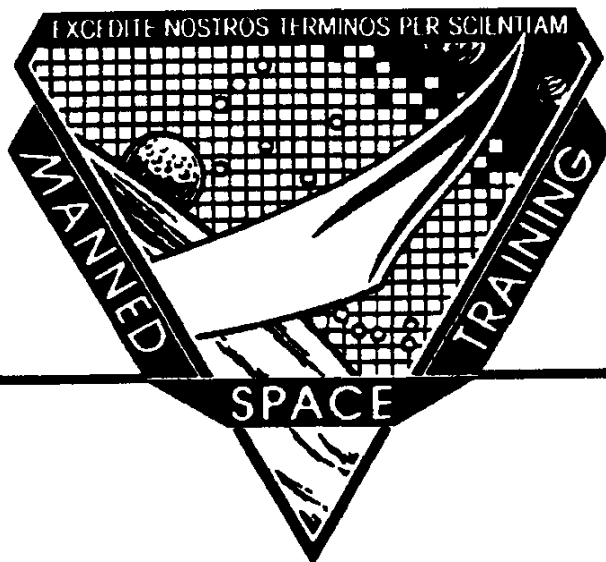


# Orbital Maneuvering System

## Orbiter Systems Training Manual OMS 2102

April 1995



**NASA**

National Aeronautics and  
Space Administration

Lyndon B. Johnson Space Center  
Houston, Texas

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OMS 2102

April 1995

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# Acknowledgments

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# Foreword

The content of this document was provided by the Network Simulation Systems Group, Communications and Payloads Training Branch, 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 training manual or any recommendations should be directed to the training manual book manager, Bill West, at (713) 483-3982/DT66.

This material is for training purposes only and should not be used as a source of operational data. All numerical data, displays, and checklist references are intended as examples. To determine any prerequisites before using this document, consult the applicable Certification Plan. For shuttle manuals, consult the Flight Operations Support Personnel Training Guide (Blue Book) or the Crew Training Catalog. For Space Station manuals, consult the appropriate Space Station Certification Training Guide or Training Administration Management System (TAMS). The applicable training package should be studied before attending any classroom session or lesson for which this is a prerequisite.

A Training Materials Evaluation is included at the end of this document. Inputs on this sheet will be used to evaluate the lesson material. You do not need to sign the sheet.

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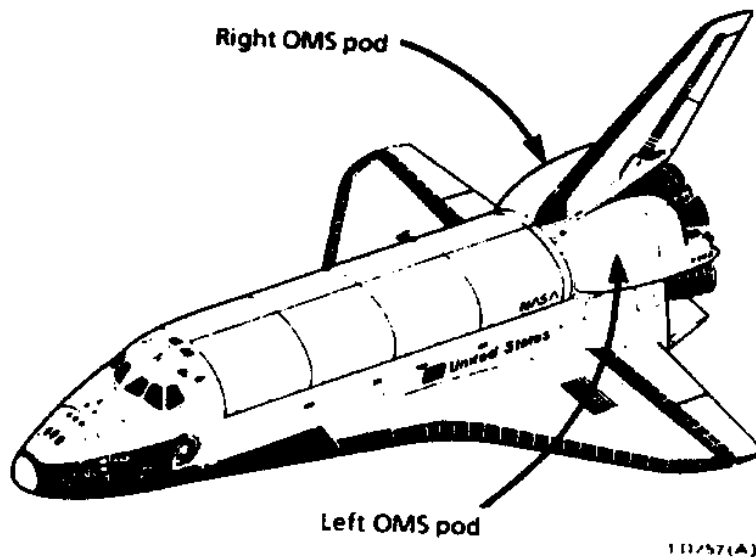
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# Section 1: Introduction

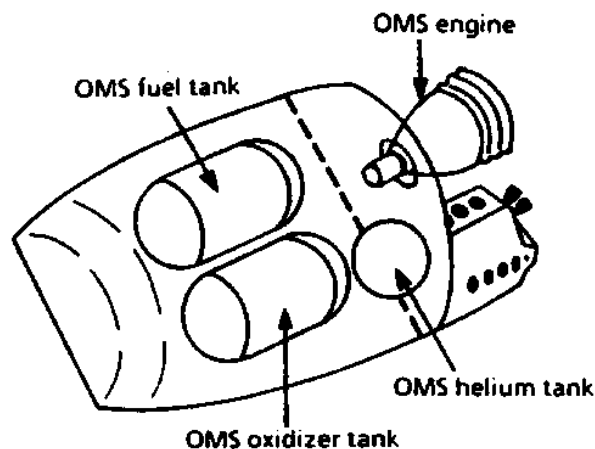
The orbital maneuvering system (OMS) provides propulsion for the space shuttle vehicle during the orbit phase of flight. It is used for orbital insertion maneuvers after the main propulsion system has shut down. It is also the primary propulsion system for orbital transfer maneuvers and the deorbit maneuver.

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 feedlines 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. These propellants are hypergolic, which means that they ignite when they come in contact with each other and so no ignition device is needed. This adds reliability to the system, but the propellants are very corrosive and poisonous 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.

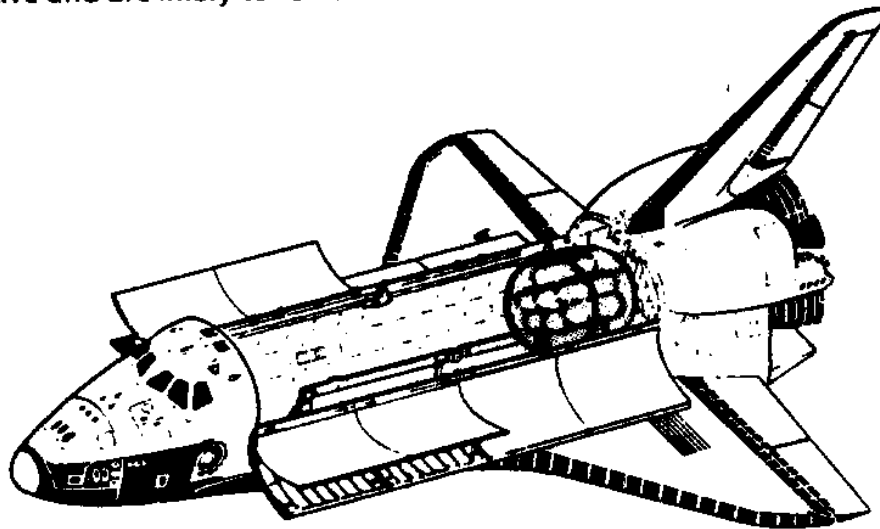
An automatic computer sequence controls all OMS burns. To start an OMS burn, the crew must load a burn target that includes a specific time of ignition (TIG). The burn starts automatically at TIG if all the controls are configured properly and stops automatically when the burn target is satisfied. The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

The OMS engines are located in gimbal mounts that allow the engine to pivot left and right and up and down under the control of electromechanical actuators. This gimbal system provides for vehicle 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.

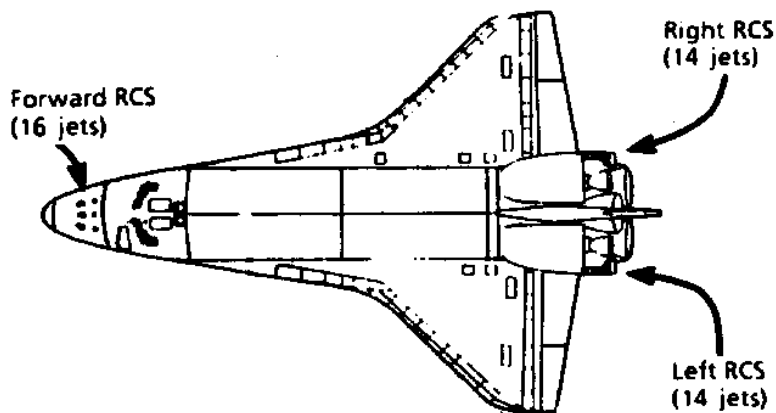
Each OMS engine produces 6000 lb of thrust with an ISP (Specific Impulse) of 313 seconds. For a typical Orbiter weight, both engines together create an acceleration of approximately 2 ft/sec<sup>2</sup> or 0.06g. Using all the propellant loaded, the OMS can provide a total velocity change ( $\Delta V$ ) of approximately 1000 ft/sec. Orbital insertion burns and deorbit burns each typically require a  $\Delta V$  of about 200 ft/sec. The  $\Delta V$  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  $\Delta V$  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 gages located in the orbiter. These switches and gages are currently inoperative and are likely to remain so.



**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, 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 cathode-ray tube (CRT) displays.

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.

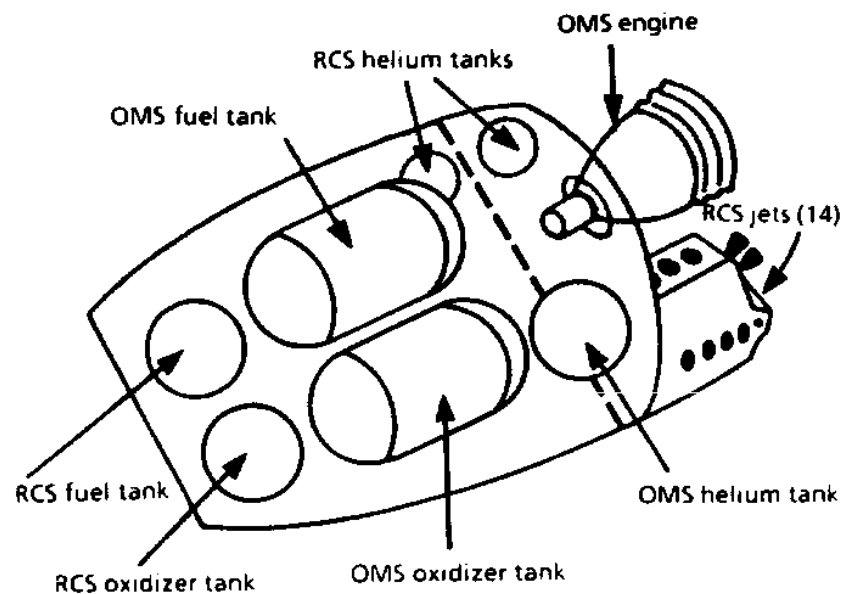
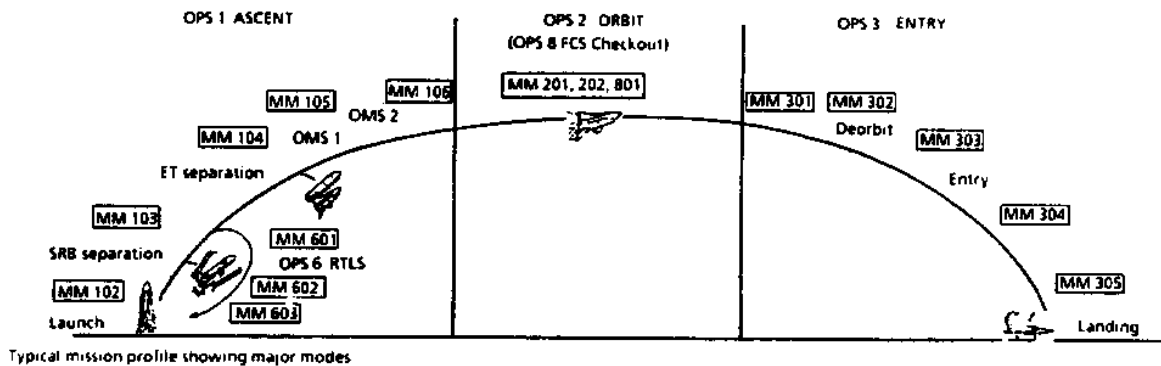


Figure 1-5. OMS pod with RCS tanks and jets

OPS 1: Ascent	MM 101	Prelaunch
	MM 102	First stage of ascent: Lift-off to solid rocket booster (SRB) separation
	MM 103	Second stage of ascent: SRB separation to external tank (ET) separation
	MM 104	Orbital insertion maneuver (OMS 1)
	MM 105	Orbital circularization maneuver (OMS 2)
	MM 106	Post-OMS 2 coast
OPS 2: Orbit	MM 201	Orbit coast
	MM 202	Orbital maneuver
OPS 8: Orbit	MM 801	Flight control system (FCS) checkout
OPS 3: Entry	MM 301	Pre-deorbit coast
	MM 302	Deorbit maneuver
	MM 303	Post-deorbit coast
	MM 304	Early phase of entry
	MM 305	Terminal phase of entry
OPS 6: Return to launch site (RTLS) abort	MM 601	Powered RTLS: RTLS selection to ET separation
	MM 602	Gliding RTLS: Early phase
	MM 603	Gliding RTLS: Terminal phase

**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 book 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 training manual on insertion, orbit, and deorbit guidance and control.

## Section 2: System Description

In this section the following components of the OMS will be discussed:

- Engine and nitrogen system
- Propellant and helium supply
- Thermal control
- Thrust vector control

### OMS Engine

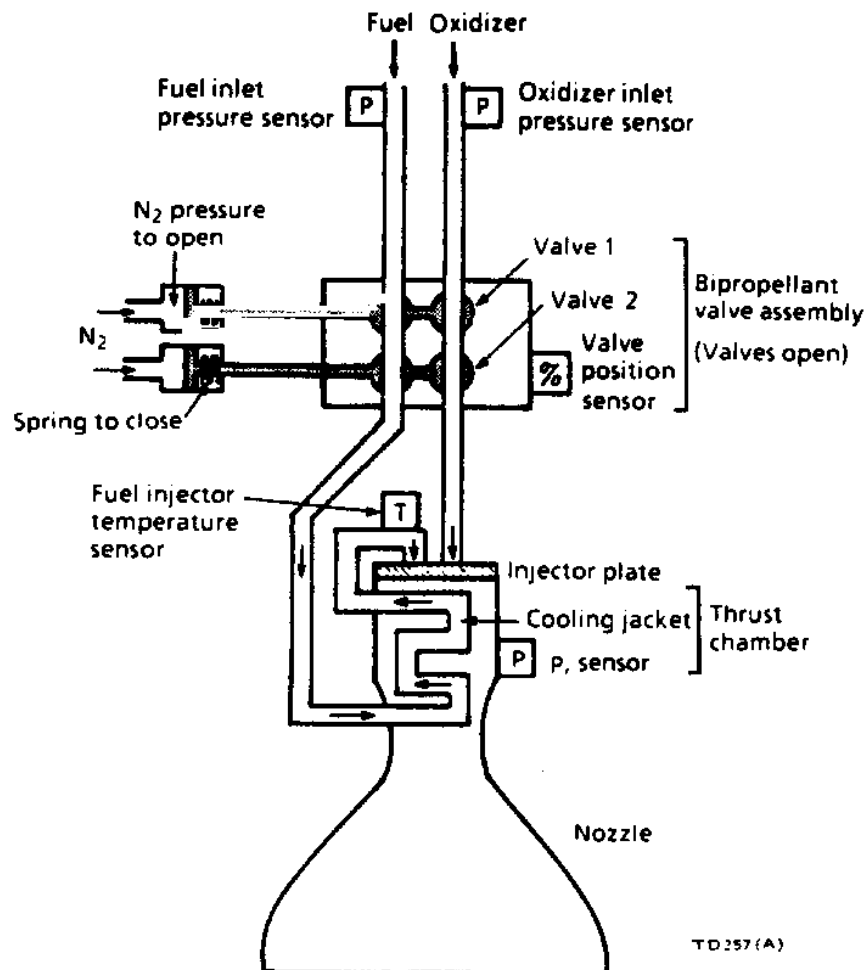


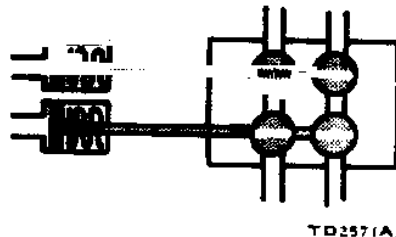
Figure 2-1. OMS schematic

## 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. 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 by the crew 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).

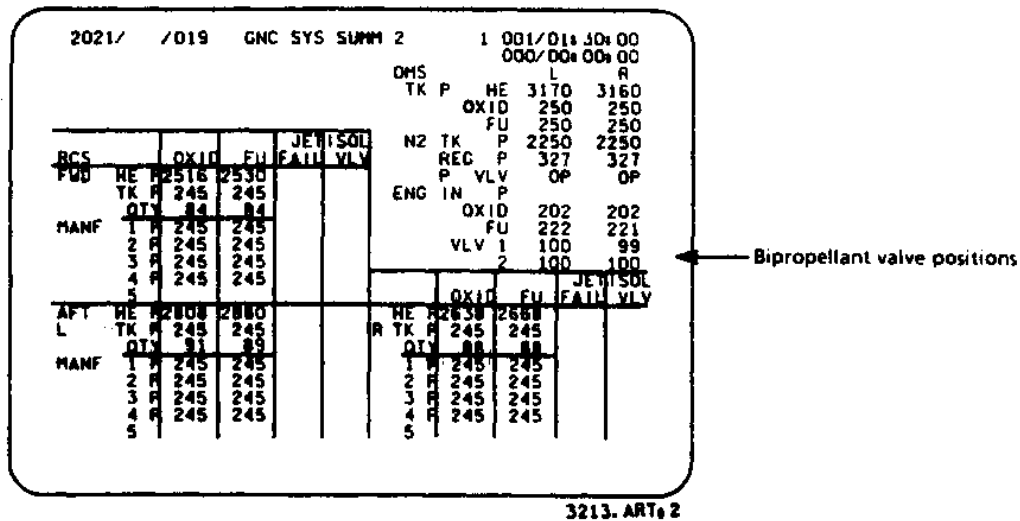


Figure 2-3. BFS GNC System Summary 2 display

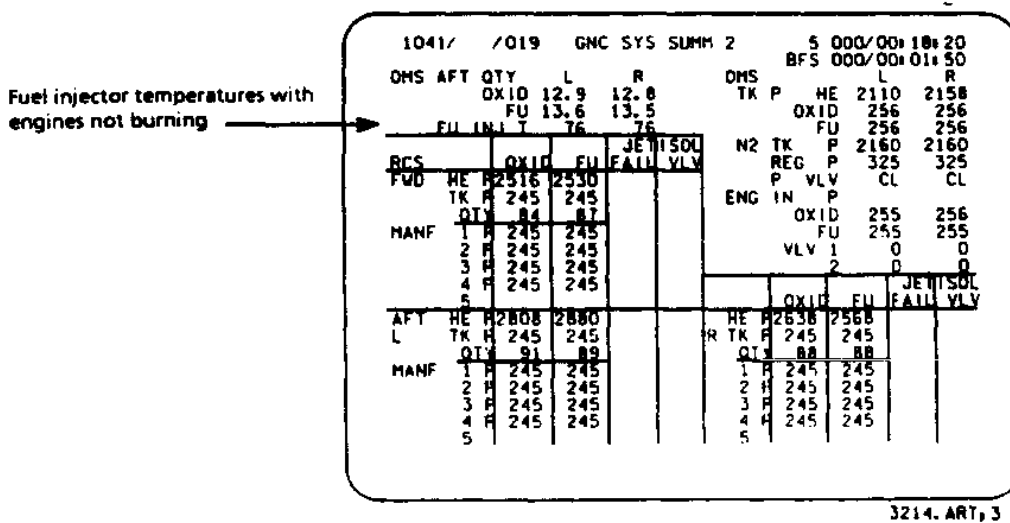


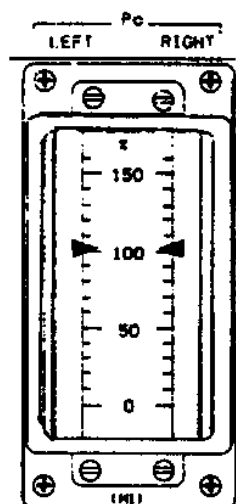
Figure 2-4. PASS GNC System Summary 2 display

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 30° and 125°F. During engine operation, when the fuel is cooling the chamber, the fuel injector temperature should be approximately 202°F. The temperature limit for safe operation is 260°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 that is wired directly to the OMS  $P_c$  gage on panel F7 (see figure 2-5). The gage is calibrated in percent. The normal  $P_c$  during a burn is between 100 and 102 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 220 psi for the fuel and 200 psi for the oxidizer, but the propellant tank pressures remain higher.



**Figure 2-5. OMS  $P_c$  gage on panel F7**



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.

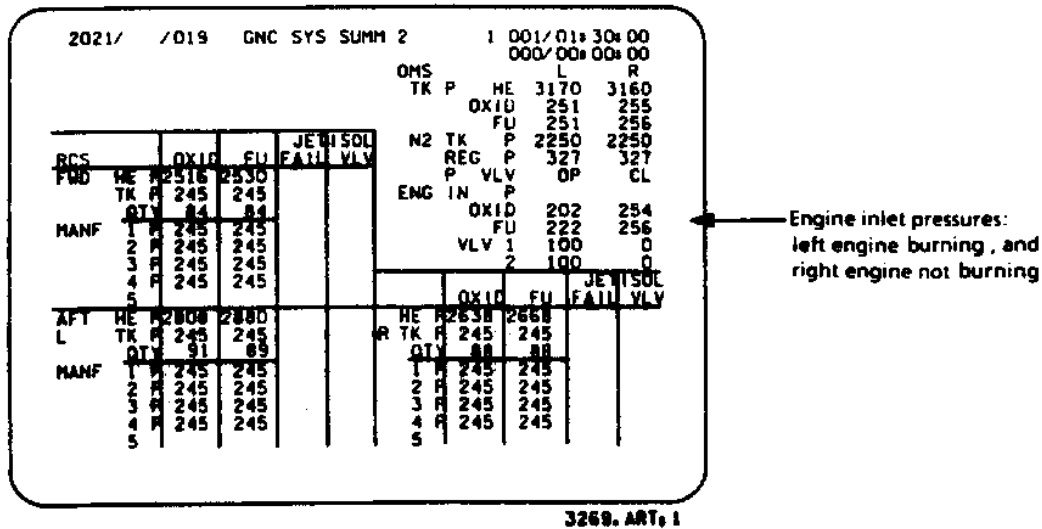


Figure 2-6. GNC SYS Summ 2 display/Eng in P's

## Nitrogen System

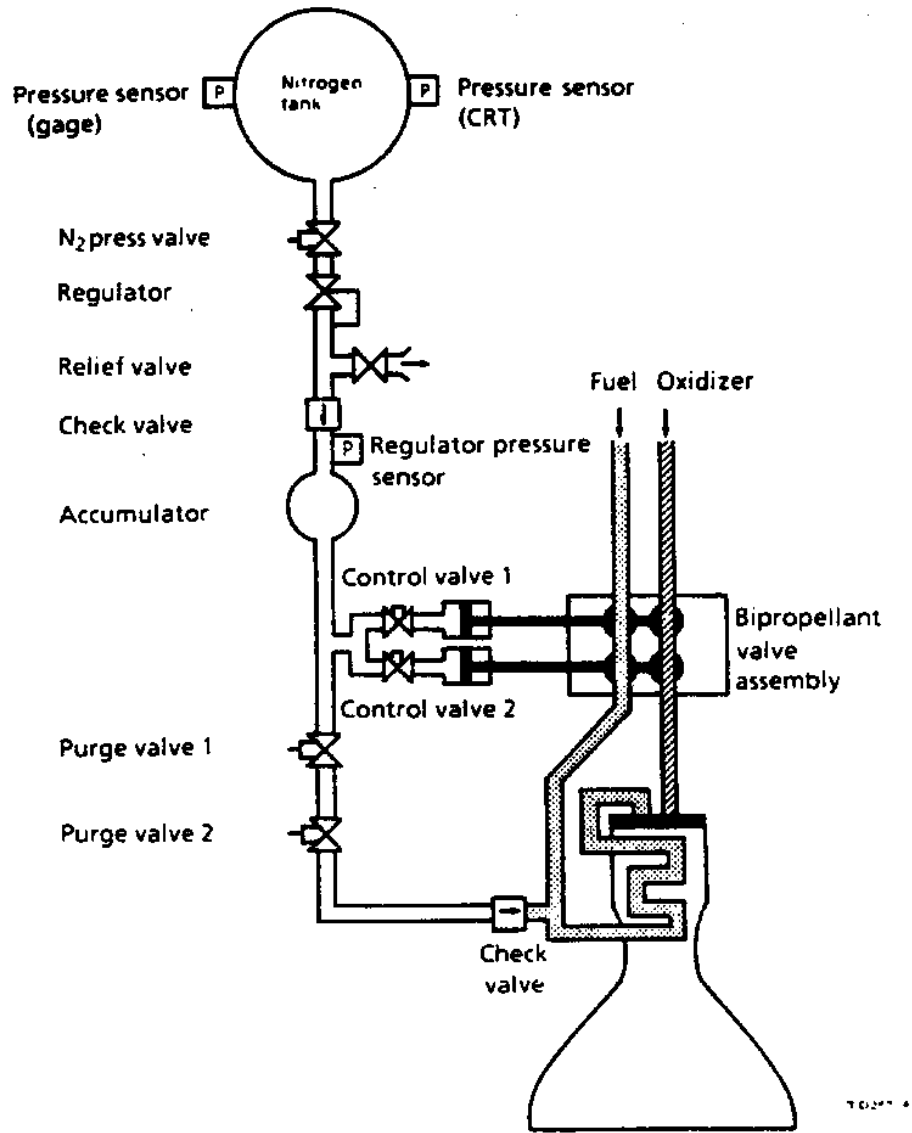
Gaseous nitrogen ( $\text{GN}_2$ ) is used to operate the engine control valves as already described and also to purge the fuel lines at the end of each burn (see figure 2-7). Each engine has a nitrogen supply tank that contains enough nitrogen to support about 15 OMS burns. The nitrogen tank has an isolation valve called the nitrogen pressurization valve or  $\text{N}_2$  press valve. (This valve is sometimes called the engine press valve.) The  $\text{N}_2$  press valve must be open for nitrogen to reach the OMS engines. The  $\text{N}_2$  press valve is controlled by the OMS engine switch on panel C3. When this switch is in the ARM/PRESS position, the  $\text{N}_2$  press valve opens. When the OMS engine switch is in any other position (ARM or OFF), the  $\text{N}_2$  press valve remains closed.

The OMS engine switch is normally placed in the ARM/PRESS position by the crew before each OMS burn and is left in the OFF position at all other times. The status of the  $\text{N}_2$  press valve can be seen on the GNC Systems Summary 2 display, which reads OP for open and CL for closed. 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  $\text{N}_2$  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  $\text{N}_2$  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 sublime, but for the first 10 minutes or so following a burn it might be dangerous to start another burn, since forcing more fuel into already frozen lines could cause damage. This situation is avoided by forcing nitrogen through the fuel lines immediately after the engine shuts down. This purge is part of the automatic OMS burn sequence and takes about 2 seconds. When a burn ends, the control valves close and the purge valves open. Nitrogen can then flow into the fuel line below the bipropellant valves, where it forces the remaining fuel through the inlet lines and cooling jacket and out through the engine.

### Nitrogen System



**Figure 2-7. Nitrogen system schematic**

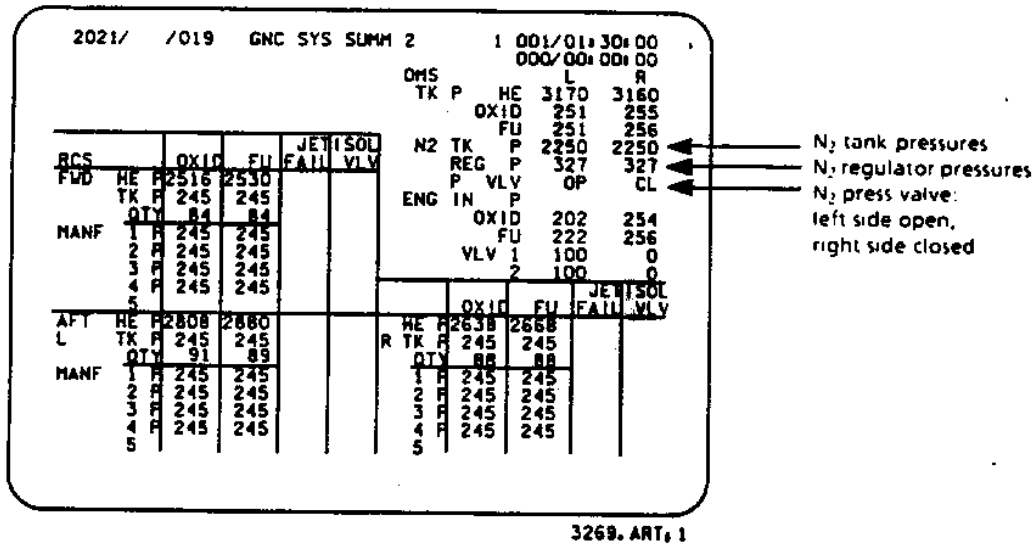


Figure 2-8. GNC system summary 2 display/N2

The automatic software will perform the purge only if the OMS engine switch is in the ARM/PRESS position and, therefore, when the N<sub>2</sub> 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<sub>2</sub> press valve is open, nitrogen for the purge is supplied by the tank. If the N<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> press valve is closed and the engine purge is automatically inhibited.

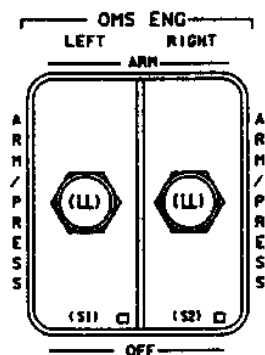
The nitrogen tank has two pressure sensors. One is wired directly to a pressure gage on panel F7. The reading from the other sensor can be found on the GNC System Summary 2 display (see figure 2-8). There is also a pressure sensor located below the regulator and check valve. Its reading is found on the GNC System Summary 2 display as REG P, and it is an indication of the accumulator pressure.

## OMS Engine Switches

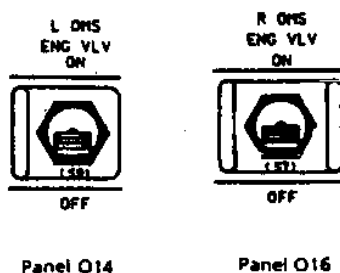
There are two sets of switches that affect OMS engine burns: the OMS engine switches and the OMS engine valve switches (see figure 2-9). There is an OMS engine valve switch for each engine (the switch for the left engine is on panel O14, and the one for the right engine is on panel O16). These switches provide power to the engine control valves. They must be in the ON position in order for the engine to burn.

The OMS engine switches on panel C3 have three positions, and it might be helpful to summarize the meaning of each position:

- ARM/PRESS: OMS ignition will occur, and the engine purge is enabled (the N<sub>2</sub> press valve is open)
- ARM: OMS ignition will occur but the engine purge will not occur (the N<sub>2</sub> 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.



OMS engine switches on panel C3



Panel O14

Panel O16

Figure 2-9. OMS engine valve switches

## Helium Tanks

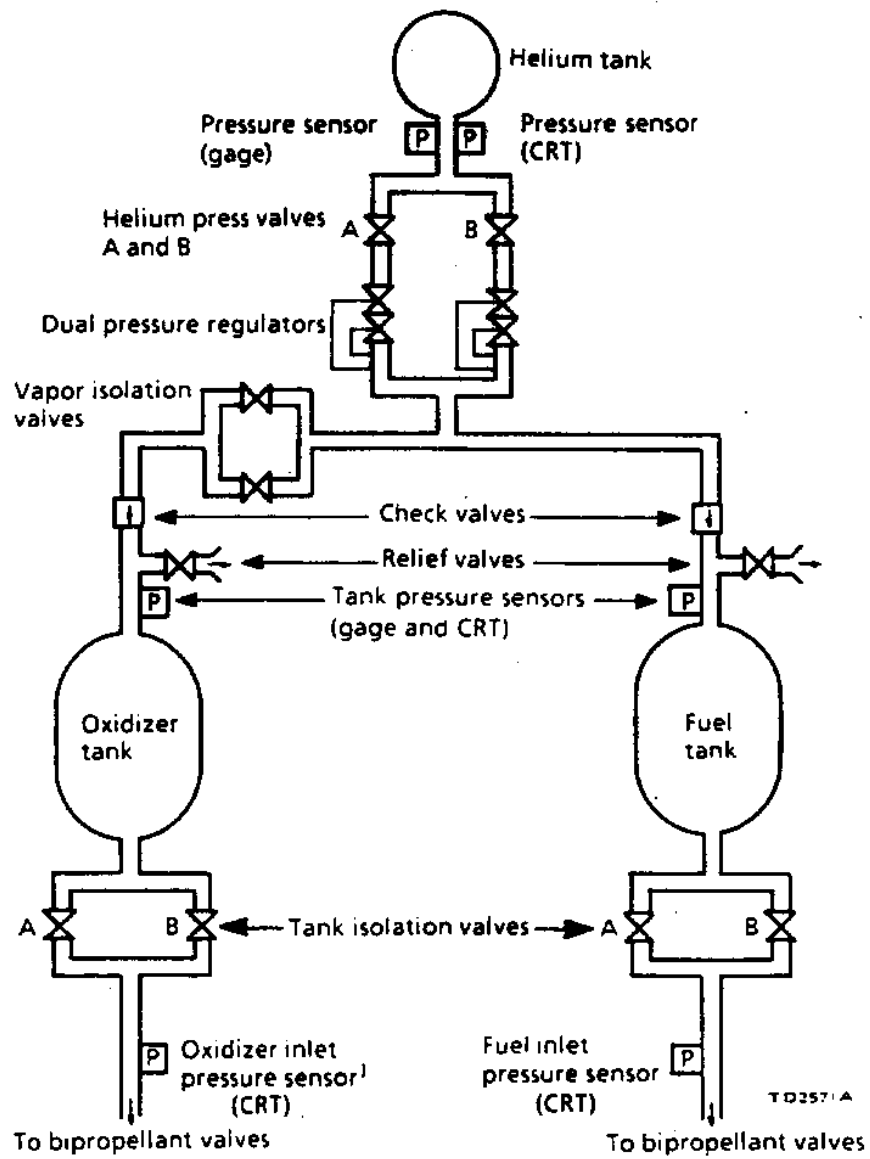
Oxidizer and fuel are supplied to each OMS engine by separate sets of propellant tanks (see figure 2-10). The OMS engine does not have fuel or oxidizer pumps, so the propellant flow must be maintained by keeping the tanks pressurized with helium. A single helium tank provides pressurization to the fuel 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.

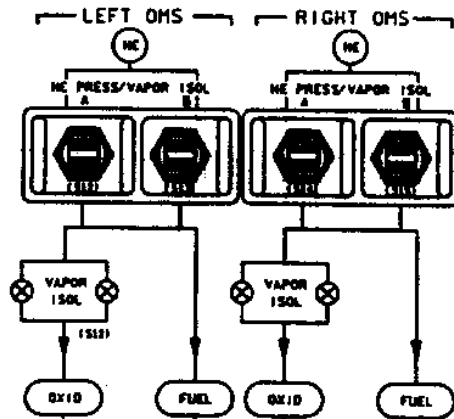
Below each helium press valve there is a pressure regulator that reduces the helium pressure from its value in the tank, which can be as high as 4800 psia (at launch) to a working pressure of approximately 250 psig. Below the regulators, the two helium lines rejoin and then split into one line that runs 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.

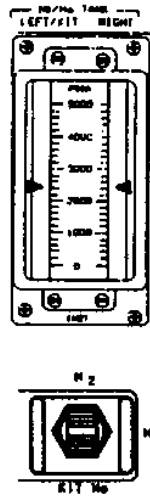
There are two pressure sensors in the helium tank. One is wired directly to a gage on panel F7 (see figure 2-11), and the reading from the other sensor appears on the GNC Systems Summary 2 display (see figure 2-12).



**Figure 2-10. Propellant and helium supply schematic**



OMS helium press/vapor isolation switches on panel O8



OMS helium and nitrogen tank pressure gages on panel F7. The switch below the gages is used to select  $N_2$ , helium, or kit helium tank pressure for display.

**Figure 2-11. OMS gages on panel F7 and He press/vapor isolation switches on panel O8**



## 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.

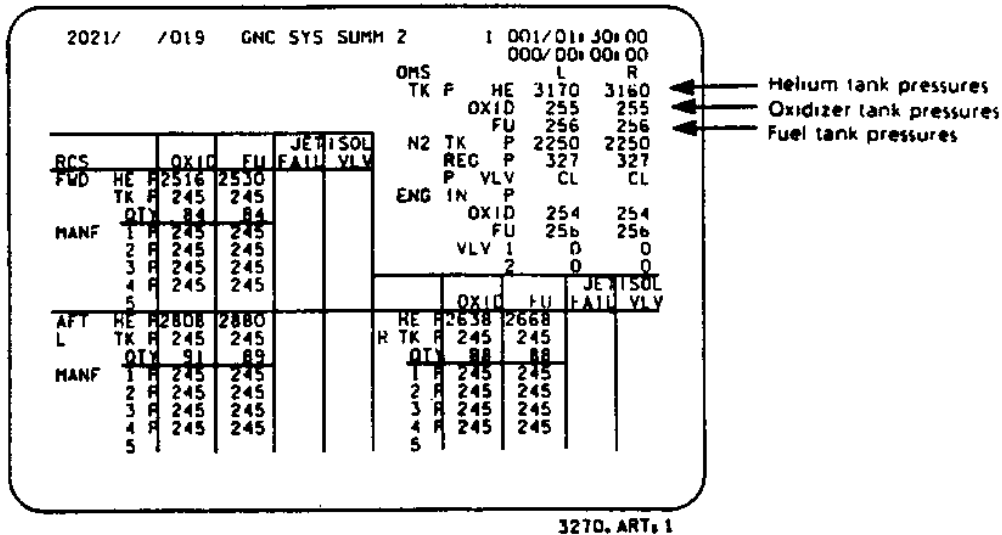


Figure 2-12. GNC system summary 2 display/tank pressures

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.

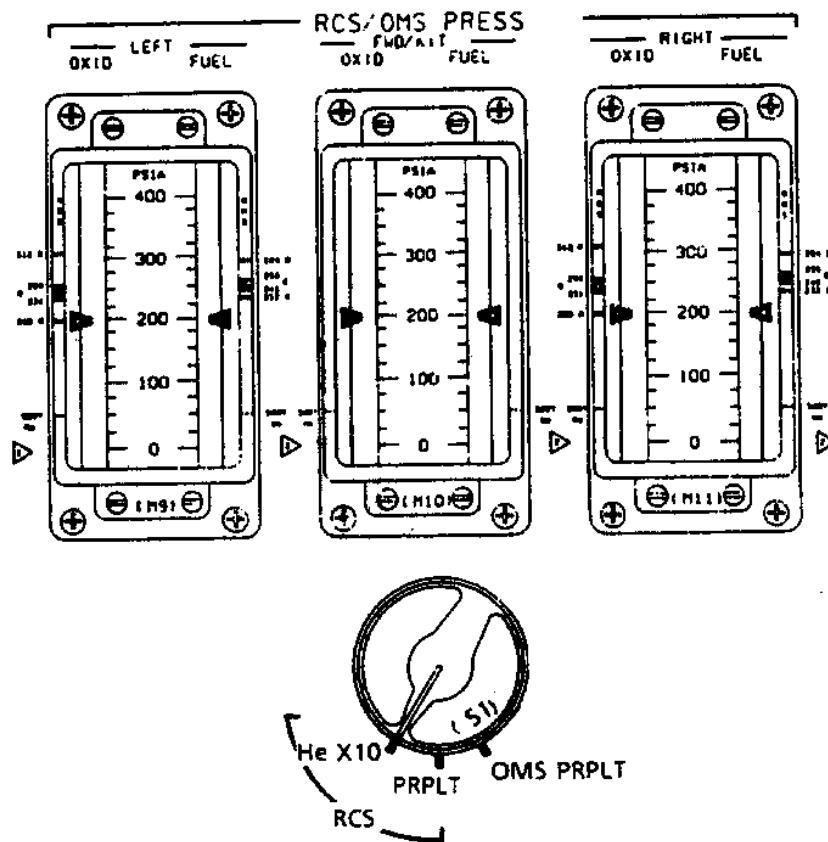
Each of the propellant tanks has one pressure sensor. This sensor is wired directly to a gage on panel O3 (see figure 2-13). The same measurement also appears on the GNC Systems Summary 2 display (see figure 2-12). This is different from the OMS helium and nitrogen tanks for which the gage and display 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 gaging is described later in this section.

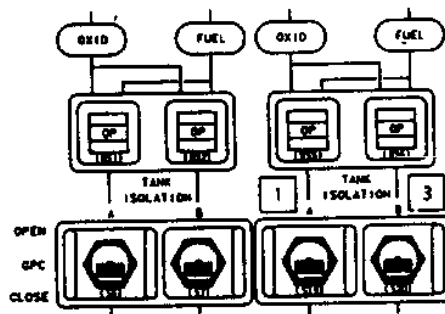
Each propellant tank has a set of tank isolation valves. These are the A and B tank isolation valves, and they are arranged in parallel to provide redundant paths for the propellant. The valves are driven open and closed by ac motors that normally use three-phase ac power but can operate on two-phase 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.



The dial below the gages is used to select OMS or RCS tank pressures for display.

**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**

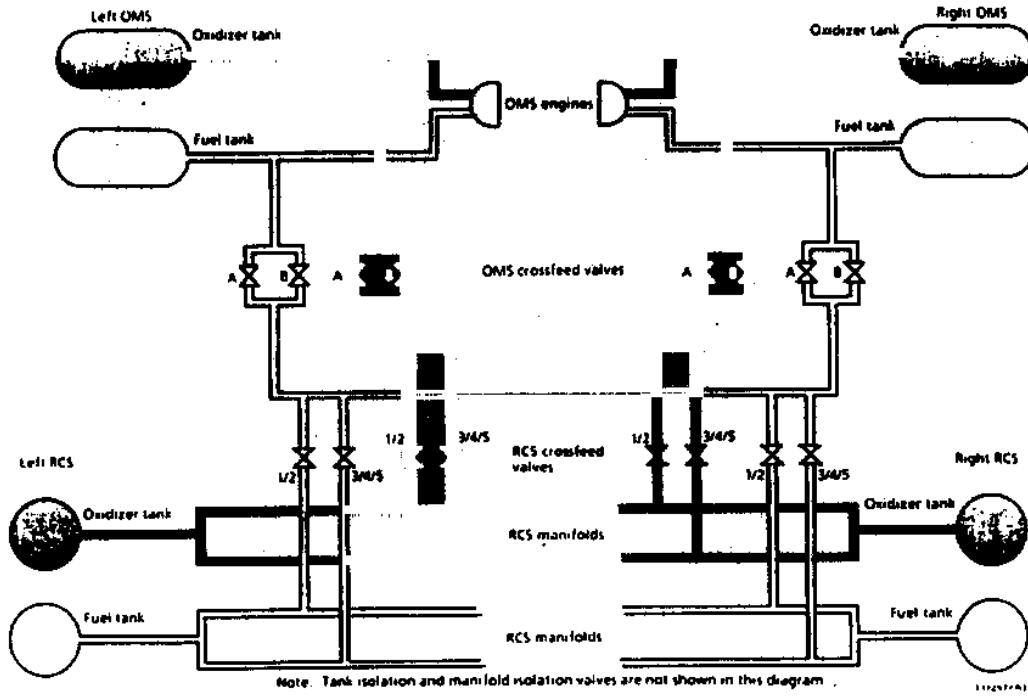
It is possible to feed the engine in one pod with propellant from the other pod. This is called an OMS crossfeed and would be done to balance the propellant weight in each pod or in situations where an OMS engine has failed.

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 the 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 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 Gaging

The gaging of OMS propellant quantity is accomplished by a combination of physical measurement with a probe inside the tank and computations performed by the gage 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 gaging 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 gaging 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 03.

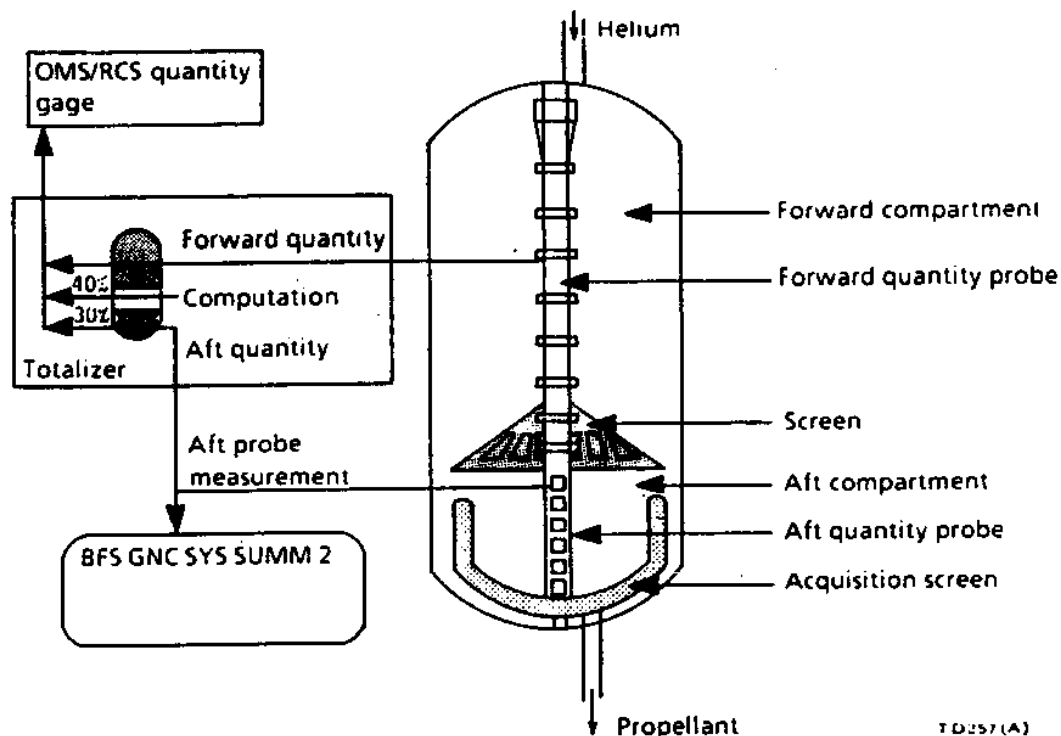
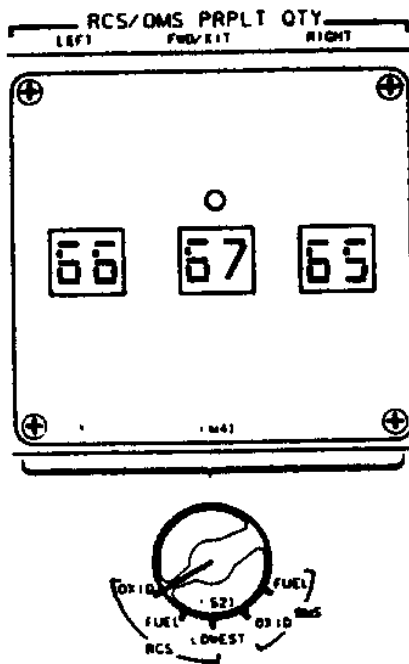


Figure 2-16. OMS quantity gaging

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



**Figure 2-17. OMS quantity meter on panel O3**

The output of the gage 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 BFS 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 ungagable 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.

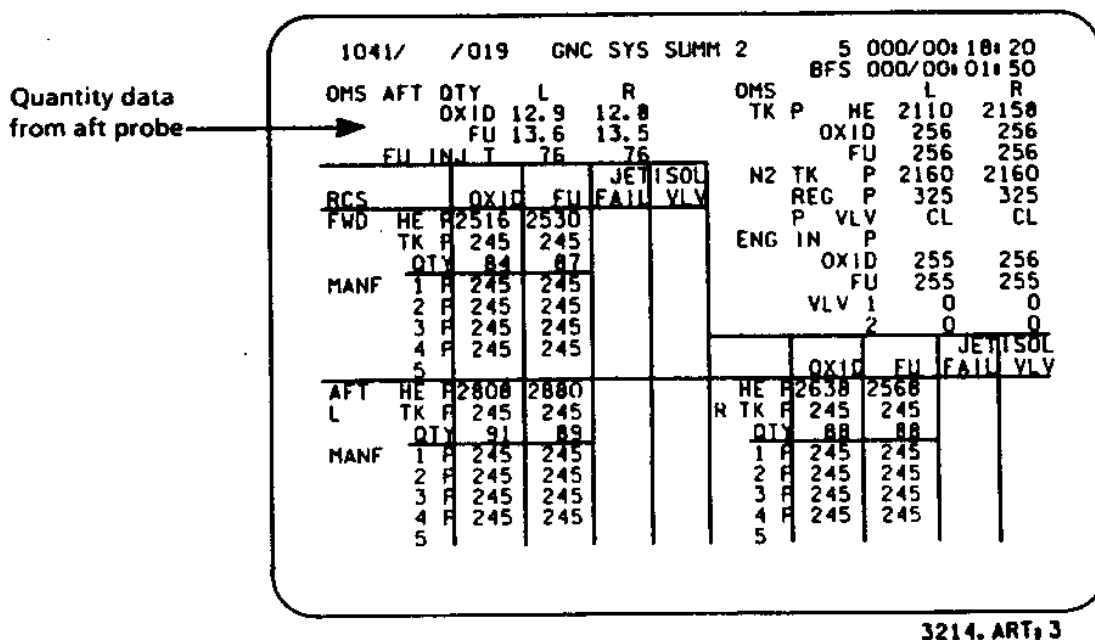


Figure 2-18. Quantity data on GNC Sys Summ 2



## 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 55° and 90° F. In the OFF position the heaters remain off at all times. Only one of the two heater 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 function when a kit is onboard. There are other switches on panel A14 for RCS heaters.

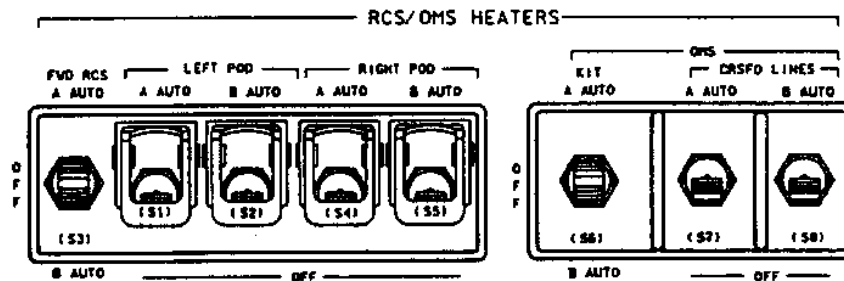


Figure 2-19. OMS heater switches on panel A14

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

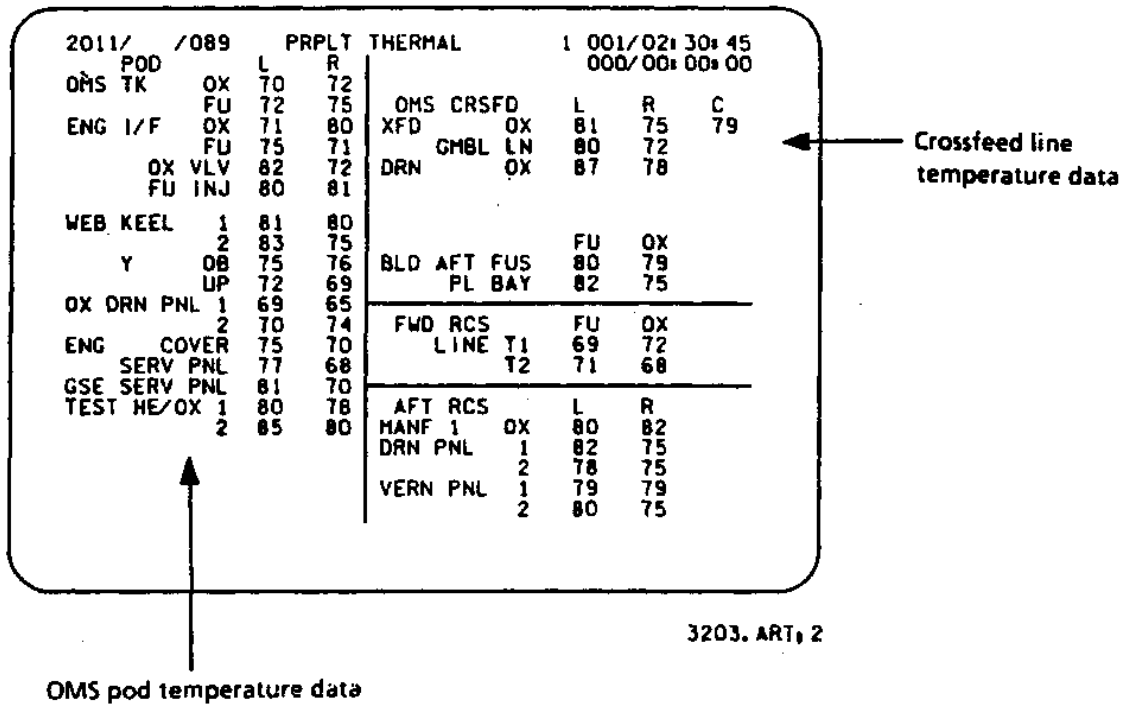


Figure 2-20. SPEC 89 propellant thermal display

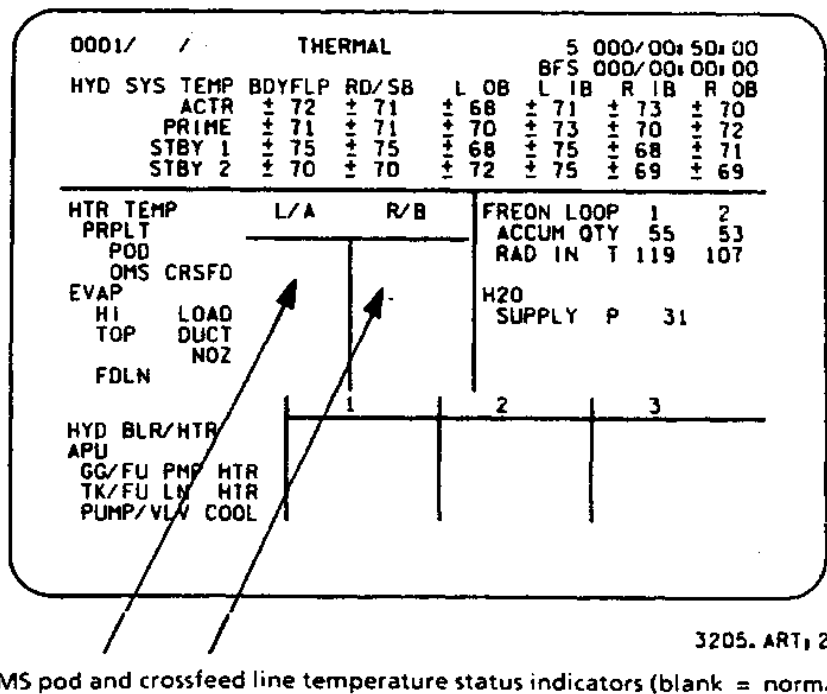


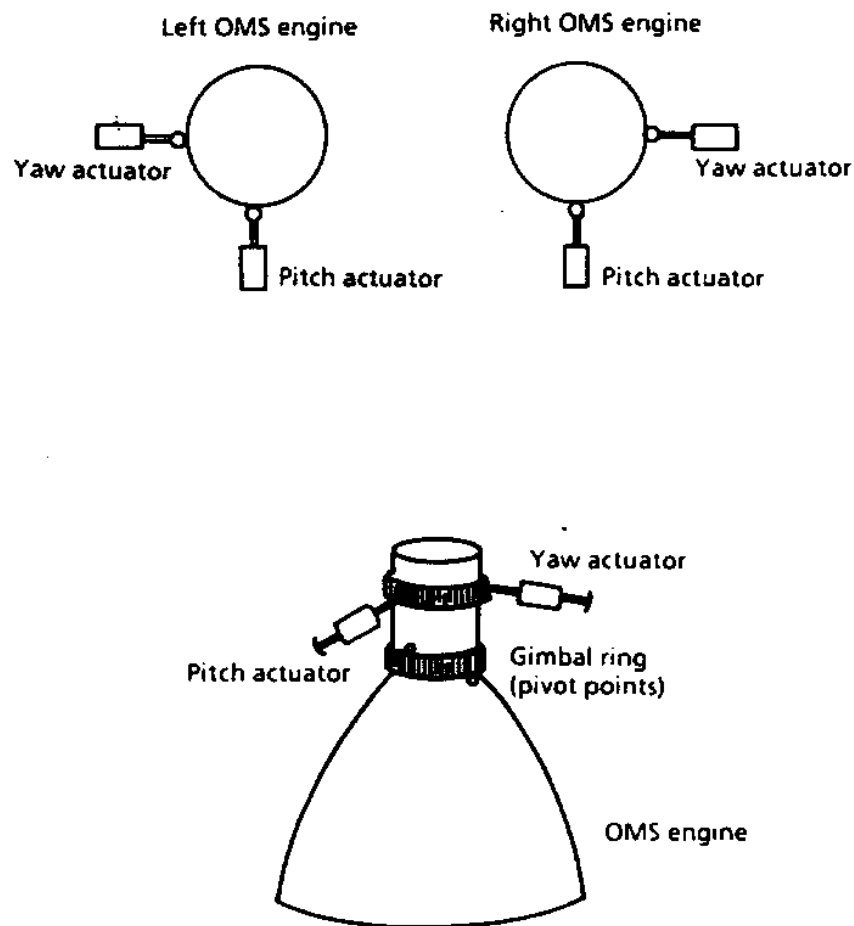
Figure 2-21. BFS thermal display

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.

## 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 up or down causes the vehicle to pitch up or down. 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.

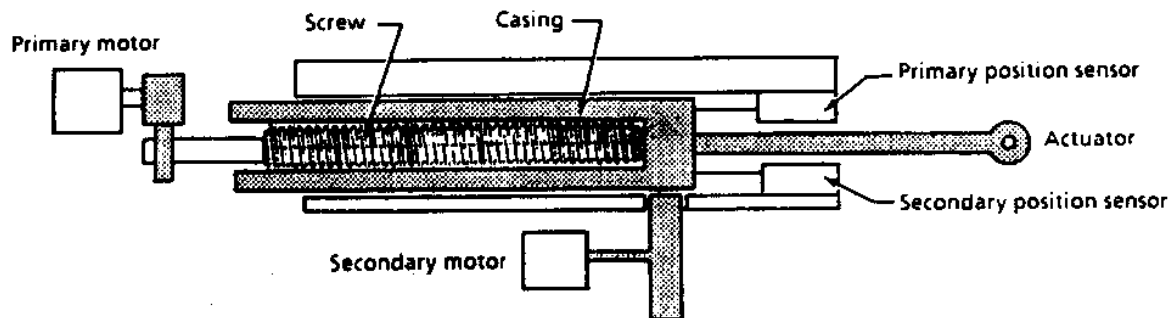
Normally, the orbiter is pointed in the proper direction at the start of a burn and only minor steering corrections are made during a burn with the OMS thrust vector control (TVC) system. Control inputs come to the TVC actuators from the DAP. These commands can be based on automatic guidance or manual 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 that 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  $0.4^\circ$ , the actuators will be commanded to move the engine back to within  $0.06^\circ$  of the correct position. As long as the error is less than  $0.4^\circ$  there will be no actuator movement.

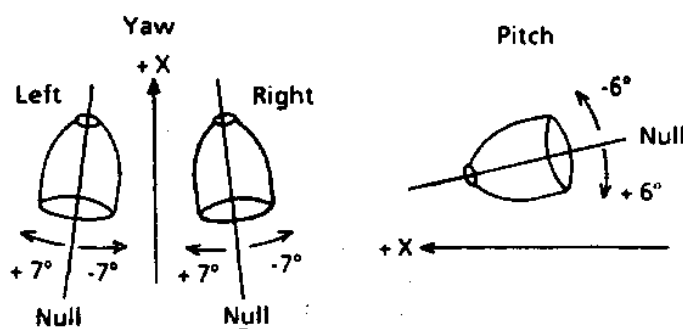


When the primary motor is driving, it rotates the screw which moves the casing in and out.  
 When the secondary motor is driving, it rotates the casing, which moves in and out against the screw.

TD257(A)

**Figure 2-23. Actuator mechanism**

The range of gimbaling movement for the OMS engines is  $\pm 6^\circ$  in pitch and  $\pm 7^\circ$  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.



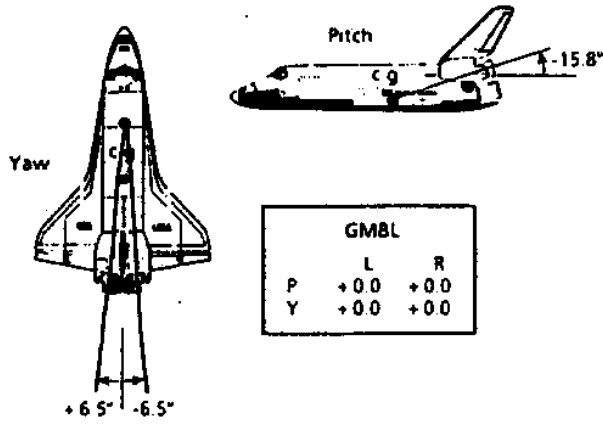
**Figure 2-24. OMS gimbaling degree-of-freedom**

The gimbaling 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. Gimbaling 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 operation.

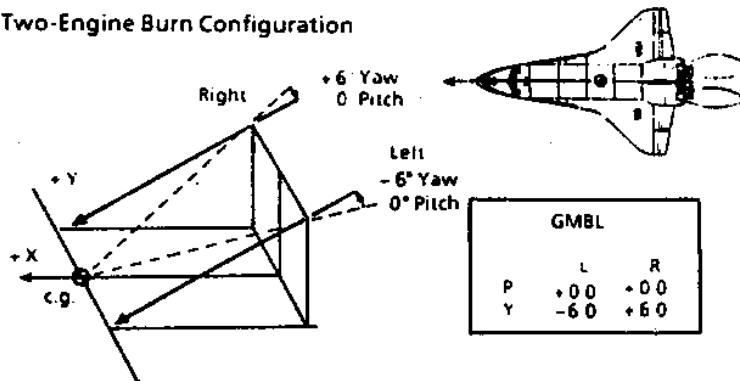
For two-engine OMS burns it is more efficient to keep the thrust vectors parallel to each other so that the resultant vector is through the c.g. rather than to point both thrust vectors individually through the c.g. (see figure 2-25). For a parallel alignment, the gimbaling angle for pitch is approximately 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  $6^\circ$  inward, which is a yaw gimbaling position of  $-6^\circ$  for the left engine and  $+6^\circ$  for the right engine.

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

Null Position



Two-Engine Burn Configuration



Single-Engine Burn Configuration

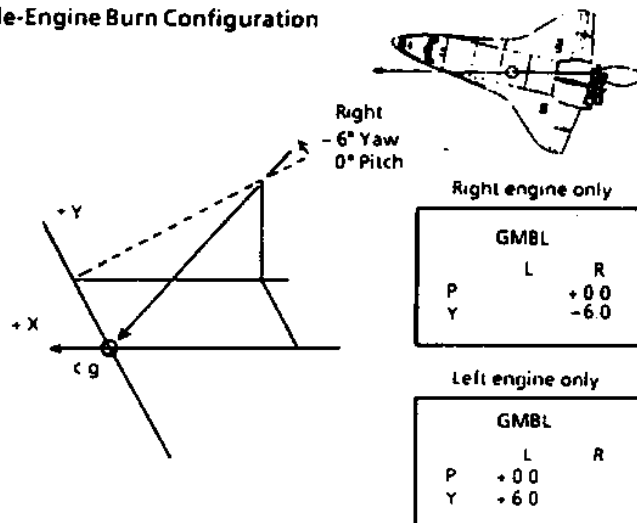


Figure 2-25. Gimbal positions during burns

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 by the crew 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 only if the actual position differs from the trim value by more than 0.4°. 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 to a CRT, those stored gimbal positions are transferred to the trim load.

There may be a slight difference between the actual gimbal positions and the new gimbal trim values. This is because the positions for the trim load are captured slightly before engine shutdown and the gimbals could move in the last moments of the burn. Also, one engine may be pitched up and the other pitched down at the end of a burn due to the need for roll control. If the difference is small, this should be no problem, and if the difference is significant, the trim load will definitely be changed.

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.

At launch the OMS engines are in a special stowed position that protects the nozzles from the airflow and main engine exhaust. At the transition to MM 104 the OMS engines move automatically to predefined trim angles for OMS 1. The gimbals will not respond to any changes in the trim load before OMS 1. Even if a change is made to use only one OMS engine instead of two, the gimbals will remain in their initial trim positions and move only in response to flight control commands once the burn is in progress. However, it is a good idea to change the gimbal trim items for single-engine OMS 1 burns because Guidance will use a new trim load to compute a new burn attitude.



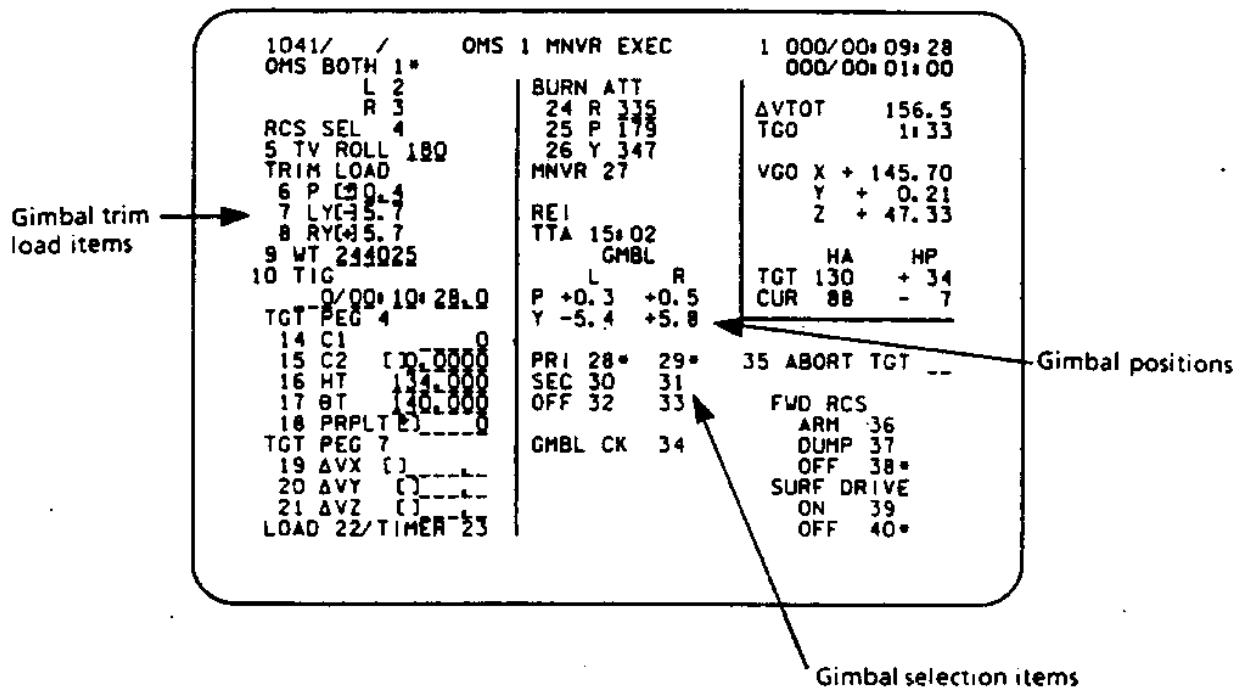


Figure 2-26. OMS maneuver display

For OMS 1, the gimbals automatically move to the trim positions at the transition to MM 104. For OMS 2 and all subsequent burns, the gimbals move to the trim positions 15 seconds before TIG.

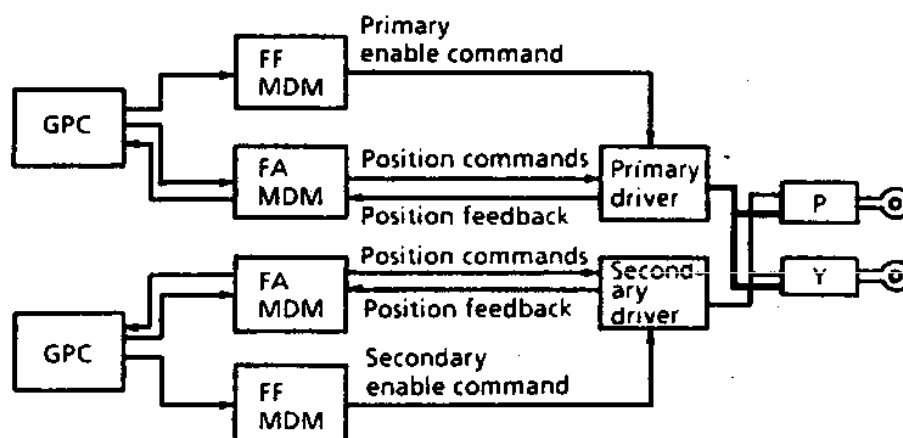
To ensure proper alignment for OMS 2, a gimbal trim load is done in MM 105 using trim values listed in the Ascent Checklist. For subsequent burns the trim load will generally not require a change. The trim load captured at the end of a previous burn should be adequate unless there is a change to the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

For the deorbit burn the crew enters the trim load in MM 301. The engines will move to the trim positions 15 seconds before TIG.

At the transition to MM 303, the OMS engines are automatically gimballed to the stowed position to protect them from the airflow during entry.

There is a software function that is used to test the gimbals before and after OMS burns. It is called a gimbal check and is activated with an item entry to the Maneuver display (Item 34). The gimbal check commands the actuators to drive through their whole range of movement. When the gimbal check is activated, 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 next to Item 34 disappears.

Normally, the gimbal check is done before and after each OMS burn (except before OMS 1 and after the deorbit 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.



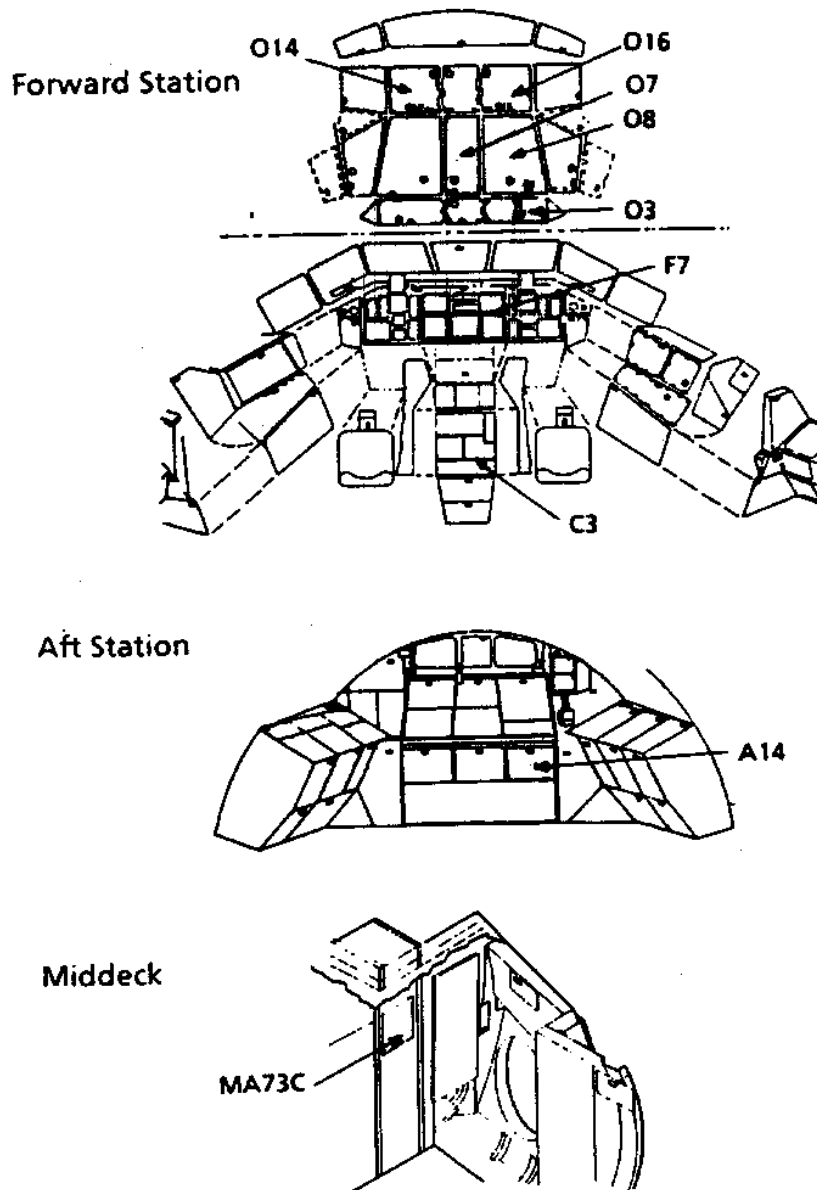
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Figure 2-27. OMS TVC commands and feedback

## Controls and Displays

This section is a summary of all of the cockpit controls and crew displays that are related to OMS operation. Some have been discussed already, and others will be covered in detail later in the book.

There are OMS switches or gages in the forward station on panels F7, O3, O7, O8, O14, O16, and C3; in the aft station on panel A14; and in the middeck on panel MA73C. Figure 2-28 (see below) shows the positions of these panels within the crew module. The following pages show detailed views of these panels.



**Figure 2-28. OMS panels**

This part of panel F7 (see figure 2-29) includes the OMS  $P_c$  gages and  $N_2$  and helium tank pressure gages at the lower left side of the panel. The switch below the  $N_2$ /He tank pressure gages is used to select nitrogen or helium tank pressure for display on the gage above.

At the top of the panel is the caution and warning light matrix, which includes lights for LEFT OMS, RIGHT OMS, OMS KIT, and OMS TVC.

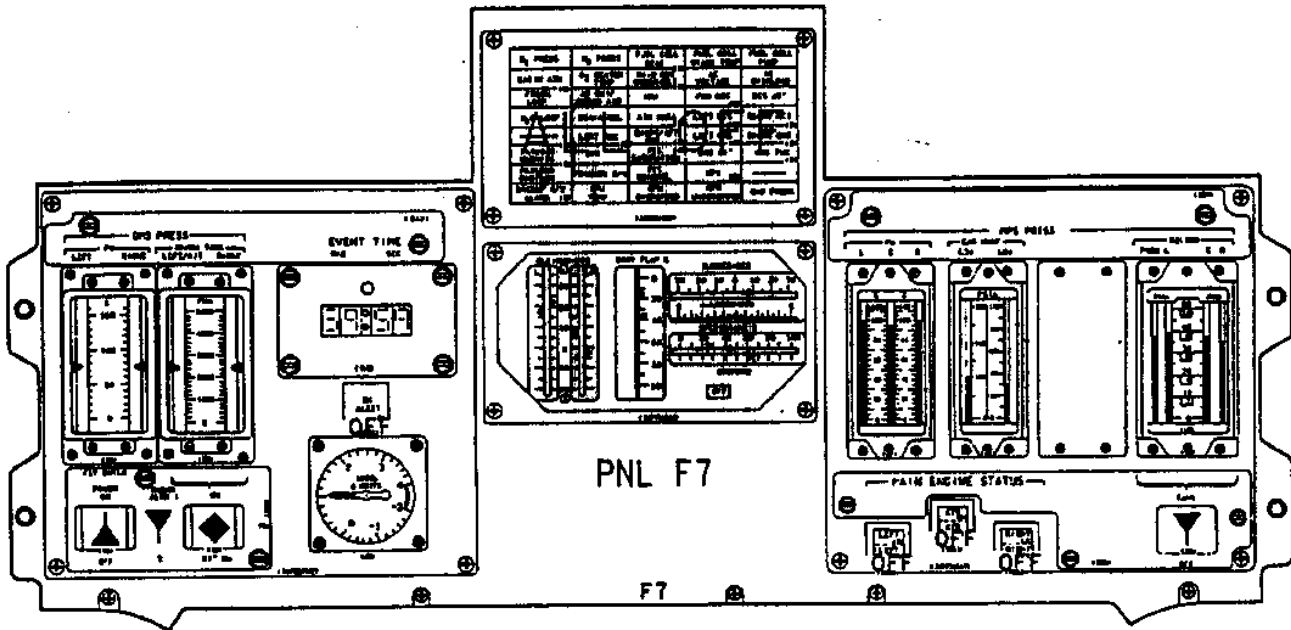


Figure 2-29. Panel F7

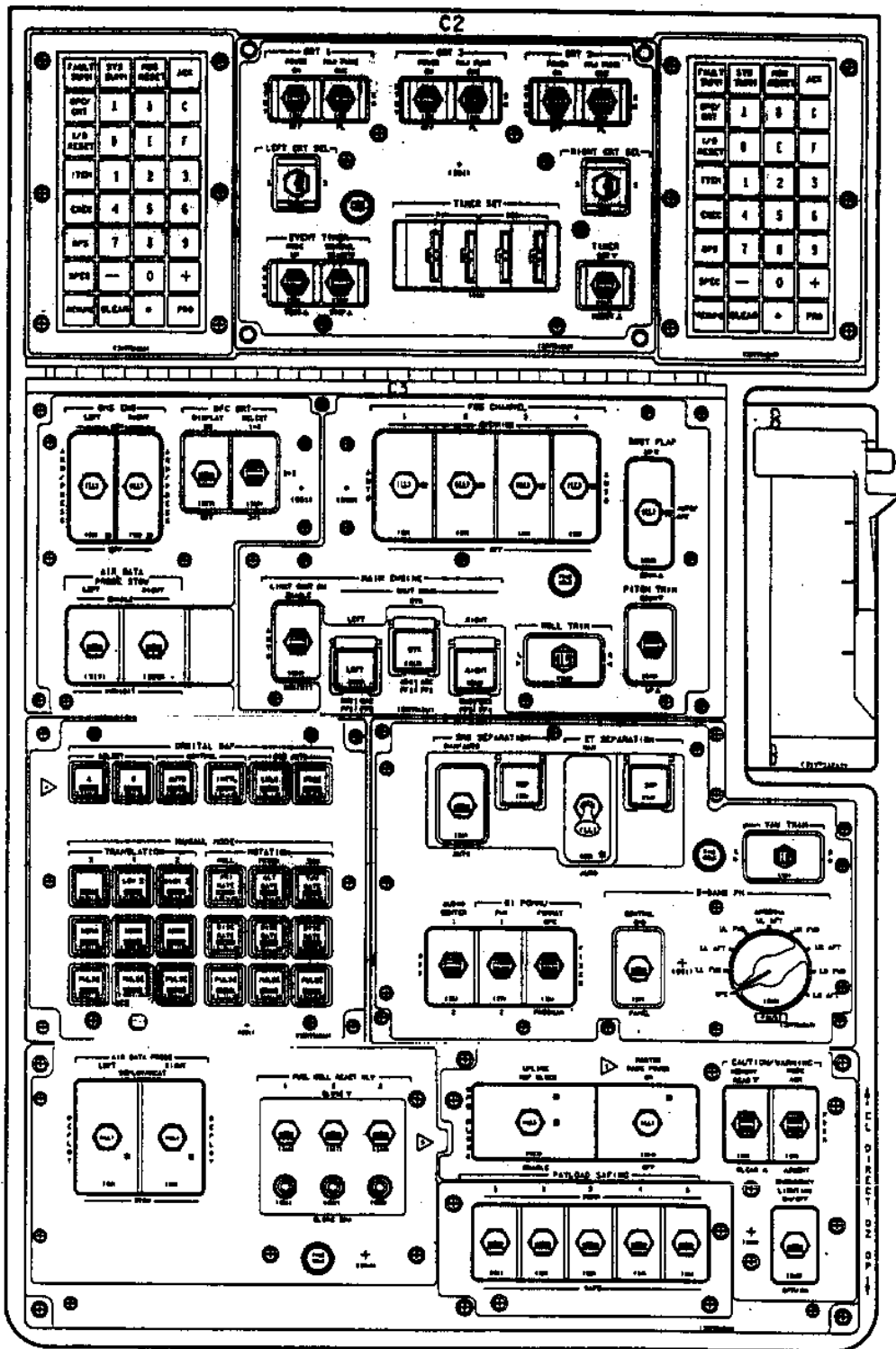


Figure 2-30. Panel C2

Panel O3 (see figure 2-31) includes RCS/OMS tank pressure gages. Below the gages, there is a rotary switch for selecting RCS or OMS measurements for display. When OMS PRPLT is selected, the oxidizer and fuel tank pressures shown on the gages are for the left, right, and OMS kit tanks.

Next to the pressure gages is the RCS/OMS propellant quantity meter. The rotary switch below the digital meter is used to select OMS or RCS quantities for display. OMS oxidizer or fuel can be selected and the respective quantities will be displayed in percent for the left OMS, right OMS, and OMS kit.

Next to the quantity meter there is a digital clock display.

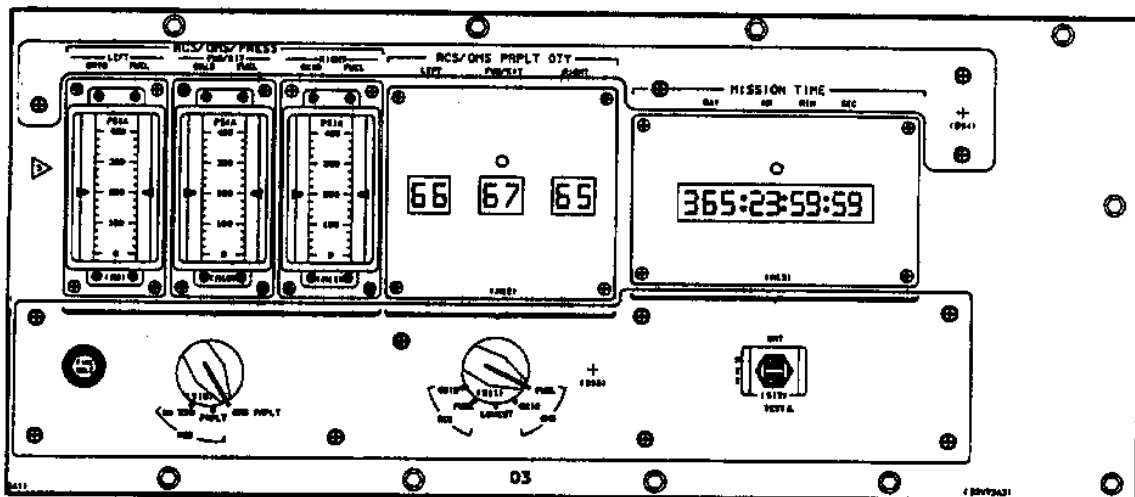


Figure 2-31. Panel O3

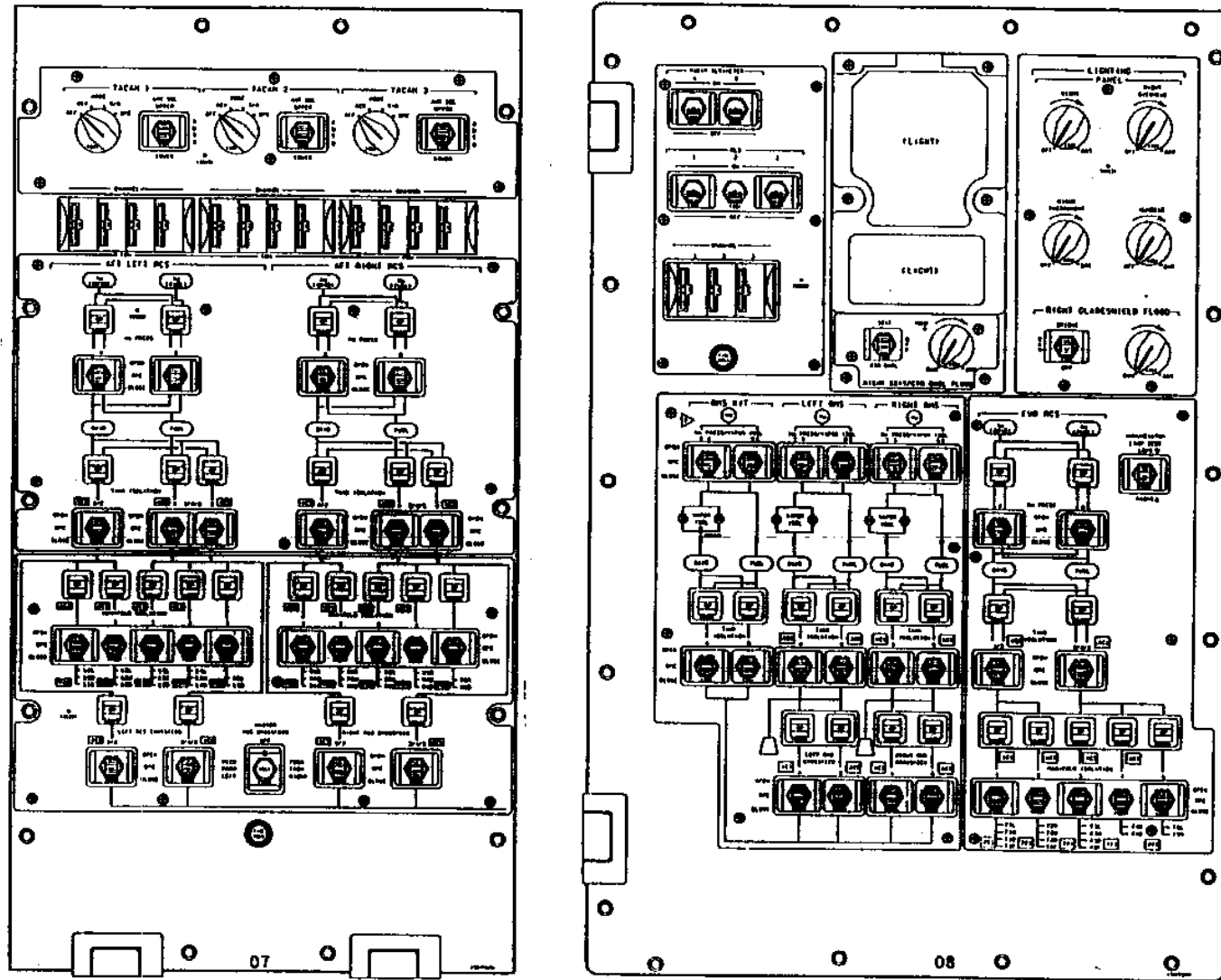


Figure 2-32. Panels O7 and O8

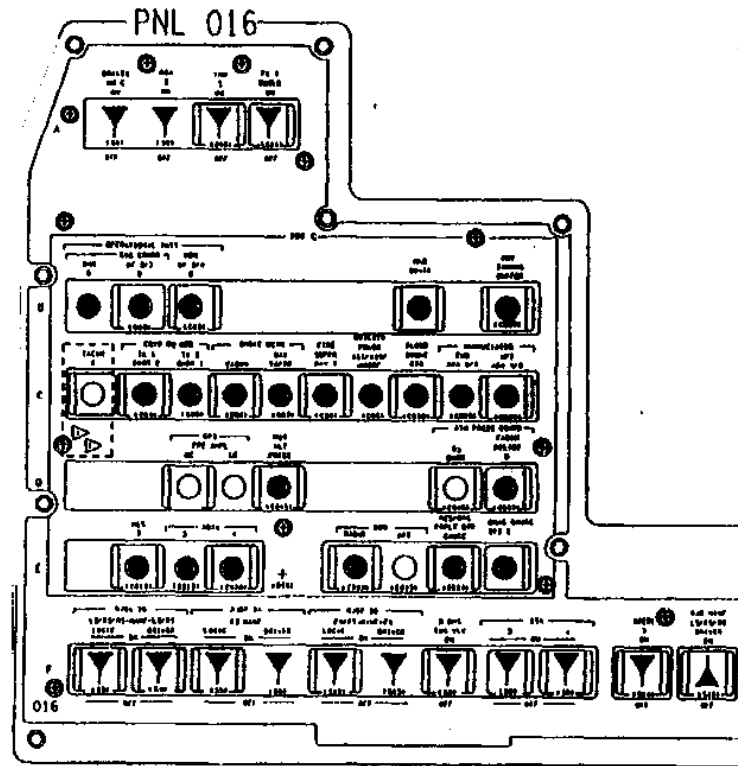
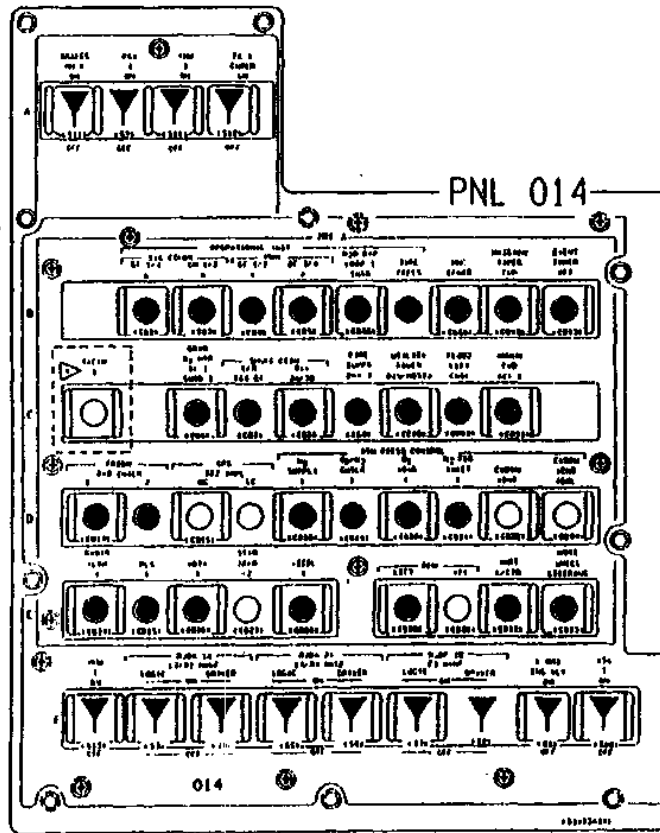


Figure 2-33. Panels O14 and O16



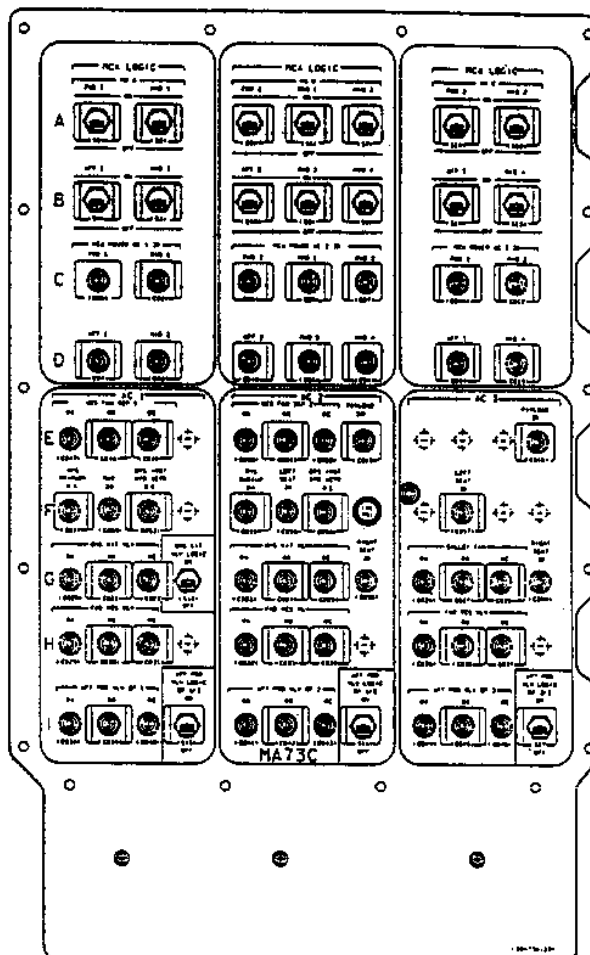
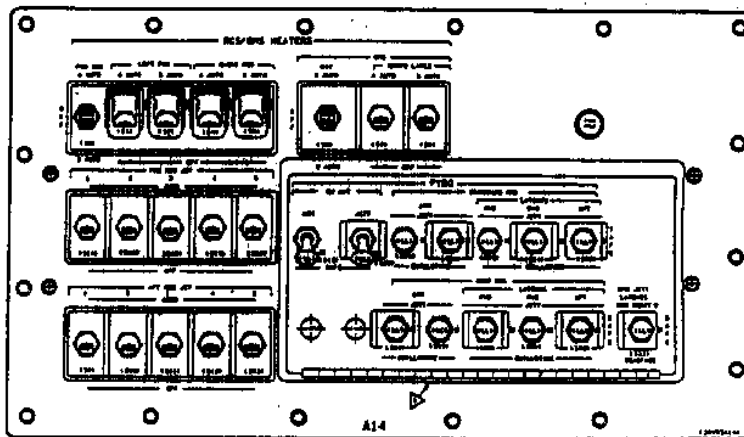


Figure 2-34. Panels A14 and MA73C

There are several CRT displays that contain OMS information. These are listed in the table and described in some detail in the following pages.

### **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.

There is a BFS version of the display that is identical to the primary display.

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

**Table 2-2. Displays with OMS information**

	Ascent (OPS 1 and 6)	Orbit (OPS 2 and 8)	Entry (OPS 3)
Guidance and control information	Maneuver, MM 104, 105, 106 only BFS Maneuver, MM 104, 105, 106 only	Maneuver, MM 202 only	Maneuver, MM 301, 302, 303 only BFS Maneuver, MM 301, 302, 303 only
System information	BFS GNC Systems Summary 2	GNC Systems Summary 2	BFS GNC Systems Summary 2
OMS-to-RCS gaging		RCS (GNC SPEC 23)*	
Thermal information	BFS Thermal (SM OPS 0)	Propellant Thermal (SM SPEC 89)	BFS Thermal (SM OPS 0)

\* The RCS display is available in OPS 3 but OMS-to-RCS gaging only functions in OPS 2 and 8

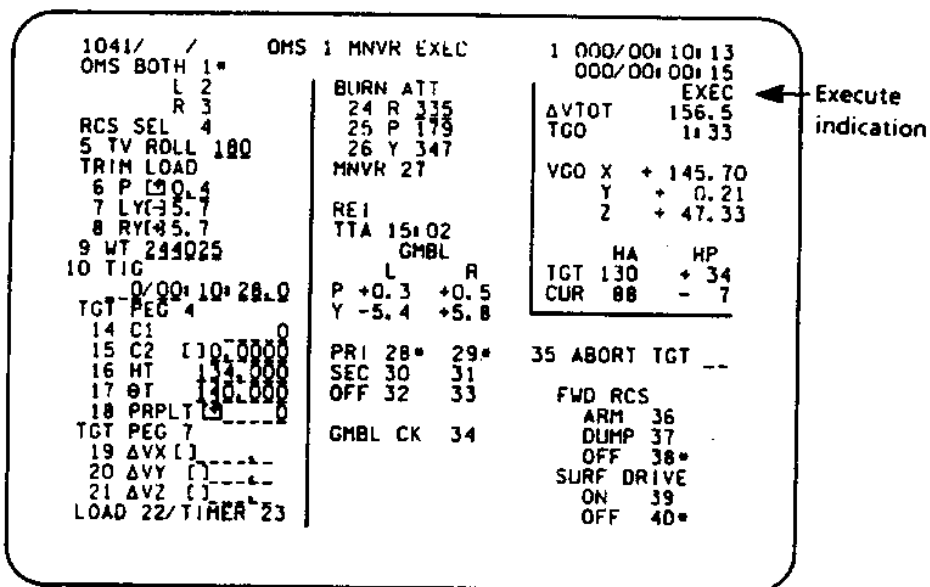


Figure 2-35. Example of an OMS 1 maneuver display

Items 1 through 4 are used to select both OMS engines, one engine, or RCS jets for an OMS burn and are mutually exclusive item entries (see figure 2-35). This information is used by Guidance and the OMS software.

OMS BOTH 1\*  
 L 2  
 R 3  
 RCS SEL 4

Item 5 is the roll attitude for OMS burns. Normally it is 180° which corresponds to a heads-down attitude. A different number could be entered, but it is seldom changed.

5 TV ROLL 180

Items 6 through 8 are used to enter gimbal trim angles for OMS burns. They are described in the section on TVC.

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 which is computed and used by Guidance. It can be changed when a more accurate weight is known.

9WT 244025

Item 10 is the time of ignition for an OMS burn in days/hours:minutes:seconds of mission elapsed time (MET). It is entered as part of a burn target.

```
10 TIG
  00 0/0 0:10:28.0
```

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 1, OMS 2, and deorbit burns. PEG 4 targets can be only used in OPS 1 and 3.

```
TGT PEG 4
 14 C1
 15 C2
 16 HT
 17  $\theta$ T
 18 PRPLT
```

Items 19 through 21 are where the target parameters are entered for another type of guidance, which is known as PEG 7 or external  $\Delta V$  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  $\Delta$ VX
 20  $\Delta$ VY
 21  $\Delta$ VZ
```

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 attitude.

```
BURN ATT
 24 R 3 3 5
 25 P 1 7 9
 26 Y 3 4 7
MNVR 27
```

These are the actual gimbal position angles.

```
      GMBL
      L   R
P   +0.3 +0.5
Y   -5.4 +5.8
```

Items 28 through 33 permit selection of primary or secondary gimbal drivers or turn off both gimbal 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

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

$\Delta VTOT$	156.5
TGO	1:33
VGO X	+ 145.70
Y	+ 0.21
Z	+ 47.33

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	154	+ 154
CUR	154	+ 30

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

Items 36 thru 40 are not applicable to OMS and will not be discussed here.



## Thermal Displays

These displays were presented in the section on thermal control. The Propellant Thermal display can be called up in OPS 2 with a keyboard entry of "SPEC 89 PRO" to a CRT 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 STANDBY and the SM major function is selected. The OMS pod temperature status is displayed below HTR TEMP PRPLT.

2011/ /089		PRPLT		THERMAL		1 001/02/ 30/ 45		
		L	R				000/00/ 00/ 00	
OMS TK	OX	70	72	OMS CRSFD	L	R	C	
	FU	72	75	XFD	OX	81	75	79
ENG I/F	OX	71	80	GMBL LN	80	72		
	FU	75	71	DRN	OX	87	78	
	OX VLV	82	72					
	FU INJ	80	81					
WEB KEEL	1	81	80					
	2	83	75					
Y	OB	75	76	BLO AFT FUS	FU	OX		
	UP	72	69	PL BAY	82	75		
OX DRN PNL	1	69	65					
	2	70	74	FWD RCS	FU	OX		
ENG COVER	75	70		LINE T1	69	72		
SERV PNL	77	68		T2	71	68		
GSE SERV PNL	81	70						
TEST HE/OX	1	80	78	AFT RCS	L	R		
	2	85	80	MANF 1	OX	80	82	
				DRN PNL	1	82	75	
					2	78	75	
				VERN PNL	1	79	79	
					2	80	75	

Propellant Thermal display (SM SPEC 89)

0001/ /		THERMAL		S 000/00/ 00/ 00			
				BFS 000/00/ 00/ 00			
HYD SYS TEMP	BDY/FLP	RD/SB	L	OB	L	RB	R
ACTR	72	71	68	71	73	70	
PRIME	71	71	70	73	70	72	
STBY 1	75	75	68	75	68	71	
STBY 2	70	70	72	75	69	69	
HTR TEMP	L/A	R/B	FHEON LOOP	1	2		
PRPLT			ACCUM QTY	55	53		
POD			RAD IN	1	119	107	
OMS CRSFD			H2O				
EVAP			SUPPLY	P	J3		
HI LOAD							
TOP DUCT							
NOZ							
FOLN							
HYD BLR/HTR							
APU							
GG/FU PHP HTR							
TK/FU LN HTR							
PUMP/VLV COOL							

BFS Thermal display (SM OPS 0)

Figure 2-37. Propellant thermal and BFS thermal displays



## RCS Display

This display is primarily for RCS data; however, in the upper right corner there are some items related to OMS gaging for OMS-to-RCS interconnect operations. These items are described in detail a little later in the book.

2011/023/			RCS		1 001/01 35:00 000/00 00:00	
RCS FWD 1*	JET FAIL		OMS PRESS	ENA		
L 2	4 LIMIT 2		L OMS 5		OMS RCS QTY	
R 3			R OMS 6		L 0.00	
			OFF 7*		R 0.00	
JET FAIL	DES INH	JET DES				
FIL	8	9				
U	10	11	HE	P	3110	3250
D	12	13	PRPLY TK	H	245	245
F	14	15			70	72
F2R	16	17		QTY	85	87
U	18	19	MANF P	1	245	245
D	20	21		2	245	245
F	22	23		3	245	245
F3L	24	25		4	245	245
U	26	27	MANF VLVS		STAT	OVBD
D	28	29		1	OP	42
F	30	31		2	OP	43
F4R	32	33		3	OP	44
D	34	35		4	OP	45
	36	37		5	OP	46
F5L	38	39				
R	40	41	JET RESET	47		

Figure 2-38. GNC 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 gaging work for the left pod?
  - d. Will OMS gaging 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 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  $0.56^\circ$  and a yaw error of  $0.39^\circ$ , 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 2-39) to answer the following questions.

RCS		OXID	FU	JET	ISOL
FWD	HE	R2516	2530	FAIL	VLV
	TK	R 245	245		
	QTY	84	84		
MANF	1	R 245	245		
	2	R 245	245		
	3	R 245	245		
	4	R 245	245		
	5				

AFT		OXID	FU	JET	ISOL
L	HE	R2808	2880	FAIL	VLV
	TK	R 245	245		
	QTY	91	89		
MANF	1	R 245	245		
	2	R 245	245		
	3	R 245	245		
	4	R 245	245		
	5				

RCS		OXID	FU	JET	ISOL
FWD	HE	R2638	2668	FAIL	VLV
	TK	R 245	245		
	QTY	88	88		
MANF	1	R 245	245		
	2	R 245	245		
	3	R 245	245		
	4	R 245	245		
	5				

Figure 2-39. Example GNC systems summary 2 display

8. Could either OMS engine be burning?
9. According to the display, the left OMS helium tank pressure is zero. Is there a way to double check this reading?
10. According to the display, the left N<sub>2</sub> press valve is open. How could you close it without turning off the OMS engine?
11. The right OMS oxidizer tank pressure appears to be low. Is there a second indication on the display to verify that the pressure in the tank is really low?
12. According to the display, the left OMS N<sub>2</sub> tank pressure is at zero. How could you verify that this is not a sensor failure?

## Answers

1. No. If an OMS engine is shut down during a burn by taking the OMS engine switch to OFF, a purge will not occur. A purge will occur only when the switch is in ARM/PRESS at the end of a burn. 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 right switch is not in ARM/PRESS.
  - c. OMS gaging will work for the left pod. OMS gaging will function as long as one OMS engine is on.
  - d. OMS gaging will work for the right pod. OMS gaging 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 burn, the larger attitude change will be in the yaw axis. This change could be seen on the ADI.
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  $0.56^\circ$  and a yaw error of  $0.39^\circ$ , the yaw actuator will not move because the error is less than  $0.4^\circ$ . The pitch actuator will move approximately  $0.5^\circ$  to correct the error of  $0.56^\circ$ .

The example GNC Systems Summary 2 display (see figure 2-40) was used to answer questions 8 - 12.

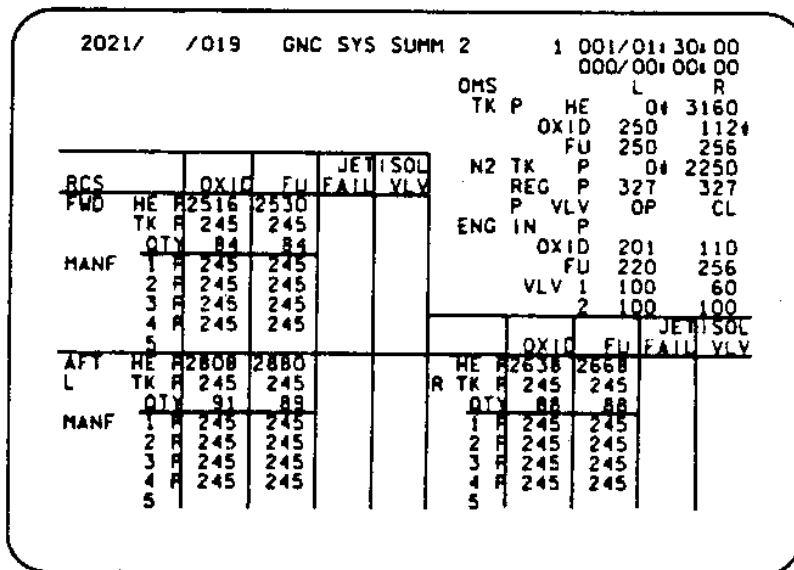


Figure 2-40. Example GNC system summary 2 display

8. Yes. Either OMS engine could be burning. The right side has one set of bipropellant valves (ENG VLV 1) only 60 percent open, so it probably is not burning. The left side could be burning, since the bipropellant valves are fully open.
9. Yes. There is a way to double check the reading of zero for the left OMS helium tank pressure on the display. The gage on panel F7 uses a separate pressure sensor. If it also reads zero, the tank pressure is probably zero.
10. According to the display, the left N<sub>2</sub> 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. Yes. There is a second indication on the display to verify that the pressure in the tank is really low when the right OMS oxidizer tank pressure appears to be low. The oxidizer inlet pressure (ENG IN P OXID) is also low.
12. According to the display, the left OMS N<sub>2</sub> tank pressure is at zero. You could use the gage on panel F7 to verify that this is not a sensor failure. This gage provides an N<sub>2</sub> tank pressure reading from a separate sensor.