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Rev. A

Space Program Operations Contract

Orbital Maneuvering System Workbook

OMS 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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United Space Alliance

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Rev. A

Orbital Maneuvering System Workbook
OMS 21002

Prepared by

Original approval obtained

Eric Zumdieck, Book Manager
USA/Guidance & Control/Propulsion department

Approved by

Original approval obtained

Miguel Sequeira, Manager
USA/Guidance & Control/Propulsion department

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C-1 – C-2	A

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 the book manager.

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If this workbook is being read as part of a formal syllabus, the reader should complete the training materials evaluation form at the end of the document. The evaluation form does not need to be signed.

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1.0 INTRODUCTION

The orbital maneuvering system (OMS) provides propulsion for the space shuttle vehicle during the orbit phase of flight. It is used for orbital insertion maneuvers after the main propulsion system has shut down. It is also the primary propulsion system for orbital transfer maneuvers and the deorbit maneuver.

The OMS is located in two independent pods in the aft end of the orbiter on either side of the vertical tail (see Figure 1-1). Each OMS pod contains one OMS engine, a fuel tank, an oxidizer tank, and a helium tank, along with propellant feed lines and other supporting equipment (see Figure 1-2). The two OMS pods are identical. Normally OMS maneuvers are done using both OMS engines together; however, a burn can be done using only one of the OMS engines. There are crossfeed lines connecting the left and right OMS pods. OMS propellant from one pod can be fed to the engine in the other pod through the crossfeed lines.

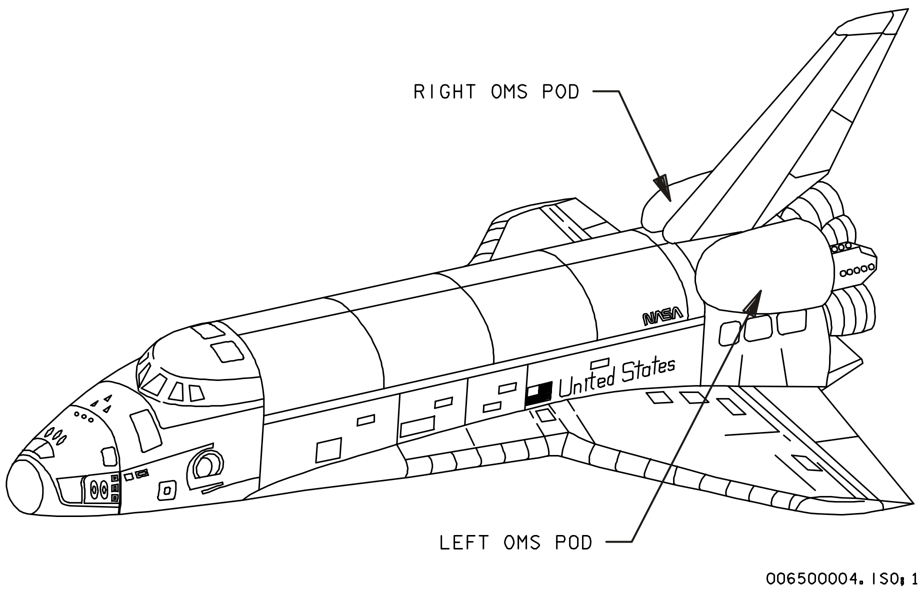


Figure 1-1. Space shuttle orbiter

The OMS engines use monomethyl hydrazine as the fuel and nitrogen tetroxide as the oxidizer. The propellants are hypergolic, which means that they ignite when they come in contact with each other, therefore no ignition device is needed. This adds reliability to the system, but the propellants are very corrosive and must be handled with care by ground crews. Both propellants remain liquid at the temperatures normally experienced. However, there are electrical heaters located throughout the OMS pods to prevent any freezing of propellants during long periods in orbit when the system is not in use.

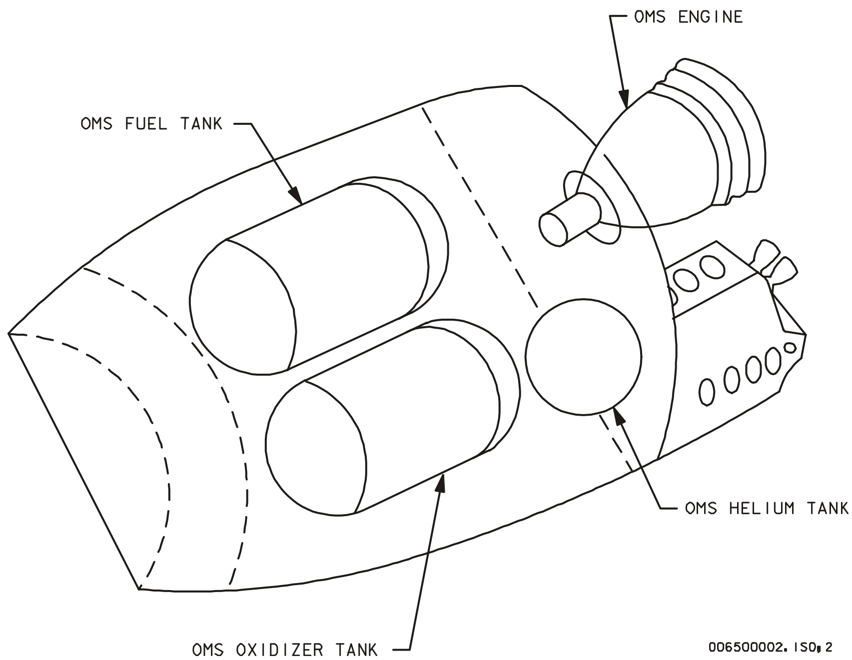


Figure 1-2. OMS pod

Each OMS engine has a gaseous nitrogen tank that provides pressurized nitrogen to operate the engine valves and purge the fuel line after burn completion. The OMS engine does not have propellant pumps; propellant flow to the engines is maintained by pressurizing the propellant tanks with helium. Propellant quantity is measured by electrical probes located inside each tank.

An automatic computer sequence controls all OMS burns. To start an OMS burn, the crew must load a burn target that includes a specific time of ignition (TIG). The burn starts automatically at TIG if all the controls are configured properly and stops automatically when the burn target is satisfied. The OMS engines can also be shut down manually at any time.

The OMS engines are located on gimbal mounts that allow the engine to pivot left and right and up and down under the control of electomechanical actuators. This gimbal system provides steering during OMS burns by controlling the direction of the engine thrust vector in response to commands from the digital autopilot (DAP) or from the manual controls.

Each OMS engine produces 6000 lbs of thrust with an ISP (Specific Impulse) of 313 seconds. For a typical orbiter weight, both engines together create an acceleration of approximately 2 ft/sec^2. Using all the propellant loaded, the OMS can provide a total velocity change (ΔV) of approximately 1000 ft/sec. A typical OMS-2 burn is around 100 ft/sec while a deorbit burn requires a ΔV of about 300 ft/sec. The ΔV required for orbital adjustments is approximately 2 ft/sec for each nautical mile of altitude change.

At one time there were plans to provide additional ΔV capability by including an OMS kit (see Figure 1-3). An OMS kit would consist of additional sets of propellant and helium tanks located in the payload bay and connected through the OMS crossfeed lines. It is unlikely that OMS kits will ever be used, but there are OMS kit switches and gauges located in the orbiter. These switches and gauges are currently inoperative.

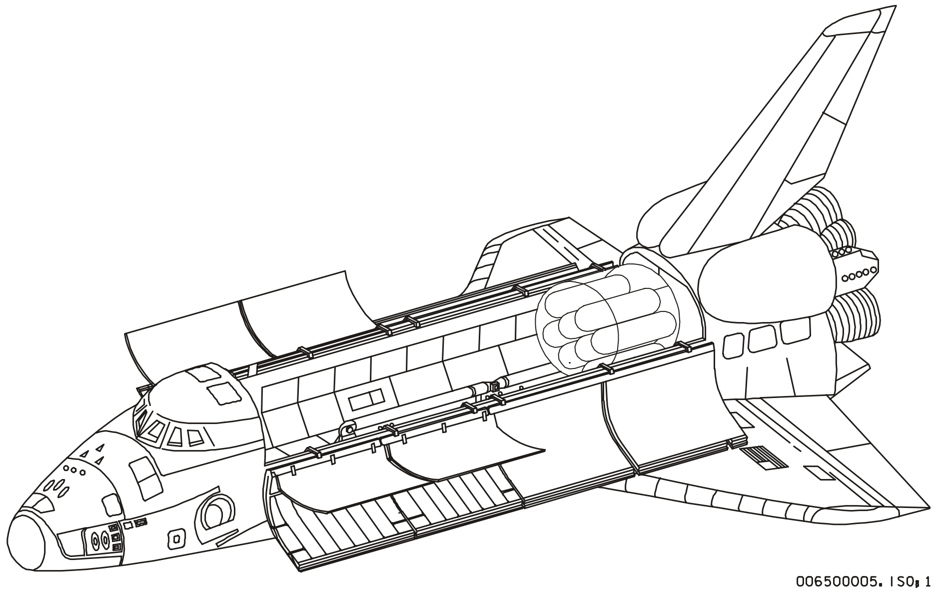


Figure 1-3. OMS kit

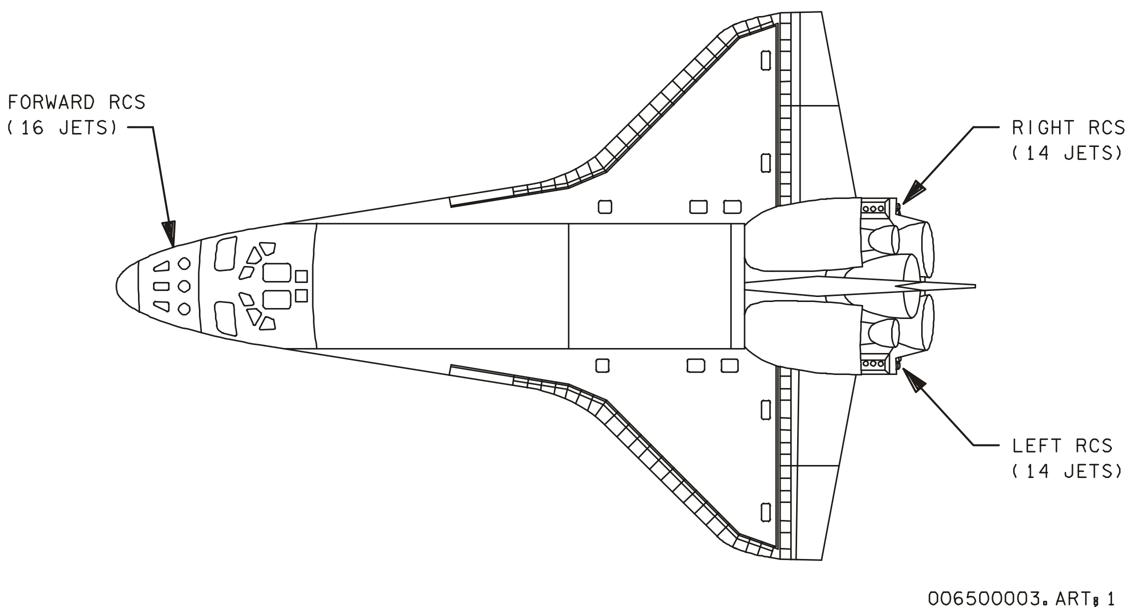


Figure 1-4. RCS modules

The reaction control system (RCS) is closely related to the OMS in some ways and should be mentioned briefly here. There are three RCS modules in the orbiter: forward, left, and right (see Figure 1-4). Each module includes a fuel tank, an oxidizer tank, two helium tanks, and a number of RCS jets. (The OMS oxidizer and fuel tanks share a single helium tank, but each of the RCS oxidizer and fuel tanks has its own helium tank.) The left RCS module is located in the left OMS pod, the right RCS module is in the right OMS pod (see Figure 1-5), and the forward RCS module is in the nose of the orbiter. There are crossfeed lines connecting the left and right RCS modules, but the forward RCS module is independent. The RCS jets are small rocket engines that are used to control the rotational attitude of the vehicle in orbit and during entry. They also provide thrust for small translational maneuvers.

The OMS and RCS use the same type of propellants. OMS propellant can be fed to the aft RCS jets by connecting the OMS and RCS crossfeed lines. This is called an OMS-to-RCS interconnect. OMS propellant is burned by the RCS jets when it is necessary to conserve RCS propellant and also in some translational maneuvers. RCS propellant is never fed to the OMS engines because the RCS tanks are too small to supply an adequate flow of propellant to an OMS engine.

The space shuttle flight computer software is contained in the five general purpose computers (GPCs). Up to four of the computers contain redundant sets of primary software (PASS), and the fifth GPC contains the software for the backup flight system (BFS). The primary 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 MEDS CRT MDUs.

The flight software is divided into operational sequences (OPS) that are subdivided into major modes (MMs), which correspond to mission phases. It will be helpful to be familiar with the OPS and major mode numbers (see Figures 1-6 and 1-7).

OMS burns can be done only in MM 104, 105, 202, and 302.

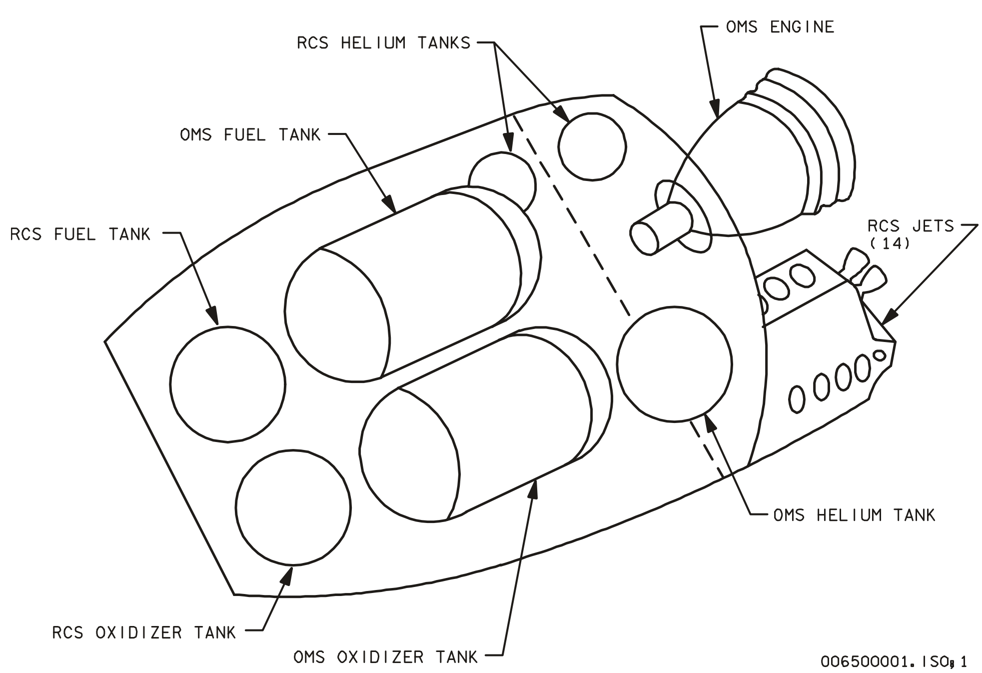


Figure 1-5. OMS pod with RCS tanks and jets

OPS 1: Ascent	MM 101	Terminal Count
	MM 102	First Stage
	MM 103	Second Stage
	MM 104	OMS 1 Insertion
	MM 105	OMS 2 Insertion
	MM 106	Insertion Coast
OPS 2: Orbit	MM 201	Orbit Coast
	MM 202	Maneuver Execute
OPS 8: Orbit	MM 801	Flight control system (FCS)/Dedicated Display Checkout Mode
OPS 3: Entry	MM 301	Predeorbit Coast
	MM 302	Deorbit Execution
	MM 303	Pre-Entry Monitor
	MM 304	Entry
	MM 305	Terminal Area Energy Management (TAEM)/Landing
OPS 6: Return to launch site (RTLS) abort	MM 601	RTLS Second Stage
	MM 602	Glide RTLS 1
	MM 603	Glide RTLS 2

Figure 1-6. Flight software

The OMS has important interfaces with the data processing system (DPS) and the electrical power system (EPS). The OMS valves and gimbal actuators receive commands and the system returns some data to the GPCs through multiplexer/demultiplexer (MDM) units. They include the four flight-critical aft (FA) MDMs and the four flight-critical forward (FF) MDMs. Electrical power is supplied to the OMS through main buses, control buses, and alternating current (ac) buses for the operation of switches, valves, instrumentation, gimbal actuators, and heaters.

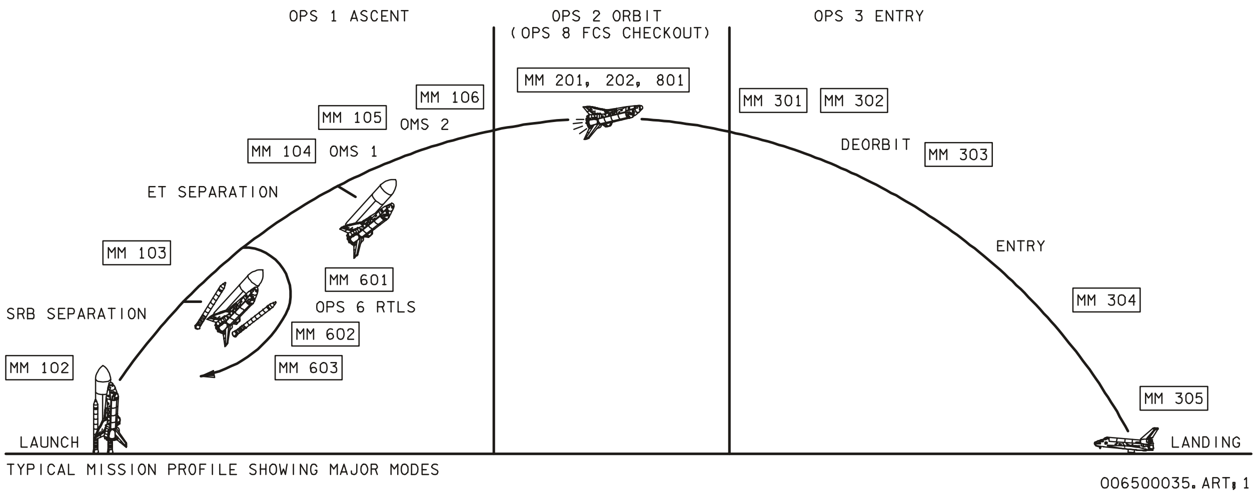


Figure 1-7. Major modes by flight phase

The rest of this workbook will cover the OMS in more detail. First there will be a description of the various components of the system, followed by a description of how the system is operated. The last part of the book provides the background information needed to understand and respond to system malfunctions. The guidance and flight control aspects of OMS operation are discussed only briefly in this book. A more detailed description is provided in the Guidance and Control Insertion/Orbit/Deorbit Workbook G&C I/O/D 21002.

2.0 SYSTEM DESCRIPTION

In this section, the following five subsystems of the OMS will be discussed:

2.1 OMS Engine and nitrogen system

2.2 Propellant and helium supply

2.3 Thermal control

2.4 Thrust vector control

2.5 OMS displays

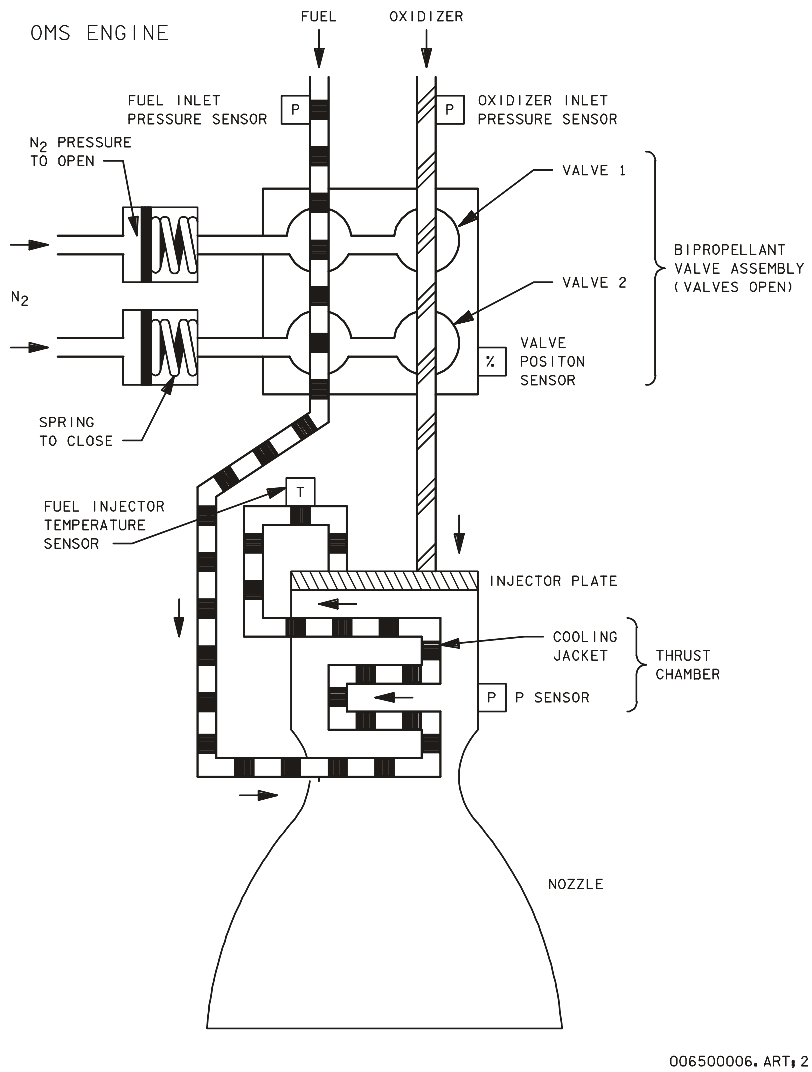


Figure 2-1. OMS schematic

2.1 ENGINE

It is in the OMS engine that the fuel is burned with the oxidizer to produce thrust. The four parts of the OMS engine that we will discuss are the bipropellant valve assembly, the injector plate, the thrust chamber, and the nozzle (see Figure 2-1).

The bipropellant valve assembly regulates the flow of propellants to the engine and thereby starts and stops an engine burn. The valve assembly consists of two fuel valves in series and two oxidizer valves in series (see Figure 2-2). Having two valves in series for each propellant provides redundant protection against leakage, but it also means that both valves must open to allow propellant flow to the engine. Each fuel valve is mechanically linked to an oxidizer valve so that they open and close together. The name bipropellant valve comes from the fact that each linked set of valves controls the flow of both propellants.

The bipropellant valves are ball valves, which rotate from fully closed (0 percent) to fully open (100 percent). The valve position in percent for each set can be read by the crew on the GNC System Summary 2 display. The position indication should read approximately 100 percent for both valve 1 and valve 2 at the start of an OMS burn and remain there throughout the burn (see Figure 2-3). If the valve position is less than 70 percent for either valve, there will probably be insufficient propellant flow and ignition will not occur.

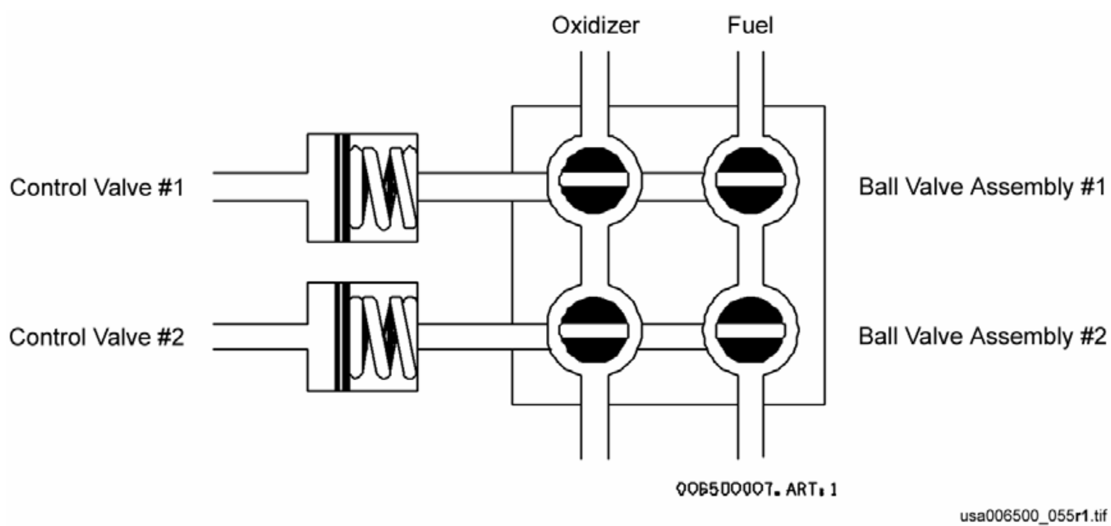


Figure 2-2. Bipropellant valves

The bipropellant valves are driven open and closed by pneumatic pistons. There is one piston for each set of bipropellant valves. The pistons are normally held in the closed position by springs. Pressurized nitrogen is used to fill the piston, which then mechanically opens the bipropellant valves. The engine control valves regulate the flow of nitrogen to the pistons and thereby control the opening and closing of the bipropellant valves. The engine control valve is a solenoid valve that responds to commands from the GPCs. Both engine control valves must operate in order for the bipropellant valves to open.

After passing through the bipropellant valves, the oxidizer line runs directly to the engine injector plate. The fuel, however, is used to cool the engine, and so it is routed through a cooling jacket around the thrust chamber before it reaches the injector plate. A temperature sensor is located near the fuel inlet to the injector, and this temperature can be read on the BFS GNC Systems Summary 2 display (see Figure 2-3). This parameter does not appear on the PASS GNC Systems Summary 2 display (see Figure 2-4).

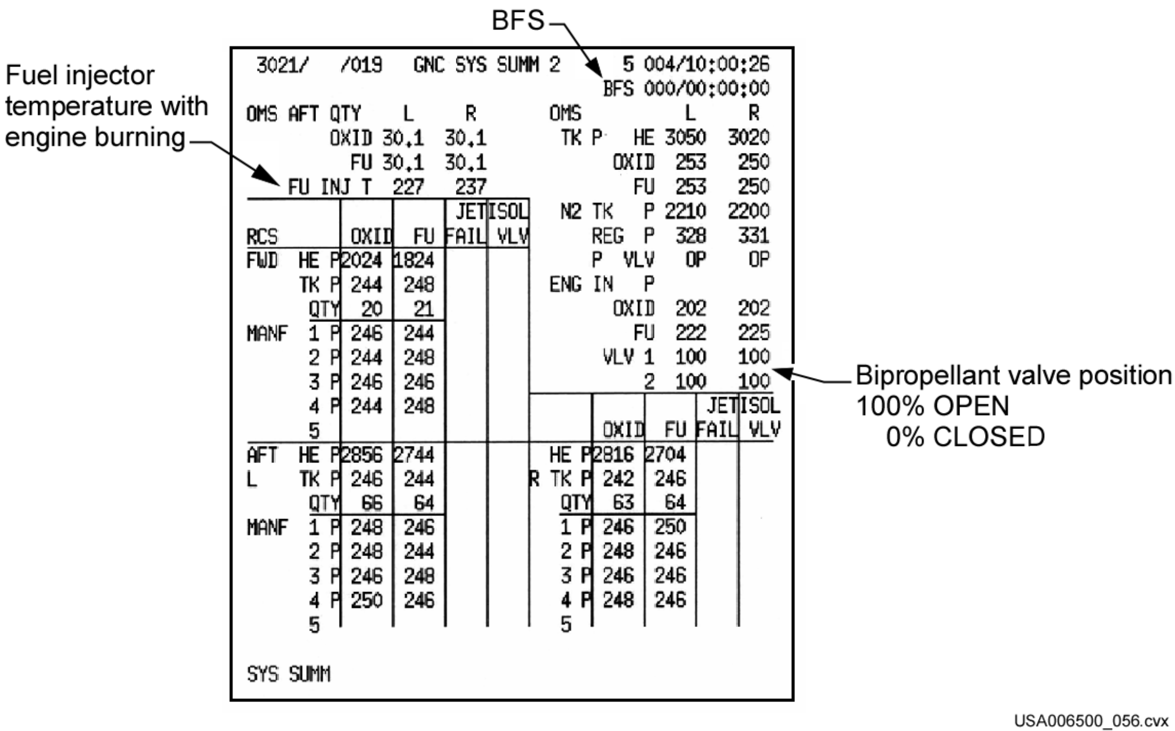


Figure 2-3. BFS GNC System Summary 2 display

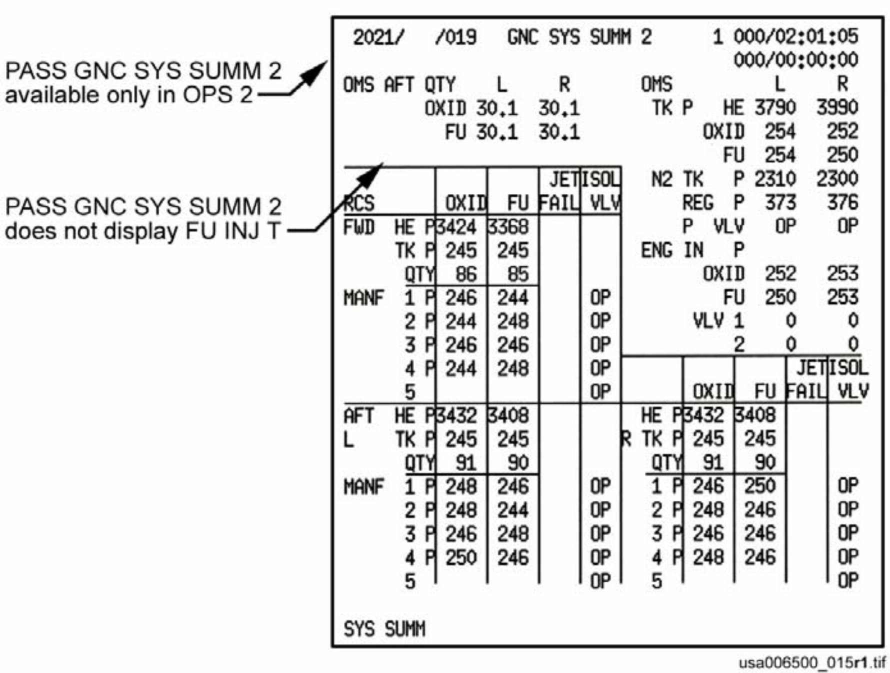


Figure 2-4. PASS GNC System Summary 2 display

Since the fuel injector temperature is the temperature of the fuel after it has passed through the chamber cooling jacket, it provides an indirect indication of the temperature of the thrust chamber walls. A high fuel injector temperature indicates that the engine may be sustaining thermal damage. The fuel normally flows to the engine at a temperature between 30º and 125º F. During engine operation, when the fuel is cooling the chamber, the fuel injector temperature should be approximately 202º F. The temperature limit for safe operation is 260º F.

The fuel and oxidizer are mixed at the injector plate in the thrust chamber. The propellants ignite on contact since they are hypergolic, and the resulting hot gas creates thrust as it exits the chamber and expands through the engine nozzle. The engine nozzle is connected to the thrust chamber. It is a lightweight aluminum alloy structure and does not have a cooling jacket.

The pressure in the thrust chamber (P_c) is measured by a sensor displayed on MEDS OMS/MPS display (see Figure 2-5). The normal P_c during a burn is between 100 and 106 percent, which corresponds to a pressure of approximately 130 psia.

There are pressure sensors in the fuel and oxidizer lines just above the bipropellant valves. These inlet pressures are shown on the GNC Systems Summary 2 display (see Figure 2-6). When the OMS Engines are not burning, the inlet pressures should match the propellant tank pressures, which are normally 254 psi. During OMS burns, propellant flow into the thrust chamber causes the inlet pressure to drop to approximately 225 psi for the fuel and 200 psi for the oxidizer.

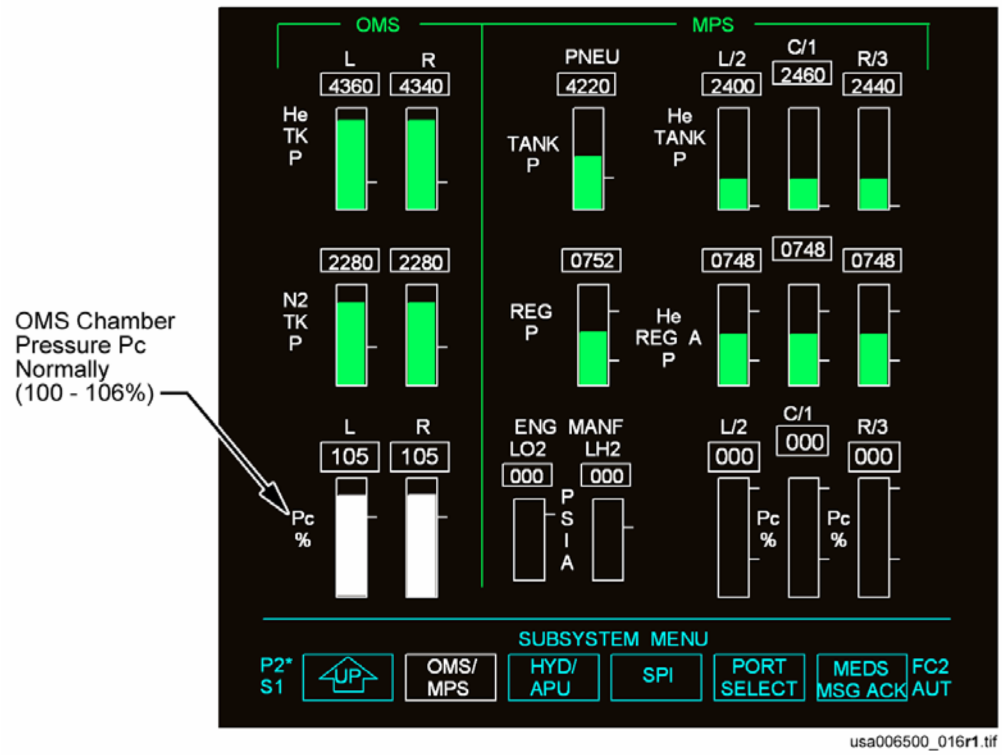


Figure 2-5. MEDS OMS/MPS display

The inlet pressures are an indirect indication of propellant flow rates. If they are abnormal, then problems should be anticipated. An imbalance in the flow rates for fuel and oxidizer will result in an incorrect mixture ratio in the thrust chamber. If the mixture becomes fuel-rich, the chamber pressure and temperature will decrease and combustion will eventually be choked off. If the mixture becomes fuel-lean, the chamber temperature will increase and engine damage could result. If the fuel-lean condition is the result of a low fuel flow rate, the situation is especially serious, since the fuel is used to cool the outside of the thrust chamber.

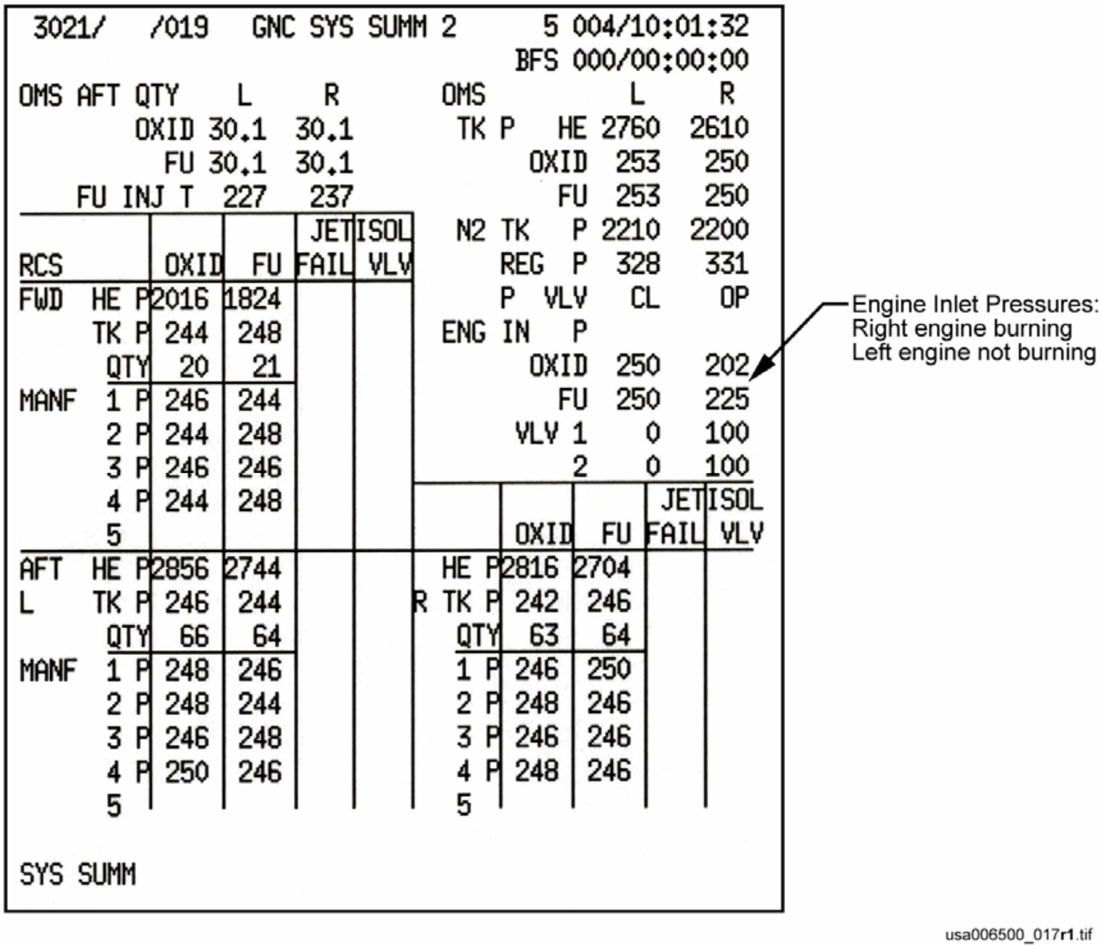


Figure 2-6. GNC SYS Summ 2 (Engine Inlet Pressures)

Nitrogen System

Gaseous nitrogen (GN_2) is used to operate the engine control valves as already described and also to purge the fuel lines at the end of each burn (see Figure 2-7). Each engine has a nitrogen supply tank that contains enough nitrogen to support about 15 OMS burns. The nitrogen tank has an isolation valve called the nitrogen pressurization valve or N_2 press valve. (This valve is sometimes called the engine press valve.) The N_2 press valve is controlled by the OMS engine switch on Panel C3. When this switch is in the ARM/PRESS position, the N_2 press valve opens. When the OMS engine switch is in any other position (ARM or OFF), the N_2 press valve remains closed.

The OMS engine switch is normally placed in the ARM/PRESS position before each OMS burn and is left in the OFF position at all other times. The status of the N_2 press valve can be seen on the GNC Systems Summary 2 display, which reads OP for open and CL for closed (see Figure 2-8). When the position of the OMS engine switch is changed, the display should be checked to see that the valve is in the proper position.

When the N_2 press valve is open, nitrogen can flow through the pressure regulator that reduces the nitrogen pressure from its tank pressure, which can be as high as 3000 psig, to the proper working pressure of 325 psig. Below the regulator there is an accumulator, which is a reservoir containing a large enough volume of nitrogen to support one or two OMS burns, even if the N_2 press valve remains closed. The accumulator is protected from upstream leaks by a one-way check valve. From the accumulator, the nitrogen flows to the engine control valves, where it can be used to operate the bipropellant valve pistons.

The second purpose of the nitrogen subsystem is to perform purges of the fuel lines following OMS burns. After an OMS burn, some fuel and oxidizer will be left in the engine inlet lines and will be subject to cold temperatures. The oxidizer does not present a problem, but the fuel, which has a higher freezing point, could freeze, especially in the cooling jacket around the thrust chamber. The frozen fuel will eventually sublimate, but for the first 10 minutes or so following a burn it might be dangerous to start another burn, since forcing more fuel into already frozen lines could cause damage. This situation is avoided by forcing nitrogen through the fuel lines immediately after the engine shuts down. This purge is part of the automatic OMS burn sequence and takes about 2 seconds. When a burn ends, the control valves close and the purge valves open. Nitrogen can then flow into the fuel line below the bipropellant valves, where it forces the remaining fuel through the inlet lines and cooling jacket and out through the engine.

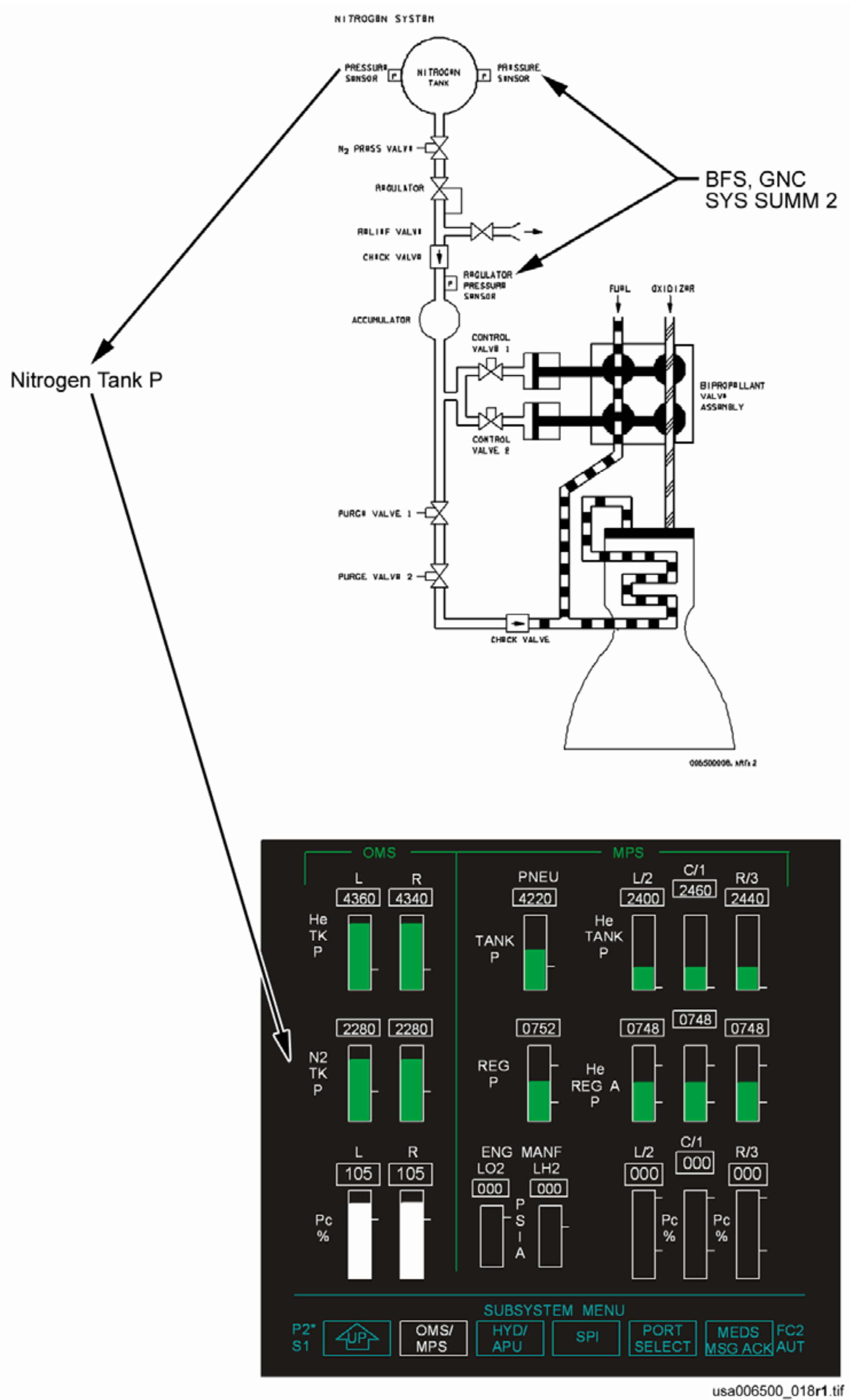


Figure 2-7. Nitrogen system schematic and MEDS OMS/MPS

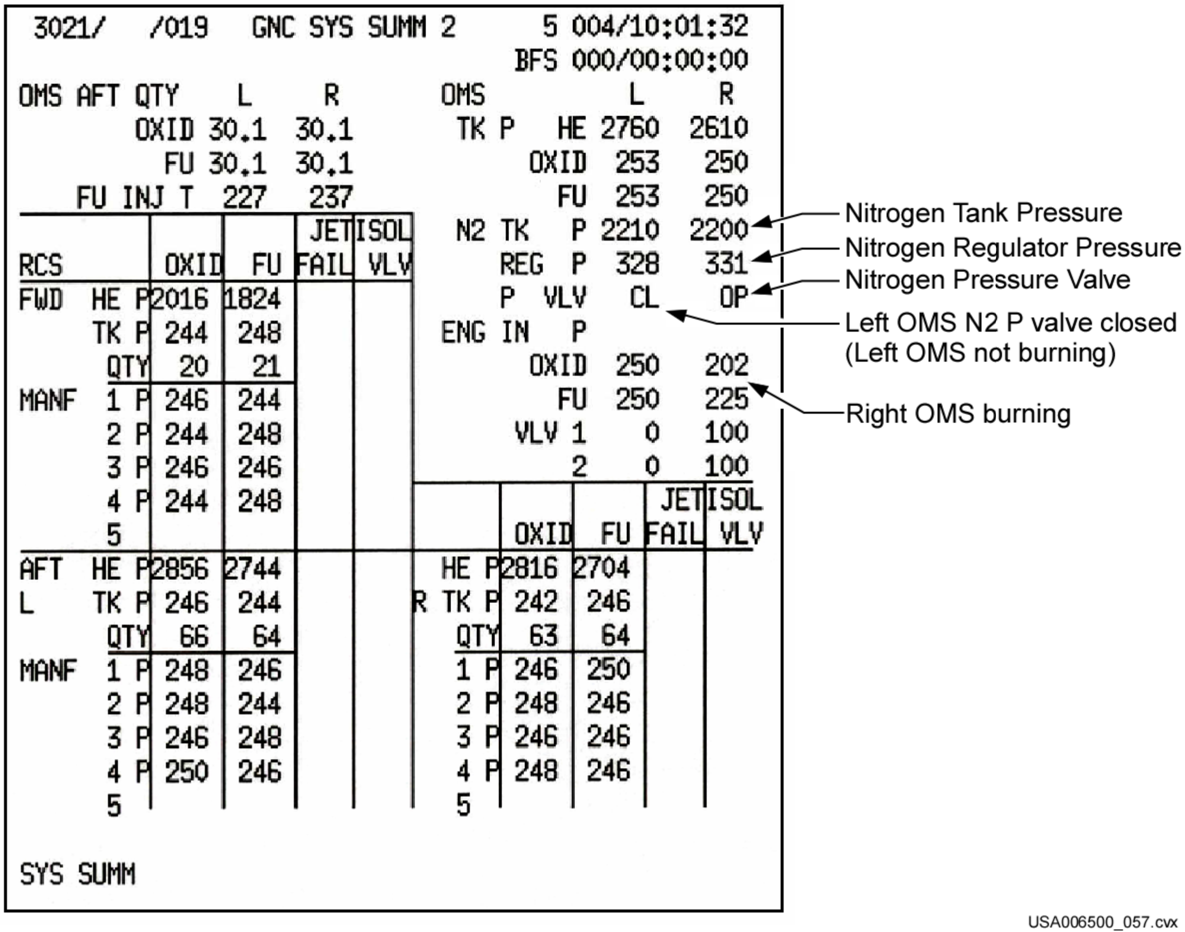


Figure 2-8. GNC System Summary 2 display/N_2

The purge is automatic only if the OMS engine switch is in the ARM/PRESS position and, therefore, when the N_2 press valve is open. For that reason, the crew should leave the OMS engine switches in ARM/PRESS for at least 2 seconds after an OMS burn so that the purge can be completed. When the N_2 press valve is open, nitrogen for the purge is supplied by the tank. If the N_2 press valve were closed, the purge would deplete the accumulator, and the OMS start capability of the accumulator would be lost. This is not normally a problem since the accumulator can be repressurized. But if the N_2 press valve were closed because of an upstream leak, it would be important to save the nitrogen in the accumulator. The purge is not as important as the need to preserve the engine restart capability. With the OMS engine switch in ARM or OFF, the N_2 press valve is closed and the engine purge is inhibited.

The nitrogen tank has two independent pressure sensors. One is displayed on MEDS OMS/MPS and the other sensor can be found on the GNC System Summary 2 display (see Figure 2-7). There is also a pressure sensor located below the regulator and check valve. Its reading is found on the GNC System Summary 2 display as REG P, and it is an indication of the accumulator pressure.

OMS Engine Switches

There are two sets of switches that are critical for OMS ignition: the OMS engine switches and the OMS engine valve switches (see Figure 2-9). There is an OMS engine valve switch for each engine (the switch for the left engine is on Panel O14, and the one for the right engine is on Panel O16). These switches provide power to the engine control valves and must be ON in order for the engine to burn. The nominal position of the OMS engine valve switch is ON for the entire mission.

The OMS engine switches on Panel C3 have three positions, and each position is summarized below:

ARM/PRESS:	OMS ignition will occur, and the engine purge is enabled (the N_2 press valve is open)
ARM:	OMS ignition will occur but the engine purge will not occur (the N_2 press valve is closed)
OFF:	OMS ignition will not occur and therefore the purge will not occur either. If one of the switches is taken to OFF at any time during a burn, the appropriate engine will shut down immediately and no purge will occur.

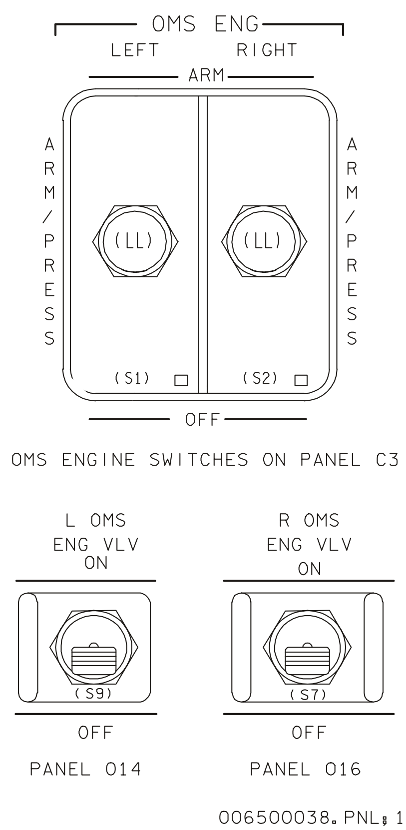


Figure 2-9. OMS Engine and OMS Engine Valve switches

2.2 PROPELLANT AND HELIUM SUPPLY

Helium Tanks

Oxidizer and fuel are supplied to each OMS engine by separate sets of propellant tanks (see Figure 2-10). The OMS engine does not have fuel or oxidizer pumps, so the propellant flow must be maintained by keeping the tanks pressurized with helium. A single helium tank provides pressurization to the fuel and oxidizer tanks. One advantage to having a single helium tank in each pod is that it helps ensure that the two propellant tanks remain at the same pressure and thus avoids incorrect mixture ratios.

The helium tank contains a supply of gaseous helium at a high pressure. The tank has two pressurization valves in a parallel arrangement: the A helium press valve and B helium press valve. This arrangement provides redundant paths for the helium to reach the propellant tanks. These valves are held closed by springs and are opened by electrical solenoids. The valves are controlled by switches on Panel O8 that have manual OPEN and CLOSE positions and also a GPC position that allows the GPCs to control the valves automatically. These valves are normally closed at all times except during OMS burns. If the switches are in the GPC position, the automatic OMS burn sequence opens the helium press valves at the start of a burn and closes them at the end of a burn.

Below each helium press valve there is a pressure regulator that reduces the helium pressure from its value in the tank, which can be as high as 4800 psia (at launch) to a working pressure of approximately 250 psig. Below the regulators, the two helium lines rejoin and then split into one line that runs to the oxidizer tank and one line that runs to the fuel tank. There are one-way quad check valves in these lines to prevent oxidizer or fuel from flowing back into the helium lines or the helium tank.

Over a long period of time it is possible for small amounts of propellant vapors to diffuse through the check valves and into the helium lines. If there were any mixing of the hypergolic propellant vapors in these lines, a reaction could occur. In order to minimize vapor diffusion, an additional set of isolation valves are therefore included in the line between the helium and the oxidizer tank. (The oxidizer was chosen because it has a higher vapor pressure than the fuel.) The vapor isolation valves provide a more positive seal than the check valves can. There are two valves in parallel so that if one vapor isolation valve gets stuck closed, one path will still remain open. The vapor isolation valves are controlled by the same switches as the helium press valves, which is why the switch is labeled “He PRESS/VAPOR ISOL” (see Figure 2-11). Both vapor isolation valves open automatically when either the A or the B helium press valve is opened. The vapor isolation valves close when both helium press valves are closed.

There are two pressure sensors in the helium tank. One is displayed on MEDS OMS/MPS (see Figure 2-11), and the reading from the other sensor appears on the GNC Systems Summary 2 display (see Figure 2-12).

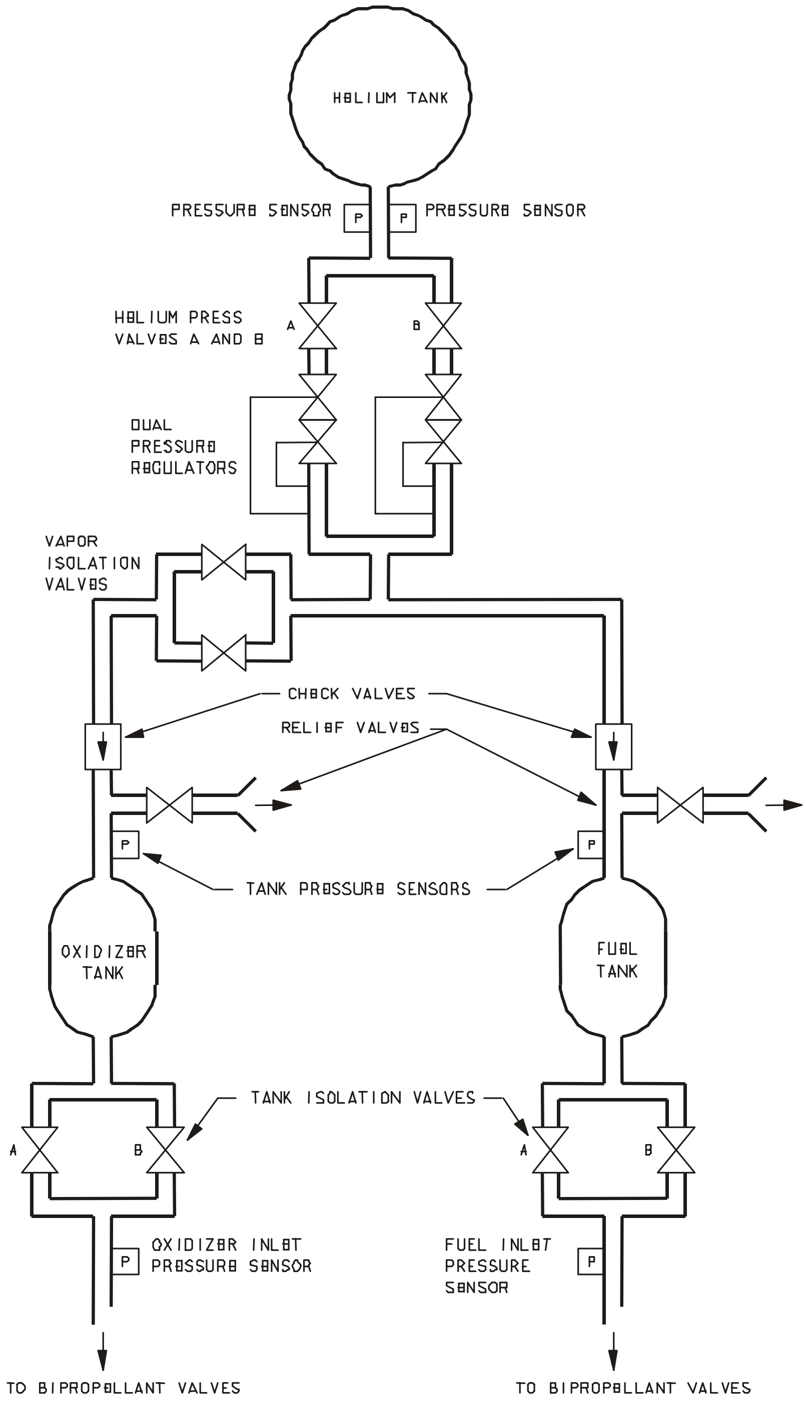


Figure 2-10. Propellant and helium supply schematic

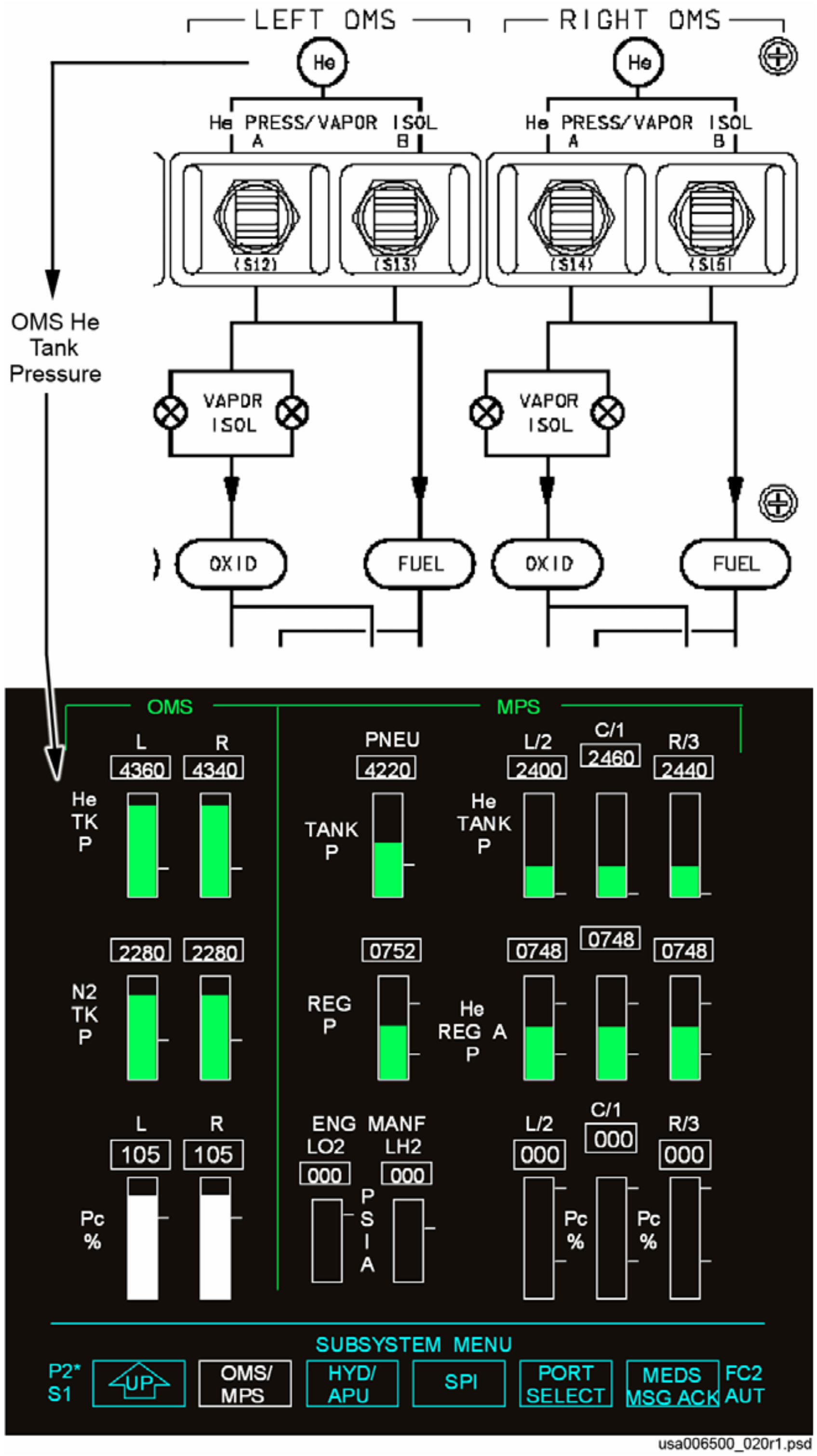


Figure 2-11. He Press/Vapor Isolation switches and MEDS OMS/MPS display Propellant Tanks

The fuel and oxidizer are stored in cylindrical tanks with a helium pressurization inlet at the forward end and a propellant outlet at the aft end. Since the OMS tanks are used in a zero gravity environment, special provisions must be made to cause propellant to flow out without allowing helium to escape. Some space vehicles have used flexible bladders to push propellant out of their tanks, but this type of system was not considered durable enough for a reusable vehicle. Instead, the OMS tanks use the capillary action of the propellant along mesh screens at the aft end to capture the fluid and move it out of the tank. The acceleration during an OMS burn will cause the fluid to move to the aft end of the tank, thus aiding propellant acquisition. Of course, there is no acceleration before the start of a burn, so the tank was designed to ensure that the aft end would always contain some propellant. This was done by placing a mesh screen across the tank; this screen divides the tank into a forward and an aft compartment. The aft compartment includes about one-third of the volume of the tank and will be completely full at launch. As long as the screen remains wet, propellant can flow into the aft compartment but it is not likely to flow back into the forward compartment because of the surface tension of the fluid.

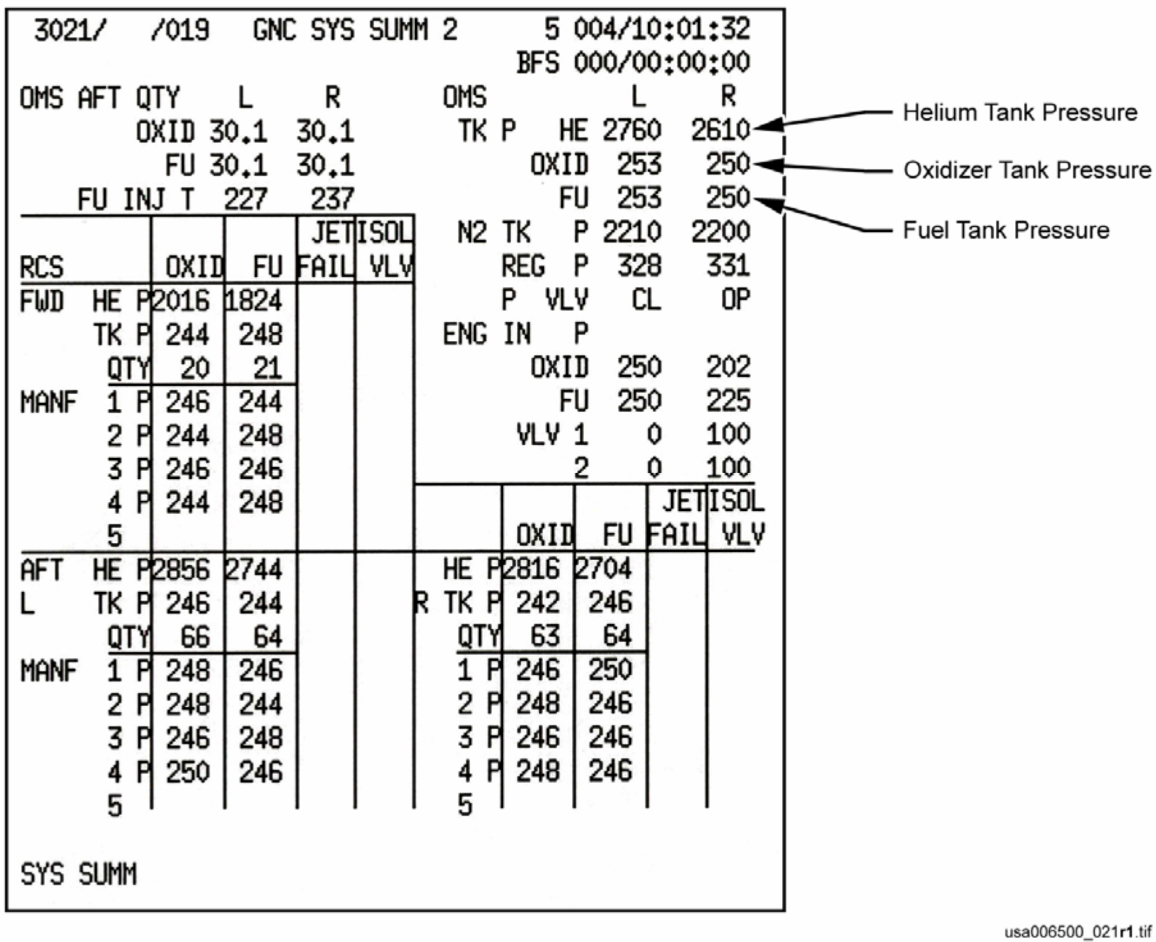


Figure 2-12. GNC System Summary 2 display (Tank Pressures)

Once acceleration begins, propellant will flow from the forward compartment into the aft compartment, which should always remain full. Helium should remain confined to the forward compartment until the fluid is below the one-third level. When an OMS burn is started with a low propellant level, the OMS burn should be preceded by a short burn with RCS jets to accelerate the vehicle slightly and cause the OMS propellant to settle to the aft end of the tanks. There can be problems with the propellant acquisition system in certain situations, and these constraints will be discussed later.

Each of the propellant tanks has one pressure sensor. This sensor is wired directly to a gauge on Panel O3 (see Figure 2-13). The same measurement also appears on the GNC Systems Summary 2 display (see Figure 2-12). This is different from the OMS helium and nitrogen tanks for which the MEDS OMS/MPS and GNC SYS SUMM 2 readouts come from two different sensors.

There is a pressure relief valve for each of the propellant tanks located below the check valves. If the pressure in the tank exceeds 305 psig, a disk will rupture to relieve the pressure overboard. From then on, any overpressure will be relieved through a poppet valve that opens at 290 psig and reseats at 285 psig.

The quantity of propellant in each tank is measured with a probe inside the tank. OMS quantity gauging is described later is this section.

Each propellant tank has a set of tank isolation valves. These are the A and B tank isolation valves, and they are arranged in parallel to provide redundant paths for the propellant. The valves are driven open and closed by ac motors that normally use three-phase ac power but can operate on two-phase power. The tank isolation valves are controlled by switches on Panel O8 (see Figure 2-14). Each tank isolation valve switch controls one valve on the fuel side and one on the oxidizer side. The switches have manual OPEN and CLOSE positions and a GPC position that enables automatic control of the valves.

Each switch has an associated talkback, which is an indicator above the switch showing the position of the valve (OP for open and CL for closed). When there is a mismatch in the positions of the fuel and oxidizer valves, the talkback will show a striped pattern called barberpole. The barberpole indication also appears momentarily whenever the valves are opening or closing. The tank isolation valves normally remain open throughout a mission. The redundant paths rejoin below the tank isolation valves, and the propellant lines continue to the bipropellant valve assembly.

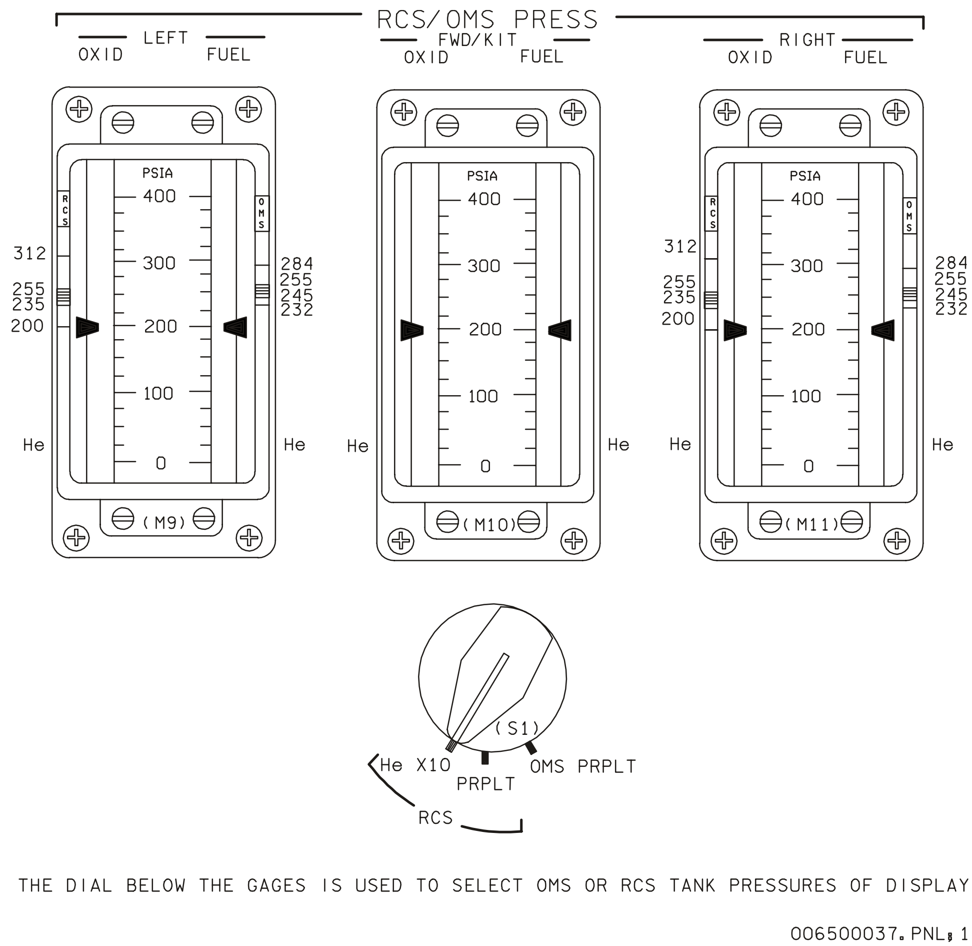


Figure 2-13. RCS/OMS propellant tank pressure gauges on Panel O3

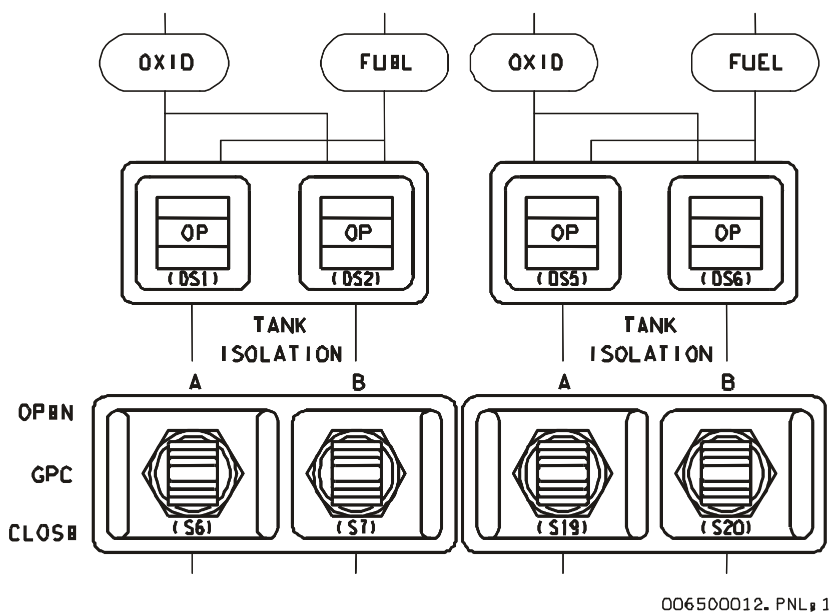


Figure 2-14. OMS tank isolation switches and talkbacks on Panel O8

Crossfeeds and Interconnects

It is possible to feed the engine in one pod with propellant from the other pod. This is called an OMS crossfeed and would be done to balance the propellant weight in each pod or in situations where an OMS engine has failed.

Crossfeed lines connect the left and right OMS propellant lines at a point between the tank isolation valves and the bipropellant valves (see Figure 2-15). Each crossfeed line has two crossfeed valves arranged in parallel to provide redundant paths for propellant flow. The valves and the switches that control them are similar to OMS tank isolation valves and switches. The switches are on Panel O8, and each one controls a valve in the fuel and oxidizer crossfeed lines.

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

It is also possible to feed OMS propellant to the aft RCS jets. This is called an OMS-to-RCS interconnect (it is not called a crossfeed). The RCS has its own crossfeed valves, which are similar to the OMS crossfeed valves and are used to crossfeed left and right RCS jets to a single set of propellant tanks. The same set of crossfeed lines are used for OMS crossfeeds, RCS crossfeeds, and OMS-to-RCS interconnects.

When an OMS-to-RCS interconnect is set up, the RCS tank isolation valves are closed with switches on Panel O7. An OMS crossfeed valve on the feeding side is opened, and then the RCS crossfeed valve is opened. The OMS crossfeed valves on the nonfeeding side are kept closed. This sequence prevents a direct connection between the OMS and RCS tanks. Normally an interconnect involves one OMS pod feeding the RCS on both sides. This type of interconnect is used during orbit operations and is set up manually. The most important use of an OMS-to-RCS interconnect would be during an ascent abort, when the interconnect setup is automatic. Interconnects will be discussed in detail in a later section.

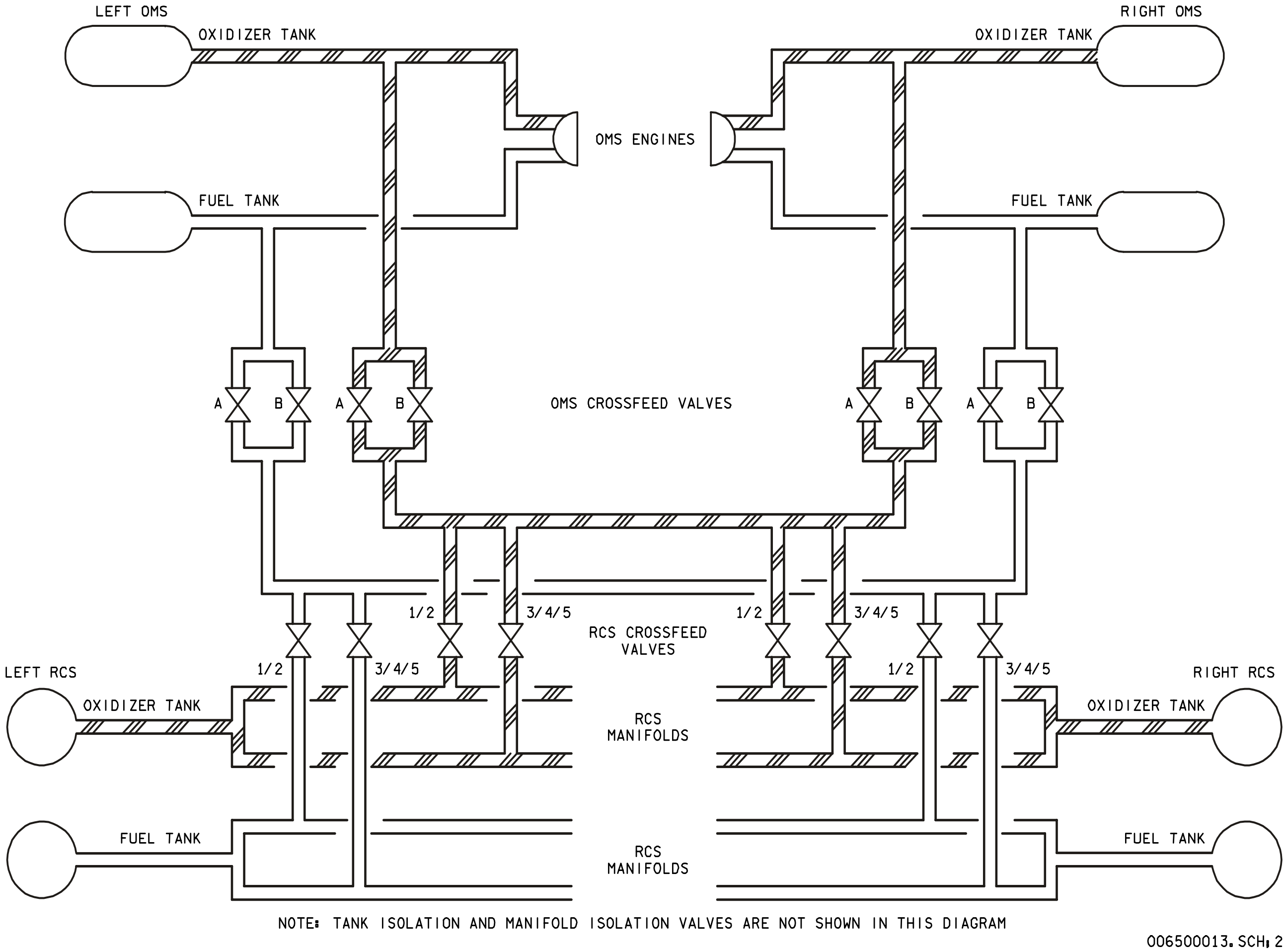


Figure 2-15. OMS and RCS crossfeed valves

Quantity Gauging

The gauging of OMS propellant quantity is accomplished by a combination of physical measurement with a probe inside the tank and computations performed by the gauge totalizer unit (see Figure 2-16). The probe is a rod that runs along the central axis of the propellant tank. It is divided into a forward probe and an aft probe. Both sections of the probe determine fluid level by measuring electrical capacitance within the probe; this measurement reflects the amount of the probe that is immersed in fluid.

There is a problem with this gauging system, since in zero gravity propellant can float freely around in the tank and there may not be a clearly defined fluid level. For this reason, the gauging system updates the quantity value only when at least one OMS engine is burning. It does not update when a burn is done using only RCS jets. Between burns, the quantity value display remains static. Also, the probes do not provide a quantity measurement during the first 15 seconds after an OMS burn starts so that there is time for the vehicle acceleration to settle the propellants and thereby establish a measurable fluid level. In this 15-second period a burn integration computation is performed and provides updates to the meter on Panel O3.

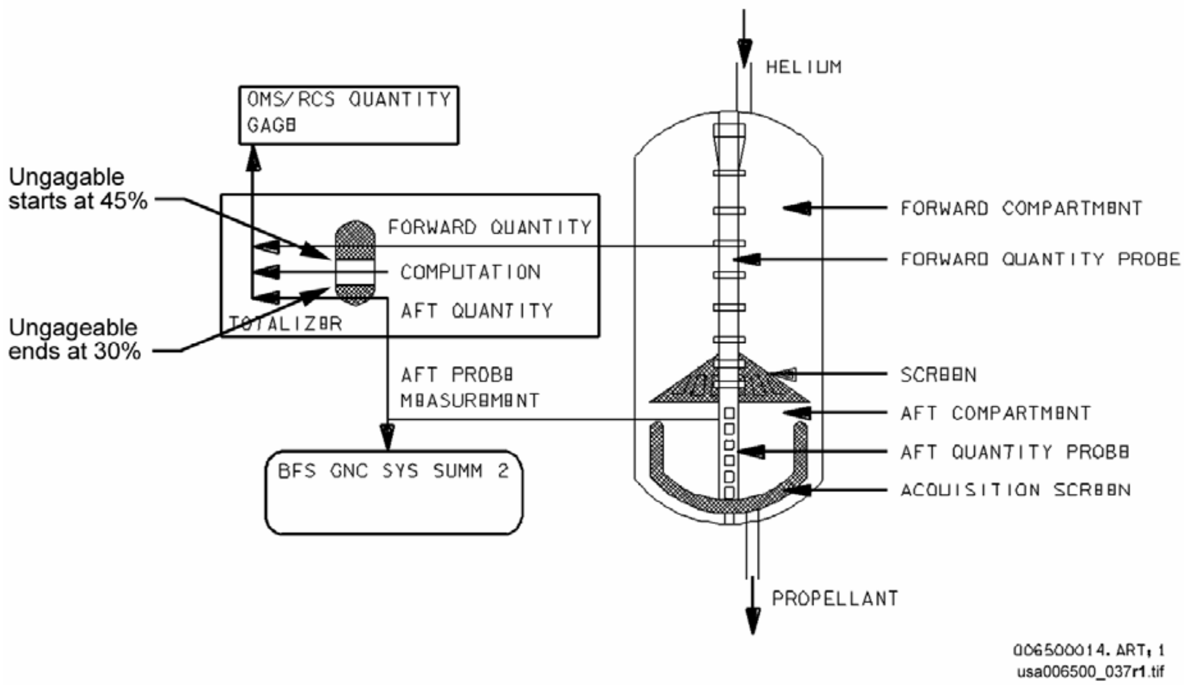


Figure 2-16. OMS quantity gauging

Another gauging problem arises when the fluid level is between 30 percent and 45 percent. That range lies between the forward and the aft sections of the probe and is known as the ungaugable region. In the ungaugable region the propellant tank screen interferes with probe measurement, so the gauge totalizer unit computes a quantity based on a standard one-engine propellant flow rate. Once the ungaugable region is entered, the computation is used for 108 seconds, and then the aft probe takes over the gauging function. The OMS gauging function operates only when at least one OMS engine is turned on.

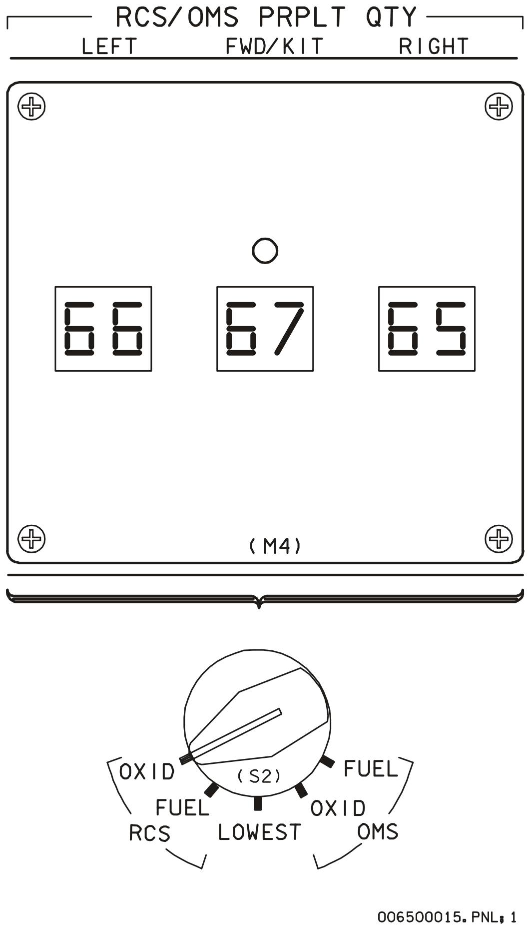


Figure 2-17. OMS/RCS quantity meter on Panel O3

The output of the gauge totalizer, whether it is the probe measurement or a computed value, is displayed on the digital meter of OMS/RCS propellant quantity on Panel O3 (see Figure 2-17). A rotary switch below the meter is used to select either OMS oxidizer or OMS fuel for display. The meter shows the quantity in percent for the left and right sides and also the OMS kit if there is one being carried. The rotary switch is also used to select RCS quantities for display on the same meter.

The GNC System Summary 2 display has a readout of the aft probe quantity (see Figure 2-18). This is a valid quantity measurement and is updated when at least one OMS engine is burning. Of course, it provides useful information only when the quantity is below the ungaugable region. As long as the propellant level is above the top of the aft probe, the display will read a static value of approximately 30 percent.

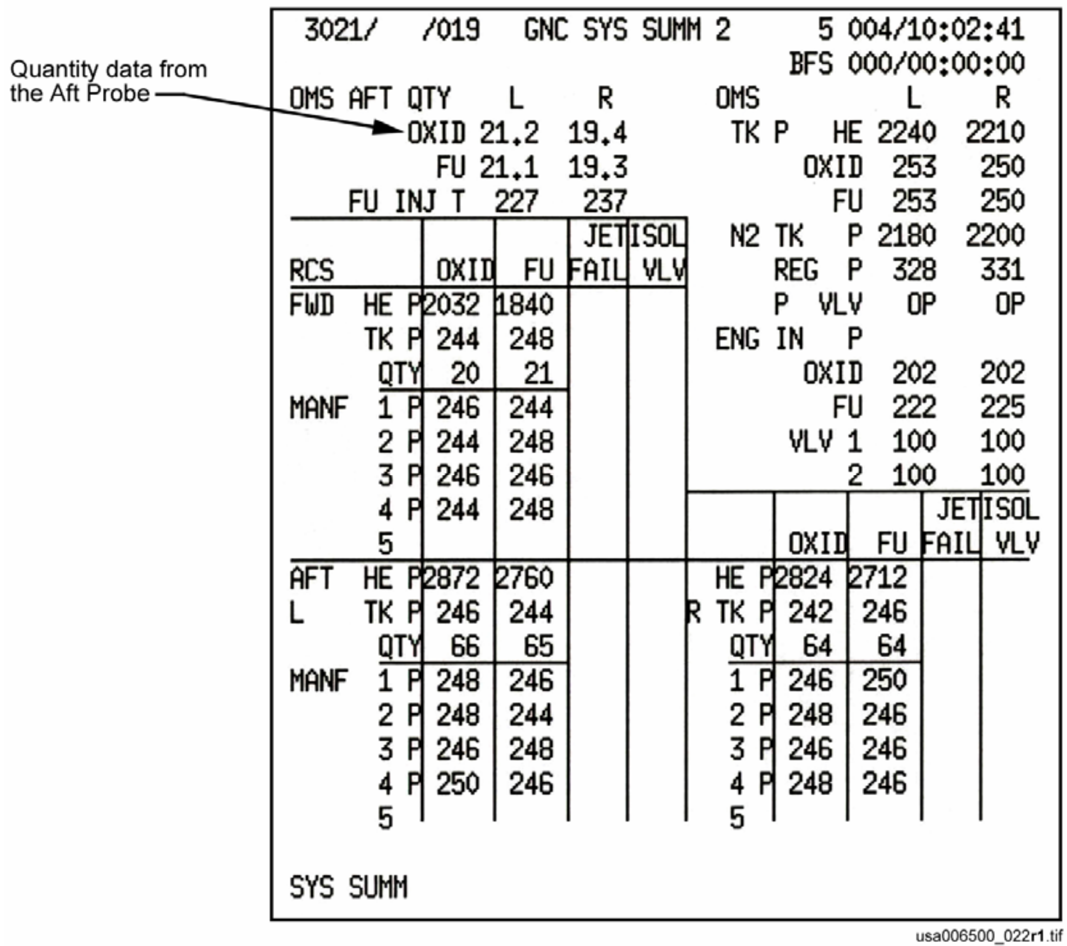


Figure 2-18. Quantity data on GNC System Summary 2

2.3 THERMAL CONTROL

The OMS pods are provided with insulation and electrical heaters to prevent the freezing of propellants in the lines while in orbit. The OMS heaters are divided into three segments: left pod, right pod, and crossfeed lines. Each segment has A and B heater circuits, which are controlled by switches on Panel A14 (see Figure 2-19). The switches have an AUTO position and an OFF position. In the AUTO position the heaters are controlled by thermostats that turn the heaters on and off to maintain temperatures between 55º and 90º F. In the OFF position the heaters remain off at all times. Only one of the two heaters circuits is used at one time. Heaters could burn out if the A and B circuits operated simultaneously, so some of the switches on this panel have protective covers to prevent heaters from being switched to AUTO inadvertently. There is a heater switch for the OMS kit, which will remain OFF. There are other switches on Panel A14 for RCS heaters.

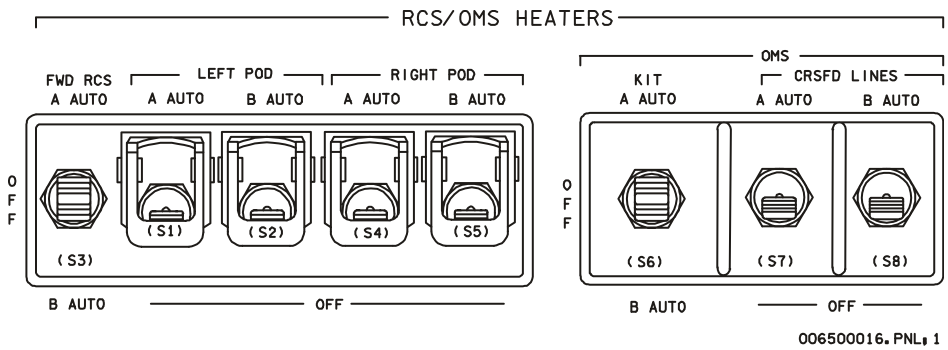


Figure 2-19. OMS heater switches on Panel A14

The OMS thermal control system normally does not require very much attention from the crew. Temperatures are monitored by the GPCs, and when the temperature is above or below a preset limit an alarm sounds and a fault message appears on the appropriate displays. During orbit operations these alarms are generated by the GPC containing OPS 2 Systems Management (SM) software and by the BFS software during ascent and entry. When crewmembers observe an alert, they can look at the display to determine the location of the thermal problem.

During orbit operations the crew would use the Propellant Thermal display (SM SPEC 89) (see Figure 2-20). The display lists the temperature measurements for many locations throughout the OMS pods. If there is a thermal alert, one or more of these temperature measurements will exceed the desired limit. Next to each temperature there is a status indicator that will either be blank if the temperature is in the normal range or indicate an M, ↓, ↑, H, or L. An M stands for missing data and means that temperature data is not being received by the GPC. A ↑ or ↓ means that the temperature is above or below the specified normal range. An H or an L means that the temperature has reached or exceeded the high or low limit that can be measured by the sensor; it usually means that the sensor has failed. The temperature data in the left half and lower right corner of the display applies to areas covered by the left and right pod heater segments. The information in the upper right corner applies to the areas served by the crossfeed line heater segment.

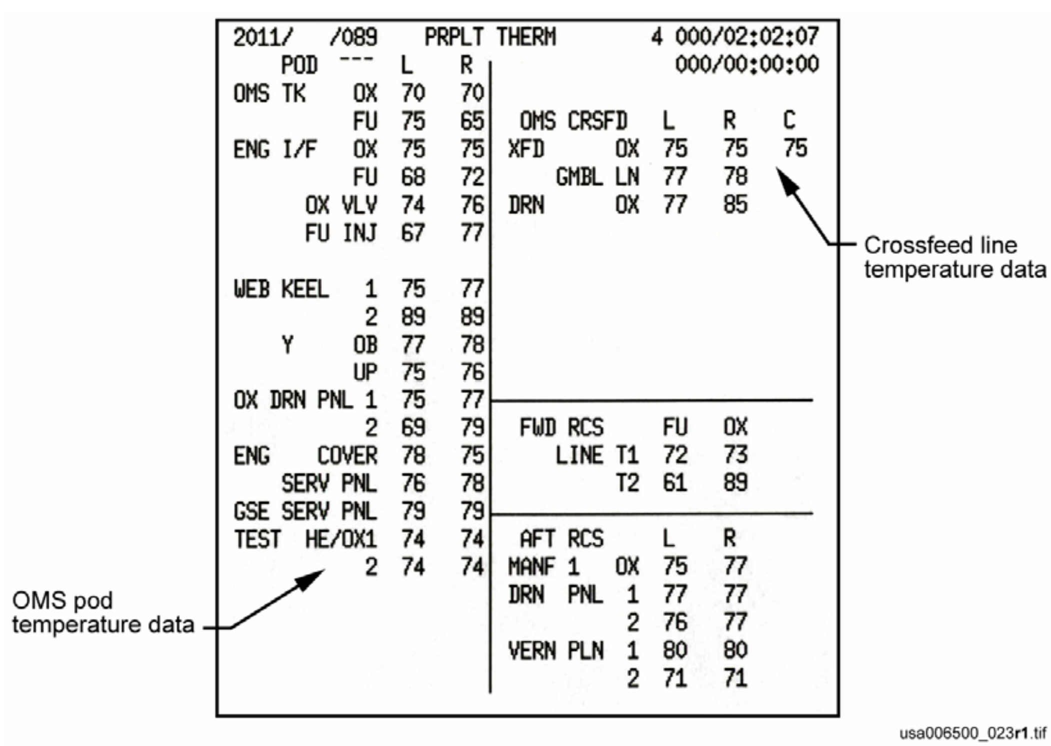


Figure 2-20. SPEC 89 propellant thermal display

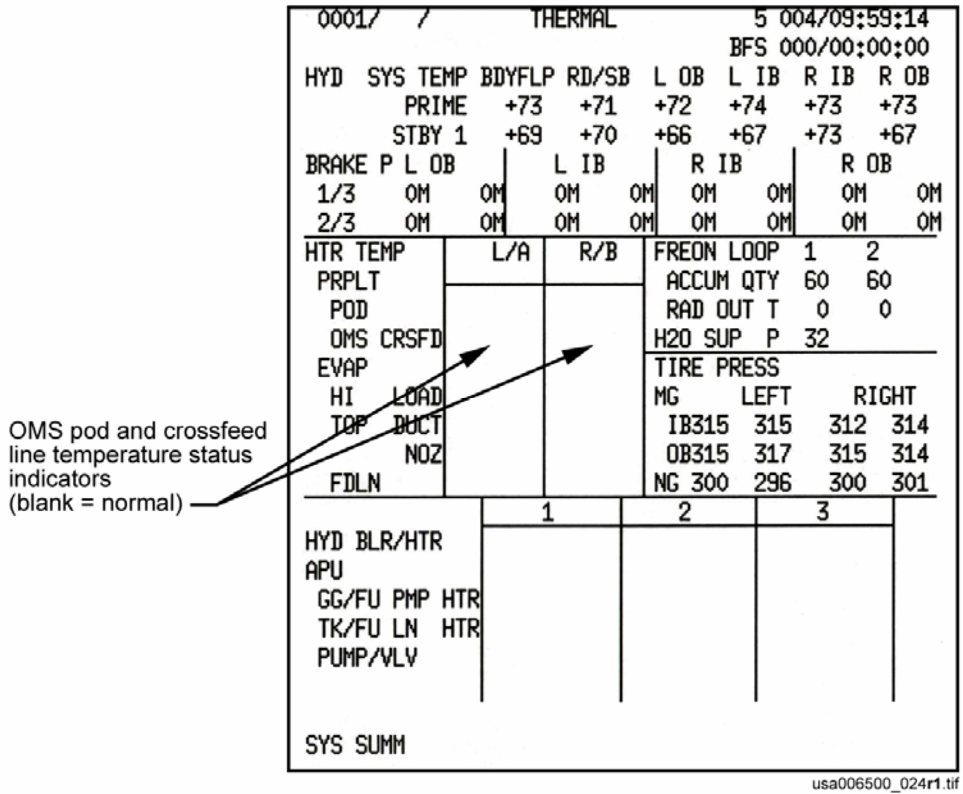


Figure 2-21. BFS thermal display

The BFS Thermal display (BFS SM OPS 0) is available at any time when the BFS computer is in RUN or STANDBY, which includes the ascent and entry phases (see Figure 2-21). The display includes thermal data for several different systems, so the OMS pod temperature information is limited. The display does not provide numerical temperature data, but for each heater segment (left Pod, right pod, and crossfeed lines) there is a string of six or seven status indicators that correspond to a selected set of temperature sensors. The status field for each sensor will either be blank for normal or else display one of the indicators as described previously (M, ↓, ↑, H, L). The DPS Dictionary has a description of this display, which lists the parameters represented by the individual status indicators.

2.4 THRUST VECTOR CONTROL

The OMS engines are attached to the orbiter in gimbal mounts, which allow the engines to pivot up and down and from side to side (see Figure 2-22). Actuators driven by electric motors control the movement of the engines and provide steering capability during OMS burns. This is possible because each engine creates a thrust vector that can be pointed in a certain direction to cause the vehicle to rotate about its center of gravity (c.g.). Pointing the thrust vector to the side causes the vehicle to yaw. Pointing the thrust vector of one engine up and the other down causes the vehicle to roll.

Normally, the orbiter is pointed in the proper direction at the start of a burn and only minor steering corrections are made during a burn with the OMS thrust vector control

(TVC) system. Control inputs come to the TVC actuators from the DAP. These commands can be based on automatic guidance or manual steering inputs from the rotational hand controller (RHC).

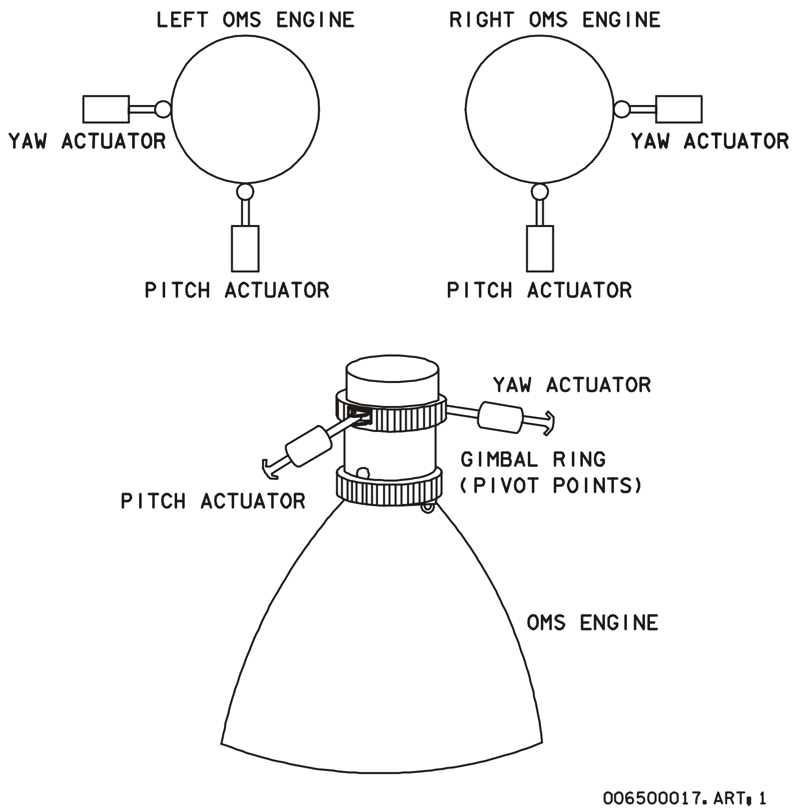


Figure 2-22. OMS gimbal actuators

Each OMS engine has two gimbal drive mechanisms for each axis: a primary gimbal system and a secondary gimbal system (see Figure 2-23). Each drives the actuators independently. If one system fails, the other can be selected to take over control. Gimbal selection is done by item entries to the Maneuver display. Item 28 selects the primary gimbal system for pitch and yaw for the left engine, Item 29 selects the primary for the right engine, Item 30 selects the secondary gimbal system for the left engine, and Item 31 selects the secondary for the right engine. Items 32 and 33 remove power from the gimbal systems for the left and right engines, respectively. Notice you can select primary for one engine and secondary for the other, but you cannot split pitch and yaw between primary and secondary systems.

The flight control system sends out gimbal commands that are compared to the gimbal actuator positions. If there is an error greater than 0.4º, the actuators will be commanded to move the engine back to within 0.06º of the correct position. As long as the error is less than 0.4º there will be no actuator movement.

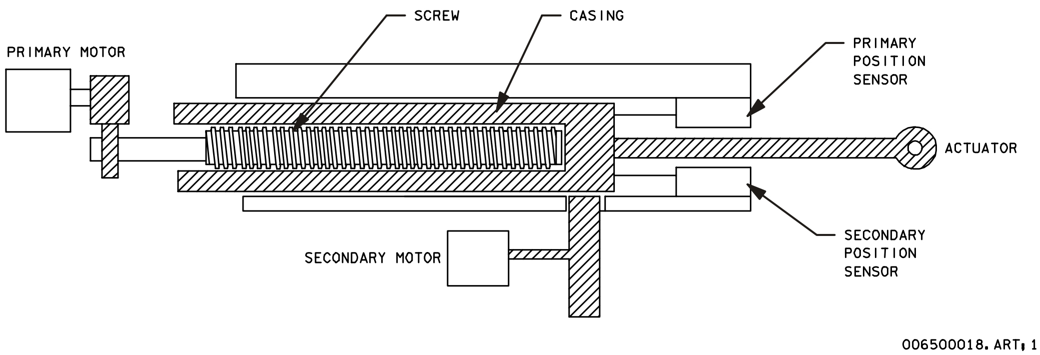


Figure 2-23. Actuator mechanism

The range of gimbal movement for the OMS engines is ±6º in pitch and ±7º in yaw (see Figure 2-24). Assuming that the vehicle is pointed in the proper direction at the start of a burn, it is necessary only to position the OMS engines so that their combined thrust vector is aligned with the c.g. to keep the orbiter on course. The OMS engines are located above and to either side of the c.g., so they are mounted with their null axes pointed upward and outward.

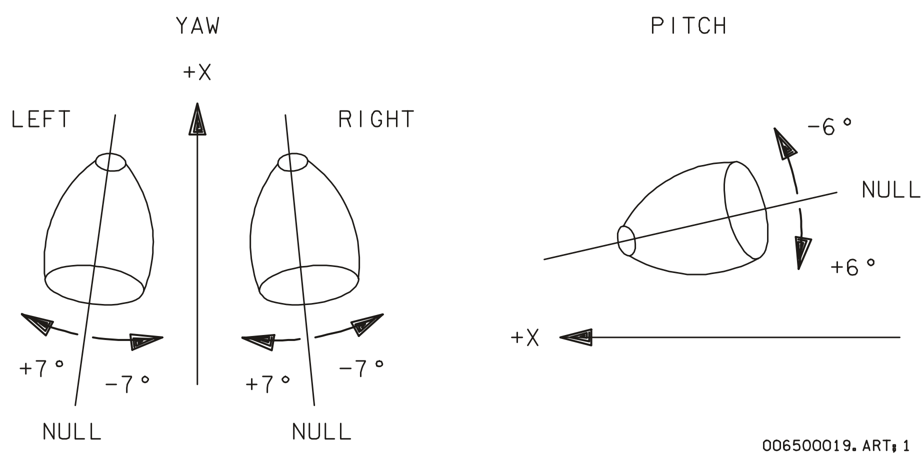


Figure 2-24. OMS gimbal degree-of-freedom

The gimbal positions can be seen by the crew on the Maneuver display. The null positions in pitch and yaw correspond to zero degrees on this display. Gimbal positions on the Maneuver display are not useful as a flight control reference during a burn. Instead, the crew uses the attitude directional indicator (ADI) to monitor vehicle attitude and the attitude errors computed by Guidance, and this provides an indirect indication of proper TVC operations.

For two-engine OMS burns it is more efficient to keep the thrust vectors parallel to each other so that the resultant vector is through the c.g. rather than to point both thrust vectors individually through the c.g. (see Figure 2-25). For parallel alignment, the gimbal angle for pitch is approximately zero since the null position in the pitch axis lies in about the same plane as the c.g. The null position for the yaw axis has the engines pointed outward. To get the engine nozzles parallel in yaw they must be moved 6º inward, which is a yaw gimbal position of -6º for the left engine and + 6º for the right engine.

For a single-engine burn the pitch gimbal angle would be the same as for a two-engine burn, but the yaw angle would be 6º outward, which is +6º for the left engine and -6º for the right engine (see Figure 2-25). The gimbal angles mentioned here are approximate; the values vary since the c.g. location depends on the vehicle configuration and propellant loading.

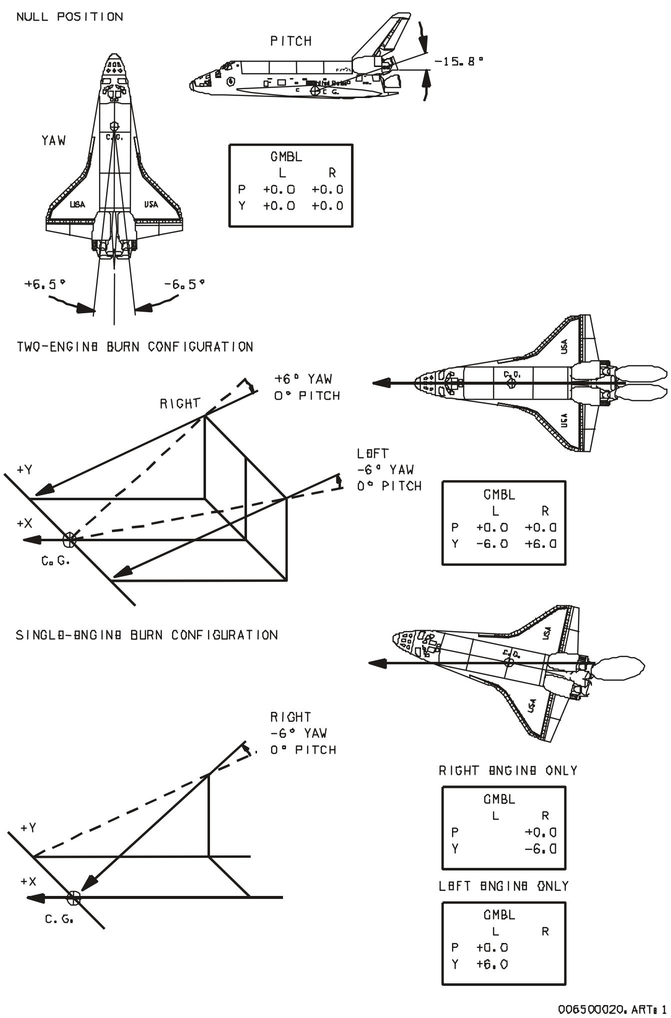


Figure 2-25. Gimbal positions during burns

To keep the orbiter on course, the flight control system actively commands the OMS gimbals to point the thrust vector through the c.g., but to start a burn in an efficient manner the gimbals are preset to be properly aligned for ignition. These preset positions are called the gimbal trim angles and appear on the Maneuver display under TRIM LOAD.

In general, the trim load is set up using item entries to the Maneuver display: Item 6 for pitch (left and right are always the same), Item 7 for left yaw, and Item 8 for right yaw (see Figure 2-26). The OMS gimbals will move 15 seconds prior to ignition only if the actual position differs from the trim value by more than 0.4º. If the difference is less than that, there will be no gimbal movement before ignition.

During the course of a burn, the c.g. will move slightly and the gimbals will remain trimmed as they respond to dynamic flight control commands. The gimbal positions existing at the end of any OMS burn, right before thrust tail-off, are stored by the computers. Whenever the Maneuver display is recalled, those stored gimbal positions are transferred to the trim load.

In some cases, the trim load captured at the end of a burn is quite adequate for a subsequent burn and no manual changes to the trim load are required. Gimbal trim setup is handled in different ways for different OMS burns.

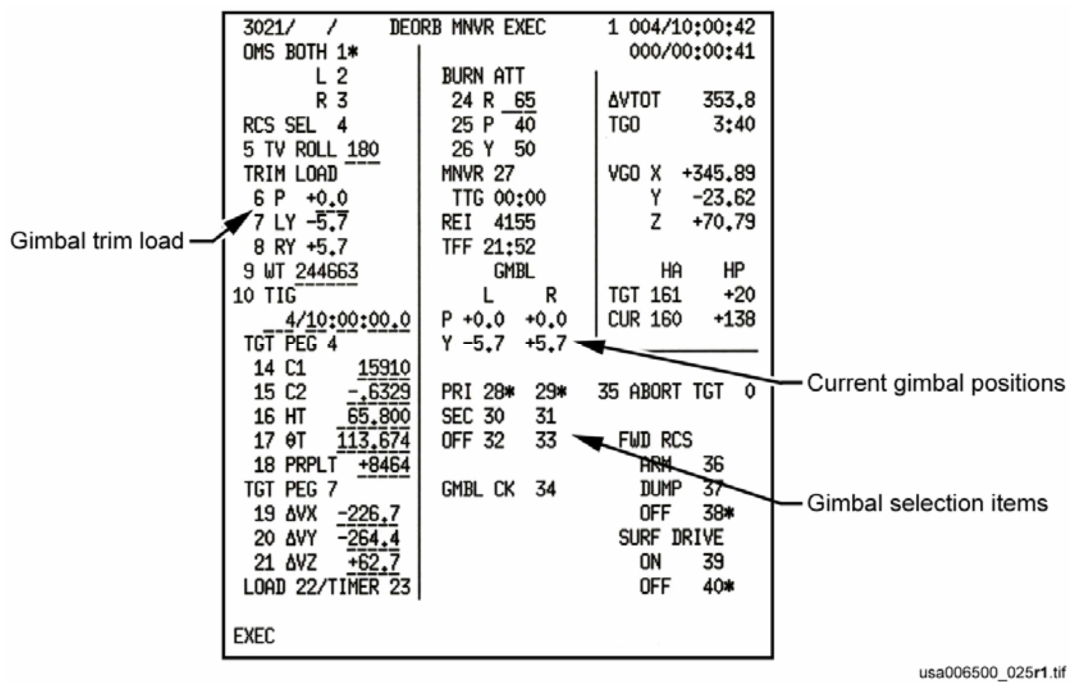


Figure 2-26. DEORB MNVR EXEC/gimbal positions

To ensure proper alignment for OMS 2, a gimbal trim load is done in MM 105 using trim values listed in the Ascent Checklist. For subsequent burns the trim load will generally not require a change. The trim load captured at the end of a previous burn should be adequate unless there is a change to the engine selection, such as that required for a single-engine burn.

The gimbal check (Item 34) commands the actuators to drive through their whole range of movement. When the gimbal check is active, an asterisk appears next to Item 34. The movement of the gimbals can be seen on the Maneuver display. The gimbal check drives the gimbal system that is selected (primary or secondary) in both the pitch and yaw directions. When the check is complete, the asterisk will disappear.

Normally, the gimbal check is done before or after each OMS burn. The secondary gimbals are checked first, followed by the primary gimbal system. A gimbal check should never be executed during a burn. If it were, the gimbal check commands would override the flight control commands, causing obvious control problems.

2.5 OMS DISPLAYS

This section is a summary of all of the displays that are related to OMS operation. We will discuss the MNVR display, GNC SYS SUMM 2, Thermal displays and RCS SPEC 23.

Maneuver Display

The maneuver display appears automatically in MMs 104, 105, 106, 202, 301, 302, and 303. The title has a prefix and a suffix that vary according to major mode and are listed below in Table 2-1. The items on this display that are relevant to OMS burns will be described briefly.

Table 2-1. OMS maneuver displays

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

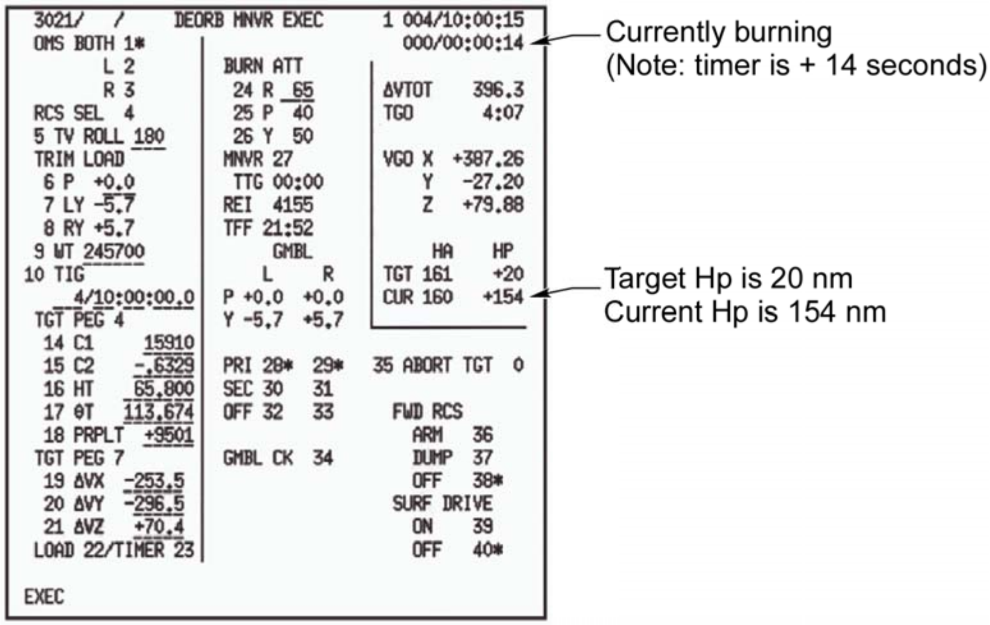


Figure 2-27. DEORB MNVR EXEC

Items 1 through 4 are mutually exclusive and used to target a two engine, one engine or RCS burn (see Figure 2-28).

OMS BOTH	1*
	L 2
	R 3
RCS SEL	4

Item 5 is the roll attitude for OMS burns. Normally it is 180º, which corresponds to a heads-down attitude.

5 TV ROLL 1 8 0

Items 6 through 8 are used to enter gimbal trim angles for OMS burns.

TRIM LOAD
6 P [+] 0.4
7 LY [-] 5.7
8 RY [+] 5.7

Item 9 is the current weight of the orbiter in pounds.

9WT 245700

Item 10 is the time of ignition for an OMS burn in days/hours: minutes: seconds of mission elapsed time (MET). TIG is a critical component of the burn target.

10 TIG
4/10:00:00

The target parameters for powered explicit guidance (PEG) are entered with items 14 through 18. This type of guidance (PEG 4) places the orbiter on course for a specific point in space and is normally used for OMS 2, and deorbit burns. PEG 4 targets can be used only in OPS 1 and 3.

TGT PEG 4
14 C1
15 C2
16 HT
17 θT
18 PRPLT

Items 19 through 21 are the target LVLH parameters for PEG 7 or external ΔV guidance. It is used to add or subtract orbital velocity and does not target the vehicle for a specific point in space. PEG 7 targets can be used in OPS 1, 2, or 3.

TGT PEG 7
19 ΔVX
20 ΔVY
21 ΔVZ

Executing Item 22 causes Guidance to compute a burn solution on the basis of the target parameters that have been entered under PEG 4 or PEG 7. Executing Item 23 sets up a timer, which counts down to TIG and is displayed on the second line at the upper right corner of the display.

LOAD 22/TIMER 23

Items 24 through 26 are the desired inertial attitude for the OMS burn which Guidance computes as part of the burn solution. Executing Item 27 causes an automatic maneuver to this pre-burn attitude. TTG will count down to maneuver complete, and time field will blank when in attitude.

BURN ATT
24 R 065
25 P 040
26 Y 050
MNVR 27
TTG 00:00

The actual gimbal position angles are shown in the middle of the display.

	GMBL L	GMBL R
P	+0.0	+0.0
Y	-5.7	+5.7

Items 28 through 31 permit selection of primary or secondary gimbal drivers. Items 32 and 33 will power OFF the respective drivers.

PRI	28*	29*
SEC	30	31
OFF	32	33

Executing Item 34 starts an automatic gimbal check sequence.

GMBL CK 34

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

EXEC

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

ΔVTOT	396.3
TGO	4:07

VGO	X	+	387.26
	Y	-	27.20
	Z	+	79.88

TGT HA and HP are the altitudes in nautical miles of the apogee and perigee for the orbit that will result from the successful completion of the targeted OMS burn. CUR HA and HP are the current apogee and perigee altitudes.

	HA	HP
TGT	161	+20
CUR	160	+154

Item 35 permits entry of a stored PEG 4 target for OMS 1 or OMS 2 with a single keystroke. It is used primarily for calling up abort to orbit (ATO) and abort once around (AOA) targets.

35 ABORT TGT

GNC Systems Summary 2 Display

There is a PASS and a BFS version of GNC Systems Summary 2 display (see Figure 2-29). The two displays are similar, but the BFS display contains some additional information. These displays can be called up by pressing the SYS SUMM key twice (the first time calls up SYS SUMM 1). A less convenient way to call them up is with a keyboard entry of “SPEC 19 PRO.” The BFS display is the only one available during ascent and entry, and the PASS display is the only one normally available during the orbit phase. The majority of the display contains RCS information. The OMS information along the top and right side has already been discussed. You should keep in mind that for OMS burns done in OPS 2, the fuel injector temperatures will not be available on the display.

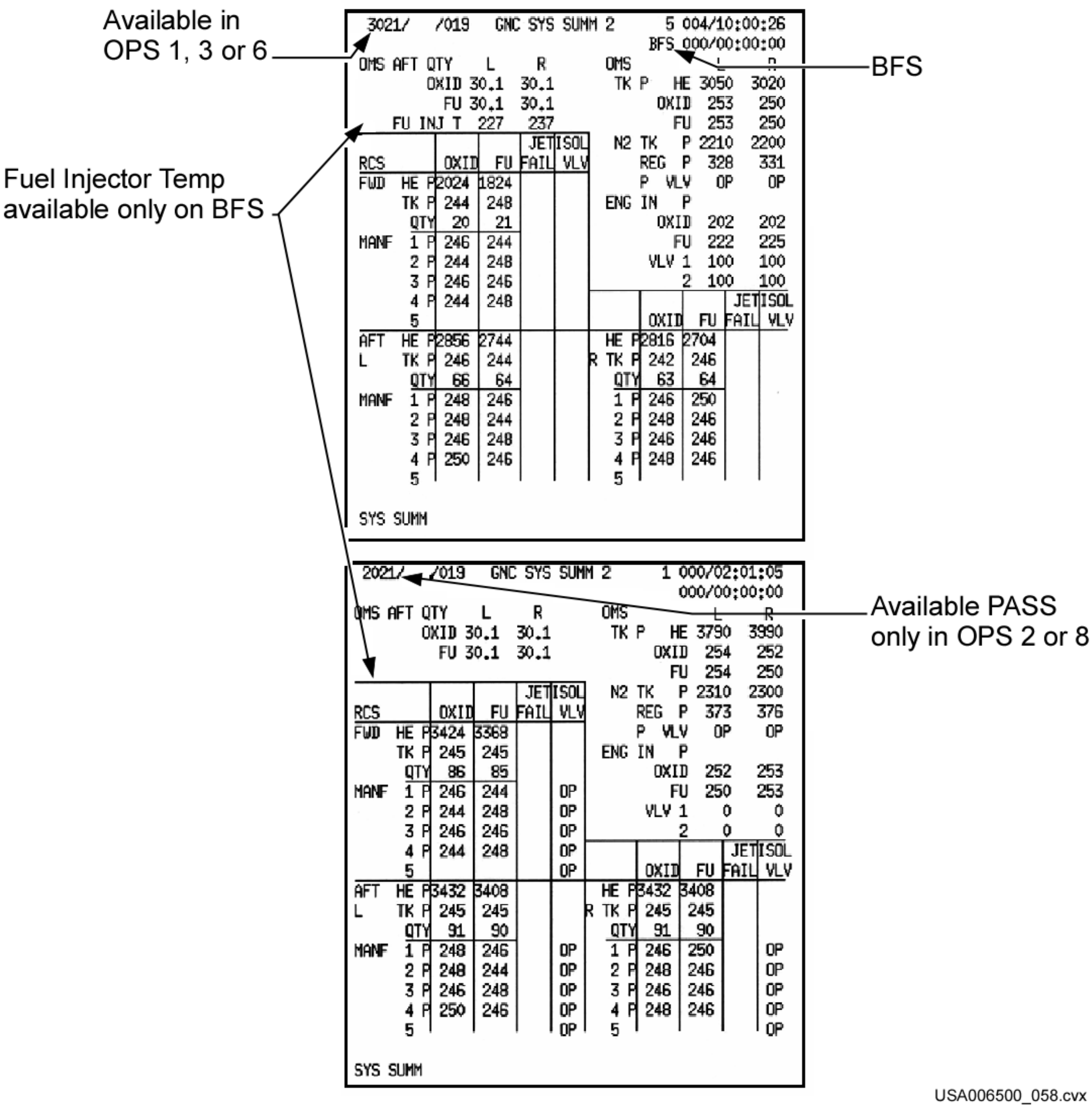


Figure 2-28. PASS and BFS GNC System Summary 2 displays

Thermal Displays

The Propellant Thermal display can be called up in OPS 2 with a keyboard entry of "SPEC 89 PRO" to a CRT MDU with the SM major function selected. Note that it shows fuel injector temperatures (ENG FU INJ) for the left and right OMS engines.

The BFS Thermal display is displayed automatically when the BFS computer is in RUN or STNDBY and the SM major function is selected. The OMS pod temperature status is displayed below HRT TEMP PRPLT.

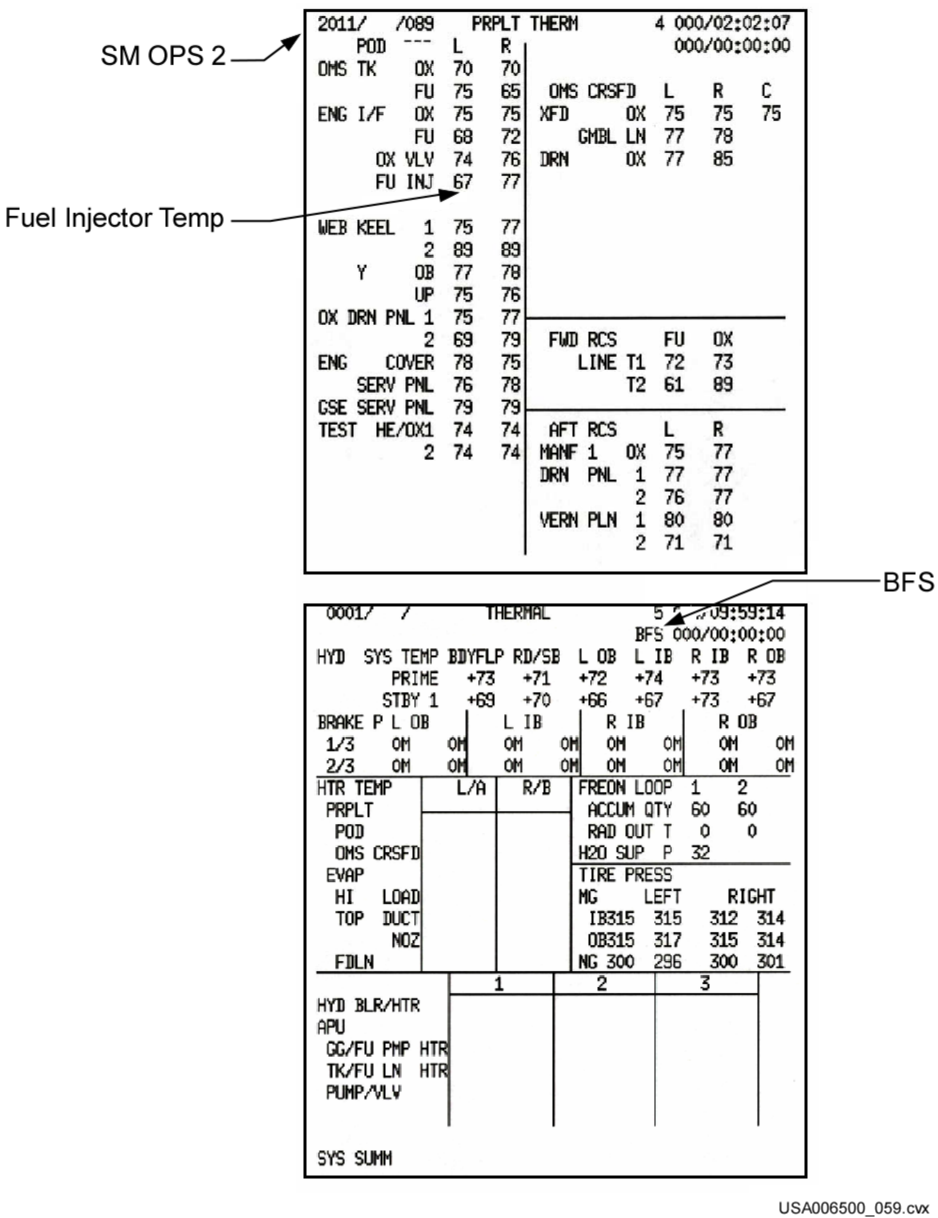
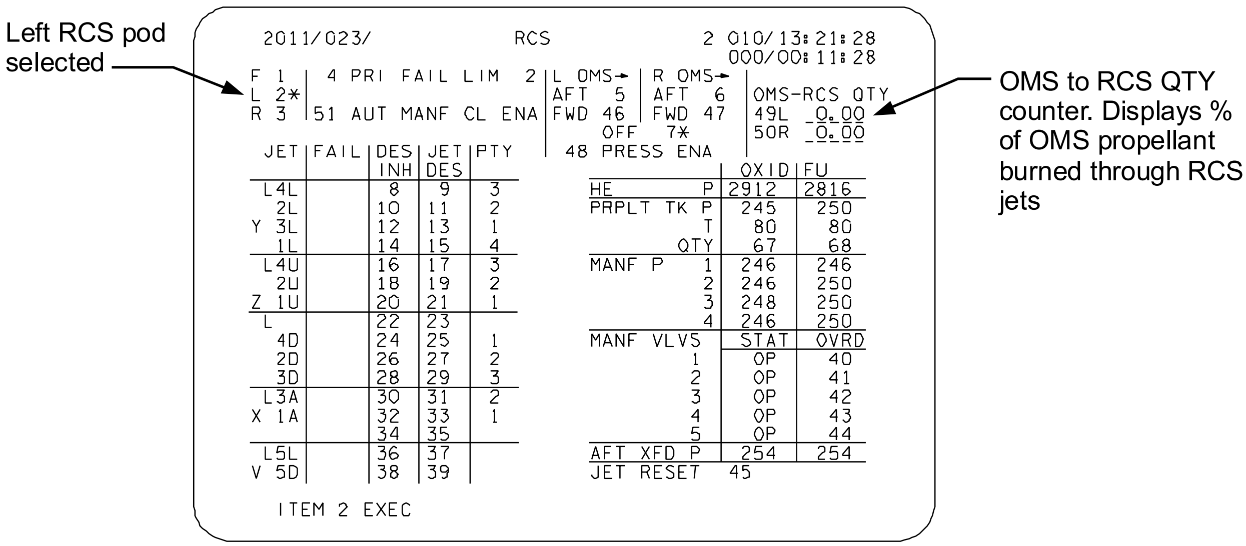


Figure 2-29. Propellant Thermal and BFS Thermal displays

RCS Display

SPEC 23 is prime for RCS pod specific data. However, in the upper right corner there are some items related to OMS gauging for OMS-to-RCS interconnect operations.



USA006500_060.cvx

Figure 2-30. SPEC 23

QUESTIONS

1. If an OMS engine is shut down during a burn by taking the OMS engine switch to OFF, will a purge occur?

2. If the left OMS engine switch is in the ARM position and the right is in OFF,

   (a) Will the left OMS engine ignite at TIG?

   (b) Will the left OMS engine have a purge at the end of the burn?

   (c) Will OMS gauging work for the left pod?

   (d) Will OMS gauging work for the right pod?

3. If the A helium press valve is closed and the B helium press valve is open, which vapor isolation valves will be open?

4. If an OMS engine failed during a 2 Engine OMS burn, would you expect the larger attitude change to be in the pitch axis or the yaw axis? Where would you look to observe this change?

5. If both OMS engines are OFF and OMS propellant is being fed to the RCS jets, does the BFS GNC Systems Summary 2 display provide any information on OMS quantity?

6. If the left OMS engine valve switch on Panel O14 is turned off during a burn, will the engine stop burning immediately?

7. If there is a pitch gimbal error of 0.56º and a yaw error of 0.39º, will either actuator be moved to correct errors and if so how much movement will there be?

Use the example GNC Systems Summary 2 display (see Figure 2-31) to answer the following questions.

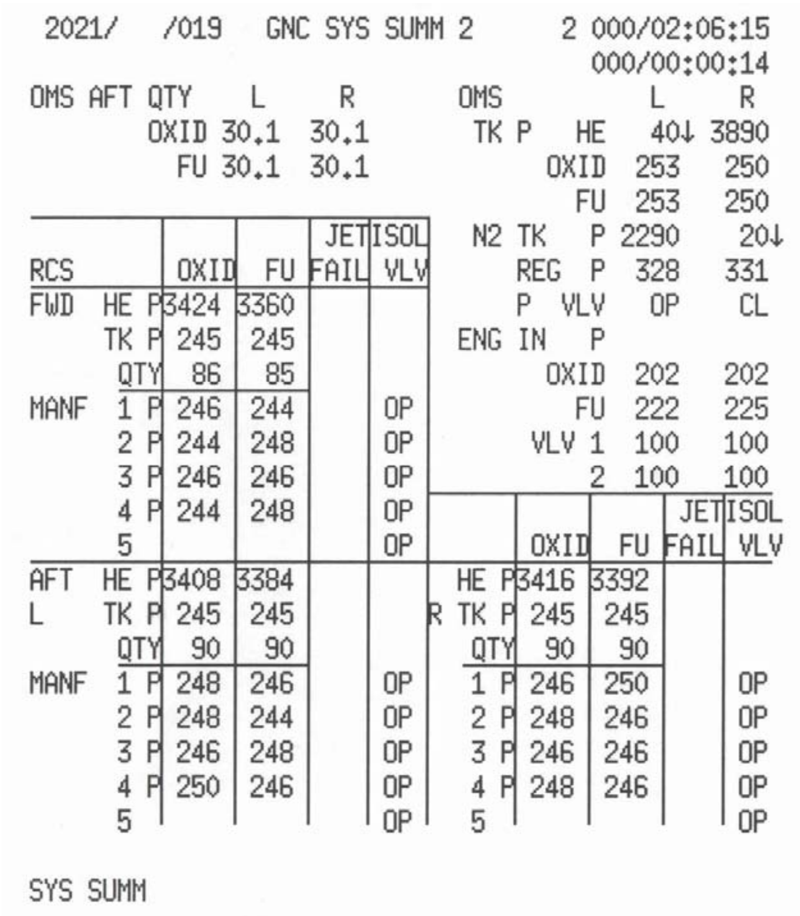


Figure 2-31. GNC Systems Summary 2/Questions

8. Are both OMS engines burning?

9. According to the display, the left OMS helium tank pressure is at 40 psi. Is there a way to double-check this reading?

10. According to the display, the left N_2 press valve is open. How could you close it without turning off the OMS engine?

11. According to the display, the right OMS N_2 tank pressure is at 20 psi. How could one verify this failure?

3.0 INTRODUCTION TO SYSTEM OPERATIONS

In this section seven nominal events and their associated procedures will be discussed.

3.1 OMS 2 Burn

3.2 Orbit OMS Burns

3.3 Deorbit Burn

3.4 Orbit OMS-to-RCS Interconnect

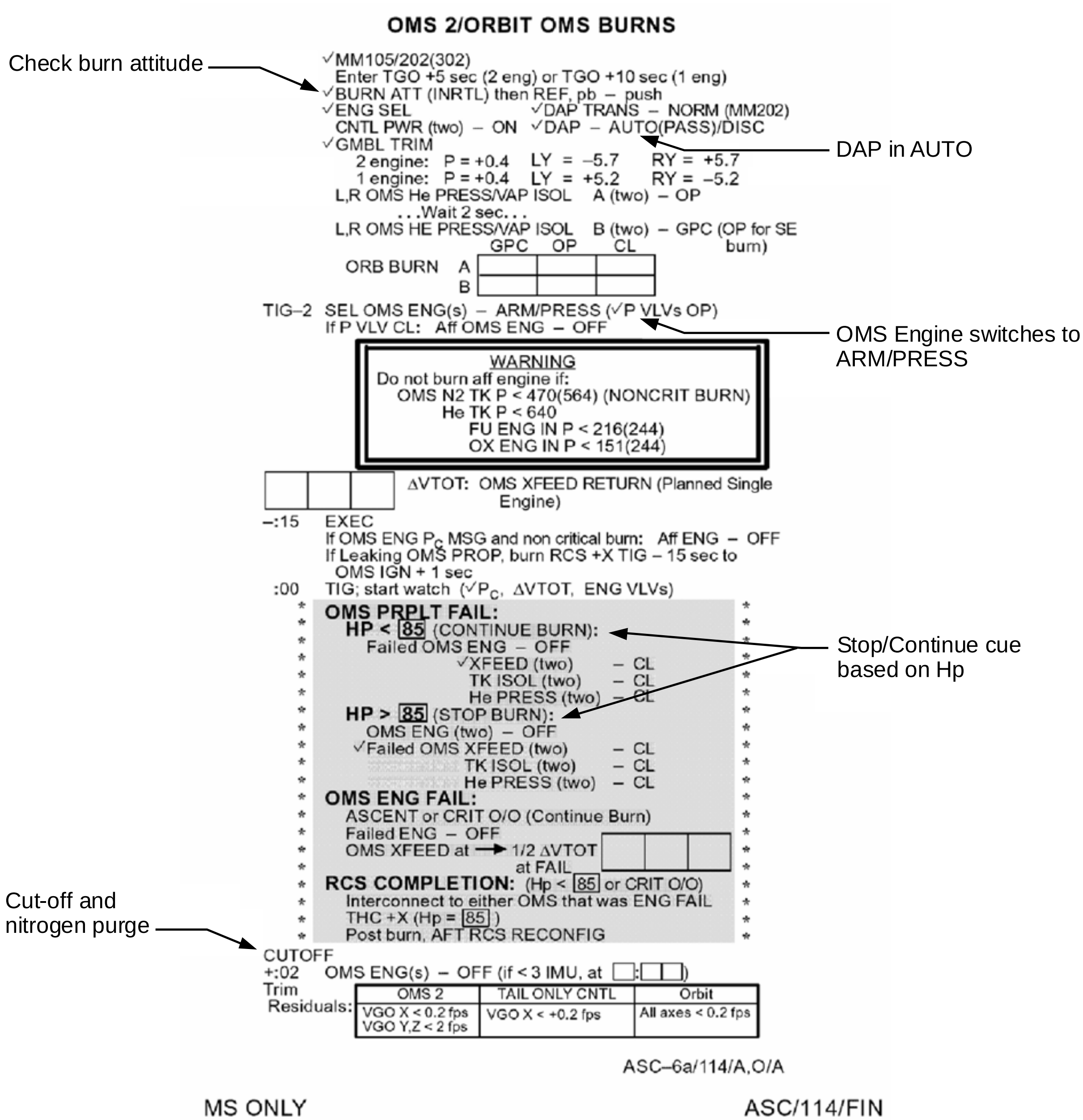
3.5 OMS Assist and Abort Dumps

3.6 OMS Switch Configurations

3.7 Constraints and Limitations

3.1 OMS 2 BURN

The OMS 2 burn is done at the apogee of the elliptical orbit established by MECO. This posigrade burn raises the perigee altitude and creates a circular orbit. For ISS flights the OMS 2 burn occurs roughly 40 minutes MET. The Ascent Checklist contains the procedures necessary to target and configure the majority of the OMS for the upcoming burn. At TIG-4 minutes a transition is made to OMS2/Orbit OMS BURNS card. This card will focus the crew and clean up any outstanding switch throws prior to ignition. The operational highlights of this procedure are noted in the margins. (See Figure 3-1) All FDF procedures should be worked thoroughly and sequentially. We will mention a few critical tasks that should be re-checked prior to executing any OMS burn. A good habit pattern is to first check that targets are loaded and the shuttle is in the proper pre-burn attitude. Second, look up on Panel O8 and confirm there is a good propellant path to the engine. Verify the Helium/Press Vapor Isolation switches match the configuration on the card. Also make sure the tank isolation talkbacks are open. Third, check that the DAP is in AUTO, and finally make sure the OMS Engine switches on C3 are in ARM/PRESS. Do not overlook the giant warning box in middle of the card. Do not burn an OMS engine if any pressures violate these limits (start box). Authorization of the burn will occur with the EXEC key. At TIG, the crew will monitor OMS Pc, delta VTOT clocking down and confirm that the bipropellant valves are open (100%). There is a stop/continue cue based on current Hp. If no failures are encountered then cut-off should occur on time with targets achieved. Allow 2 seconds for the nitrogen purge to take place prior to taking both OMS engine switches to OFF. Finally, remember to trim residuals per requirements at the bottom of the card.


OMS 2/ORBIT OMS BURNS

✓MM105/202(302)
Enter TGO +5 sec (2 eng) or TGO +10 sec (1 eng)
✓BURN ATT (INRTL) then REF, pb – push
✓ENG SEL ✓DAP TRANS – NORM (MM202)
CNTL PWR (two) – ON ✓DAP – AUTO(PASS)/DISC
✓GMBL TRIM
2 engine: P = +0.4 LY = –5.7 RY = +5.7
1 engine: P = +0.4 LY = +5.2 RY = –5.2
L,R OMS He PRESS/VAP ISOL A (two) – OP
. . .Wait 2 sec. . .
L,R OMS HE PRESS/VAP ISOL B (two) – GPC (OP for SE burn)

		GPC	OP	CL
ORB BURN	A			
	B			

TIG–2 SEL OMS ENG(s) – ARM/PRESS (✓P VLVs OP)
If P VLV CL: Aff OMS ENG – OFF

WARNING
Do not burn aff engine if:
OMS N2 TK P < 470(564) (NONCRIT BURN)
He TK P < 640
FU ENG IN P < 216(244)
OX ENG IN P < 151(244)

ΔVTOT: OMS XFEED RETURN (Planned Single Engine)

–:15 EXEC
If OMS ENG P_C MSG and non critical burn: Aff ENG – OFF
If Leaking OMS PROP, burn RCS +X TIG – 15 sec to OMS IGN + 1 sec
:00 TIG; start watch (✓P_C, ΔVTOT, ENG VLVs)

OMS PRPLT FAIL:
HP < 85 (CONTINUE BURN):
Failed OMS ENG – OFF
✓XFEED (two) – CL
TK ISOL (two) – CL
He PRESS (two) – CL
HP > 85 (STOP BURN):
OMS ENG (two) – OFF
✓Failed OMS XFEED (two) – CL
TK ISOL (two) – CL
He PRESS (two) – CL
OMS ENG FAIL:
ASCENT or CRIT O/O (Continue Burn)
Failed ENG – OFF
OMS XFEED at → 1/2 ΔVTOT at FAIL
RCS COMPLETION: (Hp < 85 or CRIT O/O)
Interconnect to either OMS that was ENG FAIL
THC +X (Hp = 85)
Post burn, AFT RCS RECONFIG

CUTOFF
+:02 OMS ENG(s) – OFF (if < 3 IMU, at ☐:☐☐)
Trim Residuals:

OMS 2	TAIL ONLY CNTL	Orbit
VGO X < 0.2 fps VGO Y,Z < 2 fps	VGO X < +0.2 fps	All axes < 0.2 fps

ASC–6a/114/A,O/A

MS ONLY ASC/114/FIN

USA006500_061.cvx

Figure 3-1. OMS 2/Orbit OMS Burn card

3.2 ORBIT OMS BURNS

OMS burns will be required during orbit operations to raise and lower the orbital altitude as part of the rendezvous. The procedures for an OMS burn in OPS 2 are located in the ORBIT OPS Checklist. The ON-ORBIT OMS BURN procedure transitions to the OMS 2/ORBIT OMS BURN cue card 4 minutes prior to TIG. This is the same cue card used for the OMS 2 Burn (Figure 3-1). Three cues listed on this card are unique to OPS 2. The major mode setting, the configuration of the DAP panel on C3 and the orbit trim residuals. An orbit burn must be performed in MM 202 as shown at the top of the card. This major mode, MNVR EXEC contains all the appropriate software modules needed to execute a burn. Check that the translation mode of the DAP is in NORM. (If RCS completion is required, then the + X RCS jets need to be fired continuously versus the default OPS 2 pulse mode.) The warning box and the stop/continue cues still apply on orbit. Also note the tighter trim requirements of .2 fps in all axes once the cut-off and purge has occurred.

An Orbit MNVR EXEC is shown in Figure 3-2. The burn targets will be provided by MCC. All orbit burns are done using a PEG 7 target. PEG 4 is not available in OPS 2.

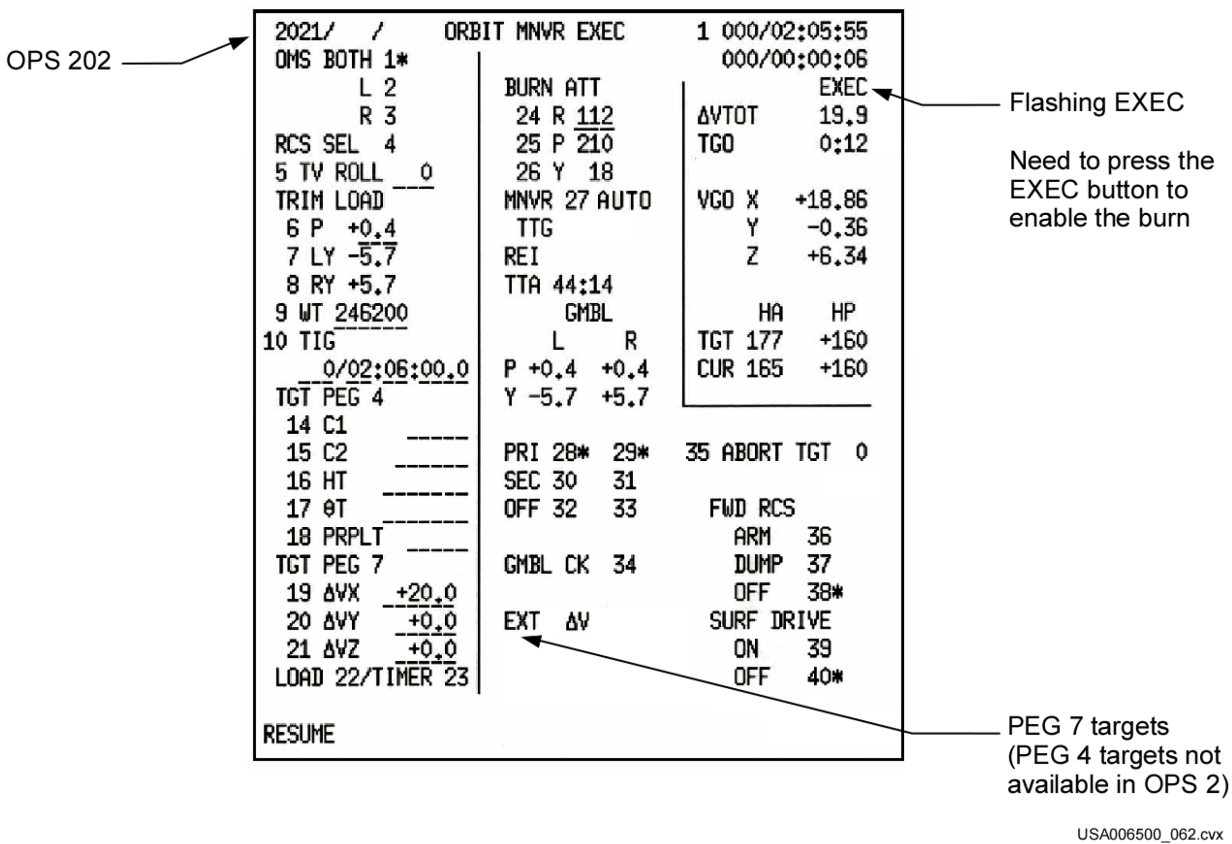


Figure 3-2. Orbit Maneuver EXEC display MM202

3.3 DEORBIT BURN

The final use of the OMS during a mission is to accomplish the deorbit burn. A retrograde burn is performed, decreasing orbital velocity and lowering the perigee altitude to nearly zero. A nominal end of mission deorbit burn to KSC will occur over the Indian Ocean and last about three minutes. The procedures for the deorbit burn are covered in the Deorbit Prep Checklist and the Entry Checklist. A special burn card is used based on the Deorbit options available. Figure 3-3 shows the nominal 2 engine deorbit burn card. The format is slightly different from the OMS 2/Orbit Burn card, but the same critical actions apply. The majority of the card is reserved for failures encountered during the burn. The stop or continue cues are once again based on current perigee. Safe Hp, (nominally 80 nm) is the point of no return. If a critical failure happens above this altitude the vehicle can remain on orbit for several revolutions. If current Hp is below 80 nm when the failure occurs, the burn is continued using RCS jets and propellant if required to achieve the final targets.

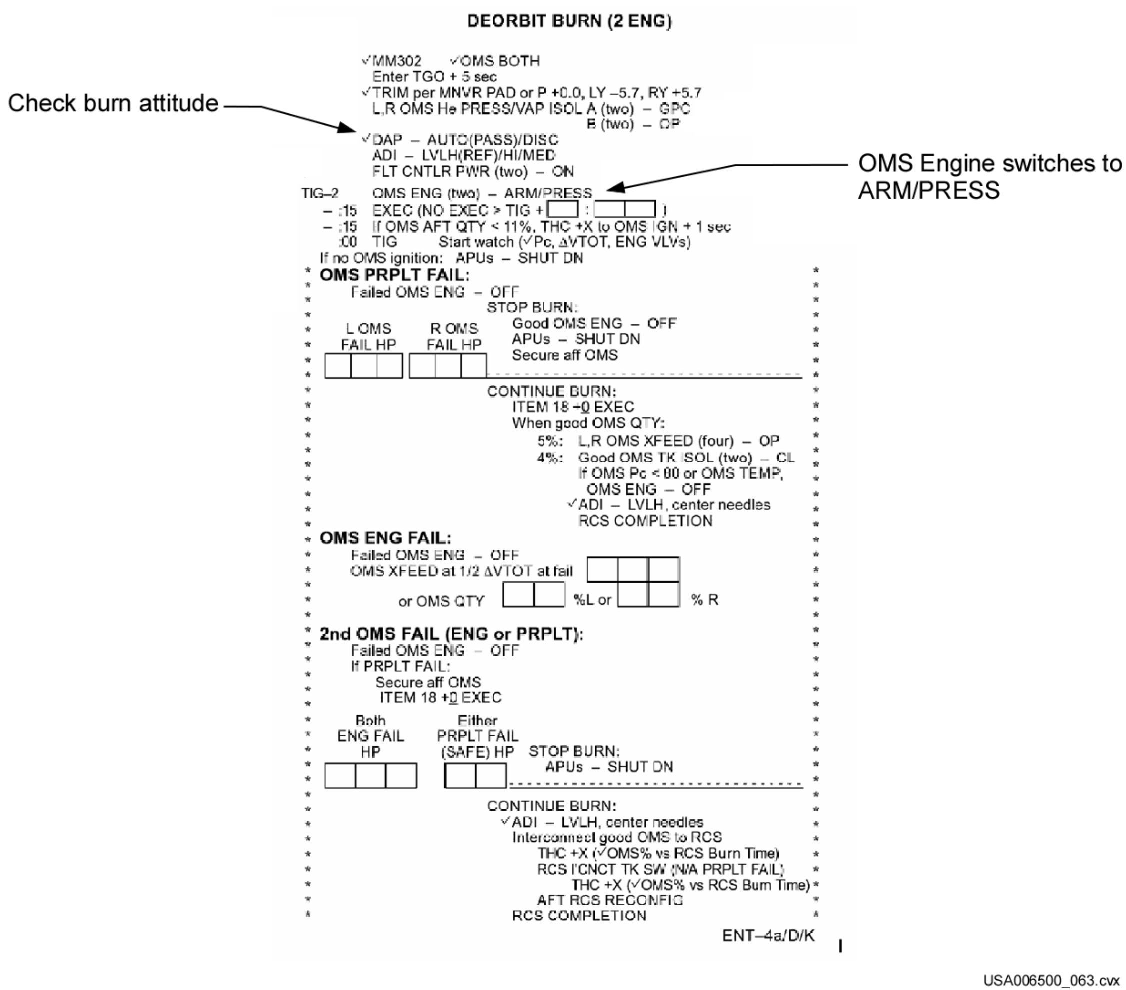


Figure 3-3. Deorbit Burn (2 ENG) card

* **RCS COMPLETION:**
THC +X to TGT HP or TOT AFT QTY 1 [ ] %

At AFT QTY 1 if CUR HP: THC +X to PREBANK/FLIP HP or TOT AFT QTY 2 [ ] % then PREBANK/FRCS COMPLETION

PREBANK/FLIP HP [ ] PREBANK/FRCS COMPLETION
AFT HP [ ] THC +X to TGT HP
TGT HP [ ]

* **FRCS COMPLETION** (if applicable):
MNVR to –X Att (pitch up at 3°/sec to VGOz = +1/4 ΔVTOT)
THC –X to TGT HP or FRCS depletion (JETS FAIL OFF)

Cut-off and nitrogen purge → CUTOFF
\+ :02 OMS ENG(s) – OFF (If < 3 IMU, at [ ] : [ ])
* AFT RCS RECONFIG if INTERCONNECT *
Trim X,Z residuals < 2 fps (< 0.5 fps if shallow)

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Figure 3-4. Deorbit Burn (2 ENG) card (cont.)

3.4 ORBIT OMS-TO-RCS INTERCONNECT OPERATIONS

The orbit interconnect is a manual procedure done to conserve RCS propellant for entry. Plans for an interconnect will vary from flight to flight and will depend on propellant loading and the in-flight assessment of propellant usage. The procedure for a Left OMS to RCS interconnect from the Orbit Pocket Checklist is shown below. (See Figure 3-5).

I'CNCT: L OMS to RCS GNC 23 RCS

NOTE
Gauging not avail in OPS 3

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

Figure 3-5. Interconnect L OMS to RCS

Free drift is selected on the DAP so that no jets will be commanded to fire. When the procedure is complete, the final talkback configuration should correspond to Figure 3-6. One can follow the propellant flow from the Left OMS to the Left and Right RCS manifolds through the OMS B crossfeed valves. The OMS A crossfeed valves are kept closed, because a single electrical bus failure could cause the loss of operation of the crossfeed valves and the OMS tank isolation valves, leaving no means of isolating the OMS from the RCS. This situation does not occur with the B crossfeed valves, because the arrangement of electrical busses is different.

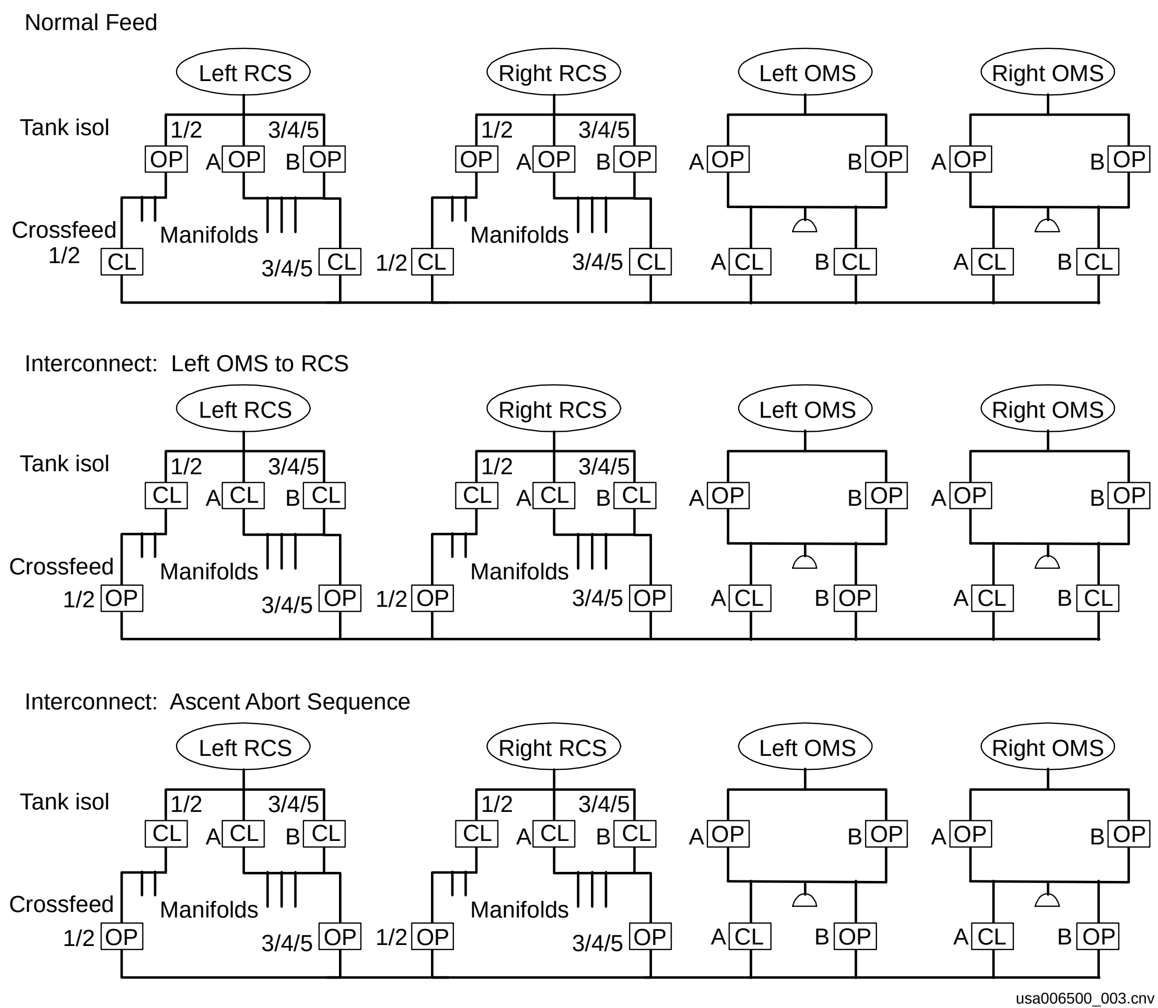
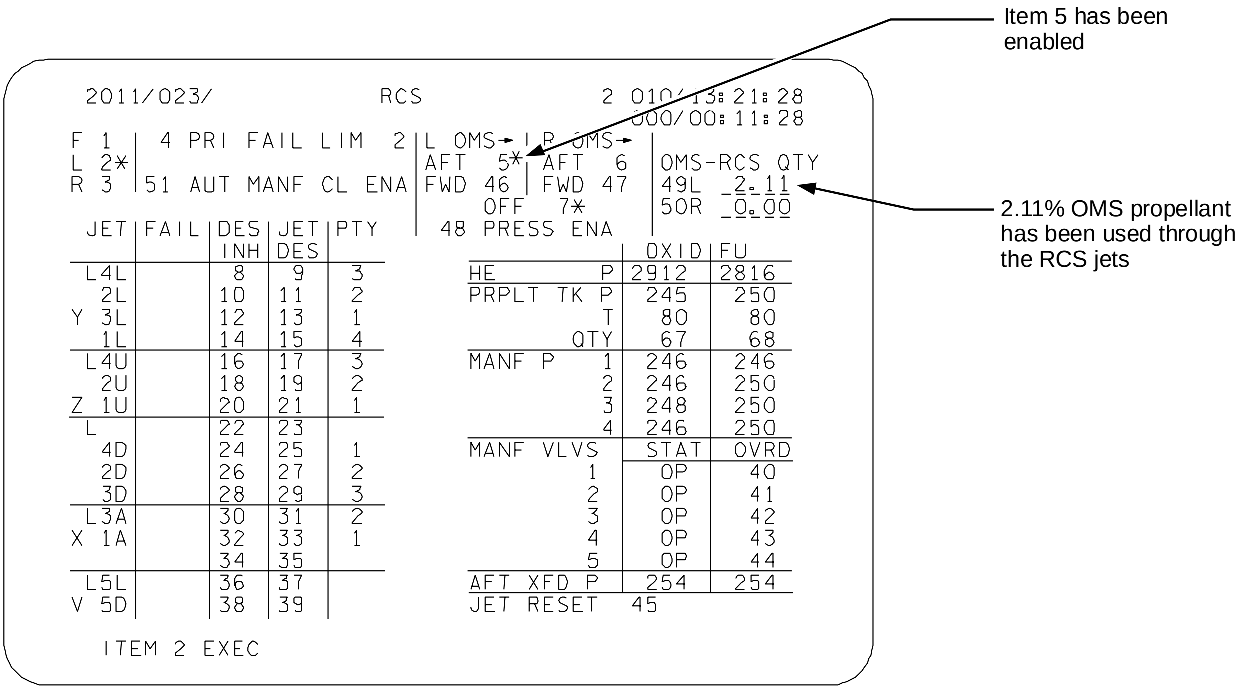


Figure 3-6. OMS/RCS crossfeed and interconnects



USA006500_066.cvx

Figure 3-7. SPEC 23 L POD L OMS interconnect

The OMS gauges will not track real time OMS propellant usage through RCS jets. The gauges will update once an OMS burn is started, but the quantity will remain static while the OMS Engine switches on Panel C3 are OFF. In order to keep account of OMS propellant burned through RCS jets, the L OMS to AFT function must be enabled. This gauging function will use a count of RCS jet firings to compute the amount of OMS propellant consumed. Figure 3-7 shows that 2.11% of OMS propellant has been burned through the RCS jets.

3.5 OMS ASSIST AND ABORT DUMPS

Nominal ascents and aborts have an automatic software sequence that will burn OMS propellant to reduce vehicle weight. This reduction in weight will increase performance pre-MECO. Since these burns are done during powered flight, the term “dump” is commonly used. We will discuss only two specific dump configurations: the OMS Assist and the RTLS abort dump.

OMS Assist

The OMS assist is a nominal OMS dump that will occur shortly after SRB separation. It is a straight feed 2 OMS engine burn. Specific mission requirements will determine the length. The duration is shown at the bottom of the OMS 1/2 TGTING card (see Figure 3-8).

Figure 3-8. Bottom of OMS 1/2 TGTING CARD

The monitoring procedure for the OMS assist is shown in the ASCENT PROCEDURES as check OMS assist (Figure 3-9). Three tasks are required by the crew in order to complete this check. First, check for nominal OMS engine chamber pressures on the MEDS OMS/MPS display. Second, call up BFS SYS SUMM 2 and take a look at the steady state oxidizer and fuel engine inlet pressures. These inlet pressures will be used to diagnose a potential blockage or failure during the OMS assist. Lastly, start a timer as a back up against potential OMS gauging failures. Once this initial check is complete the crew can return to nominal uphill monitoring tasks. The final and most often missed task is to stop the timer once the OMS assist is completed.

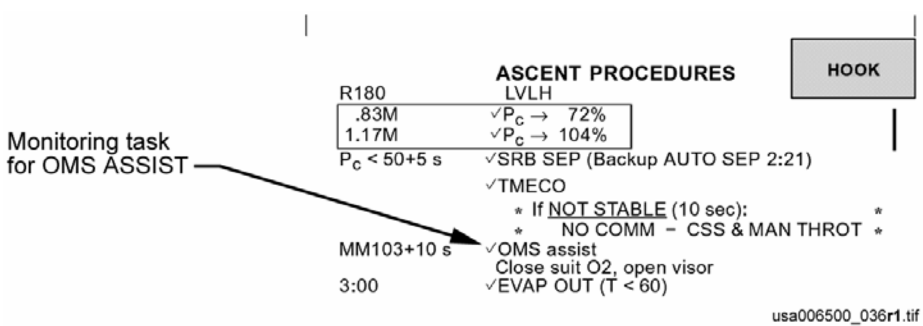


Figure 3-9. Ascent Procedures

RTLS Dump

The primary objective of the RTLS abort dump is to burn the OMS propellant to get the oxidizer and fuel tanks below the tank landing constraints. (TLC nominally < 22% OMS). This will also reduce the overall landing weight and bring the c.g. into the nominal envelope. In order to dump this large quantity of OMS propellant pre-MECO, the nominal RTLS dump configuration will use 2 OMS Engines +24 RCS jets. When the RTLS abort is executed, the valve re-configuration will happen automatically. Figure 3-6 shows the OMS and RCS talkbacks once the interconnect sequence is completed. With all six of the RCS tank isolations closed, one can see how the OMS propellant is fed to the RCS manifolds. A typical RTLS 2 OMS + 24 RCS jet dump will last around 200 seconds. The monitoring task is listed on the RTLS PLT procedures (see Figure 3-10). Only two steps are implied in this check. They are the standard OMS burn monitoring tasks - check for nominal OMS engine chamber pressures and note the steady state engine inlet pressures.

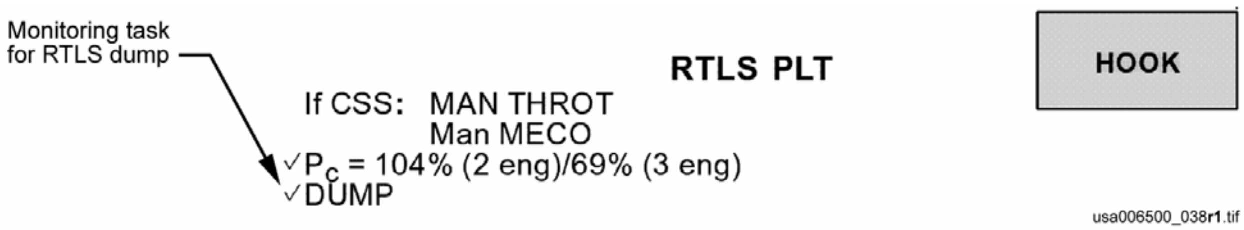


Figure 3-10. RTLS PLT procedure

3.6 OMS SWITCH CONFIGURATIONS

The configuration of OMS switches is presented for the three main phases of flight: ascent, orbit, and entry. Three specific OMS related panels that do not change during the mission will be discussed first.

Panel MA73C

The aft pod valve logic switches are always ON, and the aft pod valve circuit breakers are always pushed in. The switches provided main bus power to logic relays within the motor control assemblies, and the circuit breakers control the flow of ac power to the motors that open and close the valves. The OMS kit valve circuit breakers are left out, and the OMS kit valve logic switch is left off.

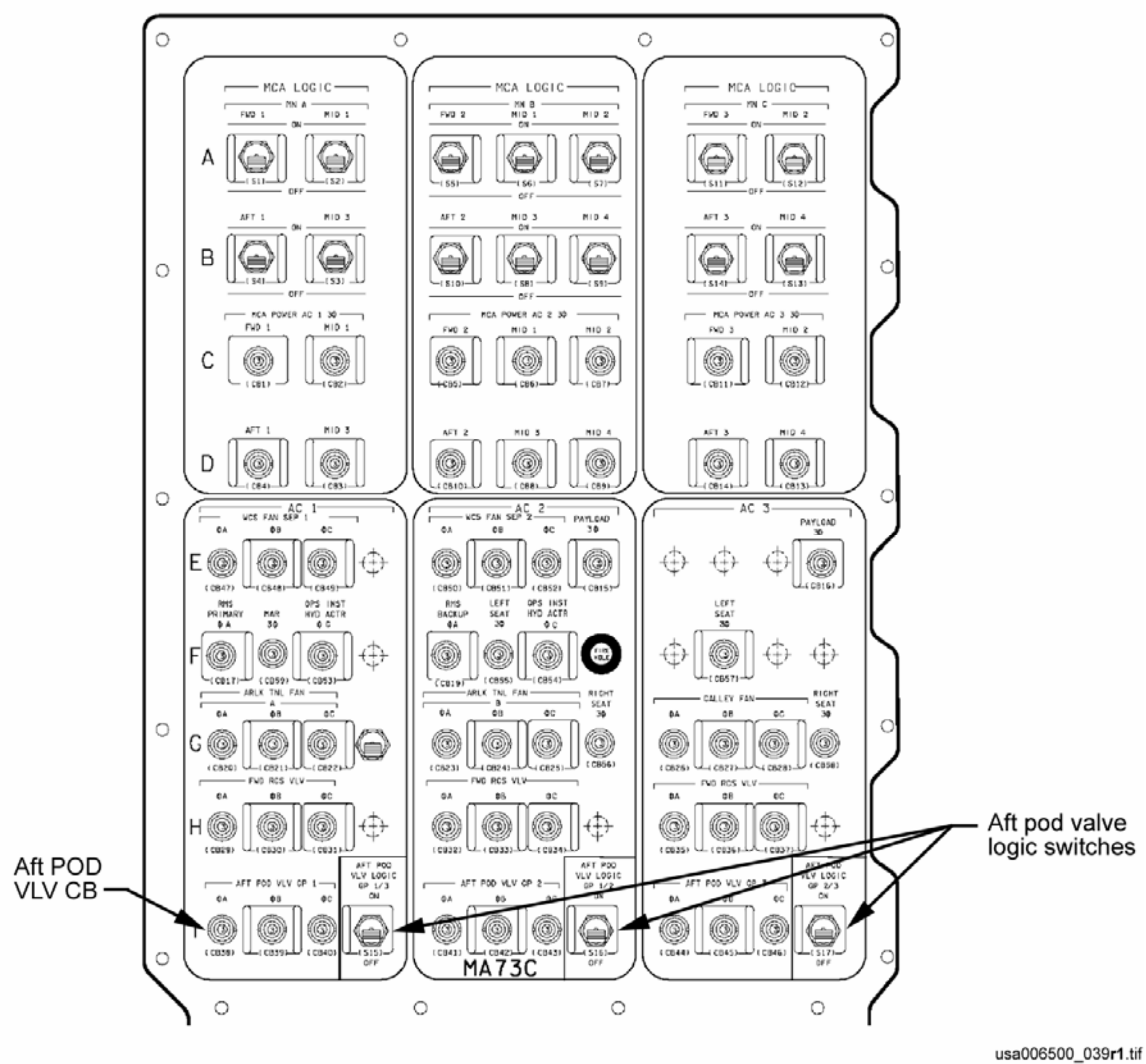


Figure 3-11. Panel MA73C

Panel O14

Only the bottom row (row F) of switches on this panel is shown. It contains the left OMS engine valve switch, which is always ON. This switch provides a power to the engine control valves for the left OMS engine and must be ON for the engine to fire.

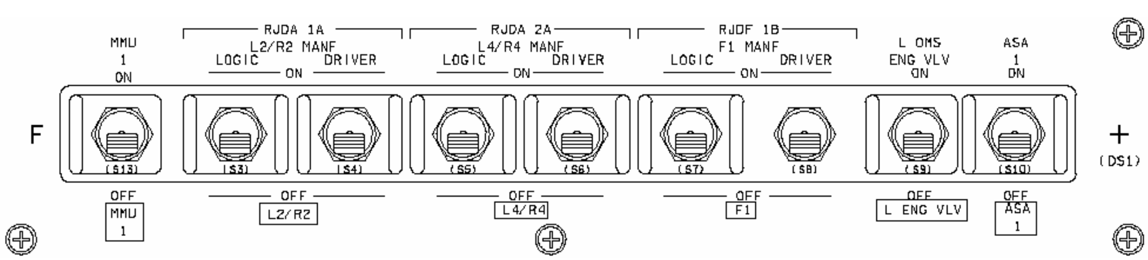


Figure 3-12. Panel O14

Panel O16

Only the bottom two rows (row E & F) are shown. The bottom row contains the right OMS engine valve switch and serves the same purpose for the right OMS engine as the Panel O14 switch does for the left engine. The switch is always ON. The row above is the RCS/OMS propellant quantity gauge circuit breaker. This circuit breaker controls the flow of electrical power to the OMS gauge equipment and is pushed in at all times.

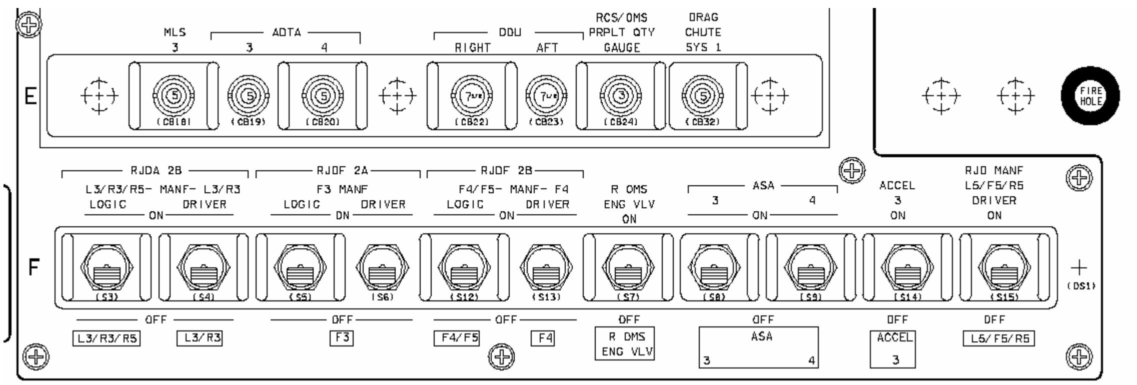


Figure 3-13. Panel O16

Configuration for Ascent

The OMS and RCS switches are configured for ascent to support an immediate OMS burn and an automatic OMS-to-RCS interconnect in case an abort dump is required. The need for switch changes during ascent is minimized because the crew reach and visibility envelope can be rather limited.

Panel O7

The four RCS helium press switches are OPEN with talkbacks showing OPEN. These valves are normally open whenever the RCS is needed, which includes the RCS maneuver ET separation, and for control during an RTLS or TAL.

The six RCS tank isolation valves are in the GPC position, and the talkbacks indicate that the valves are OPEN. As long as the switches are in the GPC position, they can be automatically configured for an abort dump

The ten RCS manifold isolation switches are in the GPC position with the talkbacks OPEN.

The four RCS crossfeed switches are in the GPC position so that the valves can be configured automatically for an abort dump. The talkbacks indicate that the valves are closed, which is their nominal position.

The RCS master crossfeed switch normally stays in the OFF position. This switch affects RCS valves only and is not nominally used in the ascent phase.

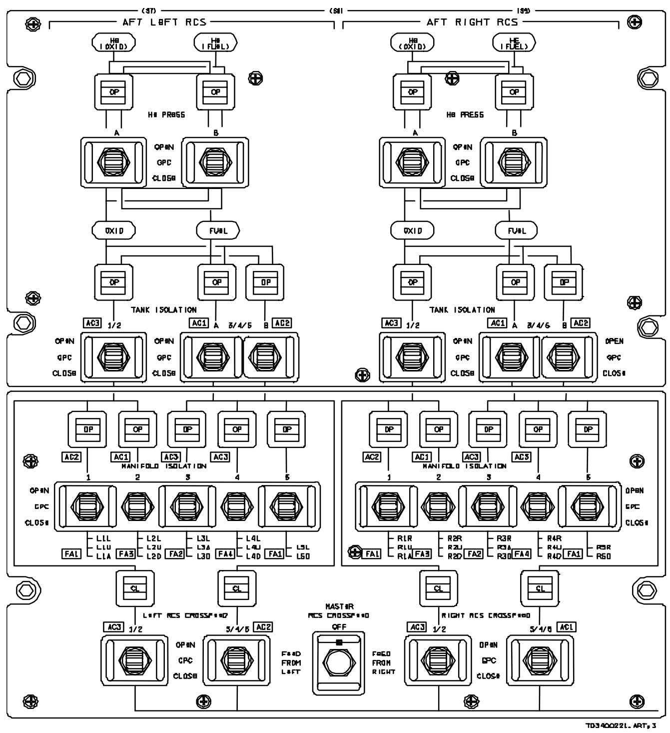


Figure 3-14. Panel O7-RCS switches

Panel O8

The OMS helium press/vapor isolation switches are in the GPC position so that the valves can automatically open at the start of the OMS ASSIST.

The OMS tank isolation switches are in the GPC position, with the talkbacks OPEN. These valves need to be open for OMS burns and abort dumps.

Both the OMS A and OMS B crossfeed switches are in the GPC position so that they can be opened automatically for an interconnect. The talkbacks should indicate that the valves are in the CLOSE position.

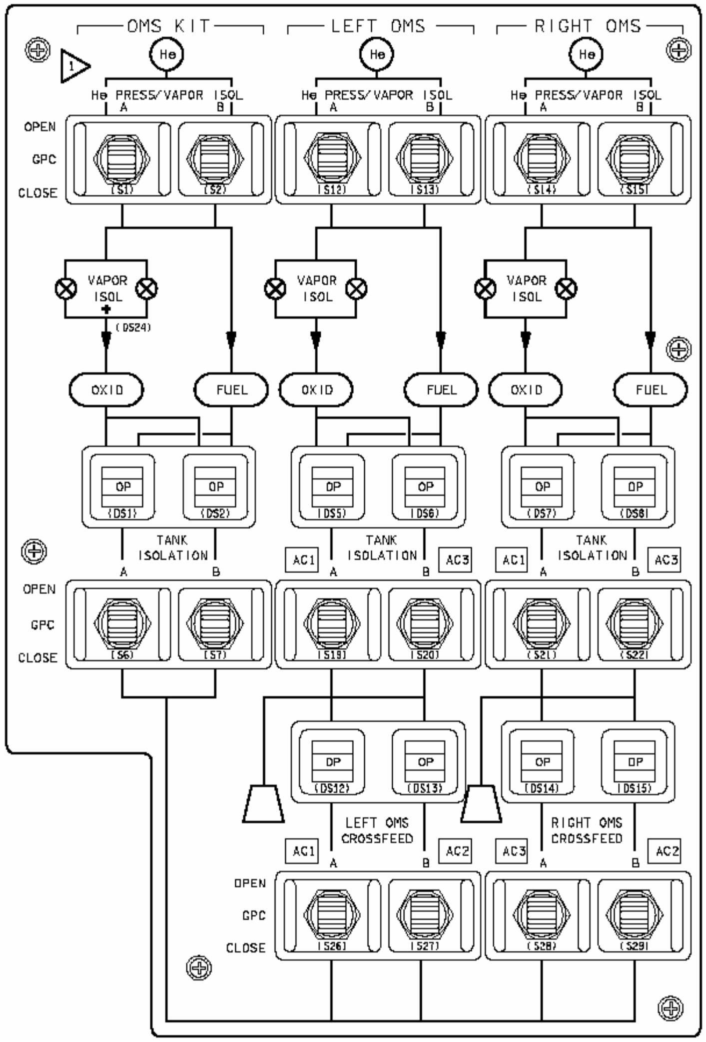


Figure 3-15. Panel O8 OMS switches

Panel C3

The OMS Engine switches are set to the ARM/PRESS position so that the engines are ready to fire for the OMS assist.

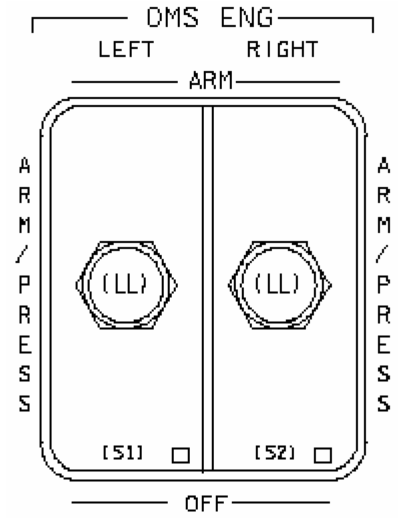


Figure 3-16. Panel C3 OMS ENG

Panel A14

The OMS left and right pod heaters are OFF for ascent, which conserves electrical power. In this time period, the temperature in the pod should not get very low. The OMS crossfeed lines run through the aft fuselage area where there are main propulsion system lines carrying cryogenic propellants; thus, the crossfeed lines might be subject to very low temperatures. For this reason, both the A and the B crossfeed line heater circuits are set to AUTO to provide redundant heating for these lines.

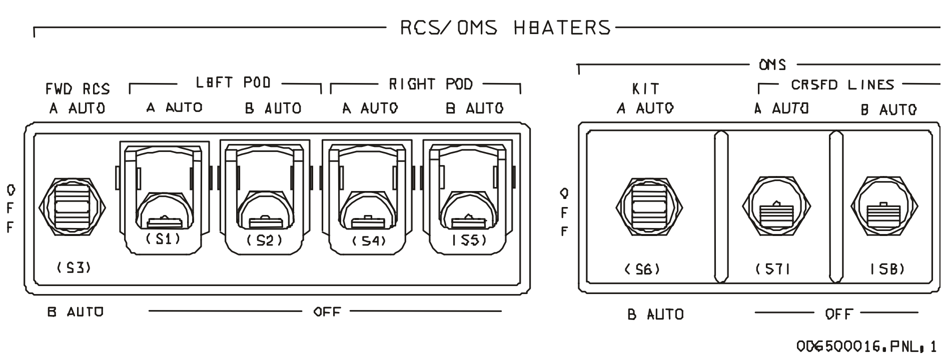


Figure 3-17. Panel A14

Configuration for Orbit

During normal orbit operations, the switch configuration is designed to provide for safe operation with a minimum amount of attention from the crew.

The rationale for the RCS switch settings will not be covered for the orbit phase, but is listed below in the Ascent Checklist post OMS 2 burn reconfiguration.

P **OMS/RCS POST BURN RECONFIG**

O7	AFT L,R RCS	
	He PRESS A (two)	– GPC (tb-OP)
	B (two)	– CL (tb-CL)
	TK ISOL (six)	– OP (tb-OP)
	√MANF ISOL 1,2,3,4 (eight)	– GPC (tb-OP)
	XFEED (four)	– CL (tb-CL)
O8	FWD RCS	
	He PRESS A	– GPC (tb-OP)
	B	– CL (tb-CL)
	TK ISOL (two)	– OP (tb-OP)
	√MANF ISOL 1,2,3,4 (four)	– GPC (tb-OP)
	L,R OMS	
	He PRESS/VAP ISOL (four)	– CL
	TK ISOL (four)	– OP (tb-OP)
	XFEED (four)	– CL (tb-CL)

POST OMS 2

5-2 ASC/114/FIN A

Figure 3-18. Ascent Checklist OMS/RCS Post Burn Reconfig

Panel O8

All four OMS helium press/vapor isolation switches are in the CLOSE position. This protects the helium tanks from any downstream leaks or regulator failures.

The OMS tank isolation valves are left in the OPEN position with the talkback OPEN. This is done so that if some failure occurs that prevents subsequent operation of these switches or valves, the valves will be open, which is preferable to having them stuck closed. With the tank isolations open, there are now two independent transducers (tank pressure and inlet pressure) that can be used to diagnose a potential problem.

The OMS crossfeed switches are in the CLOSE position with the talkback closed to ensure that the OMS and RCS remain isolated.

Panel C3

The OMS engine switches on Panel C3 remain in the OFF position during normal OPS 2 operations.

Panel A14

For normal OPS 2 operation the A circuit heater switches are set to AUTO, and the B circuit switches are OFF. This configuration permits thermostatic control of OMS pod temperatures. The procedure in the POST Insertion checklist (see Figure 3-19) will set the heaters on A14 for orbit operations.

AFT STATION CONFIG 3

	POST SEAT EGRESS	
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

Figure 3-19. Post Insertion Checklist Heater Reconfig

Configuration for Entry

Following the Deorbit burn the OMS and RCS switches are configured for entry. The procedure from the Entry Checklist is shown below.

OMS/RCS POST BURN RECONFIG

```
P   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
```

POST BURN

3-32 ENT/ALL/GEN G

Figure 3-20. Entry Checklist OMS/RCS Post Burn Reconfig

Panel O8

The OMS switches on Panel O8 are in the same positions as for the orbit phase. The pattern one can remember when looking up at Panel O8 is closed, open, closed (OMS He Press/Vapor Isolations, Tank Isolation valves, and Crossfeed valves). Again, with the tank isolation valves open, we now have transducer redundancy for the propellant tanks.

Panel C3

The OMS engine switches are taken to the OFF position after the deorbit burn and will remain there until post-landing.

3.7 CONSTRAINTS AND LIMITATIONS

The following is a list of the constraints and limitations for the OMS that are relevant to crew operations.

The minimum altitude for an OMS engine burn is 70,000 feet. Below this altitude, the pressure difference between the inside and the outside of the OMS engine nozzle could cause it to collapse.

An OMS engine should not be started again once it has burned to propellant depletion. Engine damage can result when burning an OMS engine to depletion.

For the purpose of ascent abort dumps, one OMS tank set can support the simultaneous burning of one OMS engine and 14 RCS jets, but it cannot support one OMS engine and 24 RCS jets. One OMS tank set can support the firing of 24 RCS jets if no OMS engines are burning.

The minimum nitrogen pressure required for starting an OMS engine is 299 psi for normal operation. With low nitrogen pressure, the engine control valve operations will be slower, and an abnormal start could result. For contingency operations, an N_2 tank pressure of 254 psi or an N_2 regulator pressure of 288 psi is the minimum acceptable pressure for an engine start.

In normal operations, two OMS tanks should never be connected through the crossfeed lines, and an OMS tank should not be connected to an RCS tank. This is because different tanks might be at different pressures, and connecting them together could result in forcing helium into the propellant lines. When crossfeeding to an OMS engine, only one OMS pod should feed at a time; and, when interconnected to the RCS system, the RCS tank isolation valves should be closed before the crossfeed valves are opened.

For an OMS burn with less than 11% propellant remaining; an RCS settling burn should be done to aid OMS propellant acquisition.

The OMS quantity should be less than 22 percent to remain within the structural limit for landing weight.

No OMS burns should be performed during remote manipulator system (RMS) activity because there is a danger of putting excessive torque on the arm or forcing contact between the orbiter and a payload.

QUESTIONS

Use the example Maneuver display Figure 3-21 to answer questions 1-5.

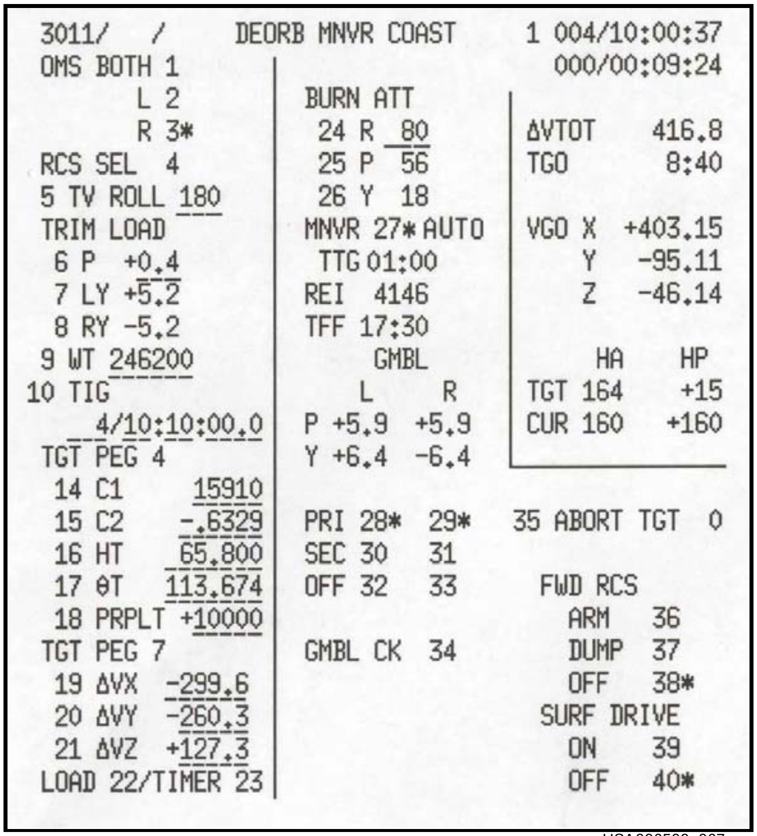


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Figure 3-21. Example DEORB MNVR COAST display

1. Which OMS engine will be used for the deorbit burn?

2. Will the right engine pitch actuator be driven by the primary or secondary motor?

3. At what MET will the OMS burn start and end?

4. What is the current perigee altitude, and by how much will it be changed by the deorbit burn?

5. Is this display indicating the correct configuration for starting a deorbit burn?

6. Why is it preferable to be in free drift when setting up an OMS-to-RCS interconnect?

7. What is the approximate range (in percent) of the ungaugable region?

4.0 SYSTEM MALFUNCTIONS

A few select system malfunctions will be discussed in this section. Selected displays and the corresponding procedures have been chosen to reinforce the concept of the system failure. The purpose is not to provide a step-by-step rational, but to develop a general understanding of the overall objective of the procedure. The following system failures will be covered:

4.1 Caution and Warning

4.2 Leak Categories

4.3 Transducer Failure

4.4 Helium Regulator Failures

4.5 Propellant Leaks and Helium Leaks

4.6 Nitrogen Leaks

4.7 Gimbal Failures

4.8 PASS OMS Engine FDI

4.9 OMS Engine Fail and Propellant Fail

4.10 Thermal

4.11 Electrical

4.1 SUMMARY OF THE OMS CAUTION AND WARNING SYSTEM

When there is a problem in the OMS system, as with other systems, the crew receives a caution and warning (C/W) alert (see Table 4-1). There are class 2 and class 3 alerts for the OMS system. Class 2 alerts can occur in all OPS and generate a master alarm light and tone and a light on the C/W matrix on Panel F7. A class 3 alert is generated by the primary GNC or SM software in OPS 2 and 8 or by the BFS software in other OPS. Class 3 alerts include an SM alert light and tone and a fault message.

The C/W matrix has four OMS lights: LEFT OMS, RIGHT OMS, OMS KIT, and OMS TVC. Each of these lights responds to one or more C/W input channels. A parameter out of limits causes the C/W light to be illuminated. The following table lists the C/W lights, the channel parameters, and the conditions that cause alerts.

Table 4-1. OMS C/W

C/W matrix light	Channels	Conditions
LEFT OMS	Left OMS oxidizer tank pressure	If pressure less than 232 or greater than 284 psi
	Left OMS fuel tank pressure	If pressure less than 232 or greater than 288 psi
	Left OMS engine	If P_c less than 80% when burning an OMS engine OR if P_c greater than 80% prior to OMS ignition
RIGHT OMS	Right OMS oxidizer tank pressure	If pressure less than 232 or greater than 284 psi
	Right OMS fuel tank pressure	If pressure less than 232 or greater than 288 psi
	Right OMS engine	If P_c less than 80% when burning an OMS engine OR if P_c greater than 80% prior to OMS ignition
OMS TVC	OMS thrust vector control system	If L/R OMS Gimbal failure

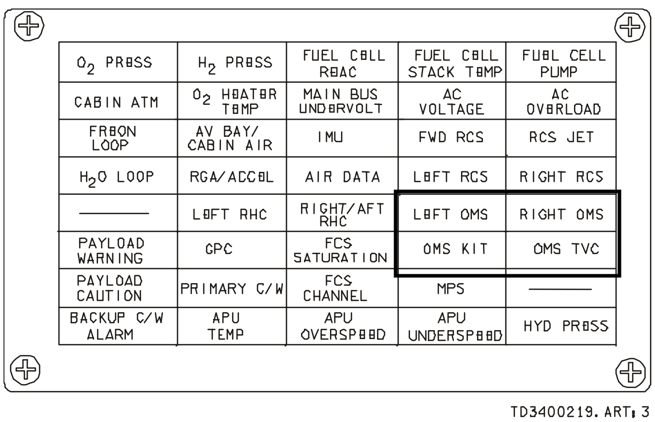

Figure 4-1. C&W Matrix Forward panel

The following table lists all the fault messages that can occur for the left or right OMS and the PASS or BFS OPS in which these messages can occur.

Table 4-2. OMS GNC fault messages

GNC fault messages	OPS		CAUSE
	Primary	BFS	
L(R) OMS GMBL	1,2,3	1,3	2º delta between OMS gimbal command and position actuator feedback for a period longer than 3.8 seconds
L(R) OMS PC	1,2,3,6	1,3,6	OMS engine P_c less than 80 percent when burning an OMS engine or if P_c greater than 80% prior to OMS ignition
L(R) OMS QTY	1,2,3,6,8	–	OMS propellant tank quantity less than 5 percent
L(R) OMS TK P	2,8	1,3	OMS oxidizer or fuel tank pressures below 234 or above 284 psi (288 psi for BFS)
	2,8	1,3,6	OMS helium tank pressure below 1500 psi, or OMS N_2 tank pressure below 1200 psi, or OMS N_2 regulator pressure above 434 or below 299 psi
L(R) OMS VLV	2	–	OMS helium press/vapor isolation valves not open during an OMS burn
L(R) OMS TEMP	1,3		OMS engine fuel injector temperature above 260º F
G23 OMS RCS QTY	2		More than 77 percent (10000 lbs) of left or right OMS propellant used during an OMS interconnect

Table 4-3. OMS SM fault messages

SM fault messages	OPS		CAUSE
	Primary	BFS	
S89 PRPLT THERM OMS	2	–	Temperature high or low at one of 11 temperature data points in the OMS pods Temperature limits vary for different points but are approximately 50º F for the low limit and 100º F for the high limit
S89 PRPLT THERM POD	2		Same as above for 32 different data points
SM0 THRM PRPLT	–	0,1,3	Same as above for 20 selected data points
S89 L (R) OMS TEMP	2	–	OMS engine fuel injector temperature above 260º F or below 36º F

4.2 LEAKS AND OTHER PROPELLANT SYSTEM FAILURES

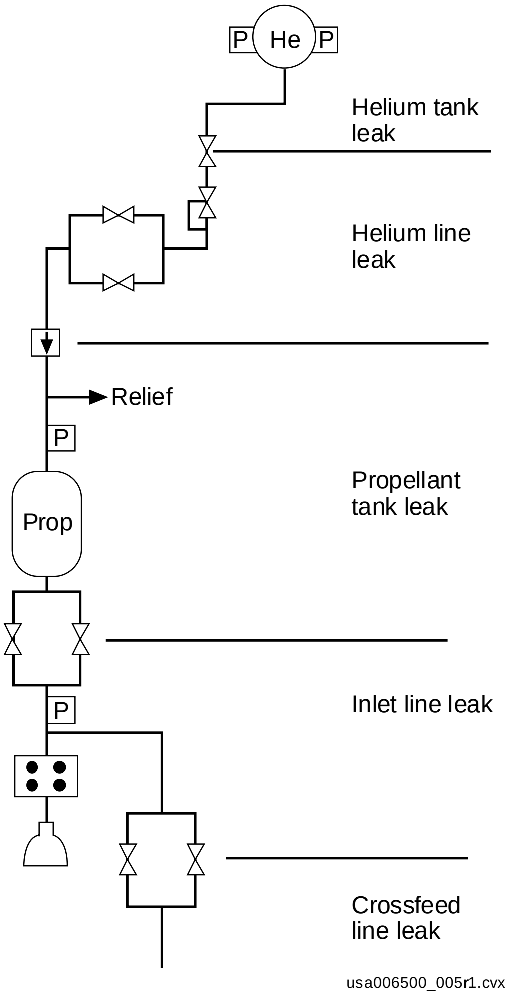

Figure 4-2. OMS leak schematic

Leak Isolation

Leaks in the propellant system could occur anywhere in the various tanks and lines (see Figure 4-2). For the purpose of crew procedures, however, all of the leaks can be put into a few categories.

1. Helium tank leak, including the line between the tank and helium press/vapor isolation valves

2. Helium line leak between helium press/vapor isolation valves and the check valves

3. Propellant tank leak (fuel or oxidizer), including the lines between the check valves and the tank isolation valves

4. Propellant line leak between the tank isolation valves and the propellant valve assembly

5. Crossfeed line leak

4.3 OMS TRANSDUCER FAILURES

When caution and warning annunciates an OMS TANK P message three initial critical tasks must be performed. Identify which system is affected, locate the appropriate procedure and cross check the initial indication. All this must be done in a timely manner. Figure 4-3 shows the indication of a Right OMS fuel tank pressure that is biased low. The caution and warning light along with the message points to the appropriate side, but one must determine which system has the problem (oxidizer, fuel, helium or nitrogen) and how that system has been affected (pressure high or low). This is done only by matching the up or down arrow on the GNC SYS SUMM 2. Figure 4-3 shows a down arrow displayed next to the right OMS fuel tank pressure of 199.

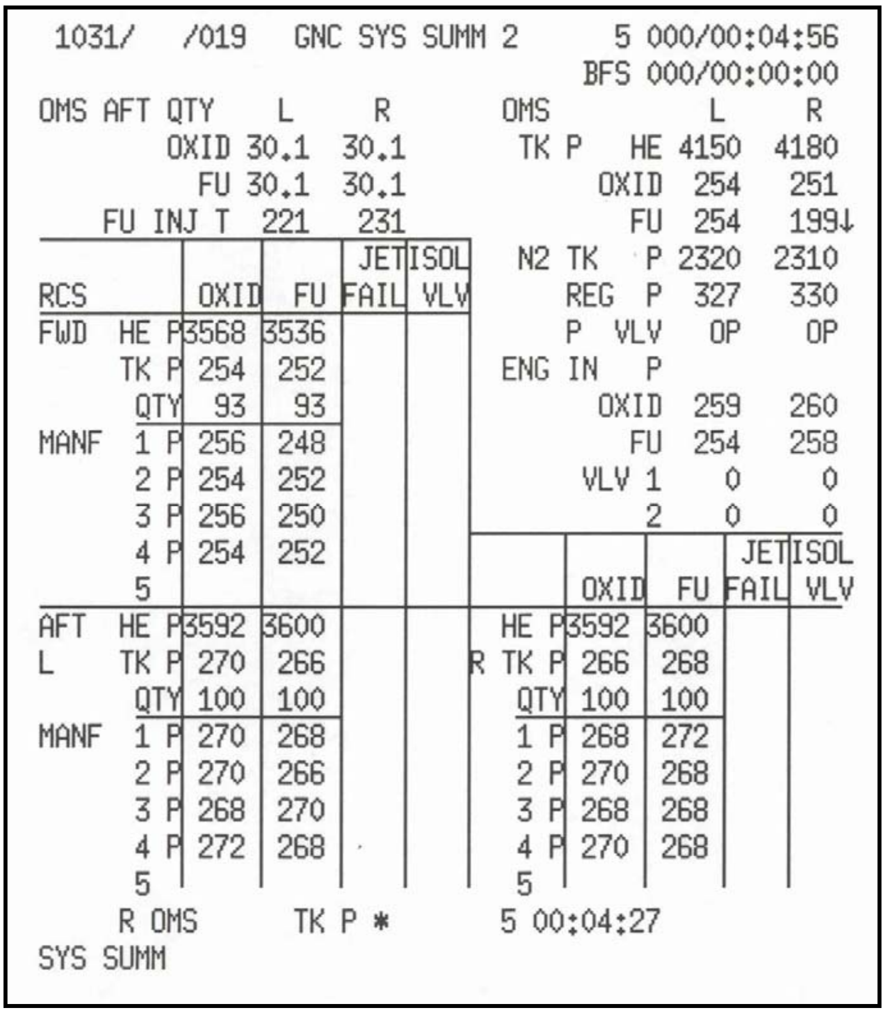

Figure 4-3. GNC SYS SUMM 2 R OMS Fuel Tank P bias low

Next, one must locate the appropriate procedure. One can see that the shuttle is in second stage, MM 103 (MET 4:56) and the OMS Engines are not burning (Ball Valves closed 0%). Compiling all this information is not easy, because the interpretation of the problem is not obvious and the title on the procedure can be cumbersome. Once the proper procedure is located, in our case, OMS TANK P LOW (OX or Fuel) NOT DUMPING, the crosscheck must be performed prior to taking any action (Figure 4-4). Do not omit this step. For our example the engine inlet P is the redundant transducer and one can see that is does not agree with the right fuel tank pressure, therefore the procedure is not entered because there is no confirming cue. Therefore, the R OMS fuel tank transducer has failed, no action.

OMS TK P LOW (↓, OX or FU) NOT DUMPING (√ENG IN P)

Figure 4-4. OMS TK P LOW AESP

Working the incorrect procedure can have bad consequences, therefore patience; good operational knowledge and situational awareness are required. This systematic approach, to identify, find the procedure and cross check, prior to throwing a single switch is good methodology, and can be applied to working any procedure.

4.4 HELIUM REGULATOR FAILURES

As stated earlier the OMS Helium system is used to pressurize both the oxidizer and fuel tanks. The parallel A and B paths both have dual regulators in series (Figure 4-5). If a set of these two regulators fail open, the helium will over press both the oxidizer and fuel tanks. Figure 4-6 is an example of the right OMS He A leg regs failed open. The oxidizer and fuel on the right OMS are at 299 and 297 psi respectively. One can see that the left and right engines are burning in OPS 302. This failure has happened during the deorbit burn and the procedure would be found on the D/O Burn Monitor card (Figure 4-7). The cross check prior to taking any action would be to see if the corresponding engine inlet pressure is also high. Both oxidizer inlet pressure (238) and fuel inlet pressure (265) confirm that the A or B set of regulators has failed open. The procedure directs you to close both the A & B He/Press vapor isolation valves in order to maintain tank pressures between 234 and 284 psi. With both of these valves closed, the pressure in the tanks will return to nominal. If the failure can be isolated to the A or B leg then the failed open leg is closed and the healthy leg is opened, thus regulating the flow of helium. At this point the procedure is complete and the crew can return to the normal deorbit burn monitoring.

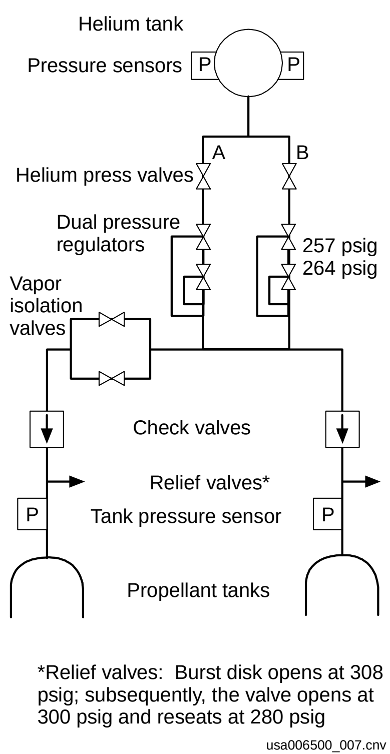

Figure 4-5. OMS HE System

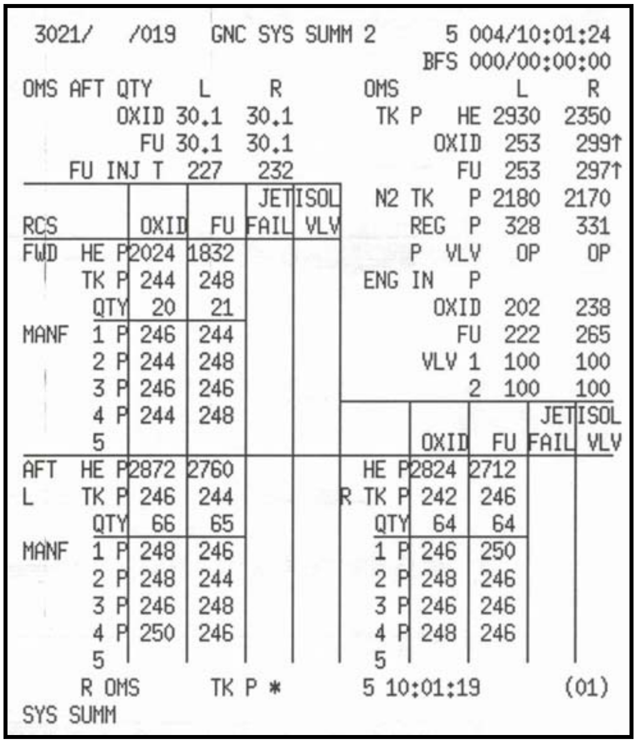

Figure 4-6. GNC SYS Summ 2

OX & FU HIGH	He PRESS/VAP ISOL (two) – CL Cycle He A(B) to maintain TK P 234-284

Figure 4-7. DEORBIT Burn Monitor card

4.5 OMS PROPELLANT LEAKS & HELIUM LEAKS

In this section we will discuss OMS Propellant and Helium leaks on orbit. The signatures and procedures will be discussed briefly. Both procedures will end up using the same burn card in OPS 2. The objective of the propellant leak is to burn the propellant rather than have it leak into the OMS pod, while the objective of the helium leak is to maximize the existing delta velocity capability.

Propellant Leaks

The signature for a propellant leak on orbit is shown in Figure 4-8. The corresponding procedure in the Orbit Pocket is shown in Figure 4-9. One can see that the redundant transducer check confirms that there is a leak on the Right OMS oxidizer. The procedure mentioned in step 30 will take care of targeting and set up a propellant path to the engine. MCC will provide out of plane or retrograde targets. The retrograde burn lowers the perigee altitude and reduces the ΔV requirement for the subsequent deorbit burn.

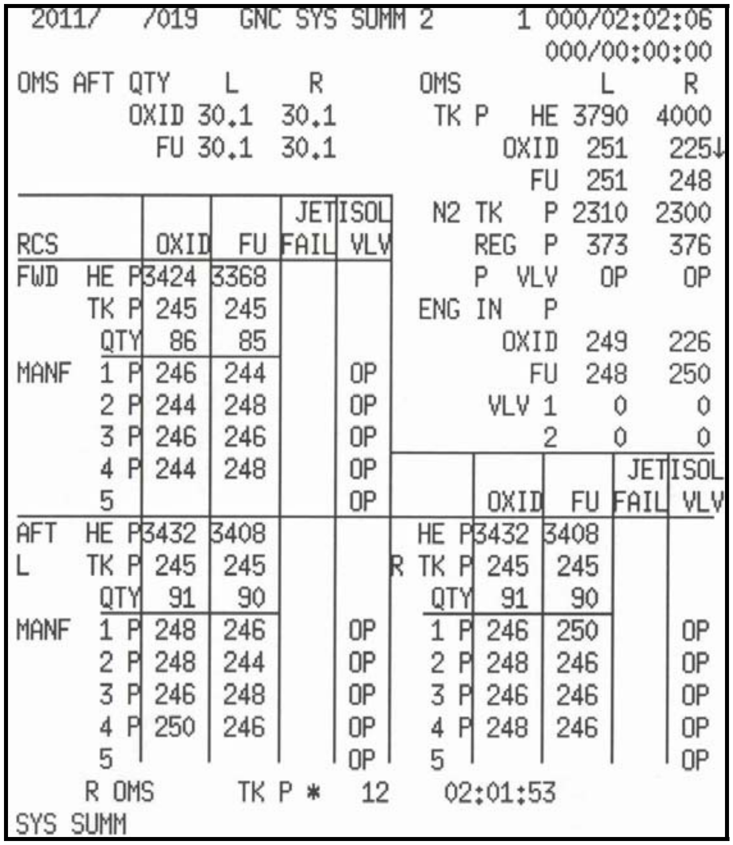

Figure 4-8. OPS 2 Right OMS Oxidizer tank leak

OMS TK P (FU or OX) LOW GNC SYS SUMM 2

1. Check with corresp ENG IN P

If ENG IN P disagrees:

2. Go to MAL, OMS, 11.1a, L(R) OMS TK P 29 >>

If aff OMS not feeding OMS/RCS I'CNCT:

29. Perform OMS SECURE, then:
30. If OMS PRPLT TK P decr:
    Go to LEAKING OMS PRPLT/He BURN >>
31. If either OMS IN P decr >>

If leak not found:

32. Go to MAL, OMS, 11.1a, L(R) OMS TK P 47

Figure 4-9. Orbit Pocket Checklist OMS TK P Low Procedures

The burn card will provide the start and shutdown cues required to deplete the leaking propellant tank (see Figure 4-10). A settling burn using the aft RCS jets is required 15 seconds prior to TIG. This will push the remaining OMS propellant to the back of the tank, in an effort to avoid helium ingestion. The shutdown cues are Pc< 80% or an Hp of 95. If a retrograde burn was performed and Pc did not drop below 80%, then one needs to retarget out-of-plane and burn to depletion. This is a time critical procedure as noted with the quick TIG, MET +10 minutes. It is important to note, one does not want to burn below current Hp of 95. The subsequent Deorbit burn will be performed on the remaining single engine.

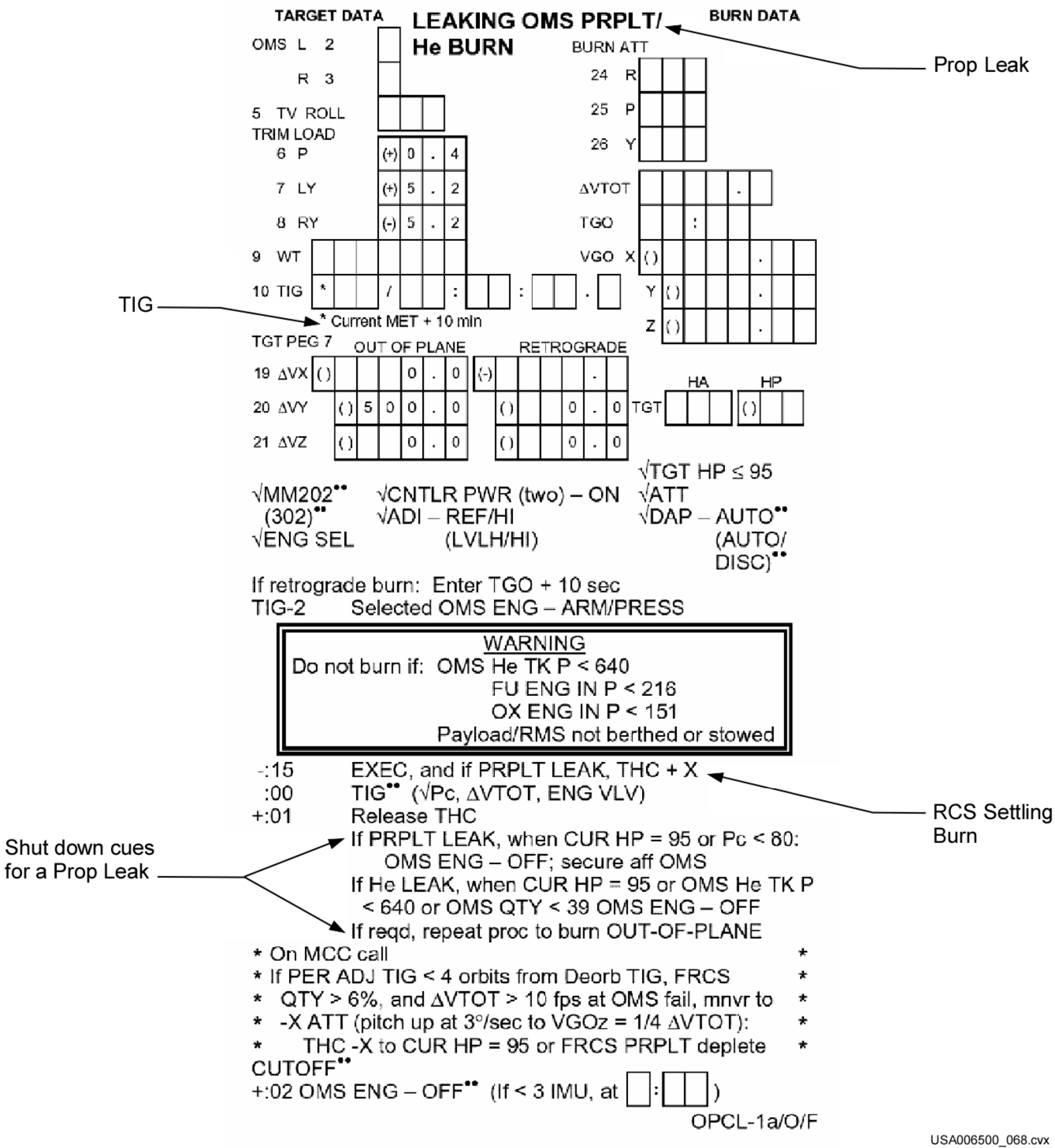

Figure 4-10. OMS Leaking PROP burn card

He LEAK

When an OMS helium tank fails, the OMS pod can still be used, but the only pressurization available is the initial pressure in the propellant tanks (ullage pressure), which drops gradually while a burn progresses. When an OMS system has only the ullage pressure in the tank it is considered to be in blowdown. The amount of ΔV capability for an OMS tank in blowdown depends on how much propellant is in the tank and how much helium is in the tank (see Figure 4-11). If the tank contains a large amount of propellant, it will have room for only a small amount of helium; consequently, the pressure in the tank will drop quickly during a burn and only a small amount of the propellant can be used. If the tank contains a small amount of propellant, there is room for a large amount of helium. In this case there will be sufficient helium pressure to support a long burn, but the propellant will be depleted quickly.

There is an optimum balance between propellant and helium in the tank that results in the maximum ΔV capability for a blowdown burn. This is called the “max blowdown” quantity and occurs at a propellant quantity level of approximately 39 percent.

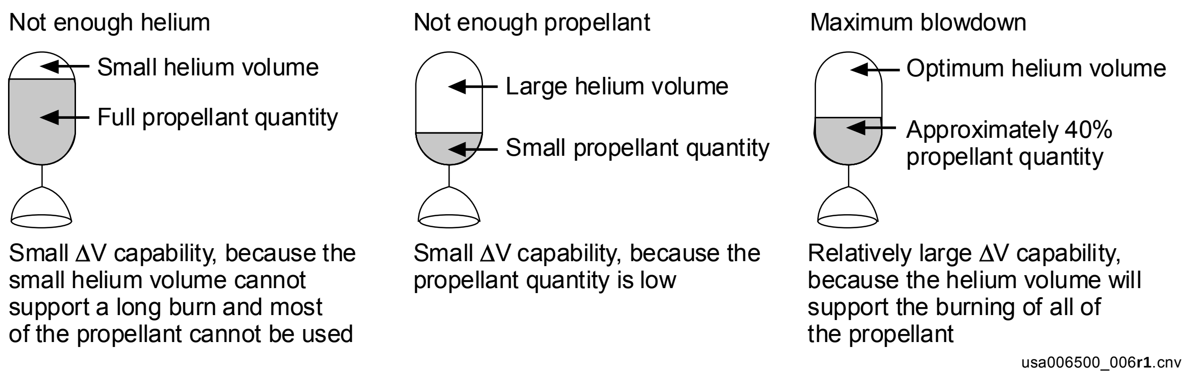

Figure 4-11. OMS blowdown burn situations

```
 2011/   /019   GNC SYS SUMM 2      1 000/02:04:01
                                      000/00:00:00
OMS AFT QTY    L     R       OMS           L     R
        OXID 30.1  30.1       TK P   HE 1370↓ 4000
          FU 30.1  30.1             OXID  251   250
                                      FU  251   248
                          JET ISOL   N2 TK    P 2310  2300
RCS        OXID   FU FAIL  VLV        REG  P  373   376
FWD  HE P 3424  3368                    P  VLV   OP    OP
     TK P  245   245             ENG IN    P
      QTY   86    85                    OXID  249   250
MANF  1 P  246   244        OP            FU  248   250
      2 P  244   248        OP          VLV 1    0     0
      3 P  246   246        OP              2    0     0
      4 P  244   248        OP                        JET ISOL
      5                     OP           OXID   FU FAIL  VLV
AFT  HE P 3432  3408             HE P 3432  3408
L    TK P  245   245           R TK P  245   245
      QTY   91    90              QTY   91    90
MANF  1 P  248   246        OP     1 P  246   250        OP
      2 P  248   244        OP     2 P  248   246        OP
      3 P  246   248        OP     3 P  246   246        OP
      4 P  250   246        OP     4 P  248   246        OP
      5                     OP     5                     OP
    L OMS       TK P     12    02:03:56
SYS SUMM
```

Figure 4-12. Left OMS He tank leak OPS 2

Figures 4-12 to 4-14 display the signatures and procedures required to complete an on-orbit OMS burn to max blowdown. Again, the objective is to get this leaking tank in the best possible state (39%), before the helium tank is considered failed at a pressure of 640 psi. Note that this is also a shutdown requirement on the LEAKING OMS PRPLT/He Burn card (see Figure 4-14).

OMS He TK P LOW | GNC SYS SUMM 2 |

1. √He TK P < 1500 or decr abnormal (| OMS/MPS | and SPEC)

If | OMS/MPS | and SPEC disagree (inst prob):

2. Go to MAL, OMS, 11.1a, L(R) OMS TK P | 63 | >>

3. √OMS He PRESS/VAP ISOL (two) – CL

If He TK P still decr:

4. (Aff) OMS He PRESS/VAP ISOL (two) – OP
5. If not at max blowdown (QTY > 39%):
   Go to LEAKING OMS PRPLT/He BURN >>
6. If I’cnct: Perform I’CNCT RETURN (RCS)(8-4), then:

If OMS TK P FU/OX decr:

7. Go to OMS TK P (FU or OX) LOW >>

If neither decr (He leg leak):

8. √MCC for OMS Burn deltas

Figure 4-13. OMS He Tank P Low Procedures

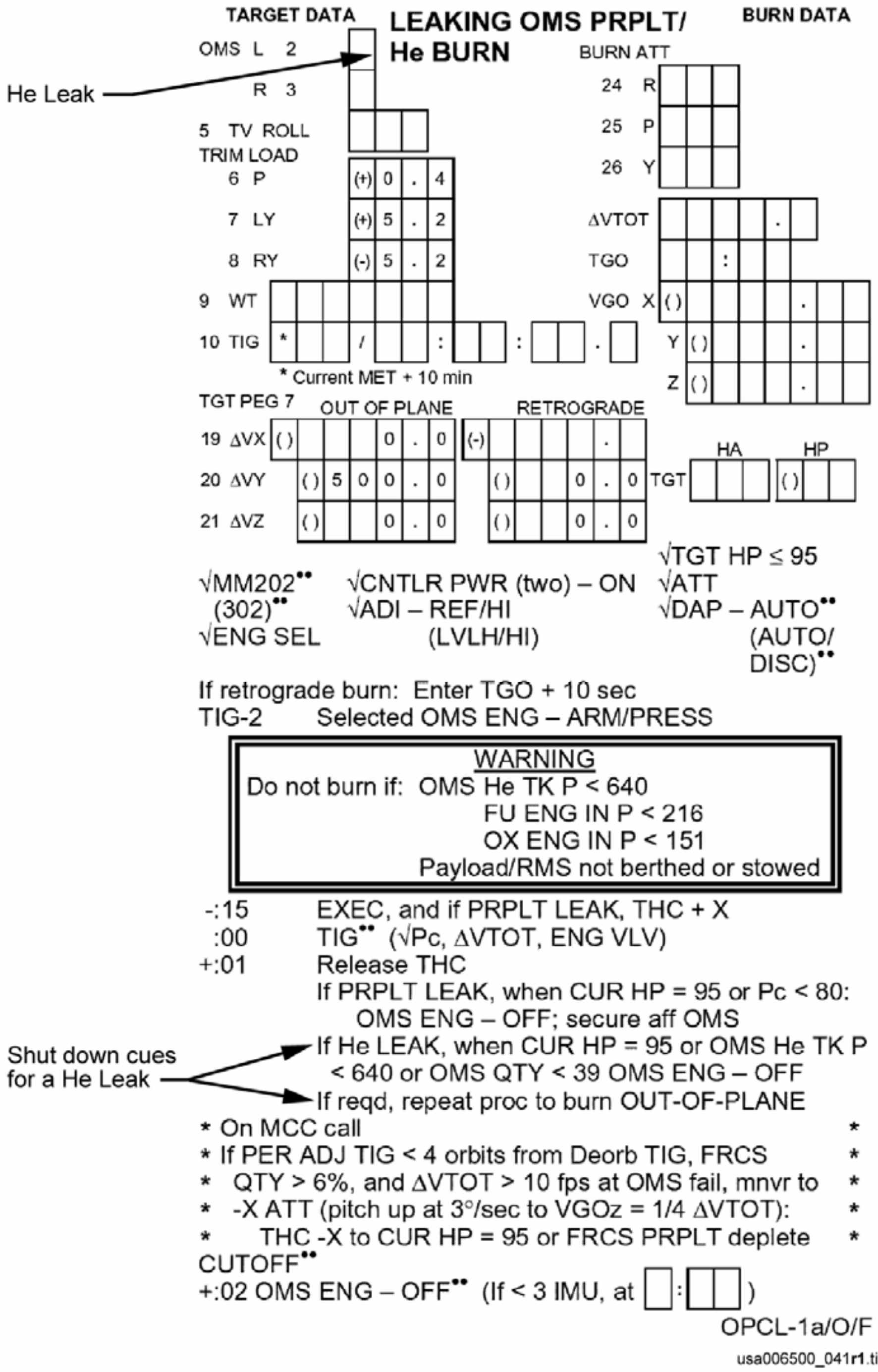

Figure 4-14. Leaking OMS HE Burn Card

4.6 NITROGEN SYSTEM FAILURES

We will discuss only two specific nitrogen system failures. The N_2 failure procedures are designed to preserve the engine start capability by maintaining regulator pressure and to sacrifice the engine purge function when necessary since it is not critical. Remember that taking the OMS engine switch to ARM or OFF closes the N_2 press valve and isolates the N_2 tank.

N_2 System Leak

The GNC SYS SUMM 2 display below (Figure 4-15) is an example of a Left OMS N_2 system leak during an OMS-2 burn. The associated procedure is on the OMS-2 Burn Monitor card. Again, the cross-check is on the procedure (Figure 4-16). Assume the N_2 tank pressure on OMS/MPS MEDS display is reading 1140 and dropping. This confirms that the N_2 system does have a leak. When the OMS engine switch is in Arm/Press, we essentially have an open system. The high pressure tank and accumulator, separated only by the regulator and check valve. At this point the leak could be anywhere in the N_2 system (see Figure 4-17). If the leak is in the tank, taking the OMS Engine to ARM at 470 psi would prevent the purge from occurring and save the remaining pressure in the accumulator for the deorbit burn. If the leak is in the accumulator, the N_2 pressure will continue to drop after the OMS Engine switch is placed in ARM. With a leak in the accumulator and the P valve closed there will be insufficient pressure to keep the ball valves open and the engine will eventually fail.

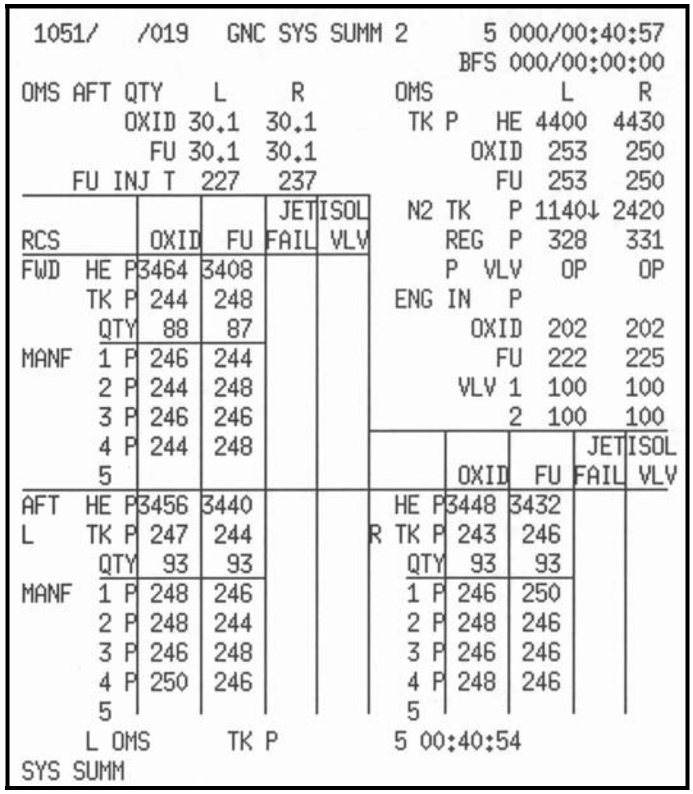

Figure 4-15. L OMS N_2 Tank P Low

OMS N2 TK P LOW (√ $\boxed{\text{OMS/MPS}}$)	At N2 TK P < 470: OMS ENG – ARM

Figure 4-16. Procedure on the OMS-2 Burn Monitor

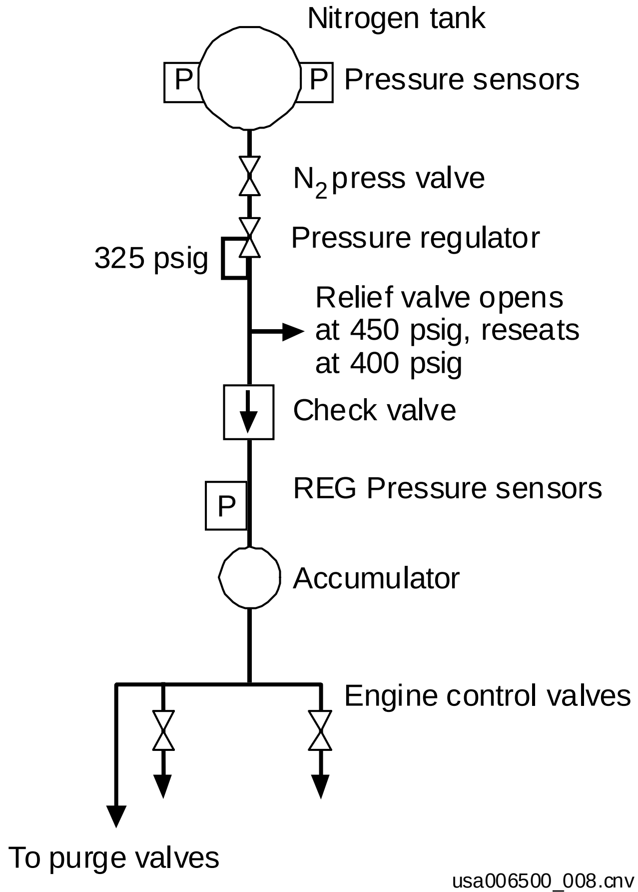

Figure 4-17. N_2 System

N_2 Regulator Pressure High

Figure 4-18 is an example of the Right OMS N_2 regulator pressure high during an OMS 2 burn. The overpressed accumulator is confirmed by seeing a decrease in the N_2 tank pressure. In our example the regulator has failed open and the N_2 is relieving overboard (see Figure 4-17). Once the relief valve is open the nitrogen can deplete rapidly. Placing the OMS ENG switch in ARM will prevent the tank from depleting.

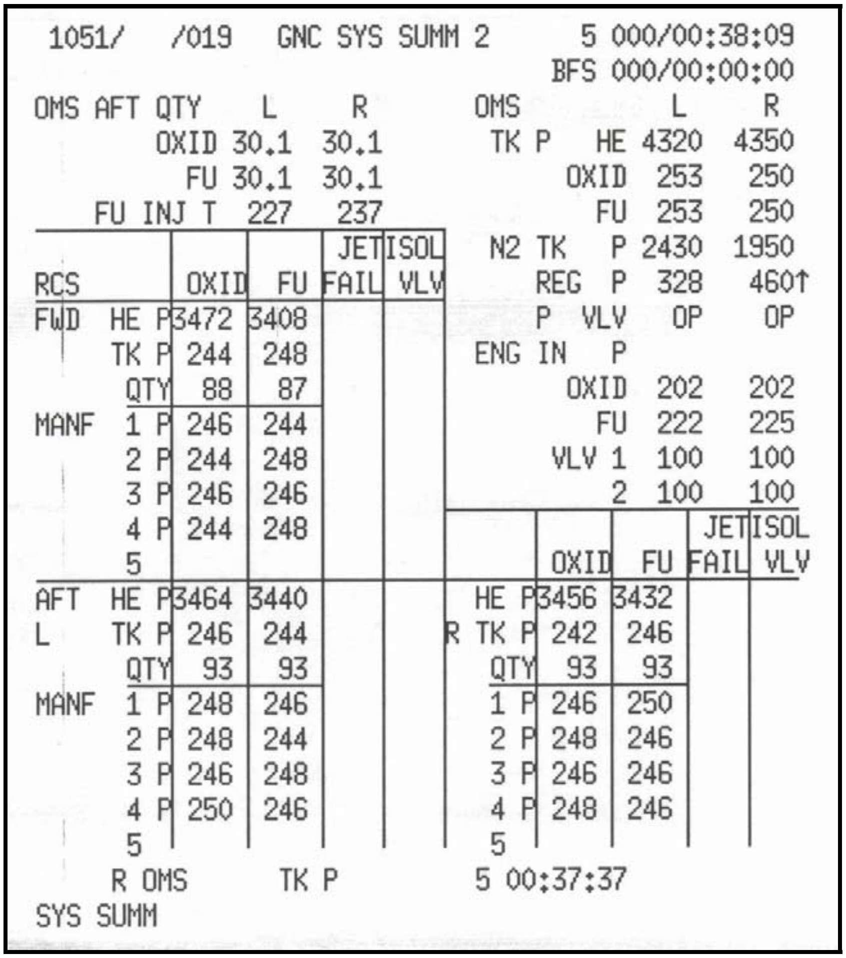

Figure 4-18. N_2 Reg P High during MM105 OMS-2

OMS N2 REG P HIGH or LOW	OMS ENG – ARM

Figure 4-19. OMS N_2 REG P HIGH OMS Burn Monitor

4.7 GIMBAL FAILURES

The OMS gimbal actuators have fault detection and identification (FDI) software. The FDI software monitors the commands and the feedback for the actuators. If, an actuator is commanded to move continuously in the same direction and the actual deflection does not match the command, a gimbal failure is annunciated. There will be a gimbal failure fault message and a down arrow on the Maneuver display next to the position indicator for the failed actuator (see Figure 4-20). The FDI software can detect a failure in an individual pitch or yaw actuator.

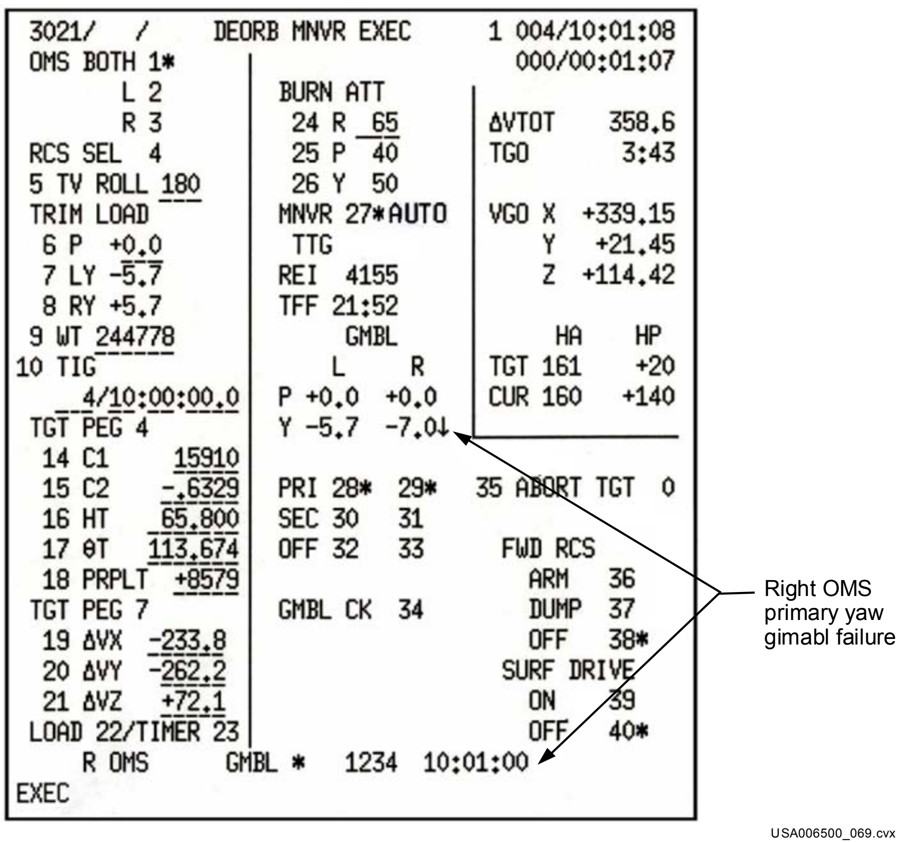

Figure 4-20. DEORB MNVR EXEC with R Gimbal fail

Gimbal failures can occur during a burn or a gimbal check. When the primary system fails, the secondary system is selected with an item entry (Figure 4-21). Even though the failure may be only in the primary pitch actuator, the secondary is selected for both pitch and yaw since there is no way to split up that selection. Any change to the gimbal selection will reset the FDI logic and remove any down arrows.

OMS GMBL	PRI fail	L(R) OMS GMBL – SEC (twice)
	SEC fail	If high RCS usage: OMS ENG FAIL

Figure 4-21. OMS gimbal fail procedure DEORBIT Burn Monitor

If the secondary system fails during a burn, there is no action unless there are obvious control problems or an excessive amount of RCS propellant is being used to maintain control, in which case the engine is considered failed and the OMS engine switch is taken OFF (Figure 4-21). High RCS usage is defined as 10% total (L+R) RCS propellant used in 30 seconds. In most cases the gimbal actuators are not moving very much during a burn. Even with a failure, the actuators should hold the engine in its last commanded position, and control problems are unlikely. If it were known in advance from a gimbal check that the primary and secondary systems have failed, the engine would not be started.

4.8 PASS OMS ENGINE FDI

PASS contains fault detection and identification (FDI) software that monitors the OMS engines and alerts the crew when there is a problem.

The FDI software checks four items:

1. The status of the two FA MDMs that transmit OMS engine P_c measurements (FA3 for left and FA4 for right)

2. OMS engine Pc measurements

3. The acceleration (or ΔV) being experienced (except during ascent dumps when the main engines are burning and the OMS ΔV contribution is too small to measure). This ΔV check is used to verify that the thrust from an OMS engine has been lost.

4. OMS engine switch positions

Missing Pc Data

If there is a failure of FA3 or FA4, the associated Pc measurement is lost and the FDI software will not be able to annunciate any failures for the affected engine even if the engine does fail.

Low Pc

If an OMS Pc measurement drops below 80 percent, an OMS Pc fault message will appear on display and an OMS light (LEFT OMS or RIGHT OMS) on the C/W matrix on Panel F7 will be illuminated. These indications can also result from the failure of a Pc sensor. There is only one Pc sensor per engine.

Low Pc and ΔV Loss

If the measured Pc is below 80 percent and there is a decrease in vehicle acceleration indicating a loss of thrust, a down arrow will appear on the Maneuver display next to the engine with low Pc.

Engine Shutdown Flag

If the P_c flag is set, P_c less than 80% when burning or P_c greater than 80% prior to OMS ignition, and the ΔV check indicates a loss of thrust, and the OMS engine switch is in the OFF position, then the engine shutdown flag is set for Guidance (see Figure 4-22). Guidance will not reconfigure for the loss of an OMS engine until the OMS Engine switch on Panel C3 is taken to OFF. Once the thrust from one OMS engine is lost, the ΔV check is automatically reset to detect a subsequent loss of thrust so that a second engine failure can be identified. The BFS does not check ΔV and only uses Pc for engine failure detection.

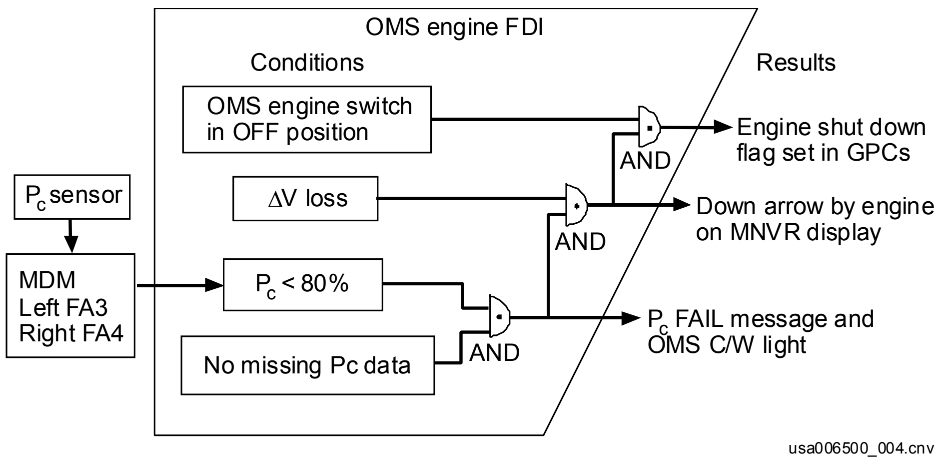

Figure 4-22. OMS engine failure detection

Figure 4-23 is an example a Left OMS Engine that has experienced all of three conditions mentioned above. Pc less than 80%, loss of acceleration and Left OMS Engine switch on C3 taken to OFF.

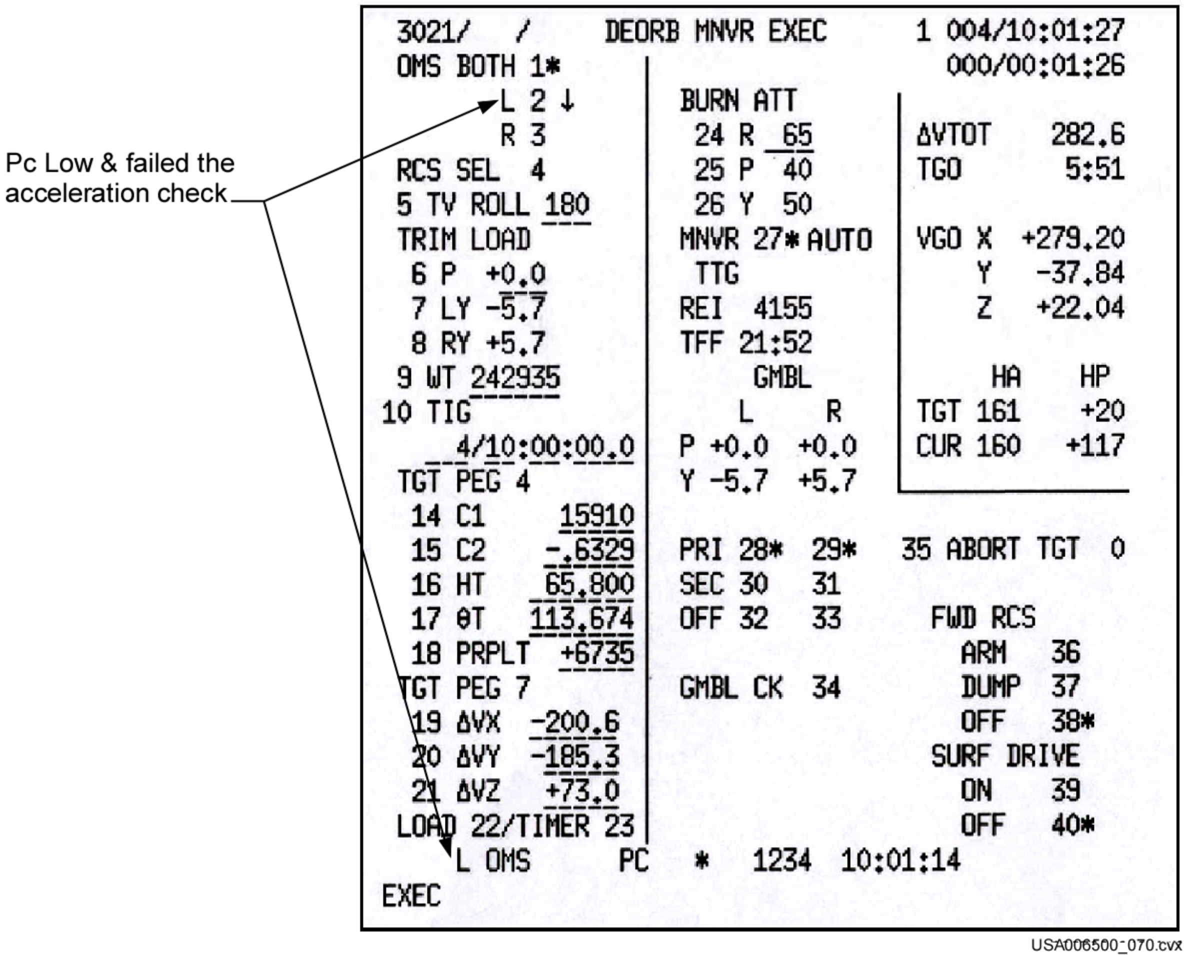

Figure 4-23. Maneuver display with Left OMS Engine Failure

4.9 ENGINE FAIL AND PROPELLANT FAIL

Previous procedures have made reference to OMS engine and propellant failures. An operational interpretation of the Flight Rule is shown below.

OMS Engine Failure: As the name implies, the OMS engine is considered unsafe to operate. However, the propellant on that side can still be used. (The OMS Engine switch is taken OFF.)

OMS Propellant Failure: Neither the propellant nor the engine can be used. (The OMS Engine is taken to OFF and the system is secured.)

There is no caution and warning attached to the OMS oxidizer and fuel engine inlet pressures. These pressures are used to diagnose engine performance. Making a propellant fail/engine fail call real time can be difficult. One needs to make sure they have all the confirming cues prior to taking an OMS engine OFF. In the next three sections we will provide the all required signatures needed to diagnose ball valve failures, oxidizer blockages and fuel blockages.

Ball Valve Failure

The first example we will discuss is a ball valve failure during and OMS-2 burn. One can see that in Figure 4-25 that the right OMS ball valve number one is reading zero. Lack of adequate propellant flow to the engine would cause the Pc to drop below 80 %. This would set the Pc fail flag on the Right OMS. The subsequent loss of acceleration would generate the down arrow on the MNVR Exec display. These two cues are listed on the burn monitor card as OMS Pc and OMS down arrow (Figure 4-24). Coupled with engine valve #1 being less than 70% on SYS SUMM 2, one has the three cues required to call the right OMS Engine as an engine failure. The Right OMS is taken to OFF.

OMS PC* & OMS ↓ (BFS: ✓accel) ENG VLV 1 or 2 $<$ 70 or OX IN P $>$ 227	OMS ENG FAIL
OX IN P $\leq$ 227 or No OX IN P	OMS PRPLT FAIL

Figure 4-24. OMS Pc block Burn Monitor Card

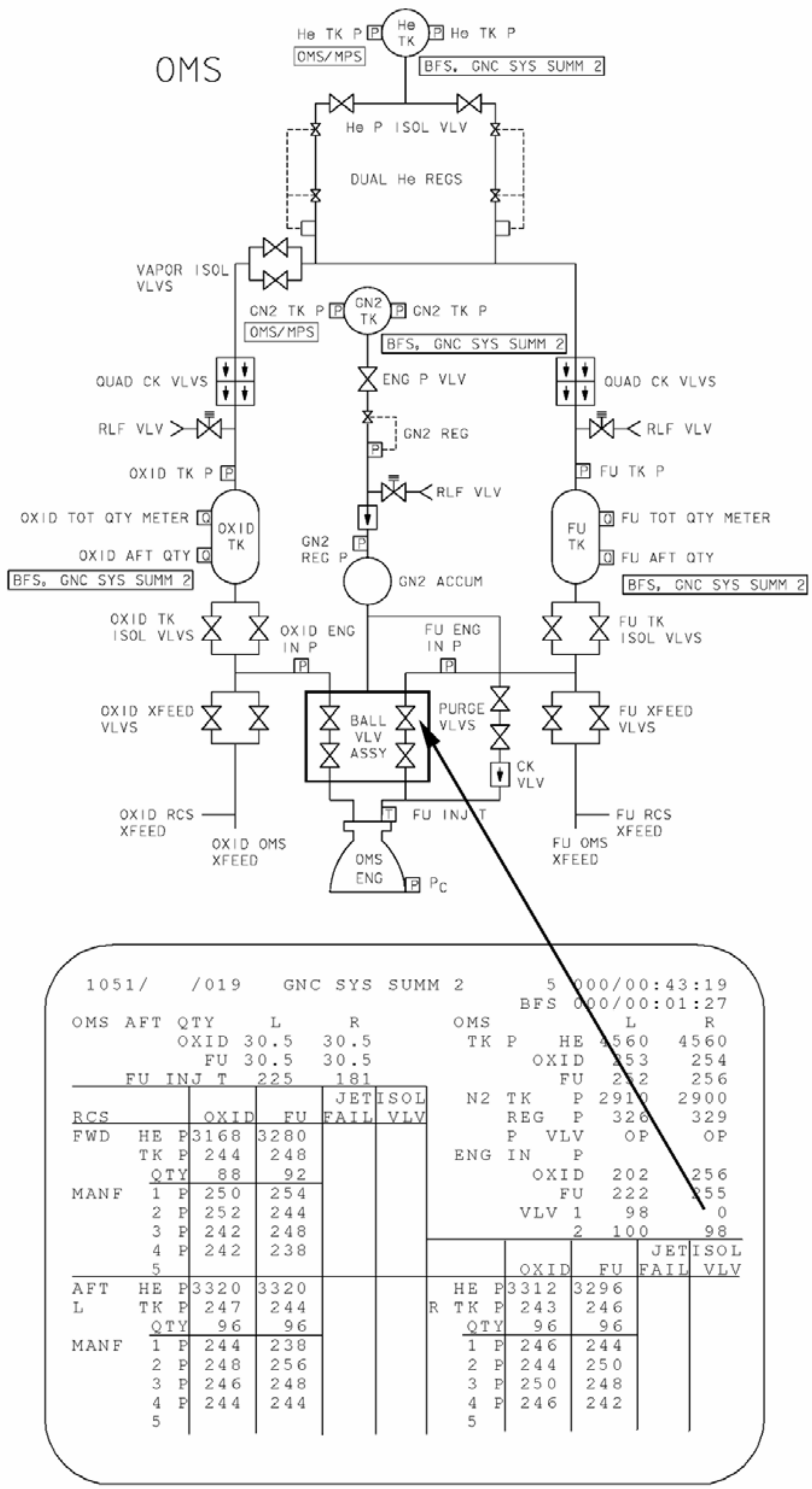

Figure 4-25. OMS schematic & SYS SUMM 2 - R OMS Engine Failure

Oxidizer Blockage

The first type of blockage we will discuss is a restriction in the oxidizer line. If the oxidizer is prevented from reaching the combustion chamber, the fuel rich mixture ratio results in a cooler, less efficient burn, which could violate the Pc low limit and reduce thrust. It is important to note that the location of the blockage will determine an engine failure or a propellant failure.

Figure 4-27 is an example of an engine failure caused by an oxidizer restriction. The first two cues are OMS Pc low and the right OMS down arrow on the MNVR EXEC display. The oxidizer inlet pressure on the right is greater than the 227 psi requirement. This rise in the oxidizer inlet pressure indicates the blockage is down stream of the transducer, therefore an engine fail. The propellant is still accessible to the left OMS engine and RCS jets through the crossfeed line.

OMS PC* & OMS ↓ (BFS: ✓accel) ENG VLV 1 or 2 < 70 or OX IN P > 227	OMS ENG FAIL
OX IN P ≤ 227 or No OX IN P	OMS PRPLT FAIL

Figure 4-26. OMS PC block on the Burn Monitor Card

Figure 4-28 is an example of a propellant failure caused by an oxidizer blockage. Again, we will get an OMS PC message and a down arrow on MNVR EXEC display, only this time the oxidizer inlet pressure is lower than the 227 requirement. The restriction in this case is upstream of the transducer (and assumed upstream of the crossfeed line), so a propellant failure has occurred.

Two useful tips that might be helpful when calling engine or propellant failures. Remember *H.E.L.P.* when monitoring the inlet pressures. *H-High pressure, E-Engine failure, L -Low pressure, P-Propellant failure*. If one sees the inlet pressure go high from the nominal steady state condition, chances are it is an engine failure. If the inlet pressure goes low then it is likely a propellant failure. Monitoring two OMS engines and four inlet pressures can be hard. When presented with an OMS Pc message, narrow your focus on the oxidizer inlet pressure, chances are the restriction is in the oxidizer line. (OMS Pc message, think oxidizer.)

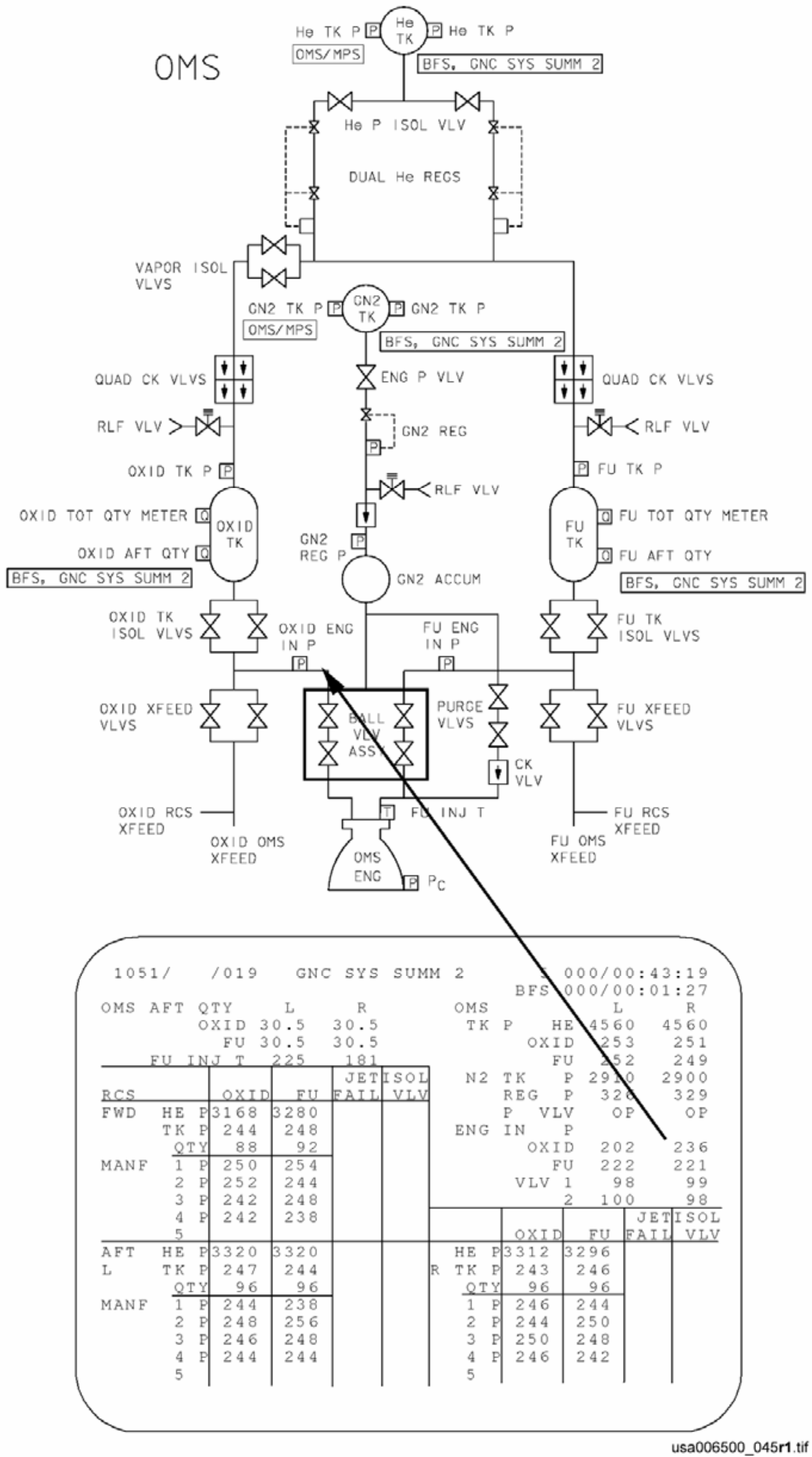

Figure 4-27. OMS schematic & SYS SUMM 2 - R OMS Engine Failure

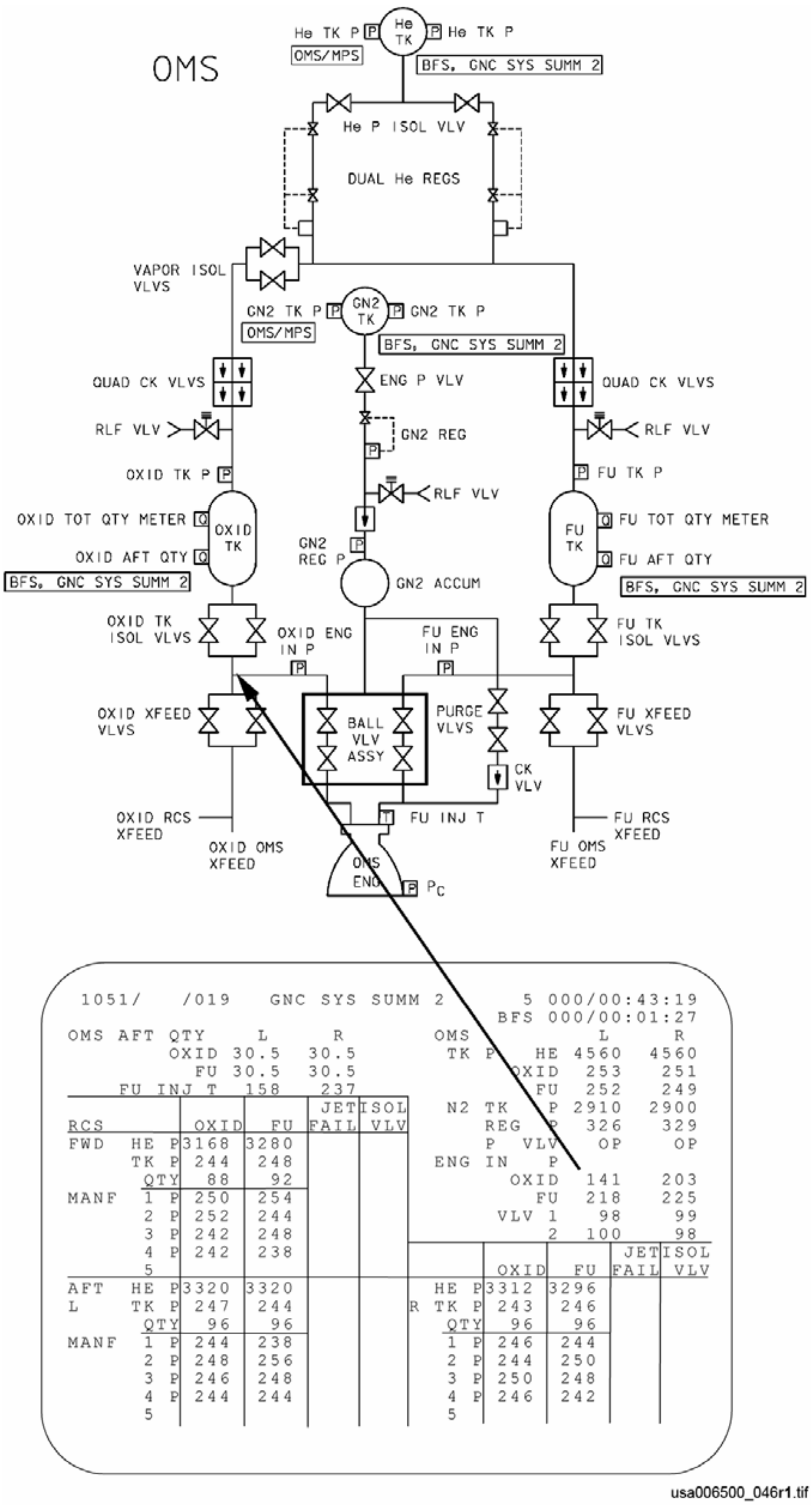

Figure 4-28. OMS schematic & SYS SUMM 2 - L OMS Propellant Failure

Fuel Blockage

The second type of blockage is a restriction in the fuel line. Fuel flow through the cooling jacket may be reduced by a fuel restriction. Without proper cooling the engine will burn hotter. In addition, the oxidizer rich mixture ratio will cause higher combustion temperatures. As with the oxidizer blockage, location will determine an engine failure or propellant failure.

Figure 4-30 *Example #1* shows an engine fail caused by a fuel restriction. The first cue is the higher fuel injector temperature on GNC SYS SUMM 2. Notice the up arrow and Left OMS TEMP message. The fuel inlet pressure of 238 psi is higher than the requirement listed on the burn monitor card. This rise in the inlet pressure indicates a blockage downstream of the fuel inlet transducer, therefore an engine fail. The propellant is still accessible through the crossfeed line.

OMS TEMP*	L	R	
FU IN P ≥	224	217	OMS ENG FAIL
≤	209	201	OMS PRPLT FAIL
or No FU IN P			

Figure 4-29. OMS TEMP block on the Burn Monitor Card

Figure 4-30 *Example # 2* is a propellant fail caused by a fuel restriction. Notice the same cues as *Example #1*. (OMS Temp message and the up arrow next to the fuel injector temperature) The fuel inlet pressure of 187 psi is lower that the 209 psi listed on the card. The restriction in this case is upstream of the transducer (and assumed upstream of the crossfeed line), so a propellant failure has occurred.

Again, remember *H.E.L.P.* when monitoring the inlet pressures. (*H-High pressure, E-Engine failure, L -Low pressure, P-Propellant failure*.) When presented with an OMS TEMP message narrow your focus to the fuel inlet pressures, chances are you have a fuel blockage that caused the temperature increase.

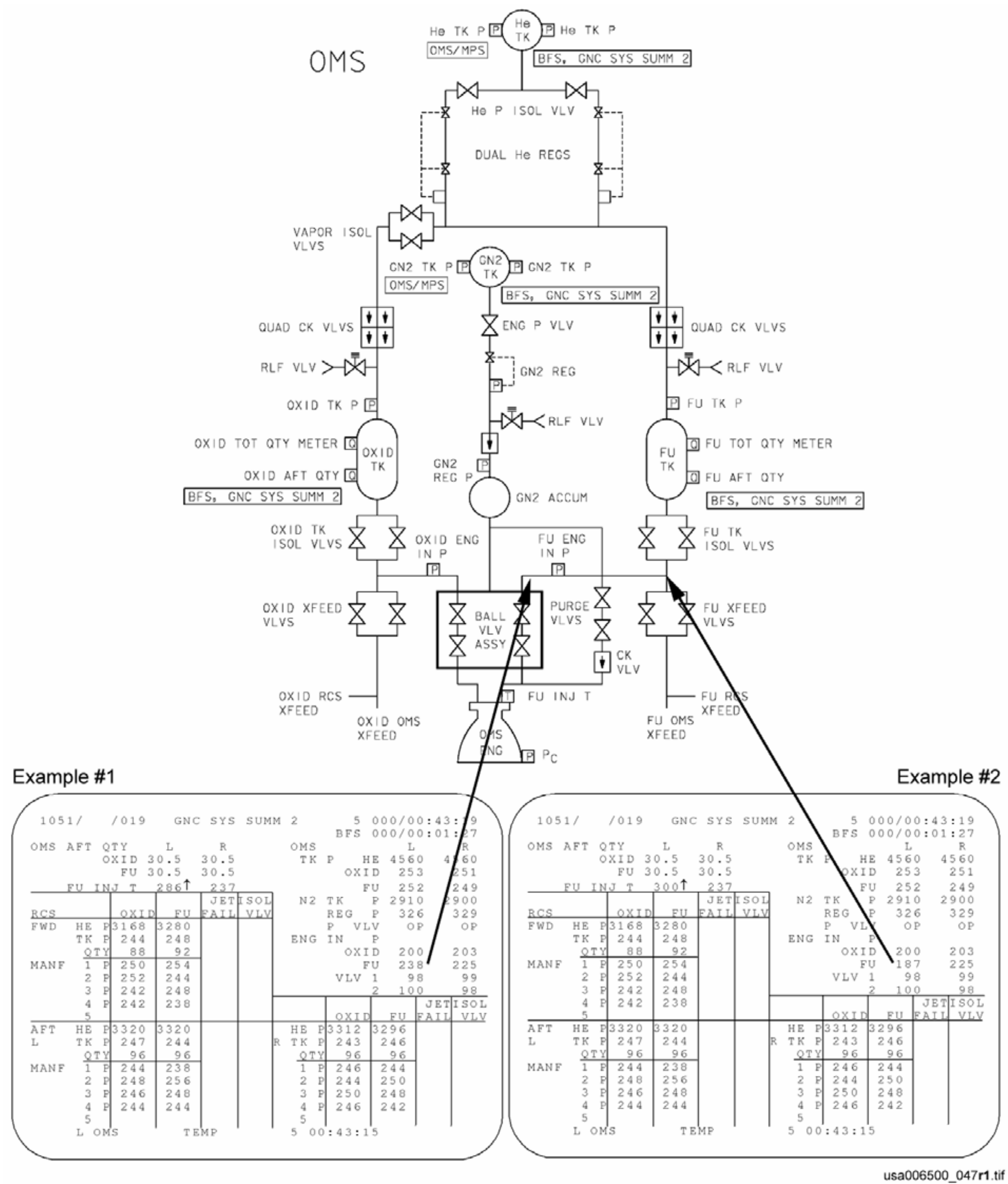

Figure 4-30. L OMS Engine Fail (Example 1) & L OMS Propellant Fail (Example 2)

4.10 THERMAL CONTROL SYSTEM FAILURES

One of the following fault messages will appear when a temperature in the OMS pods is detected to be out of limits: S89 PRPLT THERM OMS or S89 PRPLT THERM POD (generated by the primary system in OPS 2) or SM0 PRPLT THERM (generated by the BFS). These messages usually mean that a heater, thermostat, or temperature sensor has failed. On ascent, there are no crew actions, because the heater switches cannot be reached easily and a rapid response should not be necessary anyway. On orbit the Malfunction Procedures book covers the procedures, which are usually limited to switching to an alternate heater circuit with a switch on Panel A14. (See Figure 4-31.)

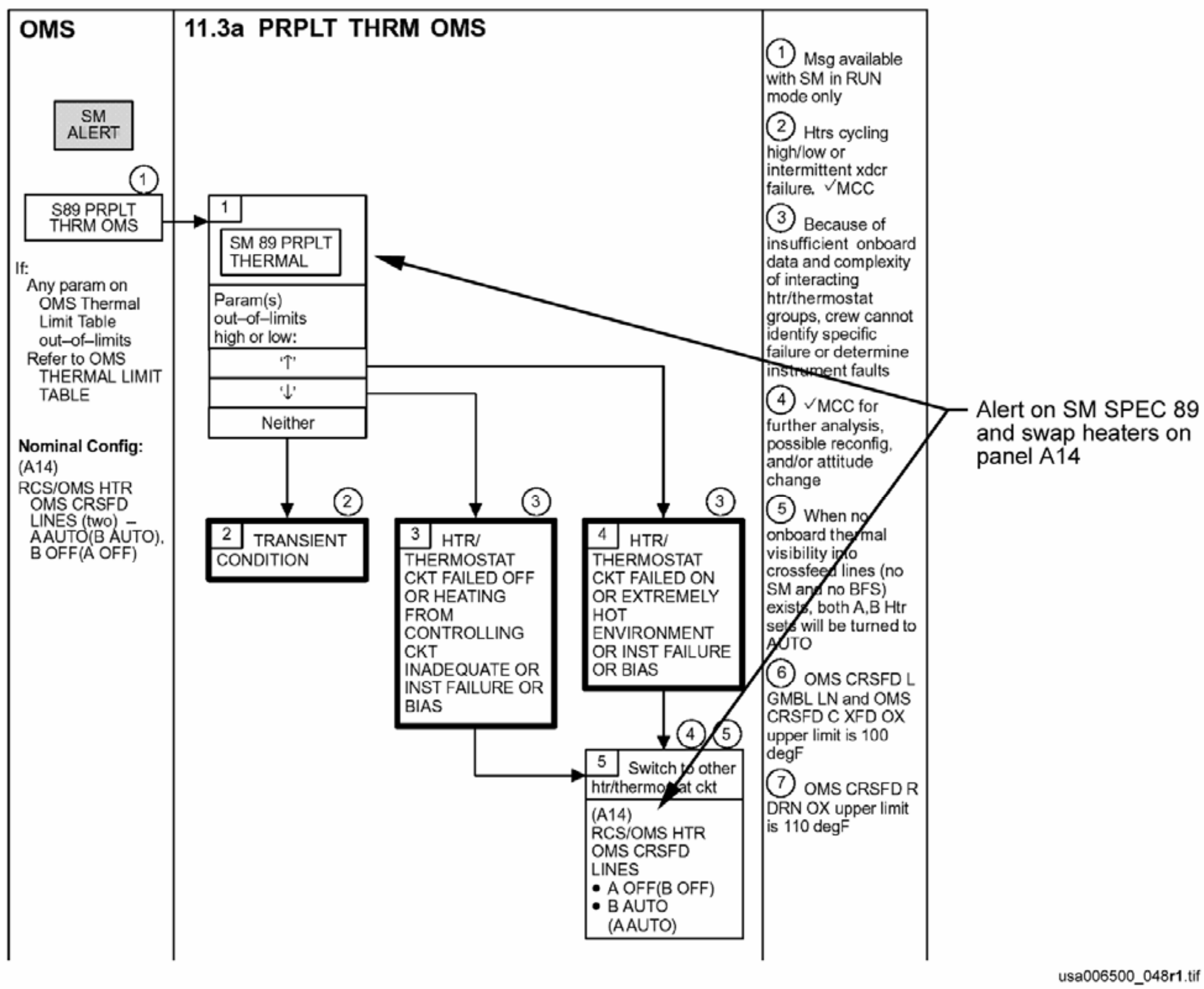

Figure 4-31. OMS MALFUNCTION Procedures Section 11

4.11 ELECTRICAL AND DATA PATH FAILURES

The operation of the OMS is dependent on electrical power supplied through various electrical buses and on components of the DPS, including GPCs and MDMs. Failures in these other systems can have significant effects on the OMS. This section will describe the basic arrangement of power and data transmission and the effects of electrical and DPS failures on the following components:

Helium press/vapor isolation valves and switches

Tank isolation and crossfeed valves and switches

ORCS PGSC application

Pressure and temperature sensors

Quantity gauging

Engine control valves and engine ignition

Thrust vector control

Pod heaters

Helium Press/Vapor Isolation Valves and Switches

There are two types of valves in the OMS propellant system: a solenoid type, like the helium press/vapor isolation valves (see Figure 4-32), and a motor driven type, like the tank isolation and crossfeed valves. The solenoid type will be discussed first.

For the solenoid-type valve, the switch has a single set of contacts that allows control bus power to activate main bus power for the valve by two possible paths: a manual open and close path or a GPC command path. If manual OPEN is selected with the switch, main bus power energizes a solenoid that opens the valve. When power is removed, the valve is closed by spring pressure. When the switch is in the GPC position, an open command can come through a specific FA MDM to open the valve using power from a different main bus. There is no GPC close command. The valve closes when the open command is no longer received or when the switch is taken to the manual CLOSE position.

Manual control of the valve can be lost if the control bus power to the switch is lost or the main bus power used for manual control is lost. GPC control of the valve can be lost if the FA MDM or GPC fail or if the main bus used for GPC control is lost.

One can deduce what would happen with different combinations of failures. There are three main buses, nine control buses, and four FA MDMs in the vehicle. The buses and MDMs are assigned to the various valves in combinations that minimize the effects of individual and multiple failures.

All four OMS helium press valves have the same design, but the bus and MDM assignments are different. The vapor isolation valves work in a similar way, but they are set up to open whenever the helium press valves are open rather than having independent control.

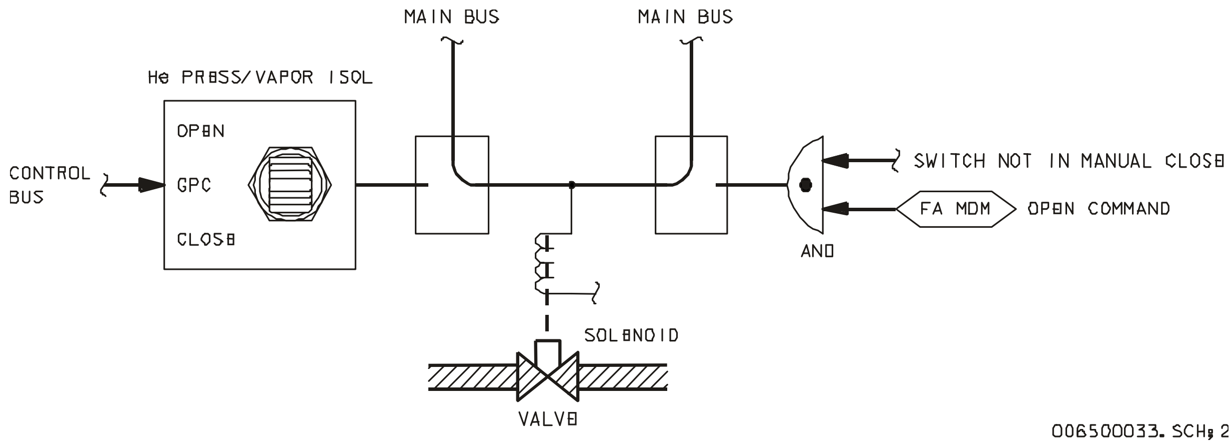

Figure 4-32. Solenoid valve schematic

Tank Isolation and Crossfeed Valves and Switches

The OMS tank isolation valves and crossfeed valves and some RCS valves are opened and closed by ac motors. The flow of ac power to motor control assemblies (MCAs) is controlled by ac circuit breakers on Panel MA73C. The MCA channels power to the valve motors and uses main bus power in its logic circuits. The logic power is carried by a special bus that is supplied by two main buses and is controlled by a switch on Panel MA73C. All the OMS and RCS motor-driven valves are divided into three valve groups (see Figure 4-33). There is an MCA for each group, and each MCA receives power from two main buses.

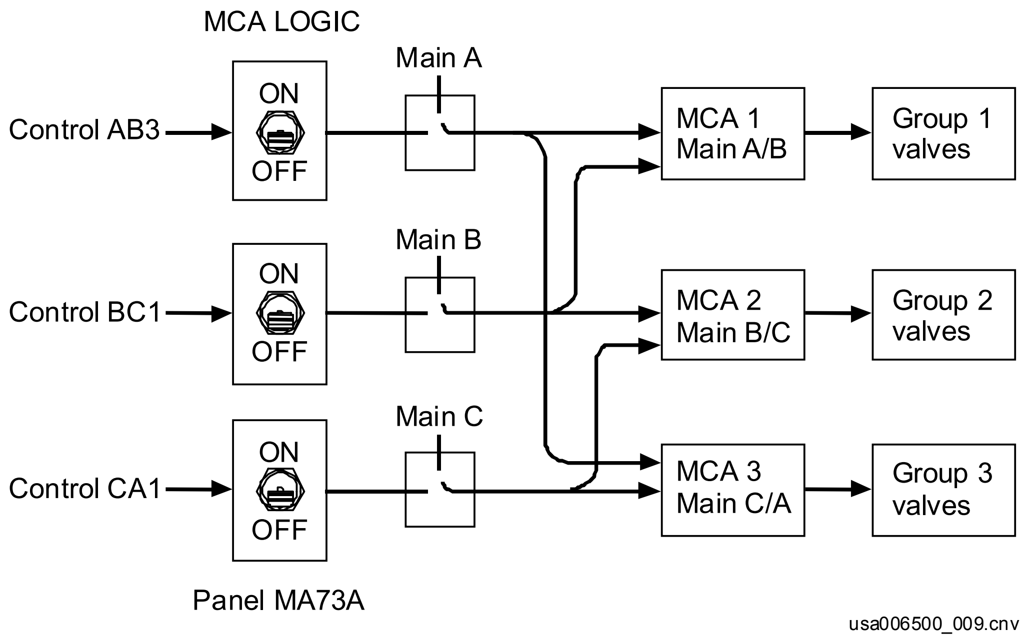

Figure 4-33. OMS valve logic power

The switches for this type valve have two sets of contacts using a different control bus for each set of contacts. There are also two FA MDMs transmitting open and close commands. The valve will respond to a GPC open command only if the switch is not in the CLOSE position and will respond to a GPC close command only if the switch is not in the OPEN position.

The manual close capability for a valve will be lost if one of the control buses for its switch is lost. The manual open capability is lost only if both control buses for the switch are lost.

The GPC close capability will be lost if one of the FA MDMs (or its associated GPC) fails. The GPC open capability can be lost only if both FA MDMs (or GPCs) fail.

The valve motors will not function if there is a loss of ac power, and the affected valves will remain stuck in their current positions. The ac motors will function if at least two of the three phases of ac bus power remain (see Figure 4-34).

MCA power, which is needed to operate the valves, can be lost only if both main bus supplies are lost or if there is a loss of control bus power to the two switches that provide logic power.

When there is a complete loss of MCA logic power, the talkbacks for the affected switches will rotate to their neutral position and show the barberpole pattern. The talkback will also show barberpole if either the fuel or oxidizer valves get stuck and there is a position mismatch between the two valves.

The procedures to deal with switch failures and talkback failures are covered in the Systems Malfunction Procedures book. By following the steps in that book, it should be possible to determine the cause of the failure.

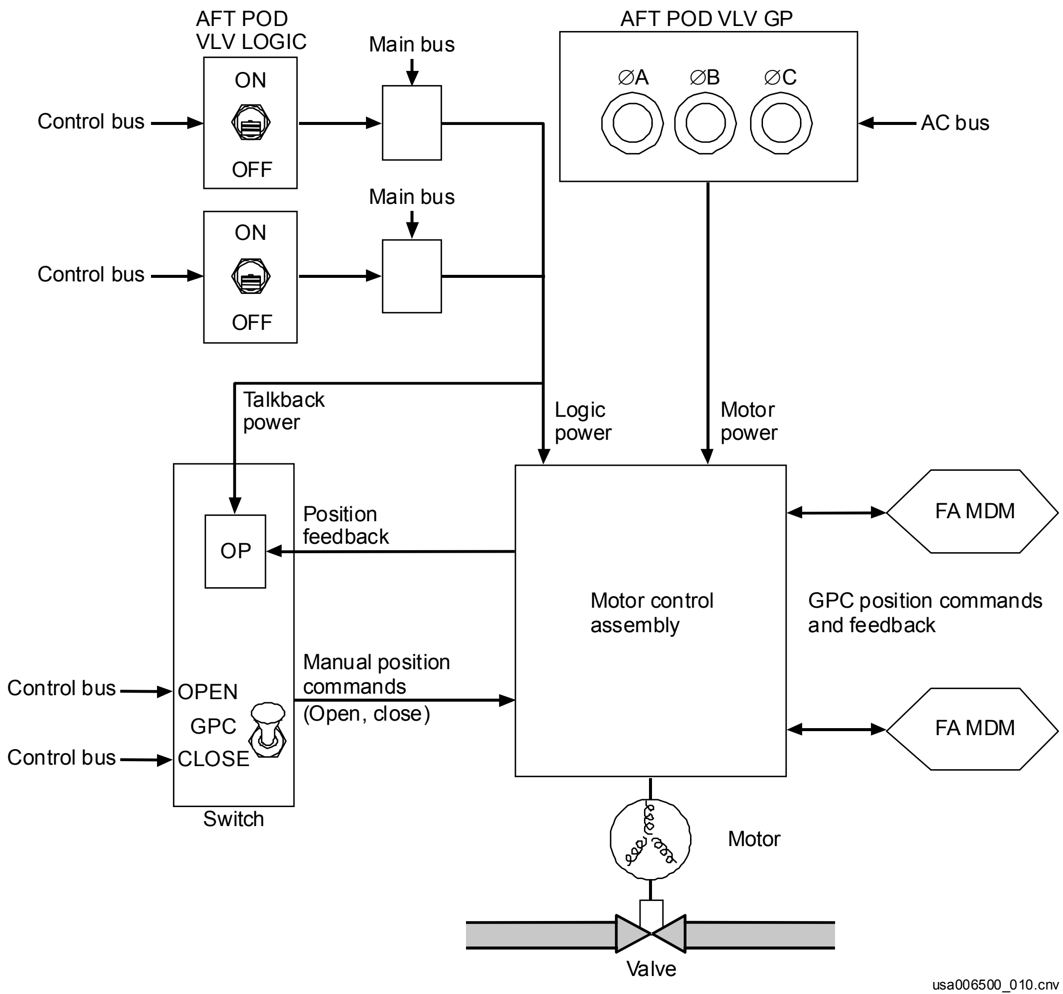

Figure 4-34. Motor-driven valve schematic

4.12 ORCS PGSC APPLICATION

The crew can determine the effects of electrical bus or MDM failures by referring to the Reference Data book that is carried onboard. Another tool the crew can use on orbit is the ORCS application found on the PGSC (Payload General Support Computer). ORCS will display a maximum of two failures. The valve legend is the key to understanding this application. A darkened or highlighted square will indicate the capability that is lost. Figure 4-35 is an example of how an MDM FA3 failure affects the OMS and RCS. One can see that with this failure the Right OMS Helium/Press Vapor Isolation Valve A has lost its GPC OP capability.

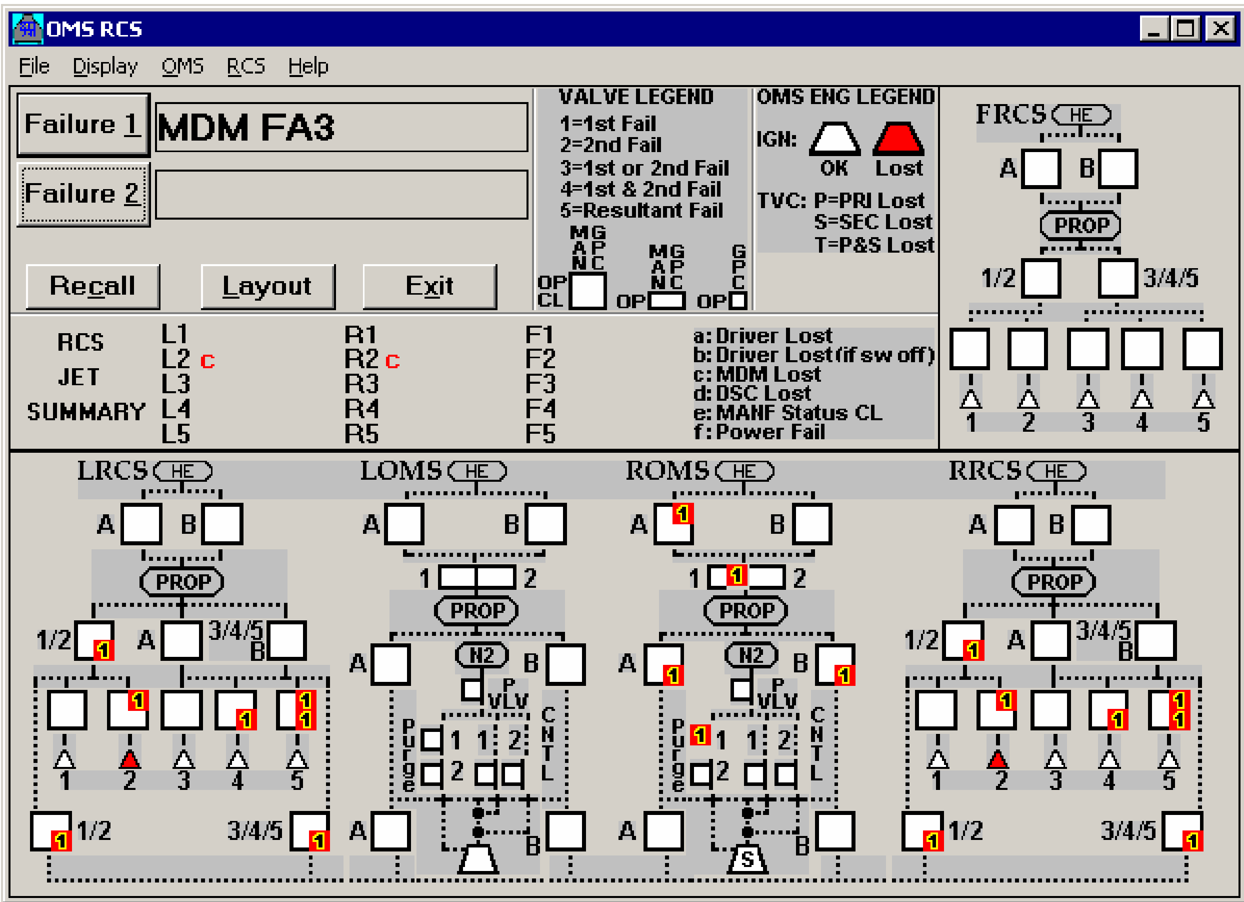

Figure 4-35. ORCS FA3 Failure

Pressure and Temperature Sensors

The OMS pressure, temperature, and valve position sensors receive power through signal conditioners; specifically, the left side uses dedicated signal conditioners (DSC) OL 1 and DSC OL 2 (OL: operational left) and the right side uses DSC OR 1 and DSC OR 2 (OR: operational right). Each signal conditioner is redundantly powered by two main buses. Some sensor outputs go directly to gauges, and others are transmitted by FA MDMs to the GPCs and, in some cases, appear on displays (see Figure 4-36). When a particular MDM or signal conditioner fails, certain OMS data is lost. Specific losses can be checked in Reference Data (Figure 4-37 example). In order to provide an overview of the effects of these types of failures, examples of some displays showing MDM and signal conditioner assignments are provided here.

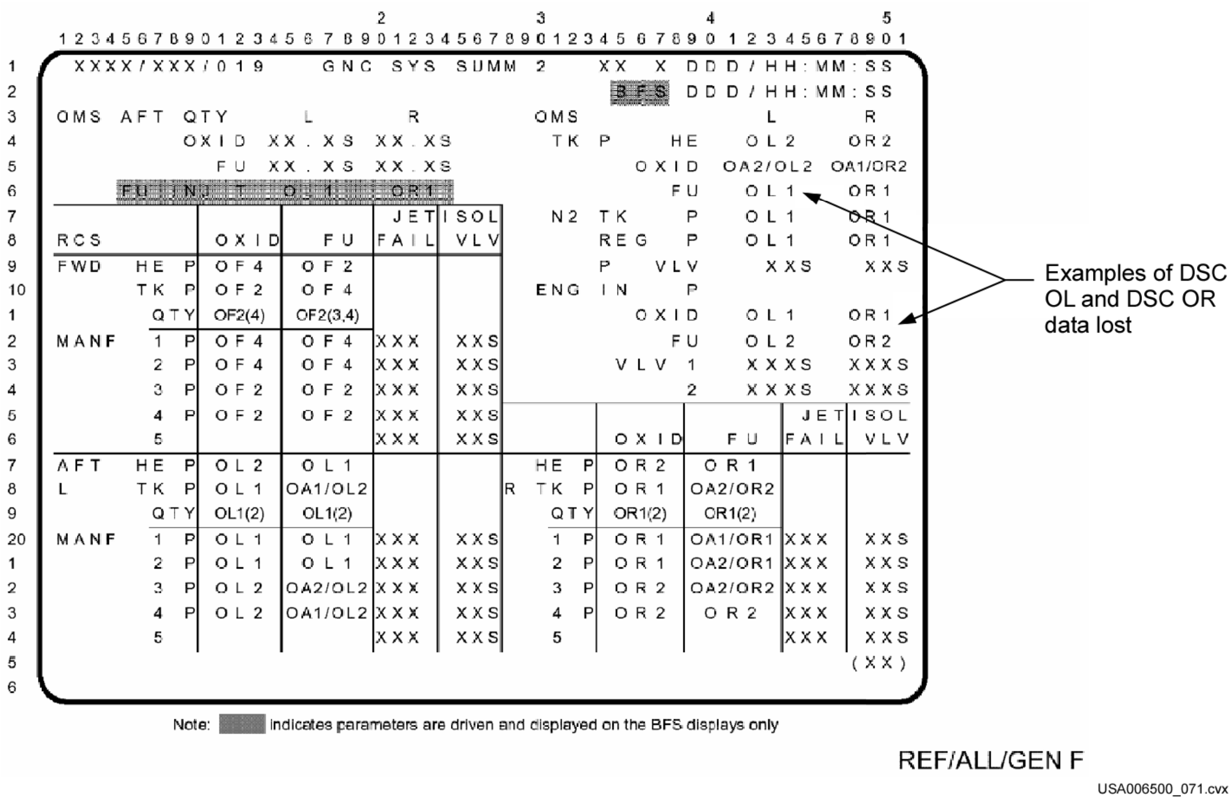

Figure 4-36. REF DATA IO DSC LOSS Impacts to GNC SYS SUMM 2

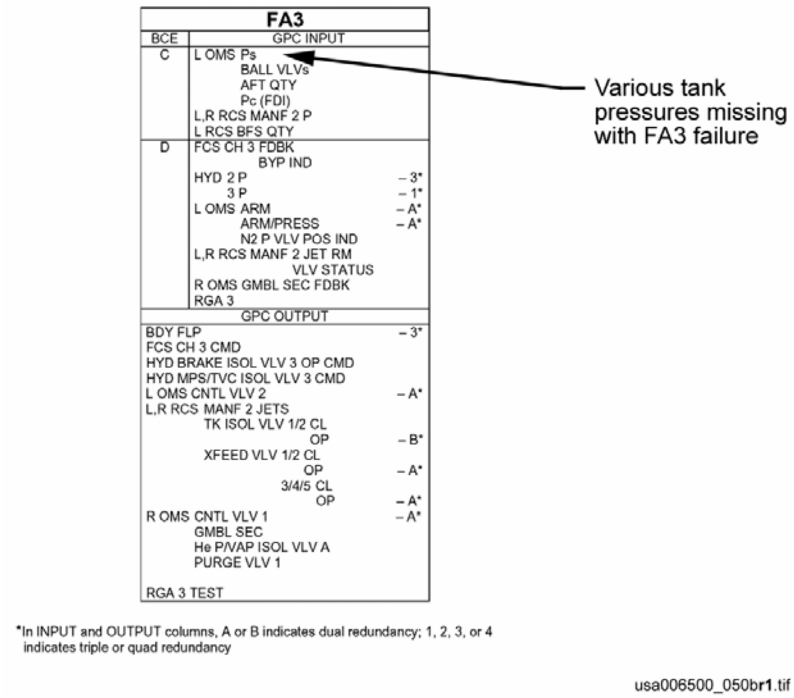

Figure 4-37. REF DATA FA3

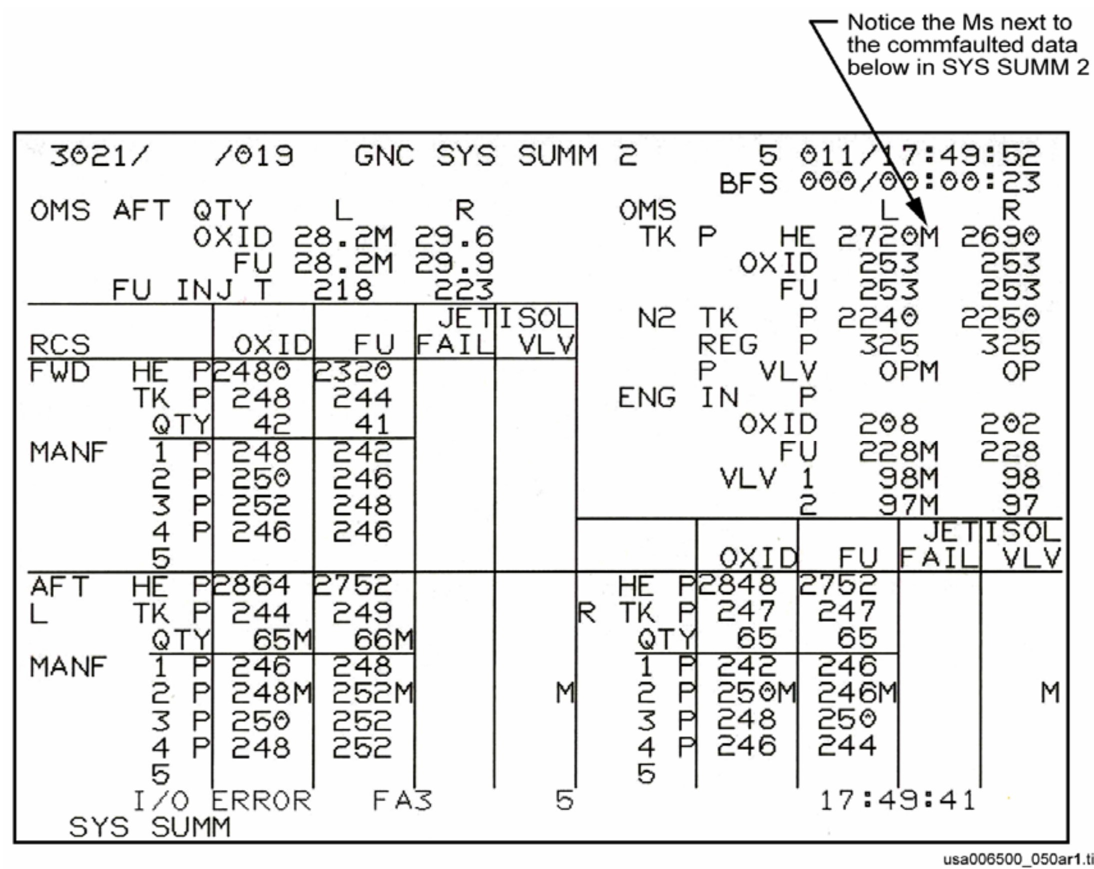

Figure 4-38. SYS SUMM 2 Display with FA3 Failure

Quantity Gauging

The OMS quantity gauging hardware and logic electronics require main bus power for operations. Each gauge unit has a single main bus source.

Left oxidizer	Main A
Left fuel	Main B
Right oxidizer	Main C
Right fuel	Main A

The panel meter is powered by the main C bus, and the numerals on the gauge require AC1 power for illumination (see Figure 4-39). The gauge output goes directly to the panel meter, but the aft probe quantity that is on the BFS GNC Systems Summary 2 display is transmitted by FA MDMs: The left fuel and oxidizer quantities on FA3 and the right fuel and oxidizer quantities on FA2. Notice in Figure 4-38 that the Left OMS aft probe is commfaulted on GNC SYS SUMM 2.

MNA

RCS/OMS Qty Meter lost

CRITICAL EQUIPMENT LOST – MNA/AC1

BUS LOST	CRITICAL FUNCTIONS/ EQUIPMENT LOST	CRITICAL REDUNDANCY LOST	INSTRUMENTATION/OTHER	OMS/RCS AFFECTED
DA1		Cryo O2/H2 Tk 1/3 Htrs A		
MNA FPC1	IDP 1 MDU CRT 1 L HUD MMU 1	LG Hyd Sys 1 Dpy (Pyros & NLG Hyd Sys 2 Dpy remain) NWS Hyd Sys 1	MCIU PDI Redundancy F RCS A Htrs	
MNA FLC1	F1 Manf Jets Bay 3 Agent Discharge			F RCS He P A (CL & GPC)
MNA FMC1	H2O Loop 1 Pump A	L Probe Mtr 1 Dpy Dsc 1	-Y S TRK SYS 1	F RCS Tk Isol 3/4/5 Manf Isol 1
MNA AC1 multi	FC1 Pumps Freon Pump 1A,2B H2O Loop 1 Pump A Av Bay Fan 1A,3B	L Probe Mtr 1 IMU Fan A PLBD Blkhd Lat,Stbd Dr Mtr Redun ET Door C/L,L Lat Mtr Redun L Dr Closure Mtr Redun Rad Port/Stbd Lat,Dpy/Sto Mtr Redun Arlk/Tnl Fan A[a]	-Y S TRK SYS 1 Door Mtr Humidity Sep A RCS/OMS Prplt Qty RMS MRL Redun WCS Fan/Sep 1 PRLA Drive Mtr Sys 1 EDO WCS Urine Fan and Sep 1 EDO WCS Commode Fan 1	L,R OMS Tk Isol A L OMS Xfeed A L,R RCS Tk Isol 3/4/5 A Xfeed 3/4/5 Manf Isol 2 F RCS Tk Isol 3/4/5 Manf Isol 1
MNA ΦA	Blr Cntlr 1B Pwr CO2 Removal Sys Cntlr 1	FCL 1 Cntlr B Rad Byp vlv Mtr H2O Loop 2 Byp Cntlr C ME Ch A R ME Ch B	H2O Loop 2 Instr RMS Shldr Brace Rel Cabin Temp Cntlr Sys 2 FC1 pH Snsr 1Φ of: WCS Fan/Sep 1 EDO WCS Urine Fan and Sep 1 (All functions lost) EDO WCS Commode Fan 1	

[a]Docking missions only

(Cont next page)

REF/ALL/GEN F
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Figure 4-39. REF DATA MAIN A

FA3

BCE	GPC INPUT	
C	L OMS Ps	
	BALL VLVs	
	AFT QTY	
	Pc (FDI)	
	L,R RCS MANF 2 P	
	L RCS BFS QTY	
D	FCS CH 3 FDBK	
	BYP IND	
	HYD 2 P	– 3*
	3 P	– 1*
	L OMS ARM	– A*
	ARM/PRESS	– A*
	N2 P VLV POS IND	
	L,R RCS MANF 2 JET RM	
	VLV STATUS	
	R OMS GMBL SEC FDBK	
	RGA 3	

GPC OUTPUT	
BDY FLP	– 3*
FCS CH 3 CMD	
HYD BRAKE ISOL VLV 3 OP CMD	
HYD MPS/TVC ISOL VLV 3 CMD	
L OMS CNTL VLV 2	– A*
L,R RCS MANF 2 JETS	
TK ISOL VLV 1/2 CL	
OP	– B*
XFEED VLV 1/2 CL	
OP	– A*
3/4/5 CL	
OP	– A*
R OMS CNTL VLV 1	– A*
GMBL SEC	
He P/VAP ISOL VLV A	
PURGE VLV 1	
RGA 3 TEST	

Left OMS AFT Quantity probe lost with FA 3 failure (reference Figure 4-38 GNC SYS SUMM2 with FA3 failure)

*In INPUT and OUTPUT columns, A or B indicates dual redundancy; 1, 2, 3, or 4 indicates triple or quad redundancy

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Figure 4-40. REF DATA FA3

OMS Engine Control Valves and Engine Ignition

OMS engine ignition occurs when the two control valves open. This will supply nitrogen to the pistons and open bipropellant valves #1 and #2. Each control valve has two coils. Only one coil is needed to open a control valve, but both control valves must open to have ignition (see Figure 4-41).

The OMS engine switch has two sets of contacts; each carries control bus power to activate a main bus power supply for the coils in the engine control valves. If one of the control buses is lost, the affected coil will not receive main bus power. If a main bus is lost, one of the coils will not operate. Certain combinations of two bus failures will prevent both coils from operating and the affected OMS engine cannot be started.

The commands to the coils arrive through FA MDMs (see Figure 4-42). If one FA MDM is lost, one coil will not operate. If certain combinations of two MDMs fail, there will be no ignition for one of the engines. There are also combinations of MDM and bus failures that will prevent ignition. There are no combinations of two buses or MDMs that will prevent ignition of both OMS engines. The combinations of failures that affect OMS ignition are shown on the OMS Failures cue card (Figure 4-44).

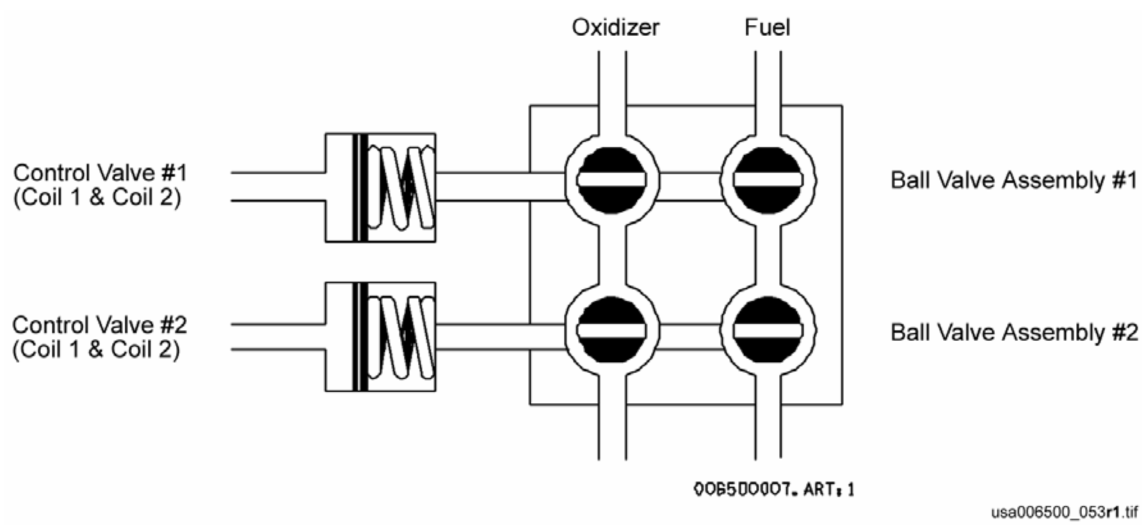
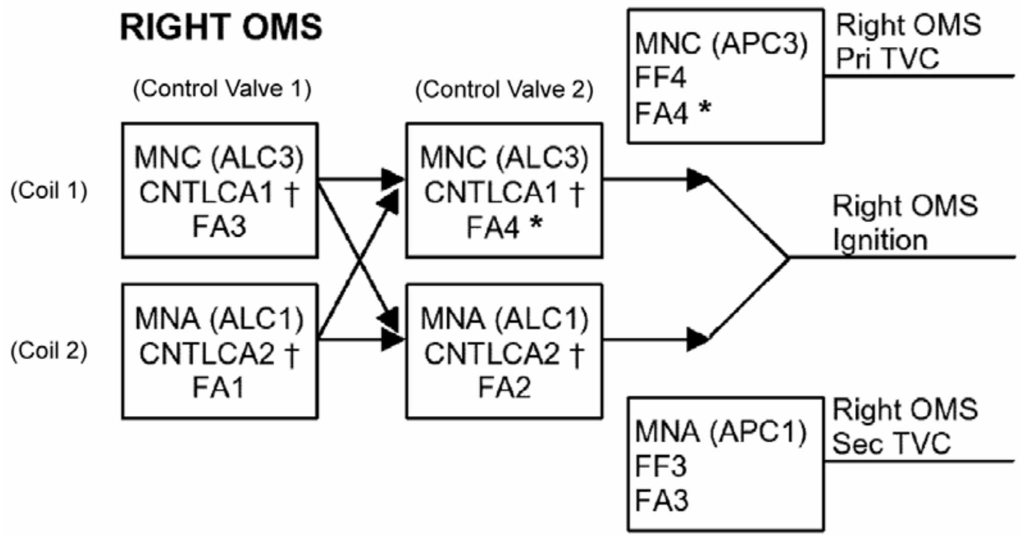


Figure 4-41. Bipropellant valves



If two FA MDMs lost		
MDMs	Preburn: ENG – OFF	During burn: MAN SHUTDN
1,2	LEFT (TVC)	BOTH
1,3	RIGHT (IGN)	LEFT
1,4	LEFT (IGN)	RIGHT
2,3	LEFT (IGN)	RIGHT
2,4	RIGHT (IGN)	LEFT
3,4	RIGHT (TVC)	BOTH

ENT-2b/114/A,O,D,E/B

MS ONLY FS 3-30 ENT/114/FIN A

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Figure 4-42. OMS Failures card

Thrust Vector Control

The OMS TVC system has a primary and secondary gimbal system for each engine. Each of the four gimbal systems has a single main bus power supply (see Table 4-4).

Each gimbal system requires an enable command that passes through an FF MDM. The enable command switches on power for the logic circuits and direct current motors that move the pitch and yaw actuators. The position commands from flight control and position feedback data pass through FA MDMs (see Figure 4-43).

If there is a main bus failure, the affected actuator will not operate and will be stuck in its current position.

If a GPC fails, the FF MDM associated with it will have the TVC enable command stuck on until the FF MDM power is cycled off and then on. If the primary enable command is stuck on and the secondary gimbals are enabled, both gimbal systems will be enabled and there could be conflicting commands to the actuator. If an FF MDM fails, the enable command from the MDM will be lost and the affected gimbal system will not function.

When a GPC fails, the position command from its associated FA MDM will remain at its current value and the gimbal will be stuck. If the FA MDM fails, the gimbal commands will go to zero, so the affected gimbal system will be unusable. Failure of a GPC or FA MDM will cause a loss of position feedback data and an M will appear on the Maneuver display where the gimbal positions normally appear.

The impact of bus and MDM failures on TVC operation can be seen on the OMS Failures card mentioned earlier.

Table 4-4. DPS and EPS interface with the OMS TVC

Actuator system	Power supply	Enable command	Position commands and feedback
Left primary	Main A	FF1	FA1
Left secondary	Main B	FF2	FA2
Right primary	Main C	FF4	FA4
Right secondary	Main A	FF3	FA3

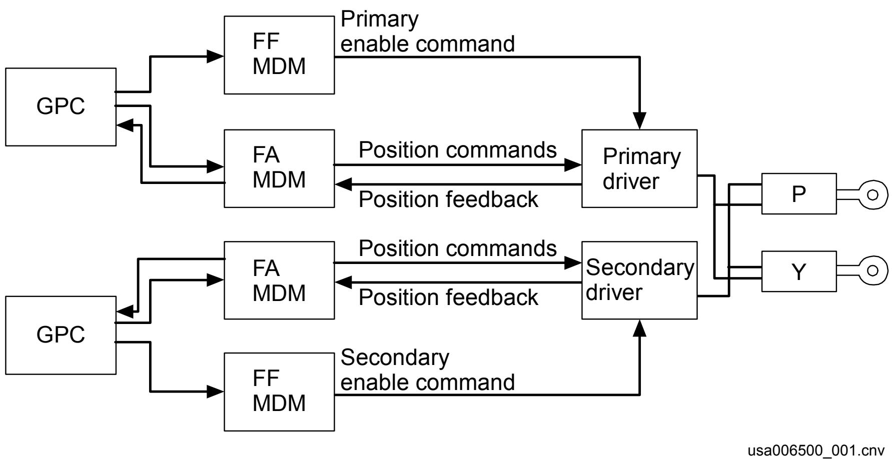


Figure 4-43. OMS Gimbal CMD and Feedback

Pod Heaters

The OMS pod and crossfeed line heaters require control bus and main bus power. The pod heaters require power from two control buses and one or two main buses in order to operate. The crossfeed line heaters require only one control bus and one main bus. Loss of a required bus causes the affected heater circuit not to operate at all, and the crew must switch to the alternate circuit to regain heater capability. The heater bus assignments are summarized below to show the general pattern for the various circuits.

Notice that for the left and right B heater circuits, there are two main buses rather than one. The loss of one main bus will affect only some of the heaters on the B circuits. The heaters are controlled by thermostats, so no interaction with the GPCs is required. The temperature measurements do pass through the MDMs and the GPCs for display purposes.

Table 4-5. OMS pod heaters

	A circuit	**B circuit**
Left pod heaters	Control AB1 and AB2 and Main A	Control BC1 and BC2 and Main B and C
Right pod heaters	Control BC1 and BC2 and Main B	Control CA1 and CA2 and Main A and C
Crossfeed heaters	Control AB3 and Main A	Control BC3 and Main B

QUESTIONS

1. Fill in the down arrows for the OMS engines as they would appear in each of the following situations.

   (a) Left OMS Pc is 0 percent, and a ΔV loss is detected.

   OMS BOTH*
   L
   R

   (b) FA4 is failed, the right OMS Pc is 0 percent, and a ΔV loss is detected.

   OMS BOTH*
   L
   R

   (c) The left OMS Pc indicated 0 percent, but no ΔV loss is detected.

   OMS BOTH*
   L
   R

2. In which cases above would there be an OMS PC FAIL message?

3. Refer to the OMS Failures cue card to determine which capabilities (left or right OMS engine ignition, left or right primary or secondary TVC) would be lost with the following failures.

   (a) Main A and FA1

   (b) Main C and control bus CA2

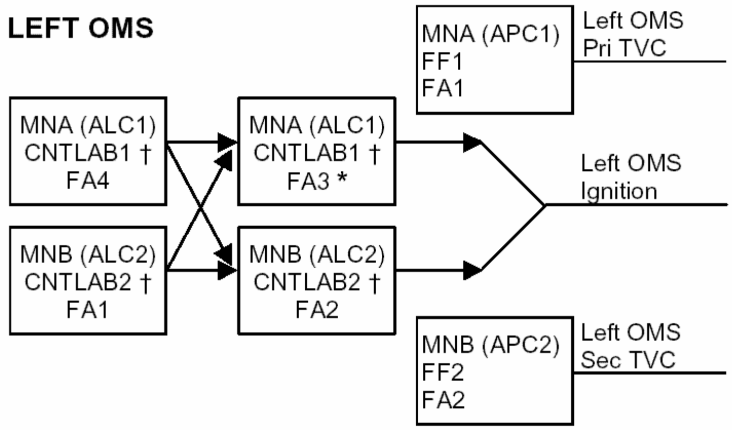
   (c) FA3 and FA4

   (d) FF1 and control bus BC2

   (e) FA2 and FF2

HOOK VELCRO | **OMS FAILURES** | HOOK VELCRO

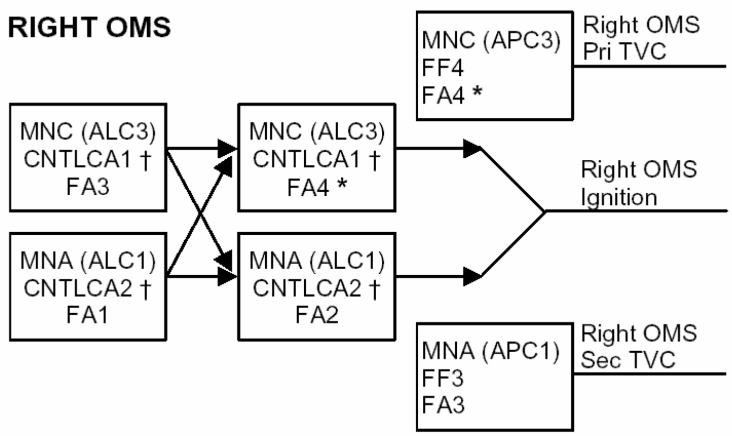
LEFT OMS



† If CNTL AB1 or AB2 (CA1 or CA2) failed and ign path still exists at OMS fail, assume L(R) OMS ↓ is PRPLT FAIL

* If L(R) Pc failed high during burn, or FA3(4) failed, at L(R) OMS fail, no guidance downmode after L(R) OMS ENG switch OFF (TGO slow, ADI needles in error, 6 ft/s underburn)

RIGHT OMS



If two FA MDMs lost		
MDMs	Preburn: ENG – OFF	During burn: MAN SHUTDN
1,2	LEFT (TVC)	BOTH
1,3	RIGHT (IGN)	LEFT
1,4	LEFT (IGN)	RIGHT
2,3	LEFT (IGN)	RIGHT
2,4	RIGHT (IGN)	LEFT
3,4	RIGHT (TVC)	BOTH

Figure 4-44. OMS Failures card

5.0 DIFFERENCES IN THE BFS

The operation of the OMS with the BFS engaged is very similar to its normal operation. The hardware is no different and the two major operational software differences are summarized below.

Automatic flight control post-MECO is not available when the BFS is engaged. Therefore all maneuvers must be done manually by using the RHC. The attitude direction indicator (ADI) error needles still provide valid guidance information for the crew to follow.

The BFS OMS Engine RM is not as complex as PASS. BFS does not perform an acceleration check. The Pc flag and down arrow are linked in the BFS. Therefore, when the BFS is engaged, an OMS Pc failure (Pc <80% during burn) will generate an OMS PC message and a down arrow. This exact failure on PASS would generate just an OMS PC message (see Figure 5-1).

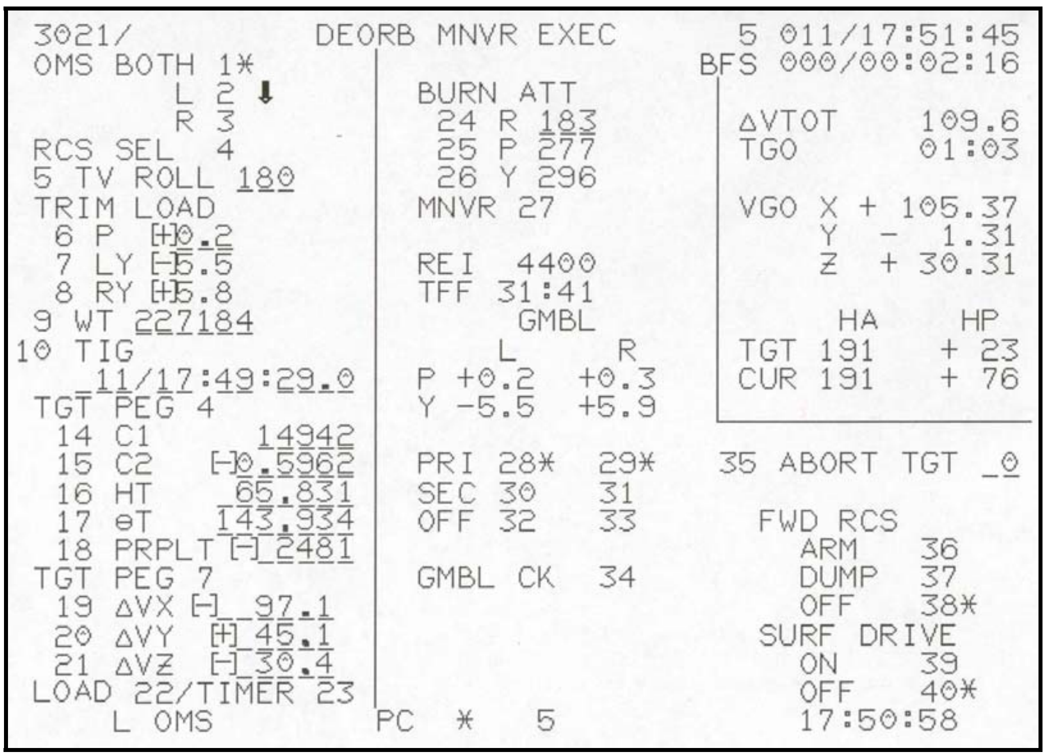


Figure 5-1. BFS DEORB MNVR EXEC with OMS Pc Failure

APPENDIX A ACRONYMS, ABBREVIATIONS, AND SYMBOLS

A	Aft
ac	alternating current
ADI	attitude direction indicator
AOA	abort once around
ATO	abort to orbit
ATT	attitude
AUTO	automatic
BFS	backup flight system
bp	barberpole
C1, C2	velocity targets for deorbit
CG	center of gravity
CK	check
CL	close
CONT	contingency
CRSFD	crossfeed
CRT	cathode-ray tube
CUR	current
C/W	caution and warning
D	down
DAP	digital autopilot
DEORB	deorbit
D/O	deorbit
DPS	Data processing system
DSC	Dedicated Signal Conditioner
ENA	enable
ENG	engine
EPS	electrical power system
ET	external tank
EXEC	execute
EXT ΔV	external ΔV
F	Fahrenheit, forward
FA MDM	flight-critical aft MDM
FCS	flight control system
FDI	Fault detection and identification
FF MDM	flight-critical forward MDM
ft/sec	feet per second
FU	Fuel
FWD	forward

GMBL	gimbal
GNC	guidance, navigation, and control
GN_2	gaseous nitrogen
GP	group
GPC	general purpose computer
H	altitude, high
HA	apogee altitude
He	helium
HP	perigee altitude
HT	target altitude
HTR	heater
I-load	initialization load
IDP	integrated display processor
IN	inlet
INH	inhibit
INJ	injector
ISOL	isolation
ISP	specific impulse of rocket motor measured in thrust (lb)/ propellant consumption (lb/s)
L	left, low
LK	leak
LN	Line
LY	left yaw
M	missing (data)
MANF	manifold
MCA	motor control assembly
MCC	Mission Control Center
MDM	multiplexer/demultiplexer
MECO	main engine cutoff
MET	mission elapsed time
MM	major mode
MNVR	maneuver
NM	nautical miles
N_2	nitrogen
O	overhead
OL	operational left
OMS	orbital maneuvering system
OMS1	First OMS burn
OMS2	second OMS burn
OP	open
OPS	operational sequence

OR	operational right
OVRD	override
OX, OXID	oxidizer
P	pitch, pressure
PAD	preliminary advisory data
P_C	chamber pressure
PEG	powered explicit guidance
PEG4	PEG, type 4
PEG7	PEG, type 7
PNL	panel
PRESS	pressure, pressurization
PRI	primary
PRO	proceed
PRPLT	propellant
psi	pounds per square inch
psia	psi, absolute
psig	psi, gauge
QTY	quantity
R	Roll, right
RCS	reaction control system
REG	regulator
REI	range to entry interface
RHC	rotational hand controller
RTLS	return to launch site
RY	right yaw
SE	single-engine
SEC	secondary
SEL	selection
SEP	separation
SM	systems management
SPEC	specialist function
SRB	solid rocket booster
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
TIG	time of ignition
TK	tank
TRANS	transition
TRANSDAP	transition DAP
TTA	time to apogee
TTC	time to circularize
TTP	time to perigee
TVC	thrust vector control
U	Up
VERN	Vernier RCS jet
VGOX, Y, Z	velocity-to-go in X, Y, and Z directions
VLV	valve
WT	weight
XFEED	crossfeed
Y	yaw
ΔV	velocity change
ΔVTOT	total velocity change
ΔVX, Y, Z	velocity change in X, Y, and Z directions
θT	target angle

APPENDIX B ANSWERS

SECTION 2 ANSWERS

1. No. If an OMS engine is shutdown during a burn by taking the OMS engine switch to OFF, a purge will not occur. A purge will only occur when the switch is in the ARM/PRESS position. Taking the switch to OFF at any time inhibits the purge sequence.

2. (a) The left OMS engine will burn because the switch is in ARM.

   (b) The left OMS engine will not have a purge at the end of the burn because the switch is not in ARM/PRESS.

   (c) OMS gauging will work for the left pod. OMS gauging will function as long as one OMS engine is on.

   (d) OMS gauging will work for the right pod. OMS gauging will function for both pods as long as either engine is on.

3. If the A helium press valve is closed and the B helium press valve is open, both vapor isolation valves will be open. Both valves will be open whenever either helium press valve is open.

4. If an OMS engine failed during a 2 Engine OMS burn, the larger attitude change will be in the yaw axis. This change could be seen on the ADI. First the shuttle would yaw to the side of the failed engine and then retrim to a single engine configuration. (Single engine trim would be yawed roughly 12 degrees to the side of the burning engine.)

5. No. If both OMS engines are off and OMS propellant is being fed to the RCS jets, the BFS GNC Systems Summary 2 display does provide information on OMS quantity. The display includes the aft probe quantity, but that will not be updating if both OMS engines are off.

6. Yes. If the left OMS engine valve switch on panel O14 is turned off during a burn, the engine will stop burning immediately. Taking the switch to OFF removes power from both engine control valves, and they will close and thereby shut down the engine.

7. If there is a pitch gimbal error of 0.56º and a yaw error of 0.39º, the yaw actuator will not move because the error is less than 0.4º. The pitch actuator will move approximately 0.5º to correct the error of 0.56º.

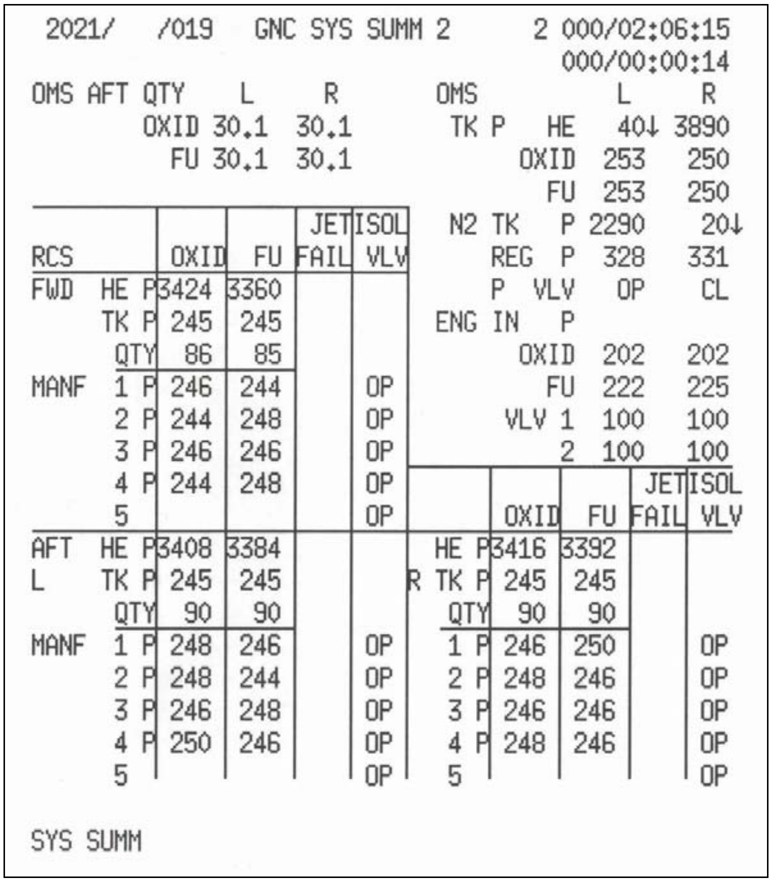


Figure B-1. Example GNC Systems Summary 2 display

8. Yes. Both OMS engines are burning. Left and Right OMS bipropellant valves are fully open. (100%)

9. Yes. There is a way to double check the reading of 40 psi for the left OMS helium tank pressure on the display. The MEDS display uses a separate pressure sensor.

10. According to the display, the left N_2 press valve is open. It could be closed without turning OFF the OMS engine by putting the left OMS engine switch in the ARM position.

11. According to the display, the right OMS N_2 tank pressure is at 20 psi. You could use the MEDS display to verify that this is not a sensor failure. The MEDS display provides an N_2 tank pressure reading from a separate sensor.

SECTION 3 ANSWERS

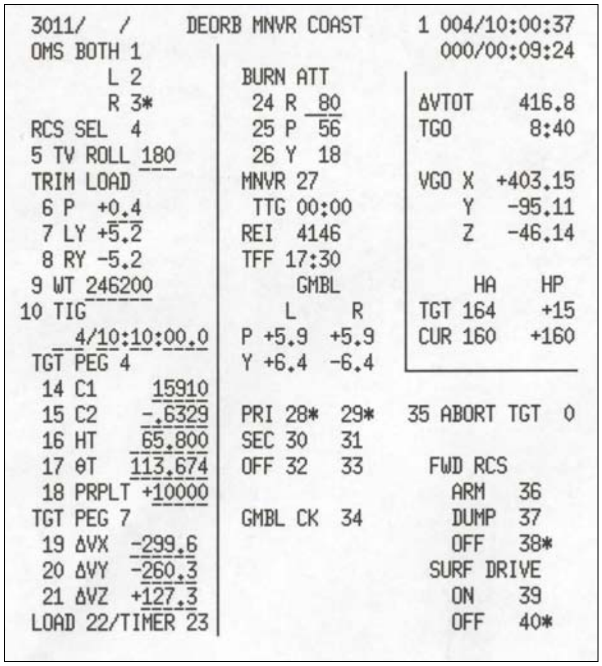


Figure B-2. Example GNC Systems Summary 2 display

1. The right OMS engine will be used for the burn. Item 3 is selected.

2. The right engine pitch actuator and yaw actuator will be driven by the primary motors. Primary is selected with Item 29.

3. The OMS burn will start at 4/10:10:00.0 and end at 4/10:18:40. The MET at TIG will be 4/10:10:00, and the burn duration should be equal to TGO (8:40).

4. The current perigee altitude is 160 nm. It will be changed by 145 nm by the burn.

5. The display does not indicate the correct configuration for starting a deorbit burn. The display indicates that the software is in MM 301. A transition to MM 302 is necessary before a burn can be started.

6. It is preferable to be in free drift when setting up an OMS-to-RCS interconnect, because the RCS jets have no propellant supply for a short time during the interconnect procedure, and jets would fail off if commanded to fire. When the vehicle is in free drift, no RCS jets are commanded to fire.

7. The approximate range (in percent) of the ungaugable region is 45 to 30 percent.

SECTION 4 ANSWERS

1. Down arrows for the OMS engines would appear as indicated in each of the following situations.

   (a) Left OMS Pc is 0 percent, and a ΔV loss is detected.

   The Left OMS engine is indicated to be failed.

   OMS BOTH*
   L ↓
   R

   (b) FA4 is failed, the right OMS Pc is 0 percent, and a ΔV loss is detected.

   There is no down arrow because the R OMS Pc data is commfaulted even though the right engine has failed.

   OMS BOTH*
   L
   R

   (c) The left OMS P indicated 0 percent, but no ΔV loss is detected.

   There is no down arrow because no ΔV loss was detected. The engine must still be providing thrust.

   OMS BOTH*
   L
   R

2. In the cases above there would be an OMS PC FAIL message in a & c.

3. The capabilities (left or right OMS engine ignition, left or right primary or secondary TVC) that would be lost with the listed failures are as follows.

   (a) Main A and FA1 – Left engine ignition, left primary TVC, right secondary TVC

   (b) Main C and control bus CA2 – Right engine ignition, right primary TVC

   (c) FA3 and FA4 – Right primary TVC, right secondary TVC

   (d) FF1 and control bus BC2 – Left primary TVC

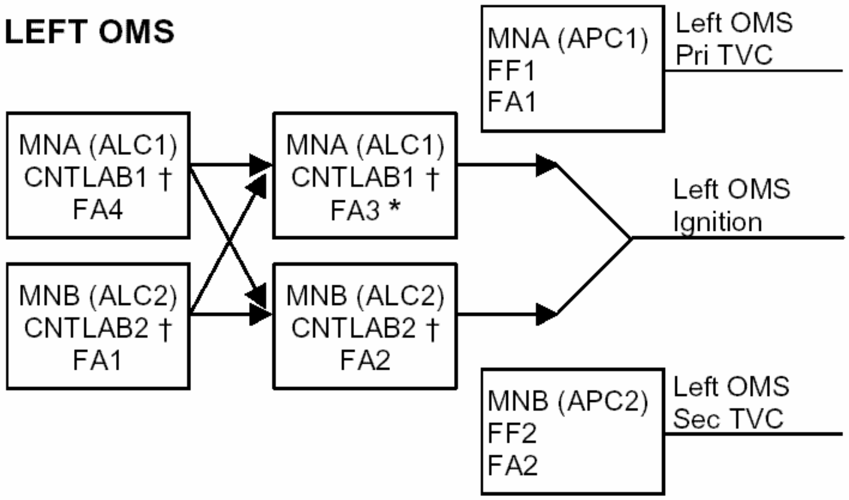
   (e) FA2 and FF2 – Left secondary TVC

HOOK VELCRO

OMS FAILURES

HOOK VELCRO

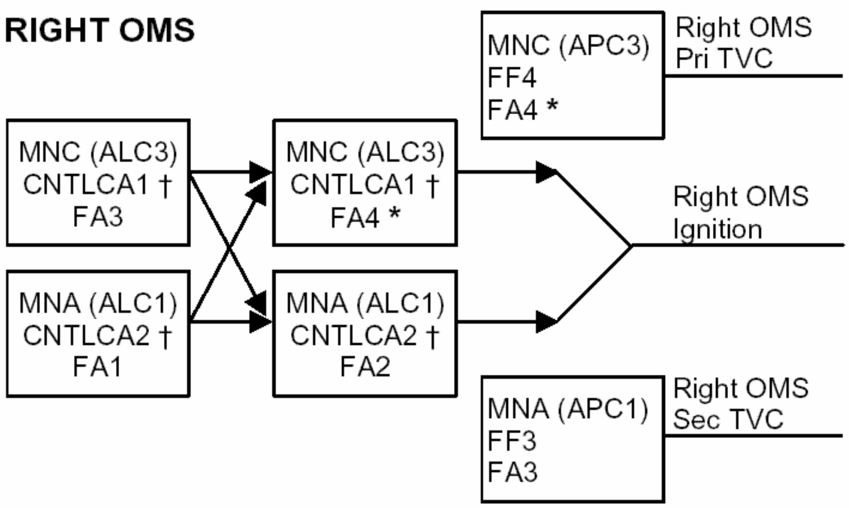
LEFT OMS



† If CNTL AB1 or AB2 (CA1 or CA2) failed and ign path still exists at OMS fail, assume L(R) OMS ↓ is PRPLT FAIL

* If L(R) Pc failed high during burn, or FA3(4) failed, at L(R) OMS fail, no guidance downmode after L(R) OMS ENG switch OFF (TGO slow, ADI needles in error, 6 ft/s underburn)

RIGHT OMS



If two FA MDMs lost		
MDMs	Preburn: ENG – OFF	During burn: MAN SHUTDN
1,2	LEFT (TVC)	BOTH
1,3	RIGHT (IGN)	LEFT
1,4	LEFT (IGN)	RIGHT
2,3	LEFT (IGN)	RIGHT
2,4	RIGHT (IGN)	LEFT
3,4	RIGHT (TVC)	BOTH

APPENDIX C SUGGESTED REFERENCE DOCUMENTS

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

9. The Shuttle Crew Operations Manual (SCOM) is a reference document for space shuttle crew members. It contains condensed information from a large number of space shuttle publications such as the FPH, FDF, workbooks, flight rules, and the SODB.

USA006500
Rev. A

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: **Orbital Maneuvering System Workbook 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. The lesson objectives are clearly stated.	☐	☐	☐	☐	☐	☐
b. The lesson objectives are clearly defined.	☐	☐	☐	☐	☐	☐
c. The lesson effectively teaches skills and information.	☐	☐	☐	☐	☐	☐
d. The lesson meets its purpose and objectives.	☐	☐	☐	☐	☐	☐

2. How satisfying is the content of this lesson?
For each statement below, mark one box on the scale:

	Strongly Disagree					Strongly Agree
a. The information is structured in a logical flow.	☐	☐	☐	☐	☐	☐
b. The content is clear.	☐	☐	☐	☐	☐	☐
c. The content is complete.	☐	☐	☐	☐	☐	☐
d. The level of detail is correct for this information.	☐	☐	☐	☐	☐	☐
e. The amount of information is effective.	☐	☐	☐	☐	☐	☐
f. The graphics contribute to my understanding.	☐	☐	☐	☐	☐	☐

3. How appealing was the presentation of this lesson?
For each statement below, mark one box on the scale:

	Strongly Disagree					Strongly Agree
a. The overall presentation is appealing.	☐	☐	☐	☐	☐	☐
b. The visuals chosen are appropriate for the lesson.	☐	☐	☐	☐	☐	☐
c. The visuals make the information more interesting.	☐	☐	☐	☐	☐	☐
d. The graphics are legibly reproduced.	☐	☐	☐	☐	☐	☐
e. The audio/visual or print quality is good.	☐	☐	☐	☐	☐	☐

4. How valuable is this information?
For each statement below, mark one box on the scale:

	Strongly Disagree					Strongly Agree
a. The lesson teaches skills and information I need.	☐	☐	☐	☐	☐	☐
b. The lesson meets my expectations.	☐	☐	☐	☐	☐	☐
c. This information is useful for later reference.	☐	☐	☐	☐	☐	☐
d. I would recommend this lesson to others.	☐	☐	☐	☐	☐	☐

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!

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