OP)
4. If RCS MANF P (OX and FU) > 130, continue;
otherwise, ✓MCC >>
5. R RCS:
✓He PRESS A(B) – GPC (tb-OP)
✓B(A) – CL (tb-CL)
TK ISOL (three) – OP (tb-OP)
6. MSTR RCS XFEED – FEED FROM R
7. DAP: as reqd

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

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

The on-orbit return to straightfeed is essentially a reversal of the secure procedures.

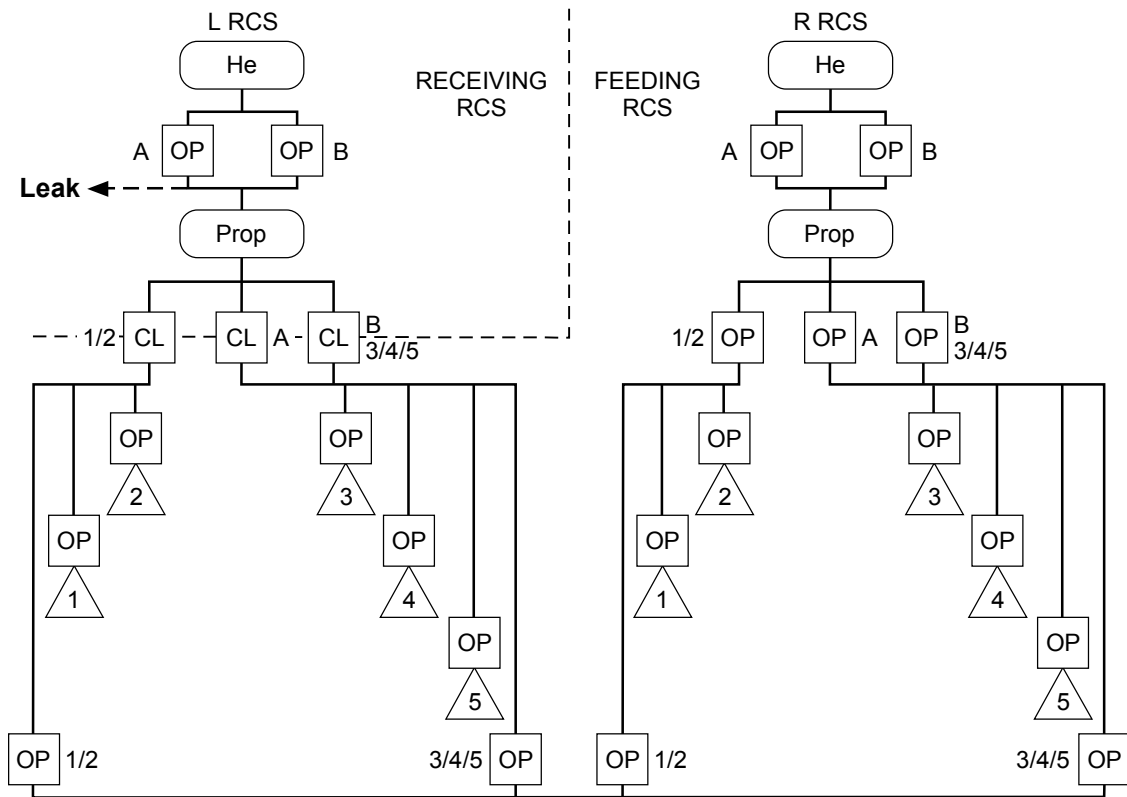
XFEED RETURN: RCS

1. DAP: FREE
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

4.3.3 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 presently no procedures exist 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 is announced on the receiving side, the leak must be upstream of the closed propellant tank isolation valves. In this case, only the helium isolation valves will have to be closed for leak isolation.



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Figure 4-4. Representative "Receiving RCS" leak during a crossfeed

If a leak is announced 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 are still open. If the leak is on this side, all manifolds evacuate and leak location is difficult to determine. If associated jets fire, they will fail off because of propellant starvation.

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 feeds a known leak unless the situation dictates otherwise (loss of control, ET SEP requirements, etc.).

Another area of concern is that crossfeeding can complicate subsequent scenarios. The majority of malfunction procedures are designed only for single failures with an assumed straightfeed configuration. These procedures may have to be modified by the crew in real time to avoid complicating the situation.

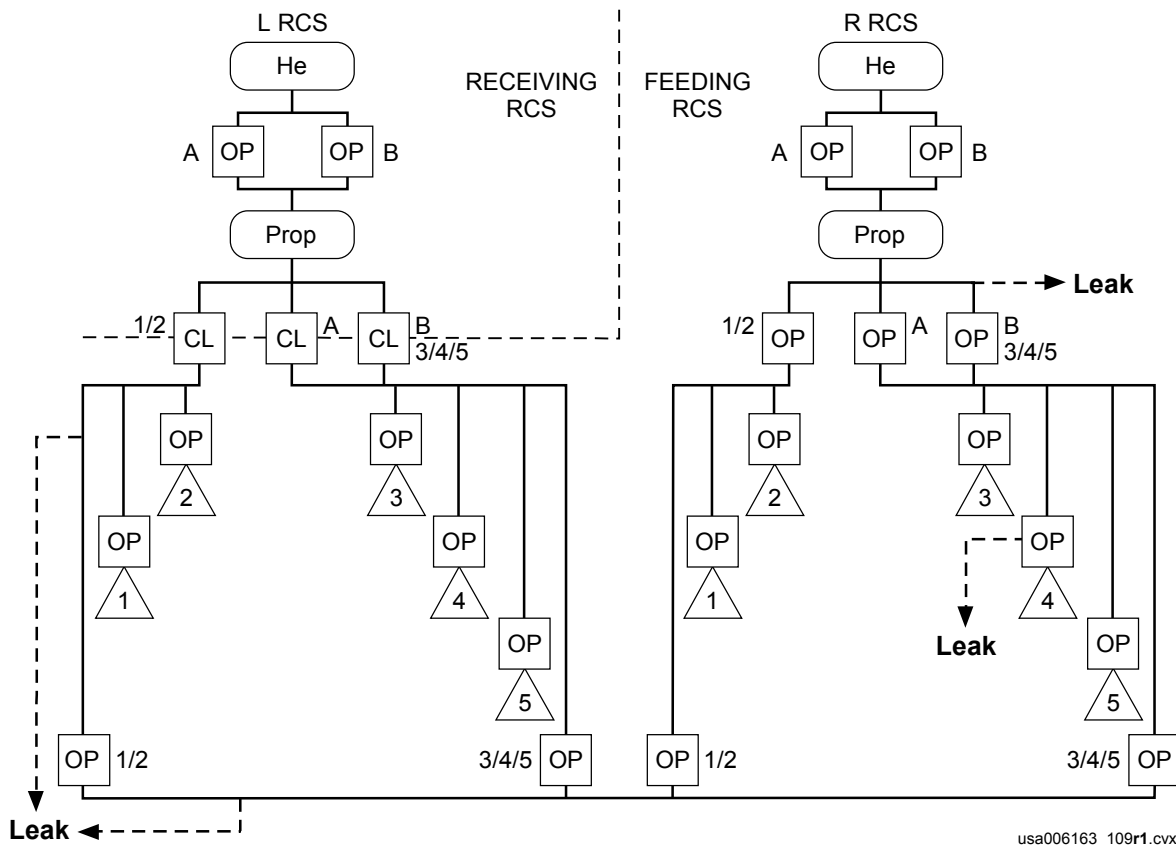


Figure 4-5. Representative "Feeding RCS" leak locations during a crossfeed

4.3.4 Interconnect

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

RCS manifolds must be continuously replenished to maintain vehicle control during ascent and entry. Therefore, the interconnect procedures during these phases of flight result in momentary instances where the OMS propellant tanks are tied to the RCS propellant tanks. However, if the OMS and RCS tanks are to be tied, the OMS tanks must be at the same (if not greater) pressure than the RCS tanks. Otherwise, the RCS tank bulkheads could collapse against the outlet, preventing further use of the RCS.

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 can cause tank damage. During this interconnect sequencing 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 SERC. During orbit and entry, the auto sequence is not available, leaving only manual procedures.

ICNCT: L OMS to RCS

1. L OMS He PRESS/VAP ISOL (two) – OP
2. \checkmark OMS TK P > RCS TK P and $\Delta P < 50$
3. L OMS XFEED (two) – OP (tb-OP)
4. L,R RCS XFEED (four) – OP (tb-OP)
TK ISOL (six) – CL (tb-CL)

The initial steps for ascent and entry manual interconnect procedures repressurize the OMS propellant tanks by opening the helium press/vapor isolation valves in the feeding system. The crossfeed lines are then pressurized after checking the OMS-to-RCS pressure differential. 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 the ascent and entry.

The on-orbit interconnect procedures differ slightly in sequencing from ascent and entry primarily to avoid tying the propellant tanks. The sequencing logic is similar to the on-orbit crossfeed procedures in regard to utilizing the DAP mode of FREE DRIFT (no jet firings) before closing the RCS tank isolation valves and opening the crossfeed valves.

ICNCT: L OMS to RCS

1. DAP: FREE
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, √MCC >>
4. √L OMS He PRESS/VAP ISOL (two) – CL
TK ISOL (two) – OP (tb-OP)
√R OMS XFEED (two) – CL (tb-CL)
L OMS XFEED A – CL (tb-CL)
B – OP (tb-OP)
5. L OMS TO AFT – ITEM 5 EXEC
6. DAP: as reqd

NOTE

Gauging not avail in OPS 3

Manifold pressure below 130 psi can indicate a leaking crossfeed line and an interconnect would not be prudent. MCC has additional insight and can provide recommendations to continue with the interconnect. If no leak is detected in the crossfeed lines (pressures not declining), the OMS propellant tanks are then connected to the crossfeed lines through just one set of crossfeed valves. (Note: Redundancy is not required because there is time available for manual reconfiguration.)

The helium isolation valves on the OMS are not opened for an on-orbit interconnect 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 is 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 is annunciated as low tank pressure in the OMS, not as an RCS leak. If an RCS leak is annunciated during an interconnect, it means the RCS leak is upstream of the closed RCS propellant tank isolation valves.

The need for blowdown is critical. If the OMS helium isolation valves are kept open and a leak develops, no C&W annunciation of the leak occurs until the helium tank reaches its C&W limit. Most of the leaking OMS propellant will then be gone and the “opposing” propellant (not leaking but in the same pod) will have a limited blowdown capability because the helium supply is now depleted. (Remember the OMS differs from the RCS in that one helium tank pressurizes both the fuel and the oxidizer tanks.) Blowdown, therefore, provides a more prudent interconnect configuration for on-orbit operations.

Once the on-orbit interconnect configuration is completed, the “RCS usage of OMS propellant” item entry on SPEC 23 (OMS AFT, item 5 or 6 on Figure 4-6) activates shuttle software calculations that estimate OMS propellant usage based upon the duration of RCS jet fire commands. This OMS AFT item entry can be made to any of the three SPEC 23 pages (F, L, R). The first OMS AFT item entry provides an automatic repressurization of the OMS propellant tanks; so the next nominal step, for leak detection purposes, is to inhibit this repressurization via the OMS PRESS ENA item entry. When the OMS AFT gauging is active, the prop usage calculations are displayed on SPEC 23 under the heading of OMS RCS QTY as percentage (0.82 = 0.82 percent of OMS propellant used).

This estimate of propellant usage is necessary because OMS quantity gauging calculations cease when the OMS engines are not firing. During these periods of OMS engine 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 caused by interconnected RCS usage after a burn is not displayed until 15 seconds after the OMS engines ignite 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. To make the estimate, the crew subtracts the OMS RCS QTY on SPEC 23 from the appropriate OMS quantity displayed on panel O3.

JET		FAIL	DES INH	JET DES	PTY	RCS		1 000/02: 53: 52 000/00: 00: 00	
F 1	4	PRI	FAIL	LIM	2	L OMS→	R OMS→		
L 2*						AFT 5	AFT 6	OMS-RCS QTY	
R 3	51	AUT	MANF	CL	ENA	FWD 46	FWD 47	49L	-0.00
						OFF	7*	50R	-0.00
						48	PRESS ENA		
								OXID	FU
L4L			8	9	3	HE	P	3416	3368
2L			10	11	2	PRPLT	TK P	245	250
Y 3L			12	13	1		T	80	80
1L			14	15	4		QTY	89	90
L4U			16	17	3	MANF	P	1	246
2U			18	19	2			2	248
Z 1U			20	21	1			3	250
L			22	23				4	248
4D			24	25	1	MANF	VLVS	STAT	OVRD
2D			26	27	2			1	OP
3D			28	29	3			2	OP
L3A			30	31	2			3	OP
X 1A			32	33	1			4	OP
			34	35				5	OP
L5L			36	37		AFT	XFD P	254	254
V 5D			38	39		JET	RESET	45	

00616301. CRT: 3

Figure 4-6. RCS display

There are several points that need to be made about SPEC 23 item entries.

When multiple on-orbit “interconnected” OMS burns are executed, an updated OMS quantity is displayed on panel O3 after each burn. The current OMS (to) RCS QTY displays are now somewhat superfluous because “OMS usage by the RCS” has been incorporated with the quantity gauging from the last burn.

In a total comm out situation, the crew must take one of the following steps:

- a. Manually track the moving point where a running total of OMS (to) RCS QTY was last accurate.
- b. “Zero out” the QTY via item entry after each burn.

However, with normal comm, the process is simplified. The OMS (to) RCS QTY is maintained as a running total and is neither zeroed out nor modified by the crew unless directed by MCC. The displayed OMS (to) RCS quantity calculations are subtracted from a baseline OMS usage number that is uplinked from MCC with the daily Execute Package. MCC determines OMS burn usage by summing the total “delta T” burn actuals and subtracting the burn actuals from prelaunch prop loading. The crew then subtracts the running total of OMS (to) RCS quantities from that baseline number to determine the remaining OMS propellant (i.e., the deorbit “delta V” capability).

The OMS (to) RCS QTY calculations are not based on valve configurations but on the duration of jet fire commands. If the crew interconnects to the right OMS, but inadvertently executes an item 5 (L OMS) on SPEC 23, the software estimates left OMS propellant usage when, in fact, right OMS propellant is being used.

To balance the usage of OMS propellant during long term interconnects, there are procedures to perform a tank switch from one side to the other. An item entry ensures that the appropriate prop usage calculation is swapped accordingly.

**I'CNCT TK SWITCH:
From L to R OMS FEED**

GNC 23 RCS

1. DAP: FREE
2. L OMS XFEED B – CL (tb-CL)
R OMS XFEED B – OP (tb-OP)
3. R OMS TO AFT – ITEM 6 EXEC
4. DAP: as reqd

The crew must realize that when the OMS AFT item entry is active, calculations continue regardless of physical valve configurations (interconnect, crossfeed, or straightfeed). When stopping an interconnect for leak isolation procedures, the OMS AFT quantity calculations must also be terminated.

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 are used to calculate and display propellant usage when, in fact, there is no usage. Similarly, a failed on jet burns propellant, but there are no calculations of propellant usage by that failed on jet because there is no fire command. Of course, when other jets fire to compensate for the failed on jet, fire commands for the compensatory jets are used for calculations.

Automatic repressurization of the OMS propellant tanks can be enabled or inhibited via the OMS PRESS ENA item entry on SPEC 23. When automatic repressurization is enabled and the OMS helium isolation switches are in GPC position, repressurization of the propellant tanks occurs when the pressure drops below a preset value. This function is particularly useful during periods of high RCS usage while interconnected. (e.g. Rendezvous maneuvers). Normally, however, the crew negates the auto repress when they place the OMS helium isolation switches in hard closed. Otherwise, the auto repress could hide a potential propellant tank leak.

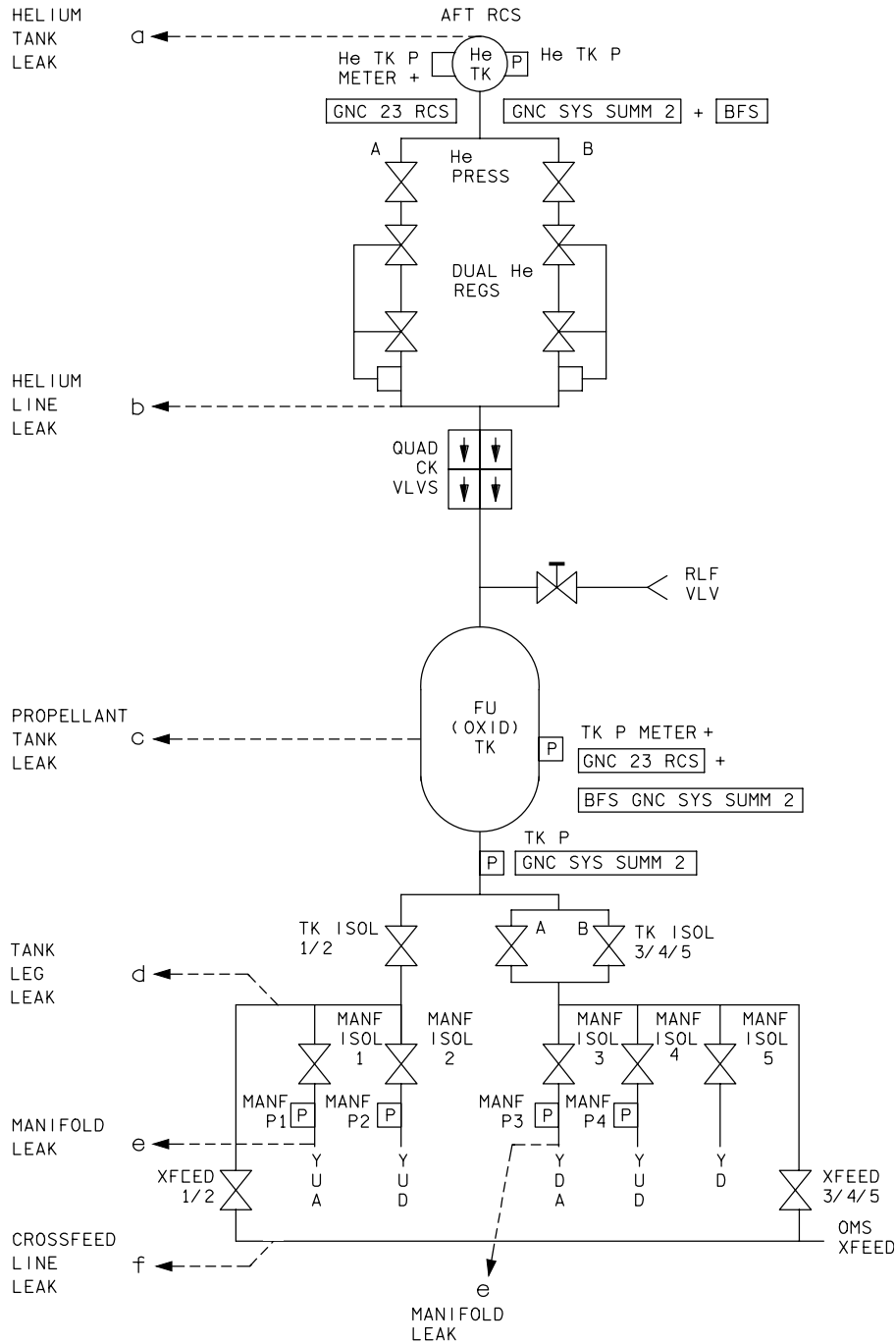
The step-by-step rationale for RCS malfunction procedures can be found in the Flight Procedures Handbook (Ascent/Orbit/Entry Pocket Checklists) Volume II, Section 8. This section of the Flight Procedures Handbook is highly recommended for followup study to this manual, or it can be used in conjunction with this manual to provide a more complete understanding of the off-nominal situations that follow.

4.3.5 Leak Isolation

Propellant or helium leaks can occur anywhere in the various tanks and lines. Procedures to isolate leaks differ slightly, dependent upon valve configuration and flight phase. These procedures were developed to provide a practical sequence of valve movement to determine the location of the leak, 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 occurs when the fuel and the oxidizer quantities in any one pod differ by more than 9.5 percent. The lower quantity indicates the propellant system with the leak.

Leaks are generally typed according to the location of the leak, as shown in Figure 4-7.



006163010, SCH# 2

Figure 4-7. Location of leaks

Leaks may occur in any of the following locations:

- Helium tank - Located upstream of the helium isolation valves. Determined by helium pressure decrease with the helium isolation valves closed.
- Helium line - Located between the quad check valves and the helium isolation valves. Determined by decreasing helium tank pressure with the helium isolation

valves open and the propellant tank isolation valves closed and by confirmation of no helium tank or propellant tank leak.

- c. Propellant tank - Located between the quad check valves and the propellant tank isolation valves. Determined by decrease in propellant tank pressure with the helium isolation and propellant tank isolation valves closed.
- d. Tank leg - 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.
- e. Manifold - Located downstream of the manifold isolation valves. Determined by a single manifold pressure decrease with the manifold valve closed. Pressure can drop to zero.
- f. Crossfeed line - Located between the RCS crossfeed valves and the OMS crossfeed valves. Determined by decreasing pressure in the left or right RCS 1/2 leg with the corresponding system secured and all OMS/RCS crossfeed valves closed, except for the affected RCS 1/2 crossfeeds.

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

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

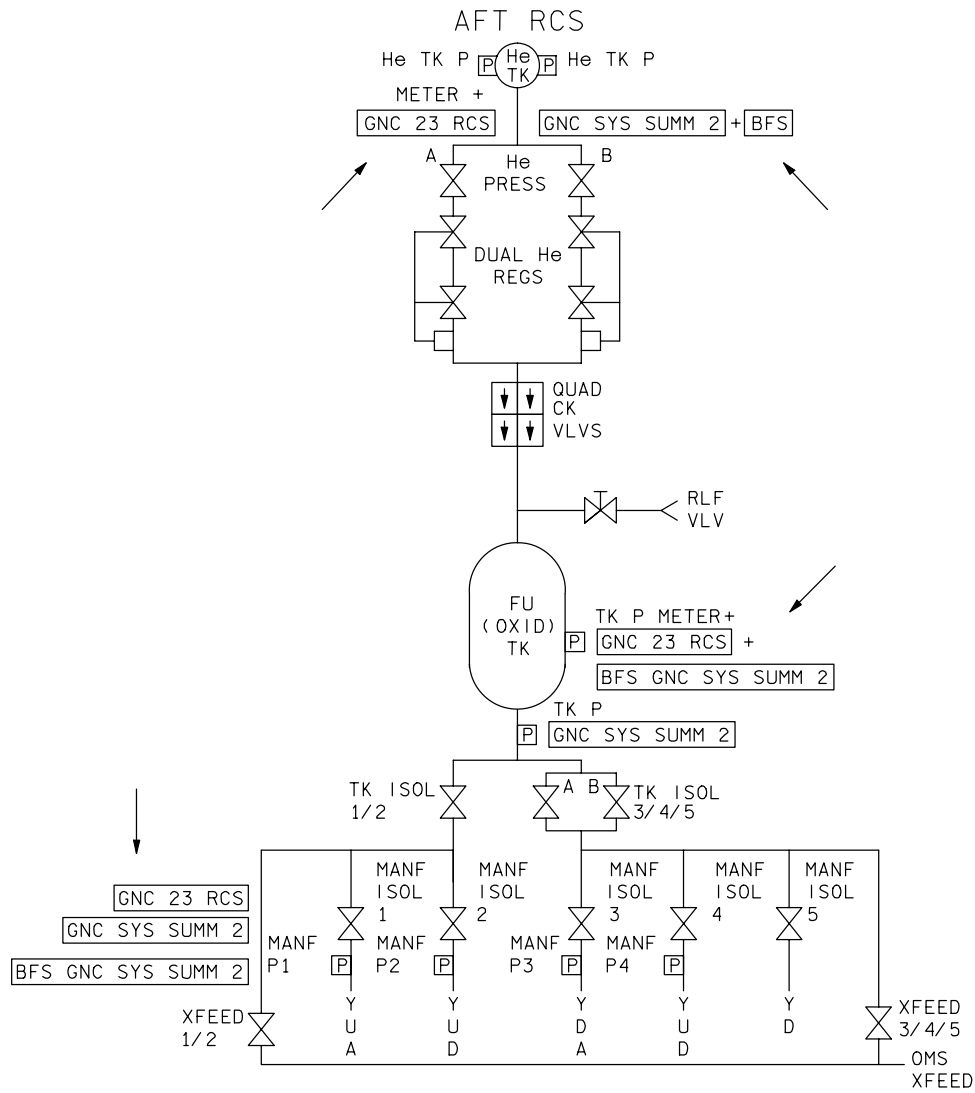
If the helium pressure drops below 456 psi, the helium tank is considered failed and the associated propellant tank is in "blowdown."

The initial goal of leak isolation is to determine the location of the leak. Before leak isolation is initiated, the crew should crosscheck sensor indications in the event of a simple sensor failure.

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 high tank pressure correct the situation and stop the venting. Leak isolation procedures should not be followed if the tank pressure is high.

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



TD3400408, ART# 5

Figure 4-8. Sensor output display destinations

If tank pressures are normal and pressure sensors give a valid leak signature, leak isolation procedures should be initiated.

RCS LEAK ISOL

BFS, GNC SYS SUMM 2

1. If FU or OXID TK P high, Go to RCS TK P HIGH >>
If FU or OXID TK P normal:
2. ✓FU(OXID) He P (O3 meter and CRT) decr
3. DAP: INRTL/PULSE
4. After proc complete, DAP: as reqd

SECURE RCS

5. Perform aff RCS SECURE, then:
If aff RCS was receiving XFEED/I'CNCT when leak occurred:
6. Go to step 9

✓SINGLE MANF

- If only one MANF P decr:
7. Return to normal config except leave (aff) MANF closed >>

✓PRPLT TK LEG (✓TWO MANF P)

- If MANF 1,2 or MANF 3,4 P decr:
8. Return to normal config except leave (aff) TK ISOL (1/2 or 3/4/5), (aff) MANFs, and corresponding XFEED vlvs closed >>

✓He TK

9. ✓He P
If AFT decr:
| 10. I'CNCT from OMS, then open good MANFs >>
If FWD decr:
| 11. Return to normal config
| 12. When He P < 456: Go to RCS SECURE >>

✓PRPLT TK

13. ✓PRPLT TK P
If AFT decr:
| 14. I'CNCT from OMS, then open (aff) MANFs >>
If FWD decr:
| 15. Leave FWD RCS secured >>

✓He LEG

16. Open He PRESS A and B. ✓He P
If AFT decr:
| 17. Close He PRESS A and B
| I'CNCT from OMS, then open (aff) MANFs >>
If FWD decr:
| 18. Return to normal config except close He PRESS A and B.
| Cycle to maintain PRPLT TK P 200-245
When He TK P < 456:
| 19. Go to RCS SECURE >>

✓XFEED LINES

- If aff RCS was feeding XFEED when leak occurred:
20. **GNC 23 RCS**
RCS L - ITEM 2 EXEC
If XFEED P decr or zero:
| 21. L,R RCS He PRESS (four) - OP (tb-OP)
| TK ISOL (six) - OP (tb-OP)
| MANF ISOL (ten) - OP (tb-OP)
| 22. MSTR RCS XFEED - OFF
| 23. Do not XFEED/I'CNCT >>

✓RCS MANF ISOL 5

24. If leak not found above: Assume RCS MANF ISOL 5 leak
25. Return to normal config except leave (aff) RCS MANF ISOL 5 - GPC (tb-CL)

Leak isolation generally begins by securing the RCS, followed by a check for any pressure decrease in a propellant line. Since the RCS is unusable when secured, the crew must evaluate the need for maintaining RCS control before closing any manifolds. Also, whenever the RCS is reconfigured, the crew should monitor the valve talkbacks associated with each switch movement. This helps to confirm that the associated switch is operational.

When a confirmed leak is isolated, situational awareness must be increased. This is especially true if ET separation has not yet occurred. The loss of isolated jets may be critical. Mission Flight Rules specify the minimum number of jets required for ET separation (see Table 4-3). More jets are required for the RTLS ET separation than are required for a nominal separation because of the increased maneuvering and aerodynamic loads on the vehicle.

Table 4-3. ET separation RCS requirements

Jet Group	Minimum Requirements	
	Nominal	RTLS
FWD DOWN	1	3
AFT LEFT	1	3
AFT RIGHT	1	3
AFT UP	1 / SIDE	2 / SIDE
AFT DN	1 / SIDE	2 / SIDE
FWD YAW	-	1 / 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 to provide adequate control. This action must not be taken without the advice and consent of MCC because the manifold reopening will feed a known leak. Once the orbiter is safely separated from the tank, the crew can initiate leak isolation procedures provided they do not interfere with the execution of a time-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). 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. For RTLS aborts, the ET SEP switch stays in AUTO because ET separation is time critical for that phase and cannot be delayed.

RTLS ET separation is a time -critical maneuver; so the crew might consider delaying the closure of manifolds if leak isolation actions are necessary close to MECO. Once the orbiter is safely separated from the tank, the crew may then initiate leak isolation procedures.

AFT RCS LK

N/A During Dump/SE Roll Cntl

(√He P decr: CRT & meter)

1. If TK P ↑: Go to TK P HIGH >>

TK P ≥ 254 and not decr (He Leak)	2. MSTR XFEED – feed from good side 3. Aff RCS He PRESS (two) – CL 4. [G51] AFT RCS – INH (ITEM 13) >>
TK P < 254 or decr (prop leak)	5. (N/A RTLS) ET SEP – MAN 6. (N/A RTLS) MPS PRPLT DUMP SEQ – STOP 7. Aff MANFs (five) – CL 8. Aff TK ISOLs (three) – CL
Single MANF leak	9. TK ISOLs (three) – OP (tb-OP), GPC 10. Good MANFs (four) – OP
QTY < 75%	11. MSTR XFEED – feed from good side
Two MANF P decr (TK leg leak)	12. Good leg TK ISOL(s) – OP (tb-OP), GPC 13. Good leg PRI MANFs (two) – OP 14. Leaking leg XFEED (one) – CL
QTY < 75%	15. MSTR XFEED – feed from good side
No MANF P decr (Prplt TK or MANF 5 leak)	16. L,R RCS XFEED (four) – OP 17. Aff RCS MANF 1,2,3,4 (four) – OP 18. Aff RCS He PRESS (two) – CL 19. MSTR XFEED – feed from good side
	20. ET SEP – AUTO 21. [G51] AFT RCS – INH (ITEM 13) 22. Post ET SEP –Z transl: MPS PRPLT DUMP SEQ – GPC

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 results 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 caused by a tank leak that cannot be isolated in an aft pod can be overcome by using a crossfeed. Remember that the forward RCS has no crossfeed capability, so a tank leak that cannot be isolated 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 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)

RTLS	1. Perform RCS SECURE, then: 2. Post PPD – reopen RCS Post ET SEP –Z transl: 3. Go to RCS SECURE >>
Pre ET SEP (N/A RTLS)	4. ET SEP – MAN 5. MPS PRPLT DUMP SEQ – STOP 6. Perform RCS SECURE, then:
Single MANF leak	7. Reopen RCS, except bad MANF 8. ET SEP – AUTO Post ET SEP –Z transl: 9. MPS PRPLT DUMP SEQ – GPC >>
TK leg leak (two MANF P Low)	10. Reopen RCS, except bad leg 11. ET SEP – AUTO Post ET SEP –Z transl: 12. MPS PRPLT DUMP SEQ – GPC >>
PRPLT TK P decr	
Post MECO	13. RATE DAMP with ARCS 14. Reopen FRCS
TK P > 200 & QTY > 0%	15. ET SEP – AUTO
TK P < 200 or QTY = 0%	16. Perform RCS SECURE, then: 17. DAP – INRTL, PITCH – PULSE 18. ET SEP pb – SEP 19. THC –Z (2 sec; –1.25°/sec) 20. THC –X and hold
At SEP (SEP init + approx 12 sec)	21. THC +Z (3 sec; +0.3°/sec) THC –Z (2 sec; –0.9°/sec) COAST (5 sec) THC +X (20 sec) After 10 sec of +X, then: PITCH – DISC RATE
	22. OPS 104 PRO, DAP – AUTO
Otherwise: (He TK or He leg)	Post MECO – reopen RCS 23. ET SEP – AUTO
Post ET SEP –Z transl	24. MPS PRPLT DUMP SEQ – GPC 25. Go to RCS SECURE

If a leak occurs in the RCS during ascent or aborts, 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. 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 and reduces any aft RCS quantity below 75 percent, then major RCS maneuvers such as ET separation must be performed in a crossfeed from the nonleaking pod. Otherwise, as a consequence of the propellant tank's design, helium could be ingested into the manifolds.

During ascent, orbit, and early entry, aft RCS leak isolation procedures call for a complete secure of the leaking pod. During late entry (MMs 304-305, 603) the demand for aft RCS control is more critical and the RCS should not be completely secured.

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)

1. If TK P ↑: Go to TK P HIGH >>

OX Leak	2. [G51] VENT DOOR CNTL – OPEN (ITEM 43)
RTLS/TAL	3. [G51] AFT RCS – INH (ITEM 13)
	4. Aff 3/4/5 MANFs – CL 5. Aff 3/4/5 TK ISOL(s) – CL
Single MANF leak	6. TK ISOL(s) – OP (tb-OP),GPC 7. Good PRI MANF (one) – OP
Two MANF P decr (TK leg leak)	8. Leaking leg XFEED (one) – CL
No MANF P decr	9. TK ISOL(s) – OP (tb-OP),GPC 10. PRI MANFs (two) – OP 11. Repeat steps 4–10 for 1/2 leg
Leak not found	12. Aff RCS He PRESS (two) – CL
He P decr (He TK leak) M > 3	13. [G51] VENT DOOR CNTL – CLOSE (ITEM 44)
	14. He PRESS (two) – OP 15. When He P < 456, MSTR XFEED – feed from good side >>
OX/FU TK P diverge (Prplt TK leak)	16. He PRESS (two) – OP 17. When QTY = 0, MSTR XFEED – feed from good side & Aff He PRESS (two) – CL >>
Leak not found	18. He PRESS (two) – OP
He P decr (He leg leak) M > 3	19. [G51] VENT DOOR CNTL – CLOSE (ITEM 44)
	20. Cycle He PRESS so 220 < TK P < 245 21. When He P < 456, MSTR XFEED – feed from good side >>
Leak not found	22. Assume MANF 5 leak
M > 3	23. [G51] VENT DOOR CNTL – CLOSE (ITEM 44)

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

A helium leak (a leak upstream from the quad check valves) causes unreliable quantity calculations. The shuttle crew needs to communicate with MCC to determine the actual propellant quantity. If there is no communication with the MCC, the crew can only estimate how much propellant remains in the leaking system.

To make an estimate, the crew uses the good quantity of the opposing propellant plus any preleak difference. For example, if quantities displayed preleak in the leaking pod were FU 38 percent, OX 40 percent, and fuel helium was leaking, then a good estimate for fuel quantity would be oxidizer quantity minus 2 percent with an adjustment for blowdown.

Once the quantity of propellant is estimated, it must be realized that not all the propellant may be usable because of 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 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 a helium leak that cannot be isolated is present (and time permits), the crew follows Orbit Pocket Checklist procedures to dump RCS propellant until the quantity reaches the maximum blowdown quantity of about 23 percent.

4.3.6 Tank Pressure Malfunctions

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

RCS TK P LOW (FU or OX)

GNC SYS SUMM 2

1. ✓FU(OX) He P (CRT & meter)
- If decr:
 2. Go to RCS LEAK ISOL, step 1 >>
- If not decr:
 3. (Aff) RCS He PRESS A(B) – CL (tb–CL)
B(A) – OP (tb–OP), GPC (tb–OP)

A low tank pressure can result from four situations.

- a. Both regulators fail to a low setting.
- b. The helium pressurization valves are closed while RCS is in use.
- c. A propellant leak occurs.
- d. 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.

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 P HIGH (FU or OX) (✓MANF P)

1. He PRESS (two) – CL
2. A – OP
- If He P decr:
 3. He PRESS A – CL
B – 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 the failed open regulator is not isolated, the situation eventually becomes a helium line leak, and a leak message is annunciated. Even after isolating the failed regulator, the affected propellant tank will remain overpressurized. Over the course of subsequent RCS jet firings, the propellant tank pressure will eventually return to normal. The crew can then rely solely on the unaffected regulator to pressurize the tank. The failed regulator could be used, if needed. In that case, though, the crew would have to manually open and close the associated helium isolation valve, as necessary.

Remember that the helium isolation valve switches control pressurization for both fuel and oxidizer tanks. When an overpressurized tank bleeds down to normal limits (about 250 psi), the opposing propellant tank may 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 reading, not on a normal reading from the high pressure tank.

An 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. The pressure imbalance tends to move the point of combustion closer to the combustion chamber walls. This could lead to a burn-through. Consequently, primary jets must be used, because they differ from the verners by having a larger combustion chamber and a different propellant injection mechanism.

4.3.7 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); SM0 PRPLT THERM (BFS). These messages usually mean that a heater, thermostat, or temperature sensor has failed. In ascent, the crew cannot act because the heater switches cannot be reached easily. Once on orbit, 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.

4.3.8 Jet Failures

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

RCS JET FAIL (ON)

1. Aff RCS MANF ISOL – CL
If MANF P > 130 and stable (false alarm):
2. Aff RCS MANF ISOL – OP
3. ✓AFT RCS RM LOSS

A failed on jet creates control difficulties because of excess thrusting. Propellant usage increases 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 continues to fire with the manifold closed, and both fuel and oxidizer pressures drop below 130 psi. (If the pressures stay above 130 psi, the fail on indication is false.)

During shuttle-docked-to-ISS (or large payload) operations in OPS2, a jet fail on could cause structural failure at the “joints” or to the less robust portions of the docked “stack.” The GPCs can automatically close the affected manifold if a jet fail on is annunciated AND the AUTO MANF CL capability has been enabled via SPEC 23, item 51.

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, steps are taken to continue to use this jet in the hope that the failure is false; i.e., the P_c sensor has failed.

To regain the use of a failed off jet, SPEC 23 must be available to reselect that jet because it has probably been auto deselected. Deselect inhibit entries are made to lower the firing priority of reselected jets. If a failure occurs on orbit, there are procedures for a hot fire test to determine if the jet is actually firing.

RCS JET FAIL (LEAK)

If OX/FU Qty diverging:

1. Aff RCS MANF ISOL – CL

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. Otherwise, the indications are most likely from a failed injector temperature sensor.

4.3.9 RM Malfunctions

The CRT/MEDS message RM DLMA MANF is annunciated if the RM software has an insufficient number of open or closed discrettes from the position microswitches for the manifold isolation valves. If a dilemma exists, the manifold status will be declared “closed” and a “?” will appear by the manifold status on the crew displays. This does not necessarily mean that the actual manifold isolation valve is closed. The valve itself could actually be open. Only the software considers the valve closed and thus automatically deselects the jets on that manifold. If the talkback indicates open and the crew wants those jets available, the manifold status can be overridden open via

keyboard entry (item 41) to SPEC 51. Table 4-4 describes the manifold and dilemma status for all possible microswitch combinations.

Table 4-4. 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	Yes
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 caused by a power failure.

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

RM DLMA MANF

If aff MANF tb – OP or switch not thrown:

1. If FRCS: MCC
2. If ARCS: G51 RCS RM MANF CL OVRD –
ITEM 41 EXEC
3. If aff MANF tb – bp: aff MANF – GPC

This item entry overrides to open all manifolds with a closed status caused by a dilemma. It does not affect the status of manifolds that are physically closed or manifolds whose statuses have been overridden to closed. If SPEC 23 is available, an individual manifold in dilemma may be overridden open via keyboard entry (items 40 to 44).

A barberpole talkback for that manifold could indicate that the ac motor is now driving the valves either open or closed (depending on the position of the isolation valve

switch.) But, because of the failed microswitch, the motors will constantly drive the valves and possibly burn themselves out. Placement of the switch in GPC takes power away from the ac motor.

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 Bus Control Element Bypass (BCE BYP) causes the loss of RM to multiple jets associated with that element.

RCS RM LOSS**GNC 23 RCS**

If vernier jets:

If loss of FAIL OFF detection:

1. Resel >>

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

If only L5L and/or R5R aff:

2. Desel aff jet >>

L5D,R5D,F5L, and/or F5R aff:

3. (Aff) RCS MANF ISOL 5 – CL (tb-CL)

4. Go to LOSS OF VERNIERS (ORB OPS, RCS) >>

If primary jets:

If loss of FAIL OFF or LK detection:

5. (Aff) jet – DES INH (*) (Reprioritize)
6. If auto deselected: Reselect
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: Ovrđ STAT closed for all MANFs
on (aff) RJD and (aff) RJD – OFF
9. (Aff) jet 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 (aff) RJD and (aff) RJD – OFF
12. (Aff) jet 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 a single jet only. Specifically, a false jet fail leak (injector temperature transducer failure) causes the loss of fail leak RM but will not affect fail on or fail off RM. A jet P_c transducer failure causes the loss of fail off RM (PASS and BFS) and fail on RM (BFS only) but does 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 on orbit and affects only 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 continued because the downfiring 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 the

jets can be reselected and vernier operations can continue. Any other type of RM loss to critical vernier jets will result in the total loss of vernier operations.

On-orbit 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 on-orbit RM loss requires additional steps. Loss of fail off or fail leak detection calls for reprioritizing the affected jet to last priority and reselecting the jet so it may be fired if needed.

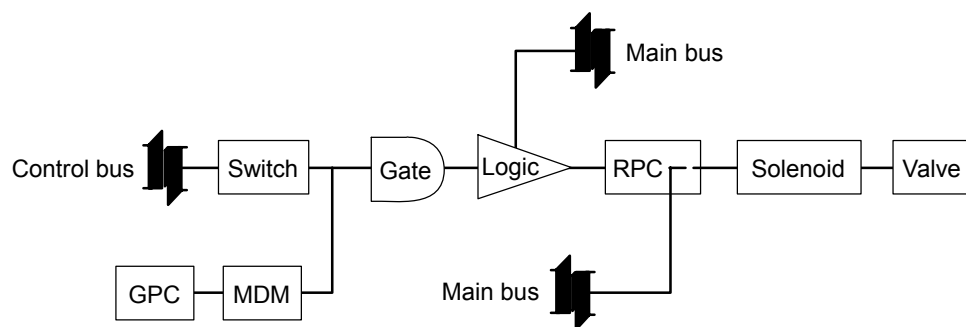
Loss of fail on detection calls for overriding the affected manifold status to closed. This removes the affected jets from the availability table because the jet drivers are turned off. This allows the manifold valves to be left open and protects against thermally induced jet fail leaks.

Commfaults caused by MDM failures and BCE bypasses automatically cause the affected manifold statuses to go closed. Turning the affected jet drivers off is all that remains to be done.

4.3.10 Electrical/Data Path Failures

The operation of the RCS is dependent on electrical power supplied through various electrical buses and sent to components of the 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.

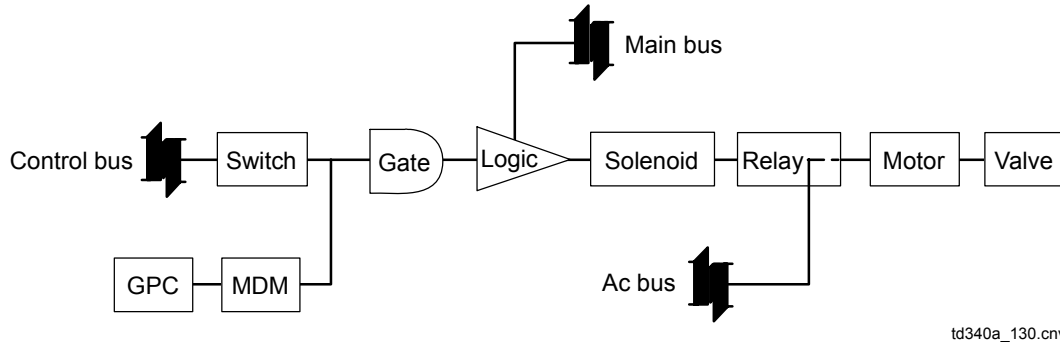
Figure 4-9 is a simplified schematic of electrical and data path flow for solenoid-driven valve operation. Switch or GPC outputs provide gate inputs to main-bus-powered logic circuits. The outputs of the logic circuit activate remote power controllers that provide main bus power control of selected valves.



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

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.



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

The detailed schematics of the RCS can be found in JSC-11174, Space Shuttle Systems Handbook, Section 11, drawings 11.4 through 11.10. Deductive analyses of these schematics reveal the results of specific combinations of electrical and data path failures.

The following paragraphs 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 Configuration Screen (ORCS) computer application for evaluating these failures is also covered in later sections.

Other areas of discussion include electrical/DPS effects on

- a. OMS-to-RCS interconnect sequence
- b. RCS-to-RCS crossfeed sequence
- c. Pressure and temperature sensors
- d. Quantity gauging
- e. Jet fire commands
- f. Pod heaters

4.3.10.1 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 of the aft right helium pressurization A valves. This schematic can be considered representative of all solenoid type valves. (The vernier manifold schematic is slightly different but similar in operation.) Refer to JSC-11174, Space Shuttle Systems Handbook, Section 11, for specific differences between the two solenoid valves.

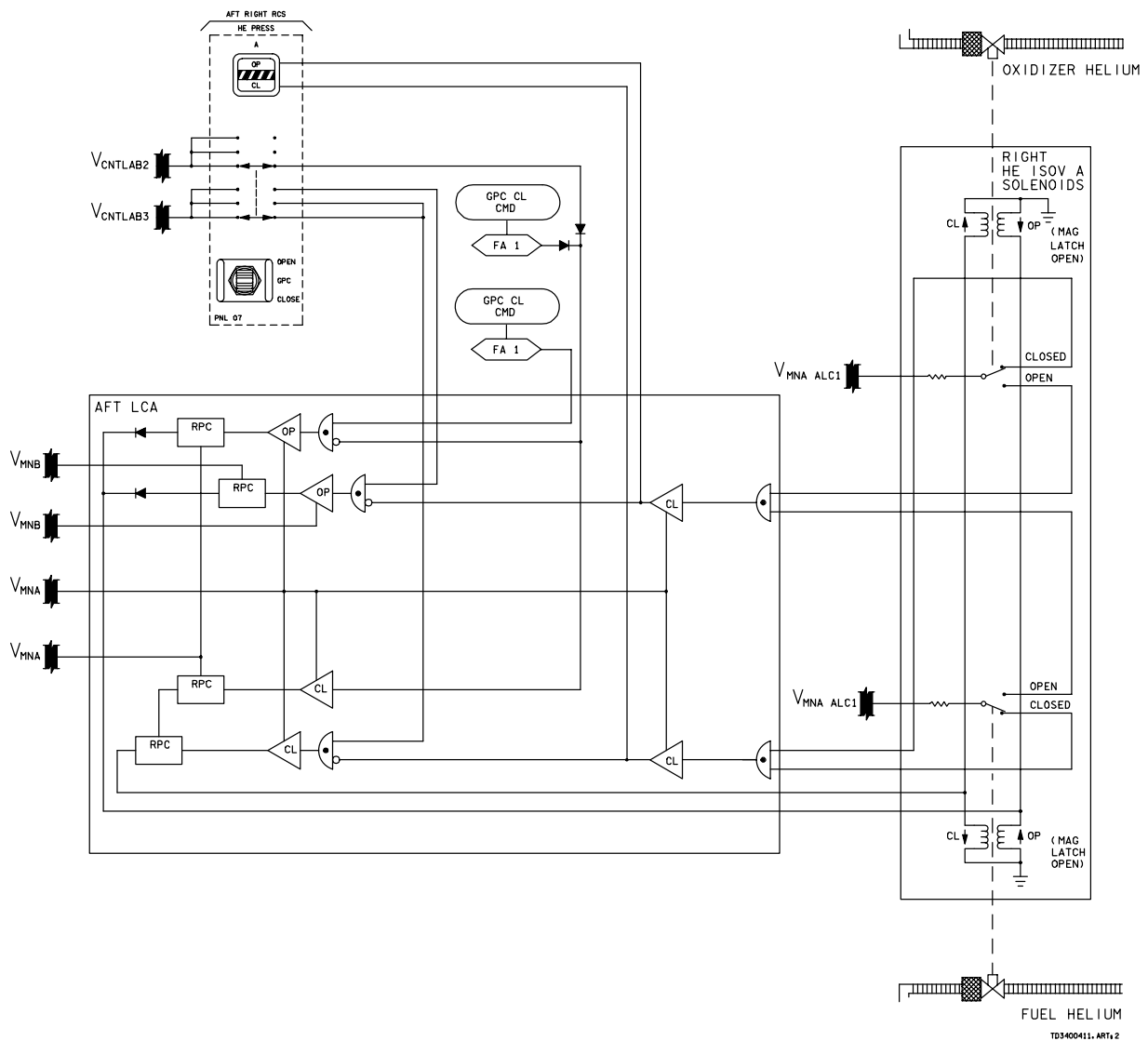


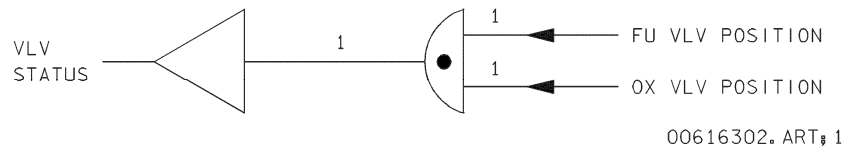
Figure 4-11. Schematic for the aft right RCS helium pressurization A valves

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 positions.

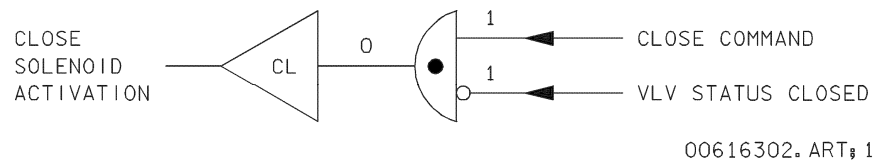
4.3.10.2 Close Operation

Placing the switch in the closed position enables control bus power flow through various gates and logic circuits to Remote Power Controllers (RPCs). 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 (LCAs) and Power Control Assemblies (PCAs) are AND gates.



For an AND (i.e., multiply the inputs) gate to make a “one” output, both “one” inputs are required. Any other combination of inputs (a one and a zero/two zeroes) gives 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 for valve status (note the “o” at the end of the valve status closed line). 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 losses occur:

- Loss of either control bus power to the switch contacts. (Note that 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

4.3.10.3 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 losses occur:

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

4.3.10.4 GPC Operation

If the switch is placed in GPC, 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) activates that portion of the circuitry. This enables the first close RPC; however, the valve will not operate until the second close RPC is activated.

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 losses occur:

- a. Loss of the dedicated MDM (or its associated GPC)
- b. Loss of control bus power to the “lower” three-contact bus of the switch
- c. Loss of main bus power to the GPC close logic
- d. 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 ensures that all close commands can override any GPC open commands. Note that the GPC open circuitry is separate from the manual open circuitry (RPCs are in parallel).

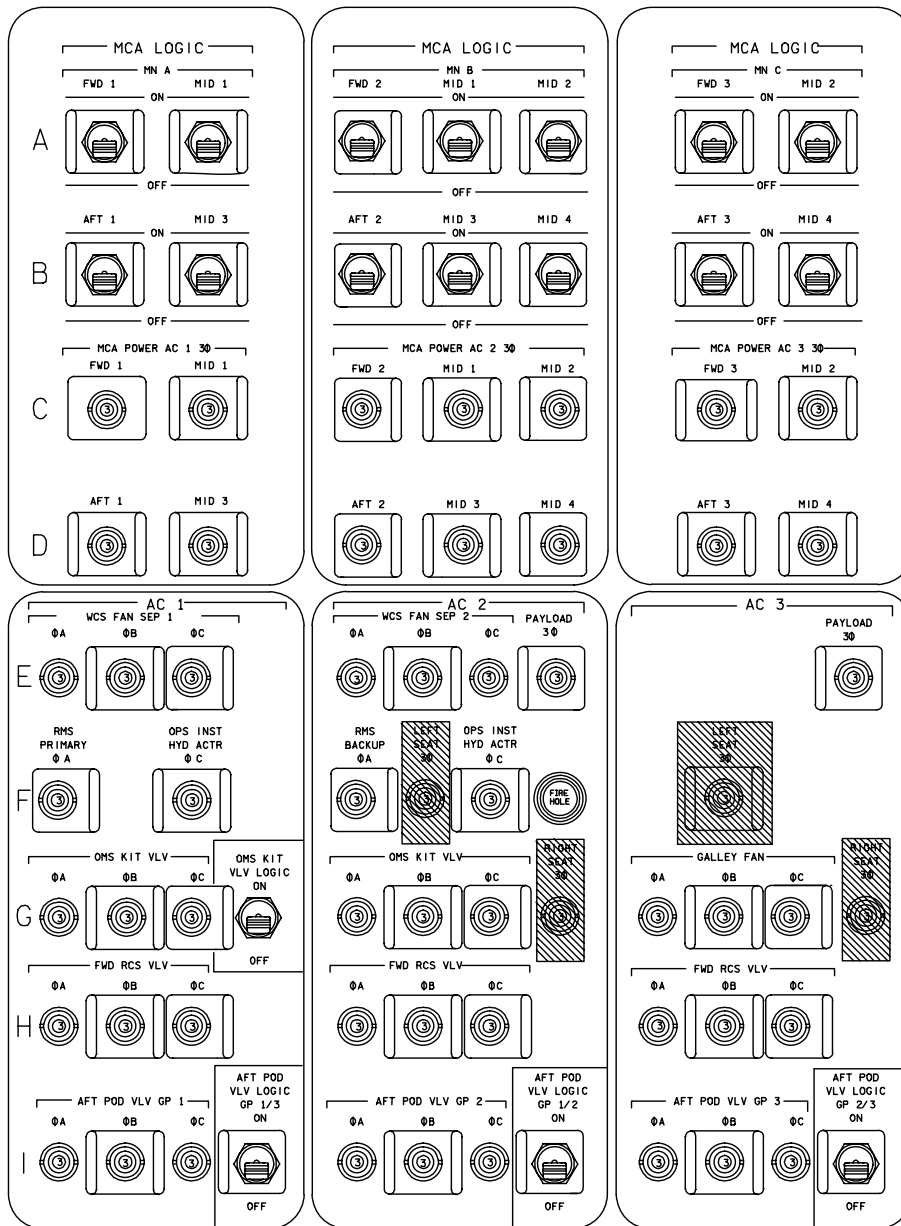
GPC open control is lost if any of the following losses occur:

- a. Loss of the dedicated MDM (or its associated GPC)
- b. Loss of main bus power to the GPC open logic
- c. 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.



TD3400412. ART. 1

Figure 4-12. Panel MA73C

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

AC1	AC2	AC3
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, and the circuit breakers can be found on row C. Each forward RCS MCA receives logic power from only one source: 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 1 of MA73C and provide power to the following fuel and oxidizer valves.

AFT POD VLV GP 1

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

AFT POD VLV GP 2

L&R	RCS TK ISOL 3/4/5B
L&R	MANF 1
L&R	OMS XFD B

AFT POD VLV GP 3

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 is 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 found on row I of MA73C. Each MCA receives inputs because of the position of the controlling valve switch. This switch provides control bus power through various gates and logic circuits in order to activate controlling relays. These relays 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 is discussed first.

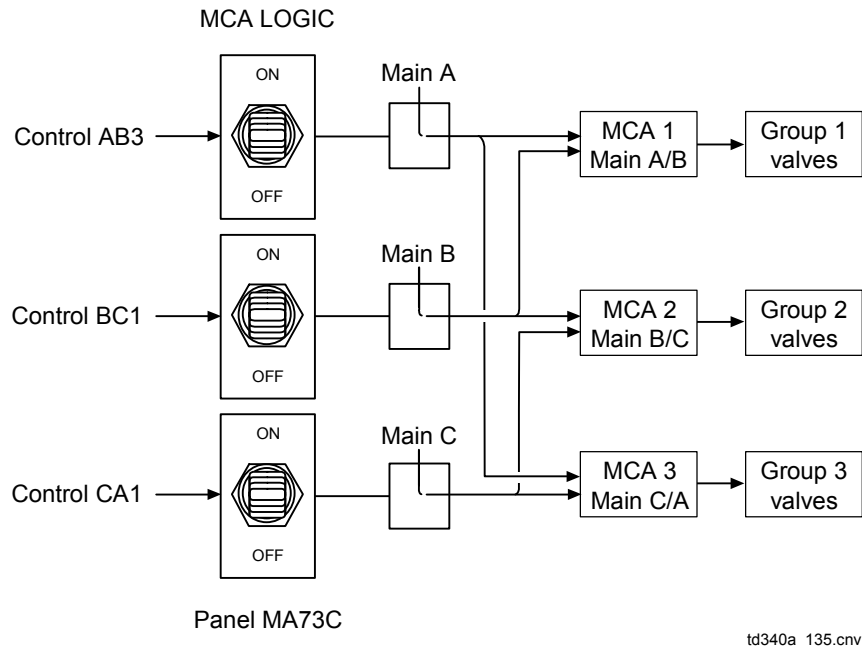


Figure 4-13. MCA logic on panel MA73C

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 because the main text provides an adequate description of valve operation.

However, for an in-depth understanding of MCA operation, read this paragraph. Figure 4-14, Figure 4-15, and Figure 4-16 show schematics for different types of MCAs. Since the fuel "wiring" is essentially identical to the wiring of the oxidizer 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 tracing the electron flow through the oxidizer side of the wiring diagram. A study of these figures provides an understanding of valve operation, manual override of GPC commands, and motor stoppage when the valves reach a desired position.

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.

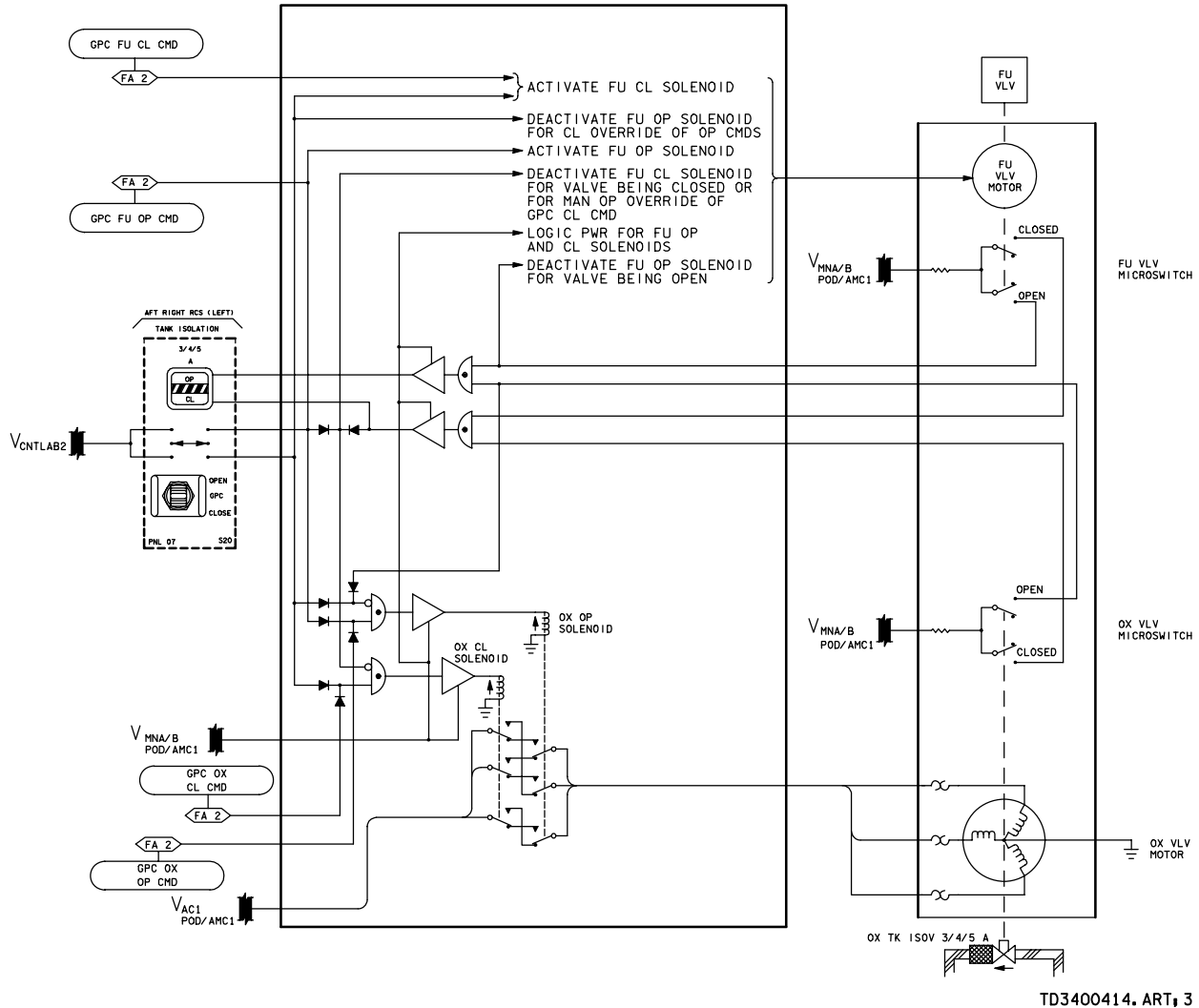


Figure 4-14. Schematic for a single contact switch

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 allows GPC activation of the affected valves, regardless of switch position.) When the valves reach the selected position, the motor is stopped. Manual close commands override any open commands.

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

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

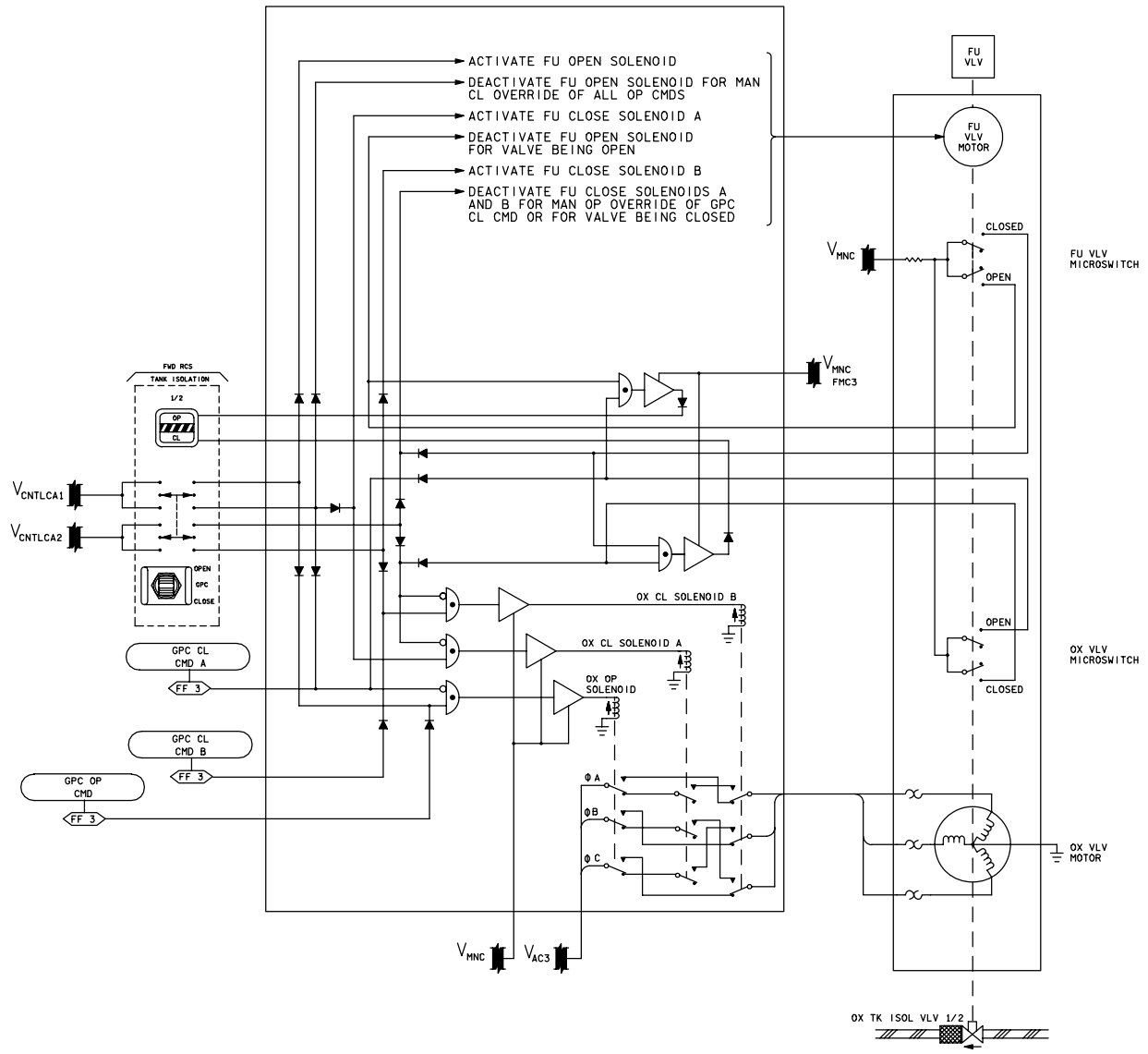
The loss of control bus power does not affect GPC operation of the valves; however, the loss of dedicated MDMs (or GPCs), logic power, or ac power will cause the loss of GPC control for the affected valves.

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 used only 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 losses occur:

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



TD3400415, ART 3

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 provides only manual open input to the close circuitry gates in order to override any GPC close command. The loss of this control bus does not affect open operation.

Manual open operation is lost if any of the following losses occur:

- a. Loss of the primary control bus (solenoid operation)
- b. Loss of main bus logic power
- c. 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 losses occurs:

- a. Loss of the dedicated MDM (or the controlling GPC)
- b. Loss of main bus logic power
- c. 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 losses occurs:

- a. Loss of the dedicated MDM (or the GPC)
- b. Loss of main bus logic power
- c. 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 with two major differences.

- a. 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. Because 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.
- b. The four-solenoid MCA GPC A and B commands are routed through different MDMs. The loss of one MDM affects only GPC close operation of the affected valves. GPC open operation is not lost with the loss of one MDM.

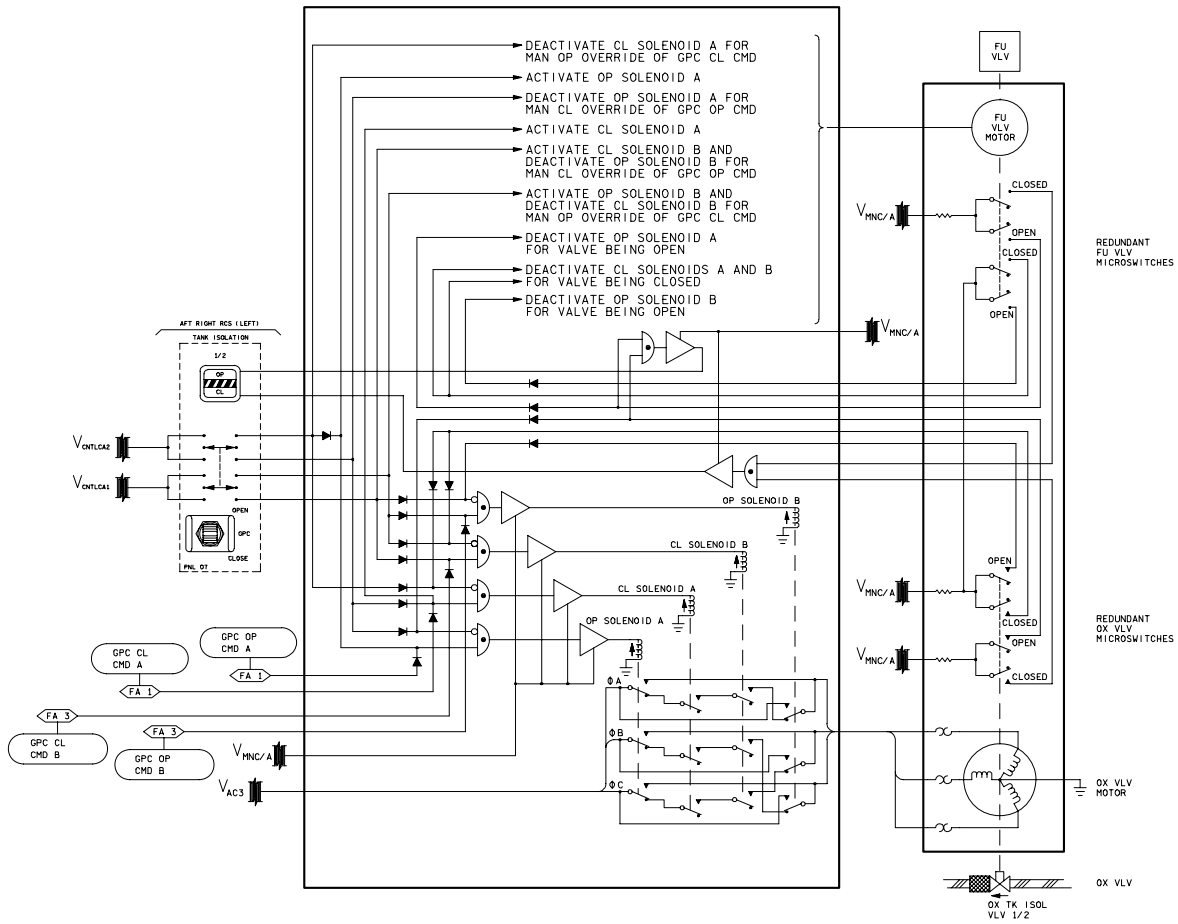


Figure 4-16. Four-solenoid MCA

Within a four-solenoid MCA, manual open operation is lost if any of the following losses occur:

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

GPC open operation is lost if any of the following losses occur:

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

Manual and GPC close operations are identical to operation of 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 exercised during orbit simulations.

The use of the ORCS computer application will greatly simplify the understanding of specific electrical or data path problems.

4.3.10.5 OMS/RCS Configuration Screen Application

The crew can determine/predict the effects on OMS and RCS valves caused by electrical bus and/or MDM failures (maximum of two failures) by using the ORCS application that is resident in the onboard Payload General Support Computer (PGSC). ORCS will display a schematic of the OMS and RCS, with a 2 x 2 matrix window for each propellant valve. When the appropriate failure is selected, any loss of capability (manual open, manual close, GPC open, GPC close) is indicated by darkened portions of the window for the affected valve with numbers that denote which failure (or combination) caused which loss. "1st & 2nd Fail" usually indicates direct loss of valve power. "Resultant Fail" usually indicates the dual failures also caused the loss of an MDM or a power controller controlling the valve.

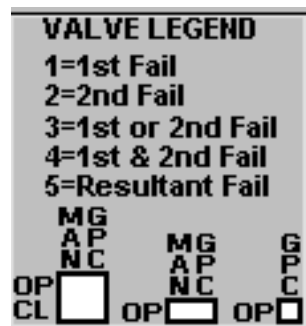


Figure 4-17 shows an ORCS display of an FA1 MDM failure.

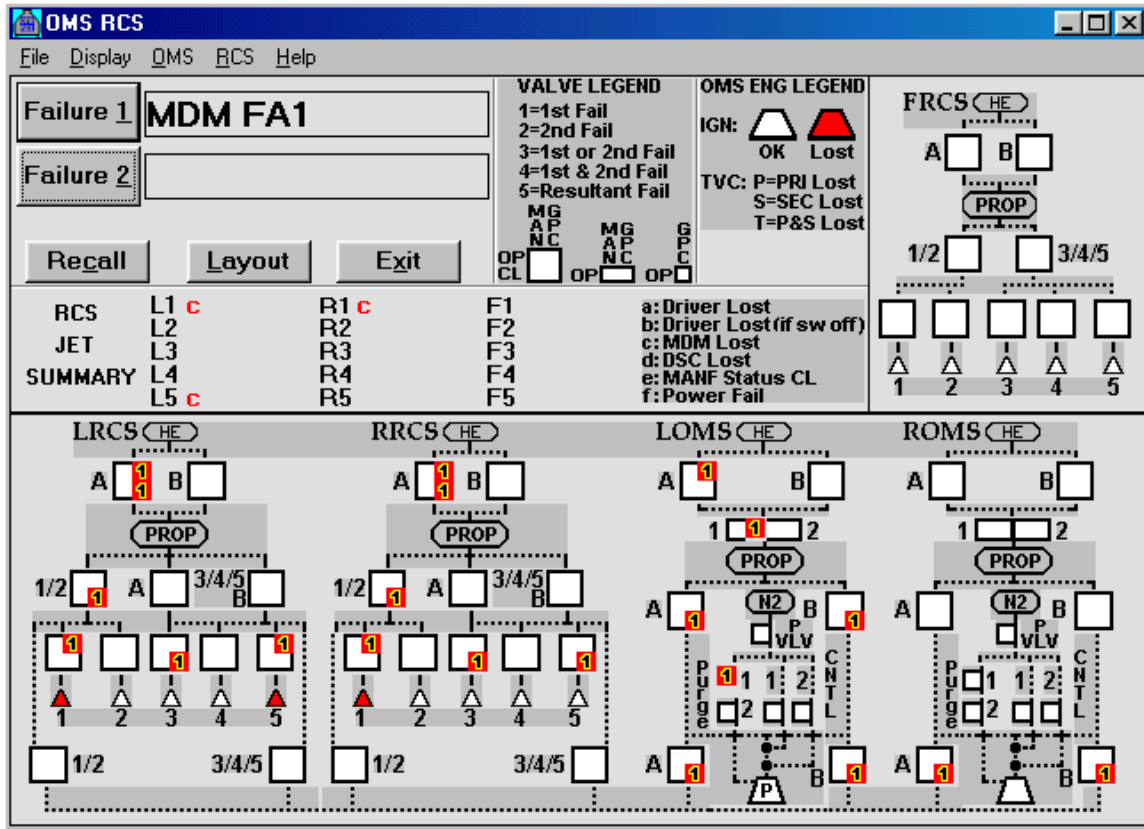


Figure 4-17. ORCS display for FA1 failure

Figure 4-18 and Figure 4-19 show two examples of combined failure effects.

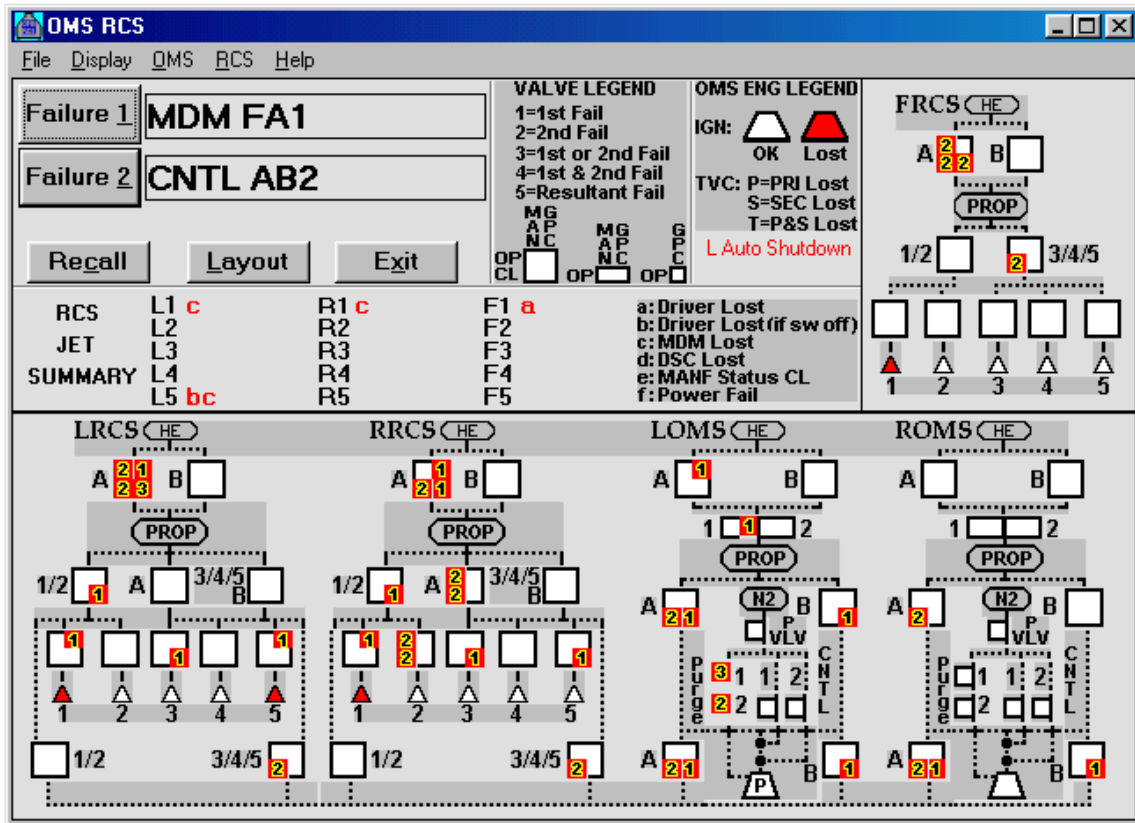


Figure 4-18. ORCS display for example combined FA1 and CNTL AB2 failures

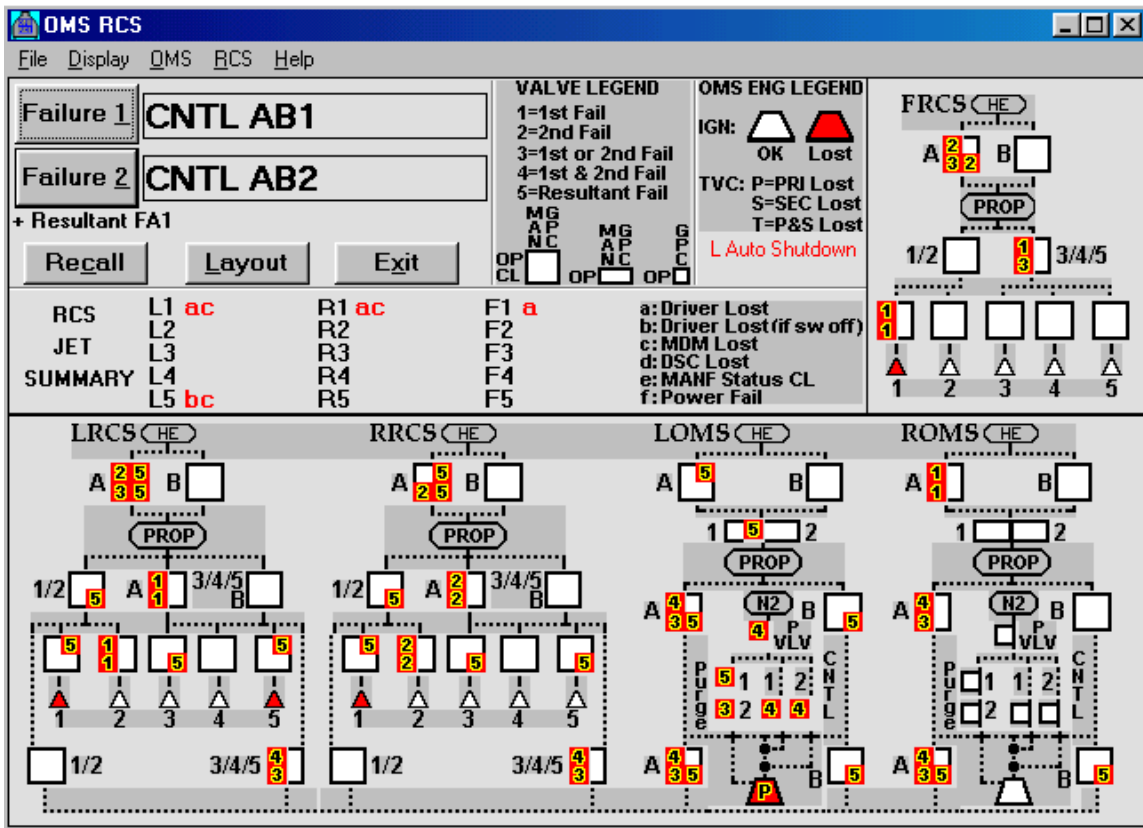


Figure 4-19. ORCS display for example combined CNTL AB1 and CNTL AB2 failures

4.3.10.6 OMS-to-RCS Interconnect Sequence

When an OMS-to-RCS interconnect is required for an abort dump or for SERC 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 causes 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 and would fail.

Smart Interconnect mitigates some of these problems. It configures “appropriate to the failure” OMS and RCS tank isolation and crossfeed valves and inhibits “appropriate to

the failure” RCS fire commands to preclude firing RCS jets that are not utilizing OMS propellant. Smart Interconnect works for up to two EPS and/or DPS problems present simultaneously.

4.3.10.7 RCS-to-RCS Crossfeed Sequence

The RCS-to-RCS crossfeed provides a means of flowing RCS propellants from one aft pod to feed the thrusters of both aft pods. Situations that would call for the execution of the sequence include RCS helium regulator failures and propellant leaks. The auto sequence is designed for time-critical phases of flight, such as ascent, where crew interaction should be minimal. The crossfeed reconfiguration portion of the sequence may be implemented to return the RCS propellant system to normal, straightfeed after an RCS crossfeed sequence has been employed. This sequence is available in OPS 1 ascent, OPS 3 entry, and OPS 6 RTLS.

The RCS-to-RCS crossfeed may be configured automatically during ascent and entry by crew movement of the master crossfeed switch to a “feed from” position or by GPC recognition of a failing propellant tank (regulated pressure falling below 210 psi). 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 close after all the RCS crossfeed valves are automatically opened and the OMS crossfeed valves are automatically closed.

Prior to any auto crossfeed, the software determines whether or not an interconnect has been commanded or if an interconnect complete flag has been set. If either is true, the crossfeed will not be performed. Then, if both are false, the software then determines if the master crossfeed switch has been configured to a FEED FROM LEFT (FFL) or a FEED FROM RIGHT (FFR) position and sets flags accordingly to always give preference to the master crossfeed switch over the GPC reg fail sequence.

The following are some examples of how the crossfeed sequence will react under certain conditions:

- a. The helium reg fail sequence issues an RCS to RCS crossfeed because of the LRCS Ox tank pressures’ falling below 210 psi. An FFR crossfeed is established. The crew then places the master crossfeed switch in FFL. The software then issues an FFL crossfeed, as preference is given to the switch.

Note: The RCS tanks will be tied during the FFL setup; so some RRCS oxidizer may be transferred to the LRCS Ox tank.

- b. The system is in an L to R crossfeed with the master crossfeed switch in FFL. The LRCS Fu tank pressures then fall below 210 psi and the helium reg fail sequence issues an FFR. Since the switch is given preference, the system stays in FFL until the crew moves the master crossfeed switch to OFF. The crossfeed configuration then becomes FFR.

Note: The RCS tanks will be tied during the FFR setup; so some RRCS fuel may be transferred to the LRCS Fu tank.

- c. The system is in an L to R crossfeed with the master crossfeed switch in FFL. An interconnected dump or SERC is issued. The interconnect will be established, and upon interconnect return, the system will return to straightfeed and then FFL.
- d. An interconnected dump or SERC is in progress. The master crossfeed switch is moved to FFR or the helium reg fail sequence calls for an FFR. Nothing will happen until post-interconnect return when the system will go to straightfeed and then FFR.

If an FA MDM or GPC fails before an auto crossfeed is initiated, affected valves will not receive commands to crossfeed. Likewise, if the failure occurs while crossfeeding, affected valves will not receive commands for an auto return to a normal feed configuration. Manual valve movements can provide a workaround for these configuration difficulties. If the valve failure is caused by a main bus or an ac problem, the valves cannot move, regardless of manual or GPC 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 also performed manually.

Figure 4-20 through Figure 4-23 show the effects of some example failures. The effects of all failures affecting crossfeeding can be identified/predicted through the use of the ORCS application on the PGSC. 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 4-20 shows the effects if FA3 (or GPC 3) failure prior to an auto crossfeed. The selection of "feed from right" configures properly except for the left RCS 1/2 tank isolation valve. The backflow of right RCS propellant into the left RCS tank wastes valuable right RCS propellant and could cause tank damage. Manually closing the valve quickly solves the problem. A different FA MDM or GPC failure causes similar results but affects different valves.

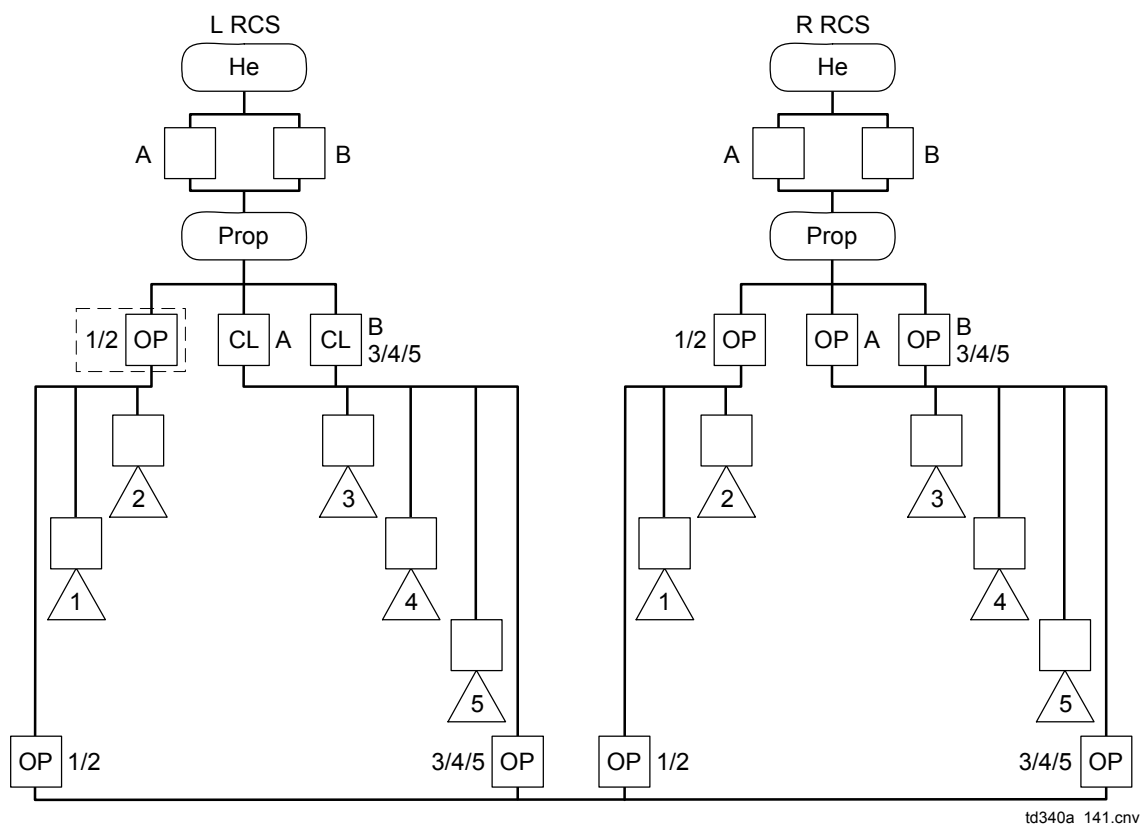


Figure 4-20. Auto crossfeed failed – FA3 failed before the crossfeed

Figure 4-21 shows the effects of FA3 or GPC 3 failure during a crossfeed configuration. An auto return to normal feed results in the tying of all RCS propellant tanks. Manual movement of the valves precludes this difficulty.

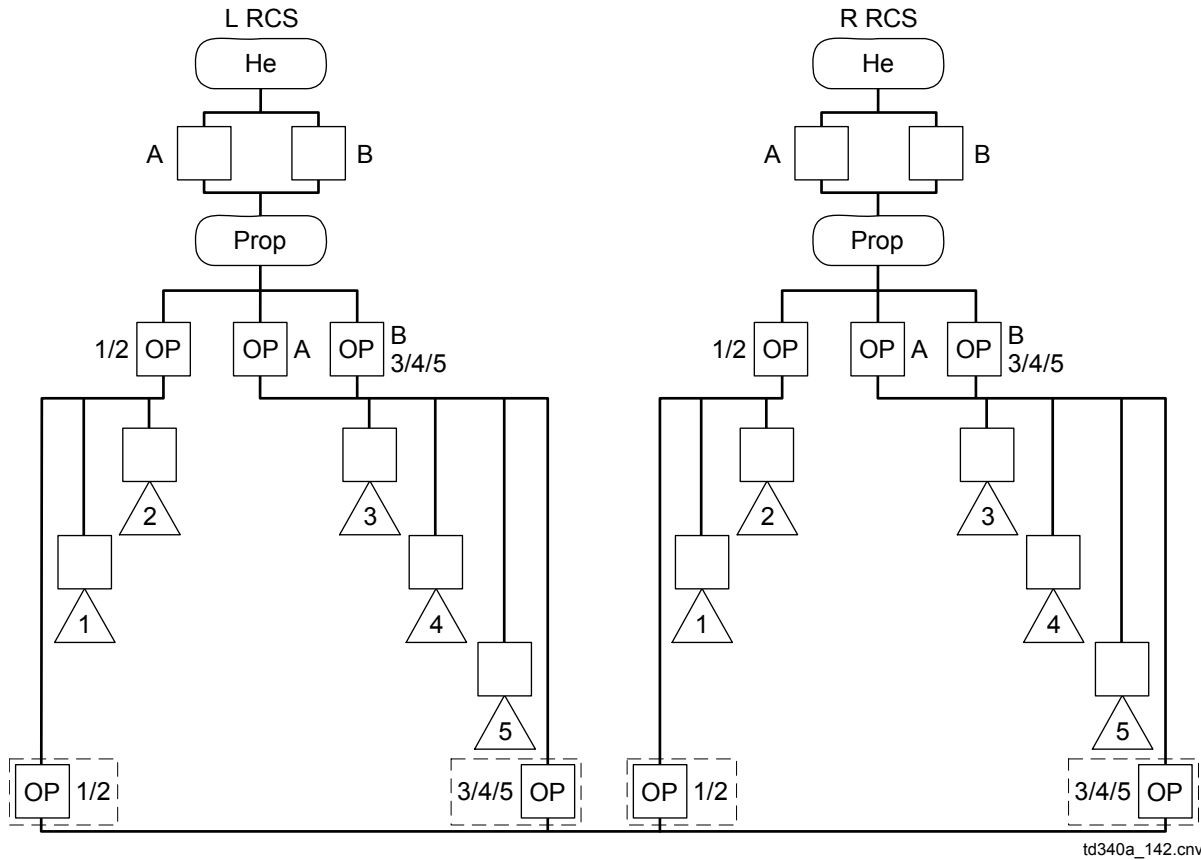
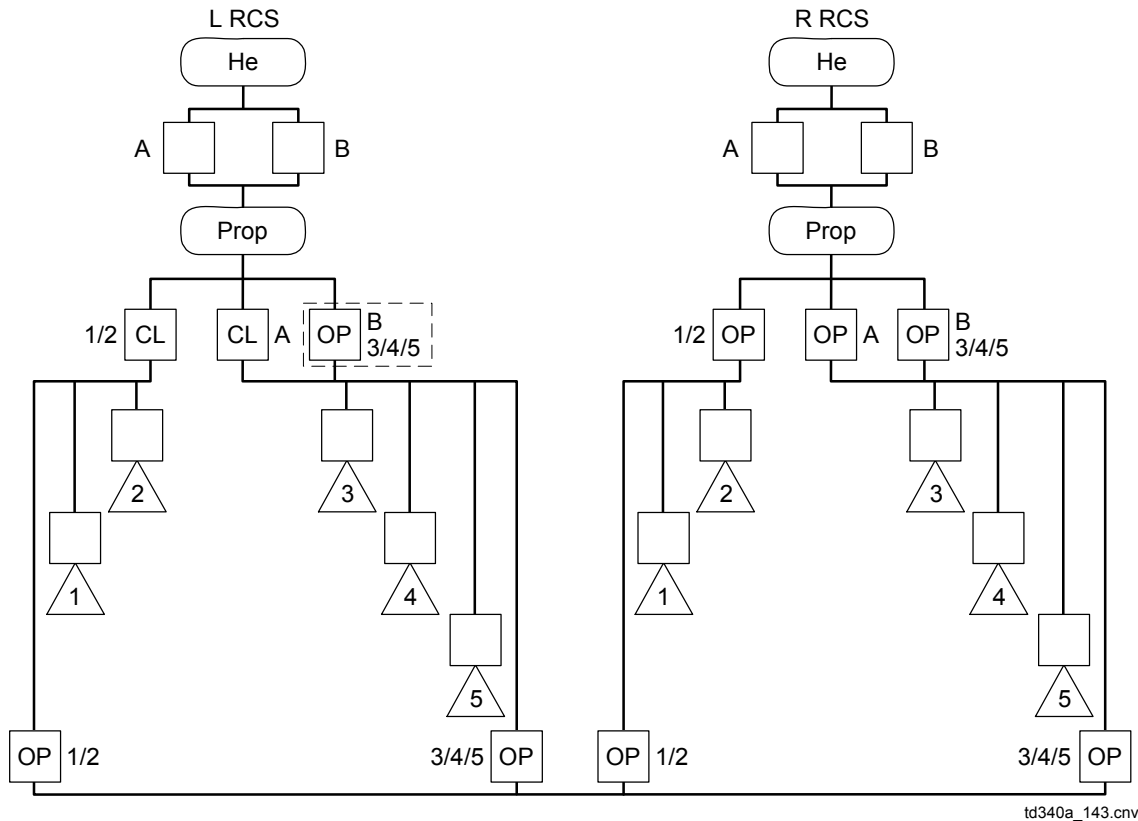


Figure 4-21. Auto return to normal feed failed – FA3 failed while crossfeeding

Electrical failures are more complex. Figure 4-22 shows the effects if main B is lost before a crossfeed is commanded. This seriously impairs 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 (i.e., the suspected leak is 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 caused by propellant starvation.



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Figure 4-22. Auto crossfeed failed – MNB failed before the crossfeed

Figure 4-23 shows the effects of a main B failure during crossfeed. This creates some configuration problems if a return to normal feed is commanded. But in this case, it is only a nuisance because the A valve on the left side is providing redundant propellant flow. A different bus or ac failure could cause more serious difficulties.

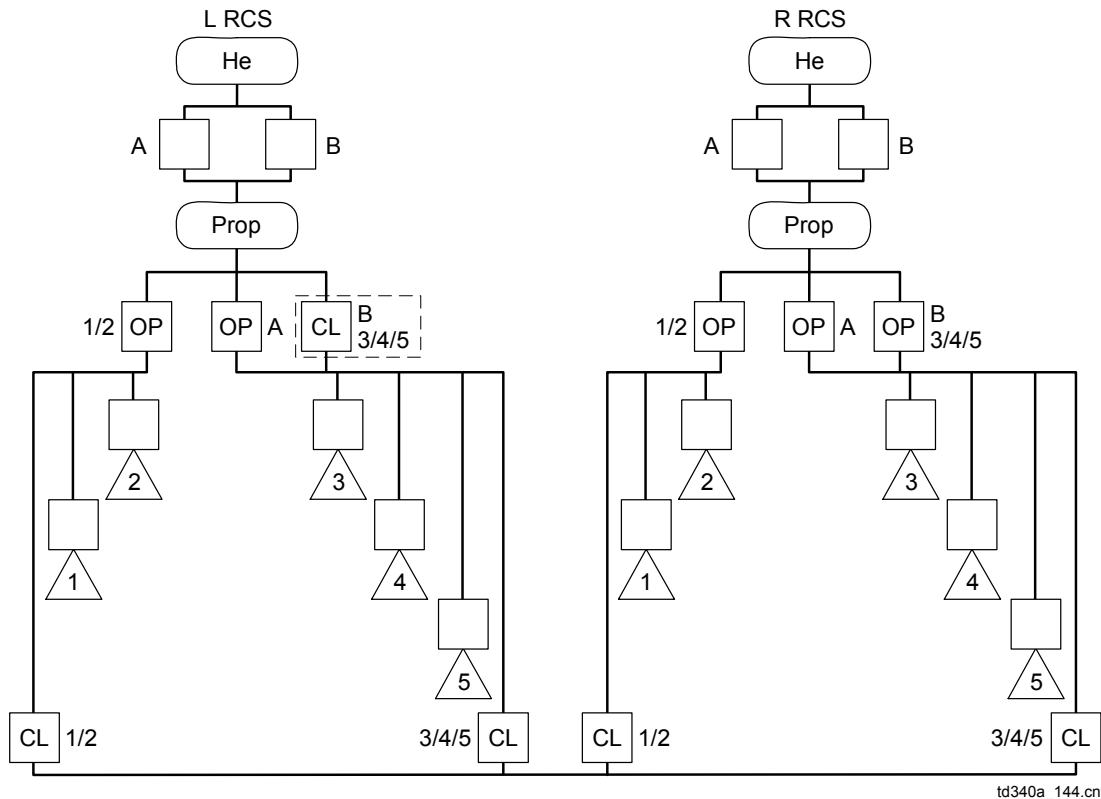


Figure 4-23. Auto return to normal feed failed – MNB failed while crossfeeding

Even though the RCS-to-RCS Crossfeed is not available in OPS 2, the software can be accessed during orbit operations by moding to OPS 3 in order to configure the valves using this sequence and then moding back to OPS 2. This on-orbit “master crossfeed trick” is especially helpful when manual control of the valves has been lost but GPC capability still remains, as is the case with control bus failures.

4.3.10.8 Pressure and temperature sensors

The RCS pressure and temperature sensors receive power through signal conditioners; specifically, the left RCS uses Dedicated Signal Conditioners (DSCs) OL1 and OL2, the right RCS uses DSCs OR1 and OR2, while the forward RCS primarily uses DSCs OF2 and OF4. Each DSC 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 are used for CRT/MEDS displays and quantity calculations.

If a particular MDM or signal conditioner fails, the associated RCS data will be lost. Specific losses can be checked in the Reference Data Book. To provide an overview of the effects of these types of failures, examples of selected onboard displays (showing

single-point MDM and signal conditioner assignments) are provided here. MDM and signal conditioner data assignment for GNC SYS SUMM 2 are shown in Figure 4-24 and Figure 4-25. Close examination of the schematics in JSC-11174, Space Shuttle Systems Handbook, provides insight into other displays.

RCS		OXID	FU	JET	ISOL			OXID	FU	JET	ISOL
FWD		HE P	FF1	FF3	FAIL	VLV			HE P	FA2	FA2
TK P		FF1	FF3						TK P	FA2	FA2
QTY									QTY	FA2	FA2
MANF		1 P	FF1	FF1					1 P	FA1	FA1
		2 P	FF2	FF2					2 P	FA3	FA3
		3 P	FF4	FF4					3 P	FA2	FA2
		4 P	FF3	FF3					4 P	FA4	FA4
		5							5		
AFT		HE P	FA1	FA1					HE P	FA2	FA2
L		TK P	FA1	FA1					TK P	FA2	FA2
QTY		FA1	FA1						QTY	FA2	FA2
MANF		1 P	FA1	FA1					1 P	FA1	FA1
		2 P	FA3	FA3					2 P	FA3	FA3
		3 P	FA2	FA2					3 P	FA2	FA2
		4 P	FA4	FA4					4 P	FA4	FA4
		5							5		

TD3400427. ART: 1

Figure 4-24. GNC SYS SUMM 2 display showing MDM assignments for RCS measurements

RCS		OXID	FU	JET	ISOL			OXID	FU	JET	ISOL
FWD		HE P	OF2	OF4	FAIL	VLV			HE P	OR1	OR2
TK P		OF4	OF2						TK P	OR1	OR2
QTY									QTY	OR1	OR2
MANF		1 P	OF4	OF4					1 P	OR1	OR1
		2 P	OF4	OF4					2 P	OR1	OR1
		3 P	OF2	OF2					3 P	OR2	OR2
		4 P	OF2	OF2					4 P	OR2	OR2
		5							5		
AFT		HE P	OL1	OL2					HE P	OR1	OR2
L		TK P	OL1	OL2					TK P	OR1	OR2
QTY									QTY	OR1	OR2
MANF		1 P	OL1	OL1					1 P	OR1	OR1
		2 P	OL1	OL1					2 P	OR1	OR1
		3 P	OL2	OL2					3 P	OR2	OR2
		4 P	OL2	OL2					4 P	OR2	OR2
		5							5		

00616307. CRT: 1

Figure 4-25. GNC SYS SUMM 2 display showing DSC assignments for RCS measurements

4.3.10.9 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 designed 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 if the primary inputs are invalid or unavailable because of 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 provides reasonably accurate PASS calculations.

Because the BFS does not have the capability to substitute inputs, the loss of any input results in invalid BFS quantity calculations.

Table 4-5 lists the primary inputs and the associated substitutes for PASS calculations along with MDM and signal conditioner assignments.

Table 4-5. Primary inputs and associated substitutes

FRCS	
Primary	Substitute
F OX HE T (FF3, OF2)	F FU HE T (FF1, OF4)
F OX HE P1 (FF3, OF2)	F OX HE P ₂ (FF2, OF2/OF4)
F OX HE P2 (FF1, OF4)	F OX HE P1 (FF3, OF2)
F OX TK P (FF1, OF4)	F OX TK OUT P (FF4, OF2)
F OX TK OUT P (FF3, OF2)	F OX TK P (FF1, OF4)
F OX TK T (FF1, OF4)	F FU TK T (FF4, OF2)
F FU HE T (FF1, OF4)	F OX HE T (FF3, OF2)
F FU HE P1 (FF1, OF4)	F FU HE P2 (FF2, OF2)
F FU HE P2 (FF3, OF2)	F FU HE P1 (FF1, OF4)
F FU TK P (FF3, OF2)	F FU TK OUT P (FF4, OF4/OF2)
F FU TK OUT P (FF1, OF4)	F FU TK P (FF3, OF2)
F FU TK T (FF3, OF2/OF3)	F OX TK T (FF1, OF4)

Table continued on following page for Aft RCS details

Table 4-5. Primary inputs and associated substitutes (concluded)**LRCS**

Primary	Substitute
L OX HE T (FA1, OL1)	L FU HE T (FA3, OL2)
L OX HE TK P1 (FA1, OL1)	L OX HE TK P2 (FA3, OL2)
L OX HE TK P2 (FA3, OL2)	L OX HE TK P1 (FA1, OL1)
L OX TK P (FA1, OL1)	L OX TK OUT P (FA3, OL1)
L OX TK OUT P (FA3, OL1)	L OX TK P (FA1, OL1)
L OX TK T (FA1, OL2)	L FU TK T (FA3, OL1/OL2)
L FU HE T (FA3, OL2)	L OX HE T (FA1, OL1)
L FU HE P1 (FA1, OL2/OA1)	L FU HE P2 (FA3, OL1)
L FU HE P2 (FA3, OL1)	L FU HE P1 (FA1, OL2/OA1)
L FU TK P (FA1, OL2/OA1)	L FU TK OUT P (FA3, OL2)
L FU TK OUT P (FA3, OL2)	L FU TK P (FA1, OL2/OA1)
L FU TK T (FA3, OL1)	L OX TK T (FA1, OL2)

RRCS

Primary	Substitute
R OX HE T (FA2, OR1)	R FU HE T (FA4, OR2)
R OX HE P1 (FA2, OR1)	R OX HE P2 (FA4, OR2)
R OX HE P2 (FA4, OR2)	R OX HE P1 (FA2, OR1)
R OX TK P (FA2, OR1)	R OX TK OUT P (FA4, OR1)
R OX TK OUT P (FA4, OR1)	R OX TK P (FA2, OR1)
R OX TK T (FA2, OR2)	R FU TK T (FA4, OR1/OR2)
R FU HE T (FA4, OR2)	R OX HE T (FA2, OR1)
R FU HE P1 (FA2, OR2/OA2)	R FU HE P2 (FA4, OR1)
R FU HE P2 (FA4, OR1)	R FU HE P1 (FA2, OA2/OR2)
R FU TK P (FA2, OR2/OA2)	R FU TK OUT P (FA4, OR2)
R FU TK OUT P (FA4, OR2)	R FU TK P (FA2, OR2/OA2)
R FU TK T (FA4, OR1)	R OX TK T (FA2, OR2)

4.3.10.10 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 4-26. 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 still allow GPC output to the RCS (jet fire commands, valve operation).

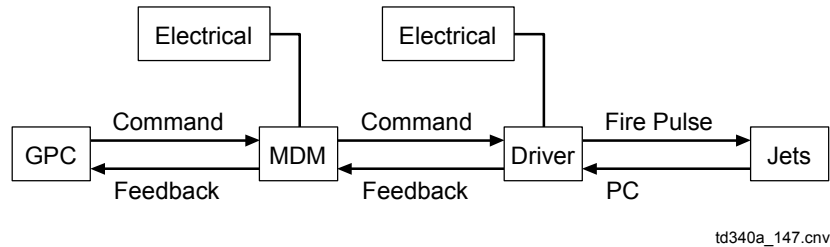


Figure 4-26. Jet fire commands

4.3.10.11 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 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 causes the affected heaters to be unusable. Procedures call for selecting another heater circuit, if available. Pod and line heater bus assignments are summarized in Table 4-6.

Table 4-6. Summary of pod and line heaters 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

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 affect only some of the heaters on the B circuit.

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

Jet heater bus assignments are shown in Table 4-7 and show the general distribution for the various circuits.

Table 4-7. Summary of jet heater bus assignments

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

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 with the 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 drops to less than 130 psi after the RCS is secured, is this an indication of a tank leg leak (two manifolds decreasing)?
4. Suppose that during a nominal ascent the P_c discrete for L2L fails high. What C&W annunciation will the crew receive?
5. How can GPC/MDM and electrical failures affect auto crossfeeds and interconnects?
6. During entry, an auto crossfeed has been executed to FEED FROM RIGHT. Subsequently, the only control bus for the Aft Right 3/4/5 B tank isolation valve has failed (CNTL BC2) and an RCS leak has annunciated for the Right RCS. The loss of this control bus has taken away manual valve operation for the 3/4/5 B isol valve. How can this valve be closed for leak isolation procedures?

5.0 DIFFERENCES IN THE BFS

5.1 OBJECTIVES

As a result of reading this section, the student should be able to identify the functional differences in the RCS while the BFS is engaged, specifically in the following areas:

- a. SERC
- b. Jet operation
- c. Jet RM
- d. Auto crossfeed

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 in the following discussion:

- a. During powered flight and ET separation, only auto flight control is available.
- b. 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 SERC if two main engines fail during ascent. The BFS software can provide an abort interconnect and support RTLS, TAL, ATO, and manual dumps.

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 does not support vernier jet operation, but it supports all primary jet firings.

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

Only the first failure provides discretetes to the jet fail limit module. If the first failure is a fail on, there is no auto deselection and also no subsequent auto deselection if subsequent jets fail off. If the first failure is a fail off, there is only one auto deselection per vehicle. There is no SPEC 23 on BFS. 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 because 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 sequencing in the BFS. If the BFS is engaged after an auto crossfeed has been configured, the "PASS-commanded" crossfeed configuration remains. The BFS recognizes the master crossfeed switch FEED FROM position in order to restrict jet firings, even though it does not command valve configurations.

This concludes the main text of the workbook; please review the appendixes for supplemental information.

If this workbook has been completed as part of a formal training syllabus, the reader is reminded to complete and submit the evaluation form at the end of this document.

APPENDIX A ACRONYMS AND ABBREVIATIONS

A	Aft
ac	Alternating current
ADI	Attitude Direction Indicator
ADTA	Air Data Transducer Assembly
ALC	Aft Load Controller
ALCA	Aft Load Control Assembly
AMC	Aft Motor Controller
AOA	Abort Once Around
APC	Aft Power Controller
APCA	Aft Power Control Assembly
APU	Auxiliary Power Unit
ARCS	Aft Reaction Control System
ATO	Abort to Orbit
ATT	Attitude
AUTO	Automatic
AV	Avionics
BCE	Bus Control Element
BFS	Backup Flight System
bp	Barberpole
BYP	Bypass
C&W	Caution and Warning
C1, C2	Velocity targets for deorbit
cb	Circuit breaker
CDR	Commander
c.g.	Center of gravity
CK	Check
CL	Close
CMD	Command
CNTL	Control
CONT	Contingency
CRSFD	Crossfeed
CRT	Cathode-Ray Tube
CSS	Control Stick Steering
CUR	Current
D	Down
D/O	Deorbit
D&C	Displays and Controls
DAP	Digital Autopilot

DEORB	Deorbit
DES	Deselect
DES INH	Deselect Inhibit
DLMA	Dilemma
DPS	Data Processing System
DSC	Dedicated Signal Conditioner
EAS	Equivalent Air Speed
EI	Entry Interface
ENA	Enable
ENG	Engine
EPS	Electrical Power System
ET	External Tank
EXEC	Execute
F	Fahrenheit
	Forward
FA	Flight-Critical Aft (MDM)
FCS	Flight Control System
FDF	Flight Data File
FES	Flash Evaporator System
FF	Flight Critical Forward MDM
FFL	Feed From Left
FFR	Feed From Right
FLC	Forward Load Controller
FLCA	Forward Load Control Assembly
FMC	Forward Motor Controller
FPC	Forward Power Controller
FPCA	Forward Power Control Assembly
FRCS	Forward Reaction Control System
FSSR	Functional Subsystem Software Requirements
FU, Fu	fuel
FWD	Forward
G&C	Guidance and Control
GG	Gravity Gradient
GMBL	Gimbal
GN ₂	gaseous nitrogen
GNC	Guidance, Navigation, and Control
GP	Group
GPC	General Purpose Computer
GRTL	Glide Return to Launch Site

GSE	Ground Support Equipment
H	High or Height
HA	Height of Apogee
He	Helium
HP	Height of Perigee
HT	Height of Target (OMS Burn Target)
HTR	Heater
I'CONNECT	Interconnect
ICNCT	Interconnect
I-load	Initialization Load
IMU	Inertial Measurement Unit
IN	Inlet
INH	Inhibit
INJ	Injector
ISOL	Isolation
JET DES	Jet Deselect
KEAS	Knots Equivalent Air Speed
L	Left
	Low
LCA	Load Control Assembly
LK	Leak
LN	Line
low g	low gravity
LRCS	Left Reaction Control System
M	Missing (data)
M _H	Mass of Helium
MANF	Manifold
MCA	Motor Control Assembly
MCC	Mission Control Center
MDM	Multiplexer/Demultiplexer
MECO	Main Engine Cutoff
MEDS	Multifunction Electronic Display System
MET	Mission Elapsed Time
MM	Major Mode
MMH	monomethyl hydrazine
MN	Main (bus)
MNVR	Maneuver
MPS	Main Propulsion System

MS	Mission Specialist
ms	Microswitch
MSTR	Master
N ₂	nitrogen
N ₂ O ₄	nitrogen tetroxide
O	Overhead
OME	Orbital Maneuvering Engine
OMS	Orbital Maneuvering System
OMS 1	The orbital insertion burn (as dictated by vehicle performance)
OMS 2	The orbital circularization burn
OP	Open
OPS	Operational Sequence Operations
ORCS	OMS/RCS Configuration Screen (computer application)
ovrd	Override
OX, Ox, OXID	oxidizer
P	Pitch Pressure
ΔP	Pressure change
PAD	Preliminary Advisory Data
PASS	Primary Avionics Software System
PBI	Pushbutton Indicator
Pc	Chamber Pressure
PCA	Power Control Assembly
PEG	Powered Explicit Guidance
PEG 4	PEG targets - closed loop
PEG 7	PEG targets - open loop
PLT	Pilot
PNL	Panel
PPA	Powered Pitcharound
PPD	Powered Pitchdown
PRD	Program Requirements Document
PRESS	Pressure Pressurization
PRI	Primary
PRO	Proceed
PROP	Propellant
PRPLT	Propellant
psf	pounds per square foot

psi	pounds per square inch
PTC	Passive Thermal Control
PTI	Program Test Input
PTY	Priority
PVT	Pressure-Volume-Temperature
PWR	Power
q, QBAR	Dynamic Pressure
QTY	Quantity
R	Right Roll
RAD	Radiator
RCS	Reaction Control System
REG	Regulator
REI	Range to Entry Interface
RGA	Rate Gyro Assembly
RHC	Rotational Hand Controller
RJD	Reaction Jet Driver
RJDA	Reaction Jet Driver Aft
RJDF	Reaction Jet Driver Forward
RM	Redundancy Management
RPC	Remote Power Controller
RRCS	Right Reaction Control System
RTLS	Return to Launch Site
SE	Single Engine
SEC	Secondary
SEL	Selection
SEP	Separation
SERC	Single Engine Roll Control
SM	Systems Management
SODB	Shuttle Operational Date Book
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 of Free Fall
TGO	Time-to-Go
TGT	Target
THC	Translational Hand Controller
THRM	Thermal
TIG	Time of Ignition
TK	Tank
TK OUT P	Lower Tank Pressure
TK P	Upper Tank Pressure
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
V_U	Volume of Propellant Ullage
VERN	Vernier
VGO X,Y,Z	Velocity-to-Go in X, Y, and Z directions
VLV	Valve
WT	Weight
XFD	Crossfeed
XFEED	Crossfeed
Y	Yaw
zero-g	Zero-gravity
Δ	Delta (usually associated with changing parameters)
ΔV	Velocity change
ΔV_{TOT}	Total Velocity change
$\Delta V_{X, Y, Z}$	Velocity Change in X, Y, and Z directions
ΘT	Target angle

APPENDIX B ANSWERS

SECTION 2

1. The valves listed below are categorized 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. 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 the OMS to the RCS. An interconnect from the RCS to OMS is unsafe and should not be done.
3. An asterisk in the JET DES column of SPEC 23 for L1L caused by a closed manifold status can be removed so that L1L is available to fire by changing the manifold status to open. One of the following methods can be used to change the status to open:
 - a. If the switch and talkback are closed, move the manifold 1 switch to open.
 - b. If the switch and talkback are open, execute an item 40 on SPEC 23 to override the manifold status to open.
 - c. If the closed manifold status is caused by a dilemma and the valves are open, use either an item 40 on SPEC 23 or an item 41 entry to SPEC 51 (OVERRIDE) to override the status to open.

Note: A JET DES item entry has no effect on closed manifold status asterisks.

4. When resetting RM on SPEC 23, the difference between a single item 45 JET RESET item entry and two identical DES INH item entries is as follows:

A single item 45 resets 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 will not change the jet priorities.

A dual DES INH entry resets the RM of an individual jet only. 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, the item 45 method may use fewer keystrokes.

5. A jet P_c discrete failed low (false fail off) has 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. Because the P_c discrete is failed low, the BFS cannot annunciate a failed on jet.

SECTION 3

1. During an RTLS, while the post-MECO RCS dump is in progress, the crew is directed to stop the dump. 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 deplete at a steady rate. When the dump stops, the RCS helium pressures should stop decreasing and stabilize, confirming the dump stop.
2. A TAL abort is selected and both OMS engines are ignited. If the abort interconnect is enabled on the override display (SPEC 51), a total of 24 RCS jets are commanded to fire (20 null jets and 4 +X jets). The RCS jets are not commanded to fire until 3 seconds after the OMS interconnect is completed.
3. An elevon drive rate of greater than 20 deg/sec causes the RCS PITCH UP jet command light to illuminate when q becomes greater than 50 psf. Recall that the pitch jets were deactivated at a q of 40, so the RCS pitch jet command lights no longer indicate RCS jet activity.
4. The RTLS ET separation occurs lower in the atmosphere than other scenarios and requires more jets to achieve the required separation.
5. During the first part of the mission, the A pressurization switches are placed in GPC with the talkbacks open to provide automatic overpressurization protection for the propellant tanks. Halfway through the mission, the B helium switches are placed in GPC for the same reason.
6. If OMS engine failures occur, an OMS to RCS interconnect is performed 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 are fired as necessary to maintain the correct burn attitude.
7. The crew stops the dump at an elapsed time of 1 minute 5 seconds. The nomograph for a four-jet dump is entered at 36 percent because this is the amount of propellant to be dumped.
8. 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

1. It is important to close the manifold isolation valves first when executing the RCS secure procedures because 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 subsequently starving.
2. When returning to normal configuration after securing the RCS during ascent and entry, the propellant tank and crossfeed isolation valve switches must be in GPC to provide automatic sequencing. If the switches are placed in the manual positions, then the auto crossfeed and auto interconnect capability is lost.
3. No. If the pressure in manifolds 2 and 3 dropped to less than 130 psi after the RCS is secured, this would not be an indication of a tank leg leak (two manifolds decreasing). Since manifolds 2 and 3 are on different legs, this would be an indication of two separate manifold leaks.
4. If the P_c discrete for L2L fails high during a nominal ascent, the crew receives no C&W annunciation 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 were then engaged, the BFS would annunciate a jet fail on (false failure). For L2L, although there is no C&W, fail off RM is lost for L2L in both PASS and BFS.
5. GPC/MDM and electrical failures can prevent auto commands from reaching the valves or prevent certain valves from properly moving. In such cases, MCC may direct the crew to manually configure the crossfeed or interconnect.
6. This valve can be closed for leak isolation in the right 3/4/5 side by placing 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. When this leg needs to be secured, the right 3/4/5 A tank isolation and the right 3/4/5 crossfeed valves should be closed manually 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 since all the other switches are in manual feed from the right, 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 remains set to restrict the number of simultaneous jet firings. (Note: This procedure may not work for all valves or all control bus failures. In some cases, the loss of a control bus can affect multiple switches and cause these switch outputs to be reading "GPC" regardless of the switch position resulting in GPC commanding even with the switch in a manual position.)

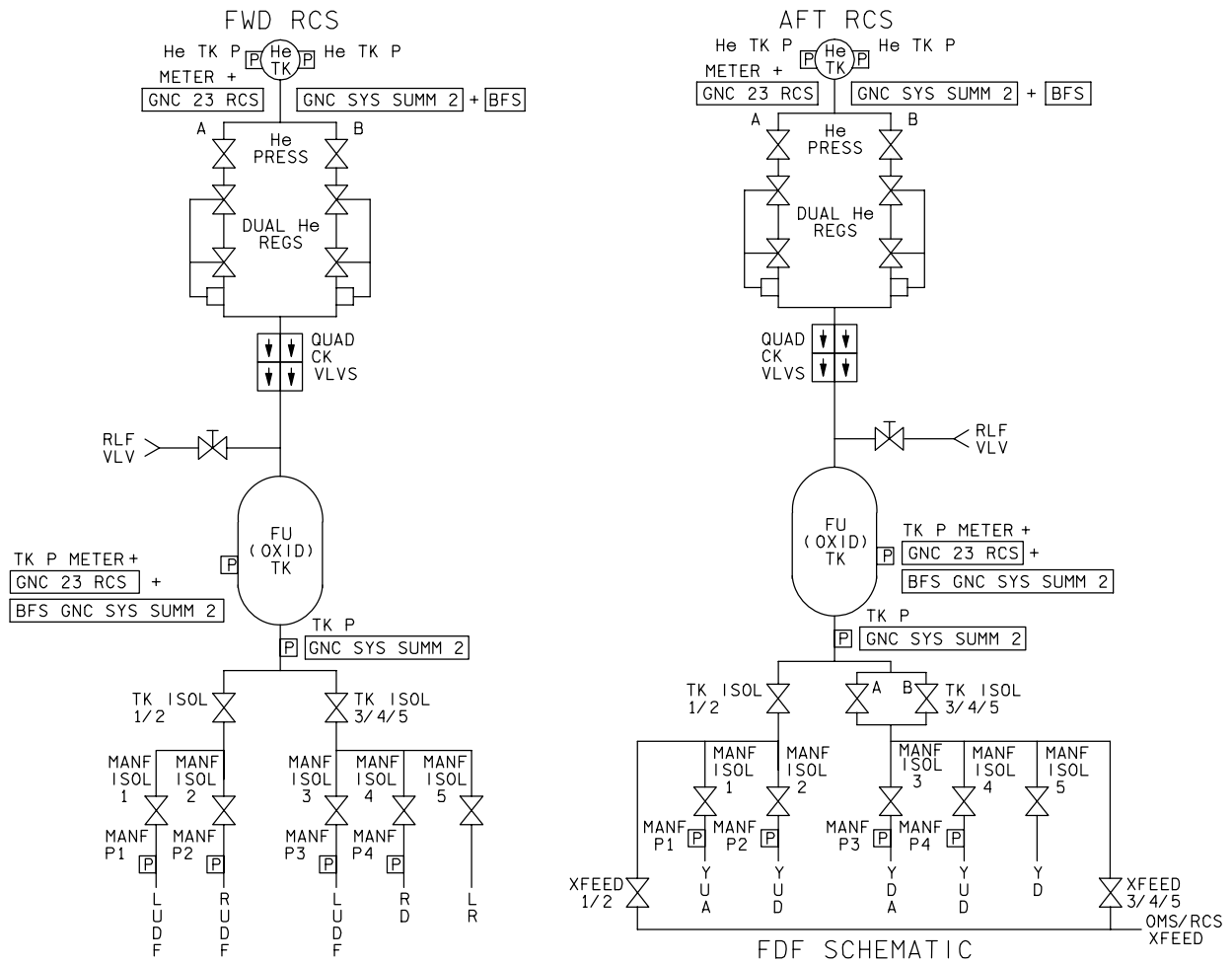
APPENDIX C

SUGGESTED REFERENCE MATERIALS

1. Referenced training materials, 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
 - a. Ascent/Aborts
 - b. Entry
 - c. Ascent/Orbit/Entry Pocket Checklists and Cue Cards
3. The procedures described in this book are specified in the following Flight Data File items:
 - a. Ascent Checklist
 - b. Orbit OPS Checklist
 - c. Entry Checklist
 - d. Ascent Pocket Checklist
 - e. Orbit Pocket Checklist
 - f. Entry Pocket Checklist Ascent /Entry Systems Procedures Checklist
 - g. Systems Malfunctions Procedures Book
 - h. Cue Cards
 - i. DPS Dictionary
 - j. Reference Data
4. The STS (Space Transportation System) Operational Flight Rules outline preplanned decisions for failure situations.
5. The Space Shuttle Systems Handbook (SSSH) contains 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) 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:
 - a. Redundancy Management
 - b. Sequencing
 - c. Displays and Controls
 - d. GNC – Flight Control Ascent
 - e. GNC – Flight Control Orbit DAP
 - f. GNC – Flight Control Entry/ Glide Return to Launch Site (GRTLs)
8. The BFS Program Requirements Document (PRD) is the BFS equivalent to the FSSR. The two volumes of relevance to the RCS are
 - a. Flight Control
 - b. Sequencing

**APPENDIX D
RCS SUMMARY**



TD3400C01. ART 1

Figure D-1. Pocket checklist schematics

Thrust	Primary jets - 870 lb Vernier jets - 24 lb			
Maximum fire duration		<u>Nominal</u>	<u>Contingency</u>	
	Aft primary	150 sec	800 sec	
	Fwd primary	150 sec	300 sec	
	Vernier	125 sec	125 sec	
Jet fail leak detection		<u>Fuel</u>	<u>Oxidizer</u>	
	Primary	<20°F	<30°F	
	Vernier	<103°F	<130°F	
Pressures		<u>Normal indication</u>	<u>C&W low limit</u>	<u>C&W high limit</u>
	Helium tank sensor	4000-456 psi	500 psi	-
	Propellant tank P sensor	243 ± 3 psi	200 psi	312 psi
	Propellant tank out P sensor	243 ± 3 psi	220 psi	300 psi
Tank unusable		<u>Crew indication</u>		
	Helium tank	Pressure < 456 psi		
	Propellant tank	Pressure < 190 psi		
Backflow through closed ISOL valves		<u>Differential pressure</u>		
	Manifolds (primary)	33-50 psi		
	Tank isolation	275-360 psi		
	Crossfeed	275-360 psi		
Helium relief	Burst disc	332 ± 8 psi		
	Valve crack	315 psi		
Maximum blowdown		<u>Crew indication</u>		
	Fwd RCS	22 percent		
	Aft RCS	23 percent		

TRAINING MATERIALS EVALUATION

Please answer the following questions regarding the lesson you just completed. Your feedback will allow us to produce more effective training materials. When completed, mail to: Manager, DT34.

TITLE/CODE OF LESSON: **Reaction Control System Workbook/RCS 21002**

SIZE OF AUDIENCE/CLASS:

1. How well did this lesson meet its purpose?

For each statement below, mark one box on the scale:

	Strongly Disagree					Strongly Agree
a. <i>The lesson objectives are clearly stated.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. <i>The lesson objectives are clearly defined.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. <i>The lesson effectively teaches skills and information.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. <i>The lesson meets its purpose and objectives.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. How satisfying is the content of this lesson?

For each statement below, mark one box on the scale:

	Strongly Disagree					Strongly Agree
a. <i>The information is structured in a logical flow.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. <i>The content is clear.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. <i>The content is complete.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. <i>The level of detail is correct for this information.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. <i>The amount of information is effective.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. <i>The graphics contribute to my understanding.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3. How appealing was the presentation of this lesson?

For each statement below, mark one box on the scale:

	Strongly Disagree					Strongly Agree
a. <i>The overall presentation is appealing.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. <i>The visuals chosen are appropriate for the lesson.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. <i>The visuals make the information more interesting.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. <i>The graphics are legibly reproduced.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. <i>The audio/visual or print quality is good.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

4. How valuable is this information?

For each statement below, mark one box on the scale:

	Strongly Disagree					Strongly Agree
a. <i>The lesson teaches skills and information I need.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. <i>The lesson meets my expectations.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. <i>This information is useful for later reference.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. <i>I would recommend this lesson to others.</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

PLEASE WRITE YOUR COMMENTS/QUESTIONS ON THE BACK OF THIS FORM.

EXPLAIN ANY NEGATIVE ANSWERS IN SPECIFIC TERMS.

THANK YOU IN ADVANCE FOR YOUR ASSISTANCE!

TITLE: Reaction Control System Workbook/RCS 21002

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