

Space Program Operations Contract

Main Propulsion System Workbook

MPS 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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**Main Propulsion System
Workbook**

MPS 21002

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PREFACE

The content of this document was provided by the United Space Alliance (USA) Guidance and Control/Propulsion Department, Space Flight Training and Facility Operations 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). 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 Main Propulsion system (MPS) provides thrust for vehicle acceleration from lift-off to Main Engine Cutoff (MECO). This phase of ascent is referred to as “powered flight” and consists of first stage and second stage.

Two Solid Rocket Boosters (SRBs) provide the majority of thrust during first stage. First stage terminates after the SRBs burn out and are jettisoned at a Mission Elapsed Time (MET) of approximately 2:05. The two SRBs are later recovered, refurbished, and reused on subsequent missions.

The MPS continues to provide thrust during second stage and may be assisted by the Orbital Maneuvering System (OMS) with an “OMS Assist” burn and/or OMS abort dumps. Second stage continues until Powered Explicit Guidance (PEG) targets are achieved or until MPS propellant is depleted, whichever comes first. At this time MECO is initiated. The External Tank (ET) is jettisoned shortly afterwards, breaks up during its subsequent atmospheric entry, and impacts in a remote ocean area. The ET is not recovered. See Figure 1-1.

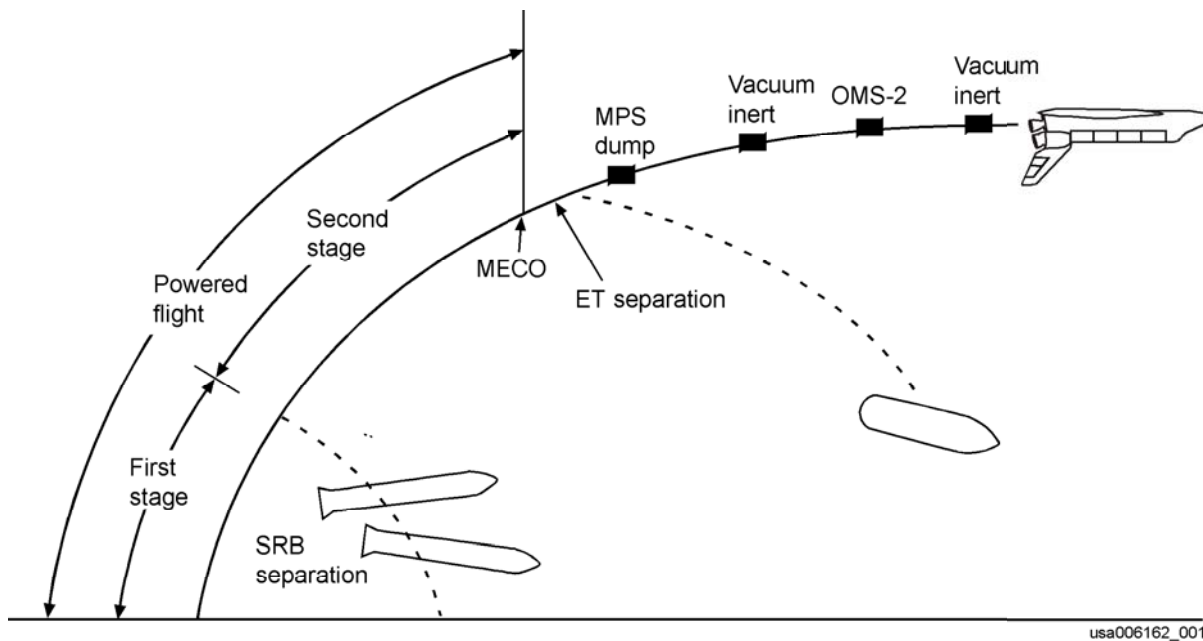
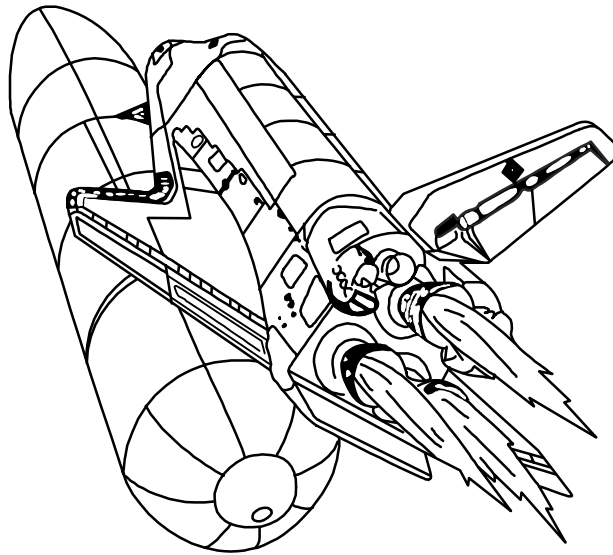


Figure 1-1. Nominal ascent profile

After MECO and prior to Operational Sequence (OPS) 2, the General Purpose Computers (GPCs) command the MPS dump and two vacuum inerts to remove the unused propellants trapped in the MPS lines.

During entry, the MPS propellant lines are repressurized with helium to prevent contaminants from being drawn into the evacuated lines. MPS helium is also used to purge the aft fuselage and OMS pods of any potentially explosive gases, such as residual MPS hydrogen or hydrazine from the Auxiliary Power Units (APUs) that may have accumulated during the flight.

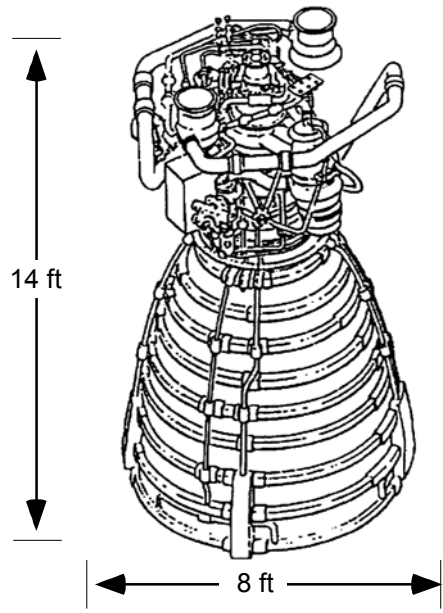
The MPS consists of three rocket engines, an external propellant tank, a propellant management system used to transport fuel and oxidizer from the tank to the engines, and a multipurpose helium system (See Figure 1-2).



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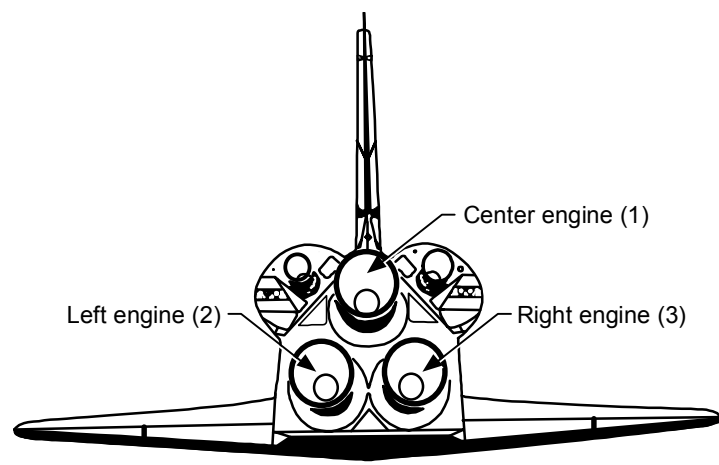
Figure 1-2. Main propulsion system

Each of the three main engines is approximately 14 feet long and has a nozzle about 8 feet in diameter. See Figure 1-3. The engines use Liquid Hydrogen (LH_2) for fuel and Liquid Oxygen (LO_2) as an oxidizer. They can be throttled over a range of 67 to 109 percent of their rated power level in increments of 1 percent. Each engine can also be gimbaled $\pm 10.5^\circ$ in pitch and $\pm 8.5^\circ$ in yaw for steering the vehicle. The engines, shown in Figure 1-4, are generally referred to as the center (engine 1), left (engine 2), and right (engine 3).



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Figure 1-3. Space shuttle main engine



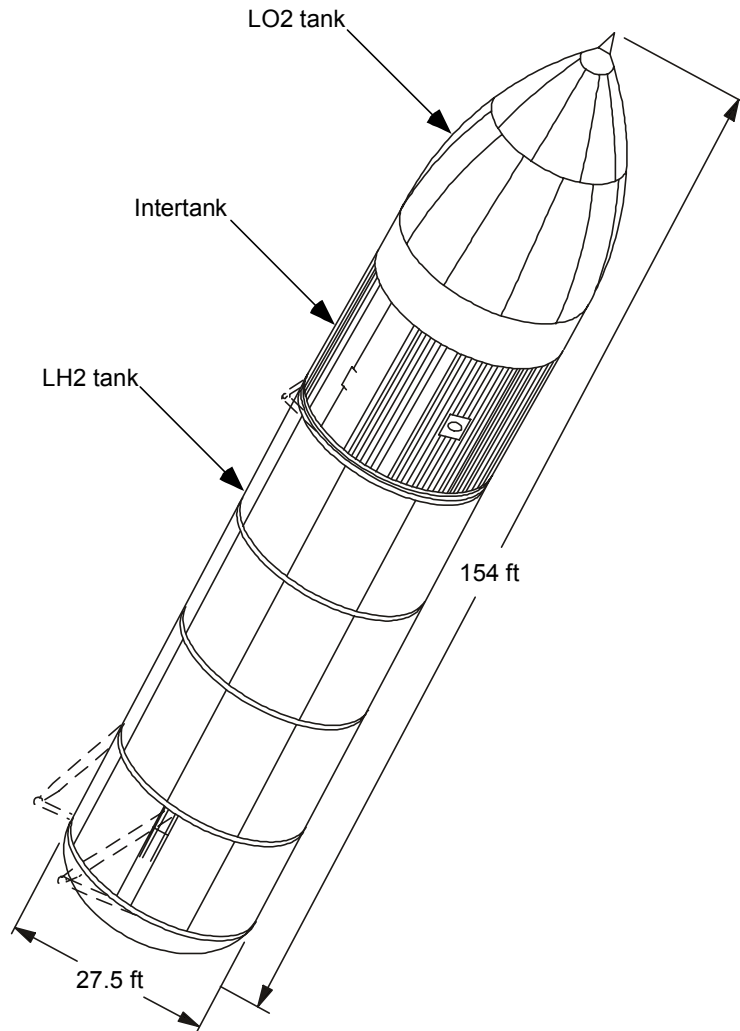
Aft view of orbiter

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Figure 1-4. Main engine numbering system

The ET contains the LH₂ and LO₂ that are burned in the main engines. At 154 feet long and 27.5 feet in diameter, it is the largest component of the space shuttle vehicle. See Figure 1-5. Since the ET is used only once, it contains a minimum amount of active components.

The propellant management system in the orbiter is a collection of manifolds, valves, and distribution lines that control the flow of propellants from the ET the main engines. During prelaunch, this system is also used to load the propellants in the ET and, post-MECO, it controls the propellant dump and vacuum inerting.



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Figure 1-5. External tank

The helium system consists of supply tanks, distribution lines, regulators, and valves that accomplish several different functions. It is used for in-flight purges within the engines and provides pressure for actuating engine valves during emergency pneumatic shutdowns. It also supplies helium pressure to actuate the pneumatically operated valves within the propellant management system. During entry, the remaining helium is used to purge the aft compartment and repressurize the MPS. Unlike the OMS and Reaction Control System (RCS), MPS helium is not used to pressurize propellant tanks.

The MPS interfaces with the orbiter hydraulic system, Electrical Power System (EPS), Master Events Controller (MEC), and Data Processing System (DPS). See Figure 1-6.

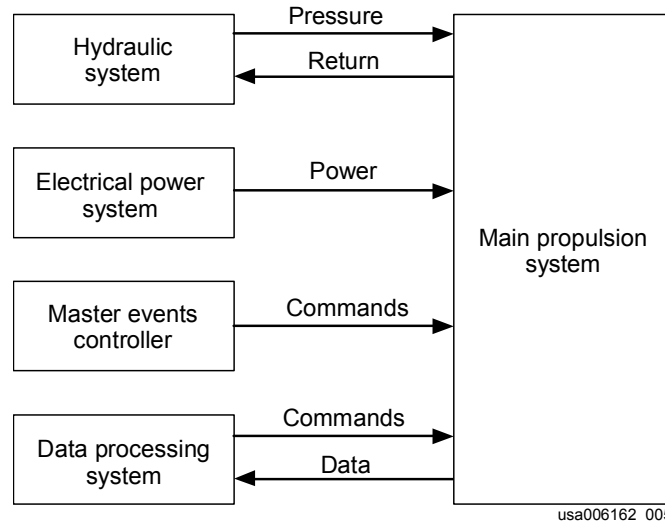


Figure 1-6. Critical interfaces with the MPS

The orbiter's three hydraulic systems supply hydraulic pressure to operate the main engines' valves and gimbal actuators.

The EPS furnishes AC power to operate the main engine controllers and DC power to operate the valves and transducers in the propellant management and helium systems.

The MEC initiates firings of pyrotechnic devices for igniting the SRBs, separating the SRBs from the ET and the ET from the orbiter.

The DPS controls most of the MPS functions with flight software contained in five General Purpose Computers (GPCs). Four of the computers contain redundant sets of primary software, and the fifth contains the Backup Flight System (BFS). The primary computers control the vehicle unless the BFS is manually engaged.

The shuttle flight software is divided into OPSs and Major Modes (MMs) that correspond to mission phases. It is helpful to be familiar with the mission sequence in terms of OPSs and MMs. Refer to Figures 1-7 and 1-8.

OPS 1: Ascent	MM 101	Terminal Count
	MM 102	First stage: Lift-off to SRB separation
	MM 103	Second stage: SRB separation to ET separation
	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	FCS/Dedicated Display Checkout
OPS 3: Entry	MM 301	Pre-deorbit coast
	MM 302	Deorbit Execute
	MM 303	Pre-Entry Monitor
	MM 304	Entry
	MM 305	TAEM/Landing
OPS 6: Return to Launch Site (RTLS) abort	MM 601	RTLS Second Stage: RTLS selection to ET separation
	MM 602	Glide RTLS 1
	MM 603	Glide RTLS 2

Figure 1-7. Shuttle operational sequences and major modes

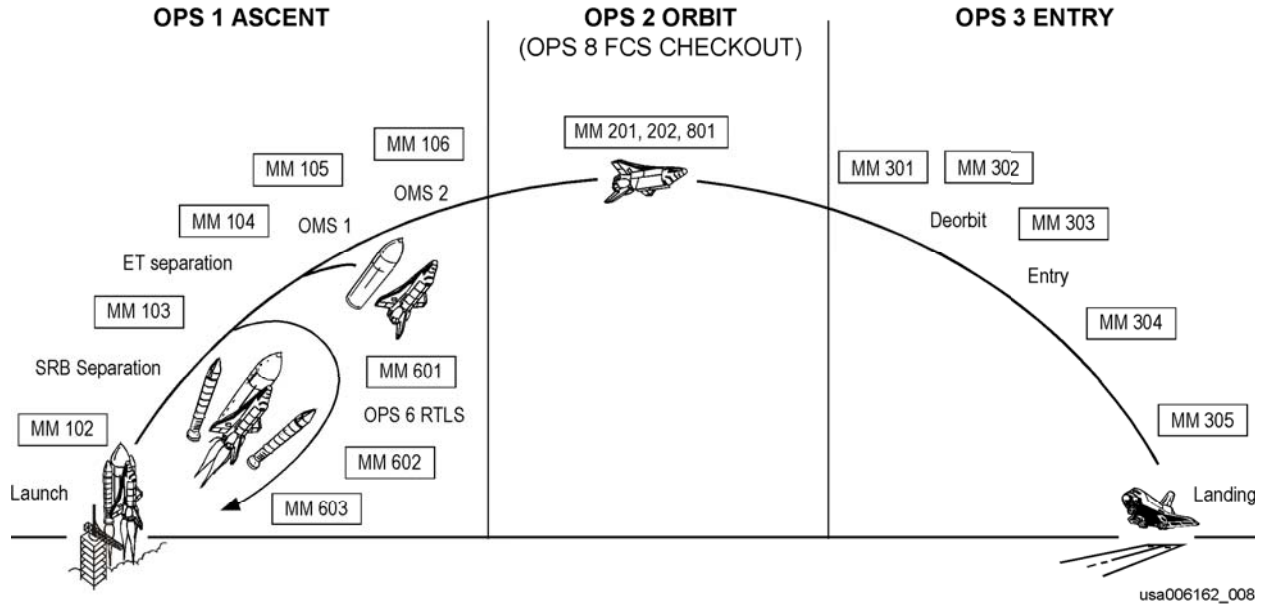


Figure 1-8. Typical mission profile showing major modes

The remainder of this manual covers the MPS in more detail. First, there is a description of the various components of the system, followed by a description of how the system is operated. The last section provides the background information needed to understand and respond to system malfunctions.

2.0 SYSTEM DESCRIPTION

2.1 OBJECTIVES

After completing this section, you should be able to

- Describe the two stages of main engine combustion
- List the five hydraulically actuated valves
- Recognize the dual purpose of LH₂
- Recognize the importance of maintaining a safe amount of LH₂ and LO₂ Net Positive Suction Pressure (NPSP)
- Identify the number of command and data paths between each main engine controller and its associated Engine Interface Unit (EIU)
- Describe how the LO₂ and LH₂ ullage pressure systems pressurize the propellant tanks in the ET
- Describe the interface between the main engines and the orbiter hydraulic systems

In this section, the following components are described:

- Space Shuttle Main Engine (SSME)
- Main engine controller
- Propellant Management System (PMS)
- Helium system
- ET
- Thrust Vector Control (TVC)

2.2 SPACE SHUTTLE MAIN ENGINE

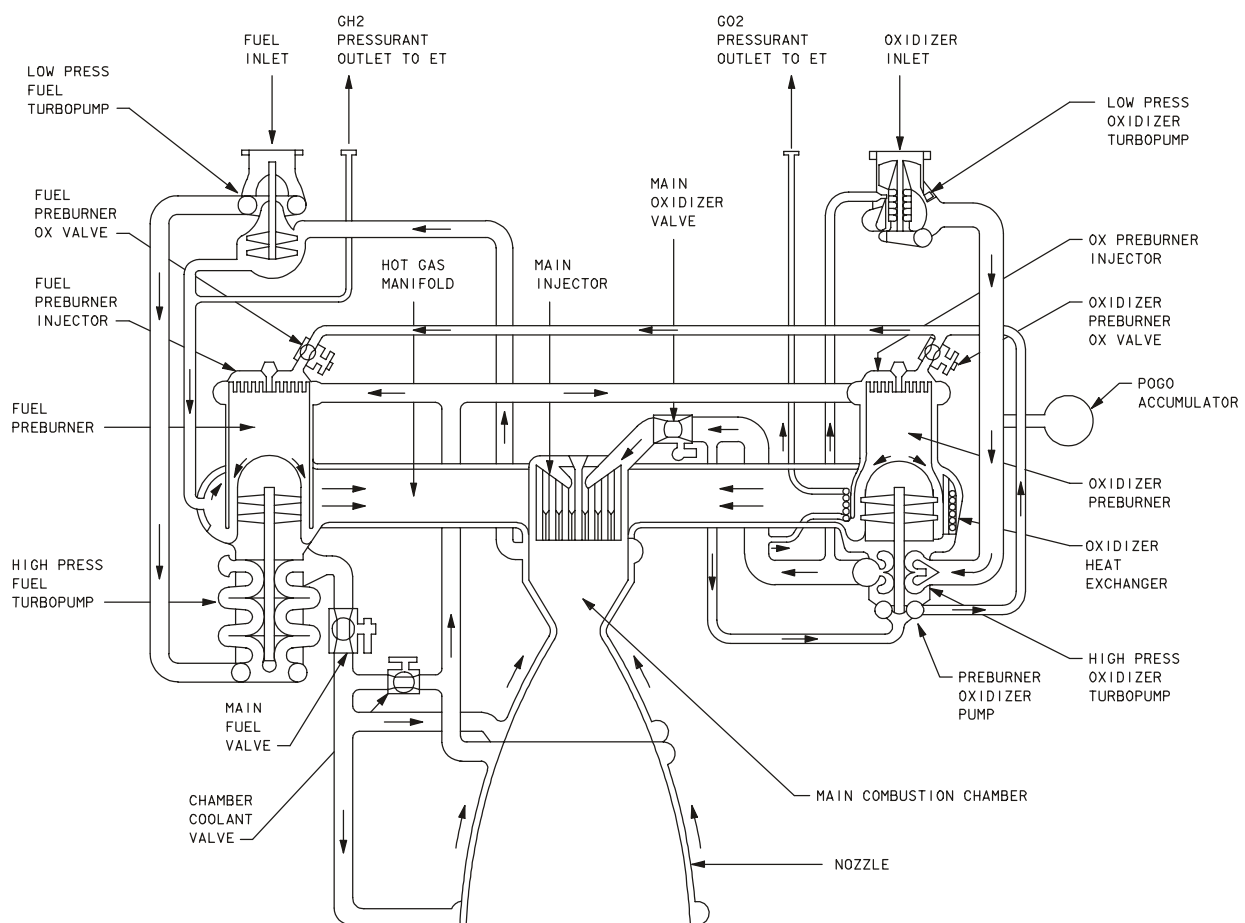
The SSMEs are reusable, high performance, liquid propellant rocket engines with variable thrust.

The main engines use LH₂ for fuel and cooling, and LO₂ as an oxidizer. Using a staged combustion cycle, the propellants are partially burned at high pressure and relatively low temperature in the two preburners, and then completely burned at high pressure and high temperature in the main combustion chamber. Each engine produces 375,000 lb of sea level thrust and 470,000 lb of vacuum thrust at 100 percent power level. The SSME major components and their functions are described as follows. Refer to Figure 2-1.

Low Pressure Fuel Turbopump (LPFTP): Boosts the fuel pressure from its low storage pressure to the pressure required at the inlet to the High Pressure Fuel Turbopump (HPFTP).

High Pressure Fuel Turbopump (HPFTP): Boosts the fuel pressure to the engine operating level and supplies hydrogen to the engine fuel and cooling circuits.

Low Pressure Oxidizer Turbopump (LPOTP): Boosts the oxidizer pressure from the manifold pressure to the level required at the inlet to the High Pressure Oxidizer Turbopump (HPOTP). The manifold pressure is the combination of the LO₂ tank ullage pressure and the head pressure generated from vehicle acceleration acting on the column of LO₂ in the ET downcomer.



TD3450201, ART, 4

Figure 2-1. Main engine schematic

High Pressure Oxidizer Turbopump (HPOTP): Consists of two pumps on a common shaft. The main pump boosts the LO₂ pressure and supplies oxidizer to the main combustion chamber, the heat exchanger, the LPOT turbine, and the preburner oxidizer pump. The preburner oxidizer pump boosts the pressure to a higher value that supports the injection of LO₂ into the fuel and oxidizer preburners.

- **Pogo Suppression System Accumulator:** The pogo accumulator, located between the LPOTP and HPOTP serves two important functions.

First, it provides capacitance in the engine oxidizer system, preventing acceleration-induced low-frequency flow oscillations from affecting the combustion process. During engine start and shutdown, it is pre- and post-charged with helium from orbiter tanks. During engine run, it is pressurized with Gaseous Oxygen (GO_2) from the heat exchanger coil.

Second, it maintains the HPOTP LO_2 inlet pressure at MECO. Maintaining pump inlet pressure above vapor pressure is required to avoid cavitation (vaporization of the fluid being pumped) and is referred to as NPSP. Allowing the LO_2 to vaporize would result in catastrophic failure of the HPOTP as the pump “unloads” and the turbine accelerates to speeds much greater than its design. HPOTP NPSP is greatly assisted during flight by vehicle acceleration acting on the tall column of dense LO_2 from the ET to the engine. However, this significant component of HPOTP NPSP is lost at MECO as acceleration quickly drops to zero. To compensate, the LO_2 pre valve is closed approximately 1 second after MECO and main engine helium is injected into the pogo accumulator. This pressurizes the HPOTP inlet while the turbine/pump spins down.

Note: Maintaining NPSP on the HPFTP is equally important. However, the ET LH_2 ullage pressure is the significant NPSP contributor instead of acceleration. At MECO, the LH_2 pre valves simply remain open (for approximately 5.5 seconds) to allow the ET ullage pressure to continue supplying NPSP as the HPFTP spins down.

- **Fuel and Oxidizer Preburners:** This is where the first stage of the combustion cycle takes place. LH_2 and LO_2 from the high-pressure turbopumps are burned in the Fuel Preburner (FPB) and Oxidizer Preburner (OPB) to create a hydrogen-rich gas. The output from the FPB drives the HPFTP turbine while the output from the OPB drives the HPOTP turbine. The hydrogen-rich gas from both turbines exhausts into the Hot Gas Manifold (HGM).
- **Hot Gas Manifold (HGM):** The HGM is the structural backbone of the engine. It supports the two preburners, the high-pressure turbopumps, and the Main Combustion Chamber (MCC). After the hot gas (generated by the preburners) drives the high-pressure turbopumps, it passes through the HGM on its way to the MCC.
- **Main Combustion Chamber (MCC):** Hydrogen-rich gas from the HGM enters the main injector assembly where it is injected into the MCC with additional oxidizer for the second, and final, stage of combustion.
- **Nozzle:** The fuel-cooled nozzle is bolted to the MCC and provides a high (69:1) thrust chamber expansion ratio.

- **Oxidizer Heat Exchanger:** The oxidizer heat exchanger converts LO_2 to GO_2 for LO_2 tank pressurization and pogo suppression. The heat exchanger receives its LO_2 from the HPOTP main pump. There is no need for a fuel heat exchanger. The LO_2 stays liquid all the way into the MCC (except for LO_2 into the heat exchanger or into the preburners) while LH_2 changes into a gas when it passes through the nozzle and MCC cooling circuits.
- **Valves:** Each SSME contains five hydraulically-operated propellant valves that are commanded by the main engine controller. These valves can also be closed pneumatically using main engine helium, which provides a backup system for engine shut down.
 - Fuel Preburner Oxidizer Valve (FPOV)
 - Controls the HPFTP turbine speed
 - Used to control the SSME mixture ratio
 - Oxidizer Preburner Oxidizer Valve (OPOV)
 - Controls the HPOTP turbine speed
 - Used to control the SSME throttle level
 - Main Fuel Valve (MFV)
 - Controls LH_2 flow during engine start and shut down
 - Remains 100 percent open during engine run
 - Main Oxidizer Valve (MOV)
 - Controls LO_2 flow during engine start and shut down
 - Remains 100 percent open during engine run
 - Chamber Coolant Valve (CCV)
 - Regulates the amount of LH_2 allowed to bypass the MCC and nozzle cooling ducts
- **Main Engine Fuel Flow:** The first place the LH_2 goes, upon entering the engine, is the LPFTP. See Figure 2-2. The LPFTP operates at approximately 15,000 rpm and boosts the fuel pressure from 30 to 306 psia. The LPFTP discharge is plumbed into the HPFTP. The HPFTP operates at about 30,000 rpm and boosts the LH_2 pressure from 306 to 5943 psia. Discharge from the HPFTP passes through the main fuel valve and breaks into three separate paths.

The first path enters the jacket of the MCC where the hydrogen is used to cool the chamber walls. It is then routed to the LPFTP where it is used to drive the turbine. Some of the exit flow from the LPFTP turbine is sent through a manifold to the ET to provide LH₂ ullage pressure. The rest goes to cool the HGM, and then it is discharged into the MCC and burned.

The second path goes through the nozzle cooling ducts. It then joins the third path from the CCV which has bypassed the cooling circuits.

The combined flow is channeled to the fuel and oxidizer preburners for combustion. The resultant hot gas drives the HPFTP and HPOTP turbines before passing through the HGM on its way to the MCC for final combustion.

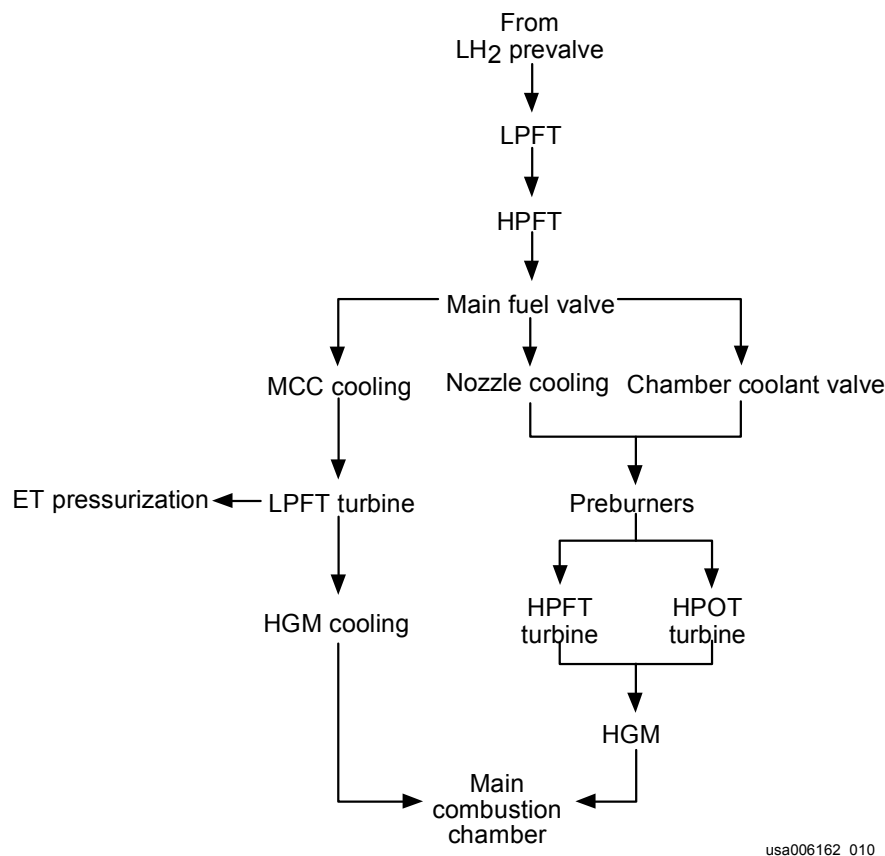


Figure 2-2. Main engine fuel flow

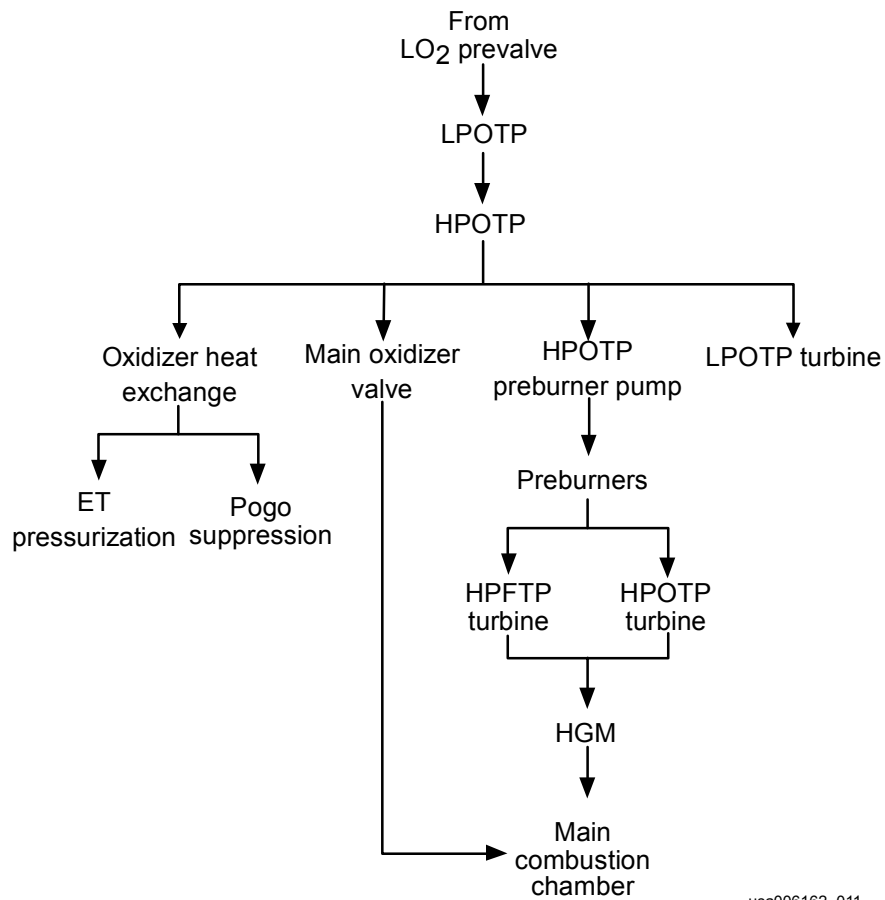
- Main Engine Oxidizer Flow:** The LO₂ first passes through the LPOT. See Figure 2-3. The LPOT operates at approximately 5000 rpm and boosts the oxidizer pressure from 100 to 419 psia. The LPOT discharge is plumbed into the HPOTP main pump. The HPOTP operates at about 22,000 rpm, and the main pump boosts the LO₂ pressure from 419 to 4040 psia. Discharge from the HPOTP main pump separates into four distinct paths.

The first path returns to drive the LPOTP turbine. The turbine exit flow is merged with the pump output.

The second path goes through the oxidizer heat exchanger where the LO₂ is converted to GO₂ for ET pressurization and pogo suppression.

The third path is routed through the MOV and into the MCC.

The fourth, and final, path is directed to the HPOTP preburner pump where the LO₂ pressure is boosted to 6960 psia and sent to the preburners. There, it is mixed with fuel and burned. The resultant hot gas drives the HPFTP and HPOTP turbines before passing through the HGM on its way to the MCC for final combustion.



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Figure 2-3. Main engine oxidizer flow

2.3 MAIN ENGINE CONTROLLER

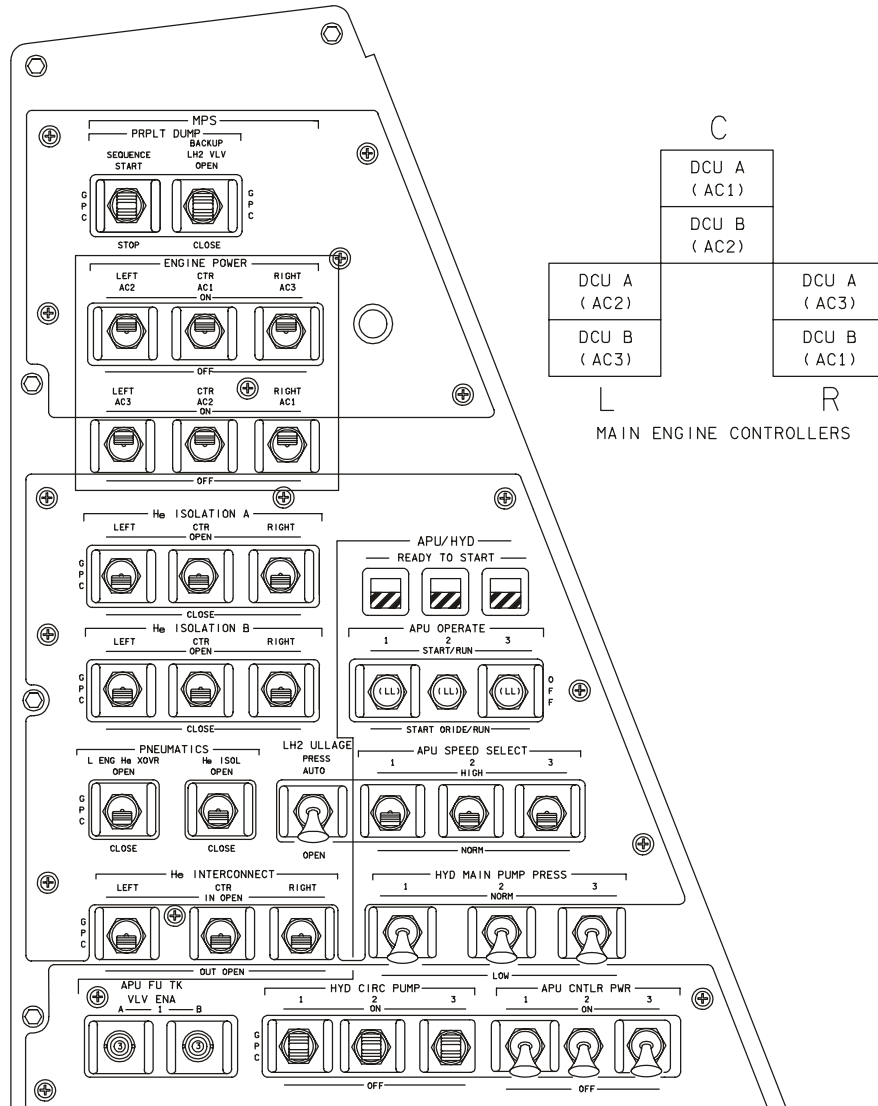
The main engine controller is an electronics package that interfaces with engine sensors, valves, and spark igniters to provide a self-contained system for engine control, checkout, and monitoring.

The tasks of a controller include

- Perform pre-launch checkout, chilldown, purges
- Perform closed-loop mixture control during mainstage
- Respond to GPC commands
 - SSME start and shut down
 - Throttle settings
 - Enable/Inhibit redline limit shutdown control
 - Propellant dump
- Perform redline limit monitoring and failure management

The SSME controller is mounted on the engine MCC and contains two redundant Digital Computer Units (DCUs). These are referred to as DCU A and DCU B. Normally, DCU A is in control and DCU B electronics are active but not in control. If DCU A fails in flight, DCU B assumes control. If DCU B subsequently fails, the engine shuts down via a pneumatic fail-safe system that does not require active control. The loss of either DCU prior to liftoff results in a launch hold.

Power to the controllers is supplied by the three AC buses in a manner that protects their redundancy. Refer to Figure 2-4. Each DCU within a controller receives its power from a different bus. The buses are distributed among the three controllers such that the loss of any two buses results in the loss of only one engine. The DCUs require all three phases of an AC bus to operate. Power to the controllers is provided through the MPS ENGINE POWER switches on Panel R2. There are two switches for each engine. The top switch is for DCU A, and the bottom switch is for DCU B.

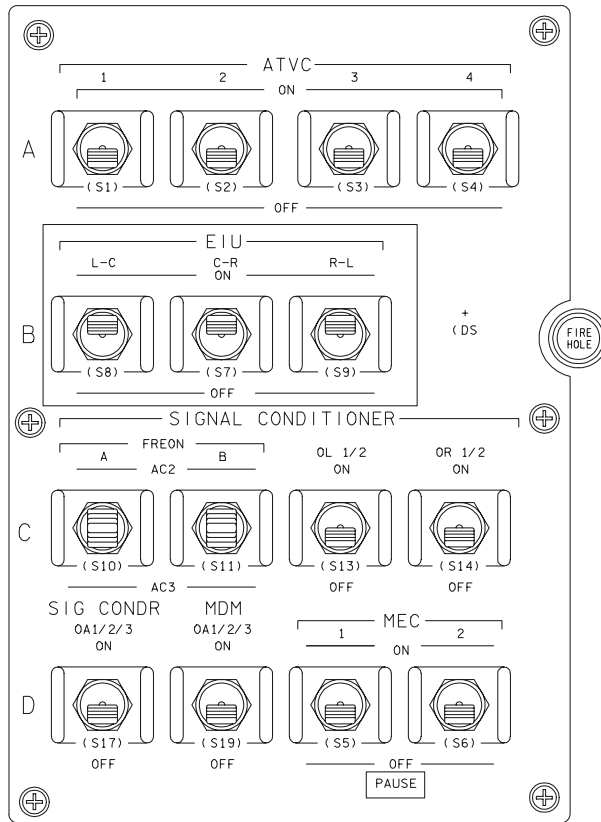


TD3450204. ART: 5

Figure 2-4. Main engine controller power distribution and crew controls on Panel R2

Each controller receives commands from the GPCs through an EIU. The EIU is a specialized Multiplexer/Demultiplexer (MDM) that interfaces the GPCs with the engine controller. Each EIU is dedicated to one SSME and communicates only with that engine controller. The three EIUs have no interface with each other.

EIU power switches are located on Panel O17. See Figure 2-5. If an EIU loses power, its corresponding engine cannot receive any commands or send data to the GPCs. This is called a command and data path failure, as described in Section 4.0. As a result, the controller maintains the last valid command until it is shut down manually via the AC power switches on Panel R2.

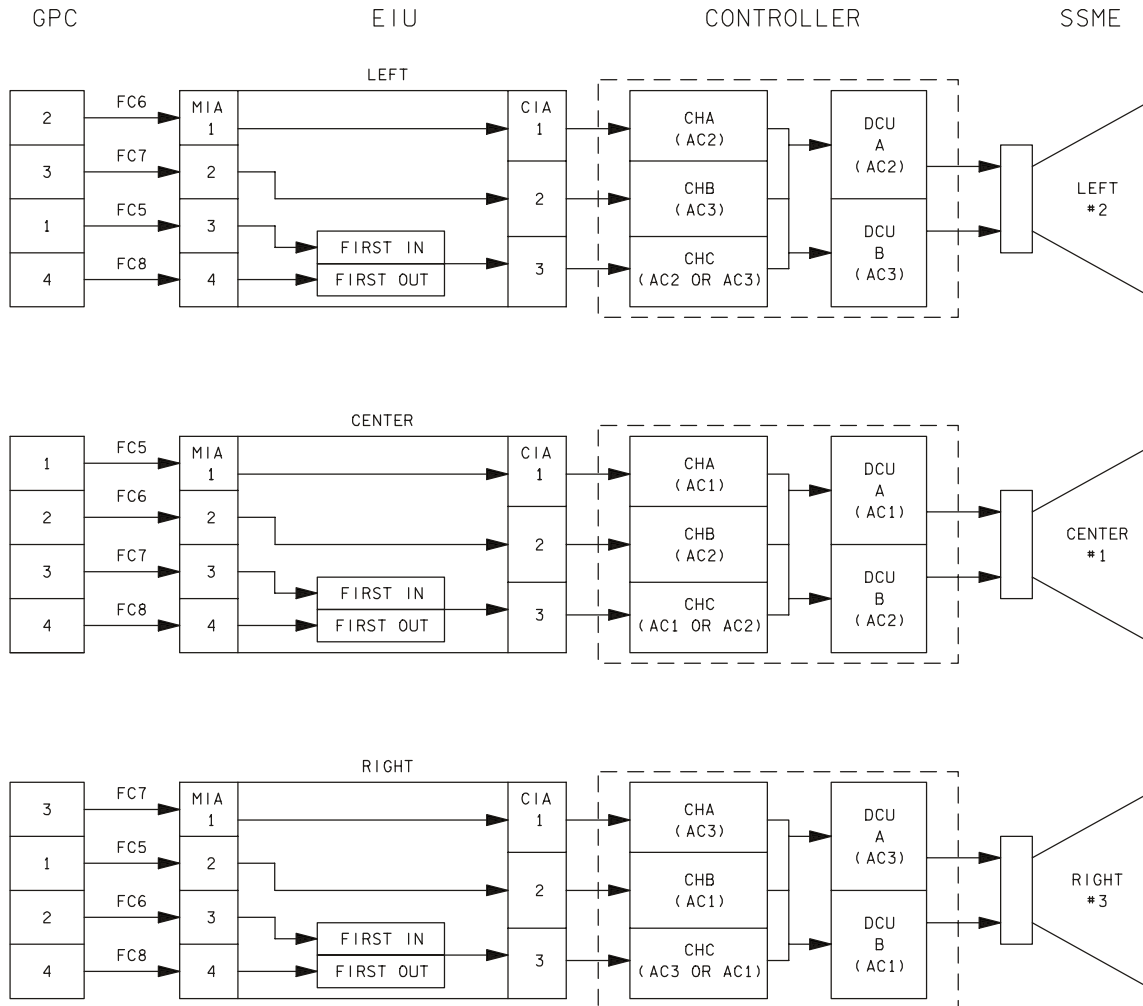


TD3450205. ART. 3

Figure 2-5. EIU power switches on Panel O17

2.3.1 Main Engine Command Flow

Each GPC operating in the redundant set issues main engine commands over its assigned Flight-Critical (FC) data bus. GPCs 1, 2, 3, and 4 usually command data buses 5, 6, 7, and 8, respectively. Each FC data bus is connected to one Multiplexer Interface Adapter (MIA) in each EIU. See Figure 2-6.



TD3450206, ART# 3

Figure 2-6. Main engine command flow

The EIU receives four engine commands from the four Primary Avionics Software System (PASS) GPCs through its four MIAs. After checking the commands for transmission errors, it passes them on to the Controller Interface Assemblies (CIAs), which output the validated commands to the controller. Commands that come through MIAs 1 and 2 are sent to CIAs 1 and 2, respectively. Commands that come through MIAs 3 and 4 are sent to CIA 3, which outputs the command that arrives first; the other command is dead-ended. This is how the EIU reduces four input commands from the GPCs to three output commands to the engine controller.

The controller receives three engine commands from the EIU through three command/data channels in its Vehicle Interface Electronics (VIE). VIE channels A, B, and C receive their inputs from CIA 1, 2, and 3, respectively. The VIE checks the commands again for transmission errors and sends the validated commands to the redundant DCU A and DCU B electronics. The DCU in control (normally DCU A) votes by comparing for identical commands. If at least two of the three commands pass voting (that is, are identical), the controller issues its own command to accomplish the function.

If command voting fails (two or all three commands fail), the controller rejects the GPC command and maintains the last command that passed voting. The GPCs will announce a command path failure when they see a reject from the controller or do not see the controller accept a new command. More information on this failure is available in Section 4.0.

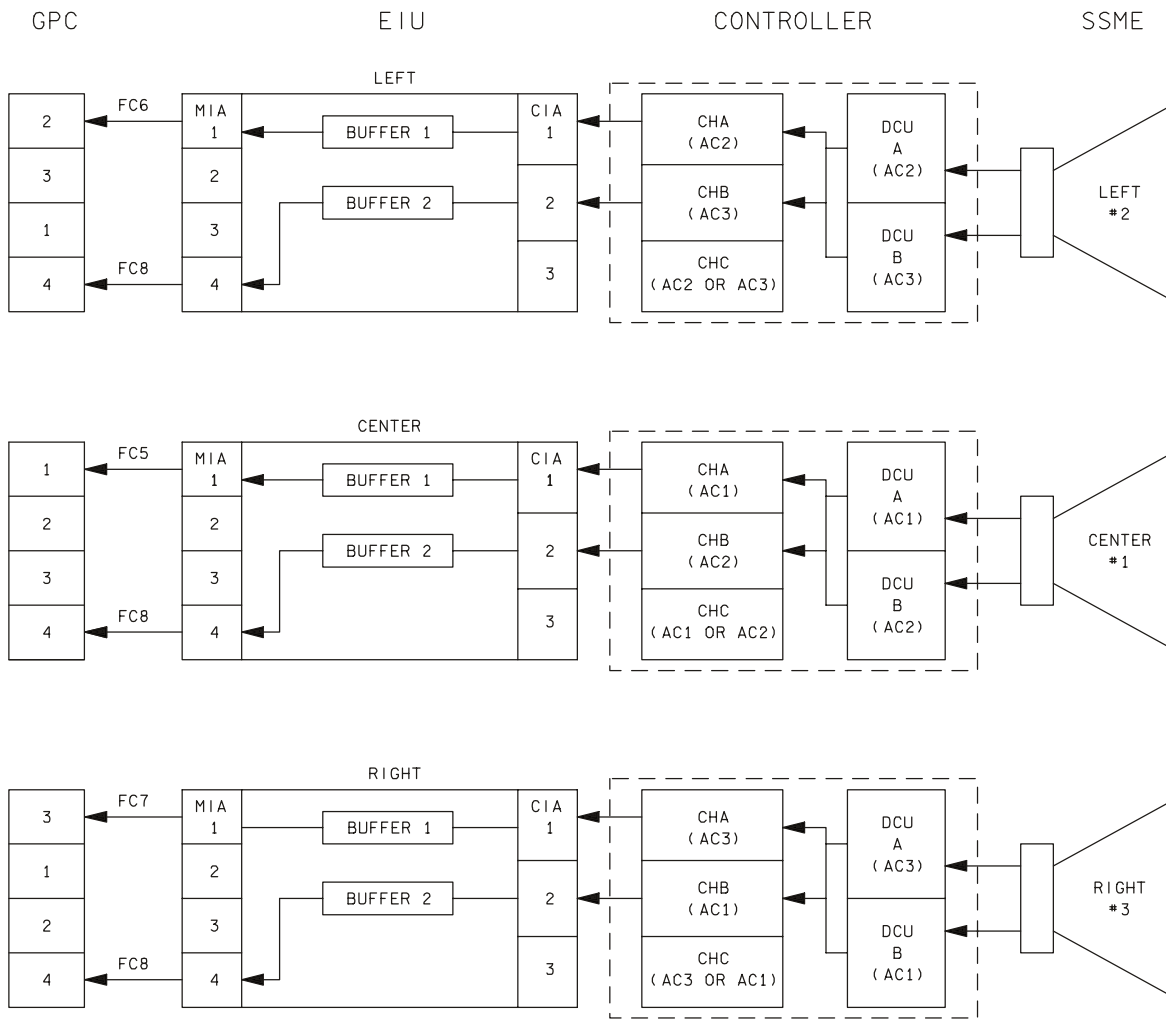
2.3.2 Main Engine Data Flow

Sensors in the engine supply data to both DCUs. The DCU in control (normally DCU A) generates both the primary and secondary data paths. Primary data consists of the first 32 words of the SSME Vehicle Data Table (VDT). Secondary data consists of the first six words of the VDT. The first six words are redundant in the primary and secondary data because they are necessary to drive SSME cockpit status indications.

Primary Data is sent to VIE channel A, and Secondary Data is sent to VIE B. VIE channel C is not used for data. See Figure 2-7.

The primary data (from VIE channel A) enters the EIU through CIA 1; secondary data (from VIE channel B) enters through CIA 2. The data is stored in the EIU until the GPCs issue a data request.

When the GPCs issue a data request, Primary data is output from the EIU through MIA 1 and Secondary data is output through MIA 4.



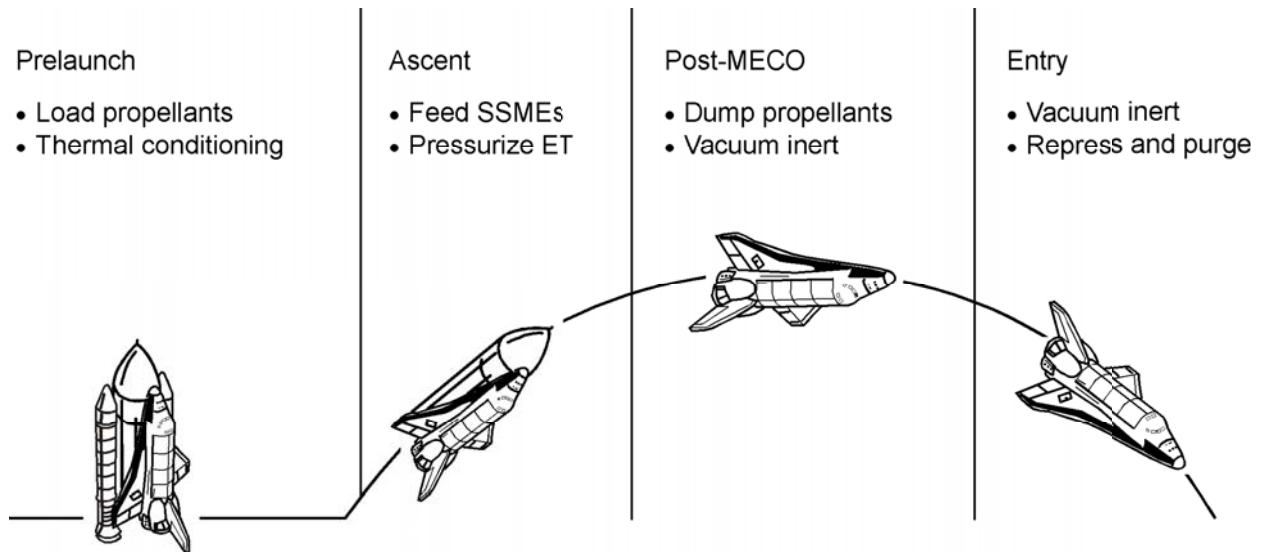
TD3450207. ART, 3

Figure 2-7. Main engine data flow

2.4 PROPELLANT MANAGEMENT SYSTEM

The MPS PMS consists of manifolds, distribution lines, and valves that transport propellants from the ET to the three main engines for combustion, and gases from the engines to the ET for tank pressurization.

The PMS is the lifeline of the MPS. See Figure 2-8. In addition to its primary function of feeding propellants to the engines during powered flight, the PMS also controls the loading of propellants before launch, the post-MECO propellant dump and vacuum inerting, and the system purge and repressurization during entry. The major components of the PMS are described as follows. Refer to Figure 2-9.



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Figure 2-8. Propellant management system functions

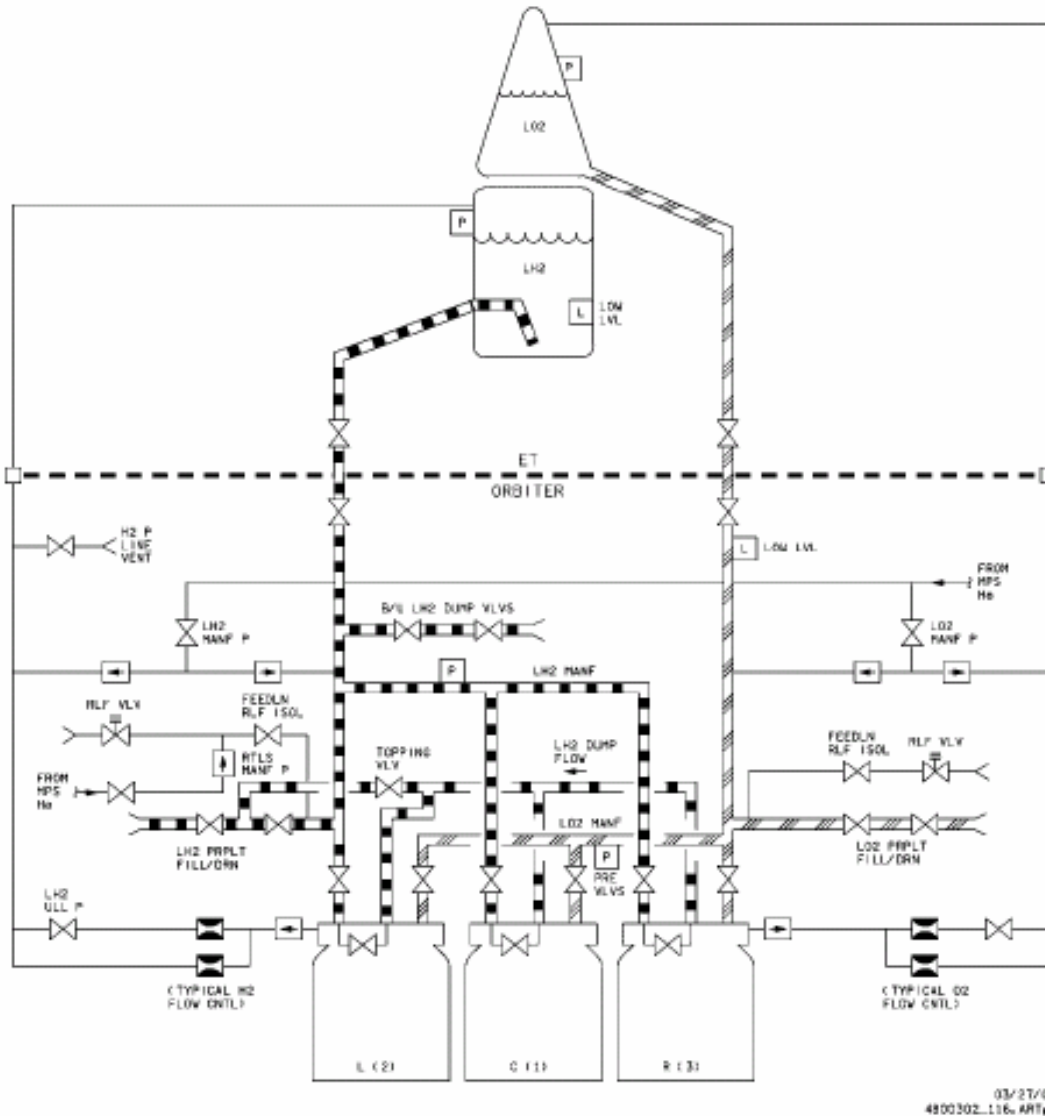


Figure 2-9. MPS propellant schematic from the Ascent Pocket Checklist

Propellant Feedline Manifolds

Propellant is delivered to the SSMEs through the LO₂ manifold and the LH₂ manifold. Each manifold consists of 17-inch and 12-inch piping. The 17-inch line carries propellant from the ET into the orbiter aft compartment where it splits into three 12-inch lines (one per engine). Each manifold ends where the 12-inch lines meet the LO₂ and LH₂ prevalves for each engine inlet.

Pressures within the LO₂ and LH₂ feedline manifolds can be monitored on the two ENG MANF meters on the Multifunction Electronic Display Subsystem (MEDS) OMS/MPS subsystem display or on the BFS GNC SYS SUMM 1 display. Refer to Figure 2-10.

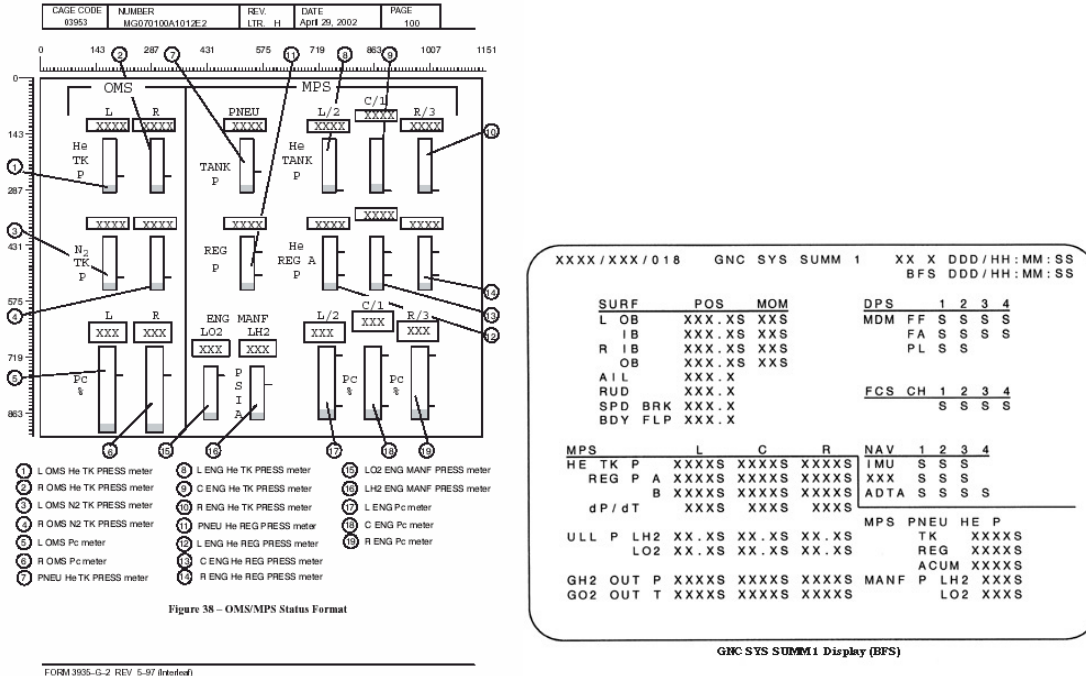


Figure 2-10. LH₂ and LO₂ manifold pressures are displayed on the MEDS OMS/MPS Display and the BFS GNC SYS SUMM 1

Feedline Disconnect Valves

The LH₂ and LO₂ feedlines each contain two disconnect valves where the orbiter meets the ET. One of the valves is on the orbiter side and the other is on the ET side. All four disconnect valves are closed automatically during the ET separation sequence. Manual control of these valves does not exist.

Fill/Drain Valves

The LH₂ and LO₂ feedlines each contain two propellant fill-drain valves arranged in series that allow filling (or draining) the ET during prelaunch operations. The fill-drain valves are used in flight for the automatic post-MECO propellant dumps and vacuum inerting. The crew has switches on Panel R4 that provide manual control of the fill-drain valves. Refer to Figure 2-11.

Manifold Relief Lines

The two relief lines, one for LH₂ and one for LO₂, connect the feedline manifolds to an overboard port. Each line contains a relief isolation valve and a relief valve in series. Opening the isolation valves (which occurs automatically after MECO) allows the relief valve to operate. The relief lines protect the feedline manifolds by allowing excessive pressure to be vented overboard. The relief isolation valves, shown in Figure 2-11, can also be controlled from Panel R4.

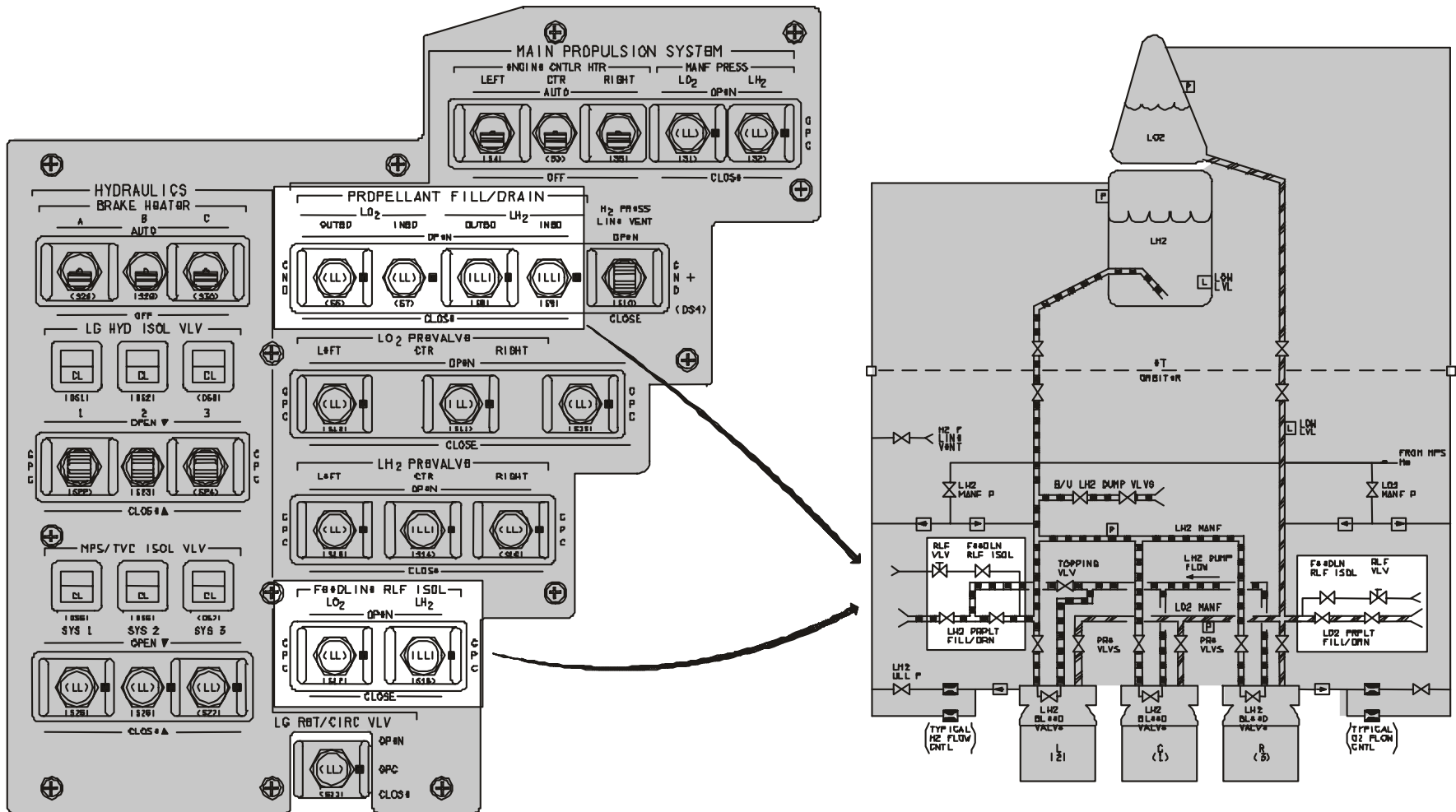


Figure 2-11. LO₂ and LH₂ fill/drain and feedline relief isolation valves are controlled from Panel R4

Backup LH₂ Dump Valves

The backup LH₂ dump line connects the LH₂ feedline manifold to an overboard port above the left wing of the orbiter. See Figure 2-12. The line, designed primarily for the post-MECO LH₂ dump during a Return to Launch Site (RTLS) abort, is also used to vent the LH₂ manifold after a nominal MECO. Since LH₂ evaporates quickly, this vent is accomplished to prevent LH₂ manifold pressure from rising and repeatedly cycling the relief valve before the propellant dump begins. Flow through the line is controlled by two valves in series (backup dump valves, also known as the RTLS dump valves). These valves are only commanded by the GPCs (no direct manual control), but the GPC command can be manually controlled from Panel R2 during OPS 1.

LH₂ Topping Valve

This valve controls the flow of LH₂ through the LH₂ recirculation line, which is used for prelaunch thermal conditioning and LH₂ tank topping/replenish. The LH₂ Topping Valve does not have a dedicated switch, but manual control is available since this valve is slaved to the LH₂ Inboard Fill/Drain switch on Panel R4.

Proper LH₂ tank fluid level is controlled during stable replenish by LH₂ flow from ground supplies. Flow enters the MPS through the outboard fill-drain valve (LH₂ inboard fill/drain valve is closed) and enters the LH₂ tank via the four-inch recirculation line and topping valve.

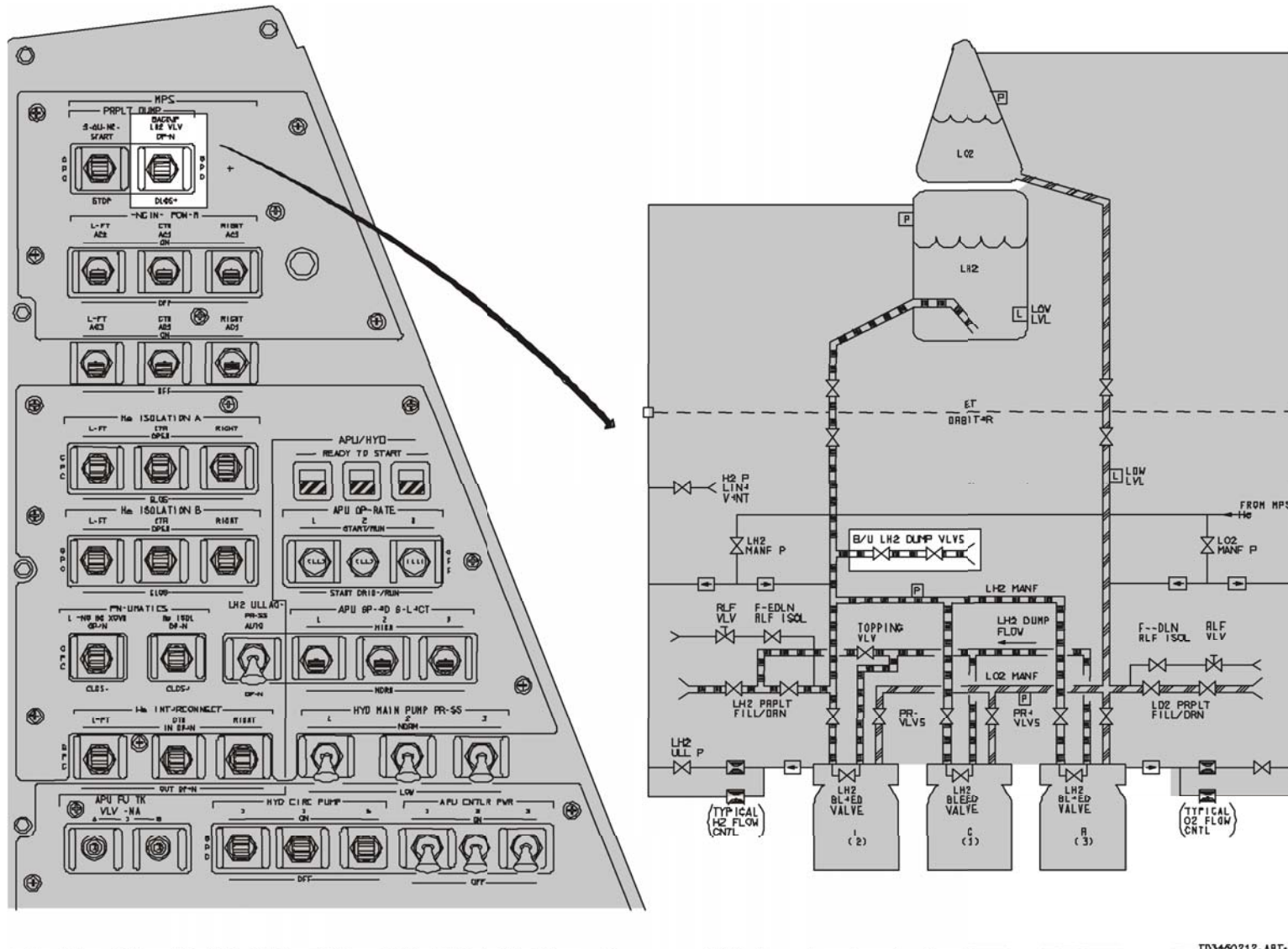


Figure 2-12. Backup LH₂ dump switch on Panel R

LH₂ and LO₂ Bleed Valves

Each engine contains an LH₂ bleed valve and an LO₂ bleed valve. They are open during prelaunch thermal conditioning to allow an exit path for propellant from the engines. They close during the engine start sequence and remain closed during engine run. They reopen post-shutdown to allow propellant trapped in the SSMEs to flow back to the manifolds. The bleed valves close again at termination of the MPS Dump.

The three LH₂ bleed valves (one in each engine) are shown on the Ascent Pocket Checklist MPS schematic. They connect the engine internal LH₂ lines with the LH₂ recirculation line.

The three LO₂ bleed valves are not shown on the Ascent Pocket Checklist MPS schematic. LO₂ flows from the engines through these valves to a port on the T - 0 umbilical during prelaunch thermal conditioning. This overboard port is closed along with the bleed valves during the engine start sequence. When the bleed valves reopen post-shutdown, they are connected to the LO₂ manifold via the Pogo Recirc valves, which are also not shown on the schematic.

Prevalves

The six engine prevalves control the flow of LH₂ and LO₂ to the three main engines. All of the pre valve functions are automatic, but manual control is available on Panel R4 as required for malfunction scenarios (See Figure 2-13).

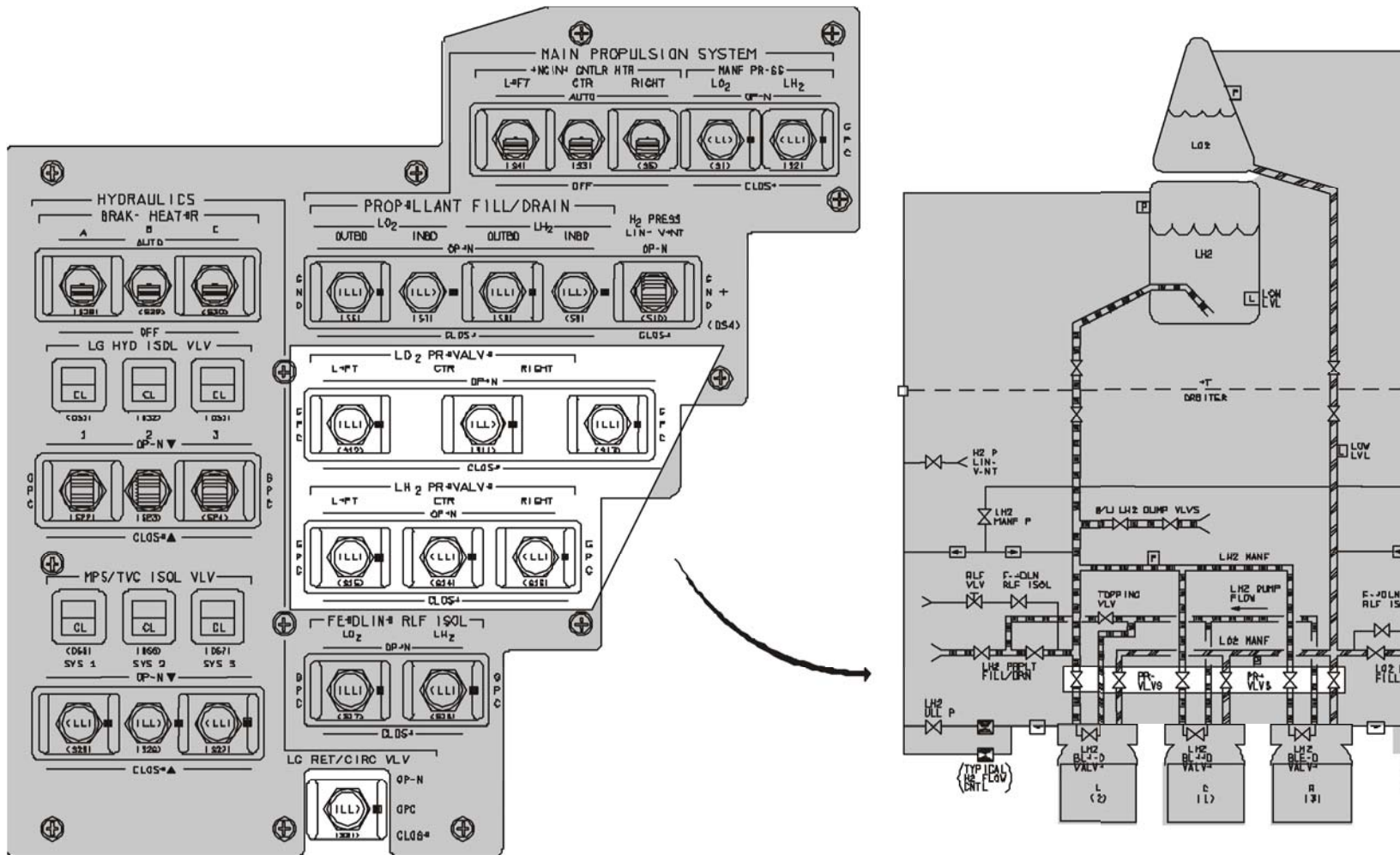


Figure 2-13. LO₂ and LH₂ prevalve switches are on Panel R4

Ullage Pressure System

Ullage refers to the volume in the ET LH₂ and LO₂ tanks not occupied by liquid propellant. The ullage pressure system consists of the sensors, lines, and valves that are used to collect gaseous propellants (gaseous hydrogen and gaseous oxygen) from the three main engines; the system supplies the gaseous propellants to the ET to maintain propellant tank pressure during engine operation. Refer to Figure 2-14.

Propellants must be supplied to the SSME with adequate head pressure for proper engine operation. During powered flight, sufficient LO₂ NPSP occurs naturally due to the high density of LO₂ and the tall column from the LO₂ tank to the engines. Sufficient LH₂ NPSP is also critical for safe engine operation and is dependant on the GH₂ ullage pressurization system.

Two ET pressurization manifolds are in the orbiter, one for GH₂ and one for GO₂. Each manifold connects the three engine ullage pressure outlets to an ET ullage pressurization line.

There are six engine ullage pressure outlet lines in the orbiter, three for GH₂ and three for GO₂. Each GH₂ line connects the LPFTP turbine outlet on one SSME to the GH₂ ET pressurization manifold. Each GO₂ line connects the oxidizer heat exchanger outlet on one SSME to the LO₂ ET pressurization manifold.

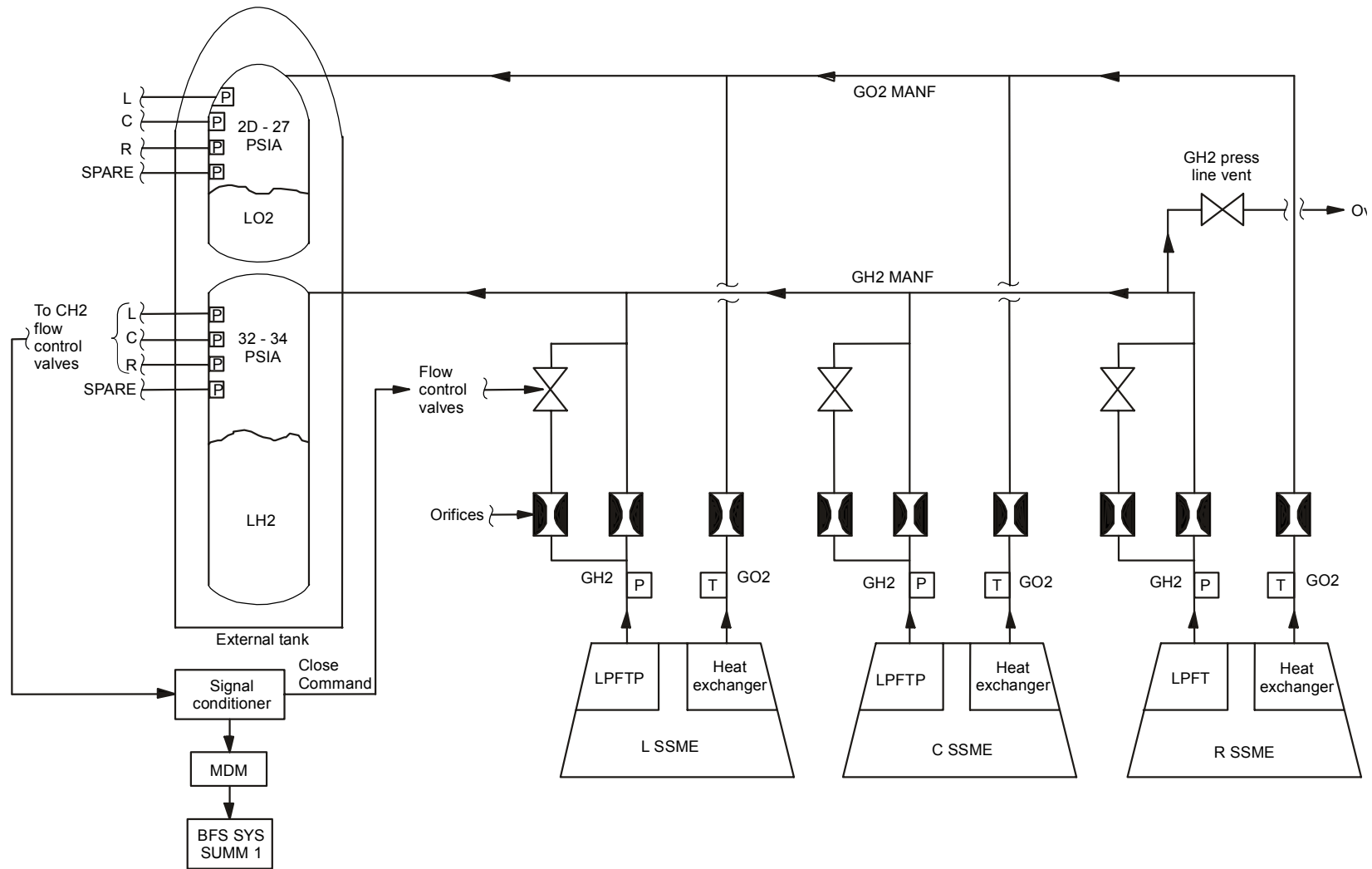
Each of the three GH₂ engine ullage pressure outlet lines contains two fixed-diameter orifices connected in parallel and one active flow control valve connected in series with one of the orifices. The combination of orifices and flow control valves is used to control the ullage pressure in the LH₂ propellant tank.

LO₂ ullage pressure outlet lines are connected to GO₂ flow control valves that are shimmed open to a fixed orifice size. LO₂ tank pressure is maintained between 20 and 27 psia by the fixed orifice.

Each GH₂ flow control valve is driven by its own ullage pressure sensor at the top of the LH₂ propellant tank. When a sensor detects low pressure, its corresponding flow control valve opens; when the pressure comes back up, the valve is closed. The set point for the GH₂ flow control valves is 33 ± 0.4 psia. The three GH₂ flow control valves can also be opened manually with the LH₂ ULLAGE PRESS switch on Panel R2. Refer to Figure 2-15. The three LH₂ and three LO₂ ullage pressure sensor outputs can be read on the BFS GNC SYS SUMM 1 display (See Figure 2-16).

A GH₂ pressurization vent line connects the ET GH₂ pressurization manifold to an overboard port. Flow through the line is governed by the GH₂ pressurization line vent valve that is controlled from Panel R4. This line is used exclusively for vacuum inerting the GH₂ pressurization manifold on orbit. Refer to Figure 2-15.

Upstream of the GH_2 flow control valve is a pressure sensor, and upstream of the GO_2 fixed orifice is a temperature sensor. The GH_2 outlet pressure and GO_2 outlet temperature are used to determine whether the engine is running when the main engine data flow to the GPCs has failed. These parameters are channelized through Operational Instrumentation-Aft (OA) MDMs and are not affected if an SSME Data Path failure occurs.



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Figure 2-14. External tank ullage pressure system

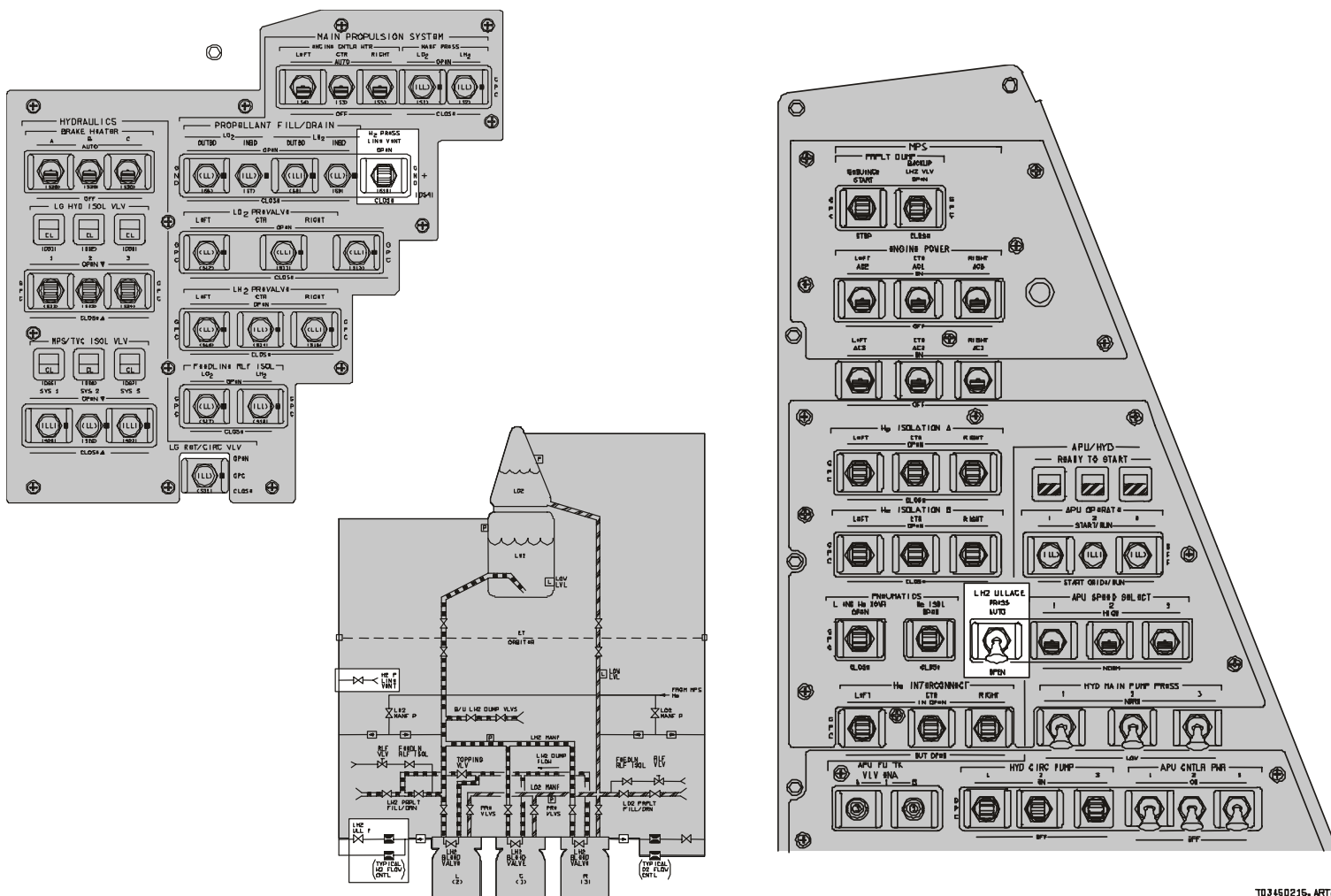


Figure 2-15. Crew controls for the ullage pressure system include the H₂ PRESS LINE VENT switch on Panel R4 and the LH₂ ULLAGE PRESS switch on Panel R2

The GH₂ OUT P on BFS SYS SUMM 1 can also be used to determine whether a GH₂ flow control valve is opened. At 104-percent power level, if the flow control valve is closed, the average GH₂ OUT P is 3180 psi. When the flow control valve opens, the GH₂ OUT P drops to 2930. At 67-percent power level, if the flow control valve is closed, the average GH₂ OUT P is 2010 psi. When the flow control valve opens, the GH₂ OUT P drops to 1880 psi.

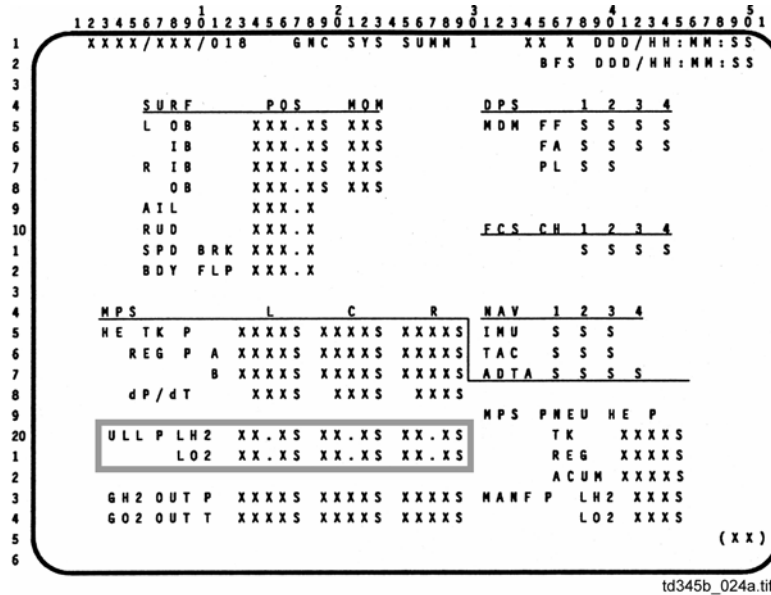


Figure 2-16. LH₂ and LO₂ ullage pressures are displayed on the BFS GNC SYS SUMM 1

Manifold Pressure Valves

The LH₂ and LO₂ manifold pressure valves route helium from the MPS helium system into the feedline manifolds. Helium is used to pressure-assist the LO₂ dump for nominal missions and pressure-assist the LH₂ dump for aborts. Both the LH₂ and the LO₂ manifolds are repressurized during entry to avoid atmospheric contamination of the vacuum-inerted manifolds. Manual control of the manifold pressure valves is available on Panel R4. See Figure 2-17.

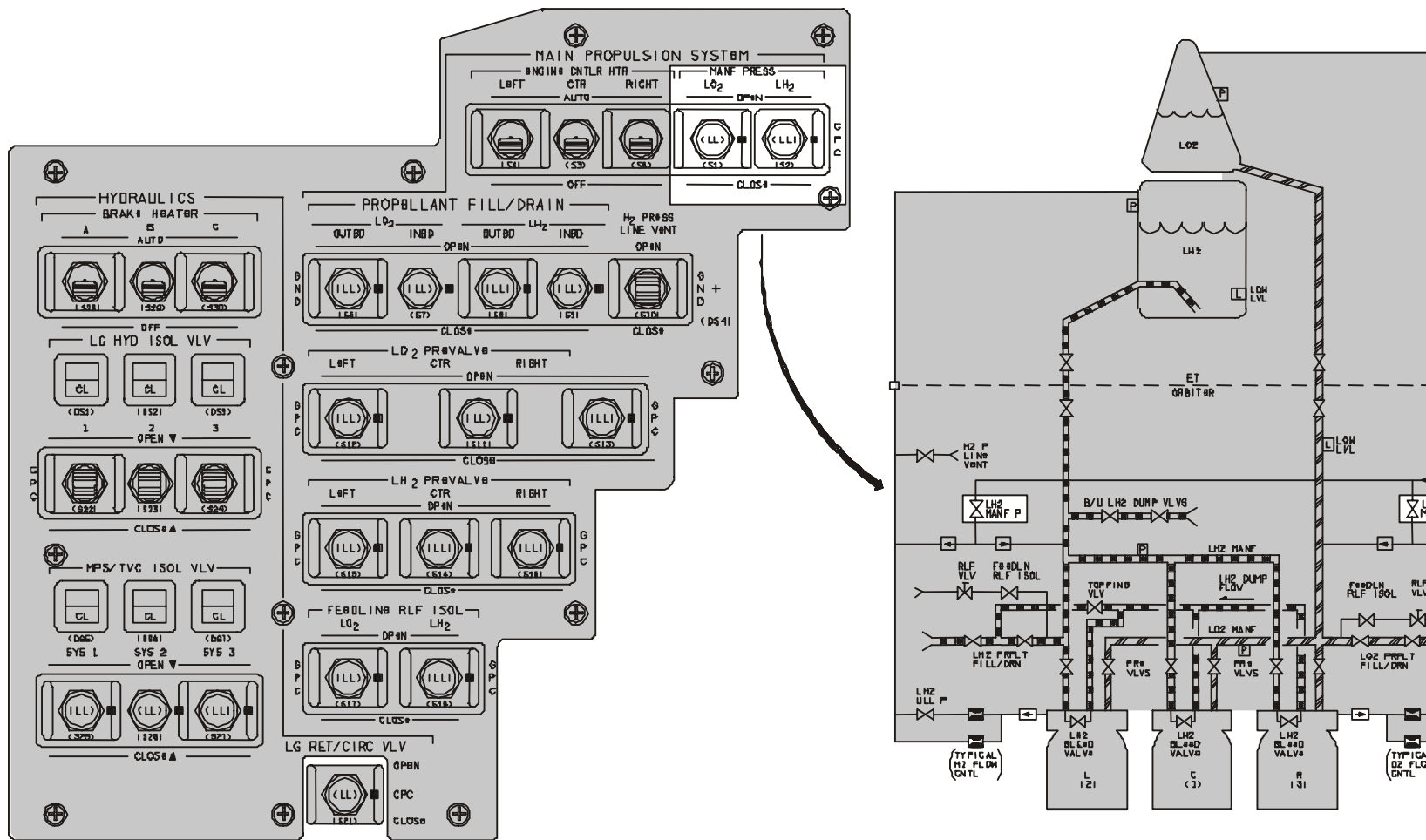


Figure 2-17. LO₂ and LH₂ MANF PRESS switches on Panel R4

Valve Types

The PMS uses two basic types of valves, pneumatically actuated and electrically actuated. Refer to Table 2-1. Pneumatic valves are used where large loads are encountered, such as in the control of liquid propellant flows. Electrical valves are used for lighter loads, such as in the control of gaseous propellant flows.

The pneumatically activated valves are divided into two subtypes, those that require pneumatic pressure to open and close the valve (type 1) and those that are spring-loaded to one position and require pneumatic pressure to move to the other position (type 2).

The electrically actuated solenoid valves are spring-loaded to one position and move to the other position when electrical power is applied.

Table 2-1. Valve types in the propellant management system

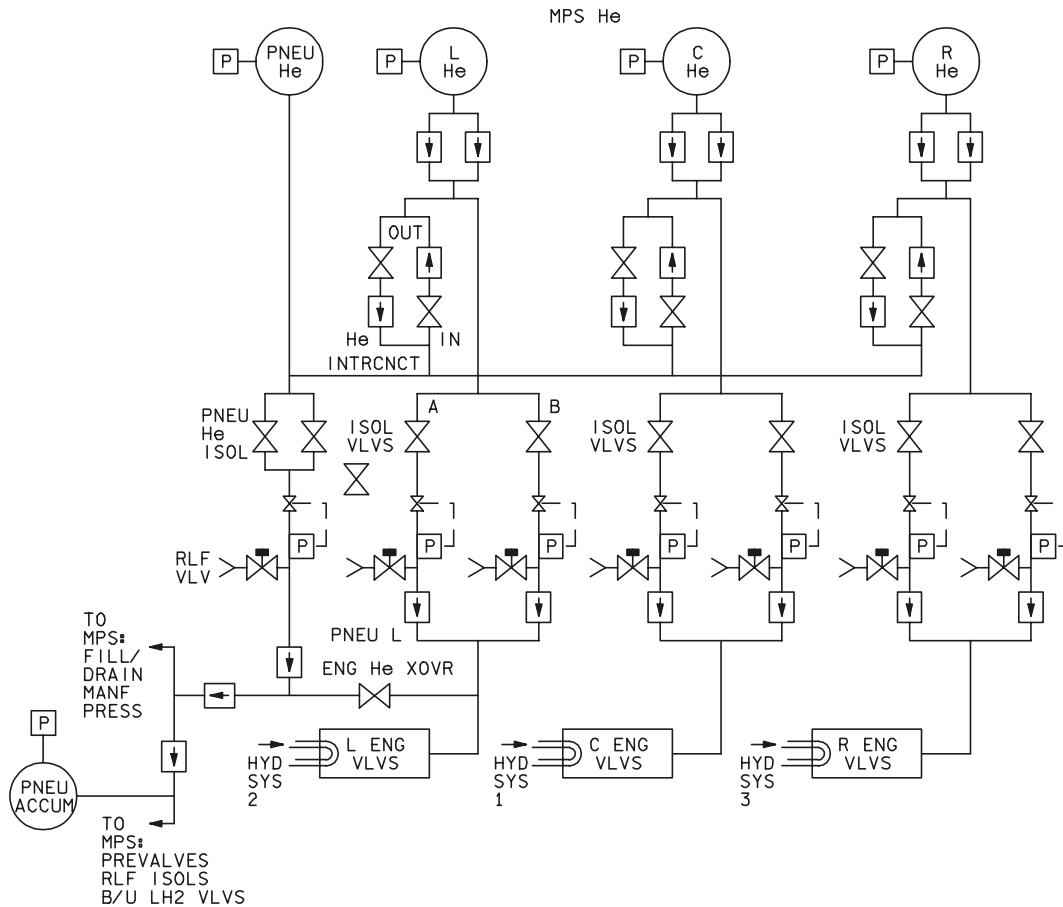
PMS Valve Types		
Pneumatic		Electric
Type 1	Type 2	
Feedline disconnect valves	Feedline relief isolation valves (NO)	Ullage pressure flow control valves (NO)
Fill/drain valves	Backup LH ₂ dump valves (NC)	GH ₂ press line vent (NC)
Prevalves	Topping valve (NC)	Manifold pressure valves (NC)
NO: Normally open - The spring force drives the valve open.		
NC: Normally closed - The spring force drives the valve closed.		

2.5 HELIUM SYSTEM

The MPS helium system consists of storage tanks, distribution lines, regulators, and valves that supply helium to the main engines and the MPS PMS.

Helium is supplied to the main engines to purge the HPOTP intermediate seal and provide inlet pressure to the HPOTP during shutdown as head pressure is lost due to loss of acceleration. It may also be used to close the engine valves during an emergency pneumatic shutdown. Post-MECO, the MPS helium is used to operate the pneumatic valves within the PMS, and to help force LH₂ or LO₂ out of the propellant lines during the post-MECO dump. During entry it is used to pressurize the MPS lines and purge the aft compartment.

The helium system is divided into four distinct subsystems, one for each of the three main engines and a fourth pneumatic system to operate the propellant valves. The major components of the system are described as follows. Refer to Figure 2-18.

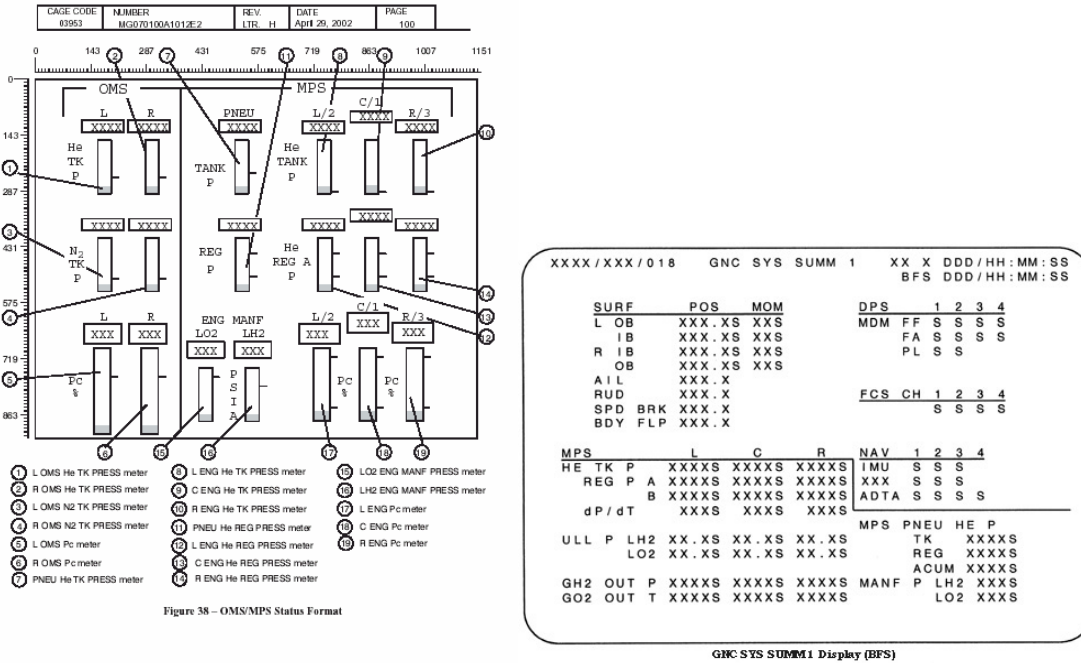


TD3450219. SCH# 5

Figure 2-18. MPS helium schematic from the Ascent Pocket Checklist

- a. **Supply Tanks:** The helium supply tanks consist of three large (17.3-cubic-foot) and seven small (4.7-cubic-foot) helium tanks. Each large tank is plumbed to two of the small tanks to form three clusters. Each cluster (shown in the pocket checklist schematic as one tank) provides helium to one of the main engines. The remaining small tank is the pneumatic helium supply.

The crew can monitor engine helium and pneumatic helium tank pressures on the MEDS OMS/MPS Display or on the BFS GNC SYS SUMM 1 display. See Figure 2-19.



- b. **Helium Isolation Valves:** Eight helium isolation valves, grouped in pairs, control the flow of helium from the supply tanks. One pair is connected to each engine tank cluster, and the fourth pair is connected to the pneumatic supply tank. In the engine helium supply systems, the isolation valves are in parallel with each valve controlling helium flow through one leg of a dual redundant supply circuit. Each leg, referred to as leg A and leg B contains an isolation valve, a regulator, a relief valve, and a check valve.

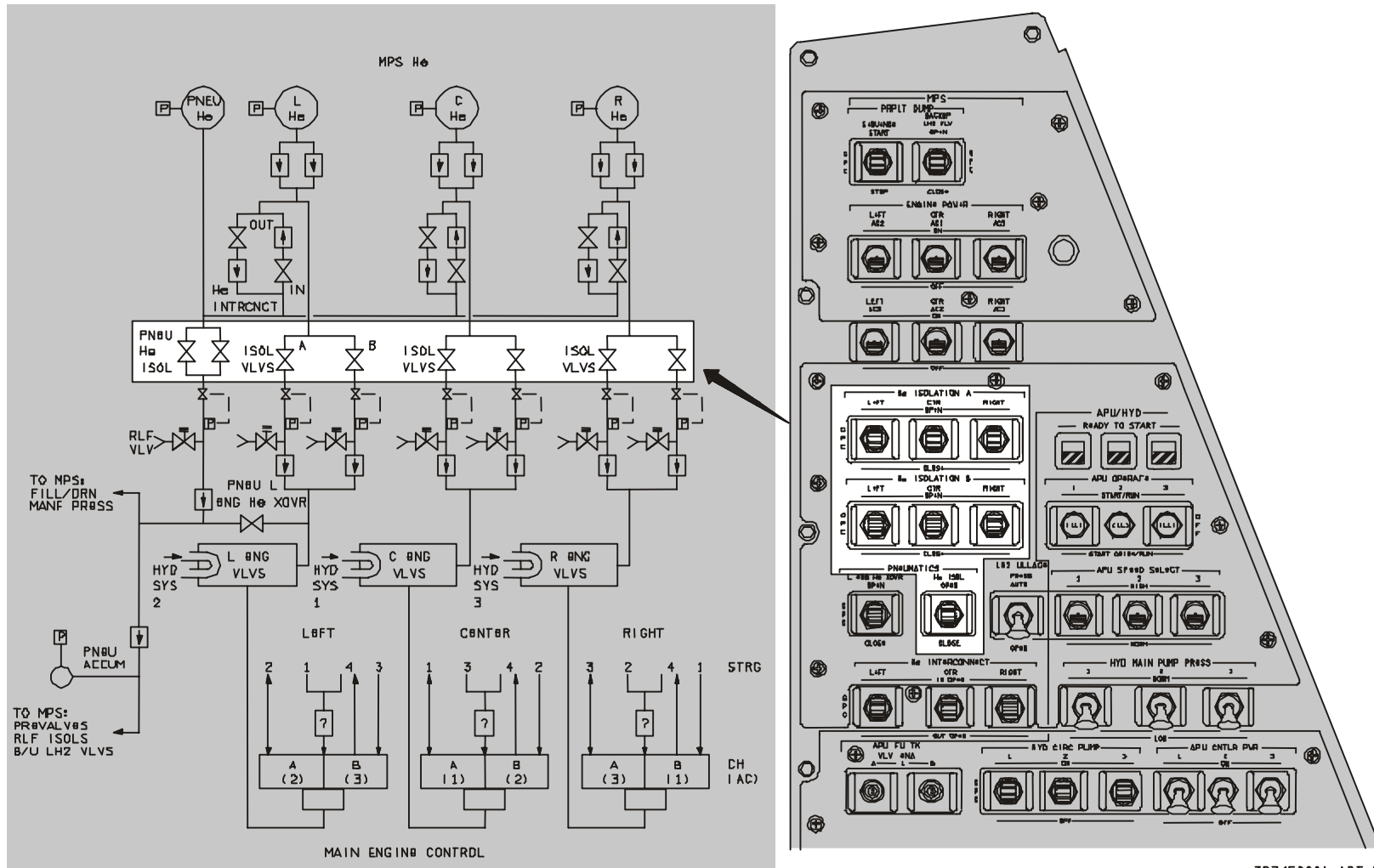
The two isolation valves for the pneumatic supply tank are also connected in parallel, but the rest of the pneumatic system consists of a single regulator, relief valve, and check valve.

Each of the engine helium isolation valves can be controlled by its own switch on Panel R2. See Figure 2-20. Both pneumatic helium isolation valves are controlled by a single switch, also on Panel R2. The six engine system regulator pressures and pneumatic system regulator and accumulator pressures can be read on the BFS GNC SYS SUMM 1 display. The three engine system leg A regulators and the pneumatic system regulator can be monitored on the MEDS OMS/MPS Display.

- c. **Pneumatic Left Engine Helium Crossover Valve:** The crossover valve between the pneumatic and left engine helium systems serves as a backup for the nonredundant pneumatic pressure regulator system. In the event of a pneumatic helium regulator failure or a leak in the pneumatic helium system, the left engine helium system can provide regulated helium through the crossover valve to the pneumatic helium distribution system. The PNEU L ENG He XOVER valve is controlled from Panel R2. See Figure 2-21.
- d. **Helium Interconnect Valves:** Each of the three engine helium supply systems has a helium “out” interconnect valve that connects it to the pneumatic supply system. Also, each has a helium “in” interconnect valve that connects the pneumatic helium supply system to that engine supply system. Each valve is connected in series with a check valve that allows flow in only one direction.

Each pair of interconnect valves is controlled by a single switch on Panel R2 (Figure 2-21). The three positions on each switch are IN OPEN, GPC, and OUT OPEN. When the switch is in the IN OPEN position, the “in” interconnect valve is open and the “out” interconnect valve is closed. The OUT OPEN position does the reverse. When in GPC, both valves are closed except when commanded open by the GPCs.

- e. **Pneumatic Accumulator:** If the pneumatic supply system were interconnected “in” to a leaking engine helium system to extend the engine run time, the pneumatic supply could be depleted by MECO. To ensure that the LO₂ prevalues are closed at MECO to meet the LO₂ NPSP requirement, a pneumatic accumulator stays charged with enough helium to close the LO₂ prevalues.



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Figure 2-20. The MPS isolation valves are controlled from Panel R

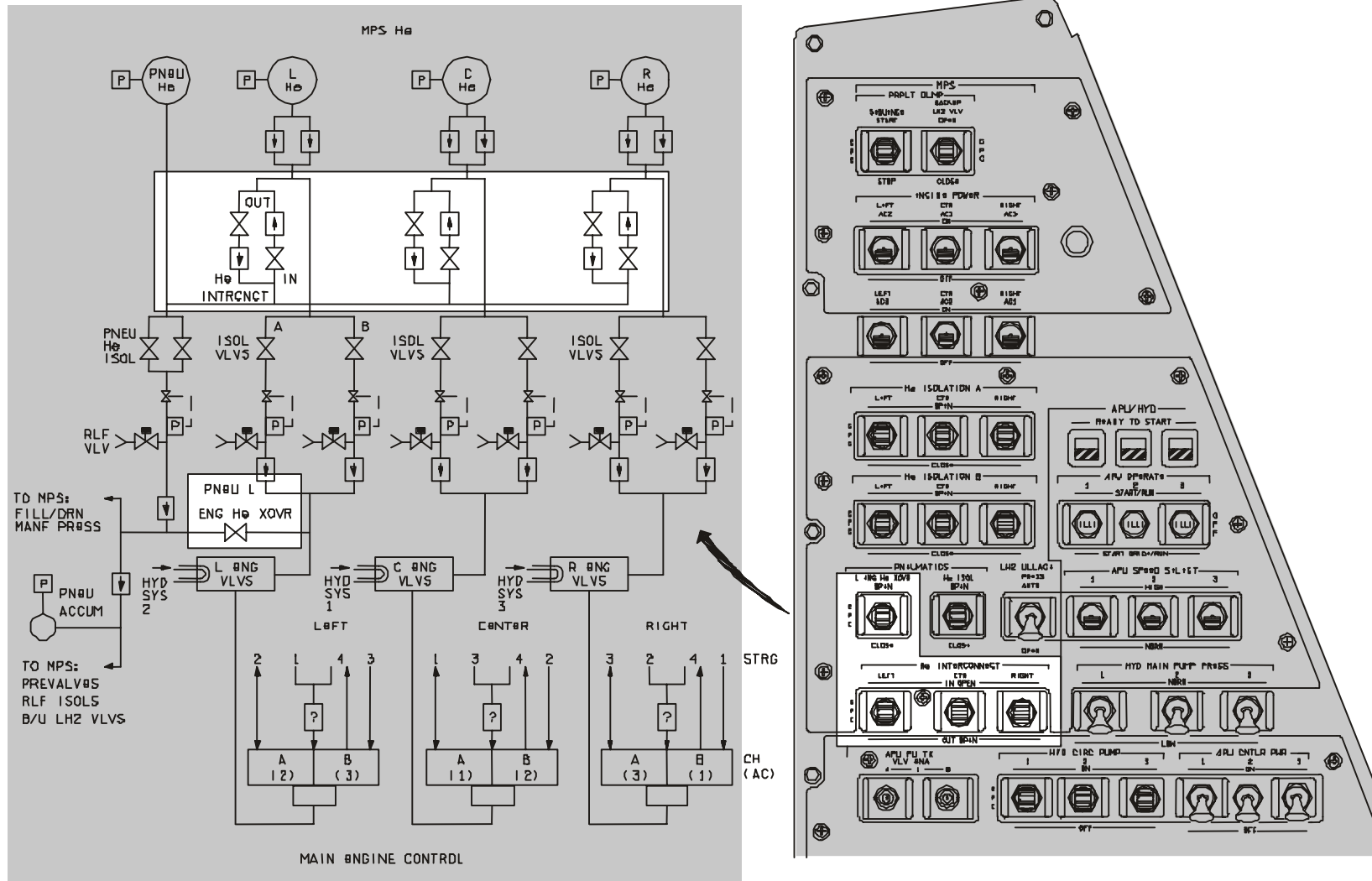


Figure 2-21. Crew controls for the L ENG He XOVR and helium interconnect valves are on Panel R2

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2.6 EXTERNAL TANK

The ET stores LH₂ and LO₂ and supplies them under pressure to the three main engines during ascent.

After MECO, the tank is jettisoned, reenters the atmosphere, and impacts in a remote ocean area. Since the tank is not recovered, it contains a minimum number of active components.

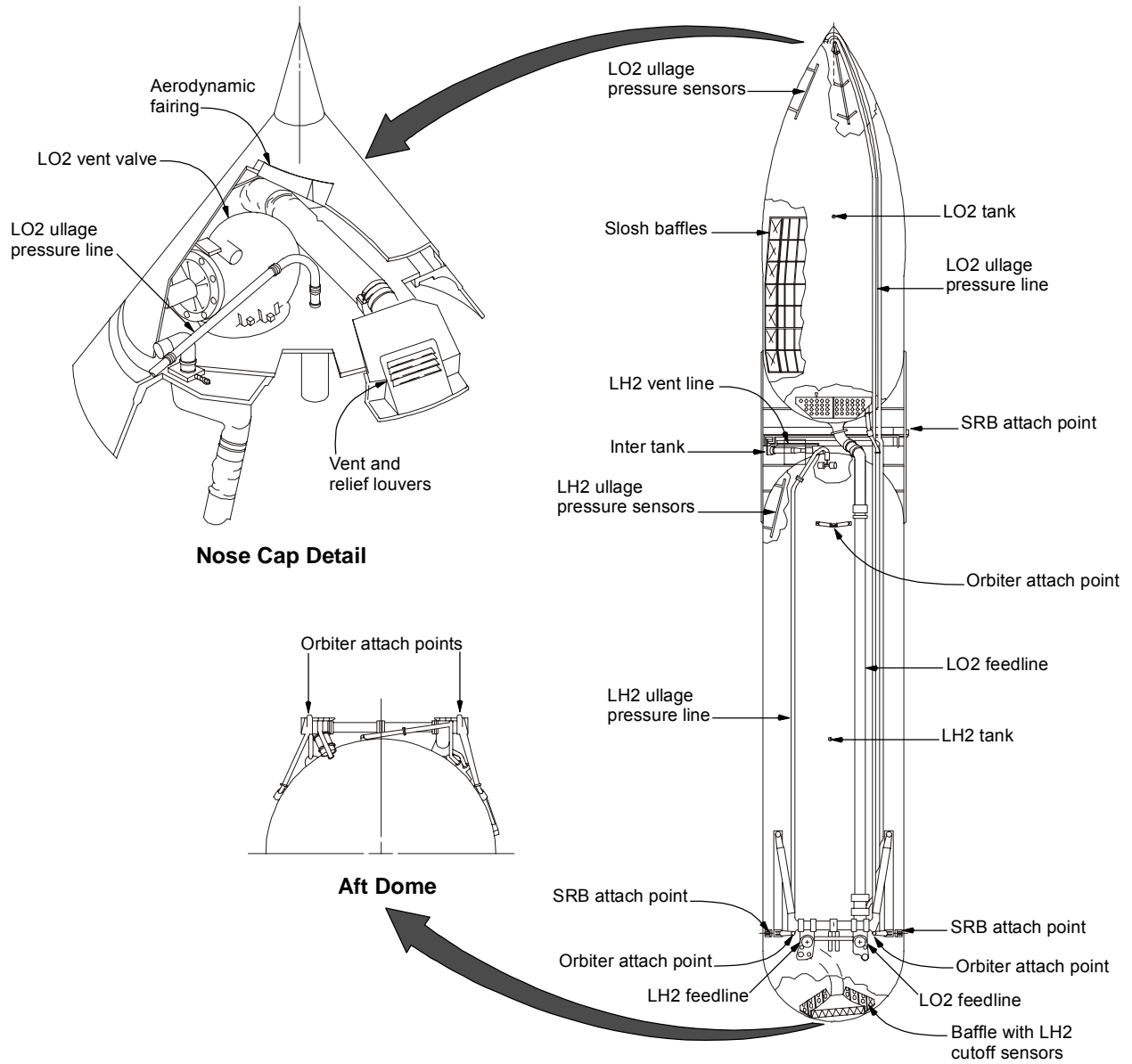
The ET is 154 feet long and measures 27.5 feet in diameter (See Figure 2-22). It is the largest element of the space shuttle and serves as the structural backbone of the vehicle during ascent. The orbiter is connected to the tank by a single forward attachment and two aft struts. The SRBs are connected by a single forward attachment and by sway braces at the aft segment. The orbiter and SRBs are separated from the ET by pyrotechnic devices.

The ET has three major components: the forward LO₂ tank, an unpressurized intertank that contains most of the electrical components, and the aft LH₂ tank. The forward tank holds approximately 143,000 gallons of LO₂. The tank nose cone is shaped to reduce drag, contains the ascent air data system, and serves as a lightning rod. The intertank houses the ET instrumentation components and contains the SRB forward attachment points. The aft tank holds approximately 385,000 gallons of LH₂ and provides the forward orbiter attachment point and the aft orbiter and SRB attachment points.

Each propellant tank has a vent and relief valve at its forward end. These dual-function valves are controlled by the ground support equipment for the vent function and are open during flight when the LH₂ ullage pressure reaches 36 psi or the LO₂ ullage pressure reaches 31 psi. The vent function is available only during prelaunch; the relief function is available only in flight. In both cases, the crew has no direct control over this valve.

There are eight propellant depletion sensors, four for LH₂ and four for LO₂. The fuel depletion sensors are located at the bottom of the LH₂ tank. The oxidizer sensors are mounted in the orbiter LO₂ feedline manifold. Should any two of the LH₂ or LO₂ depletion sensors detect a dry condition after the ET low-level arm command is received, the GPCs issue a MECO command, often referred to as a low-level cutoff.

The LH₂ tank contains four ullage pressure sensors. Three of these sensors drive the three GH₂ flow control valves. The LH₂ tank has a fourth ullage pressure which serves as a spare. It can be substituted for a failed LH₂ ullage pressure sensor prior to liftoff. The LO₂ tank contains three ullage pressure sensors which are for instrumentation only. The GO₂ repress system does not have active flow control valves. The outputs from the three sensors in each tank are shown on the BFS GNC SYS SUMM 1 display.



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Figure 2-22. External tank

2.7 THRUST VECTOR CONTROL

TVC provides attitude control and trajectory shaping by gimbaling the SSMEs.

The major TVC subsystems are the MPS TVC command Subsystem Operating Program (SOP), Ascent Thrust Vector Control (ATVC), and six hydraulic servoactuators.

a. Command Flow

Guidance and control requirements are issued to the MPS TVC SOP where they are processed and dispersed to the ATVC avionics boxes. The ATVC is a hardware package that converts digital commands from the GPCs into voltage commands for each hydraulic gimbal actuator. There are four redundant ATVC channels, each receiving commands from the GPCs and each sending commands to all six servoactuators. See Figure 2-23. Each main engine has two hydraulic servoactuators, one for pitch and one for yaw that extends or retracts to gimbal the engine (See Figure 2-24). Each actuator receives four identical commands from the four different ATVC channels. Power to the ATVC channels is controlled by four switches on Panel O17. See Figure 2-25.

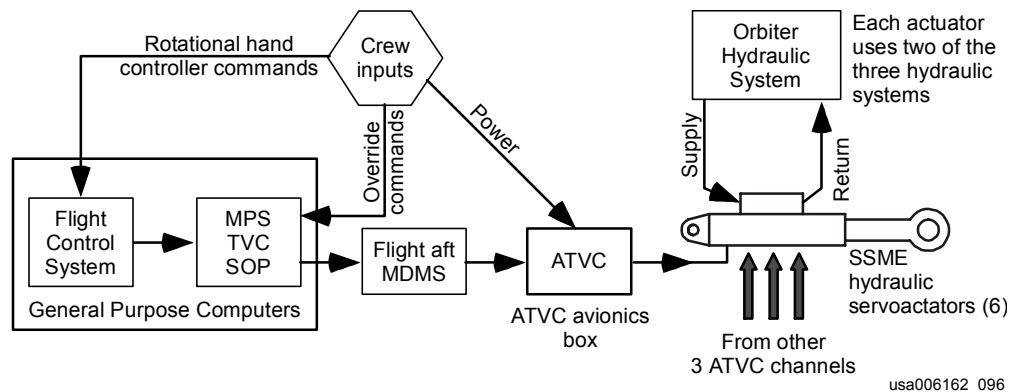
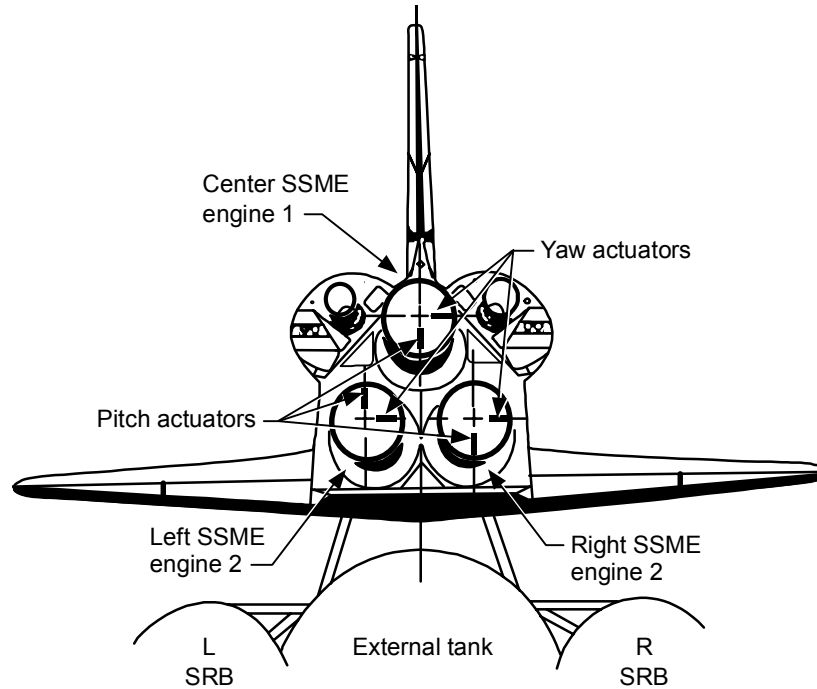
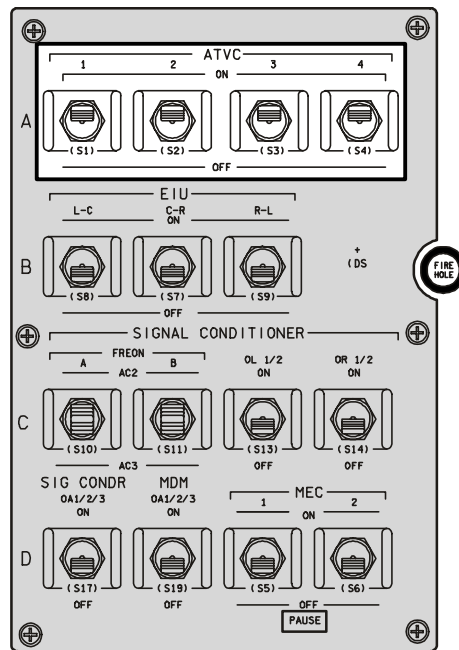


Figure 2-23. MPS TVC interfaces and command flow



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Figure 2-24. Main engine gimbal actuators

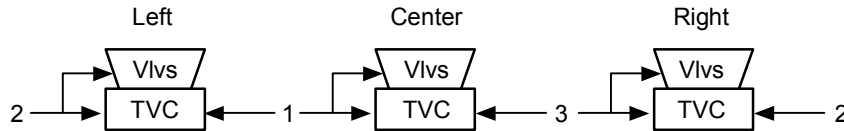


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Figure 2-25. ATVC power is controlled from Panel O17

b. Hydraulic Interface

Each gimbal actuator uses two of the three orbiter hydraulic systems for pressure, a primary source and a secondary source. Refer to Figure 2-26. Normally, the primary system is providing the required hydraulic pressure. If the primary system fails, a switching valve automatically switches over to the standby system and the actuator continues to function. For each engine, the primary hydraulic system for the pitch actuator is the standby system for yaw; conversely, the primary system for the yaw actuator is the standby system for pitch. Note that the primary hydraulic system for the pitch actuator of each engine is the same system used by the valves of that engine. The orbiter hydraulic systems interface with the MPS TVC actuators and engine valves to equally distribute the workload among the three systems. For a complete discussion on ATVC, refer to the MPS TVC 2102 training manual.



Hydraulic system*	Left engine			Center engine			Right engine		
	Eng vlv	Pitch	Yaw	Eng vlv	Pitch	Yaw	Eng vlv	Pitch	Yaw
1		S	P	P	P	S			
2	P	P	S					S	P
3					S	P	P	P	S

* Each actuator has two hydraulic systems (one primary and one backup)

P = Primary system
S = Standby system

usa006162_006

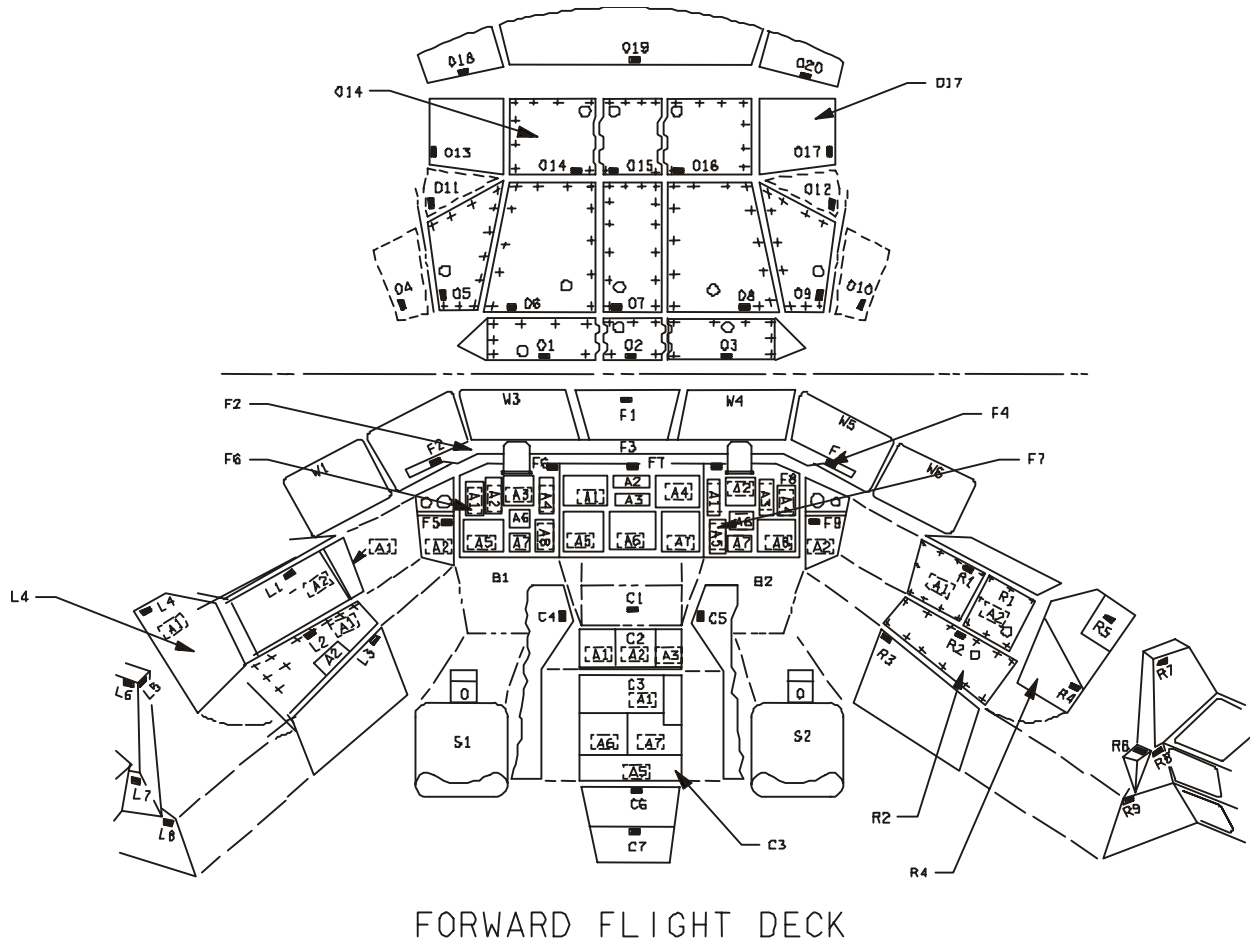
Figure 2-26. MPS TVC actuator interface with the orbiter hydraulic systems

2.8 CONTROLS AND DISPLAYS

The following is a summary of the controls and displays used to operate the MPS. Figure 2-27 shows the locations of the panels containing MPS controls on the forward flight deck.

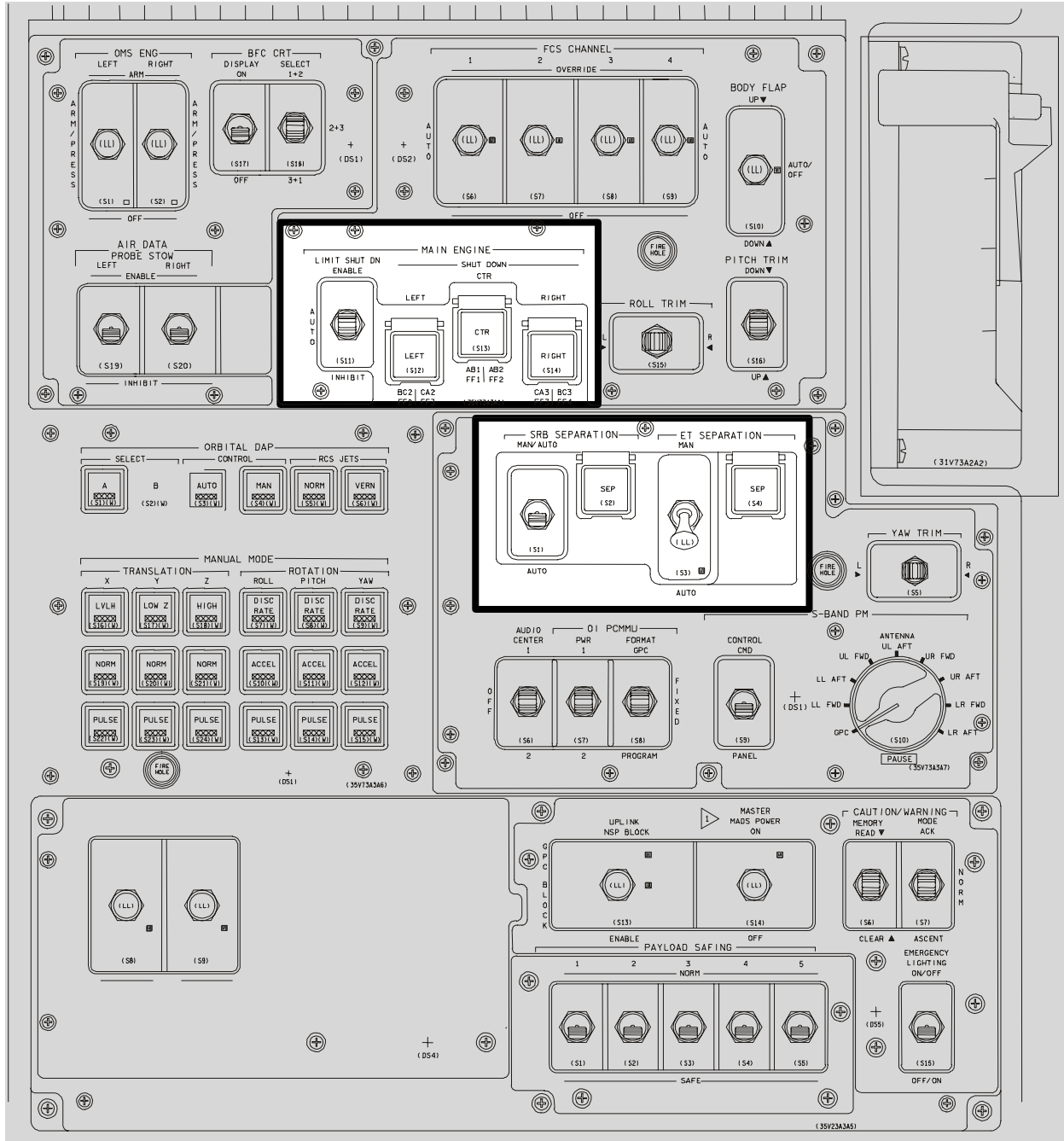
Switches and lights on center Panel C3; forward Panels F2, F4, and F7; overhead Panel O17; left Panel L4; and right Panels R2 and R4 are illustrated in Figures 2-28 through 2-35.

Most of the switches are discussed elsewhere in conjunction with their related systems or crew procedures. Figures 2-36 through 2-41 are examples of the displays used in operating the MPS. Following each figure is an explanation of the function of the control or display.



T0345022B, AR7: 1

Figure 2-27. Location of panels containing MPS controls



TD3450229.PNL1.2

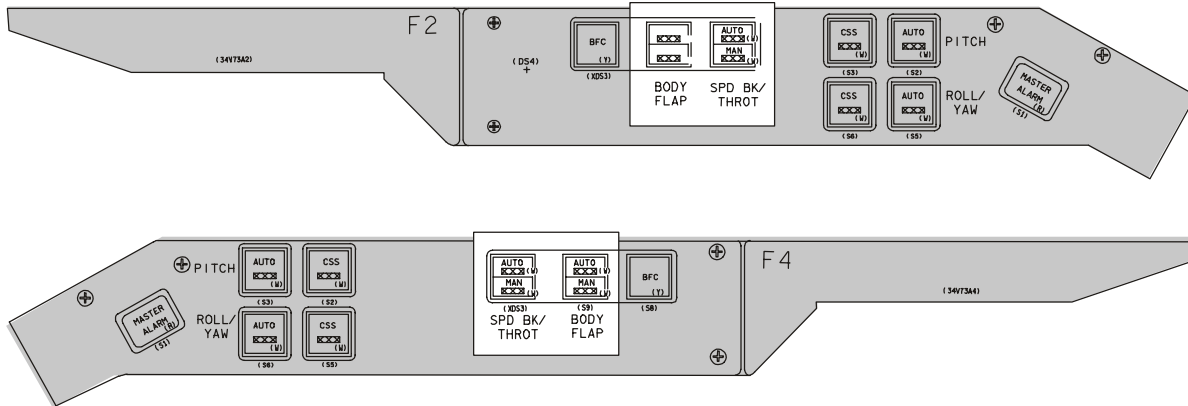
Figure 2-28. Panel C3

Control or display	Function
MAIN ENGINE LIMIT SHUT DN switch ENABLE AUTO INHIBIT	<p>Moving the switch to the ENABLE position makes the GPCs send commands to enable redline shutdown processing on all three engines. Any engine that exceeds a redline limit is then shut down automatically by its main engine controller</p> <p>With the switch in AUTO, if an engine shuts down early or an engine experiences a data path failure, the GPCs will send commands to the other two engines to inhibit redline shutdown processing.</p> <p>Moving the switch to the INHIBIT position makes the GPCs send commands to inhibit redline shutdown processing on all three engines. An engine that violates a redline limit will not be shut down by its controller</p>
MAIN ENGINE SHUT DOWN pushbuttons (pb's) (3)	<p>Pushing a MAIN ENGINE SHUT DOWN pb sends both a Shutdown command and a Safing command to the GPCs.</p> <p>The Shutdown command from the pb makes the GPCs send the required commands to shut down the specific engine</p> <p>The Safing command from the pb in combination with a Data Path failure on that engine tells Guidance and Flight Control that the engine has failed. The prevalves will also be closed on the affected engine to isolate the engine from propellant (i.e., "safe" the engine)</p> <p>Setting three Safing commands (C, L, & R) is one method to manually set the MECO CONFIRMED flag. This capability is used after MECO when the MECO CONFIRMED flag is not set automatically due to multiple Data Path failures. This method is referred to as "Three PBs post-MECO" and does not have to be performed simultaneously (staggered pb's works)</p>
SRB SEPARATION switch MAN/AUTO	<p>Note: The SRB SEPARATION MAN/AUTO position and Pb currently serve no purpose during powered flight because the flight software SRB SEP INH logic has been no-opted (body rate limits and dynamic pressure limit are set extremely high). The following descriptions for powered flight are included for historical purposes only. The functionality of these switches during landing still exists.</p> <p>The MAN position provides power to the SRB SEPARATION pb. During ascent, this allows the crew to override any software separation inhibits (body rates or dynamic pressure) by depressing the pb. An AUTO separation will still occur with the switch in this position if all separation constraints are met.</p> <p>During landing after nose gear touchdown, the crew can manually back up the Weight On Wheels (WOW) and Weight On Nose Gear (WONG) discretes</p>
AUTO	<p>Removes power from the SRB SEPARATION pb, placing the separation software in an AUTO-only mode</p>

Figure 2-28. Panel C3 (continued)

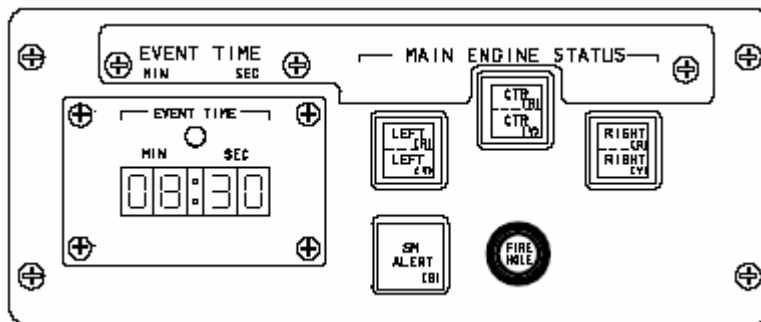
Control or display	Function
SRB SEPARATION pb	<p>Enabled if the SRB SEPARATION switch is in MAN/AUTO. When depressed, it allows the crew to override any software separation inhibits so the separation sequence can continue. The manual separation input cannot be processed until 100 seconds after SRB ignition.</p> <p>During landing after nose gear touchdown, the crew can manually back up the WOW and WONG discretes</p>
ET SEPARATION switch MAN AUTO	<p>Inhibits the automatic ET SEP sequence and provides power to the ET SEPARATION pb. During ascent, this allows the crew to inhibit an AUTO ET separation and perform a manual separation by depressing the pb.</p> <p>During landing after nose gear touchdown, the crew can manually back up the WOW and WONG discretes.</p> <p>Removes power from the ET SEPARATION pb placing the separation software in an AUTO-only mode</p>
ET SEPARATION pb	<p>Enabled if the ET SEPARATION switch is in MAN. When depressed, it initiates a manual separation, allowing the crew to override any software inhibits.</p> <p>During landing after nose gear touchdown, the crew can manually back up the WOW and WONG discretes</p>
Speedbrake/thrust controller TAKEOVER pb	<p>When depressed, signals the GPCs of the intent to engage manual throttle. Manual control of the thrust function is established by</p> <ul style="list-style-type: none"> • Depress the takeover pb (CDR & PLT AUTO THROT pb indicators extinguished) • Match the throttle position to within 4 percent of the current AUTO command (PLT's MAN THROT pbi – illuminated), and then • Release the pb <p>When MANUAL mode is established, lever is used to throttle the main engines in MM 102, 103, and 601. (Note: This lever is also used for manual speedbrake control during gliding flight.) There is no manual throttle capacity with BFS engaged. Also, only the pilot can throttle manually. The commander's lever can be used only as a speedbrake control</p>

Figure 2-28. Panel C3 (concluded)



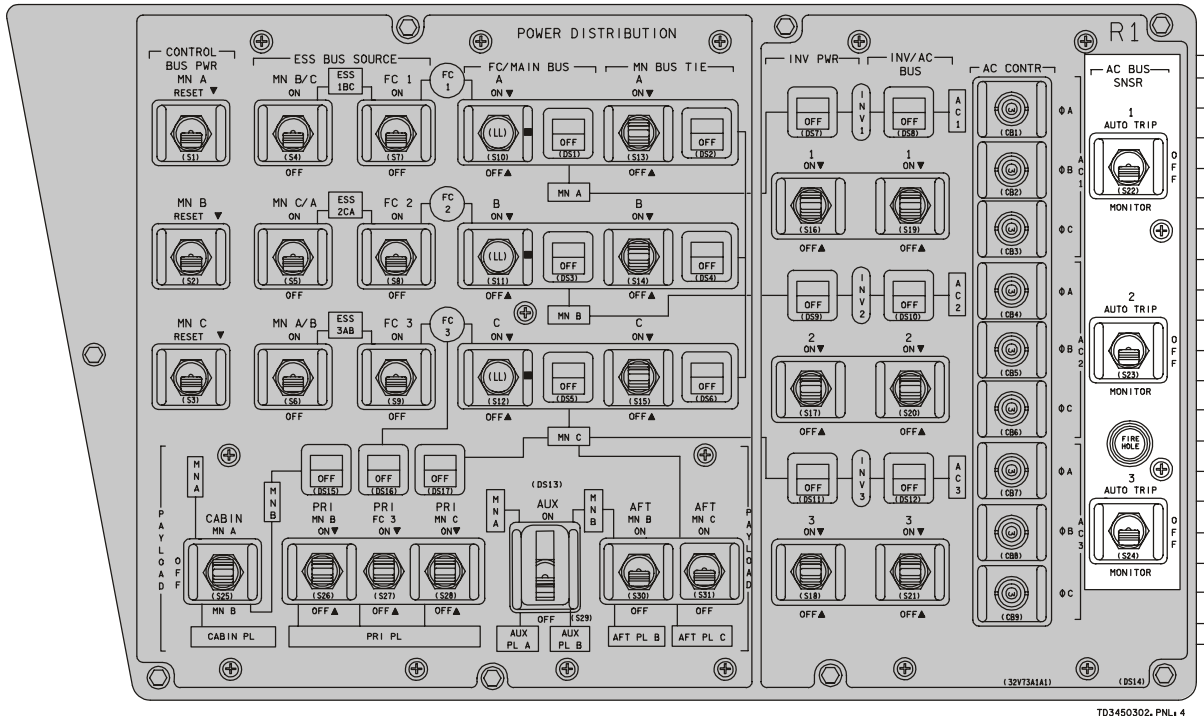
Control or display	Function
SPD BK/THROT pushbutton indicator (pbi) Depress AUTO light (white) MAN light (white) on Panel F4 (PLT) MAN light (white) on Panel F2 (CDR)	Changes the throttle function from MANUAL to AUTO (also used to control the speedbrake during gliding flight) Indicates the throttle (or speedbrake) is in the AUTO mode Indicates that the PLT has taken MANUAL throttle (or speedbrake) Indicates that the CDR has taken MANUAL speedbrake. The commander does not have manual throttle capability
BODY FLAP pbi	Primary use is for control/status of the body flap. Relating to the MPS, the body flap light is illuminated at the transition to MM 101 and is extinguished to indicate the MPS dump is complete (two minutes after dump start)

Figure 2-29. Panels F2 and F4



Control or display	Function
MAIN ENGINE STATUS lights (3) Red Yellow	The top half of the light illuminates red if its associated engine shuts down or if a redline limit is exceeded when the limit shutdown software is inhibited. All three lights illuminate at MECO and extinguish at ET separation The bottom half of the light illuminates yellow for a data path failure, command path failure, hydraulic lockup, or electrical lockup

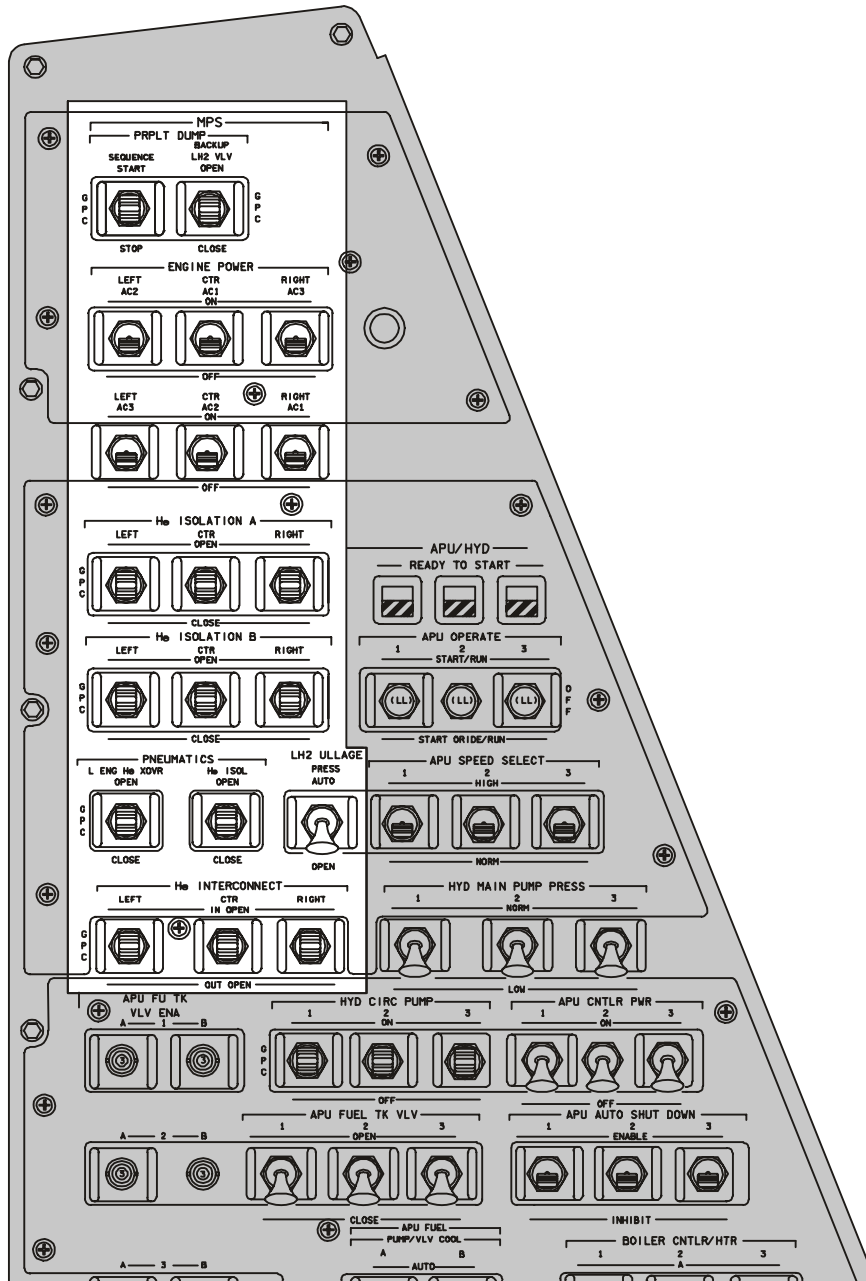
Figure 2-30. SSME status lights on Panel F7



TO3450302, PNL-4

Control or display	Function
AC BUS SNSR switches (3)	
AUTO TRIP	Provides Caution and Warning (C&W) for an AC bus over/undervoltage or overload condition and automatically trips the bus off line
OFF	Removes C&W for an AC bus over/undervoltage or overload condition Prevents a single-point failure that could take down a good AC bus. This position is selected following the first electrical malfunction to protect the main engine controllers
MONITOR	Provides C&W for an AC bus over/undervoltage or overload condition, but does not trip a bus off line. The vehicle is launched in this configuration to protect the main engine controllers

Figure 2-31. Panel R1



Control or display	Function
<p>MPS PRPLT DUMP SEQUENCE switch</p> <p>START</p> <p>GPC</p> <p>STOP</p>	<p>Manually starts the MPS propellant dump sequence after MECO CONFIRMED + 22 seconds. The sequence (including dump termination) is automatic.</p> <p>Allows the GPCs to start the MPS propellant dump at MECO CONFIRMED plus 2:02</p> <p>Inhibits the GPCs from starting the dump if it has not occurred yet</p>

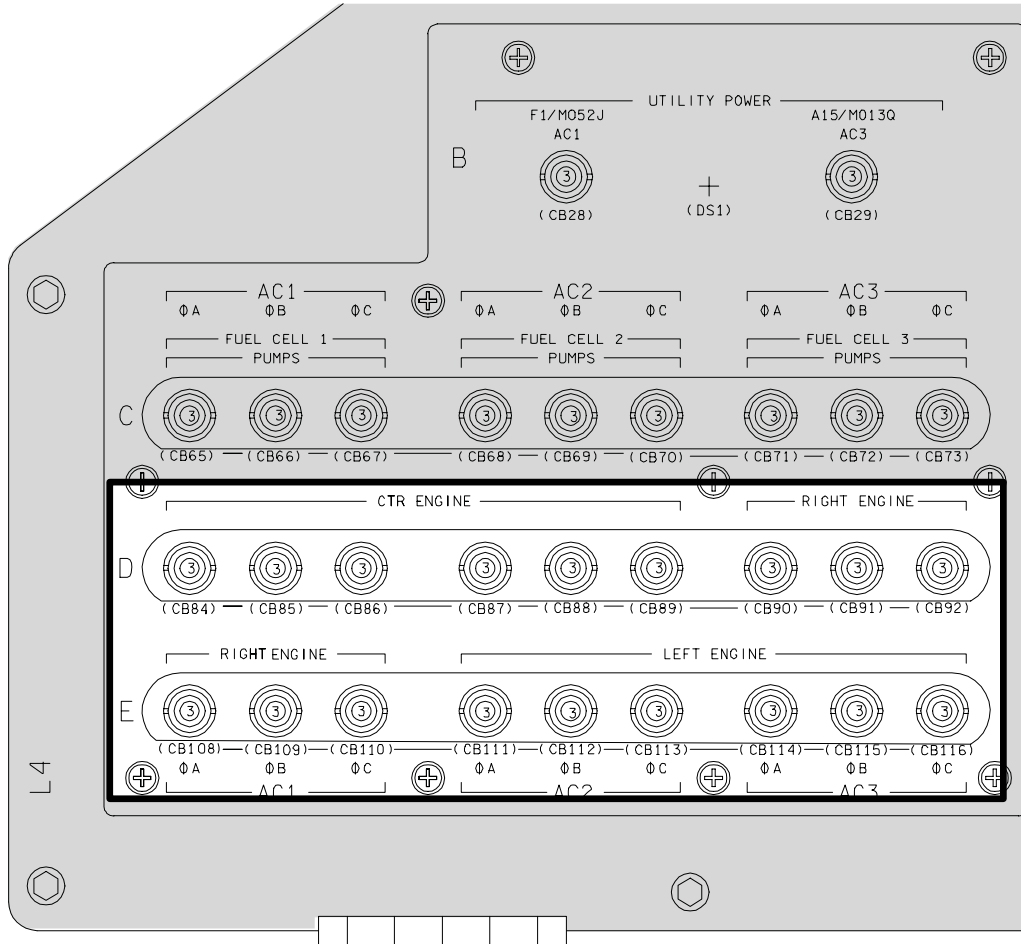
Figure 2-32. Panel R2

Control or display	Function
MPS PRPLT DUMP BACKUP LH ₂ VLV switch OPEN GPC CLOSE	Makes the GPCs send commands to open the backup LH ₂ dump valves. Operates during OPS 1 only. Allows the GPCs to control the backup LH ₂ dump valves per the automatic sequence Makes the GPCs send commands to close the backup LH ₂ dump valves. Operates during OPS 1 only
MPS ENGINE POWER switches (6) LEFT AC2 ON OFF LEFT AC3 CENTER AC1 CENTER AC2 RIGHT AC3 RIGHT AC1	Applies AC power to the left engine controller DCU A Removes AC power from the left engine controller DCU A Same as LEFT AC2 except it powers the left controller DCU B Same as LEFT AC2 except it powers the center controller DCU A Same as LEFT AC2 except it powers the center controller DCU B Same as LEFT AC2 except it powers the right controller DCU A Same as LEFT AC2 except it powers the right controller DCU B
MPS He ISOLATION switches (6) LEFT A OPEN GPC CLOSE LEFT B CENTER A CENTER B RIGHT A RIGHT B	Opens the A leg isolation valve for the left engine helium system Allows the GPCs to control the A leg isolation valve Closes the A leg isolation valve for the left engine helium system Same as LEFT A except for the LEFT B isolation valve Same as LEFT A except for the CENTER A isolation valve Same as LEFT A except for the CENTER B isolation valve Same as LEFT A except for the RIGHT A isolation valve Same as LEFT A except for the RIGHT B isolation valve
MPS PNEUMATICS L ENG He XOVR switch OPEN GPC CLOSE	Opens the L ENG He XOVR valve. Connects the Pneumatic helium system to the L Main Engine helium system (downstream of both systems' regulators) Allows the GPCs to control the L ENG He XOVR valve Closes the L ENG He XOVR valve
MPS PNEUMATICS He ISOL switch OPEN GPC CLOSE	Opens the two pneumatic helium isolation valves Allows the GPCs to control the valves Closes the two pneumatic helium isolation valves

Figure 2-32. Panel R2 (continued)

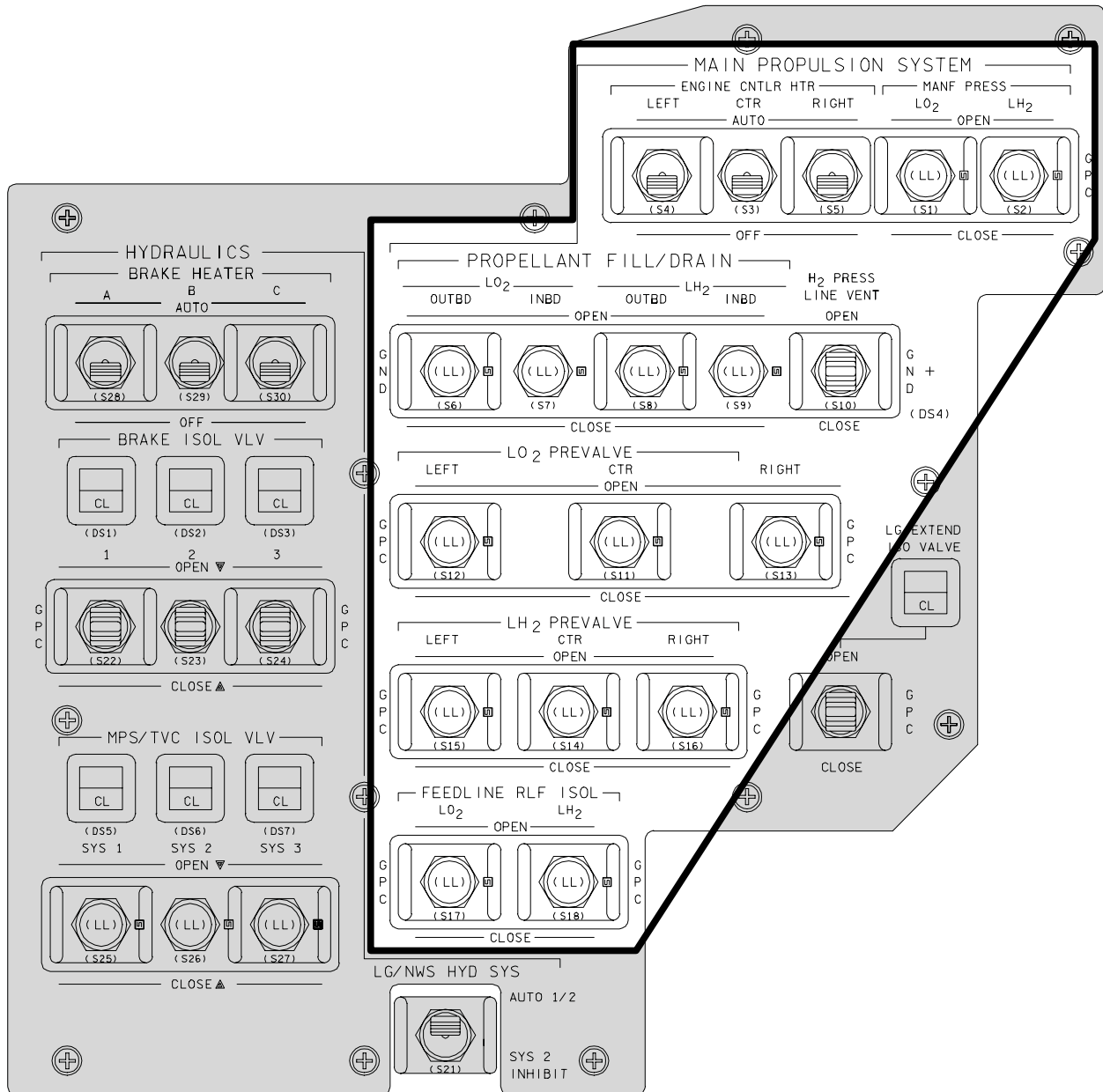
Control or display	Function
<p>MPS He INTERCONNECT LEFT switch</p> <p> IN OPEN</p> <p> GPC</p> <p> OUT OPEN</p> <p>MPS He INTERCONNECT CENTER switch</p> <p>MPS He INTERCONNECT RIGHT switch</p>	<p>Opens the inlet interconnect valve, allowing helium from the pneumatic tank and interconnect manifold to supply the left engine system. Inhibits power to the outlet interconnect valve to ensure that it remains closed</p> <p>Allows the GPCs to control the interconnect valves</p> <p>Opens the outlet interconnect valve, allowing helium from the left engine system to supply the interconnect manifold and pneumatic system. Inhibits power to the inlet interconnect valve to ensure that it remains closed</p> <p>Same as the INTERCONNECT LEFT except for the center helium system</p> <p>Same as the INTERCONNECT LEFT except for the right helium system</p>
<p>MPS LH₂ ULLAGE PRESS switch</p> <p> AUTO</p> <p> OPEN</p>	<p>Enables automatic control of the three GH₂ flow control valves which open and close to maintain proper ullage pressure in the LH₂ tank</p> <p>Opens the three GH₂ flow control valves, allowing maximum flow from the engines to the LH₂ tank, thus increasing ullage pressure</p>

Figure 2-32. Panel R2 (concluded)



Control or display	Function
CTR ENGINE AC1 ØA, ØB, ØC cb (3)	Supplies AC power to the center engine controller DCU A
CTR ENGINE AC2 ØA, ØB, ØC cb (3)	Supplies AC power to the center engine controller DCU B
RIGHT ENGINE AC3 ØA, ØB, ØC cb (3)	Supplies AC power to the right engine controller DCU A
RIGHT ENGINE AC1 ØA, ØB, ØC cb (3)	Supplies AC power to the right engine controller DCU B
LEFT ENGINE AC2 ØA, ØB, ØC cb (3)	Supplies AC power to the left engine controller DCU A
LEFT ENGINE AC3 ØA, ØB, ØC cb (3)	Supplies AC power to the left engine controller DCU B

Figure 2-33. Panel L4



Control or display	Function
MAIN PROPULSION SYSTEM ENGINE CNTLR HTR switches (3) LEFT AUTO OFF CTR RIGHT	These switches are nonfunctional

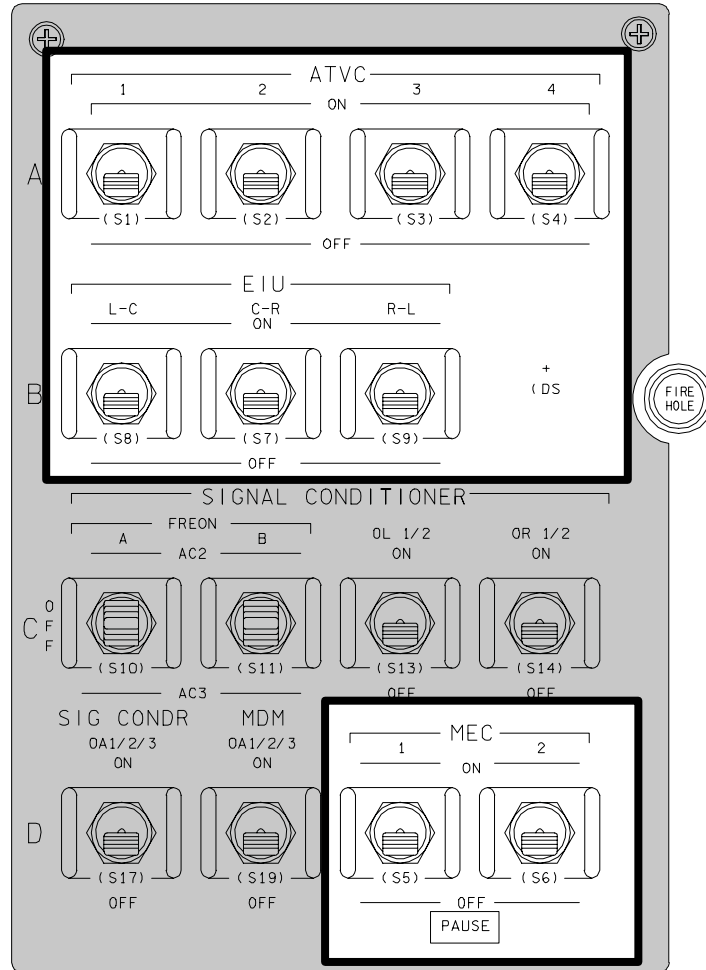
Figure 2-34. Panel R4

Control or display	Function
MPS MANF PRESS LO ₂ switch OPEN GPC CLOSE MPS MANF PRESS LH ₂ switch	Opens the LO ₂ manifold pressure valves, allowing helium to flow into the LO ₂ feedline manifold Allows the GPCs to control the LO ₂ manifold pressure valves Closes the LO ₂ manifold pressure valves, isolating the LO ₂ feedline manifold from the helium supply Same as the MPS MANF PRESS LO ₂ switch except for the LH ₂ feedline manifold
MPS PROPELLANT FILL/DRAIN LO ₂ OUTBD switch OPEN GND CLOSE MPS PROPELLANT FILL/DRAIN LO ₂ INBD switch MPS PROPELLANT FILL/DRAIN LH ₂ OUTBD switch MPS PROPELLANT FILL/DRAIN LH ₂ INBD switch OPEN GND CLOSE	Opens the LO ₂ outboard fill/drain valve Allows the GPCs or launch processing system to control the valve Closes the LO ₂ outboard fill/drain valve Same as MPS PROPELLANT FILL/DRAIN LO ₂ OUTBD switch except for the LO ₂ inboard fill/drain valve Same as MPS PROPELLANT FILL/DRAIN LO ₂ OUTBD switch except for the LH ₂ outboard fill/drain valve Opens the LH ₂ inboard fill/drain valve and the LH ₂ topping valve Allows the GPCs or launch processing system to control the valves Closes the LH ₂ inboard fill/drain valve and the LH ₂ topping valve
MPS H ₂ PRESS LINE VENT switch OPEN GND CLOSE	Opens the MPS H ₂ PRESS LINE VENT valve, allowing GH ₂ in the line to vent overboard Allows the GPCs, through the launch processing system, to open the valve. If an OPEN command is not present, the valve closes Closes the MPS H ₂ PRESS LINE VENT valve
MPS PREVALVE switches (6) LO ₂ LEFT OPEN GPC CLOSE LO ₂ CTR LO ₂ RIGHT LH ₂ LEFT LH ₂ CTR LH ₂ RIGHT	Opens the LO ₂ prevalve to the left main engine Allows the GPCs to control the valve Closes the LO ₂ prevalve to the left main engine Same as LO ₂ LEFT except for the center engine Same as LO ₂ LEFT except for the right engine Same as LO ₂ LEFT except LH ₂ prevalve for the left engine Same as LO ₂ LEFT except LH ₂ prevalve for the center engine Same as LO ₂ LEFT except LH ₂ prevalve for the right engine

Figure 2-34. Panel R4 (continued)

Control or display	Function
MPS FEEDLINE RLF ISOL LO ₂ switch	
OPEN	Opens the LO ₂ feedline relief isolation valve which allows the relief valve to vent an over-pressure condition in the LO ₂ manifold
GPC	Allows the GPCs to control the valve
CLOSE	Closes the LO ₂ feedline relief isolation valve
MPS FEEDLINE RLF ISOL LH ₂ switch	Same as MPS FEEDLINE RLF ISOL LO ₂ switch except for the LH ₂ manifold

Figure 2-34. Panel R4 (concluded)

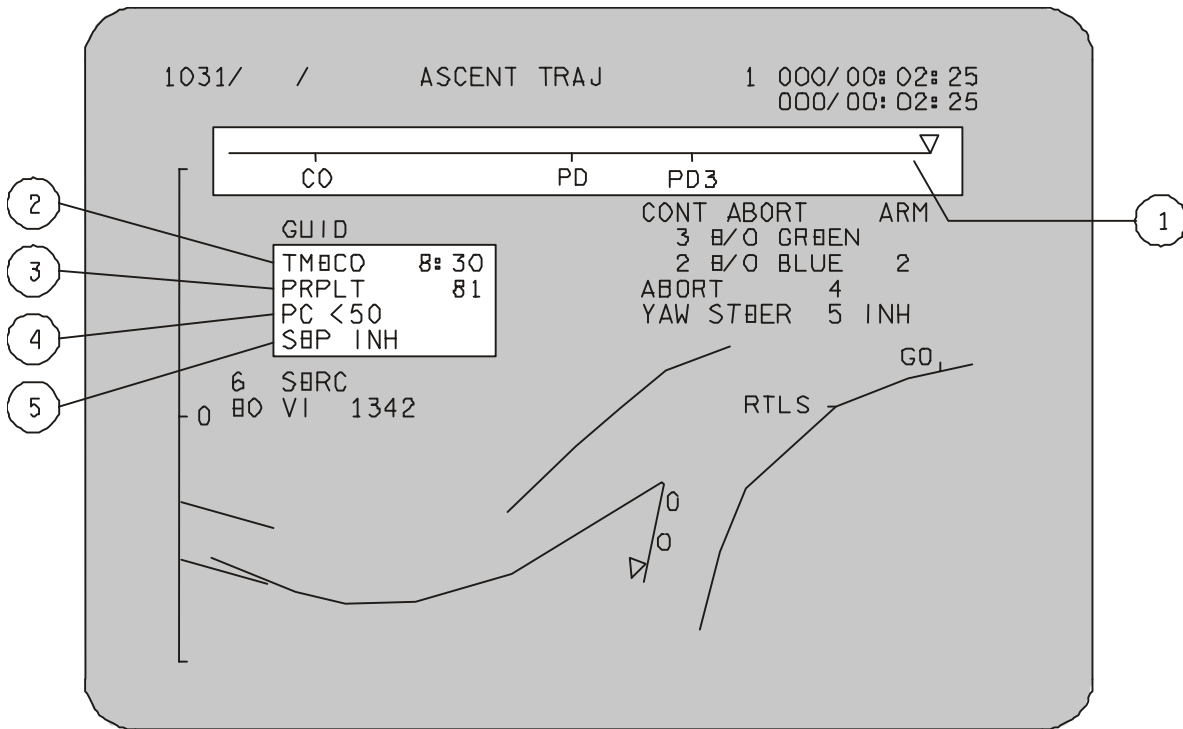


Control or display	Function
ATVC 1 switch ON	Applies power to the ATVC 1 electronics that process the position commands to the channel 1 main engine and SRB hydraulic actuator servovalves. Also applies power to the hydraulic actuator isolation valve drivers
OFF	Removes power from the ATVC 1 electronics
ATVC 2 switch	Same as ATVC 1 switch except ATVC 2 and channel 2
ATVC 3 switch	Same as ATVC 1 switch except ATVC 3 and channel 3
ATVC 4 switch	Same as ATVC 1 switch except ATVC 4 and channel 4

Figure 2-35. Panel O17

Control or display	Function
EIU L-C switch ON OFF EIU C-R switch EIU R-L switch	Applies power to the left and center EIUs, enabling command and data transfer between the GPCs and left and center engine controllers Removes power from the left and center EIUs Same as EIU L-C switch except for the center and right EIUs and engine controllers Same as EIU L-C switch except for the right and left EIUs and engine controllers Note: Switches are redundant to each other. Only one needs to be on to supply power to its two associated EIUs, and two switches must be off to remove power from any EIU
MEC1 switch ON OFF MEC 2 switch	Applies power to MEC 1, enabling the MEC launch, staging, and ET separation functions Removes power from MEC 1 Same as MEC 1 except MEC 2

Figure 2-35. Panel O17 (concluded)



TD3450238. CRT; 2

Control or display	Function
1 Delta range scale	The ΔR scale is active only during an RTLS abort The scale across the top is delta range (ΔR). ΔR is the glide range potential based on energy state minus present range from the landing site. Current ΔR is indicated by a moving triangle. Tick marks are placed <ul style="list-style-type: none"> Where powered pitchdown normally occurs at MECO minus 20 seconds for the two-engine RTLS case (PD) Where powered pitchdown occurs for a three-engine RTLS case (PD3) Where MECO occurs (CO)
2 TMECO	TMECO is the predicted time of MECO, in minutes and seconds from lift-off
3 PRPLT	PRPLT indicates the percent of propellant remaining in the ET
4 Pc<50	Pc <50 is displayed when the SRB chamber pressures drop below 50 psi prior to separation
5 SEP INH	SEP INH is displayed in MM 102 if SRB AUTO separation is inhibited and is blanked upon transition to MM 103. SEP INH is also displayed in MM 103 if ET AUTO separation is inhibited

Figure 2-36. PASS ASCENT TRAJ display

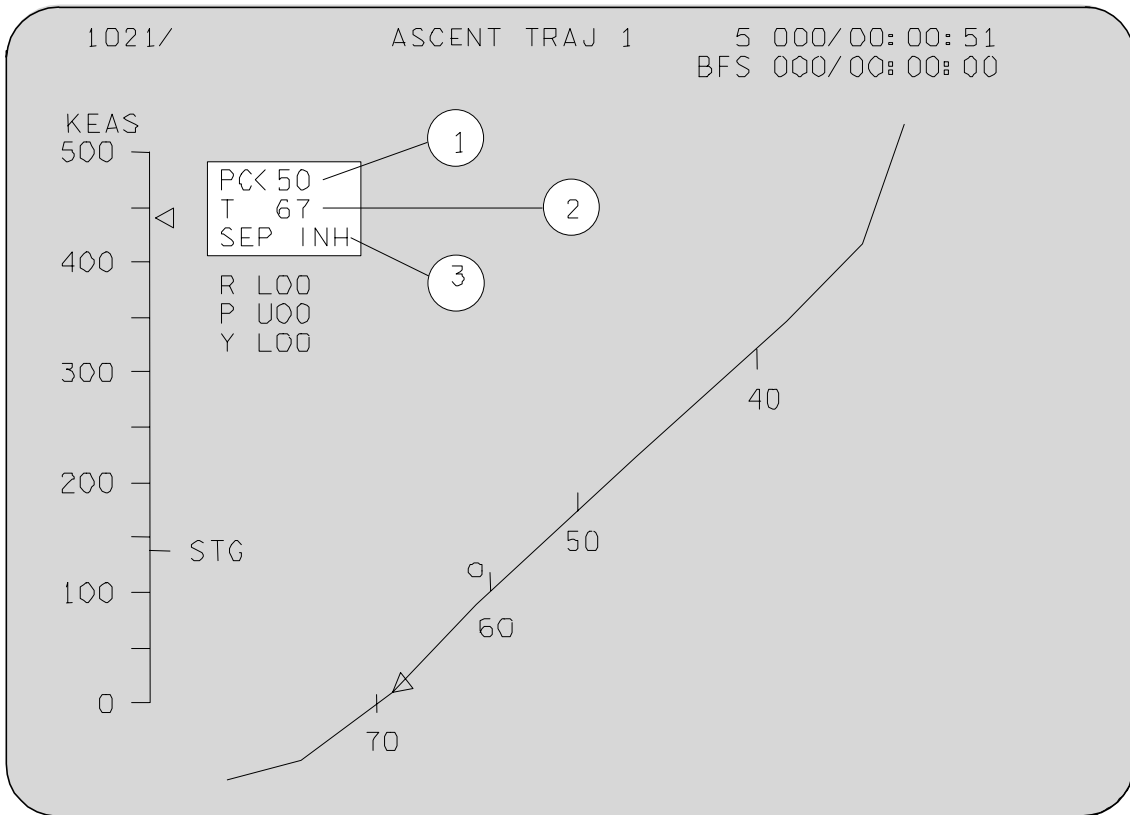
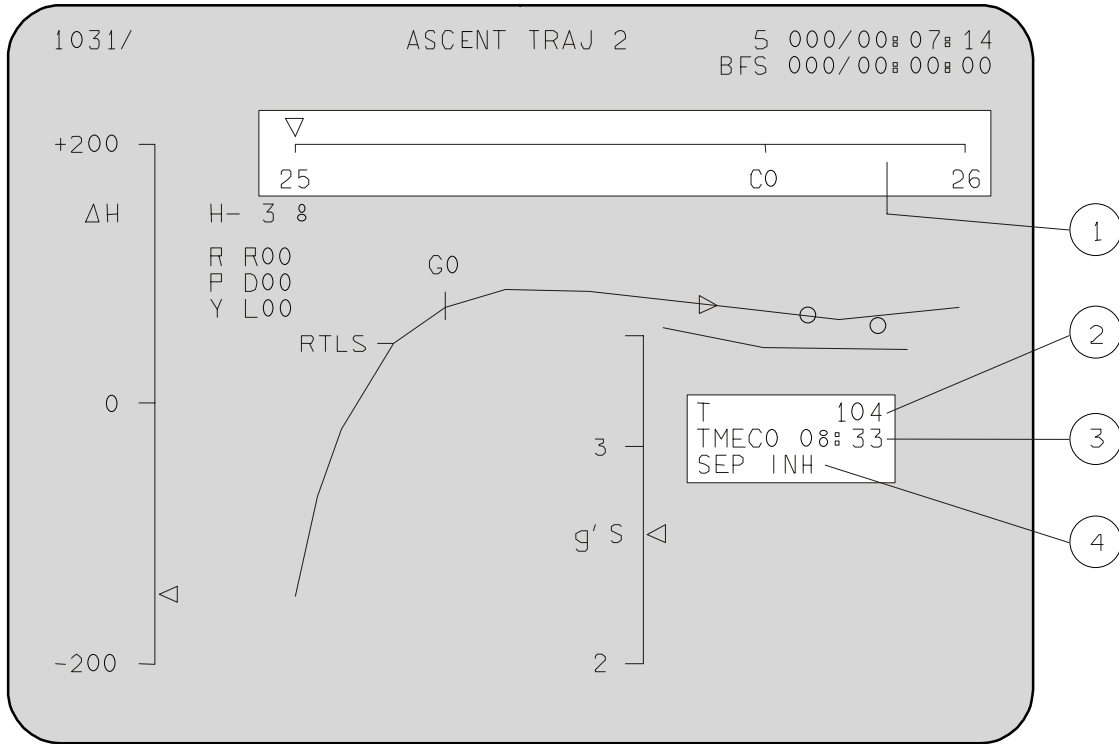


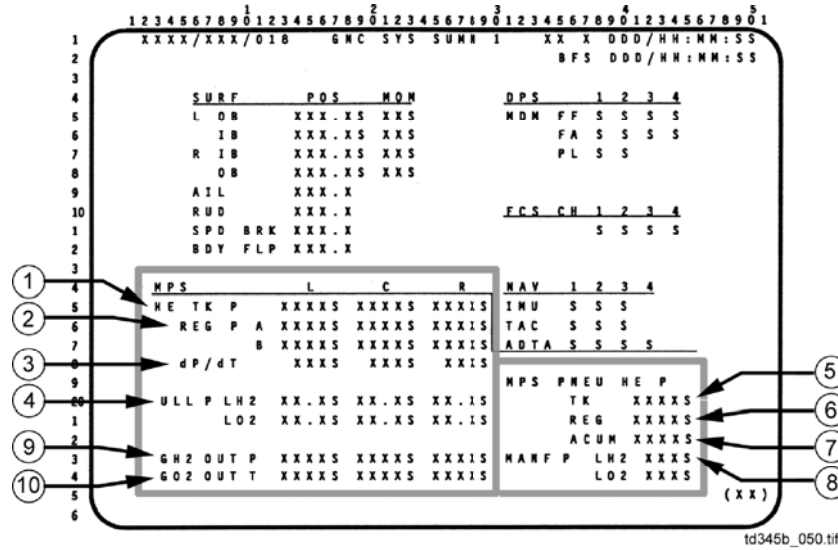
Figure 2-37. BFS ASCENT TRAJ 1 display



TD3450240, CRT, 3

Control or display	Function
1 Inertial velocity scale	The scale across the top is an inertial velocity scale within mission-dependent, I-loaded limits (1000 fps apart). Current velocity is indicated by a moving triangle. A tick mark indicates where MECO should occur (CO). This scale is active for a nominal ascent or Transoceanic Abort Landing (TAL) abort. This scale is rescaled on a TAL to represent the appropriate target velocity, but the labels (25, 26) do not change.
2 T	T indicates the throttle command, in percent, generated by the BFS
3 TMECO	TMECO is the predicted time of MECO, in minutes and seconds, from lift-off
4 SEP INH	SEP INH is displayed if ET AUTO separation is inhibited

Figure 2-38. BFS ASCENT TRAJ 2 display



Control or display	Function
1 MPS HE TK P	Displays the left, center, and right helium tank pressures. An ↓ and C&W alarm are generated if pressure drops below 1150 psi
2 MPS HE REG P A B	Displays the left, center, and right helium regulator A pressures. An ↓ and Systems Management (SM) alert are generated if pressure drops below 679 psi. An ↑ and SM alert are generated if pressure exceeds 810 psi. A C&W alarm sounds if pressure drops below 680 psi or exceeds 810 psi Same as REG A except there is no C&W alarm associated with the B regulators
3 MPS HE dP/dT	Displays flow rates, in psi per 3 seconds, from the left, center, and right helium tanks. Nominal flow rate is 12 psi per 3 seconds but, since the display reads only in multiples of 10, the nominal reading is 10. An ↑ and SM alert are generated if dP/dT exceeds 20
4 MPS ULL P LH ₂ LO ₂	Displays ullage pressure from the three active sensors in the LH ₂ tank. An ↓ and SM alert are generated if pressure drops below 28 psi. An ↑ and SM alert are generated if pressure exceeds 48.9 psi Displays ullage pressure from the three active sensors in the LO ₂ tank. An ↓ and SM alert are generated if pressure drops below 0. An ↑ and SM alert are generated if pressure exceeds 29 psi
5 MPS PNEU HE TK P	Displays the pneumatic helium tank pressure. An ↓ and SM alarm are generated if pressure drops below 3800 psi
6 MPS PNEU HE REG P	Displays the pneumatic regulator pressure. An ↓ and SM alert are generated if pressure drops below 700 psi. An ↑ and SM alert are generated if pressure exceeds 810 psi
7 MPS PNEU HE ACUM P	Displays the pneumatic accumulator pressure. An ↓ and SM alert are generated if pressure drops below 700 psi
8 MPS MANF P LH ₂ LO ₂	Displays pressure in the LH ₂ feedline manifold. An ↑, SM alert, and C&W alarm are generated if pressure exceeds 65 psi Displays pressure in the LO ₂ feedline manifold. An ↑, SM alert, and C&W alarm are generated if pressure exceeds 249 psi
9 MPS H ₂ OUT P	Displays the GH ₂ outlet pressure. An ↓ and SM alert are generated if pressure drops below 1050 psi
10 MPS O ₂ OUT T	Displays the GO ₂ outlet temperature. An ↓ and SM alert are generated if temperature drops below 125° F

Figure 2-39. BFS GNC SYS SUMM 1 display (DISP 18)

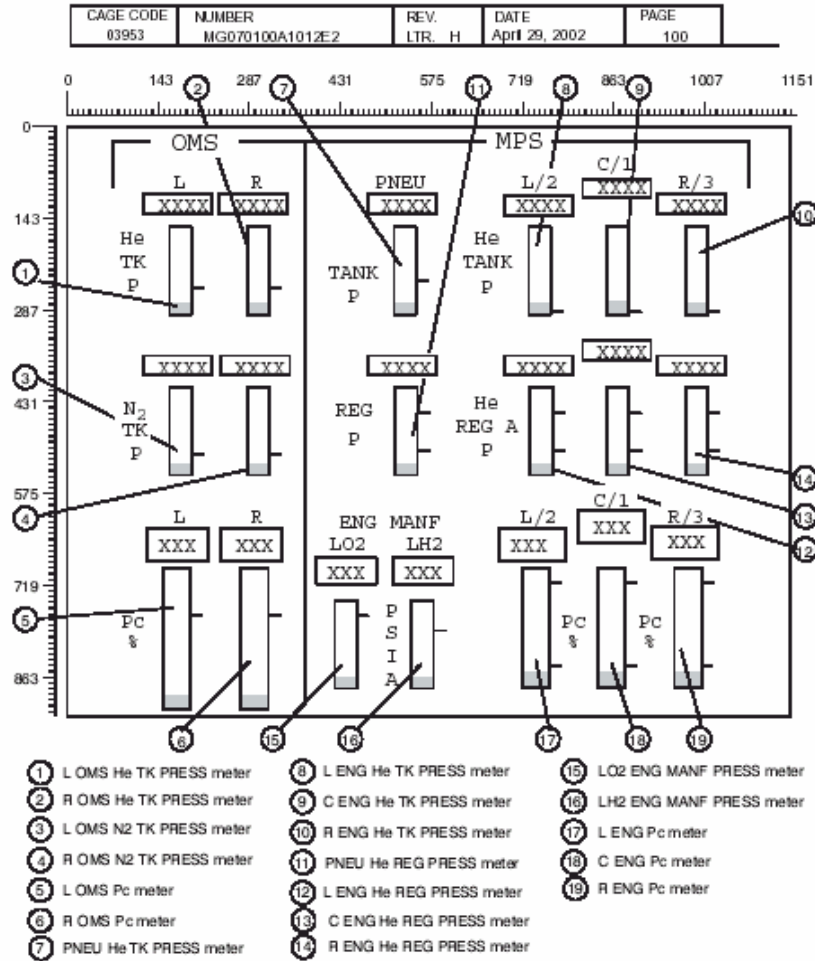


Figure 38 – OMS/MPS Status Format

FORM 3935-G-2 REV 5-97 (Interleaf)

Figure 2-40. MEDS OMS MPS display

Control or display	Function
17-19 MPS PRESS Pc meters	Display center, left, and right main engine combustion chamber pressure in percent. The scales read from 45 percent to 109 percent with tick marks at 67 percent and 104 percent. The bar color is white when Pc is ≥ 65 percent and red when Pc is < 65 percent. These meters are driven by outputs from MDMs, FF1, FF2, and FF3, respectively.
15, 16 MPS PRESS ENG MANF meters LO ₂ LH ₂	<p>Displays LO₂ manifold pressure in the line between the ET and the main engines (0 to 300 psia). The bar color is green when LO₂ manifold pressure ≤ 249 psia and red when LO₂ manifold pressure > 249 psia.</p> <p>Displays LH₂ manifold pressure in the line between the ET and the main engines (0 to 100 psia). The bar color is green when LH₂ manifold pressure ≤ 65 psia and red when LH₂ manifold pressure > 65 psia.</p> <p>This meter is driven directly by the hardware pressure sensor (there is no MDM between the sensor and the meter). The same pressure sensor reading is displayed on the BFS GNC SYS SUMM 1</p>
7-14 MPS PRESS HELIUM meters	<p>Center, left, and right MPS helium supply tank pressures (0 to 5000 psia). The bar color is green when helium tank pressure ≥ 1150 psia and red when helium tank pressure < 1150 psia.</p> <p>Pneumatic supply tank pressure (3000 - 5000 psia). The bar color is green when pneumatic helium tank pressure ≥ 3800 psia and red when helium tank pressure < 3800 psia.</p> <p>Display pneumatic regulator pressure and center, left, and right A regulator pressures (600 to 900 psia). The bar color is green when helium regulator pressure is between 680 and 810 psia. The bar color is red when helium tank pressure < 680 or > 810 psia.</p> <p>This meter is driven directly by the hardware pressure sensor (there is no MDM between the sensor and the meter). The same pressure sensor reading is displayed on the BFS GNC SYS SUMM 1</p>

Figure 2-40. MEDS OMS MPS display (concluded)

```

XXXX / 051 /          OVERRIDE          XX X DDD / HH : MM : SS
                                   DDD / HH : MM : SS
ABORT MODE          ENTRY FCS
TAL          1X          ELEVON          FILTER          ATMOSPHERE
ATO          2X          AUTO  17X          NOM  20X          NOM          22X
ABORT        3X          FIXED 18X          ALT  21X          N POLE  23X
THROT MAX    4X          SSME REPOS 19 XXX          S POLE  24X
      ABT  50X
      NOM  51X
PRPLT DUMP
XXX ICNCT 5 XXXX
OMS DUMP
      ARM  6X
      START 7X
      STOP  8X
9 QUAN / SIDE  XXX
OMS DUMP TTG  XXX

AFT RCS 13      XXX
14 TIME        XXX

FWD RCS 15      XXX
16 TIME        XXX

IMU STAT ATT DES          PRL
1S XXXX X 25X          SYS AUT DES
2S XXXX XXX 26X          1S 28X 31X
3S XXXX          27X          2S 29X 32X
                                   3S 30X 33X

ADTA          H          u          M          DES
L 1S XXXXXX ±XX.X X.XX 34X
3S XXXXXX ±XX.X X.XX 35X
R 2S XXXXXX ±XX.X X.XX 36X
4S XXXXXX ±XX.X X.XX 37X

ET SEP          ROLL MODE XXXXXX
AUTO 38X          AUTO SEL 42X
SEP 39X          WRAP MODE 45 XXX
ET UMB DR          VENT DOOR CNTL
CLOSE 40X          OPEN 43X XX
RCS RM MANF          CLOSE 44X XX
CL OVRD 41

```

```

XXXX / 051 /          OVERRIDE          XX X DDD / HH : MM : SS
                                   BFS DDD / HH : MM : SS
ABORT MODE          ENTRY FCS
TAL          1X          ELEVON          FILTER          ATMOSPHERE
ATO          2X          AUTO  17X          NOM  20X          NOM          22X
ABORT        3X          FIXED 18X          ALT  21X          N POLE  23X
THROT MAX    4X          SSME REPOS 19 XXX          S POLE  24X
      ABT  50X
      NOM  51X
PRPLT DUMP
XXX ICNCT 5 XXXX
OMS DUMP
      ARM  6X
      START 7X
      STOP  8X
9 QUAN / SIDE  XXX
OMS DUMP TTG  XXX

AFT RCS 13      XXX
14 TIME        XXX

FWD RCS 15      XXX
16 TIME        XXX

IMU DES ATT          AA          RGA          SURF
1 25X X LRU DES DES DES
2 26X          1 31X 35X 39X
3 27X          2 32X 36X 40X
          3 33X 37X 41X
          4 34X 38X 42X
ET SEP          AUTO 28X
          SEP 29X          ROLL MODE
          WRAP MODE 45 XXX
ET UMB DR          CLOSE 30X          COMM          XXXX
          TDRS          46X
          VENT DOOR CNTL          STDN - HI 47X
          OPEN 43X XX          STDN - LO 48X
          CLOSE 44X XX          SGLS          49X

```

Figure 2-41. OVERRIDE display (SPEC 51)

Control or display	Function
ITEMs 4, 50, & 51	<p>These ITEM Entries rescale the SBTC (PASS only) and reset the maximum allowable guidance throttle command. As of the time of this writing, these throttle settings are:</p> <ul style="list-style-type: none"> • ITEM 4 = 109 percent • ITEM 50 = 104.5 percent • ITEM 51 = 104.5 percent <p>After an ITEM 4 has been executed, max throttles are obtained per the following:</p> <ul style="list-style-type: none"> • IF AUTO THROTTLES, Guidance will command: <ul style="list-style-type: none"> • MM 102: 109 percent only if an SSME has failed. • MM 103: 109 percent if not g-limiting. • MM 601 (pre PPA): 109 percent only if an SSME has failed. • MM 601 (post PPA): Enables settings higher than 104 percent if guidance commands it. • IF MAN THROTTLES (PASS only) <ul style="list-style-type: none"> • With SBTC full forward, 109 percent is commanded regardless of major mode or SSME configuration
PASS ITEMs 38 & 39 BFS ITEMs 28 & 29	<p>These ITEM entries allow the crew to select the ET SEP AUTO mode or to initiate ET SEP. An * is displayed when either item is selected. Both items are legal only in MM 102, 103, 104, 105, 106, and 601</p>

Figure 2-41. OVERRIDE display (SPEC 51) (concluded)

Questions

After completing these questions, compare your answers with those answers on Page B-1.

1. Identify three parts of the main engine where combustion takes place.
 - a.
 - b.
 - c.
2. Identify the five hydraulically actuated valves in a main engine.
 - a.
 - b.
 - c.
 - d.
 - e.
3. True or False. In addition to its role as oxidizer, LO₂ is also used to cool the main engines.
4. What can happen to the LO₂ turbopump at MECO if there is an inadequate supply of helium?
5. How many command and data paths are there between each main engine controller and its associated EIU?
6. True or False. The ullage pressure system uses MPS helium to pressurize the propellant tanks in the ET.
7. True or False. The crew can control the LO₂ ullage pressure system.
8. Briefly describe the interface between the center main engine and the orbiter hydraulic systems.

3.0 SYSTEM OPERATIONS

3.1 OBJECTIVES

After completing this section, you should be able to

- a. Describe the required crew MPS inputs during the powered flight phase of a normal ascent
- b. Explain why the SSMEs are throttled back in first stage and 1 minute prior to MECO
- c. Locate the ports through which the LO₂ and LH₂ are dumped during the post-MECO MPS propellant dump
- d. Describe the SSME controller interface with the orbiter electrical power system
- e. Recognize the importance of setting the MECO Confirmed flag
- f. Explain when the SSME controllers should be powered off
- g. Describe the purpose of the MPS helium system during ascent and entry
- h. Describe the SSME interface with the orbiter AC electrical power system
- i. Explain why the SSME controllers should not be powered off until after the MPS dump is complete

In this section, nominal MPS operations from crew ingress through landing are discussed. Our primary objective is to learn the MPS-related Flight Data File (FDF) procedures and understand their rationale. The procedures discussed in this section can be found in the Ascent and Post Insertion Checklists. Other functions that require little or no crew input, such as the MPS propellant dump, are also described. All events are presented in sequential order and are separated into four mission phases: prelaunch, powered flight, post-MECO, and entry.

3.2 SSME THERMAL CONDITIONING

At the start of ET Loading (at approximately T - 6 hours), LO₂ and LH₂ propellants also begin circulating through the SSMEs to chill the components to cryogenic temperatures. SSME thermal conditioning continues throughout ET loading / stable replenish and terminates at approximately T - 9 seconds in preparation for engine start.

3.3 SSME LH₂ CHILLING CIRCUIT

Each SSME has an LH₂ recirculation pump and recirculation pump valve that allows LH₂ to be pumped from the manifold, around each closed LH₂ prevalue, and into the SSME. LH₂ passes through each engine's LPFTP and HPFTP, but cannot pass further into the cooling ducts of the SSME because the MFV is closed. Instead, the LH₂ exits each SSME via the LH₂ bleed valve, into the LH₂ recirculation line, and finally into the ET.

3.4 SSME LO₂ CHILLING CIRCUIT

The LO₂ is also chilling the oxidizer components of the SSMEs. The LO₂ flows from the manifold, through the open LO₂ prevalues, and into the engines. Once in the engine, the LO₂ flows through the LPFTP and through the HPFTP but cannot flow into the combustion chamber because the MOV is closed. A very small amount of LO₂ flows out of the intermediate seal turbopump drains and is vented overboard through a drain line that opens near the bottom of the nozzle. This is the white vapor seen coming out near the nozzle during prelaunch. Most of the LO₂ exits the engines from the pogo accumulator and from the LO₂ bleed valve. Here the LO₂ flow from each engine is manifolded together and flows out the overboard bleed valve, through the T - 0 umbilical, and back to the facility. The LO₂ flowrate through the overboard bleed valve is about 18 lb/sec.

3.5 PERFORMANCE MARGIN

Both the LO₂ and LH₂ tanks are always loaded to the 100-percent level. The ET loading is not flight-specific; only the MPS performance margin changes from flight to flight. The 100-percent level of LH₂ provides more than enough fuel to complete any mission. The mission-specific requirements determine how much LO₂ is needed. If less than 100-percent LO₂ is required for a particular mission, then that mission will have some performance margin

3.6 DRAIN BACK HOLD TIME

After the APUs are started at T - 5:00 minutes, the LO₂ inboard fill/drain valve closes at T - 4:55. No more LO₂ comes in from the facility, but the overboard bleed valve is still open, so the LO₂ in the tank “drains back” to the facility at 18 lb/sec. **Drain back hold time** is defined as the time past the planned T - 0 that the launch sequence can be held during LO₂ drain back until all the performance margin has drained away.

For example, 16,200 lb of LO₂ margin starts draining at approximately T - 5 minutes and takes 15 minutes to drain at 18 lb/sec, leaving 10 minutes of drain back hold time. For this much performance margin, holding for more than 10 minutes past the planned T - 0 time would result in draining too much LO₂ and not having enough to make the nominal MECO target. Drain back hold time is computed before the mission and computed in real time based on day-of-launch loading information from KSC. **Drain back hold time is directly related to the amount of performance margin.**

The LO₂ in the downcomer is warmer than the LO₂ in the tank and is warmer than the LO₂ coming from the facility. When drain back starts, the LO₂ engine inlet temperature starts to rise as the warm LO₂ from the downcomer flows through the engine. When all the warm LO₂ from the downcomer has drained away, the LO₂ engine inlet temperature starts to decrease as cold LO₂ from the tank flows through the engine. If drain back continues too long, the LO₂ engine inlet temperature goes below the limit for a successful engine start. When this happens, the LPS issues a launch hold. Therefore, the maximum value of drain back hold time is the length of time required to drain the

LO₂ downcomer. For example, the amount of LO₂ in the downcomer is calculated by multiplying the density of LO₂ by the volume of the downcomer (a cylinder, 100 feet long, 17 inches in diameter). This amount of LO₂ (~11,186 lb) takes approximately 10 minutes to drain at 18 lb/sec, giving the **maximum of 5 minutes of drain back hold time**. If the performance margin drain back hold time is **more** than 5 minutes, the LO₂ inlet temperature limit is violated before the performance margin limit. If the performance margin drain back hold time is **less** than 5 minutes, the performance margin limit is violated before the LO₂ inlet temperature limit.

Tank topping and thermal conditioning are terminated, and the propellant tanks are pressurized with ground support helium for engine start. At T - 3 minutes, the LO₂ tank is pressurized to approximately 21 psi and at T - 2 minutes, the LH₂ tank is pressurized to approximately 47 psi. The main engines are commanded to start at ~T - 6.6 seconds, allowing about 4 seconds for the three chamber pressures to reach 90 percent (a requirement for SRB ignition) and 3 seconds for twang. (Twang is the vehicle oscillation that occurs at main engine start.) Then, at T - 0, the SRBs ignite for lift-off.

3.7 PRELAUNCH

Power to the main engine controllers is protected with the AC bus sensors in MONITOR.

The Astronaut Support Person (ASP) takes the AC bus sensors on Panel R1 to MONITOR during the T - 3 hour hold (See Figure 3-1). These sensors are not part of the MPS, but this procedure is accomplished for the protection of the main engines. Each engine controller is powered by two of the three AC buses, one for each DCU. Therefore, the loss of one bus results in a loss of controller redundancy on two engines, and the loss of any two buses causes the associated engine to shut down. In MONITOR, the AC bus sensor provides C&W for an over/undervoltage or overload condition, but they do not trip a bus off line.

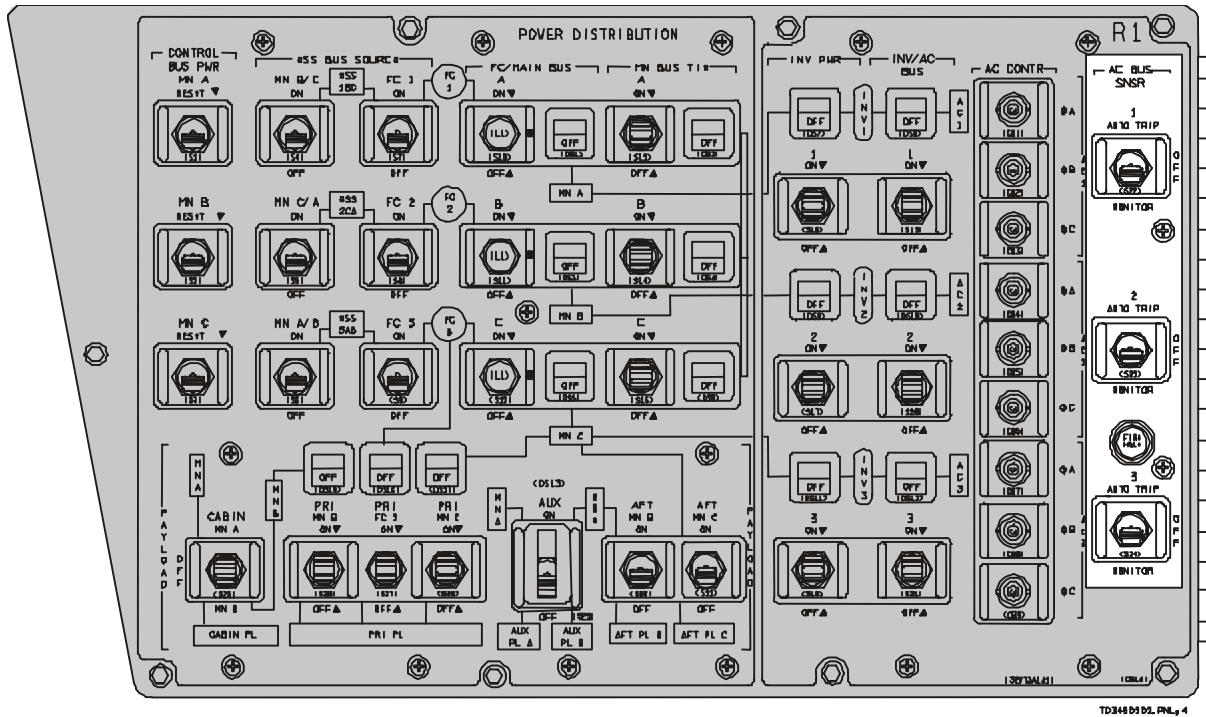
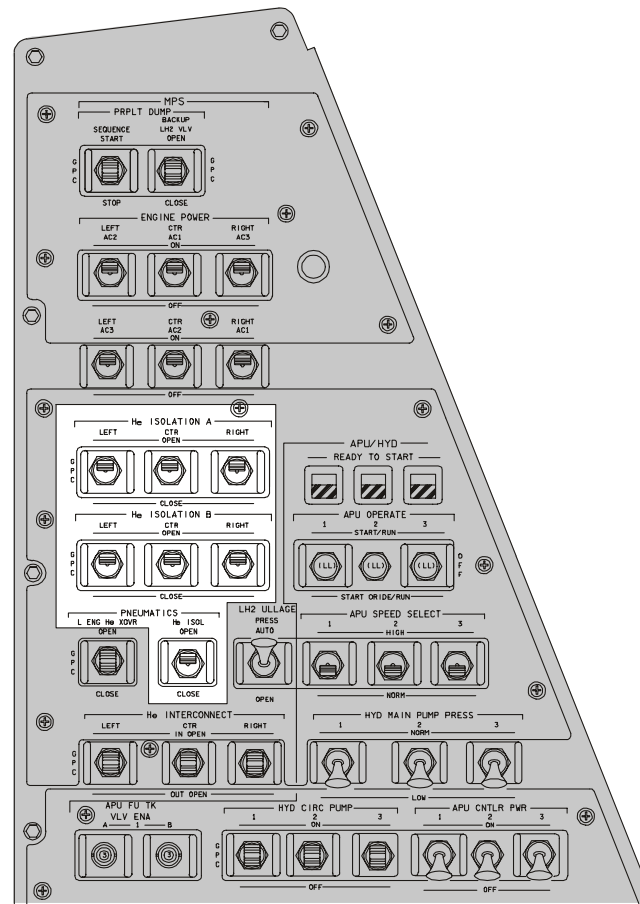
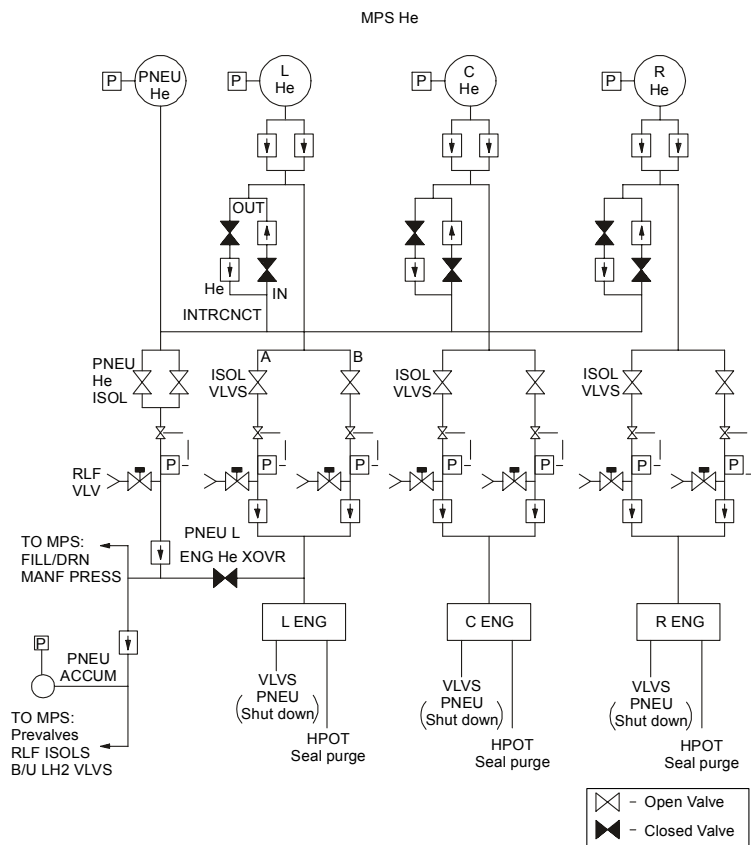


Figure 3-1. The ASP takes the AC bus sensors on Panel R1 to MONITOR at T - 3 hours

When the crew enters the orbiter 2 hours before lift-off, the MPS is nearly ready for launch. The ET is loaded, and is continually topped off to replenish propellants that are lost due to boil off and thermal conditioning as propellants are circulated through the SSMEs.

The He ISOLATION switches on Panel R2 are the only MPS switches which must be reconfigured by the crew prior to launch. They are moved to the manual open position at T - 16 minutes. Although the GPCs maintain open commands to these valves until the post-MECO MPS dump termination, the manual open switch position protects against an unexpected loss of the GPC open command. All other MPS switches are configured for launch prior to crew ingress.

-16:00 **MPS** **He Reconfiguration**
 (-26:00) R2 MPS He ISOL A, B (six) -OP
 PNEU He ISOL -OP



usa006162_098

Figure 3-2. The MPS He RECONFIGURATION is part of the prelaunch procedures in the Ascent Checklist; the helium system and MPS switches on Panel R2 are shown in their launch configuration

3.8 POWERED FLIGHT

The crew's primary role, during ascent, is one of monitoring.

The crew's workload during ascent has been kept to a minimum. This is especially true for the MPS, which normally requires no crew input during powered flight. The MPS functions that should be monitored include SSME Thrust Level, SRB Separation, Helium Systems, ET Ullage Pressure, MECO, and ET Separation.

Monitor Thrust Level

Current SSME thrust level is displayed on the lower right hand corner of the MEDS OMS/MPS display. The PASS throttle command is not directly displayed. The thrust level that BFS would command if it were engaged is displayed on the BFS TRAJ (See Figure 3-3).

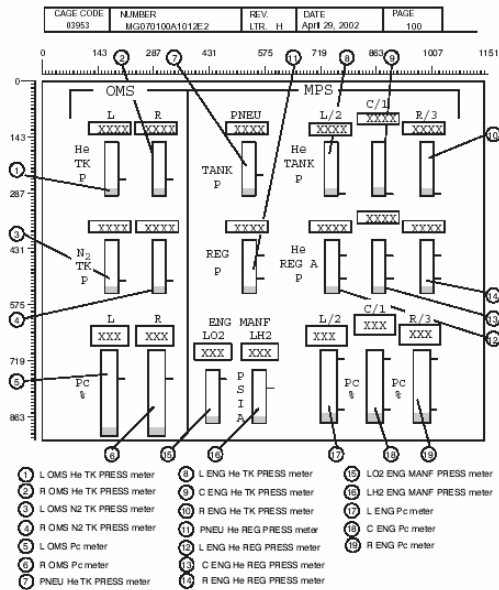


Figure 38 - OMS/MPS Status Format

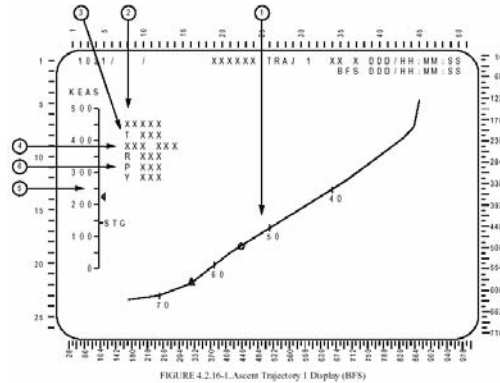


FIGURE 4.2.16-L-Ascent Trajectory 1 Display (BFS)

Figure 3-3. MEDS OMS/MPS display and thrust-commanded display on the BFS ASCENT TRAJ 1

The GH₂ OUT P and GO₂ OUT T data varies with throttle levels as indicated in Table 3-1 and can be monitored on the BFS GNC SYS SUMM1 display.

Table 3-1. GH₂ OUT P Data

Power Level	Predicted GH ₂ Outlet Pressures	
	FCV Closed	FCV Open
67	2010	1880
72	2170	2020
100	3040	2800
104.5	3180	2930
109	3320	3050

The main engines are commanded to 100 percent for engine start and then to the thrust level required for the flight (normally 104 percent) shortly after lift-off. As dynamic pressure rises, the engines are throttled back to reduce aerodynamic loading. This is called the thrust bucket because of the way the thrust plot appears on a graph (See Figure 3-4). Although the bucket duration and thrust level vary with each mission, a typical bucket runs from about 40 to 55 seconds MET, during which all three SSMEs throttle back to reduce thrust. The casting shape of the SRB propellant is designed to also reduce thrust in this region. At approximately 55 seconds MET, the engines are throttled up to the mission-required thrust level and remain there until 3g throttling. The throttle levels of the thrust bucket are published in the Ascent Checklist, but the actual values during flight may be different, based on the SRB performance being higher (hot SRBs) or lower (cold SRBs) than expected. Guidance raises the bottom of the bucket for “cold” SRBs. Guidance will command a two-stage bucket if SRB performance is higher than expected.

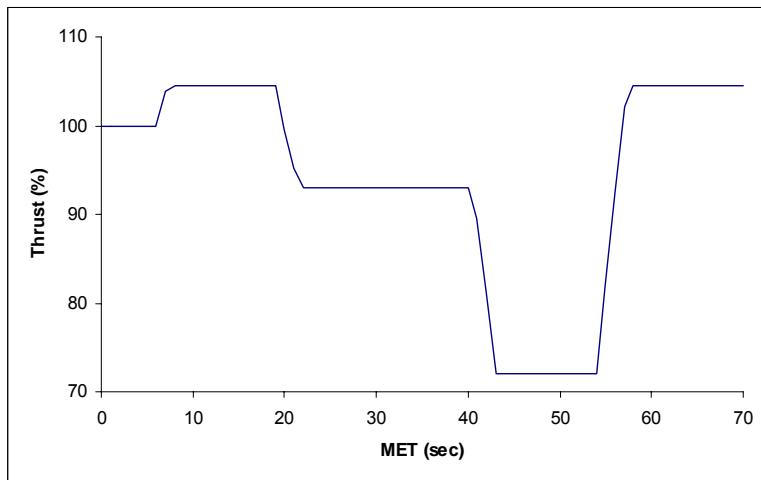
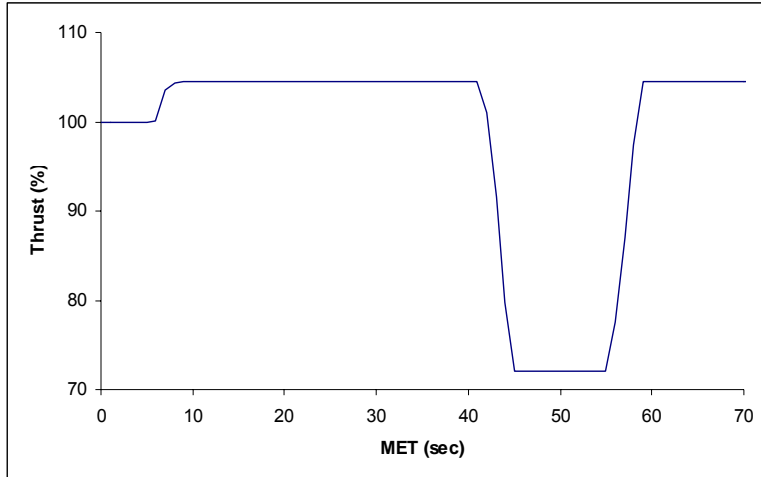


Figure 3-4. Typical examples of single-stage and two-stage thrust buckets

When vehicle acceleration approaches 3g at approximately 1 minute before MECO, the engines throttle back to maintain acceleration at 3g to prevent excessive stress on the vehicle. Then, at approximately 6 seconds prior to MECO, the engines are throttled back to 67 percent in preparation for shutdown.

Table 3-2 summarizes the thrust levels throughout a nominal ascent:

Table 3-2. Nominal ascent thrust levels summary

MISSION EVENT	EVENT TIME OR CUE	THRUST LEVEL
Main Engine Start	T - 6.6 sec	100 percent
Tower Clear	Vrel > 60 fps (~T + 4 sec)	100 percent or 104 percent (flight-specific)
Thrust Bucket	(~T + 40 sec)*	(~72 percent)*
Throttle Up	(~T + 55 sec)*	104 percent
3g Throttling Note: G-forces are displayed on both BFS ASC TRAJ 2 and the MEDS Accel Tape	~MECO - 1:00	SSMEs throttle as required to maintain 3 G-forces
MECO Prep	~MECO - 6 sec	3 SSMEs running: 67 percent <3 SSMEs running: 91 percent

*Thrust bucket cues and throttle levels are flight specific and are given in the Ascent Checklist p. FB 2-5.

Monitor SRB Sep

No crew action is required for SRB Sep.

The SRBs burn out after about 2 minutes of flight. Appearance of an overbright "Pc <50" (chamber pressure of the SRBs in psi) on the PASS and BFS TRAJ displays indicates to the crew that the SRB separation sequence has begun. Actual separation occurs after allowing about 5 seconds for thrust tail-off.

If the GPCs fail to receive the proper indication from the SRBs, then the SEP sequence will be started when an I-loaded backup timer expires. SRB SEP will then occur ~2:20 MET. This is commonly referred to as a "Backup AUTO SEP" or a "Delayed SEP."

The software SRB Sep inhibits have effectively been no-opted by setting the body rate limits to 999 deg/sec and the qbar limit to 999 psf.

Monitor Helium Systems

Monitoring the helium system requires knowing both where to check the helium and what the proper values should be. Due to the importance of the helium system, its status should be checked periodically throughout ascent.

It is important to make the distinction between the main engine helium system with the pneumatic helium system. Any references to the pneumatic system will specifically state “pneumatic.”

MPS helium pressures are displayed on the BFS GNC SYS SUMM 1 display and the MEDS OMS/MPS display. See Figure 3-5.

Main Engine Helium

BFS SYS SUMM 1 is the primary source of main engine helium information and displays the following values:

- HE TK P - Pressure in each main tank (psia)
- REG P A - Pressure in each regulator A (psia)
- REG P B - Pressure in each regulator B (psia)
- dP/dT - Rate of change in pressure in each main tank (psi/3 sec)

The MEDS OMS/MPS display provides an additional display for some of the same values:

- Pressure in each main tank
- Pressure in each regulator A

Note: The MEDS display uses the same transducers as BFS SYS SUMM 1.

To monitor the main helium system, do the following:

1. Verify that dP/dT is 10 for all three systems.
2. Check that no status indicators (arrows) are displayed.
3. Confirm that all the tanks are depleting similarly and that all REGs are operating at ~750 psia.

Pneumatic Helium

BFS SYS SUMM 1 is the primary source of pneumatic helium information and displays the following values:

- PNEU TK - Pressure in the pneumatic tank (psia)
- PNEU REG - Pressure in the one pneumatic regulator (psia)
- PNEU ACUM - Pressure in the pneumatic accumulator (psia)

The MEDS OMS/MPS display provides an additional display for some of the same values:

- Pressure in the pneumatic tank
- Pressure in the pneumatic regulator

Note: The MEDS display uses the same transducers as BFS SYS SUMM 1.

To monitor the pneumatic helium system, do the following:

1. Verify that the pneumatic tank pressure remains constant.
2. Verify that the pneumatic regulator and accumulator pressures remain constant at ~750 psia.

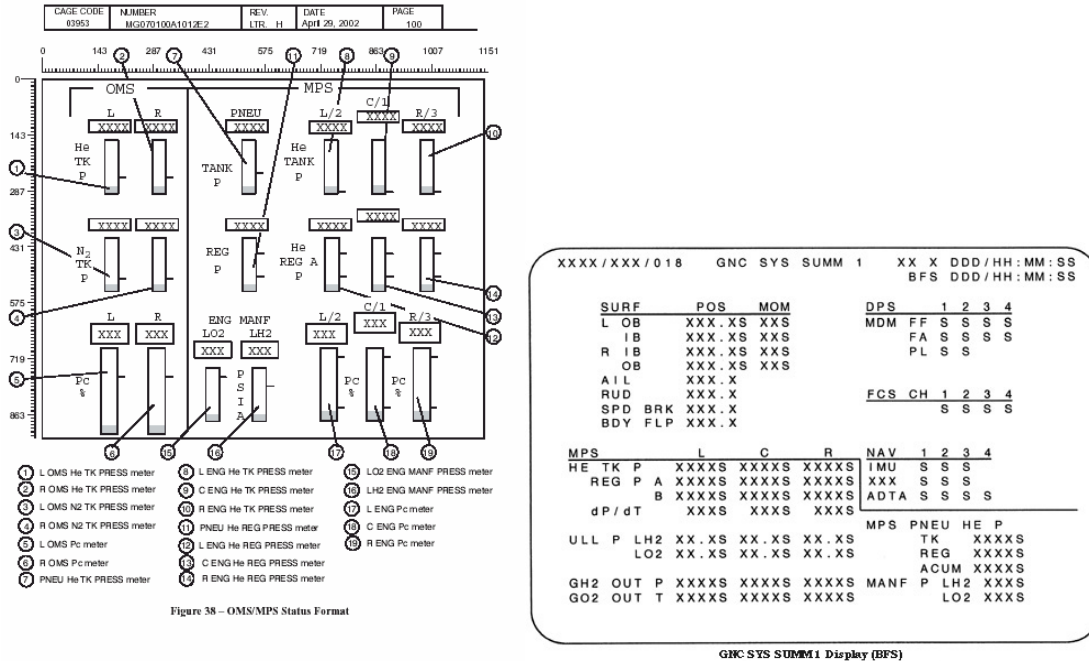


Figure 3-5. MPS helium and manifold pressures are displayed on the MEDS OMS/MPS display and BFS GNC SYS SUMM 1

Monitor the ET Ullage Pressure

Monitoring ullage pressure is not an absolutely critical task for the crew during ascent but the system can be quickly scanned after checking the helium system.

BFS SYS SUMM 1 is the only source of ET ullage pressure information and displays the following values:

- ULL P LH₂ L (C, R) - H₂ ullage pressure readings for the left, center, and right SSME sensors
- ULL P LO₂ L (C, R) - O₂ ullage pressure readings for the left, center, and right SSME sensors

To monitor the ET ullage pressures, do the following:

1. Verify that the values displayed for each tank are similar.
2. Check that no status indicators (arrows) are displayed.

Monitor MECO

MECO and shortly thereafter is a potentially busy period as the crew monitors all of the vehicle functions and must also evaluate the ascent performance. It is therefore important to understand the nominal MECO cockpit indications as listed below.

The following are four key cockpit indications for MECO:

- Main engine status lights on Panel F7 illuminate RED
- Cutoff bug on BFS ASCENT TRAJ 2 will pass the “CO” tickmark
- Zero Chamber Pressure (Pc) indications for the three SSME throttles
- Digital Auto Pilot (DAP) lights illuminate (AUTO/DISCRETE) to signify that the MECO confirm flag has been set

MECO confirm (“setting the MECO confirm flag”) means that the GPCs recognize that MECO has occurred. This is necessary before the GPCs will begin the ET SEP sequence.

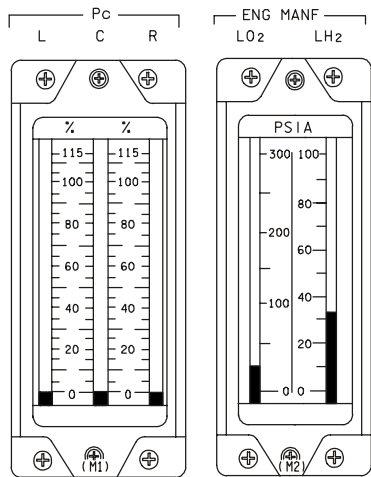
MECO Confirm will be set automatically by either of the following two events:

- The GPCs see three main engine Pc's < 30 percent
- The GPCs see two main engine Pc's < 30 percent and the third engine has a data path failure.

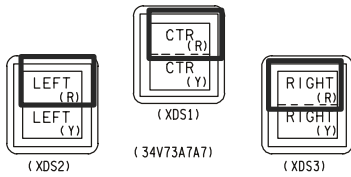
MECO Confirm can be set manually by either of the following three actions:

- Depress all three main engine shutdown pb's (simo not required)
- OPS 104 PRO keyboard entry
- Perform a fast ET SEP

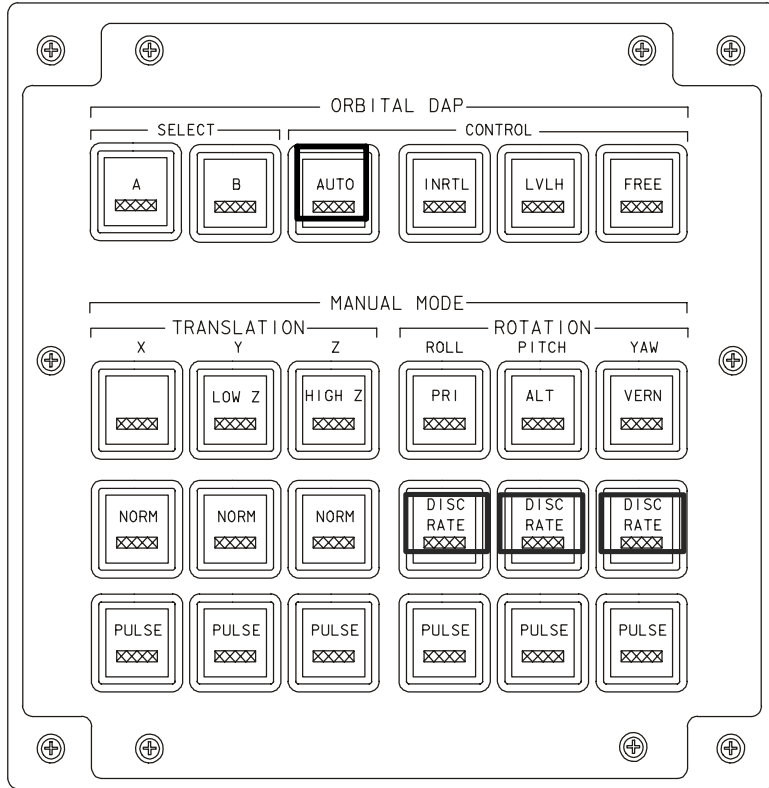
Section 4.0 will cover when these manual methods for MECO confirm are used.



— MAIN ENGINE STATUS —



PANEL F7



PANEL C3

TD3450306. PNI 3

Figure 3-6. At MECO, the red main engine status lights illuminate and the Pc meters drop to 0 percent. The DAP lights illuminate a few seconds later when the MECO confirmed flag is set

The following automatic valve actions occur between MECO and ET-SEP:

MPS MECO EVENTS		
TIME	EVENT	
MECO	LH ₂ FEEDLINE REL ISOL	OPEN
	LO ₂ FEEDLINE REL ISOL	OPEN
	PNEU XOVER	OPEN
	LH ₂ RECIRC DISC	CLOSED
MECO+1.158	LO ₂ PREVALVE (C)	CLOSED
	LO ₂ PREVALVE (L)	CLOSED
	LO ₂ PREVALVE (R)	CLOSED
MECO+7.6	LH ₂ PREVALVE (C)	CLOSED
	LH ₂ PREVALVE (L)	CLOSED
	LH ₂ PREVALVE (R)	CLOSED
	LO ₂ AND LH ₂ 17" LATCH	UNLOCK
MECO+8.6	LO ₂ 17" DISC	CLOSED
	LH ₂ 17" DISC	CLOSED
MECO+13.4	BACK UP DUMP VALVES	OPEN
	ET/ORB UMB PLATES RETRACT	
MECO+16.0	SSME BLEED VALVES	OPEN
MECO+19.44	ET SEP	

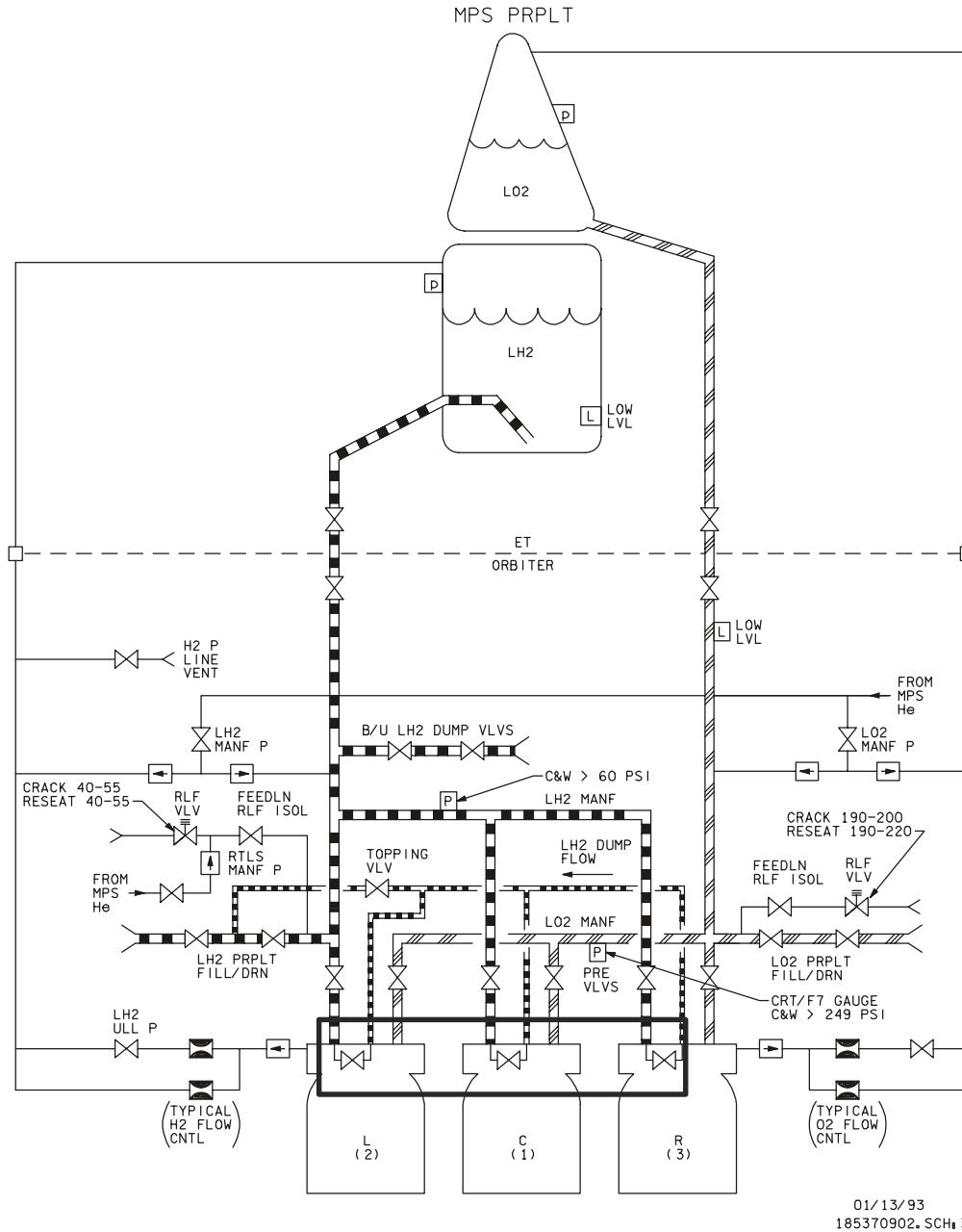


Figure 3-7. MPS propellant valve sequence (MECO-ET SEP)

Monitor ET SEP

ET separation is the next critical event after MECO. No crew action is required for a nominal ET SEP. Off-nominal procedures are discussed in Section 4.0.

ET SEP occurs in two parts:

- Physical separation of the orbiter and the ET
- -Z translation of the orbiter away from the ET

Cockpit indications for ET SEP:

- SSME Status Lights extinguish (physical separation)
- Transition to MM104 (-Z translation complete)

3.9 POST ET SEP

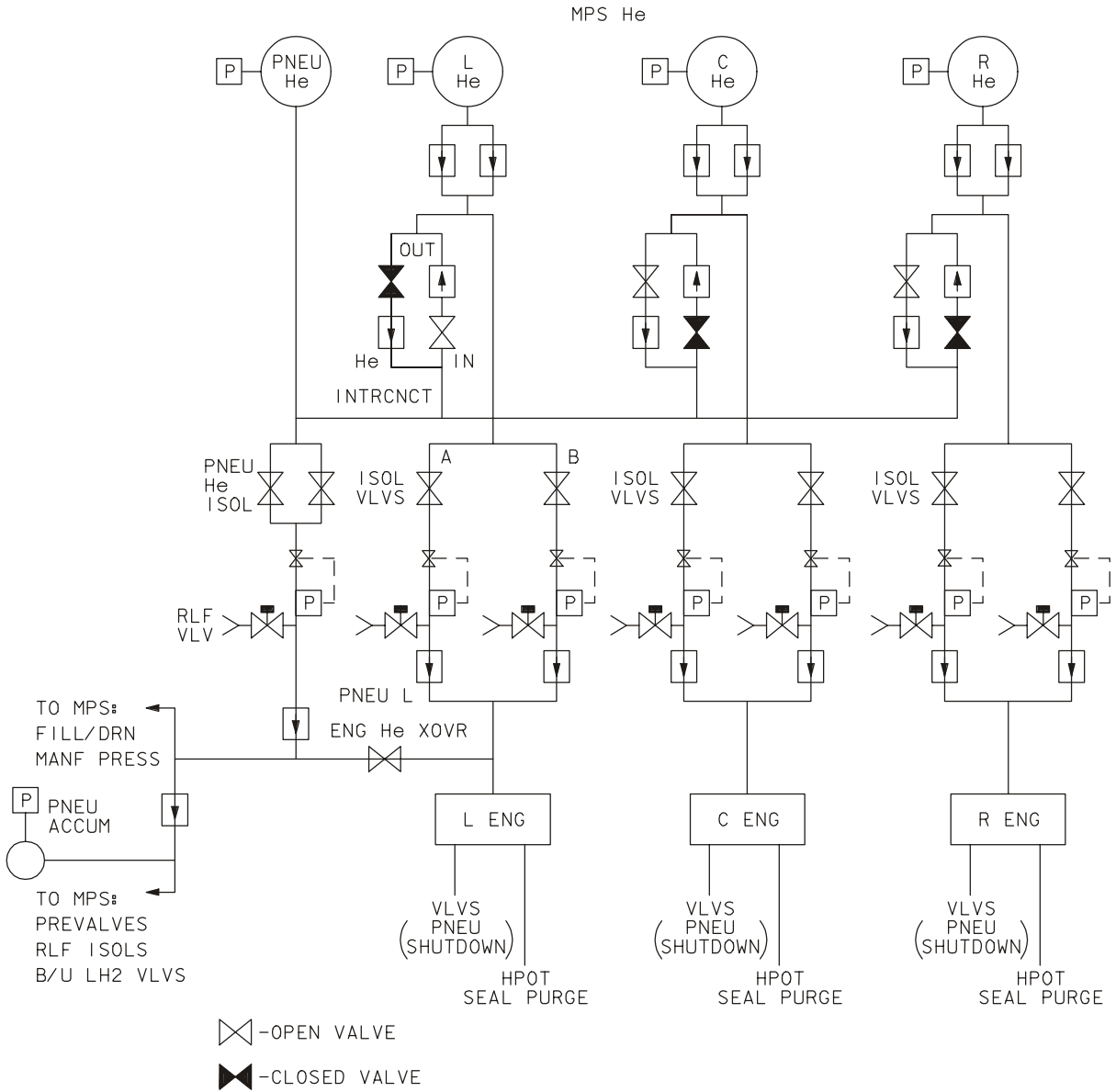
The primary task of the MPS after ET SEP is to evacuate the unused propellant trapped in the feedline manifolds (~4200 lb).

This MPS dump is performed for the following reasons:

- Shift the orbiter center of gravity forward
- Prevent trapped LH₂ from combining with the atmosphere during entry and creating an explosion hazard.
- Prevent the residual propellants from spuriously venting on-orbit, which would produce navigation errors and could also contaminate experiments in the payload bay.
- Prevent corrosion or any possible overpressurization in the propellant lines.

Propellant evacuation is accomplished through an automatic MPS propellant dump and vacuum inerts, which are mostly transparent to the crew.

After ET SEP, the MPS helium system automatically reconfigures to provide helium pressure for the dump (See Figure 3-8). The center and right OUT interconnects open, and the left IN interconnect opens. This allows all SSME helium tanks to supply the pneumatic system through two redundant paths: high pressure through the interconnect line and regulated pressure through the PNEU L ENG He XOVER (opened at MECO). The system is now ready for the simultaneous dump of LO₂ and LH₂ at MECO + 2:02.



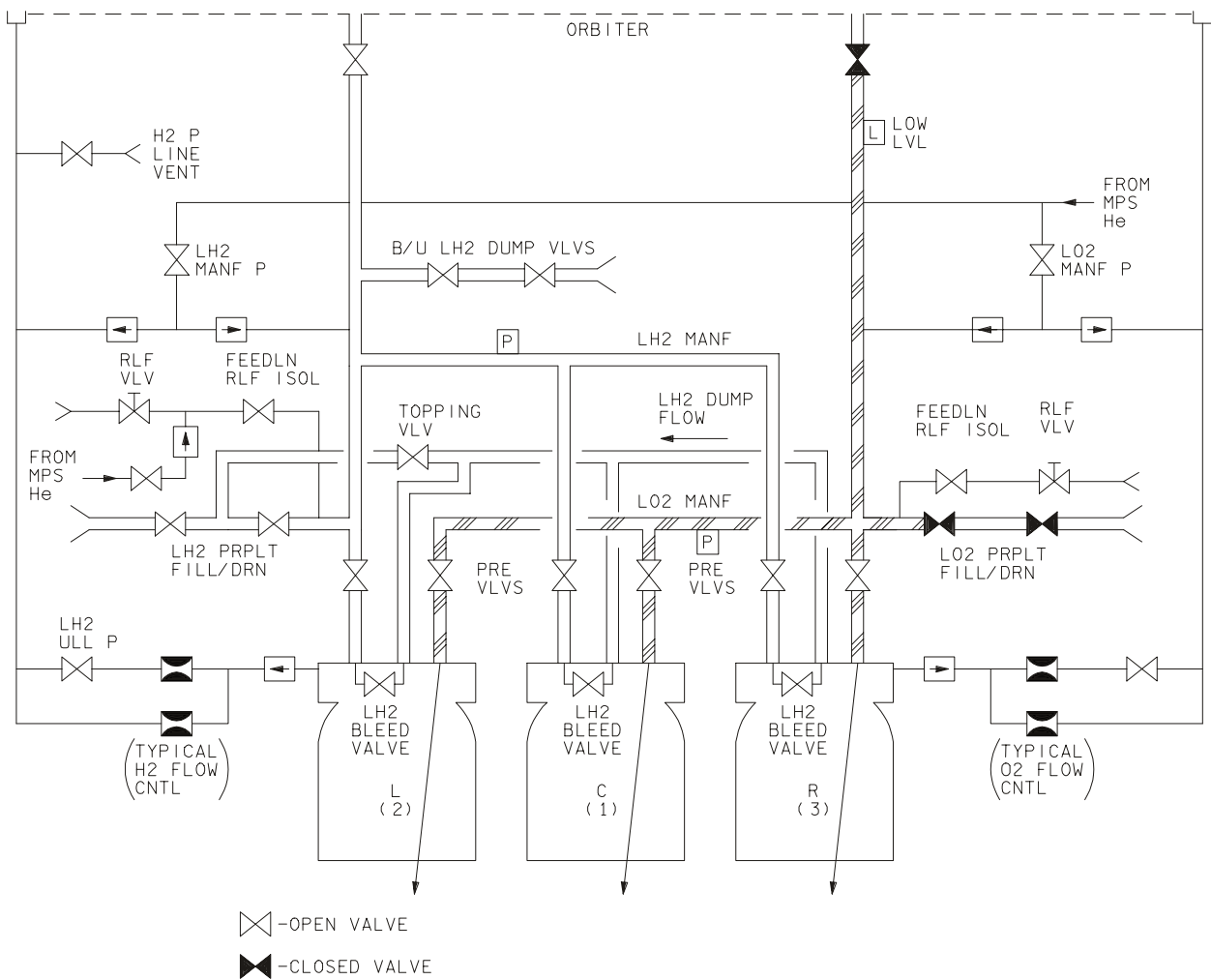
TD3450308. ART 8

Figure 3-8. MPS helium reconfiguration prior to the propellant dump

The LO₂ is dumped through the three SSME combustion chambers and out the engine bells. See Figure 3-9.

The dump sequence starts automatically at MECO + 2:02. At this time, the three LO₂ prevalues and the three SSME MOVs open. The LO₂ dump is pressure-assisted by helium by opening the LO₂ Manf Press valves for the first 90 seconds. The LO₂ manifold pressure valves then close, and the LO₂ manifold is allowed to blow down for another 30 seconds. The LO₂ dump terminates after a total dump time of 2 minutes by closing the MOVs.

<u>MET</u>	<u>EVENT</u>
MECO + 2:02	"DUMP START" LO ₂ MANF P VLV - OP LO ₂ PREVALVES - OP SSME MOV'S - OP
MECO + 3:32	LO ₂ MANF P VLV - CL
MECO + 4:02	MOV'S - CL "DUMP STOP"



TD3450310. ART: 8

Figure 3-9. LO₂ dump sequence

The LH₂ is dumped out the left side of the orbiter through the LH₂ fill/drain valves. See Figure 3-10.

The LH₂ manifold began venting through the Backup Dump Valves when these valves were opened at MECO + 13 seconds. This vent is located on the port side of the orbiter at X₀ = 1334 and Z₀ = 315.

The LH₂ dump starts automatically at MECO + 2:02. At this time, the LH₂ inboard and outboard fill/drain valves, prevalues, and topping valve open. LH₂ is dumped out the fill/drain valves without the aid of helium pressure.

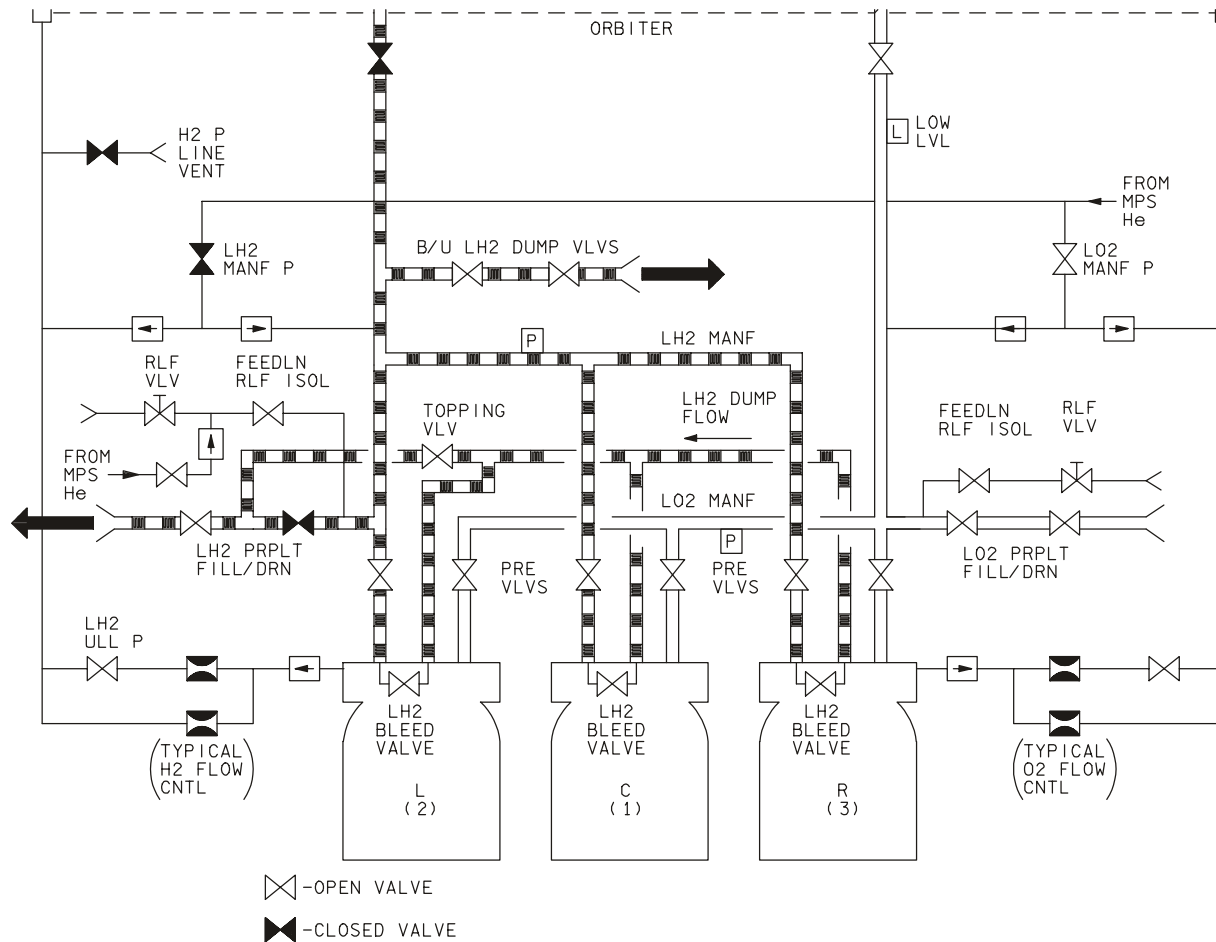
The residual LH₂ in the SSMEs passes through the high and low pressure fuel turbopumps, through the three open prevalues, and back to the orbiter LH₂ 17-inch manifold. LH₂ is also dumped from the SSME fuel bleed valves to the 4-inch LH₂ recirculation line, through the open LH₂ topping valve and overboard through the LH₂ Outboard Fill/Drain valve.

Two minutes after the automated MPS dump sequence begins, the LH₂ outboard Fill/Drain (F/D) valve, LH₂ topping valve, SSME fuel bleed valves, and LH₂ backup dump valves are closed.

Now that the LH₂ and LO₂ dumps are complete, the PNEU L ENG He XOVER valve and the MPS helium interconnect valves are closed. The GPC open commands for the C, L, and R Helium (He) isolation valves are also terminated, but the valves remain open until the switches are moved from OPEN to GPC in the MPS PWRDN/ISOL procedure.

Note: The MPS dump normally starts automatically at MECO + 2:02. It can also start any time between MECO + :22 and MECO + 2:02 by manually moving the MPS Dump switch to START or automatically if the LH₂ manifold pressure is between 60 and 90 psi.

<u>MET</u>	<u>EVENT</u>
MECO + 0:13	B/U LH ₂ DUMP VLVS - OP
MECO + 2:02	“DUMP START” LH ₂ I/B FILL/DRAIN - OP LH ₂ O/B FILL/DRAIN - OP LH ₂ TOPPING VLV - OP LH ₂ PREVALVES - OP
MECO + 4:02	B/U LH ₂ DUMP VLVS - CL LH ₂ O/B FILL/DRAIN - CL LH ₂ TOPPING VLV - CL “DUMP STOP”



TD3450311. ART 10

Figure 3-10. LH₂ dump sequence

The Left and Right AUTO Body Flap lights go out at 120 seconds after dump start to indicate that the dump sequence is complete.

This cue is important because the MPS dump should be completed prior to APU shutdown. If an APU is shut down prior to MPS dump completion, the affected SSME controller will pneumatically close the MOV due to the loss of hydraulic pressure, which eliminates an LO₂ dump path.

The MPS powerdown procedure removes AC power from the main engine controllers.

The Pilot (PLT) performs the MPS Powerdown procedure, which is located in the post OMS-1 section to secure the MPS for orbit and entry operations (See Figure 3-11). The six MPS ENGINE POWER switches on Panel R2 are taken to OFF, removing all power to the main engine controllers. It is important that this portion of the procedure not be performed until after the MPS dump is complete because the main oxidizer valves cannot be opened once power is removed from the controllers.

The six helium isolation valves are also closed by taking the switches to GPC. This isolates the three main engine helium tanks from the engines. The NOTE after the procedure alerts the crew to expect multiple master alarms as the helium pressure in the now isolated regulators bleeds down. Pressure is normally regulated at 750 psi. A master alarm annunciates for any of the main engine helium regulators whose pressure drops below 680 psi prior to OPS 2. Finally, the PLT verifies that the three He INTERCONNECT valves are all in the GPC position, isolating the left, center, and right helium tanks from the common manifold. The PNEU He ISOL switch is taken to the GPC position, but the valves remain open until MPS vacuum inerting is complete.

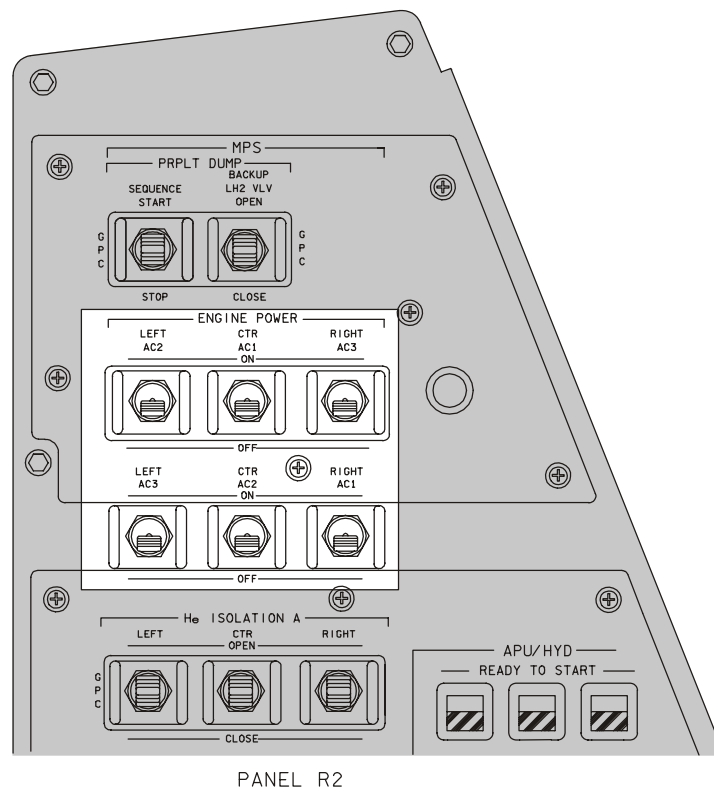


Figure 3-11. The MPS powerdown is accomplished as a part of the post-OMS-1 procedure in the Ascent Checklist

After the MPS powerdown is complete, the PLT opens the MPS H₂ PRESS LINE VENT for 1 minute to inert the GH₂ pressurization manifold. Since the H₂ PRESS LINE VENT outlet is located in the umbilical compartment, ET Umbilical Door closure is not performed until the MPS GH₂ Inerting procedure is complete. This avoids venting GH₂ into a sealed compartment.

Vacuum inerting allows any residual traces of LH₂ and LO₂ trapped in the propellant lines after the dump to be vented into space.

The vacuum inerting prevents any overpressure that might burst the lines and precludes intermittent venting, which could impact vehicle attitude or contaminate experiments. Valves open to vent propellant manifolds into space.

The first vacuum inert sequence starts 15 minutes after Dump Stop and lasts for 2 minutes. It is part of the automatic dump sequence. The GPCs open the LO₂ outboard and inboard F/D and LH₂ backup dump and topping valves. The GPCs verify that the manifold pressure is below 30 psi; otherwise, the LO₂ fill/drain valves are not opened. High LO₂ manifold pressure causes a rolling moment when vented out the fill/drains.

Two minutes later the sequence is terminated by closing the LO₂ outboard F/D valve and the LH₂ backup dump and topping valves.

A second LH₂ vacuum inert occurs automatically when the crew performs the OPS 106 PRO. The GPCs open the LH₂ Backup Dump and Topping valves for 2 minutes and then close them. Ten seconds later, the GPCs perform a ten second pressurization of the LH₂ manifold using the LH₂ Manifold Press valves. This is performed as an in-flight pressure decay check of the LH₂ manifold.

Post Insertion Procedures

At approximately 55:00 MET, the SSME circuit breakers on Panel L4 are manually opened. Power was previously removed from the SSME controllers during the MPS Powerdown procedure, but this step protects against shorts by removing AC power from that portion of the power buses that are not in use.

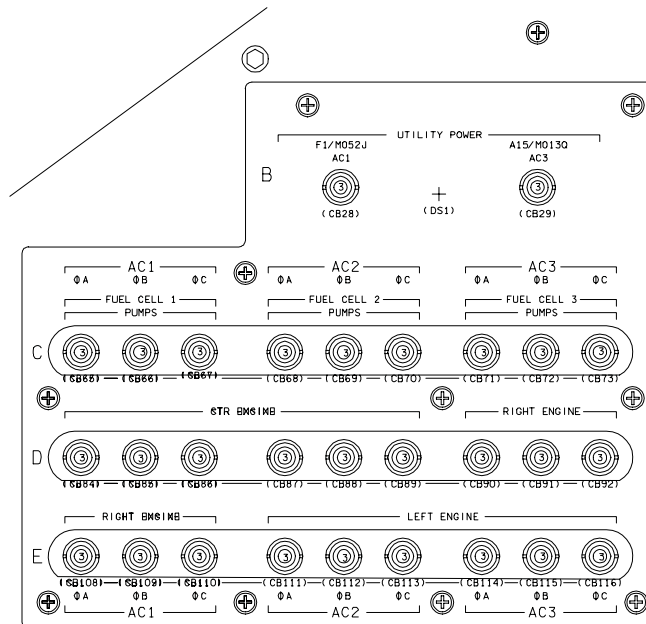
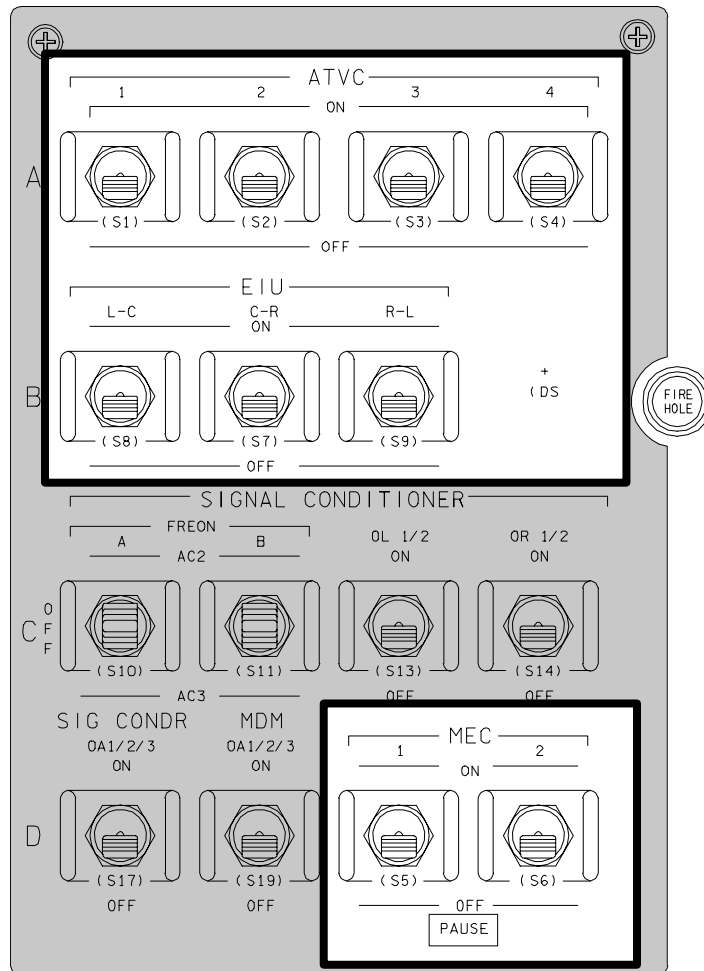


Figure 3-12. Panel L4 reconfiguration in the Post Insertion Checklist

The Panel O17 reconfiguration (found in the AFT STATION CONFIG block) removes power from the four ATVC channels, the three EIUs, and the two MECs. The 2-second delay between MECs ensures that spurious shutdown signals cannot act as a fire command to any pyrotechnic devices.

The EIUs and MECs remain off for the remainder of the mission. Prior to entry, the ATVCs are turned on again to reset the main engines in their stow position.



- 017 :A ATVC (four) - OFF
- :B EIU (three) - OFF
- :D MEC 1 - OFF, wait 2 sec, then
- 2 - OFF

Figure 3-13. Panel O17 reconfiguration in the Post Insertion Checklist

3.10 ENTRY

During entry, the MPS accomplishes three automatic functions: propellant line inerting, propellant line repressurization, and aft compartment and OMS pod purge.

At MM 303, the helium system is automatically configured in preparation for the purge and repressurization. The center, left, and right helium isolation A and B valves and the PNEU He ISOL valves are opened. The A regulators have hardwire C&W to alert a regulator fail high. The B regulators do not have hardwired C&W. Both A and B regulators have software C&W. At MM 303, the left IN and center and right OUT interconnect valves and the PNEU L ENG He XOVER valve are opened.

Also, at MM 303, the LH₂ manifold is inerted by opening the backup LH₂ dump valves.

At the V_{rel} = 5300 ft/sec (approximately 110,000 feet altitude), the LO₂ prevalues and the LH₂ backup dump valves are closed by the GPCs to terminate inerting. The LH₂ and LO₂ propellant lines are pressurized with helium to prevent atmospheric contamination during entry, eliminating the need for a lengthy cleanup prior to the next flight. The two OMS pods, the LH₂ ET umbilical cavity, and the aft compartments are purged with helium of any potentially explosive H₂ that may have accumulated during the flight. The purge continues through landing (See Figure 3-14).

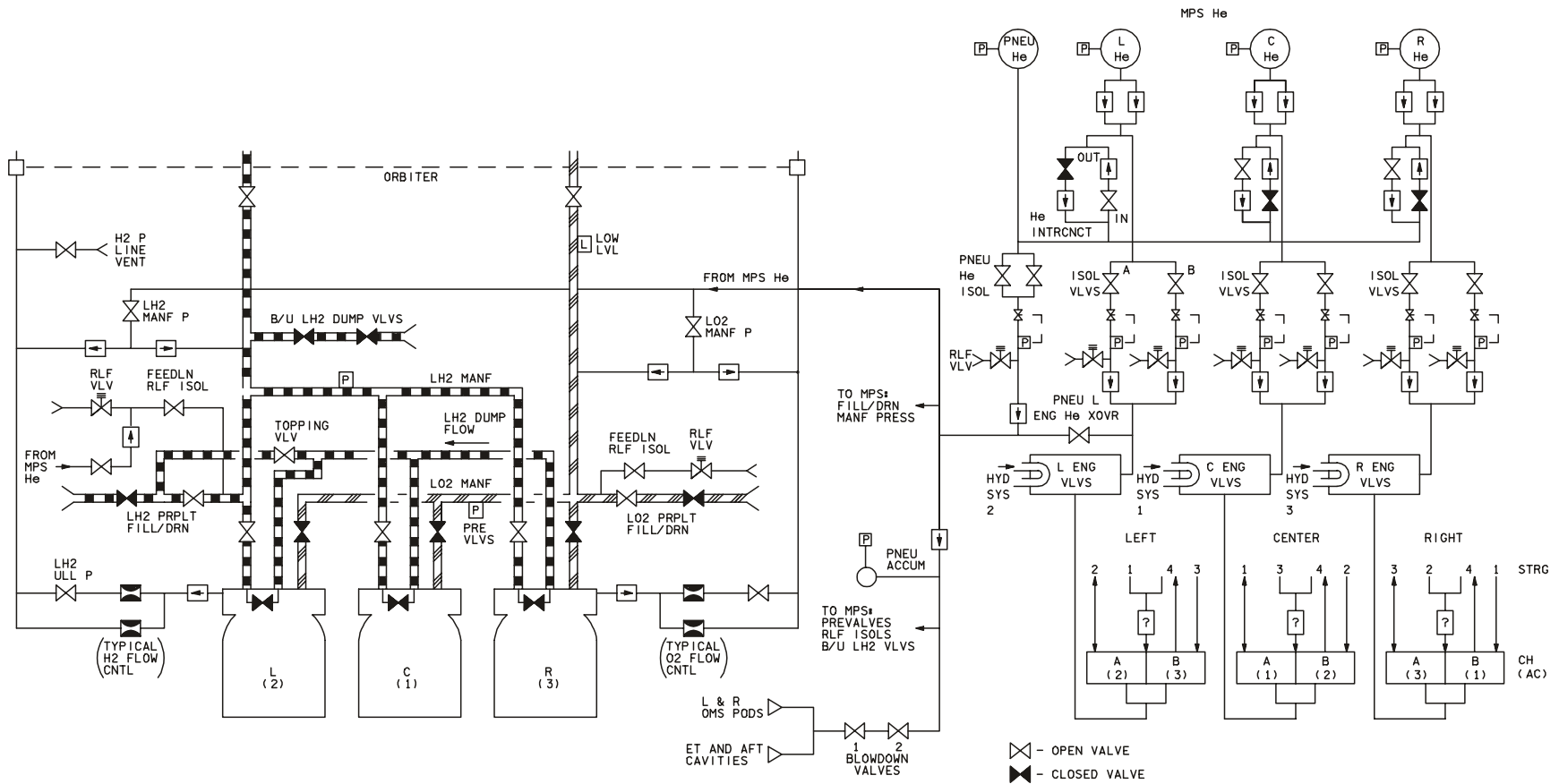


Figure 3-14. In MM 304, the helium system is automatically reconfigured for the entry purge and repressurization

TD345315A. SCH 3

Questions

After completing these questions, compare your answers with those on page B-2.

1. What MPS crew inputs are required during powered flight of a nominal ascent?
2. Why are SSMEs throttled in first stage and prior to MECO?
3. What are the LH₂ and LO₂ dump paths during the post-MECO MPS propellant dump?
4. Explain the importance of protecting the AC buses during ascent.
5. Why is it important to set the MECO confirmed flag?
6. Why is it important to wait for the MPS dump to complete before performing the MPS powerdown?
7. What is the purpose of the MPS helium system during ascent and entry?

4.0 SYSTEMS MALFUNCTIONS

4.1 OBJECTIVES

After completing this section, you should be able to

- List which MPS malfunctions cause the red and amber-colored engine status light on Panel F7 to illuminate
- Name the scenarios that require a stuck throttle to be shut down manually prior to MECO and describe why
- Describe how the MECO confirmed flag can be set manually if there are two data path failures at MECO
- Describe what happens to the redline limits on the remaining two engines if the limit shutdown switch is in AUTO and one engine fails, or one engine has a data path failure
- Name the best indicator of an MPS helium leak
- Describe the correct procedure required for an ET SEP INH message

4.2 GENERAL NOTES ON WORKING MPS MALFUNCTIONS

Cockpit indications can break

Multiple cockpit cues are used by crewmembers in working through MPS malfunctions. It is important to realize that just as the different orbiter systems can break, many of these cues can also “break.”

The primary MPS cockpit cues that are susceptible to “breaking” are:

1. Main Engine Status lights (Panel F7),
2. Pc meters (MEDS OMS/MPS display),
3. Integrated Display Processors (IDPs)

The Main Engine Status lights and Pc meters receive input via FF MDMs 1, 2, and 3 for the C, L, and R SSMEs respectively. If an FF (or the GPC driving that FF) is failed, then the Main Engine Status Light and Pc meter for that respective SSME will be failed static and they will not provide any cues for subsequent failures. If the FF or string is regained, then the main engine status light will begin working properly.

GPC failures are a likely contributor to SSME Command Path Failures and Data Path Failures. In these cases, the associated Main Engine Status Light and Pc meter will not provide proper failure cues.

IDPs are very useful in working malfunction cases because they provide the crew significant data. However the data displayed on the IDPs may be comm faulted by DPS failures. Also, IDPs are susceptible to failures (GPC failures, power failures, etc) and may not always be available to provide the information you desire.

Be aware that cockpit cues can “break,” and sometimes when they do they can be misleading. Avoid this type of confusion by using multiple cues whenever possible for any failure.

MPS MAL
FDF
procedures

The following are a few notes and guidelines on MPS Malfunction FDF procedures:

1. MPS Malfunction procedures rarely spend time “diagnosing” what went wrong. It is usually evident right away what the malfunction is, and the procedures are reaction steps to safely deal with the malfunction.
2. If there is no procedure that applies to your situation, no action is required.

Regarding the MPS CMD/HYD/ELEC table on the MPS Cue Card (AESP, p. MS A8-3, CC 10-2):

1. Consult each row of the table from the top down. Take action on the very first row that applies to your situation.
 2. Any time you complete an action for a malfunction, or a new malfunction occurs, re-consult each row of the table from the top down. Take action on the very first row that applies to your situation.
-

4.3 FLIGHT DATA FILE

The MPS procedures for powered flight are located on the following cue cards for the PLT (see Figure 4-1) or in the Ascent/Entry Systems pages for MS 2:

- “MPS 1” contains procedures for SSME and propellant malfunctions
- “MPS 2” is a schematic for DPS, AC, and hydraulic interfaces with the SSMEs
- “MPS Helium P” contains procedures for MPS and Pneumatic helium malfunctions
- “ET SEP” contains procedures for a dilemma with the ET-SEP switch (on Panel C3)

SSME FAIL/SHUTDOWN
AC BUS SNSR (three) - OFF
If 2 ENG remaining:
o MAIN ENGINE LIMIT
SHUT DN - BNA/AUTO
If 1 ENG remaining:
When MPS PRFLT = 2%
MAN THROT P₀ → 67%
At CO: Shut dn MN ENG (pb)

MPS DATA
VMOC, accel, He dP/dt,
MPS H2 OUT P,
MPS O2 OUT P
If SSME fail (MECO or 3 cues):
ATTN MN ENG SHUTDOWN pb - push
If 3 ENG remaining:
o MAIN ENGINE LIMIT
SHUT DN - BNA/AUTO
If no occur:
Assume MPS CMD
If mult (No MECO Confirm):
Post MECO:
MN ENG SHUTDOWN pb
(three) - push (stmc)

MPS LH2 ULL
o If 2(3) P₀ < 28.0 or > 34.0:
MPS LH2 ULL PRESS - OP
When all P₀ > 34.0:
MPS LH2 ULL PRESS - AUTO

MPS DUMP INHIBIT
Post MECO:
ATTN MPS ENG PWR (two) - OFF
LO2(H2) PRE VLV - CL

CMD/HYD/ELEC
If 2 HYD SYS failed:
MAIN ENGINE LIMIT SHUT DN - INH
[TRNG] Display - Cue SERC, ITEM 6
[EXED] If gimbal/eng fails

It	When	Shutdown:
2 Pos stuck > 85% & 3 ENG RTLS	MECO -3:00	1 att MN ENG CMD: (AC pb)** HYD: (pb)
2 HYD SYS failed & Nom/ATO/TAL/ 2 ENG RTLS	Nom/ATO, SE PRESS TAL: SE TAL 2 ENG RTLS 2 OUT RED	ENG/HYD SID (2/1 & 2/3) C (2/1 & 2/2) L (2/2 & 2/3) R ELEC: (pb)
He & SID reqd	Nom/ATO and 3 ENG: V > 23K 2 ENG: V > 24.5K TAL: V > 22.5K RTLS: a = -1	ATTN MN ENG (pb) ATTN MN ENG (AC pb)** If 2 CMD: repeat
MPS CMD(s)**		1 att MN ENG HYD: (pb) ELEC: (pb)
2 MPS HYD/ELEC & 3 ENG Nom/ATO/TAL		ATTN MN ENG (pb)
1 MPS HYD/ELEC & 3 ENG Nom/ATO	V > 23K	ATTN MN ENG (pb)

AESP-11a/AH

MPS He P (Pre MECO)

1. [G51]

If after MECO -30:
2. Shut dn MN ENG per MPS
CMD/HYD/ELEC >>>

If He REG P T or L:
3. AT He ISOL - CL

Otherwise:
4. AT He ISOL A - CL
If no decr in dP/dt:
5. AT He ISOL A - OP
B - CL
If no decr in dP/dt:
6. AT He ISOL B - OP

If any ENG failed:
7. Failed ENG He ICNCT -
OUT OP

If not isolatable:
8. Shut dn MN ENG per
MPS CMD/HYD/ELEC
If when TK P < 1150 or
REG P < 67%:
9. AT He ICNCT - IN OP

If isolated:
10. AT He ICNCT - IN OP
If TK P < 2200 @ MECO -30:
11. Shut dn MN ENG per
MPS CMD/HYD/ELEC

Post ET SEP:
12. He ICNCT(s) - GPC

AESP-15a/A/A

MPS PNEU TK (REG) P

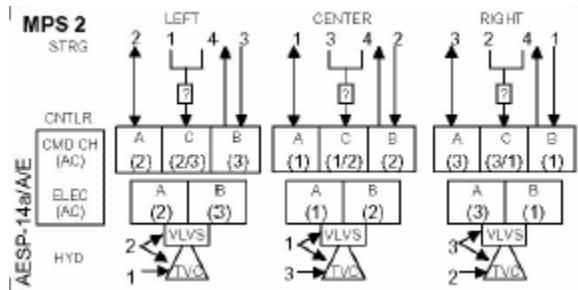
If after MECO -30:
At MECO -30:
1. LENG He XOVR - OP >>>

2. PNEU He ISOL - CL

If PNEU ACUM P decr:
At MECO -30:
3. PNEU He ISOL - OP,
Wait 5 sec, then
4. LENG He XOVR - OP >>>

If PNEU TK P decr:
5. PNEU He ISOL - OP

FIRE HOLE UNDER CARD



'ET SEP MAN' [G51] ET SEP

Post MECO:
1. ET SEP AUTO - ITEM 38 (BFS 28)
2. If ET SEP pb reqd:
ET SEP SEP - ITEM 39 (BFS 29)

AESP-13a/A/E

Figure 4-1. MPS malfunction cue cards

4.4 ASCENT MPS MALFUNCTIONS COVERED IN THE MPS MAL 1 SST

4.4.1 SSME Fail/Shut down

What causes an SSME Fail/Shutdown? An SSME Failure will occur when any one of the four redline parameters being monitored by the SSME controller (see Figure 4-2) violates its operating limits. Assuming that shutdown limits are enabled, the controller will shut down (or “fail”) the SSME. An SSME Shutdown may be initiated by the crew for certain malfunction cases.

Note: An SSME will also fail if all power to its SSME controller is lost. Initially this type of failure mode will appear as a Data Path Failure. Refer to Section 4.4.5, Data Path Failure, for identification cues and more information.

How to Identify The indications of an SSME Failure are:

1. Visual and audible Master Alarm
2. Red Main Engine Status light (Panel F7)
3. “SSME FAIL C (L, R)” fault message
4. Pc meter driven to zero (MEDS OMS/MPS display)
5. “MPS H₂ OUT P C (L, R)” fault message on BFS
6. “MPS O₂ OUT T C (L, R)” fault message on BFS
7. Loss of acceleration (in 2nd stage)

Note: It is likely that not all of these indications will annunciate onboard. Refer to Section 4.2, General Notes on Working MPS Malfunctions, for further information.

What Needs to Happen Following an SSME Fail or Shutdown, the primary concern is to protect the remaining SSMEs (and the remaining AC buses). To do so, the AC Bus Sensors (Panel R1) are taken to OFF and limits are reenabled. The AC Bus Sensor action is required due to possible single-point failures in the bus sensor monitor electronics that could inadvertently trip a good AC bus offline. Re-enabling the main engine limit shutdown software is required to regain redline shutdown protection for the remaining engines.

Following an SSME Fail or Shutdown, Mission Control Center (MCC) calls will advise the crew of any abort requirement.

The Procedure AESP, p. MS A8-2, CC 10-2:
SSME FAIL/SHUTDN (The MPS Cue Card)

This procedure directs the crew to take the three AC Bus Sensor switches on Panel R1 to OFF. If only one SSME has failed (two ENG remaining), the main engine limit shutdown software (see Figure 4-3) is reenabled by taking the Main Engine Limit switch to ENA then AUTO after checking with MCC. The additional procedure steps for two SSMEs failed (one ENG remaining) are not explained here. This information is covered in Section 4.5.3 of this workbook (Single SSME Completion).

**Bottom Line:
What You Need
to Know**

1. If an "SSME FAIL C (L, R)" fault message is annunciated, it is absolutely, positively, 100 percent certain that the SSME is down.
2. There is nothing you can do about a failed/shutdown SSME other than protect the remaining SSMEs. Therefore, AC Bus Sensors are taken to OFF and the main engine limit shutdown software is reenabled.
3. Expect subsequent MCC calls regarding abort modes.

References Flight Rule A5-2A, A5-103, A5-111
Booster Systems Console Handbook, SCP 2.1.7

4.4.2 SSME Redline Limits and the Limit Switch

**What are
Redlines?**

There are four main engine operating parameters (temperatures and pressures) that have been designated as critical to SSME operation (see Figure 4-2). These "redline" parameters are monitored by the SSME controller to assure that the SSME is performing within safe operating limits. The redline limits are set to guard against uncontained SSME damage.

The actual redline parameters and limits are defined in Flight Rule A5-2(E).

**Redline
Exceeded**

If a redline limit is exceeded, the SSME controller will want to shut down the SSME immediately. However, it is not always desirable to have an SSME shut down. Thus, the Main Engine Limit Shut Down switch is used to inform the controller whether or not we will allow the SSME to be shut down for exceeding a redline.

**Main Engine
Limit Shutdown
switch**

The MAIN ENGINE LIMIT SHUT DN switch (Panel C3, see Figure 4-3) determines whether or not the SSME controller will shut down the SSME that exceeds a redline limit.

This table describes the function of the three-position switch:

POSITION	FUNCTION
Enable	GPC sends commands to enable a redline shutdown to all three engines.
Auto	After the first SSME shutdown or data path failure, the GPCs send commands to inhibit a redline shutdown to the other two engines.
Inhibit	GPC sends commands to inhibit a redline shutdown to all three engines

**Red Main
Engine Status
Light**

A Main Engine Status Light (Panel F7) illuminated red means only one of two things:

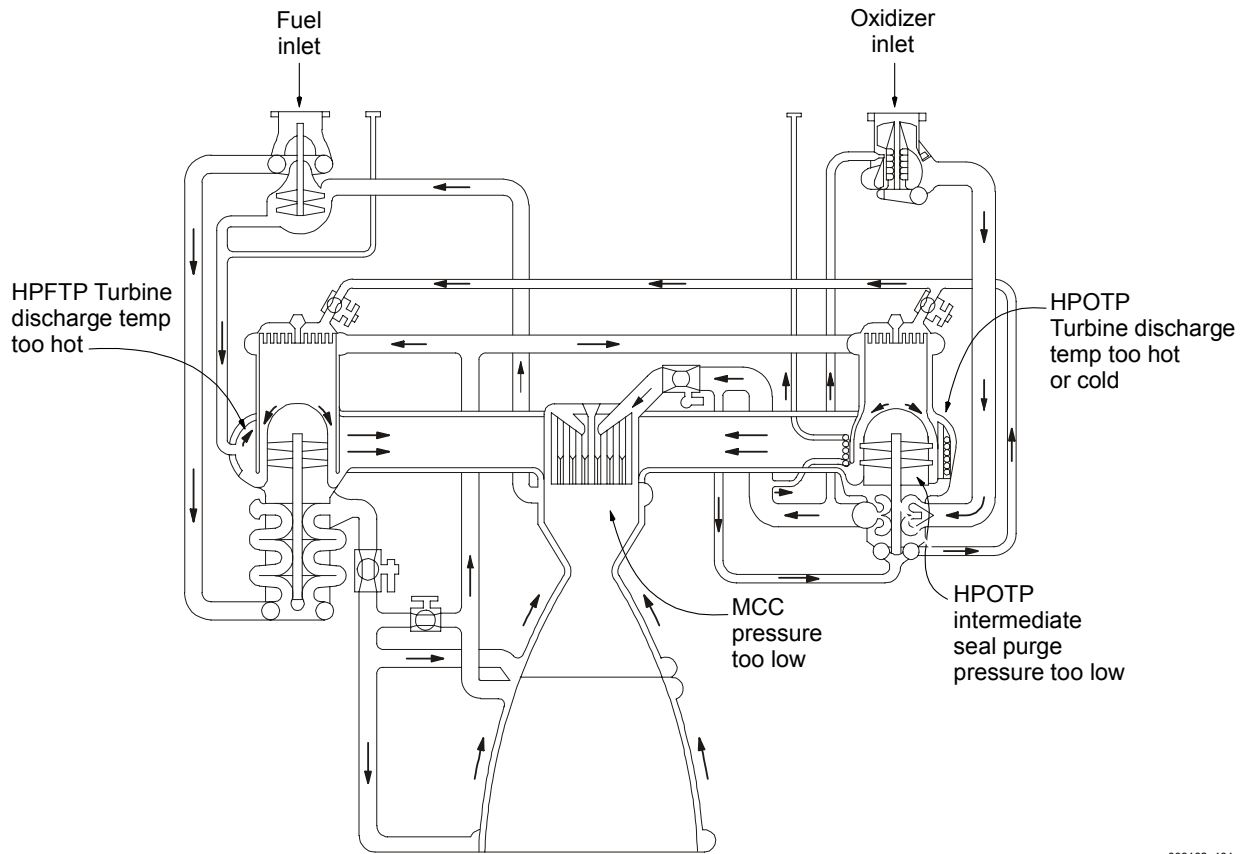
1. The SSME has failed.
2. The SSME is exceeding a redline but redline limits are inhibited.

**Bottom Line:
What You Need
to Know**

1. The Main Engine Limit switch determines whether or not an SSME will be shut down if redline limits are exceeded.
2. All Limit switch actions are on MCC call. There are only four exceptions to this rule (SSME fail with two engines remaining, Data Path Fail with three engines running, two hydraulic systems failed, or BFS engage and one SSME failed).

References

Flight Rule A5-2E, A5-103
Booster Systems Console Handbook, SCP 2.1.11



usa006162_101

Figure 4-2. The four main engine redline parameters

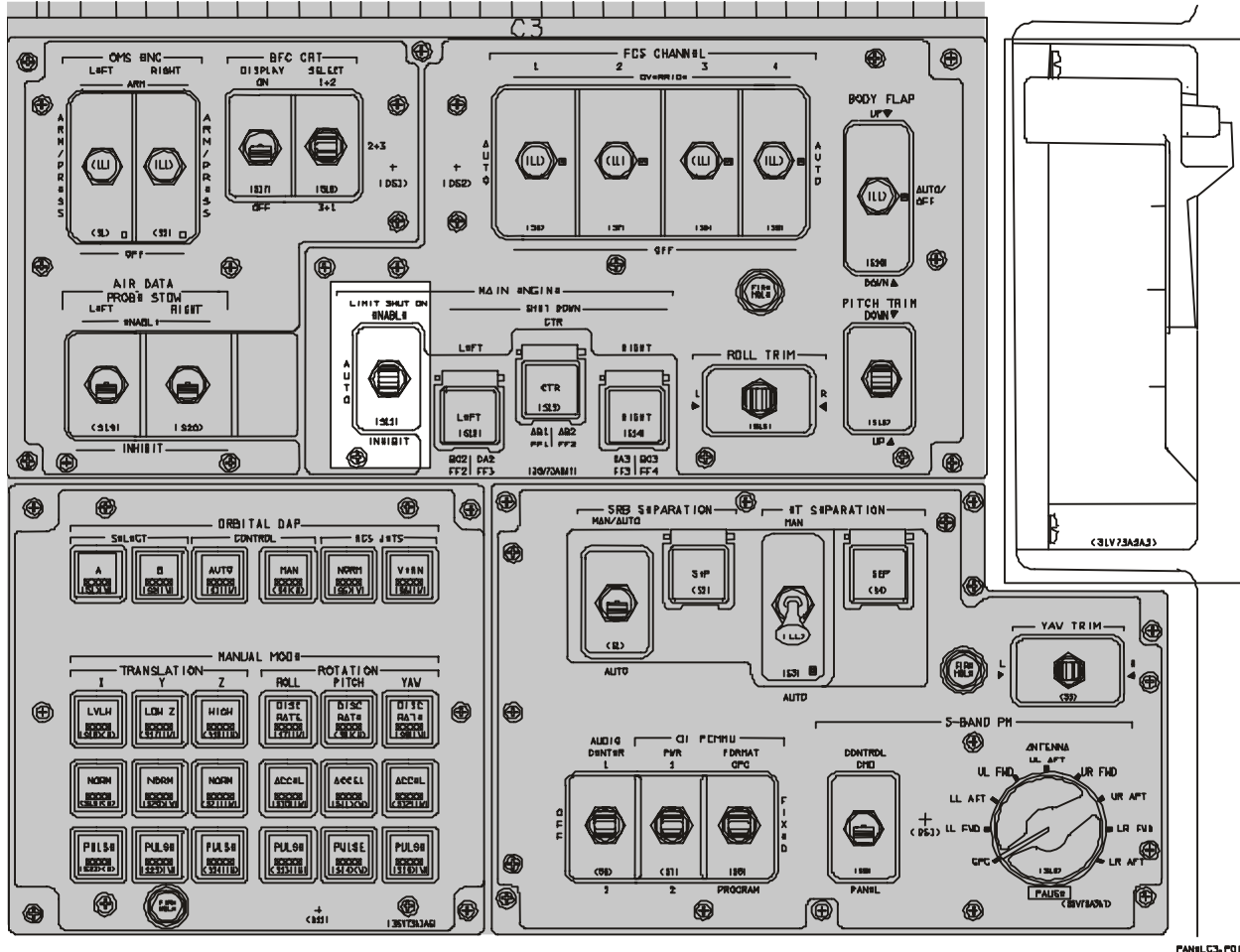


Figure 4-3. Main engine limit shutdown switch on Panel C3

SSME FAIL/SHUTDOWN
AC BUS SENS (three) - OFF
If 2 ENG remaining:
o MAIN ENGINE LIMIT SHUT ON - ENNAUTO
If 1 ENG remaining:
When MPS PRFLT = 2%:
MAN THROT Fc -> 67%
AC CO - Shut dn MN ENG (pb)

MPS DATA
√MCC, accel, Hd dVdt,
MPS H2 OUT P,
MPS O2 OUT T,
If SSME fail (MCC or 3 cues):
AT MN ENG SHUT DN pb - push
If 3 ENG remaining:
o MAIN ENGINE LIMIT SHUT ON - ENNAUTO
If no sstrm
Assume MPS CMD
If mult (No MEDO Contnm):
Post MEDO:
MN ENG SHUT DN pb (three) - push (sim)

MPS LH2 ULL
o If 2(3) Ps < 28.0 or > 34.0:
MPS LH2 ULL PRESS - OP
When all Ps > 34.0:
MPS LH2 ULL PRESS - AUTO

MPS DUMP INHIBIT
Post MEDO:
AT MPS ENG PWR (two) - OFF
LOQ(H2) PRE VLV - CL

CMD/HYD/ELEC
MPS 1
If 2 HYD SYS failed:
MAIN ENGINE LIMIT SHUT DN - INH
TRAC Display - Due SERC, ITEM 6
(EXEC if gimbalng eng fails)

It	When	Shut down:
2 Prc stuck > 85% & 3-ENG RTLS	MEDO - 2:00	1 off MN ENG CMD: (AC pb)** HYD: (pb)
2 HYD SYS failed & Norm/AUTO/ITAL/ 2-ENG RTLS	Norm/AUTO: SE PRESS TAL: SE TAL 2-ENG RTLS: 2 OUT RED	ENG/HYD: S/D (2) & (3) L (2) & (3) R ELEC: (pb)
Hy & S/D req'd	Norm/AUTO and: 3 ENG: V > 29K 2 ENG: V > 24.5K	AT MN ENG (pb) AT MN ENG (AC pb)** (If 2 CMD): reposit
MPS CMD(s)**	TAL: V > 22.5K RTLS: α = -1	1 AT MN ENG: HYD (pb) ELEC (pb)
2 MPS HYD/ELEC & 3-ENG Norm/AUTO	V > 23K	AT MN ENG (pb)

AESP-11a/W/H

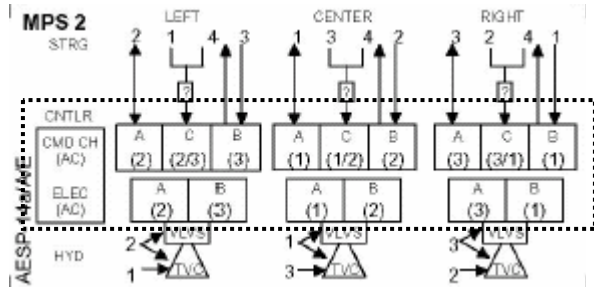


Figure 4-4. ENGINE FAIL cue card procedure and AC bus distribution to the main engine controllers

4.4.3 Hydraulic or Electric Lockup

What Causes a Hydraulic Lockup? An Hydraulic Lockup occurs when the SSME controller senses any one of the five hydraulically actuated engine valves outside the limits of where it is expected to be. This may occur due to a malfunction in a hydraulic system (such as an APU failure) or a failure of one of the engine valves.

Because the valve(s) position is now suspect, the controller will not issue any new throttling commands and will thus “lock” the SSME at its current throttle setting.

What Causes an Electric Lockup? An Electric Lockup occurs when the SSME controller loses either Pc or fuel flow rate data, both of which are required to set the proper mixture ratio. Pc and fuel flow rate data are internal to the SSME system.

Because the mixture ratio can no longer be controlled, the controller will not issue any new throttling commands and will thus “lock” the SSME at its current throttle setting.

How to Identify The indications of a Hydraulic or Electric Lockup are:

1. SM alert light and tone
2. Amber Main Engine Status light (Panel F7)
3. “MPS HYD C (L, R)” or “MPS ELEC C (L, R)” fault message
4. No change in Pc meter during throttling (MEDS OMS/MPS display)

Note: It is likely that not all of these indications will annunciate onboard. Refer to Section 4.2, General Notes on Working MPS Malfunctions, for further information.

What Needs to Happen A single Hydraulic or Electric Lockup at 104 percent power level is no impact at all **unless we are at risk of having a low-level cutoff**. However, in some cases MCC may not be able to accurately predict whether or not a low-level cutoff will occur, so action must be taken assuming one will.

Analysis indicates that for a safe shutdown to occur with three SSMEs and a low-level cutoff, all three SSMEs must shut down from 67 percent. (Based on NPSP requirements.) In this case, if one of the SSMEs cannot throttle to 67 percent, then it must be shut down before the low-level cutoff occurs.

The Procedure	<p>AESP, p. MS A8-3, CC 10-2 (The MPS Cue Card): MPS CMD/HYD/ELEC</p> <p>This procedure directs the crew to shut down the single Hydraulic or Electric Lockup shortly before MECO only if <u>all</u> of the following criteria are met:</p> <ol style="list-style-type: none">1. Nominal or ATO trajectory (Trajectories other than Nominal/ATO are not at risk of a low-level cutoff),2. Three SSMEs are running (If less than three SSMEs are running this procedure does not apply),
MPS 2 Cue Card	<p>AESP, p. CC 10-4, MS A8-3</p> <p>This cue card is for information only; part of it indicates how the hydraulic systems interface with the SSMEs for valve actuation and ATVC gimbaling.</p>
Bottom Line: What You Need to Know	<ol style="list-style-type: none">1. Shut down (pb only at $V_i = 23k$) the single Hydraulic or Electric Lockup if: the trajectory is Nominal/Abort To Orbit (ATO) and three SSMEs are running.2. If APU 1 (2, 3) fails, expect a Hydraulic Lockup on the C (L, R) SSME respectively within ~1 minute.
References	<p>Flight Rule A5-3A&B, A5-108 Booster Systems Console Handbook, SCP 2.1.5</p>
Expected Changes:	<p>OI-30 Flight Software changes the LO₂ Low-Level Cutoff Logic to set the three-engine timer to zero when an SSME throttle is stuck higher than 75 percent. (If three SSMEs are running, the GPCs normally delay the MECO command by .358 seconds after an LO₂ Low-level depletion has been detected.) As of July, 2004, the analysis which will eliminate the shutdown requirement for a single Hyd or ELEC Lockup is not complete. Upon successful completion of this analysis, the plan is to remove this shutdown requirement from the Flight Rules and onboard procedures.</p>

4.4.4 Command Path Failure

What Causes It? An SSME Command Path Failure occurs when at least two of the three command channels voted by the SSME controller are not identical.

SSME commands are susceptible to DPS failures (GPCs, strings, flight criticals), EIU failures, AC Bus failures, and SSME command channel failures in the controller.

The SSME controller will compare the commands within its three command channels. If at least two of the three commands are identical then the command is passed to the controller electronics for execution. But, if two of the three commands are not identical, a Command Path Failure is declared and the SSME controller informs the GPCs, which then annunciate the failure onboard to the crew.

How to Identify The indications of a Command Path Failure are:

1. SM alert light and tone,
2. Amber Main Engine Status light (Panel F7)
3. "MPS CMD C (L, R)" fault message
4. No change in Pc meter during throttling (MEDS OMS/MPS display)

Note: It is likely that not all of these indications will annunciate onboard. Refer to Section 4.2, General Notes on Working MPS Malfunctions, for further information.

What Needs to Happen

An SSME with a Command Path Failure will not accept ANY commands, including a command to shut down. Therefore the crew must intervene and shut down the SSME before MECO.

Using the Main Engine Shut Down pb (Panel C3) will not work because this tells the GPCs to send out a shutdown command, which the SSME controller will reject. The SSME must be shut down by taking the two associated Engine Power switches (commonly referred to as ACs) on Panel R2 to OFF. This action removes all power from the SSME controller and the SSME shuts down pneumatically.

When an SSME is shut down using the Engine Power switches, the GPCs do not know what happened. From the GPC perspective, data is no longer being sent from the SSME controller and therefore a Data Path Failure message is annunciated. To "inform" the GPCs that the SSME has been shut down, the associated Main Engine Shut Down pb must be pushed. Refer to Section 4.4.5, Data Path Failure, for additional details.

- The Procedure** AESP, p. MS A8-3, CC 10-2 (The MPS Cue Card):
MPS CMD/HYD/ELEC
- This procedure directs the crew to shut down the affected SSME by the AC/pb method at the appropriate boundary. (If two Command Path Failures exist the procedure is run again to shut down the second affected SSME.) Rationale for the various boundaries is explained in the Flight Rule referenced below.
- MPS 2 Cue Card** AESP, p. CC 10-4, MS A8-3
- Part of this cue card provides a diagram of the SSME command and data flows and shows how string and AC failures impact the command channel portion of the controller. This cue card is for information only and may be used to anticipate or determine what will cause a Command or Data Path Failure.
- Bottom Line:
What You Need
to Know**
1. Command Path Failures must ALWAYS be shut down manually pre-MECO.
 2. Command Path Failures must ALWAYS be shut down by the AC/pb method.
- References** Flight Rule A5-3C, A5-106A
Booster Systems Console Handbook, SCP 2.1.4

4.4.5 Data Path Failure

- What causes It?** An SSME Data Path Failure occurs when both data streams from an SSME controller do not reach the GPCs. This can occur from various combinations of failures in the SSME controller command channels, EIU, flight-critical MDMs, and/or the GPCs.
- For a Data Path Failure, all GPC insight into the status of that SSME is lost.
- How to Identify** The indications of a Data Path Failure are:
1. SM alert light and tone
 2. Amber Main Engine Status light (Panel F7)
 3. "MPS DATA C (L, R)" fault message
 4. Pc meter drops to zero (MEDS OMS/MPS display)
- Note: It is likely that not all of these indications will annunciate onboard. Refer to the Section 4.2, General Notes on Working MPS Malfunctions, for further information.

What Needs to Happen

For a Data Path Failure, the first step is to diagnose the health of the SSME.

The SSME will be in one of the following conditions:

1. The SSME has failed “behind” the Data Path Failure. This occurs when the SSME controller loses total power. The SSME shuts down pneumatically, but because the SSME controller is no longer communicating with the GPCs, a Data Path Failure is annunciated.
2. Data Path Fail only, no other hidden failures. The SSME will throttle and perform nominally.
3. A Command Path Failure is “hidden” behind the Data Path Failure. This situation is likely because Command Path Failures and Data Path Failures both involve failures in the communication flow between the GPCs and the SSME controllers.

Cues to Diagnose

The crew has three onboard cues that can be used to diagnose whether an SSME with a Data Path Failure is running:

1. The loss of acceleration due to an SSME failure can be identified in 2nd stage. In addition to the physical sensation, the ASCENT ADI cue card contains a graph of expected vehicle acceleration versus Propellant (PRPLT) remaining to determine the number of SSMEs running.
2. “MPS He P C (L, R)” fault message on BFS SYS SUMM 1 due to a shutdown POGO charge usage, followed by zero dP/dT (constant Tank P).
3. “MPS H₂ OUT P C (L, R)” and “MPS O₂ OUT T C (L, R)” fault messages and down arrows next to these two parameters on BFS SYS SUMM 1.

If the SSME Has Failed

If it is determined that the SSME has failed behind the Data Path Failure, the GPCs must be “informed.” This is accomplished by pushing the respective Main Engine Shut Down pb (Panel C3).

This action is VERY important to:

1. Inform Guidance & Flight Control about the SSME Fail.
2. Close the associated prevalves.

When the pb is pushed, the “SSME FAIL C (L, R)” fault message, and a visual and audible Master Alarm are annunciated.

This action is referred to by several of the following terms:

1. “Moding guidance,” although this is only part of what happens
2. “Setting the fail flag,” because the “SSME FAIL C (L, R)” fault message is annunciated
3. “Setting the safing flag,” because this is the term used in the flight software

If the SSME is Running

Notice that all of the cues determine only if the SSME is still running. If it is, the crew has no easy cue to determine whether the SSME has a “hidden” Command Path Failure. Therefore, the crew will assume a Command Path Failure unless told otherwise by MCC.

SSME Limits

When a Data Path Failure occurs, SSME redline limits are automatically inhibited on the other remaining SSMEs. This occurs in case the SSME has actually failed. Once the health of the SSME is known, and it is confirmed that all three engines are still running, limits will be reenabled. If previous SSME failures have occurred, MCC calls will advise the crew of any Main Engine Limit Shut Down switch (Panel C3) actions.

The Procedure AESP, p. MS A8-2, CC 10-2:
MPS DATA (The MPS Cue Card)

This procedure advises the crew to call MCC for insight, while also checking the on-board cues described above.

If MCC calls the SSME failed, or if at least three of the four cues show the SSME is failed, the crew is then directed to push the Main Engine Shut Down pb (Panel C3) for the reasons described above. Following this, the crew should work any required actions in the SSME FAIL/SHUTDN procedure.

If the SSME is still running, and all three engines remain, limits will be reenabled, with MCC concurrence. MCC will inform the crew if a Command Path Failure is “hidden” behind the Data Path Failure. (If no comm, assume that the Command Path Failure is there.) If it is determined that a Command Path Failure does exist, work the associated procedure for MPS Command (CMD).

The end of this procedure has steps to work in case of multiple Data Path Failures (i.e., more than one SSME). This case is covered in Section 4.5.4 of this workbook.

Late Data Path Failures A late Data Path Failure is one that occurs after approximately MECO-30 seconds. In this timeframe, the crew is essentially “no comm” because they do not have time to check with MCC to determine if a “hidden” Command Path Failure exists.

For these late cases the crew should act quickly to assume “no comm” and shut down the SSME per the Command Path Failure procedure.

MPS 2 Cue Card AESP, p. CC 10-4, MS A8-3

Part of this cue card provides a diagram of the SSME command and data flows and shows how string and AC failures impact the command channel portion of the controller. This cue card is for information only and may be used to anticipate or determine what will cause a Command or Data Path Failure.

**Bottom Line:
What You Need
to Know**

1. The number one step in a Data Path Fail situation is to determine if the SSME is running. Check with MCC and check on-board cues.
2. If the SSME has failed, push the pb and work the SSME FAIL/SHUTDN procedure.
3. If the SSME is running, expect an MCC call to re-enable limits and to verify Command Path status.

References Flight Rule A5-2C, A5-4, A5-103E, A5-104, A5-105
Booster Systems Console Handbook, SCP 2.1.3

4.4.6 Main Engine Helium Leak

What is It? A main engine He leak is any “hole” in the system from the tank to the SSME itself that causes higher than normal usage of He.

How to Identify The indications of a main engine He leak are:

1. SM alert light and tone
2. “MPS He P C (L, R)” fault message on BFS
3. $dP/dT > 20$ with an up arrow on BFS SYS SUMM 1

Note: dP/dT is the prime cue for verifying a He leak.

- **Normal helium usage: $dP/dT = 10$**
- **C&W annunciates: $dP/dT > 20$**

If a He regulator pressure (He REG P) goes out of limits:

1. Visual and audible Master Alarm
2. “MPS He P C (L, R)” fault message on BFS
3. An up or down arrow appears next to that applicable REG P on BFS SYS SUMM 1

When a He tank pressure (HE TK P) drops below 1150 psia:

1. Visual and audible Master Alarm
2. “MPS He P C (L, R)” fault message on BFS
3. A down arrow appears next to that applicable TK P on BFS SYS SUMM 1

Review Uses of He Recall from MPS OPS the two important uses of main engine He on ascent:

1. Purge the HPOTP Intermediate Seal. (Keep the SSME running.)
2. POGO Post-charge at MECO. (Shut the SSME down.)

Key Concepts

Now, to really understand the rationale for dealing with He leaks, YOU MUST UNDERSTAND THE FOLLOWING KEY CONCEPTS:

1. It takes significant He to safely shut down an SSME in zero-gravity (MECO). This He is required to support the POGO Post-charge.
2. It requires much less He to shut down an SSME under acceleration (while other SSMEs are still running). In this situation, very little He is required for the POGO Post-charge. Therefore, on an SSME with a He leak, we can avoid the large zero-gravity shutdown He requirements by shutting down the SSME shortly before MECO. This is called a “pre-MECO” shutdown. This allows us to devote the vast majority of the He supply to keeping the SSME running as long as possible.
3. The preferred method of shutting down an SSME with a He leak is to push the MAIN ENGINE SHUT DOWN pb (Panel C3). This method is called a “pb only” shutdown and the controller will shut down the SSME hydraulically. The “AC/pb” method is not preferred to shut down an SSME with an He leak because this creates a pneumatic shutdown, which requires additional main engine He for the shutdown.

What Needs to Happen

For the first step we want to see if we can seal off, or “isolate,” the leaking area. Each He system has two redundant legs. If the leak is in one of these legs (between the isolation valve and the check valve), the leak can be isolated by closing the He ISOLATION valve (Panel R2). In this case, He will continue to flow through the other leg, but will not flow through the leaking leg.

Thus, we will first determine if the leak is “isolatable” or “non-isolatable.” Once this is known, further action can be taken.

If the Leak is Isolatable

When a leak is isolated, all of the He that flows to the SSME must now pass through only one He leg. This only becomes an issue for a zero-gravity shutdown, because in order to push the same amount of He to the POGO Post-charge through only one leg requires an even higher He tank pressure.

If this “zero-gravity, single REG” He requirement can be met, the SSME will be allowed to run to MECO. If it cannot, the SSME will be shut down pre-MECO.

Additionally, we can “save” some of the main engine He for MECO by interconnecting to the pneumatic He system while the SSME is running.

**If the Leak is
Non-Isolatable**

First priority is to keep the SSME running as long as possible. If the main engine He tank pressure becomes so low that SSME failure will occur shortly, we can gain additional run time by interconnecting to the pneumatic He.

In non-isolatable He leak cases it is possible that:

1. The SSME has enough He remaining to meet zero-gravity shutdown He requirements, and the SSME will be allowed to run to MECO, or
2. The SSME cannot meet zero-gravity shutdown He requirements and is therefore shut down pre-MECO, or
3. The SSME depletes all main engine He and all pneumatic He, and fails before MECO due to exceeding the He redline limit.

The Procedure

AESP, p. MS A8-4, CC 10-7 (The MPS He Cue Card):
MPS He P (Pre MECO)

This procedure is divided into several "blocks":

First block: Check dP/dT to verify if the leak is real. If it is, continue.

Second block: Applies for "late leaks" within 1 minute of MECO. In this case there is not enough time to go through the entire evaluation process and it is most conservative to just shut down the SSME pre-MECO.

Third block: This is where it is determined if the leak is isolatable or non-isolatable. If one of the REG pressures is out of limits it is likely the leak is there, so close that associated He ISOLATION valve (Panel R2). If both REGs look okay, then we will try a shot in the dark and first look for the leak on the A side, then the B side. If at any time when an isolation valve is closed the dP/dT goes back to 10, the leak has been isolated to that leg.

Fourth block: If any SSME has failed, take its He INTERCONNECT switch (Panel R2) to OUT OP so that this He may be used in the other systems if required.

Fifth block (Non-isolatable He leaks): The SSME will be shut down (pb only) pre-MECO. This is the most conservative action to put on the cue card and only MCC can call for a different action. If (before the SSME is shut down) the tank pressure drops below 1150 psi, interconnect to pneumatic He to gain additional run time.

Sixth block (Isolated leaks): Interconnect to pneumatic He right away to save main engine He for "zero-gravity, single REG" He requirements. If the tank pressure is below 2200 one minute before MECO, the requirement cannot be met and therefore shut down the SSME (pb only) pre-MECO.

Seventh block: Post-MECO interconnects are returned to GPC such that they can be commanded to the proper configurations for the MPS Dump and Vacuum Inerting.

- Bottom Line:**
- What You Need to Know**
1. Check dP/dT (If dP/dT = 10, you do not have a leak).
 2. If the leak is isolated: Interconnect to pneumatic helium right away. If at one minute before MECO the tank pressure < 2200, shut down the SSME (pb only) pre-MECO.
 3. If the leak is non-isolatable: Interconnect to pneumatic He if the tank pressure drops below 1150. Shut down the SSME (pb only) pre-MECO if it makes it that far.
 4. MCC has more tools than you do; they may tell you to do something different.

References Flight Rule A5-10, A5-151A, A5-152A&B, A5-153
Booster Systems Console Handbook, SCP 2.2.8

4.4.7 Pneumatic Helium Leak

What is It? A pneumatic He leak is a “hole” anywhere in the pneumatic system that causes higher than normal usage of pneumatic He. (Recall that during nominal ascent pneumatic He is not being used and the tank pressure remains constant.)

How to Identify The indications of a pneumatic He leak are:

When the pneumatic tank pressure drops below 3800:

1. SM alert light and tone
2. “MPS PNEU TK” fault message on BFS SYS SUMM 1
3. A down arrow by MPS PNEU HE TK P on BFS SYS SUMM 1

While working the pneumatic leak procedure, the pneumatic Reg and/or Accumulator pressure may decrease:

If the pneumatic Reg (Accumulator) pressure drops below 700 psi:

1. SM alert light and tone
2. “MPS PNEU REG (ACUM)” fault message on BFS SYS SUMM 1
3. A down arrow by MPS PNEU HE REG (ACUM) P on BFS SYS SUMM 1

What Needs to Happen

Recall that on a nominal ascent, the first (and critical!) job of pneumatic He is to provide actuation pressure to close the prevalues at MECO. Prevalve closure must occur for the POGO Post-charge to work properly and safely. Recall also that the He contained in the accumulator is sufficient for this.

Any leak in the pneumatic He system will first appear as decreasing tank pressure because the system is totally open from top to bottom. We can close the pneumatic He isolation valve with the PNEUMATIC He ISOL switch (Panel R2) (effectively pinching the system between the tank and the regulator) and determine where the leak is:

- If tank pressure continues to drop, the leak is in the tank.
- If only Reg pressure continues to drop, the leak is between the isol valve and the first downstream check valve (the "Reg system").
- If accumulator pressure continues to drop, the leak is in the accumulator.

In the event of a pneumatic He leak, the primary focus is to ensure that the accumulator is fully "charged" (pressurized to 750 psi) at MECO.

If the pneumatic system is in question, the L ENG He XOVR switch (Panel R2) can be taken open to allow the Left main engine He to help pressurize the accumulator.

The Procedure

AESP, p. MS A8-4, CC 10-7 (The MPS He Cue Card):
MPS PNEU TK (REG) P

This procedure is divided into several "blocks":

First block: Applies for "late leaks" within 1 minute of MECO. In this case there is not enough time to go through the evaluation process and it is most conservative to just take the L ENG He XOVR switch (Panel R2) to open to help pressurize the accumulator for MECO.

Second block: Effectively pinches the system between the tank and the regulator so that we can determine where the leak is located.

Third block (Accumulator leak): At 30 seconds before MECO, reopen the PNEU He ISOL (Panel R2) to repressurize the accumulator with pneumatic He. Then, open the L ENG He XOVR (Panel R2) to allow the Left main engine helium to "help" pressurize the accumulator.

Fourth block (Tank leak): The leak is in the tank and it cannot be isolated. Reopen the PNEU He ISOL (Panel R2) to supply pressure to the accumulator for as long as the tank has pressure. The accumulator is good and is not leaking; therefore no further action is required.

Note that there are no actions to take after block 2 if the leak is in the Reg system.

**Bottom Line:
What You need
to Know**

1. The accumulator must be fully charged going in to MECO to support prevalve closure.
2. For accumulator leaks, the pneumatic He and the Left Engine He Xovr are used to pressurize the accumulator.

References

Flight Rule A5-11, A5-151B&C
Booster Systems Console Handbook, N/A

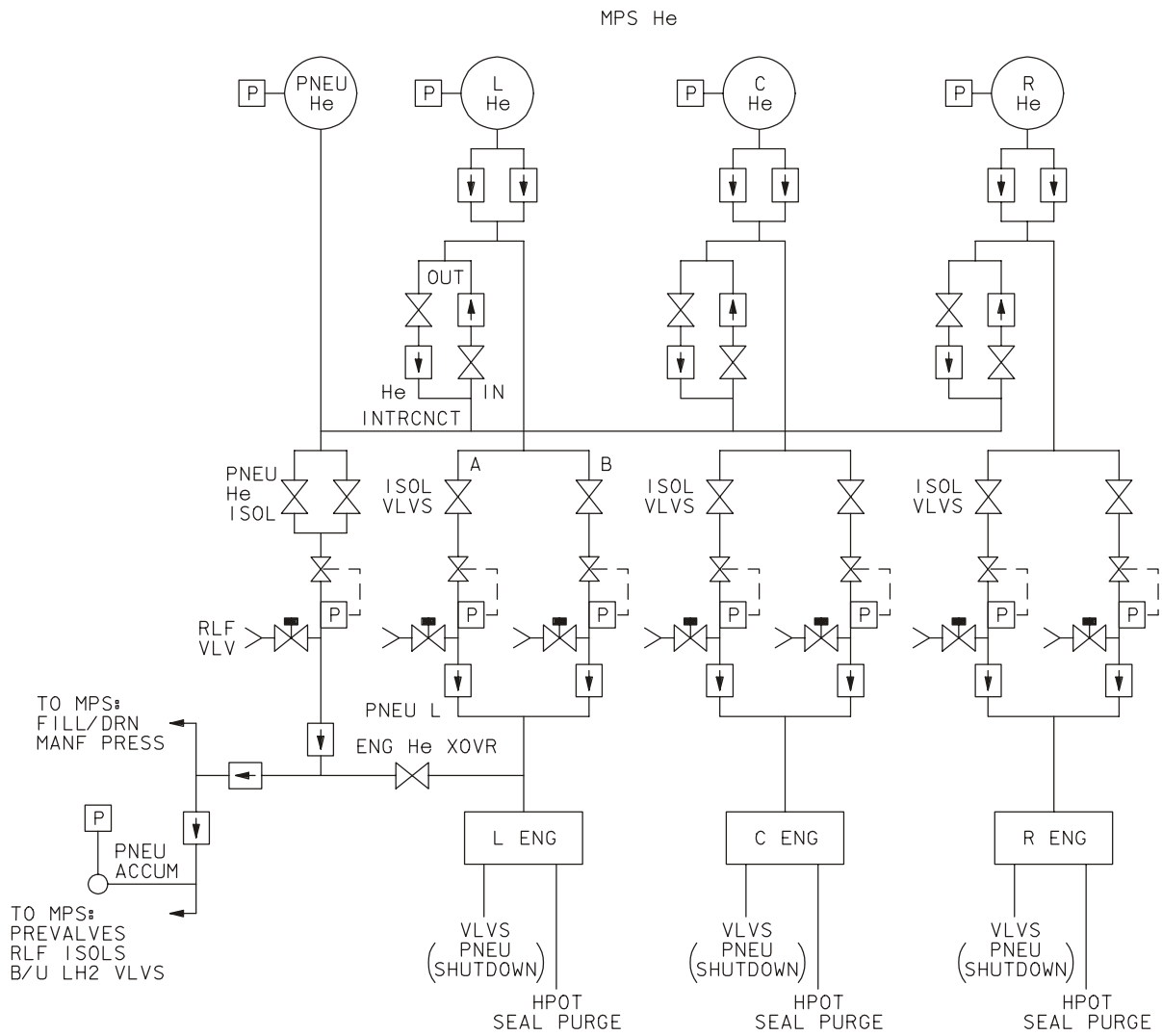


Figure 4-5. Each main engine has its own helium supply system with dual redundant regulator legs

MPS He P (Pre MECO)

1. $\sqrt{dP/dT}$

If after MECO -60:

- Shut dn MN ENG per MPS CMD/HYD/ELEC >>

If He REG P ↑ or ↓:

- Aff He ISOL - CL

Otherwise:

- Aff He ISOL A - CL

If no decr in dP/dT:

- Aff He ISOL A - OP
B - CL

If no decr in dP/dT:

- Aff He ISOL B - OP

If any ENG failed:

- Failed ENG He I'CNCT - OUT OP

If nonisolatable:

- Shut dn MN ENG per MPS CMD/HYD/ELEC

If/when TK P < 1150 or REG P < 879:

- Aff He I'CNCT - IN OP

If isolated:

- Aff He I'CNCT - IN OP

If TK P < 2200 @ MECO -60:

- Shut dn MN ENG per MPS CMD/HYD/ELEC

Post ET Sep:

- He I'CNCT(s) - GPC

Figure 4-6. Cue card procedure for an MPS helium leak (pre-MECO)

```

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
2 XXXX/XXX/018 GNC SYS SUMM 1 XX X DDD/HH:MM:SS
3 BFS DDD/HH:MM:SS
4
5 SURF POS MOM DPS 1 2 3 4
6 L OB XXX.XS XXS MDM FF S S S S
7 IB XXX.XS XXS FA S S S S
8 R IB XXX.XS XXS PL S S
9 OB XXX.XS XXS
10 AIL XXX.X
11 RUD XXX.X FCS CH 1 2 3 4
1 SPD BRK XXX.X S S S S
2 BDY FLP XXX.X
3
4 MPS L C R NAV 1 2 3 4
5 HE TK P XXXXS XXXXS XXXXS IMU S S S
6 REG P A XXXXS XXXXS XXXXS TAC S S S
7 B XXXXS XXXXS XXXXS ADTA S S S S
8 dP/dT XXXS XXXS XXXS
9
10 ULL P LH2 XX.XS XX.XS XX.XS MPS PNEU HE P
11 L02 XX.XS XX.XS XX.XS TK XXXXS
12 REG XXXXS
13 ACUM XXXXS
14 GH2 OUT P XXXXS XXXXS XXXXS MANF P LH2 XXXS
15 G02 OUT T XXXXS XXXXS XXXXS L02 XXXS
16 (xx)

```

td345b_084.tif

Figure 4-7. BFS SYS SUMM 1

MPS PNEU TK(REG) P	
If after MECO -80:	
At MECO -30:	
1.	L ENG He XOVR – OP >>
2.	PNEU He ISOL – CL
If PNEU ACUM P deor:	
At MECO -30:	
3.	PNEU He ISOL – OP,
Wait 5 sec, then:	
4.	L ENG He XOVR – OP >>
If PNEU TK P deor:	
5.	PNEU He ISOL – OP

Figure 4-8. Cue card procedure for MPS pneumatic helium

4.4.8 Low ET LH₂ Ullage Pressure

What is It?	ET LH ₂ ullage pressure below 28.0 psi, at which point C&W will annunciate.
How to Identify	The indications of low ET LH ₂ ullage pressure are: <ol style="list-style-type: none"> 1. SM alert light and tone 2. “MPS LH₂/O₂ ULL” fault message on BFS SYS SUMM one 3. A down arrow by LH₂ ULL P on BFS SYS SUMM one
What needs to Happen	<p>Adequate ET LH₂ ullage pressure is very important to meet LH₂ NPSP requirements for SSME operation. Exceptionally low ET LH₂ ullage pressure (and thus low LH₂ NPSP) could result in SSME failures due to redline limit violations.</p> <p>There are only three types of failures (or combinations of failures) that may lead to low LH₂ ullage pressure:</p> <ol style="list-style-type: none"> 1. Ullage gas leak (hole in the tank), 2. Failed closed Flow Control Valve (FCV), or 3. Failed high ullage pressure sensor. (This will close the respective FCV. Taking the LH₂ ULL PRESS switch (Panel R2) to OPEN will force the flow control valve open.) <p>The basic theory is that you can lose one FCV (to the closed state) and be OK. If you lose two FCVs you may have LH₂ ullage pressurization problems and actions will be required.</p>
The Procedure	<p>AESP, p. MS A8-2, CC 10-2 (The MPS Cue Card): MPS LH₂ ULL</p> <p>This procedure has a diamond next to it, which means to contact MCC for further insight, but if no comm then continue with the procedure.</p> <p>This procedure was written to address cases A, B, and C of the following:</p>

Failures causing low LH ₂ ullage pressure	Initial BFS SYS SUMM 1 ULL P LH ₂ readings	Result after taking the LH ₂ ULL PRESS switch to OP
A. Two FCV failed closed <u>or</u> ullage gas leak	Three actual low	No change for FCV case
B. Two ULL P sensors fail high	One actual low, Two false high	Tank will repress
C. One FCV failed closed and one ULL P sensor fail high	Two actual low, One false high	Tank will repress
*D. Two ULL P sensors fail low	One actual high, Two false low	Tank may overpress and vent overboard

*Case D will lead the crew to follow the cue card procedure when it is not optimal to do so and may cause the ET to vent GH₂ overboard through the relief valve. However, the risk of case D was deemed acceptable in order to allow the cue card to protect for case C.

**Bottom Line:
What you need
to know**

1. Check with MCC if you have comm before working the procedure.
2. When working an ullage press case, the LH₂ ULL PRESS switch will likely have to be cycled between OP and AUTO a couple times to maintain the proper ullage pressure.

References

Flight Rule A5-154
Booster Systems Console Handbook, SCP 2.2.5

4.4.9 ET SEP Inhibit

What is it?

An ET SEP INH will occur if either:

1. Vehicle rates exceed 0.7 deg/sec in any axis, or
2. GPCs cannot verify that one of the feedline disconnect valves has closed. (This may be due to either a failure of the valve, or a failure of the valve indications read by the GPCs.)

How to identify

The indications of an ET SEP Inhibit are:

1. SM alert light and tone
2. 'ET SEP INH' fault message
3. 'SEP INH' is displayed flashing and overbright on the ASCENT TRAJ displays

What needs to happen	<p>If the SEP INH is due to high rates:</p> <ol style="list-style-type: none"> 1. Null the rates and SEP nominally. <p>If the SEP INH is due to feedline disconnect valves:</p> <ol style="list-style-type: none"> 1. If a feedline disconnect valve has failed open, we do not want to SEP from the ET until the pressure in the ET and the MPS manifolds dissipates. Attempting a SEP while pressures are high risks the possibility of re-contact with the ET. (Due to propulsive venting through the failed open valve). 2. To dissipate the pressure in the system, the MPS Dump is started while still on the ET. By 6 minutes after MECO the MPS Dump is complete and the system has had adequate time to dissipate to an acceptable pressure for SEP. 3. ET SEP must occur before an OMS burn, and we do not want to SEP during the MPS Dump. Therefore, if an OMS 1 burn must be performed soon (before MECO + 6 minutes), the MPS Dump is delayed, we accept the risk that the pressures will not adequately dissipate, and perform the SEP at OMS 1 TIG - 1:30. After SEP the MPS Dump is performed.
If RTLS or TAL	<p><u>If RTLS:</u> There is no time to wait on the ET, therefore all SEP INHs (for both rates or feedline disconnects) are overridden and SEP occurs automatically.</p> <p><u>If TAL:</u> SEP INHs for feedline disconnect valves are overridden and SEP occurs automatically. SEP INHs for rates are <u>not</u> overridden and rates must be damped (either automatically or manually) before automatic SEP will occur.</p>
The procedure	<p>ASC C/L, p. FB 2-5, FB 2-8, 3-2:</p> <p>This procedure first directs the crew to check vehicle rates on the ADI. If rates are out of limits, null the rates and then SEP from the ET. If rates are not out of limits, it is assumed that the problem is a feedline disconnect valve failure. If possible, wait on the ET for 6 minutes while pressures dissipate and then SEP. If an OMS 1 burn must be performed soon, perform the SEP first (accepting the risks involved), then start the MPS Dump, and then perform the OMS 1 burn.</p>
Bottom Line: What you need to know	<ol style="list-style-type: none"> 1. For nominal / ATO trajectories, wait 6 minutes before ET SEP if you can. 2. If an OMS 1 burn is imminent, performing SEP before the burn is more critical than waiting for the pressures to dissipate before ET SEP. Additionally, we will not SEP during the OMS burn. 3. If RTLS: SEP INHs do not prevent automatic ET SEP. 4. If TAL: SEP INHs only prevent automatic ET SEP if rates are high.
References	<p>Flight Rule A5-202 Booster Systems Console Handbook, SCP 2.2.6</p>

4.5 ASCENT MPS MALFUNCTIONS COVERED IN THE MPS MAL 2 SST

4.5.1 Two Stuck Throttles

What is It? This case covers any of the following scenarios for three SSMEs running:

1. Two Hydraulic Lockups (not dual APU failures)
2. Two Electric Lockups
3. One Hydraulic Lockup and one Electric Lockup
4. RTLS and two stuck throttles of any type (Command Path Fail, Hydraulic Lockup, or Electric Lockup).

What Needs to Happen If two of three operating SSMEs have stuck throttles, the vehicle will be unable to throttle back sufficiently at 3G throttling. Therefore, manual shutdown of one SSME will be required to prevent violation of 3.5g acceleration limits.

If there is one Hydraulic Lockup and one Electric Lockup, priority is given to shut down the Hydraulic Lockup because, due to the nature of the failures, it is likely running worse than the SSME in Electric Lockup.

If the two lockups are both Hydraulic Lockups, or both Electric lockups; it technically does not matter which SSME is shut down. As a standard (and the procedure does not state this), the crew should use the chart on the same cue card for two HYD SYS failed to determine which SSME to shut down.

Note: The procedure for RTLS also covers for Command Path Failures. If one of the stuck throttles is a Command Path Failure, it is given 1st priority for shut down because Command Path Failures always, always, always require manual shutdown no matter what.

The Procedure: AESP, p. MS A8-3, CC 10-2 (The MPS Cue Card):
RTLS MPS CMD/HYD/ELEC

Two Pcs stuck > 85 percent
And 3-ENG RTLS

Due to the extremely dynamic nature of the RTLS trajectory, it is most preferable to not shut down any of the SSMEs. However, if two SSMEs are stuck above 85 percent, the vehicle will exceed 3.5G's before MECO and therefore one of the SSMEs must be shut down pre-MECO. Analysis indicates that the optimal shutdown point for the RTLS trajectory is at MECO-2:00.

Note: As soon as an SSME is shut down at MECO-2:00 on an RTLS, the vehicle pitches up dramatically, almost to vertical. This is a known and accepted vehicle response where no crew action is required.

If the stuck throttles are of different types, the procedure states to shut down one SSME based on the following priority: CMD Path Fail, HYD Lockup, ELEC Lockup.

The Procedure: AESP, p. MS A8-3, CC 10-2 (The MPS Cue Card):
Nom/ATO/TAL MPS CMD/HYD/ELEC

Two MPS HYD/ELEC
And 3-ENG Nom/ATO/TAL:

This procedure directs the crew to shut down one of the affected SSMEs shortly before MECO. The procedure states if there is one HYD Lockup and one ELEC Lockup, shut down the HYD Lockup.

If the two lockups are both Hydraulic Lockups or both Electric lockups, use the chart on the same cue card for two HYD SYS failed to determine which SSME to shut down (as described above in "What needs to happen").

**Additional
TAL/RTLS
Actions**

Note that if you abort RTLS or Transoceanic Abort Landing (TAL) with two stuck throttles, MCC will call for some additional actions regarding manual throttles per Flight Rule 8-61. The specific actions and the rationale will be covered at a later training date.

**Bottom Line:
What You Need
to Know**

1. One of the affected SSMEs must be shut down (pb only) pre-MECO to avoid exceeding 3.5 G-forces.
2. If the two lockups are of different types, shutdown priority is given on the cue card (top down). If the two lockups are of the same type, use the chart on the cue card for two HYD SYS failed to determine which SSME to shut down.

References

Flight Rule A5-109
Booster Systems Console Handbook, SCP 2.1.6

4.5.2 Two Hydraulic Systems Failed

What is It?	Any combination of failures that cause the loss of two Hydraulic Systems.
Review MPS Uses of Hyd Systems	<ol style="list-style-type: none"> 1. Each SSME uses one Hydraulic System to operate its five main valves. 2. Each SSME nominally uses two Hydraulic Systems for ATVC control, but can operate fully on only one system. <p>Therefore, what this really means is the following:</p> <ol style="list-style-type: none"> 1. Loss of one Hydraulic System will result in one SSME Hydraulic Lockup. 2. Loss of two Hydraulic Systems will result in two SSME Hydraulic Lockups <p>AND one of the Hydraulically Locked SSMEs will also be non-gimballing.</p>
What Needs to Happen	<p>Vehicle control is acceptable with three SSMEs running and one of them non-gimballing.</p> <p>The real concern in this case is if one of the gimballing (“good”) SSMEs were to fail. Simulator testing has verified that a loss of control is almost certain to occur, usually very quickly, when one of two running SSMEs is non-gimballing and SERC is not active. Even if SERC is invoked, a loss of vehicle control is still possible, especially during very dynamic vehicle maneuvers such as powered pitch around on an RTLS.</p> <p>With all this in mind, the first goal is to avoid an RTLS by keeping the gimballing SSMEs running. Thus, to prevent an inadvertent shut down of a good SSME, the Limit switch is taken to Inhibit. MCC will advise the crew when to re-enable limits.</p> <p>In the event that a gimballing SSME does fail, Single Engine Roll Control (SERC) must be invoked immediately to prevent a loss of control. To minimize crew response time to these events, SERC (ITEM 6 on the TRAJ) will be cued and executed immediately upon recognition of the failure of a gimballing SSME.</p>
Nominal/ATO TAL/2-ENG RTLS	The next goal is to shut down the non-gimballing SSME as soon as vehicle performance will safely allow. This shutdown point is single-engine capability, and is the point where the performance risk of a good SSME failing following shut down of the non-gimballing SSME is minimized (except for the two ENG RTLS case.)
3-ENG RTLS	The 3-ENG RTLS scenario is the exception where the non-gimballer is allowed to run to MECO as long there is no danger of exceeding 3.5 G’s (Reference Section 4.5.1, Two Stuck Throttles).

The procedure: AESP, p. MS A8-3, CC 10-2 (The MPS Cue Card):
1st Part MPS CMD/HYD/ELEC

The first part of this procedure directs to take the Main Engine Limit switch (Panel C3) to Inhibit and cue SERC. SERC will be executed only if a gimbaling SSME fails, or has failed. Expect subsequent MCC calls on when to re-enable limits.

The procedure: AESP, p. MS A8-3, CC 10-2 (The MPS Cue Card):
2nd Part MPS CMD/HYD/ELEC

Two HYD SYS Failed

And Nom/ATO/TAL/2-ENG RTLS

This part of this procedure will have the crew either:

- Nom/ATO: Shut down the non-gimbaling SSME at SE PRESS
- TAL: Shut down the non-gimbaling SSME at SE TAL
- 2-ENG RTLS: Shut down the non-gimbaling SSME at 2 OUT RED on the TRAJ

Review: AESP, p. CC 10-4, MS A8-3

MPS 2 Cue Card

This cue card is for information only; part of it indicates how the hydraulic systems interface with the SSMEs for valve actuation and ATVC gimbaling.

**Bottom Line:
What You Need
to Know**

1. Prevent inadvertent shut down of the gimbaling (“good”) SSMEs, therefore take the Main Engine Limit switch to Inhibit and cue SERC (ITEM 6). Expect subsequent MCC calls on when to re-enable limits.
2. If Nom / ATO, shut down the non-gimbaling SSME (pb only) at SE PRESS.
3. If TAL, shut down the non-gimbaling SSME (pb only) at SE TAL.
4. If 2-ENG RTLS, shut down the non-gimbaling SSME (pb only) at 2 OUT RED on the TRAJ.

References

Flight Rule A8-61 (Covers shutdown philosophy)
Flight Rule A5-103G (Covers SSME limits management)
Booster Systems Console Handbook, SCP 2.1.6

4.5.3 Single SSME Completion (Two SSMEs Failed/Shutdown)

What is It?	Anytime two SSMEs have failed/shut down and only one SSME is running to MECO is a SE Completion case.
What Needs to Happen	<p>For SE Completion cases it is very likely that a low-level cutoff will occur. Analysis indicates that for a safe shutdown to occur with one SSME running and a low-level cutoff, the SSME must be shut down from 91 percent or below.</p> <p>Thus, we need to make sure that this last running SSME is at 91 percent or below before the low-level cutoff occurs.</p>
What Auto Will Do	<p>Regardless of the number of SSMEs running, at a point approximately 6 seconds before TMECO, Auto will throttle back the SSMEs to protect for a possible low-level cutoff.</p> <p>If three SSMEs are running, Auto will throttle the SSMEs to 67 percent.</p> <p>If two or one SSMEs are running, Auto will throttle the SSME(s) to 91 percent.</p> <p>If a low-level cutoff occurs no earlier than approximately TMECO-6 seconds, Auto will completely take care of it.</p>
When the Crew Must Intervene	<p>The problem arises when the vehicle experiences a low-level cutoff before TMECO-6 seconds (before Auto performs the throttling). This will occur in cases where the vehicle has had major performance hits and is expecting a large underspeed. In these cases, the crew must throttle back the SSME before the low-level cutoff occurs.</p> <p>How do you know if you are in this case? Only MCC can tell you. To be conservative, crew procedures are written to assume that SE completion cases will <u>always</u> require crew intervention to throttle the SSME to 67 percent, unless you are RTLS or MCC calls otherwise.</p> <p>The crew cue at which to perform the manual throttling is two percent propellant remaining on the PASS ASCENT TRAJ display. Two percent propellant remaining will always occur before a low-level cutoff.</p>
RTLS	RTLS is the exception because RTLS guidance calculates the propellant remaining and will protect against low-level cutoffs. This is true for both nominal RTLS guidance and RTLS Contingency Abort guidance. Crew intervention is never required for an RTLS SE completion.

**Manual
Throttles**

Recall the technique for establishing manual throttles:

Manual throttling is initiated by depressing the takeover pb only on the pilot's Speedbrake Thrust Controller (SBTC) and releasing the takeover pb while matching the SBTC to within four percent of the last guidance throttle command. Subsequently, manual settings between 67 percent and 104 percent (109 percent if max throttle selected) can be commanded by moving the SBTC.

Though not required for SE Completion cases, recall the technique for returning to Auto throttling:

Manual throttling is terminated by depressing either Speedbrake/Throttle PBI located close to the CSS/AUTO PBI group on the eyebrow panel.

Manual MECO

If the crew has the throttles in manual control, the GPCs will command the SSMEs to shut down for a low-level cutoff, however they will not command a guidance-initiated MECO at TMECO. Therefore remember the phrase: **Manual throttles = Manual MECO!!!**

Although a manual MECO can be performed by simply pushing the SSME pb(s) for the SSME(s) that are still running at the cutoff point, the preferred method (though not always called for in the procedures) is to push **all three SSME pb's simo** at the cutoff point. This method protects for SSME pb failures (as discussed in this document for SSME pb's) and helps ensure that MECO Confirm is set (as discussed in this document for Multiple Data Path Failures).

The Procedure

The procedure for SE Completion is located in four places:

1. AESP, p. MS A8-2, CC 10-2 (The MPS Cue Card):
SSME FAIL/SHUTDN
2. ASC C/L, p. FB 2-5 (ASCENT PROCEDURES)
3. ASC C/L, p. FB 2-15 (TAL PLT)
4. ASC C/L, p. 2-30 (CONTINGENCY ABORT)

This procedure has the crew watch for two percent propellant remaining on the PASS ASCENT TRAJ. At this point, take manual throttles back to 67 percent. A low-level cutoff should occur before TMECO, but if somehow the SSME is still running, shut down the SSME (3 pb's) at the C/O mark on the BFS TRAJ.

- Bottom Line:
What You Need
to Know**
1. Whenever you are SE Completion, **always** perform the two percent manual throttling/manual MECO steps. There are only two exceptions to this rule:
 - (a) MCC tells you not to perform the steps, or
 - (b) Do not perform the steps for any RTLS SE completion.

References Flight Rule A5-112

4.5.4 Multiple SSME Data Path Failures

What is It? This case applies anytime two or more SSMEs experience Data Path Failures in powered flight. Note that any time an SSME is manually shut down by the AC/pb method, a Data Path Failure is created for that SSME.

This case is not related to, and should not be confused with, the DPS MULTI DATA PATH LOSS procedure.

What Needs to Happen Multiple SSME Data Path Failures “interfere” with the automatic setting of MECO Confirm. MECO Confirm must be set before the vehicle will proceed on to the ET SEP sequence.

If MECO Confirm does not get set automatically, it must be set manually. Recall that the crew indication that MECO Confirm has been set is the DAP lights illuminate on Panel C3.

**Auto Setting
MECO Confirm** There are two ways that the GPCs will set MECO Confirm automatically:

1. All three SSME Pc's < 30 percent, or
2. Two SSME Pc's < 30 percent and one Data Path Failure.

Recall that for a Data Path Failure, the GPCs cannot see the current Pc for that SSME.

**Manual Setting
MECO Confirm** There are three ways to manually set MECO Confirm:

1. Push all three SSME pb's
2. Enter an OPS 104 PRO
3. Fast SEP (ET SEP switch to MAN and push the SEP pb). This option is only available in:
 - OPS 102 (PASS or BFS)
 - OPS 601 (PASS only)
 - OPS 103 with two SSMEs failed (PASS only)

Note: If MECO Confirm is set while the SSMEs are running, all of the SSMEs will immediately be commanded to shut down.

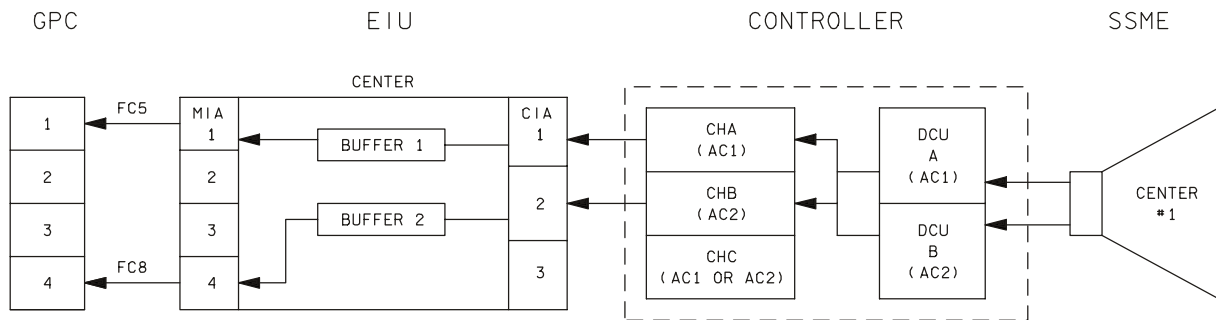
The Procedure AESP, p. MS A8-2, CC 10-2:
MPS DATA (The MPS Cue Card)

This procedure directs the crew to take action post-MECO. For multiple SSME Data Path Failures (No MECO Confirm), push all three SSME pb's simo.

RTLS RTLS is unique because the DAP lights never illuminate when MECO Confirm is set (because RTLS does not use trans DAP). The crew has no positive feedback that the vehicle has set MECO Confirm and entered the ET SEP sequence. This is important because a timely ET SEP is very critical on an RTLS. For these reasons, **it is advised for RTLS to always push all three SSME pb's simo, post-MECO.**

- Bottom Line:**
What You Need to Know
1. Whenever you have multiple SSME Data Path Failures you will not get Auto MECO Confirm, and you will not get ET SEP until you manually set MECO Confirm.
 2. Except on an RTLS, DAP lights are your prime cue for verifying MECO Confirm.
 3. For RTLS, it is a good habit to always push all three SSME pb's simo, post-MECO. (You will never hurt yourself and will occasionally save yourself.)

References Flight Rule A5-113
Booster Systems Console Handbook, SCP 2.1.3



TD3450402, ART. 3

Figure 4-9. Typical main engine data path flow (center engine); a data path failure results when both paths are interrupted

4.5.5 SSME Pushbuttons

When are SSME pb's Used SSME pb's are only used in off-nominal cases. The three functions of the SSME pb's are:

1. Manual shutdown of an SSME
2. Set the fail flag on an SSME that has failed/shut down behind a Data Path Fail. This action is important to:
 - Inform Guidance and Flight Control of the SSME Fail.
 - Close the associated prevalves (safing command).
3. Set MECO Confirm (for Multi-Data Path Fail cases).

SSME PB Mechanics

Each SSME pb has two contacts: each contact is powered by a CNTL bus and the status of that contact is carried to the GPCs by an FF MDM. The specific control buses and FF MDMs are printed on Panel C3 below each pb.

SSME pb's are susceptible to FF MDM failures, CNTL bus failures, and individual contacts failed open or closed.

pb Conditions

From the crew standpoint, an SSME pb will be in one of three conditions:

4. Fully Operational – There are no failures on the pb and it will perform any of the three functions listed above.
5. Commfaulted – One (not both) of the pb contacts has an associated FF MDM that is commfaulted and it will only perform functions 2 and 3 above, i.e., set the fail flag on an SSME with a Data Path Fail and set MECO Confirm. To shut down an SSME with a Commfaulted pb you must use the AC/pb shutdown method.
3. Broken – If the pb has any other failures (or combinations of failures) other than what is described for a Commfaulted pb, the pb is totally broken and useless for any of the three functions listed above.

**“Failed Open”
Contact**

One type of broken pb is caused by a contact “failed open.” The term “failed open” will be used to describe a contact that has either power failed due to a CNTL bus failure, or the contact is contaminated and will not make the electrical connection. In either case, when the pb is pushed the failed open contact will not indicate that the pb is being pushed.

If a pb is pushed with one good contact and the other contact failed open, the pb is in dilemma (GPCs cannot tell if it is really being pushed or not), and a “ME SHDN SW C (L, R)” fault message is generated.

Once C&W has annunciated for a pb, that pb can never be used to shut down an SSME. However, the pb can be used to set the fail flag on an SSME with a Data Path Fail or set MECO Confirm if the failed open contact is either:

1. Fixed (CNTL bus recovered or contamination clears), or
2. Commfaulted as described below.

**“Hiding” a
Failed Open
Contact**

If an SSME pb has one contact failed open it is useless. However, with a commfault on top of the failed open contact, the pb will work as a Commfaulted pb because the commfault “hides” the failed open contact.

MCC will call the crew if the following procedure is required:

1. Determine which FF MDM commfault will mask the contact failure,
2. Power cycle the respective FF MDM (OFF and back ON) to create a temporary commfault,
3. Push the respective SSME pb, and
4. Enter an I/O RESET EXEC to regain the FF MDM.

**SSME PB
Summary**

The following table summarizes failure impacts and functions of SSME pb’s:

Pushbutton Condition	Shut down SSME?	Set Fail Flag? (Data Path Fail)	Set MECO Confirm?
1. Fully Operational (No failures)	Yes	Yes	Yes
2. Commfaulted (One commfault on a good <u>or</u> failed open contact)	No	Yes	Yes
3. Broken (Any other failures)	No	No	No

The Procedure	<p>There is no <u>procedure</u> addressing SSME pb failures!</p> <p>The AESP for FF MDM and CNTL bus failures make <u>no</u> mention of SSME pb's.</p> <p>Your primary source of information is the printed CNTL bus and FF MDM information on Panel C3 below each pb.</p> <p>A secondary source of information is REF DATA:</p> <ul style="list-style-type: none"> - REF DATA for CNTL bus failures indicates the SSME pb's in the CRITICAL FUNCTIONS / EQUIPMENT LOST column. - REF DATA for FF MDM failures indicates that only the shutdown capability of the pb is lost (S/D INOP).
You Can Hurt Yourself - BAD!	<p>There are two scenarios in which an SSME pb becomes essentially an SSME detonator. Pushing the pb in these scenarios will close the SSME prevalves without the SSME being commanded to shut down (still running). This situation could rupture the propellant feedlines and result in uncontained SSME damage and loss of vehicle.</p> <ol style="list-style-type: none"> 1. An SSME is running with a Command and Data Path Failure. 2. An SSME is running with a Data Path Failure, and its pb is Commfaulted.
BFS	<p>Note: Everything discussed in this section applies to PASS only. The BFS pb logic is very simple: any failure at all on either contact totally fails out the pb for any use.</p>
Bottom Line: What You Need to Know	<ol style="list-style-type: none"> 1. SSME pb information is printed below the pb's on Panel C3. 2. An SSME pb must be Fully Operational (no failures) to shut down an SSME. If the pb has <u>any</u> failures, the AC/pb shutdown method must be used. 3. A Commfaulted pb will only work to set the fail flag or set MECO Confirm. 4. An SSME pb contact that is failed open can be "hidden" with an associated FF commfault.
References	<p>Flight Rule A5-105 Booster Systems Console Handbook, SCP 2.1.12</p>

4.5.6 Main Engine Helium Leak and ALC Bus Failed

What is It?	<p>ALC 1 (2, 3) failed impacts main engine He leak cases for the C (L, R) SSMEs respectively.</p> <p>Recall how the Systems buses are organized: MN X → APC (X+3) → ALC X</p>								
What Needs to Happen	<p>Loss of ALC 1 (2, 3) results in the A He Isolation valve failing closed for the C (L, R) SSME. Subsequent closure of the B He Isolation valve during the leak isolation procedure would starve the SSME of He and cause it to fail on the helium redline. This will likely result in an uncontained shutdown. The SSME helium redline was not designed to protect against the immediate starvation of helium.</p> <p>If ALC 1 (2, 3) is failed, He leak isolation must not be performed on the C (L, R) SSME.</p>								
The Procedure	<p>AESP, p. MS A5-5: MN A, MN B, MN C and SUBBUS [APC4 (5, 6) or ALC1 (2, 3)]</p> <p>These Systems procedures for loss of main or sub-bus power inform the crew to not isolate He leaks on the respective SSME.</p> <p>Also, REF DATA makes note for ALC failures that the respective “Me He Isol A” is lost.</p>								
Other Cues	<p>It just so happens that there is a good cue on BFS SYS SUMM 1 for the crew to use to indicate if ALC 1 (2, 3) is down. This is a great place for this cue because this is the display the crew will be using if there is a He leak!</p> <p>The signal conditioners for the C (L, R) ullage pressure transducers are powered by ALC 1 (2, 3). When the signal conditioners lose power, the signal conditioner output for ullage pressure is read by the GPCs as 12.0 psi (LH₂) and 0.0 psi (LO₂).</p> <p>Therefore, do not isolate a main engine He leak if the respective BFS SYS SUMM 1 ullage pressure looks like the following:</p> <table><tr><td>ULL P</td><td>LH₂</td><td>12.0</td><td>↓</td></tr><tr><td></td><td>LO₂</td><td>0.0</td><td></td></tr></table>	ULL P	LH ₂	12.0	↓		LO ₂	0.0	
ULL P	LH ₂	12.0	↓						
	LO ₂	0.0							
Bottom Line: What You Need to Know	<p>If the BFS SYS SUMM 1 ullage pressure appears as shown above, do not isolate main engine He leaks on that SSME. If isolation is attempted, the SSME will fail (probably uncontained) when the B He Isolation valve is closed.</p>								
References	<p>Flight Rule A5-151A Booster Systems Console Handbook, SCP 2.2.8</p>								

4.5.7 DPS and EPS Fail Impacts to SSME Powered Flight

Big Picture Certain DPS and EPS failures can have impacts to the SSMEs in powered flight. This section covers the following DPS and EPS issues:

1. Single GPC Fail to Synch
2. Multiple DPS failures
3. BFS Engage
4. SSME controller redundancy

GPC Fail to Synch

AESP, p. MS A3-2: PASS GPC FAIL

The single failure GPC 1 (2, 3) Fail to Synch (FTS) will cause the C (L, R) ME status light to falsely illuminate amber while the SSME is operating nominally. The following explains why:

1. An FTS GPC cannot see any data coming back from the other two SSMEs and declares Data Path Failures on them. The perceived Data Path Failures cause the FTS GPC to send commands to INH limits. These commands are not accepted by any SSME due to the two of three voting logic in the controllers. The FTS GPC 1 (2, 3) now declares a Command Path failure on its respective C (L, R) SSME, and illuminates the amber light. The FTS GPC will also annunciate the two Data Path Failures and one Command Path Failure on its respective IDP. (Note: The FTS GPC cannot illuminate the ME status light for the other two SSMEs because it does not control those lights.)
2. In reality, all three SSMEs are operating nominally and it is only the FTS GPC that perceives any problem. The only thing lost is a level of redundancy in the SSME command and data path flows for each SSME. It is optimal to take the FTS GPC to STBY, HALT as soon as possible to prevent any further erroneous command from being sent to the SSMEs and possibly interfering with the command voting logic.

What are the keys to remember?

1. A single GPC 1 (2, 3) FTS will cause the C (L, R) ME status light to falsely illuminate amber.
2. Do not believe the fault messages (Fault Summ) of an FTS GPC. Check the Fault Summ of a good GPC for the real story.
3. Per the procedure, if at all possible, take the FTS GPC to STBY, HALT.

Multiple DPS Failures

AESP, p. MS A3-2: PASS GPC FAIL

Two or more DPS failures (GPCs/Flight Criticals) in powered flight could possibly create Command Path Failure(s) on the SSME(s). This procedure contains a note to the crew that if two GPC/FA/FCS CHs ↓, check (or really be prepared for) MPS CMD Path Failures.

BFS Engage

AESP, p. MS A3-6: POST BFS ENGAGE

The BFS does not have single-engine roll capability; therefore if we are BFS engaged we must have at least two SSMEs running. When we are on the BFS with only two SSMEs running, SSME limits should be inhibited to prevent a redline shut down of either of the running SSMEs. This procedure will have the crew, post BFS engage and one SSME failed, to take the Limit switch (Panel C3) to Inhibit.

Note: There are only four places in the FDF that direct the crew to move the Main Engine Limit switch. All four have now been covered in this document.

SSME Controller Redundancy

AESP, (several of the EPS powered flight procedures)
AESP, p. CC 10-4, MS A8-3

AC bus failures will power fail electronics (and command channels) within the SSME controllers. Therefore, any single AC bus loss will fail the redundant electronics on two SSMEs, thus putting them one additional failure away from shut down (failing).

Whenever any SSME is one AC bus loss away from shutting down, AC Bus Sensors (Panel R1) should be taken to OFF. This action is required due to possible single-point failures in the bus sensor monitor electronics that could inadvertently turn off a remaining AC power bus.

Some electronics failures in the controller that put an SSME one AC bus loss away from shutting down are transparent to the crew. In these cases, MCC will call the crew that they have either “lost electronics A(B)” or lost “controller A(B)”, and “take the AC Bus Sensors to OFF.”

**Bottom Line:
What You Need
to Know**

1. FTS GPCs will cause erroneous indications for the SSMEs.
2. There are a few SSME-related steps for powered flight in the AESP, DPS and EPS procedures.
3. MCC may call to take AC Bus Sensors to OFF for controller and electronics failures which are transparent to the crew.

References

Flight Rule A5-111 (Controller Redundancy)
Booster Systems Console Handbook, SCP 2.1.2 (Controller Redundancy)

4.5.8 MPS Helium Leak (Post ET SEP)

What is It?	Any “hole” in the MPS He system that is identified after ET SEP.
How to Identify	<p>dP/dT is not calculated post-MECO, so the first crew C&W indication of a post-MECO He leak is when the tank pressure (He TK P) drops below 1150 psia:</p> <ol style="list-style-type: none">1. Visual and audible Master Alarm2. “MPS HE P C (L, R)” fault message on BFS3. A down arrow appears next to that applicable TK P on BFS SYS SUMM 14. MPS light on the Panel F7 C&W matrix illuminates
What Needs to Happen	<p>MPS He leaks post-MECO do not pose a threat to vehicle safety. Our main goal is to isolate the leak so that we save enough He for the nominal entry He purge and manifold re-pressurization.</p> <p>MPS He leak isolation post-MECO is complicated because shortly after MECO the He systems are interconnected together. (A leak in either the Pneumatic or Left He system can also leak out the Center and Right He).</p> <p>For post-MECO He leaks, it is best to check with MCC for any actions. If that is not possible, the following procedure may isolate the leak.</p>
The Procedure	<p>APCL, p. 9-3: MPS He P (Post ET Sep)</p> <p>The procedure has the crew close the He Isolation valves on the tank that has dropped below 1150 psi. If a second tank also drops below 1150, the leak could be in the pneumatic system and therefore the Pneumatic He Isolation valves should be closed.</p> <p>The two steps in this procedure have diamonds next to them, which mean to contact MCC for further insight, but if no comm then continue with the procedure.</p>
Bottom Line: What You Need to Know	<p>The best action for post-MECO MPS He leaks is to check with MCC. If that is not possible, work the procedure.</p>
References	Flight Rule A5-208

4.5.9 ET SEP MAN/AUTO

What is It? The ET SEP switch is a three contact switch. It is susceptible to Flight Forward (FF) MDM failures, DSC OF failures, and individual contacts failed open or closed.

For certain combinations of failures, switch Redundancy Management (RM) cannot determine the physical position of the switch. In these cases, switch RM will no longer look at the physical position of the switch, will declare a default position in the software, and will issue an applicable fault message.

What Needs to Happen in OPS 1

For ET SEP switch failures in OPS 1:

1. The switch defaults to the MAN position
2. An "ET SEP MAN" fault message and SM Alert are annunciated

Post-MECO, the crew will make keypad inputs to set the ET SEP switch back to the AUTO position so that ET SEP will occur.

What Needs to Happen on a TAL Abort or OPS 6

For ET SEP switch failures on a TAL Abort or OPS 6 (RTL5):

1. The switch defaults to the AUTO position,
2. An "ET SEP AUTO" fault message and SM Alert are annunciated.

Action is not required for an ET SEP AUTO. ET SEP will occur nominally.

Note: If the ET SEP switch failure occurs before TAL or RTL5 is declared, the software will default to MAN and then will default to AUTO (and annunciate to the crew) when the TAL or RTL5 is declared.

Why the Difference?

The answer is easy: the ET SEP window is very small (no time to mess around); therefore, we want the ET SEP switch in AUTO for a nominal SEP.

In OPS 1, we want to have the capability to wait on ET SEP until we can assure the vehicle is in a safe SEP configuration. (For example, forward and aft RCS leak procedures call for the ET SEP switch in the MAN position until the RCS system is configured for ET SEP.) Thus, for OPS 1 it is most conservative for the ET SEP switch to default to the MAN position.

The Procedure AESP, p. MS A8-2, CC 10-8:
ET SEP MAN

Post-MECO, this procedure has the crew set the ET SEP switch back to AUTO in the software (SPEC 51: ITEM 38 EXEC). This enables the ET SEP sequence to begin.

If a subsequent ET SEP INH annunciates, work the ET SEP INH procedure as normal and when it calls to push the ET SEP pb, enter a SPEC 51:
ITEM 39 EXEC.

**Bottom Line:
What You Need
to Know**

1. ET SEP MAN requires no action until post-MECO. When you are ready for ET SEP, work the procedure.
2. SPEC 51: ITEM 38 (BFS 28) sets the switch to AUTO in the software. ITEM 39 (BFS 29) is like pushing the SEP pb in the software.
3. For TAL or RTLS, "ET SEP AUTO" requires no action.

References Booster Systems Console Handbook, SCP 2.2.6

4.5.10 MPS Dump Inhibit

What is It?	MCC will call for an MPS DUMP INHIBIT anytime an SSME is failed/shut down pre-MECO and the Booster flight controller determines that there may be damage to the propellant lines.
What Needs to Happen	<p>This procedure will inhibit dumping MPS propellant through the damaged propellant lines. This will prevent excessive leakage of propellant into the aft compartment, thereby minimizing a potentially hazardous condition.</p> <p>Before the MPS Dump starts, we want to isolate the damaged area by closing the five main engine valves and the SSME bleed valves (accomplished by powering off the SSME controller). Then we will close the prevalues on either of the LO₂ side, the LH₂ side, or both per MCC call. (This minimizes the dump and vacuum inerting impacts to only the side that was determined to be damaged.)</p>
The Procedure	<p>AESP, p. MS A8-2, CC 10-2: MPS DUMP INHIBIT</p> <p>This procedure powers off the affected SSME controller, and then closes the affected prevalues (LO₂, LH₂, or both).</p>
Bottom Line: What You Need to Know	<ol style="list-style-type: none">1. This procedure is only initiated by MCC call.2. This procedure should be performed on either of the LH₂, the LO₂, or both per MCC call. If MCC does not specify, ask.3. For this procedure to be effective, it must be completed before MPS Dump start: Nom/ATO: MECO + 2:02 TAL: MM 304 RTLS: MECO + 0:25
References	<p>Flight Rule A5-201 Booster Systems Console Handbook, SCP 2.2.10</p>

4.5.11 Single DPS or EPS Fail: Impacts to MPS Dump/Vacuum Inerting

Big Picture	<p>DPS failures can break the GPCs capability to command certain MPS valves. If these valves are needed for the MPS dump or vacuum inerting, crew switch throws will be required to move the valves.</p> <p>EPS failures can break MPS valves. No command (either from GPCs or crew switch throw) will move them. In these cases, the only alternative is to move other valves that are not broken.</p> <p><i>A general note:</i> DPS failures break GPC commanding of a valve, CNTL bus failures break crew switches, and Electrical bus failures break the valves.</p>
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- Single Main Bus Fail** MN A or MN B (or their subbuses) failed in the post-MECO timeframe has two impacts to the MPS dump/vacuum inerting:
- The automatic LH₂ dump will be unable to move all necessary valves and therefore the dump will be incomplete. (Crew switch throws will not move the broken valves either.) All we can do to help the dump is to open other valves that are not broken. Thus, the crew will open the B/U Dump valves post-MECO. MCC will call to close the B/U Dump valves after the dump is complete to configure for the auto vacuum inertings.
- Single GPC or FA Fail** A GPC or FA failed in the post-MECO timeframe has two impacts to the MPS dump/vacuum inerting:
- The automatic LH₂ dump will be unable to command all necessary valves and therefore the dump will be incomplete. To help the dump, the crew will open the B/U Dump valves post-MECO. The crew will close the B/U Dump valves after the dump is complete to configure for the auto vacuum inertings.
- The Procedures** APCL, pp. 5-25 – 5-30:
BUS LOSS ACTION for MN A: DA1, APC4, and ALC1
 MN B: DA2, APC5, and ALC2
- These procedures all direct the crew to open the B/U LH₂ valves (Panel R2).
- APCL, p. 3-5: PASS GPC (1st FAIL)
 p. 3-6: FA MDM I/O ERROR
- Contained in these procedures are steps to open the B/U LH₂ valves. (Note: The B/U LH₂ valve steps have a diamond next to them, which means to contact MCC for further insight, but if no comm then continue with the procedure.)
- APCL, p. 9-3: MPS VACUUM INERT
- This procedure is worked only upon direction from MCC. Twenty minutes after dump stop, this procedure has the crew open the MPS fill/drain valves to inert the system. The procedure is split between Activation and Termination, and further split between LO₂ and LH₂. This allows MCC to easily call to work only the parts of the inerting procedure that are required.
- Also, at the top of the procedure there is a check of the LO₂ manifold pressure. If LO₂ MANF P > 30 psia, a rolling moment will result from opening the LO₂ fill/drains. In this case, the crew should check with MCC for further actions.

Bottom Line: There are MPS-related steps within several of the EPS and DPS procedures. Follow the procedures thoroughly and in a timely manner.
What You Need to Know

References Flight Rule A5-205B (covers DPS impacts to LH₂ dump)
Flight Rule A5-206 (covers manual vacuum inerting)
Booster Systems Console Handbook, SCP 2.2.12

4.5.12 DPS Multi-Data Path Loss Impacts to MPS

Big Picture Dual GPC/FAs failed severely impact the automatic capability to relieve pressure in the prop manifolds (particularly LH₂) immediately post-MECO and during the dump. GPC commanding of many valves is lost but the crew switches still work to move critical MPS valves and relieve the manifold pressure. Dual GPC/FA failures can also mask GPC insight into the feedline disconnect valves. If the GPCs cannot determine proper valve closure, an ET SEP INH will result.

The Procedure

AESP, p. A3-5:

MULT DATA PATH LOSS (Non-Recov)

1. Expect "SEP INH" (FDLN Fail) for GPC/FA combos 2&3, 2&4. For these combos, the feedline disconnect valves may have closed properly, but the failures mask GPC insight of the valve positions. The GPCs assume the valve(s) are failed open and will annunciate an ET SEP INH. The crew should then work the ET SEP INH procedure as normal, assuming a failed feedline disconnect valve.
2. MPS FDLN RLF ISOL (two) – OP: **This is an extremely critical MPS procedure!** This action provides a relief path for the rising LH₂ manifold pressure post-MECO and should be worked before MECO + 25 sec.
In some of the cases, the dual GPC/FA failures prevent the LH₂ relief isolation valve as well as the LH₂ backup dump valves and LH₂ fill/drain valves from opening automatically after MECO. Flight data indicates that the LH₂ manifold pressure will rise to the manifold burst pressure within 75 seconds. This excessive pressure could rupture the feedline manifold and result in damage to the aft compartment and possible loss of vehicle.
3. MPS PREVLVs (six) – OP: This action ensures that all of the MPS prevalues are open at dump start. This action is not critical to vehicle safety but is required for proper MPS dump and vacuum inerting. For this procedure to be effective, **it must be completed before MPS Dump start:**

Nom/ATO:	MECO + 2:02,
TAL:	MM 304,
RTLS:	MECO + 0:25.

The most restrictive time reference is MECO + 0:25, so this is used as the standard for all of the time critical steps in this procedure.
4. RTLS/TAL: MPS LH₂ F/D INBD, OUTBD – OP: Dual GPC/FA failures result in degraded automatic LH₂ dumps for RTLS and TAL. These post-MECO switch throws ensure an LH₂ dump path and thus help preclude residuals in the LH₂ system, which can constitute a ground hazard and interfere with normal post-landing convoy operations.

Note: For some combos and when crew workload permits, MCC will call late on entry to close the Fill/Drain valves.

**Bottom Line:
What You Need
to Know**

The MPS-related steps within the DPS MULT DATA PATH LOSS procedure are usually time critical and are sometimes safety critical. Work this procedure in a timely manner (within 25 seconds).

References Flight Rule A5-203C (covers manf overpress for multi-DPS failures)
 Flight Rule A5-210 (covers entry dump fail/actions for DPS failures)
 Booster Systems Console Handbook, SCP 2.2.6 (ET SEP INH)
 Booster Systems Console Handbook, SCP 2.2.11 (FdIn Rlf Isol)

4.5.13 High LH₂/L₂O Manifold Pressure (Post-MECO)

What is It? In the post-MECO timeframe, manifold pressure is considered high if it exceeds the C&W limits of:

LH₂ - 65 psi, or
 LO₂ - 249 psi.

How to Identify The indications of high LH₂ or LO₂ manifold pressure are:
 If in OPS 1:

1. Visual and audible Master Alarm
2. "MPS LH₂/O₂ MANF" fault message on BFS
3. An up arrow appears next to the applicable MANF P on BFS SYS SUMM 1

If in OPS 2:

1. Visual and audible Master Alarm
2. MPS light on the Panel F7 C&W matrix illuminates
3. High manifold pressure reading on the MEDS OMS/MPS display

What Needs to Happen Manifold pressure that exceeds C&W limits needs to be relieved as soon as possible.

While in OPS 1 (pre-MPS Dump): The easiest way to relieve manifold pressure is to start the MPS Dump right away. The MPS Dump will start automatically if LH₂ manifold pressure indicates between 60 and 90 psi (and the Dump Sequence switch is in GPC). Therefore the crew will probably never get a C&W message because Auto will correct the problem before C&W annunciates.

While in OPS 2: The easiest way to relieve manifold pressure is to perform another vacuum inerting.

The Procedure ORB OPS, p. 8-2:
 MPS VACUUM INERT

This procedure has the crew perform another vacuum inerting to relieve high pressure in the MPS LH₂ manifold. The only way the crew will ever work this procedure is if MCC calls for it.

OPCL, p. 9-2:
 MPS C/W

The crew will work this procedure if they get an MPS C&W alert while in OPS 2. This procedure is another vacuum inerting to relieve the high pressure in the MPS manifold(s).

**Bottom Line:
What You Need
to Know**

1. High MPS manifold pressure is only a concern post-MECO when there are propellant residuals in the system.
2. There are several procedures for high MPS manifold pressure, work the one that applies to your current timeframe/situation.

References

Flight Rule A5-203
Booster Systems Console Handbook, SCP 2.2.13

4.5.14 MPS He Regulator Fail During Entry

What is It?

If an MPS He regulator fails high, the high pressure will relieve through its associated relief valve and into the aft compartment. As long as the vent doors are open to vent the aft compartment this is no problem. However, on entry the vent doors are closed at approximately D/O burn - 25 minutes and not opened until $V_{rel} = 2400$ ft/sec.

If an MPS He regulator fails high during entry when the vent doors are closed, the aft compartment could be over pressurized within 15 seconds. The damage resulting from such over pressurization may range from minimal damage to possible loss of vehicle.

How to Identify

If an He regulator pressure (HE REG P) goes out of limits:

1. SM alert light and tone
2. "MPS He P C (L, R)" fault message on BFS
3. An up or down arrow appears next to that applicable REG P on BFS SYS SUMM 1
4. High regulator pressure reading on the MEDS OMS/MPS display
5. MPS light on the Panel F7 C&W matrix illuminates (for Reg A failures only).

When is It Most Likely?

The MPS He Isolation valves are commanded open on entry at the transition to MM 303. Although a Regulator could fail open anytime it is pressurized (when the He Isolation valves are open), there are 2 times that a regulator failing open is most likely:

1. At the transition to MM 303: this is when the He Isolation valves are opened and the regulators are pressurized for the first time since ascent.
2. At $V_{rel} = 5300$ ft/sec: this is when the nominal aft compartment purge with He begins and the regulators are actually flowing He for the first time since ascent.

What Needs to Happen

If an MPS He regulator fails high during entry when the vent doors are closed, the associated He Isolation valve should be closed as quickly as possible to discontinue flow to that regulator.

The Procedure EPCL, p. 9-2, and
AESP, p. MS E8-2:
MPS He (PNEU REG) P/C&W LIGHT

For any regulator fail that trips C&W, this procedure will have the crew close the associated He Isolation valve if the vehicle above Mach 2.4 (vent doors are closed).

Bottom Line: An MPS He regulator failing high during entry is potentially dangerous
What You Need to Know to the vehicle and crew. If the vent doors are closed (above Mach 2.4), close the associated He Isolation valve as quickly as possible.

References Booster Systems Console Handbook, SCP 2.2.9

Questions

After completing these questions, compare your answers with those answers on Page B-3.

1. Which MPS malfunctions cause the red engine status light on Panel F7 to illuminate?
2. Which MPS malfunctions cause the amber engine status light on Panel F7 to illuminate?
3. Why must an SSME with a command path failure be shut down manually prior to MECO?
4. If there are two data path failures at MECO and one main engine shutdown pb is inoperable due to a control bus failure, how can you set the MECO confirmed flag?
5. If the limit shutdown switch is in AUTO and one engine fails, what happens to the redline limits on the remaining two engines?

6. If the limit shutdown switch is in AUTO and one engine has a data path failure, what happens to the redline limits on the remaining two engines?

7. Why does the crew check with MCC for low LH₂ ullage pressure?

8. What is the best indicator of an MPS helium leak?

9. If the ET SEP switch fails, what position does the software default for a nominal uphill? What is the default when the TAL or RTAL flag is set?

10. During powered flight, an ET SEP MAN message is received. Post MECO, the crew performs the correct procedure and sets the default back to AUTO (SPEC 51 ITEM 38 EXEC). After this is done, an ET SEP INHIBIT message is received. What procedure should be performed next?

5.0 DIFFERENCES IN THE BFS

5.1 OBJECTIVES

MPS operations with the BFS engaged are almost identical to PASS normal operations. Naturally, the hardware is no different; the software differences are summarized as follows.

- a. Redundant set launch sequence does not exist in the BFS; a launch is not attempted if the BFS is the only operating computer.
- b. BFS has all of the MPS SM caution and warning for ascent (helium, ET, manifolds, engine outlet) and entry (helium regulators). BFS does not announce any GNC switch redundancy management dilemmas (PASS only). Both PASS and BFS have SSME status (Pc, HYD/ELEC/CMD, data, engine fail).
- c. BFS has no commfault capability, which results in different logic for switch processing. Both contacts are required on the SSME pb indicator to set a manual shutdown flag in order to mode guidance and close the prevalues. If the contacts disagree, no command is issued.
- d. BFS does not read the LH₂ Backup Dump switch.
- e. BFS does not have manual throttles.
- f. Single-engine roll control is not available in the BFS; therefore, the limits are not reenabled after the first engine failure.

APPENDIX A - ACRONYMS AND ABBREVIATIONS

APU	Auxiliary Power Unit
ASP	Astronaut Support Person
ATO	Abort to Orbit
ATVC	Ascent Thrust Vector Control
BFS	Backup Flight System
C&W	Caution and Warning
c.g.	center of gravity
C/O	Cut Off
cb	Circuit Breaker
CCV	Chamber Coolant Valve
CIA	Controller Interface Assembly
CMD	Command
CRT	Cathode-Ray Tube
DAP	Digital Auto Pilot
DCU	Digital Computer Unit
DPS	Data Processing System
DSC	Dedicated Signal Conditioner
EIU	Engine Interface Unit
EPS	Electrical Power System
ET	External Tank
FC	Flight Critical
FCS	Flight Control System
FCV	Flow Control Valve
FDF	Flight Data File
FDO	Flight Dynamics Officer
FF	Flight Forward
FPB	Fuel Preburner
FPOV	Fuel Preburner Oxidizer Valve
FTS	Fail To Synch
GH ₂	gaseous hydrogen
GO ₂	gaseous oxygen
GPC	General Purpose Computer
He	Helium
HGM	Hot Gas Manifold
HPFTP	High Pressure Fuel Turbopump
HPOTP	High Pressure Oxidizer Turbopump

IDP	Integrated Display Processor
IDS	Integrated Documentation Services
JSC	Johnson Space Center
LH ₂	liquid hydrogen
LO ₂	liquid oxygen
LPFTP	Low Pressure Fuel Turbopump
LPOTP	Low Pressure Oxidizer Turbopump
MCC	Main Combustion Chamber Mission Control Center
MDM	Multiplexer/Demultiplexer
MEC	Master Events Controller
MECO	Main Engine Cutoff
MEDS	Multifunction Electronic Display System
MET	Mission Elapsed Time
MFV	Main Fuel Valve
MIA	Multiplexer Interface Adapter
MM	Major Mode
MOD	Mission Operations Directorate
MOV	Main Oxidizer Valve
MPS	Main Propulsion System
MS	Mission Specialist
NASA	National Aeronautics and Space Administration
NPSP	Net Positive Suction Pressure
OF	Operational Forward
OMS	Orbital Maneuvering System
OPB	Oxidizer Preburner
OPOV	Oxidizer Preburner Oxidizer Valve
OPS	Operational Sequence
PASS	Primary Avionics Software System
pb	Pushbutton
pbi	Pushbutton Indicator
Pc	Chamber Pressure
PEG	Powered Explicit Guidance
PLT	Pilot
PMS	Propellant Management System
POGO	Prevention of Coupled Structure Propulsion Instability
PPA	Powered Pitcharound
PRPLT	Propellant
psi	pounds per square inch
psia	pounds per square inch absolute

RCS	Reaction Control System
RM	Remote Manipulator
RTLS	Return to Launch Site
SBTC	Speedbrake/Thrust Controller
SEP	Separation
SERC	Single Engine Roll Control
SM	Systems Management
SOP	Subsystem Operating Program
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
T – 0	Liftoff
TAL	Transoceanic Abort Landing
TAMS	Training Administration Management System
TIG	Time of Ignition
TVC	Thrust Vector Control
VDT	Vehicle Data Table
VIE	Vehicle Interface Electronics
WONG	Weight on Nose Gear
WOW	Weight on Wheels

APPENDIX B ANSWERS

Answers to Section 2.0

1. Combustion takes place in
 - a. The fuel preburner (first stage)
 - b. The oxidizer preburner (first stage)
 - c. The main combustion chamber (second stage)
2. The five hydraulically actuated valves in a main engine are the following:
 - a. Main Fuel Valve (MFV)
 - b. Main Oxidizer Valve (MOV)
 - c. Fuel Preburner Oxidizer Valve (FPOV)
 - d. Oxidizer Preburner Oxidizer Valve (OPOV)
 - e. Chamber Coolant Valve (CCV)
3. False. LH_2 (fuel) is used to cool the main engines.
4. The LO_2 turbopump could cavitate and overaccelerate (catastrophic) at MECO if there is an inadequate supply of helium to prevent vaporization of LO_2 .
5. There are three command paths and two data paths between each controller and its EIU.
6. False. The ullage pressure system uses GH_2 and GO_2 from the three main engines to pressurize the LH_2 and LO_2 tanks in the ET.
7. False. The crew can control the LH_2 flow control valves only. The LO_2 tank is pressurized through a fixed orifice.
8. The interface between the center main engine and the orbiter hydraulic systems is as follows. The center engine uses hydraulic system 1 to operate its internal valves and hydraulic systems 1 and 3 for TVC. Hydraulic system 1 is primary for the pitch actuator and secondary for yaw; hydraulic system 3 is primary for yaw and secondary for pitch.

Answers to Section 3.0

1. No MPS crew inputs are required during powered flight of a nominal ascent. The main MPS task for the crew is monitoring.
2. The SSMEs are throttled back to reduce aero loads in first stage and to reduce vehicle acceleration prior to MECO.
3. LH₂ is dumped out the left side of the orbiter through the LH₂ fill/drain valves, and LO₂ is dumped through the main engines during the post-MECO MPS propellant dump.
4. Two SSMEs will lose one controller each if a single AC bus fails.
5. It is important to set the MECO confirmed flag because it allows the ET SEP sequence to begin.
6. The impact on the MPS dump sequence if the controllers are powered down before the sequence is finished is the LO₂ portion of the dump will be terminated.
7. The purpose of the MPS helium system during ascent and entry is to purge the HPOTP seal, provide backup SSME shutdown capability, pressurize the dump during ascent, repressurize the propellant lines, and purge the aft compartment and OMS pods during entry.

Answers to Section 4.0

1. The following MPS malfunctions cause the red engine status light on Panel F7 to illuminate: an engine shutting down due to exceeding redline limits, or an engine exceeding redline limits with limits inhibited.
2. A data path failure, command path failure, hydraulic lockup, and electrical lockup all cause the amber status light on Panel F7 to illuminate.
3. The command path failure (MPS CMD) must always be shut down manually prior to MECO because it is not capable of responding to GPC shutdown commands and would run to propellant depletion (catastrophic).
4. When multiple data path failures are present at MECO and an inoperable PB due to a control bus failure, the MECO confirmed flag is set by comm faulting the appropriate FF MDM, and then depressing all three shutdown pb's.
5. If the limit shutdown switch is in AUTO and one engine fails, the redline limits on the remaining two engines are inhibited.
6. If the limit shutdown switch is in AUTO and one engine has a data path failure, the redline limits on the remaining two engines are inhibited.
7. The crew checks with MCC for low LH₂ ullage pressure because the MCC has more insight into the problem. MCC directs the crew on manual throttle actions for flow control valve problems or ullage leaks. The ullage pressure switch overrides only failed LH₂ ullage pressure sensors.
8. A high helium tank dP/dT reading on the BFS GNC SYS SUMM 1 display is the best indicator of a helium leak. Note that there is no dP/dT indicator for the pneumatic helium tank.
9. If the ET SEP switch fails during a nominal uphill or ATO, it defaults to MANUAL. If it fails on a TAL or RTLS, it defaults to AUTO.
10. The ET SEP INH procedure in the Ascent Checklist on the ascent procedures page should be performed after an ET SEP INHIBIT message is received. The same page is duplicated in the PLT flipbook.

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