

Shuttle Flight Operations Manual

Volume 8A
Main Propulsion Systems

Flight Operations Directorate
Crew Training and Procedures Division

Preliminary
October 1979



National Aeronautics and
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Seattle Flight Operations Manual

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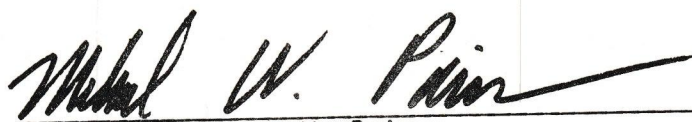
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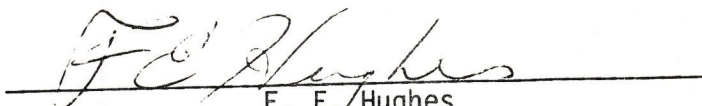
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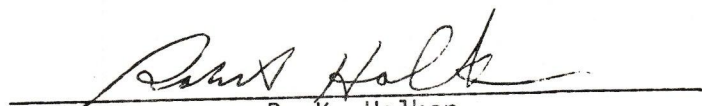


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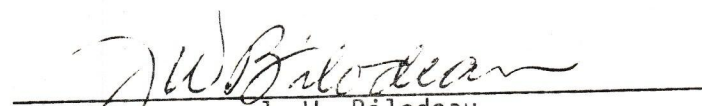
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SECTION 1.0 INTRODUCTION

1.1 FUNCTIONS OF THE MAIN PROPULSION SYSTEM

The Main Propulsion System (MPS), assisted by two Solid Rocket Boosters (SRB's) during the initial phases of the ascent trajectory, provides the vehicle velocity increment (ΔV) from lift-off to a predetermined velocity prior to orbit insertion. Once the two SRB's burn out and are jettisoned, the MPS continues to burn for an additional 6 min and 42 sec. At the predetermined velocity, the MPS is shut off (MECO), the external tank jettisoned, and the Orbital Maneuvering System (OMS) ignited to provide the final ΔV required for orbital insertion. (figs. 1-1 and 1-2). The magnitude of the ΔV supplied by the MPS will be dependent on payload weight, mission trajectory requirements, and system limitations.

Coincident with the start of the OMS burn, the remaining MPS propellants will be dumped through the bells of the three Space Shuttle Main Engines (SSME's). Sometime during orbit, the crew will vacuum inert the MPS by opening valves which will allow any remaining propellants to be vented into space.

Just before entry, the crew will repressurize the MPS propellant lines with helium to prevent contaminants from being drawn into the lines during entry. The last activity involving the MPS will occur at the end of the landing rollout at which time the onboard helium storage tanks will be blown down to safe the system.

1.2 DEFINITION OF MAJOR SUBSYSTEMS

The MPS consist of the following major subsystems:

- A. Three Space Shuttle Main Engines (SSME's)
- B. Three SSME Controllers (SSMEC's)
- C. External Tank (ET)
- D. Orbiter MPS
 - Propellant Management Subsystem (PMS)
 - Helium subsystem
- E. Four Ascent Thrust Vector Control (ATVC) units
- F. Six SSME hydraulic servo actuators

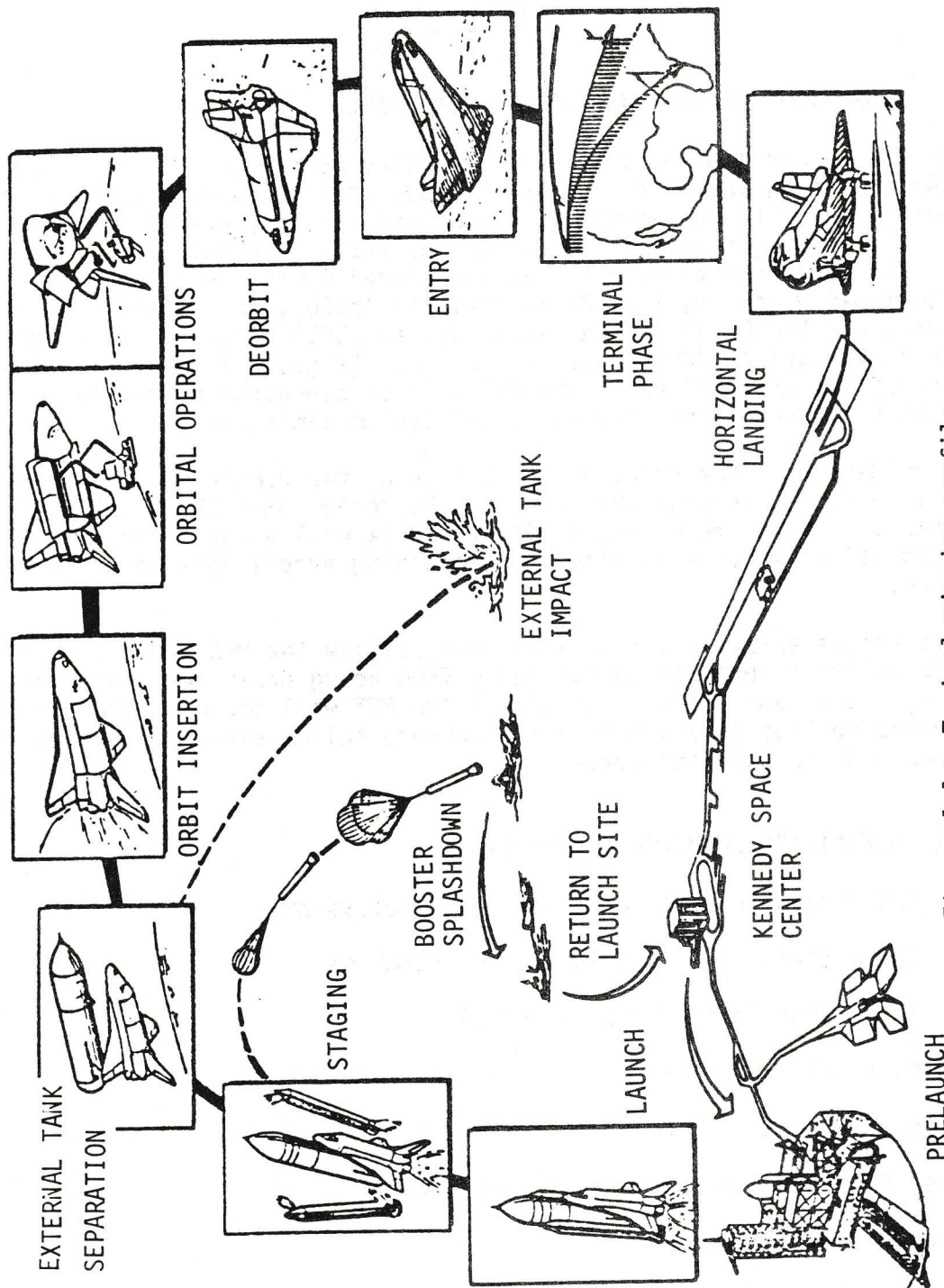


Figure 1-1.- Typical mission profile.

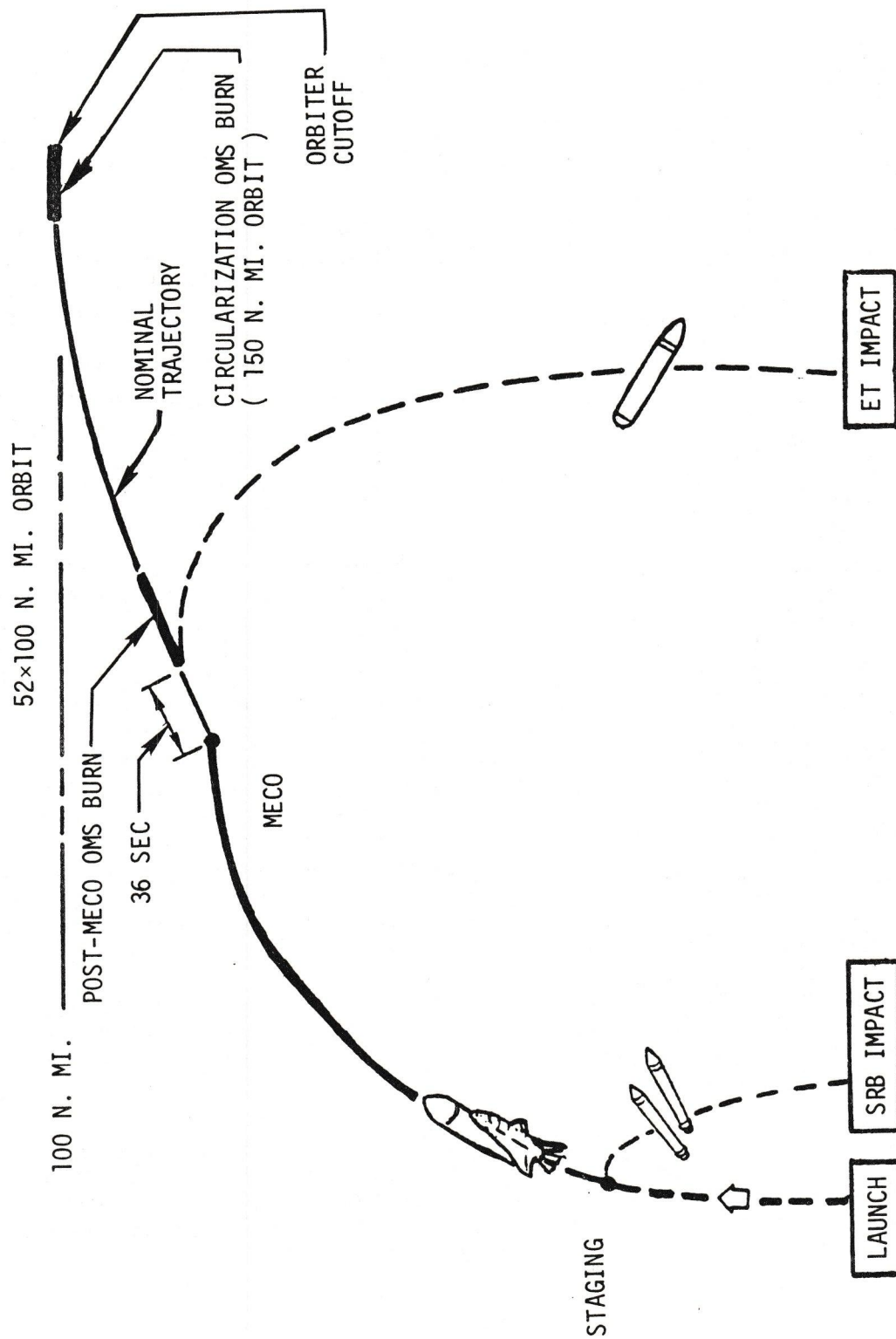


Figure 1-2.- Space Shuttle ascent trajectory profile.

Each major subsystem is defined as follows:

- PM04 • Space Shuttle Main Engine (SSME): The SSME's are reusable, high-performance, liquid-propellant rocket engines with variable thrust. They are ignited on the ground at launch and operate in parallel with the SRB's during the initial ascent phase and continue to operate for an approximate 480-sec total firing duration.
- PC01-PC63 • Space Shuttle Main Engine Controller (SSMEC): The SSMEC is an electronic package mounted on the SSME. It operates in conjunction with engine sensors, valves actuators, and spark igniters to provide a self-contained system for engine control, checkout, and monitoring.
- PM01 • External Tank (ET): The externally mounted propellant tank contains the fuel (liquid hydrogen) and oxidizer (liquid oxygen) which is burned in the three main engines. After all three engines cut off (MECO), the propellant tank is jettisoned, reenters the earth's atmosphere, and impacts in a remote ocean area. The ET is not recoverable, and for this reason, contains a minimum number of active components.
- PM02 • Orbiter MPS (Propellant Management Subsystem): The propellant management system is a system of manifolds, distribution lines, and valves by which the liquid propellants pass from the ET to the SSME's, and where gaseous propellants pass from the SSME's to the ET. All the valves related to the propellant management subsystem are under direct control of the GPC's and are either electrically or pneumatically actuated.
- PM03 • Orbiter MPS (Helium Subsystem): The helium subsystem consists of a series of helium supply tanks and their associated regulators, check valves, distribution lines, and control valves. The helium subsystem supplies helium which is used within the engine for in-flight purges, and provides pressure for actuating engine valves during emergency pneumatic shutdowns. The balance of the helium is used to provide pressure to actuate all of the pneumatically operated valves within the propellant management subsystem.
- SV ?? • Ascent Thrust Vector Control (ATVC): The ATVC is an electronics package (four in all) mounted in the aft avionics bays. They furnish command signals to the hydraulic servoactuators and fault detection of the hydraulic servoactuators.
- H ??? • SSME Hydraulic Actuator: The SSME hydraulic actuators are the hardware devices used to gimbal the main engines. There are two actuators per SSME, one for pitch motion and one for yaw motion. They convert electrical commands received from the GPC's into hydraulic pressure which is mechanically used to gimbal the SSME's.

1.3 LOCATION OF MAJOR SUBSYSTEMS

- The three SSME's are grouped in a cluster and attached to the rear of the Orbiter, aft of the payload bay compartment (figs. 1-3 and 1-4).
- Each of the three SSMEC's is attached to the forward end of one of the SSME's.
- The ET is attached to the bottom of the Orbiter and extends forward of the nose of the Orbiter (fig. 1-3). The ET is attached to the Orbiter by a single forward attachment strut and two aft attachment struts.
- All of the Orbiter MPS is located in the compartment aft of the payload compartment (fig. 1-4).

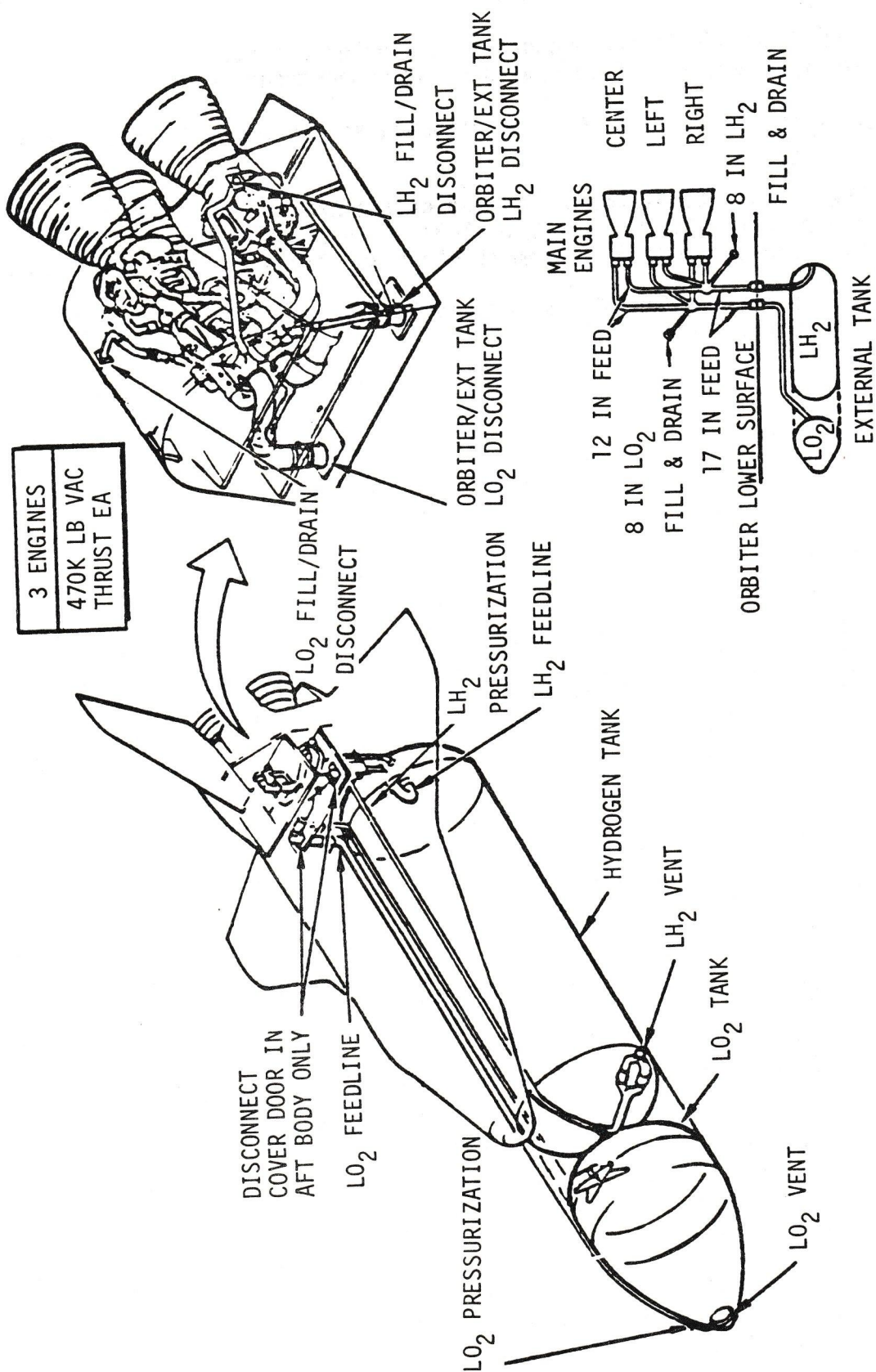


Figure 1-3.- Main propulsion system.

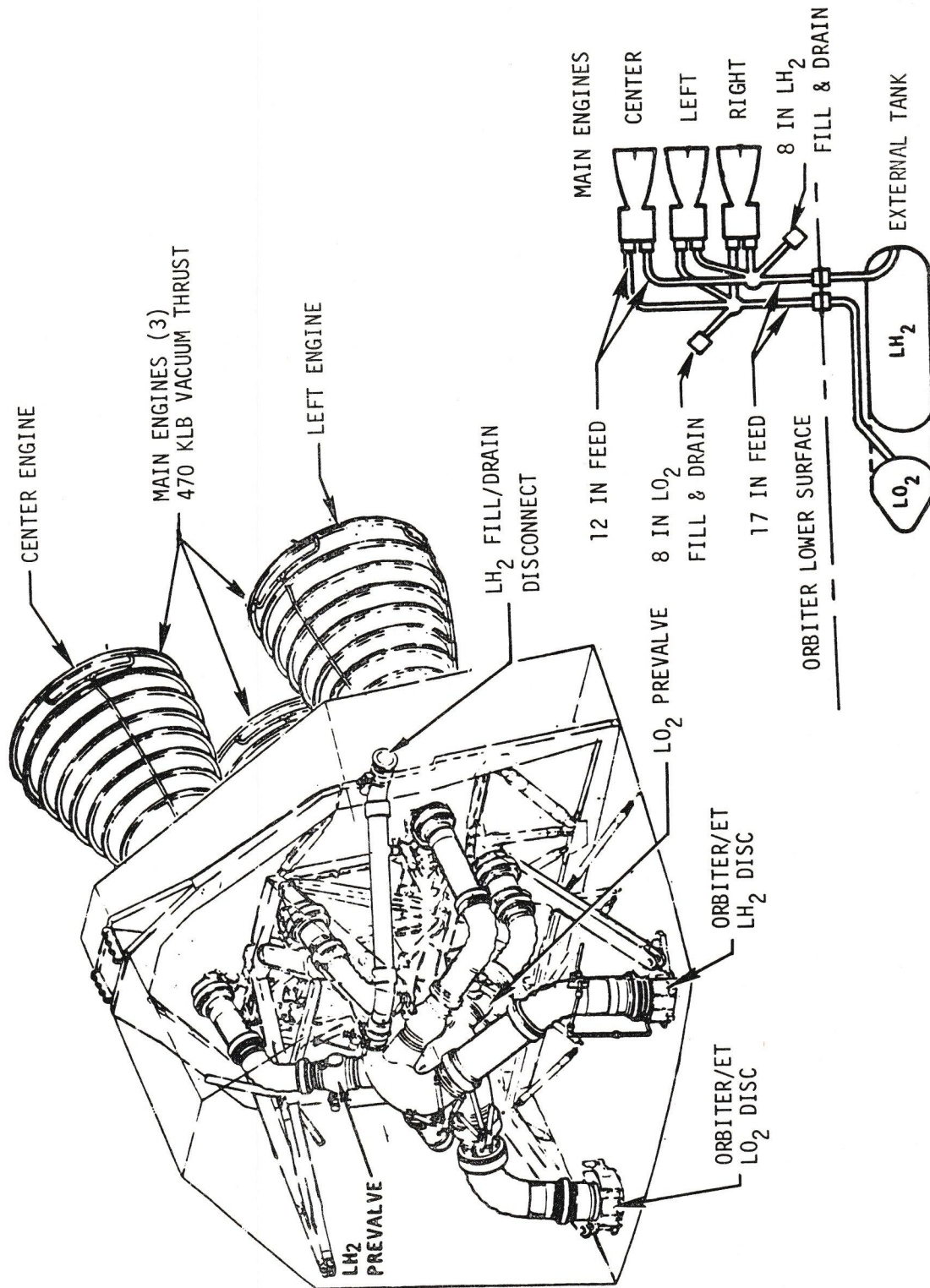


Figure 1-4.- Orbiter main propulsion system.

SECTION 2.0 SYSTEMS INTERFACES

2.1 MPS EXTERNAL SYSTEM INTERFACE

The MPS interfaces with other systems as shown in figure 2-1 and as stated below:

2.1.1 Inputs

- A. General Purpose Computers (GPC's) - Furnish commands to the SSMEC, individual valves within the Orbiter MPS, and commands to the ATVC.
- B. Hydraulic system - Furnishes hydraulic pressure to operate the SSME valves and main engine gimbal actuators.
- C. Electrical Power System (EPS) - Furnishes 115-V ac power to operate the SSMEC's and 28-V dc power to operate the Orbiter MPS valves, transducers, engine controller heaters, and the ATVC's.
- D. Master Events Controller (MEC) - Initiates firings of pyrotechnic devices for separating the external tank from the Orbiter.
- E. SRB range safety system - Furnishes cross-strapping signals to ensure all range safety commands are activated within the SRB's and ET.

2.1.2 Outputs

- A. GPC's - Receive performance and status data from the engine controllers and Orbiter MPS.
- B. Caution & Warning (C&W) system - Receives engine inlet manifold pressures from the propellant management subsystem and helium supply, and regulated pressures from the helium subsystem.
- C. Cockpit panel meters - Receives various MPS performance parameters.
- D. Pulse Code Modulation (PCM) master measurement unit - Receives all MPS telemetry parameters inputs for ground monitoring of MPS.
- E. Vehicle - Receives thrust forces from the MPS engines.

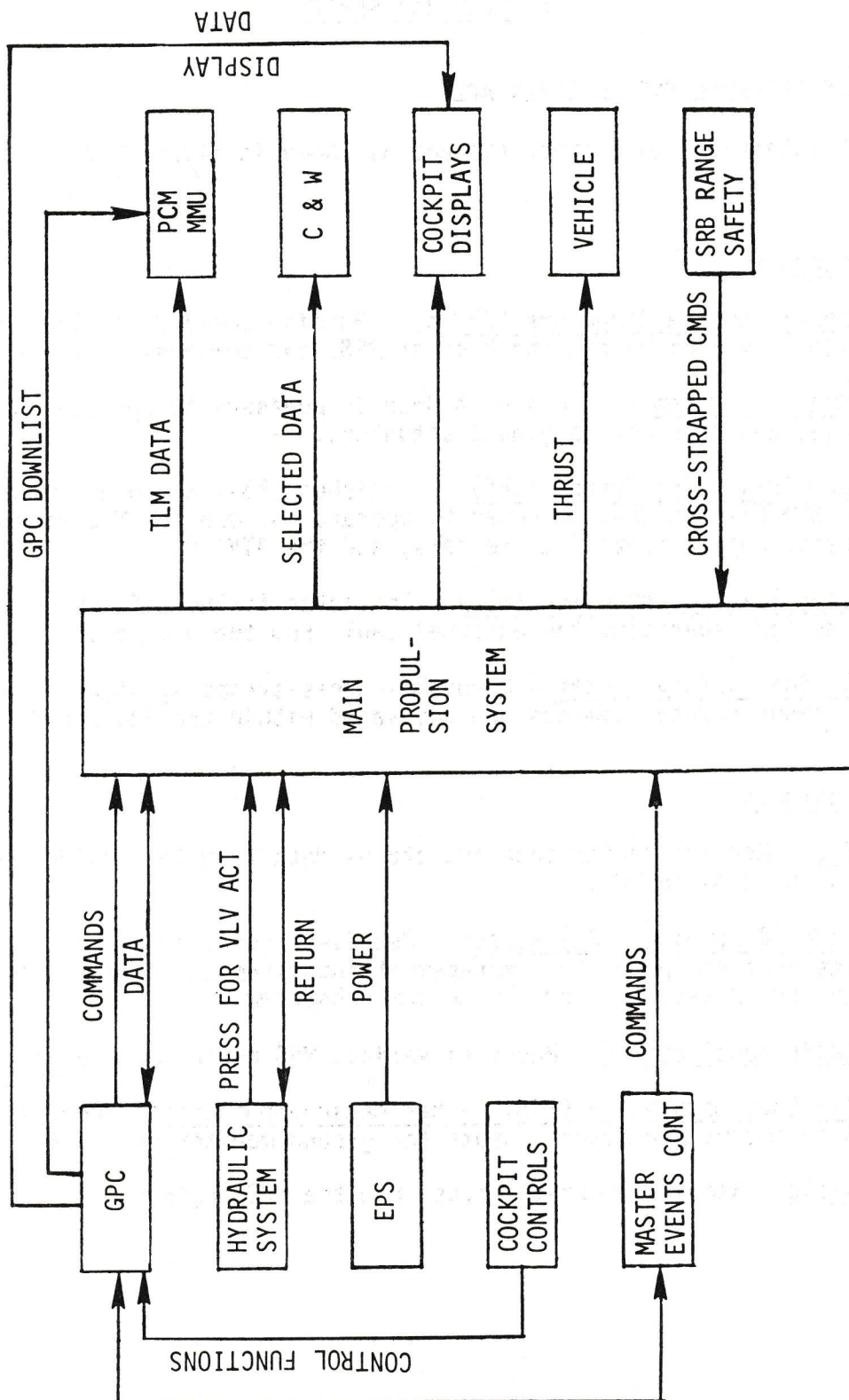


Figure 2-1.- The MPS interfaces with other vehicle systems.

2.2 MPS SUBSYSTEM INTERFACE

The MPS subsystems interface with each other as shown in figure 2-2 and as stated below:

2.2.1 Outputs

- A. ET - The ET furnishes the propellant management system with the propellants needed to run the SSME's.
- B. SSME - Each SSME produces thrust necessary to place the Shuttle in orbit. During engine operation, gaseous propellants are sent to the propellant management system and engine data are sent to the SSMEC. Before launch, LH2 is sent to the ET via the propellant management system.
- C. Propellant Management System (PMS) - The PMS furnishes the SSME's with liquid propellants from the ET and the ET with gaseous propellants from the SSME's.
- D. Helium supply - The helium supply furnishes helium to the PMS and the SSME's.
- E. SSMEC - The SSMEC furnishes commands to the SSME. There is one controller per SSME. Engine data and status received by the controller from the SSME's are issued to the engine interface unit.
- F. Engine Interface Unit (EIU) - The EIU issues main engine commands received from the GPC to the main engine controller. When engine data and status are received by the EIU, the data are held in a buffer until a GPC request for data is received by the EIU. There is one EIU per SSME.
- G. Engine gimbal actuator - Furnishes gimbal motion to the main engines. There are two actuators per SSME, one for pitch motion and one for yaw motion. Hydraulic pressure status for each servovalve is issued to the ATVC.
- H. ATVC - Sends position commands to the engine gimbal actuators which are received from the GPC's. Hydraulic isolation commands are directed to the engine gimbal actuators that obtain faulty servovalves with excessive hydraulic pressure. In conjunction with this, a servovalve isolation signal is transmitted to the GPC's (C&W).

PMO1

PMO2

PMO3

PMO4

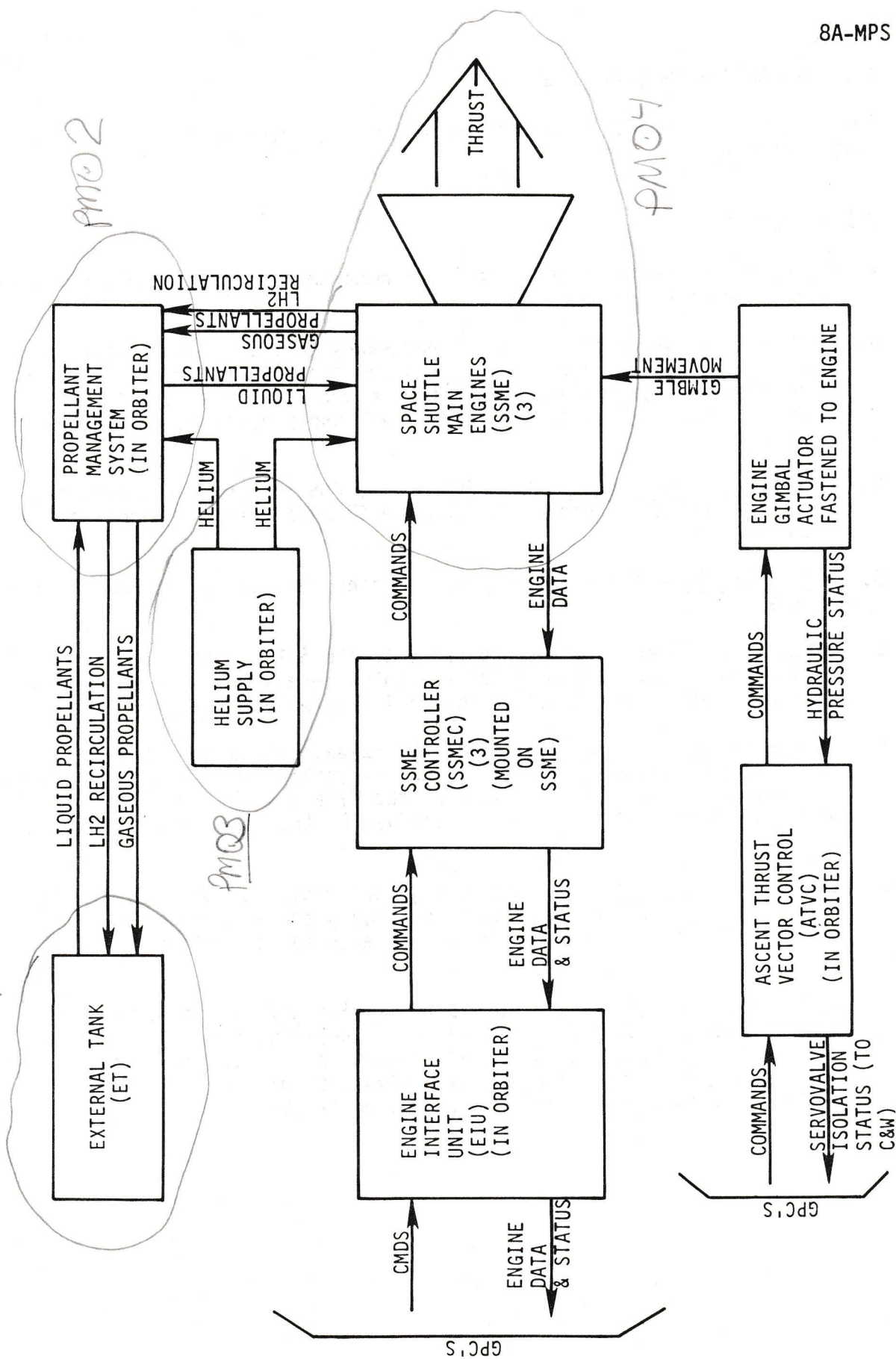


Figure 2-2.- The MPS subsystem interface.

SECTION 3.0

MPS SUBSYSTEM FUNCTIONAL DESCRIPTION

3.1 SPACE SHUTTLE MAIN ENGINE

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The Orbiter vehicle Main Propulsion System (MPS) consists of three Space Shuttle Main Engines (SSME's). The SSME's are reusable, high-performance, liquid-propellant rocket engines with variable thrust (fig. 3.1-1). They are ignited on the ground at launch and operate in parallel with the SRB's during the initial ascent phase and continue to operate for an approximate 480-sec total firing duration. Each of the rocket engines operate at a mixture ratio (liquid oxygen/liquid hydrogen) of 6:1 and a chamber pressure of approximately 3000 psia to produce a sea level thrust of 375,000 lb and a vacuum thrust of 470,000 lb. The engines are throttleable over a thrust range of 65 to 109 percent of the design thrust level. This provides a higher thrust level during lift-off and the initial ascent phase, and allows Orbiter acceleration to be limited to 3g during the final ascent phase. The engines are gimballed ($\pm 10.5^\circ$ for pitch and $\pm 8.5^\circ$ yaw) to provide pitch, yaw, and roll control during the Orbiter boost phase.

Significant in meeting performance requirements is a staged combustion power cycle with high combustion chamber pressures. In the SSME staged combustion cycle, the propellants are partially burned at high pressure and relatively low temperature in the preburners, then completely burned at high temperature and pressure in the main chamber before expanding through the high-area-ratio nozzle. Hydrogen fuel is used to cool all combustion devices directly exposed to high-temperature combustion products. An electronic engine controller automatically performs checkout, start, mainstage, and engine shutdown functions.

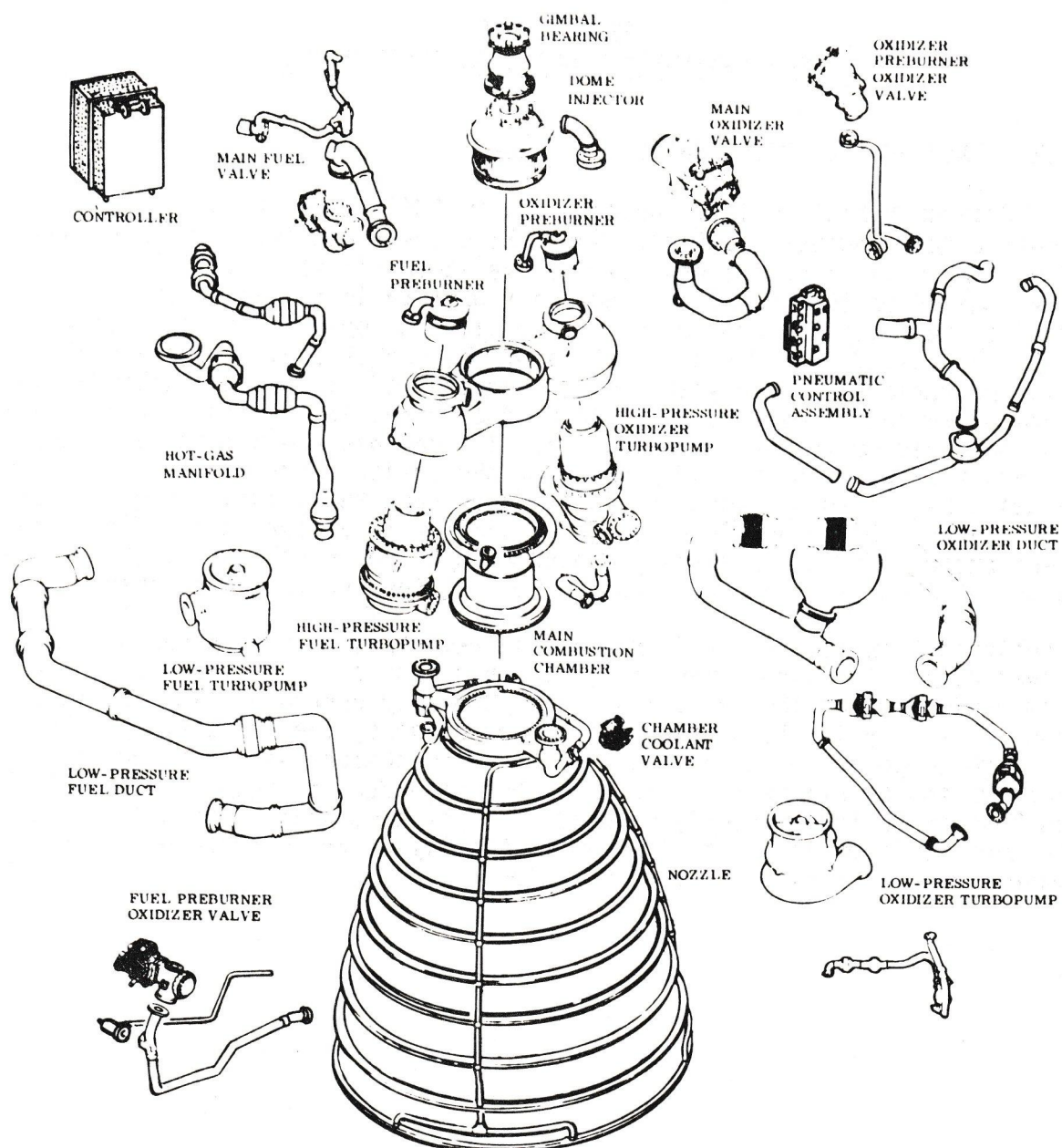


Figure 3.1-1.- The SSME major components.

PM04

8A-MPS

3.1.1 SSME Subsystem Functions

Four turbopumps, two low-pressure and two high-pressure, are key components in establishing the physical characteristics of the SSME system. The Low-Pressure Fuel Turbopump (LPFTP) and the Low-Pressure Oxidizer Turbopump (LPOTP) are located 180° apart. The High-Pressure Fuel Turbopump (HPFTP) and High-Pressure Oxidizer Turbopump (HPOTP), also located 180° apart, are mounted between the two low-pressure pumps. The LPFTP and LPOTP are connected to the vehicle propellant ducting and are supported in a fixed position by the vehicle structure. The discharge of each low-pressure pump is connected to the inlet of the high-pressure pump by ducts that have flexible joints, permitting deflection required during gimbaling. The LPOTP and LPFTP are axial-flow-type pumps that operate at relatively low speeds and provide the pressure increase required at the inlets of the respective high-pressure turbopump.

The HPFTP is a three-stage, centrifugal flow-type pump, driven by a two-stage hot gas turbine and is flange-attached to the Hot Gas Manifold (HGM). It supplies hydrogen to the engine fuel circuits.

The HPOTP is flange-attached to the HGM and consists of two centrifugal-type pumps on a common shaft driven by a two-stage hot gas turbine. The main pump supplies oxidizer to the main chamber injector, the heat exchanger, LPOTP turbine, and the preburner oxidizer pump. The preburner oxidizer pump raises the pressure of the oxidizer and supplies it to the fuel and oxidizer preburners.

The HGM is the structural backbone of the engine package, supporting the two preburners, high-pressure pumps, main injector, and main chamber. It interconnects the Fuel and Oxidizer Preburners (FPB and OPB) to the main chamber injector. Both FPB and OPB are welded to the HGM and generate the fuel-rich gases that power the HPFTP and HPOTP. Each preburner consists of a combustor with fuel-cooled liner and a baffled, coaxial-element injector.

The main injector and dome assembly is welded to the HGM. It is a baffled, coaxial-element injector, with dual faceplates that are transpiration-cooled by gaseous hydrogen. The gimbal bearing is bolted to the main injector and dome assembly and is the thrust interface between the engine and vehicle. It enables the engine to be gimballed for thrust vector control. The Main Combustion Chamber (MCC) is bolted to the HGM and consists of an internal coolant liner and an external structural jacket. The coolant liner has longitudinal channels to form a fuel-cooled, up-pass cooling circuit.

The nozzle is bolted to the MCC and is constructed of tapered tubes reinforced by a structural jacket with insulated hat bands. The tubes provide an up-pass fuel coolant circuit that is supplied with hydrogen through three down-pass transfer ducts connected to the aft inlet manifold.

The controller is attached to the MCC by three shock-mount fittings. It is a solid-state, integral electronics package contained in a pressurized aluminum case assembly. It sequences, controls, and monitors all engine functions during checkout and operation of the engine.

3.1.2 SSME Propellant Flow

The SSME uses a staged combustion cycle in which propellants are partially burned at high pressures and relatively low temperature in the preburners and then completely burned at high pressure and temperature in the MCC (fig. 3.1-2).

The propellant system uses four turbopumps. The two low-pressure turbopumps operate at relatively low speed to permit low pressures in the vehicle tanks. The function of these pumps is to provide sufficient pressure increase at the inlets of the high-pressure turbopumps to permit them to operate at high speeds. The discharge from the low-pressure turbopumps is fed to the inlets of the high-pressure turbopumps.

Approximately 75 percent of the flow from the HPOTP goes to the MCC. Approximately 10 percent is directed to the preburner pump, which raises the pressure to that required by the preburners. Small quantities are bled through the heat exchanger for oxidizer tank pressurization and pogo suppression. The balance of the oxidizer drives the hydraulic turbine powering the LPOTP and is then recirculated to the inlet of the HPOTP.

Approximately 20 percent of the HPFTP discharge flow is used to cool the MCC, drive the low-pressure fuel turbopump turbine, cool the hot gas manifold and injector, and provide fuel tank pressurant. The remaining fuel is first used to cool the nozzle, then supply the preburners.

The hot gas hydrogen-rich steam from the fuel and oxidizer preburners drives the high-pressure pump turbines, then flows to the main injector where it is mixed with additional oxidizer and fuel and injected into the MCC.

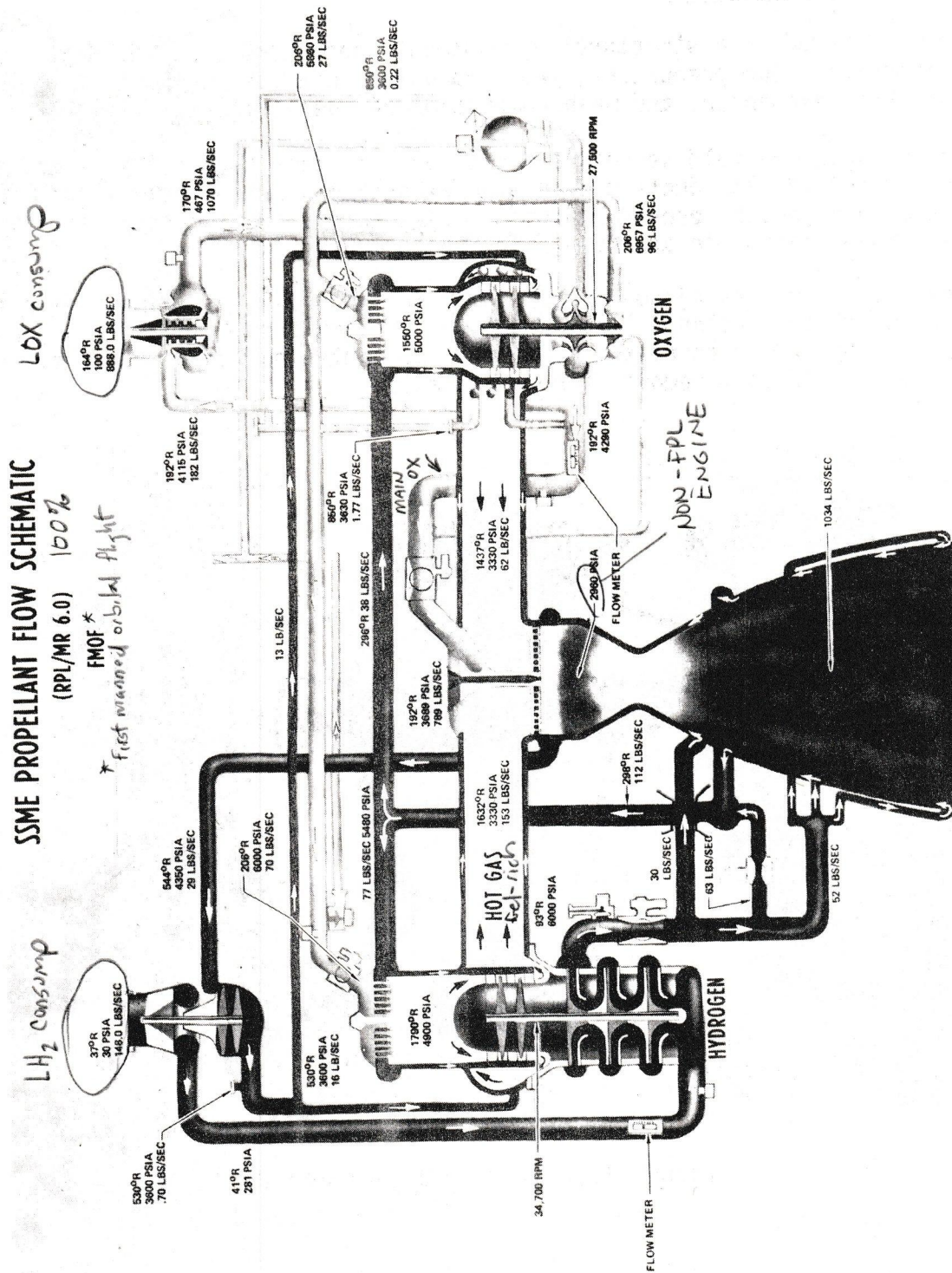


Figure 3.1-2.- The SSME propellant flow schematics.

3.1.3 SSME Powerhead

The powerhead is a structural arrangement consisting of eight major engine components: Two preburners, two turbopumps, hot gas manifold, main injector, heat exchanger, and main combustion chamber (fig. 3.1-3).

The hot gas manifold serves as the structural base for the powerhead. This manifold also ducts the turbine exhaust gases from both turbines to the main injector, providing uniform flow across the injector face, which is a major factor in achieving high performance.

The preburners are close-coupled to their turbines, resulting in minimum-length hot gas ducting. The turbopumps are mounted to the hot gas manifold to provide a compact package and are canted outboard from the vertical to permit easy removal for maintenance.

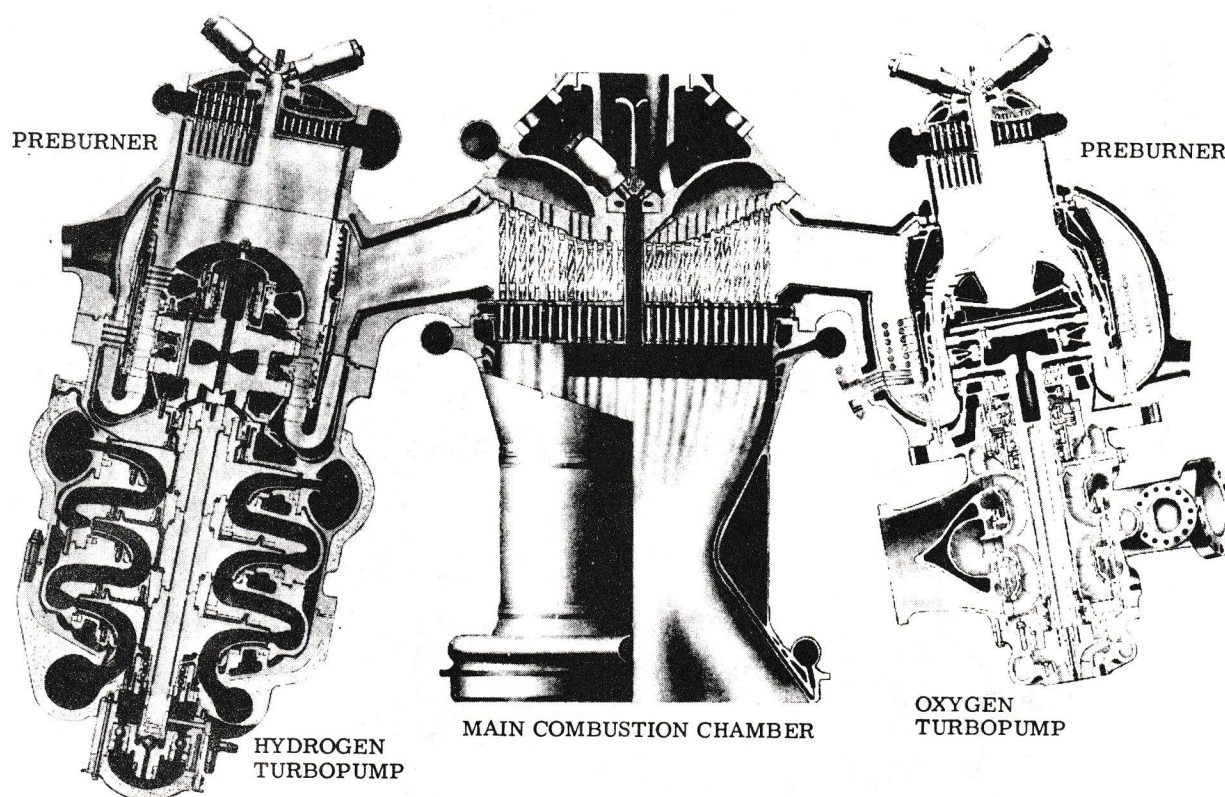


Figure 3.1-3.- The SSME powerhead.

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3.1.4 Hot Gas Manifold

The Hot Gas Manifold (HGM) is a double-walled, hydrogen-gas-cooled structural support and fluid manifold. It is the structural backbone of the engine and interconnects and supports the preburners, high-pressure turbopumps, main combustion chamber, and main injector (fig. 3.1-4).

The HGM conducts hot gas (hydrogen-rich steam) from the turbines to the main injection elements of the main chamber injector. The area between the wall and liner provides a coolant flow path for the hydrogen gas that exhausts from the low-pressure fuel turbopump turbine, protecting the outer wall and liner against the temperature effects of the hot gas from the preburners. This hydrogen, after cooling the manifold, is the fuel for the injector baffle elements, and also the coolant for the primary faceplate, secondary face, and the main combustion chamber acoustic cavities.

The oxidizer side of the HGM has a canted flange to which the HPOTP is stud-mounted. Heat exchanger tube supports are welded to the inner wall on the oxidizer side of the HGM. Two hot gas transfer tubes route the HPOTP turbine exhaust gas to the main injector torus manifold, where it is radially directed into the hot gas cavity of the main injector. The oxidizer preburner is welded to the upper end of the oxidizer side of the HGM.

The fuel side of the HGM also has a canted flange, to which the HPFTP is stud-mounted. Three hot gas transfer tubes route the HPFTP turbine exhaust gas to the main injector torus manifold where it is radially directed into the hot gas cavity of the main injector. The fuel preburner is welded to the upper end of the fuel side of the HGM. Instrumentation ports, which are also used for internal inspection of the injectors and turbines, are located throughout the HGM.

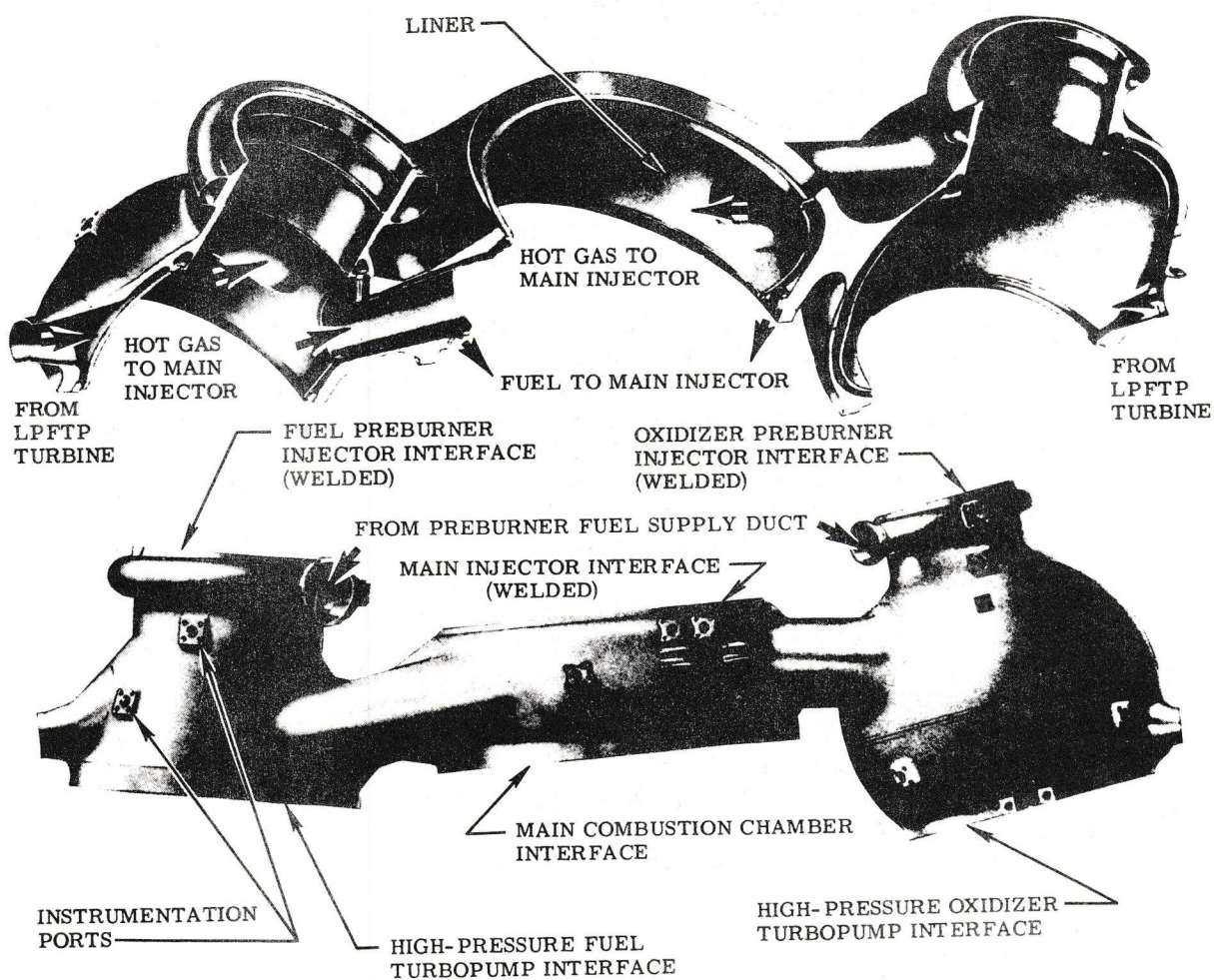


Figure 3.1-4.- Hot gas manifold.

3.1.5 Preburners and Injection Elements

Two preburners are used in the SSME (fig. 3.1-5). Both burn hydrogen and oxygen to generate a variable hot gas supply to power the high-pressure turbopumps. They operate at a low mixture ratio with gaseous hydrogen from the nozzle coolant circuit combined with hydrogen bypassed through the chamber coolant valve, and liquid oxygen from the preburner oxidizer pump. Specific operating levels of the preburners are controlled by regulating the oxidizer flowrate with the preburner oxidizer valves.

The preburner injector is a baffled, coaxial-element injector that mixes the gaseous hydrogen and liquid oxidizer in correct proportions and uniformly distributes and injects the propellants into the combustion chamber. The coaxial elements are contained by the upper interpropellant plate and a lower faceplate in a pattern of closely spaced concentric rows. Each element consists of an orificed center tube (oxidizer post) and an outer fuel sleeve that has a series of orifices in its periphery. Oxidizer entering the oxidizer manifold is uniformly distributed within the oxidizer dome over the interpropellant plate and enters the oxidizer post through the post orifice. Hydrogen from the fuel manifold passes radially into the injector fuel cavity formed by the interpropellant plate and faceplate. From the fuel cavity, the hydrogen enters the annulus of the coaxial elements through the fuel sleeve orifices. The high velocity of the low-density fuel (relative to the density and velocity of the oxidizer) produces a high rate of atomization and thorough mixing. Coaxial injection and baffles maintain stable combustion in the preburners. Hydrogen flows through axial passages in each baffle for cooling and is discharged radially into the combustion chamber.

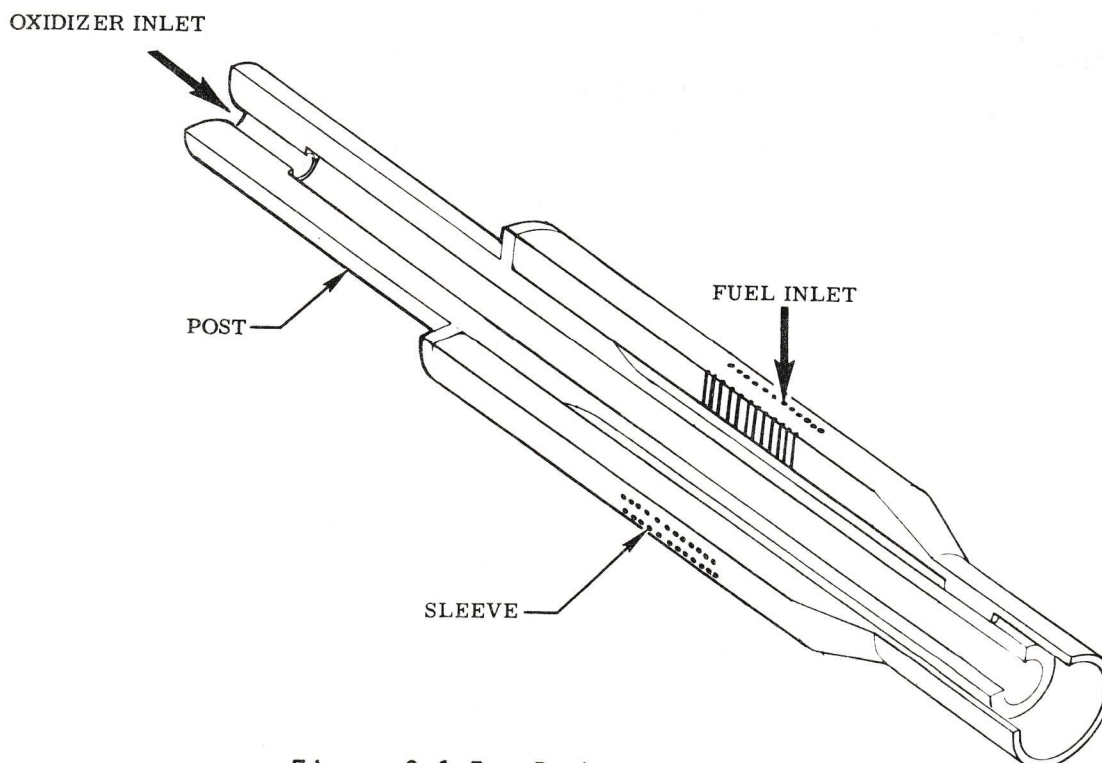


Figure 3.1-5.- Preburner injector.

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3.1.6 Fuel Preburner

The Fuel Preburner (FPB) is supported by the HGM, to which it is welded, and is close-coupled to the HPFTP (fig. 3.1-6). The FPB consists of three major parts: (1) injector, (2) Augmented Spark Igniter (ASI) chamber, and (3) combustion chamber.

The ASI unit, a small injector and combustion chamber with two spark igniters located in the center of the injector, initiates ignition of propellants in the preburner. The injector has a single pair of impinging oxidizer orifices and eight hydrogen orifices directed tangentially around the oxidizer. The propellants are ignited by dual-redundant spark igniters.

The FPB combustion chamber is a fuel-cooled, double-walled chamber in which energy is generated to power the HPFTP. The chamber, consisting of an outer wall and a liner, is welded to the injector/dome and HGM. Fuel coolant is provided between the outer wall and liner by hydrogen from the fuel manifold. The fuel coolant is discharged at the lower end of the liner into the hot gas powering the HPFTP turbine.

Geometry

Internal diameter, in.	10.43
Combustor length, in.	4.37
Injector configuration	Concentric orifice
Number of elements	264
Baffle length, in.	2.25

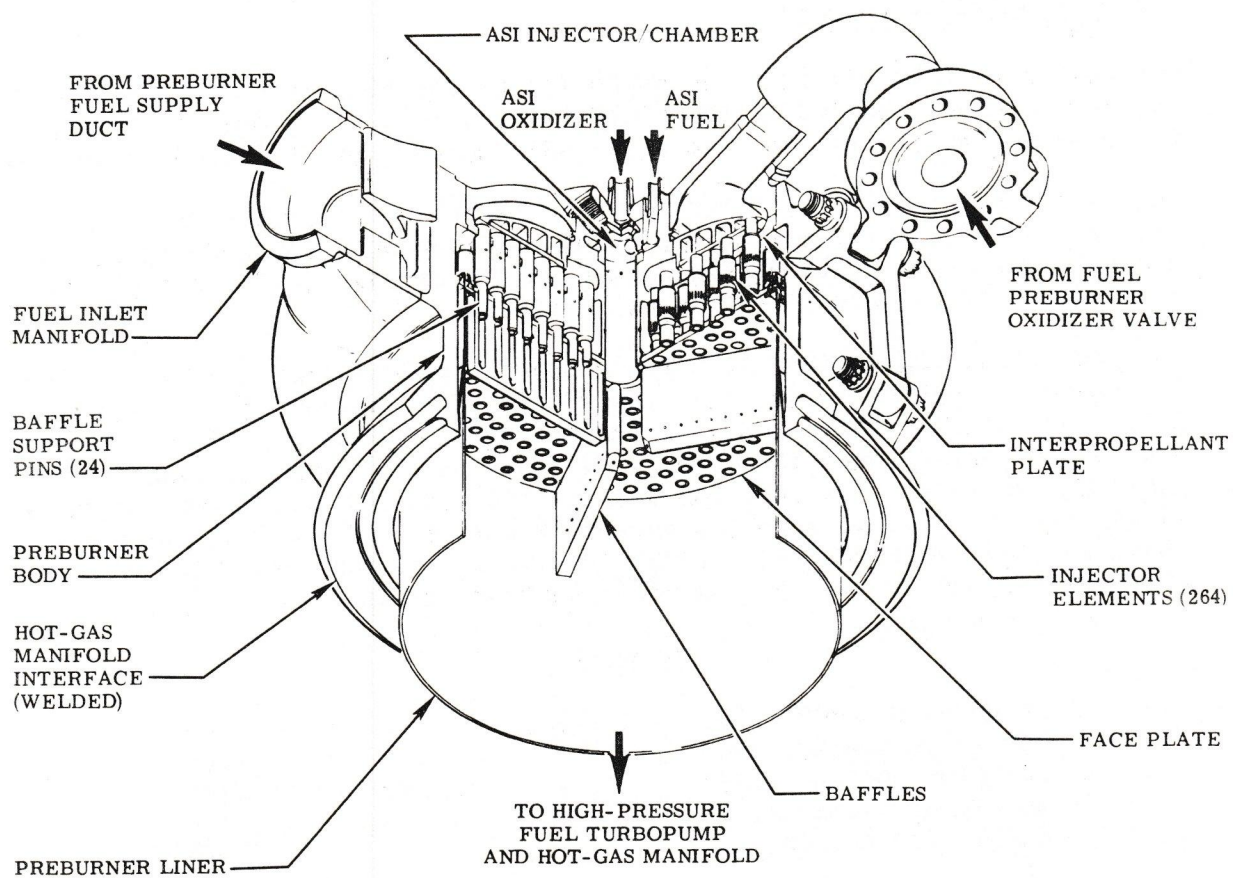


Figure 3.1-6.- Fuel preburner.

3.1.7 Oxidizer Preburner

The Oxidizer Preburner (OPB) is supported by the HGM, to which it is welded, and is close-coupled to the HPOTP (fig. 3.1-7). The OPB consists of three major parts: (1) injector, (2) ASI chamber, and (3) combustion chamber.

The ASI unit initiates ignition of propellants in the preburner. The injector has a single pair of impinging oxidizer orifices and eight hydrogen orifices directed tangentially around the oxidizer. The propellants are ignited by dual-redundant spark igniters.

The OPB combustion chamber is a fuel-cooled double-walled chamber in which the energy is generated to power the HPOTP. The chamber, consisting of an outer wall and a liner, is welded to the injector/dome and HGM. Fuel coolant is provided between the outer wall and liner by hydrogen supplied from the fuel manifold. The fuel coolant is discharged at the lower end of the liner into the hot gas powering the HPOTP turbine. Fuel from the fuel inlet manifold is conducted through the preburner body to a turbine coolant manifold for use in cooling HPOTP turbine components.

Geometry

Internal diameter, in.	7.43
Combustor length, in.	4.25
Injector configuration	Concentric orifice
Number of elements	120
Baffle length, in.	2.25

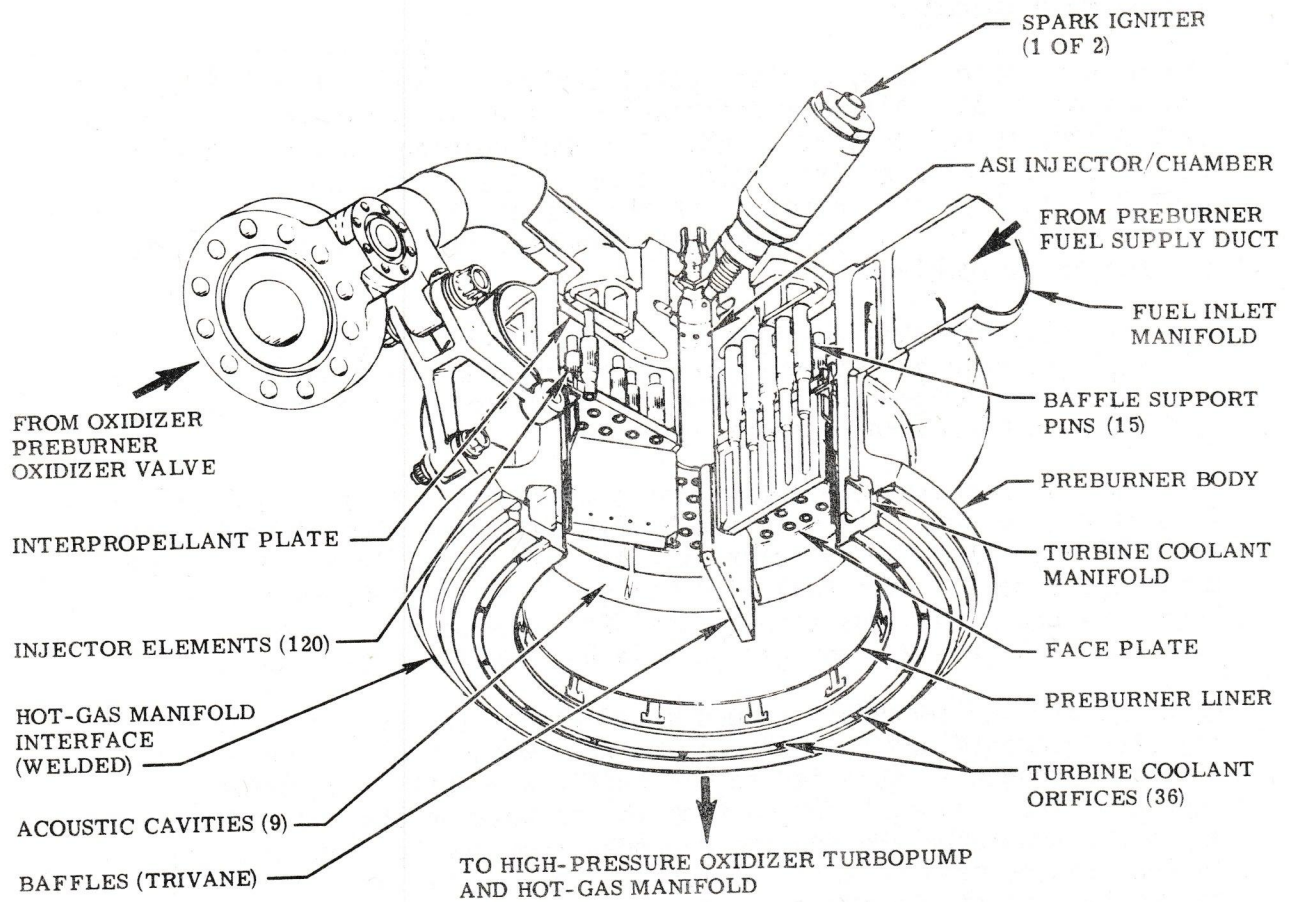


Figure 3.1-7.- Oxidizer preburner.

3.1.8 Main Injector

The main injector is a baffled, coaxial-element-type injector that efficiently mixes and uniformly distributes propellants to the MCC. The injector body is welded to the HGM. A gimbal bearing mounts to the forward end of the injector and transmits thrust loads to the vehicle thrust structure. Basically, the injector assembly is an all-welded assembly consisting of a structural body, injection elements, two porous metal plates, and the ASI assembly.

The ASI unit initiates ignition of propellants in the MCC. The injector has a single pair of impinging oxidizer orifices and eight hydrogen orifices directed tangentially around the oxidizer. The propellants are ignited by dual-redundant spark igniters.

The coaxial injection elements consist of 525 main injection elements and 75 baffle elements. The main and baffle injection elements are supplied with oxidizer from the injector oxidizer manifold. The main injection elements are supplied with fuel-rich hot gas from the turbine exhaust of the high-pressure turbopumps through the HGM. The baffle elements are supplied with gaseous hydrogen used in the HGM coolant circuit.

Both primary and secondary porous metal plates are supported by the injector elements and form the cavity from which part of the HGM cooling circuit hydrogen is supplied to the baffle elements. The primary plate separates the cooling hydrogen from the combustion chamber and the secondary plate separates the cooling hydrogen from the hot gas that is supplied as fuel to the main injector elements. Both plates are transpiration-cooled by part of the HGM cooling circuit hydrogen.

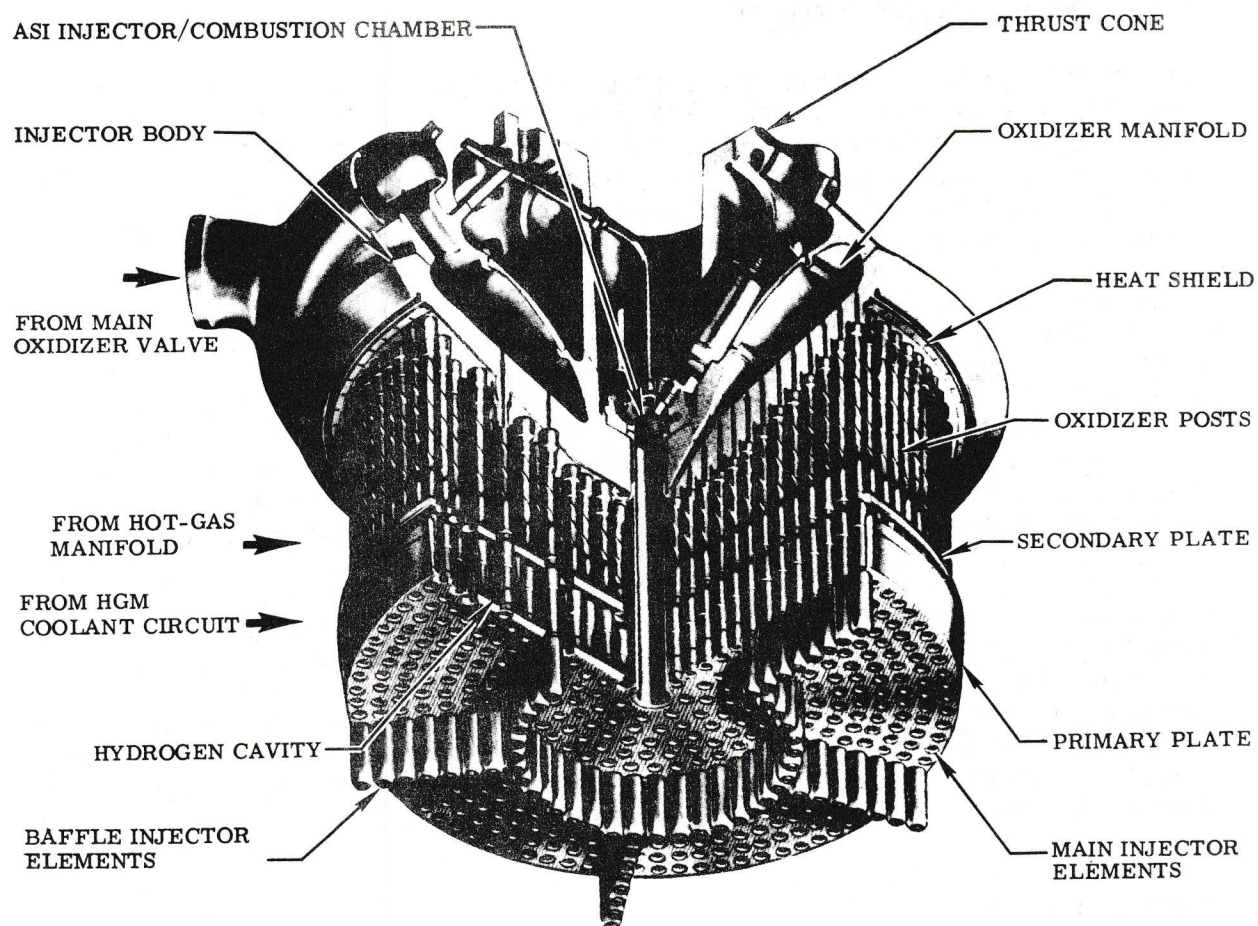


Figure 3.1-8.- Main injector.

3.1.9 Main Injector Elements

The main injector elements are bipropellant, gas/liquid, coaxial fluid injection devices (fig. 3.1-9). They meter, mix, and distribute propellants into the MCC by providing a flow field consisting of a low-velocity liquid oxygen core that is surrounded by a high-velocity, hydrogen-rich hot gas shroud. The main injector uses 525 main injector elements and 75 baffle elements, uniformly spaced radially and circumferentially across its face.

Each main injector element assembly consists of a hollow post within a sleeve that is secured by a retainer and nut between the primary and secondary plates of the main injector. Each post is welded to the injector body and is ported to the injector oxidizer manifold through a metering orifice in the injector body. The posts are recessed from the primary faceplate to provide initial contact between the liquid oxygen stream and hot gas at a region of maximum velocity ratio. The upper end of the posts have four helically wound spoilers machined in their outer perimeter to eliminate vibration induced by the hot gas flow.

The retainer clamps the secondary plate to the sleeve and contains six equally spaced orifices that direct the hot gas into the annulus surrounding the post. The sleeve with the post forms the annulus for the hydrogen-rich hot gas. Centering lugs are machined in the sleeve to ensure concentricity of the post and hot gas annulus. A nut secures the primary faceplate to the sleeve and forms the cup in which the initial contact between the liquid oxygen and hot gas takes place.

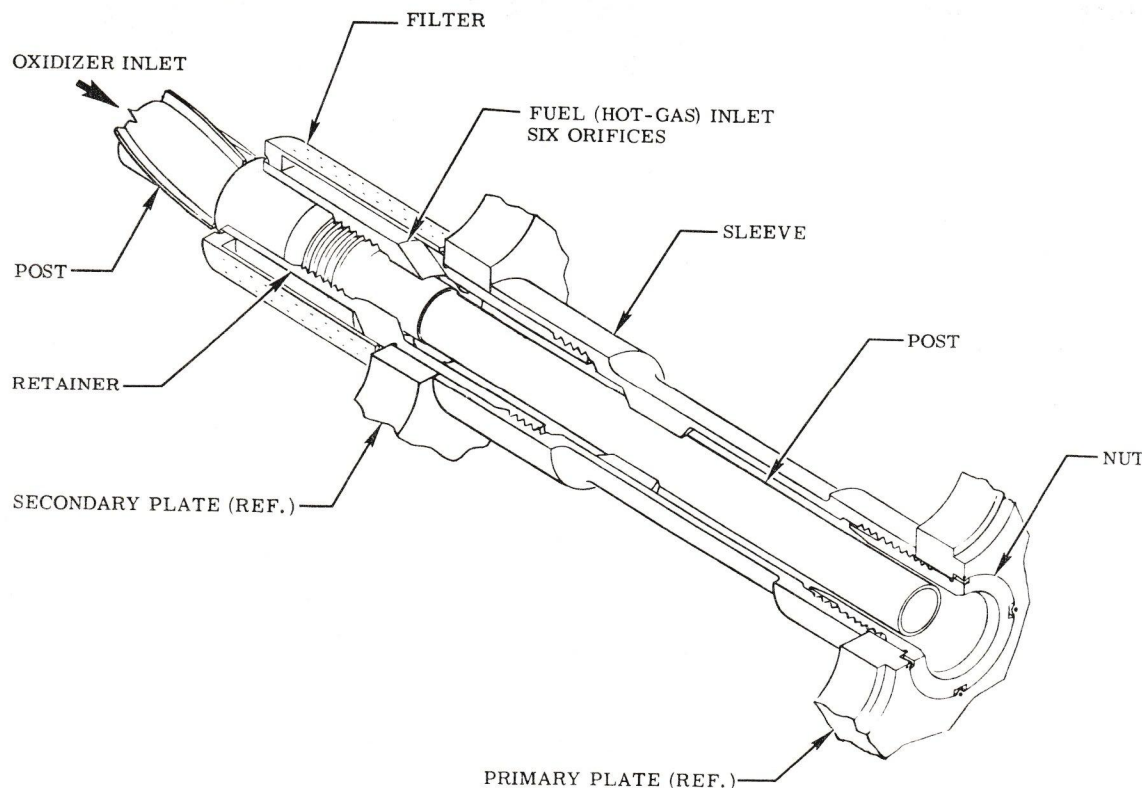


Figure 3.1-9.- Main injector element.

3.1.10 Main Injector Baffle Elements

The main injector baffle elements are bipropellant, gas/liquid, coaxial, fluid-injection devices that divide the face of the injector into six combustion compartments to prevent combustion instability modes below a frequency of 4680 Hz (fig. 3.1-10). Seventy-five baffle elements, along with 525 main elements, meter, mix, and distribute propellants into the MCC. The baffle elements extend 2 in. below the primary faceplate and provide a flow field consisting of a low-velocity liquid oxygen core that is surrounded by a high-velocity, cold hydrogen gas shroud.

Each main injector baffle element assembly consists of a post, a retainer, a sleeve, a jacket, and a core. The sleeve, jacket, and core are brazed together into an integral component. Each post is hollow, welded to the injector body, and ported to the injector oxidizer manifold through a metering orifice in the injector body. The upper end of the posts have four helically wound spoilers machined into their outer perimeter to eliminate vibration induced by the hot gas flow to the main injector elements.

The retainer threads (LH) to the posts and clamps the secondary plate to the sleeve which is threaded (RH) to the retainer. The sleeve is hollow throughout its length and has 16 rows of orifices, which direct the cold hydrogen gas into the annulus formed by the post and sleeve. From this annulus the cold hydrogen gas is redirected through holes in the sleeve and into the annulus formed by the jacket and core.

The inner wall of the jacket has milled rectangular channels to provide convective cooling of the baffle element exposed to the high temperature in the MCC. The geometry of the baffle tip provides both a smooth external gas transition and initiates early propellant interaction at the baffle tip.

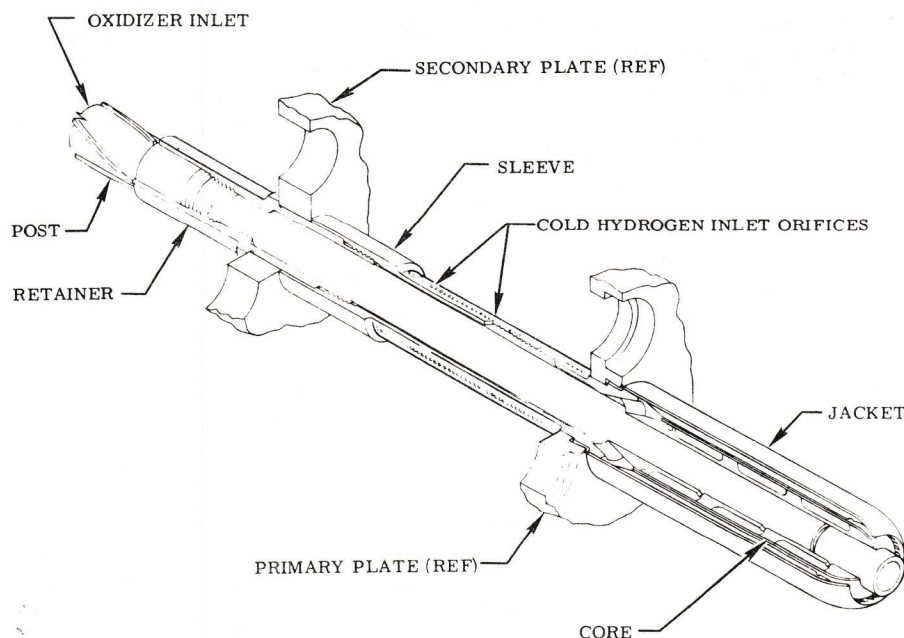


Figure 3.1-10.- Main injector baffle element.

3.1.11 Main Combustion Chamber

The MCC is a cylindrical, regeneratively cooled, structural chamber that contains the burning propellant gases and initiates their expansion from the chamber throat to a ratio of 5:1. It is flange-attached to the HGM. The MCC consists of a coolant liner, a high-strength structural jacket, coolant inlet and outlet manifolds, a throat ring, and two actuator struts (fig. 3.1-11).

The chamber coolant liner provides the coolant flow path for the MCC. It consists of a chamber machined to the same contour as the ID of the structural jacket. The outer surface has 390 milled axial coolant channels that are closed out by an electroforming process that deposits a copper barrier, followed by a nickel closeout over the coolant channels. The channels are ported to coolant inlet and outlet manifolds of the chamber jacket to provide an up-pass circuit for MCC fuel coolant. At the upper end of the liner near the injector face are 30 acoustic cavities that damp out high-frequency baffle compartment oscillations.

The chamber jacket provides the structural strength of the MCC. The jacket is approximately 20 in. long and is formed and machined in two matched halves. The halves are placed around the liner and welded to each other and to inlet and outlet coolant manifolds, which in turn are welded to the liner. A throat ring is welded to the structural jacket to provide additional strength. Two thrust vector control actuator strut assemblies are bolted to the MCC.

Geometry

Number of acoustic cavities	30
Injector end diameter, in.	17.74
Throat area, in. ²	83.41
Injection end to throat length, in. . . .	14.00
Contraction ratio	2.96:1
Expansion ratio	5.0:1

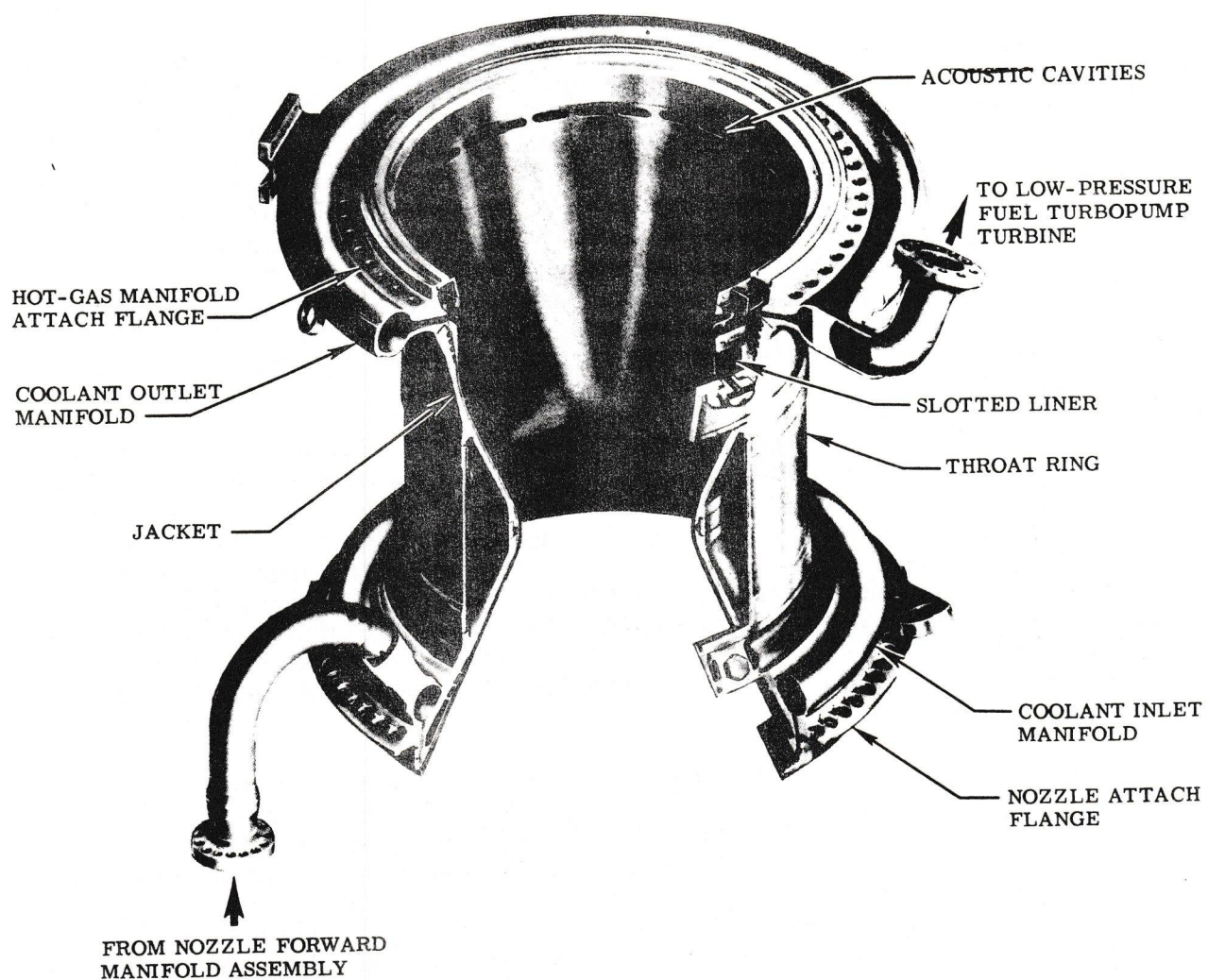


Figure 3.1-11.- Main combustion chamber.

3.1.12 Nozzle Assembly

The nozzle assembly is a fuel-cooled, 80.6-percent bell nozzle that provides a 77.5:1 thrust chamber expansion ratio. It is approximately 113 in. long and has a 94-in. exit outside diameter. It is bolted to the MCC at the 5:1 expansion ratio plane (fig. 3.1-12).

The nozzle assembly basically consists of a forward manifold subassembly and a stacked nozzle subassembly. The forward manifold subassembly distributes hydrogen to the main chamber and nozzle cooling circuits, and provides the flanges for attaching the nozzle assembly to the MCC, Main Fuel Valve (MFV), and preburner fuel supply duct. The nozzle assembly allows continued expansion of the combustion gases exiting the MCC to provide the maximum thrust efficiency possible.

The forward manifold subassembly is welded to the stacked nozzle subassembly. The forward manifold subassembly consists of the manifold shell, diffuser, mixer, Chamber Coolant Valve (CCV) housing, and the CCV duct. The diffuser inlet interfaces with the downstream end of the MFV and distributes hydrogen to the fuel circuits. The diffuser directs fuel to the nozzle coolant inlet manifold, the MCC coolant inlet manifold, the CCV, and the ASI's. The fuel system purge check valve is attached to the diffuser. The mixer mixes fuel from the CCV with fuel from the nozzle coolant outlet and directs it to the Oxidizer Preburner (OPB) and Fuel Preburner (FPB).

The stacked nozzle subassembly consists of 1080 tubes that are connected to a coolant inlet manifold at the nozzle exit and to a coolant outlet manifold at the nozzle forward end. The nozzle tubes provide an up-pass cooling circuit between the inlet and outlet manifolds. The hydrogen through the circuit is directed to a mixer where it joins the hydrogen flow through the CCV and is used as the fuel for the preburners. The nozzle coolant tubes are enclosed in a structural jacket that has nine insulated reinforcing hat bands to provide hoop strength for the assembly.

A vehicle-to-engine heat shield support ring is welded to the forward end of the structural jacket and is the engine attach point for the vehicle-supplied heat shield.

Overboard drain line extensions interface with the engine oxidizer, fuel, hot gas, and hydraulic drain systems.

Geometry

Attach point area ratio	5.0:1
Exit area ratio	77.5:1
Length (throat to exit)	121
Exit diameter (inside/outside), in.	90.7/94
Number of tubes	1080
Number of feed ducts	3

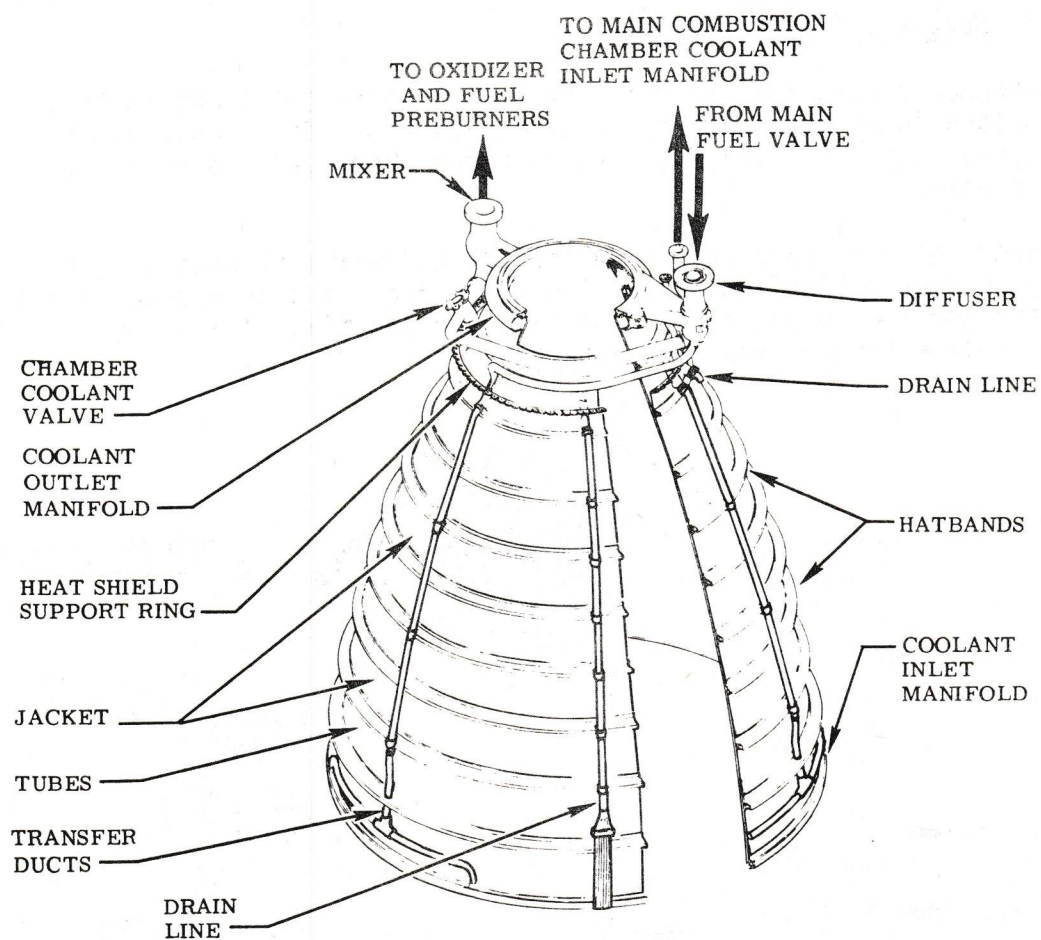


Figure 3.1-12.- Nozzle assembly.

3.1.13 Nozzle Diffuser and Mixer

The diffuser routes fuel from the Main Fuel Valve (MFV) outlet to the nozzle coolant inlet manifold, MCC coolant inlet manifold, CCV, and to the ASI's (fig. 3.1-13). The fuel system purge check valve also attaches to the diffuser.

The mixer receives cold fuel from the CCV and mixes it with fuel from the nozzle coolant outlet manifold. The mixed fuel is then routed to the oxidizer and fuel preburners. The diffuser and mixer are integral parts of the nozzle forward manifold assembly.

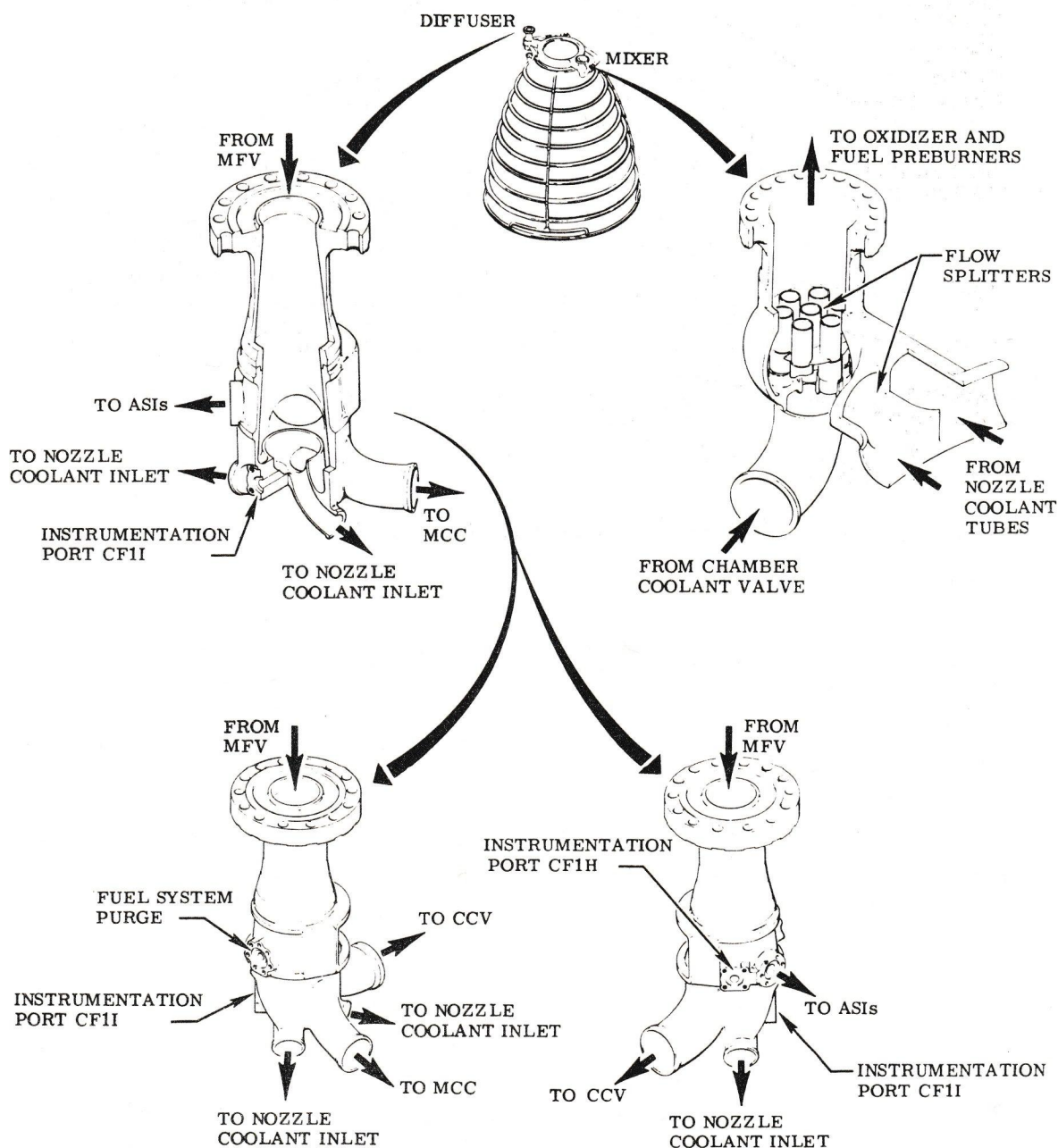


Figure 3.1-13.- Nozzle diffuser and mixer.

3.1.14 Nozzle Thermal Insulation

Thermal protection for the nozzles is required because of the thermal environment the exposed portion of the nozzles experience during the launch, ascent, on-orbit, and reentry phases of a mission (fig. 3.1-14).

The primary insulation consists of two layers of metallic batting covered with a metallic foil and screen. Secondary insulation (an additional two layers of batting and screen) will be used to provide protection as required for each vehicle engine installation position and to maintain interchangeability for all engine positions.

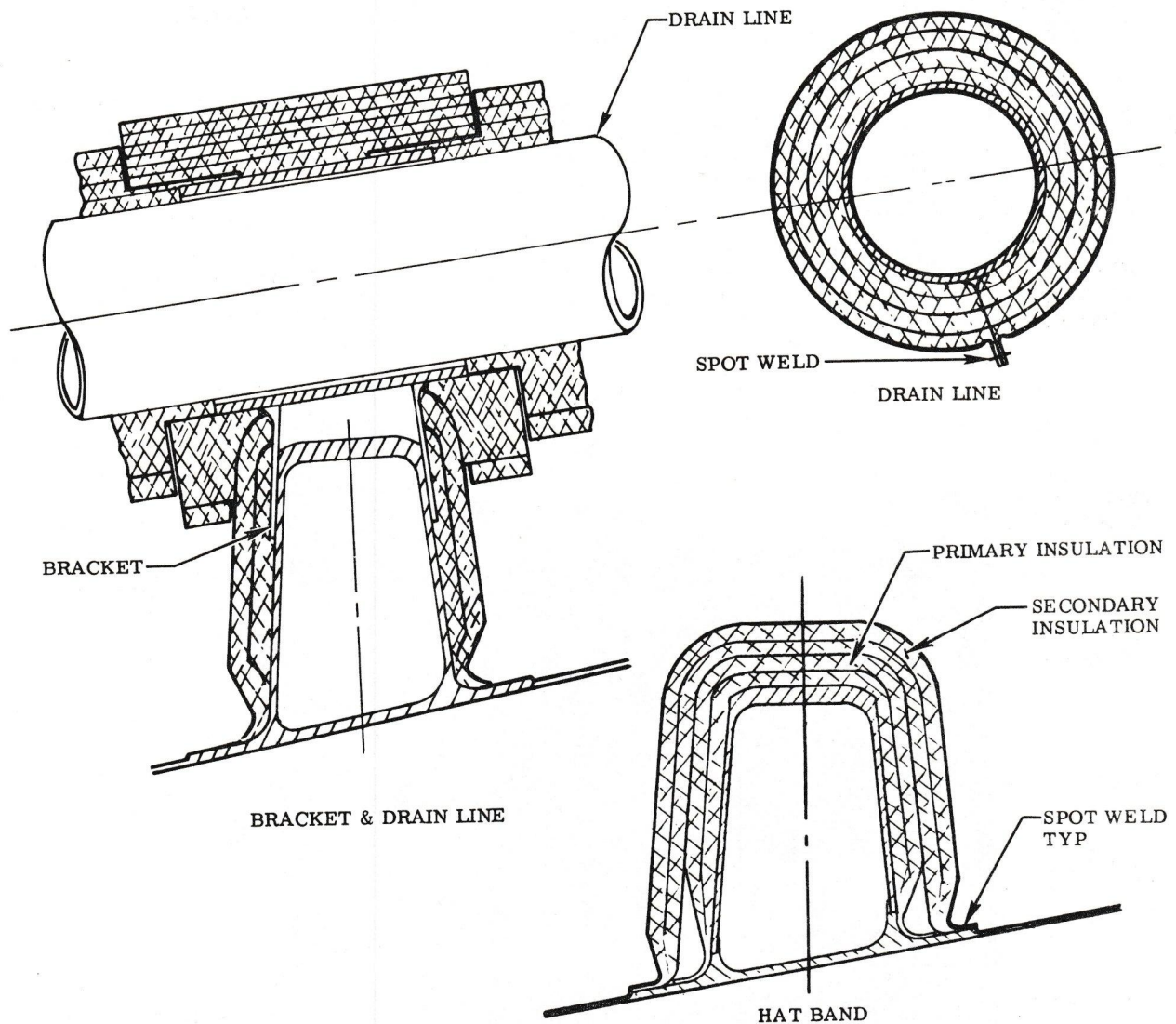


Figure 3.1-14.- Nozzle thermal insulation.

3.1.15 Low-Pressure Oxidizer Turbopump

The Low-Pressure Oxidizer Turbopump (LPOTP) is an axial-flow pump driven by a six-stage turbine that is powered by liquid oxygen (fig. 3.1-15). During engine start and mainstage, the LPOTP maintains sufficient pressure to the High-Pressure Oxidizer Turbopump (HPOTP) to permit the HPOTP to operate at high speeds. Turbine-drive fluid is tapped from the HPOTP discharge and, after powering the turbine, is injected into the pumped fluid through a port between the turbine discharge and pump discharge volutes. The combined flows are then routed to the HPOTP inlet. Since the pumped fluid and turbine drive fluid are both liquid oxygen and the LPOTP is located upstream of the oxidizer valves, the requirement for dynamic seals, purges, and drains has been eliminated.

The rotor is supported by two liquid-oxygen-cooled ball bearings. The turbine-end bearing coolant flow path is from the last stage of the turbine, through the bearing, hollow rotor, radial holes in the rotor, and to the inducer discharge. Coolant for the inducer-end bearing is from the turbine inlet, through the rotor labyrinth seal, through the bearing, and to the inducer discharge. A redundant-element, magnetic-type speed transducer is installed on the turbine end of the turbopump housing. The LPOTP is a Line Replaceable Unit (LRU) and has an approximate overall dimensional envelope of 18 by 18 in.

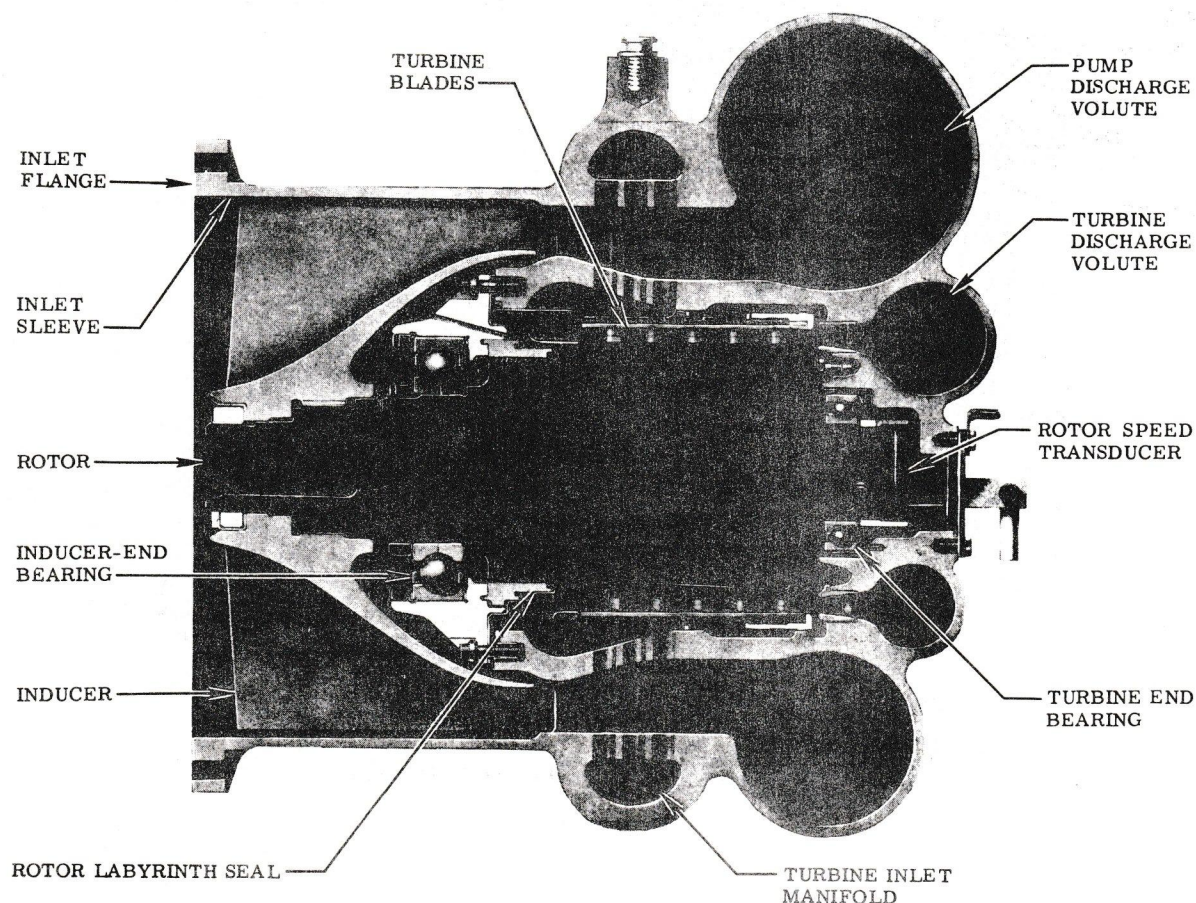


Figure 3.1-15.- Low-pressure oxidizer turbopump.

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3.1.16 Low-Pressure Fuel Turbopump

The Low-Pressure Fuel Turbopump (LPFTP) is an axial-flow pump driven by a two-stage turbine that uses gaseous hydrogen (GH₂) as the power medium (fig. 3.1-16). During engine start and mainstage operation, the LPFTP maintains sufficient pressure to the High-Pressure Fuel Turbopump (HPFTP) to permit the HPFTP to operate at high speeds. The turbine is driven by GH₂ from the MCC coolant valve manifold.

The inducer and shaft are supported by three liquid-hydrogen-cooled (LH₂) ball bearings. The bearing coolant is the leakage across the inducer discharge labyrinth seal. The coolant flows through the pump end bearings and turbine bearing and is returned to the pump inlet through passages in the shaft, bearing bearing spacer, and inducer.

Before engine start, leakage from the pump into the turbine is prevented by a spring-loaded-closed, propellant pressure-actuated-open, lift-off seal. During engine start, the seal nose is separated from its mate ring when increasing fuel pressure overcomes the spring force. A positive separation between the seal nose and mate ring is maintained until engine shutdown when fuel pressure decreases below spring force. During operation, leakage from the turbine into the pump is minimized by the pump and turbine seals. A redundant-element, magnetic-type speed transducer is installed in the pump volute to monitor shaft speed. Access ports in the vehicle duct allow periodic inspection of the inducer blades for damage. Inspection is performed with a fiber optic borescope.

The LPFTP is an LRU and has an overall dimensional envelope of approximately 18 by 24 in.

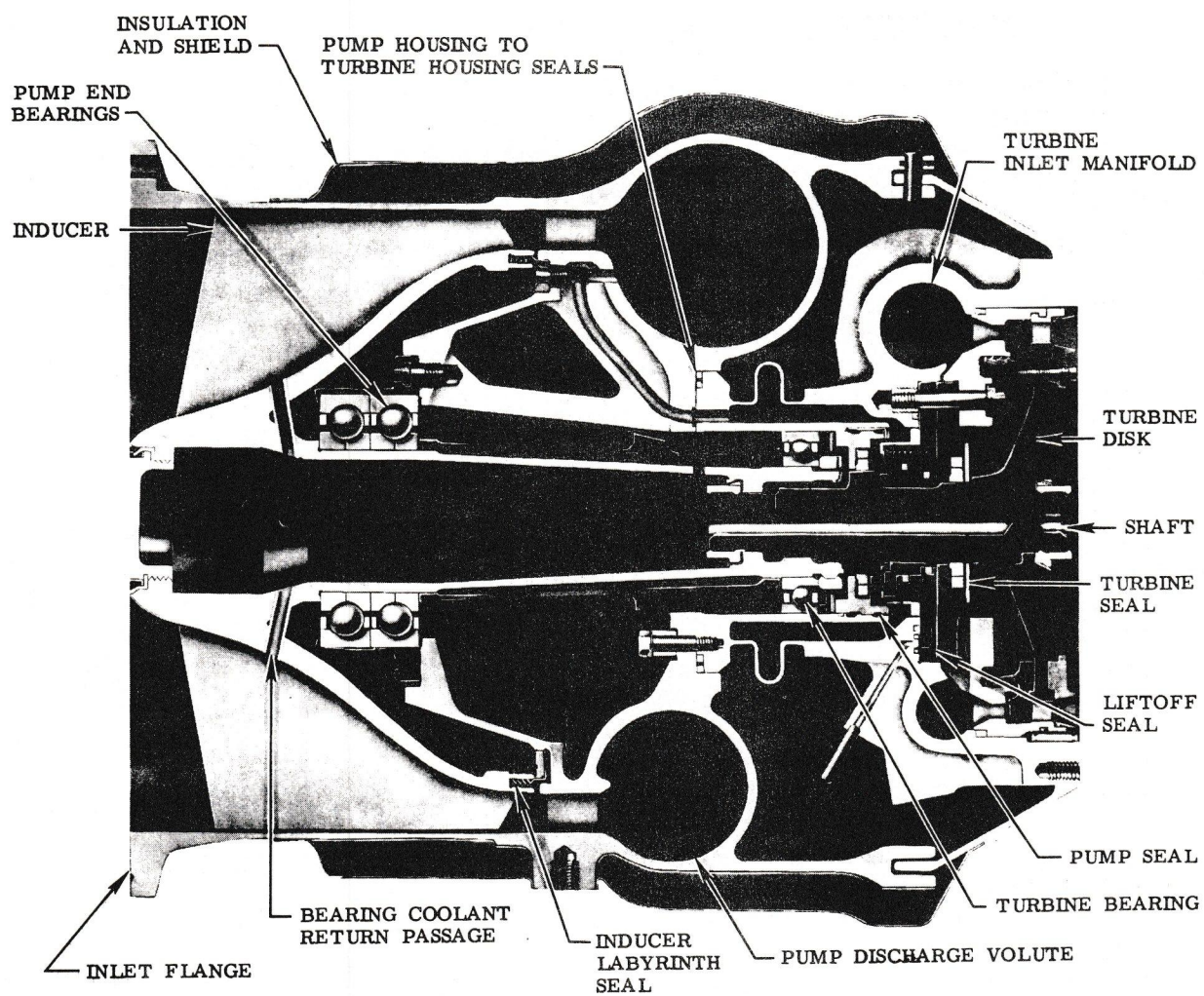


Figure 3.1-16.- Low-pressure fuel turbopump.

3.1.17 High-Pressure Oxidizer Turbopump

The High-Pressure Oxidizer Turbopump (HPOTP) consists of two single-stage centrifugal pumps on a common shaft that are directly driven by a two-stage hot gas turbine (fig. 3.1-17). The main pump receives oxidizer from the LPOTP and supplies oxygen at an increased pressure to the LPOTP turbine, the heat exchanger, preburner pump, and the thrust chamber injector. The preburner pump further increases the pressure to the level required by the Oxidizer Preburner (OPB) and Fuel Preburner (FPB). The turbine is powered by hot gas (hydrogen-rich steam) supplied by the OPB. Mixing of oxidizer and hot gas is prevented by seals, a purge, and drains. Two duplex sets of liquid-oxygen-cooled ball bearings support the rotating parts. The HPOTP is flange-attached to the Hot Gas Manifold (HGM) and is canted at a 10° angle out from the engine centerline. The HPOTP is an LRU with an overall dimensional envelope of approximately 24 by 36 in.

The HPOTP main pump has a single inlet with 50-50 flow split into a double-entry, common outlet impeller. Liquid oxygen enters the main pump through the main pump housing where the flow split is made. Inlet vanes direct the flow to the impeller inlet guide vanes, which in turn direct the flow to the impeller inlets. The impeller has four full and four partial blades in each half. After passing through the impeller, the flow is redirected into the discharge volute by diffuser vanes.

Turbopump shaft bearings are cooled by liquid oxygen from the preburner pump. Coolant for the preburner-end bearings is through the preburner pump impeller hub labyrinth seal, through the bearings, and to the main pump impeller inlet. The turbine-end bearings coolant is through the preburner impeller bolt, through the hollow shaft, through the bearings, and to the main pump impeller inlet. Pump shaft axial thrust is balanced in that the double-entry main impeller is inherently balanced and the thrusts of the preburner pump and turbine are equal but opposite. Residual shaft thrust is controlled by a self-compensating, non-rubbing, balance piston which utilizes orifices located at the tip and inner diameter of the main shrouds to control the leakage, and consequently, the pressure acting on the respective shrouds. Mixing of oxidizer and turbine gas is prevented by a dynamic shaft seal package that is between the main pump and the turbine.

The seal package consists of a labyrinth-type primary oxidizer seal, a purged controlled-gap intermediate seal, and two controlled-gap turbine hot gas seals. Drain cavities with overboard drain lines are located between the primary oxidizer seal and the intermediate seal, between the intermediate seal and secondary turbine seal, and between the secondary and primary turbine seals. To further ensure against the mixing of oxidizer and turbine gas, a helium purge is applied between the elements of the intermediate seal during engine operation.

The preburner pump has a single-entry impeller that discharges oxidizer through diffuser vanes into the discharge volute. The preburner pump housing is flange-mounted to the main pump housing. Impeller seals interface with labyrinths cut in the outside diameter of the impeller shroud and hub to minimize leakage back to the pump inlet and control the flow for cooling the preburner pump-end bearings.

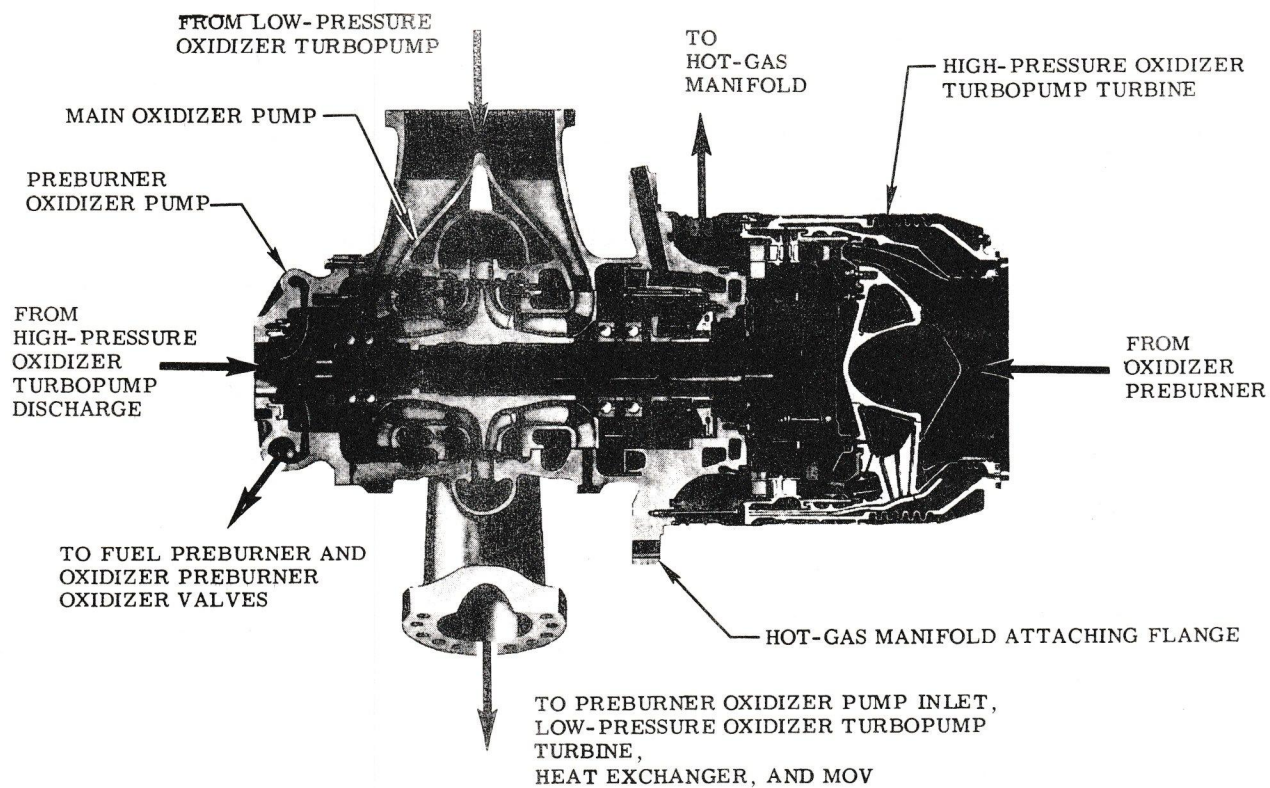


Figure 3.1-17.- High-pressure oxidizer turbopump.

3.1.18 High-Pressure Oxidizer Turbopump Turbine

The high-pressure oxidizer turbopump turbine is powered by hot gas generated by the OPB (fig. 3.1-18). Hot gas enters the turbine and flows across the shielded support struts, through the first- and second-stage nozzles and blades, and is discharged into the HGM. The turbine rotors are mated through a curvic coupling and are held together with a circle of bolts. The second-stage rotor is integral with the pump shaft. Turbine blade-to-house leakage is minimized by lands on the outer perimeter of the blade shrouds that run against seals in the turbine housing.

All components of the turbine are cooled by gaseous hydrogen flowing over or through them. Coolant is supplied from the OPB coolant jacket. After cooling the turbine components, the coolant is exhausted into the hot gas flow stream.

Turbine-to-OPB sealing is accomplished by a pair of concentric bellows that load dual seals in the turbine inlet flange to the OPB. Turbine component materials are primarily nickel- and cobalt-base alloys. The diameter of the turbine rotors with blades is approximately 11 in.

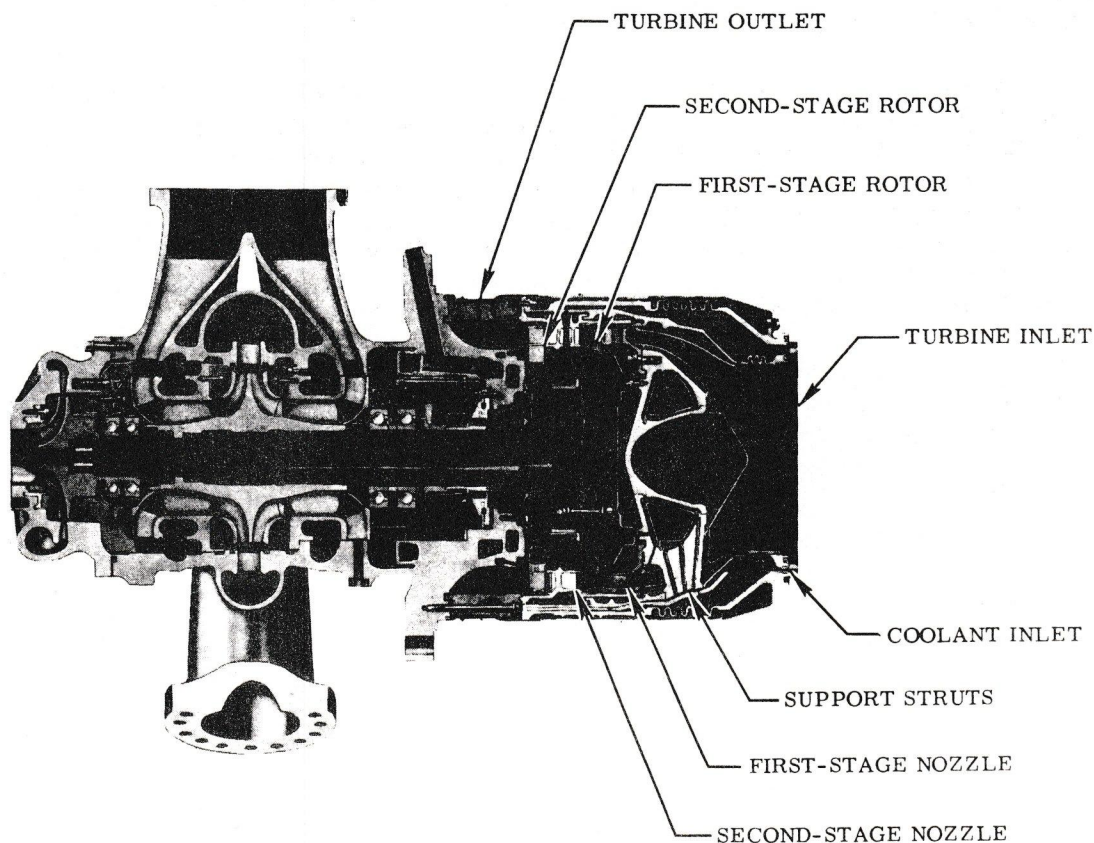


Figure 3.1-18.- High-pressure oxidizer turbopump turbine.

3.1.19 High-Pressure Fuel Turbopump

The High-Pressure Fuel Turbopump (HPFTP) is a three-stage centrifugal pump that is driven by a two-stage hot gas turbine (fig. 3.1-19). The pump receives fuel from the LPFTP and supplies it at increased pressure, through the MFV, to thrust chamber assembly coolant circuits. The turbine is powered by hot gas (hydrogen-rich steam) generated by the FPB.

Fuel flows in series through the three impellers from pump inlet to outlet, with flow redirected between the impellers by interstage diffusers.

Coolant flow across the pump-end bearings is provided by the first-stage impeller backplate wear-ring flow. The coolant is returned to the inlet of the first-stage impeller. Coolant flow to the turbine-end bearings is supplied from the pump balance piston cavity through the shaft static lift-off seal.

Axial rotor thrust is controlled by a self-compensating, double-acting balance piston that operates between high- and low-pressure orifices to maintain thrust at zero during normal operation. A thrust bearing located at the pump inlet end of the rotating assembly controls rotor thrust during start and cutoff transient operations.

Before engine start, leakage from the pump into the turbine is prevented by a spring-loaded-closed, propellant pressure-actuated-open, lift-off seal. During engine start, the seal nose is separated from its mate ring when increasing fuel pressure overcomes the spring force. A positive separation between the seal nose and mate ring is maintained until engine shutdown when actuating pressure decreases below spring force. Propellant flow through the seal and mate ring is used to cool the turbine-end bearings and the turbine components.

The HPFTP is flange-attached to the HGM and is canted out from the engine centerline at a 10° angle. The HPFTP is an LRU with an overall dimensional envelope of approximately 22 by 44 in.

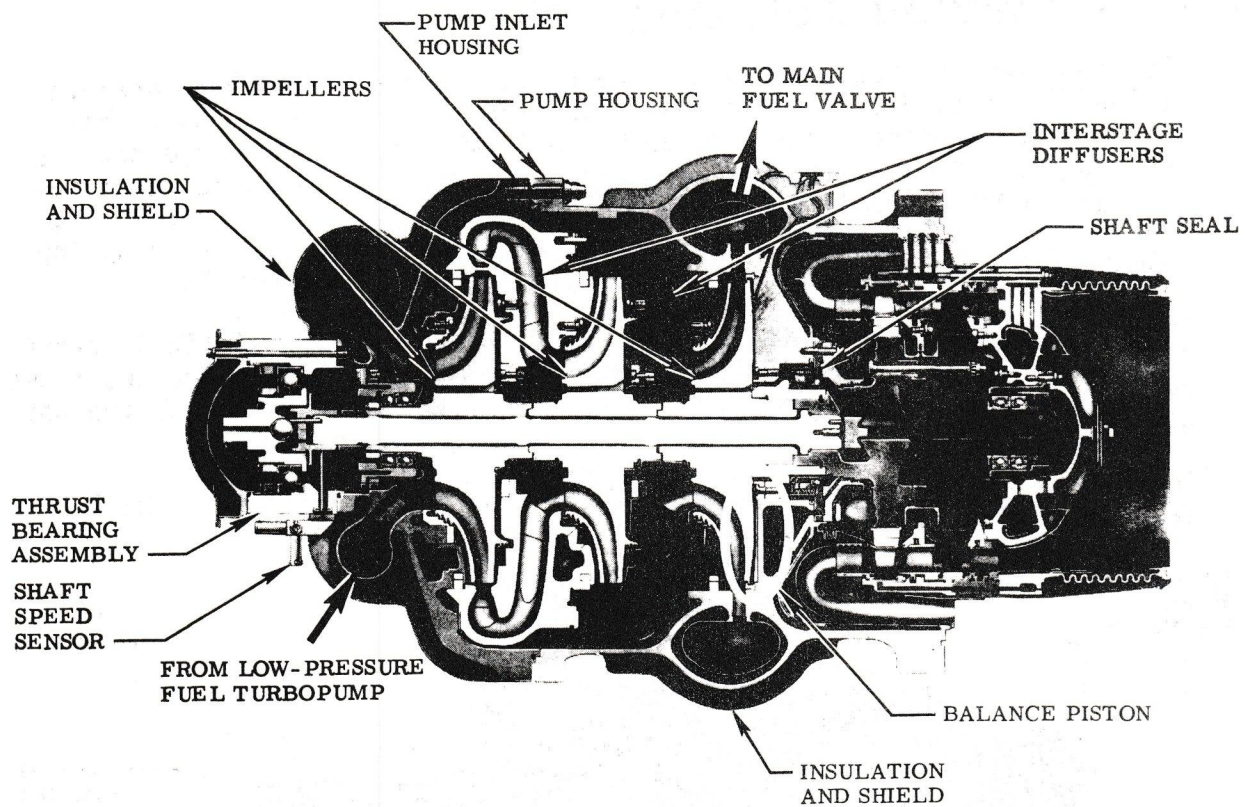


Figure 3.1-19.- High-pressure fuel turbopump.

3.1.20 High-Pressure Fuel Turbopump Turbine

The high-pressure fuel turbopump turbine is powered by hot gas generated by the FPB (fig. 3.1-20). Hot gas enters the turbine and flows across the shielded support struts, through the first- and second-stage nozzles and blades, and is discharged into the HGM. The turbine disks are mated through a curvic coupling and are held together with a circle of bolts. The two-stage turbine transmits torque to the pump by a splined coupling between the second-stage wheel and the pump third-stage impeller.

Bearing and turbine coolant is supplied through the shaft static lift-off seal when the seal is actuated at engine start. The turbine coolant flows over or through the hot gas components and is then exhausted into the hot gas flow stream.

Turbine-to-FPB sealing is accomplished by a bellows that loads a Naflex seal against the FPB flange.

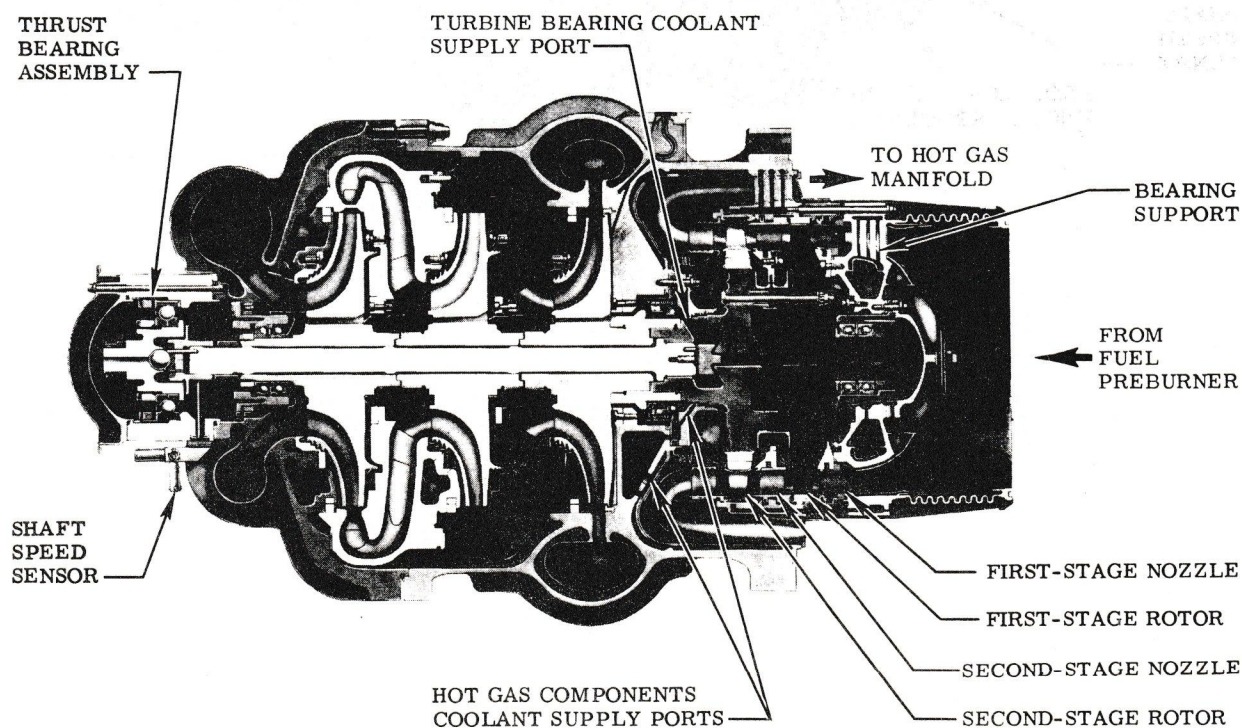


Figure 3.1-20.- High-pressure fuel turbopump turbine.

3.1.21 Heat Exchanger

The heat exchanger has a multipath, single-pass, coilpack installed in the oxidizer side of the HGM and an orificed bypass line directly outside (fig. 3.1-21). It converts liquid oxygen to gaseous oxygen for vehicle oxygen tank pressurization and the pogo system accumulator. The coil pack consists of a helically wound, small tube approximately 30.6 in. long, in series with two larger, parallel tubes each approximately 310 in. long. The tubes are attached to supports welded to the HGM coolant jacket inner wall. The crossflow of hot turbine exhaust gases from the HPOTP provides the heat source.

Liquid oxygen tapped off the discharge side of the HPOTP is supplied to the inlet of the heat exchanger through an anti-flood valve. The oxygen is heated to a gas in the small tube (first stage) and nearly to the heating gas temperature in the two larger tubes (second stage). The orificed bypass line injects an unheated portion (approximately 35 percent) of the total oxygen flow into the outlet of the coils for control of temperature/flowrate operating characteristics. Orifices in the vehicle and pogo system control total heat exchanger oxygen flowrate.

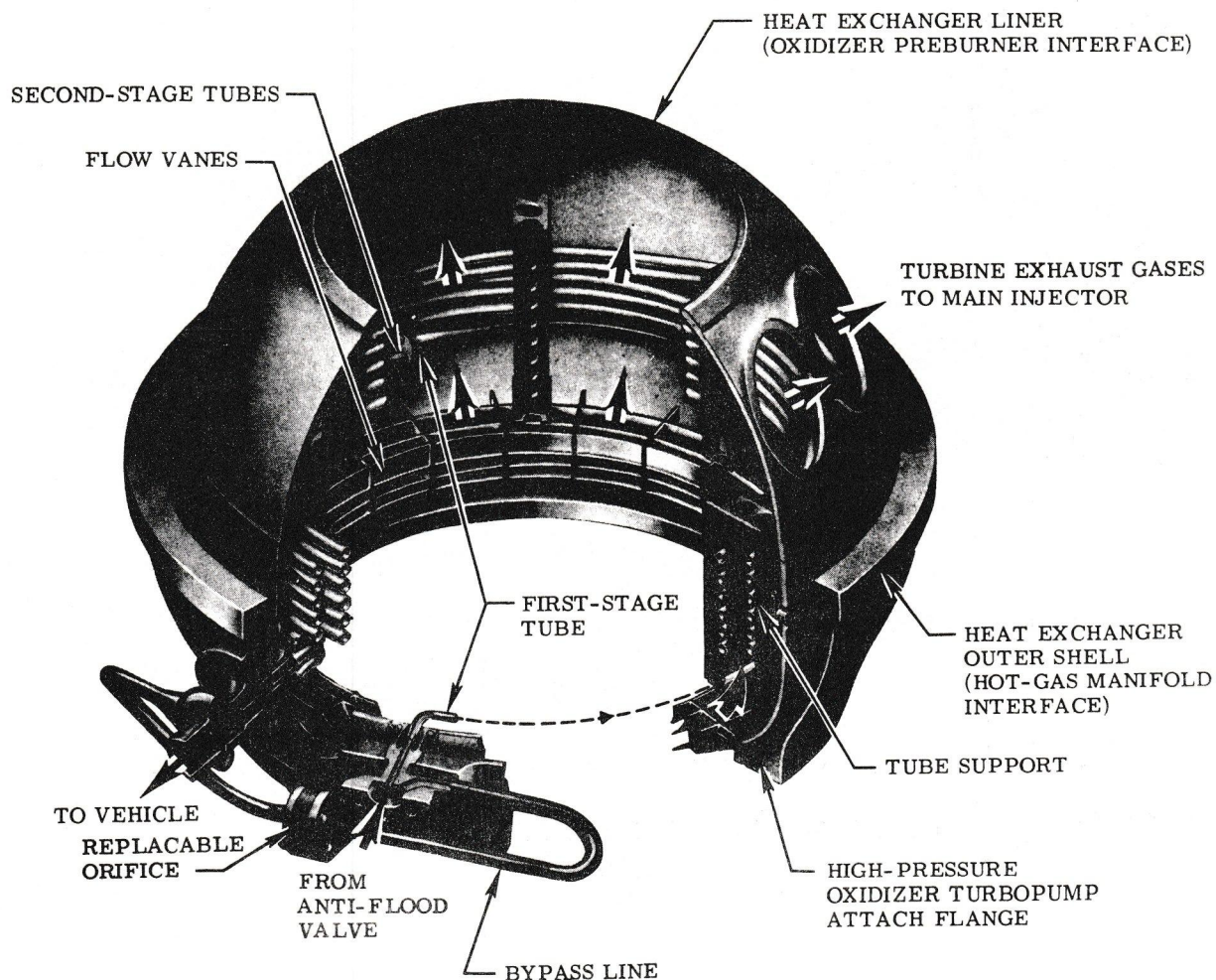


Figure 3.1-21.- Heat exchanger.

3.1.22 Pogo Suppression System

A pogo suppression system is provided to prevent the transmission of low-frequency flow oscillations into the high-pressure turbopump, and ultimately to prevent main combustion chamber pressure (engine thrust) oscillations (fig. 3.1-22). Flow oscillations transmitted from the Space Shuttle vehicle are suppressed by a gas-filled accumulator, which is flange-attached to the HPOTP inlet duct. The system consists of a 0.6-ft³ accumulator with an internal standpipe, helium precharge valve package, gaseous oxygen (GO₂) supply valve package, and two recirculation isolation valves (one recirculation isolation valve is located on the Orbiter). Gaseous oxygen provided to the accumulator from the heat exchanger discharge is used as the compliant medium following an initial helium precharge. A continuous GO₂ flow is maintained at a rate governed by a standpipe in the accumulator, which is orificed to regulate the GO₂ overflow over the engine operating power level range. The system is sized to provide sufficient GO₂ to replenish condensation at the minimum GO₂ flowrate and to permit sufficient GO₂ overflow at the maximum decreasing pressure transient in the LPOTP discharge duct. At all other conditions, excess gaseous and liquid oxygen are recirculated back to the LPOTP inlet through the engine oxidizer bleed duct.

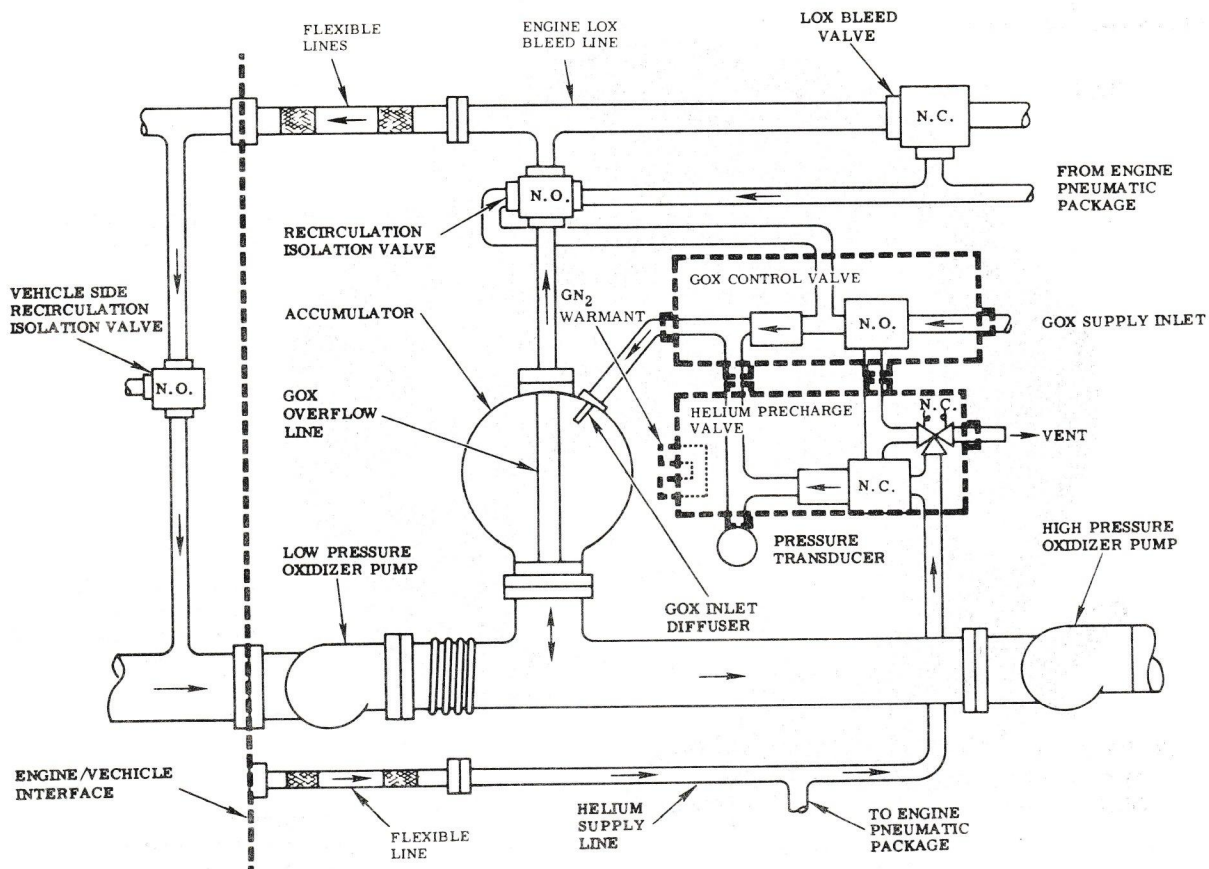


Figure 3.1-22.- Pogo suppression system schematic.

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3.1.23 Pogo Suppressor

The pogo suppressor is a gas-filled accumulator that serves as a capacitance in the liquid oxygen (LO2) flow circuit and prevents low-frequency flow oscillations from being transmitted into the HPOTP (fig. 3.1-23). During engine operation, G02 is obtained from the heat exchanger discharge. During engine start, the accumulator is charged with helium 1.5 sec after the start command to provide pogo protection until the heat exchanger is operational and G02 is available.

The accumulator is partially chilled by LO2 during the engine chilldown operation. Prestart actuation of the recirculation isolation valve allows the accumulator to fill to the overflow line inlet level. This level is sufficient to preclude gas ingestion at start.

The overflow line in the accumulator controls the liquid level at all engine operating points. The orifices are sized to accept the maximum overflow (G02) occurring within the engine operating range. This flow is routed through the engine LO2 bleed line across the gimbal plane to a point upstream of the LPOTP. For most operating conditions, the recirculated G02 will condense prior to reaching the LPOTP inlet.

The accumulator contains an annular ring and cruciform baffles to minimize sloshing of the liquid, and is flange-mounted to the low-pressure oxidizer duct at the inlet of the HPOTP. The pogo suppressor is an LRU.

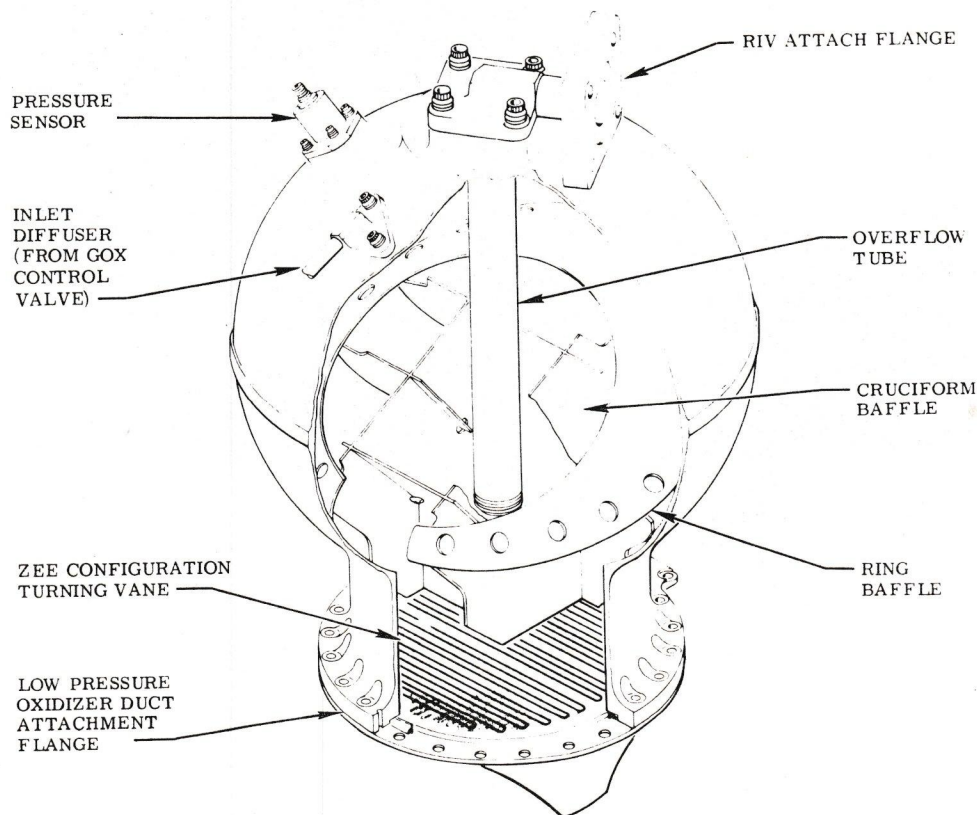


Figure 3.1-23.- Pogo suppressor.

3.1.24 Pogo Helium Precharge Valve

The Helium Precharge Valve (HPV) assembly provides helium pressurant to the pogo accumulator during engine start until gaseous oxygen is available from the engine heat exchanger (fig. 3.1-24).

The HPV is a spring-loaded-closed pneumatically actuated-open poppet valve. It has an integral check valve at its outlet port. The helium supply is filtered by a 15- μ absolute filter at the HPV inlet.

A dual coil, normally closed solenoid valve is mounted on the HPV and provides pilot control of the normally closed HPV and the normally open Gaseous Oxygen Control Valve (GCV).

During the engine start preparation phase, the HPV body is warmed by the main injector oxidizer dome nitrogen purge that flows through the HPV body before being routed to the main injector. The HPV is an LRU.

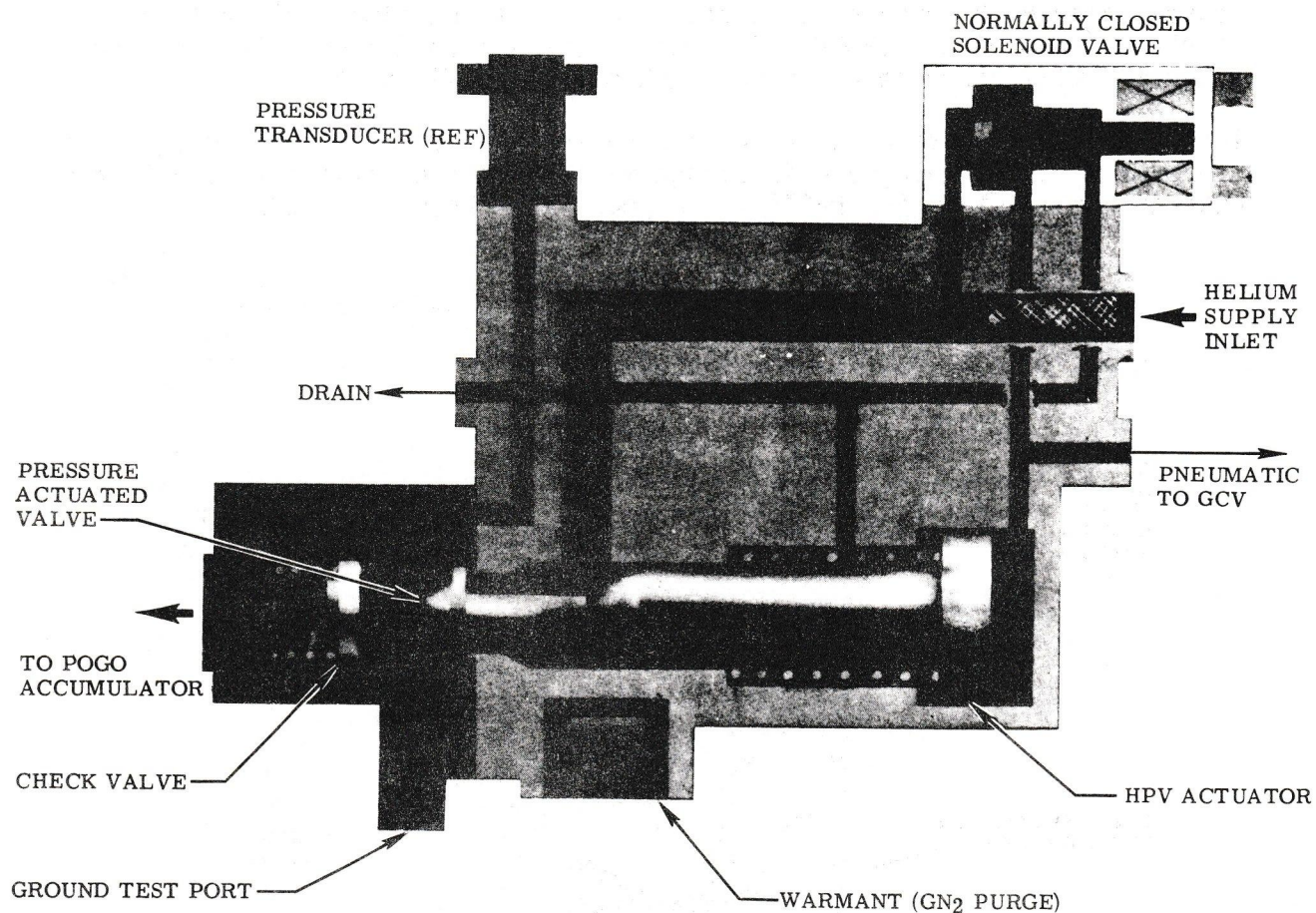


Figure 3.1-24.- Pogo helium precharge valve.

3.1.25 Pogo Gaseous Oxygen Control Valve

The Gaseous Oxygen Control Valve (GCV) provides gaseous oxygen pressurant to the pogo accumulator during engine operation after the engine heat exchanger begins functioning (fig. 3.1-26).

The GCV is a bellows-loaded open, pneumatically actuated-closed poppet valve. It has an integral check valve at its outlet port. The pilot solenoid valve mounted on the HPV controls the operation of the normally closed HPV and the normally open GCV.

A bleed orifice provides fail-operate valve actuation to the open position. Pneumatic pressure to the closing side of the actuator is also applied to the opening side through a bleed orifice. This will cause the valve to reopen approximately 2 sec after the application of closing pressure.

Operation of the Recirculation Isolation Valve (RIV) is ensured by routing gaseous oxygen from the GCV to the override port of the RIV. The GCV is an LRU.

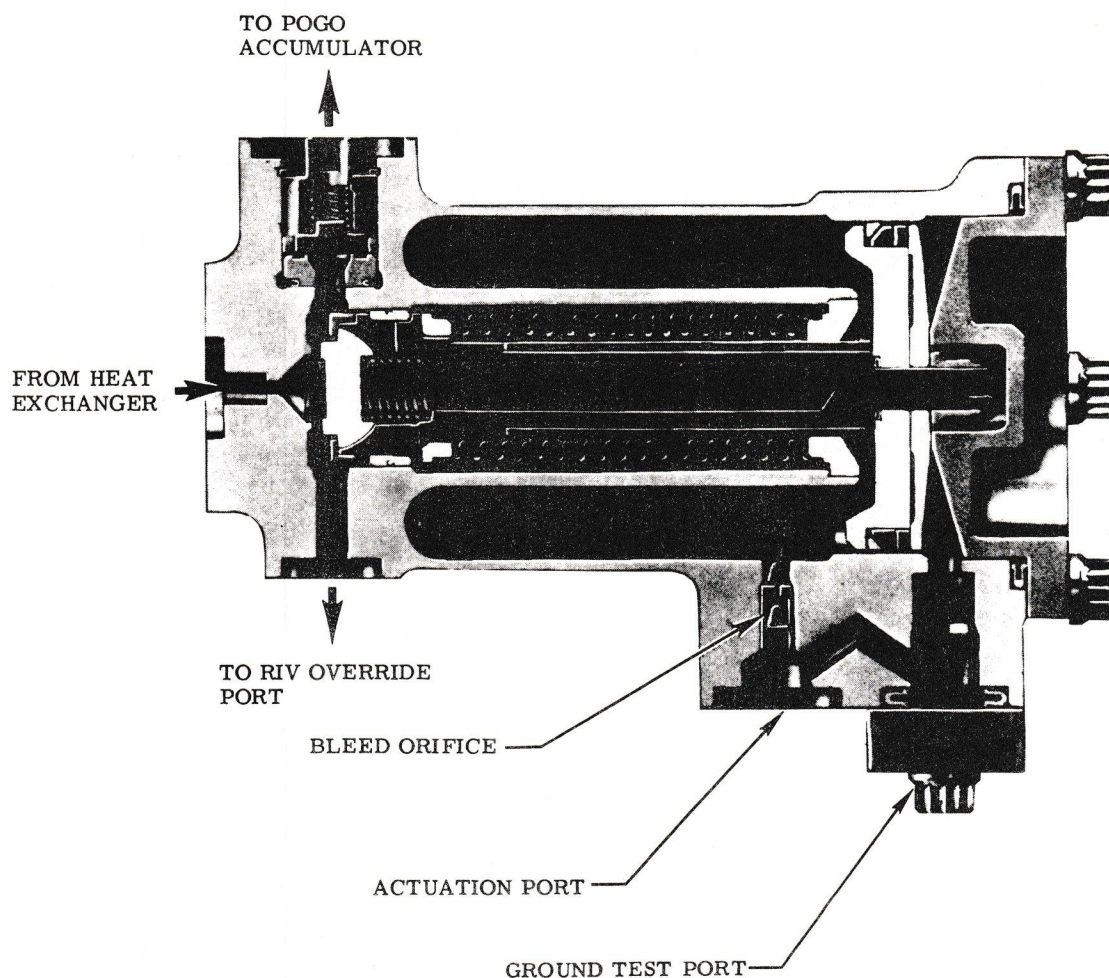


Figure 3.1-25.- Pogo gaseous oxygen control valve.

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3.1.26 Recirculation Isolation Valve

The Recirculation Isolation Valve (RIV) prevents a short circuit in the engine oxidizer system during the propellant conditioning mode of engine start preparation (fig. 3.1-26). The normally open RIV is actuated closed by the same pneumatic pressure that opens the normally closed oxidizer bleed valve.

The RIV is a bellows-loaded open, pneumatically actuated-closed poppet valve. Operation is ensured by routing gaseous oxygen from the override port of the GCV to the opening side of the RIV actuator when the GCV is opened. A Linear Variable Differential Transformer (LVDT) is used for valve position indication. The RIV is an LRU.

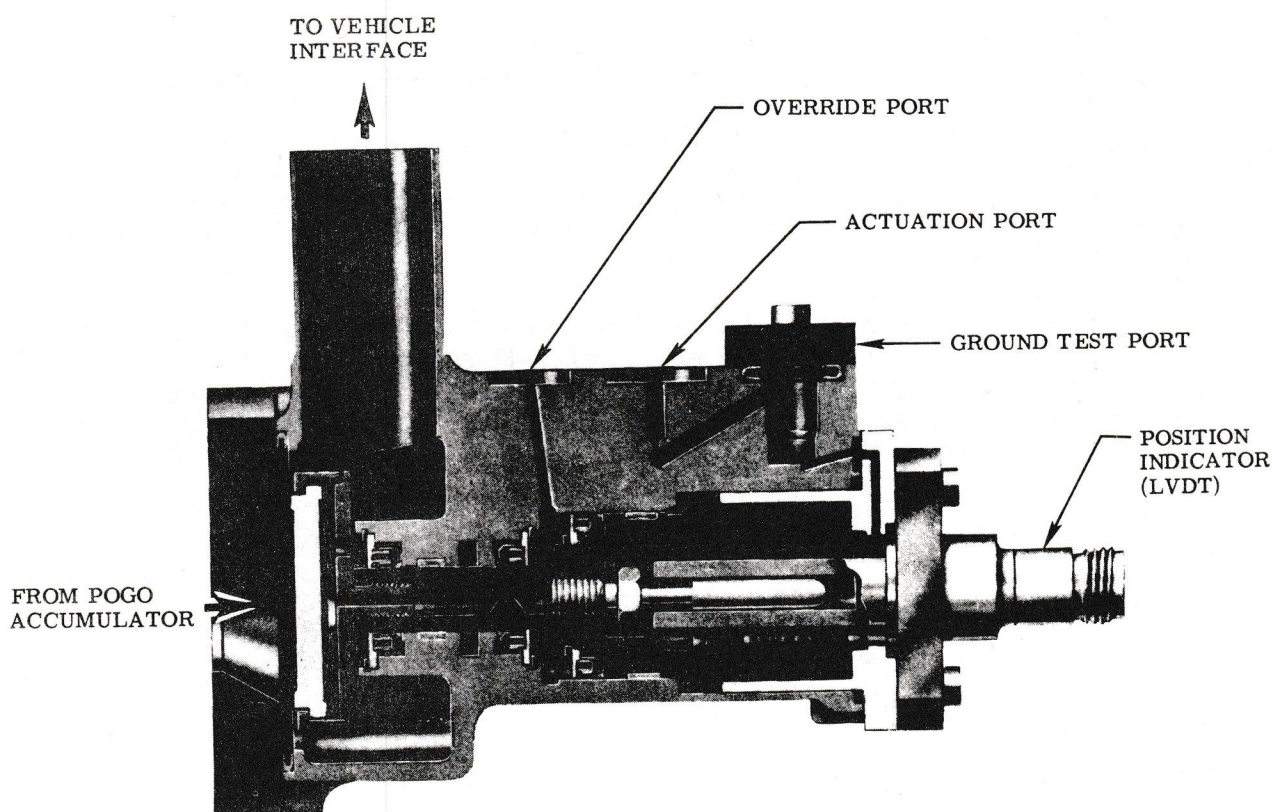


Figure 3.1-26.- Recirculation isolation valve.

3.1.27 Interconnects

Engine interconnects are divided into three categories: main propellant articulating ducts, fluid interface lines, and component interconnects (fig. 3.1-27).

Main propellant articulating ducts interconnect the nongimbaled low-pressure turbopumps to components of the engine that gimbal. The ducts are of the wraparound type and have rigid and flexible sections. The flexible sections consist of a convoluted bellows, a bellows sleeve, and a tension restraint. Three types of tension restraints are used. One has external yokes and gimbal ring with shear pins, another has internal tripods with mating ball and socket, and the third has an internal ball and socket.

Fluid interface lines are the vehicle-to-engine lines for recirculation of propellants, propellant tank pressurants, hydraulics, and pneumatics. Three types of lines are used: Articulating flexible ducts, flexible lines with overbraided convoluted bellows sections, and a rigid line.

Fuel ducts and lines in the propellant recirculation (conditioning) system are insulated to prevent liquid air condensation and to help maintain the fuel temperature at the desired level.

Interconnects with separable connections have bolted flange joints. The basic flange configuration is a modified ASME design with a pilot adjacent to the fluid passage. The pilot design maintains a direct in-line load path at the flange ID under all operating conditions to provide clamping of the joint seal.

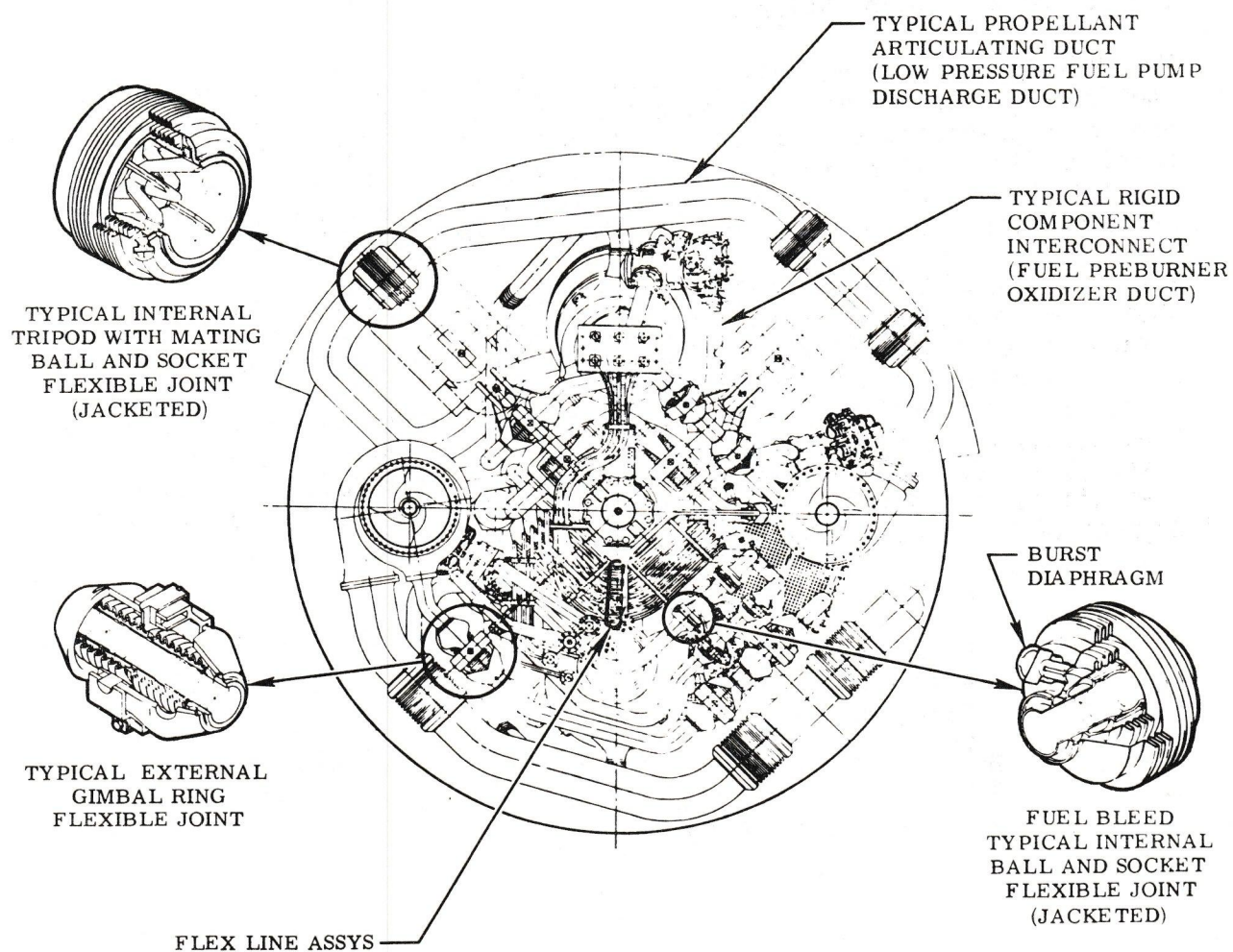


Figure 3.1-27.- Interconnects.

3.1.28 Main Oxidizer Valve

The Main Oxidizer Valve (MOV) is a ball-type valve with a 2.5-in. propellant flow passage flange-mounted between the main chamber oxidizer dome and the high-pressure oxidizer duct (fig. 3.1-28). The valve controls oxidizer flow to the main chamber LO₂ dome and main chamber ASI and is operated by a hydraulic servoactuator mounted to the valve housing. The servoactuator receives its control signals from the controller.

The valve consists of two major moving components: The integral ball/shaft/cams and the ball seal retracting mechanism. The ball inlet seal is a machined plastic, bellows-loaded closed seal. Redundant shaft seals, with an overboard drain cavity between them, prevent leakage along the shaft (actuator end) during engine operation. Inlet and outlet throttling sleeves align the flow to minimize turbulence and the resultant pressure loss. Ball seal wear is minimized by cams and a cam follower assembly that displaces the seal away from contact with the ball during the initial degrees of ball travel when being opened. The MOV is an LRU.

Geometry

Flow passage diameter, in.	2.500
Ball diameter, in.	5.125
Shaft diameter (seal), in.	1.875
Valve length, in.	10.25

$$\text{flow area} = 4.9087 \text{ in}^2$$

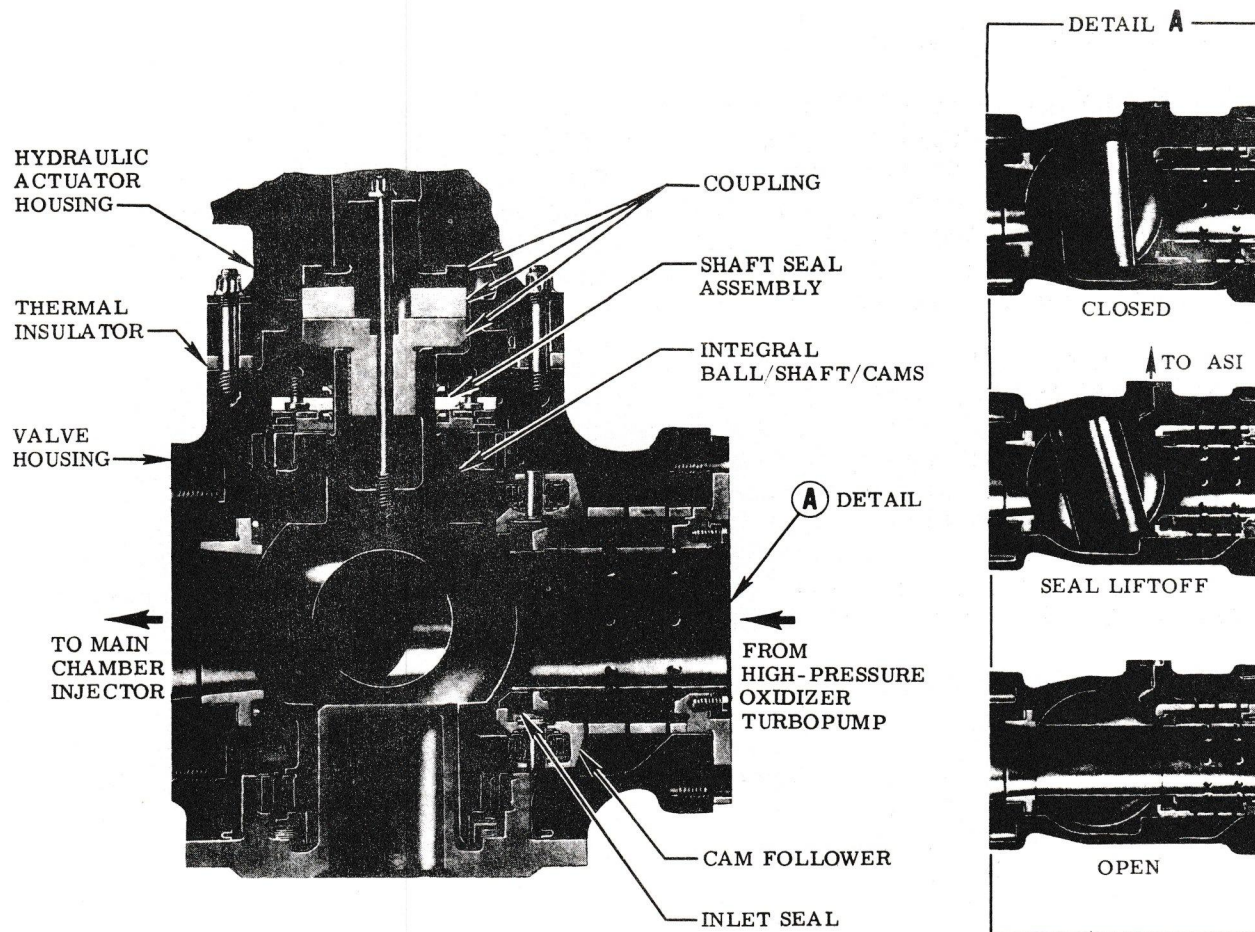


Figure 3.1-28.- Main oxidizer valve.

3.1.29 Main Fuel Valve

The Main Fuel Valve (MFV) is a hydraulically actuated, ball-type valve with a 2.5-in. propellant flow passage (fig. 3.1-29). The MFV is flange-mounted between the high-pressure fuel duct and coolant inlet distribution manifold of the thrust chamber nozzle. The valve permits or stops the flow of fuel to the thrust chamber coolant circuits, the LPFTP turbine, HGM coolant circuit, and the OPB, FPB, and the three ASI's. Valve position is controlled by commands from the engine controller.

The valve consists of two major moving components: The integral ball/shaft/cams and the ball seal retracting mechanism. The ball outlet is a machined plastic, bellows-loaded closed seal. Redundant shaft seals, with an overboard drain cavity between them, prevent leakage along the shaft (actuator end) during engine operation. Inlet and outlet throttling sleeves align the flow to minimize turbulence and the resultant pressure loss. Ball seal wear is minimized by cams and a cam follower assembly that displaces the seal away from contact with the ball during the initial degrees of ball travel when being opened. The MFV is an LRU.

Geometry

Flow passage dimensions, in.	2.500
Ball diameter, in.	5.125
Shaft diameter (seal), in.	1.875
Valve length, in.	10.25

flow area = 4.9087 in²

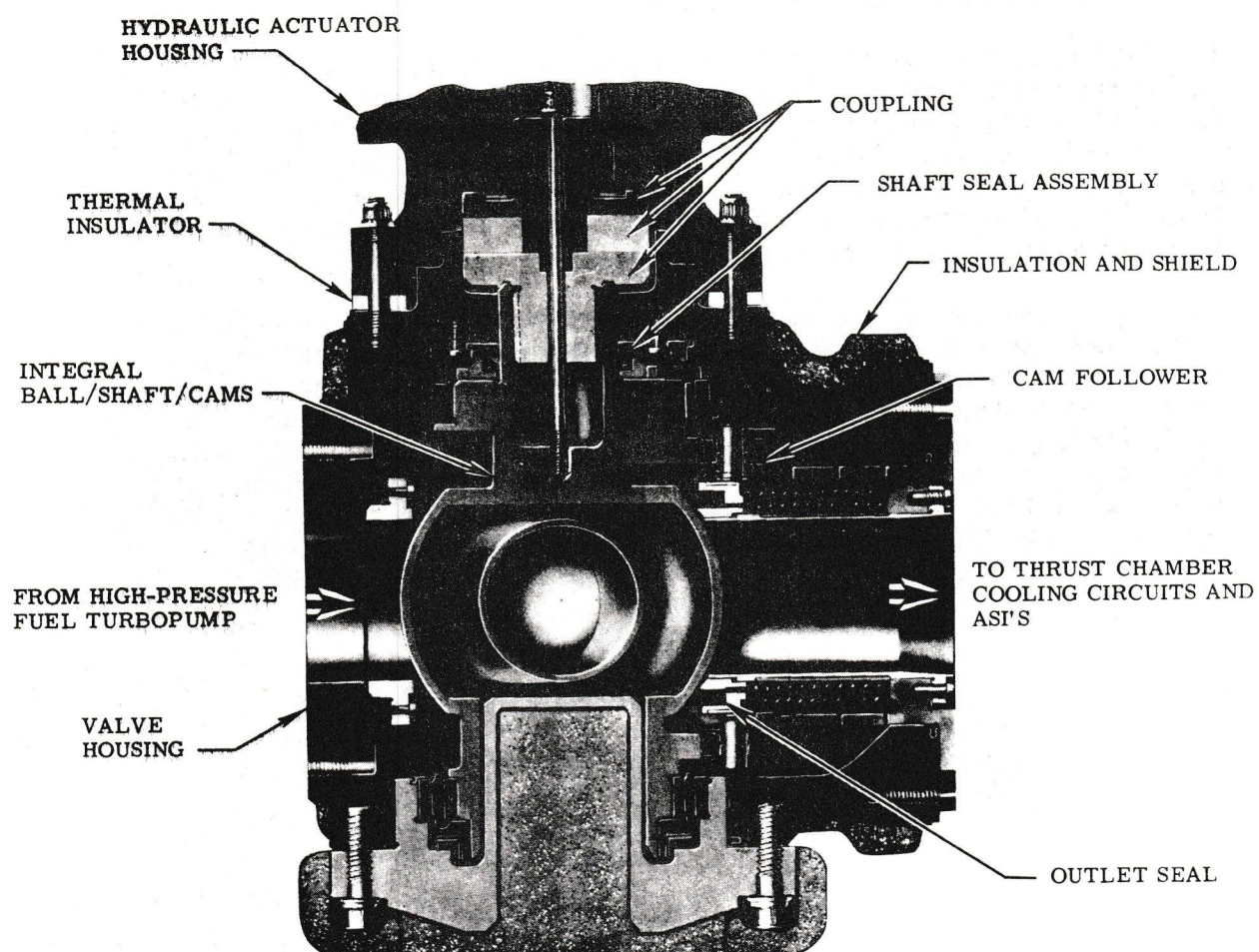


Figure 3.1-29.- Main fuel valve.

3.1.30 Fuel Preburner Oxidizer Valve

The Fuel Preburner Oxidizer Valve (FPOV) is a hydraulically actuated, ball-type valve with a 1.1-in. propellant flow passage (fig. 3.1-30). The FPOV is flange-mounted between the oxidizer supply line to the FPB and the FPB oxidizer inlet. The valve permits or stops the flow of oxidizer to the FPB and the FPB ASI. Valve position is controlled by commands from the engine controller; during mainstage operation the valve is modulated to maintain the desired engine mixture ratio.

The valve consists of two major moving components: The integral ball/shaft/cams and the ball seal retracting mechanism. The ball inlet seal is a machined plastic, bellows-loaded closed seal. Redundant shaft seals, with an overboard drain cavity between them, prevent leakage along the shaft (actuator end) during engine operation. Inlet and outlet throttling sleeves align the flow to minimize turbulence and the resultant pressure loss. Ball seal wear is minimized by cams and a cam follower assembly that displaces the seal away from contact with the ball during the initial degrees of ball travel when being opened. The FPOV is an LRU.

Geometry

Flow passage diameter, in.	1.100
Ball diameter, in.	2.968
Shaft diameter (seal), in.	1.100
Valve length, in.	6.812

$$\text{flow area} = 0.9503 \text{ in}^2$$

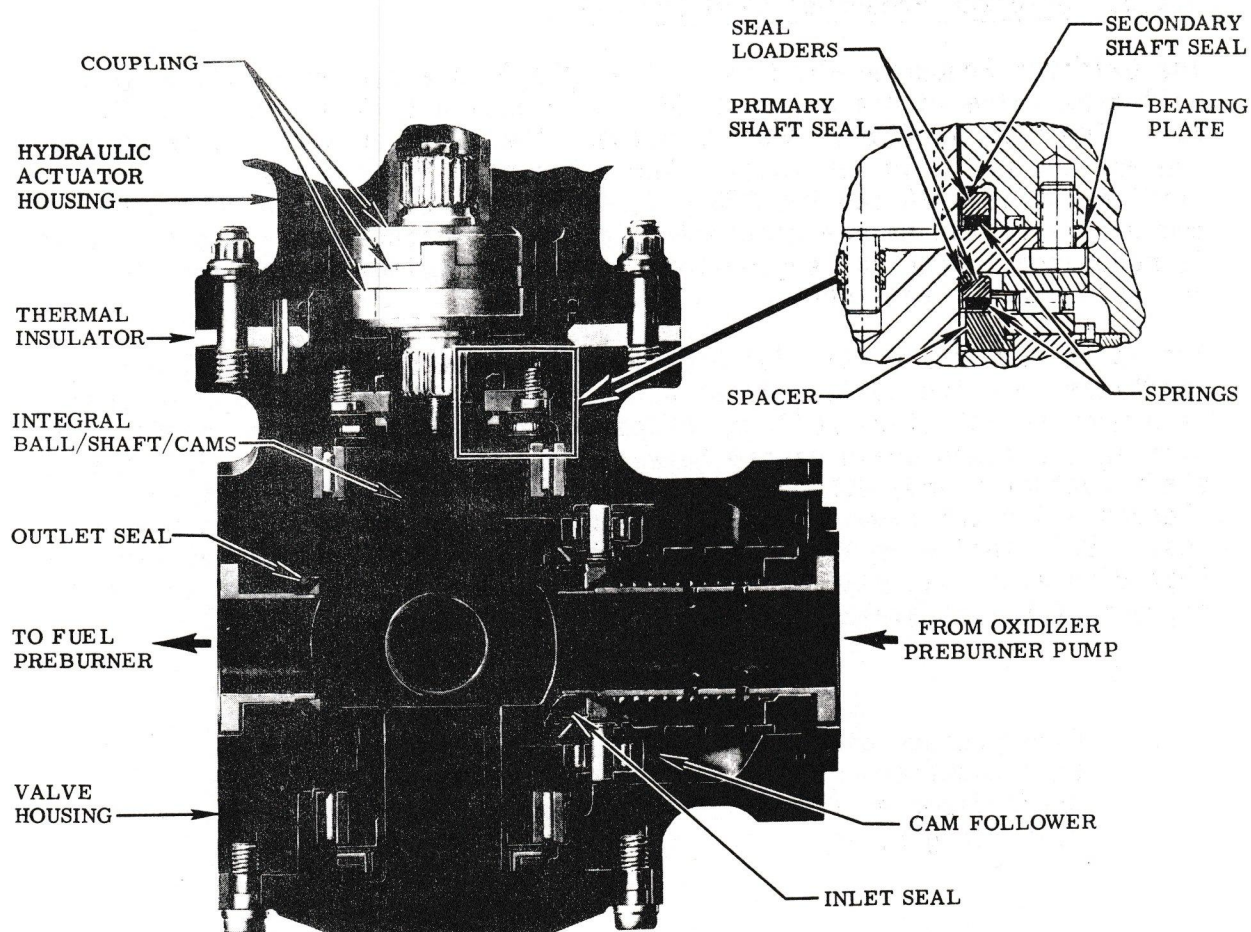


Figure 3.1-30.- Fuel preburner oxidizer valve.

3.1.31 Oxidizer Preburner Oxidizer Valve

The Oxidizer Preburner Oxidizer Valve (OPOV) is a hydraulically actuated, ball-type valve with a 1.1 by 0.285-in. propellant flow slot (fig. 3.1-31). The OPOV is flange-mounted between the oxidizer supply line to the OPB and the OPB oxidizer inlet. The valve permits or stops the flow of oxidizer to the OPB and the OPB ASI. Valve position is controlled by commands from the engine controller; during mainstage operation the valve is modulated to control engine thrust between Minimum Power Level (MPL) and Full Power Level (FPL).

The valve consists of two major moving components: The integral ball/shaft/cams and the ball seal retracting mechanism. The ball inlet seal is a machined plastic, bellows-loaded closed seal. Redundant shaft seals, with an overboard drain cavity between them, prevent leakage along the shaft (actuator end) during engine operation. Inlet and outlet throttling sleeves align the flow to minimize turbulence and the resultant pressure loss. Ball seal wear is minimized by cams and a cam follower assembly that displaces the seal away from contact with the ball during the initial degrees of ball travel when being opened. The OPOV is an LRU.

Geometry

Flow passage dimensions, in.	1.100 X 0.374
Ball diameter, in.	2.968
Shaft diameter (seal), in.	1.100
Valve length, in.	6.812

flow area = 0.4114 in²

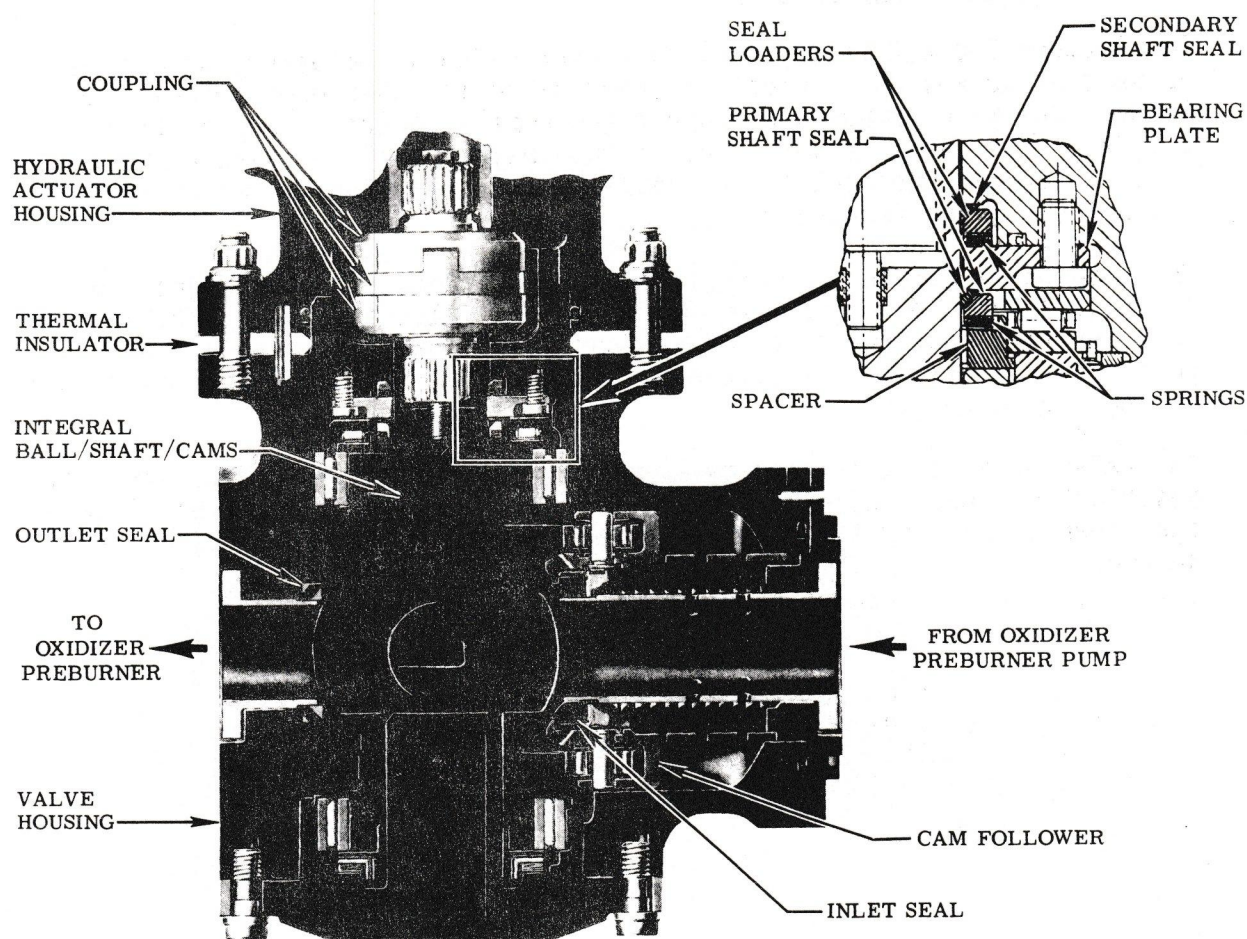


Figure 3.1-31.- Oxidizer preburner oxidizer valve.

3.1.32 Chamber Coolant Valve

The Chamber Coolant Valve (CCV) is a hydraulically actuated, gate-type valve that serves as a throttling control to maintain proper fuel flow through the main combustion chamber and nozzle coolant circuits (fig. 3.1-32). The valve is installed in the chamber coolant valve duct, which is an integral component of the nozzle forward manifold assembly and provides the housing for the valve.

The gate has a 1.6-in. flow passage. The CCV does not have a gate seal as it is located downstream of the main fuel valve and is not required to be a positive shutoff valve. Redundant shaft seals, with an overboard drain cavity between them, prevent leakage along the shaft (actuator end) during engine operation.

The valve gate is positioned by commands from the engine controller. Its position is scheduled linearly with thrust reference so as to be 50 percent open at MPL and full open at Rated Power Level (RPL). The valve is an LRU.

Geometry

Flow passage diameter, in.	1.600
Gate diameter, in.	2.500
Shaft diameter (seal), in.	1.100
Valve length, in.	7.729

$$\text{flow area} = 2.0106 \text{ in}^2$$

8A-MPS

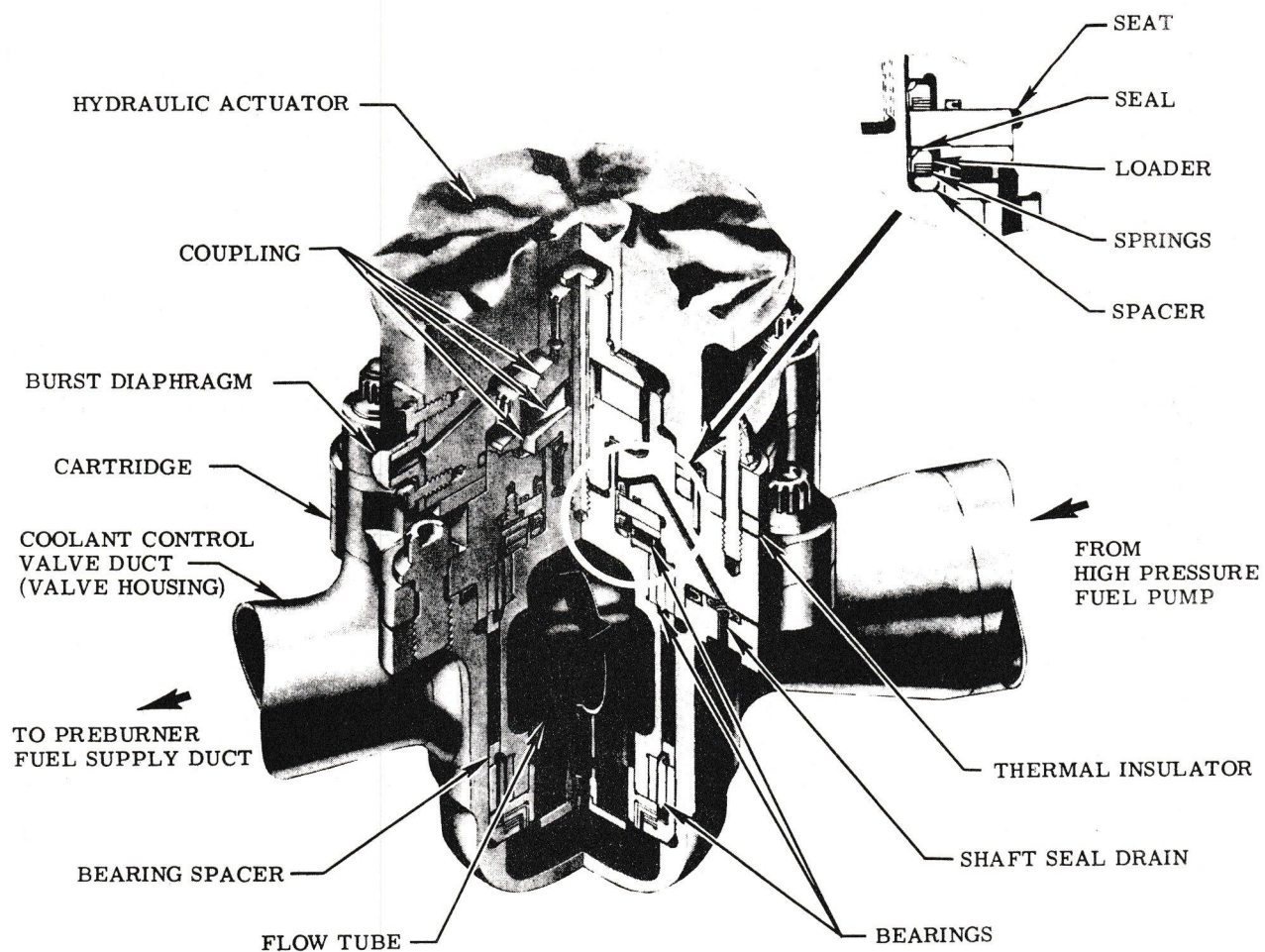


Figure 3.1-32.- Chamber coolant valve.

3.1.33 Propellant Valve Hydraulic Actuators

Hydraulic power is provided for the operation of five valves in the propellant feed system (oxidizer preburner oxidizer, fuel preburner oxidizer, main oxidizer, main fuel, and chamber coolant valves). Servoactuators mounted to the propellant valves convert vehicle-supplied hydraulic fluid pressure to rotary motion of the actuator shaft as a function of electrical input command (fig. 3.1-33).

Two servovalves, which are integral parts of each servoactuator, convert the electrical command signal from the engine controller to hydraulic flow to position the valve actuator. The dual servovalves provide redundancy that permits a single servovalve failure with no change in actuator performance. A fail-operate servoswitch is used to automatically select the redundant servovalve upon failure of a single servovalve. A fail-safe servoswitch is used to hydraulically lock up the servoactuator upon failure of both servovalves.

A dual, redundant, Rotary Variable Differential Transformer (RVDT) is connected to the actuator shaft and returns two electrical signals of position to the controller.

All actuators are capable of utilizing an emergency shutdown system to pneumatically close the propellant valves. Pneumatic sequence valves in the oxidizer and fuel preburner actuators provide for a proper closing sequence of the propellant valves during an emergency shutdown condition. A pneumatic sequence valve in the chamber coolant valve actuator is used to terminate the engine post-shutdown purges.

Operating Parameters

Supply pressure, psig	700 to 3100
Return pressure, psig	200 nom, 250 max
Flowrates, gpm:	
Steady state	2.5 min
Transient	12

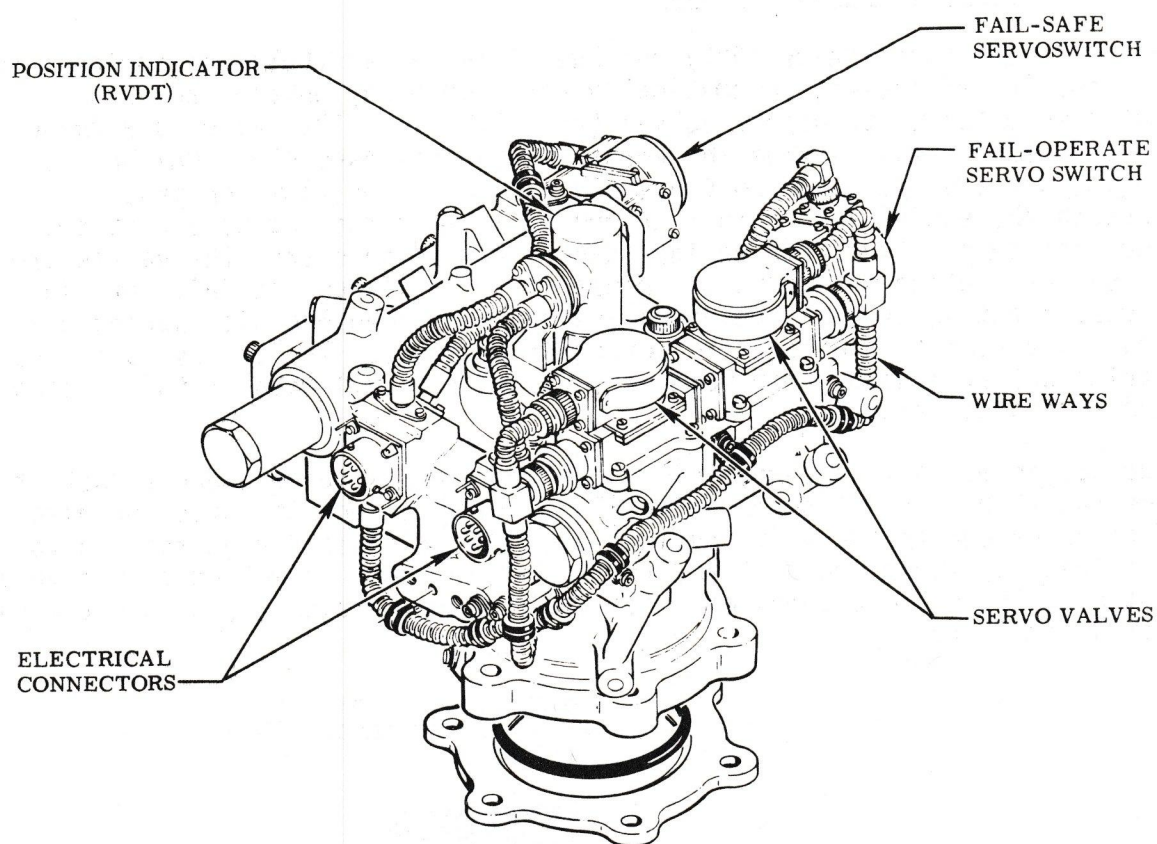


Figure 3.1-33.- Propellant valve hydraulic actuators.

3.1.34 Propellant Bleed Valves

The Oxidizer Bleed Valve (OBV) and Fuel Bleed Valve (FBV) are spring- and bellows-loaded-closed, pneumatically actuated-open, unbalanced-area, metal-to-metal seat, poppet valves (fig. 3.1-34). The valves are opened by pneumatic pressure from the Pneumatic Control Assembly (PCA) during engine start preparation to provide a recirculation flow for propellants through the engine to ensure that propellants in the engine are at the required temperatures for engine start. At engine start, the valves are closed by venting the actuation pressure. The valves are fail-safe in pressure acting on the unbalanced area poppet, combined with spring and bellows forces to overcome the actuation pressure. The valves have Linear Variable Differential Transformers (LVDT's) for full-open or full-closed position indication.

The OBV inlet is flange-mounted to the preburner oxidizer supply duct at the Fuel Preburner Oxidizer Valve (FPOV) location and the oxidizer bleed duct is welded to the valve outlet. The FBV inlet is flange-mounted to the fuel high-pressure duct and the fuel bleed duct is welded to the valve outlet. The valve assemblies, with their ducts, are LRU's, as are the position indicators.

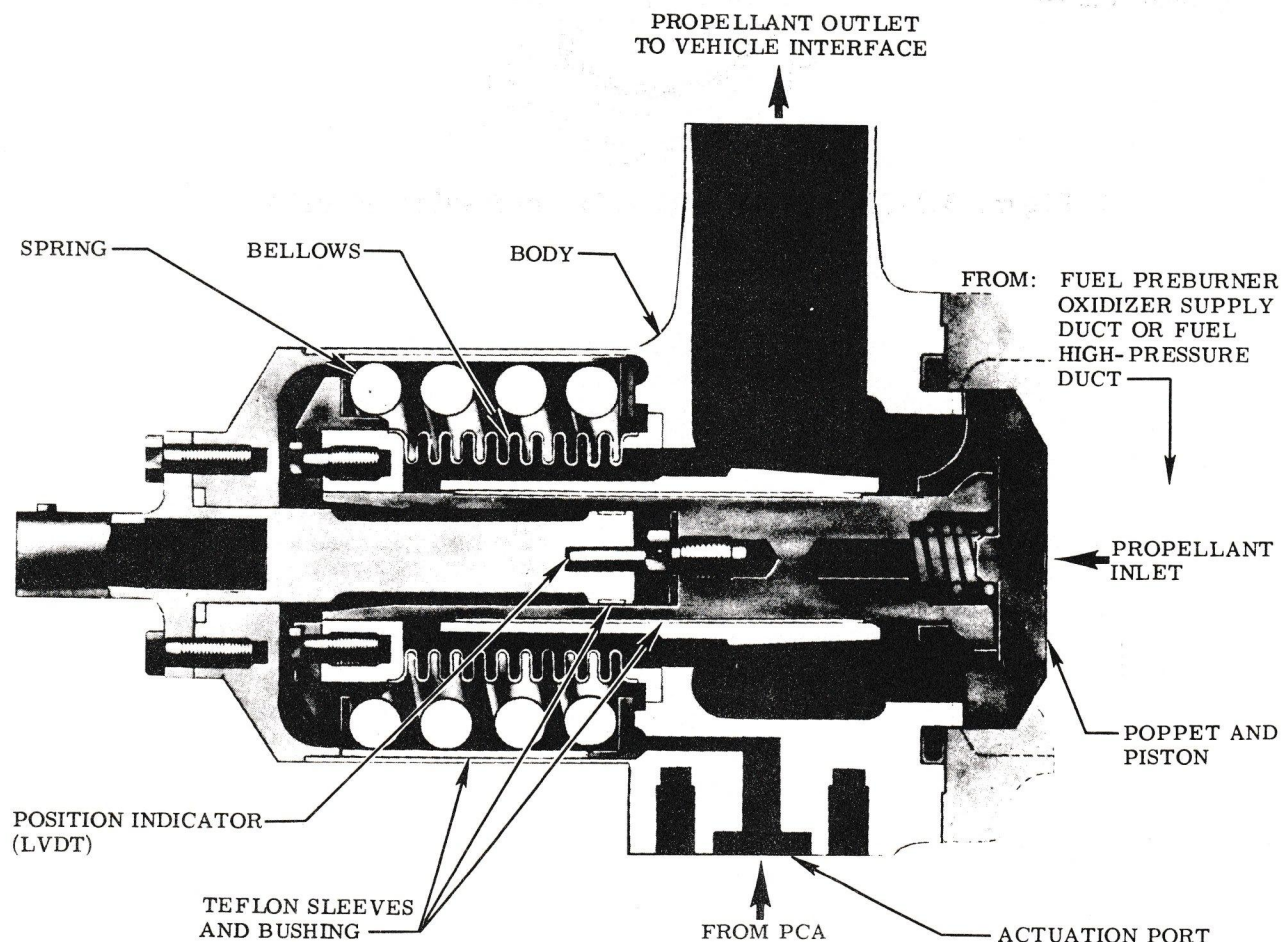


Figure 3.1-34.- Propellant bleed valve.

3.1.35 Anti-Flood Valve

The Anti-Flood Valve (AFV) is a spring-loaded, normally closed poppet-type valve (fig. 3.1-35). It prevents the flow of liquid oxygen into the heat exchanger until there is sufficient heat applied to the heat exchanger during engine start to convert the liquid oxygen to gaseous oxygen.

The AFV can be checked out on the ground without disturbing line connections, and an LVDT that serves as a valve dual-position indicator. The valve assembly, with its duct, is an LRU.

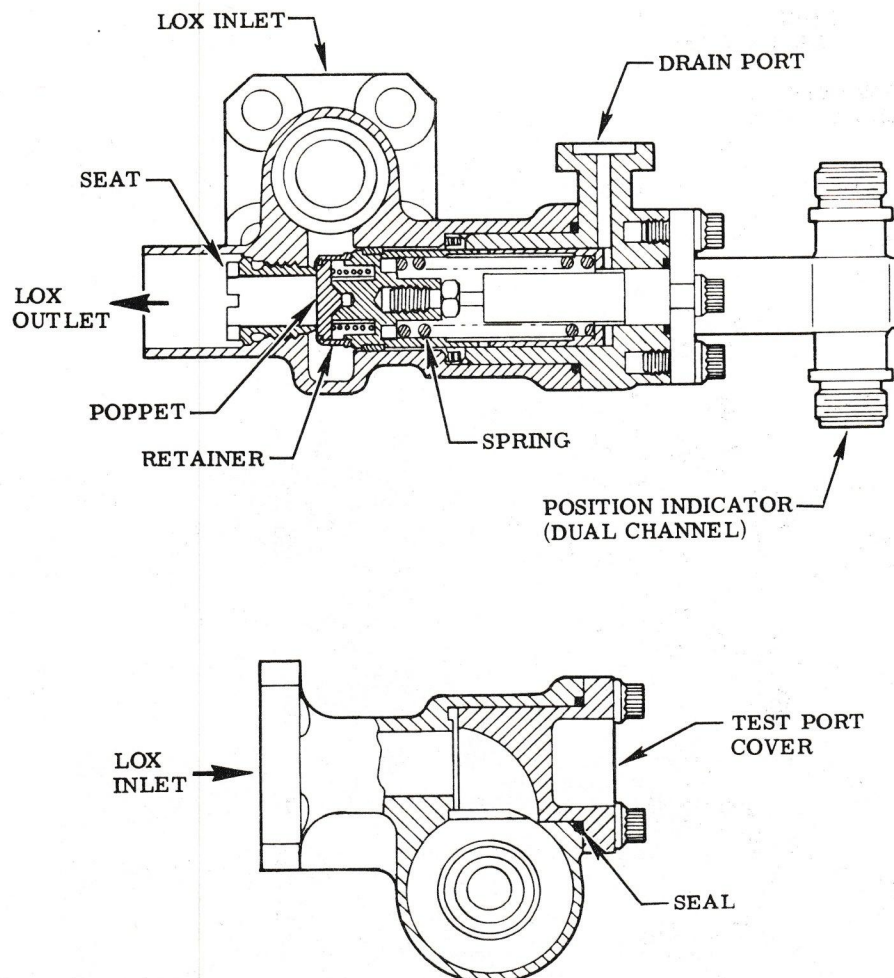


Figure 3.1-35.- Anti-flood valve.

3.1.36 Pneumatic Control Assembly

The Pneumatic Control Assembly (PCA) provides control of vehicle-supplied helium for prestart, flight, and shutdown for purges, for bleed valve operation, and for emergency shutdown control of the main propellant valves in the event of electrical power loss to the engine (fig. 3.1-36). The PCA also routes ground-controlled gaseous nitrogen to the main chamber, HPOTP intermediate seal and preburner oxidizer dome for prestart purges. The PCA consists of a ported manifold to which solenoid valve, pressure sensors, and Pressure-Actuated Valves (PAV) are attached. The PCA is an LRU.

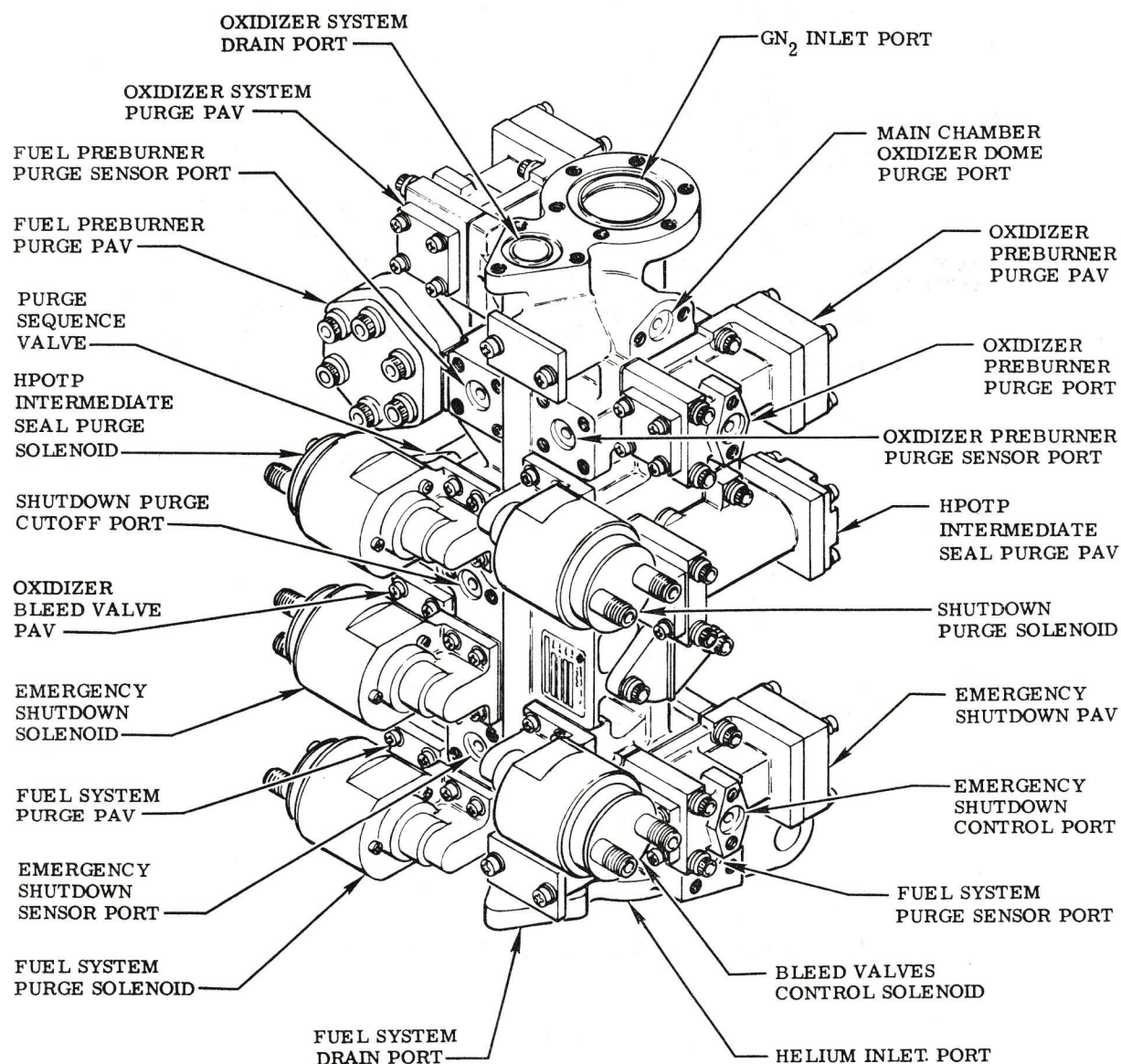


Figure 3.1-36.- Pneumatic control assembly.

3.1.37 Purge Check Valves

The pneumatic control system purge check valves are spring-loaded, normally closed, pressure-actuated open, poppet valves that isolate propellants from the pneumatic systems (fig. 3.1-37). The purge check valves, with their attached lines, are LRU's.

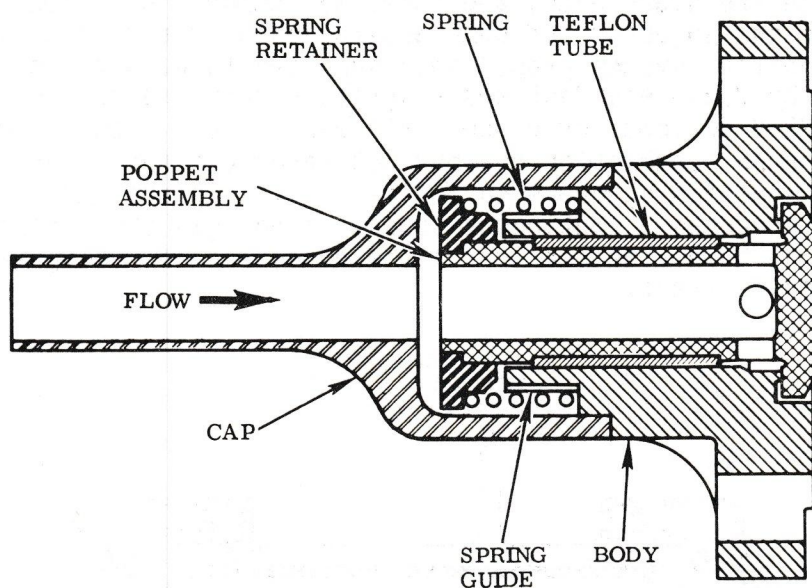


Figure 3.1-37.- Purge check valves.

3.1.38 Ignition System

The ignition system is an ASI-type that initiates combustion of main propellants in the Main Combustion Chamber (MCC) and in the fuel preburner and oxidizer preburner (fig. 3.1-38). The system consists of six spark igniters, which have the spark exciter electronic circuitry integrally packaged with the spark plug, and three ASI combustion chambers, which are parts of the injector and dome assemblies of the main chamber and preburners. Ignition system propellants supplied to each of the ASI chambers are ignited by dual-redundant spark igniters that are controlled and supplied with 28-V dc power by redundant power sources from the engine controller. The ASI combustion chamber hot gases discharge into the MCC and preburner combustion chambers to ignite the main propellants. The ignition system produces a continuous supply of hot gas throughout the engine duty cycle, although the electrical energy source is removed within 3.5 sec after engine start.

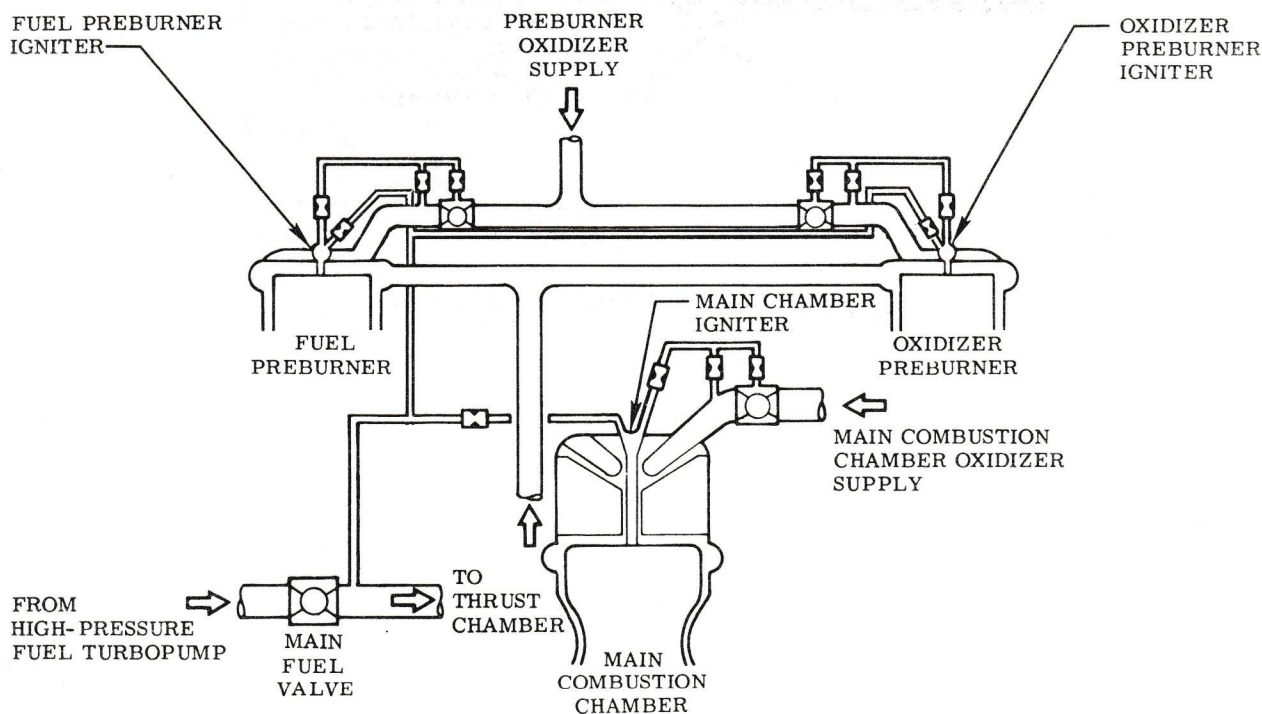


Figure 3.1-38.- Ignition system.

3.1.39 ASI Injector/Combustion Chamber

The ASI injector and combustion chamber augment the spark igniters in establishing ignition of the main propellants for the main and preburner combustion chambers (fig. 3.1-39).

Both injectors and chambers are integral parts of the main chamber and preburner injector assemblies. The oxidizer injector consists of two orifices, 180° apart, that direct the ASI oxidizer into the centerline of the ASI chamber at the plane of the spark igniter electrodes.

Eight orifices comprise the fuel injector, directing the ASI fuel tangentially into the ASI combustion chamber at a plane approximately 0.5 in. downstream of the oxidizer orifices. This injection flow pattern creates an oxidizer-rich condition in the vicinity of the spark igniter electrodes prior to ignition. After ignition, the flow pattern develops into a relatively low mixture ratio environment around the spark igniter electrodes and an oxidizer-rich core along the combustion chamber length surrounded by a fuel-rich zone that protects the ASI combustion chamber walls.

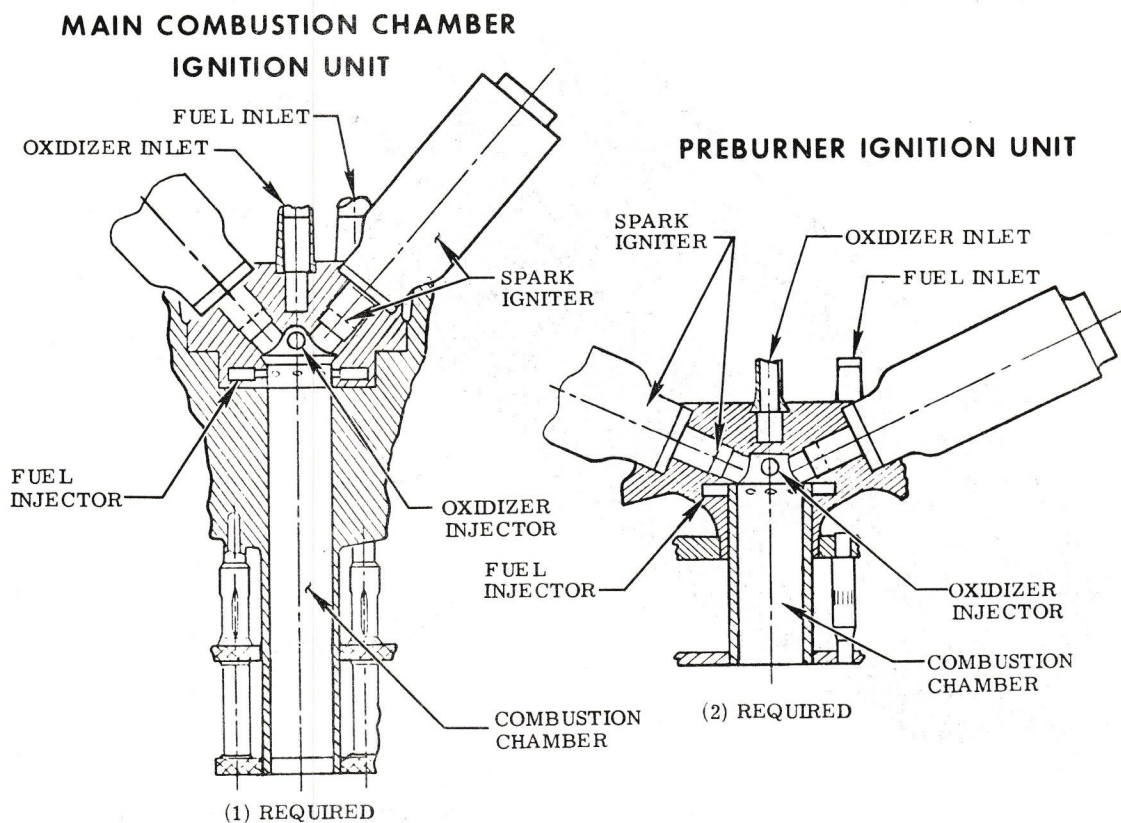


Figure 3.1-39.- The ASI injector/combustion chamber.

3.1.40 Spark Igniter

The spark igniter is a dual-series-gap, high-voltage, inductive-discharge sparking device that ignites the propellants supplied to the ignition system (fig. 3.1-40). The spark igniter combines a spark plug and spark exciter electronics in an integral, hermetically sealed unit that transforms a low-level 28-V dc input into a 10-kV output at a minimum of 50 sparks per sec.

The dual-surface spark gaps are in series and are formed by the center electrode and intermediate electrode, and by the intermediate electrode and outer electrode (igniter housing).

Two igniters are installed in threaded ports of the ASI chambers. A captive Naflex seal, which is retained by an elastomeric seal that ensures positive seal placement during installation, seals the interface of igniter and ASI chamber. The elastomeric seal serves as a secondary seal, and the area between the two seals is ported to a monitoring port to permit the measurement of leakage past the Naflex seal. The unit is an LRU and is approximately 5.75 in. long and 2.0 in. at its maximum diameter.

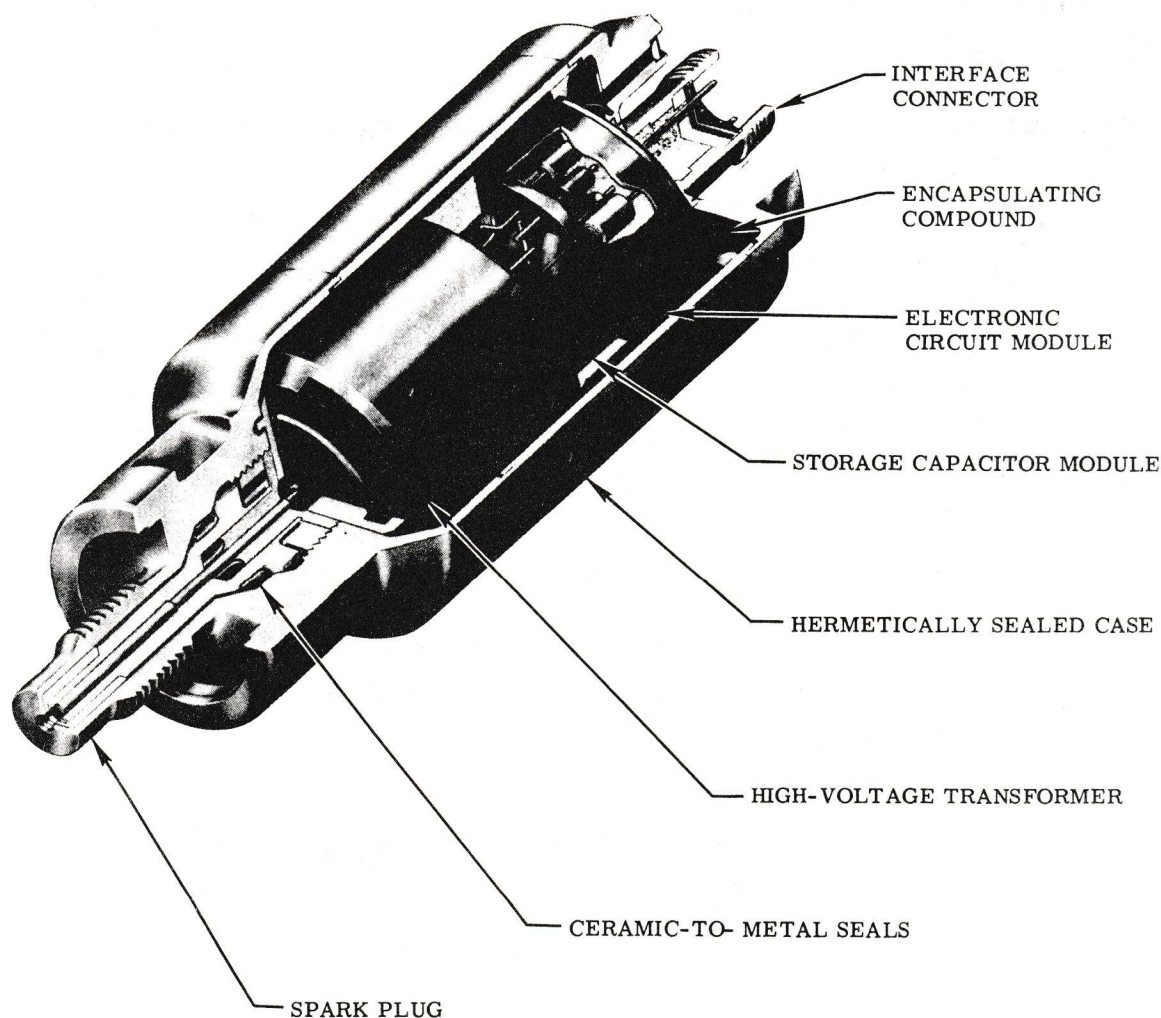


Figure 3.1-40.- Spark igniter.

3.1.41 Gimbal Bearing

The gimbal bearing assembly is a spherical, low-friction, universal joint that has ball and socket bearing surfaces (fig. 3.1-41). The bearing assembly provides the mechanical interface with the vehicle for transmitting thrust loads and permits angulation of the actual thrust vector about each of two vector control axes. The gimbal bearing is attached to the engine main injector thrust cone by 10 bolts through offset bushings that allow lateral positioning of the bearing. The gimbal bearing position is established by optical alignment during engine building to ensure that the actual thrust vector is within 30 min of arc to the engine centerline and 0.60 in. of the gimbal center. Cyclic life is obtained by low-friction, anti-galling bearing surfaces that operate under high loads. The assembly has an overall dimensional envelope of approximately 11.3 by 14 in.

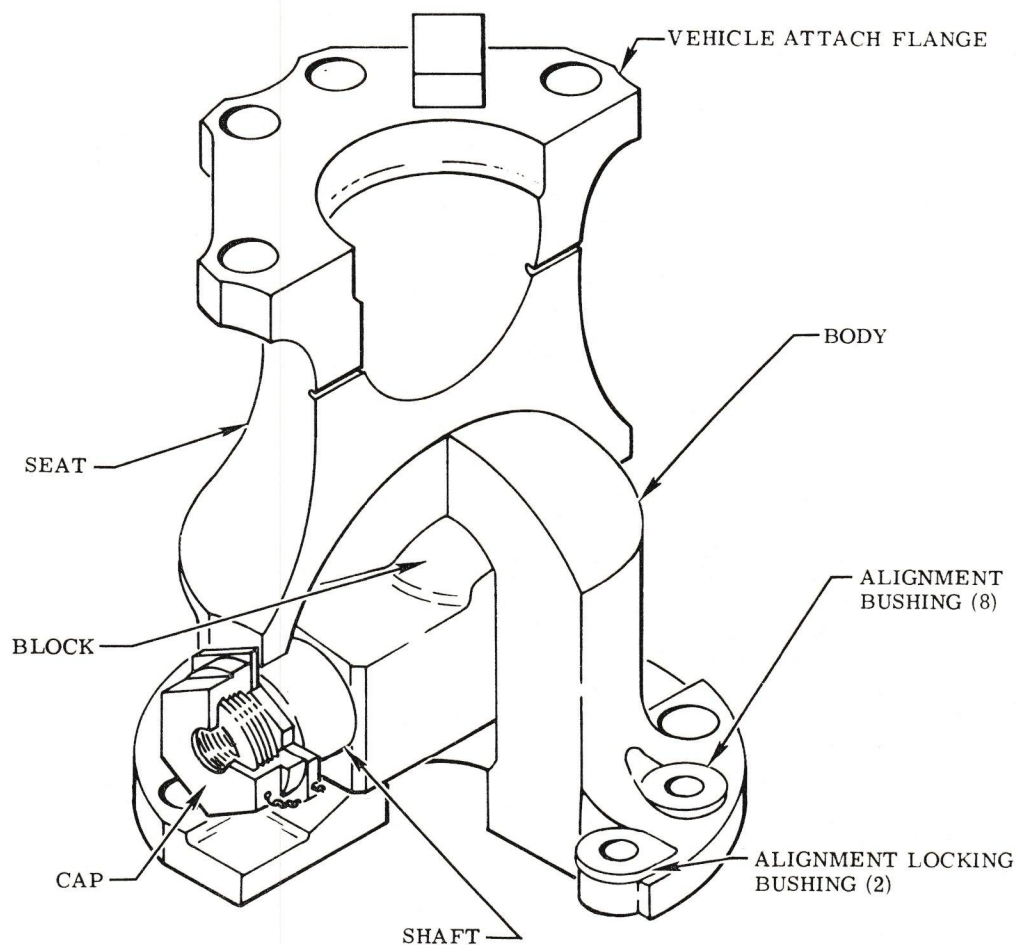


Figure 3.1-41.- Gimbal bearing.

3.1.42 Critical Operating Parameters and Their Limits

Table 3.1-1 contains a list of sensor shutdown limits (redlines) used to monitor the status of each SSME. If the limits associated with these parameters are exceeded, the SSMEC receiving the signal will shut down the main engine it monitors.

TABLE 3.1-1.- CONTROLLER-MONITORED REDLINES

Redline parameter	Activation time, sec from engine start (T-3.8 sec)	SSMEC delay, msec	Limit, upper lower	Shutdown initiated by	Notes
Ignition confirmation limit (one-time check)	2.3	40	$\frac{610}{1000}$ psia	Four outputs out of 2 pressure transducers	If either limit is exceeded, the engine will be shut down.
MCC chamber pressure	>2.3	60	1000 psia min	Four outputs out of 2 pressure transducers	If this limit is exceeded, the engine will be shut down.
HPOT discharge temperature	>2.3	40	1660° R max	Two transducers out of 2 transducers	If this limit is exceeded, the engine will be shut down.
HPOT intermediate seal purge	Engine start	20	$\frac{170}{650}$ psia	Two outputs out of 1 transducer	If either limit is exceeded, the engine will be shut down.
HPFD speed minimum limit (one-time check)	<1.26	40	4200 rpm min	Two outputs out of 1 transducer (magnetic pickup coils)	If this limit has not been reached, the engine will be shutdown.
Anti-flood valve position	2.3	40	80 percent open	Two outputs out of 1 transducer	If this limit has not been reached, the engine will be shut down.
HPOT secondary seal cavity	Engine start	60	$\frac{5}{85}$ psia	Two outputs out of 1 transducer	If either limit is exceeded, the engine will be shut down.
FASCOS	Engine start	50	10g RMS	Six accelerometers; vote 4 out of 6 must exceed redline	If this limit is exceeded, the engine will be shut down.

If the transducers used to monitor the engines fail, the SSMEC could shut down an engine from the loss of the ability to monitor the limit. The sensor failure engine shutdowns are shown in table 3.1-2.

TABLE 3.1-2.- REDLINE SENSOR FAILURE

Redline parameter	Sensors	Failure initiated by
HPOT discharge temperature	Two temperature transducers	Loss of 2 transducers results in an engine shutdown.
HPOT intermediate seal	One pressure transducer (2 outputs)	Loss of both outputs results in engine shutdown.
HPOT secondary seal cavity	One pressure transducer	--
FASCOS	Six accelerometers 3 axial/3 radial	Four accelerometer failures result in engine shutdown.
MCC pressure	Two pressure transducers (4 outputs)	Loss of 1 output from each transducer results in electronic lockup.
Anti-flood valve position (one-time check)	Two position indicators off one linear voltage transformer (LVOT)	Loss of both outputs will shut the engine down (before SRB ignition).
Ignition confirmation limit (one-time check)	Two pressure transducers (4 outputs)	Loss of 1 output from each transducer results in engine shutdown.
HPFP speed minimum limit (one-time check)	One transducer (2 outputs)	Loss of both outputs from the transducer results in engine shutdown (before SRB ignition).

3.1.43 Data Tables and FiguresTABLE 3.1-3.- ENGINE SYSTEM WEIGHTS^a

Conditions, lb	Dry	Wet
Prestart	6656	7172
Operating	DNA	7183
Burnout	DNA	7103

^aEngine weights include DFI scar weight but do not include DFI equipment weight.

TABLE 3.1-4.- ENGINE SYSTEM CENTER OF GRAVITY

Axes, in. (a)	Dry	Wet
$\bar{X}^b$	-43.8 ± 3.0	-42.6 ± 3.0
$\bar{Y}$	± 2.0	± 1.0
$\bar{Z}$	± 1.0	± 2.0

^aSee fig. 3.1-42 for reference axes.

^bReferenced from Y-Z plane.

TABLE 3.1-5.- ENGINE GIMBALED MASS CENTER OF GRAVITY

Axes, in. (a)	Dry	Wet
$\bar{X}^b$	-36.9 ± 3.0	-36.0 ± 3.0
$\bar{Y}$	± 2.0	± 1.0
$\bar{Z}$	± 1.0	± 2.0

^aSee fig. 3.1-42 for reference axes.

^bReferenced from the gimbal center.

TABLE 3.1-6.- ENGINE SYSTEM GIMBALED MOMENTS OF INERTIA AT ZERO GIMBAL ANGLE

Axes, slug-ft ² (a)	Dry	Wet
I_{XX}^b	1038	1143
I_{YY}^c	4325	4504
I_{ZZ}^d	4283	4417

^aSee fig. 3.1-42 for reference axes.

^bReferenced from Y-Z plane.

^cA line parallel to the Y-Y axis passing through the gimbal center.

^dA line parallel to the Z-Z axis passing through the gimbal center.

^eGimbal mass weight 6097 lb, dry.

^fGimbal mass weight 6568 lb, wet.

TABLE 3.1-7.- ENGINE PROPELLANT WEIGHTS

Conditions, lb		L02	LH2
Steady-state propellant weight	Prestart	497	19
	Burnout	428	19
Transient propellant consumption:	Start ^{a,e}	^c 1130	245
	Shutdown ^b	^d 600	240
	Shutdown ^b	280	120

^aStart to RPL.

^bShutdown from MPL.

^cRequired from vehicle; does not include 50 lb expelled from accumulator.

^dRequired from vehicle; does not include 19 lb expelled from accumulator.

^eIncludes propellant required to prime injector volume.

TABLE 3.1-8.- VEHICLE CONNECTION INTERFACE POINTS

Interface number (a)	Description	End configuration
①	Gimbal bearing	Machine flange
②	Gimbal actuator attach point -Y axis	
③	Gimbal actuator attach point -Z axis	Clevis
④	Oxidizer, engine inlet	Fixed flange
⑤	Fuel, engine inlet	Fixed flange
⑥	Fuel, tank pressurant	Swivel flange
⑦	Oxidizer tank pressurant	Swivel flange
⑧	Nitrogen supply	Swivel flange
⑨	Helium supply	Swivel flange
⑩	Fuel bleed (recirculation)	Swivel flange
⑪	Oxidizer bleed (recirculation)	Swivel flange
⑫	Hydraulic supply	Quick disconnect
⑬	Hydraulic return	Quick disconnect
⑭	Connector space on interface panel	
⑮	Reserved for future use	
⑯	Power, ac J-1	Electrical connector
⑰	Power, ac J-2	Electrical connector
⑱	Pwr, dc & controller temp J-6	Electrical connector

^aInterface numbers are as shown on fig. 3.1-42.

TABLE 3.1-8.- VEHICLE CONNECTION INTERFACE POINTS - Concluded

Interface number (a)	Description	End configuration
①9	Comm & data trans interface J-3	Electrical connector
②0	Comm & data trans interface J-4	Electrical connector
②1	Comm & data trans interface J-5	Electrical connector
②2	Heat shield	Mounting ring
②3	Controller cooling	Fixed flange
②4	Pogo DFI J-203	Electrical connector
③1	Thermal DFI J-11, SSME #1 ^b	Electrical connector
③2	Thermal DFI J-12, SSME #1 ^b	Electrical connector
③3	Thermal DFI J-13, SSME #2 ^b	Electrical connector
③4	Thermal DFI J-14, SSME #2 ^b	Electrical connector
③5	Thermal DFI J-15, SSME #2 ^b	Electrical connector
③6	Thermal DFI J-16, SSME #3 ^b	Electrical connector
③8	HPFTP bearing drying purge	Fixed flange
③9	Main combustion chamber purge I/F flange	Fixed flange
⑥2	Turbine primary seal purge	Adapter P/N RG001641-001
⑥3	Nozzle purge	AN815-4
⑥4	Nozzle purge	AN815-4

^aInterface numbers are as shown on fig. 3.1-42.

^bVehicle 102 only, engines 2004, 2005, 2006 only.

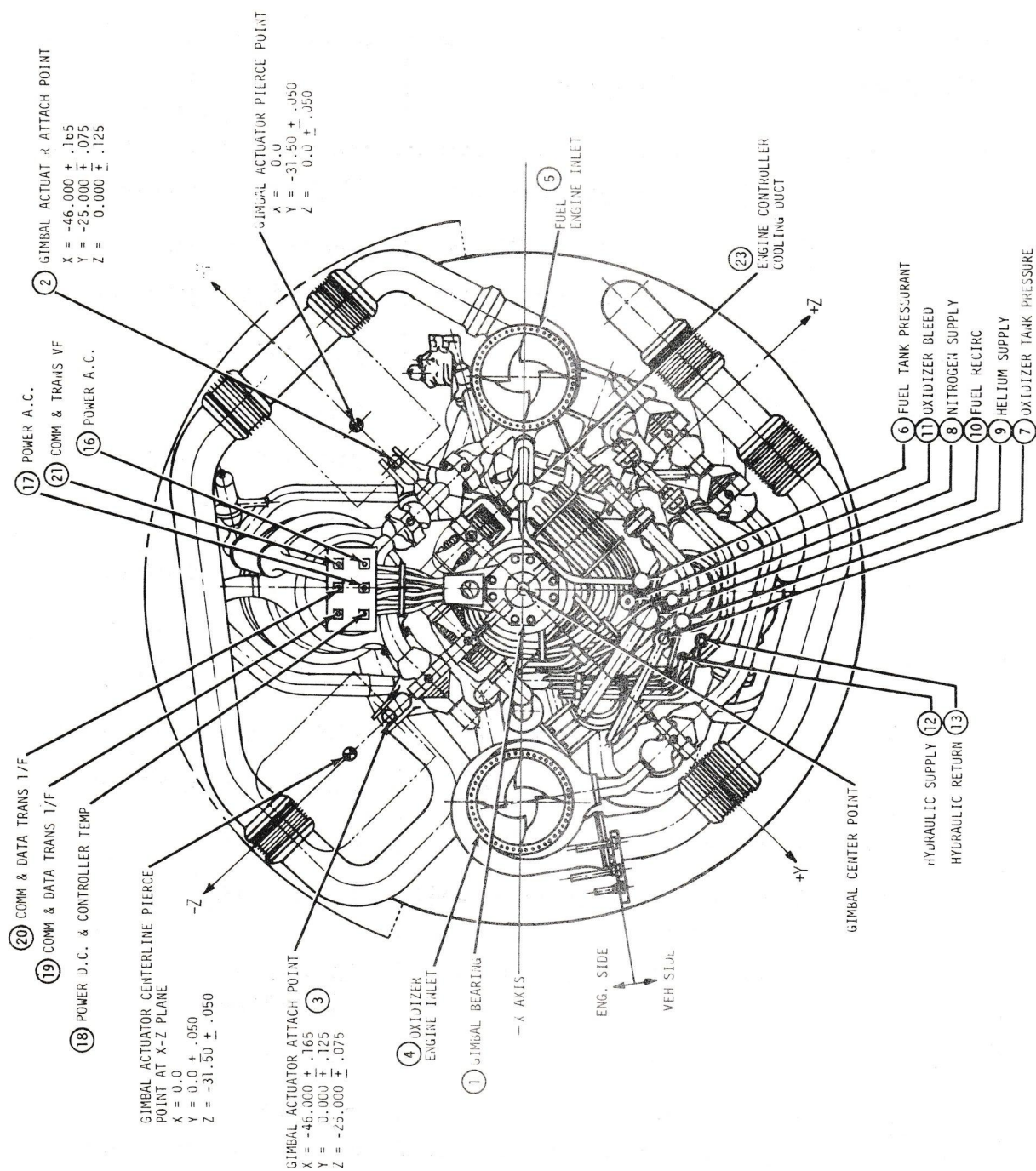


Figure 3.1-42.- The SSME interface points, top view.

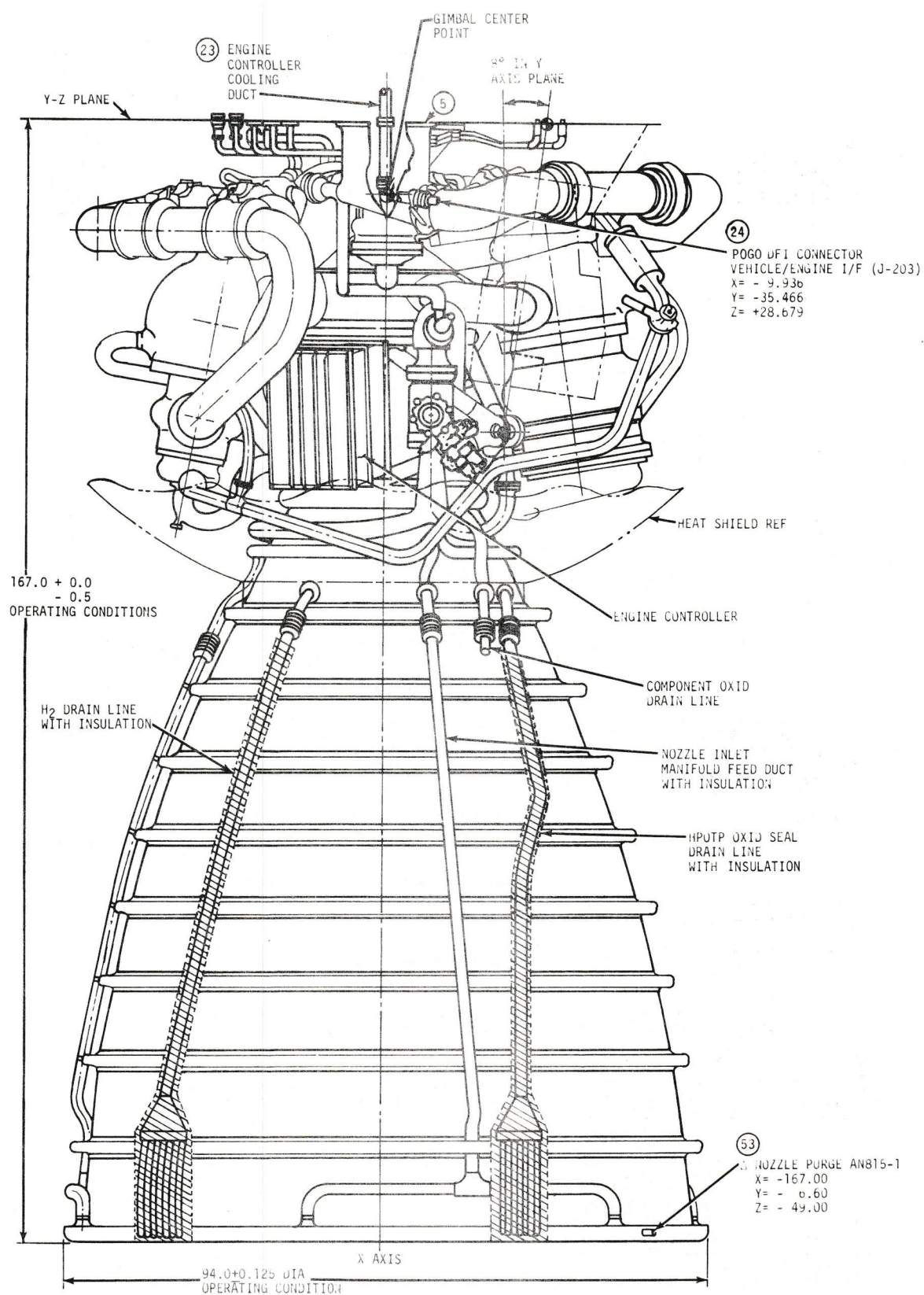


Figure 3.1-43.- The SSME, controller side.

THERMAL DFI CONNECTORS
(VEHICLE 102 ONLY)
(ENGINE 2004, 2005, 2006 ONLY)

ENG. POS	CONN	ENG. COORDINATES			I/F NO.
		X	Y	Z	
#1	J-11	-7.240	+34.318	-16.862	(31)
#1	J-12	-8.560	+36.931	-18.698	(32)
#2	J-13	-7.240	+34.318	-16.862	(33)
#2	J-14	-8.560	+36.931	-18.693	(34)
#2	J-15	-11.320	+38.668	-19.908	(35)
#3	J-16	-7.420	+35.015	-17.350	(36)

(3)
GIMBAL ACTUATOR ATTACH POINT
X = -46.000 ± .165
Y = 0.000 ± .125
Z = -25.000 ± .075

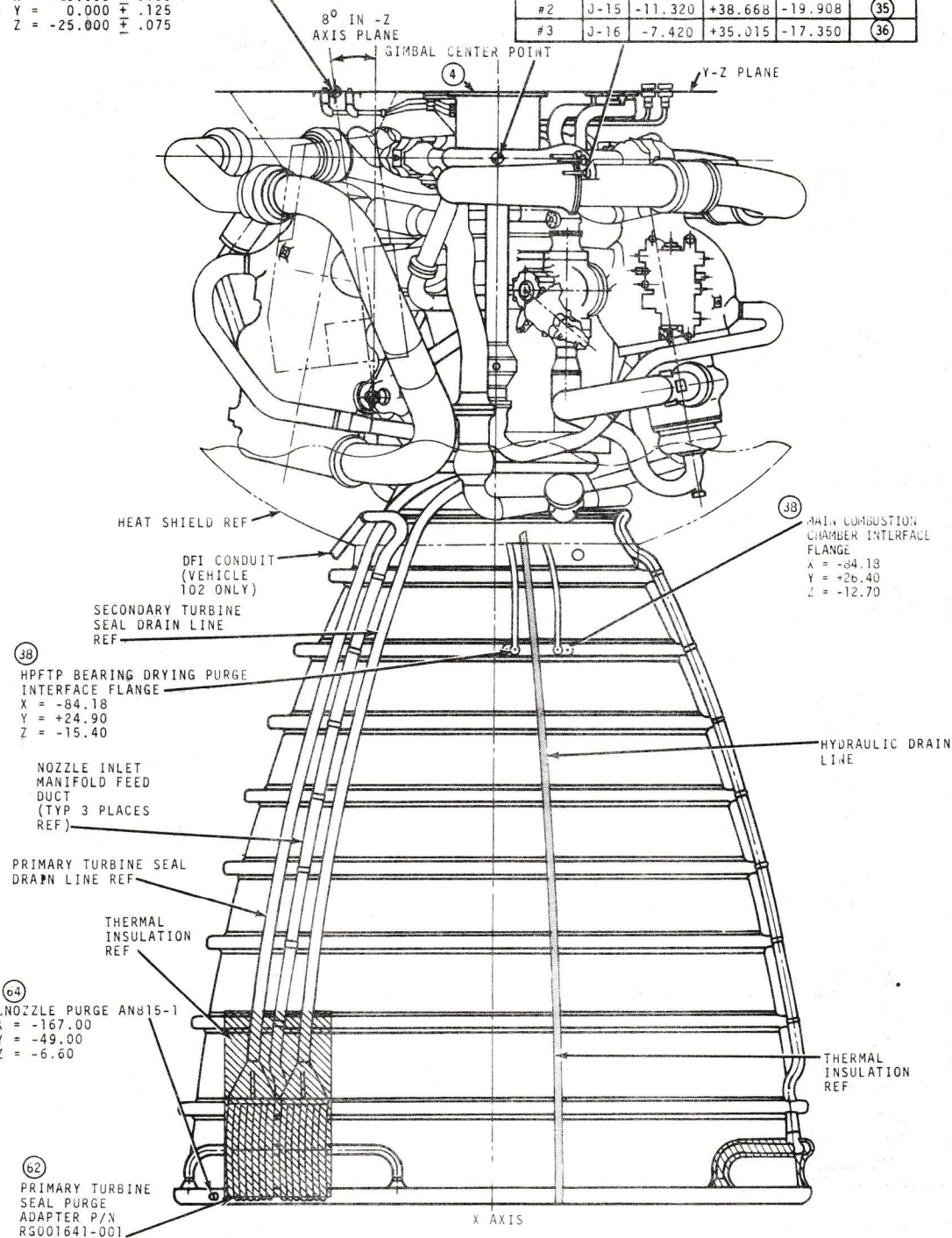


Figure 3.1-44.- The SSME, LPOTP side.

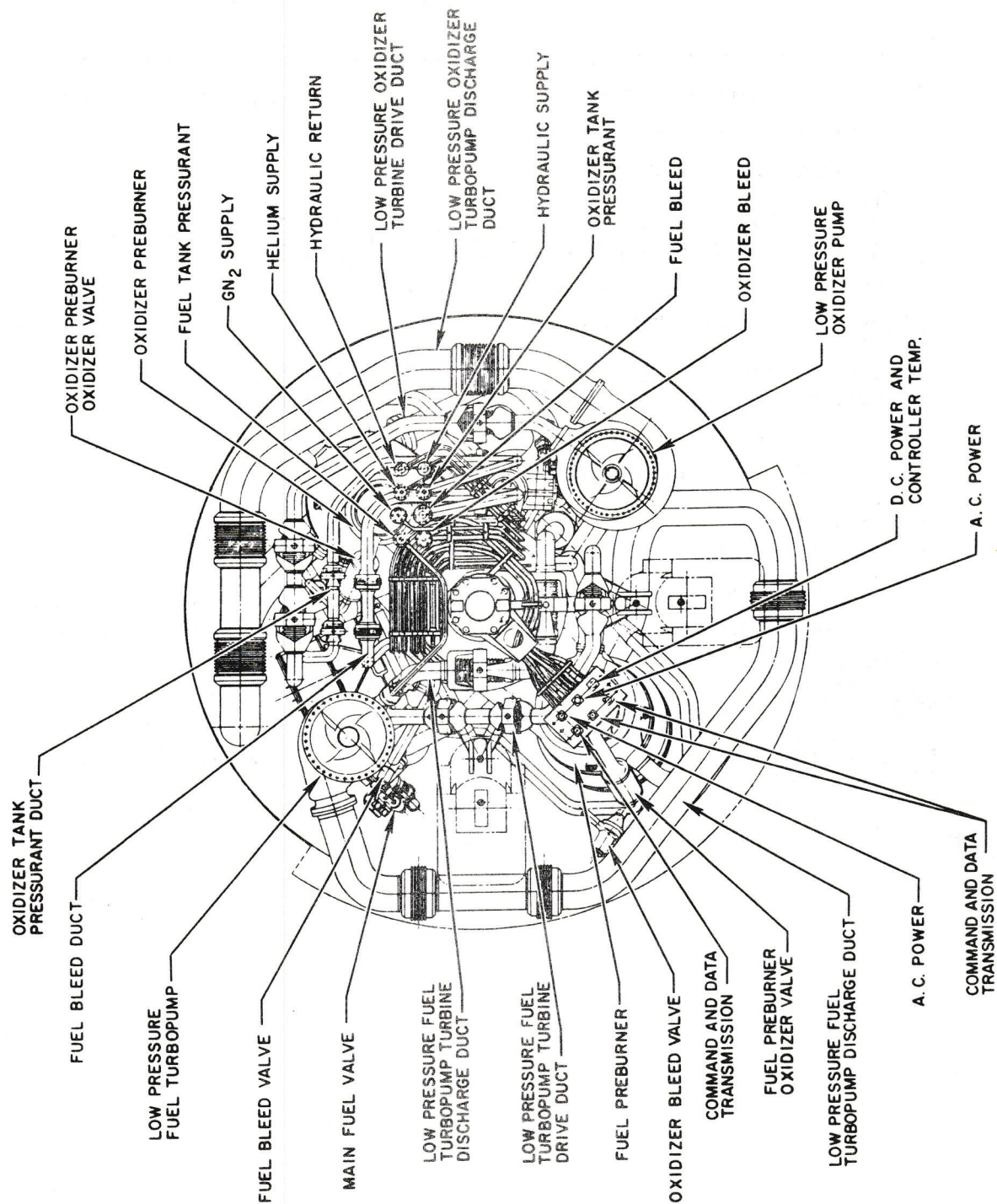


Figure 3.1-45.- The SSME component location, looking aft.

TABLE 3.1-9.- SSME OPERATING CONDITIONS

Operating conditions	Sea level	Vacuum
Full Power Level (FPL) ^{a,b} :		
Thrust, lbf	417,300	512,300
Specific impulse, (lbf-sec)/lbm ^d . .	≥369.0	≥453.0
Rated Power Level (RPL) ^{a,b} :		
Thrust, lbf	375,000	470,000
Specific impulse, (lbf-sec)/lbm ^d . .	≥316.4	≥452.9
Minimum Power Level (MPL) ^{a,b} :		
Thrust, lbf	(c)	305,500
Specific impulse, (lbf-sec)/lbm ^d . .		≥451.3

^aPower level is variable in 1-percent increments (4700 lb) of RPL from FPL to MPL by electrical signal.

^bAll values referenced to the propellant inlet condition ranges specified in fig. 3.1-46.

^cThe engine will not be capable of operation at sea level conditions without the use of altitude test facilities or restrainer arms at RPL and above.

^dAll values referenced to the nominal pressurant tapoffs.

TABLE 3.1-10.- HYDRAULIC TRANSIENTS AT ORBITER/SSME INTERFACE

Transient	Maximum duration, msec	Supply pressure, psig	Return pressure, psig	Engine ΔP , psid
Surge	140	3500 max	270 max ^d	3500 max ^a
Dropout	140	2300 min ^c	0 min	2300 min ^b

^aHydraulic quiescent flow (2.0 gpm per engine) per fig. 3.1-49 will be exceeded when pressure drop exceeds 3100 psid.

^bNormal engine operation will result below 2430 psid, provided thrust command rates are less than or equal to 10 percent per sec. Engine shutdown under this condition may result in engine-contained (fail-safe) damage.

^cSSME shutdown with Orbiter-supplied hydraulic pressure below 2700 psi will create abnormal interface conditions which may cause contained engine damage and yet assure a fail-safe condition relative to the mission.

^dIncludes the Orbiter and SSME-induced transients at the return system interface.

TABLE 3.1-11.- ENGINE EXTERNAL LEAKAGE

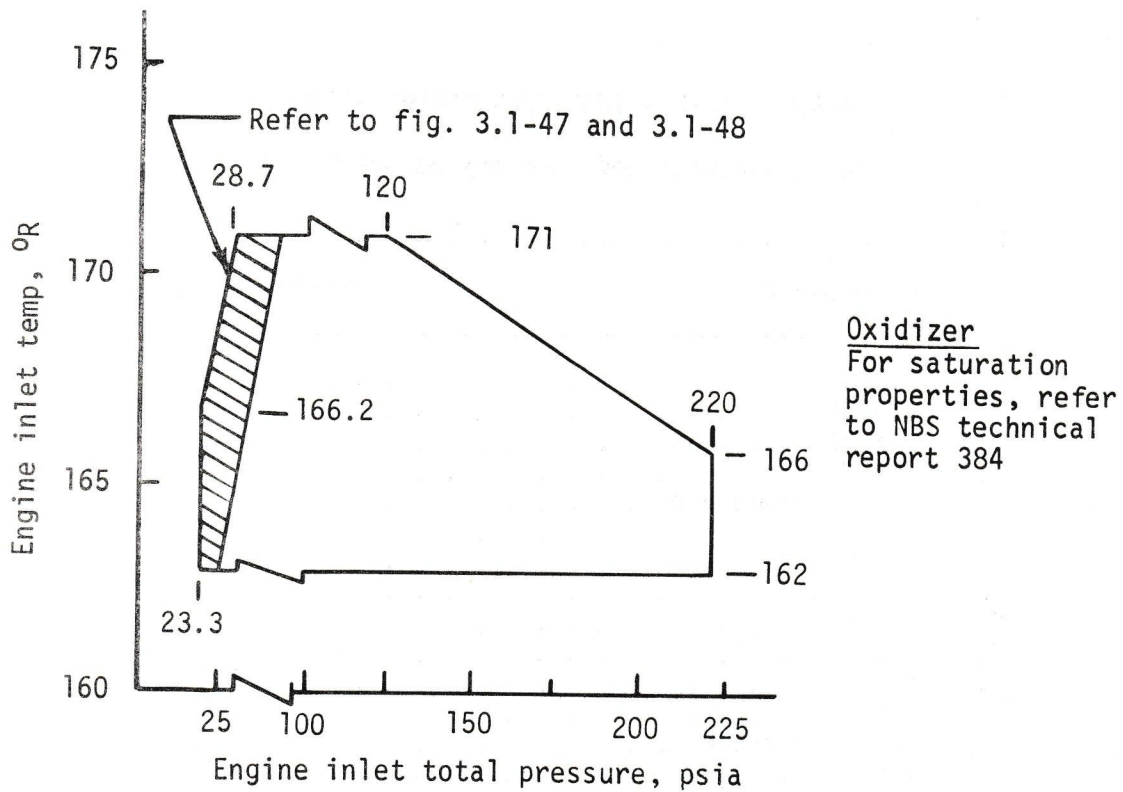
Leakage source	Leakage exit location	Operation phase	Media	Flow, scfm (a)
Hot gas separable joints	Forward of Orbiter heat shield	Launch	Hot gas (GH2/H2O)	250
Oxidizer separable joints	Forward of Orbiter heat shield	Prelaunch Launch	GOX GOX	30 260
Fuel separable joints	Forward of Orbiter heat shield	Prelaunch Launch	GH2 GH2	30 2,500
Oxidizer bleed valve	Fluid connect panel ^b	Launch	GOX	7,000
Fuel bleed valve	Fluid connect panel ^b	Launch	GH2	70,000
Fuel drains	Fuel drain lines at nozzle exit	Prelaunch Launch	GH2 GN2 GH2 GHe Hot gas (GH2/H2O)	1,700 225,000 4,000 45,000 3,000,000
Oxidizer drain	Oxidizer drain line exit aft of Orbiter heat shield	Prelaunch Launch	GOX GOX GHe	15,000 300,000 45,000
Hydraulic drain	Hydraulic drain line exit aft of Orbiter heat shield	Prelaunch Launch	Hydraulic fluid Hydraulic fluid	.1 cc/min .1 cc/min
Internal to thrust chamber	Thrust chamber nozzle exit	Prelaunch	GOX GH2 GN2 GHe	1,800 21,000 380,000 255,000

^aMaximum leakage rate during the life of the engine under normal operating conditions.

^bLeakage specified as past bleed valve seat when in closed position. Leakage is routed to Orbiter lines.

TABLE 3.1-12.- ENGINE/COMPONENT WEIGHTS
(Engine contract end item dry weight 6,618 lb)

Component	Weight, lb
LPOTP	199
LPFTP	171
HPOTP	517
HPFTP	767
Pogo accumulator	31
HPV	9
GCV	5
RIV	7
HGM	557
OPB	84
FPB	139
HE	23
Main injector	378
MCC	466
Nozzle	1,207
Gimbal bearing	104
MOV	93
MFV	74
MVA	28 each
OPBOV/FPBOV	34 each
PBVA	26
CCV	26
CCVA	26
OBV/FBV	8 each
AFV	5
Controller	210
PCA	46



Values referenced to Y-Z plane

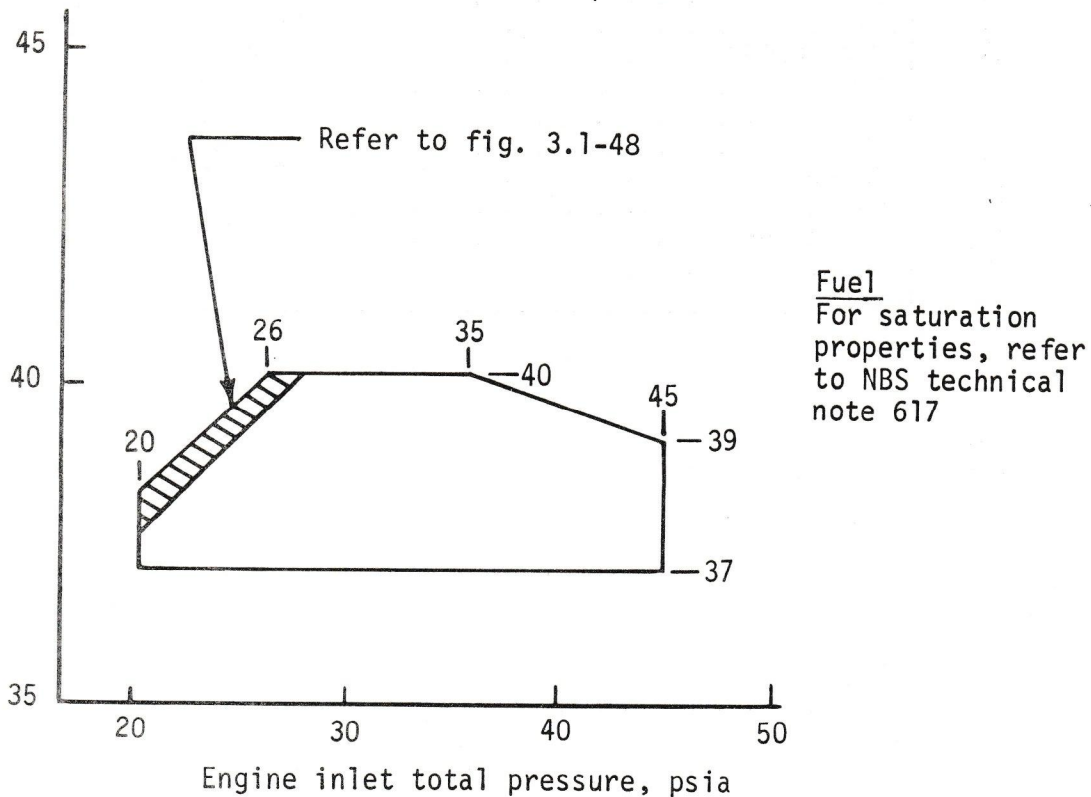


Figure 3.1-46.- Engine propellant inlet conditions (mainstage operation).

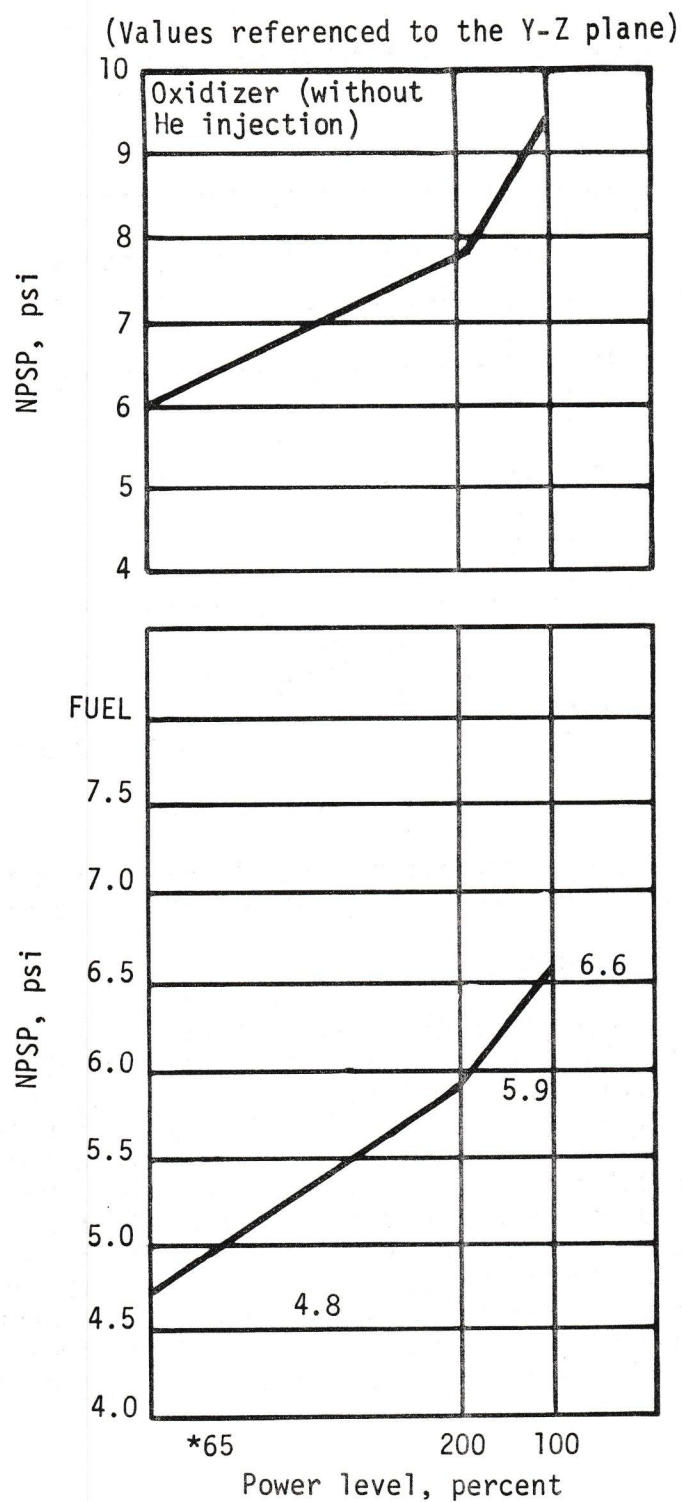


Figure 3.1-47.- Minimum NPSP at steady-state mainstage operation.

Note: values referenced to the Y-Z plane

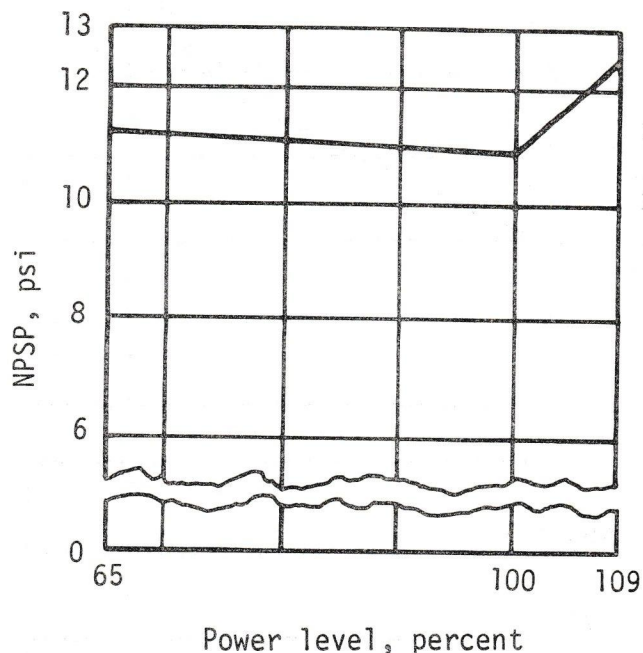


Figure 3.1-48.- Minimum NPSP at steady-state mainstage operation with 0.32 lb/sec helium ingestion.

Minimum Operating Inlet NPSP

The minimum engine operating NPSP requirements vs. power level for both liquid oxygen and liquid hydrogen are shown in figure 3.1-47. The requirements of figure 3.1-47 apply with GOX flow recirculation from the pogo suppressor when injected at a location 3 ft or higher from the vehicle/engine interface. The engine is capable of ingesting the helium returned from the engine accumulator to the vehicle L02 feedline. The maximum helium flow rate from the engine accumulator into the L02 feedline will not exceed 0.027 lb/sec. The maximum helium flow rate from the L02 feedline into the engine low-pressure pump will not exceed 0.032 lb/sec. This helium will be entrained in the L02 supply from 5.0 sec after the engine start signal until 40.0 sec after the engine start signal. The minimum operating NPSP while ingesting helium is shown in figure 3.1-48.

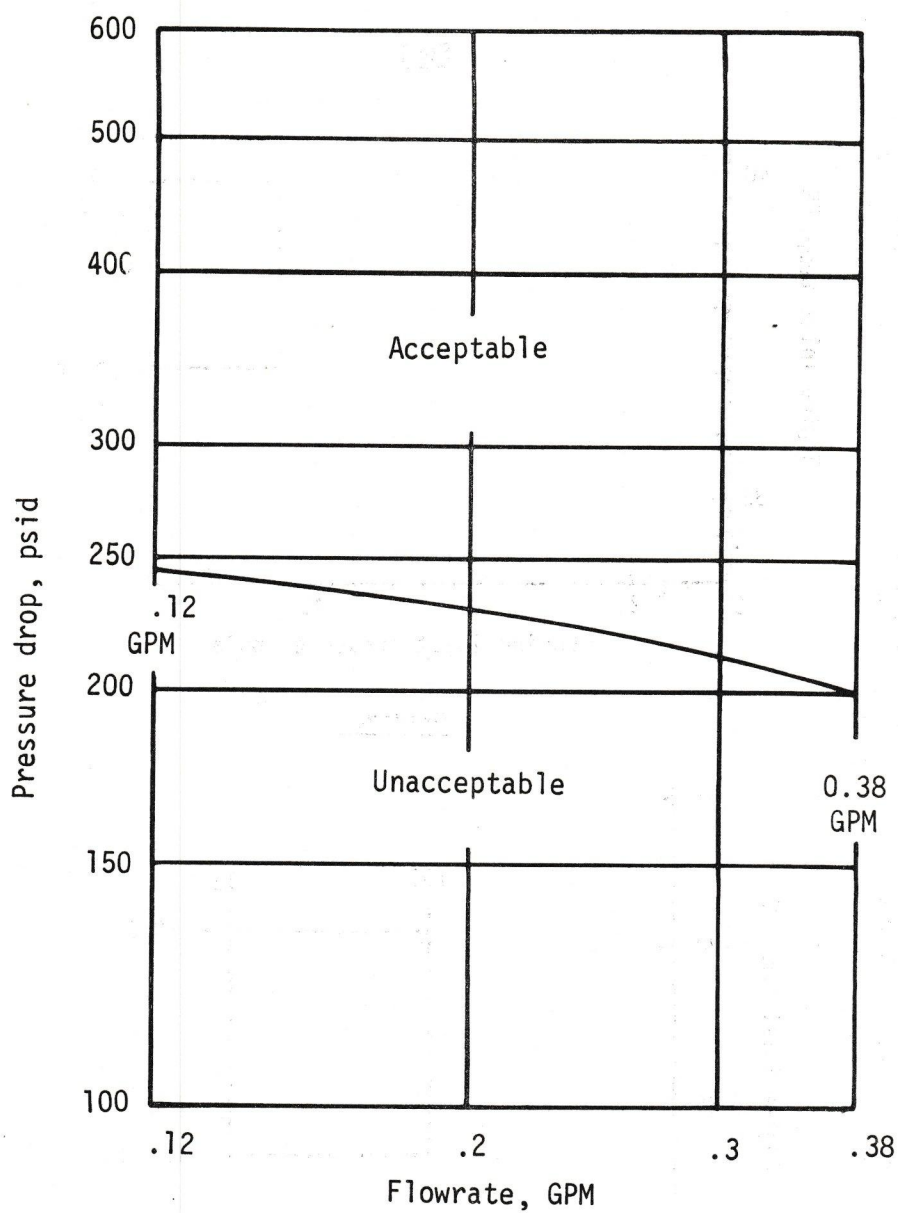


Figure 3.1-49.- Prelaunch warmant flow hydraulic fluid requirement.

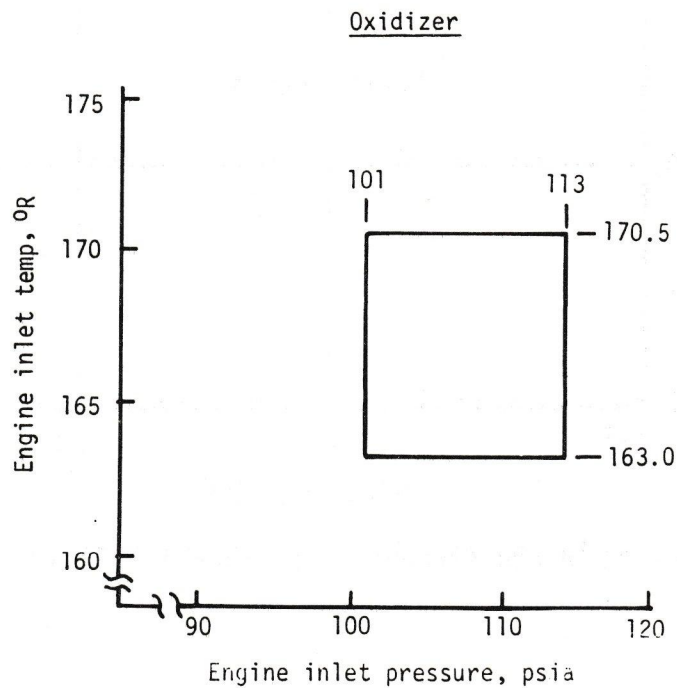
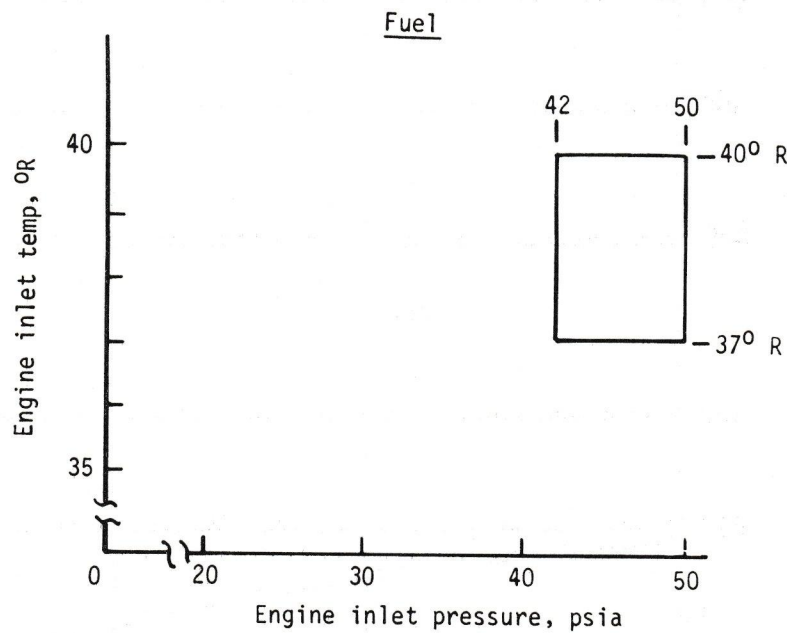


Figure 3.1-50.- Prestart propellant conditions.

Engine Prestart Propellant Conditions

The engine propellant conditions will be maintained so as to prevent engine-initiated geysering in the liquid oxygen feed system subsequent to the time liquid oxygen is supplied to the engine. The effect of post-pressurization ground hold, the conditions of figure 3.1-50 and the conditions of prestart boattail environment will be accommodated.

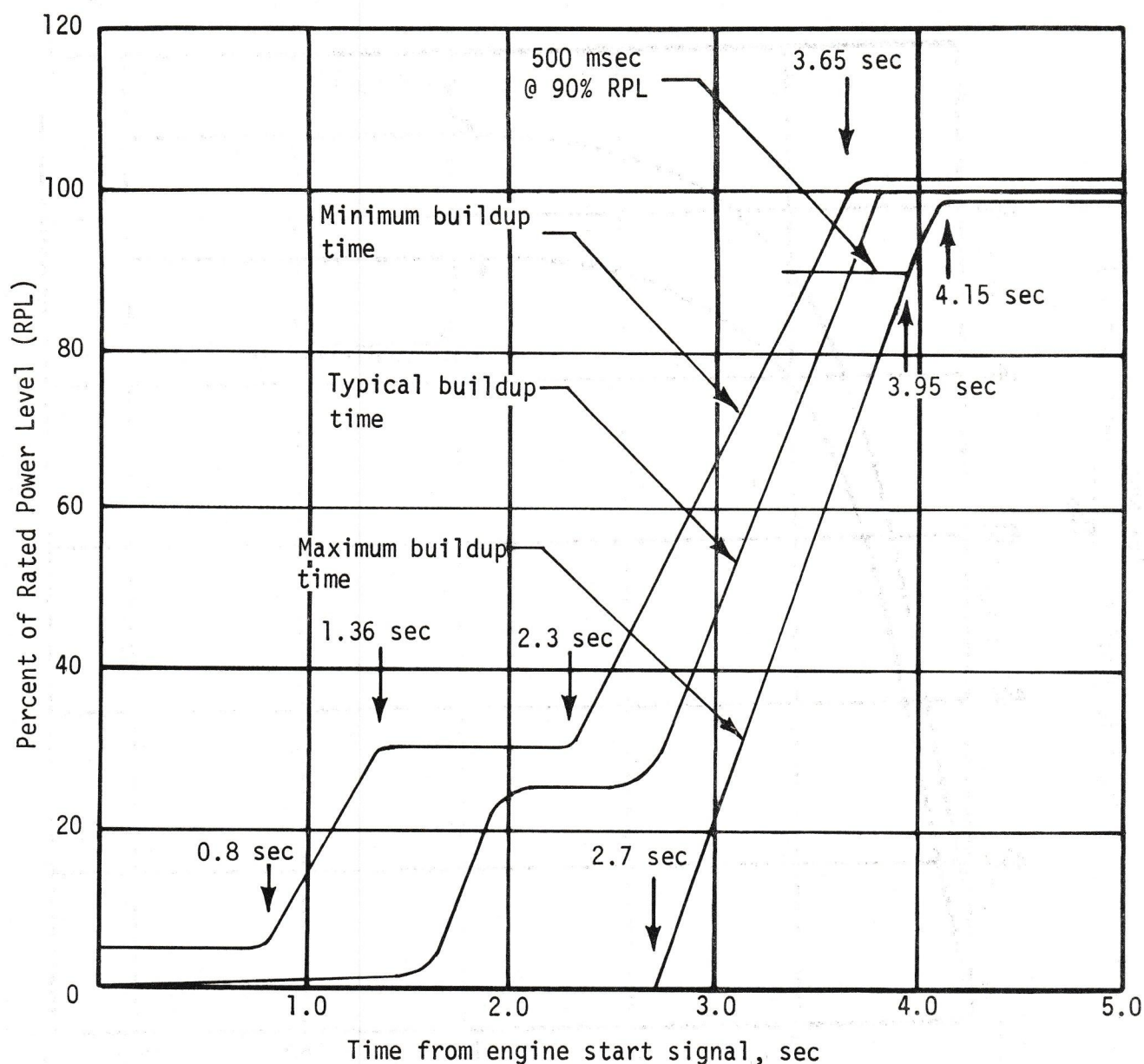


Figure 3.1-51.- Thrust buildup limits.

Engine Starting Time

The engine will be capable of accelerating from the start signal to RPL in 3.9 sec nominal with a dispersion of ± 0.25 sec as shown in figure 3.1-51. The engine will operate at a mixture ratio of 6.0 ± 1 percent which will be achieved within 5.0 sec after engine start signal.

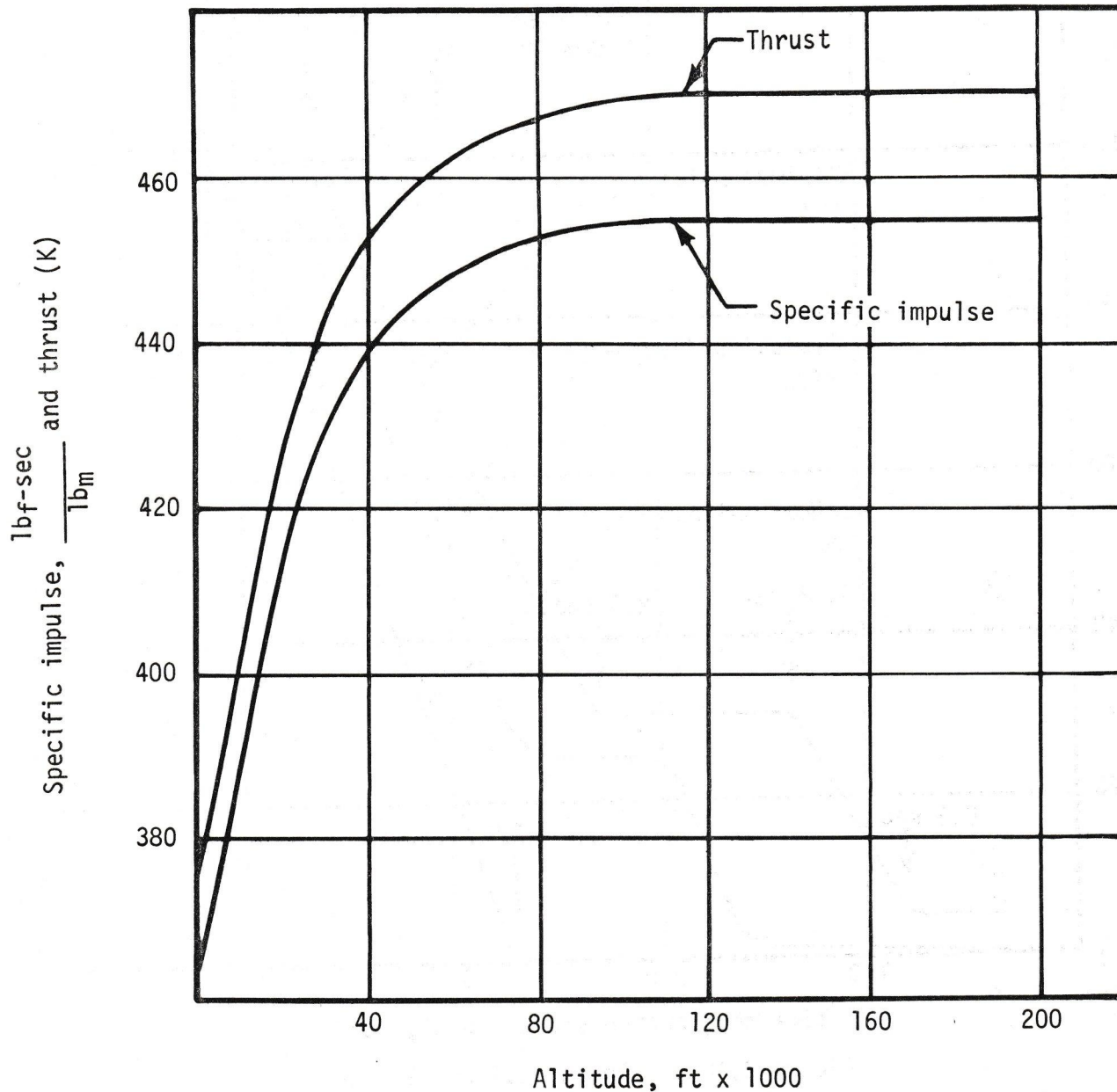


Figure 3.1-52.- Nominal specific impulse and thrust as a function of altitude.

The engine operating conditions for thrust and specific impulse are shown in Table 4.2.4-1. Specific impulse as a function of thrust level and altitude is shown in figure 3.1-52. Nominal engine inlet flowrates are LOX 886 lb/sec, and fuel 148 lb/sec.

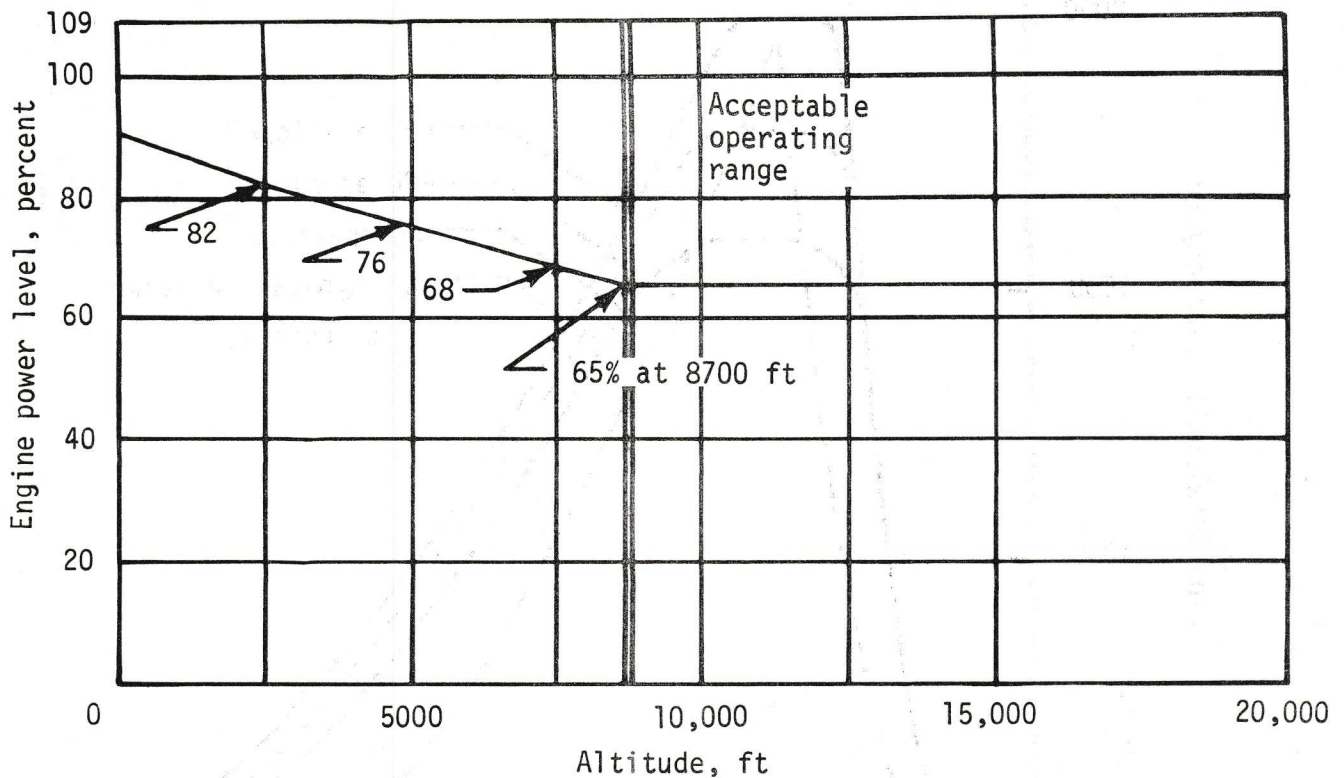


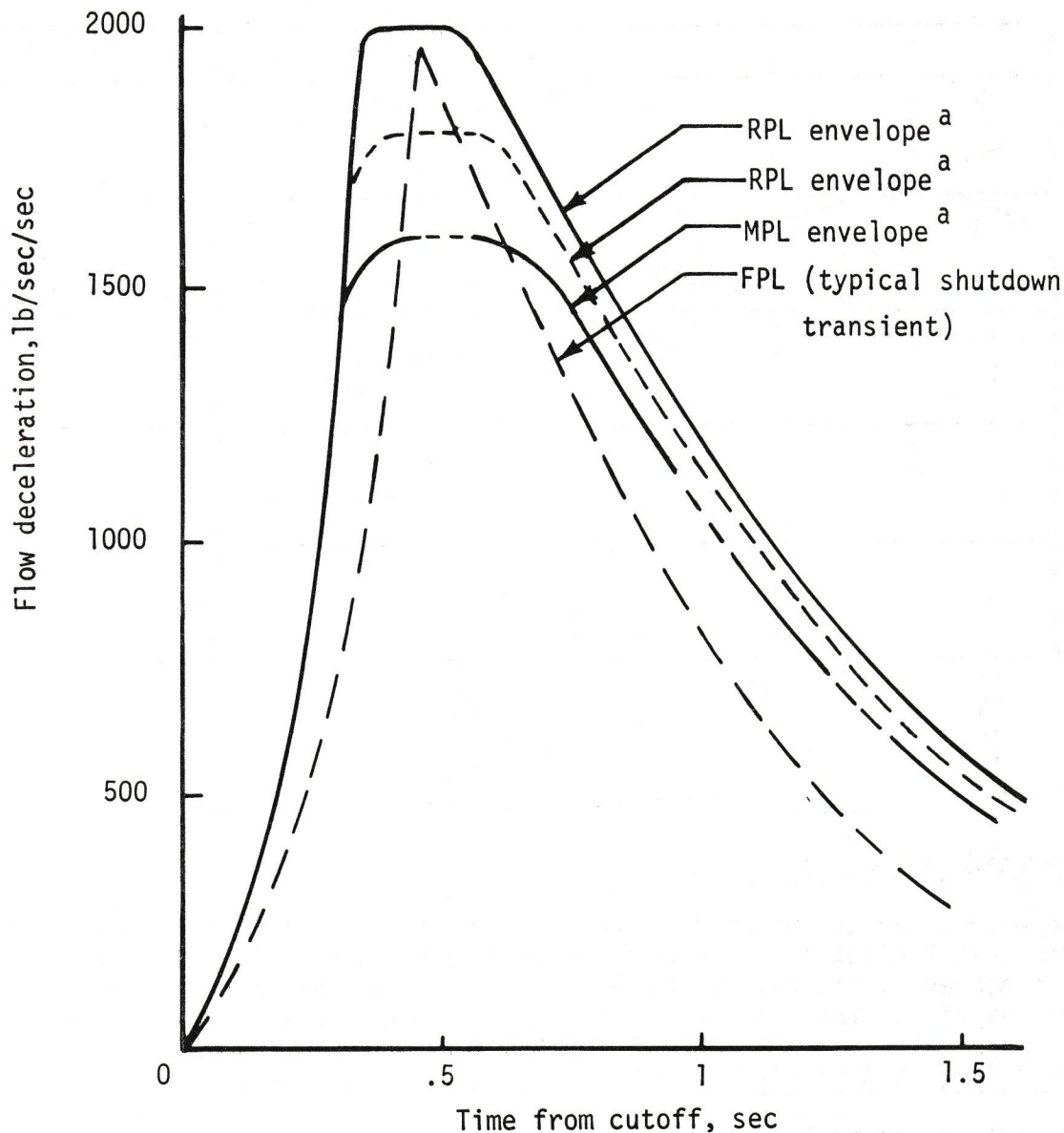
Figure 3.1-53.- Engine power level vs. altitude.

Operation at Sea Level

The engine can be operated at sea level conditions without the use of altitude test facilities or restrainer arms at RPL and above. Once RPL has been achieved, the engine may be throttled to 90 percent of RPL without the use of altitude test facilities or restrainer arms.

Throttling at Altitude

The engine can be throttled at altitudes from 0 to 8700 ft in accordance with the limitations of figure 3.1-33. At altitudes above 8700 ft, no throttling limitations exist.



^a The envelope includes the variation of shutdown transients for all engines.

Figure 3.1-54.- Maximum SSME L02 flow deceleration during shutdown.

The SSME will not generate oxidizer flow decelerations greater than the values shown in figure 3.1-54. The SSME will not generate fuel flow decelerations greater than 375 lb/sec/sec.

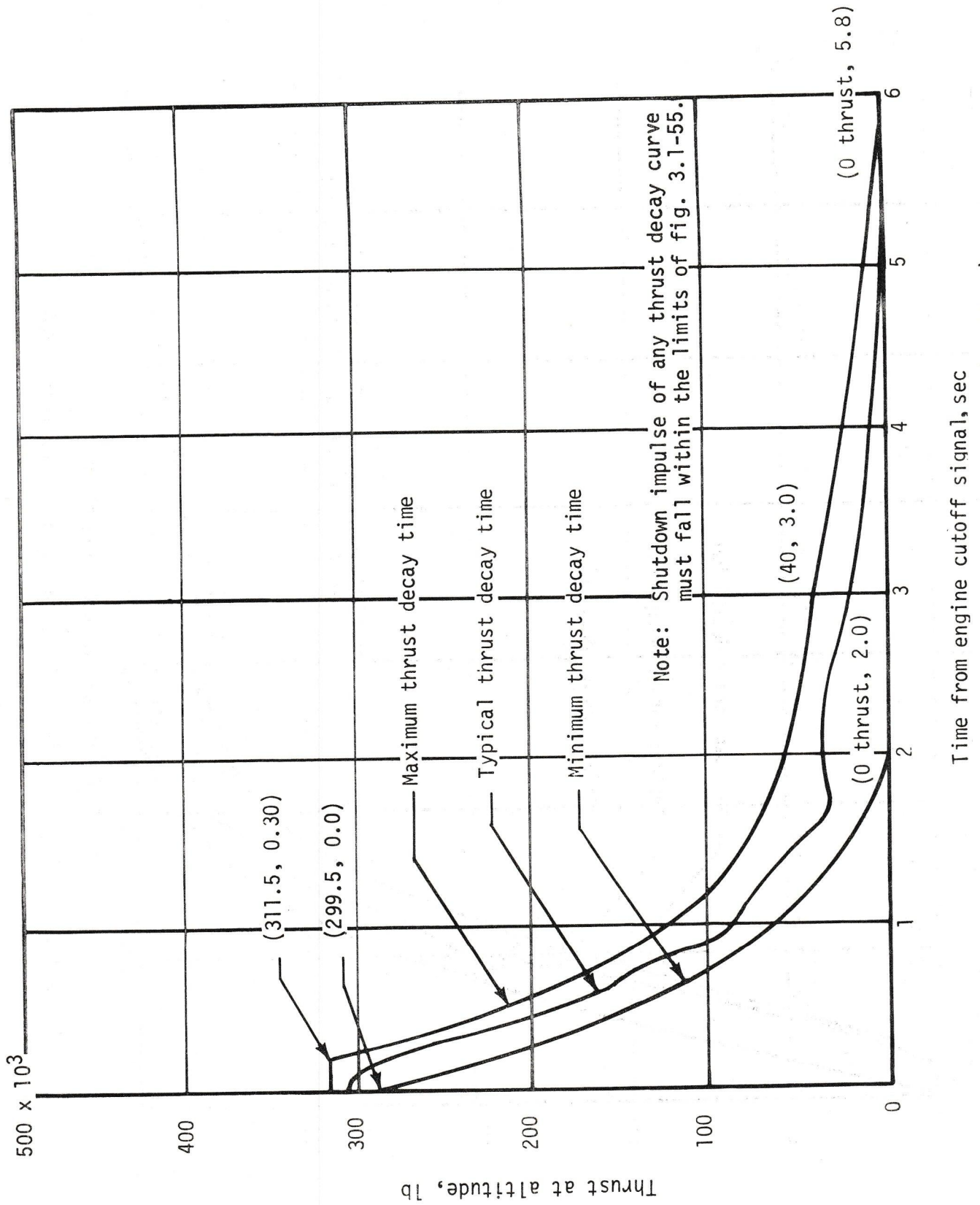


Figure 3.1-55.- Engine shutdown thrust decay from MPL (altitude).

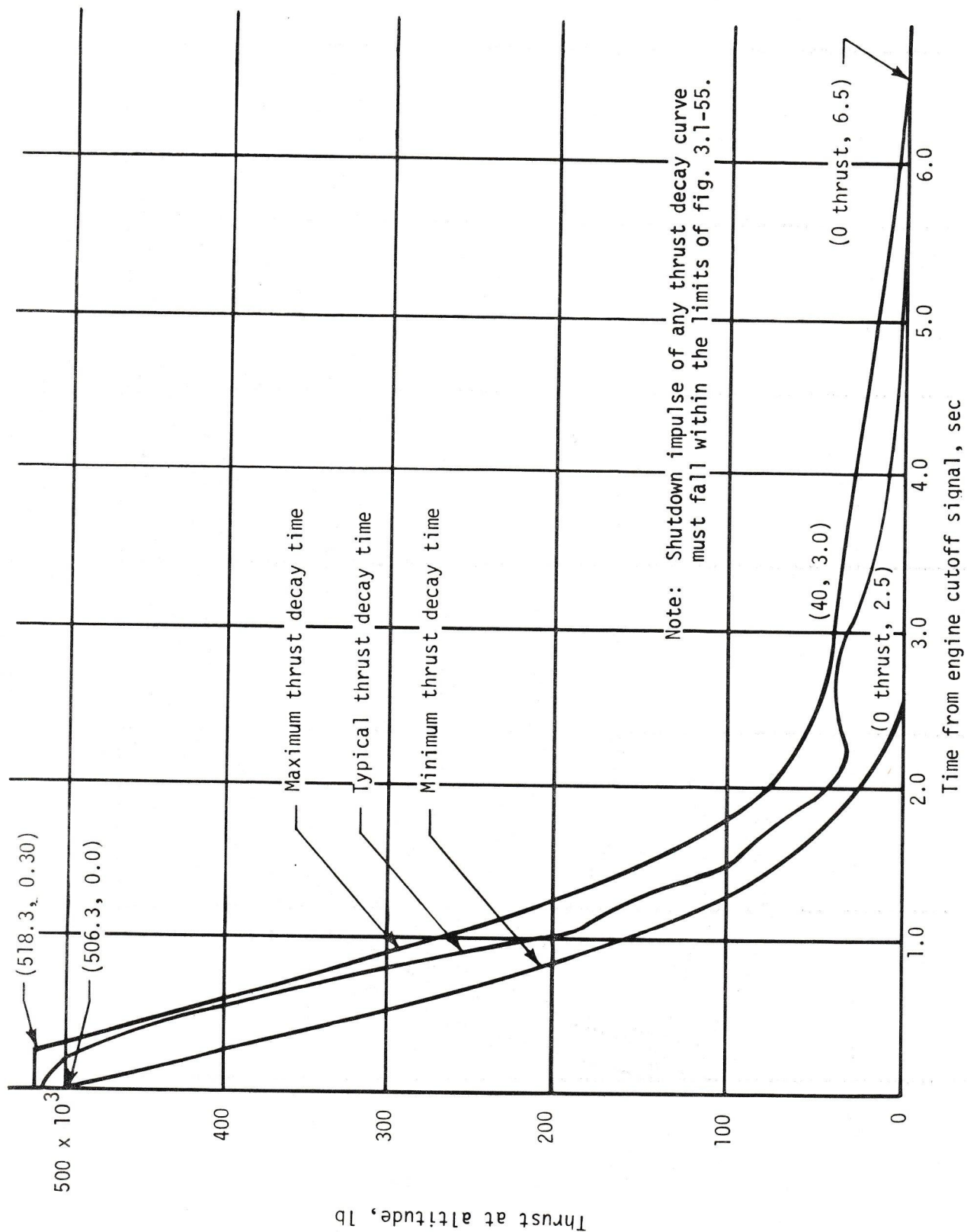


Figure 3.1-56.- Engine shutdown thrust decay from FPL (altitude).

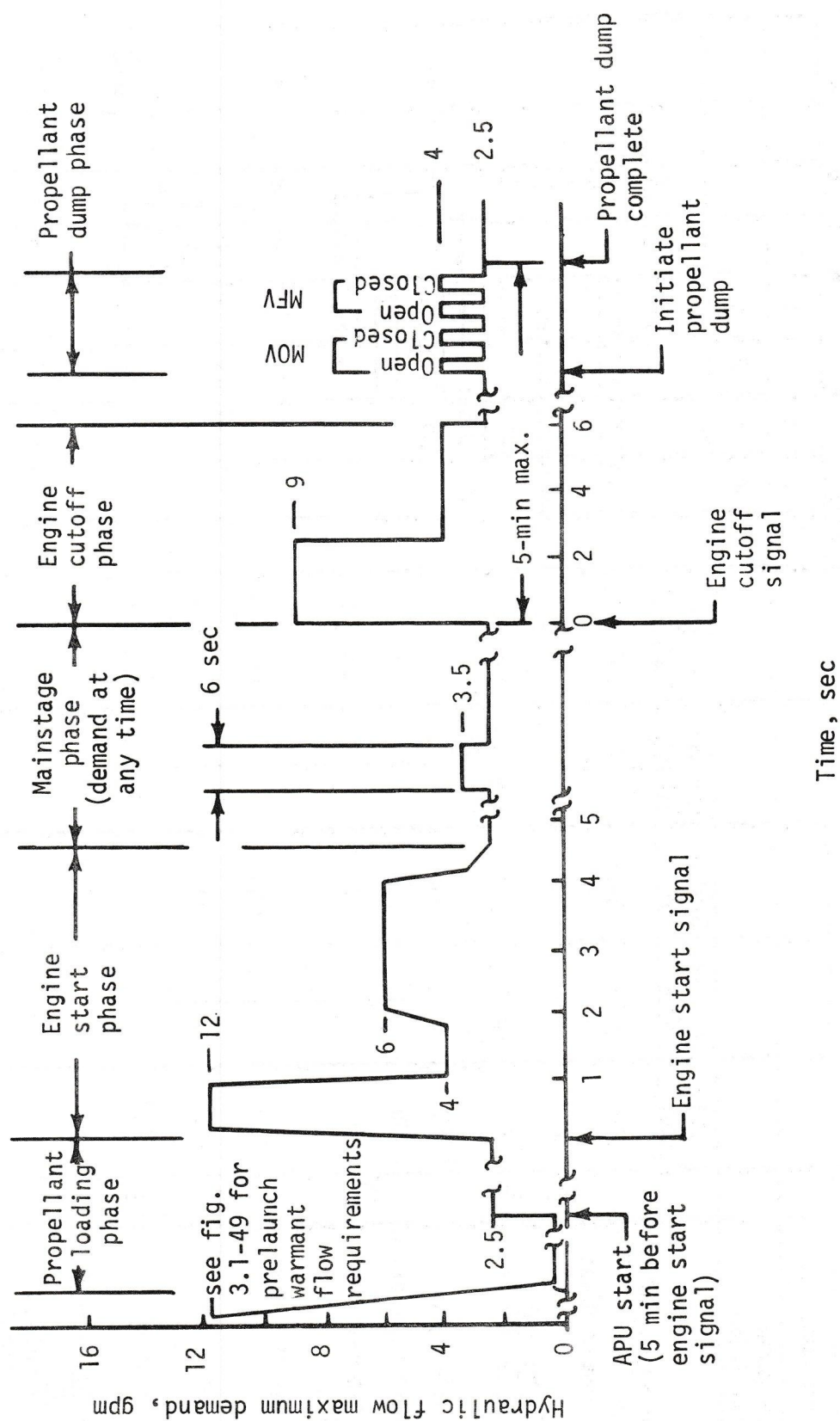
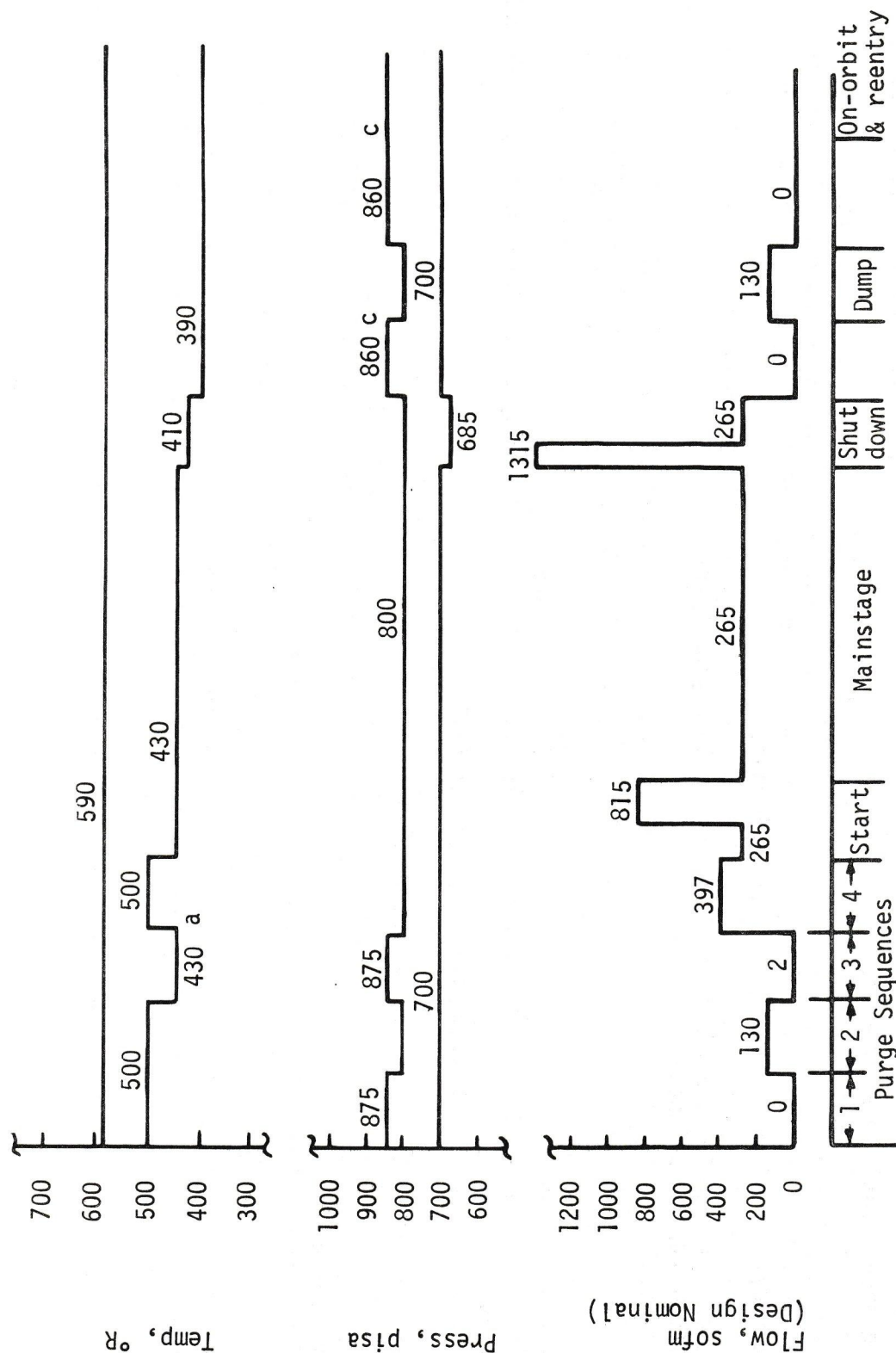


Figure 3.1-57.- Engine hydraulic flow requirements.

I/F No.	Pressure, psia	Temperature, deg R	Flow, scfm				
				1	2	3	4
Purge sequence no.				4	3	57	3
Minimum purge duration (min)							
Ground nitrogen, ^g Oxidizer dome HPOTP intermediate seal ^a	Design nom., n	I/F var- iation	Design ^f nom., n				
	600	+ 50	590				
Vehicle helium ^b Fuel system purge	600	+ 50	9590				
	750	see fig. 3.1-59	530				
Bleed valve act.	750		530				
Component fuel drain	750		530				
HPOTP intermediate seal	750		530				
Preburner shutdown purge	750		530				
POGO supression	750		530				
Oxidizer inlet feed system ^k	17.7	(m)	530				
Ground nitrogen or helium Oxidizer inlet feed system ^j	17.7	+ 2	530				

- aFor on-orbit propellant dump, the fuel system purge will be initiated for 10-sec minimum subsequent to oxidizer dump and prior to initiation of fuel dump.
- bEngine helium consumption includes additional helium per figure 3.1-59 for each time the emergency shutdown solenoid is deenergized.
- cThe engine pneumatic requirements during FRT are identical to the operation requirements except for purge sequence duration requirements.
- dThe GN2 purge is ground-controlled. GN2 purge activation will be simultaneous with purge sequence no. 1 command and will be within specified pressure limits in less than 5 sec after receipt of this command. Deactivation of GN2 purge will be such that the pressure requirements of figure 3.1-60 are met.
- eIncludes the effects of SSME hardware tolerances.
- fNitrogen purge temperatures must be within the I/F temperature requirements for a minimum of 30 min and must be unheated for a minimum of 30 min prior to engine start.
- gLeft blank intentionally.
- hPost static firing and pad abort purge requirements are specified in figure 3.1-61.
- iOxidizer inlet feed system purge is required on the ground at all times prior to purge sequence no. 1 except when liquid oxygen is present in the engine or when the HPOTP drains and thrust chamber exit (or throat) are covered, when the system is required to be vented to accomplish engine checkouts or maintenance activity, or when the vehicle is in a controlled (TBD) atmosphere.
- jStart of oxidizer inlet feed system purge is required prior to reaching an altitude of 100,000 ft during reentry.
- kFlow is applicable at an ambient pressure of 14.7 psia.
- lPurge must ensure that the oxidizer feed system pressure is greater than local ambient pressure at all times, and does not exceed a maximum of 50 psia.
- mDesign nominal parameters define the engine flow control equivalent orifice area.
- nPreburner shutdown purge is controlled by MEC and will not be applied during the period from start, to start +2.0 sec.
- oBleed valves closed at start enable signal before start.
- pGN2 purge through the HPOTP intermediate seal is terminated by the SSME valves when the helium HPOTP intermediate seal purge is initiated.
- qPostflight purge requirements are specified in figure 3.1-62.
- rPogo accumulator post charge is controlled by the MEC and will not be applied during the period from start, to start +2.4 sec.

Figure 3.1-58.- Engine pneumatic requirements.



aFlow is design nominal and does not correlate with pressure temperature I/F variations.
 bTemperature requirements of 4300 R maintained through first 30 sec of purge sequence no. 4.
 cFor ground shutdown, pressure valves may reach 875 psia.
 dFor RTLS abort, the minimum helium temperature is 3950 R and minimum pressure is 685 psia from engine start +600 sec through engine shutdown.

Figure 3.1-59.- Engine requirements (helium).

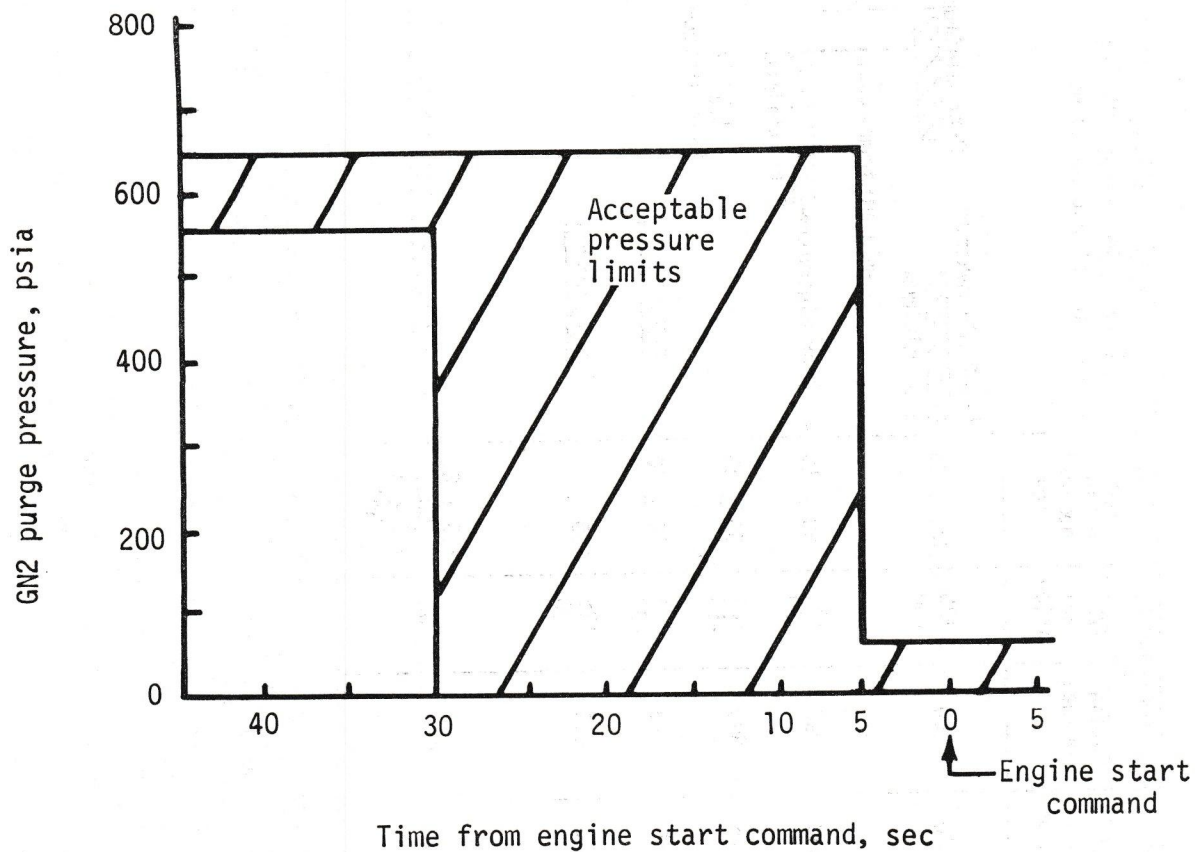


Figure 3.1-60.- The GN2 purge pressure deactivation requirements.

TABLE 3.1-13.- SSME POST SHUTDOWN PURGE REQUIREMENTS (FRF AND LAUNCH ABORT)

Purge description	I/F no.	Pressure, psia		Temperature, °F or		Flow, scfm	Purge timeline (time from engine cutoff)
		Design nominal	I/F variation	Design nominal	I/F variation		
Nitrogen							
Oxidizer dome ^a and HPOTP intermediate seal	8	600	±50	590	+35 -30	330 ± 25	
HPFTP bearing drying	38	600	±50	590	+35 -30	80 ± 10	
HPOTP turbine seal ^{b,g}	62	25	±5	590	+35 -55	50 ± 20	
Main combustion chamber ^b	39	600	±50	590	+35 -30	90 ± 20	
Nozzle ^b	63 64	600	±50	590	+35 -30	150 ± 30	
Ground nitrogen or helium oxidizer inlet feed system ^h	4	17.7	±2	530	±130	3.5 ± 2 (GN2) 9.5 ± 5 (He)	

^aSSME purge as used prestart, purge sequence 1 through 4, GN2 supplied through Orbiter/SSME interface.
^bFacility supplied using drag-on lines. The HPOTP turbine seal purge interface for the flight nozzle is located at the exit of the turbine primary seal drain line. These purges shall not be applied until liquid propellants have been removed from the engine.

^cOxidizer dome purge shall not be applied prior to removal of preburner shutdown purge.

^dIncludes only the effects of hardware tolerances.

^eMain combustion chamber and nozzle drying purges must be concurrent.

^fPurge until dew point of effluent gas is within 50 of supply gas dew point.

^gHPOTP turbine seal purge must not be applied without oxidizer dome purge.

^hOxidizer inlet feed system purge is required on the ground at all times prior to purge sequence no. 1 except when liquid oxygen is present in the engine or when the HPOTP drains and thrust chamber exit (or throat) are covered, or when the vehicle is in a controlled (TBD) atmosphere, or when the system is required to be vented to accomplish engine checkout or maintenance activity.

TABLE 3.1-14.- SSME POST-FLIGHT PURGE REQUIREMENTS

Purge description	I/F no.	Pressure, psia		Temperature, OR		Flow, scfm	Purge timeline (time after landing)
		Design nominal	I/F variation	Design nominal	I/F variation		
Nitrogen ⁱ Oxidizer dome ^{b,f} and HPOTP intermediate seal	8	600	±50	590	+35 -30	330 ± 25	
		25	±5	590	+35 -55	50 ± 20	
HPOTP turbine seal ^{c,f}	62						
HPFTP bearing drying ^c	38	600	±50	590	+35 -30	80 ± 10	
Main combustion chamber ^{c,e}	39	600	±50	590	+35 -30	90 ± 20	
Nozzle ^{c,e}	63 64	600	±50	590	+35 -30	150 ± 30	
Nitrogen or helium Oxidizer inlet feed system ^{d,j}	4	17.7	±2	530	±130	3.5 ± 2 (GN2) 9.5 ± 5 (He)	

^aIncludes the effects of hardware tolerance.

^bSSME GN2 purge as used prestart for purge sequences no. 1 through no. 4 supplied through the Orbiter/SSME interface.

^cFacility supplied using drag-on lines. The HPOTP turbine seal purge interface for the flight nozzle is located at the exit of the turbine primary seal drain line. These purges shall not be applied until liquid propellants have been removed from the engine.

^dOxidizer inlet feed system purge is required prior to start of post-flight purges.

^eMain combustion chamber and nozzle drying purges must be concurrent.

^fHPOTP turbine seal purge must not be applied without oxidizer dome purge.

^gPurge until effluent dew point is within 50 F of supply gas dew point.

^hOxidizer dome purge shall continue 10 min, minimum after completion of all other drying purges.

ⁱAir meeting SSME nitrogen dew point, particulate and hydrocarbon requirements may be used.

^jOxidizer inlet feed system purge is required on the ground at all times prior to purge sequence no. 1 except when liquid oxygen is present in the engine, when HPOTP drains and thrust chamber exit (or throat) are covered, when the vehicle is in a controlled (TBD) atmosphere, or when the system is required to be vented to accomplish engine checkout or maintenance activity.

PC

8A-MPS

3.2 SSMEC

3.2.1 Controller

The controller, which is an electronic package mounted on the SSME, operates in conjunction with engine sensors, valves, actuators, and spark igniters to provide a self-contained system for engine control, checkout, and monitoring (fig. 3.2-1). The controller provides:

- A. Engine flight-readiness verification.
- B. Engine start and shutdown sequencing.
- C. Closed-loop thrust and propellant mixture ratio control.
- D. Sensor excitation; valve, actuator, and spark igniter control signals.
- E. Engine performance limit monitoring.
- F. Onboard engine checkout.
- G. Response to vehicle commands and transmission of engine status, performance, and maintenance data to the vehicle.

The controller provides responsive control of engine thrust and mixture ratio through the digital computer in the controller, updating the instructions to the engine control elements 50 times per sec (every 20 msec). Additionally, precise engine performance is achieved through closed-loop control, utilizing 16-bit computation, 12-bit input/output resolution, and self-calibrating analog-to-digital conversion. Engine reliability is enhanced by a dual-redundant control system that allows normal operation after the first failure and a fail-safe shutdown after a second failure. High-reliability electronic parts are used throughout the controller.

The digital computer is programable, allowing modification of engine control equations and constants by change of the stored program (software). The controller is packaged in a sealed, pressurized chassis with cooling provided by convection heat transfer through pin fins as part of the main chassis. The electronics are distributed on functional modules with special provisions for thermal and vibrational protection. The controller is an LRU.

- COMPUTER CONTROL OF ENGINE
- SIZE: 23.5 X 14.5 X 17.0 INCHES
- TEMPERATURE
 - 50F TO +95F OPERATING
 - 200F TO +200F NON OPERATING
- VIBRATION ENVIRONMENT
 - DECAYING SINE: 24 G'S PEAK
 - RANDOM: 22.5 G'S RMS
- INPUT POWER
 - 115-VOLT, 400-HZ, 3-PHASE AC
 - 28-VOLT DC
 - 490 WATTS (STANDBY)
 - 600 WATTS (MAINSTAGE)
- HEAT TRANSFER
 - FORCED AIR COOLING (GROUND CHECKOUT)
 - CONVECTION COOLING (ENGINE OPERATION)

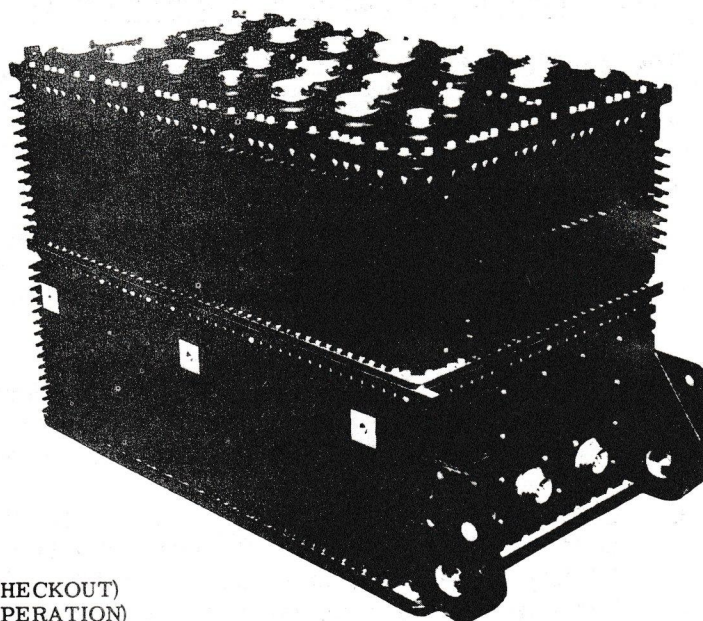


Figure 3.2-1.- The SSME controller.

3.2.2 Controller Functional Organization

The controller is functionally divided into five subsystems. Each of the five functional subsystems is duplicated to provide dual-redundant capability.

- A. Input electronics - Receives data from all engine sensors, conditions the signals and converts to digital values for processing by the digital computer. Engine control sensors are dual-redundant. Engine limit sensors are dual-redundant and maintenance data sensors are non-redundant.
- B. Output electronics - Converts the computer digital control commands into voltages suitable for powering the engine spark igniters, the off/on valves, and the propellant valve actuators.
- C. Computer interface electronics - Controls the flow of data within the controller, input data to the computer, and computer output commands to the output electronics. Provides the controller interface with the vehicle engine Electronics Interface Unit (EIU) for receiving engine commands (triple-redundant channels) from the vehicle and transmission of engine status and data (dual-redundant channels) to the vehicle. The computer interface electronics includes the watchdog timers that determine which channel of the dual-redundant mechanization is in control.
- D. Digital computer - An internally stored, general-purpose digital computer that provides the computational capability necessary for all engine control functions. The 2-mil Nondestructive Readout (NDRO) plated-wire memory has program storage capacity of 16,384 data and instruction words (17-bit words; 16 bits for program use, 1 bit for parity). Typical computer instruction times are 2 sec add and 9 sec multiply. The total engine major cycle times is 20 msec.
- E. Power supply electronics - Converts the 115-V, 3-phase, 400-Hz vehicle power to the individual power supply voltage levels required by the engine control system, and monitors the level of power supply channel operation within satisfactory limits.

3.2.3 MEC Power

The MEC uses ac power obtained through panel L4 circuit breakers (fig. 5-4, table 5-4) and panel R2 MPS ENGINE POWER switches (fig. 5-7, table 5-7). The routing of ac power to the MEC power supplies A and B is shown in figure 3.2-2 (reference sec. 3.2.2, paragraph E). A third power supply is derived from power supplies A and B except for the Vehicle Interface Electronics (VIE) circuitry that processes the GPC engine command output by the EIU. That circuitry is powered by power supply C.

3.2.4 MEC Heater Power

Each of the MEC's heaters is powered by main bus power through an RPC (fig. 3.2-3). The RPC is controlled via the MAIN PROPULSION SYSTEM ENGINE CNTLR HTR switch (fig. 5-8, table 5-8) on panel R4 which routes control bus power to the RPC's. The heaters are normally not used until after MECO. The heaters' purpose is to act as a survival heater during the remainder of the mission.

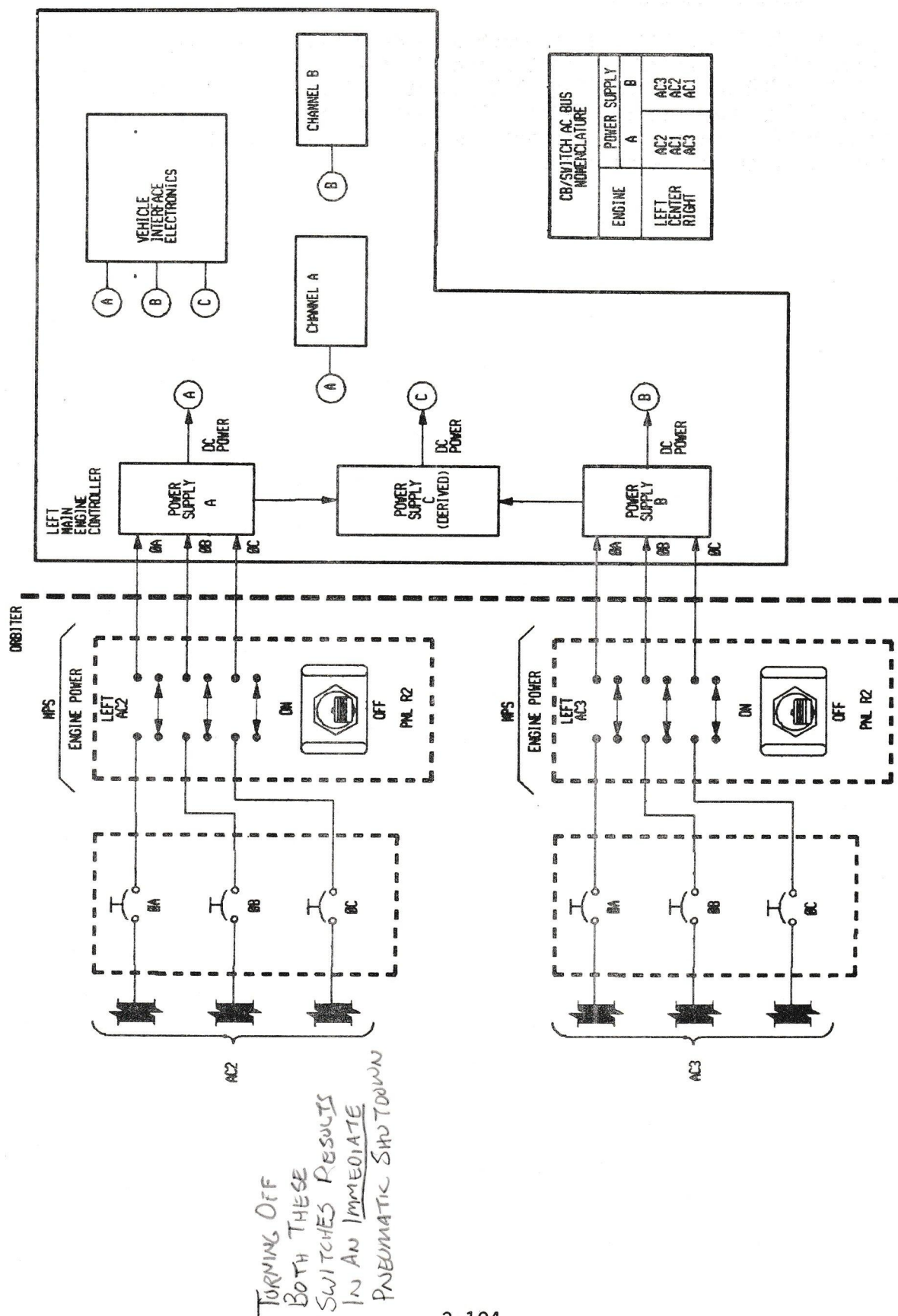
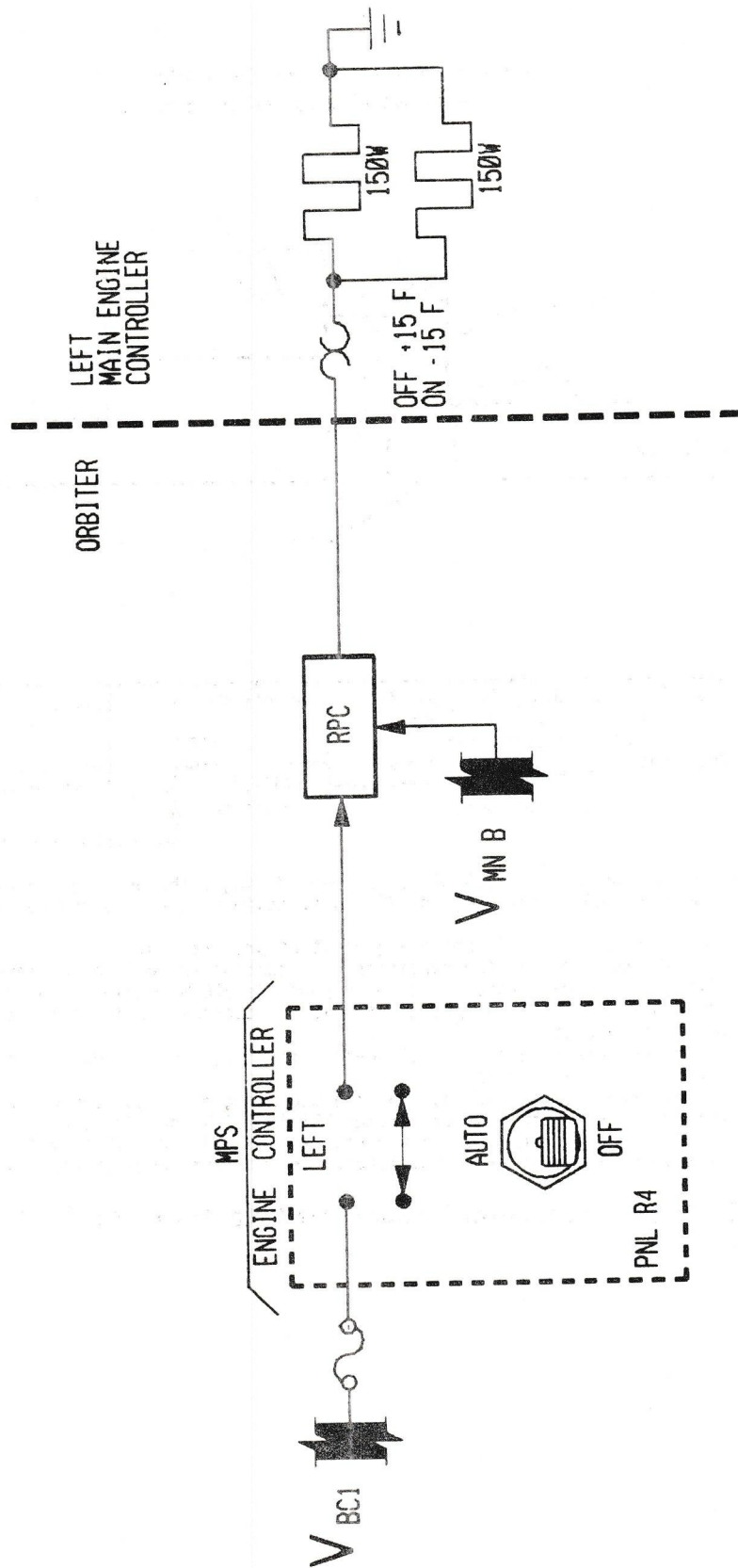


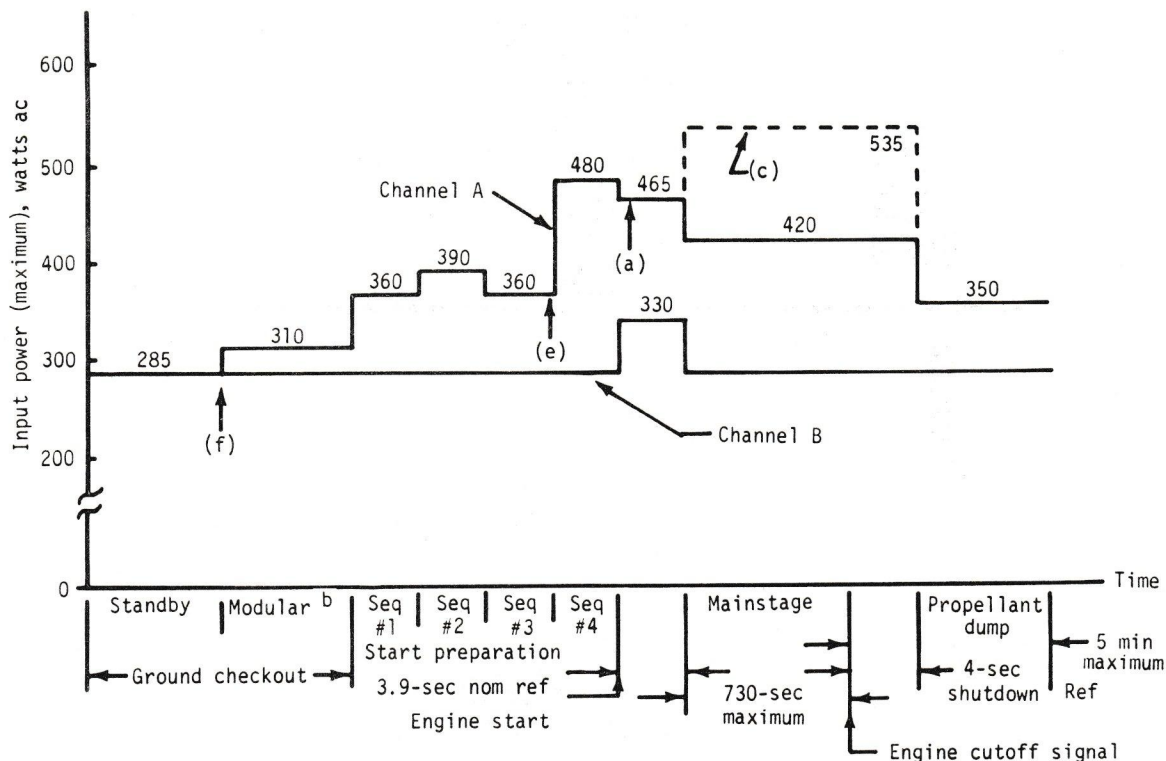
Figure 3.2-2.- The MEC power.



ENGINE	BUSES	
	CONTROL	MAIN
LEFT	BC1	MNB
CENTER	AB1	MNA
RIGHT	CA1	MNC

Figure 3.2-3.- Main engine heater power.

Note: Profile defines controller input power for channel A output electronics in control



^aChannel A power is 750 W, maximum, for 200 msec, maximum, during a channel A power recovery during engine start. Channel B power is 900 W, maximum, for 200 msec, maximum, during a channel B power recovery during engine start.

^bFRT power corresponds with power profile beginning at start preparation.

^cChannel A power is 535 W, maximum, for the condition of a controller failure in channel A (channel A output electronics in control) during mainstage. Channel B power is 570 W, maximum, for the condition of a controller failure in channel B (channel B output electronics in control) during mainstage. Failure conditions are a shorted igniter power output.

^dController power is applied continuously from at least 7 min prior to introduction of propellants to the engine to the completion of propellant dump.

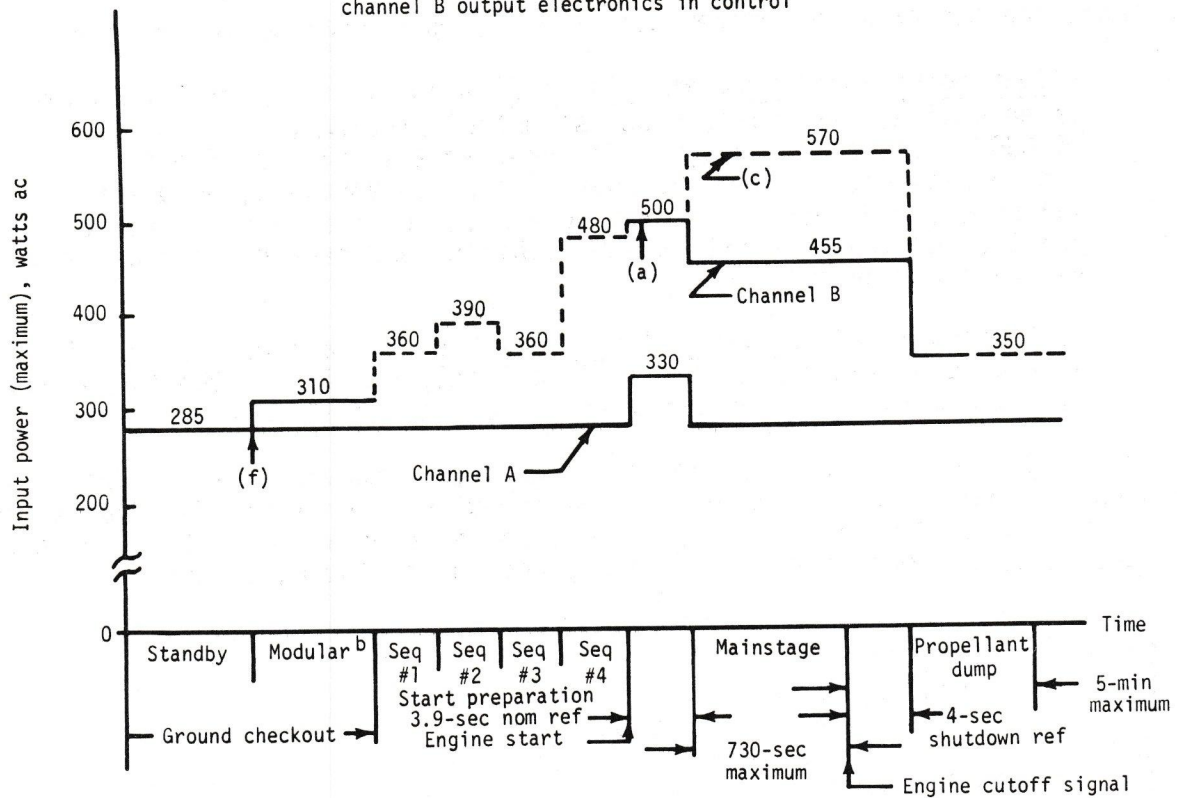
^ePower is 700 W, maximum, for 200 msec, maximum, at the beginning of purge sequence no. 4.

^fWorst case peak power for modular checkout other than FRT is 700 W for 200 msec, maximum.

^gDuring initial controller turnon or during a power recovery, a 0.4-msec, 12-A typical surge current will occur on any one of the three 200-V ac L-L input lines. The maximum surge current is 14-A.

Figure 3.2-4.- Engine ac electrical power profile (channel A in control).

Note: Profile defines controller input power for channel B output electronics in control



^aChannel A power is 750 W, maximum, for 200 msec, maximum, during a channel A power recovery during engine start. Channel B power is 900 W, maximum, for 200 msec, maximum, during a channel B power recovery during engine start.

^bFRT power corresponds with power profile beginning at start preparation.

^cChannel A power is 535 W, maximum, for the condition of a controller failure in channel A (channel A output electronics in control) during mainstage. Channel B power is 570 W, maximum, for the condition of a controller failure in channel B (channel B output electronics in control) during mainstage. Failure condition is a shorted igniter power output.

^dController power is applied continuously from at least 7 min prior to introduction of propellants to the engine to the completion of propellant dump.

^ePower is 700 W, maximum, for 200 msec, maximum, at the beginning of purge sequence no. 4.

^fWorst case peak power for modular checkout other than FRT is 700 W for 200-msec, maximum.

^gDuring initial controller turnon or during a power recovery, a 0.4-msec, 12-A typical surge current will occur on any one of the three 200-V ac L-L input lines. The maximum surge current is 14-A.

Figure 3.2-5.- Engine ac electrical power profile (channel B in control).

3.2.5 Controller Software

There are two primary written controller computer software programs.

- A. Flight operational program (flight 2) - The flight operational program is an online, real-time, process control program written in the DAP-16 MOD 2 assembly language. The program will process inputs from engine sensors; control the operation of servovalves, actuators, solenoids, and spark igniters; accept and process vehicle commands; provide and transmit data to the vehicle; and provide checkout and monitoring capabilities.
- B. Test operational program (flight 1) - The test program is used in support of engine testing. It is functional, similar to the flight operational program, but differs with respect to implementation.

The flight operational program is designed on a modular basis. The highest-level modular elements of the computer program are defined as Computer Program Components (CPC). The computer program consists of a data base, which is organized into tables, and the following 15 CPC's:

CPC 1	Executive
CPC 2	Self-test
CPC 3	Sample problem
CPC 4	Start preparation control
CPC 5	Power range control
CPC 6	Post-shutdown
CPC 7	Vehicle command processing
CPC 8	Sensor data processing
CPC 9	Failure response
CPC 10	Output command and monitoring
CPC 11	FRT overlay
CPC 12	Actuator overlay
CPC 13	Sensor overlay
CPC 14	Pneumatics overlay
CPC 15	Redundancy verification overlay

The data base tables are organized into an interrupt table, interrupt masked table, direct memory access input table, vehicle data table, engine status word table, failure flags and strike counter table, common constants table, and temporary storage table.

The first 27 sectors of the computer memory are called the resident area (sectors 0 through 37, octal). The remaining five sectors are called the overlay area. Each sector contains 512 words. The resident area will always contain the same basic computer program configuration. The overlay area (sectors 33 through 37, octal) will normally contain one of the CPC overlay configurations.

3.2.6 Controller Operational Program

During application of the above CPC's, the operational program performs data processing functions for failure detection and status supplied to the vehicle.

As system operation progresses through an operating phase, different combinations of control functions are operative at different times. These combinations within a phase are defined as operating modes. Operating mode definitions for all operating phases are described as follows:

Checkout Phase

The operational program is initiated to begin active control, monitoring, or checkout.

- A. Standby mode - A waiting mode of controller operation during which active control sequence operations are in process. Monitoring functions which do not affect engine hardware component status are continually active during this mode. Such functions include processing of vehicle commands, status update, and controller self-test. During the checkout phase, the capability to allow loading data and instructions into computer memory is provided. This permits updating of software program and data as necessary to proceed with the engine firing operations or checkout operations.
- B. Component checkout mode - A checkout or engine leak test is performed on an individual engine system component.

Start Preparation Phase

System purges and propellant conditioning are performed in preparation for engine start.

- A. Purge sequence no. 1 mode - First purge sequence of the start preparation phase is in progress. Functions include oxidizer system and intermediate seal purge operation.
- B. Purge sequence no. 2 mode - Second purge sequence of start preparation is in progress. Functions include fuel system purge operation, and continuation of purges initiated in purge sequence no. 1.
- C. Purge sequence no. 3 mode - Third purge sequence of start preparation is in progress. Functions include propellant recirculation (bleed valve operation).
- D. Purge sequence no. 4 mode - Fourth purge sequence of start preparation is in progress. Functions include fuel system purge after propellant drop.
- E. Engine ready mode - The ready stage of start preparation in which proper engine thermal conditions for start have been attained and other criteria for start have been satisfied. Functions include a continuation of purge sequence no. 4 functions.

Start Phase

Covers operations for starting or engine firing beginning with scheduled open-loop operation of propellant valves.

- A. Start initiation mode - Initial functions associated with the start sequence are in progress. These include all functions prior to ignition confirmed. The thrust control loop has been closed.
- B. Thrust buildup mode - Ignition has been detected by monitoring of MCC pressure and closed-loop thrust buildup sequencing is in progress.

Mainstage Phase

Automatically entered upon successful completion of the start phase.

- A. Normal control mode - Mixture ratio control has been initiated. Thrust control is operating normally.
- B. Electrical lockup mode - Engine propellant valves are electrically held in a fixed configuration as existed at initiation of this mode. All control loop computations are suspended.
- C. Hydraulic lockup mode - All fail-safe valves are deactivated to hydraulically hold the propellant valves in a fixed configuration as existed at the initiation of this mode. All control loop computations are suspended.

*F/S off → failure has occurred
F/S on → Engine normal*

Shutdown Phase

Covers operations to reduce engine MCC pressure and drive all valves to effect full engine shutdown.

- A. Throttling to MPL mode - Shutdown is in progress at a programmed shutdown thrust reference level above MPL.
- B. Valve schedule throttling mode - Shutdown is at a stage in the sequence where the programmed thrust reference has decreased below MPL.
- C. Propellant valves closed mode - The shutdown sequence is in the stage following closure of all liquid propellant valves. Shutdown purge and verification sequences are in progress.
- D. Fail-safe pneumatic mode - Fail-safe pneumatic shutdown is in progress.

Post Shutdown Phase

Represents the state the SSME and MEC enter at completion of engine firing.

- A. Standby mode - A waiting mode of controller operations with functions identical to those of standby during checkout. This is the normal mode of post shutdown entered after completion of the shutdown phase.
- B. Terminate sequence mode - Termination of a purge sequence by a command from the vehicle is in progress. All propellant valves are being closed, and all solenoid and torque motor valves are being deenergized.
- C. Oxidizer dump mode - Oxidizer dump sequence being performed.
- D. Fuel dump mode - Fuel purge and dump sequence are in operation.

TABLE 3.2-1.- THE SSME ENGINE STATUS WORD

Bit	1	2 3	4 5 6	7	8	9 10 11	12 13 14	15 16
Func	Mem load status	Cmd stat	Channel status	FRT stat	Limit control	Phase in effect	Operating mode in phase	Engine self-test status
<u>Bit 1 - Memory load status</u>								
0	Non-soft load mode (accepts GPC commands)							
1	Software load mode (accepts S/W commands)							
<u>Bits 2-3 - Command status</u>								
00	No command received since last VIE transmission							
01	Command rejected (invalid BCH/vote)							
10	Command rejected (not compatible with operating mode or not in table of commands)							
11	Command accepted							
<u>Bits 4-6 - Channel status</u>								
000	All channels O.K.							
001	Error, channel 1							
010	Error, channel 2							
011	Error, channels 1 and 2							
100	Error, channel 3							
101	Error, channels 1 and 3							
110	Error, channels 2 and 3							
<u>Bit 7 - FRT status</u>								
0	Normal (flight)							
1	FRT							
<u>Bit 8 - Limit control</u>								
0	Inhibit							
1	Enable							
<u>Bits 9-11 - Phase in effect</u>								
000	Not used							
001	Checkout							
010	Start prep							
011	Start							
100	Mainstage							
101	Shutdown							
110	Post shutdown							
111	Not used							

TABLE 3.2-1.- THE SSME ENGINE STATUS WORD - Concluded

Bits 12-14 - Operating mode in phase						
	<u>Checkout</u>	<u>Start prep</u>	<u>Start</u>	<u>Mainstage</u>	<u>Shutdown</u>	<u>Post shutdown</u>
000	--	--	--	--	--	--
001	Stby	Purge seq 1	Start	Normal	Throt to MPL	Stby
010	--	Purge seq 2	Thrust buildup	--	Throt to zero	Oxid dump
011	--	Purge seq 3	Elec hold	Elec hold	Prop vlv closed	Fuel dump
100	Component C/O	Purge seq 4	Hyd lock	Hyd lock	Pneumatic shutdown	--
101	--	--	--	--	--	--
110	--	Eng ready	--	--	--	--
110	--	--	--	--	--	Term seq
Bits 15-16 - Engine self-test status						
00	FASCOS limit exceeded					
01	Engine O.K.					
10	Major component failed					
11	Engine limit exceeded					

3.2.7 SSME Control Components

The major components that perform main engine control are:

- A. SSME Systems Operating Program (SOP)/SSME Hardware Interface Program (HIP) - The SSME SOP and SSME HIP are applications software residing in the GPC's. Each PASS GPC (nominally GPC's 1, 2, 3, and 4) contains an SSME SOP. The BFS GPC (nominally GPC 5) contains the SSME HIP. With PASS in control, the PASS GPC's operating in a redundant set will send commands to the Engine Interface Units (EIU's) for transmission to the engine controller. With PASS in control, the BFS does no commanding. The PASS GPC's will request data from the EIU's, which are sent to both the PASS and BFS GPC's. With BFS in control, the BFS will send commands to, and request data from the EIU's. With BFS in control, the PASS GPC's neither command nor listen.
- B. EIU - The EIU is a specialized MDM that interfaces the GPC's with the MEC's computer. When engine commands are received by the EIU, the EIU sends them to the engine controller. When SSME data are received by the EIU, the data are held in a buffer until a GPC request for data is received by the EIU. The EIU then sends data to each GPC. Each EIU is dedicated to one SSME and communicates only with the engine controller that controls that SSME. The EIU's have no interface with each other.
- C. MEC - The MEC is a digital computer with associated electronics that controls all main engine components and operations. The engine controller receives engine commands transmitted by the GPC's through the EIU dedicated to that engine controller. The engine controller will issue its own commands corresponding to the received command to the main engine components. Main engine data are sent to the engine controller where the data are stored in a Vehicle Data Table (VDT) in the computer's memory. Controller status data compiled by the engine controller's computer are also added to the VDT. The VDT is periodically output by the engine controller to the EIU for transmission to the GPC's.

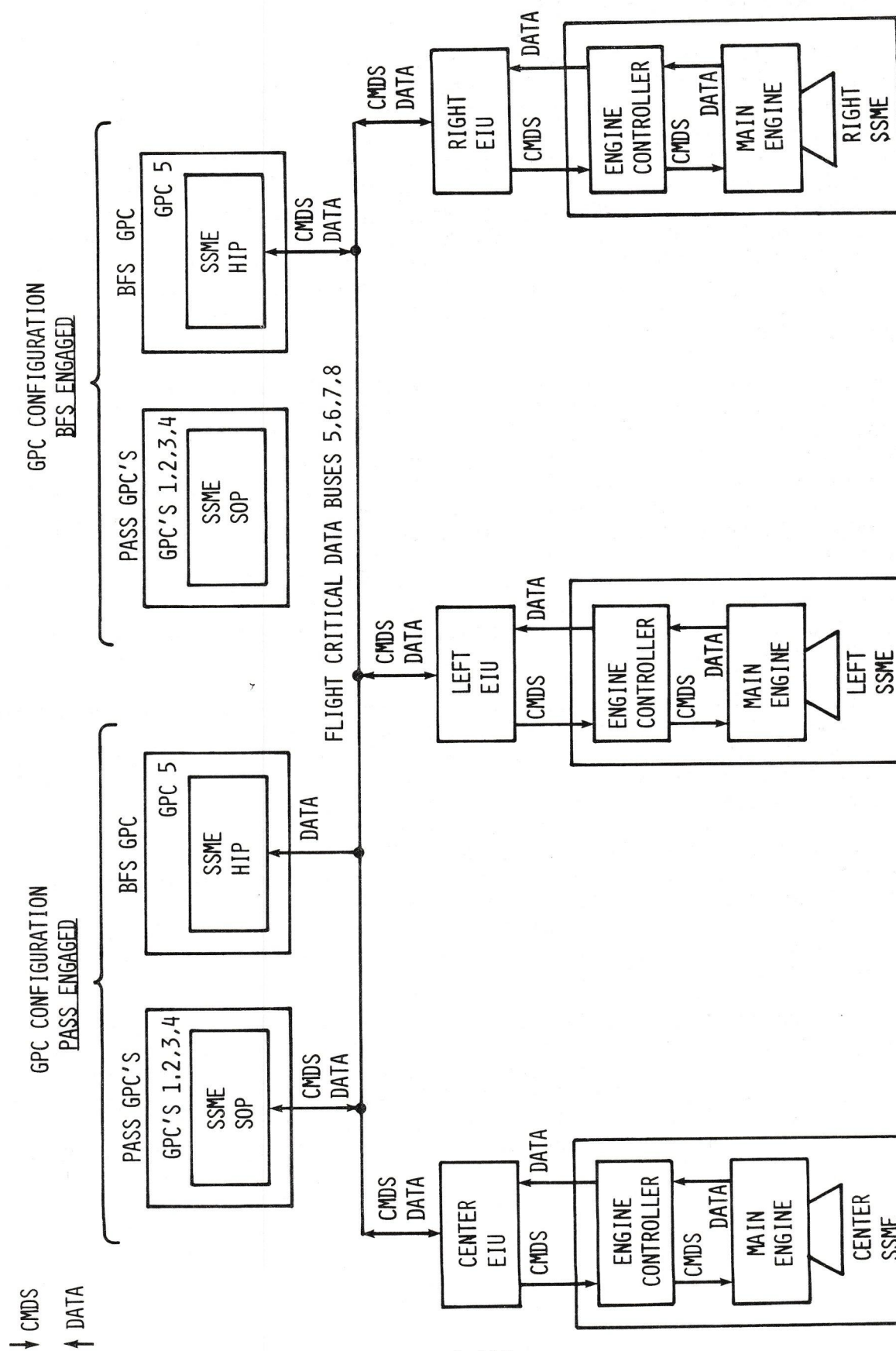


Figure 3.2-6.- The MEC overview.

3.2.8 Main Engine Command Flow

Each PASS GPC (fig. 3.2-7) operating in a redundant set will issue main engine commands to the EIU's for transmission to their corresponding engine controllers in the following manner: The SSME SOP in each PASS GPC will monitor command request flags. When a command request flag is set, the SSME SOP obtains an engine command from the COM POOL (where data are stored) corresponding to the command flag that is set. The engine command is output by each PASS GPC over its assigned Flight-Critical (FC) data bus (a total of four GPC's outputting over four FC data buses). Therefore, each EIU will receive four commands. The nominal ascent configuration has GPC's 1, 2, 3, and 4 outputting on FC data buses 5, 6, 7, and 8, respectively. Each FC data bus is connected to one Multiplexer Interface Adapter (MIA) in each EIU.

The EIU checks the received engine commands for transmission errors. If there are none, the EIU passes the validated engine commands on to the Controller Interface Assemblies (CIA's) which output the validated engine commands to the engine controller. Any engine command that does not pass validation is not sent to the CIA and is dead-ended in the EIU's MIA. Commands that come through MIA's 1 and 2 are sent to CIA's 1 and 2, respectively. Commands that come to MIA's 3 and 4 pass through a CIA 3 data select logic. This logic outputs the command that arrives at the logic first from either MIA 3 or 4. The other command is dead-ended in CIA 3 select logic. The selected command is output through CIA 3. In this manner, the EIU reduces the four commands sent to the EIU to three commands output by the EIU.

The engine controller VIE receives the three engine commands output by its EIU, checks for transmission errors (hardware validation), and sends controller hardware-validated engine commands to controller channel A and B electronics. Normally, channel A electronics is in control with channel B electronics active, but not in control. If channel A fails, channel B will assume control. If channel B subsequently fails, the engine controller will shut down the engine pneumatically. The channel in control will perform voting on the commands. If two or three commands pass voting, the engine controller will issue its own commands to accomplish the function commanded by the GPC's. If command voting fails; i.e., two or all three commands fail, the engine controller will maintain the last command that passed voting.

For BFS engaged (fig. 3.2-8), the only major change is that all eight FC data buses are assigned to one GPC; i.e., GPC 5. Thus, GPC 5 (with BFS in control) will command FC data buses 5, 6, 7, and 8 for main engine control through the SSME HIP. The SSME HIP will perform the same main engine command functions as the SSME SOP. The command flow through the EIU's and engine controllers remains the same for BFS engaged as for PASS engaged.

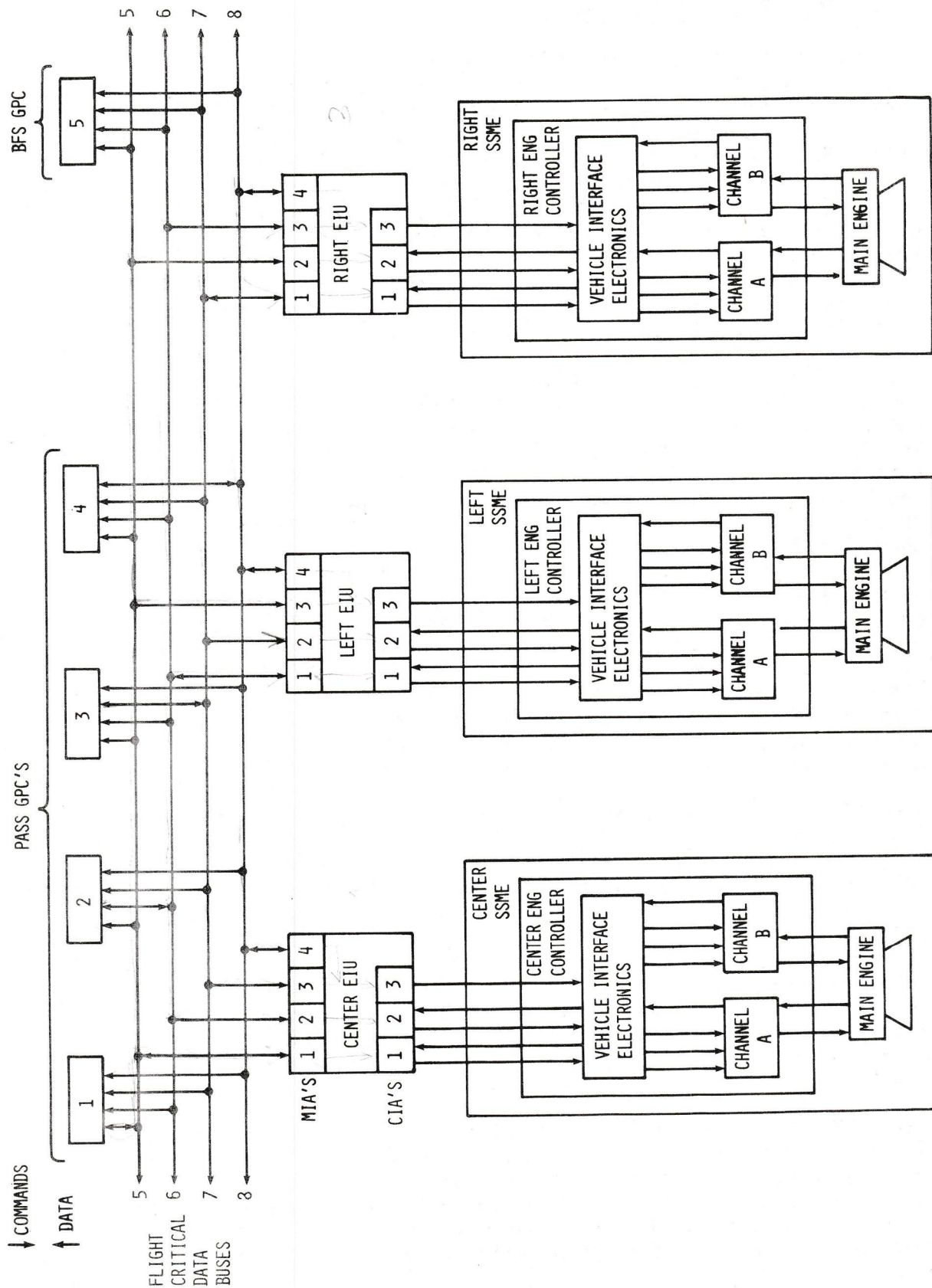


Figure 3.2-7.- The MEC - PASS engaged.

3.2.9 Main Engine Data Flow

The engine controller provides all the SSME data to the GPC's (figs. 3.2-7 and 3.2-8). Sensors in the engine feed pressures, temperatures, flow rates, turbopump speeds, valve position, and servovalve actuator positions to the engine controller. The engine controller assembles this data into a VDT. The engine controller also adds status data of its own to the VDT. The VDT's output by channels A and B go to the VIE for transmission to the EIU's. The VIE outputs over both data paths. The data paths are called PRI and SEC. Note that channel A VDT is (normally) sent over both PRI and SEC data paths. If channel B assumes control (channel A has failed), then the VIE would output the channel B VDT over both PRI and SEC data paths. (The VIE requires the SWITCH VDT command from the GPC's in order for the VIE to output the channel B VDT.)

The VDT is sent by the controller to the EIU. Note that there are only two data paths versus three command paths between the engine controller and the EIU. The data path that interfaces with CIA 1 is called PRI data. The data path that interfaces with CIA 2 is called SEC data. PRI and SEC data are held in buffers until the GPC's send a DATA REQUEST command to the EIU's. The GPC's request both PRI and SEC data. PRI data will be output only through MIA 1 on each EIU. SEC data will be output only through MIA 4 on each EIU.

At prelaunch, the PASS GPC's will look at both PRI and SEC data each cycle. Loss of either PRI or SEC data will result in data path failure and either engine ignition inhibit or pad shutdown of all three engines. At T-0, the PASS GPC's will request both PRI and SEC data from each EIU. For no failures, only PRI data are looked at. If there is a loss of PRI data (which can occur between the engine controller channel A electronics and the SSME SOP), then the SEC data are looked at. If both PRI and SEC data remain bad for four GPC cycles, the channel B VDT is selected by the GPC in the controller VIE for output to the EIU's. This action is irreversible once channel B VDT is selected; i.e., channel A data cannot be looked at again. Again, only PRI data are looked at. If PRI data are bad, then SEC data are looked at. If both PRI and SEC data (channel B VDT) remain bad for four GPC cycles, the SSME SOP issues a data path failure. The data path failure results in a class 3 alarm (SM alert) with the CRT message "MPS DATA," and an amber main engine status light. The SSME SOP also compares command-sent flags set by the SOP, with command status output by the engine controller. If the engine commands did not arrive at the engine controller or if the engine controller rejects a command, then a command path failure is issued which results in a class 3 alarm (SM alert) with the CRT message "MPS CMD" and an amber main engine status light.

The SSME SOP will output to applications software the data required to drive the Pc meter and the main engine status lights (red and amber). The Pc meter displays main engine chamber pressure. The red main engine status light is turned on when any engine redline limit parameter is exceeded, or any engine shut down. The amber main engine status light is driven by command path failure, data path failure, hydraulic lockup, and/ or electronic hold.

For data path failures, the Pc meter corresponding to the engine having the data path fail will be driven to zero. In addition, the prevalve closure inhibit commands will be removed, and the limit shutdown inhibit command will be sent to the other two engines.

The PASS configuration has been explained above. For BFS (fig. 3.2-7), the major change is that all data go to the GPC 5 only. The SSME data flow functions are the same as the SSME SOP.

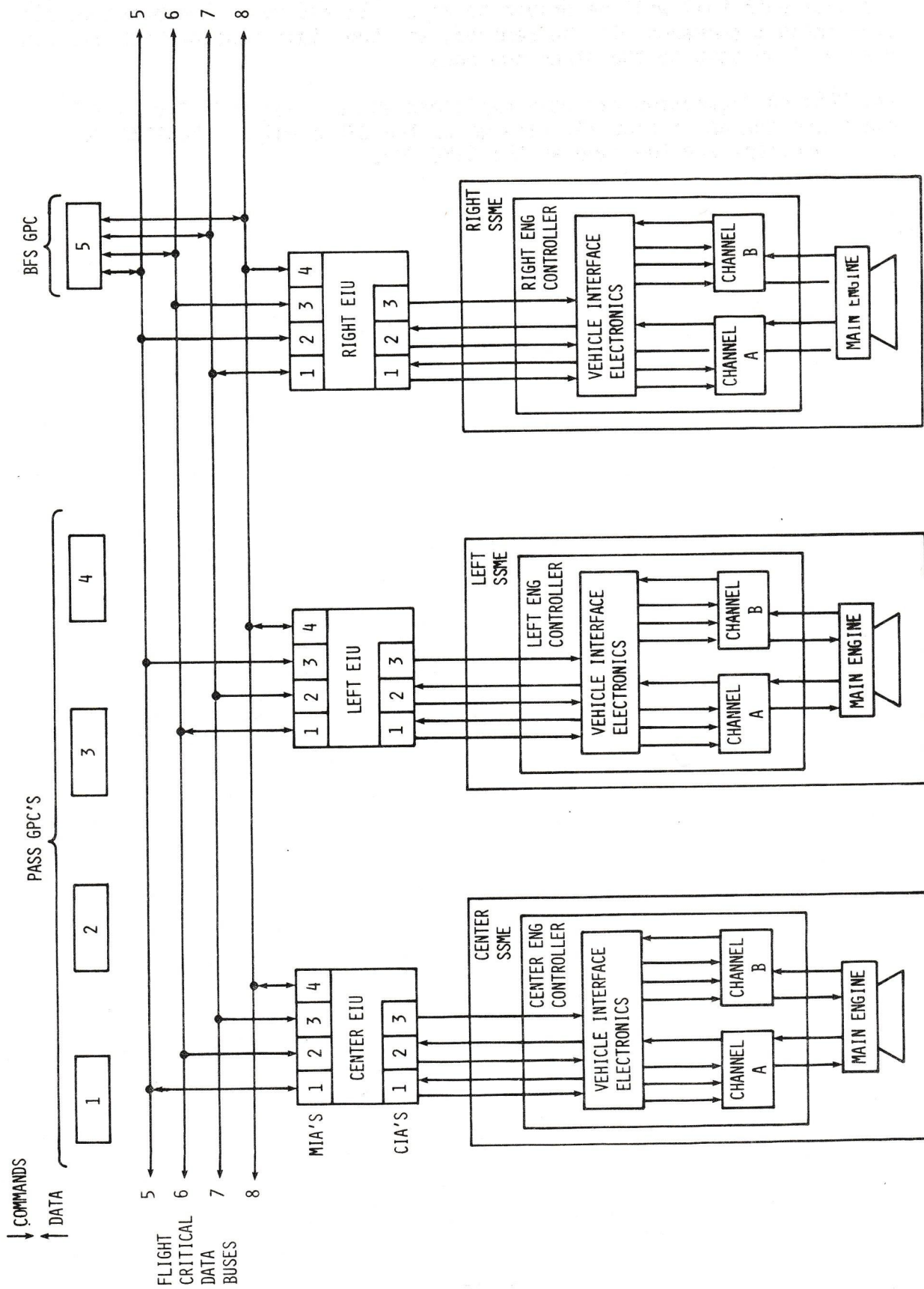


Figure 3.2-8.- The MEC - BFS engaged.

TABLE 3.2-2.- THE SSME DATA - Concluded

Data	Data word	Full-scale range
OPOV command	89	--
Selectable entries (appended data)	90-97	--
Vehicle command	98	--
Vehicle command	99	--
Hard failure test no. (list)	100-102	--
Hard failure parameter value (list)	103-105	--
Soft failure test no. (list)	106-115	--
Soft failure parameter value (list)	116-125	--
Checkout test step number	126	--
Ground data tag word 1	127	--
Ground data tag word 2	128	--

3.3 EXTERNAL TANK

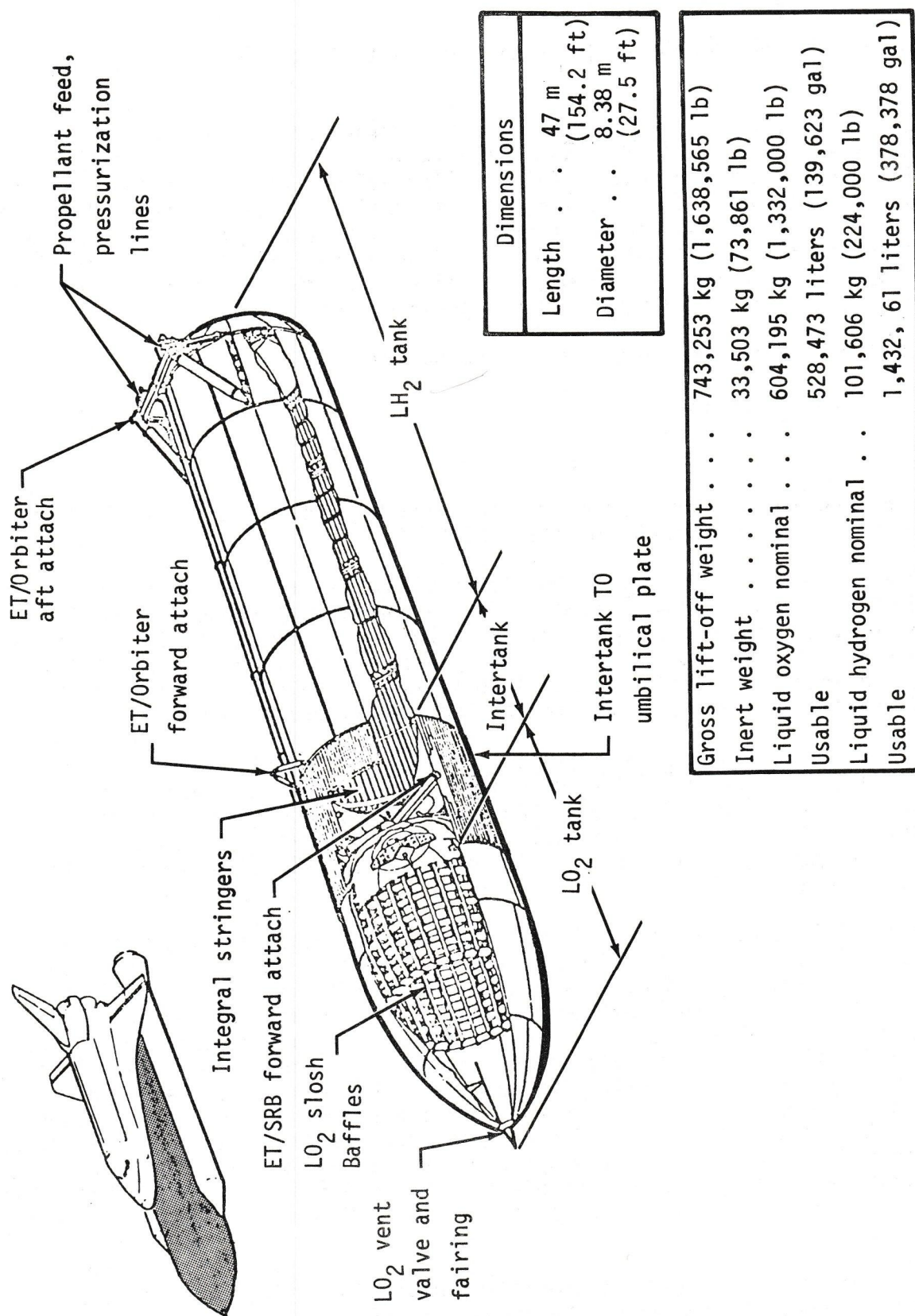
3.3.1 ET General Description

The externally mounted propellant tank contains the fuel (liquid hydrogen) and oxidizer (liquid oxygen) which is burned in the three main engines. After all three engines cut off (MECO), the propellant tank is jettisoned, reenters the earth's atmosphere, and impacts in a remote ocean area. The external tank is not recoverable and for this reason, contains a minimum number of active components.

The ET is made up of three structural assemblies (fig. 3.3-1): A forward tank, which carries the liquid oxygen; an intertank assembly, which contains most of the electrical components; and an aft tank, which carries the liquid hydrogen.

The ET is connected to the Orbiter by a single forward attachment strut and two aft attachment struts. At the aft attachment struts, the ET is also connected to the Orbiter through a number of umbilicals which carry fluids, gases, signals, and electrical power between the tank and the Orbiter. These umbilicals are collected into two bundles. Each bundle is permanently connected to the ET at one end, physically supported by one of the rear attachment struts and terminated in an umbilical plate. Each ET umbilical plate mates with a corresponding Orbiter umbilical plate. The umbilical plates help to maintain alignment among the various umbilicals. Physical strength at the joint is provided by bolting corresponding umbilical plates together. When the GPC commands ET separation, the bolts are severed by pyrotechnic devices.

Each of the two SRB's is connected to the ET, one on the left side of the ET, the other on the right side.



All weights approximate

Figure 3.3-1.- External tank.

3.3.2 ET Components

The ET contains the following major components (figs. 3.3-2, 3.3-3, and 3.3-4)

3.3.2.1 Vent and relief valves. - At the forward end of each propellant tank is a vent and relief valve. This valve is a dual-function valve which can be opened by either GSE-supplied helium (vent) or excessive tank pressure (relief). The vent function is available only in prelaunch; once lift-off has occurred, only the relief function is operable. The L02 tank will relieve at an ullage pressure of 24 psig, the LH2 tank at an ullage pressure of 36 psig. The crew has no direct control over the position of the vent and relief valves in either prelaunch or ascent.

Normal tank pressure ranges during ascent are:

L02 - 35 to 36 psia

LH2 - 32 to 34 psia

(Note: During prelaunch, the LH2 tank will be pressurized to 42.5 psia to meet the start requirement of the SSME LPFT.)

3.3.2.2 Tumble vent valve. - The L02 tank has, in addition to the vent and relief valve, a separate, pyrotechnically operated, propulsive, tumble vent valve. The tumble vent valve will be opened during the ET separation sequence. The thrust force provided by opening the tumble valve will impact an angular velocity to the ET to assist in the separation maneuver and provide more positive control of the reentry aerodynamics.

3.3.2.3 Propellant depletion sensors. - There are eight propellant depletion sensors. Four of the sensors sense fuel depletion, and the other four sense oxidizer depletion. The four fuel depletion sensors are mounted in the bottom of the fuel tank. The four oxidizer depletion sensors are mounted in the Orbiter L02 feedline manifold downstream of the feedline disconnect.

During prelaunch, the LPS will test each of the propellant depletion sensors. If any are found to be in a failed condition, the LPS will set a flag in the GPC SSME OPS sequence logic which will instruct the GPC to ignore the output of that particular sensor. During main engine burn, the GPC will constantly compute the instantaneous mass of the vehicle. (Because of the usage of propellants from the ET, vehicle mass will be constantly decreasing.) When the computed vehicle mass matches a predetermined, I-loaded value, the GPC will arm the propellant depletion sensors. After this time, if any two of the "good" fuel depletion sensors (those not flagged during prelaunch) or any two of the "good" oxidizer depletion sensors indicate a "dry" condition, the GPC's will issue a MECO command. Note that this type of MECO is a backup to the nominal MECO which is based on vehicle velocity.

It is highly desirable, in a propellant depletion situation, that the oxidizer level sensors sense the condition before the fuel sensors. This is to ensure that all depletion cutoffs are fuel-rich. Oxidizer-rich cut-

WRONG

offs of the SSME's can cause burning and severe erosion of engine components. To ensure that the oxidizer level sensors sense depletion first, a +1100 lbm bias is included in the amount of LH2 loaded in the ET; this amount is over and above that dictated by the 6:1 (oxidizer lbm/fuel lbm) engine mixture ratio. The position of the oxidizer propellant depletion sensors was chosen such that the maximum amount of oxidizer can be consumed in the engines while allowing sufficient time to cut off the engines before the oxidizer pumps cavitate (run dry).

3.3.2.4 Ullage pressure transducer.- There are four ullage pressure transducers located at the top end of each propellant tank (LO2 and LH2). One of the four transducers is considered a spare and is normally in an off-line mode. During prelaunch, the GSE will normally perform a checkout of the four transducers. If one of the three active transducers is determined to be "bad," then that transducer can be taken off-line and the output of the spare transducer selected. The crew can also perform this operation after lift-off, via the GPC keyboard; however, because of the short time period involved (lift-off to MECO), this would probably be impractical.

The three active ullage pressure sensors provide outputs for CRT display and control of ullage pressure within their particular propellant tanks. For CRT display purposes, GPC processing selects the middle value output of the three transducers and displays this single value. For ullage pressure control, all three outputs are used.

3.3.2.5 Propellant umbilicals.- The ET has five propellant umbilicals, two for the LO2 tank and three for the LH2 tank. One of the LO2 tank propellant umbilicals carries LO2, the other carries GO2. The LH2 tank has two umbilicals that carry LH2 and one that carries GH2. The smaller (in diameter) of the two umbilicals that carry LH2 is designated the ET LH2 recirculation umbilical and is used only during the LH2 chilldown sequence in prelaunch.

3.3.2.6 Electrical umbilicals.- The ET has two electrical umbilicals, each made up of many smaller electrical cables. These electrical cables carry electrical power from the Orbiter to the ET and the two SRB's and bring back to the Orbiter telemetry from the SRB and the ET. (Note: The OI and DFI telemetry that comes back from the SRB's is conditioned, digitized, and multiplexed in the SRB's themselves. The DFI telemetry that comes back from the ET is conditioned, digitized, and multiplexed in the ET; however, the ET OI measurements that come back to the Orbiter are the "raw" transducer outputs and must be processed within the Orbiter telemetry system.)

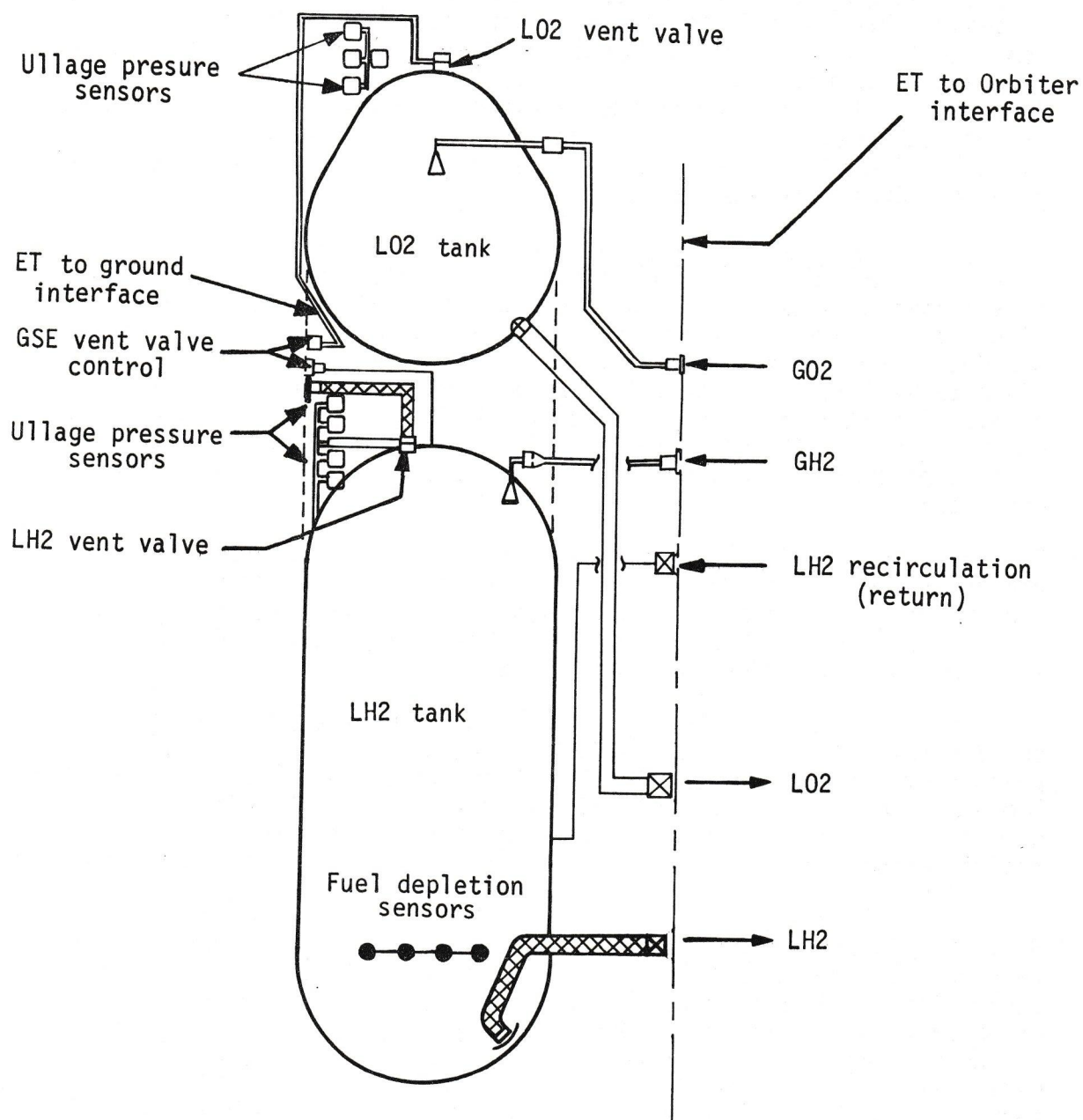


Figure 3.3-2.- External tank schematic.

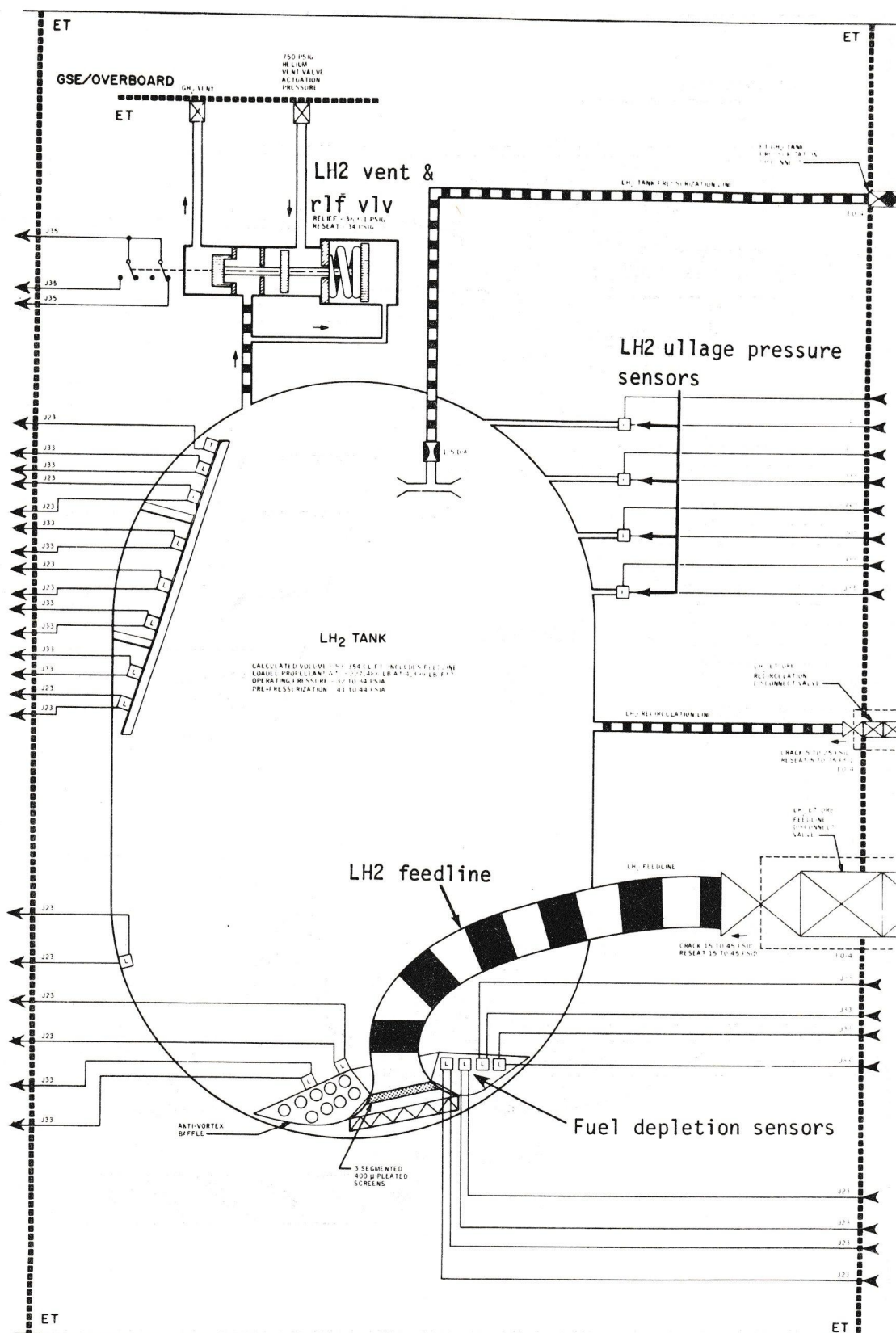


Figure 3.3-4.- External tank schematic, LH2 tank detail.

3.3.3 ET Fluid Flow

3.3.3.1 Oxidizer flow.- During prelaunch, GSE-supplied L02 is loaded through the propellant management subsystem in the Orbiter, exits the Orbiter at the L02 feedline disconnect valve, and flows through the ET L02 umbilical into the L02 tank. Once the loading process is completed, the L02 vent and relief valve in the ET is closed and the L02 tank is pressurized to 21.0 psig by GSE-supplied helium injected into the G02 pressurization line.

During engine burn, L02 flows out of the ET, through the ET L02 umbilical, and enters the Orbiter at the L02 feedline disconnect valve. Pressurization in the tank is maintained by G02 tapped from the three SSME's and supplied to the L02 tank through the ET G02 umbilical. The interface between the ET G02 umbilical and the Orbiter is a self-sealing quick-disconnect. The ET L02 umbilical, the ET G02 umbilical, and one ET electrical umbilical are grouped together in a single bundle and connect to the Orbiter at the right-hand Orbiter umbilical plate.

3.3.3.2 Fuel flow (fig. 3.3-2).- During prelaunch, GSE-supplied LH2 is loaded through the propellant management subsystem in the Orbiter, exits the Orbiter at the LH2 feedline disconnect valve, and flows through the ET LH2 umbilical into the LH2 tank. Once the loading process is complete, the LH2 vent and relief valve in the ET is closed and the LH2 tank is pressurized to 42.5 psia by GSE-supplied helium injected into the GH2 pressurization line. Approximately 45 min before engine start, three electrically powered LH2 pumps in the Orbiter will begin to circulate LH2 out of the ET, through the three SSME's and back to the ET via a special ET LH2 recirculation umbilical. The purpose of this recirculation is to chill down all the LH2 lines between the ET and the HPFT in the SSME such that this path is free of any GH2 bubbles and is at the proper temperature for engine start. LH2 recirculation ends approximately 6 sec before engine start.

During engine burn, LH2 flows out of the ET, through the ET LH2 umbilical, and enters the Orbiter at the LH2 feedline disconnect valve. Pressurization in the tank is maintained by GH2 tapped from the three SSME's and supplied to the LH2 tank through the ET GH2 umbilical. The interface between the ET GH2 umbilical, and the Orbiter is a self-sealing quick-disconnect. The ET LH2 umbilical, the ET LH2 recirculation umbilical, the ET GH2 umbilical, and one electrical umbilical are grouped together in a single bundle and connected to the Orbiter at the left-hand Orbiter umbilical plate.

3.4 ORBITER MPS - PROPELLANT MANAGEMENT SUBSYSTEM

3.4.1 Propellant Management Subsystem Function

During engine burn, propellants under tank pressure flow from the ET to the Orbiter through two umbilicals; one for LH2 and the other for LO2 (fig. 3.4-1). Within the Orbiter, the propellants pass through a system of manifolds, distribution lines, and valves to the main engines. This system is the Propellant Management Subsystem (PMS). It should be noted at this point that all the valves within the Orbiter are under the direct control of the GPC's and are either electrically or pneumatically actuated.

The PMS also provides a path which allows gases tapped from the three engines to flow back to the ET, through two gas umbilicals, to maintain pressures in the fuel and oxidizer tanks.

The PMS also functions during phases other than engine burn. During prelaunch, it is used to control the loading of propellants in the ET. During orbit, it controls propellant dump, vacuum inerting, and system repressurization (for entry).

3.4.2 The PMS Components

The PMS contains the following major components (fig. 3.4-2).

3.4.2.1 Liquid propellant supply and distribution network.- The network is composed of all the liquid propellant lines used to load propellants during prelaunch, feed propellants to the SSME's during engine burn, and dump residual propellants after ET separation. Specifically, the network consists of:

- A. Propellant feedline manifolds - There are two 17-in.-diameter manifolds in the Orbiter, one for LO2 and one for LH2. Both of the manifolds have a feedline disconnect valve at one end and two fill and drain valves (one inboard, one outboard), connected in series at the other end. The feedline manifolds connect to the ET liquid propellant umbilicals at the feedline disconnect valve and to either GSE liquid propellant umbilicals (prelaunch only) or overboard at the outboard fill and drain valves.

Between the feedline disconnect valves and the inboard fill and drain valves are three outlets for the three engine propellant feedlines and one outlet for the propellant feedline relief line. (The LH2 feedline manifold contains an extra outlet for the LH2 Return to Launch Site (RTLS) feedline dump line. See paragraph D below.) Pressures (in psia) within the LO2 and the LH2 feedline manifolds can be monitored on the two ENG MANF meters on panel F7 or on the CRT display GNC SYS SUMM 1 (BFS).

- B. Engine propellant feedlines - There are six 12-in.-diameter feedlines in the Orbiter, three for LO2 and three for LH2. Each of the LO2 engine propellant feedlines connects to the LO2 feedline manifold at

one end and to the LPOT inlet of one of the SSME's at the other end. Likewise, each of the LH2 engine propellant feedlines connects to the LH2 feedline manifold at one end and to the LPFT inlet of one of the SSME's at the other end. There is one pre valve in each of the six engine propellant feedlines. The pre valves are designated as left, center, or right (engine) LO2 pre valve; or left, center, or right (engine) LH2 pre valve.

- C. Propellant feedline relief line - There are two 1-in.-diameter relief lines in the Orbiter, one for LO2 and one for LH2. Each relief line connects to one of the propellant feedline manifolds at one end and to an overboard port at the other end. Each relief line contains a relief valve and an electrically actuated relief isolation valve. The isolation valve is mounted in series with, and upstream of, the relief valve. Flow through the relief line and relief valve is enabled by deenergizing the normally open isolation valve, allowing it to open.

The position of the relief isolation valve (2) is controlled by one of two FEEDLINE RLF ISOL switches on panel R4. Normally these switches are left in the GPC position. With the switches (2) in this position, both relief isolation valves will be opened automatically immediately after MECO.

The purpose of the relief lines is to prevent excessive pressure buildups, generated by heatup and expansion of the propellants in the feedline manifolds, by allowing the pressure to be vented overboard through the relief valves.

- D. LH2 RTLS feedline dump line - This is a single 2-in.-diameter line which connects to the LH2 feedline manifold at one end and to an overboard port at the other end. (The overboard port is located on the outer skin of left side of the Orbiter between the OMS pod and the upper surface of the wing.) The line is used exclusively for dumping residual LH2 during an RTLS abort. There is no nominal function for this line. Flow through the line is controlled by two series-connected, normally closed, LH2 RTLS dump valves (one inboard, one outboard) which are mounted in the line. The LH2 RTLS dump valves are controlled automatically by GPC commands. The crew has no direct control of these valves.

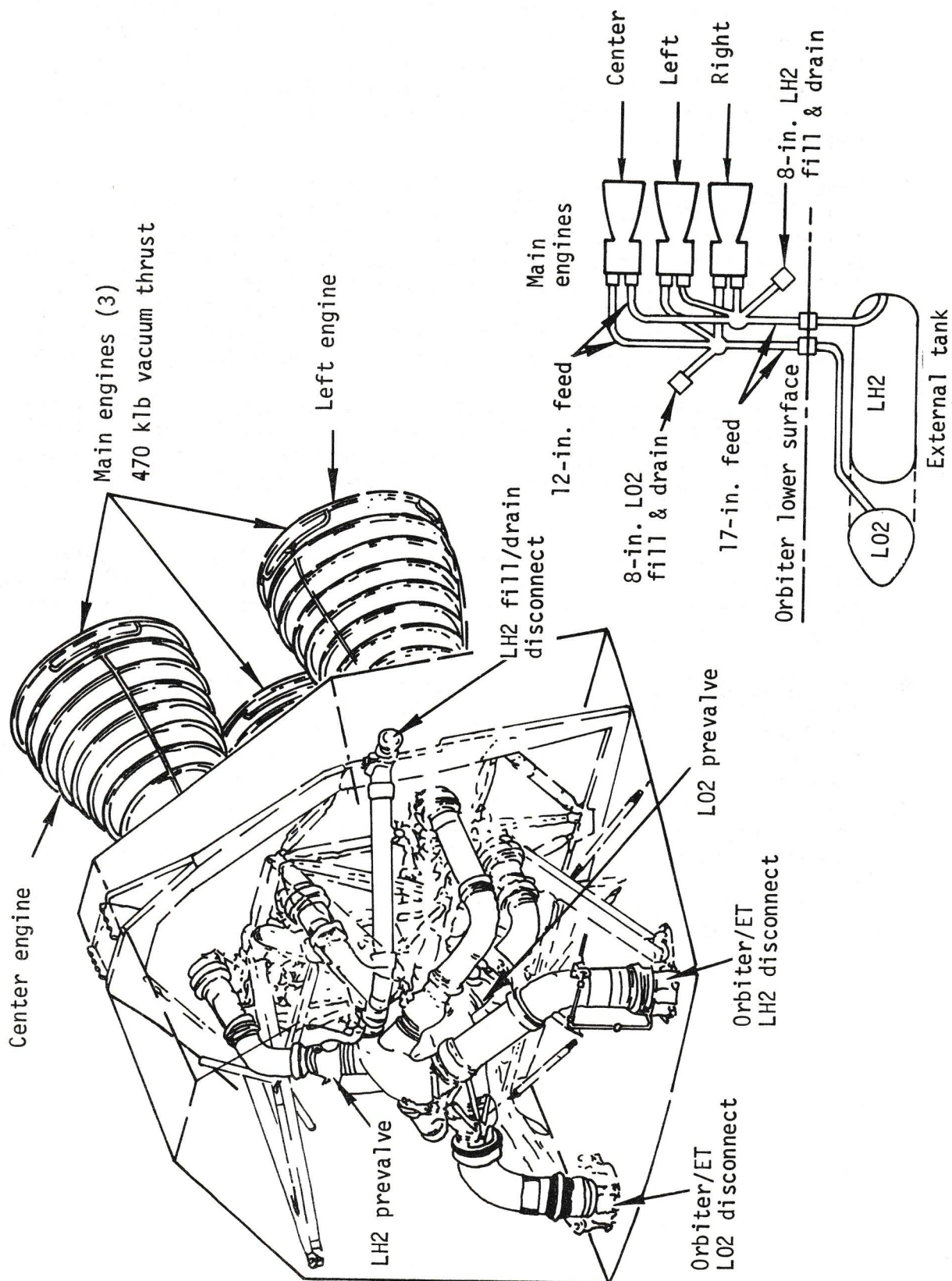


Figure 3.4-1.- Orbiter main propulsion system.

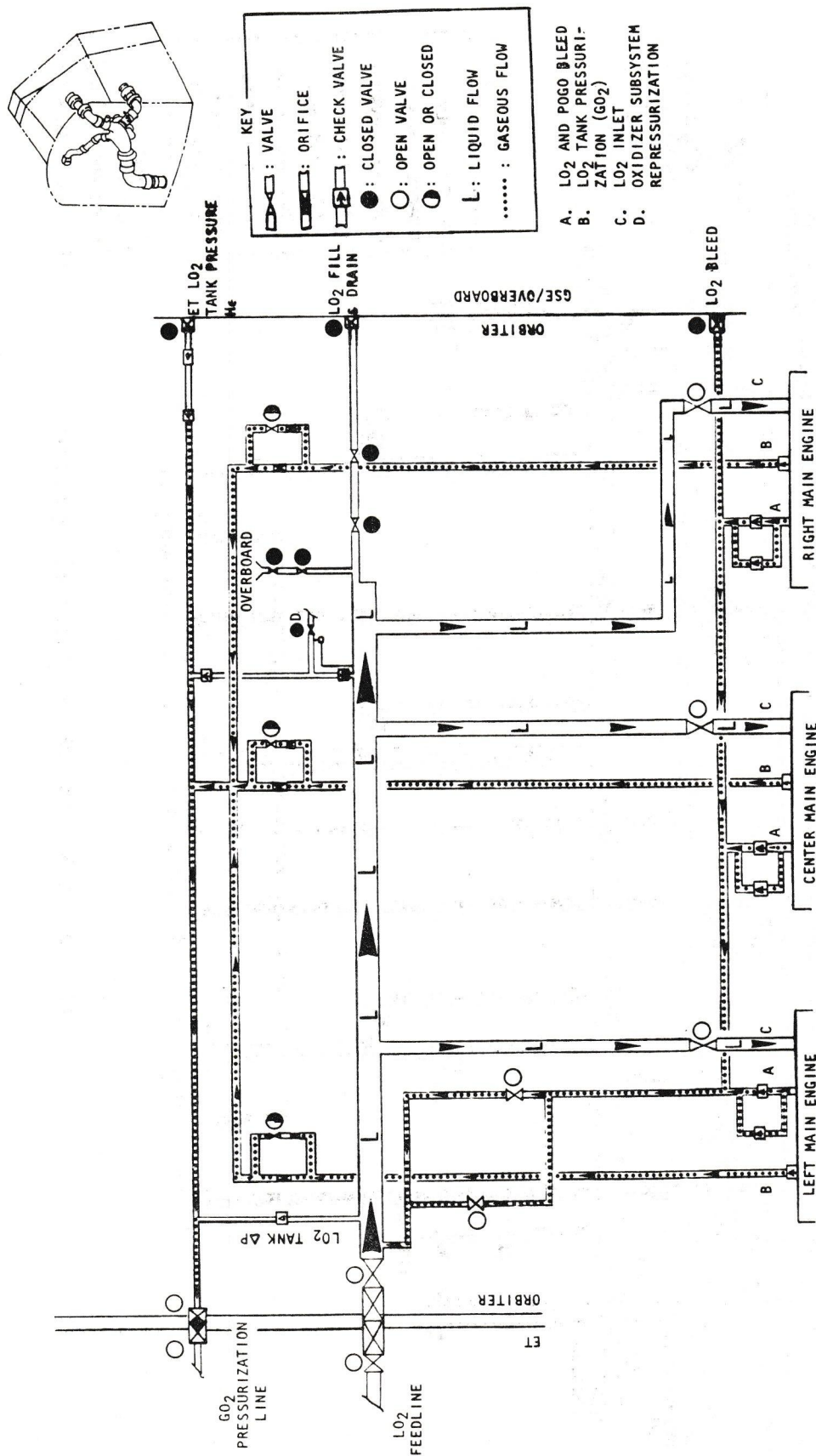


Figure 3.4-2.- The PMS ~~fuel~~ flow, mainstage.

oxidizer

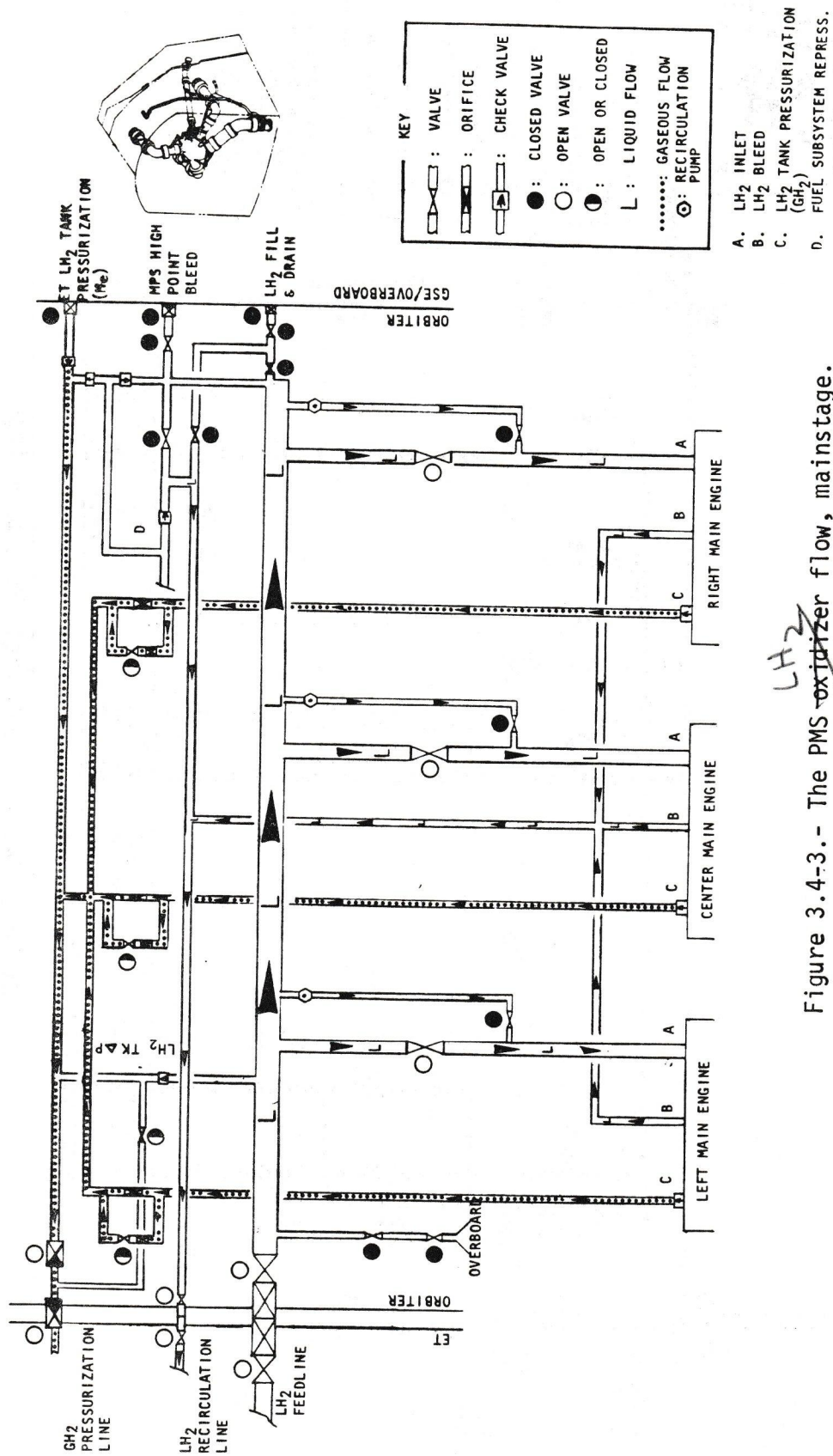


Figure 3.4-3.- The PMS oxidizer flow, mainstage.

3.4.2.2 Gaseous propellant collection and supply network.- The network consists of all the lines used to collect and supply gaseous propellants (G02 and GH2) from all three SSME's to the ET to maintain propellant tank pressure during main engine burn. (Note: This network has no major function after ET separation.) Specifically, the gaseous propellant collection and supply network consists of:

- A. Engine ET pressurization output lines - There are six 0.63-in.-diameter pressurization lines in the Orbiter, three for G02 and three for GH2. Each of the G02 pressurization lines connects to oxidizer heat exchanger outlet of one of the SSME's at one end and the G02 ET pressurization manifold at the other end. Each of the GH2 pressurization lines connects to the LPFT turbine outlet of one of the SSME's at one end and the GH2 ET pressurization manifold at the other end. Each of the six pressurization output lines contains two orifices connected in parallel and one flow control valve connected in series with one of the orifices. This combination of orifices and flow control valves is used to control ullage pressure in the two ET propellant tanks (secs. 3.4.3.1 and 3.4.3.2.)
- B. ET pressurization manifolds - There are two 2-in.-diameter manifolds in the Orbiter, one for G02 and one for GH2. At each end of both manifolds are self-sealing quick-disconnects. The pressurization manifolds connect to the ET gaseous propellant umbilicals at one set of quick-disconnects and to the GSE helium pressurization umbilicals at the other set of quick-disconnects. The GSE helium pressurization umbilicals (2) are used for the initial pressurization of the ET propellant tanks during prelaunch.

Each pressurization manifold contains inlets for the three engine ET pressurization output lines. (The ET GH2 pressurization manifold contains, in addition to the three inlets, an outlet for the GH2 pressurization vent line. See paragraph C below.)

- C. GH2 pressurization vent line - This is a single line which connects to the ET GH2 pressurization manifold line at one end and to an overboard port at the other end. This line is used exclusively for vacuum inerting the GH2 pressurization lines during orbit. Flow through the line is controlled by the normally closed GH2 pressurization line vent valve which is mounted in the line. This valve is controlled by the GH2 PRESS LINE VENT switch on cockpit panel R4.

3.4.2.3 Valves.- There are two basic types of valves used in the PMS; those that are pneumatically actuated and those that are electrically actuated. Pneumatically actuated valves are used where large loads are encountered, such as in the control of liquid propellant flows. Electrically actuated valves are used where lighter loads are encountered, such as in the control of gaseous propellant flows.

Pneumatically actuated valves can be further 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 following is a list of the type 1 valves:

- LH2 feedline disconnect valve
- L02 feedline disconnect valve
- LH2 prevalues (3)
- L02 prevalues (3)
- LH2 inboard fill/drain valve
- L02 inboard fill/drain valve
- LH2 outboard fill/drain valve
- L02 outboard fill/drain valve

Figure 3.4-4 illustrates a typical propellant valve of this type. Each type 1 valve actuator is equipped with two electrically actuated solenoid valves. Each of the two solenoid valves controls helium pressure to either an "open" port or a "close" port on the actuator. Energizing the solenoid valve connected to the "open" port will allow helium pressure to open the pneumatic valve. Similarly, closing of the pneumatic valve is performed by energizing the solenoid valve connected to the "close" port.

Removing power from a solenoid valve not only removes helium pressure from the corresponding port of the pneumatic actuator, but also allows the helium pressure trapped in that side of the actuator to vent overboard. Removing power from both solenoids allows the pneumatic valve to remain in its last commanded position.

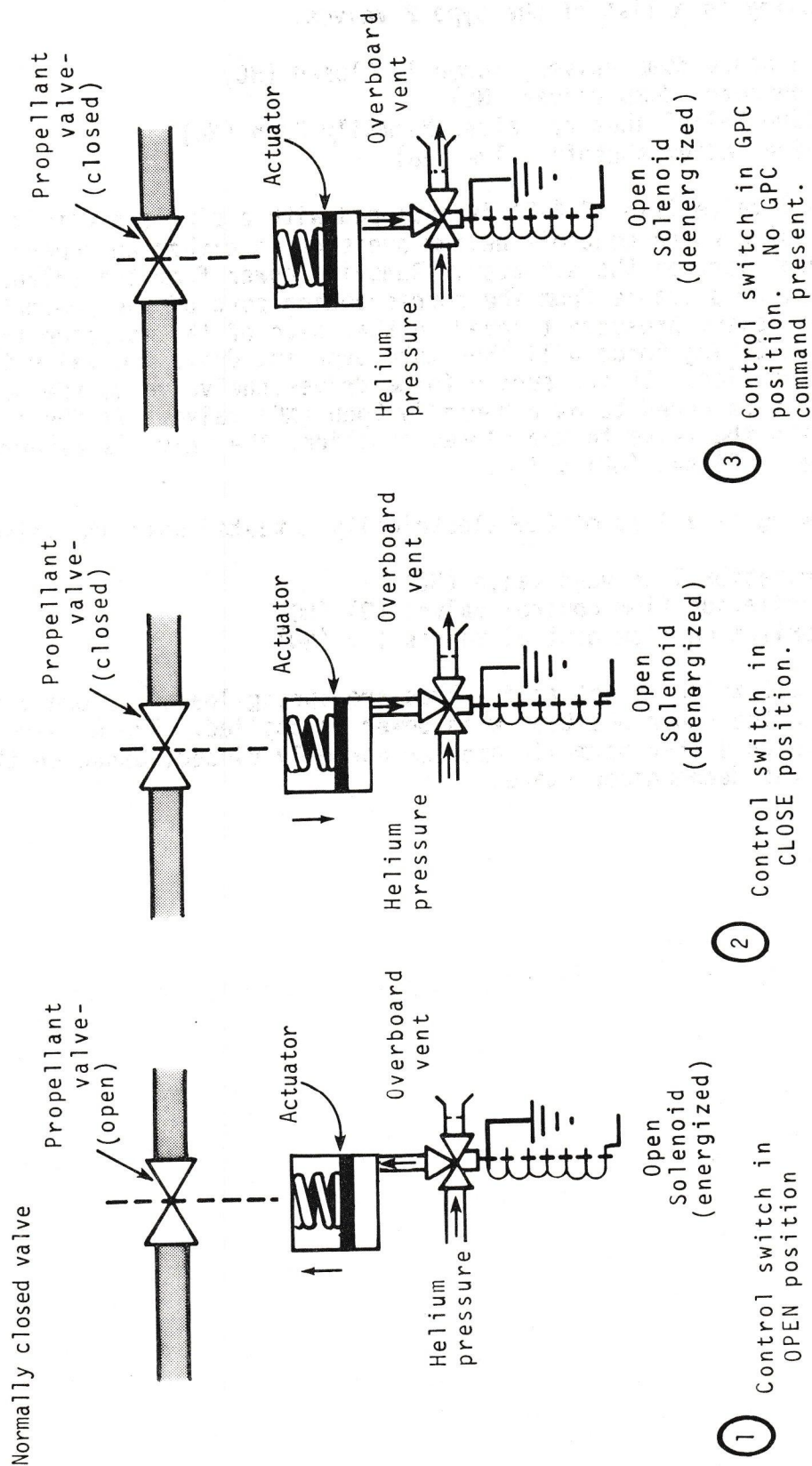


Figure 3.4-4.- The PMS typical pneumatically actuated propellant valve, type 1.

The following is a list of the type 2 valves:

- LH2 RTLS inboard dump valves, Normally Closed (NC)
- LH2 RTLS outboard dump valves (NC)
- LH2 feedline relief shutoff valve, Normally Open (NO)
- L02 feedline relief shutoff valve (NO)

Each type 2 valve (fig. 3.4-5) is equipped with a single electrically actuated solenoid valve which controls helium pressure to either an "open" port or a "close" port on the actuator. Removing power from the solenoid valve removes helium pressure from the corresponding port of the pneumatic actuator and allows helium pressure trapped in that side of the actuator to vent overboard. Spring force will then take over and drive the valve to the opposite position. If the spring force drives the valve to the open position, the valve is referred to as a Normally Open (NO) valve. If the spring force drives the valve to the closed position, the valve is referred to as a Normally Closed (NC) valve.

The following is a list of the electrically actuated solenoid valves;

- H2 pressurization line vent valve (NC)
- GH2 pressurization flow control valves (3) (NO)
- G02 pressurization flow control valves (3) (NO)

The above electrically actuated valves are spring-loaded to one position and move to the other position when power is applied. These valves are referred to as either normally open or normally closed, based on their position in the deenergized state.

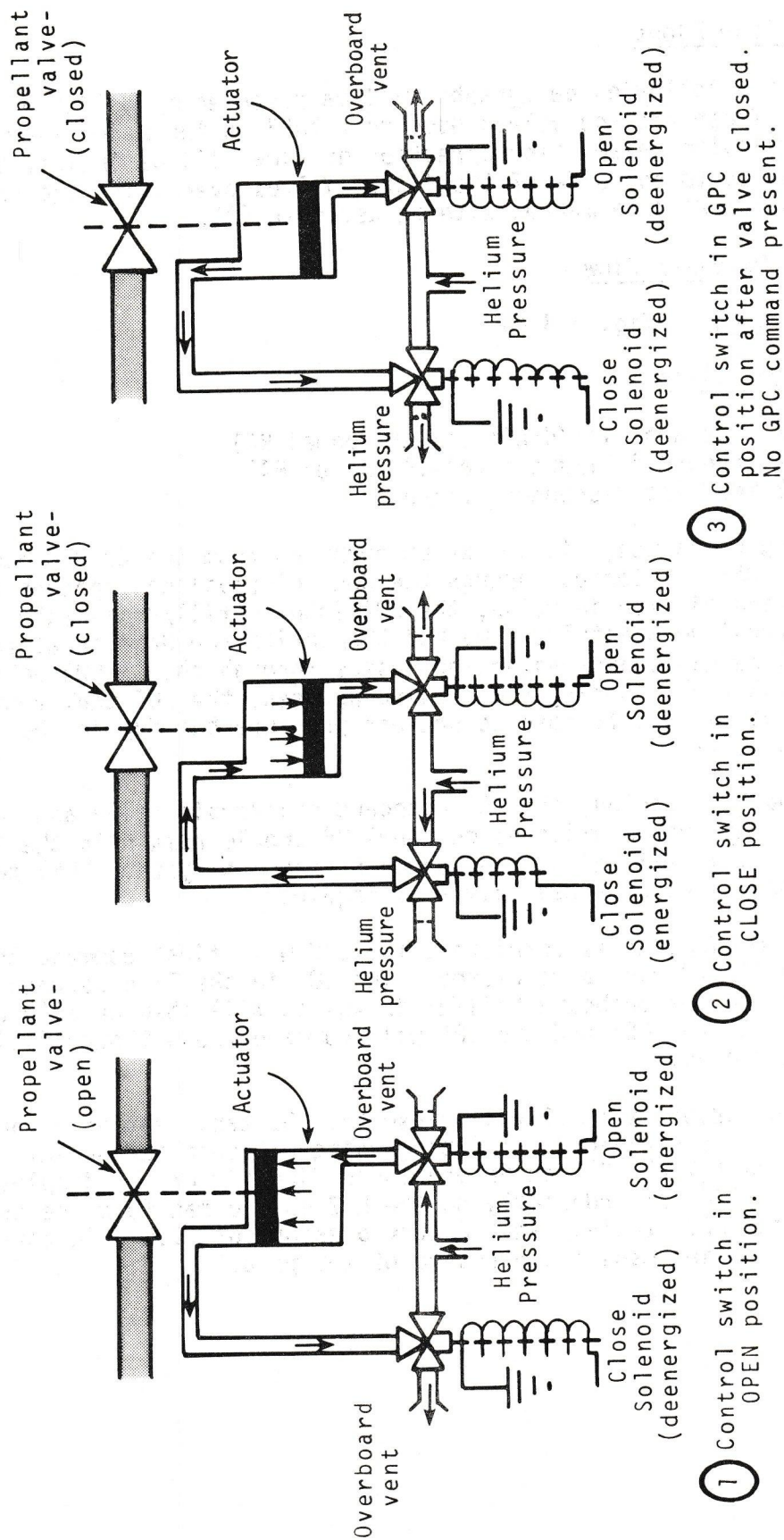


Figure 3.4-5.- The PMS typical pneumatically actuated propellant valve, type 2.

3.4.3 Fluid Flows

Each of the following paragraphs will be preceded by a list of active valves. These are the valves used to establish the major flow path(s) in that particular phase. The direction of flow will be indicated by an arrow placed to one side of the list. Valves over which the crew has direct control will be marked with an asterisk (*).

3.4.3.1 Oxidizer Flow.-

A. Prelaunch: (fig. 3.4-6)

Active valves

- ↓ L02 outboard fill/drain valve* (panel R4)
- ↓ L02 inboard fill/drain valve* (panel R4)
- ↓ L02 feedline disconnect valve

During prelaunch, liquid oxygen supplied from the Ground Support Equipment (GSE) is loaded through the GSE/L02 umbilical, passes through L02 outboard fill/drain valve, the L02 inboard fill/drain valve and the L02 feedline manifold. The L02 then exits the Orbiter at the L02 feedline disconnect valve and passes through the ET L02 umbilical into the L02 tank. During the loading process, the L02 tank vent and relief valve is left open to prevent pressure buildup in the tank due to L02 boiloff.

During L02 loading, the L02 outboard fill/drain valve and L02 inboard fill/drain valve switches on panel R4 should remain in the GND position. This will allow the Launch Processing System (LPS) to control the positions of these valves as required.

When L02 loading is completed, the LPS will first command the L02 inboard fill/drain valve closed. The L02 in the line between the inboard and the outboard fill/drain valves will then be allowed to drain back into the GSE and the LPS will command the outboard fill/drain valve closed.

At T-00:02:55, the LPS will close the L02 tank vent valve and the tank will be pressurized to 21.0 psig using GSE-supplied helium. L02 tank pressure (ET ULL P) can be monitored directly on CRT display GNC SYS SUMM 1 (BFS) or indirectly on the L02 engine manifold pressure meter on panel F7. (Note: An L02 tank pressure of 21.0 psig corresponds to an L02 engine manifold pressure of 105 psia.)

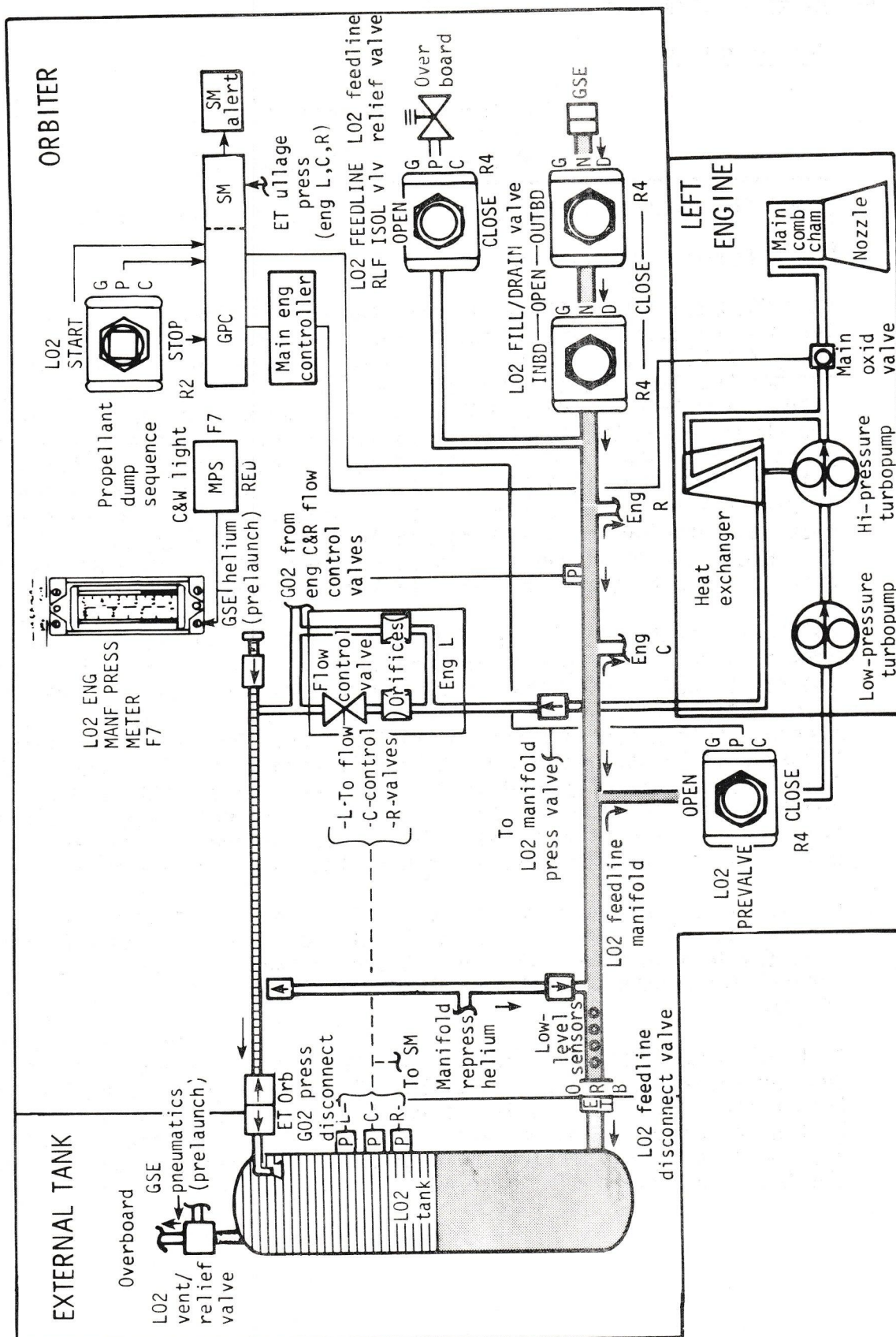
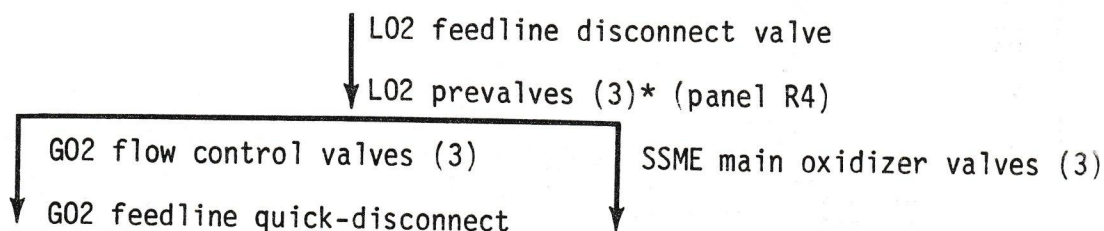


Figure 3.4-6.- The MPS oxidizer flow, prelaunch.

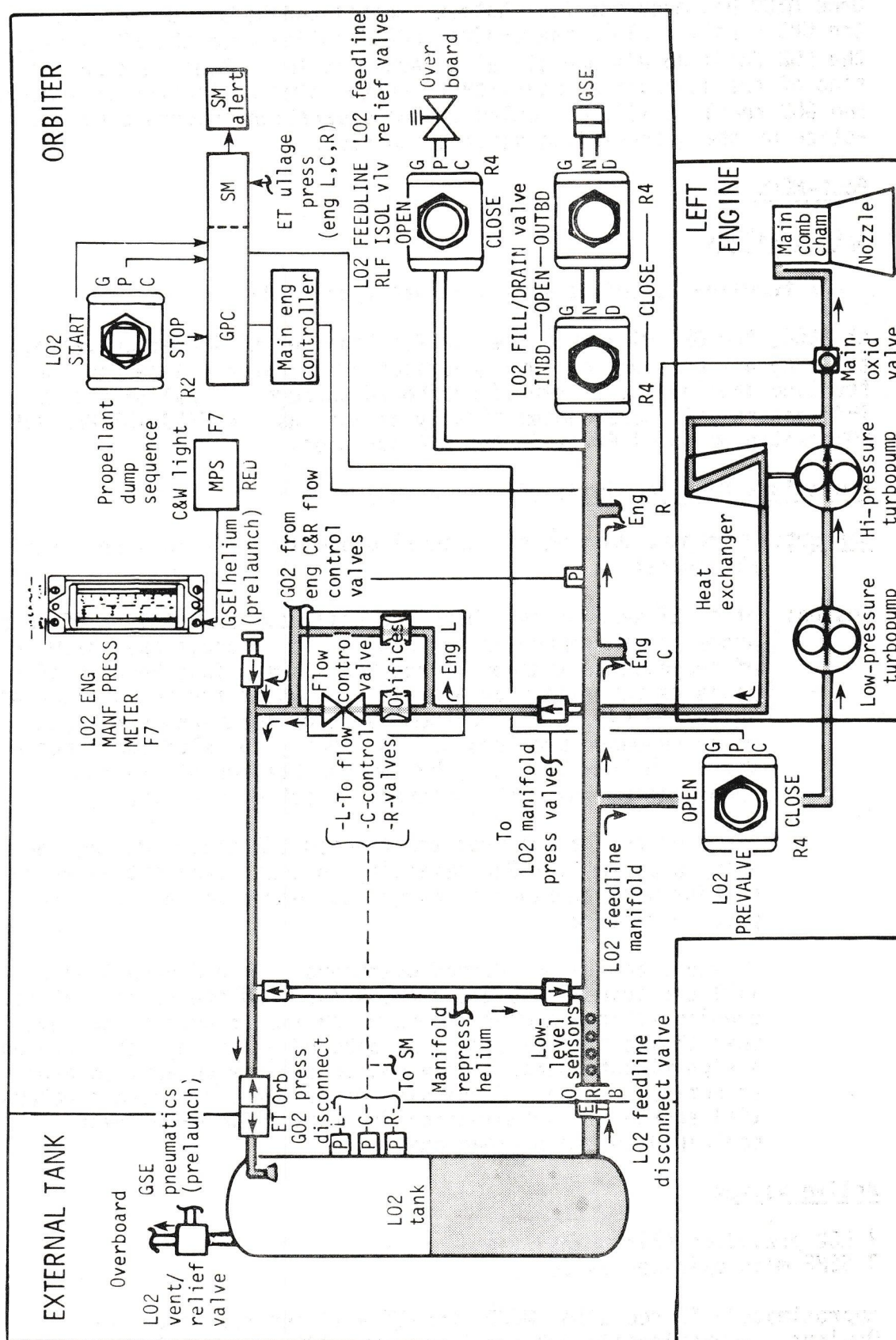
B. Ascent: (fig. 3.4-7)Active valves

At T-00:00:03.8, the GPC will issue the engine start command, opening the main oxidizer valve in the engine. Between main oxidizer valve opening and MECO, L2 flows out of the ET, through the ET L2 umbilical and the L2 feedline disconnect valves and into the L2 feedline manifold. From this manifold, L2 is distributed to the engines through the three engine L2 feedlines. In each line, L2 passes through the prevalue and enters the main engine at the inlet to the Low-Pressure Oxidizer Turbopump (LPOT). In the engine, a small portion of the L2 is diverted into the oxidizer heat exchanger. In the heat exchanger, heat generated by the High-Pressure Oxidizer Turbopump (HPOT) is used to convert liquid oxygen into gaseous oxygen (G02). This G02 is then directed back to the ET to maintain G02 tank pressure.

G02 flow back to the ET begins at the outlet of the heat exchanger. From this point, G02 passes through a check valve, then splits into two paths, each containing a flow control orifice. One of these paths also contains a valve which is normally controlled by one of three pressure transducers located in the L2 tank. During ascent, tank pressure is maintained between 20 and 22 psig by the orifices in the two lines and the action of the flow control valve. When pressure in the tank reaches 22 psig, the valve closes, and when pressure drops below 20 psig the valve opens. Tank pressures greater than 24 psig will cause the tank to relieve through the tank vent and relief valve.

Downstream of the two flow control orifices and the pressure control valves, the G02 lines empty into the ET G02 pressurization manifold. This single line then exits the Orbiter at the G02 pressurization disconnect and passes through the ET G02 umbilical into the top of the L2 tank.

Although normal MECO is based on the attainment of a specified velocity, the engine can also be shut down by L2 depletion, should MECO occur before the specified velocity is reached. L2 depletion is sensed by four oxidizer depletion sensors located in the L2 feedline manifold. Any two of the four sensors indicating a "dry" condition will cause the GPC's to issue a MECO command to the engine controllers.



Once MECO has occurred (by whatever means) and before ET separation, the GPC's will isolate the Orbiter L02 feedline from the ET by closing the L02 feedline disconnect valve (actually two valves, one on each side of the separation interface). At the time of Orbiter/ET separation, the G02 feedline will be sealed at the separation interface by the action of the self-sealing quick-disconnect.

C. Post-MECO

Active valves

L02 feedline relief isolation valve* (panel R4)

At MECO, the GPC will open the L02 feedline relief isolation valve, allowing any pressure buildup generated by oxidizer trapped in the feedline manifold to be vented overboard through the relief valve. This action will occur automatically as long as the FEEDLINE RLF ISOL L02 switch on panel R4 is in the GPC position.

D. Propellant dump (nominal) (figure 3.4-8)

Concept: Overboard dumping of residual propellants is required after ET separation.

Reason: After ET separation, there are still approximately 1700 lb of propellants trapped in the SSME's and an additional 3700 lb of propellants trapped in the PMS lines. This 5400 lb of propellants represents an overall c.g. shift for the Orbiter of approximately 7 in. Non-nominal c.g. locations can create major guidance problems during reentry for RTLS abort maneuvers. The residual L02, by far the heavier of the two propellants, poses the greatest impact on c.g. travel.

The greatest hazard from the trapped LH2 occurs during reentry when any LH2/GH2 remaining in the propellant lines may combine with atmospheric oxygen to form a potentially explosive mixture.

In addition, unless dumped overboard, trapped propellants will sporadically outgas through the feedline relief valves, causing vehicle accelerations which are of such a low level that they cannot be sensed by onboard guidance, yet represent a significant source of navigation error when applied over an entire mission. Outgassing propellants are also a potential source of contamination for scientific experiments contained in the payload bay.

Active valves

↓ L02 prevalues (3)* (panel R4)
↓ SSME main oxidizer valves (3)

Approximately 11 sec after MECO, the ET will separate from the Orbiter. Approximately 109 sec later, the OMS 1 burn will begin.

only
Coincident with the start of this burn, the GPC will automatically initiate the MPS L02 dump (if the MPS PRPLT DUMP SEQUENCE L02 switch on panel R2 is in the GPC position). The GPC will not initiate its own portion of the L02 dump sequence, but will also command the main engine controller to initiate its portion of the sequence as well. The overall L02 dump sequence is as follows:

- GPC commands L02 manifold repress valves (2) open (requires MANF PRESS L02 switch on panel R4 to be in GPC position).
- Engine controller commands SSME main oxidizer valve open.
- GPC commands L02 pre valve open (requires L02 pre valve switches (3) to be in GPC position).

The preceding actions will cause the L02 trapped in the feedline manifold to be expelled, under pressure from the helium subsystem, through the engine bells of the three engines. If the MPS PRPLT DUMP SEQUENCE L02 switch on panel R2 is left in the GPC position, the L02 dump will continue for 140 sec. At the end of this period, the GPC will automatically terminate the dump by closing the L02 manifold repress valves (2), waiting 10 sec and then closing the L02 pre valves, and (3) commanding the engine controller to close the main oxidizer valve. If necessary, the crew can perform the L02 dump manually by utilizing the START and STOP positions of the MPS PRPLT DUMP SEQUENCE L02 switch.

Note: Even when the L02 dump is performed manually, all valve opening and closing sequences are still automatic. Thus, placing the MPS PRPLT DUMP SEQUENCE L02 switch in the START position will cause the GPC to immediately begin commanding all of the required valves open automatically and in the proper sequence. The L02 dump will continue for as long as the switch is in the START position. Likewise, placing the switch in the STOP position will cause the GPC to begin commanding all of the required valves closed automatically and in the proper sequence. The earliest time a manual L02 dump can be performed is MECO + 10 sec.

Caution

1. The SSME's require a cooldown of at least 10 sec after MECO before initiating a manual L02 dump.
2. The GPC software (MPS dump sequence) will automatically initiate the L02 dump at one time only -- at initiation of the OMS 1 burn. If the switch is not in the GPC position at that time, the L02 dump must be initiated manually.
3. Once the L02 dump has been initiated and the MPS PRPLT DUMP SEQUENCE L02 switch placed in the STOP position, the GPC will no longer monitor any of the positions of this switch. For this reason, the L02 dump cannot be reinitiated, manually or otherwise.

E. Propellant dump (RTLS) (fig. 3.4-9)Active valves

- ↓ L02 prevalues (3)* (panel R4)
- ↓ SSME main oxidizer valves (3)

If MECO is preceded by an RTLS abort, the subsequent MPS L02 dump will begin 10 sec after the ET separation command is issued (simultaneous with the start of the LH2 dump). The dump will be initiated and terminated automatically by the GPC's (regardless of the position of the MPS PRPLT DUMP SEQUENCE L02 switch on panel R2).

The L02 dump sequence for the RTLS mode will be similar to the L02 dump sequence for the nominal mode; however, the timing will be different and the L02 feedline manifold will not be pressurized. (L02 manifold repress valves (2) remain closed throughout the entire dump.) Due to the geometry of the L02 feedline manifold and its orientation to the Orbiter's acceleration vector during RTLS abort, very little L02 will actually be lost overboard during the L02 dump. For this reason, the RTLS L02 "dump" should be considered as more of a venting process rather than a dump.

In the case of the nominal L02 dump, the GPC's terminate the dump 140 sec after initiation. In the RTLS mode, the GPC's will terminate the L02 dump upon the Orbiter's reaching a ground relative velocity of 4500 ft/sec.

In the RTLS mode, L02 is dumped through the bells of the three SSME's just as in the normal mode; however, in the RTLS mode, the engines will be gimbled to the entry stow position rather than the normal dump position.

No vacuum inerting or system repress will be performed following an RTLS abort.

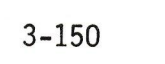


Figure 3.4-9.- The MPS oxidizer flow, RTLS oxidizer dump.

G. Vacuum inerting (fig. 3.4-10)Active valves

- | L02 prevalues (3)* (panel R4)
- | L02 inboard fill/drain valve* (panel R4)
- ↓ L02 outboard fill/drain valve* (panel R4)

Upon completion of the MPS L02 dump, the pilot will immediately initiate the MPS LH2 dump. At approximately 00:19:00 GET (after the MPS LH2 dump), the pilot will initiate the procedure for vacuum inerting the Orbiter L02 and LH2 lines. Vacuum inerting allows any traces of L02 or LH2 left over after the propellant dumps to be vented into space. For L02, vacuum inerting is accomplished by opening the L02 prevalues (3), the L02 inboard fill/drain valve, and the L02 outboard fill/drain valve. These valves are opened by placing their corresponding switches on panel R4 in the OPEN position. Approximately 30 min will be allowed for vacuum inerting. Both the L02 lines and the LH2 lines will be inerted simultaneously. At the end of the 30-min time period, the pilot will close the L02 outboard fill/drain valve by placing its corresponding switch on panel R4 in the CLOSE position. The L02 prevalues (3) and L02 inboard fill/drain valve will be left open. To conserve electrical power after the completion of the L02 vacuum inerting sequence, the switches for the three L02 prevalues will be left in the GPC position and the switches for the L02 fill/drain valves (2) will be left in the GND position. With the switches in these positions, power is removed from the opening and closing solenoids of the corresponding valves. Since the valves are pneumatically actuated (and not spring-loaded to one position), the valves will remain in their last commanded positions.



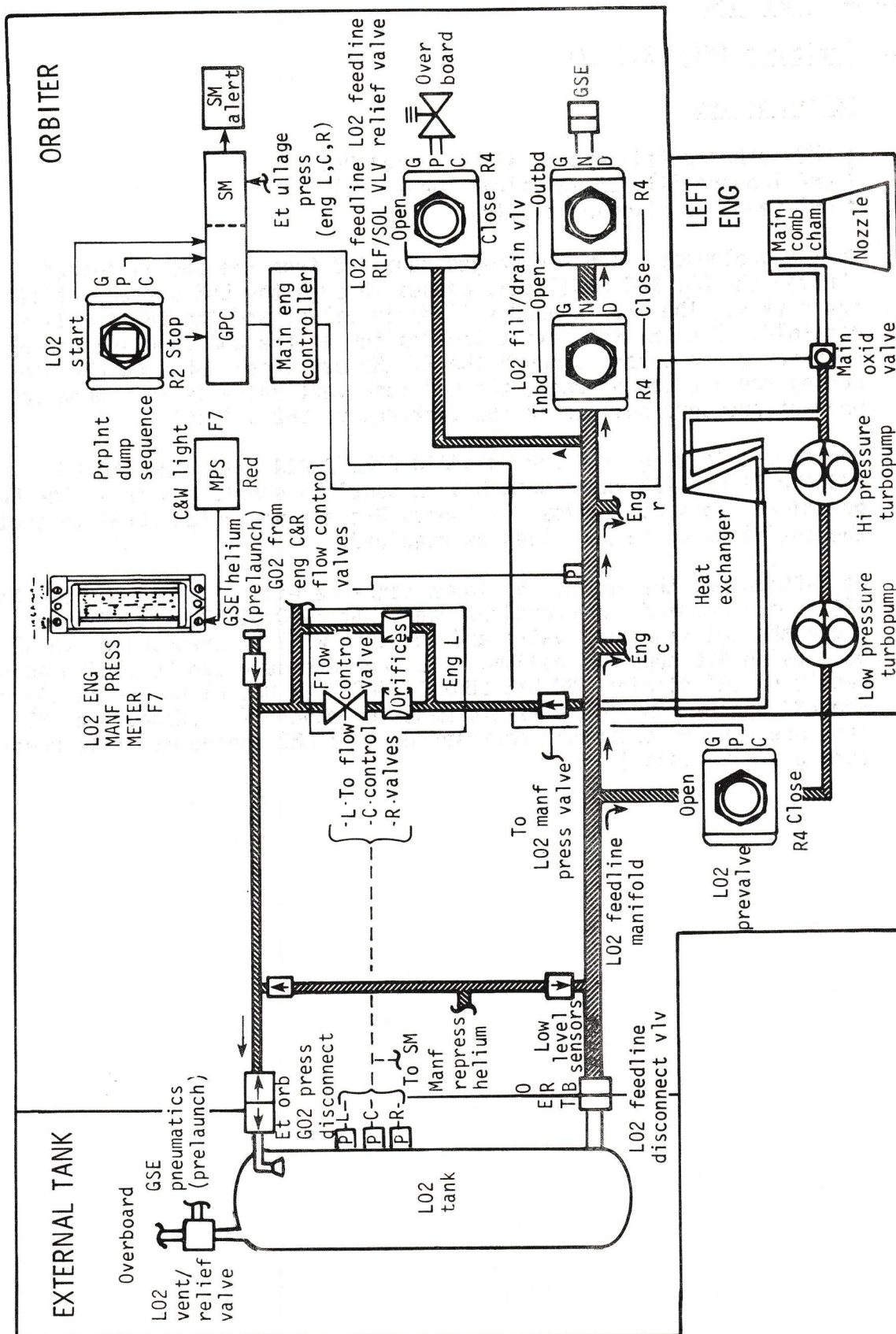


Figure 3.4-11.- The MPS oxidizer flow, manifold repress.

3.4.4 Fuel Flow

A. Prelaunch (fig. 3.4-12)

Active valves

- | LH2 outboard fill/drain valve* (panel R4)
- | LH2 inboard fill/drain valve* (panel R4)
- ▼ LH2 feedline disconnect valve

During prelaunch, liquid hydrogen supplied from the GSE is loaded through the GSE LH2 umbilical, passes through the LH2 outboard fill/drain valve, the LH2 inboard fill/drain valve, and the LH2 feedline manifold. The LH2 then exits the Orbiter at the LH2 feedline disconnect valve and passes through the ET LH2 umbilical into the LH2 tank. During the loading process, the LH2 tank vent valve is left open to prevent pressure buildup in the tank due to LH2 boiloff.

During LH2 loading, the LH2 OUTBOARD FILL/DRAIN valve and the LH2 INBOARD FILL/DRAIN valve switches on panel R4 should remain in the GND position. This will allow the Launch Processing System (LPS) to control the positions of these valves as required.

At T-00:00:07, the engine chilldown sequence will be completed and the GPC's will command the prevalves open. At T-00:01:52, the LPS will close the LH2 tank vent valve and the tank will be pressurized to 42.5 psia using GSE-supplied helium. LH2 tank pressure can be monitored directly on CRT display GNC SYS SUMM 1 (BFS) (ET ULL P) or indirectly on the LH2 engine manifold pressure meter on panel F7. (Note: An LH2 tank pressure of 42.5 psia corresponds to a LH2 engine manifold pressure of 44.96 psia.)

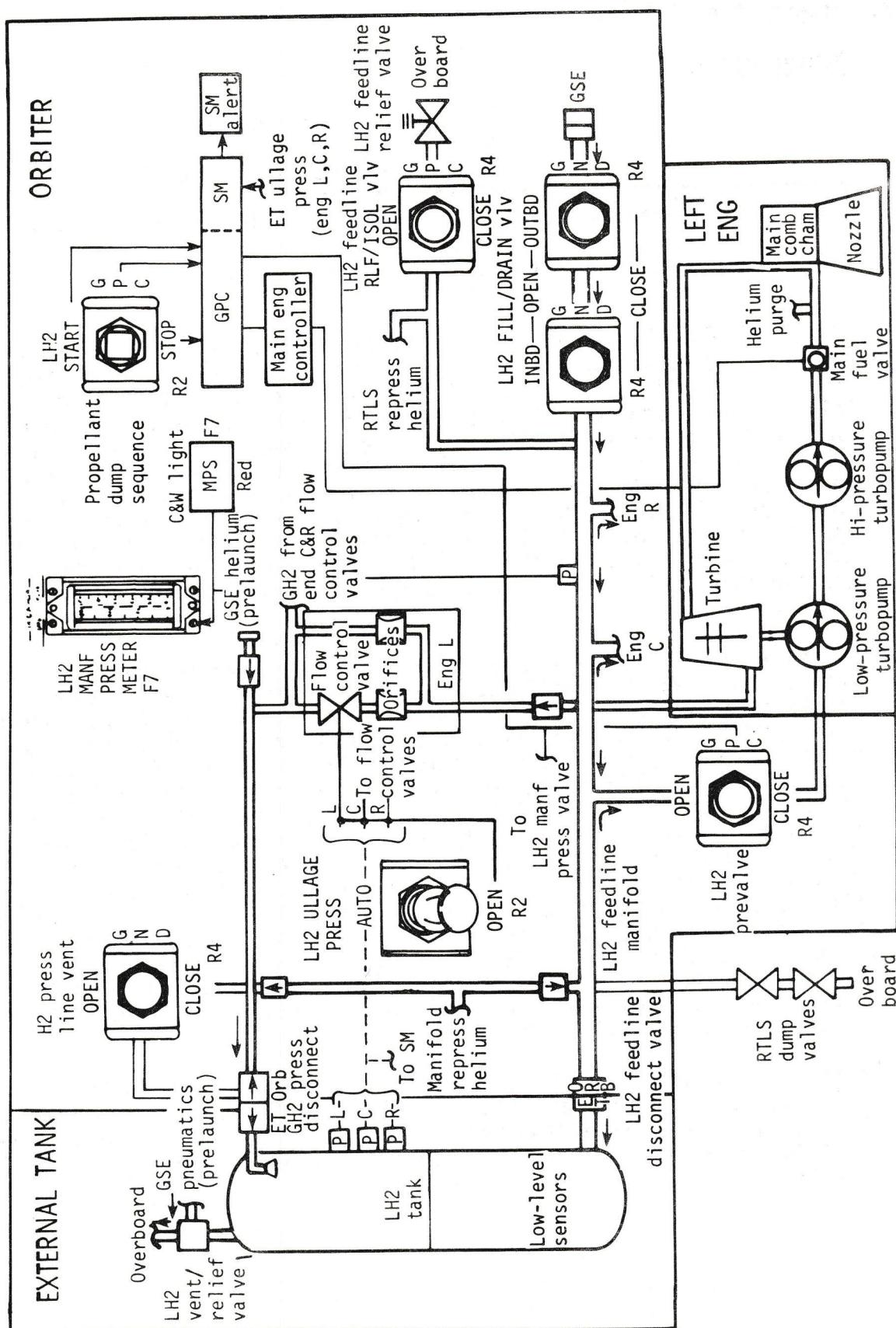
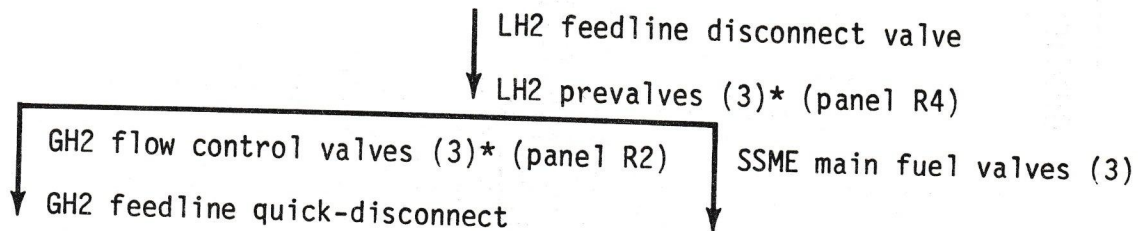


Figure 3.4-12.- The MPS fuel flow, prelaunch.

B. Ascent (fig. 3.4-13)Active valves

At T-00:00:03, the GPC will issue the engine start command, opening the main fuel valve in the engine. Between main fuel valve opening and MECO, LH2 flows out of the ET through the ET LH2 umbilical and the LH2 feedline disconnect valve into the LH2 feedline manifold. From this manifold, LH2 is distributed to the engines through the three engine LH2 feedlines. In each line, LH2 passes through the prevalue and enters the main engine at the inlet to the Low-Pressure Fuel Turbopump (LPFT). In the engine, the liquid hydrogen is used to cool various engine components and in the process is converted to gaseous hydrogen (GH2). The majority of this GH2 is burned in the engine; a smaller portion is directed back to the ET to maintain LH2 tank pressure.

GH2 flow back to the ET begins at the turbine outlet of the LPFT. GH2 tapped from this line first passes through a check valve and then splits into two paths, each containing a flow control orifice. One of these paths also contains a valve which is normally controlled by one of three pressure transducers located in the LH2 tank. During ascent, tank pressure is maintained between 32 and 34 psia by the orifices in the two lines and the action of the flow control valve. When pressure in the tank reaches 34 psia, the valve closes, and when pressure drops below 32 psia, the valve opens. Tank pressures greater than 37 psia will cause the tank to relieve through the tank vent valve. In the event tank pressure falls below TBD psia (LH2 engine manifold pressure less than TBD psia), the crew will place the LH2 ULLAGE PRESS switch on panel R2 in the OPEN position. This switch position will cause the three flow control valves to go to and remain in the full open position. (Normally the LH2 ULLAGE PRESS switch will be left in the AUTO position.)

Downstream of the two flow control orifices and the flow control valves, the GH2 lines empty into the ET GH2 pressurization manifold. This single line then exits the Orbiter at the GH2 pressurization disconnect and passes through the ET GH2 umbilical into the top of the LH2 tank.

Although normal MECO is based on the attainment of a specified velocity, the engine can also be shut down by LH2 depletion, should it occur before the specified velocity is reached. LH2 depletion is sensed by four fuel depletion sensors located in the bottom of the LH2 tank. Any two of the four sensors indicating a dry condition will cause the GPC's to issue a MECO command to the engine controller.

Once MECO has occurred (by whatever means), and before ET separation, the GPC's will isolate the Orbiter LH2 feedline from the ET by closing the LH2 feedline disconnect valve (actually two valves, one on each side of the separation interface). At the time of Orbiter/ET separation, the LH2 feedline will be sealed at the separation interface by the action of the self-sealing quick-disconnect valve.



C. Post-MECOActive valves

LH2 feedline relief isolation valve* (panel R4)

At MECO, the GPC will open the LH2 feedline relief isolation valve, allowing any pressure buildup generated by fuel trapped in the feedline manifold to be vented overboard through the relief valve. This action will occur automatically as long as the FEEDLINE RLF ISOL LH2 switch on panel R4 is in the GPC position.

D. Propellant dump (nominal) (fig. 3.4-14)Active valves

- ↓ LH2 prevalues (3)* (panel R4)
- ↓ SSME main fuel valves (3)

Approximately 11 sec after MECO, the ET will separate from the Orbiter. Approximately 109 sec later, the OMS 1 burn will begin. Coincident with the start of this burn, the GPC will automatically initiate the MPS LO2 dump.

At the termination of the MPS LO2 dump, the GPC will automatically initiate the MPS LH2 dump (if the MPS PRPLT DUMP SEQUENCE LH2 switch on panel R2 is in the GPC position). The GPC will not only initiate its own portion of the LH2 dump sequence, but will also command the main engine controller to initiate its portion of the sequence as well. The overall LH2 dump sequence is as follows:

OBSOLETE

- Engine controller commands 10-sec helium purge of engine fuel lines.
- GPC commands LH2 manifold repress valve open (requires that the MANF PRESS LH2 switch on panel R4 be in the GPC position).
- Engine controller commands SSME main fuel valve open.
- GPC commands LH2 prevalue open (requires that the LH2 PREVALVE switches (3) be in GPC position).

The preceding actions will cause the LH2 trapped in the feedline manifold to be expelled under pressure from the helium subsystem through the bells of the three engines. If the MPS PRPLT DUMP SEQUENCE LH2 switch on panel R2 is left in the GPC position, the LH2 dump will continue for 40 sec. At the end of this time period, the GPC will automatically terminate the dump by closing the LH2 manifold repress valves (2) and command the engine controller to close the main fuel valve. The LH2 prevalue will be left open for the rest of the mission. If necessary, the crew can perform the LH2 dump manually by utilizing the START and STOP positions of the MPS PRPLT DUMP SEQUENCE (LH2 switch).

Note: Even when the LH2 dump is performed manually, all valve opening and closing sequences are still automatic. Thus, placing the MPS PRPLT DUMP SEQUENCE LH2 switch in the START position will cause the GPC to immediately begin commanding all of the required valves open automatically and in the proper sequence (assuming that the L02 dump was completed before placing the MPS PRPLT DUMP SEQUENCE LH2 switch in the START position). The LH2 dump will continue for as long as the switch is in the START position. Likewise, placing the switch in the STOP position will cause the GPC to begin commanding all of the required valves closed automatically and in the proper sequence.

Caution

1. GPC software requires that the L02 dump be completed before the initiation of the LH2 dump, regardless of whether the LH2 dump is initiated automatically by the GPC or manually by the crew.
2. The GPC software (MPS dump sequence) will automatically initiate the LH2 dump at one time only -- at completion of the L02 dump. If at that time the switch is not in the GPC position, the LH2 dump must be initiated manually.
3. Once the LH2 dump has been initiated and the MPS PRPLT DUMP SEQUENCE LH2 switch placed in the STOP position, the GPC will no longer monitor any of the positions of this switch. For this reason, the LH2 dump cannot be reinitiated, manually or otherwise.

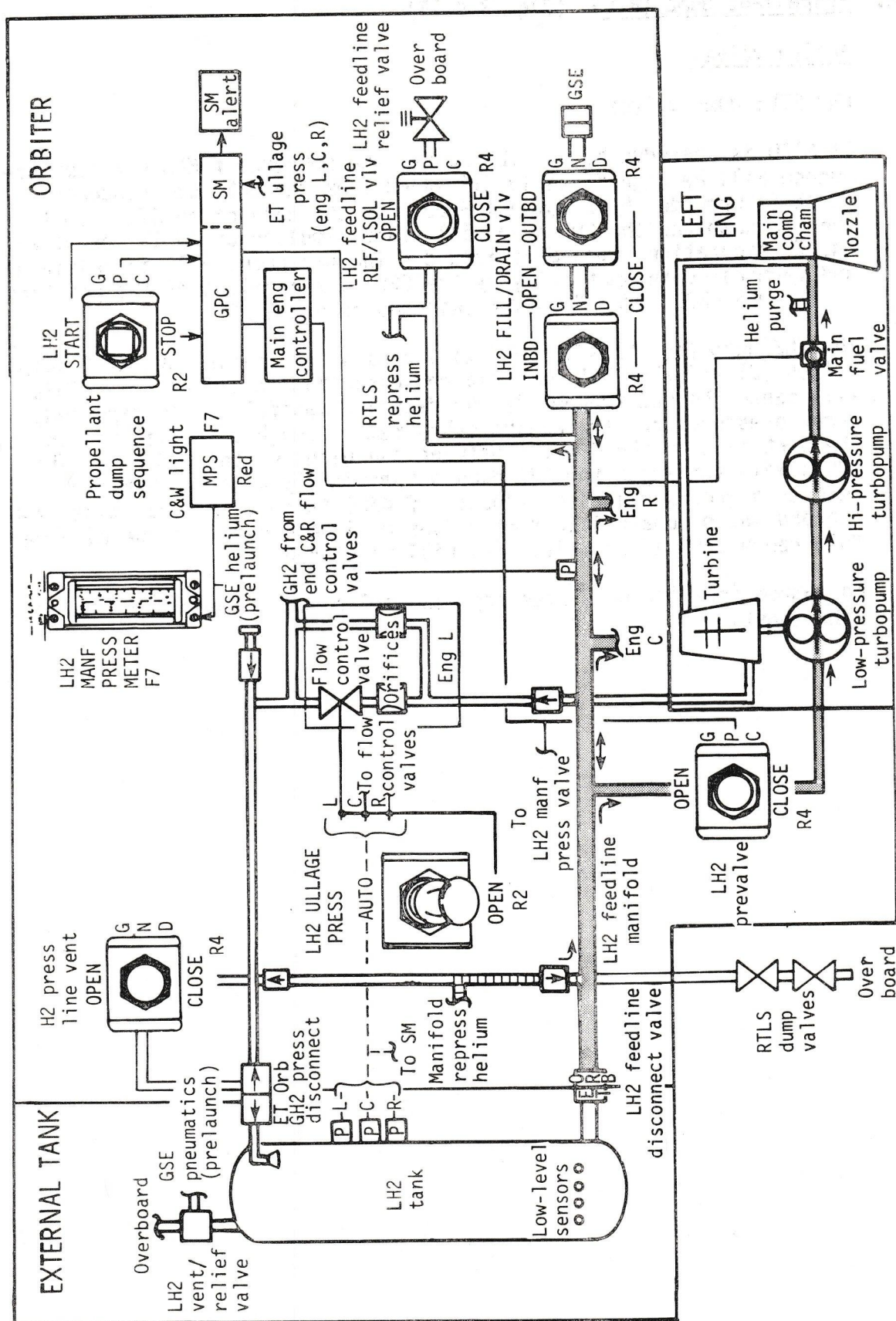


Figure 3.4-14.- The MPS fuel flow, nominal fuel dump.

E. Propellant dump (RTLS) (fig. 3.4-15)Active valves

LH2 RTLS dump valves

If MECO is preceded by an RTLS abort, the subsequent MPS LH2 dump sequence will be significantly different from the LH2 dump sequence which is preceded by a nominal MECO. In the case of an RTLS abort, the LH2 dump and the LO2 dump will start simultaneously 10 sec after the ET separation command is issued. The two dumps will be initiated and terminated automatically by the GPC's, regardless of the positions of the MPS PRPLT DUMP SEQUENCE switches on panel R2.

The LH2 dump for the RTLS mode will consist of opening the RTLS dump valves (2) and the RTLS manifold repressurization valves (2). This will cause the LH2 trapped in the feedline manifold to be expelled, under pressure from the helium subsystem, through a special opening on the port side of the Orbiter between the wing and the OMS pod. The GPC's will terminate the LH2 dump automatically when the Orbiter reaches a ground relative velocity of 4500 ft/sec. At that time, the inboard and outboard RTLS dump valves will be closed and the RTLS manifold repressurization valves (2) will be closed.

No vacuum inerting or system repress will be performed following an RTLS abort.

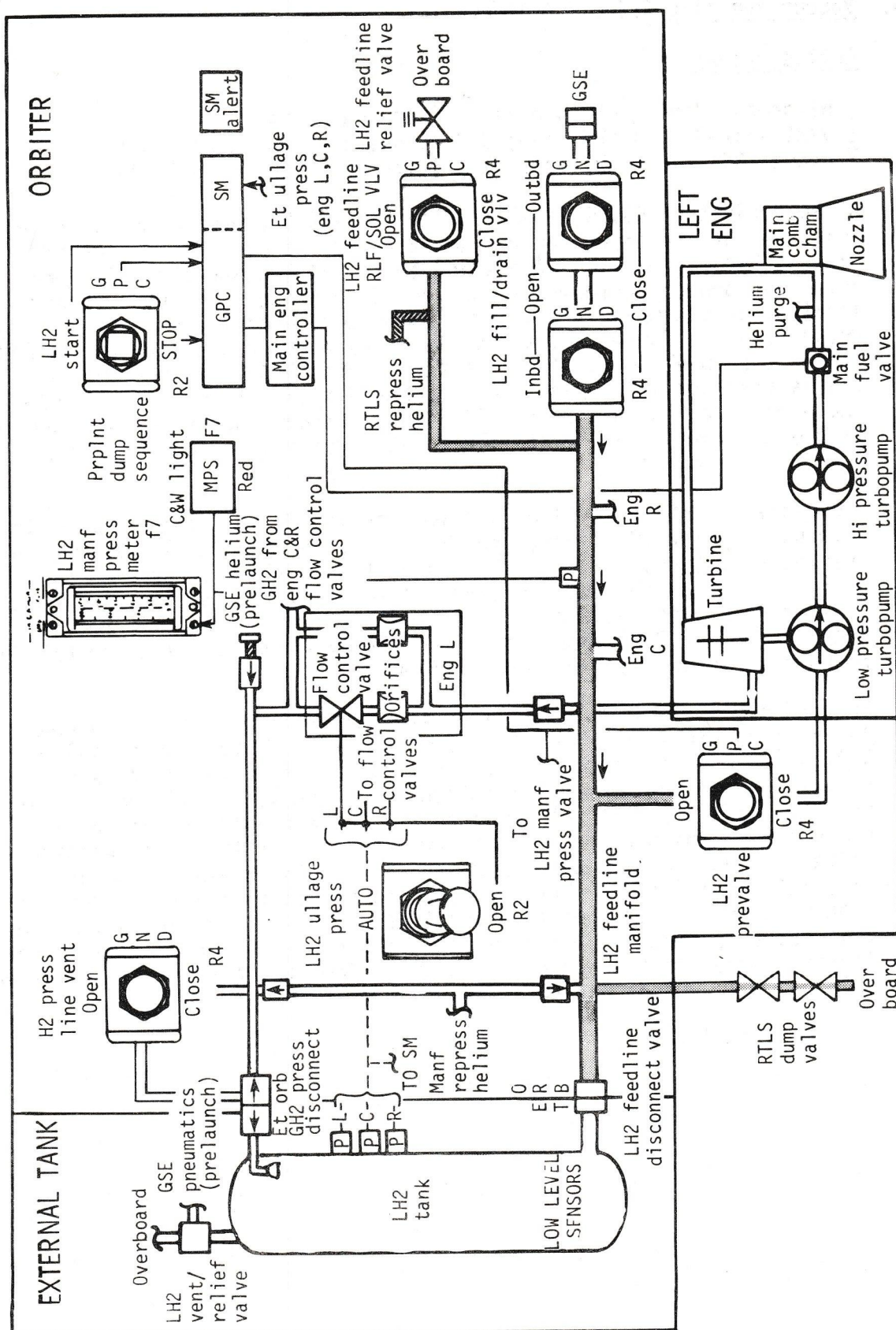


Figure 3.4-15.- The MPS fuel flow, RTLS fuel dump.

G. Vacuum inerting (fig. 3.4-16)Active valves

↓ H2 press line vent valve* ↓ (panel R4)	↓ LH2 prevalues (3)* (panel R4) ↓ LH2 inboard fill/drain valve (panel R4) ↓ LH2 outboard fill/drain valve (panel R4)
--	--

At approximately 00:19:00 GET (after the MPS LH2 dump), the pilot will initiate the procedure for vacuum inerting the Orbiter LO2 and LH2 lines. Vacuum inerting allows any traces of LO2 and LH2 left over after the propellant dumps to be vented to space. For LH2, vacuum inerting is accomplished by opening the LH2 inboard and outboard fill/drain valves. These valves are opened by placing their corresponding switches on panel R4 in the OPEN position. (Note that the LH2 prevalues (3) were left open after the LH2 dump.) At this time the ET GH2 pressurization manifold will also be vacuum inerted by opening the H2 pressurization line vent valve. This valve is controlled by a switch on panel R4.

Approximately 30 min will be allowed for vacuum inerting. During this time period, the LO2 lines, the LH2 lines, and the GH2 lines will be inerted simultaneously. At the end of the 30-min time period, the pilot will close the LH2 outboard fill/drain valve and the H2 pressurization line vent valve by placing their corresponding switches on panel R4 in the CLOSE position. The LH2 prevalues (3) and the LH2 inboard fill/drain valve will be left open.

To conserve electrical power after the completion of the LH2 vacuum inerting sequence, the switches for the three LH2 prevalues will be left in the GPC position and the switches for the LH2 fill/drain valves (2) and the H2 pressurization vent line valve will be left in the GND position. With the switches in these positions, power is removed from the opening and closing solenoids of the corresponding valves. Since the prevalues and the fill/drain valves are pneumatically activated (and not spring-loaded to one position) the valves will remain in their last commanded positions. The H2 pressurization line vent valve is electrically activated; however, it is normally closed (spring-loaded to the closed position). Removing power from the valve solenoid will therefore leave the valve closed.

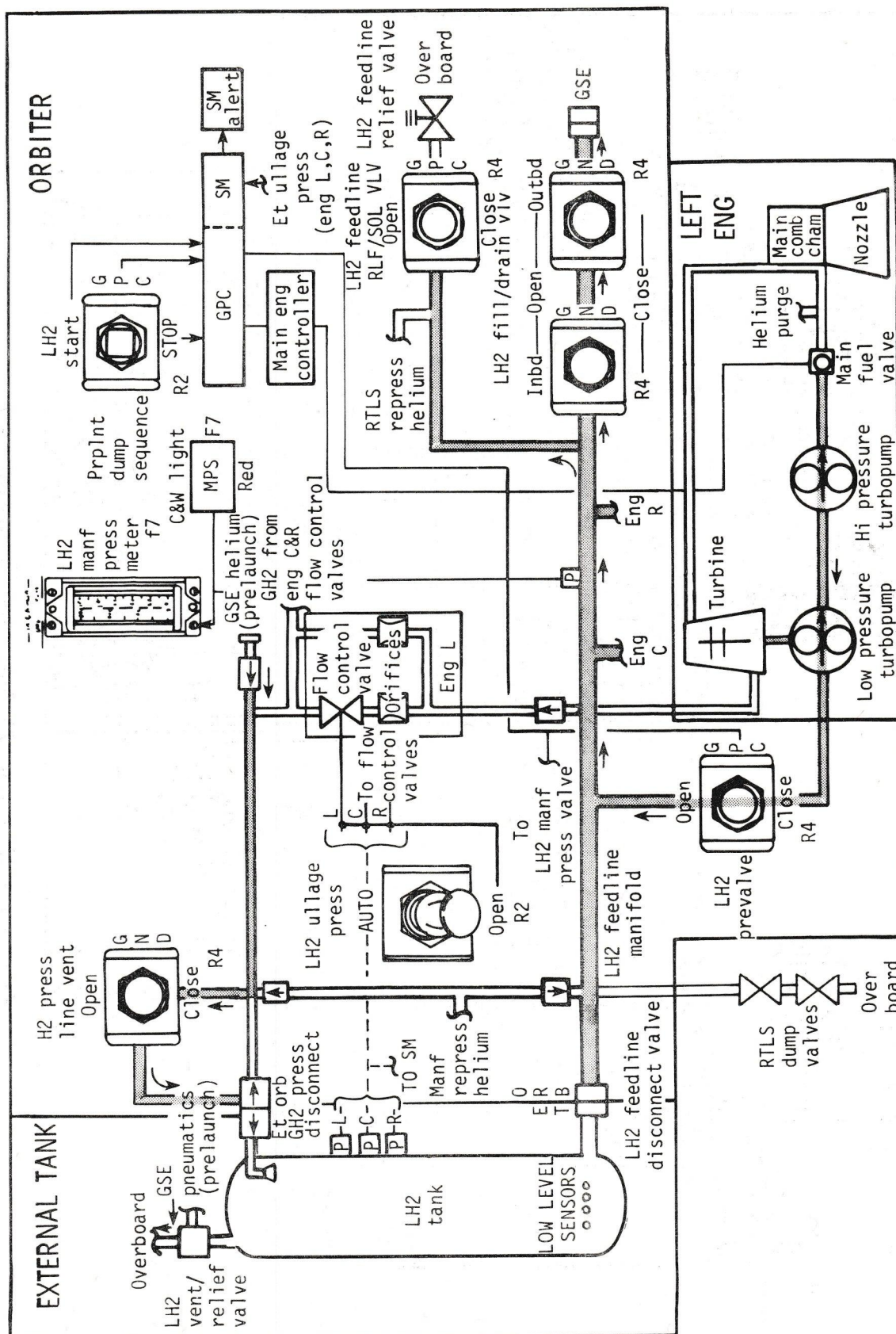


Figure 3.4-16.- The MPS fuel flow, vacuum inerting.

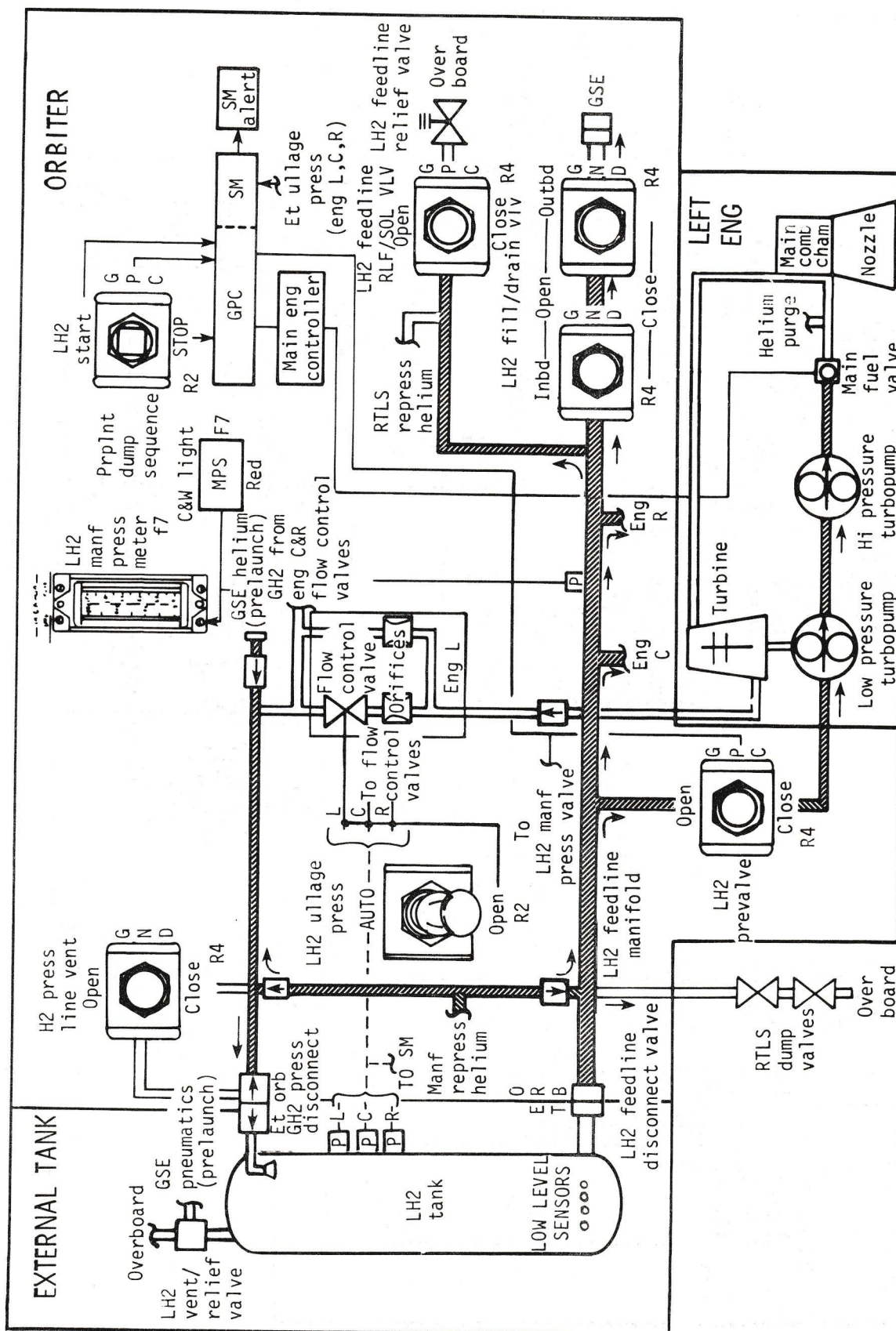


Figure 3.4-17.- The MPS fuel flow, manifold repress.

3.5 ORBITER MPS - HELIUM SUBSYSTEM GENERAL DESCRIPTION

The helium subsystem consists of seven 4.7-ft³ helium supply tanks, three 17.3-ft³ helium supply tanks and their associated regulators, check valves, distribution lines, and control valves (fig. 3.5-1). Four of the 4.7-ft³ helium supply tanks are located within the Orbiter aft of the payload bay area. The other three 4.7-ft³ supply tanks and the three 17.3-ft³ supply tanks are located below the payload bay in the mid-body area of the Orbiter. Each of the 17.3-ft³ supply tanks is plumbed to two of the 4.7-ft³ supply tanks (one in the mid-body, the other in the aft body) to form three sets of three tanks. Each set of tanks, thus formed, normally provides helium to only one engine and for this reason is commonly referred to by the engine's designation; for example, "left engine helium." This helium is used within the engine for in-flight purges, and provides pressure for actuating engine valves during emergency pneumatic shutdowns.

The remaining 4.7-ft³ helium supply tank (the one which is not connected to a 17.3-ft³ tank) is called the "pneumatic helium" supply tank. It normally provides pressure to actuate all of the pneumatically operated valves within the propellant management subsystem.

Each of the four helium supply circuits described above (three engine helium and one pneumatic helium) will operate independently until after MECO when the three "out" helium interconnect valves will be opened, connecting all circuits to a common manifold. This interconnection can be performed manually by the crew; however, normally the GPC will automatically interconnect the circuits just before the start of the MPS propellant dump.

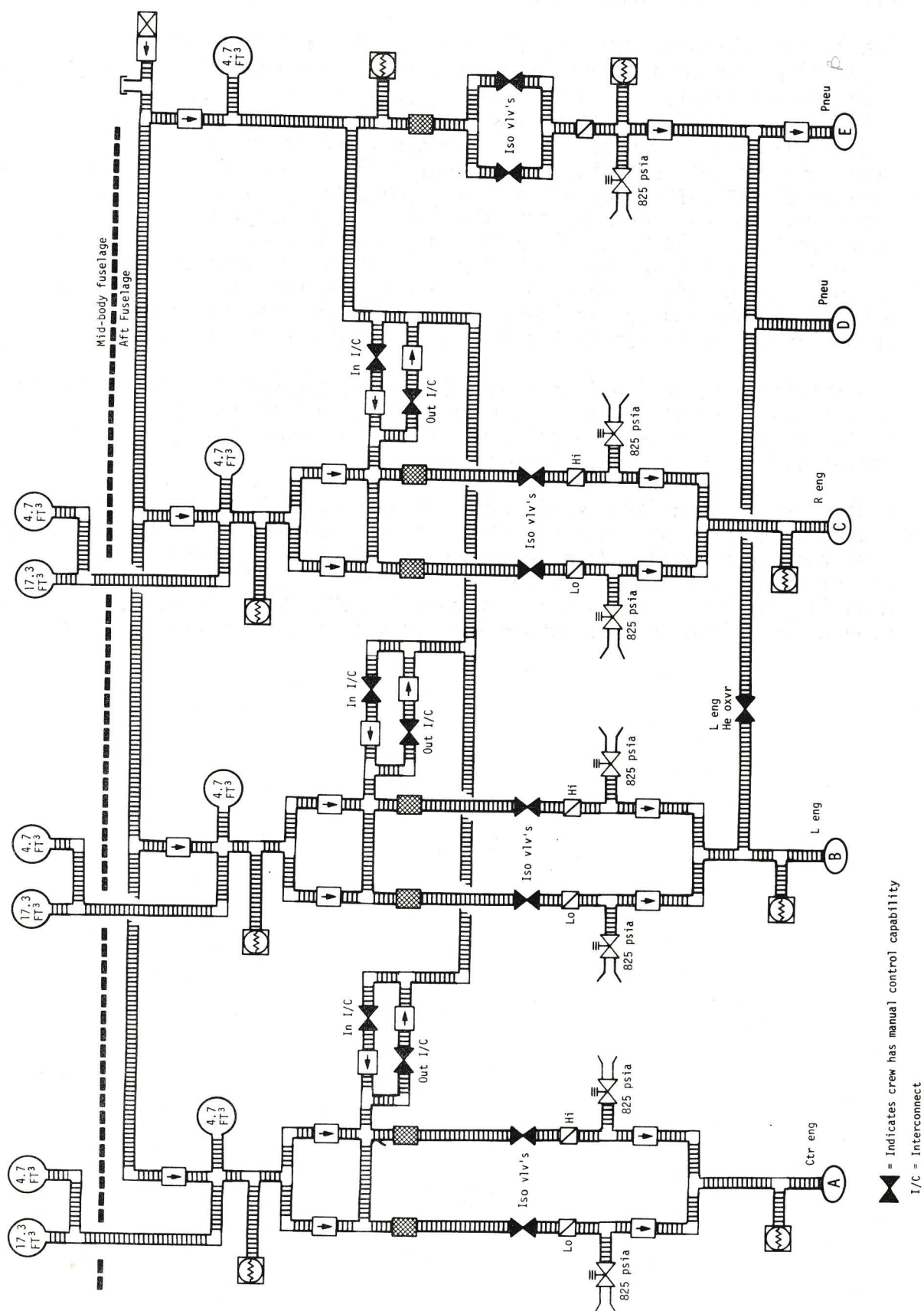


Figure 3.5-1.- Helium subsystem - storage and regulation.

3.5.1 Helium Subsystem Components

The helium subsystem contains the following major components (fig. 3.5.1).

3.5.1.1 Supply tank.- Each engine helium supply tank cluster consists of two 4.7-ft³ supply tanks and one 17.3-ft³ supply tank. One of the 4.7-ft³ tanks and the 17.3-ft³ tank are located in the mid-body area of the Shuttle under the payload bay liner, in an area originally reserved for additional PRSD cryogenic storage. The 17.3-ft³ tank is identical to that used in the OMS. The remaining 4.7-ft³ tank is located in the rear of the Shuttle, aft of the payload bay bulkhead. The single 4.7-ft³ pneumatic helium supply tank is also located in this area. Prior to lift-off, all helium supply tanks will be pressurized to a nominal value of 4200 psia.

3.5.1.2 Valves.- All of the valves in the helium subsystem (with the exception of the supply tank isolation valves) are spring-loaded to one position and electrically actuated to the other position. The supply tank isolation valves are spring-loaded to the closed position and pneumatically actuated to the open position.

Control of valve position is via electrical signals from either the GPC's or a manual switch. Although the crew can control the positions of some of the valves through cockpit switches, all of the valves can be controlled automatically by the GPC's.

3.5.1.3 Supply tank isolation valves.- There are eight supply tank isolation valves in the helium subsystem, grouped in pairs. One pair of valves is connected to each engine helium supply tank cluster and one pair is connected to the pneumatic supply tank. In the case of the engine helium supply tanks, each pair of isolation valves is connected in parallel, with each valve in the pair controlling helium flow through one leg of a dual-redundant helium supply circuit. Each helium supply circuit contains two check valves, a filter, an isolation valve, a regulator, and a relief valve.

The two isolation valves connected to the pneumatic supply tank are also connected in parallel, but the rest of the corresponding helium supply circuit consists of a filter, the two isolation valves, a regulator, a relief valve, and a single check valve.

Each isolation valve (with the exception of the two pneumatic helium isolation valves) can be individually controlled by its own cockpit switch. The two pneumatic helium isolation valves are controlled by a single switch on panel R2.

3.5.1.4 Interconnect valves.- Each engine helium supply tank cluster has two interconnect (crossover) valves associated with it. Each valve in the pair of interconnect valves is connected in series with a check valve. Because of the check valves, helium can flow through the interconnect valves in one direction only. The check valves are oriented in such a manner that one interconnect valve controls helium flow in one direction and the other interconnect valve controls helium flow in the opposite direction. The "in" interconnect valve controls He flow into the associated engine helium distribution lines from the pneumatic helium supply tank. The "out"

interconnect valve controls helium flow out of the associated engine helium supply tank cluster to the pneumatic helium distribution lines.

Each pair of interconnect valves is controlled by a single cockpit switch. This switch has three positions: IN OPEN/OUT CLOSE, GPC, and IN CLOSE/OUT OPEN. With the switch in the IN OPEN/OUT CLOSE position, the "in" interconnect valve will be opened and the "out" interconnect valve closed. The IN CLOSE/OUT OPEN switch position will do the reverse. With the switch in the GPC position, the "out" interconnect valve is opened automatically at the beginning of the LO2 dump and closed automatically at the end of the LH2 dump. In the event of an RTLS abort, the GPC switch position will cause the "in" interconnect valve to open automatically at MECO and close automatically 20 sec later. (If the corresponding engine was shut down prior to MECO, however, its "in" interconnect valve will remain closed at MECO.) At any other time, placing the switch in the GPC position results in both interconnect valves closing and remaining closed.

There is an additional crossover (interconnect) valve connected between the left engine helium supply and the pneumatic helium distribution system. In the event of a pneumatic helium regulator failure, (note - only one regulator in this line) this crossover valve would be opened, the pneumatic helium isolation valves closed and the left engine helium supply would then provide regulated helium pressure through the crossover valve to the pneumatic helium distribution system. This crossover valve is controlled by its own three-position cockpit switch. The three switch positions are labeled OPEN, GPC, and CLOSE. The function of the GPC position is presently undefined.

3.5.1.5 Manifold pressurization valves.- (fig. 3.5-2) - The manifold pressurization valves are located downstream of the pneumatic helium pressure regulator and are used to control the flow of helium to the propellant manifolds during nominal propellant dumps and manifold repressurization. There are four of these valves, grouped in pairs. One pair of valves controls helium pressure to the LO2 propellant manifolds, and the other pair controls helium pressure to the LH2 propellant manifolds.

3.5.1.6 LH2 RTLS dump pressurization valves.- (fig. 3.5-2) - The LH2 RTLS dump pressurization valves are located downstream of the pneumatic helium pressure regulator and are used to control the pressurization of the LH2 propellant manifolds during an RTLS LH2 dump. There are two of these valves, connected in series. Unlike the LH2 manifold pressurization valves, the LH2 RTLS dump pressurization valves cannot be controlled from the cockpit. During an RTLS abort, valves will be opened and closed automatically by GPC commands.

One additional difference between the nominal and the RTLS LH2 dumps is in the routing of the helium and the location at which it enters the LH2 feedline manifold. For the nominal LH2 dump, helium passes through the LH2 manifold pressurization valves and enters the feedline manifold in the vicinity of the LH2 feedline disconnect valve. For the RTLS LH2 dump, helium passes through the LH2 RTLS dump pressurization valves and enters the feedline manifold in the vicinity of the LH2 inboard fill/drain valve (on the inboard side).

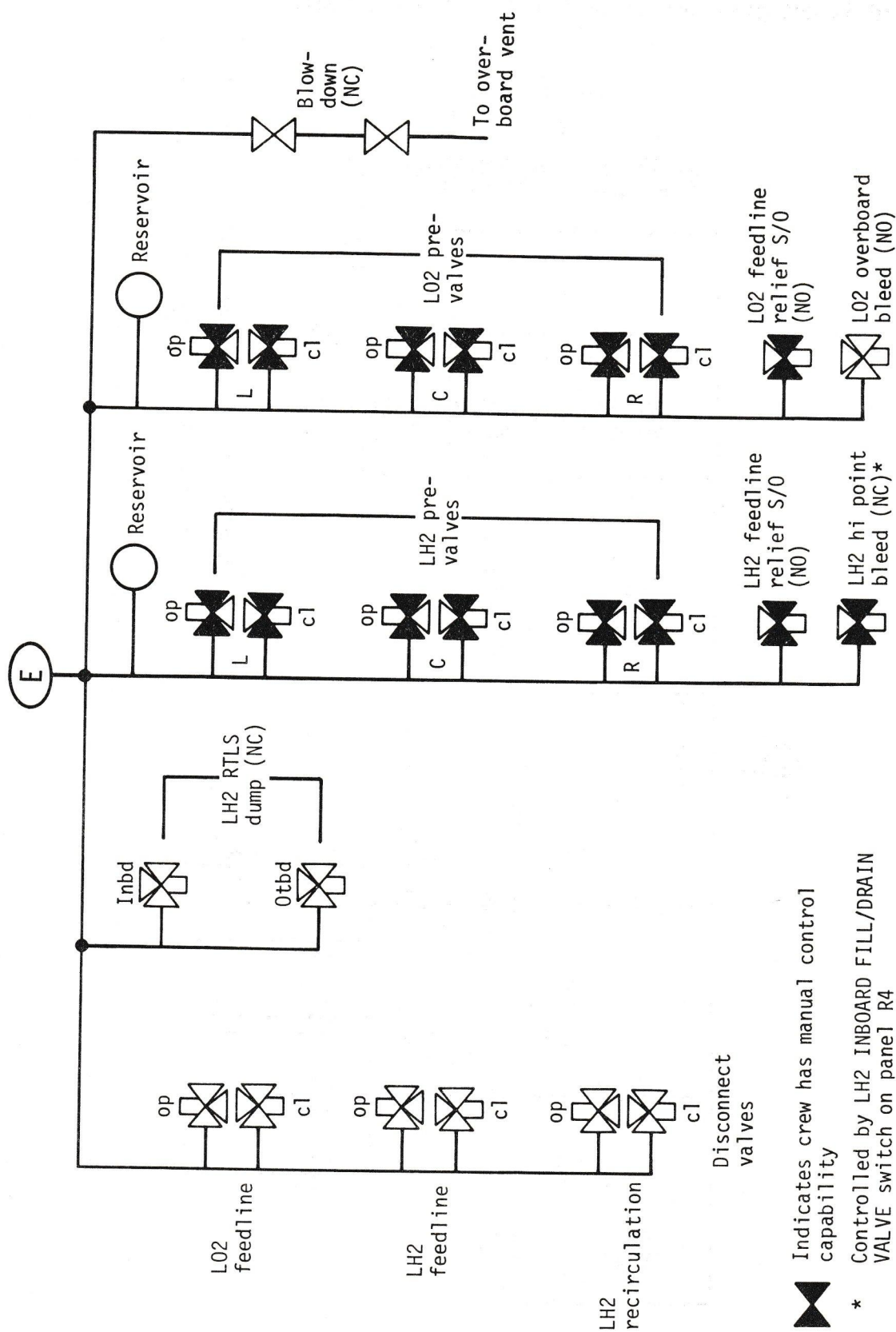


Figure 3.5-3.- Helium subsystem - pneumatic helium distribution.

3.5.1.7 Pressure regulators.- Each engine helium supply tank cluster has two pressure regulators, operating in parallel. Each regulator controls pressure in one leg of a dual-redundant helium supply circuit and is designated either a "hi" regulator or a "lo" regulator. The hi regulator is set to provide a nominal outlet pressure of 800 psig; the lo pressure regulator is set to provide a nominal outlet pressure of 715 psig. Having the two regulators set for different values of outlet pressure provides a variable flow capability for the system. When system demand is low, only the hi regulator will operate; when demand increases, the lo regulator will begin to operate, doubling the flow capacity of the system.

The pressure regulator for the pneumatic helium supply tank is not redundant and is set to provide outlet pressures in the range of 715 psig to 770 psig. Downstream of this regulator are two more regulators - the LH2 manifold pressure regulator and the LO2 manifold pressure regulator (fig. 3.5-3). These regulators are used only during MPS propellant dump and manifold repressurization. Both regulators are set to provide outlet pressures in the range of 20 to 25 psig. Flow through the regulators is controlled by the appropriate set (2) of normally closed manifold pressurization valves.

3.5.1.8 Relief valves.- Downstream of each pressure regulator (with the exception of the two manifold repress regulators) is a relief valve. The purpose of the relief valve is to protect the downstream helium distribution lines from overpressurization (and rupture) in the event the associated pressure regulator fails fully open. The two relief valves in each engine helium supply circuit will probably be set to different values, reflecting the differences in the settings of the corresponding "lo" and "hi" regulators; however, the settings of the relief valves are presently TBD. The relief valve in the pneumatic helium supply circuit is set to relieve at 825 ± 25 psig and reseal at 785 psig.

3.5.1.9 Pneumatic control assembly.- (fig. 3.5-4) - There is one Pneumatic Control Assembly (PCA) mounted on each of the three SSME's. The PCA is essentially a manifold which is pressurized by one of the engine helium supply circuits and contains solenoid valves to control and direct that pressure to perform various essential functions. The solenoid valves are energized by discrete (on/off) commands from the output electronics of the associated SSMEC. Functions controlled by the PCA include in-flight purges of the fuel system, HPOT intermediate seal cavity and preburner oxidizer domes, and pneumatic shutdown.

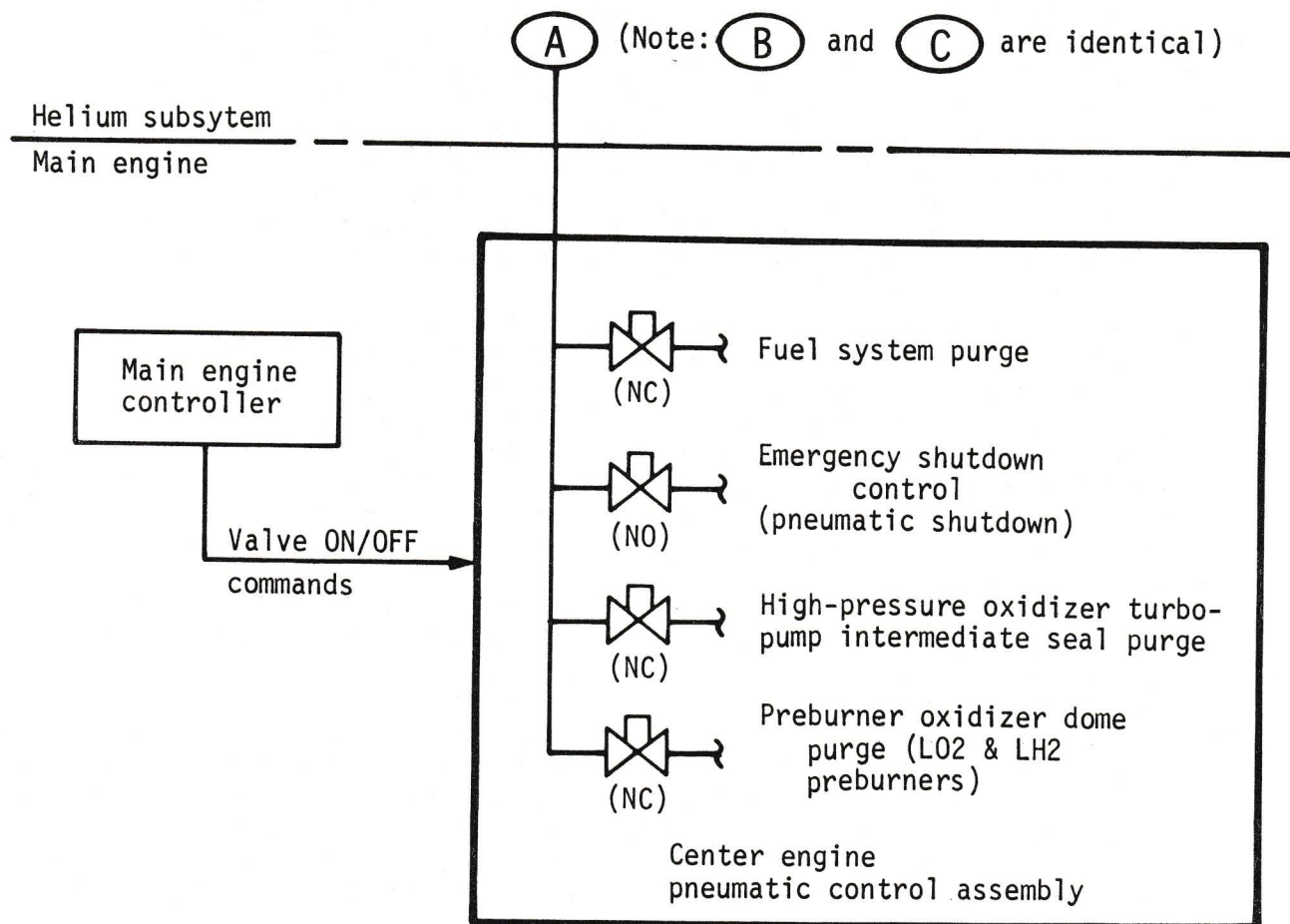


Figure 3.5-4.- Helium subsystem - engine helium distribution.

3.5.2 Helium Flow

3.5.2.1 Prelaunch.- During prelaunch, the pneumatic helium circuit supplies pressure to operate the LH2 and LO2 prevalves. The LH2 and LO2 inboard fill drain valves, and the LH2 and LO2 outboard fill drain valves. The three engine supply helium circuits are not used.

At the time the crew enters the Orbiter, all 10 helium supply tanks will be partially pressurized to approximately 2000 psia. Helium regulated pressure will be 750 psig $\pm$ 35 psig. Helium supply tank and regulated pressures can be monitored on the same four-scale meter on panel F7. A switch associated with the meter selects either supply or regulated pressure to be displayed on the meter. Engine helium supply and regulated pressures are also available on the GNC SYS SUMM 1 (BFS) CRT display.

At the time the crew enters the Orbiter, the eight helium isolation valves will be open and their corresponding control switches on panel R2 will be in the GPC position. All helium interconnect valves will be closed and their corresponding control switches on panel R2 will also be in the GPC position. One of the crew's first actions (at T-00:25:00) will be to place the seven HELIUM ISOLATION switches on panel R2 in the OPEN position. This will not change the position of the helium isolation valves. It will, however, inhibit LPS control of valve position.

At T-00:08:59, the helium supply tanks will be pressurized to their final lift-off value of 4200 psia. This process will be a gradual one so as to prevent excessive heat buildup in the supply tanks.

3.5.2.2 Ascent.- Beginning at engine ignition (T-00:00:04), helium will flow out of the nine engine supply tanks, pass through the isolation valves, the pressure regulators and check valves, and enter the engine at the inlet to the PCA. The PCA is essentially a manifold which contains solenoid valves to control and direct helium pressure to perform various essential functions. The solenoid valves are energized by discrete (on/off) commands from the output electronics of the engine controller.

One essential function performed by the PCA is the continuous (T-00:00:04 to MECO +6 sec) purging of the High Pressure Oxidizer Turbopump (HPOT) intermediate seal cavity. This cavity is between two seals, one of which contains the hot, fuel-rich gas in the oxidizer turbine and the other contains the liquid oxygen in the oxidizer turbopump. Leakage through one or both of the seals could result in a catastrophic explosion if allowed to accumulate. Continuous, overboard purge of this area prevents this accumulation from occurring.

Another important function of the PCA during ascent is to provide the capability for an emergency, backup mode of closing the engine propellant valves using helium pressure. (In a "normal" engine shutdown, the engine propellant valves are hydraulically actuated.)

3.5.2.3 Post MECO.- Beginning at MECO, the PCA will perform a 6-sec purge of the engine preburner oxidizer domes, and a 2-sec post charge of the pogo accumulator. The purpose of this purge is to ensure that no residual

propellant remains in this area to cause an unsafe condition and to prevent a water hammer effect in the LOX manifolds of the SSME. The helium usage caused by this purge and the coincident HPOT intermediate seal cavity purge can be observed by monitoring the three engine helium tank pressures on the MPS PRESS HELIUM meter on panel F7. The three pressure measurements are also available on CRT format GNC SYS SUMM 1 (BFS).

After the 6-sec purge is completed, the GPC will interconnect the pneumatic helium and engine helium supply circuits by opening the three "out" interconnect valves (this requires that corresponding switches on panel R2 be in the GPC position). This action will connect all 10 helium supply tanks to a common manifold and is necessary to ensure that there is sufficient helium available to perform the coming LO2 and LH2 propellant dumps.

During the MPS LO2 dump, pressure from the helium supply tanks will be used to actuate the LO2 prevalues and to force the residual LO2 out of the LO2 feedline manifold.

At the initiation of the MPS LH2 dump sequence, helium from the supply tanks will be used to purge the engine fuel lines prior to the actual dump. During the MPS LH2 dump, pressure from the helium supply tanks will be used to actuate the LH2 prevalues and to force the residual LH2 out of the LH2 feedline manifold. At the end of the LH2 dump, the GPC will close the interconnect valves and all of the supply tank isolation valves (this requires that corresponding switches for interconnect valves and isolation valves on panel R2 be in the GPC position.)

3.5.2.4 RTLS abort.- If MECO is preceded by an RTLS abort, the GPC will automatically open the "in" interconnect valves at MECO for all engines which were not shut down prior to MECO. This allows helium from the pneumatic supply tank to flow into the corresponding engine helium circuits during the 6-sec preburner oxidizer dome purge and a 2-sec pogo accumulator post charge. (It is assumed that in an RTLS abort at least one engine will be shut down prematurely and the preburner dome purge and pogo post charge for this engine would be provided from its own engine supply tank cluster. Since the remaining engine(s) will be forced to burn for a longer than nominal period of time, the continuous HPOT intermediate seal purge will consume a larger than normal amount of engine helium and there may be insufficient helium to perform the required preburner dome purge unless supplemented by helium from the pneumatic supply tank.)

Twenty sec after MECO, the GPC will automatically close the "in" interconnect valves.

Following an RTLS abort, there will be no purge between the subsequent MPS LO2 and LH2 dumps as there is in the nominal MECO case (since the two dumps start simultaneously).

For the LO2 dump, pressure from the pneumatic helium supply tank will be used only to actuate the LO2 prevalues. Since, in this case, the LO2 feedline manifold is not pressurized, the LO2 manifold pressurization valves will remain closed for the entire dump.

For the LH2 dump, pressure from the pneumatic helium supply tanks will be used to actuate the two (in series) RTLS dump valves and force the residual LH2 out of the LH2 feedline manifold. In the RTLS mode, the helium which is injected into the feedline manifold enters the manifold between the LH2 inboard fill/drain valve and the LH2 prevalues. In the nominal MECO case, the helium enters the manifold in the vicinity of the LH2 feedline disconnect valve.

19 min
 3.5.2.5 Vacuum inerting.- At approximately TBD, the pilot will begin the vacuum inerting of the Orbiter LO2 and LH2 feedline manifolds and the LH2 tank pressurization line. This is a totally manual sequence. During the sequence, pressure from the helium supply tanks is used to actuate the two LO2 fill/drain valves and the two LH2 fill/drain valves. Helium is provided for valve actuation through the two pneumatic helium isolation valves. Since these valves were closed by the GPC at the end of the MPS LH2 dump, the pilot must open the valves before attempting to open the fill/drain valves. The pneumatic helium isolation valves are opened by placing their corresponding switch on panel R2 in the OPEN position.

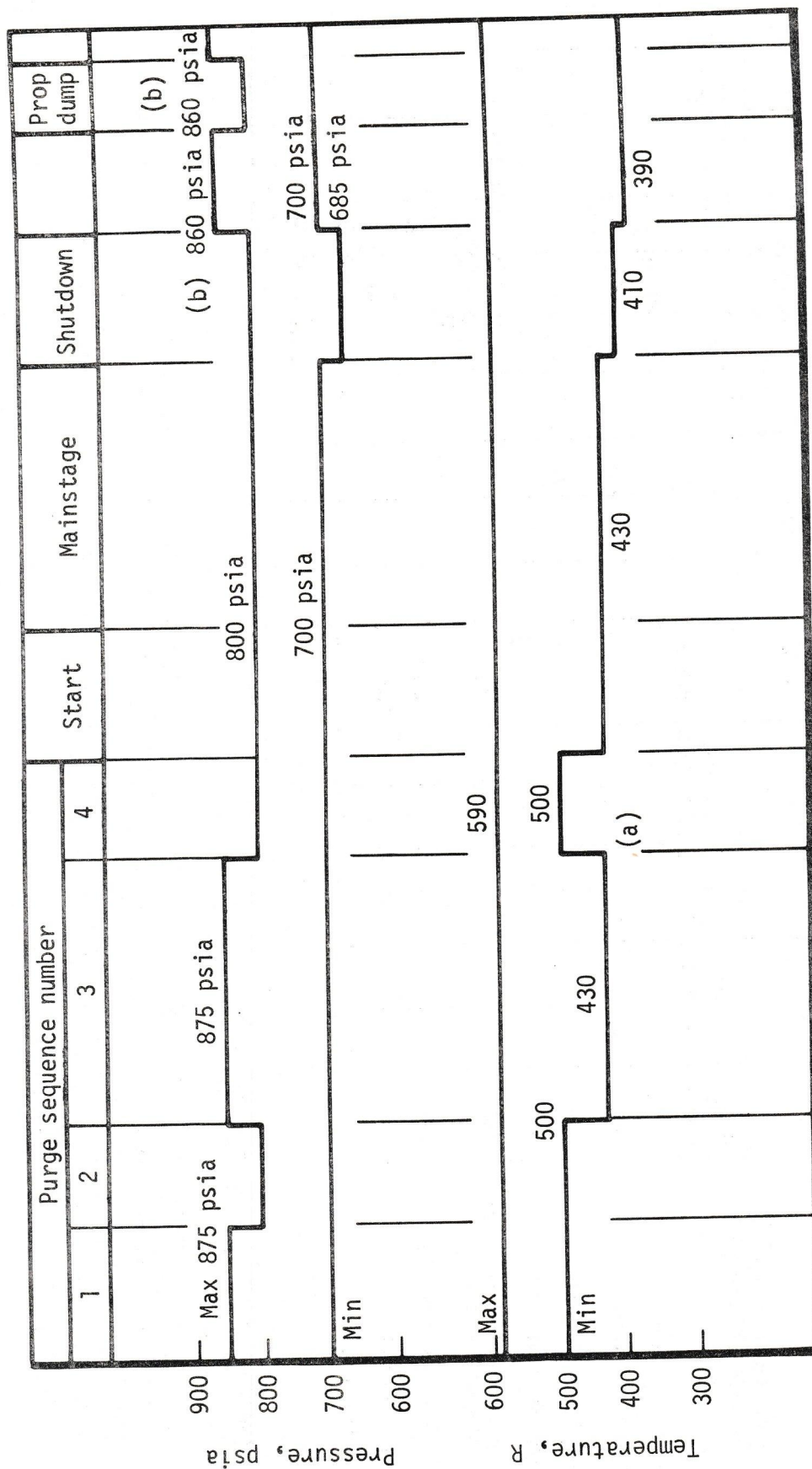
If additional helium is required to open and close the fill/drain valves, it can be obtained by opening the eight engine helium supply isolation valves and the three "out" interconnect valves. (Like the pneumatic helium isolation valves, these valves were also closed by the GPC at the end of the MPS LH2 dump.) The engine helium supply isolation valves are opened by placing their corresponding switches on panel R2 in the OPEN position. The "out" interconnect valves are opened by placing their corresponding switches on panel R2 in the IN CLOSE/OUT OPEN position.

Approximately 30 min will be required for vacuum inerting. At the end of this time period, the LO2 and LH2 outboard fill/drain valves will be closed. Following this, the helium isolation valves and interconnect valves will be closed using the appropriate switches on panel R2. The purpose of closing these valves is to ensure that the helium supply tanks are isolated from any leakage in the downstream lines during orbital operations. (Remember that helium is required to perform the MPS manifold repress prior to entry.)

3.5.2.6 Manifold repress.- Sometime during the early portion of the entry timeline, the propellant feedline manifolds and the ET pressurization lines will be repressurized with helium from the helium subsystem. This pressurization is required to prevent atmospheric contamination from being accidentally drawn into the manifolds and lines during entry. (Removing contamination from the manifolds or lines can be a long and costly process since it involves disassembly of the affected part.) Like vacuum inerting, manifold repress is a totally manual sequence and will be performed by the pilot.

Manifold repress is enabled by opening the LO2 and the LH2 manifold pressurization valves. These valves are controlled by switches on panel R4. Because of the location of panel R4, the pilot may not be able to reach switches on this panel while suited and strapped in his seat. For this reason, the LO2 and the LH2 manifold pressurization switches will be placed in their OPEN positions prior to crew strap-in. It should be noted

that opening the manifold pressurization valves only enables manifold repress. Later in the entry timeline, the pneumatic isolation valves will be opened to allow helium to flow through the manifold pressurization valves and into the feedline manifolds and pressurization lines. At that time, the engine helium isolation valves and the "out" interconnect valves will also be opened to ensure that there is sufficient helium to perform the repressurization. Because of overboard leakage through the SSME's, all of the helium subsystem valves which were opened during the manifold repress sequence will be left open until vehicle touchdown and rollout. In this way, any helium loss caused by the overboard leakage will be immediately replenished from the helium supply tanks.



a Temperature requirements of 430° R maintained through the first 30 sec of purge sequence no. 4.
 b For ground shutdown, values may reach 875 psia.

Figure 3.5-5.- The SSME helium requirements.

TABLE 3.5-1.- SSME PNEUMATIC REQUIREMENTS FOR FLIGHT

Purge sequence number Min. purge duration (min)	Pressure, psia ^h		Temperature, °F ^h		Flow, scfm ^h	Propellant drop		Start Shutdown		Reentry
	Design nominal	Interface variation	Design nominal	Interface variation		1	2	3	4	
Vehicle helium ^c										
Fuel system purge	750	See fig.	530	See fig.	130 ± 7					
Bleed valve actuation	750	2	530	2	2 ± 1					
Component fuel drain	750		530		265 ± 6					
High-pressure oxidizer pump intermediate seal	750		530		1050 ± 75					
Preburner shutdown purge ^j	750		530		550 ± 25					
Pogo suppression	750		530		9.5 ± 5 (f)					
Oxidizer inlets	17.7	(g)	530	±130						

^aIncludes the effects of hardware tolerances.

^bFor on-orbit propellant dump, the fuel system purge is initiated for 10-sec minimum subsequent to oxidizer dump and prior to initiation of fuel dump.

^cEngine helium consumption may include an additional 0.1 lb in the event that pneumatic shutdown is necessary.

^dThe engine pneumatic requirements during FRT are identical to the operation requirements except for purge sequence duration requirements.

^ePurge required prior to reaching an altitude of 100,000 ft during reentry.

^fFlow at ambient pressure of 14.7 psia.

^gPurge must ensure that the oxidizer feed system pressure is greater than local ambient pressure at all times, but not to exceed 50 psia.

^hDesign nominal parameters define the engine flow equivalent orifice area.

ⁱBleed valves closed at start enable signal before start.

^jPreburner shutdown purge is controlled by MEC and will not be applied during the period from start to start +2.0 sec.

TABLE 3.5-2.- HELIUM USAGE SCHEDULE

Usage	Mission			
	NOM, 1b	ATO, 1b	AOA, 1b	RTLS, 1b
Prelaunch (4000 psia, 580° R)	195.4	195.4	195.4	195.4
Fuel system purge (10 sec)	-0.7	-0.7	-0.7	-0.7
HPOT purge (10 sec)	-1.4	-1.4	-1.4	-1.4
Boost:				
Accumulator fill	-1.1	-1.1	-1.1	-1.1
HPOT purge	-77.2	-78.0	-75.5	-83.0
Redundant engine shutdown	-0.3	-0.2	-0.2	-0.2
P/B purge	-3.6	-2.4	-2.4	-2.4
Valve actuation	-1.5	-1.5	-1.5	-1.5
Helium system failure	0	-47.1	-48.3	-60.8
Mass remaining (at MECO + 16 sec)	109.6	63.0	64.3	44.3
Unusable residual (at MECO + 16 sec)	-67.1	-47.0	-47.0	-47.0
Design margin	+42.5	+16.0	+17.3	-2.7
Propellant dump:				
Feedline pressure	-9.2	-9.2	-9.2	-6.6
Feedline leakage	-0.1	-0.1	-0.1	-0.1
Fuel system purge	-0.6	-0.6	-0.6	--
Deorbit:				
Feedline repress	-5.2	-5.2	-5.2	--
Leakage	-26.7	-26.7	-26.7	--
Mission leakage	-5.0	-5.0	-0.7	--
Unusable residual (100 psia, 400° R)	-7.9	-5.4	-5.4	-5.4
Usable residual (at touchdown)	+54.9	+10.8	+16.4	+32.2

aSSME bottles at 925 psia, 440° R. MPS bottle at 1750 psia, 430° R.

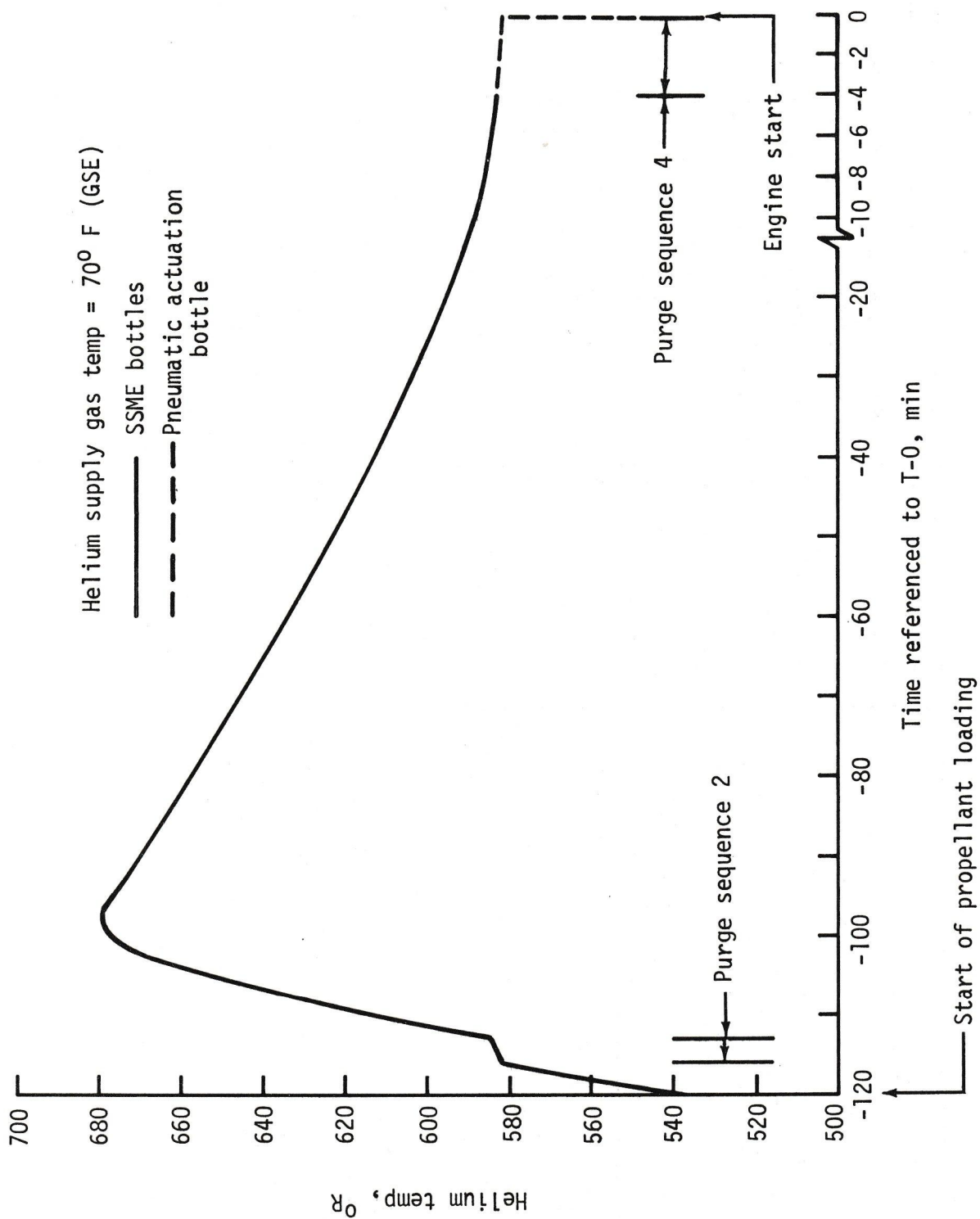


Figure 3.5-6.- Worst case helium storage temperature prediction.

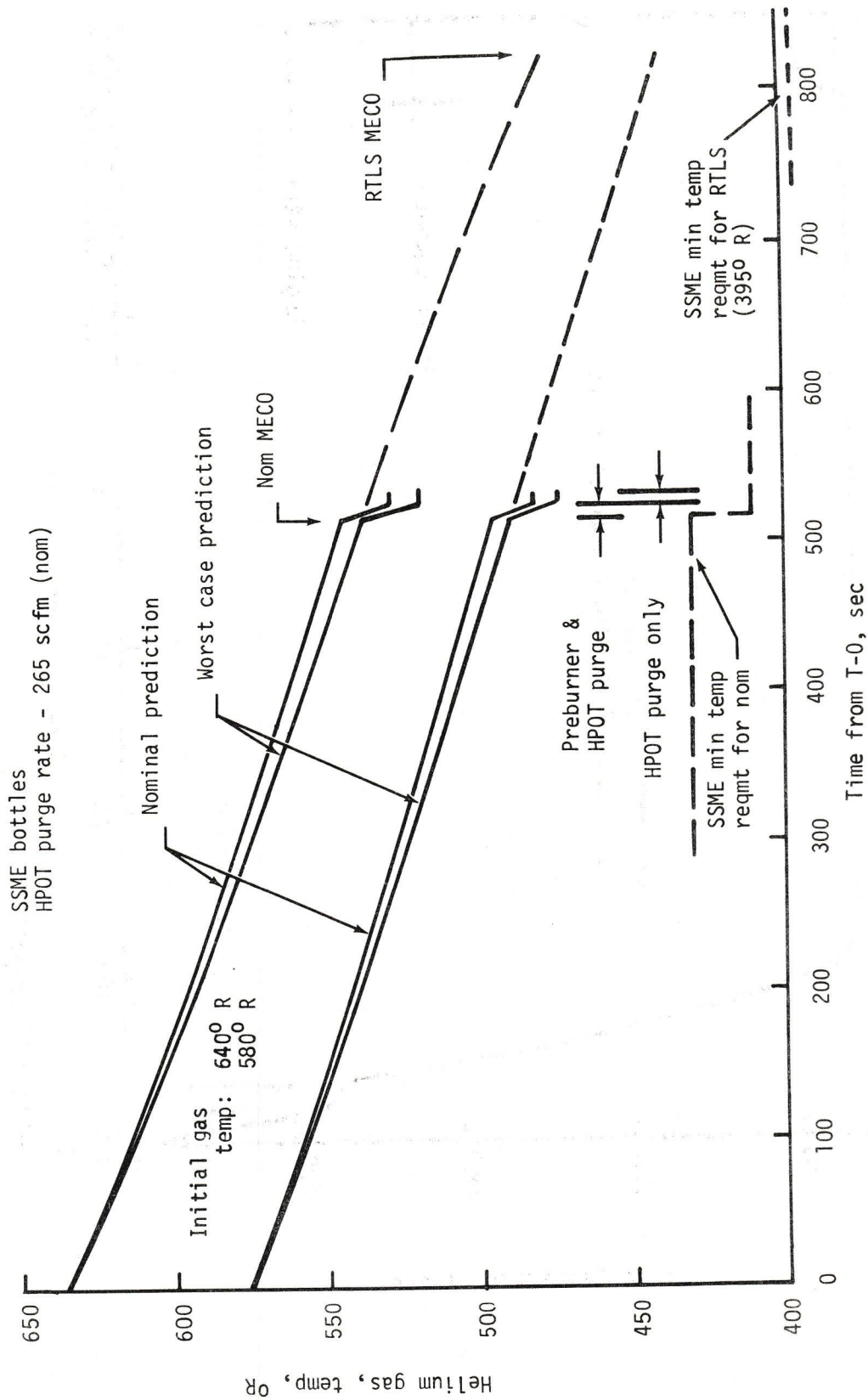


Figure 3.5-7.- Helium system storage bottle temperature history.

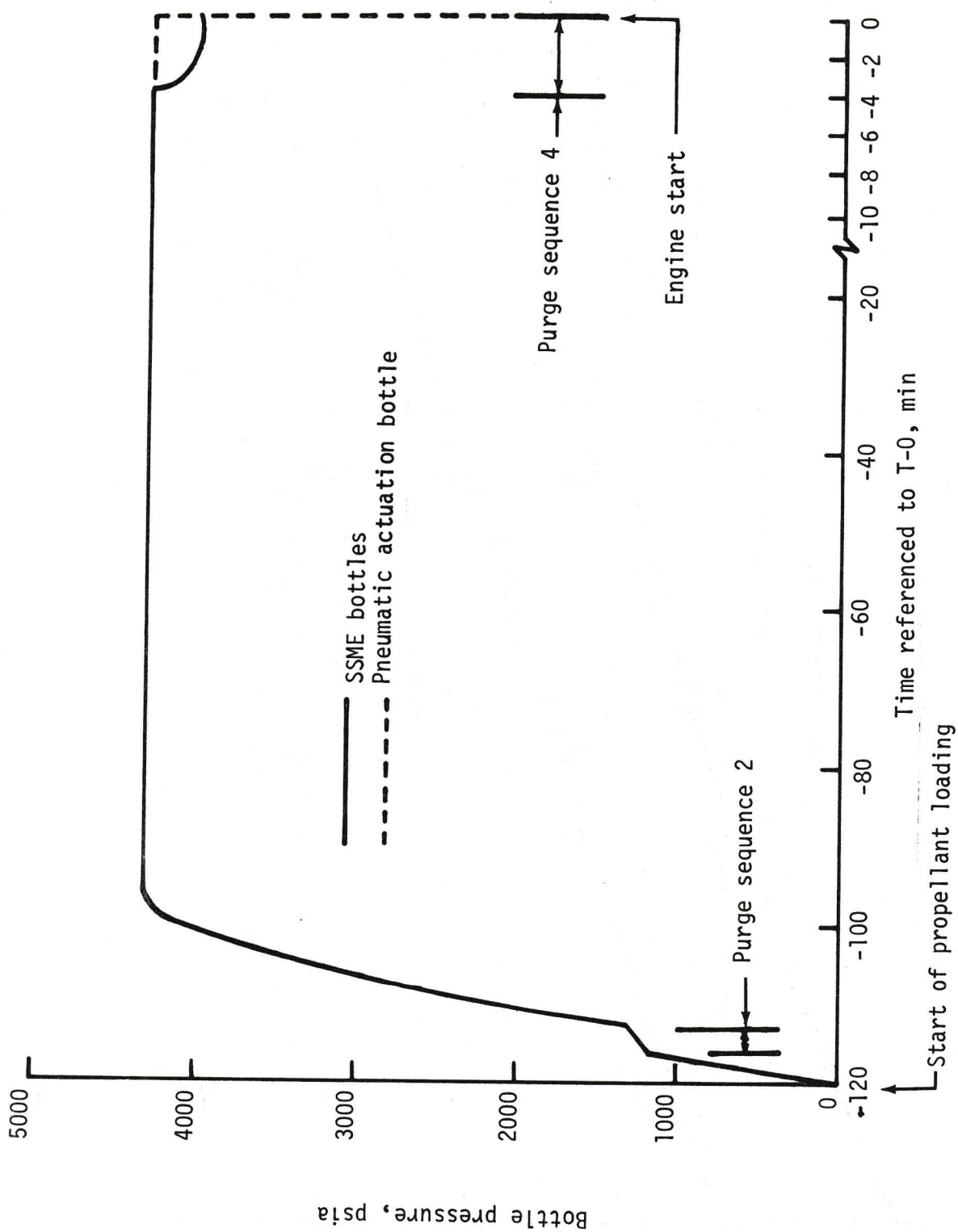


Figure 3.5-8.- Minimum helium storage pressure history.

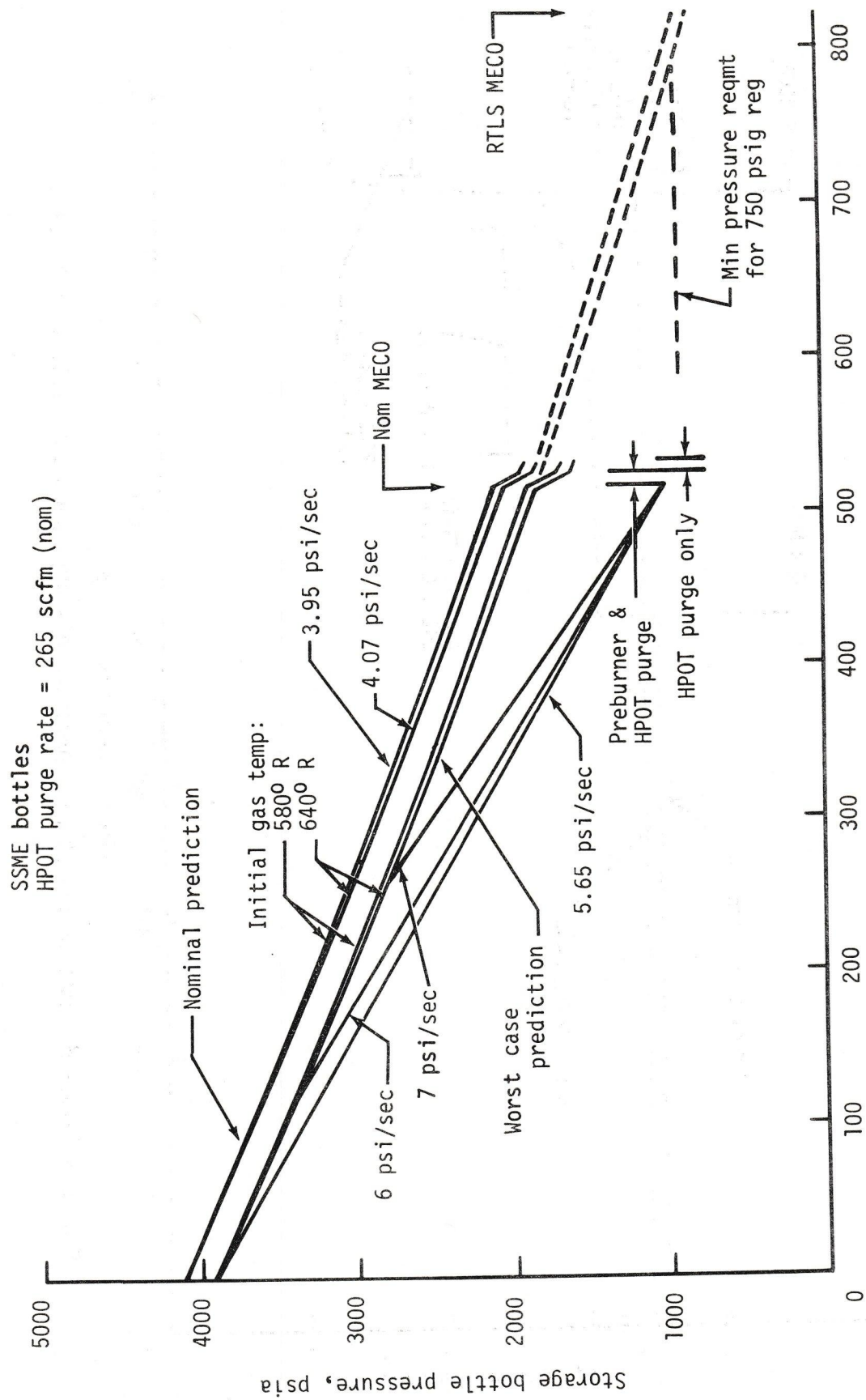


Figure 3.5-9.- Helium system storage bottle pressure history.

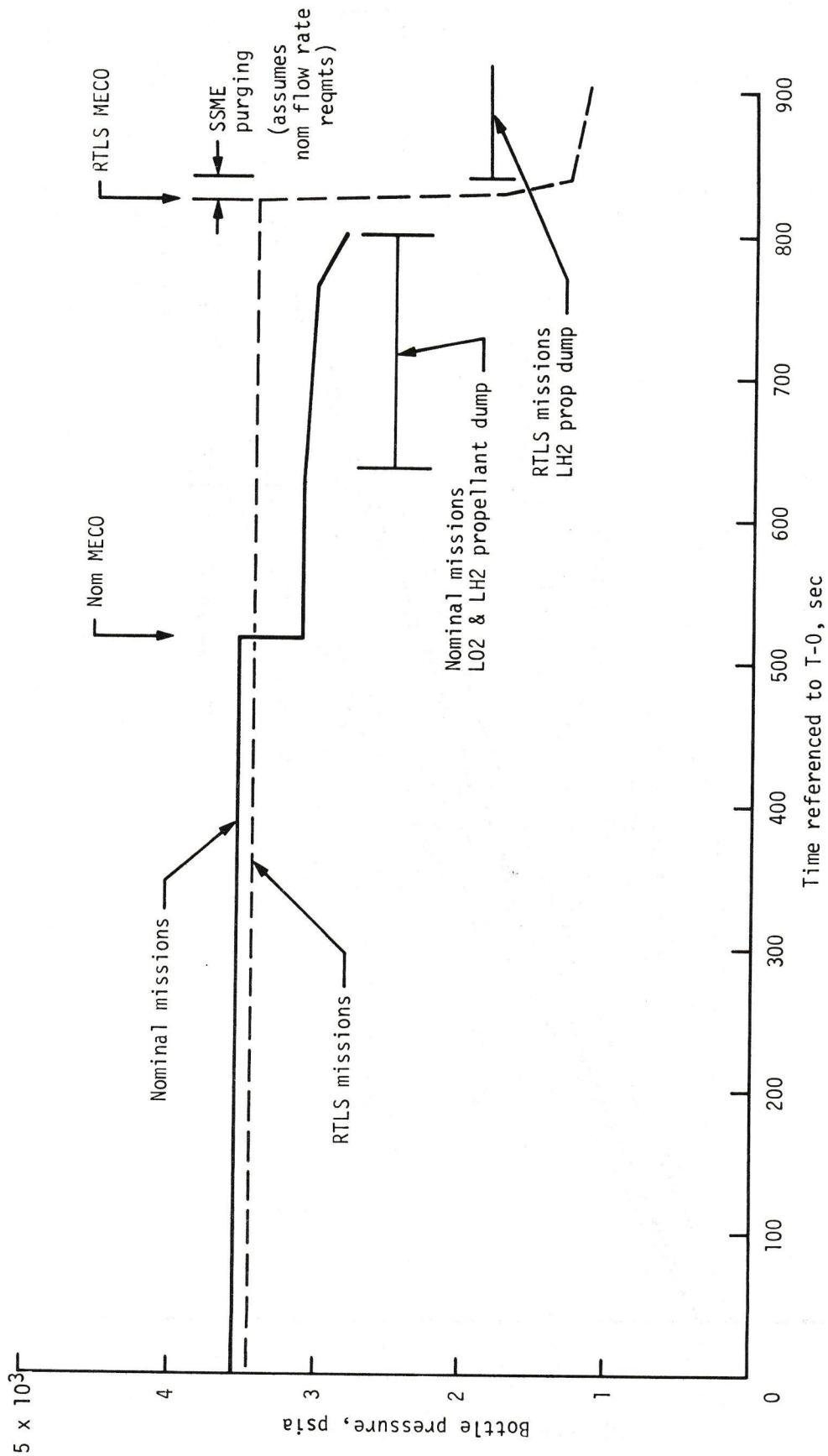


Figure 3.5-10.- Minimum helium storage pressure history, pneumatic actuation bottle.

3.6 THRUST VECTOR CONTROL

3.6.1 Purpose

The Thrust Vector Control (TVC) provides attitude control and trajectory shaping by gimbaling of the SSME's and SRB's.

3.6.2 TVC Major Subsystems

The major subsystems comprising TVC are the hydraulic servoactuator, Ascent Thrust Vector Control (ATVC), and the Main Propulsion System Thrust Vector Control Command Subsystem Operating Program (MPS TVC CMD SOP). The hydraulic servoactuators are the hardware subsystems which gimbal the main engines. There are two actuators per SSME: one for yaw motion and one for pitch motion. Each actuator is fastened to the Orbiter thrust structure and to the powerhead of one of the three SSME's. The ATVC is an avionics hardware package which provides gimbal commands and fault detection for each MPS hydraulic gimbal actuator. There are four ATVC's, each receiving position commands from the MPS TVC CMD SOP which resides in the GPC's. The MPS TVC CMD SOP is essential in processing the position commands before issuing these commands to each ATVC. Discussion of these subsystems follows in each of the subsequent sections.

3.6.3 TVC Subsystems

The major subsystems comprising TVC are:

- Six hydraulic servoactuators
- TVC SOP
- Four ATVC avionics boxes

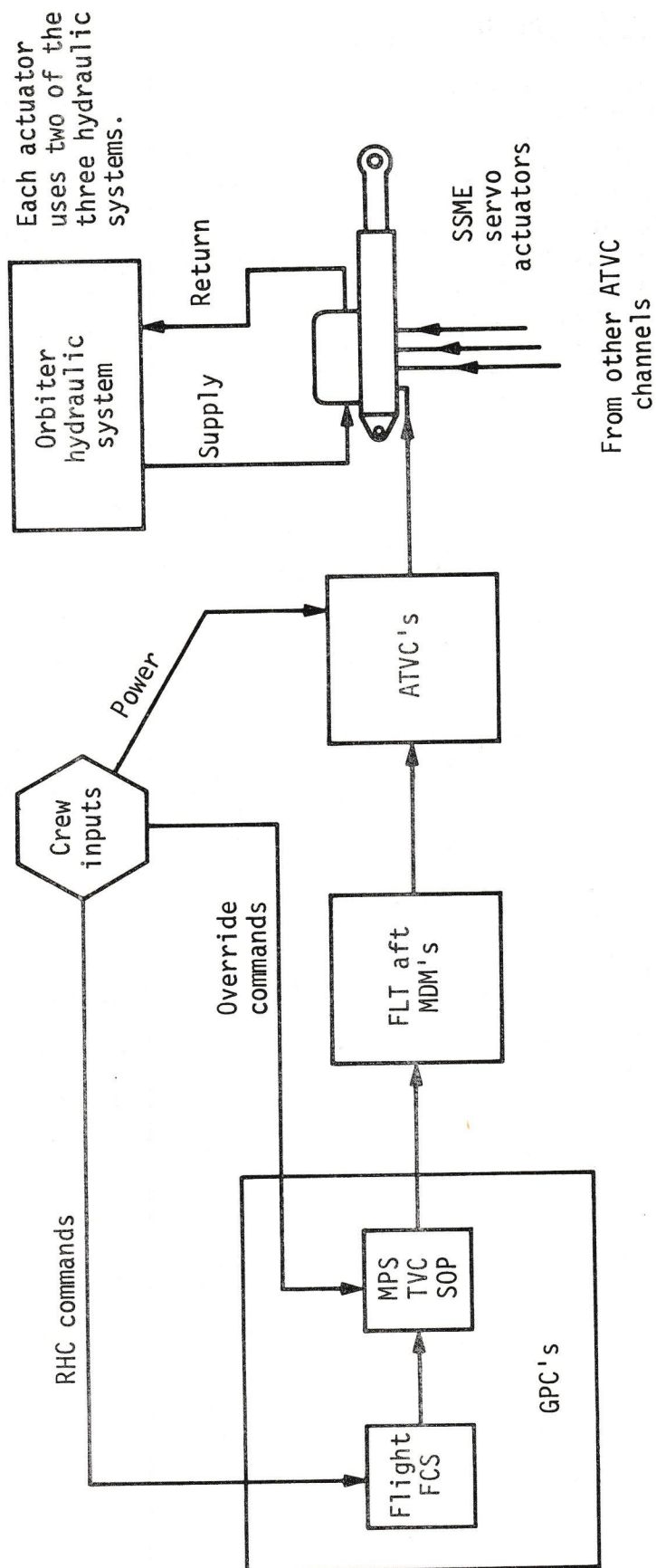
3.6.4 SSME TVC Interface Flow

The interfaces between the MPS TVC primary subsystems and other Orbiter systems (crew inputs and hydraulics) are shown in figure 3.6-1.

3.6.4.1 Command flow summary.- The MPS TVC command flow starts in the GPC where the Flight Control System (FCS) generates the TVC position commands, and is terminated at the SSME servoactuators where the actuators gimbal the SSME's in response to the commands. All the MPS TVC position commands generated by the FCS are issued to the MPS TVC CMD SOP where they are processed and disbursed to their corresponding Flight Aft Multiplexer-Demultiplexers (FA MDM). The FA MDM's separate these linear discrete commands and disburse them to the ATVC channel which generates equivalent command voltages for each command issued. These voltages are in turn sent to the servoactuators commanding the SSME hydraulic actuator to extend or retract gimbaling the main engine to which it is fastened.

3.6.4.2 Crew inputs.- Crew inputs fall into two categories - override commands and ATVC power. Override commands are issued to the MPS TVC CMD SOP residing in the GPC's. These commands inhibit any ATVC channel from activating its hydraulic actuator fault detection system. ATVC electrical power is supplied to all the ATVC channels by the crew through a series of four ATVC power switches and four FCS channel monitor switches.

3.6.4.3 Orbiter hydraulic system.- Each actuator uses two of the main hydraulic systems for hydraulic pressure to generate the force necessary to gimbal the main engines. One hydraulic system is used as a primary system and one as a secondary system (backup). Hydraulic pressure is supplied to the actuator and is returned to the Orbiter hydraulic supply while maintaining a working pressure of 3000 psig.



3.6-1.- The SSME TVC interface flow.

3.6.5 SSME Hydraulic Actuator Locations

Each SSME has two hydraulic actuators providing pitch and yaw gimbal capability for each main engine. Each actuator location in relation to the three main engines is shown in figure 3.6-2. Note that the left SSME pitch actuator is on the upper half of the pitch axis rather than the lower half, as with the other two main engines. The actuator orientation shown was developed to accommodate the amount of room in the Orbiter aft thrust structure. Each hydraulic actuator is fastened to the Orbiter thrust structure and to the main combustion chamber of its corresponding SSME. The pitch actuators are mounted perpendicular to the yaw actuators and gimbal the engines in relation to their axis (pitch gimbal up or down, and yaw gimbal left or right).

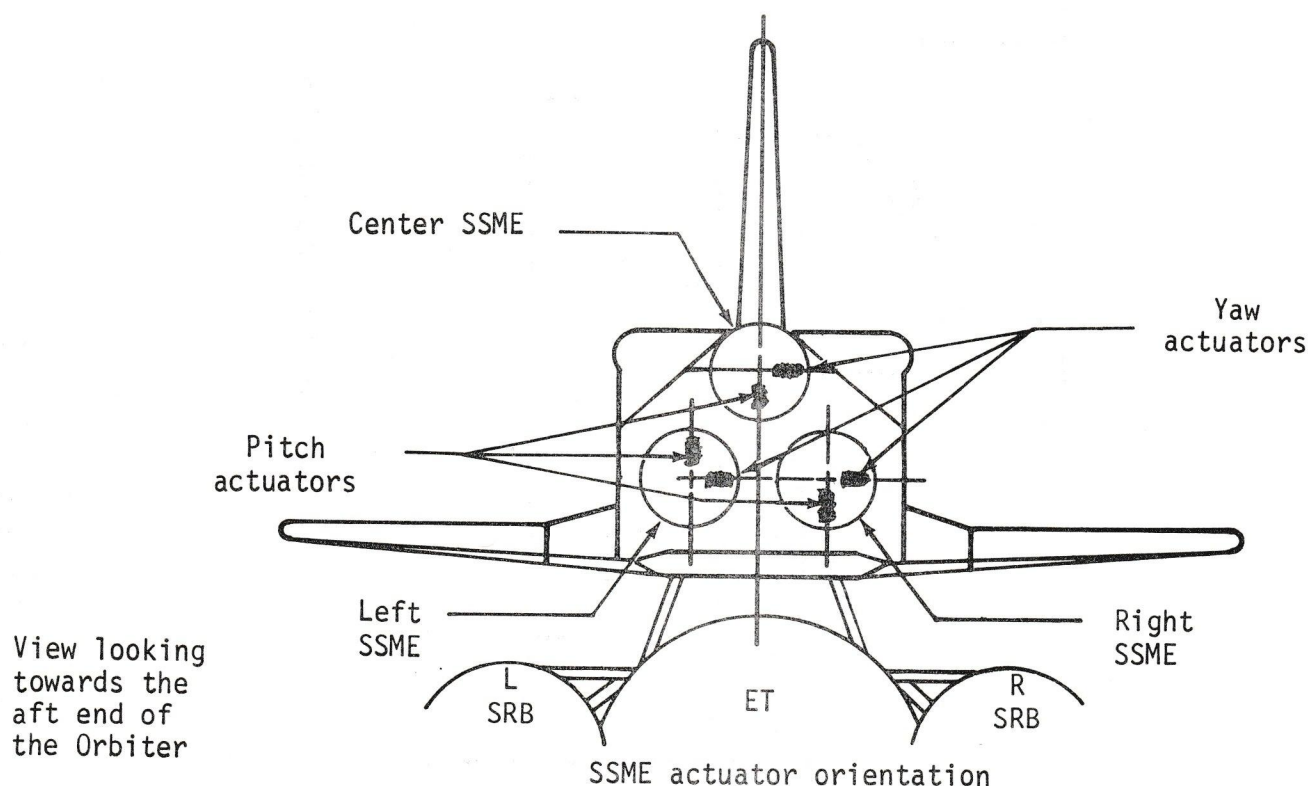
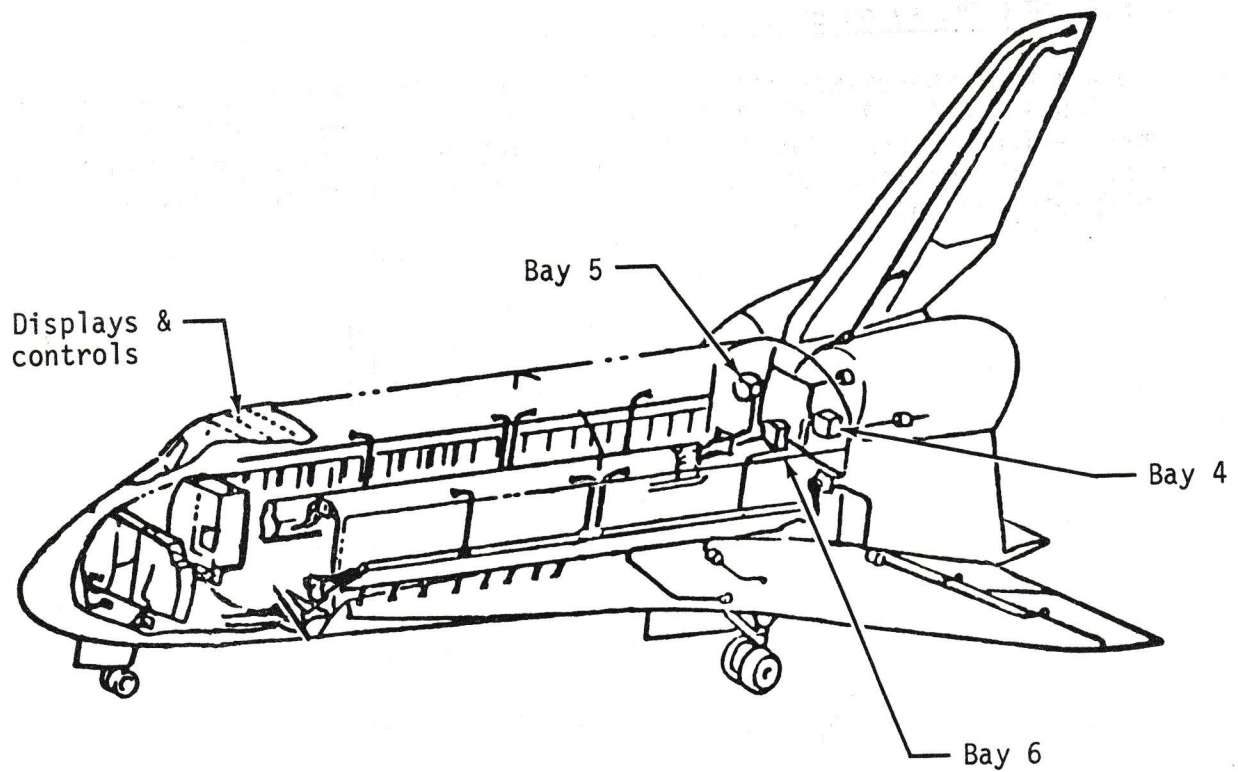


Figure 3.6-2.- The SSME gimbal actuator location.



The TVC avionics are located in avionics bays 4, 5, and 6. These bays are located in the aft end of the Orbiter.

Figure 3.6-3.- Location of Orbiter avionics bays.

3.6.6 MPS TVC Avionics Location

The avionics subsystems located in the three aft avionics bays are shown in figure 3.6-4. All MPS TVC avionics subsystems are located in these three avionics bays. The FA MDM's and ATVC "black boxes" are outlined in heavy black outline. Each MPS TVC avionics subsystem is cooled with coldplate cooling.

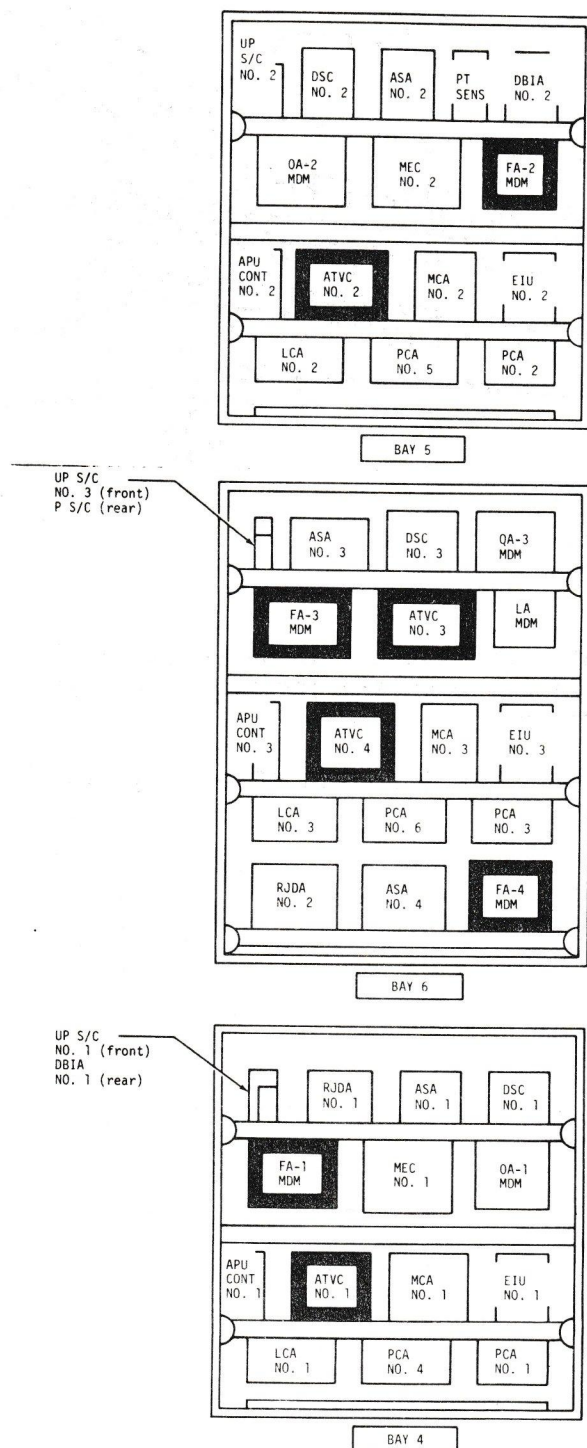


Figure 3.6-4.- Avionics bays 4, 5, and 6.

3.6.7 MPS Hydraulic System Distribution

In figure 3.6-1 it was shown that the SSME servoactuators interface with the Orbiter hydraulic system and that the actuators use two of the three Orbiter hydraulic systems; one system as a primary system and the other as a standby system. Figure 3.6-5 shows the MPS TVC hydraulic system distribution. The Orbiter hydraulic supply is distributed to all six SSME TVC actuators via three MPS/TVC isolation valves (one valve per hydraulic system). In order for the actuators to receive hydraulic pressure, these valves must be open. The valves are normally closed during on-orbit operation to protect against possible hydraulic leaks downstream of the isolation valves and also because there is no need to gimbal the main engines from a STOW position during on-orbit operation. Note that each actuator has its own hydraulic switching valve. The purpose of the switching valve is to receive hydraulic supply pressure (two of the three Orbiter hydraulic supplies), and provide a single source pressure to the actuator. Each switching valve receives a primary source and a secondary source. Normally, the primary supply is directed to the actuator, but if the system were to fail and lose hydraulic pressure, the switching valve would automatically switch over to the standby system and the actuator would continue to function on the standby system. Note that each pitch actuator and the main engine (engine valves) employ the same hydraulic supply pressure as a primary source of hydraulic pressure (table 3.6-1). Distribution of the hydraulic systems among the actuators and engine valves was done so as to equally distribute the hydraulic workload among the three hydraulic systems.

TABLE 3.6-1.- MPS HYDRAULIC SYSTEM DISTRIBUTION

Hydraulic system number	Left engine			Center engine			Right engine		
	Eng vlv	Pitch	Yaw	Eng vlv	Pitch	Yaw	Eng vlv	Pitch	Yaw
1		S1	P	P	P	S1			
2	P	P	S1					S1	P
3					S1	P	P	P	S1

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

P = Primary system

S1 = Standby system

3.6.8 Command Flow Overview

A complete overview of the command flow through all the MPS TVC subsystems is shown in figure 3.6-6. There are six MPS TVC actuators which respond to command voltages issued from four ATVC channels. Each ATVC channel has six MPS drivers and four SRB drivers which have identical avionics (note ATVC 1). They convert any analog command issued by its corresponding MDM into an equivalent command voltage and issue it to their hydraulic actuator. Note that each actuator receives four identical command voltages from four different MPS drivers, each located in different ATVC channels. The SRB TVC command flow is discussed in the SFOM, Vol. 8B, SRB.

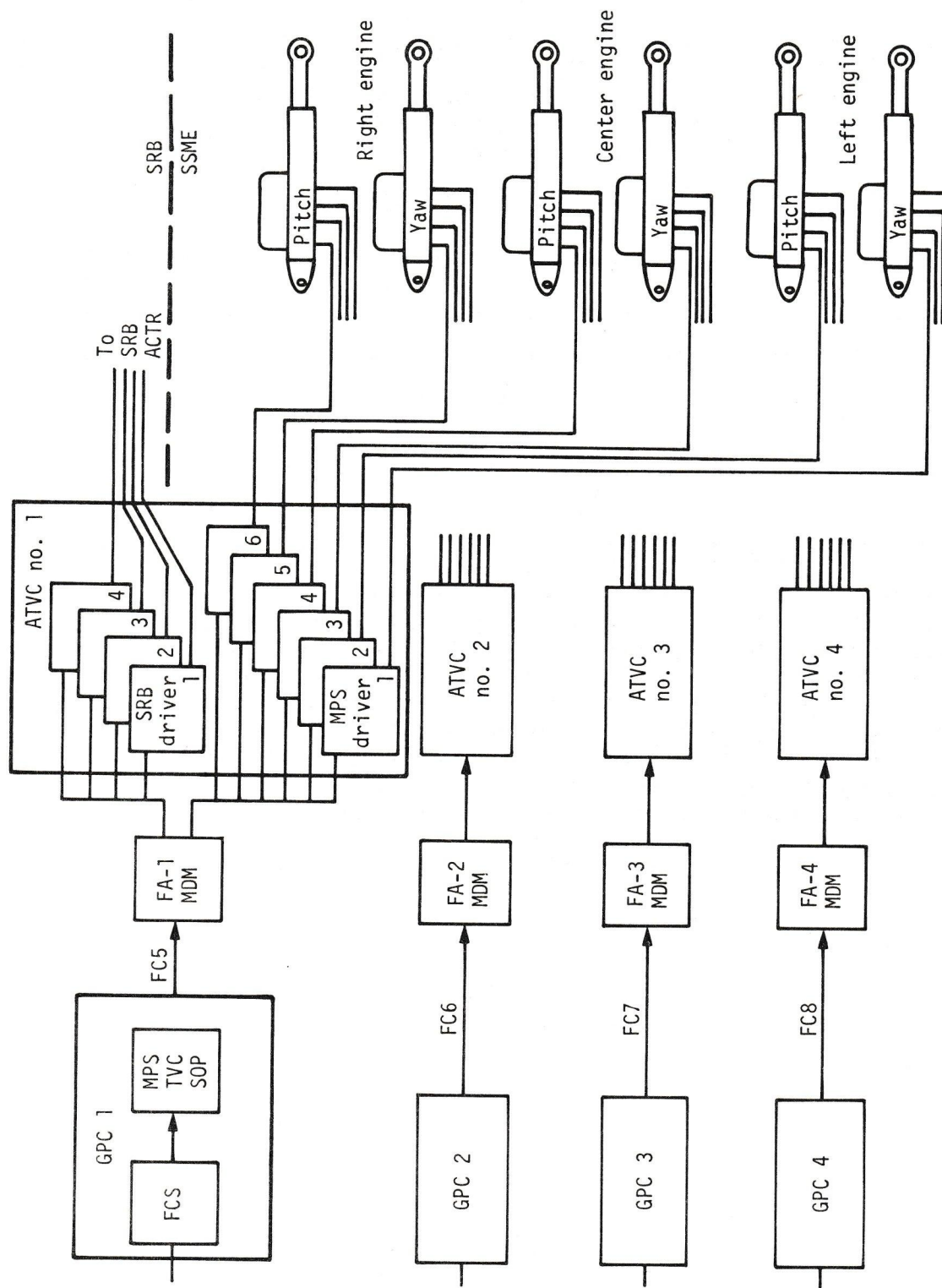


Figure 3.6-6.- Command flow overview.

3.6.9 Typical SSME Actuator (Servoactuator Subsystems)

Each SSME actuator is comprised of four servovalves, one secondary actuator, one primary actuator, and a switching valve (fig. 3.6-7). The primary actuator (cylinder and piston/ram) moves the SSME in response to command hydraulic pressure from the secondary force-sum actuator. The primary actuator sends primary hydraulic pressure data to the Development Flight Instrumentation (DFI) and actuates a mechanical position feedback which is linked to the four servovalves. The secondary force-sum actuator (power valve) routes the hydraulic source pressure to the primary actuator, causing it to extend or retract in response to the sum of the servovalve commands (command pressure). Each of four servovalves (secondary actuators) receives position commands and converts them to a proportional hydraulic command pressure to position the secondary force-sum actuator. The servovalves each have a hydraulic pressure transducer used to measure the hydraulic resistance pressure the servovalves exert on each other. These resistance pressures are generated at the secondary force-sum actuator where all four servovalve command pressures are summed to drive the power spool.

The switching valve (not shown in fig. 3.6-7) provides source hydraulic pressure from a selected hydraulic system. The secondary hydraulic pressure data for each servovalve are sent to the servovalve's corresponding ATVC for processing. If the hydraulic pressure exceeds a 2200-psig limit for more than 120 msec, an isolation command will be issued, removing that servovalve from operation.

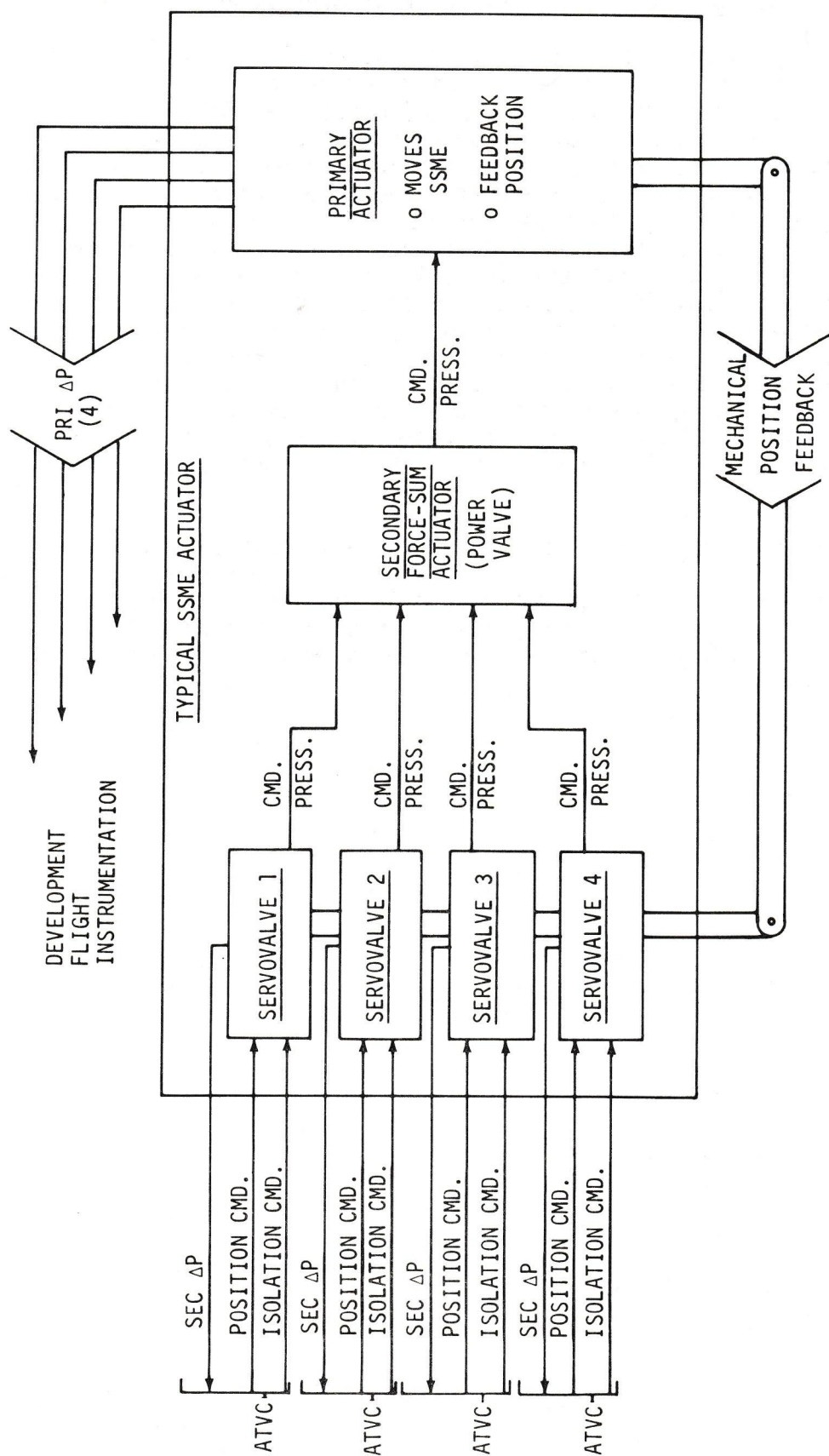


Figure 3.6-7.- Typical SSME actuator.

3.6.10 SSME Actuator Operational Characteristics

Each of the six SSME servoactuators is designed to produce linear motion to gimbal an SSME in either a pitch axis or a yaw axis. The servoactuators employed receive four separate position commands and convert them to an equivalent hydraulic pressure which drives a main ram that is fastened to an SSME. Figure 3.6-8 shows a simplified schematic of the SSME hydraulic servoactuator general arrangement. Each actuator has a main ram assembly which is fastened to the powerhead of an SSME. The actuator ram, which is mounted to the large piston 1, is hydraulically driven by a primary hydraulic pressure imbalance on either side of the large piston. The ram shuttles in a linear motion, either extending or retracting. The power spool 2, is what determines whether the actuator ram will extend or retract and how much it will move. The power spool generates the primary hydraulic pressure imbalance by shuttling in a linear motion, causing primary hydraulic pressure to flow on either the back side or front side of the large piston. The power spool is hydraulically driven by four servovalves 3, taking a command from an ATVC driver and converting it to an equivalent secondary hydraulic pressure. The sum of the secondary hydraulic forces generated by the servovalves drives the power spool. Each servovalve assembly has its own secondary ΔP transducer which measures the secondary hydraulic resistance that servovalve generates relative to its three counterparts. If the measured secondary hydraulic pressure becomes excessively high, an isolation valve (connected to each servovalve) will isolate the failed servovalve from operation.

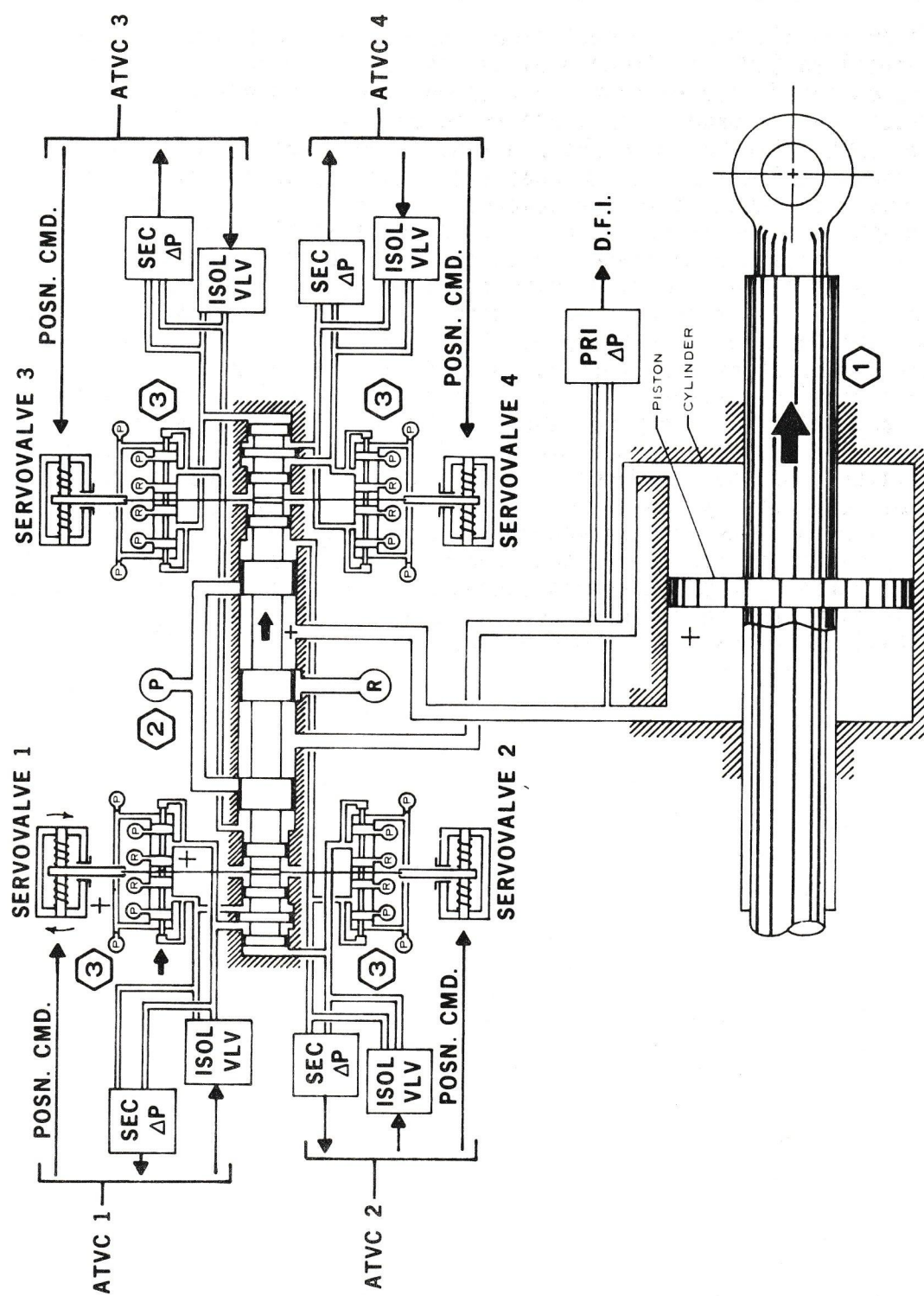


Figure 3.6-8.- Typical actuator.

3.6.11 SSME Servoactuator Orientation

The main function of the SSME servoactuators is to change each SSME's thrust vector direction as needed during the flight sequence of the Orbiter. The three pitch actuators can gimbal the main engines up or down $10^{\circ}30'$ maximum from the installed null position (fig. 3.6-8), and the yaw actuators can gimbal the main engines left or right $8^{\circ}30'$ maximum from the installed null position (fig. 3.5-9). The installed null position for the left and right main engines is $10^{\circ}00'$ up from the X-axis in a -Z direction, and $3^{\circ}30'$ outboard from an engine center line parallel to the X-axis. The center engine's installed null position is $16^{\circ}00'$ above the X-axis for pitch, and right on the X-axis for yaw. When any engine is in an installed null position, the other engines cannot have an engine-to-engine collision with that engine.

Gimbal rate is 10 deg/sec minimum, 20 deg/sec maximum. Gimbal acceleration is 45 deg/sec² minimum, 1719 deg/sec² maximum (Shuttle Operational Data Book, Vol. 1, Rev A).

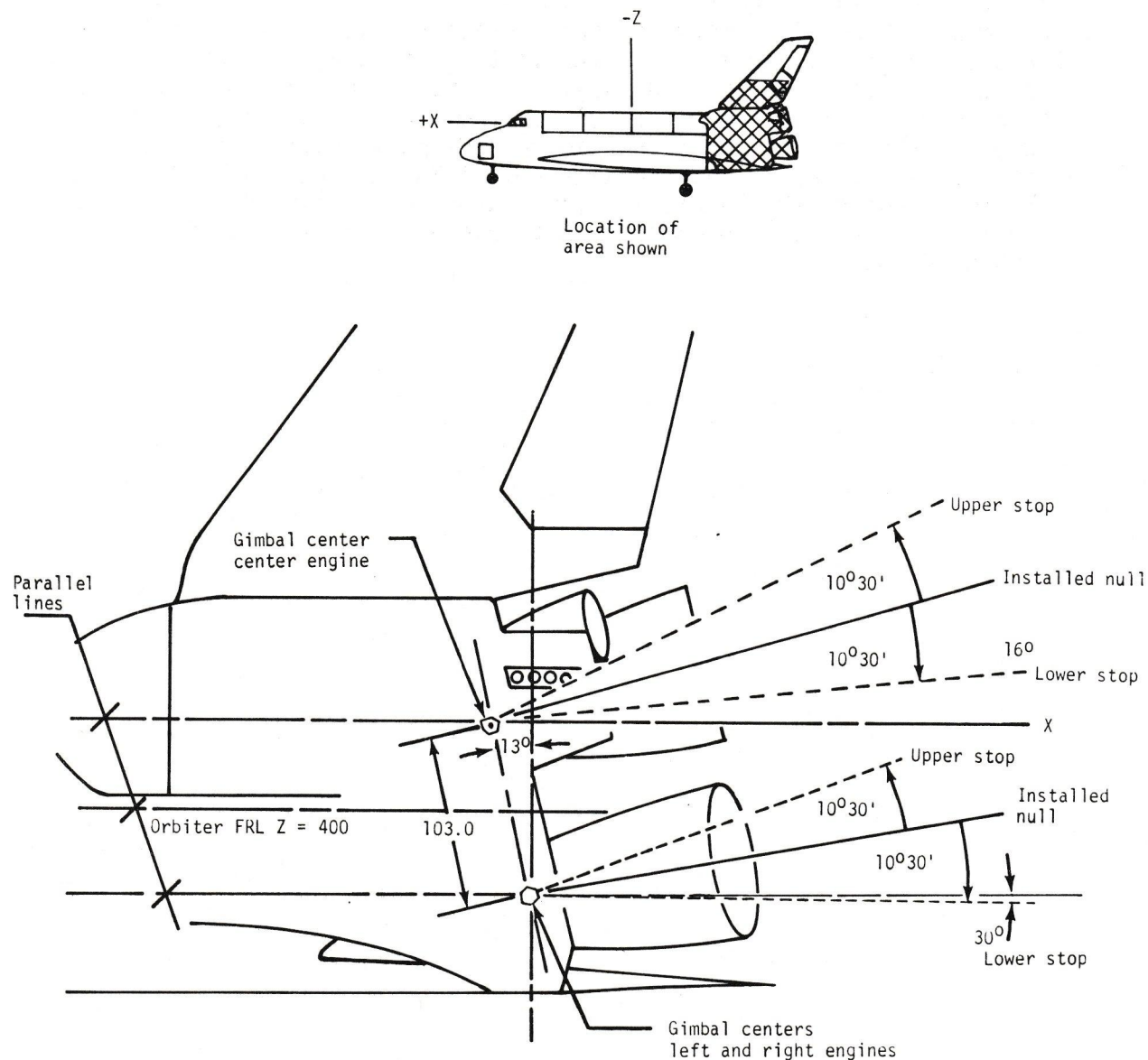


Figure 3.6-9.- The SSME gimbal pitch axis.

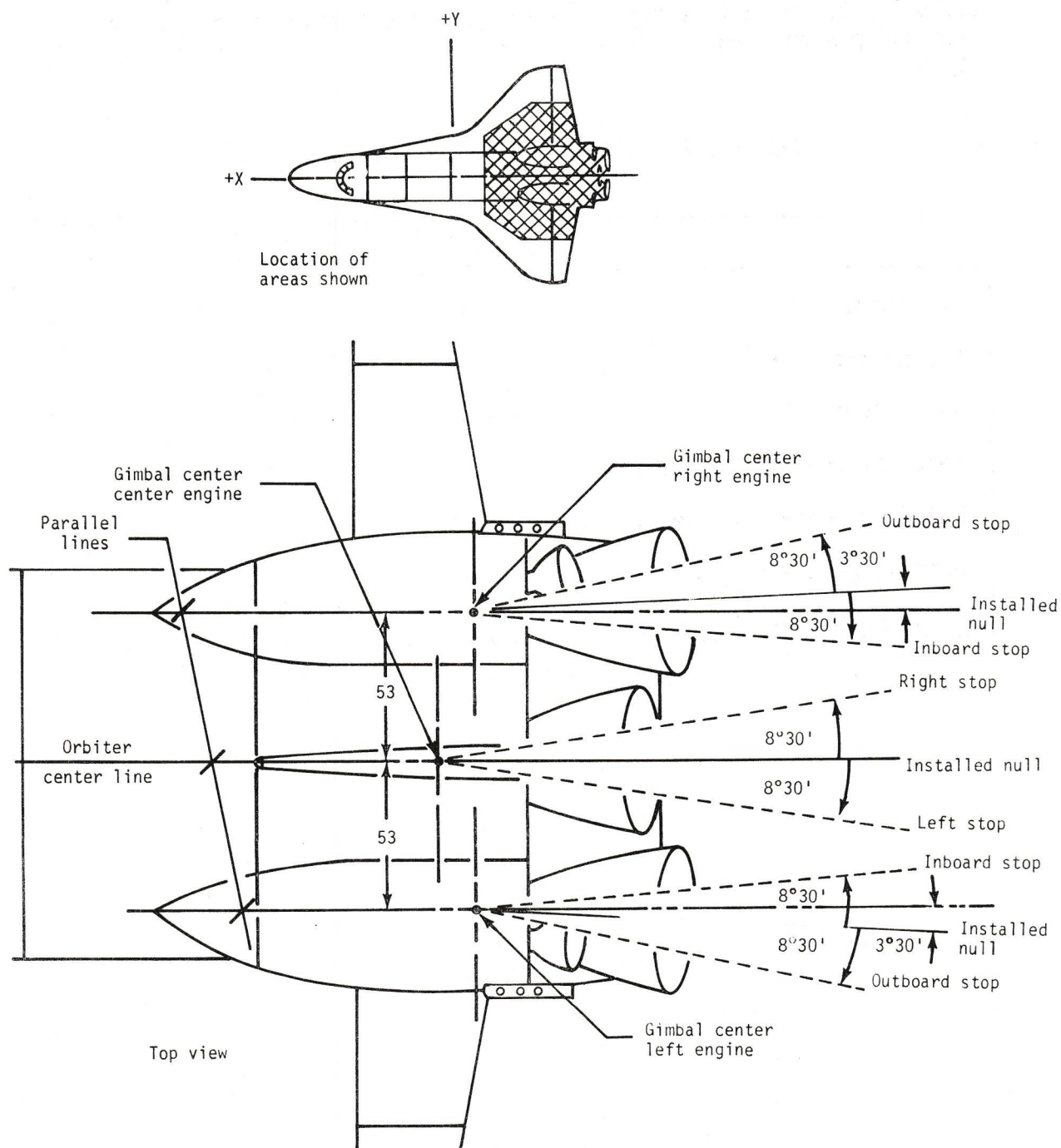


Figure 3.6-10.- The SSME gimbal yaw axis.

The design specifications for the SSME gimbal actuators are listed in table 3.5-2. Note that the center engine pitch actuator has a larger rated load and piston area. This is to compensate for aeroloads on the center engine.

TABLE 3.6-2.- ACTUATOR PHYSICAL CHARACTERISTICS

	Center engine pitch	Left & right engine pitch	Yaw
Actuators vehicle	1	2	3
Piston area, in. ²	24.8	20.0	20.0
Rated load, lb	48,200	38,900	38,900
Total stroke, in.	10.8	10.8	8.8
Rated velocity, in./sec . . .	5.7	5.7	5.7
Approx. peak flow, gpm . . .	50	45	45
Actuator weight, lb	263	245	240

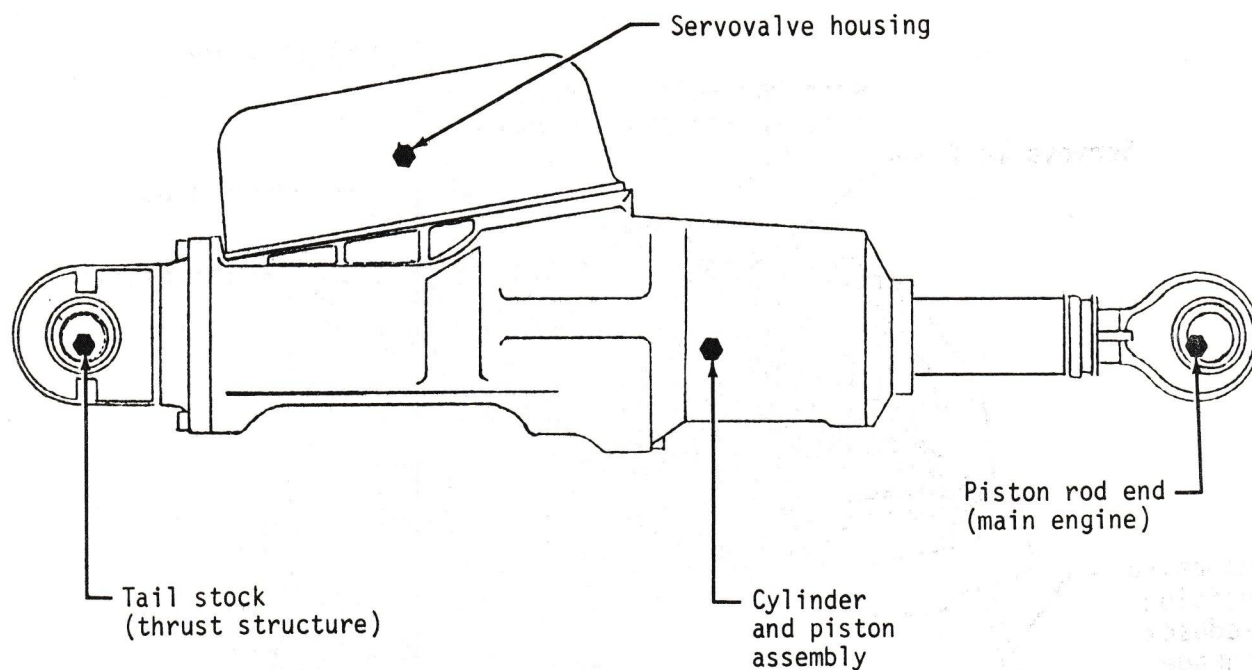


Figure 3.6-11.- Main engine electrohydraulic servoactuator (exterior physical characteristics).

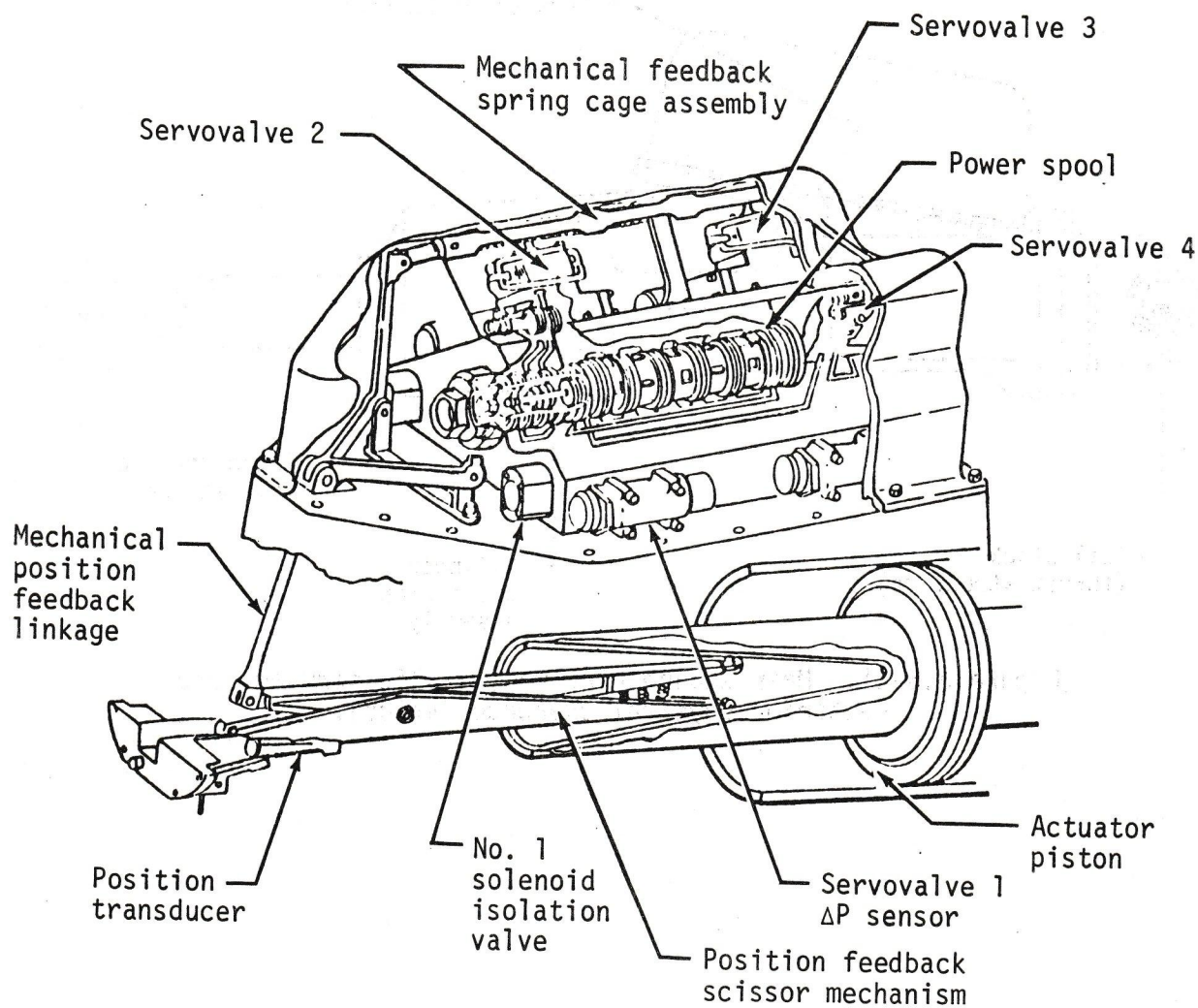


Figure 3.6-12.- Typical actuator assembly.

3.6.12 ATVC Command Processing

Figure 3.5-11 shows the path for a position command through one ATVC driver going to the actuator servovalve which that driver controls. The output of the MPS TVC CMD SOP goes to the Electrohydraulic (EH) valve driver in the ATVC driver. The output of the EH valve driver goes to the EH servovalve which is the actuator port. The EH valve works in conjunction with the other three ports to effect the desired command. Feedback to the EH valve driver is provided by the redundant channel equalization logic, which monitors the secondary ΔP . If the ΔP is greater than ± 1175 psi, then:

- A Δ voltage is applied to the actuator command through a summer in the EH valve driver.
- The Δ voltage reduces the actuator command which, in turn, reduces the ΔP .
- The Δ voltage is applied slowly, reaching its full value in 8 sec.

There is no crew indication of commands.

3.6.13 ATVC Fault Detection

The fault detection and response performed by the ATVC is shown in figure 3.6-11. Secondary ΔP is monitored by ΔP fault detection logic. If the secondary ΔP is greater than or equal to ± 2200 psi for 120 msec or longer, the output of the ΔP fault detection logic will turn on the isolation valve driver, energizing the isolation valve on the actuator. The isolation valve equalizes pressure on both sides of the hydraulic supply, thus allowing the EH valve to float and offer no resistance to changes in actuator position. This condition is called a popped port. Popped ports can also occur if the ATVC power supply (which powers everything but the isolation valve driver) fails. Port popping allows the remaining ports to move the power spool without causing secondary hydraulic force fights, and will occur only if the FCS channel switch on panel C3 is in AUTO for that ATVC channel. Port popping will result in:

- A class 2 alarm.
- System FCS CH (1, 2, 3, 4) CRT message.
- A down arrow under the FCS channel for MPS on the GNC SYS SUMM 1 CRT display.
- A backup C&W light.

Port popping can also be performed by FCS channel SW-OFF (ATVC SW-ON) for that ATVC channel. This step will isolate all corresponding ports on the MPS and SRB actuators. This results in down arrows for the MPS and SRB servovalves for that ATVC channel on the GNC SYS SUMM 1 CRT display.

3.6.14 Override Commands

The effects of override commands are shown in fig. 3.6-11. Override commands are used to prevent port popping. Override commands are used to override the ΔP fault detection logic, and must be present for at least

120 msec in order to take effect. The override command inhibits the ΔP fault detection logic from applying power to the isolation valve driver. If a port is already popped (isolated), the override inhibit in the ΔP fault detection logic will remove power from the isolation valve driver. Presence of an override inhibit in the ΔP fault detection logic will remove any down arrows from the GNC SYS SUMM 1 CRT display. Removal of the override command will not restore an isolated EH servovalve unless the secondary ΔP is less than ± 2200 psi.

Override commands are generated by:

- The ~~Range Safety~~ ^{Redundant Set} (R/S) launch sequence to prevent port popping during ignition transients.
- The SSME SOP during the main engine shutdown phase.
- The FCS channel switches, whenever a crewman places the switch to override.

Note: Placing FCS CH (1, 2, 3, 4) switch in override positions causes corresponding override status for that channel.

3.6.15 Bypass Monitor Short

Each ATVC MPS and SRB driver has a bypass monitor which was designed to activate the isolation valve driver in response to an item entry through the keyboard by the crew. Due to design modifications, it is not possible for the crew to perform an item entry relative to the bypass monitor logic. Therefore, the crew cannot isolate any individual EH valve for MPS and SRB channels.

If an MDM were to fail, the channels wired to the bypass monitor could possibly fail, generating a signal (short) which could activate the bypass monitor. This would isolate the EH valve pertaining to the driver. If this occurs, there is no way to remove the faulty bypass command through an item entry or through the override monitor.

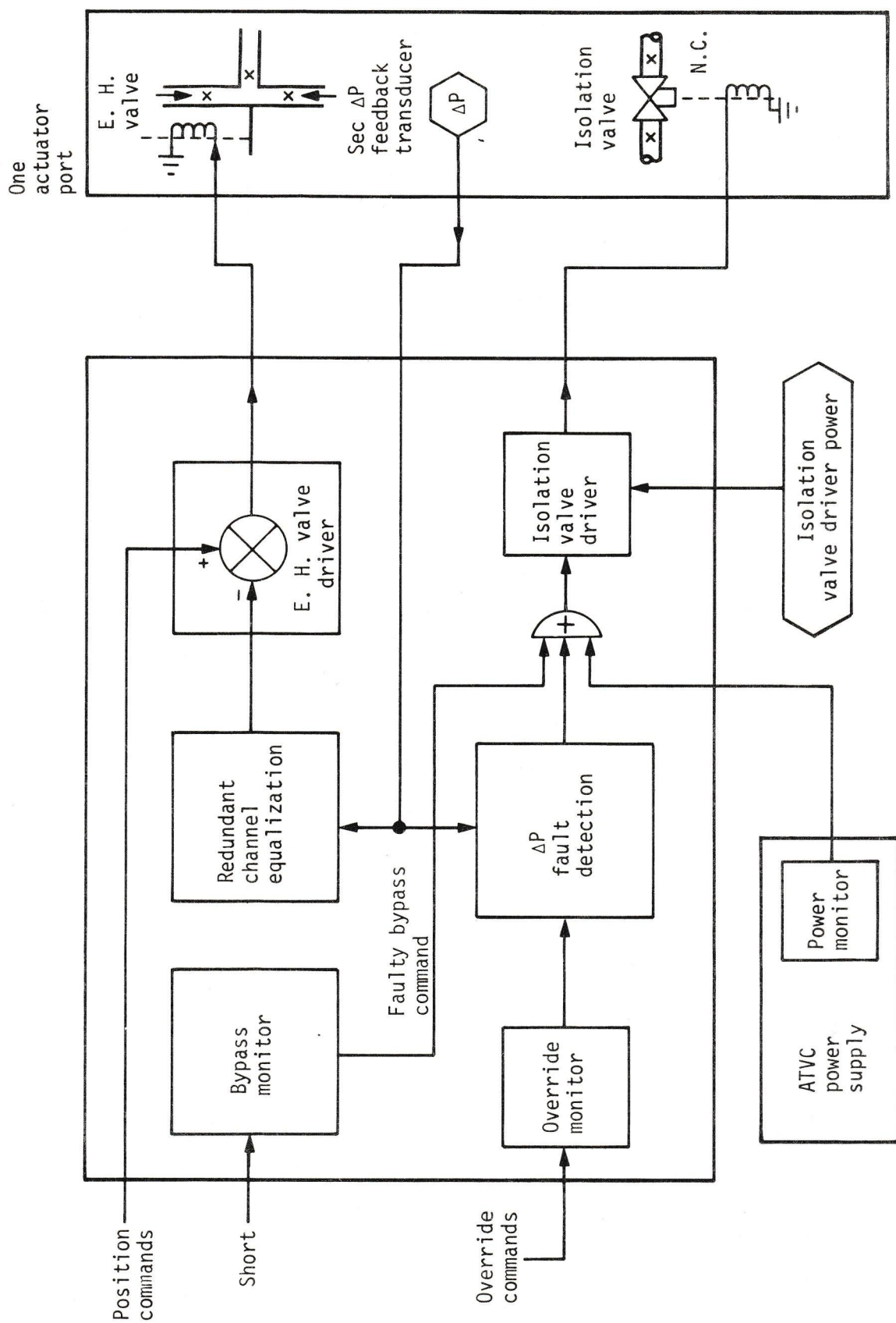


Figure 3.6-13.- The MPS ATVC driver.

SECTION 4.0 MALFUNCTION DETECTION

There are three separate means of detecting malfunctions within the MPS:

- Main engine controller
- Caution and warning system
- GPC

4.1 MAIN ENGINE CONTROLLER-DETECTED MALFUNCTION

The Main Engine Controller (MEC), through its network of sensors, has access to numerous engine operating parameters. A group of these parameters have been designated as critical operating parameters and for these parameters special limits have been defined. These limits are outlined in section 4.2.

Operating outside these limits can cause significant engine damage and jeopardize crew safety. Because of the rapidity with which it is possible to exceed these limits, the engine controller has been programmed to sense the limits and automatically cut off the engine if the limits are exceeded. In addition, the engine controller will signal the GPC, via certain bits in the engine status word, that an operating limit has been violated. The GPC will then illuminate, in red, the upper half of the corresponding MAIN ENGINE STATUS light on panel F7. Although a shutdown as a result of an operating limit violation is normally automatic, the crew can, if necessary, inhibit an automatic shutdown through the use of the LIMIT SHUT DN switch on panel C3.

The LIMIT SHUT DN switch has three positions: ENABLE, AUTO, and INHIBIT. The ENABLE position allows any engine which violates operating limits to be shut down automatically. The AUTO position allows only the first engine which violates operating limits to be shut down automatically; if either of the two remaining engines subsequently violates operating limits, it will be inhibited from automatic shutdown. The INHIBIT position inhibits all automatic shutdowns. (Note, however, that in all cases the red status lights will still indicate out-of-limits conditions.)

The MEC also has a self-test feature whereby it can detect certain malfunctions involving its own sensors and control devices (table 4-2). This class of malfunction is considered somewhat less critical than the operating limit violations discussed previously and for this reason, there is no automatic shutdown associated with these failures. For each of the three engines, this type of failure will be indicated to the crew by the illumination, in amber, of the lower half of its corresponding MAIN ENGINE STATUS light on panel F7.

4.1.1 Critical Operating Parameters and Their Limits

The following conditions will illuminate the red status light, and if limit shutdown is enabled, cut off the engine.

1. High-pressure oxidizer turbine discharge temperature: none, 1900°
limits shown are wrong
2. ~~Main combustion chamber pressure:~~ *R. High-Pressure Fuel turbine discharge T* 1000 psia, none.
3. High-pressure oxidizer turbopump intermediate seal purge pressure: 170 psia, 650 psia.
4. High pressure oxidizer turbopump secondary seal purge: 5 psia, 85 psia.
5. ~~Flight Acceleration Safety Cutoff System (FASCOS):~~ *High Pressure Fuel Pump Coolant Line Pressure* 10g.

In addition to these limit shutdown parameters, indication of shutdown or post shutdown phase in the engine status word will illuminate all three red status lights.

4.1.2 Conditions Which Will Illuminate Amber Engine Status Light

1. For each of the two parameters below, loss of data from both pairs of its four sensors will illuminate the amber engine status light. This failure will result in an electronic hold condition for the affected SSME. Each parameter has four sensors grouped in two pairs. To fail both pairs, it is only necessary to fail one sensor from each pair.
 - A. Fuel flow rate
 - B. Pc sensors
2. Hydraulic lockup.
3. Command path failure; loss of two or more command channels to the engine or command reject.
4. Loss of both data channels from the engine controller.

Conditions 1A and 1B will result in an electronic hold of all propellant valve actuators on the affected engine. In an electronic hold, the actuators are electronically maintained in the positions existing at the time of the second sensor failure. In addition, the engine controller of the affected engine will signal the GPC's, via certain bits in the appropriate engine status word, that an electronic hold is in effect.

It should be noted that in the case of either a hydraulic lockup or an electronic hold, all engine throttling capability for the affected engine is lost; subsequent throttling commands to that engine will not change the thrust level.

4.2 CAUTION AND WARNING SYSTEM-DETECTED MALFUNCTION

Certain critical Orbiter MPS telemetry parameters are hardwired to the Caution and Warning (C&W) systems. These parameters are limit-sensed within the C&W system. If a violation of any of the limits is detected, the C&W system will illuminate the red MPS indicator on the C&W panel.

Table 4-1 is a list of the MPS telemetry parameters which are limit-sensed by the C&W system, with their respective limits.

The MPS C&W indicator has special significance for the crew, since a number of the conditions defined above will require crew action. For example: An MPS engine LH2 manifold pressure below the minimum setting will require the crew to pressurize the external LH2 tank with the H2 ULLAGE PRESSURIZATION switch (panel R2). A low helium pressure may require the crew to interconnect the pneumatics helium tank and the engine helium tanks, using the He INTERCONNECT valve switches on panel R2 for whichever engine helium system is affected.

4.3 GPC-DETECTED MALFUNCTION

The Guidance, Navigation, and Control (GN&C) major function in the GPC's has the capability to detect certain specified out-of-limit or fault conditions of the Main Propulsion System (MPS). This capability is achieved within the GN&C software by defining limits and checking for predefined bit patterns in both Orbiter MPS and SSME telemetry parameters.

There are two basic types of GPC-detected malfunctions:

1. Class 2 malfunctions
2. Class 3 malfunctions

Each of the above classes of malfunctions is processed and displayed to the crew in a different manner.

TABLE 4-1.- MPS C&W LIMITS

MPS limits	Minimum setting	Maximum setting
MPS engine LO2 manifold pressure	None	249 psia
MPS engine LH2 manifold pressure	28 psia	60 psia
MPS helium pressure C	1150 psia	None
MPS helium pressure L	1150 psia	None
MPS helium pressure R	1150 psia	None
SM parameters		
MPS helium regulated pressure C	None	820 psia
MPS helium regulated pressure L	None	820 psia
MPS helium regulated pressure R	None	820 psia
MPS helium dp/dt L	None	20 psia
MPS helium dp/dt C	None	20 psia
MPS helium dp/dt R	None	20 psia
MPS engine LH2 ullage pressure	30 psia	46 psia
MPS engine LO2 ullage pressure	0 psig	29 psig

Class 2 MPS malfunctions are detected by the backup C&W processing of the GPC's. When this processing detects a class 2 malfunction, it illuminates the BACKUP C/W ALARM on panel F7, issues a class 2 alarm tone and generates a class 2 fault summary message which appears on all CRT displays. Table 4-2 is a list of the backup C&W parameters, their limits, and corresponding messages. Note that this list is virtually identical to the parameters limit-sensed by the C&W system (although the limits on the two lists may be different). For this reason, the illumination of the C&W MPS light will normally be accompanied by the illumination of the BACKUP C/W ALARM light and its attendant alarms (audio, CRT message).

Class 3 MPS malfunctions/conditions are detected by either the SSME Subsystem Operating Program (SOP) or special systems monitoring processing. When a class 3 malfunction is detected, the GPC will illuminate the SM ALERT indicator on panel F7, issue a class 3 alarm tone, and generate a class 3 fault summary message which will appear on all CRT displays. Table 4-3 is a list of the MPS class 3 malfunctions conditions and their corresponding fault summary messages. The first four conditions on this table are detected by the SSME SOP; the last four conditions are detected by special systems monitoring processing. The conditions which are detected by the SSME SOP are identical to those which illuminate the amber MAIN ENGINE STATUS light (sec. 4.1.2). For this reason, the illumination of the amber MAIN ENGINE STATUS light will normally be accompanied by the illumination of the SM ALERT light and its attendant alarms (audio, CRT messages). The ET ullage pressures out of limits will not light the amber MAIN ENGINE STATUS light.

4.4 MPS MISSION TIMELINE

The flight crew will enter the Shuttle at approximately T-01:45:00. At that time the MPS will be configured as follows:

- Propellant tanks empty (although propellant line chilldown, which is the initial phase of the propellant loading sequence, will be in progress).
- External tank LH2 and LO2 vent valves open (tank pressures equal to ambient).
- LH2 and LO2 prevalues open.
- Supply tanks in the helium subsystem partially pressurized to 2000 psia).
- Helium supply tank isolation valves open.
- Engine controller in start preparation phase.
- Purge sequence no. 3 in progress.

Most of the MPS functions performed during prelaunch are sequenced through the Launch Processing System (LPS). Crew control inputs are minimal. In the narrative that follows tables 4-2 and 4-3, it will be assumed, unless stated otherwise, that all of the prelaunch MPS functions described are sequenced by the LPS.

TABLE 4-2.- MPS BACKUP C&W PARAMETERS

Parameter	Minimum press	Maximum press	Class alarm & CRT message
MPS engine LO2 manifold pressure	0 psig	29 psig	2 SYS MPS MANF P LO2
MPS engine LH2 manifold pressure	30 psia	46 psia	2 SYS MPS MANF P LH2
MPS helium pressure C	1150 psia	None	2 SYS MPS HE TK P C
MPS helium regulated pressure C	None	820 psia	2 SYS MPS HE REG P C
MPS helium pressure L	1150 psia	None	2 SYS MPS HE TK P L
MPS helium regulated pressure L	None	820 psia	2 SYS MPS HE REG P L
MPS helium pressure R	1150 psia	None	2 SYS MPS HE TK P R
MPS helium regulated pressure R	None	820 psia	2 SYS MPS HE REG P R

TABLE 4-3.- GPC-DETECTED MALFUNCTIONS

Condition	Class alarm & CRT message
Electronic hold ^a	3 MPS ELEC 3 MPS ELEC 3 MPS ELEC
Hydraulic lockup ^a	3 MPS HYD 3 MPS HYD 3 MPS HYD
Loss of two or more command channels or command reject between the GPC to the SSMEC ^a	3 MPS CMD 3 MPS CMD 3 MPS CMD
Loss of both data channels between the SSMEC to the GPC ^a	3 MPS DATA 3 MPS DATA 3 MPS DATA
ET ullage pressure less than 30 psia more than 46 psia	3 SYS ET ULL P LH2
ET ullage pressure less than 0 psia more than 29 psia	3 SYS ET ULL P LO2

^aDetected by SSME SOP.

SECTION 5.0
DISPLAYS AND CONTROLS

5.1 MAIN PROPULSION SYSTEM DISPLAYS AND CONTROL FUNCTIONS

TABLE 5-1.- PANEL C3

Nomenclature/ position	Function	Remarks
MAIN ENGINE LIMIT SHUT DN sw		
ENABLE	Allows any main engine which violates operating limits to be shut down automatically by its own engine controller.	
AUTO	Allows only the first main engine which violates operating limits to be shut down automatically. Engine controllers for the two remaining engines will be inhibited from shutting down their respective engines as a result of an operating limit violation.	
INHIBIT	Prevents any main engine shutdown automatically as a result of an operating limit violation.	
MAIN ENGINE SHUT DOWN LEFT pb	When depressed during engine burn, causes an immediate shutdown of the corresponding main engine.	Pushbuttons have spring-loaded covers (guards).
MAIN ENGINE SHUT DOWN CTR pb	Same as SHUT DOWN LEFT pb except center engine.	
MAIN ENGINE SHUT DOWN RIGHT pb	Same as SHUT DOWN LEFT pb except right engine.	

TABLE 5-1.- PANEL C3 - Concluded

Nomenclature/ position	Function	Remarks
ET SEPARATION sw MAN AUTO	Inhibits GPC-initiated ET separation sequence. With the switch in this position, the ET SEP pb's must be depressed to initiate ET separation sequence. Once MECO has occurred, depressing the ET SEP pb will initiate the ET separation and override any separation inhibits present. Enables GPC-initiated ET separation sequence.	Lever-lock switch. Locks in this position.
ET SEPARATION SEP pb	If the ET SEPARATION lever-lock switch to the left of this pb is in the MAN position and MECO has occurred, depressing this pushbutton will initiate the ET separation sequence. Otherwise, depressing this pushbutton will have no effect.	Pushbutton has spring-loaded cover (guard).

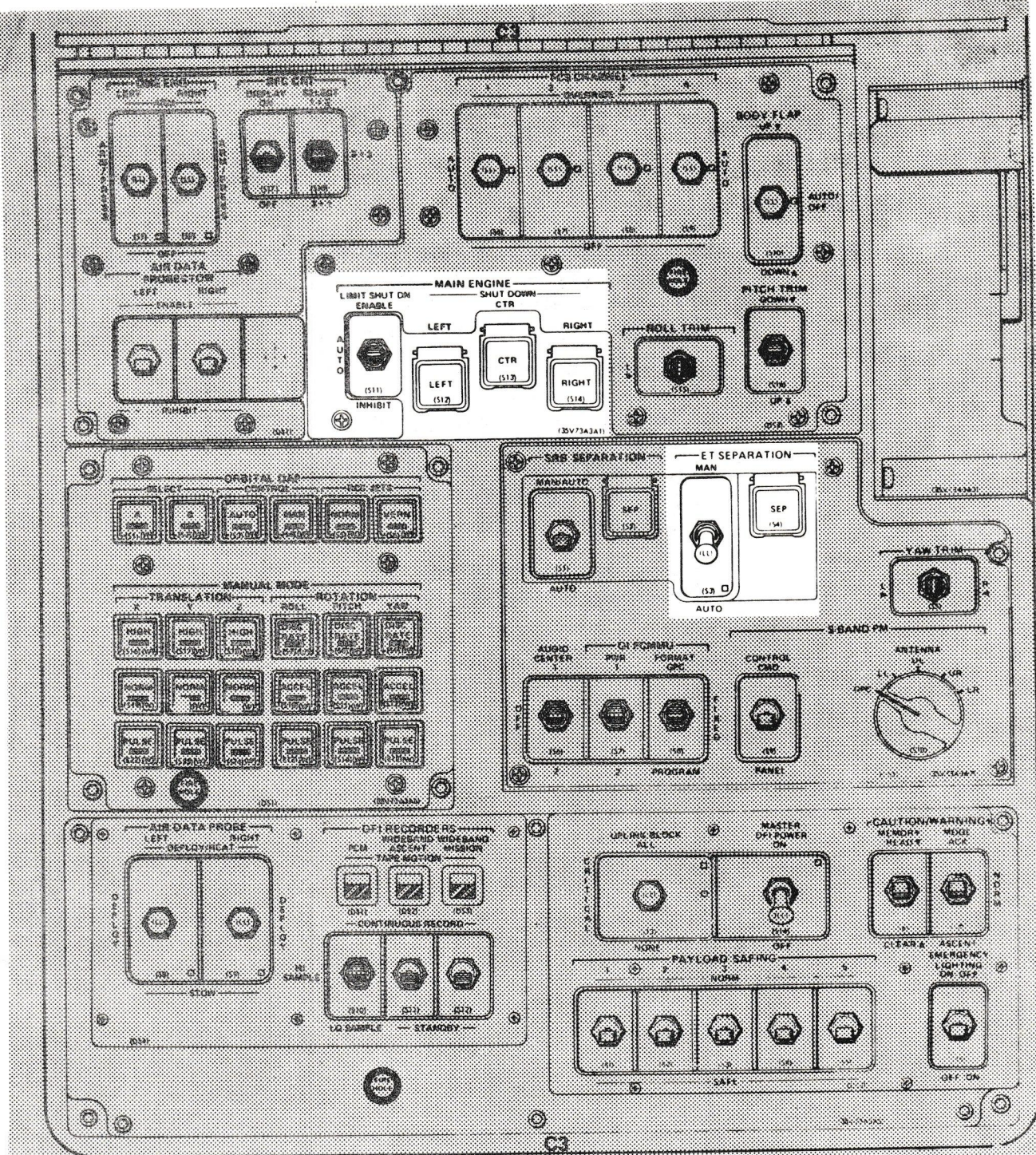


Figure 5-1.- Panel C3.

TABEL 5-2.- PANEL F6

Nomenclature/ position	Function	Remarks
INSTRUMENT POWER sw		
FLT MPS	Provides power to the MPS Pc meter, the MPS ENG MANF pressure meters, the MPS HELIUM pressure meter and the G&C dedicated displays.	The MPS meters are on panel F7.
OFF	Removes power from the MPS Pc meter, the MPS ENG MANF pressure meter, the MPS HELIUM pressure meter and the G&C dedicated displays.	
FLT	Provides power to the G&C dedicated displays only.	

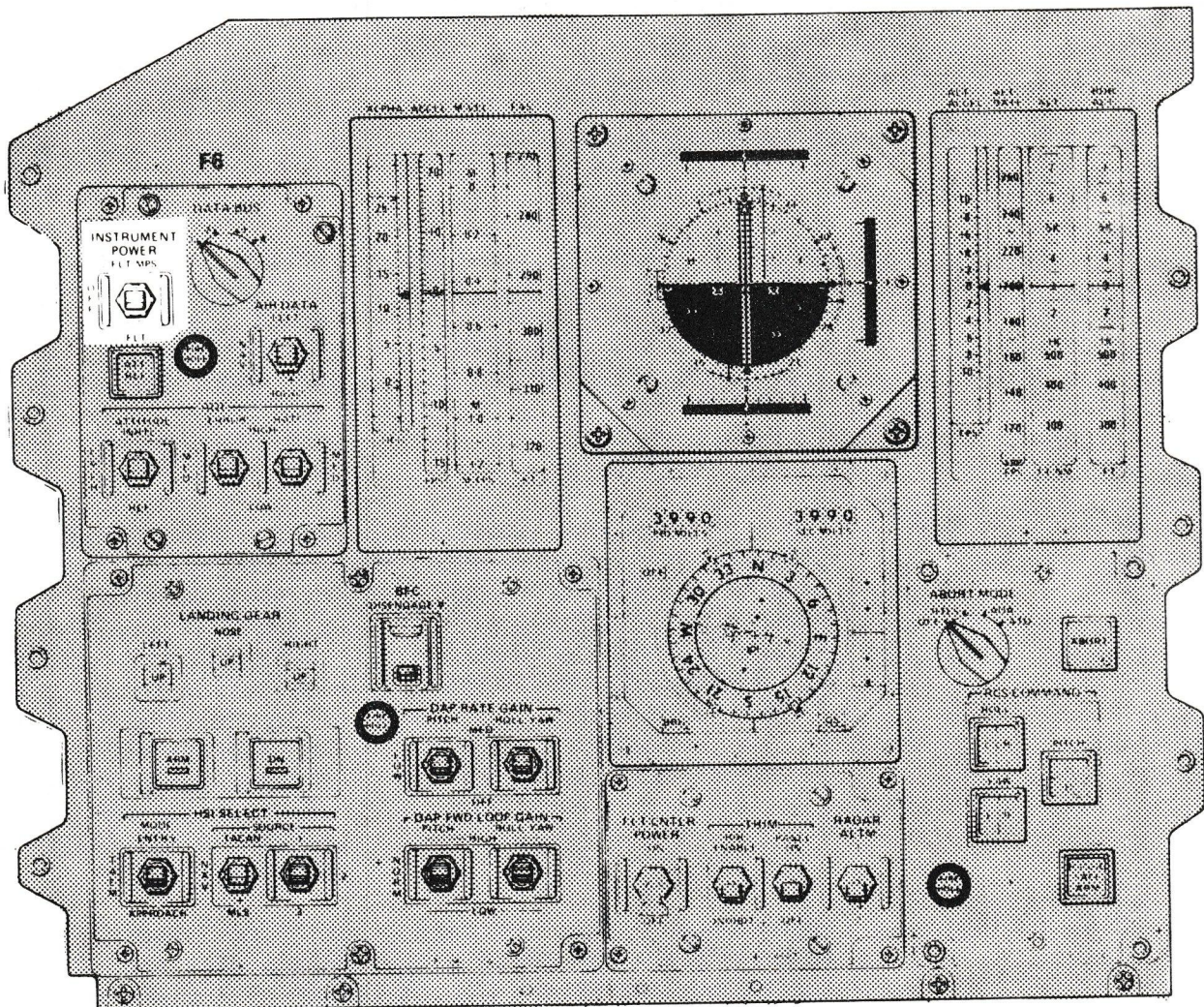


Figure 5-2.- Panel F6.

TABLE 5-3.- PANEL F7

Nomenclature/ position	Function	Remarks
C/W lt matrix:		
MPS	When illuminated, indicates any of the following parameters out of limits: MPS ENG LO2 MANF PRESS MPS ENG LH2 MANF PRESS MPS He PRESS L MPS He PRESS C MPS He PRESS R	On C/W panel, red indicator. A class 2 audible alarm tone will accompany the illumination of this indicator light.
BACKUP C/W ALARM	When illuminated, indicates the GPC software has detected any of the following parameters out of limits: MPS ENG LO2 MANF PRESS MPS ENG LH2 MANF PRESS MPS He PRESS L MPS He PRESS C MPS He PRESS R	in C/W panel, red indicator. A class 2 audible alarm will accompany the illumination of this indicator light. The appropriate class 2 fault summary message will appear on all CRT displays.
SM ALERT lt	When illuminated, indicates GPC software has detected an ET separation inhibit (during ET separation sequence). MPS He REG PRESS L MPS He REG PRESS C MPS He REG PRESS R	A class 3 audible alarm will accompany illumination of this blue light. Appropriate class 3 fault summary message will appear on all CRT displays.
MPS PRESS Pc meter	Indicates main engine thrust chamber pressure in percentage of reference chamber pressure (2995 psia). Range: 0 to 115 percent in 5-percent increments.	
MPS PRESS ENG MANF meter	Indicates LO2 and LH2 engine manifold pressure in psia. Ranges: LO2 - 0 to 300 psia in 50-psi increments LH2 - 0 to 100 psia in 10-psi increments	

TABLE 5-3.- PANEL F7 - Continued

Nomenclature/ position	Function	Remarks
MPS PRESS HELIUM meter	Indicates helium supply or regulated pressure for the pneumatic helium tank, the left engine helium tank, the center engine helium tank, and the right engine helium tank. Ranges: Supply - 0 to 5000 psia in 500-psi increments Regulated - 0 to 1000 psia in 100-psi increments	Accompanying switch on panel F7 selects supply or regulated pressure for display.
MAIN ENGINE STATUS LEFT lt		Upper half of each indicator is red, lower half is amber. Determined on an individual basis.
red	Indicates any of the following parameters out-of-limits: HPOT intermediate seal purge HPOT disc temp HPOT secondary seal drain Flight Accelerometer Safety Cutoff System (FASCOS) ME chamber press	
off	Any engine shutting down will cause the corresponding red status light to be illuminated. When the previously defined parameters are within limits, during prelaunch, when the corresponding engine is in mainstage phase, or after ET structural separation.	
amber	Indicates any of the following conditions: 1. Loss of data from both pairs of sensors for fuel flow rate. 2. Electronic hold. 3. Hydraulic lockup. 4. Loss of 2 or more channels from the SSMEC. 5. Loss of both data channels to the SSMEC.	

TABLE 5-3.- PANEL F7 - Concluded

Nomenclature/ position	Function	Remarks
MAIN ENGINE STATUS CTR lt	Same as ENGINE STATUS LEFT lt except center engine.	
MAIN ENGINE STATUS RIGHT lt	Same as ENGINE STATUS LEFT lt except right engine.	
MPS PRESS HELIUM sw		
TANK	Selects the helium supply tank measurements for display on the MPS PRESS HELIUM meter (PNEU L, C, R) on panel F7.	
REG	Selects the helium regulator outlet measurements for display on the MPS PRESS HELIUM meter on panel F7.	

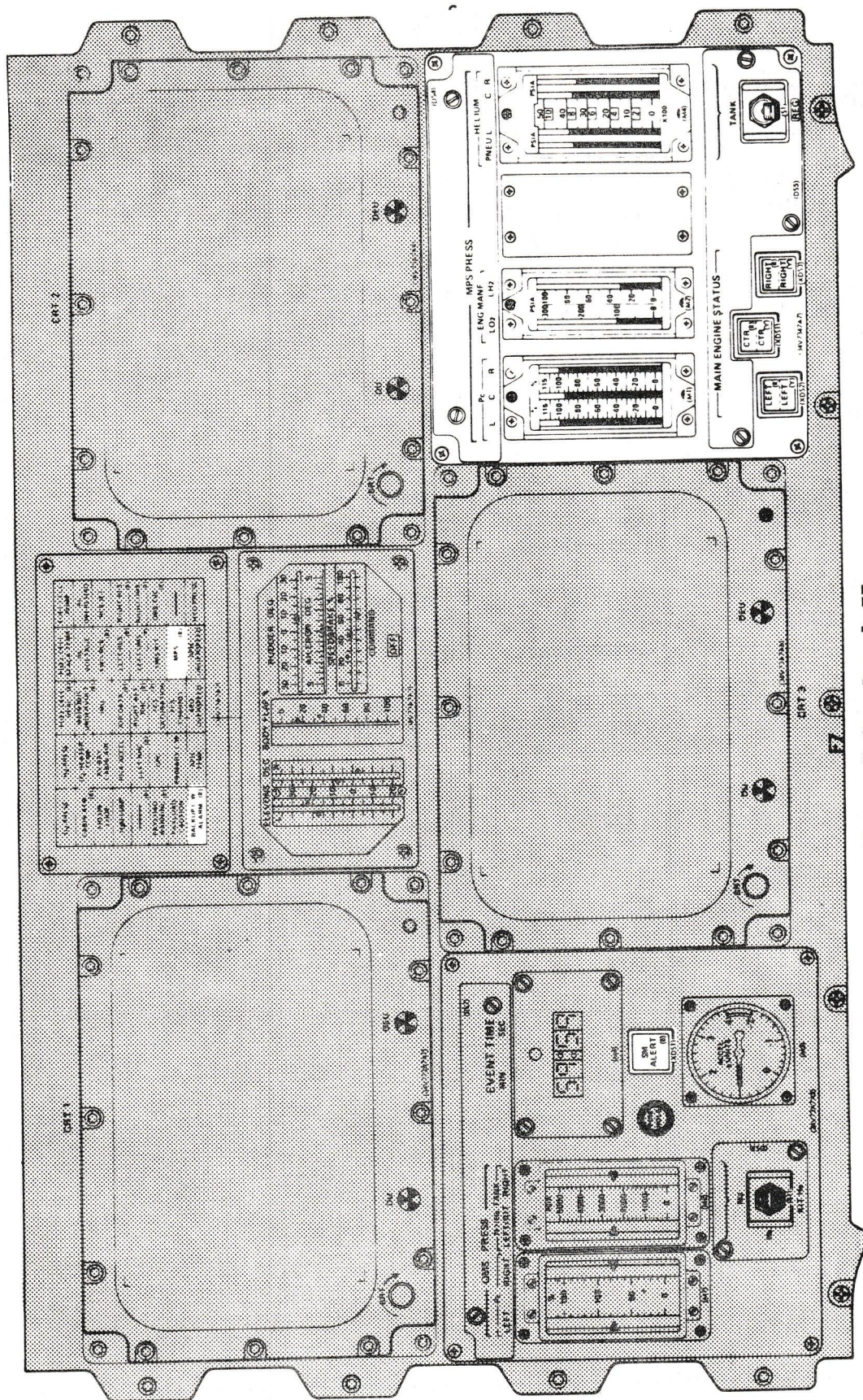


Figure 5-3.- Panel F7.

TABLE 5-4.- PANEL L4

Nomenclature/ position	Function	Remarks
cb AC1 ϕ A, ϕ B, ϕ C CTR ENGINE	Provide a single phase of ac power to the center engine controller.	
cb AC2 ϕ A, ϕ B, ϕ C CTR ENGINE	Provide a single phase of ac power to the center engine controller.	
cb AC3 ϕ A, ϕ B, ϕ C RIGHT ENGINE	Provide a single phase of ac power to the right engine controller.	
cb AC1 ϕ A, ϕ B, ϕ C RIGHT ENGINE	Provide a single phase of ac power to the right engine controller.	
cb AC2 ϕ A, ϕ B, ϕ C LEFT ENGINE	Provide a single phase of ac power to the left engine controller.	
cb AC3 ϕ A, ϕ B, ϕ C LEFT ENGINE	Provide a single phase of ac power to the left engine controller.	

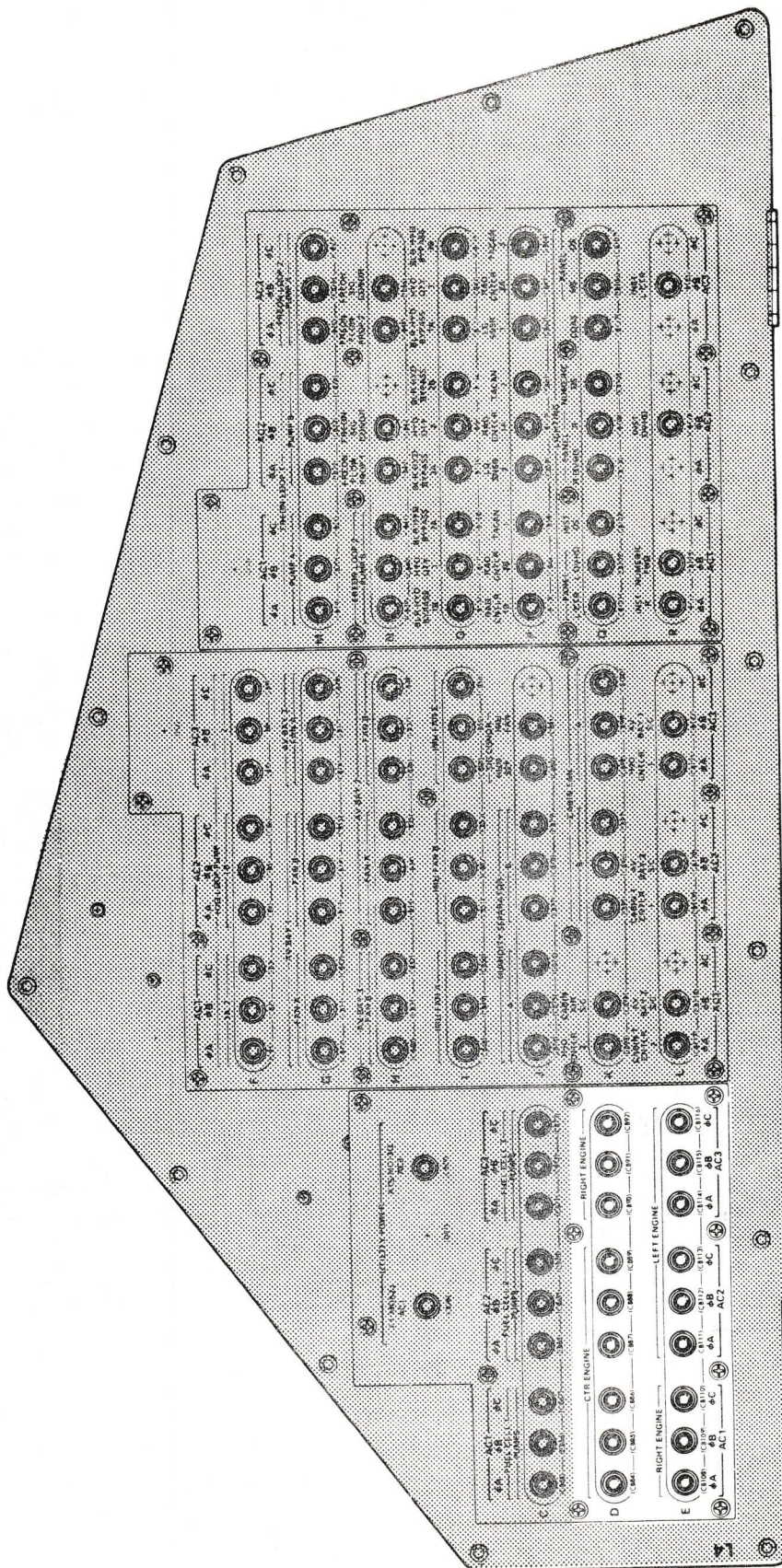


Figure 5-4.- Panel L4.

TABLE 5-5.- PANEL 014

Nomenclature/ position	Function	Remarks
INST L/CTR	Provides vehicle dc power to the INSTRUMENT POWER FLT/MP5 switch on panel F6.	

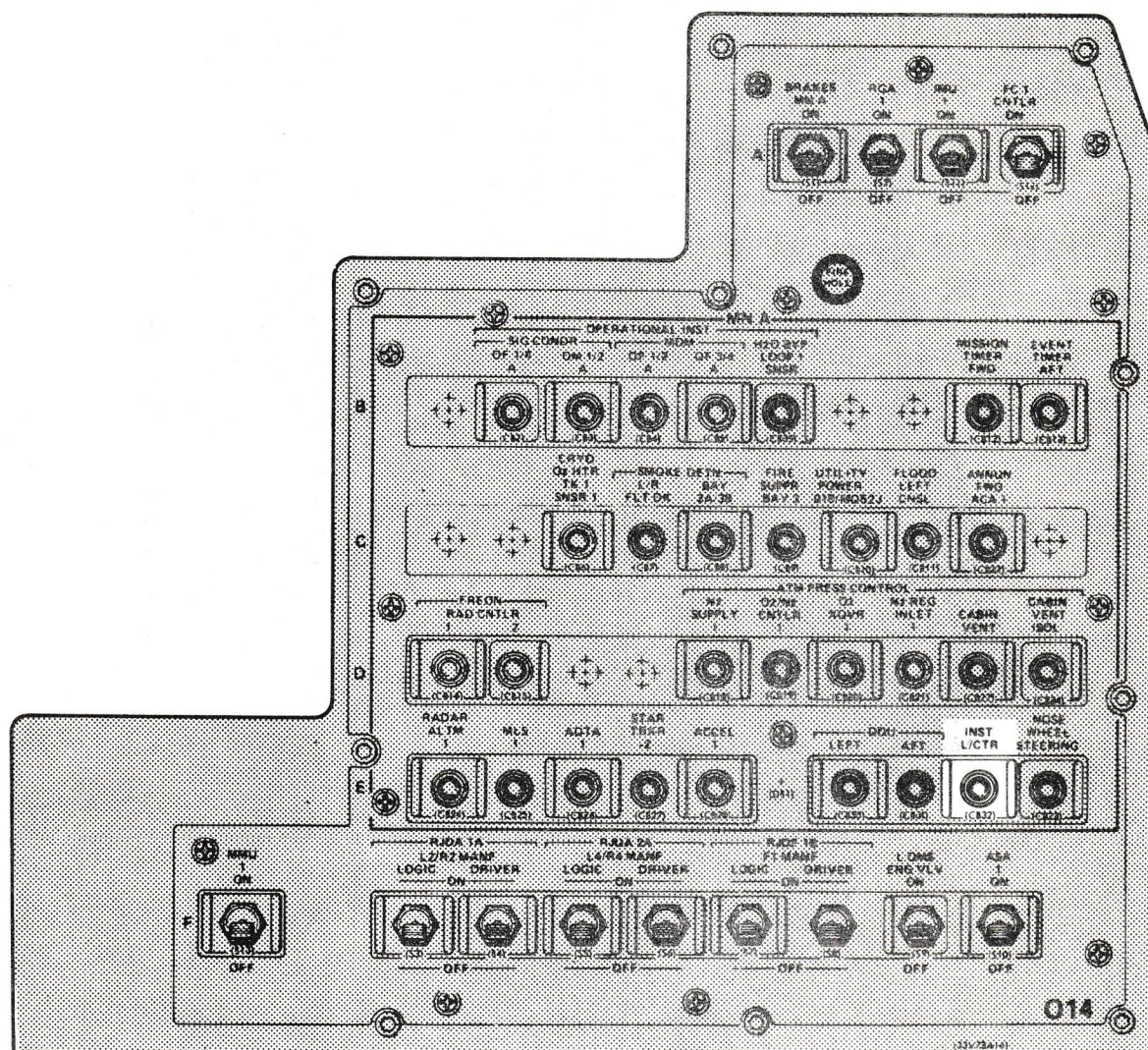


Figure 5-5.- Panel 014.

TABLE 5-6.- PANEL 017

Nomenclature/ position	Function	Remarks
ATVC 1, 2, 3, 4 sws		
ON	Provides vehicle dc power to the corresponding ascent thrust vector controller.	
OFF	Removes vehicle dc power from the corresponding ascent thrust vector controller.	
EIU LEFT sw		
ON	Provides vehicle dc power to the corresponding EIU.	
OFF	Removes vehicle dc power from the corresponding EIU.	Removing power from an EIU during main engine burn will prevent the corresponding engine controller from receiving commands from the GPC's and the GPC's from receiving data from the controller. In this situation, the corresponding engine cannot be throttled and cannot be shut down by GPC command.
EIU CTR sw	Same as EIU LEFT sw except center engine.	
EIU RIGHT sw	Same as EIU LEFT sw except right engine.	

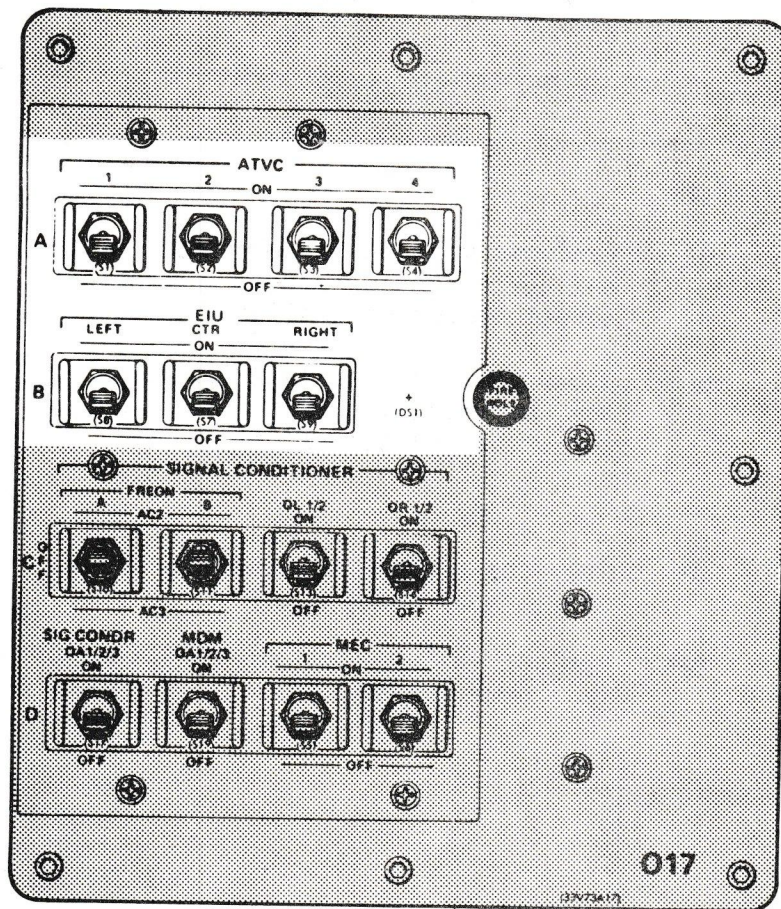


Figure 5-6.- Panel 017.

TABLE 5-7.- PANEL R2

Nomenclature/ position	Function	Remarks
MPS PRPLT DUMP SEQUENCE L02 sw		
START	After MECO, will initiate the L02 dump sequence. Dump will continue for as long as the switch is in this position.	Will initiate dump if the GPC has not already automatically initiated the L02 dump sequence. Crew should allow main engines to cool down for 10 sec after MECO before initiating dump sequence.
GPC	Allows GPC to initiate the L02 dump sequence automatically at the beginning of the OMS-1 burn and/or terminate the L02 dump automatically after a preset time interval has elapsed (presently 140 sec).	
STOP	If L02 dump is in progress, will immediately terminate dump sequence. If L02 dump has not yet occurred, will inhibit GPC from initiating dump sequence automatically.	

TABLE 5-7.- PANEL R2 - Continued

Nomenclature/ position	Function	Remarks
MPS PRPLT DUMP SEQUENCE LH2 sw		
START	After completion of the L02 dump, will initiate the LH2 dump sequence. Dump will continue for as long as the switch is in this position.	Will initiate dump if the GPC has not already automatically initiated the LH2 dump sequence.
GPC	Allows GPC to initiate the LH2 dump sequence automatically at the end of the L02 dump and/or terminate the LH2 dump automatically after a preset time interval has elapsed (presently 40 sec).	
STOP	If LH2 dump is in progress, will immediately terminate dump sequence. If LH2 dump has not yet occurred, will inhibit GPC from initiating dump sequence automatically.	
MPS ENGINE POWER LEFT AC2 sw		
ON	Provides ac bus 2 power to the left engine controller.	If both switches which provide ac power to a given engine controller are placed in OFF while the engine is burning, the corresponding main engine will experience an immediate pneumatic shutdown.
OFF	Removes ac bus 2 power from the left engine controller.	

TABLE 5-7.- PANEL R2 - Continued

Nomenclature/ position	Function	Remarks
MPS ENGINE POWER CTR AC1 sw		
ON	Provides ac bus 1 power to the the center engine controller.	
OFF	Removes ac bus 1 power from the center engine controller.	See remarks for LEFT AC2 switch.
MPS ENGINE POWER RIGHT AC3 sw		
ON	Provides ac bus 3 power to the right engine controller.	
OFF	Removes ac bus 3 power from the right engine controller.	See remarks for LEFT AC2 switch.
MPS ENGINE POWER LEFT AC3 sw		
ON	Provides ac bus 3 power to the left engine controller.	
OFF	Removes ac bus 3 power from the left engine controller.	See remarks for LEFT AC2 switch.
MPS ENGINE POWER CTR AC2 sw		
ON	Provides ac bus 2 power to the center engine controller.	
OFF	Removes ac bus 2 power from the center engine controller.	See remarks for LEFT AC2 switch.
MPS ENGINE POWER RIGHT AC1 sw		
ON	Provides ac bus 1 power to the right engine controller.	
OFF	Removes ac bus 1 power from the right engine controller.	See remarks for LEFT AC2 switch.

TABLE 5-7.- PANEL R2 - Continued

Nomenclature/ position	Function	Remarks
MPS He ISOLATION A LEFT sw		
OPEN	Opens the corresponding engine helium supply tank isolation valve.	Allows helium from the corresponding engine supply tank to flow to its engine's pneumatic control assembly.
GPC	Allows the LPS to command the corresponding engine helium supply tank isolation valve open or closed.	Used for prelaunch checkout.
CLOSE	Closes the corresponding engine helium supply tank isolation valves.	To be used during prelaunch operations and/or during phase for isolating helium supply tank leaks.
MPS He ISOLATION A CTR sw	Same as ISOLATION A LEFT switch except for center engine.	
MPS He ISOLATION A RIGHT sw	Same as ISOLATION A LEFT switch except for right engine.	
MPS He ISOLATION B LEFT sw	Same as He ISOLATION A LEFT switch except for B supply.	
MPS He ISOLATION B CTR sw	Same as He ISOLATION B LEFT switch except center engine.	
MPS He ISOLATION B RIGHT sw	Same as He ISOLATION B LEFT switch except right engine.	

TABLE 5-7.- PANEL R2 - Continued

Nomenclature/ position	Function	Remarks
MPS PNEUMATICS L ENG He XOVR sw		
OPEN	Opens the corresponding engine helium supply tank crossover valve.	Allows engine helium to flow into pneumatic helium manifold.
GPC	Allows the LPS to command the corresponding engine helium supply tank crossover valve open or closed.	Used for prelaunch checkout.
CLOSE	Closes the corresponding engine helium supply tank crossover valve.	
MPS PNEUMATIC He ISOL sw		
OPEN	Provides signals to logic circuits which power the PNEU He supply valve 1 and 2 coils, opening the valves and supplying pneumatic pressure for the MPS pneumatically operated valves.	
GPC	Removes power from logic circuits, allowing GPC inputs to control the valves.	
CLOSE	Provides signals to the logic circuits such that power is removed from the valve coils, closing the valves and removing the pneumatic supply from the MPS valves.	

TABLE 5-7.- PANEL R2 - Continued

Nomenclature/ position	Function	Remarks
MPS He INTERCONNECT LEFT sw		
IN OPEN/ OUT CLOSE	Opens the "in" He interconnect valve and closes the "out" He interconnect valve of the corresponding engine.	This position allows helium to flow from the pneumatic tank to the engine helium supply tanks.
GPC	The "out" interconnect valve will open automatically at the beginning of the LO2 dump and close automatically at the end of the LH2 dump. In the event of an RTLS abort, the GPC will cause the "in" interconnect valve to open automatically at MECO and close automatically 20 sec later. If the corresponding engine was shut down prior to MECO, its "in" He interconnect valve will remain closed at MECO.	This position allows helium to flow from the engine He supply to the pneumatic He supply.
IN CLOSE/ OUT OPEN	Opens the "out" interconnect valve and closes the "in" interconnect valve for a corresponding engine.	This position allows He to flow from the engine He tanks to the pneumatic He supply tank.
MPS He INTERCONNECT CTR sw	Same as He INTERCONNECT LEFT sw except center engine.	
MPS He INTERCONNECT RIGHT sw	Same as He INTERCONNECT LEFT sw except right engine.	

TABLE 5-7.- PANEL R2 - Concluded

Nomenclature/ position	Function	Remarks
MPS LH2 ULLAGE PRESS sw		
AUTO	Allows each of the 3 LH2 ullage pressure transducers in the ET to control the position of their respective GH2 flow control valves in the Orbiter.	Lever-lock switch. Locks in AUTO position.
OPEN	Moves all 3 GH2 flow control valves to their full open positions, regardless of LH2 ullage pressure. Gives maximum pressurization rate for the LH2 tank.	Crew will use this position if LH2 tank ullage pressure drops below 31.5 psia.

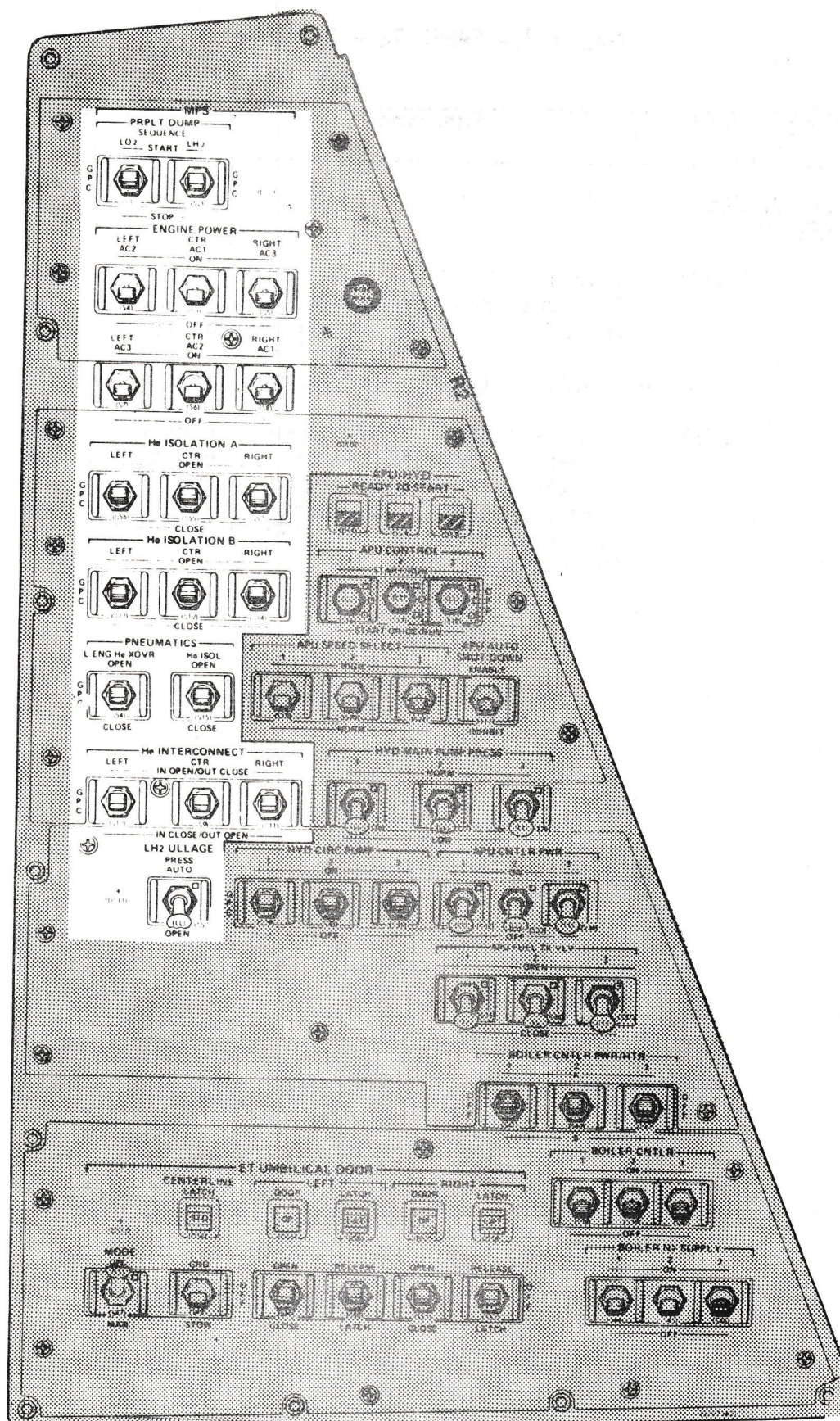


Figure 5-7.- Panel R2.

TABLE 5-8.- PANEL R4

Nomenclature/ position	Function	Remarks
HYDRAULICS MPS/TVC ISOL VLV SYS 1 tb		
OP	Indicates the loop 1 MPS/TVC isolation valve is open.	
CL	Indicates the valve is closed or a loss of tb input signal.	
HYDRAULICS MPS/TVC ISOL VLV SYS 2 tb	Same as the MPS/TVC ISOL VLV SYS 1 tb except loop 2.	
HYDRAULICS MPS/TVC ISOL VLV SYS 3 tb	Same as the MPS/TVC ISOL VLV SYS 1 tb except loop 3.	
HYDRAULICS MPS/TVC ISOL VLV SYS 1 sw		The actual valve transfer requires hydraulic pressure. Solenoid valves supply hydraulics to a piston which opens and closes the valve.
OPEN ▽	Provides signals to Load Control Assemblies (LCA's) that power the open coil of the loop 1 MPS/TVC isolation valve, opening the valve and supplying SYS 1 hydraulics to the engine propellant valve and gimbal actuators.	
ctr	Removes the open and close signals, allowing the valve to remain in its last position.	
CLOSE Δ	Same as the OPEN position except closes the valve and isolates the hydraulics from the MPS/TVC.	
HYDRAULICS MPS/TVC ISOL VLV SYS 2 sw	Same as the MPS/TVC ISOL VLV SYS 1 switch except loop 2.	
HYDRAULIC MPS/TVC ISOL VLV SYS 3 sw	Same as the MPS/TVC ISOL VLV SYS 1 switch except loop 3.	

TABLE 5-8.- PANEL R4 - Continued

Nomenclature/ position	Function	Remarks
MAIN PROPULSION SYSTEM ENGINE CNTLR HTR LEFT sw		
AUTO	Applies a signal to an RPC that powers a thermostatically controlled heater, allowing automatic temperature control of the left engine controller.	
OFF	Removes the signal, disabling the heater.	
MAIN PROPULSION SYSTEM ENGINE CNTLR HTR CTR sw	Same as the ENGINE CNTLR HTR LEFT switch except the center engine controller.	
MAIN PROPULSION ENGINE CNTLR HTR RIGHT sw	Same as the ENGINE CNTLR HTR LEFT switch except the right engine controller.	
MAIN PROPULSION SYSTEM MANF PRESS LO2 sw		Lever-lock switch.
OPEN	Opens the LO2 manifold pressurization valves (2). Allows pneumatic supply helium to pressurize the LO2 feedline manifold.	Crew will use this position for manifold repress just prior to entry.
GPC	Allows the GPC to command the LO2 manifold pressurization valves either open or closed.	Switch locks in this position. Normal position for LO2 propellant dump.
CLOSE	Closes the LO2 manifold pressurization valves (2).	

TABLE 5-8.- PANEL R4 - Continued

Nomenclature/ position	Function	Remarks
MAIN PROPULSION SYSTEM MANF PRESS LH2 sw		Lever-lock switch.
OPEN	Opens the LH2 manifold pressurization valves (2). Allows pneumatic supply helium to pressurize the LH2 feedline manifold.	Crew will use this position for manifold repress just prior to entry.
GPC	Allows the GPC to command the LH2 manifold pressurization valves either open or closed.	Switch locks in this position. Normal position for LH2 propellant dump.
CLOSE	Closes the LH2 manifold pressurization valves (2).	
MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LO2 OUTBD sw		Lever-lock switch.
OPEN	Opens the corresponding propellant fill/drain valve. Allows GSE-supplied propellant to flow into feedline manifolds (to ET) during prelaunch and residual propellants to flow out of the feedline manifolds during vacuum inerting (after propellant dump).	
GND	Allows the LPS to command the corresponding propellant fill/drain valve open or closed.	Switch locks in this position. Used in prelaunch for propellant loading.
CLOSE	Closes the corresponding propellant fill/drain valve.	
MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LO2 INBD sw	Same as FILL/DRAIN LO2 OUTBD switch except the inboard valve.	

TABLE 5-8.- PANEL R4 - Continued

Nomenclature/ position	Function	Remarks
MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LH2 OUTBD	Same as FILL/DRAIN L02 OUTBD switch except LH2 system.	
MAIN PROPULSION SYSTEM PROPELLANT FILL/DRAIN LH2 INBD	Same as FILL/DRAIN L02 OUTBD switch except LH2 system and inboard valve.	
MAIN PROPULSION SYSTEM GH2 PRESS LINE VENT sw		
OPEN	Opens the GH2 pressurization line vent valve. Allows GH2 pressurization manifold in the Orbiter to vent overboard during vacuum inerting.	
GND	Allows the LPS to command the GH2 pressurization line vent valve open or closed.	Used for prelaunch checkout.
CLOSE	Closes the GH2 pressurization line vent valve.	
MAIN PROPULSION SYSTEM L02 PREVALVE LEFT sw		Lever-lock switch.
OPEN	Opens the corresponding L02 prevalve.	
GPC	Allows the GPC to command the corresponding L02 prevalve open or closed.	Switch locks in this position.
CLOSE	Closes the corresponding L02 prevalve.	
MAIN PROPULSION SYSTEM L02 PREVALVE CTR sw	Same as L02 PREVALVE LEFT sw except center engine.	
MAIN PROPULSION SYSTEM L02 PREVALVE RIGHT sw	Same as L02 PREVALVE LEFT sw except right engine.	

TABLE 5-8.- PANEL R4 - Continued

Nomenclature/ position	Function	Remarks
MAIN PROPULSION SYSTEM LH2 PREVALVE LEFT sw		Lever-lock switch.
OPEN	Opens the corresponding LH2 prevalue.	
GPC	Allows the GPC to command the corresponding LH2 prevalue open or closed.	Switch locks in this position.
CLOSE	Closes the corresponding LH2 prevalue.	
MAIN PROPULSION SYSTEM LH2 PREVALVE CTR sw	Same as LH2 PREVALVE LEFT switch except center engine.	
MAIN PROPULSION SYSTEM LH2 PREVALVE RIGHT sw	Same as LH2 PREVALVE LEFT switch except right engine.	
MAIN PROPULSION SYSTEM FEEDLINE RLF ISOL LO2 sw		
OPEN	Opens the corresponding propellant feedline relief isolation valve.	No nominal use of this position - contingencies only.
GPC	Allows the GPC to command the corresponding propellant feedline relief isolation valve open or closed. GPC will normally command valve open at MECO to allow any pressure buildup in propellant lines to be vented overboard. Closed during propellant dump.	Switch locks in this position.
CLOSE	Closes the corresponding propellant feedline relief isolation valve.	No nominal use of this position - contingencies only.

TABLE 5-8.- PANEL R4 - Concluded

Nomenclature/ position	Function	Remarks
MAIN PROPULSION SYSTEM FEEDLINE RLF ISOL LH2 SW	Same as FEEDLINE RLF ISOL L02 switch except LH2 system.	

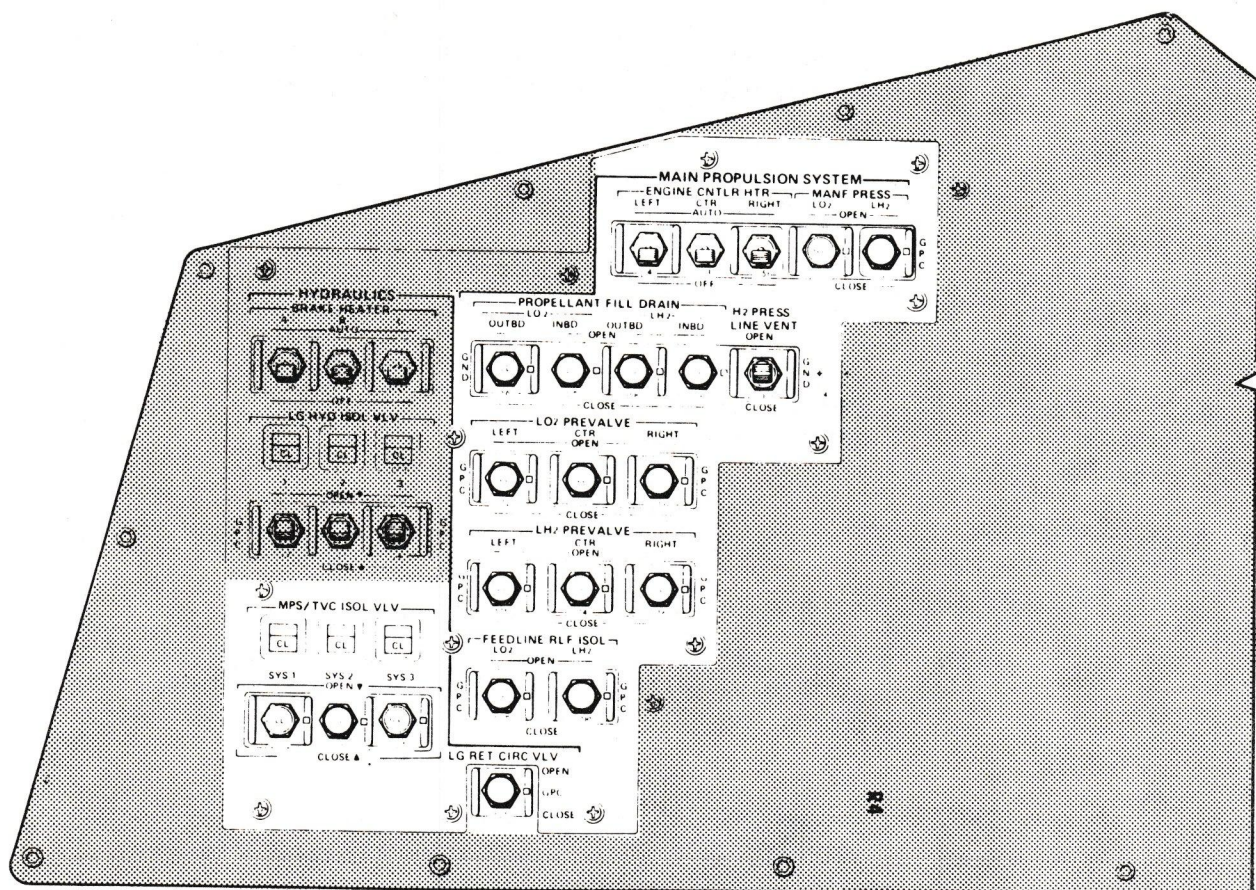


Figure 5-8.- Panel R4.

GNC SYS SUMM 1 Display

For the MPS, helium tank (HE TK) and regulator (HE REG) pressures in psia and HE system pressure decay rate (HE dP/dT) in psia/sec are displayed for the three engines. These parameters are monitored to detect leaks or regulator problems that require manual crossover or helium tank isolation. The external tank ullage pressures (ET ULL P) are displayed in psia for LH2 and in psig for LO2. Manifold pressures (MANF P) for the same propellants are displayed in psia. The status indicators for helium tank pressures (HE TK P) display a "↓" if the pressure falls beneath its lower limit. The status indicator for HE system pressure decay (HE dP/dT) displays an "↑" if the pressure decay rate goes above the upper limit. For external tank ullage pressure (ET ULL P) and LH2 manifold pressure (MANF P) the status indicators displayed are "↑" or "↓" to indicate operation above or below the tolerance band. For LO2 manifold pressure (MANF P), and helium regulator pressure (HE REG P), an "↑" is displayed to indicate that an upper limit has been exceeded. Except for ET ullage pressure and HE system pressure decay, an "M" is displayed for a commfault and the parameter data are blanked. The parameters on this format subsection are only supported in MM 101, 102, 103, and 601 and are blank in all other MM's.

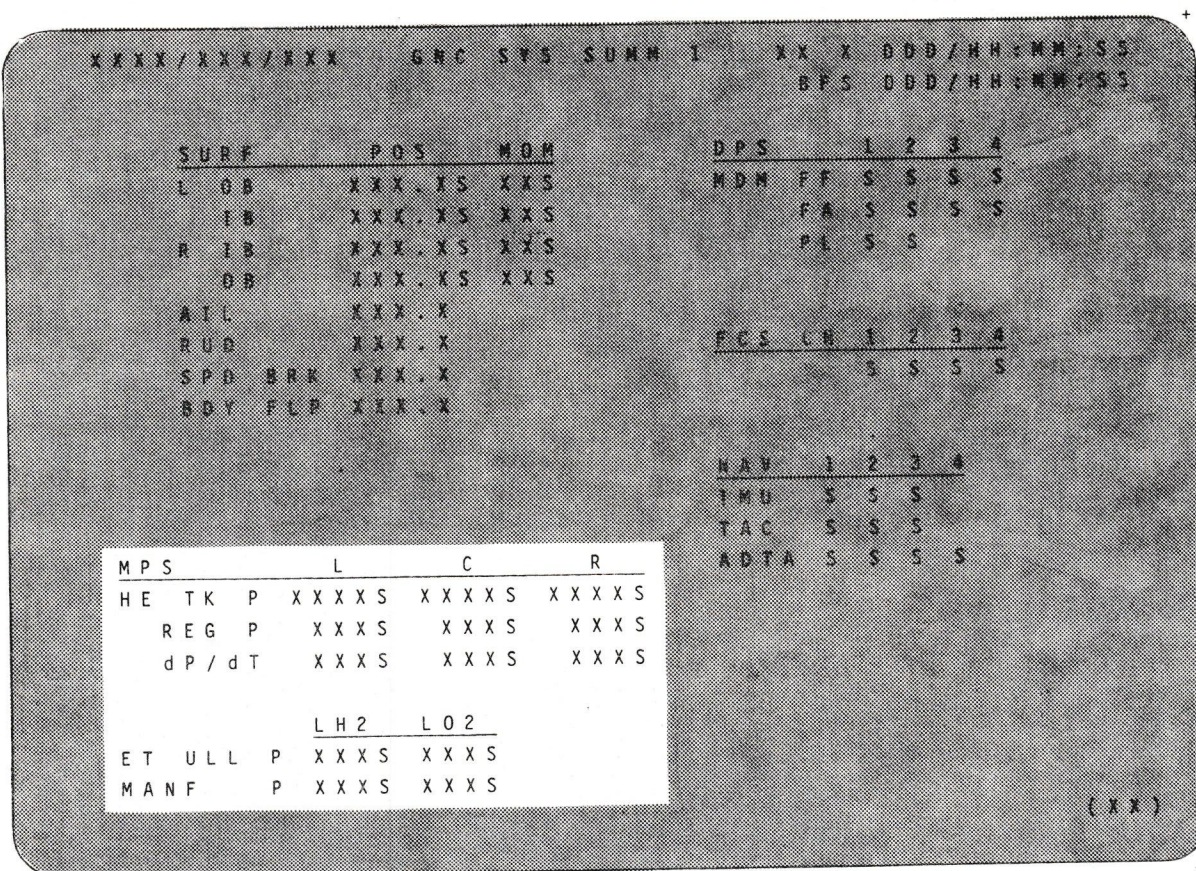


Figure 5-9.- GNC SYS SUMM 1 generic display.

ASCENT TRAJ 1 Display

ASCENT TRAJ 1. A GNC operational sequence (OPS) display available in OPS 1 (BFS only). It is used to monitor guidance performance during stage 1.

The central plot is an altitude vs. velocity relative to launch site profile from the mission trajectory. A horizontal line intersects the curved line at 75,000 ft to indicate the highest ejection altitude. Tick marks on the curved line correspond to inertial ADI angles of 70°, 60°, 50°, and 40°. The current vehicle state from navigation is shown by a moving triangle () which has an update rate of 1920 ms. The predicted state for 20 sec in the future is indicated by a circle (o), also updated at 1920 ms. Abort mode capability is also indicated as shown.

PC < 50 (SRB chamber pressure less than 50 psi) appears on the display whenever that discrete is sent to the staging sequence.

T is a digital readout of throttle command to the engines in percent. Range is 50-100 percent, with an update rate of 960 ms. "SEP INH" is displayed flashing if the SRB SEP inhibit discrete is set by the SRB SEP sequencer.

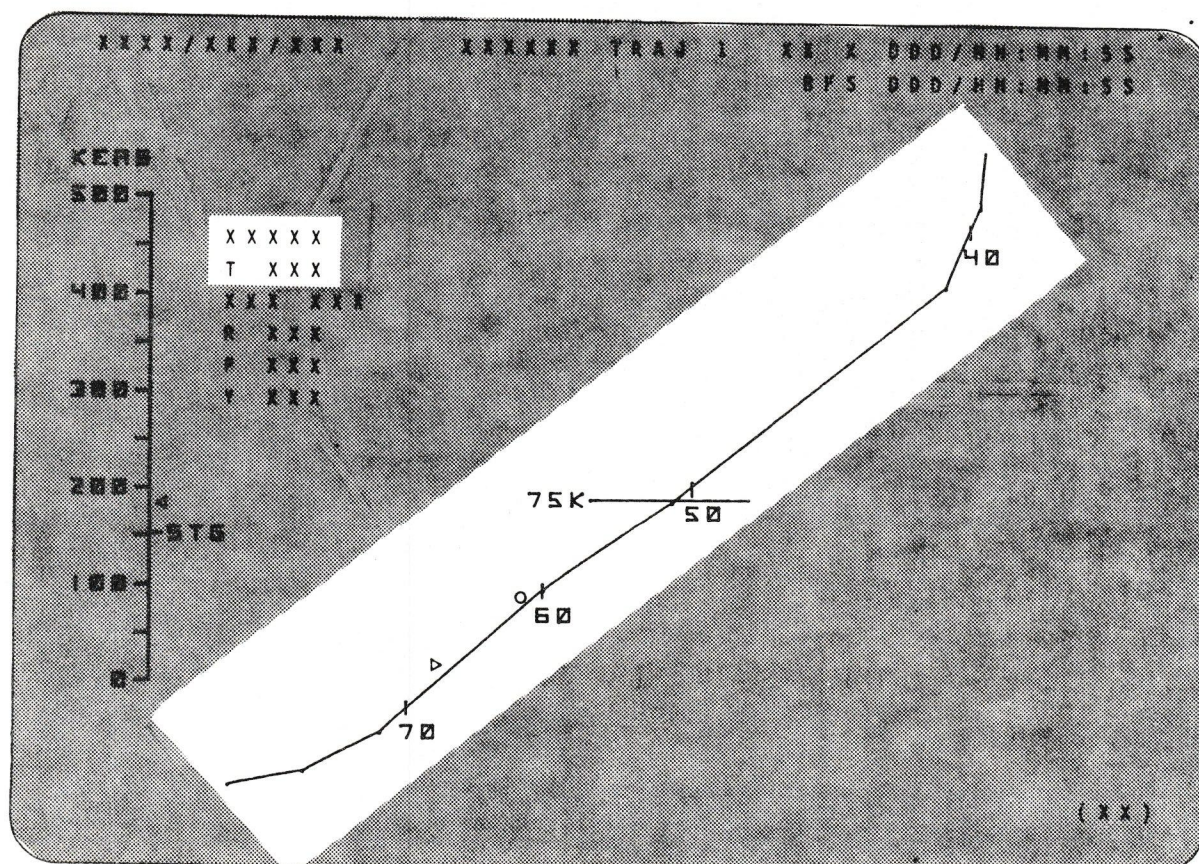


Figure 5-10.- ASCENT TRAJ 1 generic display.

ASCENT TRAJ 2 Display

T is the throttle command in percent and is updated every 960 ms. TMECO is predicted time of MECO (from lift-off) from guidance. Update rate is 1920 msec. "SEP INH" is displayed flashing if the ET SEP inhibit discrete is set by the ET SEP sequencer.

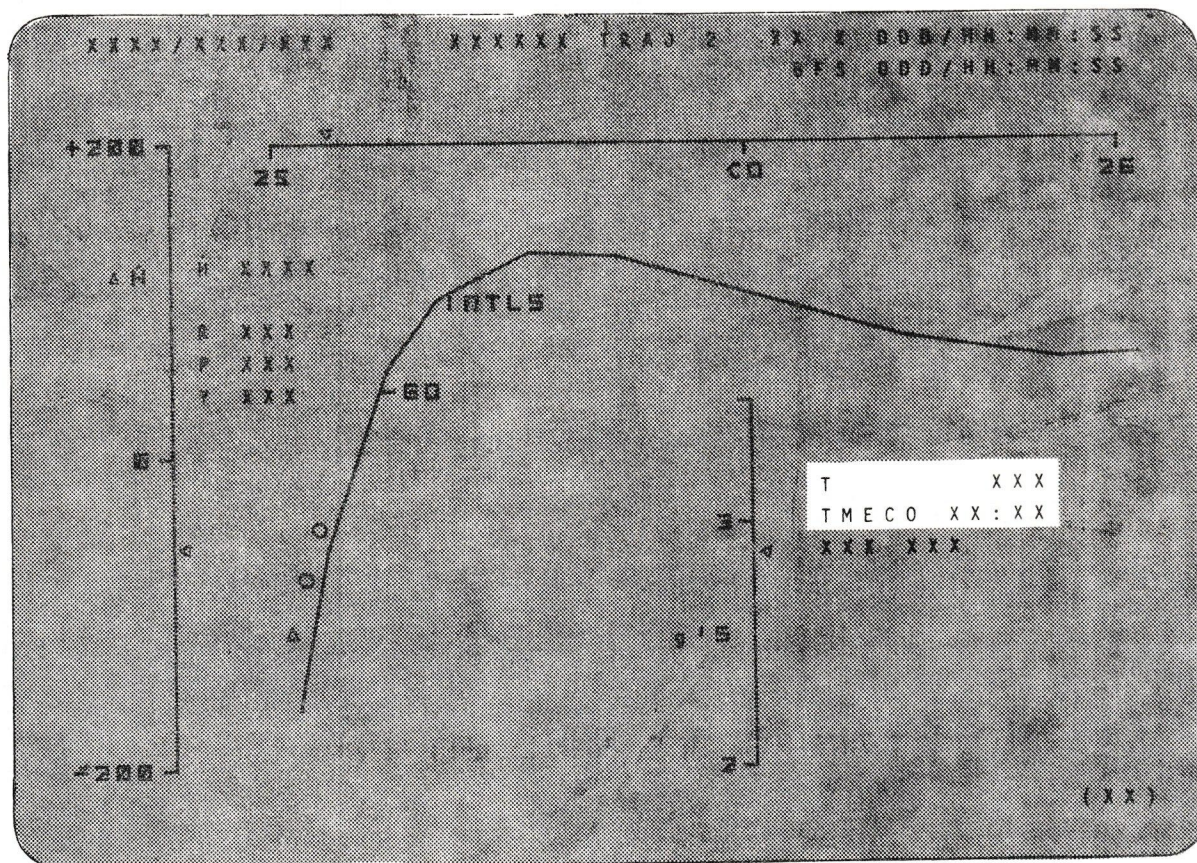


Figure 5-11.- ASCENT TRAJ 2 generic display.

RTLS TRAJ 2 Display

The RTLS TRAJ 2 display is up during MM 601. It provides trajectory, loads, attitude, and guidance information to the crew. The crew uses this display to monitor automatic guidance or to fly the abort using manual guidance.

The mission-dependent central plot is an altitude vs. horizontal component of relative velocity profile for a last-time abort. No scale appears on the display. Current vehicle state is indicated by a moving triangle, with the predicted state for 30 sec and 60 sec in the future indicated by circles. Update rate is 1920 ms. A vertical line intersects the curved line where horizontal relative velocity is zero, and the sign attached to velocity must change at this point to prevent doubling back.

TMECO is the predicted time of MECO, from guidance. It reads in minutes and seconds from lift-off. Update rate 1920 ms. "SEP INH" is displayed flashing at the XXX.XXX position below "TMECO" if the ET SEP inhibit discrete is set by the ET SEP sequencer.

PRPLT - Percent propellant remaining in the ET

T - Commanded throttle (%)

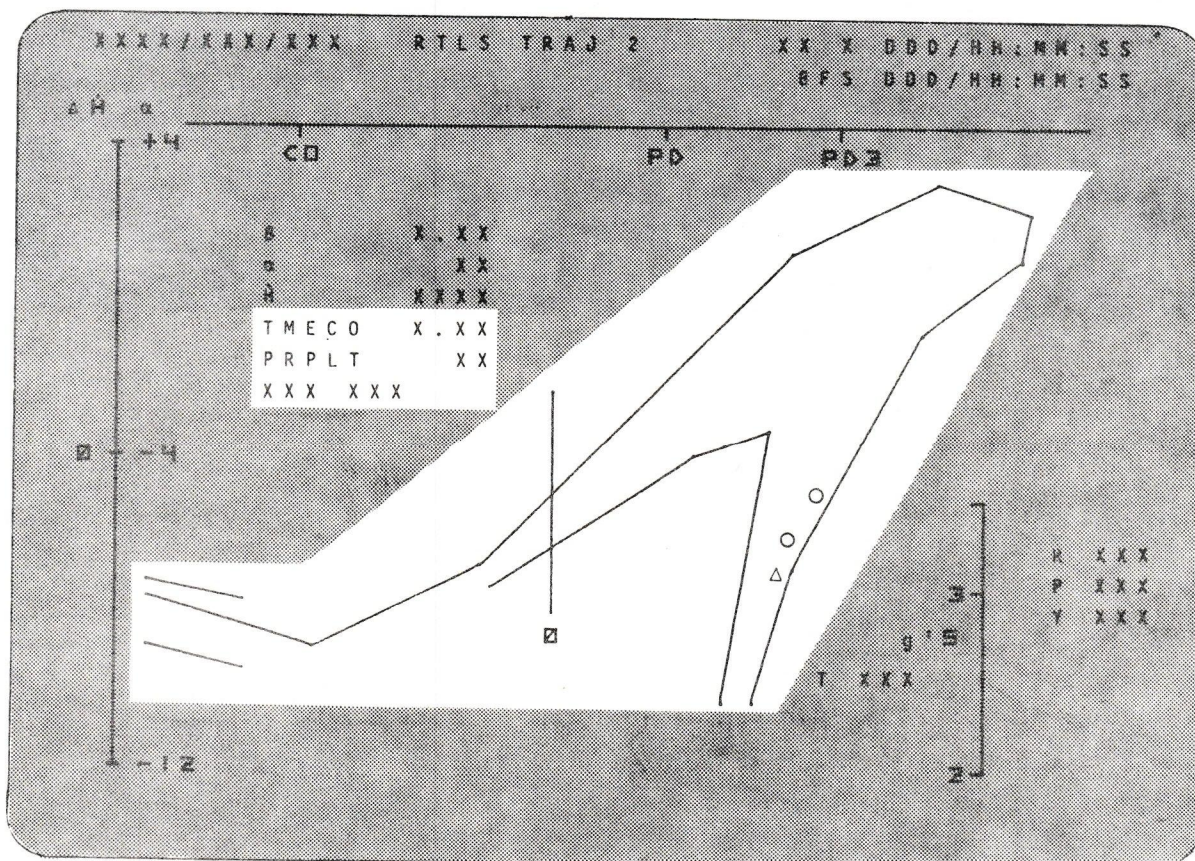


Figure 5-12.- RTLS TRAJ 2 generic display.

SECTION 6.0 MISSION SEQUENCE

6.1 NOMINAL MISSION SEQUENCE

The two mission sequences shown in figure 6-1 are the nominal mission sequence and the Return to Launch Site (RTLS) mission sequence.

The nominal mission sequence is divided into six different phases:

- Prelaunch (T-1:45 to T-0:00:0)
- Ignition (0:00:00)
- Ascent (0:00:00 to 00:08:55)
- Post-MECO (0:08:55 to 00:11:04)
- Postinsertion (00:11:04 to 00:15:00)
- Preentry

A nominal mission sequence is a mission sequence that renders no malfunctions which would lead to an abort sequence (RTLS, AOA, ATO). The mission profile takes into account 10 significant events ranging from prelaunch activities to horizontal landing activities (fig. 6-1). The significant events throughout a complete nominal mission profile are shown in figures 6-2 and 6-3.

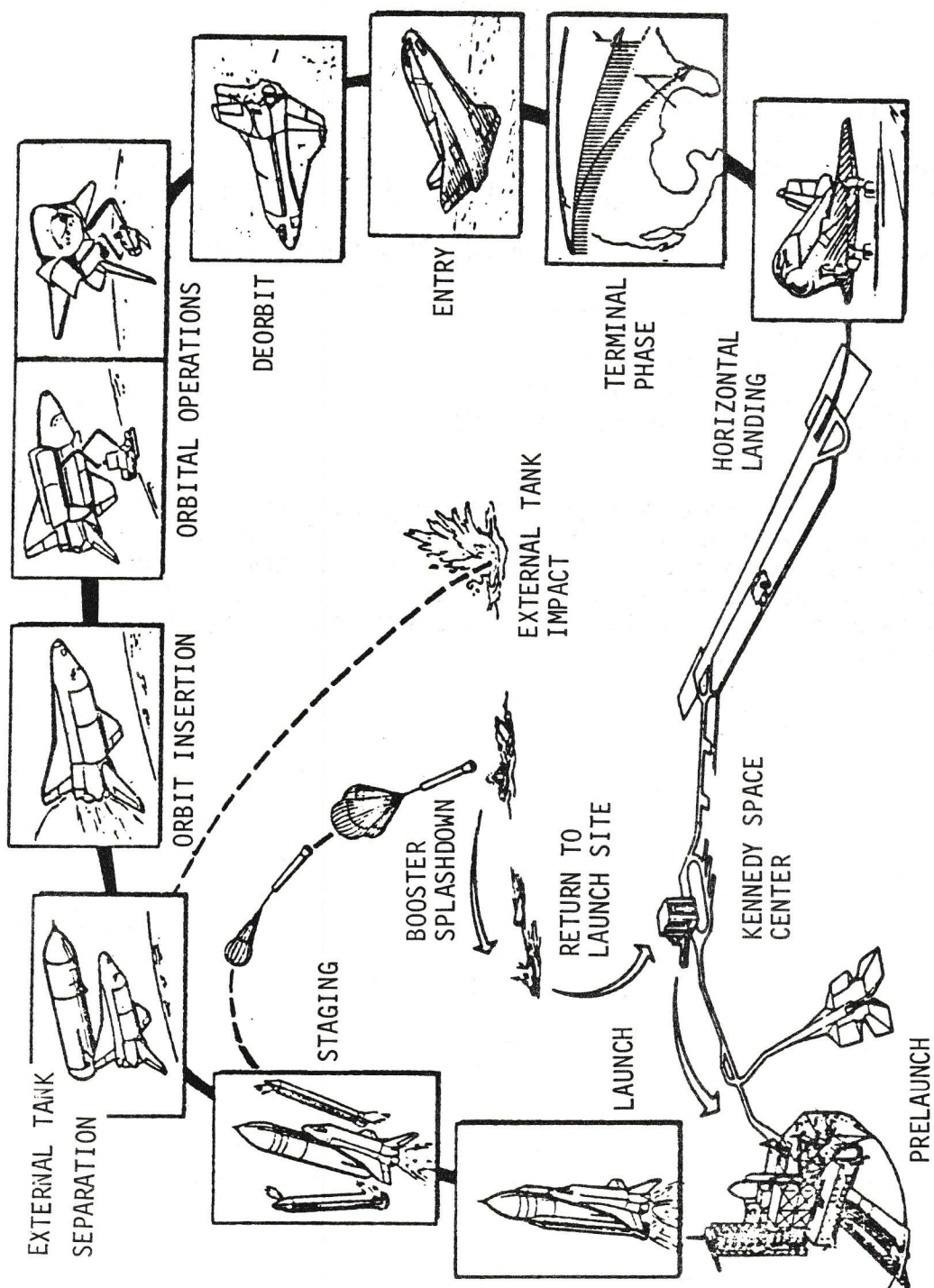


Figure 6-1.- Nominal mission profile.

LAUNCH CO

5

4

3

2

▲ MTU/GMT VERIFICATION
0-4:22:00

CREW INGRESS & HATCH CLOSEOUT 01:05:01

CREW

SRB RGA'

- ▲ SSME CONTROLLER HEATER ON
- ▲ OMS HEATER PWR ON
- ▲ ET RSS PURGE - ON LESS THAN 1% O2 & H2
- ▲ ORB PLB/ET I/T ENG AFT COMPT 1% O2/N2
- ▲ ENG 1, 2 & 3 LO2/LH2 PREVALVES - CLOSED
- ▲ ET/ORB LO2 DISC PURGE - ON
- ▲ HAZARDOUS GAS DETECTION SYS OPERATIONAL
- ▲ VERIFY MLP PURGES - ON
- ▲ ET NOSE CONE ANTI-ICING PURGE - ON
- ▲ LO2 & LH2 T-O CARRIER PLATE PURGE - ON
- ▲ T-5 HR SWITCH LIST COMPLETE
- ▲ LO2 FACILITY CHILLDOWN COMPLETE

PRESSURIZE MPS HE BTL'S TO FLT PRESS 4K

MPS HE BTL'S

MPS ENG 1, 2 & 3 LN2 PREVLVS OPEN
LH2 SYSTEM PRECHILL 03:30:00

SLOW FILL LH2 TO 2% 02:55:00
LH2 FAST FILL TO 88%
LH2 TOPPING TO

1 2/3

SSME HE PUR

FACILITY LO2 XFER SYS CHILLDOWN 04:20:00

▲ MPS ENG 1, 2 & 3 LO2 PREVALVES OPEN 04:50:00

FILL ORBITER LINE ENGINE ET CHILLDOWN 04:30:00

▲ START LO2 XFER SYS INITIAL FILL SEQ 04:30:00

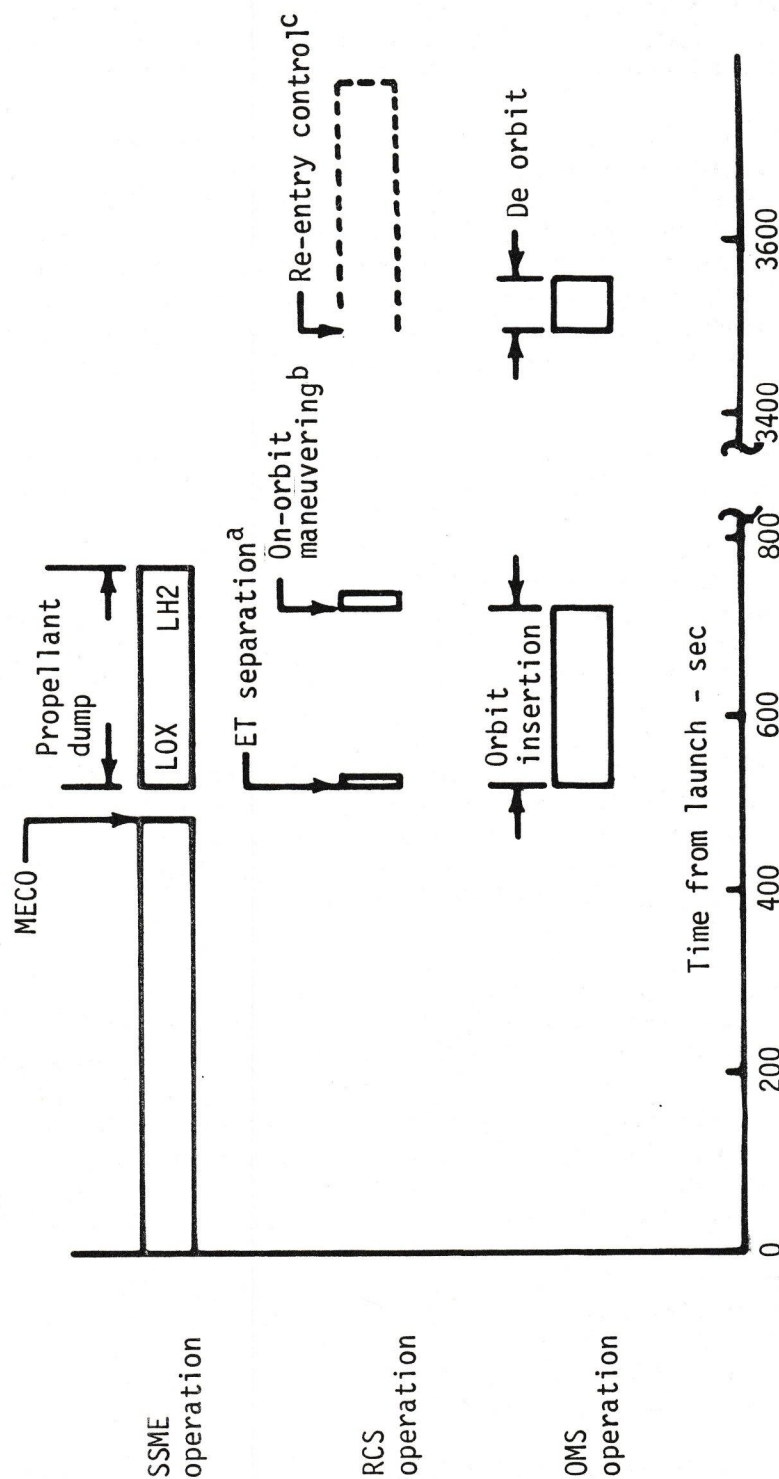
SLOW FILL

FAST FILL LO2 TO
LO2 FILL

COUNTDOWN



Figure 6-2.- Launch countdown.



^aThree aft (-Z) RCS engines burn for 5.43 sec at ET separation.

^bTwo adjacent aft (-Z) RCS engines burn for 16.54 sec at OMS shutdown.

^cOne aft (-Z) RCS engine burns for 1.0 sec at 10 sec after initiation of entry and intermittently thereafter.

Figure 6-3.- The SSME, OMS, and RCS operations timeline.

Most of the MPS functions performed during prelaunch are sequenced through the Launch Processing System (LPS). Crew control inputs are minimal. In the narrative that follows, it will be assumed that all of the prelaunch MPS functions described are sequenced by the LPS unless stated otherwise.

At T-04:20:00, the fast fill portion of the L02 loading sequence will begin and will be followed immediately by the initiation of the fast fill portion of the LH2 loading sequence. By T-02:05:00, the LH2 and L02 tanks will be essentially filled and the corresponding GSE will be operating in a propellant topping mode. Also at T-02:05:00, the LH2 chilldown sequence will be initiated by opening the LH2 recirculation valves and starting the LH2 recirculation pumps. At T-02:03:54 (1 min, 6 sec later), as part of the LH2 chilldown sequence, the LH2 prevalues will close and remain closed until T-00:00:06.

Beginning at T-00:30:00 and continuing for 10 min, the Range Safety System (RSS) on the External Tank (ET) will be checked out and operation of the RSS receiver verified.

At T-00:25:00, the crew will override LPS control of the helium isolation valves by moving the six MPS He ISOLATION switches on panel R2 from the GPC position to the OPEN position. This action will not change the positions of the helium isolation valves, but it will inhibit LPS control of these valves.

At T-02:10:00, the MPS helium supply tanks, which were at 2000 psia for most of prelaunch, will begin to be pressurized to their final lift-off value of 4000 psia. The entire process will require approximately 1 hr, 5 min. MPS purge sequence 4 (fuel system purge) will begin at T-00:04:00, followed closely by the start of the MPS engine gimbaling tests at T-00:03:00.

During the MPS engine gimbaling tests, each gimbal actuator will be operated through a "canned" profile of extensions and retractions. If all actuators function satisfactorily, the MPS engines will be gimbaled to predefined start positions at T-00:02:50. The engines will remain in these positions until after engine ignition. In the predefined start positions, the engines are gimbaled in an outward direction (away from one another) such that the engine start transient will not cause the engine bells to contact one another during the start sequence.

The ET L02 tank pressurization starts at T-00:02:55 when the L02 tank vent valve is closed. Once the valve is closed, the tank is pressurized to 21 psig, using GSE-supplied helium. In a like manner, the ET LH2 tank vent valve will be closed at T-00:01:52 and the LH2 tank pressurized to a value of 42.5 psia, also using GSE-supplied helium.

At T-00:00:25, the onboard automatic Redundant Set (RS) launch sequence will be enabled by the LPS. From this point on, all sequencing will be performed by the GPC's in the redundant set, based on the onboard clock time. The GPC's will, however, still respond to hold, resume count, and recycle commands from the LPS. At T-00:00:15, the GPC's will begin to issue arming commands for the SRB ignition Pyro Initiator Controllers (PIC's), the holddown release PIC's and Time Zero (T-0) umbilical release

(PIC's), the holddown release PIC's and Time Zero (T-0) umbilical release PIC's. When the count reaches T-3.46 sec, if the PIC voltages are within limits and all three engine controllers are indicating ENGINE READY, the GPC's will issue engine start commands to the three SSME's. If the above conditions are not met in 4.0 sec, the engine start commands will not be issued and the GPC's will proceed to a countdown hold condition.

If all three SSME's reach 90 percent of their rated thrust and less than 4 sec have passed since the ignition command was issued, the GPC's will issue the commands to fire the SRB ignition PIC's, the holddown release PIC's and the T-0 umbilical release PIC's. Lift-off occurs almost immediately due to the extremely rapid thrust buildup by the SRB's. The time that the SRB ignition commands are issued is defined as being T-0.

If one or more of the three SSME's do not reach 90 percent of their rated thrust in less than 4 sec from the SSME ignition command, all SSME's will be shut down, the SRB's will not be ignited, and a countdown hold condition will exist. Between lift-off and Main Engine Cutoff (MECO), as long as the SSME's perform nominally, all MPS sequencing and control functions will be executed automatically by the GPC's. During this time period, the crew's main duty will be to monitor MPS performance, back up automatic functions, if required, and provide manual inputs in the event of MPS malfunctions.

Beginning at T-0, the SSME gimbal actuators which were locked in their special preignition positions are first commanded to their null positions for SRB start and then allowed to operate as needed to provide thrust vector control.

The normal SSME thrust (Pc) level setting for lift-off is 100 percent, although some high-orbit missions and missions involving heavy payloads may require the maximum setting of 109 percent. The initial thrust level (Pc) setting is normally maintained until approximately 31 sec into the mission, when the GPC's throttle back the engines to 65 percent. The purpose of the lower throttle setting is to minimize structural loading while the Orbiter is passing through the region of maximum aerodynamic pressure (Q_{max}). Q_{max} normally occurs around 63 sec Mission Elapsed Time (MET). The MET is measured from T-0. At 65 sec MET, the engines are once again throttled to 100 percent and remain at that setting until approximately 00:07:40 MET.

The SRB's will burn out at 00:02:02 MET and will be separated from the Orbiter by GPC command, via the Mission Events Controller (MEC) and the SRB separation PIC's. In the event of a failure in the automatic SRB separation sequence, the crew has the capability to initiate the separation sequence manually.

Beginning at 00:07:40 MET, the engines will be throttled back to maintain vehicle acceleration at, or less than, 3g. The 3g limit is an operational limit devised to prevent excessive physical stresses on the crew. Eight sec before MECO, the engines will be throttled back to the 65-percent level.

At around 00:08:44 MET, assuming that the vehicle has attained the required velocity, the GPC's will issue cutoff commands to the SSME's. The time that all three SSME's confirm that they have received the cutoff command is called "MECO Confirmed."

Once MECO has been confirmed, the GPC's will execute the ET separation sequence. The ET separation sequence requires 11 sec and includes the following major events (listed in chronological order):

1. Arming of separation PIC's
2. Closure of LH2 and LO2 prevalues
3. Firing of ET tumble system pyrotechnic
4. LH2 and LO2 feedline disconnect valve closure
5. Gimbaling of SSME's to MPS propellant dump position (full down)
6. ET signal conditioners power off (dead facing)
7. Firing of umbilical unlatch pyrotechnics
8. Retraction of umbilical plate (hydraulic)

At this point, the GPC's will check for ET separation inhibits. If any of the following conditions are not satisfied, automatic separation will be inhibited:

- o Vehicle pitch rate ≤ 0.2 deg/sec
- o Vehicle roll rate ≤ 0.2 deg/sec
- o Vehicle yaw rate ≤ 0.2 deg/sec

The presence of an automatic separation inhibit will be signified to the crew by the appearance of the message "SEP INH" on the ASCENT TRAJ 1 and 2 displays or RTLS TRAJ 1 and 2 displays. The message will appear over-bright and flash.

If all of the above conditions are met, the GPC's will issue the commands to fire the ET separation pyrotechnics. (Note: In a manual ET separation or RTLS abort, the inhibits will be overridden.)

At separation, the Orbiter will begin an RCS -Z translation separation maneuver to move it away from the ET. This maneuver will take 13 sec and result in a -Z delta component of approximately 11 ft/sec. The ET suborbital trajectory will carry it to an impact location in the Indian Ocean.

The OMS-1 ignition occurs 109 sec after ET structural separation. Coincident with the start of OMS-1, the MPS LO2 dump will begin. During the MPS LO2 dump, pressure from the MPS helium subsystem and vehicle acceleration produced by the OMS burn is used to expel overboard through the bells of

the three SSME's the LO2 trapped in the Orbiter feedlines. At the conclusion of the LO2 dump, the LH2 dump will begin. During the MPS LH2 dump, the trapped LH2 will be expelled through the bells of the SSME's in a manner similar to that of the LO2 dump. After the two dumps, the SSME's will be gimballed to their entry positions. In the entry positions, the bells of the three engines will be moved inward (toward one another) to reduce aerodynamic heating effects during entry.

After the engines are positioned for entry, the crew will safe the MPS. (This is scheduled to occur at 00:15:00 MET.) Safing is done manually and consists of turning off power to the engine controllers and EIU, closing the helium supply isolation valves, and placing the engine controller heaters in the auto mode. Sometime after MPS safing and before entry, the crew will perform vacuum inerting of the MPS. Vacuum inerting is initiated and controlled manually. It allows residual GH2 and GO2 trapped in the MPS manifolds and feedlines to be vented into space through the LH2 and LO2 fill and drain valves.

Just before entry, the crew will use the helium remaining in the helium supply tanks to repressurize the MPS manifolds and feedlines. Repressurization prevents contaminants from being drawn into the manifolds and feedlines during entry. Like vacuum inerting, MPS repressurization is performed manually.

6.2 THE MPS RTLS ABORT SEQUENCE

The RTLS abort is the intact abort mode that provides a suborbital return capability of the Orbiter, crew, and payload directly to the KSC Shuttle landing field within approximately 22 min after lift-off for aborts initiated during the first 278 sec of ascent. The RTLS was basically designed to protect against loss of thrust of a single SSME, but its inherent capabilities also provide a three-SSME return capability for time-critical failures requiring an immediate return on early ascent. A typical RTLS profile and its associated flight phases are presented in figure 6-4. The ET separation is shown in more detail in figure 6-5.

There are three defined abort modes: RTLS, AOA, and ATO, but only the RTLS has any impact on the MPS mission sequence.

An RTLS abort can be initiated anytime between T-0 and 4 min, 38 sec MET (for STS-1). Note that these times are all before nominal MECO. In an RTLS abort, the trajectory is lofted and shaped (fig. 6-4) such that at MECO:

- Only 2 percent of the total propellant remains in the ET.
- The vehicle velocity vector is directed back towards the launch site.
- The vehicle is at the correct altitude and possesses the proper energy to reach the landing site via a "safe" glide path.

The MPS sequencing prior to an RTLS MECO is identical to the nominal case; however, MPS sequencing after an RTLS MECO is significantly different from the nominal case. Due to the short length of time available before reaching the reentry interface, the MPS propellant dump timeline has been compressed and some of the nominal post-MECO events eliminated entirely. Table 6-1 details the differences between an MPS RTLS abort sequence and an MPS nominal ascent sequence.

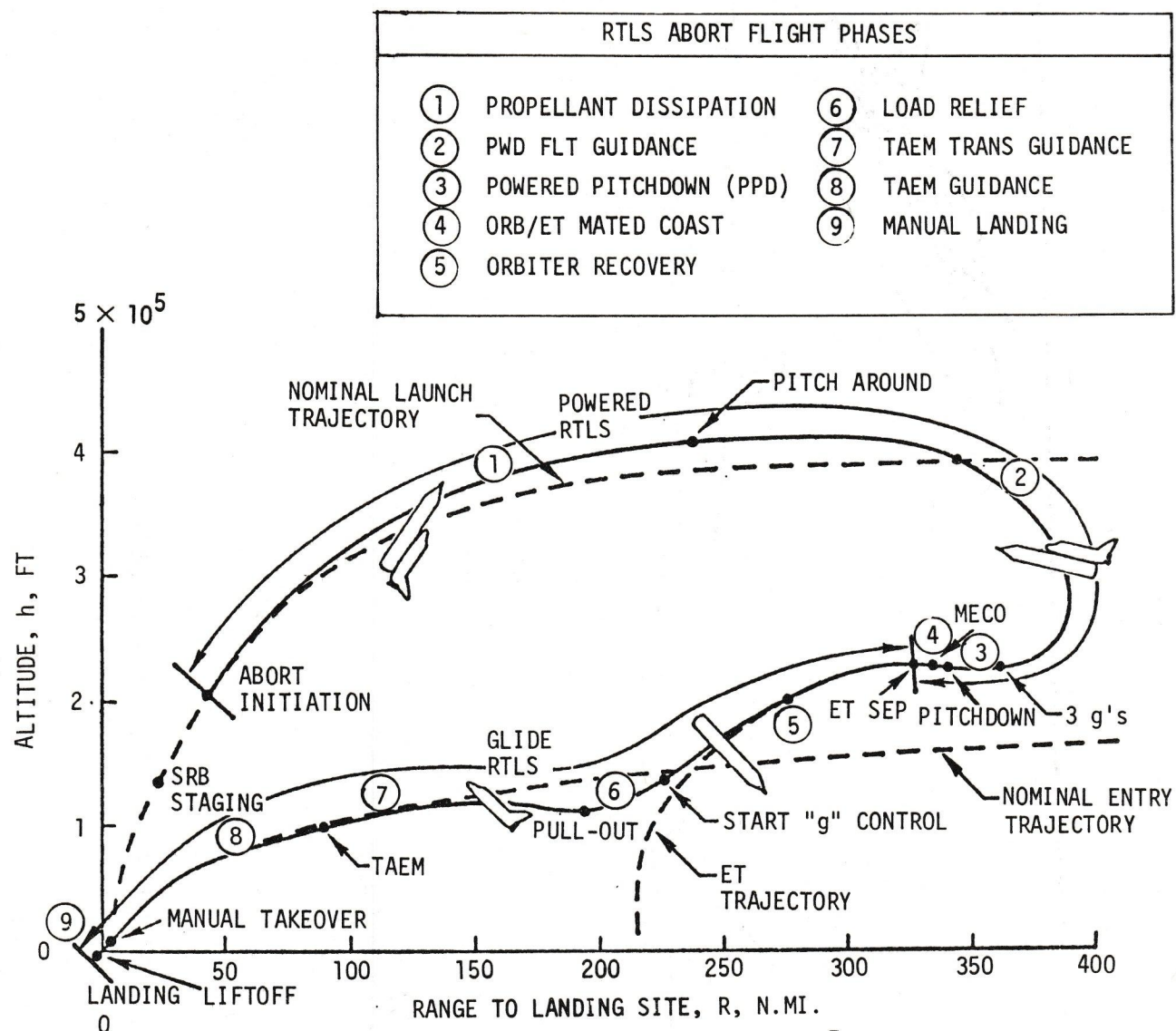


Figure 6-4.- Typical RTLS profile.

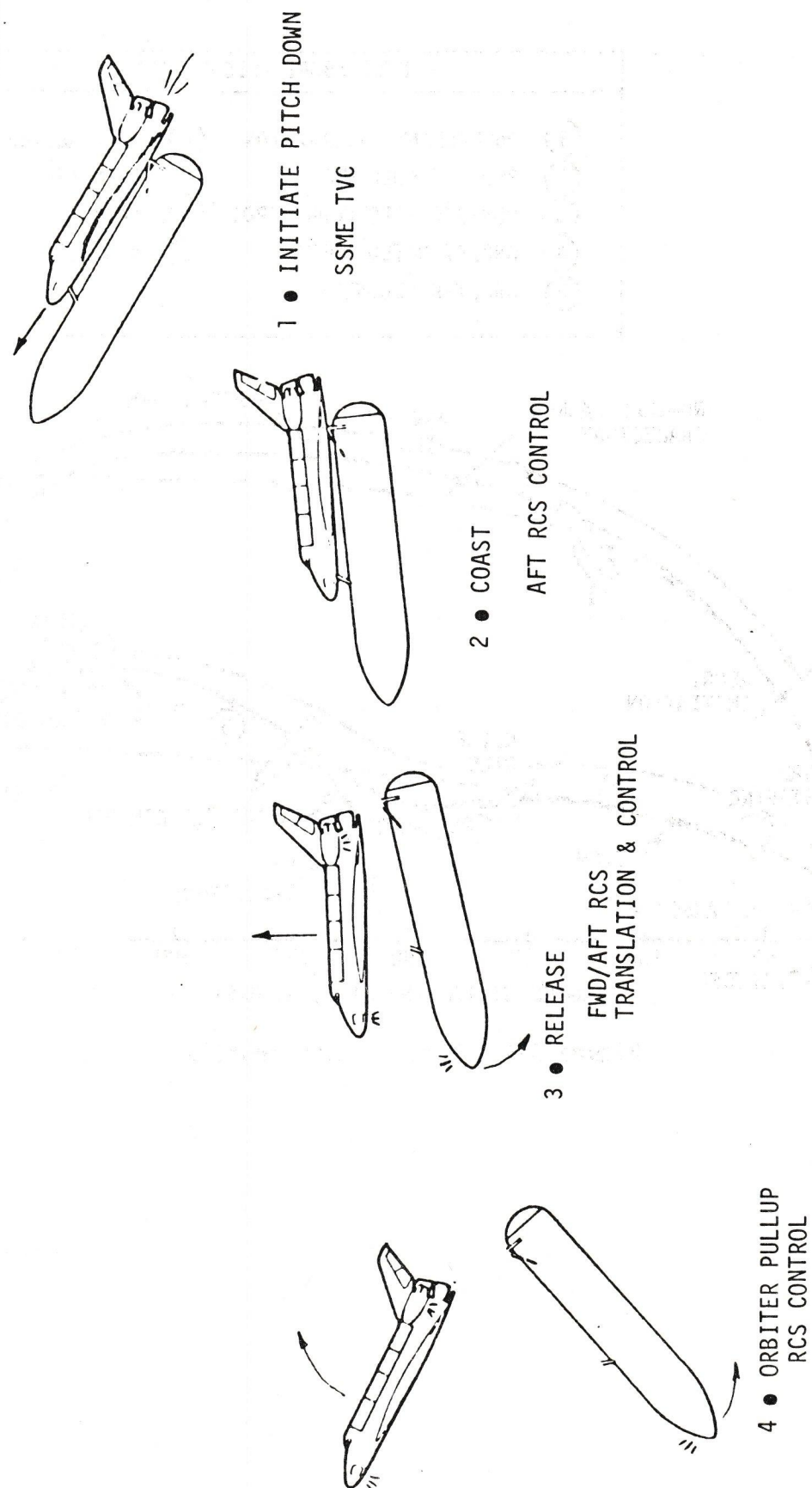


Figure 6-5.- The ET separation (RTL).

TABLE 6-1.- DIFFERENCES BETWEEN MPS RTLS ABORT SEQUENCE AND
MPS NOMINAL ASCENT SEQUENCE

MPS RTLS abort sequence	MPS nominal ascent sequence
RTLS MECO based on percentage of total propellant remaining.	Nominal MECO based on velocity.
SSME's gimbaled to entry stow position at MECO.	SSME's gimbaled to dump position at MECO.
Three sec allowed for Orbiter umbilical plate retraction after ET/umbilical unlatch.	Seven sec allowed for Orbiter umbilical plate retraction after ET/umbilical unlatch.
Angle-of-attack, sideslip angle, and vehicle rates checked for automatic ET separation.	Only vehicle rates checked for inhibits for automatic ET separation.
Disconnect valve position is not an automatic ET separation inhibit.	Any disconnect valve not closed is an automatic ET separation inhibit.
Automatic ET separation sequence bypasses all separation inhibits after 6-sec delay.	Automatic ET separation sequence does not bypass separation inhibits.
RCS jets not inhibited from firing during ET structural separation.	RCS jets inhibited from firing during ET structural separation.
ET umbilical doors closed and latched automatically.	ET umbilical doors closed and latched by manual crew input.
MPS propellant dump starts at ET separation + 10 sec.	MPS propellant dump will start at ET separation +109 sec.
MPS propellant dumps always performed automatically, regardless of position of the propellant dump switches.	MPS propellant dumps will perform automatically as long as the propellant dump sequence switches (panel R2) are in the GPC position.
L02 dump and LH2 dumps initiated simultaneously.	L02 dump initiated first and the LH2 dump is initiated when the L02 dump is completed.
L02 dump terminated after 280 sec or 100k ft, whichever occurs first.	The L02 dump is terminated after 105 sec.

TABLE 6-1.- DIFFERENCES BETWEEN MPS RTLS ABORT SEQUENCE AND
MPS NOMINAL ASCENT SEQUENCE - Concluded

MPS RTLS abort sequence	MPS nominal ascent sequence
LH2 dump terminated at 100k ft.	The LH2 dump is terminated after 57 sec.
LH2 dumped overboard through special RTLS dump port.	LH2 is dumped overboard through the engine bells.
SSME's already in entry stow position at termination of MPS propellant dumps.	SSME's positioned in a dump position followed by a reposition to the entry stow position.
Crew is "heads up" at ET separation.	Crew is "heads down" at ET separation.

APPENDIX A ACRONYM LIST

AOA	Abort Once Around	MCC	Main Combustion Chamber
ATO	Abort To Orbit	MDM	Multiplexer-Demultiplexer
ATVC	Ascent Thrust Vector Control	ME	Main Engine
		MFV	Main Fuel Valve
CCV	Chamber Coolant Valve	MMU	Master Measurements Unit
CDF	Confined Detonating Fuse	MNT RCDR	Maintenance Recorder
CIA	Computer Interface Adapter	MOV	Main Oxidizer Valve
CMD	Command	MPL	Minimum Power Level
CRT	Cathode Ray Tube	MPS	Main Propulsion System
C&W	Caution and Warning		
		NC	Normally Closed
EIU	Engine Interface Unit	NO	Normally Open
EMR	Engine Mixture Ratio	NSI	NASA Standard Initiator
EPS	Electrical Power System		
ET	External Tank	OBV	Oxidizer Bleed Valve
		OI	Operational Instrumentation
FBV	Fuel Bleed Valve	OMS	Orbital Maneuvering System
FC	Flight-Critical	OPB	Oxidizer Preburner
FC 5	Flight-Critical Data Bus 5	OPOV	Oxidizer Preburner Oxidizer Valve
FC 6	Flight-Critical Data Bus 6		
FC 7	Flight-Critical Data Bus 7		
FC 8	Flight-Critical Data Bus 8	PAV	Pressure Actuated Valves
FPB	Fuel Preburner	Pc	Chamber Pressure
FPL	Full Power Level	PCA	Pneumatic Control Assembly
FPOV	Fuel Preburner Oxidizer Valve	PCM	Pulse Code Modulation
		PIC	Pyrotechnic Initiator Controller
GCV	Gaseous Oxygen Control Valve		
GH2	Gaseous Hydrogen	RCS	Reaction Control System
GND	Ground	RIV	Recirculation Isolation Valve
GO2	Gaseous Oxygen		
GPC	General Purpose Computer	RPC	Remote Power Controller
GSE	Ground Support Equipment	RPL	Reference Power Level
		RS	Redundant Set (Computers)
HGM	Hot Gas Manifold	RSS	Range Safety System
HPFT	High Pressure Fuel Turbopump	RTLS	Return to Landing Site (Abort)
HPV	Helium Precharge Valve		
		S&A	Safe and Arm
LH2	Liquid Hydrogen	SM	System Management
LO2	Liquid Oxygen	SOP	Subsystem Operating Program
LPFT	Low Pressure Fuel Turbopump	SRB	Solid Rocket Booster
LPOT	Low Pressure Oxidizer Turbopump	SSME	Space Shuttle Main Engine
LP RCDR	Loop Recorder	SSMEC	Space Shuttle Main Engine Controller
LPS	Launch Processor System		
LRU	Line Replaceable Unit		
LSC	Linear Shaped Charge		
LVDT	Linear Variable Differential Transformer	TLM	Telemetry
		TVC	Thrust Vector Control

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