

1.1 SSME OVERVIEW

1.1.1 Introduction

The orbiter vehicle main engine propulsion system consists of three space shuttle main engines (SSME's). They are grouped in a cluster of three and are attached to the rear of the orbiter, aft of the payload bay compartment. The SSME's are re-usable, high performance, rocket engines with variable thrust. They use liquid hydrogen and liquid oxygen as propellants. Ignited on the ground at launch, they operate in parallel with the solid rocket boosters (SRB's) during the initial ascent phase, continuing for a total firing duration of approximately 520 seconds.

Each of the rocket engines operates at a mass mixture ratio (lbs./sec. liquid oxygen/lbs./sec. liquid hydrogen) of approximately 6:1 and a main combustion chamber pressure of approximately 2,747 psia (at 100% rated power level). At rated power level (RPL) each engine provides a sea level thrust of approximately 375,000 lbs. and a vacuum thrust of approximately 470,000 lbs. The engines can be throttled over a thrust range of 67 to 104 percent of the RPL. Full power level (FPL), 109 percent of RPL, can be commanded via an item entry on SPEC 51, the override crew CRT display. With the OI-28 updates there are now three throttle selections on SPEC 51. These selections are max throttles, abort throttles, and nominal throttles. Currently, the I-load for max throttles is 109%, and the I-loads for abort and nominal throttles are 104%. As of April 2003, an effort is underway to change the abort throttle level to 109%, but it is unclear if that change will be made. The engines are gimballed ($\pm 10.5^\circ$ for pitch and $\pm 8.5^\circ$ for yaw) to provide pitch, yaw, and roll control during the orbiter boost phase.

The SSME design features a staged-combustion power cycle with high combustion chamber pressures. This design was significant in meeting performance requirements. RPL operation is at a main combustion chamber pressure of approximately 2,747 psia and at 104.5% power level, the MCC chamber pressure is approximately 2,870 psia. In the SSME staged-combustion cycle, the propellants are partially burned at high pressure (5,000 psia) 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. The nozzle has an expansion ratio of 77.5 to 1. The specific impulse performance (ISP) of about 452.5 seconds is greater than any previous large thrust rocket engine. Hydrogen fuel is used to cool all combustion devices directly exposed to high-temperature combustion products. Engine weight is approximately 7,400 lbs and an electronic engine controller automatically performs engine checkout, start, mainstage, shutdown, and post-shutdown functions.

1.1.2 Space Shuttle Main Engine Types

Currently (2003) there is one type of SSME in the fleet; Block II. In the past there were First Manned Orbital Flight (FMOF), Phase 1, Phase II, Block I, Block IA, and Block IIA SSMEs. The modifications made to these original engine designs were to improve the safety and the reliability of the engine. The modifications from the Phase II engine to the Block I engine included a new high-pressure oxidizer turbopump (HPOTP), two-duct powerhead, and single coil heat exchanger. The thrust and ISP for the two types of SSME's were approximately equal. The modification between the Block IA SSME and the Block IIA was a larger throat MCC. And the newest Block II engine adds a new Pratt & Whitney high-pressure fuel turbopump (HPFTP) to the Block IIA engine.

1.1.3 Schematics

Systems briefs in Section 1 contain descriptions of flows, hardware, software, redlines, and controls of the SSME systems. The following drawings are overviews of the main engine propulsion system.

Figure 1.1-I - Orbiter main propulsion system.

Figure 1.1-II - SSME propellant flow schematic.

Figure 1.1-III - SSME major components.

Figure 1.1-IV - SSME component location (looking aft).

Figure 1.1-V - SSME installation/orientation and interfaces (looking aft).

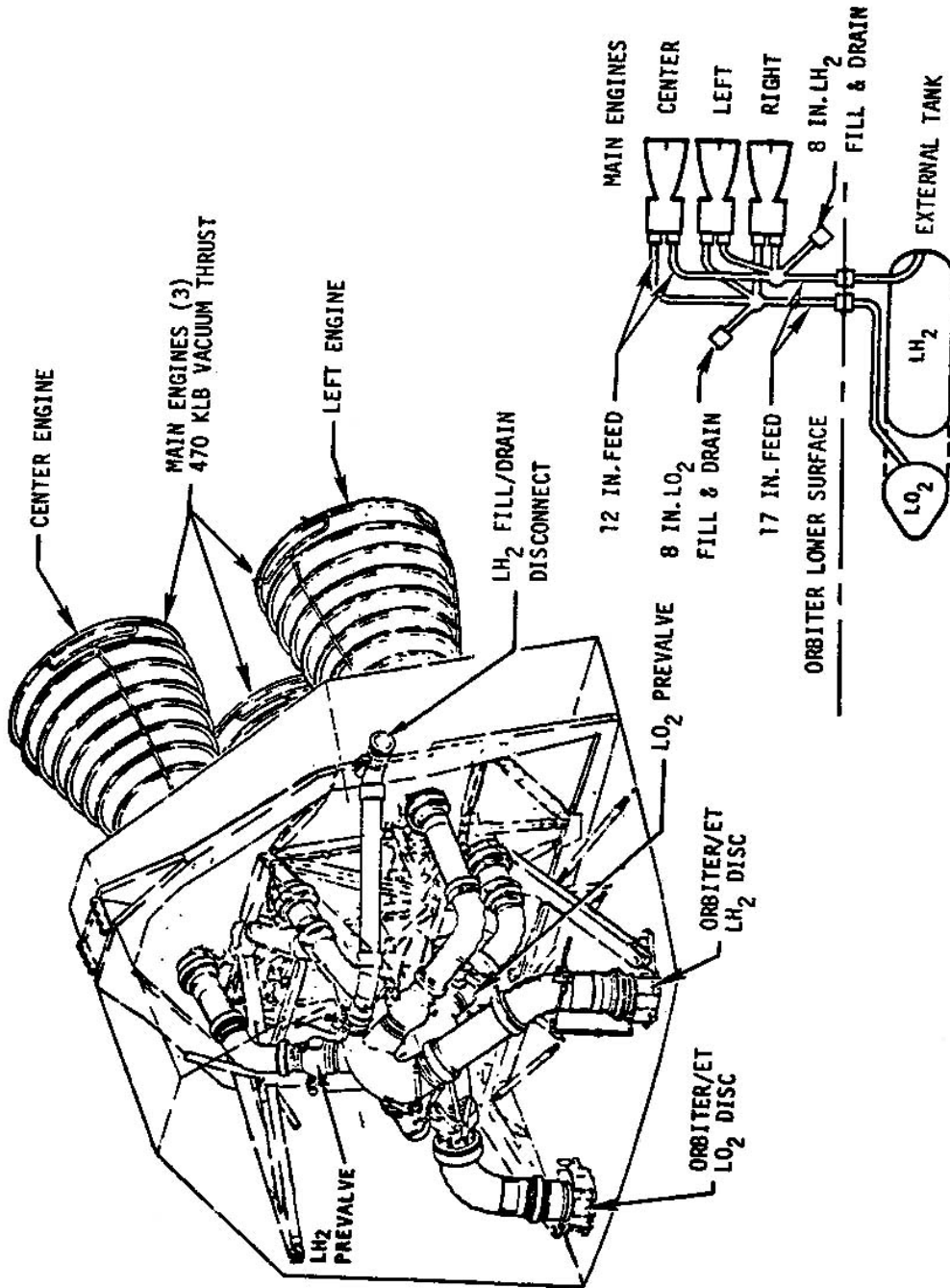


Figure 1.1-1. - Orbiter main propulsion system.

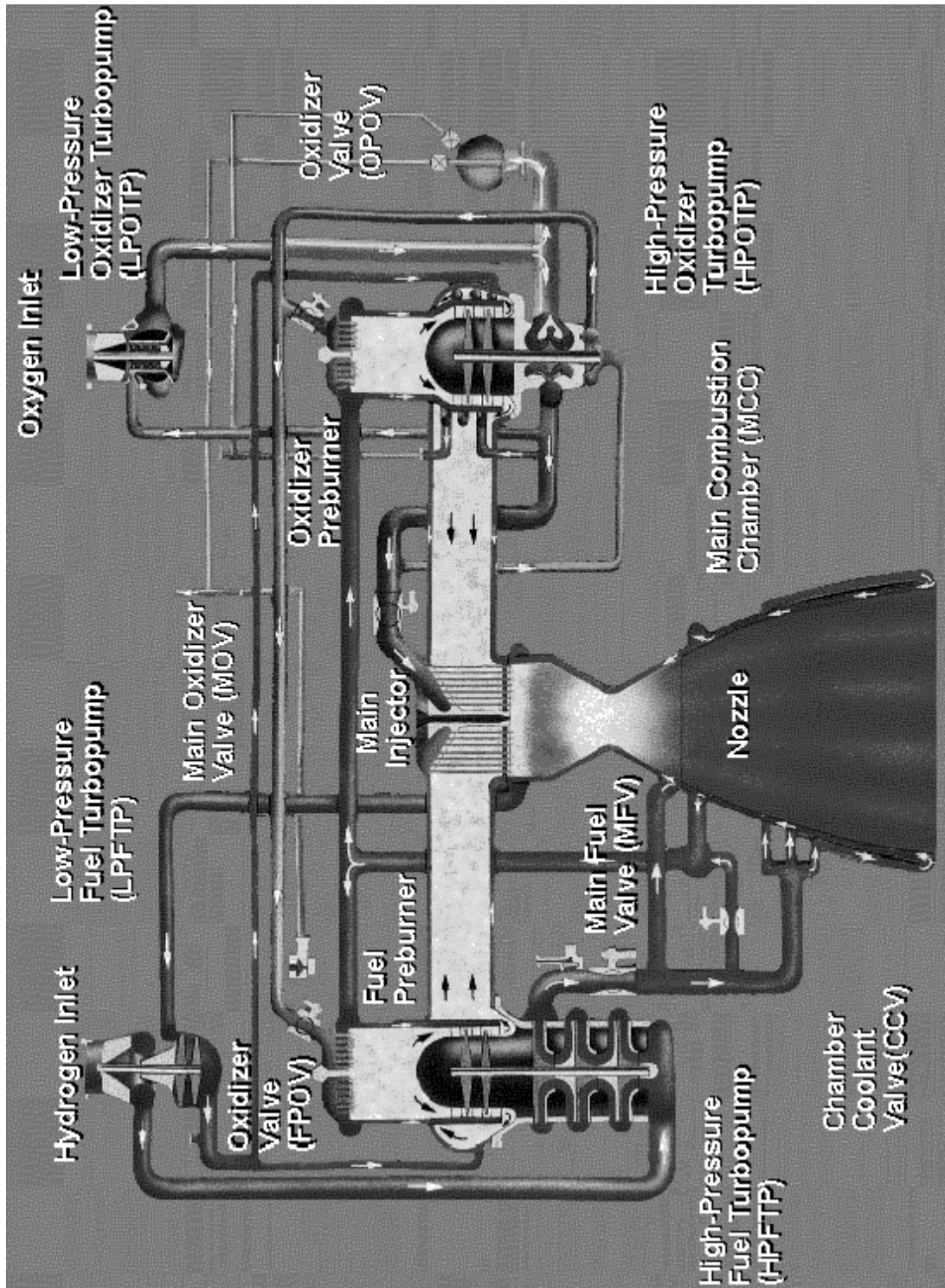


Figure 1.1-II - SSME propellant flow schematic.

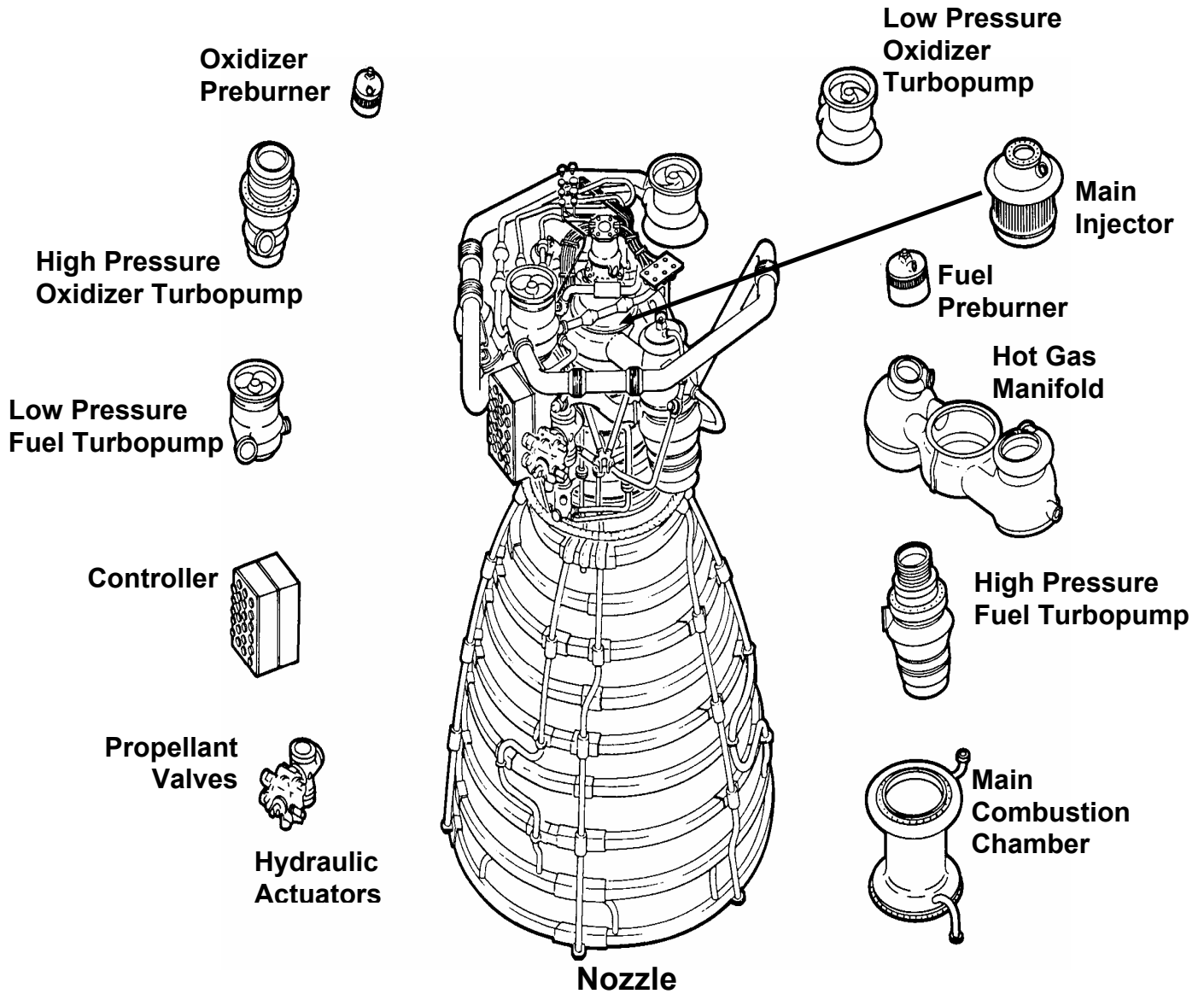


Figure 1.1-III – SSME major components.

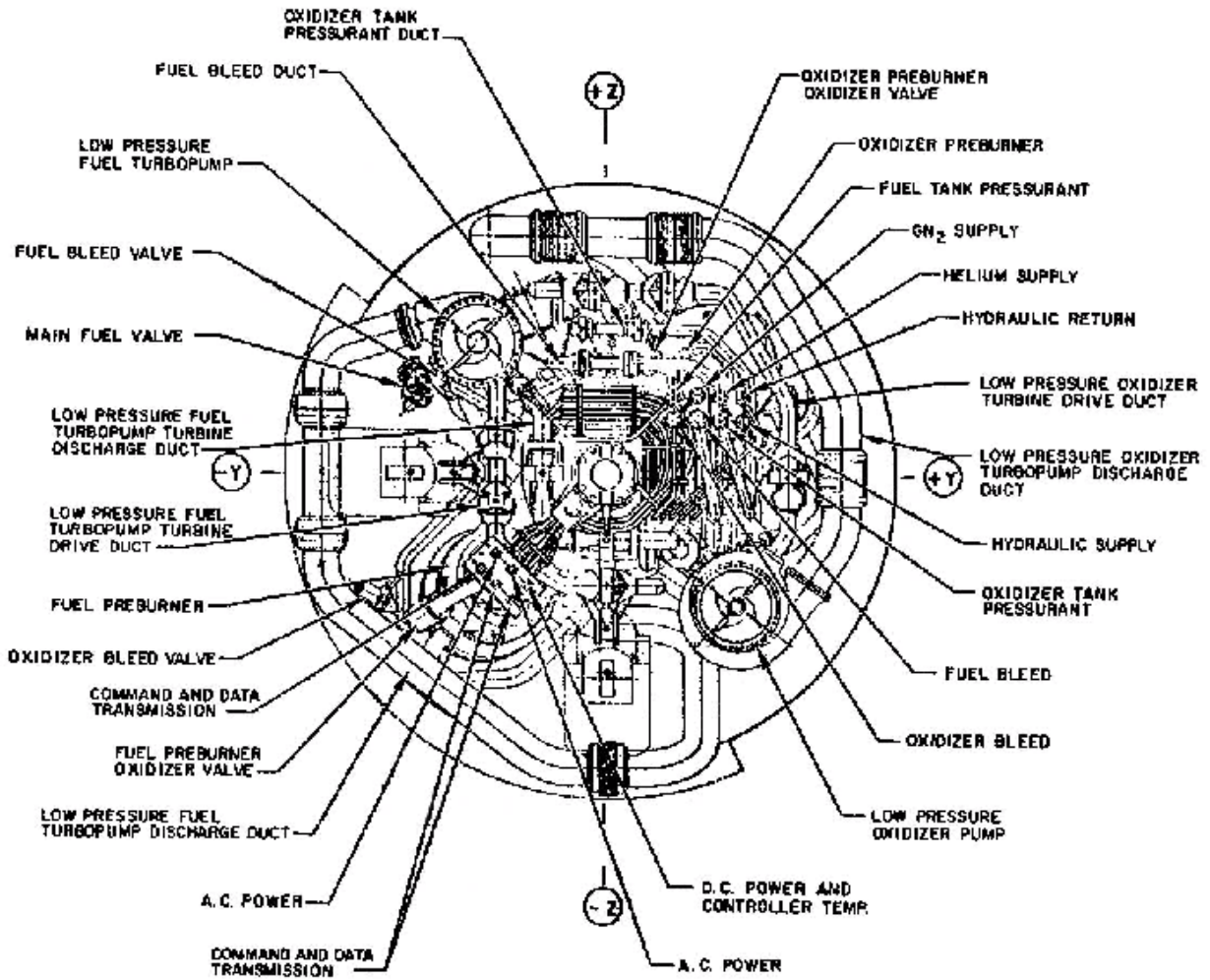


Figure 1.1-IV - SSME component location (looking aft)

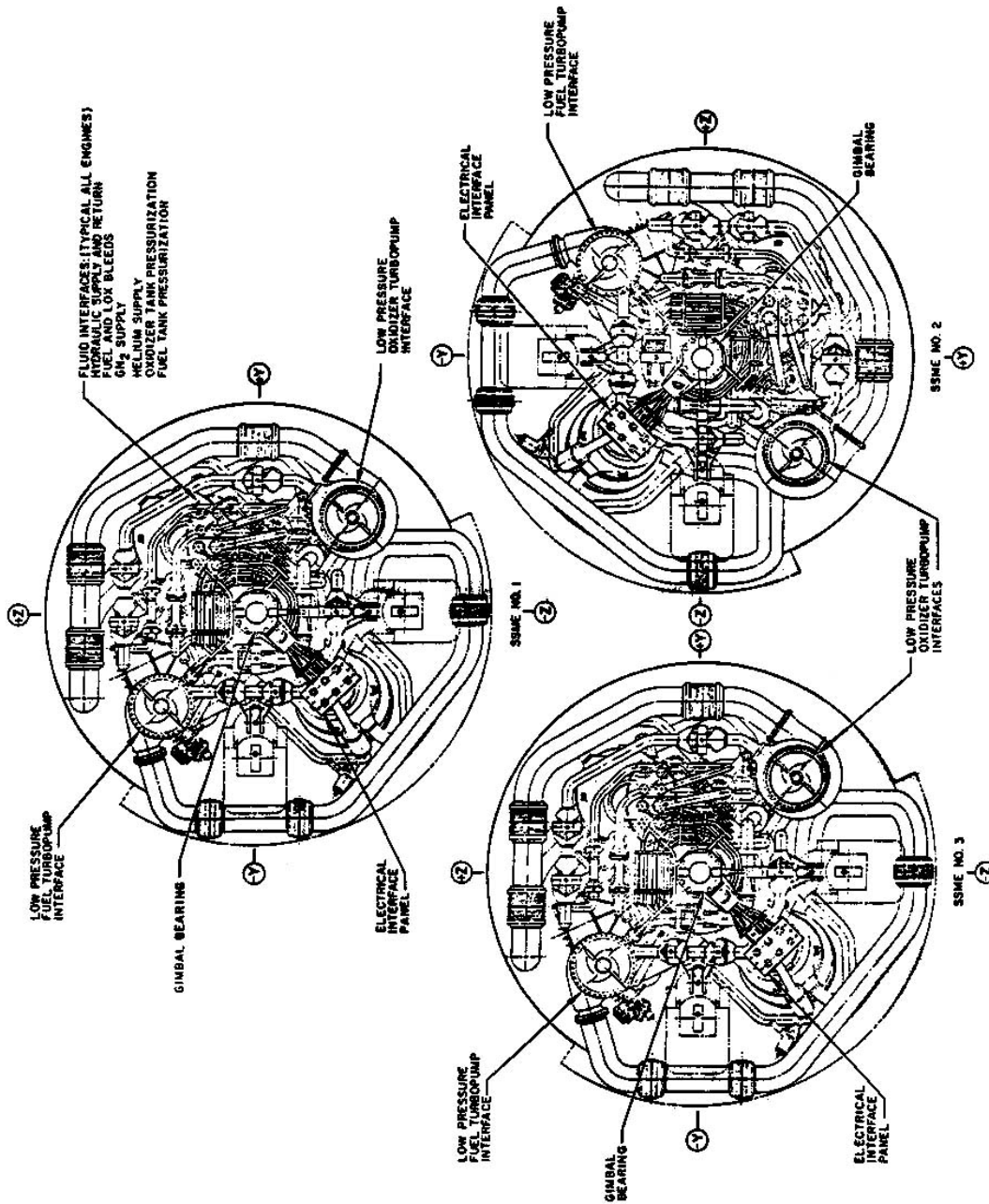


Figure 1.1-V. – SSME installation orientation and interfaces (looking aft).

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1.2 SSME PROPELLANT FLOW

1.2.1. Overview/General Description

The SSME (Figure 1.2-1) uses a staged combustion cycle in which propellants are partially burned at high pressures and relatively low temperatures in the preburners and then completely burned at high pressure and temperature in the main combustion chamber (MCC).

The propellant system uses four turbopumps. The two low-pressure turbopumps operate at relatively low speed to allow low ullage pressures in the propellant 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 high-pressure oxidizer turbopump (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 turbine powering the low-pressure oxidizer turbopump (LPOTP) and is then recirculated to the inlet of the HPOTP.

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

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

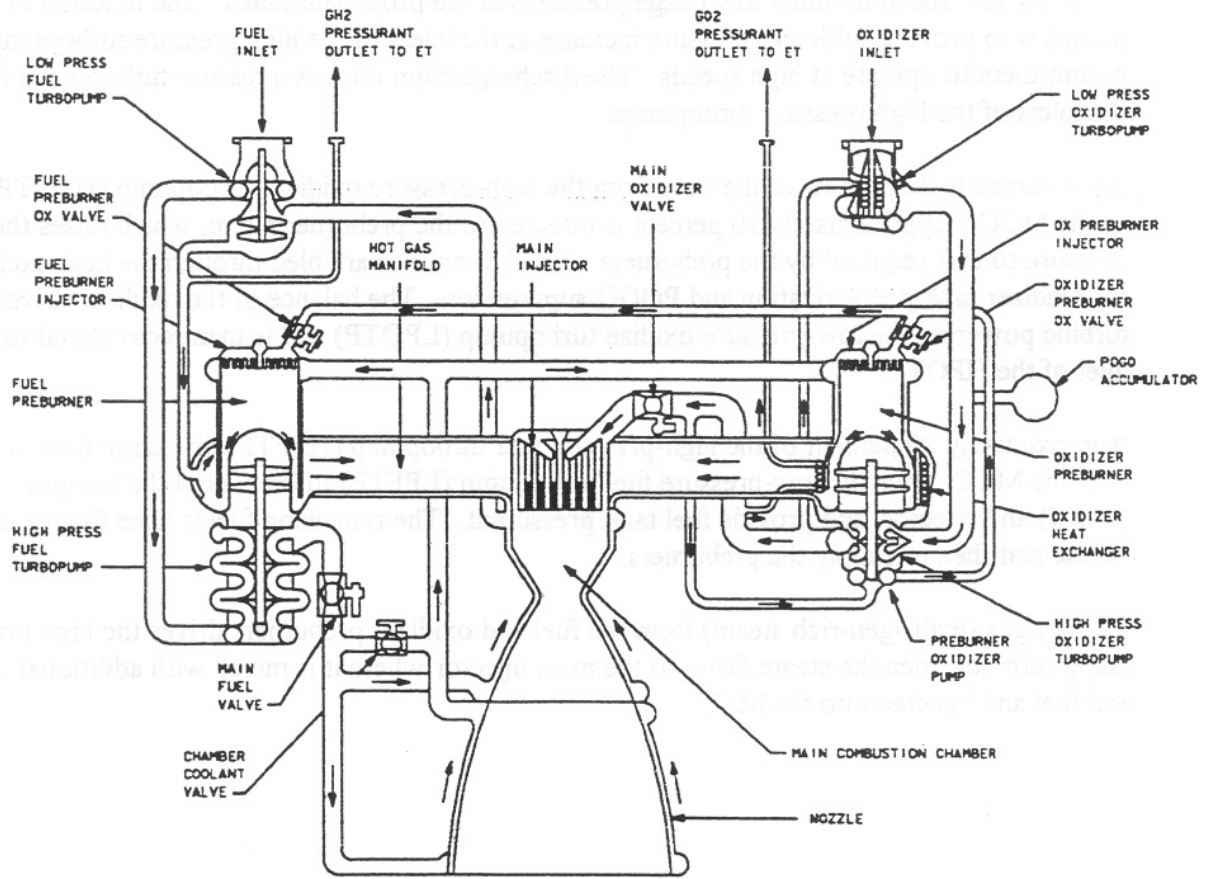


Figure 1.2-I – The SSME propellant flow schematic

1.2.2 Propellant Flow System Components

1.2.2.1 *Hot-Gas Manifold (HGM)*

The hot-gas manifold (Figure 1.2-II) conducts hot gas (hydrogen-rich steam) from the turbines to the main injector elements of the main chamber injector. The area between the wall and the liner provides a coolant flow path for the hydrogen gas that exhausts from the LPFTP 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. The LPFTP turbine exhaust gas is also the coolant for the primary faceplate, the secondary faceplate, and the injector baffle elements.

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 (OPB) 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. Two 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 (FPB) is welded to the upper end of the fuel side of the HGM.

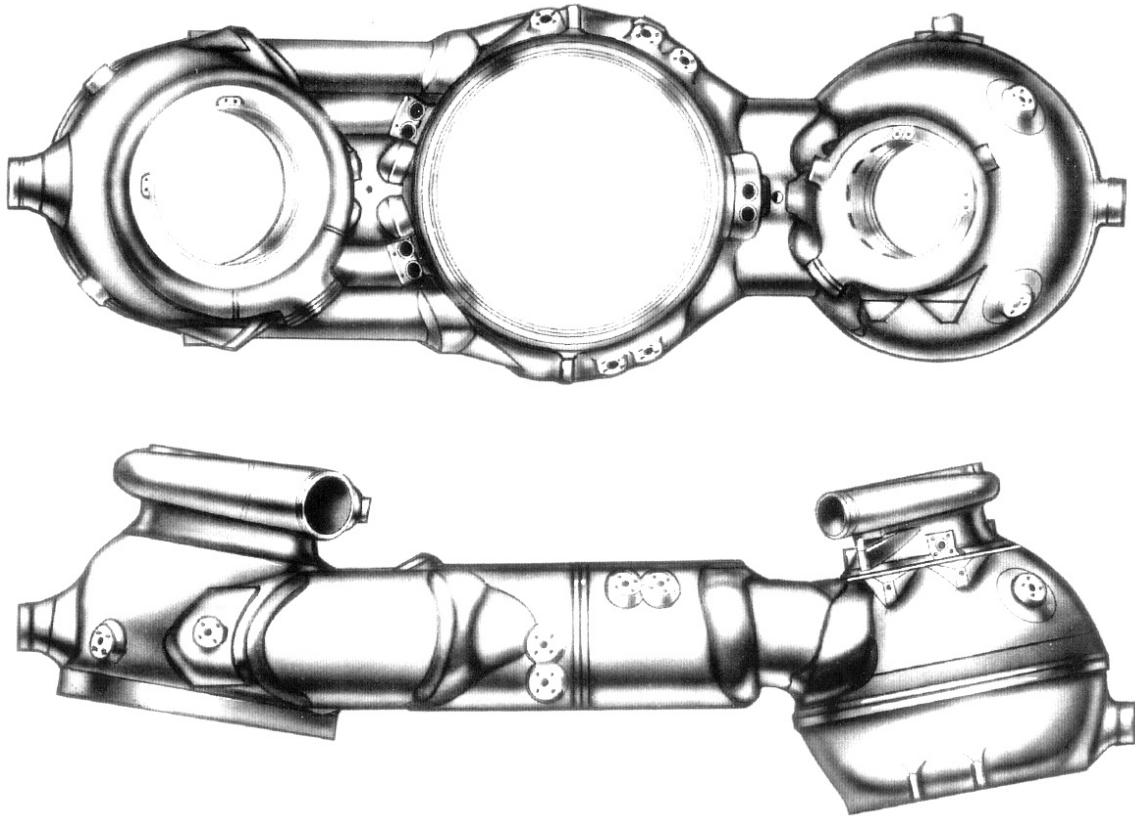


Figure 1.2-II – SSME Hot Gas Manifold (Ref. 1)

1.2.2.2 Preburners

Two preburners 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 flow rate with the preburner oxidizer valves. There are both a fuel preburner (Figure 1.2-III) and an oxidizer preburner (Figure 1.2-IV).

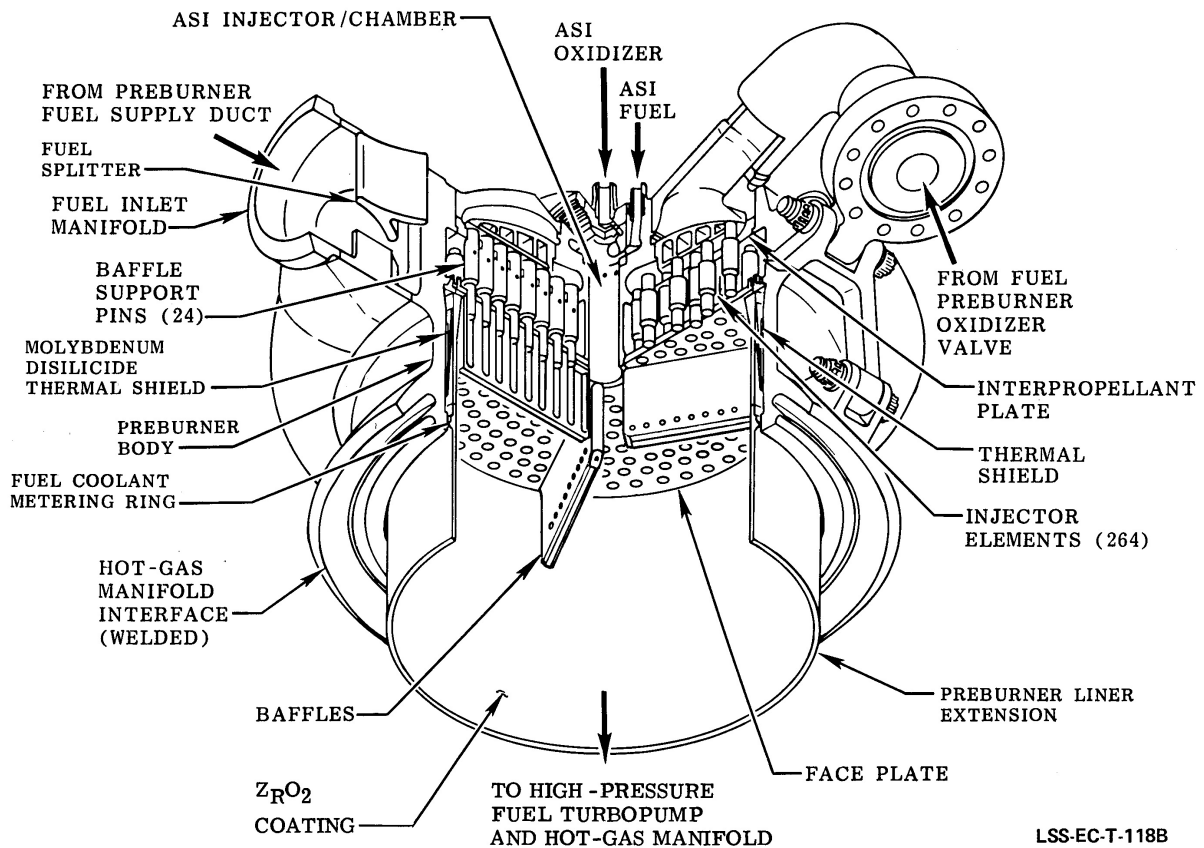
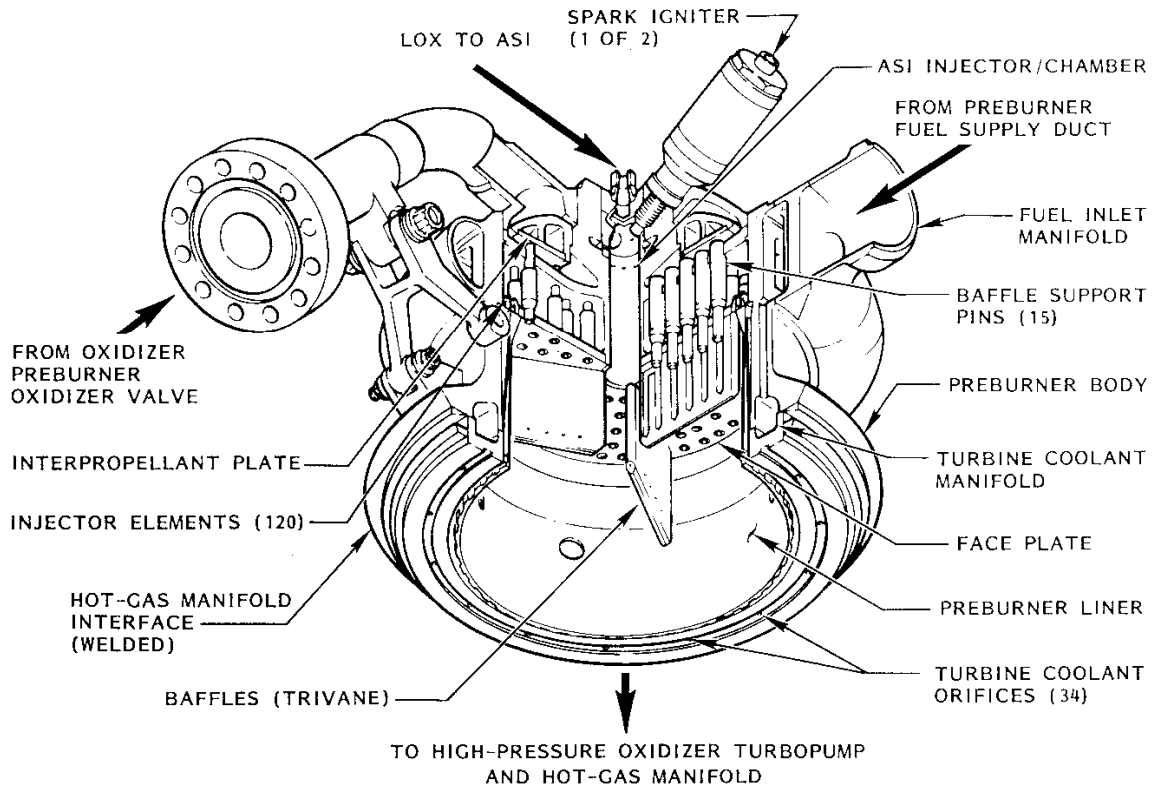


Figure 1.2-III – Fuel Preburner (Ref. 2)

OXIDIZER PREBURNER



LSS-EC-T-119B

Figure 1.2-IV – Oxidizer Preburner(Ref. 2)

1.2.2.3 Main Injector

The main injector (Figure 1.2-V) receives liquid oxygen from the HPOTP (via the high pressure oxidizer duct and the main oxidizer valve), cold hydrogen gas from the hot-gas manifold coolant circuit, and fuel-rich hot gas from the fuel and oxidizer preburners (via the hot-gas manifold). The main injector then efficiently mixes all these fluids and uniformly distributes them to the MCC for additional combustion.

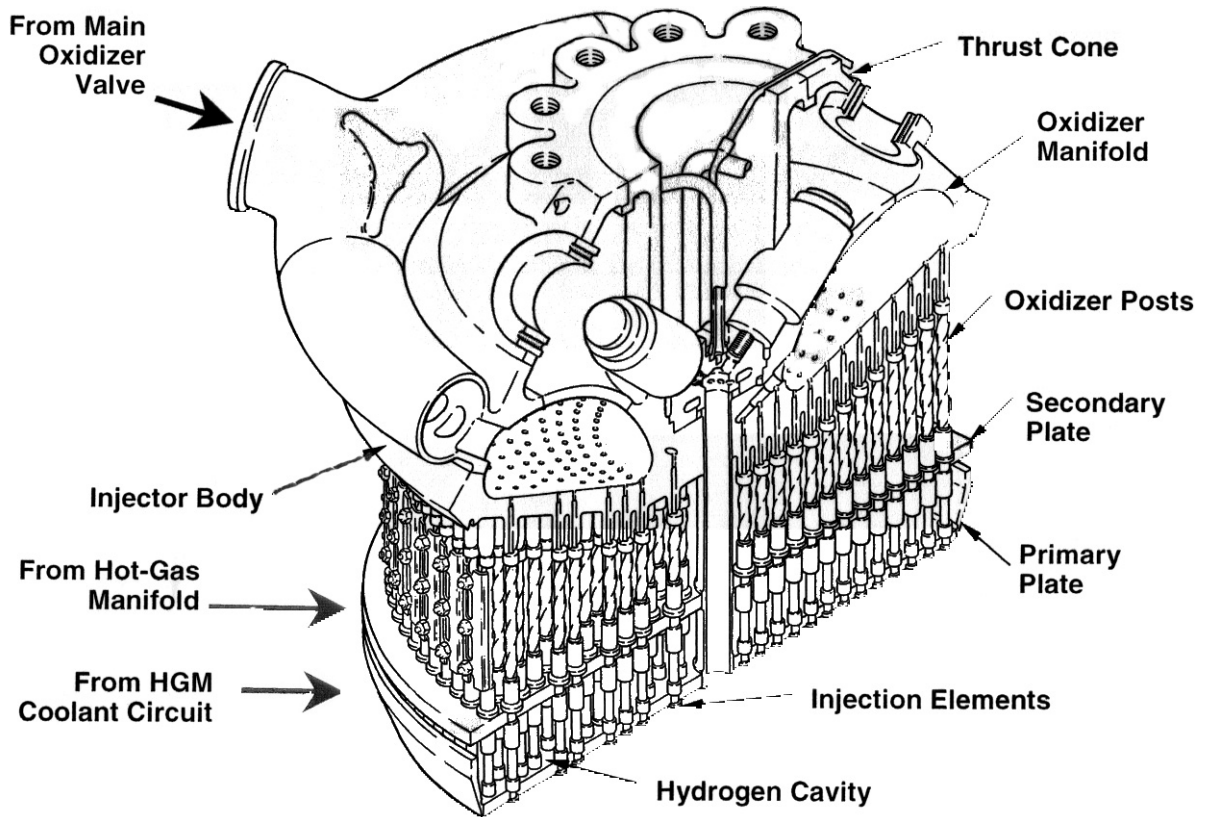


Figure 1.2-V – Main Injector (Ref. 3)

1.2.2.4. - Main Combustion Chamber

The MCC (Figure 1.2-VI) receives propellants from the main injector, contains free burning propellant gases, and initiates their expansion from the chamber to the throat at a ratio of 4.48:1. The chamber coolant liner provides the coolant flow path for the MCC. The channels are ported to the coolant inlet and outlet manifolds of the chamber jacket to provide an up-pass circuit for MCC fuel coolant.

MAIN COMBUSTION CHAMBER

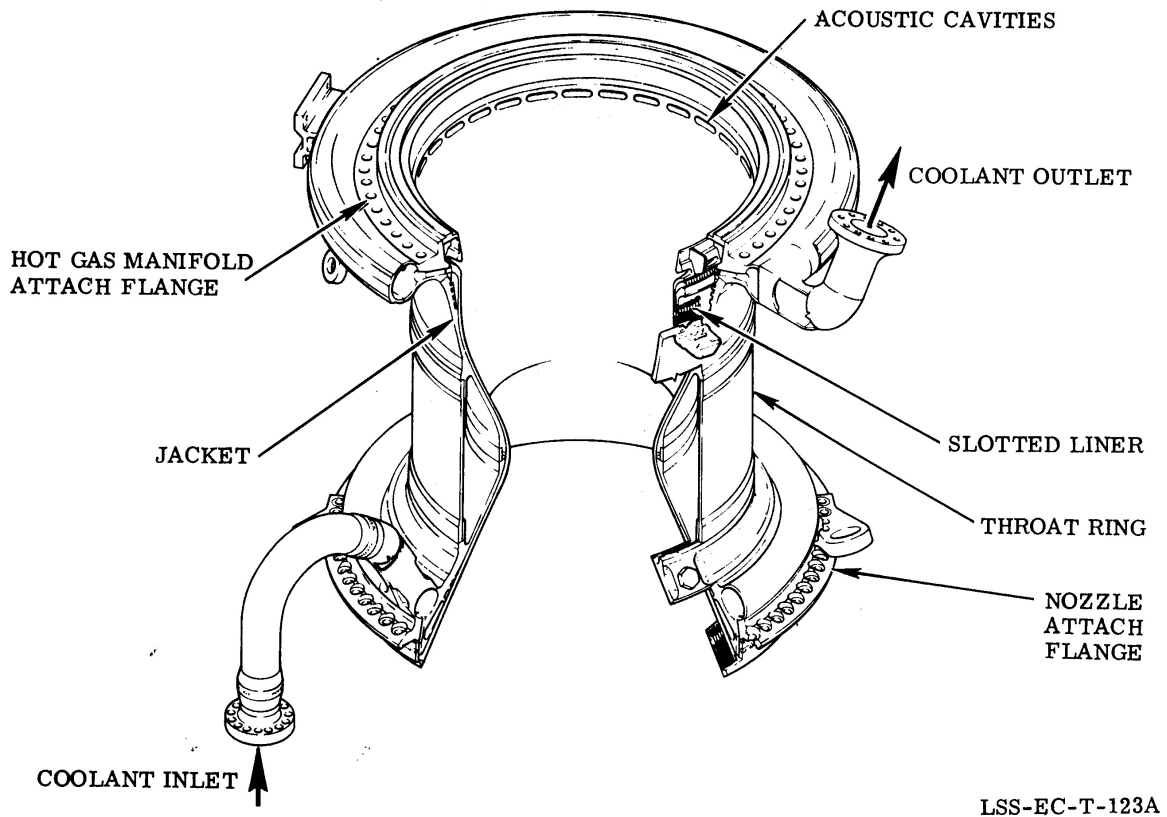


Figure 1.2-VI – Main Combustion Chamber (Ref. 2)

1.2.2.5. Nozzle Assembly

The SSME nozzle (Figure 1.2-VII) consists of 1,080 stainless steel tubes, a structural jacket, 9 hatbands, a coolant inlet manifold, a coolant outlet manifold, 3 fuel transfer ducts, 3 steerhorns, a diffuser, a mixer, and 6 drain lines. The nozzle subassembly provides an up-pass cooling circuit between the inlet and outlet manifolds. The diffuser inlet (Figure 1.2-VIII) interfaces with the downstream end of the main fuel valve (MFV) and distributes hydrogen to the fuel circuits. The diffuser directs fuel to the three fuel transfer ducts, the MCC coolant inlet manifold, the chamber coolant valve (CCV), and the augmented spark igniters (ASIs). Fuel flowing through each transfer duct splits at each steerhorn to enter the nozzle coolant inlet manifold at six points. The hydrogen through the nozzle coolant circuit is then directed to a mixer where it joins the bypass flow from the CCV. The resulting hydrogen flow is used as the fuel for the preburners.

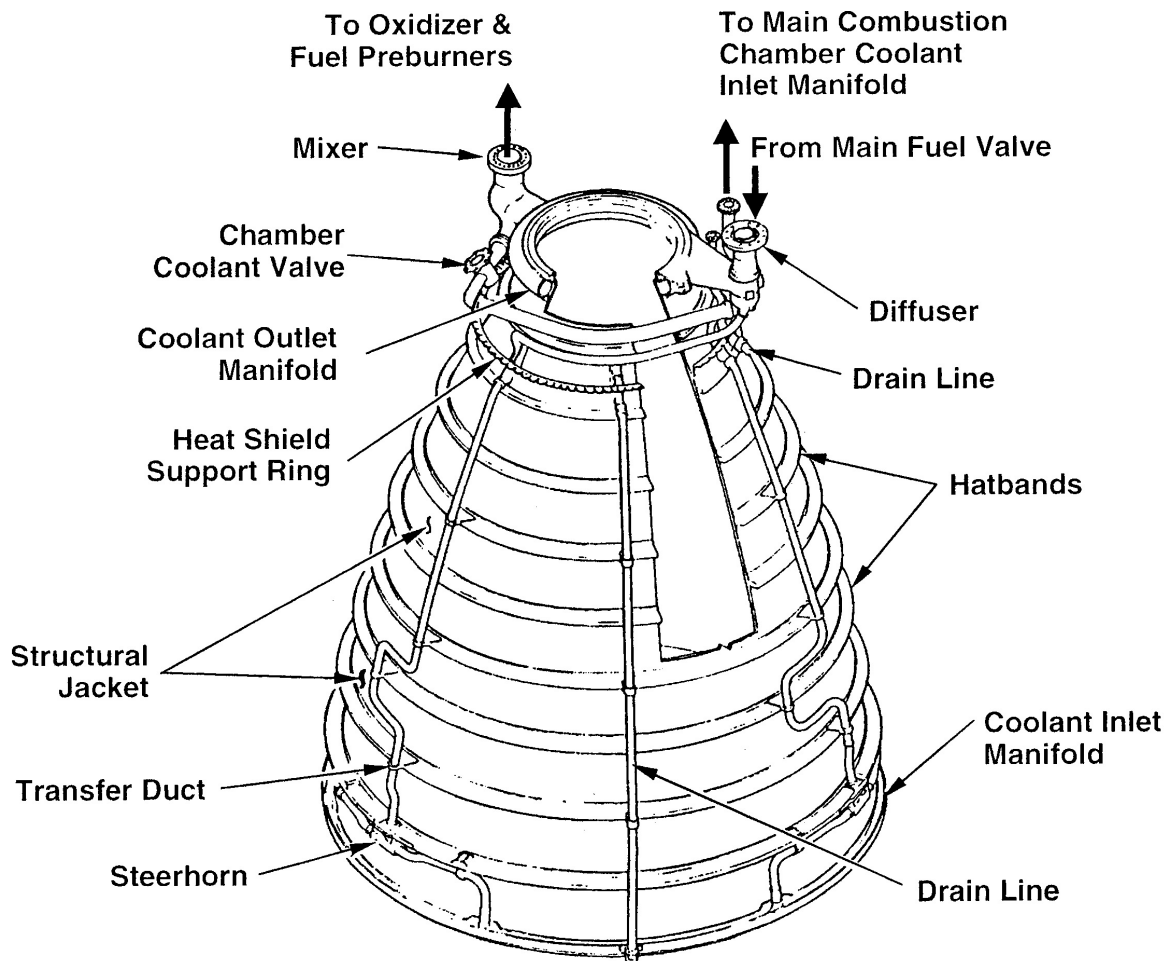


Figure 1.2-VII – Nozzle Assembly (Ref. 3)

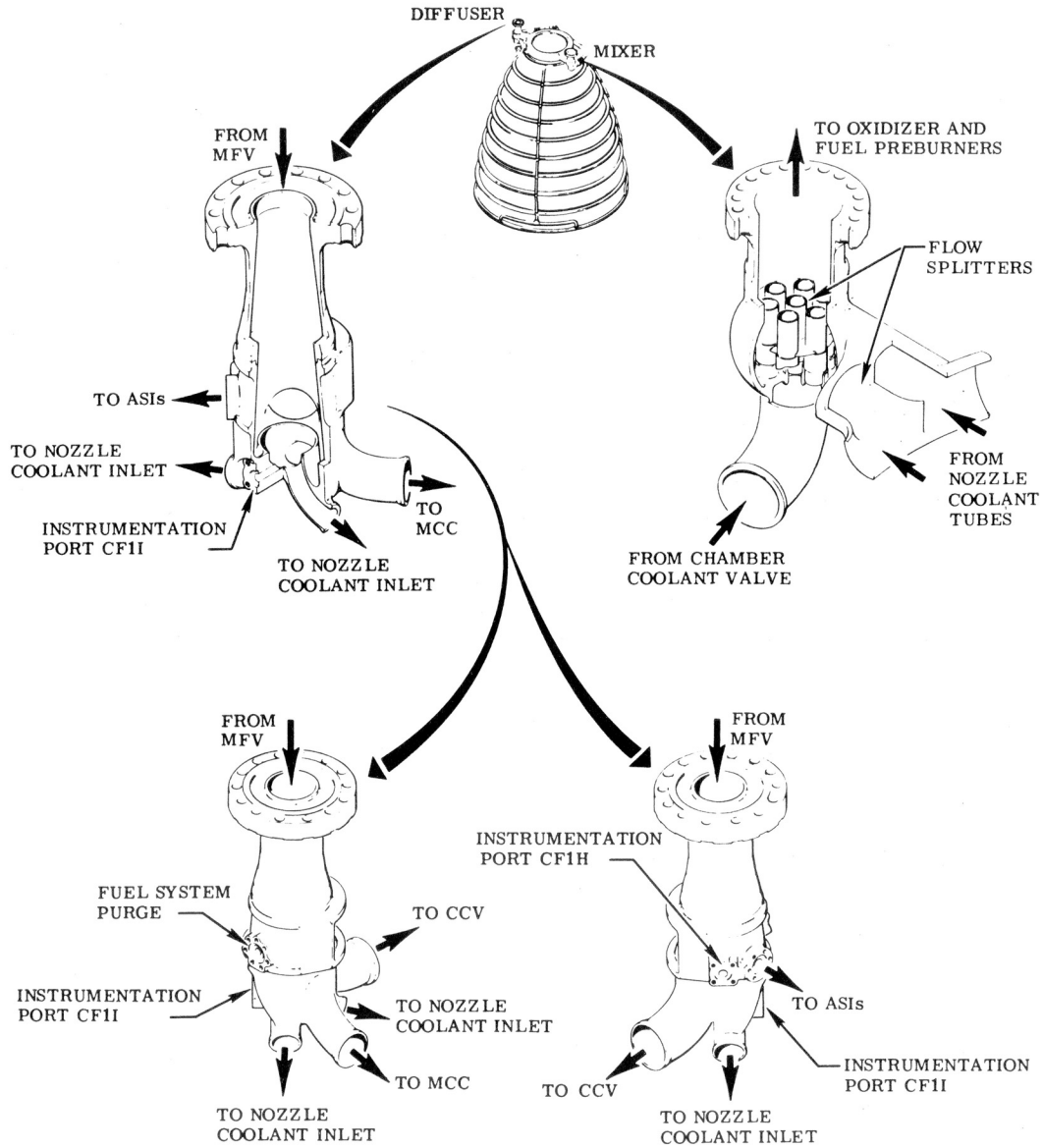


Figure 1.2-VIII – Nozzle diffuser and mixer

1.2.2.6 Low-Pressure Oxidizer Turbopump

The LPOTP (Figure 1.2-IX) is powered by liquid oxygen. During engine start and mainstage, the LPOTP maintains sufficient pressure to the 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.

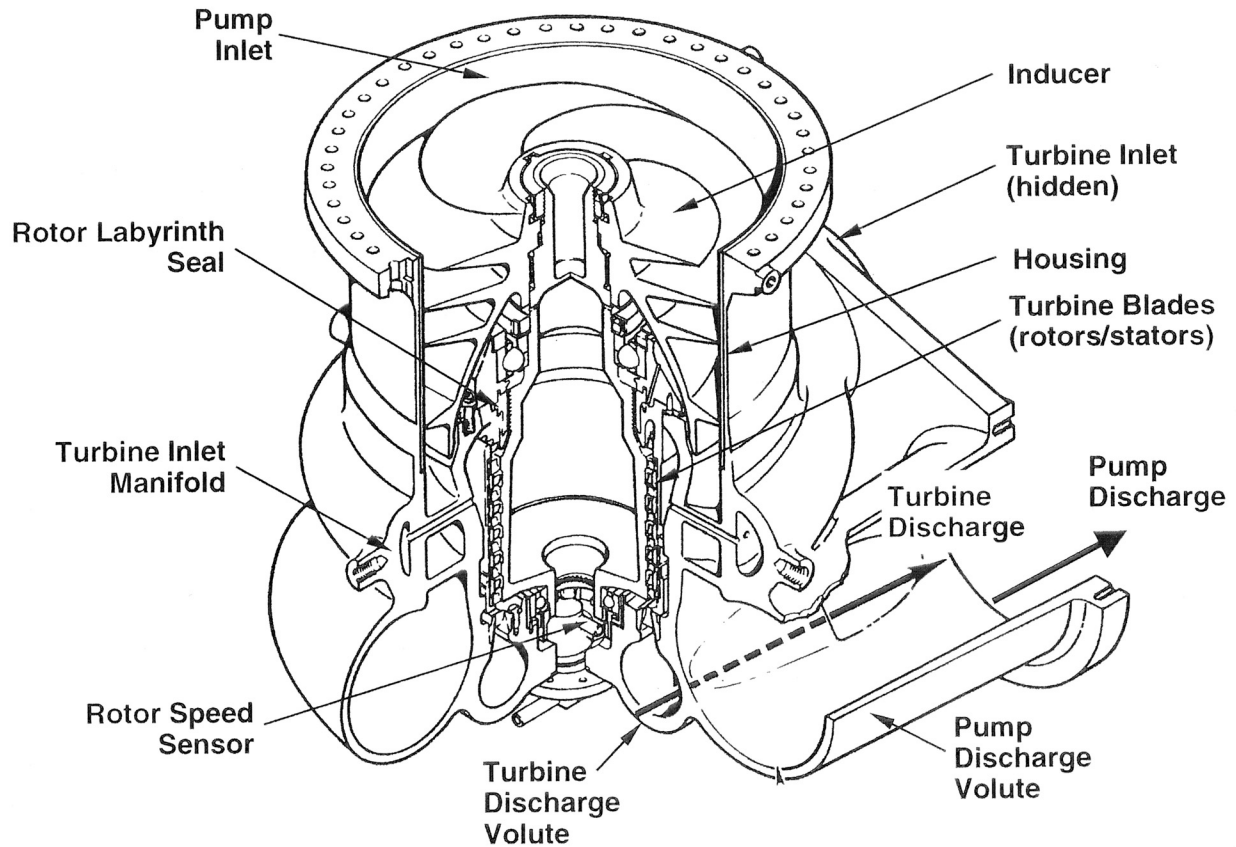


Figure 1.2-IX – Low-Pressure Oxidizer Turbopump

1.2.2.7 Low-Pressure Fuel Turbopump

The LPFTP (Figure 1.2-X) uses gaseous hydrogen (GH₂) as the power medium. During engine start and mainstage operation, the LPFTP maintains sufficient pressure to the HPFTP to permit the HPFTP to operate at high speeds. The turbine is driven by GH₂ from the MCC coolant manifold. The LH₂ coolant flows through the pump end bearings and turbine bearing. The coolant is then returned to the pump inlet through passages in the shaft, bearing spacer, and inducer.

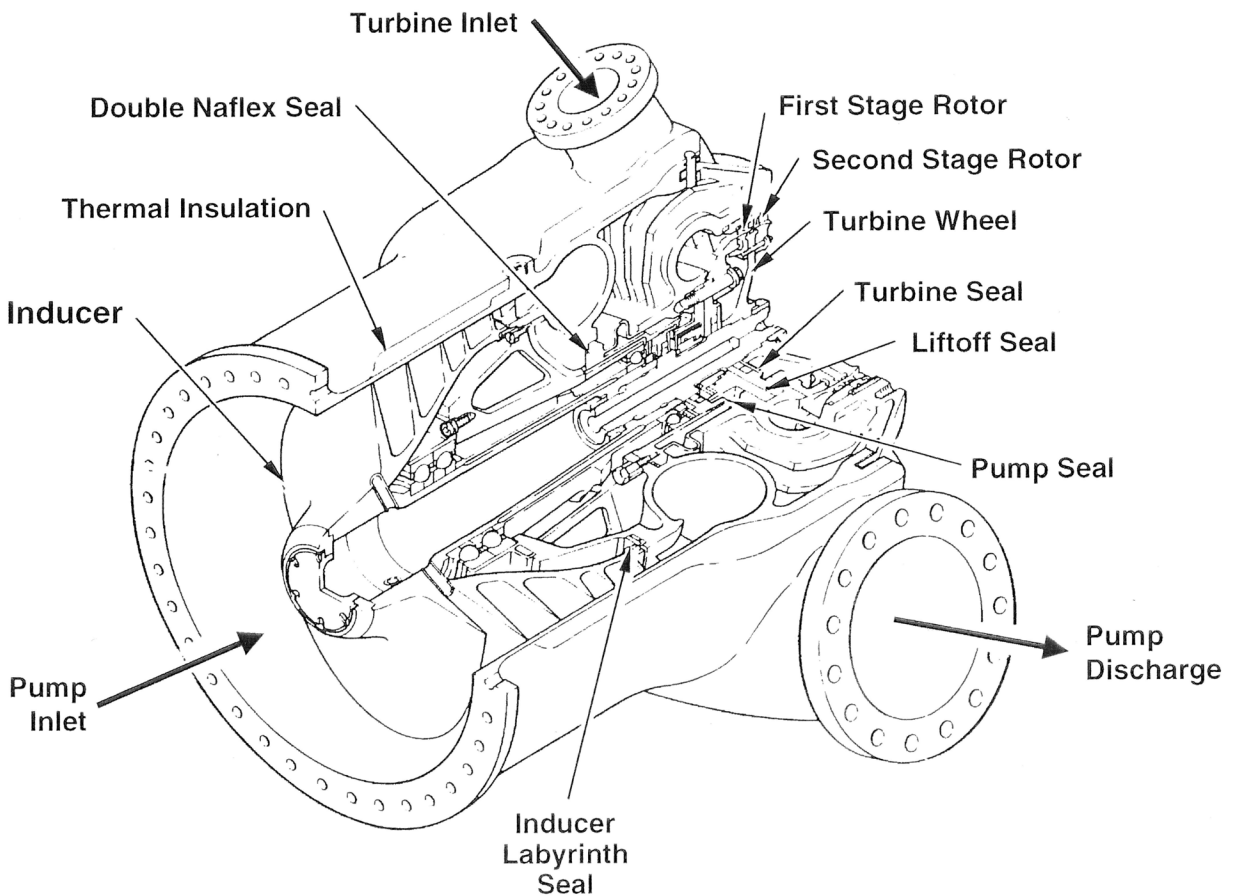


Figure 1.2-X – Low Pressure Fuel Turbopump

1.2.2.8 High-Pressure Oxidizer Turbopump

The HPOTP is directly driven by a hot-gas turbine. The HPOTP contains both a double-entry main impeller and a single-entry preburner oxidizer boost impeller (Figure 1.2-XI). Liquid oxygen enters the main pump through the main pump inlet housing, where the flow is split 50-50 into the main impeller. A portion of the flow is ducted into the boost impeller for preburner injection. Inlet vanes direct the flow to the main impeller inlets. After passing through the main impeller, the output flow is redirected into the discharge volute by diffuser vanes.

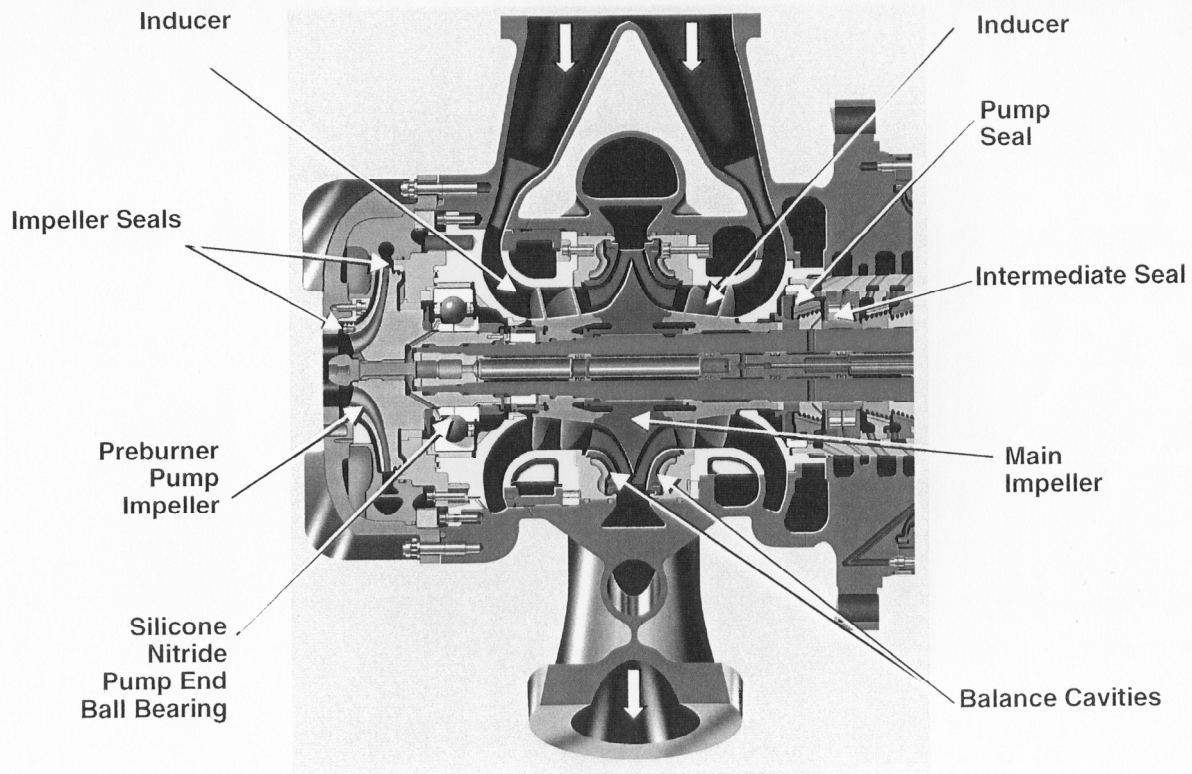


Figure 1.2-XI – High-Pressure Oxidizer Turbopump

1.2.2.9 High-Pressure Oxidizer Turbopump Turbine

The high-pressure turbopump turbine (Figure 1.2-XII) is powered with hot gas generated in the OPB. Hot gas enters the turbine and flows across the shielded support struts and through the first, second, and third-stage nozzles and blades; the hydrogen-rich gas is then discharged into the HGM. All components are cooled by GH2 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.

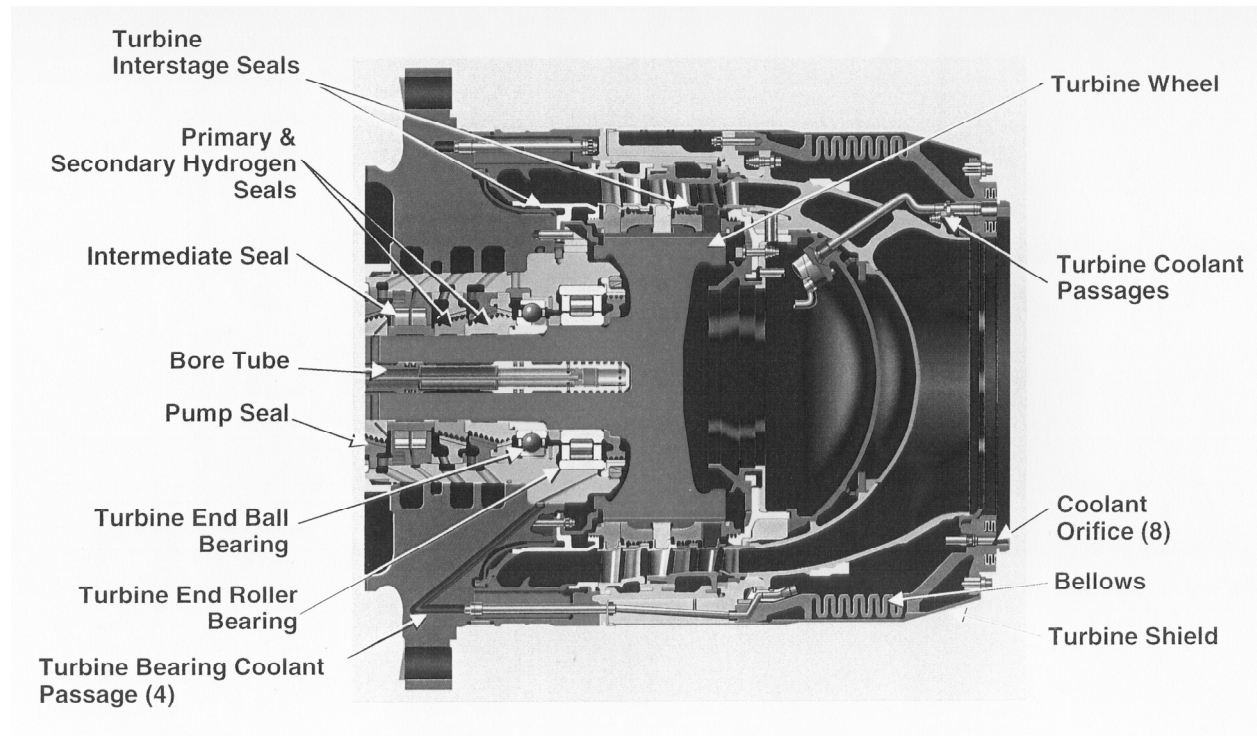


Figure 1.2-XII – High-Pressure Oxidizer Turbopump Turbine

1.2.2.10 High-Pressure Fuel Turbopump

The HPFTP is directly driven by a hot-gas turbine (Figure 1.2-I). The pump receives fuel from the LPFTP and supplies it at increased pressure, through the MFV, to the thrust chamber assembly coolant circuits and the nozzle coolant manifold. Fuel flows in series through the three impellers from pump inlet to outlet, with flow redirected between the impellers by interstage diffusers.

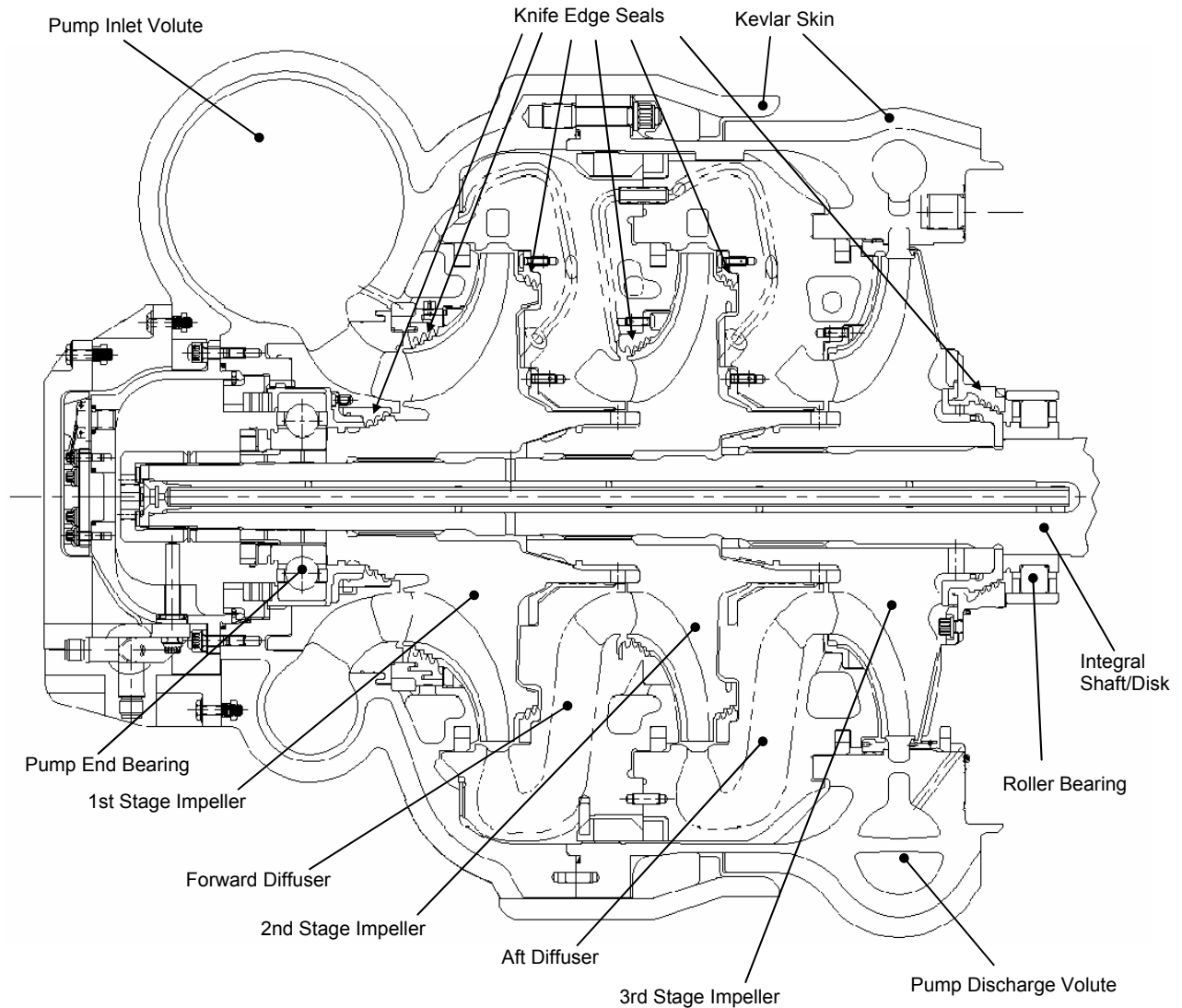


Figure 1.2-XIII – High-Pressure Fuel Turbopump

1.2.2.11 High-Pressure Fuel Turbopump Turbine

The turbine is powered with hot gas generated in the FPB (Figure 1.2-XIV). Hot gas enters the turbine and flows across the shielded support struts and through the first and second-stage nozzles and blades; the hydrogen-rich gas is then discharged into the HGM. The turbine coolant flows over or through the hot-gas components and is then exhausted into the hot-gas flow stream.

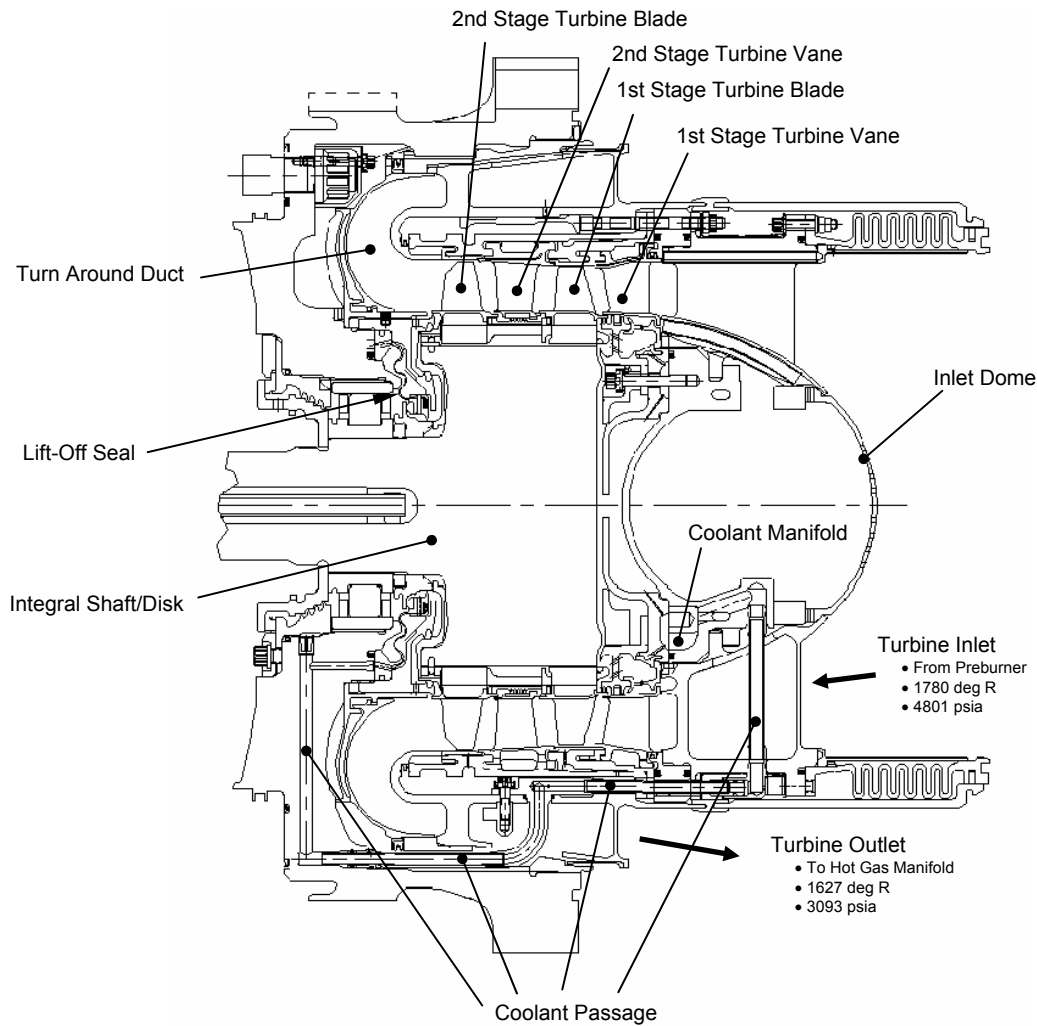


Figure 1.2-XIV – High-Pressure Fuel Turbopump Turbine

1.2.2.12 Heat Exchanger (HEX)

The heat exchanger (Figure 1.2-XV) converts liquid oxygen into gaseous oxygen for vehicle oxygen tank pressurization and pogo suppression system accumulator pressurization. Liquid oxygen, tapped off the discharge side of the HPOT, is supplied to the inlet of the HEX through the anti-flood valve (AFV). The oxygen is heated to a gas in a single coil tube. The heat exchanger coil is heated by the HPOT turbine exhaust gas. The orifice bypass line injects an unheated portion of the total oxygen flow into the outlet of the coil for control of temperature/pressure operating characteristics.

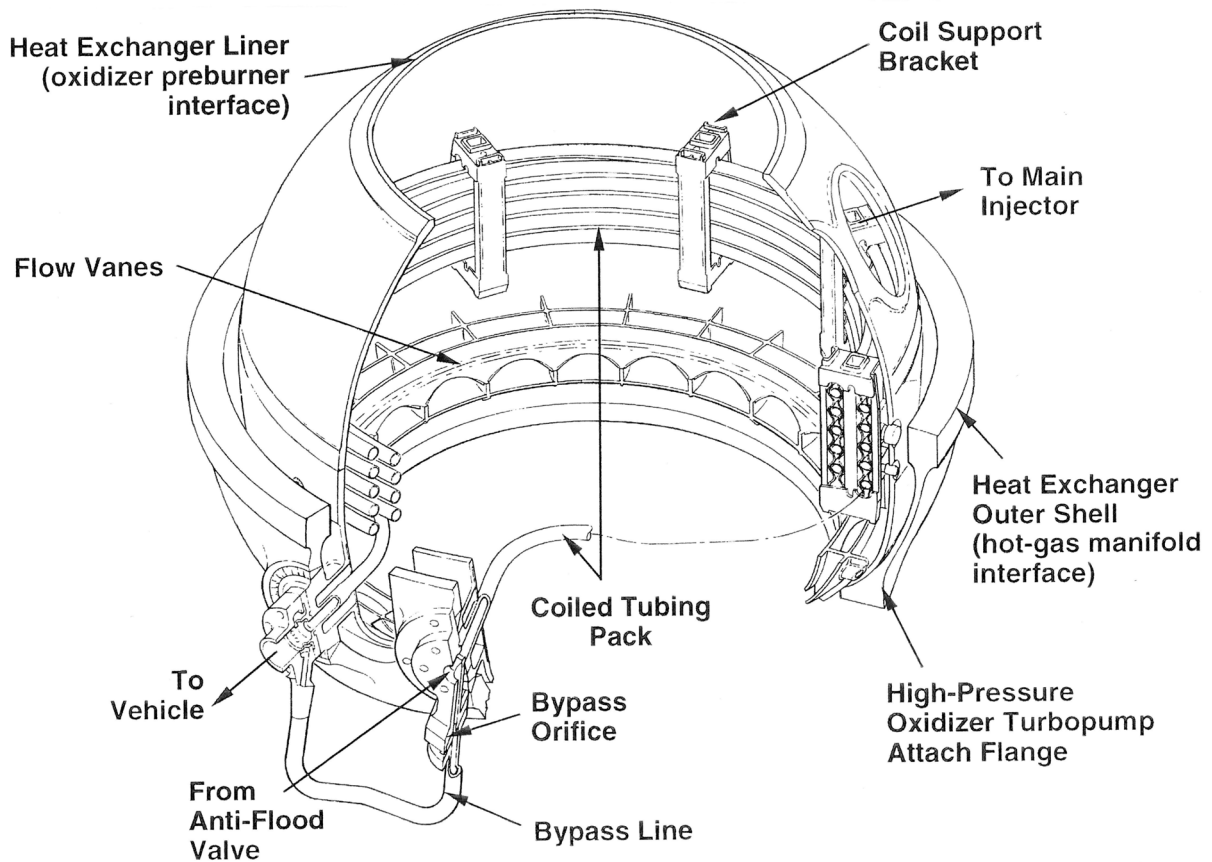


Figure 1.2-XV – SSME Heat Exchanger

1.2.2.13 POGO Suppression System

Pogo is a longitudinal vehicle instability due to closed-loop coupling of the vehicle structure (including payload), engines, and propellant delivery system. Low-frequency (5-20 Hz) propellant flow and pressure oscillations affect the performance of the propellant pumps (primarily the head rise) and thus affect the combustion process in the main combustion chamber (MCC). The end result is that the crew is bounced around like they are riding a Pogo stick. See SB 1.14 for more information on the POGO system.

Flow oscillations transmitted from the Space Shuttle vehicle are suppressed by a gas-filled accumulator, which is flange-mounted to the low-pressure oxidizer duct (Figure 1.2-XVI). GO₂ provided to the accumulator from the HEX is used as the compliant medium following an initial helium precharge. A continuous GO₂ flow is maintained at a rate governed by the engine operating point. Liquid level in the accumulator is controlled by a standpipe in the accumulator, which is constructed with orifices to regulate the GO₂ overflow throughout the engine operating power level range. The system is sized to provide sufficient GO₂ to replenish condensation at the minimum GO₂ flow rate 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 to the LPOTP inlet through the engine oxidizer bleed duct.

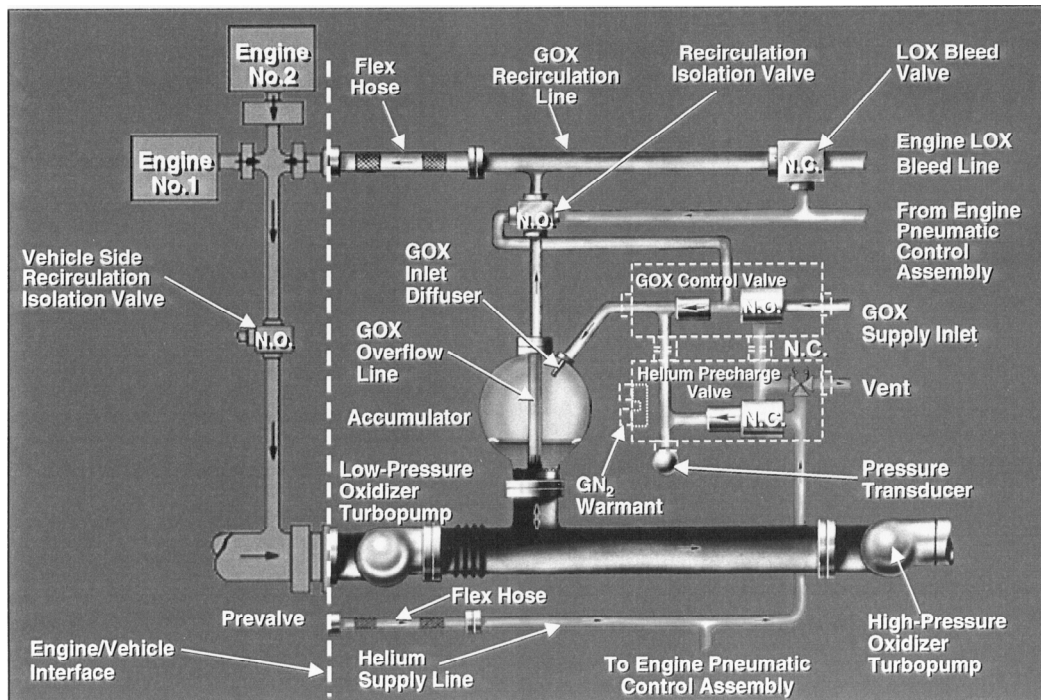


Figure 1.2-XVI – Pogo Suppression System

1.2.2.14 Valves (reference Figure 1.2-I)

A. Recirculation Isolation Valve (RIV)

The RIV prevents a short-circuit in the engine oxidizer system during the propellant conditioning mode of engine start preparation.

B. Main Oxidizer Valve (MOV)

The MOV controls oxidizer flow to the main combustion chamber LO2 dome and main combustion chamber ASI.

C. Main Fuel Valve (MFV)

The MFV permits or stops the flow of fuel to the thrust chamber coolant circuit, the LPFTP turbine, the HGM coolant circuit, the OPB, the FPB, the nozzle coolant manifold, and the three ASIs.

D. Fuel Preburner Oxidizer Valve (FPOV)

The FPOV permits or stops the flow of oxidizer to the FPB and the FPB ASI. This valve throttles to control mixture ratio.

E. Oxidizer Preburner Oxidizer Valve (OPOV)

The OPOV permits or stops the flow of oxidizer to the OPB and the OPB ASI. The valve throttles to control pressure in the MCC, and therefore engine power level.

F. Chamber Coolant Valve (CCV)

The CCV serves as a throttling control to maintain proper fuel flow through the main combustion chamber and nozzle coolant circuits. It is installed in the chamber coolant valve duct.

G. Propellant Bleed Valves

The Oxidizer Bleed Valve (OBV) and the Fuel Bleed Valve (FBV) provide a recirculation flow path for the propellants to ensure that the engine components are at the required temperatures for engine start.

H. Anti-Flood Valve (AFV)

The AFV prevents liquid oxygen from entering the heat exchanger until sufficient heat is applied to the HEX during engine start to convert the liquid oxygen to gaseous oxygen.

I. Purge Check Valves (PCV)

These valves isolate propellants from the pneumatic systems.

1.2.2.15 ASI Injector/Combustion Chamber

Orifices comprising the fuel injector direct the ASI fuel into the ASI combustion chamber downstream of the oxidizer orifices (Figure 1.2-XVII). This injection flow pattern creates an oxidizer rich condition prior to ignition in the vicinity of the spark igniter electrodes. After ignition, the flow pattern develops into a relatively low mixture ratio environment around the spark igniter electrodes, with an oxidizer-rich zone that protects the ASI combustion chamber walls.

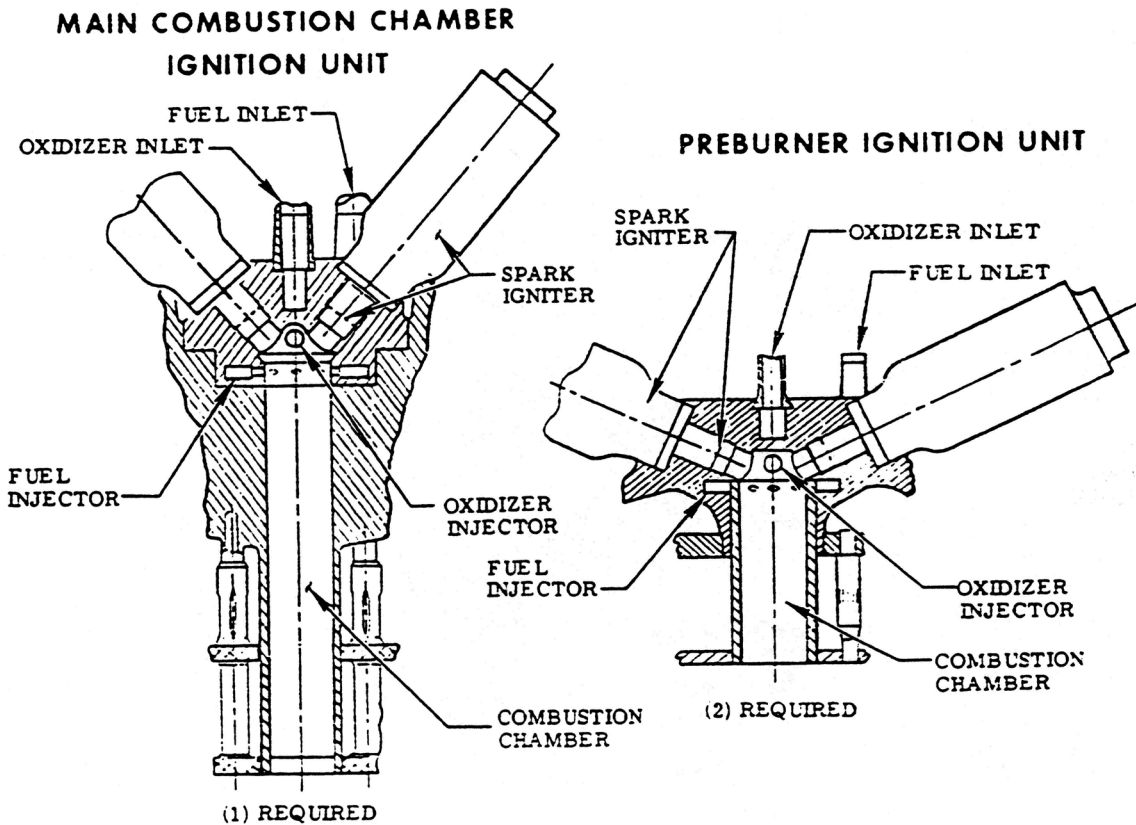


Figure 1.2-XVII – The ASI Injector/Combustion Chamber

1.2.2.16 Fluid Interface Lines

Fluid interface lines are the vehicle-to-engine lines for recirculation of propellants, propellant tank pressurants, hydraulics, and pneumatics. Fuel ducts and lines in the propellant recirculation (conditioning) system are insulated to prevent liquid air condensation and to help maintain fuel temperature at the desired level.

Main propellant articulating ducts interconnect the non-gimbaling low-pressure turbopumps to engine components that are gimbaled.

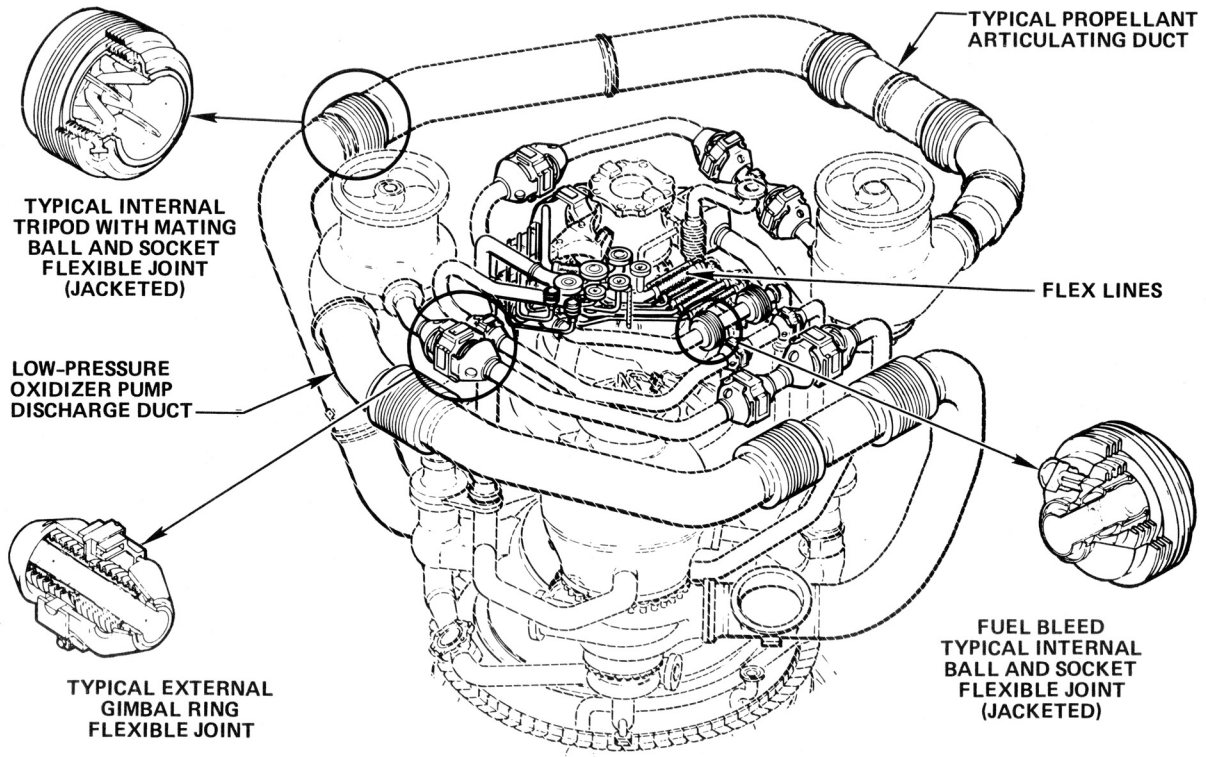


Figure 1.2-XVIII – Fluid Interface Lines

1.2.3 References

1. Space Shuttle Main Engine Orientation, Course No. ME-105RIR, Rockwell/Rocketdyne, June 1995.
2. SSME Orientation (Part A – Engine), Course No. ME-110(A)RIR, Rockwell/Rocketdyne, December 1991.
3. Space Shuttle Main Engine Description, Boeing/Rocketdyne, September 1998.

1.3 SSME VALVE SCHEMATICS

1.3.1 General

There are five primary SSME valves used to control the flow of propellants. These valves are as follows:

- Oxidizer preburner oxidizer valve (OPOV)
- Fuel preburner oxidizer valve (FPOV)
- Chamber coolant valve (CCV)
- Main fuel valve (MFV)
- Main oxidizer valve (MOV)

The Pogo suppression system has the following valves:

- Pogo recirculation isolation valve (RIV)
- Pogo helium precharge valve (HPV)
- Pogo gaseous oxygen control valve (GCV)

The remaining SSME valves described in this systems brief include:

- Propellant bleed valves
- Antiflood valve (AFV)
- Helium purge check valve
- Normally open solenoid valve
- Normally closed solenoid valve
- Pressure actuated valves
- Propellant valve hydraulic actuators

1.3.2 Functional Description

1.3.2.1 Oxidizer Preburner Oxidizer Valve

The OPOV is shown in Figure 1.3-I. The OPOV is a retracting seal ball valve with a slot flow passage. A rectangular flow passage, instead of a hole, makes valve opening versus ball rotation a linear function. This is desirable, since the OPOV is the engine throttle valve. The OPOV, which is flange mounted between the oxidizer supply line to the oxidizer preburner (OPB) and the OPB oxidizer inlet, controls oxidizer flow to the OPB and the OPB augmented spark igniter (ASI). At engine ignition, the OPOV is ramped open to start flow and continues ramping through thrust buildup. During ascent, it is modulated to control engine thrust between minimum power level (MPL) and full power level (FPL).

The OPOV assembly consists of three moving components: a shaft/ball assembly, a cam follower, and a bellows/ball seal. The ball, cam, and shaft are connected to form a rigid throttling spool. The ball inlet seal is a machined plastic, bellows-loaded, closed seal. Redundant shaft seals, with an overboard drain 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 from the ball during the initial degrees of ball travel. During initial opening of the valve, the shaft rotates 15° and actuates the cam mechanism to retract the ball seal. Retracting the ball seal from the ball allows oxidizer flow around the ball and through the clearance space of the downstream seal, providing oxidizer flow to the OPB ASI. During the last 15° of shaft motion, the cam follower rides down the cam and allows the ball seal to be held against the ball by the spring load of the bellows/cam follower.

The OPOV dimensions are shown below.

Flow passage dimensions	1.100 x 0.374 in.
Ball diameter	2.968 in.
Shaft diameter	1.100 in.
Valve length	6.812 in.

The OPOV is actuated by a hydraulic actuator that mounts to the valve housing and transmits rotary force to the shaft coupling.

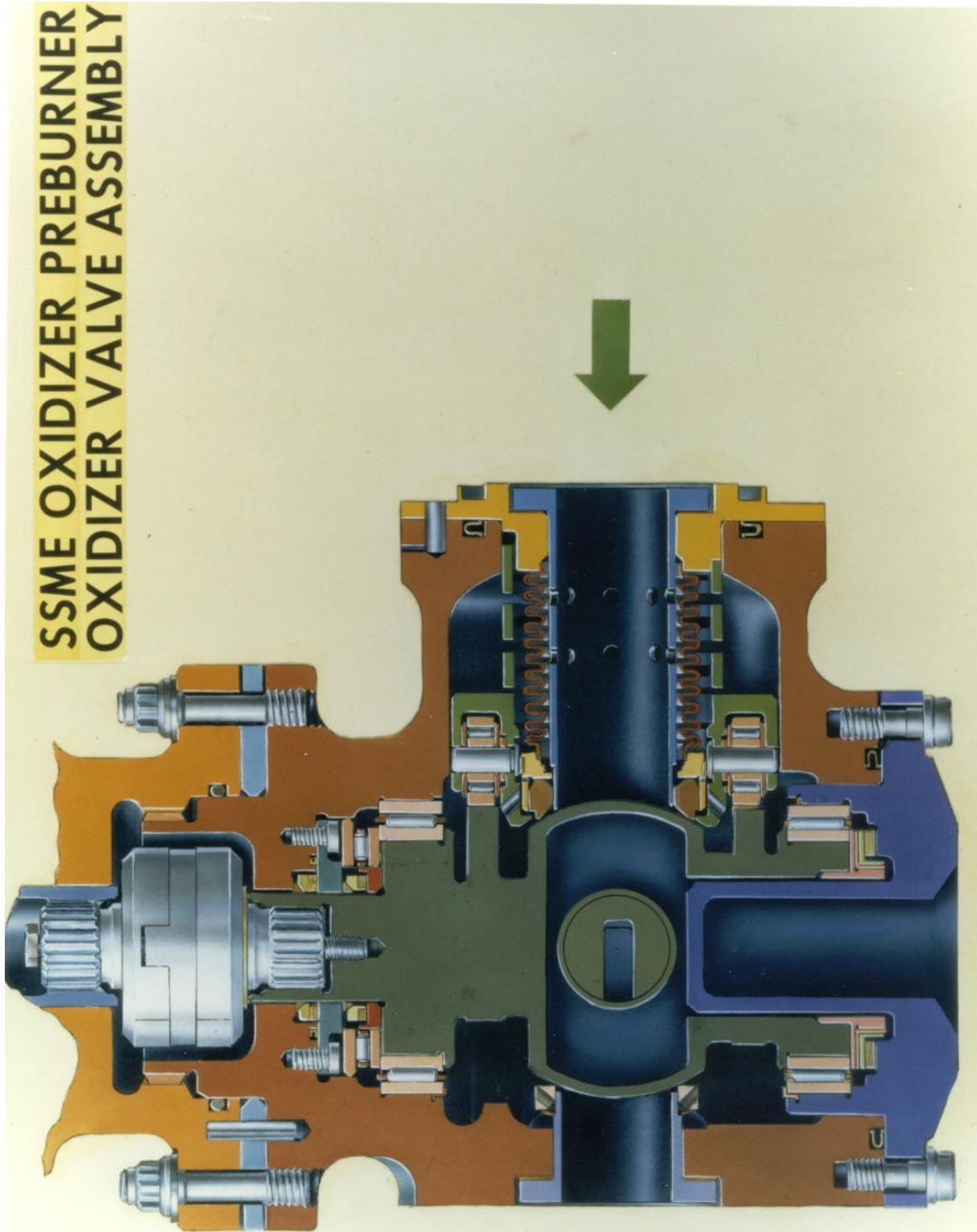


Figure 1.3-I – OPOV

1.3.2.2 Fuel Preburner Oxidizer Valve

The FPOV (Figure 1.3-II) is a retracting seal ball valve with a tubular flow passage. The tubular flow passage makes variation of fuel flow a nonlinear function of valve position. The FPOV is flange mounted between the supply line to the fuel preburner (FPB) and the FPB inlet and controls oxidizer flow to the FPB and the FPB ASI. At engine start, the FPOV is ramped open to initiate fuel flow and continues ramping to control the mixture ratio through thrust buildup. In mainstage, the FPOV is modulated to control the inlet mixture ratio.

The FPOV assembly consists mainly of three moving components: a shaft/ball, a cam follower, and a bellows/ball seal. The ball inlet seal is a machined plastic, bellows-loaded, closed seal. Redundant shaft seals, with an overboard drain 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 displace the seal from the ball during the initial degree of ball travel. During initial opening of the valve, the shaft rotates 15° and actuates the cam mechanism to retract the ball seal. Retracting the ball seal from the ball allows oxidizer flow around the ball and through the clearance space of the downstream seal, providing oxidizer flow to the FPB ASI.

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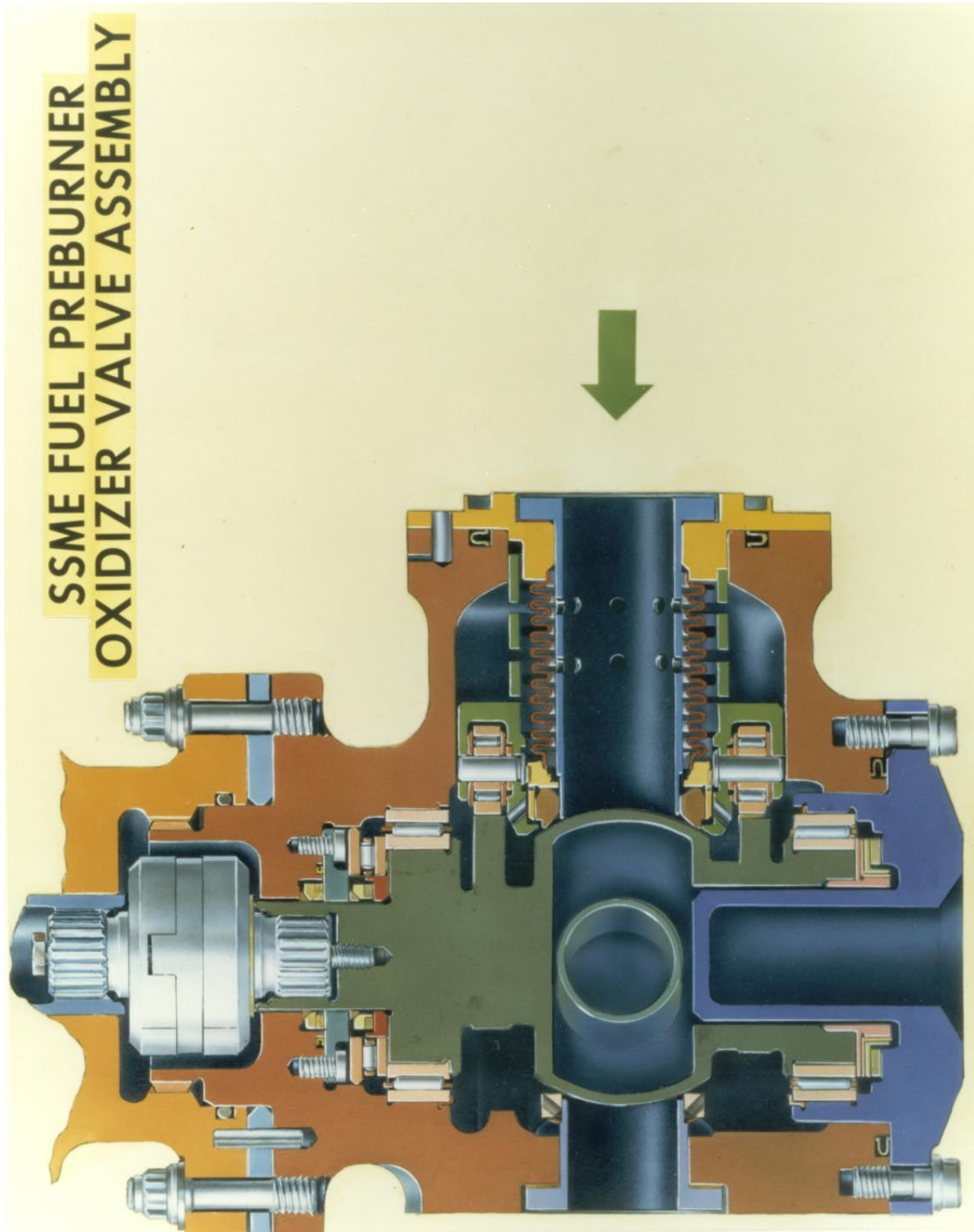


Figure 1.3-II – FPOV

1.3.2.3 Chamber Coolant Valve

The chamber coolant valve (CCV) is shown in Figure 1.3-III. It is a hydraulically actuated, rotating tubular gate valve that regulates fuel flow through the main combustion chamber (MCC) coolant passages, the nozzle coolant tubes and the preburners. Flow through the CCV goes to the preburners. The valve is installed as an integral component of the nozzle forward manifold assembly, the CCV duct. The valve body is welded into the line with the operational portion bolted in. Since the CCV is a bypass control valve and not a shutoff valve, gate seals are not installed. Redundant shaft seals, with an overboard drain cavity between them, prevent leakage along the shaft during engine operation.

The CCV dimensions are shown below.

Flow passage diameter	1.600 in.
Gate diameter	2.5 in.
Shaft diameter	1.100 in.
Valve length	7.729 in.

The CCV position is varied linearly with engine chamber pressure such that it is partially open at MPL and nearly full open at rated power level (RPL). The CCV gate is rotated by a hydraulic actuator, which is mounted to the top of the valve.

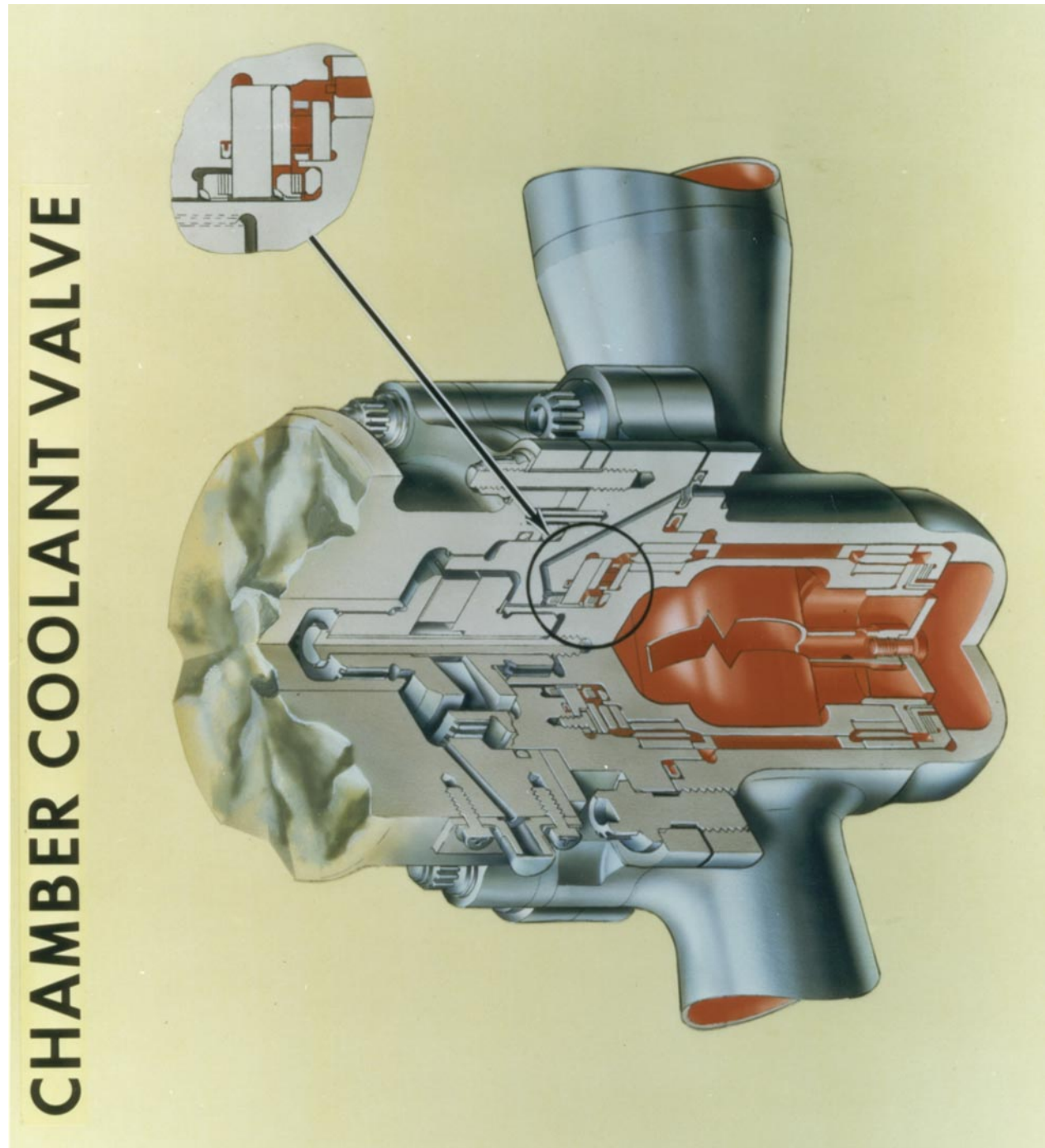


Figure 1.3-III – CCV

1.3.2.4 Main Fuel Valve

The MFV is shown in Figure 1.3-IV. The MFV is a ball valve with a 2.5-inch tubular flow passage. The MFV is flange-mounted between the high pressure fuel duct and nozzle diffuser. The valve controls the flow of fuel from the HPFTP to the coolant circuits and preburners. The MFV is actuated to a full-open position at start, scheduled full-open during mainstage operation, and actuated to full-close position at engine shutdown.

The MFV basically has three moving components: a shaft/ball assembly, a cam follower, and a bellows/ball seal. The ball, cam, and shaft are connected to form a rigid throttling spool. 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. During initial opening of the valve, the shaft rotates approximately 10° and actuates the cam mechanism to lift the ball seal. After this initial rotation, the ball seal is fully retracted. During the final portion of valve motion the cam follower rides down ramps on the cams and allow the ball seal to be held against the ball by the spring load of the bellows.

The MFV hydraulic actuator mounts to the valve housing and transmits rotary force to the shaft coupling. Dual shaft seals in both the valve and actuator, with vents between the seals, control leakage into the coupling cavity. The coupling cavity is protected against overpressurization by a burst diaphragm.

The MFV dimension are shown below.

Flow passage	2.500 in.
Ball diameter	5.125 in.
Shaft diameter	1.875 in.
Valve length	10.25 in.

The valve housing is insulated with molded insulation to prevent formation of liquid air and to assist in the chilldown process.

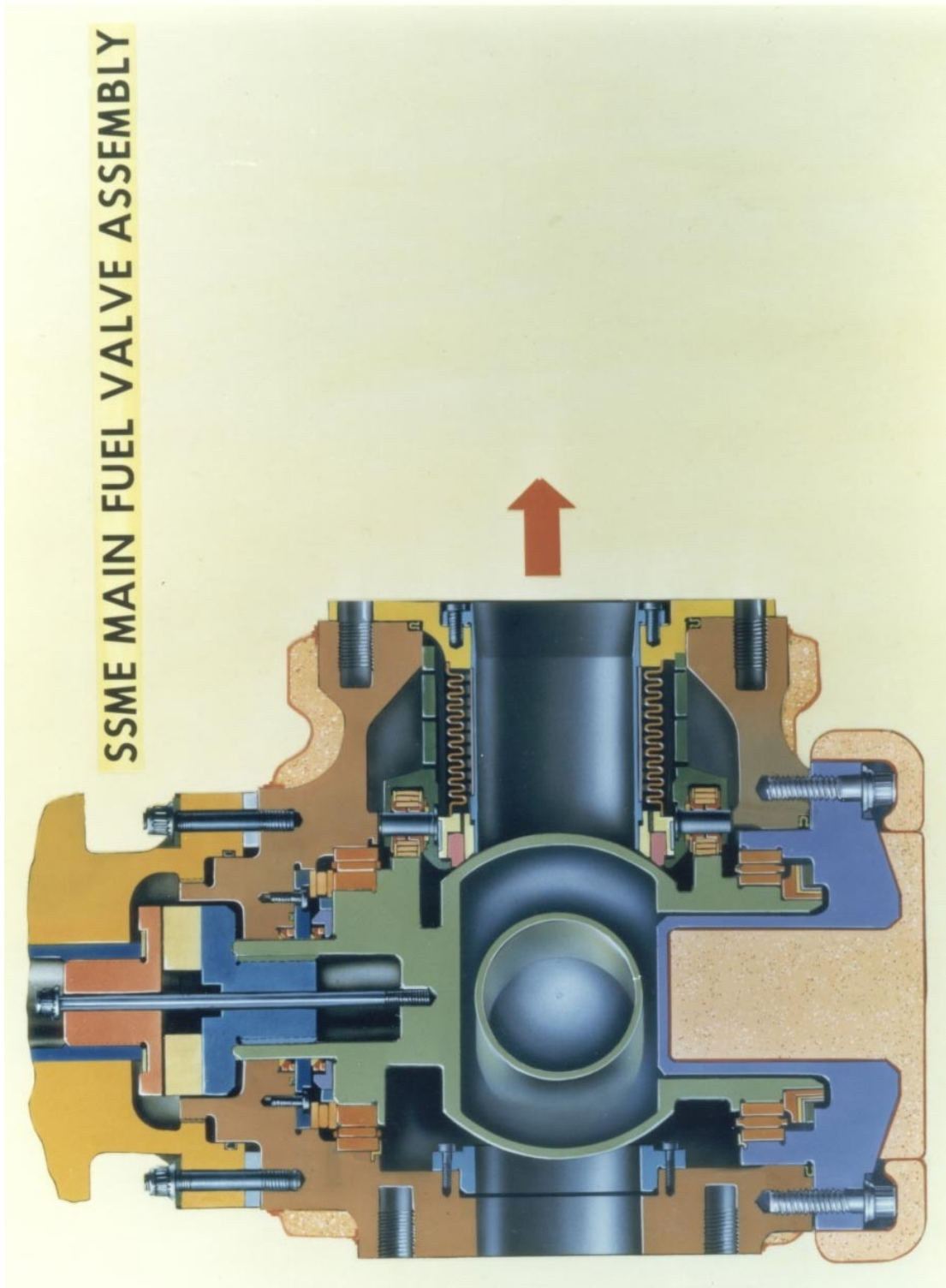


Figure 1.3-IV – MFV

1.3.2.5 Main Oxidizer Valve

The MOV is shown in Figure 1.3-IV. The MOV is similar to the MFV. The parts labeled in Figure 1.3-IV also apply to figure 1.3-V. The MOV is a ball valve with a 2.5-inch tubular flow passage. The MOV is flange-mounted between the main chamber oxidizer dome and the high pressure oxidizer duct.

The valve controls oxidizer flow to the main injector oxidizer dome and MCC augmented spark igniter (ASI) chamber. At engine start, the MOV initially is ramped open to start ignition flow, then scheduled open as engine thrust builds up from MPL to RPL. During mainstage, the MOV is scheduled full-open. At cutoff, the MOV is scheduled closed until engine thrust decays to MPL and then ramped to full-close.

The MOV has three moving components: a shaft/ball assembly, a cam follower, and a bellow/ball seal. The ball, cam, and shaft are connected to form a rigid throttling spool. During initial opening of the valve, the shaft rotates approximately 10° and actuates the cam mechanism to lift the ball seal. Retracting the ball seal from the ball allows oxidizer flow through the clearance space around the ball, providing oxidizer flow to the MCC ASI. After this initial shaft rotation, no further motion of the ball seal occurs. During the final portion of valve closing, the cam follower rides down ramps on the cams and allows the ball seal to be held against the ball by the spring load of the bellow.

The MOV hydraulic actuator mounts to the valve housing and transmits rotary force to the shaft coupling. Dual shaft seals in both the valve and the actuator, with vents between the seals, prevent leakage into the coupling cavity. The coupling cavity is protected against overpressurization by a burst diaphragm.

The MOV dimensions are shown below.

Flow diameter	2.5 in.
Ball diameter	5.125 in.
Shaft diameter	1.875 in.
Valve length	10.25 in.

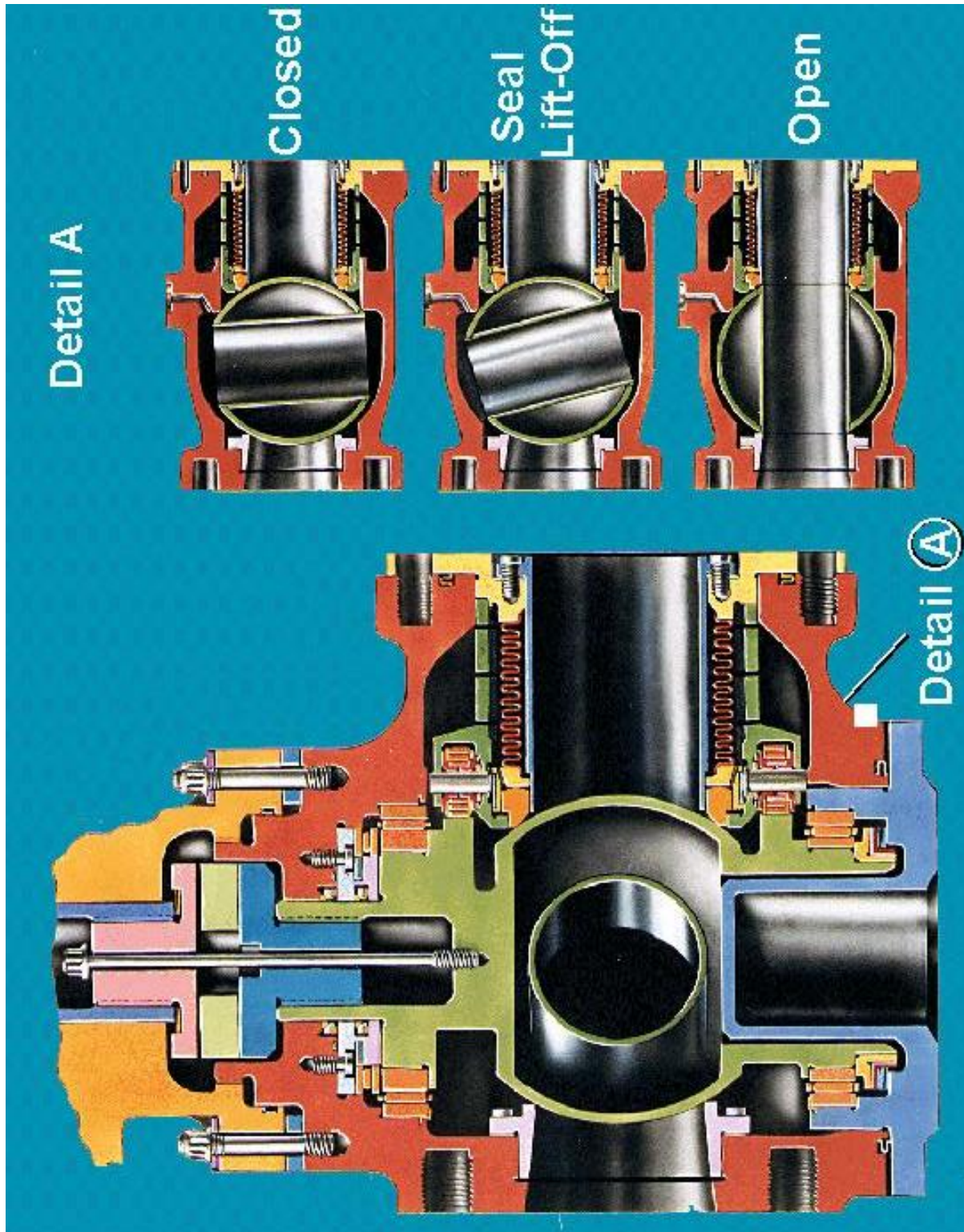


Figure 1.3-V – MOV

1.3.2.6 Pogo Recirculation Isolation Valve

The Pogo recirculation isolation valve (RIV) is shown in Figure 1.3-VI. It is a bellows-opened, pneumatically-closed poppet valve. The RIV is flange mounted to the exterior of the Pogo suppression accumulator. The valve provides flow from the Pogo overflow tube (standpipe) to the LO2 bleed line. The RIV is closed during engine preparation for start in order to thermally condition the system. LO2 flow is forced through the engine and out the oxidizer bleed valve (OBV). Pneumatic pressure, which opens the OBV, closes the RIV.

During engine operation the RIV is opened to allow excess GOX in the Pogo accumulator to flow back to the LO2 manifold to be recondensed. To ensure that the RIV opens, GOX pressure from the Pogo GOX control valve is routed to the RIV override port. A drain between the actuator shaft seals precludes leakage of the high-pressure GOX into the oxidizer bleed line.

The RIV incorporates a linear variable differential transducer (LVDT) position indicator that converts valve position to an electrical signal. The controller monitors the electrical signal to verify valve position during the propellant conditioning and engine start phases. The signal serves as a maintenance recording parameter during the remaining phases.

POGO SYSTEM RECIRCULATION ISOLATION VALVE

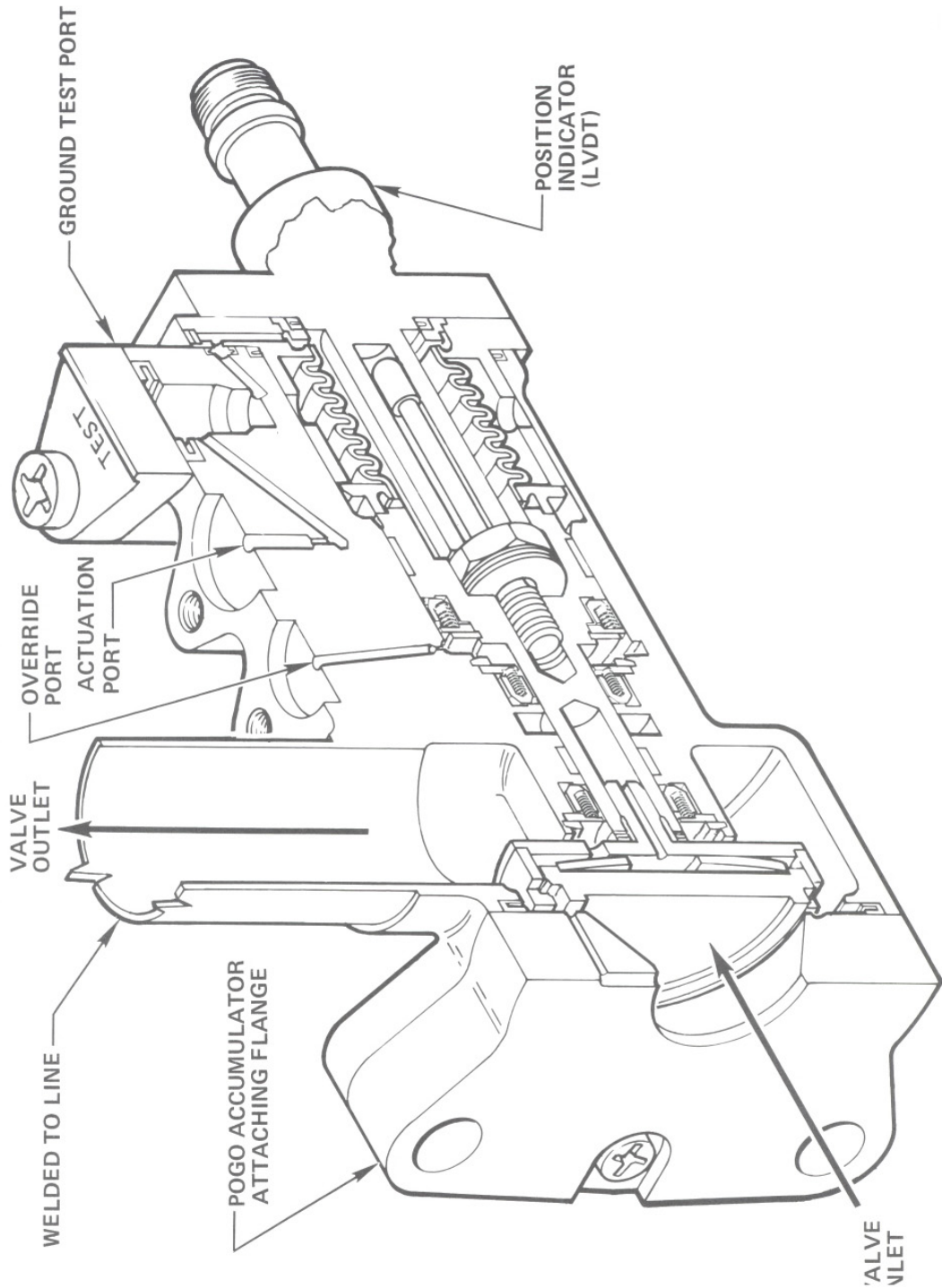


Figure 1.3-VI – RIV

1.3.2.7 Pogo Helium Precharge Valve

The helium precharge valve (HPV), shown in Figure 1.3-VII, is a spring-loaded closed, pneumatically opened poppet valve. The HPV assembly provides helium pressurant to the Pogo accumulator during engine start until GOX is available from the engine heat exchanger. The pneumatic pressure that opens the HPV is also used to close the Pogo GOX control valve. The HPV is also used to provide helium to the accumulator as a post-charge at engine shutdown.

The HPV has an integral check valve at its outlet port. The helium supply is filtered by a 15-micron 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 GCV.

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

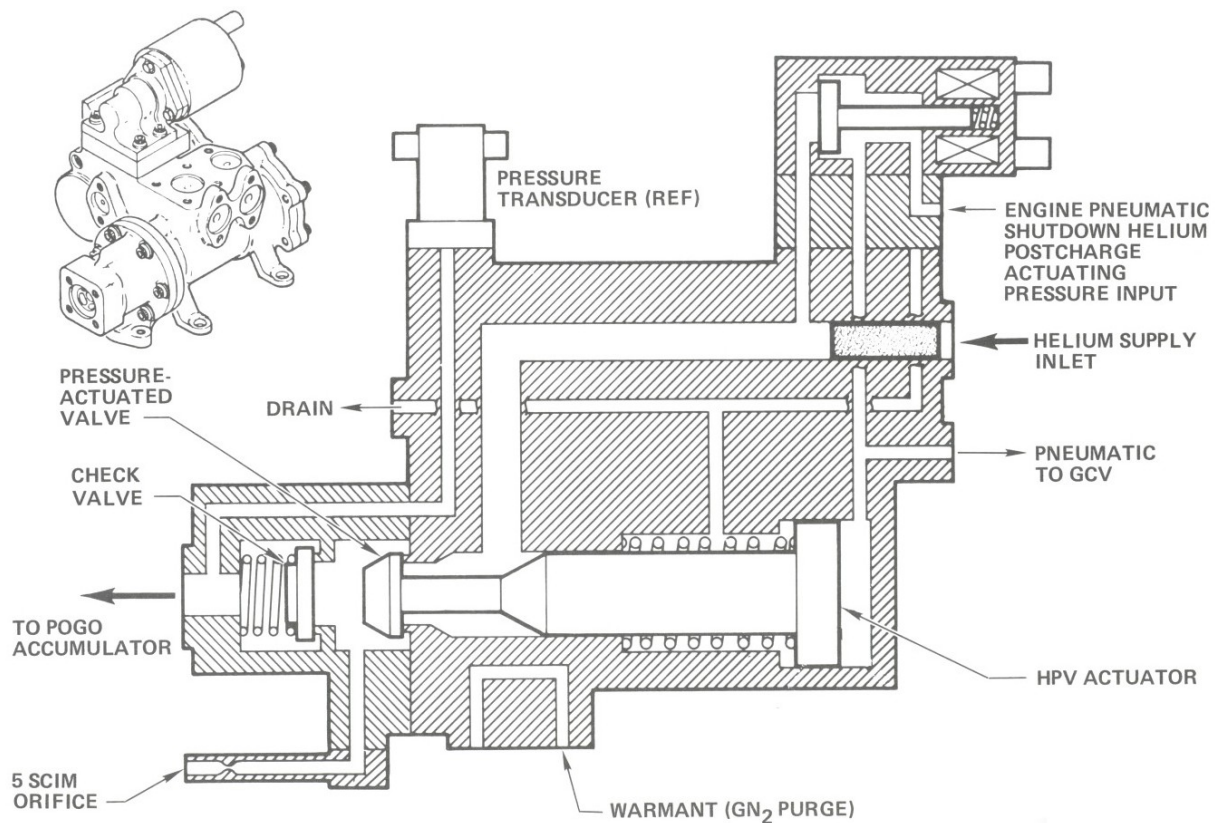


Figure 1.3-VII – Pogo helium precharge valve

1.3.2.8 Pogo Gaseous Oxygen Control Valve

The gaseous oxygen control valve (GCV), shown in Figure 1.3-VIII, is a bellows opened, pneumatically closed poppet valve. Pogo suppression is accomplished by a gas-filled accumulator in the LOX feedline at the HPOTP inlet. GOX is used as the compliant medium subsequent to an initial helium precharge. During engine start this helium precharge ensures rapid charging of the accumulator to provide Pogo protection during lift-off and the early part of boost. GOX generated in the heat exchanger is used to maintain the accumulator charge during the remainder of boost.

The GOX control valve assembly prevents reverse LOX flow from the accumulator from entering the heat exchanger during engine thermal conditioning and blocks GOX flow during engine start to enable the helium precharge. This assembly combines a pressure-actuated GOX supply valve and a check valve in the same housing.

A bleed orifice from the closing to the opening side of the actuator piston provides for automatic opening of the valve 3 to 10 seconds after control pressure is applied. The poppet pivots so it can align itself with the seat. When the GCV is open, it supplies GOX to the override port on the RIV, which closes the RIV.

POGO SYSTEM GOX CONTROL VALVE

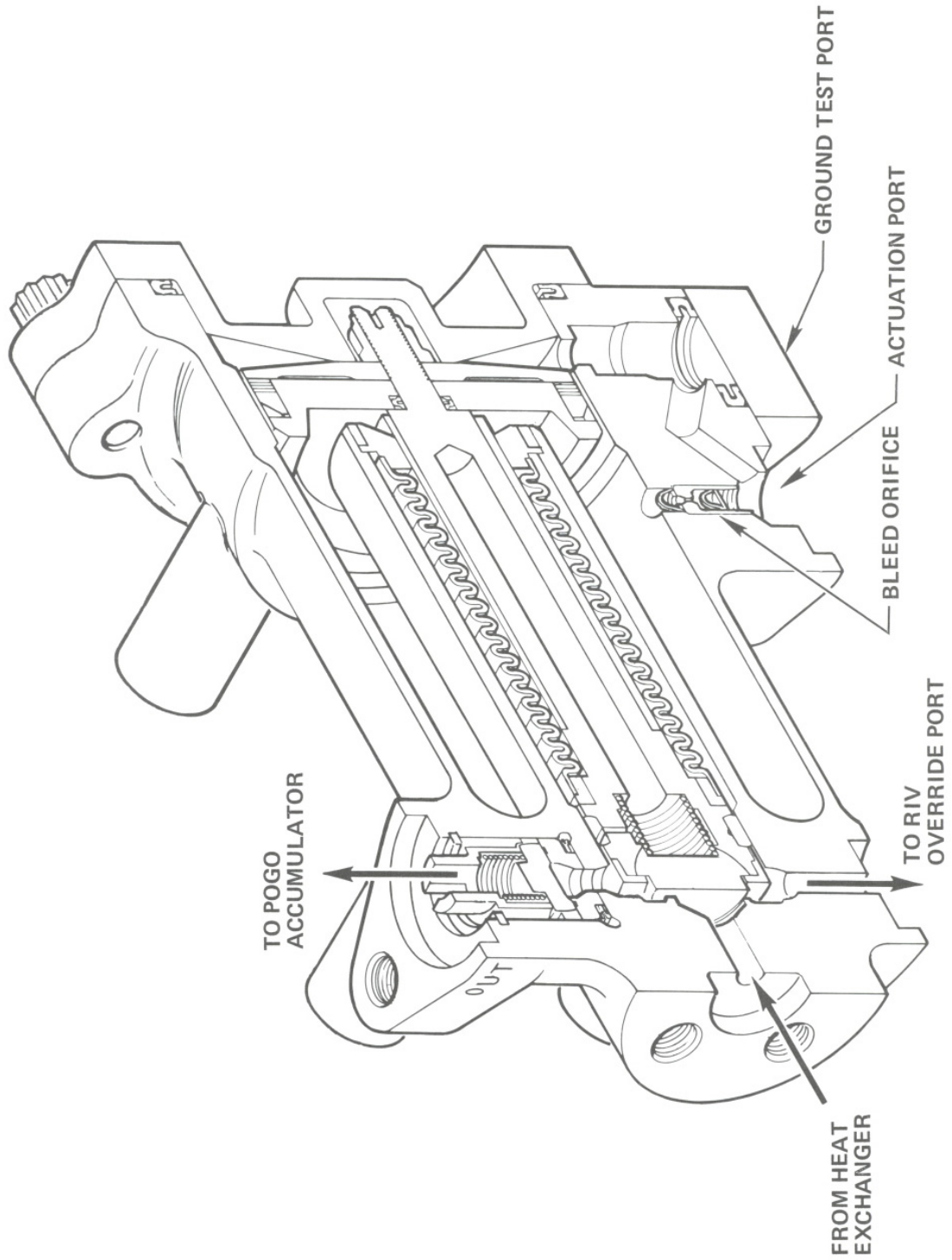


Figure 1.3-VIII – GCV

1.3.2.9 Propellant Bleed Valves

The oxidizer bleed valve (OBV) and the fuel bleed valve (FBV) are identical, see Figure 1.3-IX.

The OBV and FBV are pneumatically opened, spring-loaded closed, metal-to-metal poppet valves. The metal poppet is self-aligning to its metal seat. Both valves are open by pneumatic pressure from the pneumatic control assembly (PCA) during engine start preparation. This provides 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 that propellant pressure acting on the poppet, combined with spring and bellows forces will close the valves when pneumatic pressure is not vented. Both valves have LVDTs to indicated poppet position.

The OBV inlet is flange-mounted to the preburner oxidizer supply duct at the 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.

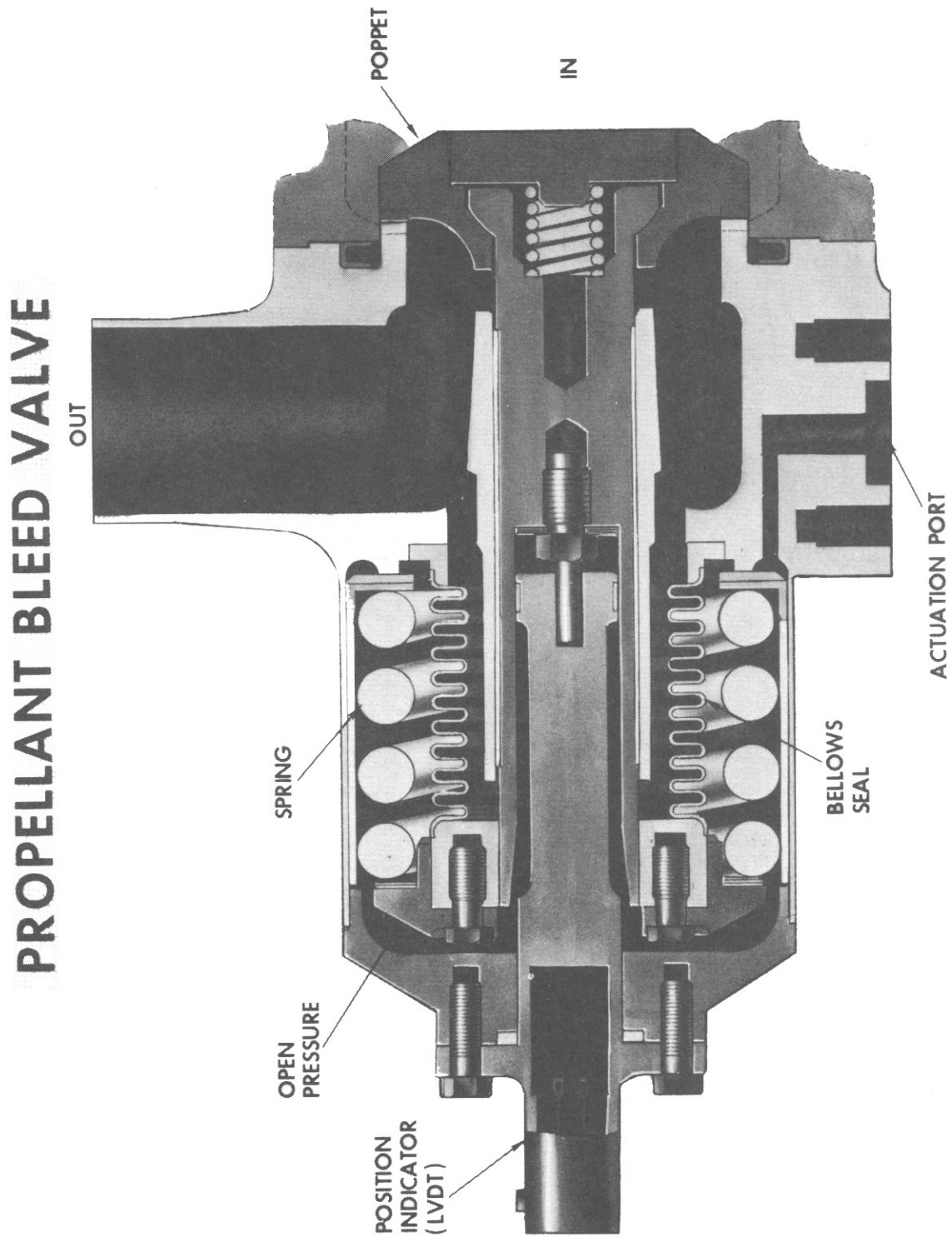


Figure 1.3-IX – OBV and FBV

1.3.2.10 Heat Exchanger Antiflood Valve

The antiflood valve (AFV) is shown in Figure 1.3-X. The AFV prevents LOX from entering the heat exchanger (HEX) until sufficient heat is available in the high-pressure oxidizer turbopump turbine exhaust gas to vaporize the LOX for oxidizer tank pressurization. The AFV also functions as a pressure relief valve in the reverse direction to prevent heat exchanger overpressurization.

The AFV is a poppet-type valve, spring-loaded closed with one dynamic seal to control oxidizer leakage between the piston and valve housing. Leakage past the piston is vented through the oxidizer drain port. The poppet pivots so it can align itself with the seal. A dual channel position indicator is incorporated in the design to enable controller monitoring of valve position. A ground actuation port is also provided to enable in-place checkout without breaking engine connections.

The AFV is set to open during the start phase. The oxidizer system pressure is an indicator of an adequately heated heat exchanger, and the AFV is adjusted to actuate open when the oxidizer system pressure reaches a predetermined value. The controller monitors the AFV position during the SSME start phase to verify ignition. The controller will initiate engine shutdown in the event the valve is not open at the proper time during this phase. The AFV closes when the oxidizer system pressure decays.

ANTI-FLOOD VALVE

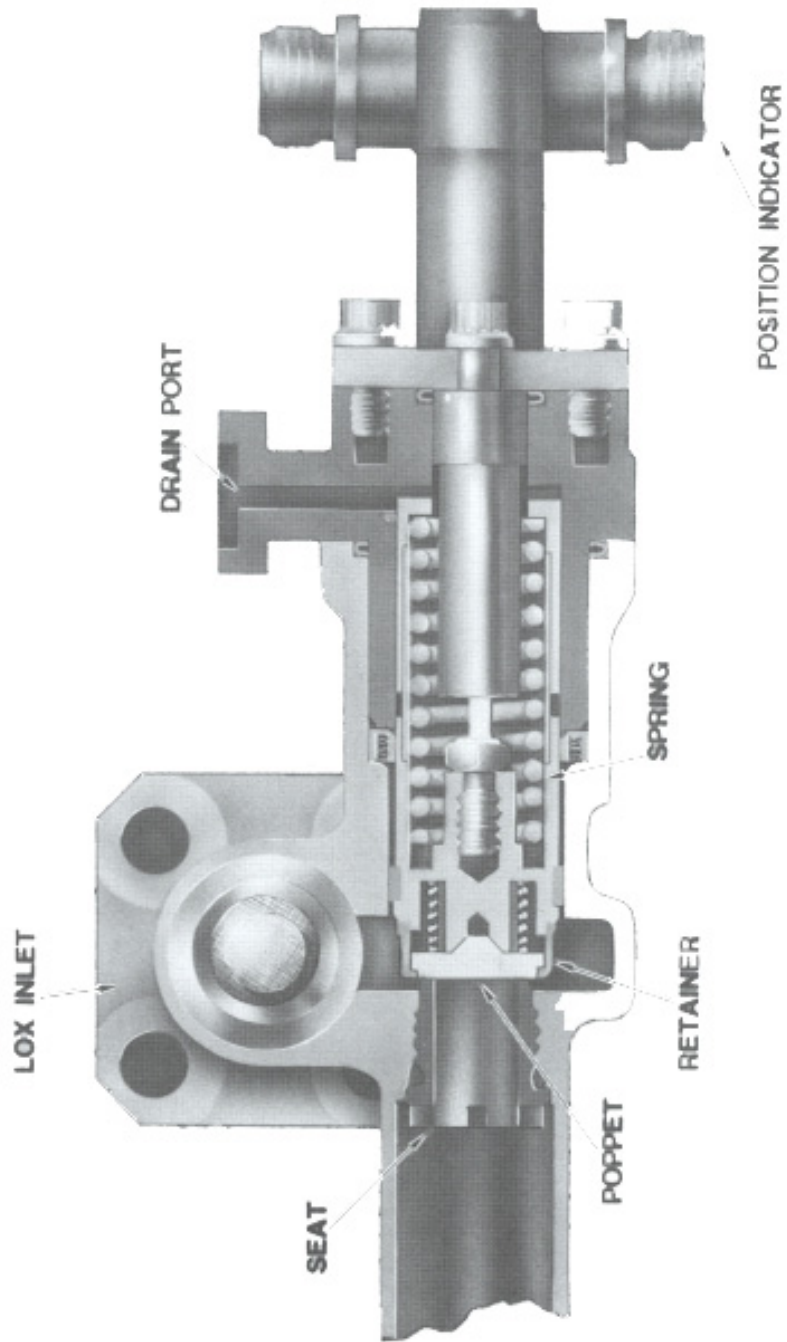


Figure 1.3-X – AFV

1.3.2.11 Helium Purge Check Valve

A schematic of the helium purge check valve is shown in Figure 1.3-XI. The pneumatic control system purge check valves are spring-loaded, normally closed, pressure-actuated open poppet valves that isolate propellants from the pneumatic systems. Helium purge check valves are used in the oxidizer preburner oxidizer dome, fuel preburner oxidizer dome, main combustion chamber oxidizer dome, downstream of the main fuel valve, and in the HOPTP turbine seal cavity.

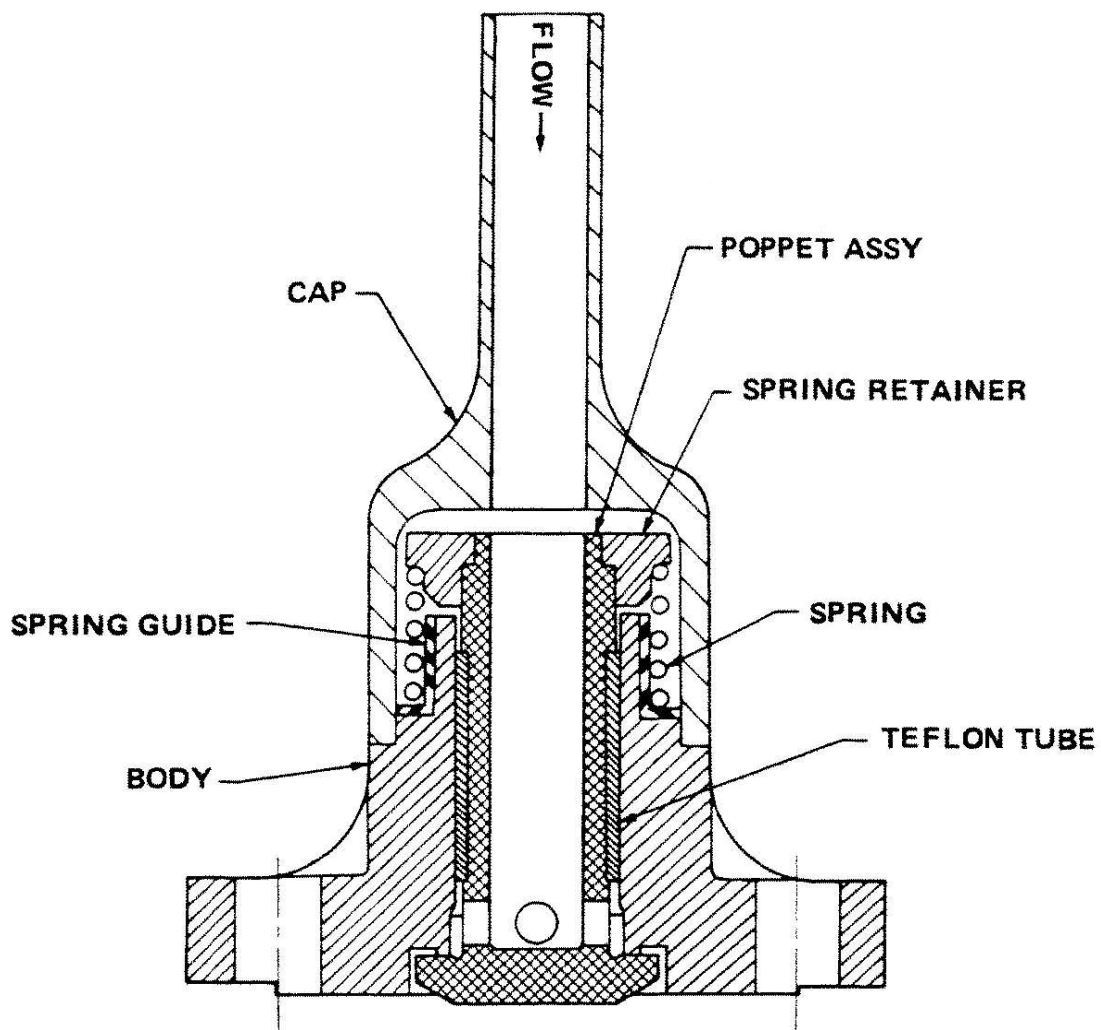


Figure 1.3-XI – Helium purge check valve

1.3.2.12 Normally Open Solenoid Valve

The schematic for a normally open solenoid valve is shown in Figure 1.3-XII. An example of this type of valve is the emergency shutdown solenoid valve.

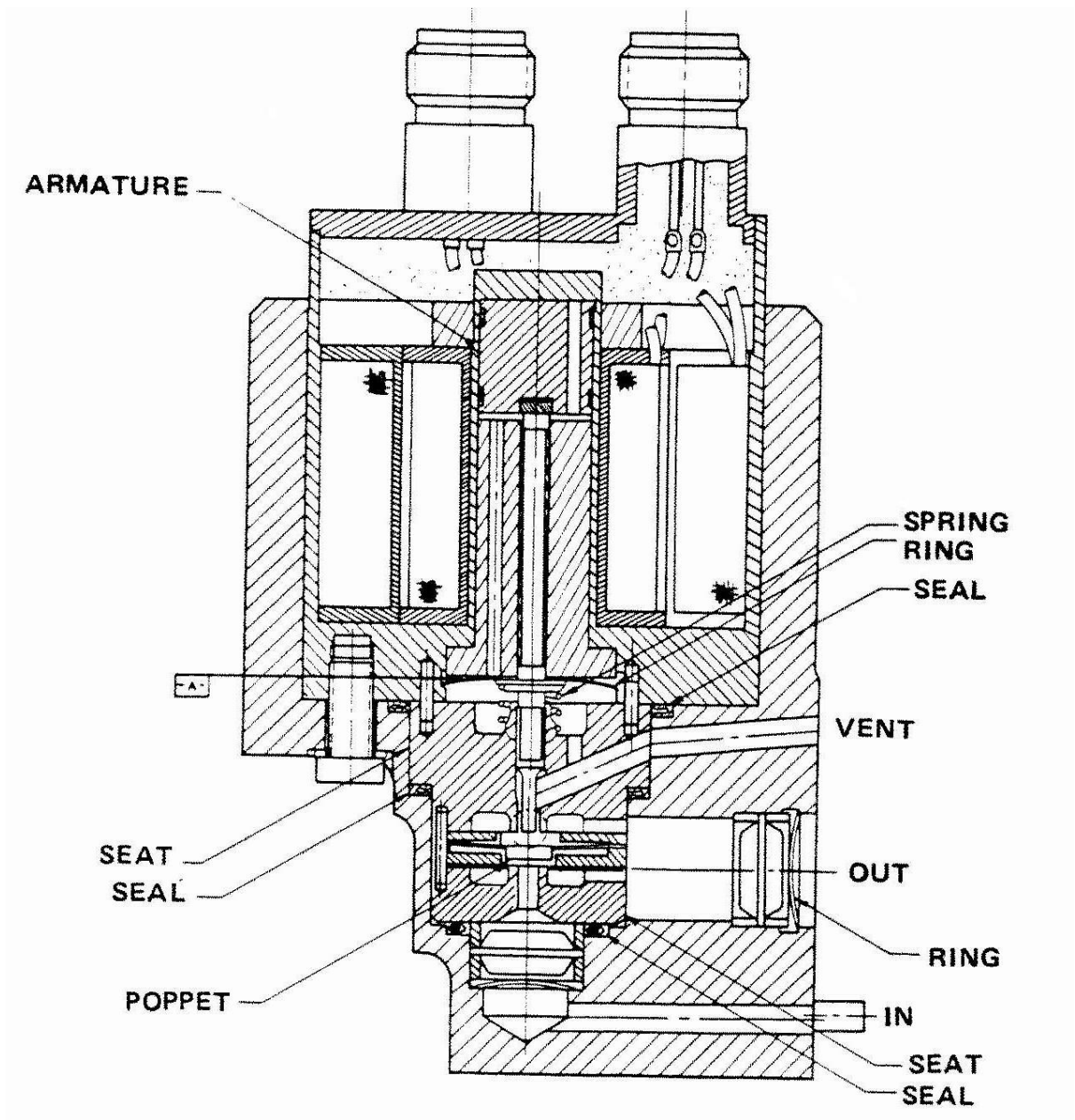


Figure 1.3-XII – Normally open solenoid valve

1.3.2.13 Normally Closed Solenoid Valve

A schematic of a normally closed solenoid valve is illustrated in Figure 1.3-XIII. The following valves are normally closed solenoid valves: fuel system purge solenoid, bleed valve control solenoid, HPOTP intermediate seal purge solenoid, oxidizer preburner dome purge solenoid, and helium precharge valve solenoid.

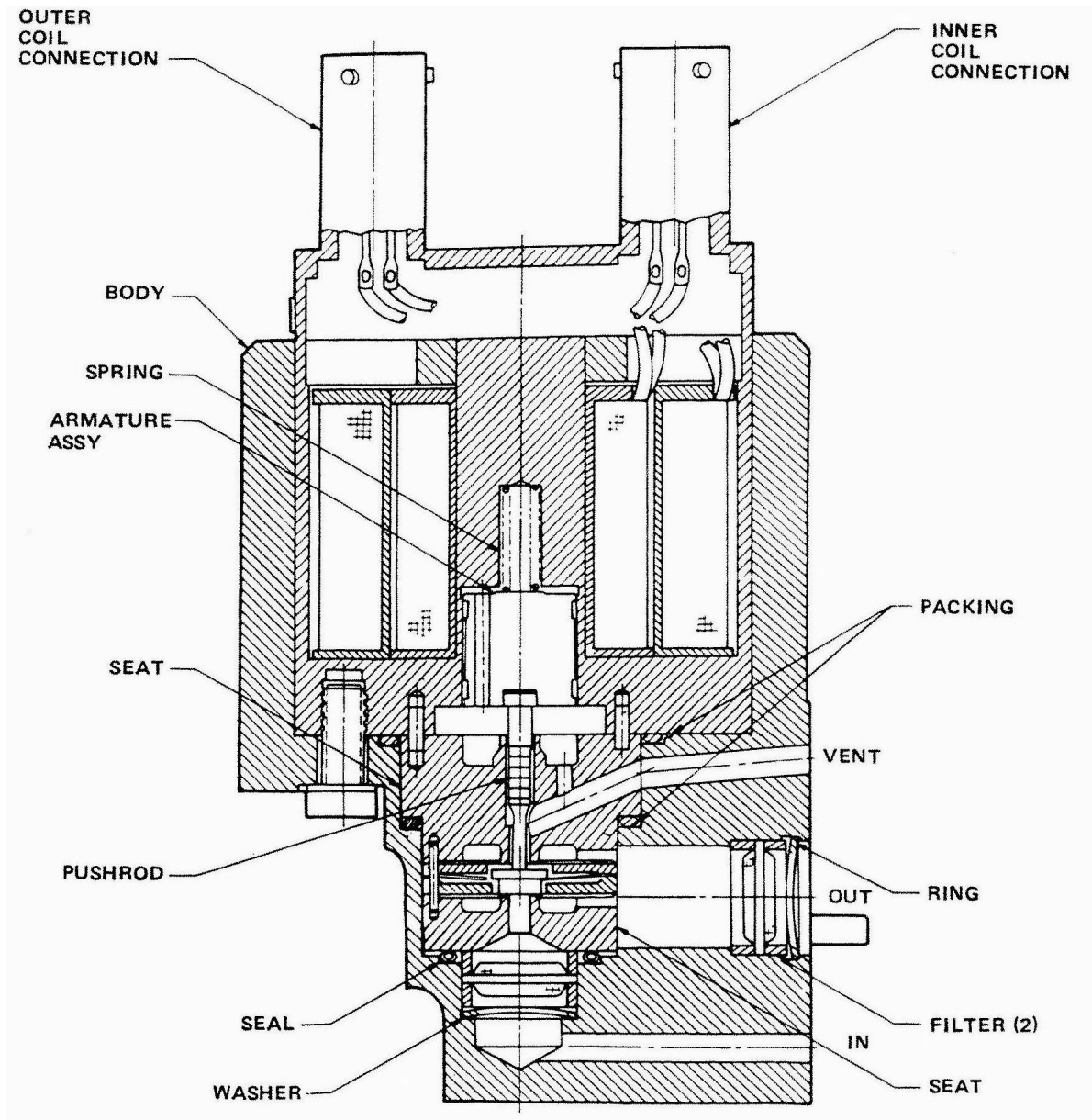
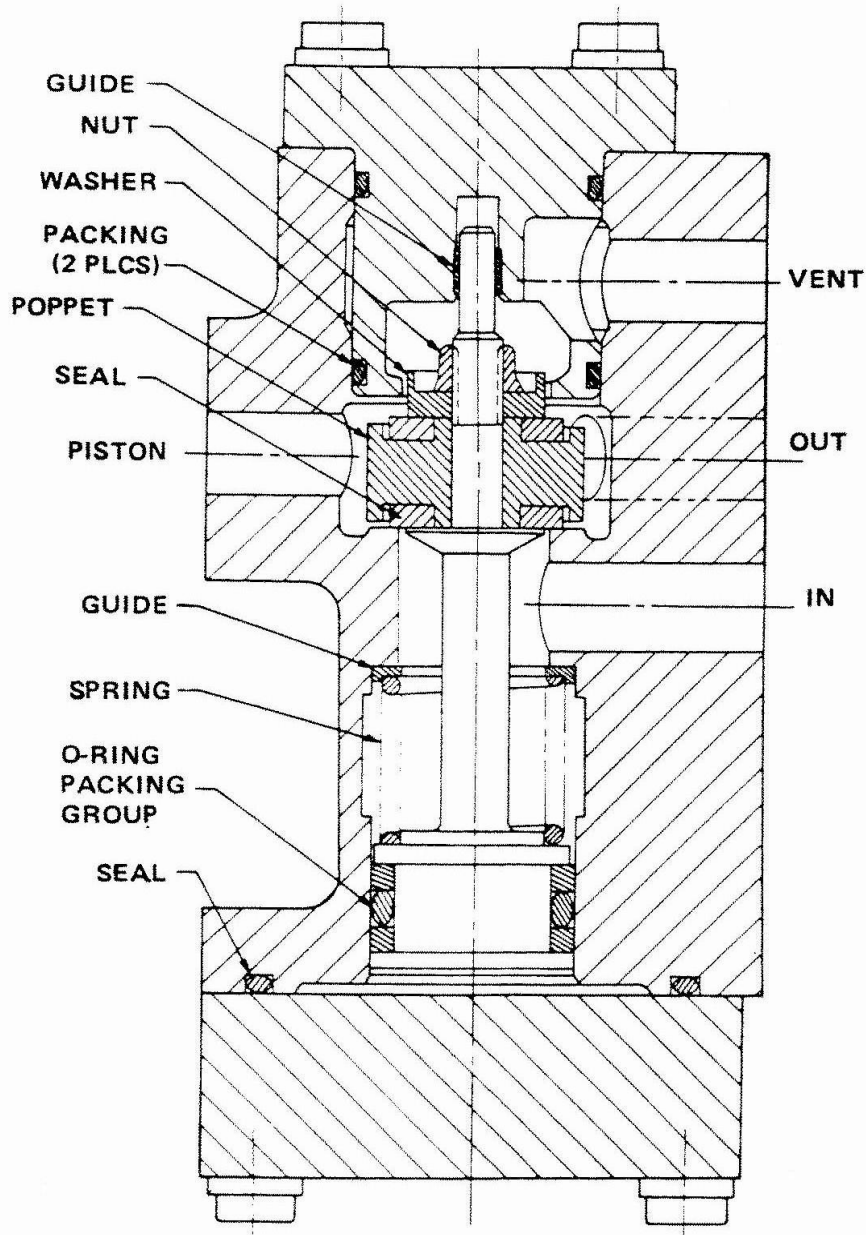


Figure 1.3-XIII – Normally closed solenoid valve

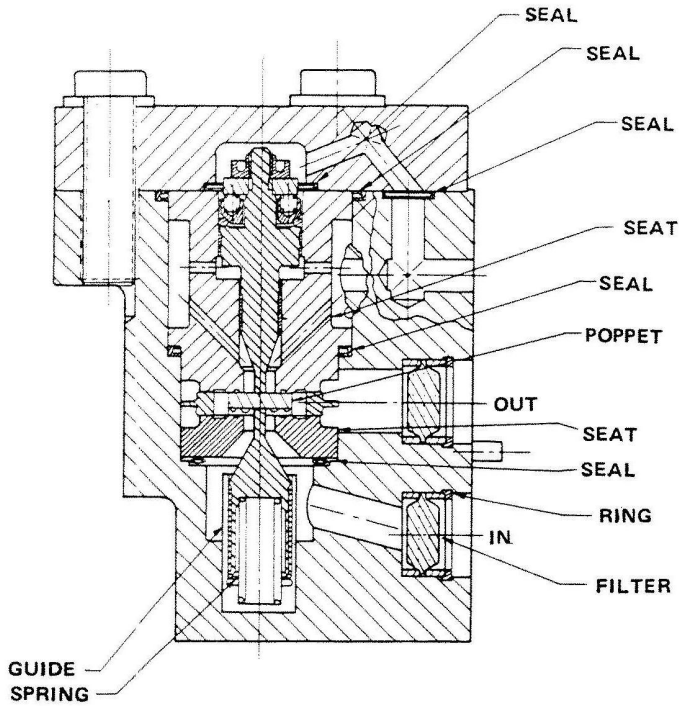
1.3.2.14 Pressure Actuated Valves

The schematics of pressure actuated valves are shown in Figure 1.3-XIV.

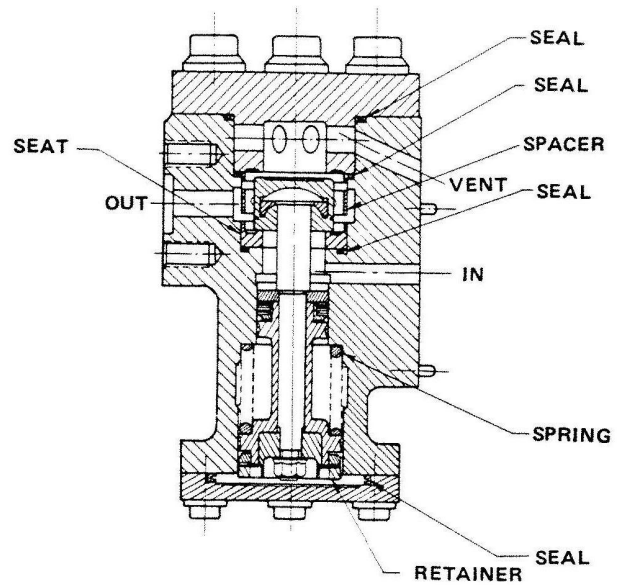


Examples: Emergency Shutdown Control Valve, Oxidizer Bleed Valve, Fuel System Purge Valve, Oxidizer Bleed Valve, Oxidizer System Purge Valve.

Figure 1.3-XIV – Pressure-actuated valves (fig. 1 of 3).

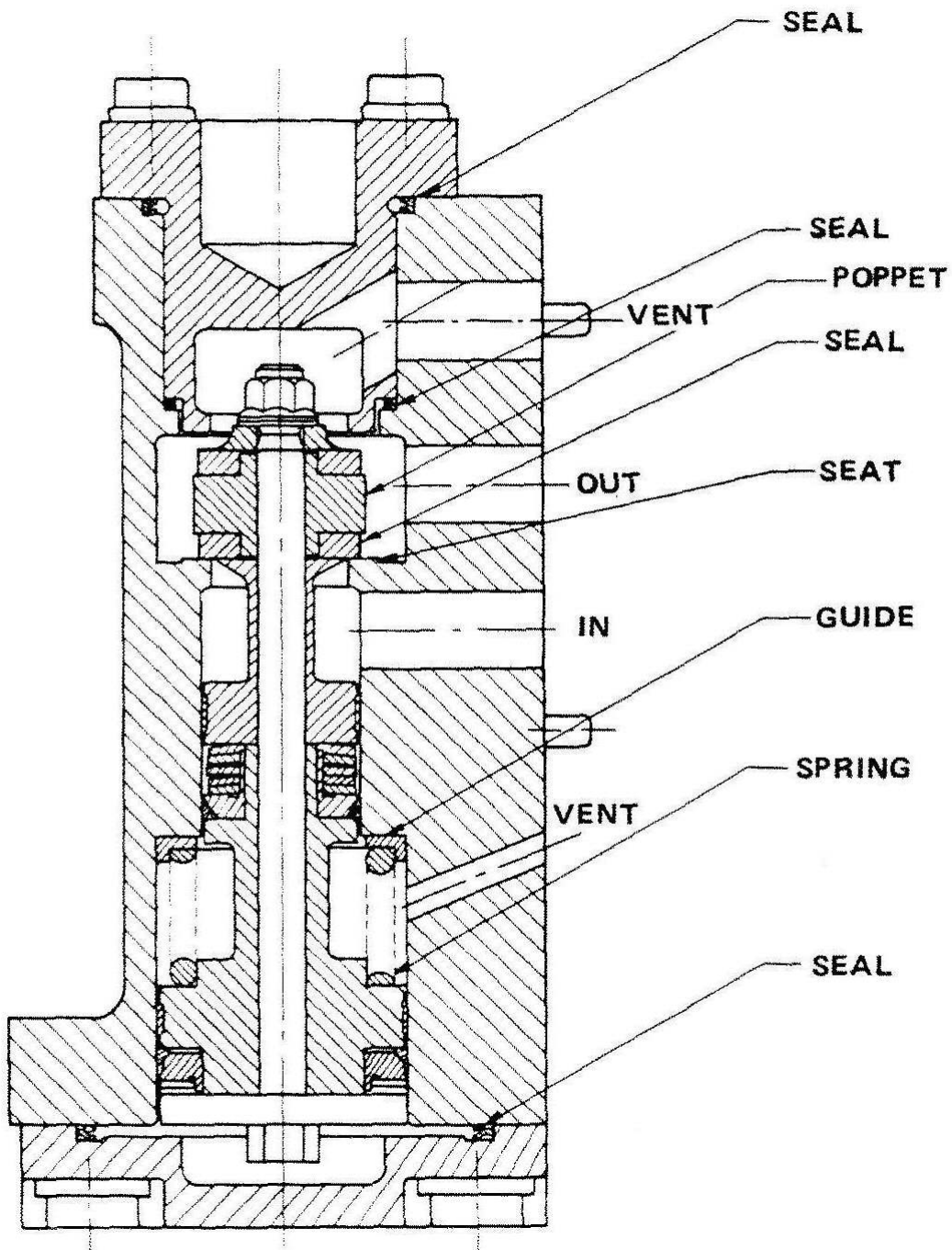


Left: Purge Sequence Valve



Right: Fuel Preburner Purge Valve.

Figure 1.3-XIV – Pressure-actuated valves (fig. 2 of 3)



HPOTP Intermediate Seal Purge Valve

Figure 1.3-XIV – Pressure-actuated valves (fig. 3 of 3)

1.3.2.15 Propellant Valve Hydraulic Actuators

A cutaway view of a typical actuator is shown in figure 1.3-XV. A main propellant valve actuator and a preburner valve actuator are included in Figure 1.3-XVI. A cross section of a propellant valve actuator is shown in Figure 1.3-XVII.

Hydraulic power is provided for the operation of the 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.

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

A heater is installed on the MFV actuator neck (at the valve interface flange) to maintain the hydraulic fluid at the required temperature.

A dual, redundant, rotary variable differential transformer (RVDT) is connected to the actuator shaft and returns two electrical signals of actuator position to the controller.

All hydraulic actuators are capable of using an emergency shutdown system to pneumatically close the propellant valves. Pneumatic sequence valves in the OPB and FPB actuators provide for a proper closing sequence of the propellant valves for an emergency shutdown condition. A pneumatic sequence valve in the CCV actuator is used to terminate the engine post shutdown purges.

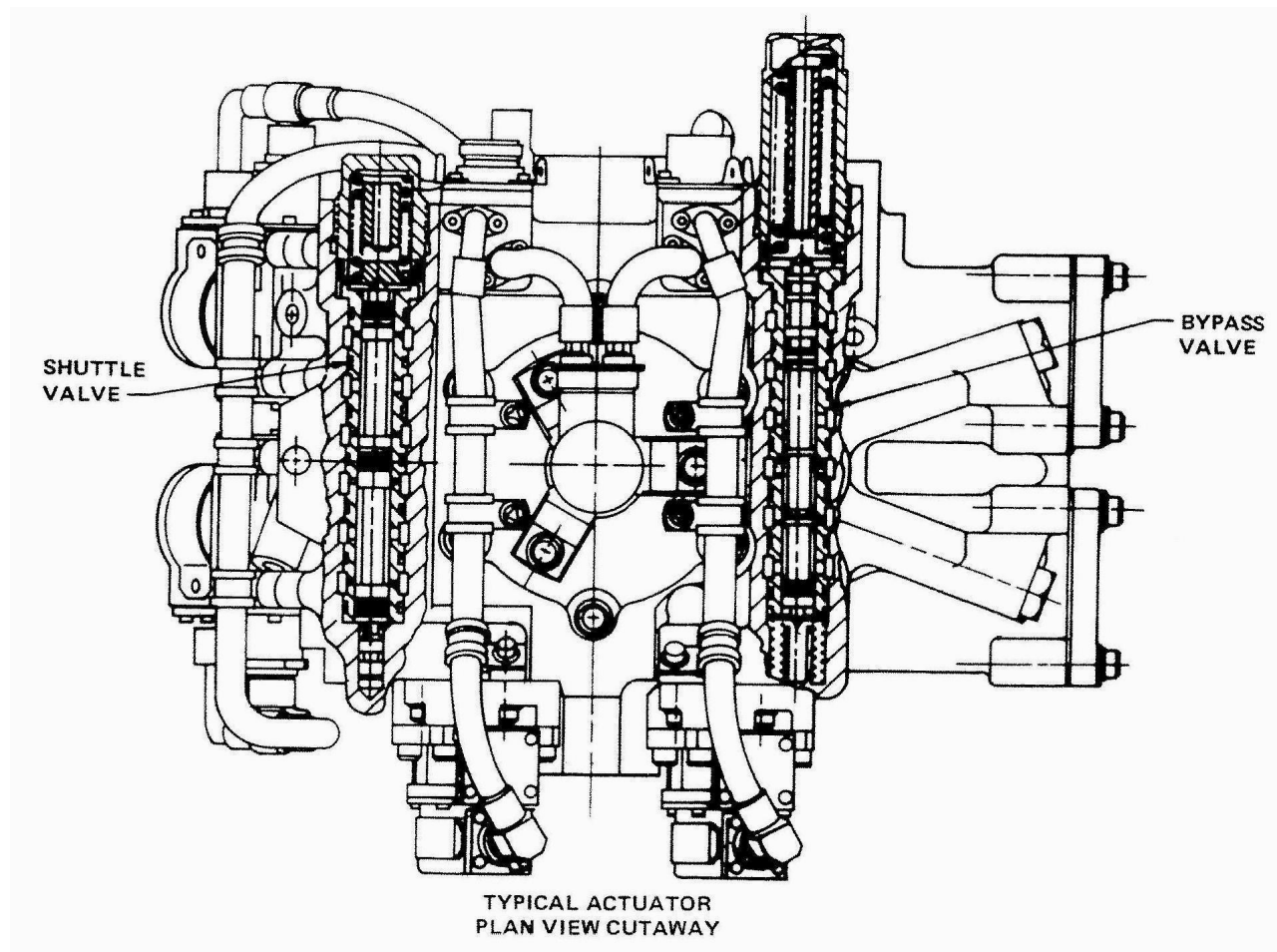


Figure 1.3-XV – Propellant valve actuator cutaway view

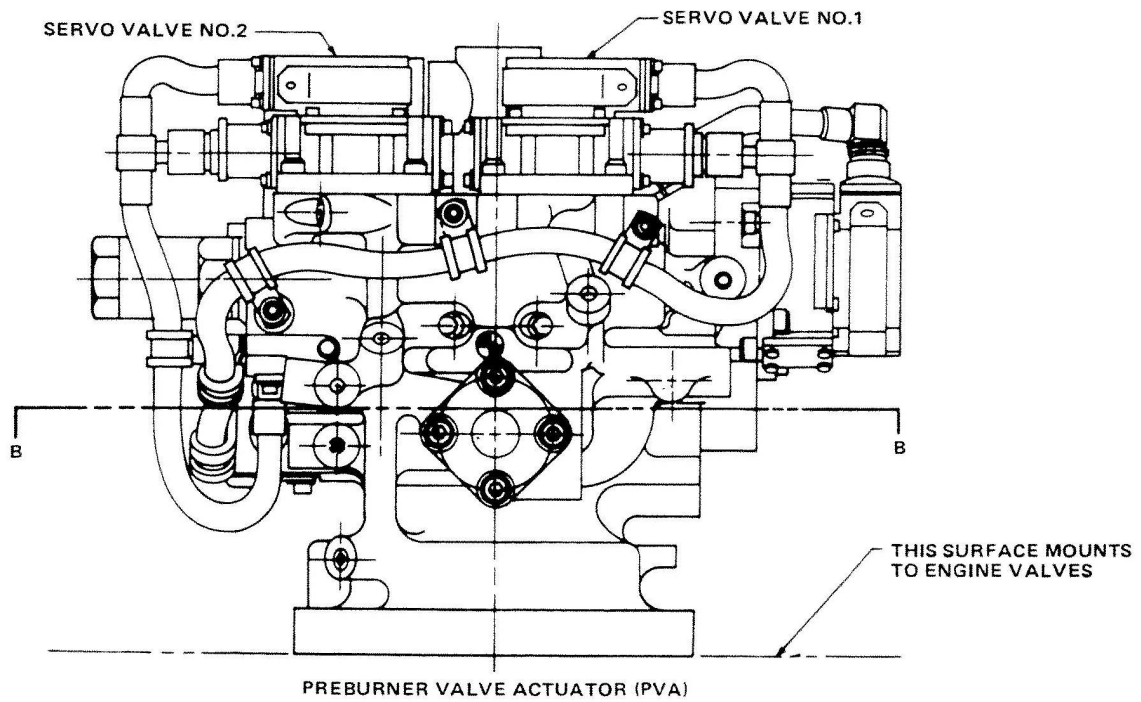
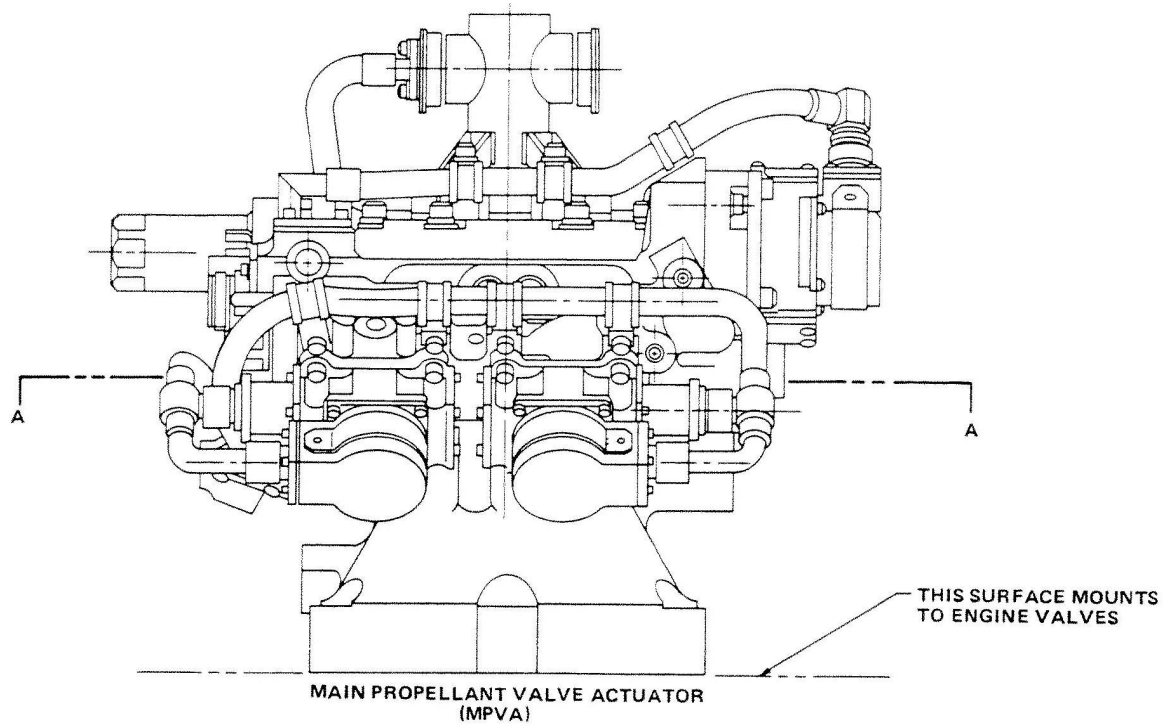


Figure 1.3-XVI – Propellant valve actuators

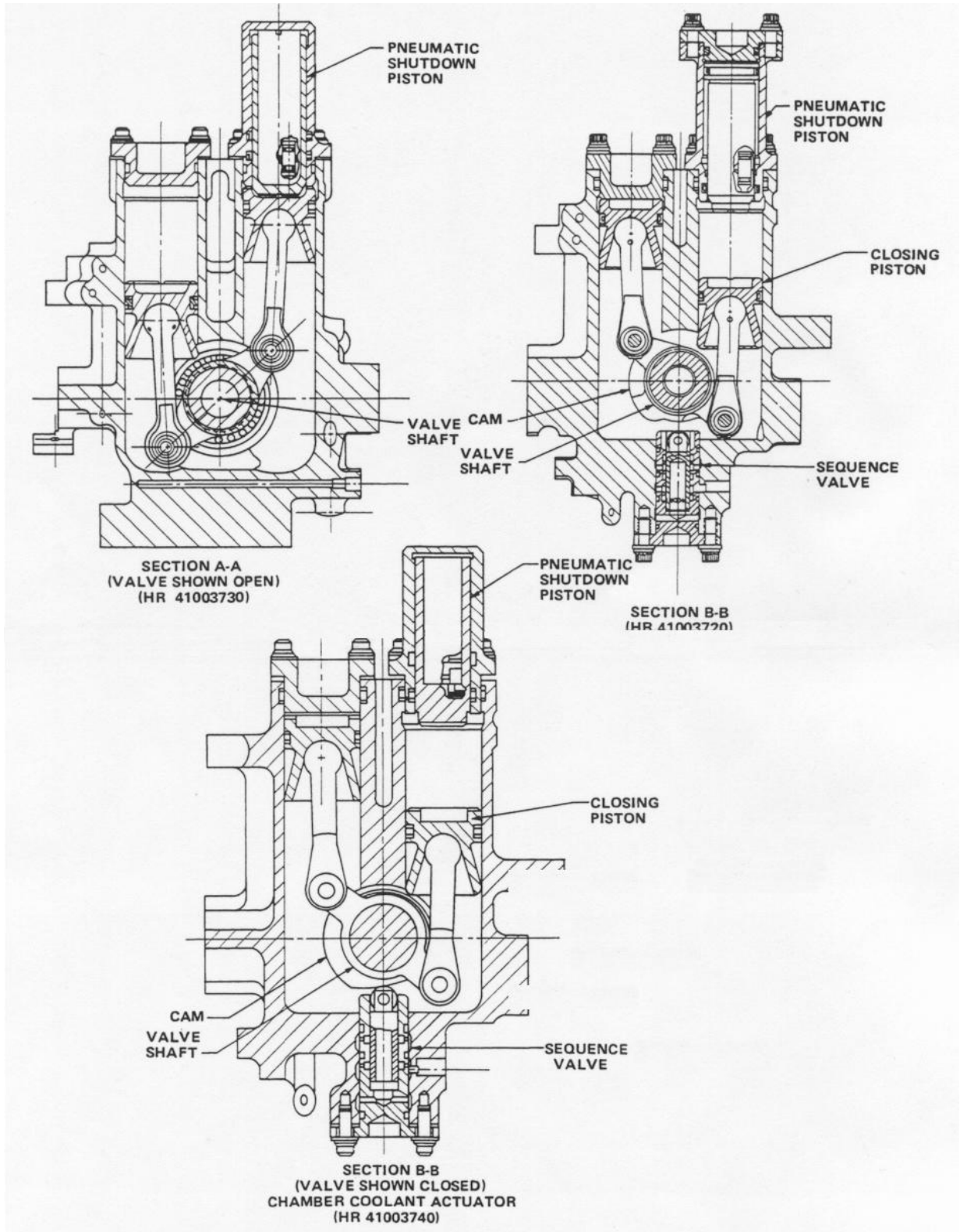


Figure 1.3-XVII – Propellant valve actuator cross section



Figure 1.3-XVIII – Propellant valve actuator

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1.4 SSME PURGE/ACTUATOR OPERATIONS

1.4.1 Hydraulic Actuator Description

Each of the five engine ball valves is controlled by a fail operational/ fail-safe actuator. The actuators are hydraulically driven and are designed with a pneumatic piston that is used for redundant closing of the valve at engine shutdown. The actuator hardware includes channel A and B servo-valves, a fail-to-operate servoswitch, a shuttle valve, a fail-safe servoswitch, a bypass valve, and a pneumatic sequence valve.

1.4.1.1 Servovalves

Individual servovalves are dedicated to channel A and channel B of the main engine controller (Figures 1.4-I and 1.4-II). The servovalve controls the movement of the actuator by metering hydraulic flow to either the open or closed side of the actuator piston. The servo pulls a flapper valve toward either an opening or closing orifice, which creates a pressure unbalance across the servopiston and allows pressure to enter either the open or closed side of the actuator. Channel A of the controller is normally in control. The rotational variable differential transformer (RVDT) measures the actuator position as a percent of travel. The position is sent to the input electronics box in the controller where it is demodulated. The position is then sent to a servovalve driver where the actuator position is compared to the commanded position. Note that if the valve does not move, the OE will keep trying to move the valve at a certain ramp rate and the target valve position increases. The measured position is also used in an analog model to detect actuator channel errors. The error between the measured position and the commanded position is cumulative for each controller major cycle. If this combined error exceeds 6 percent, valve control is switched to channel B by means of the fail-to-operate servoswitch. The servoactuator A failure is reported with an octal failure identification (FID) 015 and an octal delimiter in vehicle data table word 5. The FID indicates that a servoactuator has failed. The delimiter indicates the channel and valve that failed.

1.4.1.2 Fail to Operate Servoswitch/ Shuttle Valve

When channel A servovalve is in control, the fail-to-operate servoswitch is in the de-energized state. The servoswitch driver in the output electronics energizes the fail-to-operate servoswitch when a 6 percent cumulative error is detected on channel A.

The flapper valve is energized to cover the channel B orifice. A pressure activated slide valve allows hydraulic pressure to be channeled to the shuttle valve where a spring-loaded slide valve is moved to the channel B position, thus allowing the channel B servovalve driver to control hydraulic pressure to the actuator (ref. Figure 1.4-III).

1.4.1.3 Fail Safe Servoswitch

Once the channel B servovalve takes control, monitoring is done by the output electronics to check that the cumulative error between the commanded and measured positions is less than 10 percent. The fail safe servoswitch controls the bypass valve which locks hydraulic pressure simultaneously on the open and closed actuator pistons if both channel A and channel B servovalves fail. While channel B servovalve is in control, the fail-safe servoswitch is in the energized state. This switch maintains a positive pressure on the bypass valve to allow normal hydraulic flow to the open or closed actuator pistons. If the fail-safe servoswitch is de-energized, a flapper valve unbalances a slide valve, which then vents holding pressure from the bypass valve (reference Figure 1.4-IV).

1.4.1.4 Bypass Valve

The bypass valve will move to the bypass position when both channel A and B servovalves fail or when hydraulic pressure is lost to the actuator. Pressure is simultaneously locked on the open and closed actuator pistons to prevent actuator movement.

1.4.1.5 Hydraulic Lockup

When any of the five engine valves fail the channel A and B checks, the engine will be defined as being in "hard hydraulic lockup." Since it is not desirable for the other engine valves to move when one of the five is locked, the controller software will command all the valves into hydraulic lockup so that affects on mixture ratio and power level can be minimized. The loss of hydraulic pressure from an APU will send all five valves into "soft lockup" if hydraulic pressure drops below 1100 psia. Soft lockup implies that the controller actuator channel checks have not been violated. If no power level commands are being sent, it may take 20 to 60 seconds for the valve to fail the actuator checks. The errors generated by the FPOV and OPOV closed loop control software will be summed until the 6 percent and 10 percent error limits are violated. If hydraulic pressure is somehow recovered prior to hard lockup, the engine may come out of soft hydraulic lockup and normal engine operation can be resumed. Once the engine is in hard lockup, however, it will stay locked through engine shutdown. The engine design specifications state that the engine must operate if hydraulic pressure is greater than 1500 psia and that it must go into hydraulic lockup below 1100 psia. Actually, lockup may occur at any pressure below 1500 psia. After lockup occurs, the mixture ratio tends to drift upward while chamber pressure tends to drift down. No significant change in high-pressure oxidizer turbopump (HPOTP) or high-pressure fuel turbopump (HPFTP) turbine discharge temperature should occur since both the FPOV and OPOV tend to drift downward. Figure 1.4-V shows the result of some of the hydraulic lockup testing that has occurred. One lockup occurred during the flight of STS-3 when APU 3 was manually shut down due to a high return lube oil temperature. The right engine (2005) ran stable at 82 percent power level through main engine cutoff (MECO) (22 seconds) when it shut down pneumatically.

1.4.1.6 Pneumatic Shutdown

An engine in hydraulic lockup can no longer be throttled or shut down hydraulically. The engines are designed with a pneumatic control assembly that includes an emergency shutdown solenoid. This solenoid valve is redundantly powered. When shutdown is commanded (at MECO or because of redline exceedance) or when ac power is removed from the controller, the emergency shutdown solenoid is de-energized. Helium pressure at approximately 750 psi is channeled to the bypass valve and to the pneumatic shutdown piston. The bypass valve is moved against a spring force to a position that vents any remaining hydraulic pressure from the open and closed pistons. The pneumatic piston pushes against the closed hydraulic piston and forces the valve closed. On the OPOV and FPOV a pneumatic sequence valve mechanically sequences helium through the five engine ball valves in order to simulate the hydraulic shutdown valve sequence. These two sequence valves are controlled by cams on the OPOV and FPOV actuator shafts. The OPOV routes pneumatic pressure to the MOV and FPOV. After the FPOV moves, pneumatic pressure is routed to close the MFV and the CCV. Figure 1.4-VI shows how pneumatic helium closes the valves. Figures 1.4-VIII(k) and 1.4-VIII(l) show how helium is routed for a pneumatic shutdown with and without engine purges.

1.4.2 SSME Pneumatic Control Assembly

The previously discussed pneumatic shutdown is not the only function of the pneumatic control assembly (Figure 1.4-VII). This piece of hardware uses five solenoid valves to operate eight pressure activated valves (PAV's), which control pneumatic helium flow for engine purges and SSME shutdown. A dedicated engine helium supply system sends 750 psi regulated pressure to each engine. Figures 1.4-VIII(a) through 1.4-VIII(l) show how helium is used during prelaunch purges, in-flight purges, and shutdown activation and purges. Figure 1.4-VIII(b) also shows how ground supplied nitrogen is used for engine postflight maintenance.

1.4.2.1 Ground Controlled GN₂ Purge

During ground maintenance (purge sequence 1-4) and turnaround operations, a GN₂ drying purge is supplied to the main chamber oxidizer dome, HPOTP seal package, OPOV, FPOV, HPOTP and HPFTP preburner domes. Figure 1.4-VIII(b) shows how this purge is accomplished. This purge also maintains a positive inerting purge pressure that prevents ingestion of dust or water vapor between flights.

1.4.2.2 Fuel System Purge

Since nitrogen will freeze when it contacts cryogenic hydrogen, a 125-scfm helium purge is used to clear nitrogen from the high-pressure engine passages. The purge occurs during purge sequences 2, 3, and 4 and is introduced downstream of the MFV. Figure 1.4-VIII(c) shows how this purge is accomplished. Frozen nitrogen can cause blockage of engine coolant passages and injector tubes which could result in engine damage during engine start and main stage operations.

1.4.2.3 Bleed Valve Activation and Component Fuel Drain

Bleed valve activation and component fuel drain occur during purge sequences 3 and 4. Cavities in the LPFTP, HPFTP and CCV are drained via the component fuel drain line. These cavities are purged with a 2-scfm helium flow in preparation for engine start. The bleed valve activation allows hydrogen and oxygen to bleed through the engine for propellant conditioning. The LO2 bleed valve is used to drain back the LO2 tank to the prescribed flight mass starting at lift-off minus 5 minutes. At the START ENABLE signal, the bleed valves close and the POGO precharge purge is initiated. The bleed valves open again at post-shutdown standby and remain open for the duration of the propellant dump sequence. The LH2 bleed valve is used to provide a dump path between the LH2 manifold and the fill and drain line for the LH2 dump (ref. Figure 1.4-VIII(d)).

1.4.2.4 HPOTP Intermediate Seal Package Purge

During purge sequence 4 and main stage, a 260-scfm helium purge is activated via the HPOTP intermediate seal purge solenoid valve and a pressure activated valve. This purge is required for safe engine operation since it separates fuel in the turbine end from oxidizer in the pump end of the HPOTP. The controller automatically commands engine shutdown if this purge is lost. Redline monitoring is done on the intermediate seal. Shutdown is commanded if the intermediate seal pressure is less than 159 psia (Block II/IIA). Operation of this purge is shown in Figure 1.4-VIII(e).

1.4.2.5 Preburner Shutdown Purge

During shutdown the fuel preburner and oxidizer preburner LO2 domes are purged to prevent H2 and O2 ignition in the O2 dome. Figure 1.4-VIII(f) shows how these preburner purges are accomplished during a normal shutdown.

1.4.3 SSME Start Preparation Phase Modes

System purges and propellant conditioning are performed in preparation for engine start. Figures 1.4-VIII(g) through (j) show how helium is routed for purge sequences 1, 2, 3, and 4. Figures 1.4-IX(a) through (d) illustrate the valve timing required for these purges. Figure 1.4-X shows the helium requirements for purges 1, 2, 3, and 4, main stage, and post-MECO operations. Following is a brief discussion of the prelaunch purges and SSME start phase.

1.4.3.1 Purge Sequence 1 Mode

Functions include verification of propellant valve positions. During this sequence, facility initiates ground oxidizer system and HPOT intermediate seal gaseous nitrogen purges.

1.4.3.2 Purge Sequence 2 Mode

Functions include initiation of onboard helium purge of fuel system (high-flow) and continuation of purges initiated in purge sequence 1. The high-flow helium purge is enabled by energizing the Fuel System Purge Solenoid. This sequence starts about 3 minutes prior to purge sequence 3 (which is approximately T-6:00 hours).

1.4.3.3 Purge Sequence 3 Mode

Functions include propellant recirculation (bleed valve operation) and continuance of fuel and oxidizer system purges previously initiated. Note that the high-flow fuel system purge will change to a low-flow purge approximately 10 sec after purge sequence 3 initiation by energizing the Bleed Valve Solenoid and deenergizing the Fuel System Purge Solenoid. Also, a 10 sec vehicle helium HPOT IMSL purge is commanded at the initiation of Purge Sequence 3. This purge sequence starts during the T-6:00 hour hold.

Note: Block II SSME's do not utilize a variable-flow fuel system purge, and remain at the high-flow purge condition from the start of Purge Sequence 2.

1.4.3.4 Purge Sequence 4 Mode

Functions include return to high-flow fuel system purge (opposite action as than described above) and continuance of GN₂ purges initiated in purge sequence 1. All fail-safe solenoid valves are energized. Small valve movement (-0.5 to -1.0 percent) towards the closed position should be seen on the MFV, MOV, FPOV, and OPOV. Additionally, the vehicle HPOT IMSL

purge is initiated by energizing the HPOT IMSL Purge Solenoid. This purge sequence begins after the APU's have started and is usually about T-4:00 minutes.

1.4.3.5 Engine Ready Mode

“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 4 function. Engine ready occurs about 1:50 minutes prior to launch.

1.4.3.6 Start Initiation Mode

Initial functions associated with start sequence are in progress. These include all functions prior to ignition confirmed, at 2300 msec. All purges off and verified. Bleed valves closed and verified. Igniters energized and verified. Thrust control loop is closed.

1.4.3.7 Thrust Buildup Mode

Ignition has been detected by monitoring main combustion Chamber pressure, and closed-loop thrust buildup sequencing is in progress. Mixture ratio control loop is closed. POGO suppression accumulator is precharged with helium for 2 seconds. MFV, MOV, and CCV are scheduled.

1.4.4 Galling of Bypass Valve and Shuttle Valve

There have been multiple occurrences (8) of bypass valves and shuttle valves galling between 1988 and 1994. Although the exact cause of this galling could not be determined, several changes were made to alleviate the problem. These changes include an anti-rotation feature, measures to reduce sleeve deflection, material changes, and increase in sleeve thickness. These redesigned valves began to fly on the Block-II engines. Figure 1.4-XI shows a typical shuttle valve.

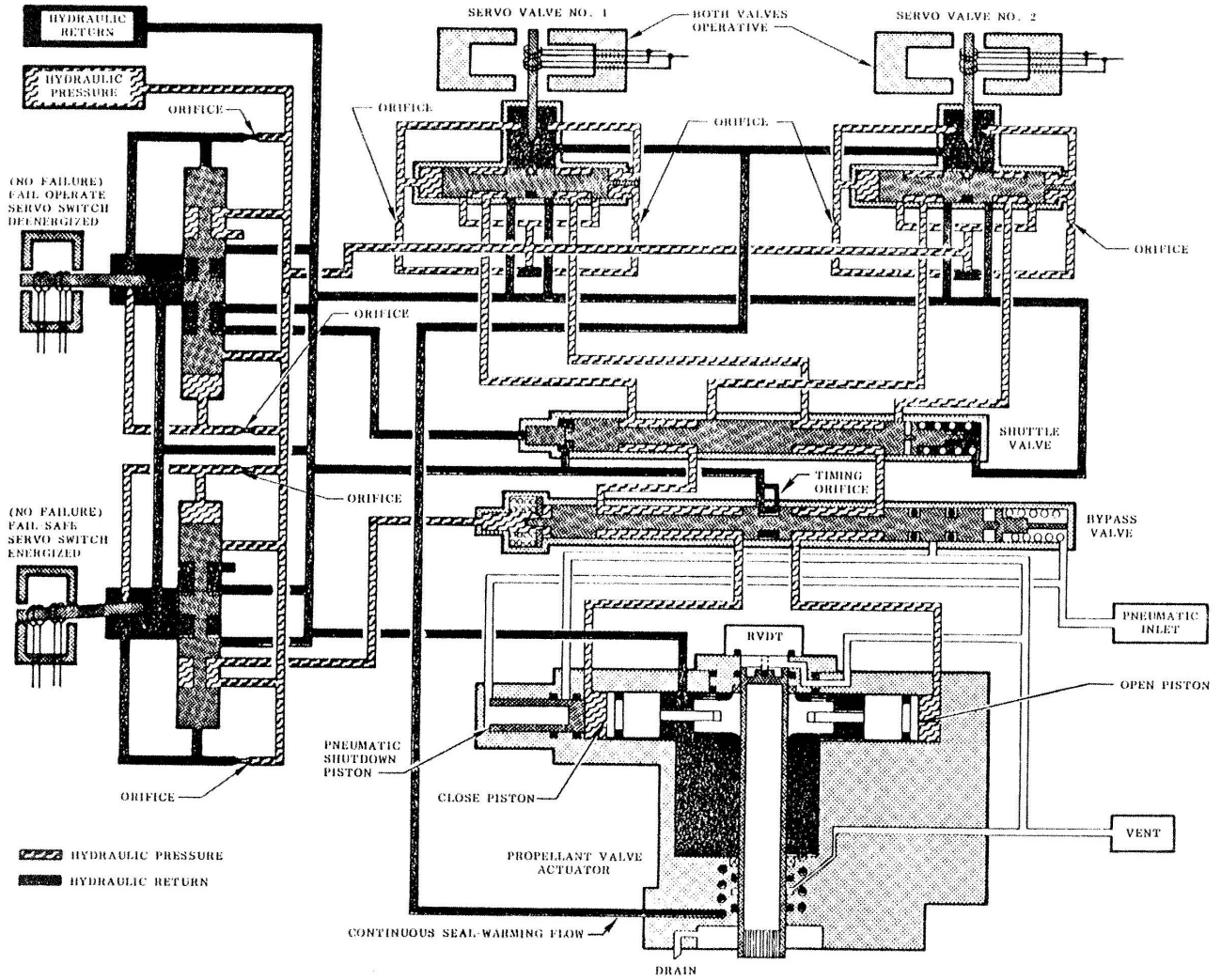


Figure 1.4-I - Main fuel and main oxidizer valve servoactuator (normal operation)

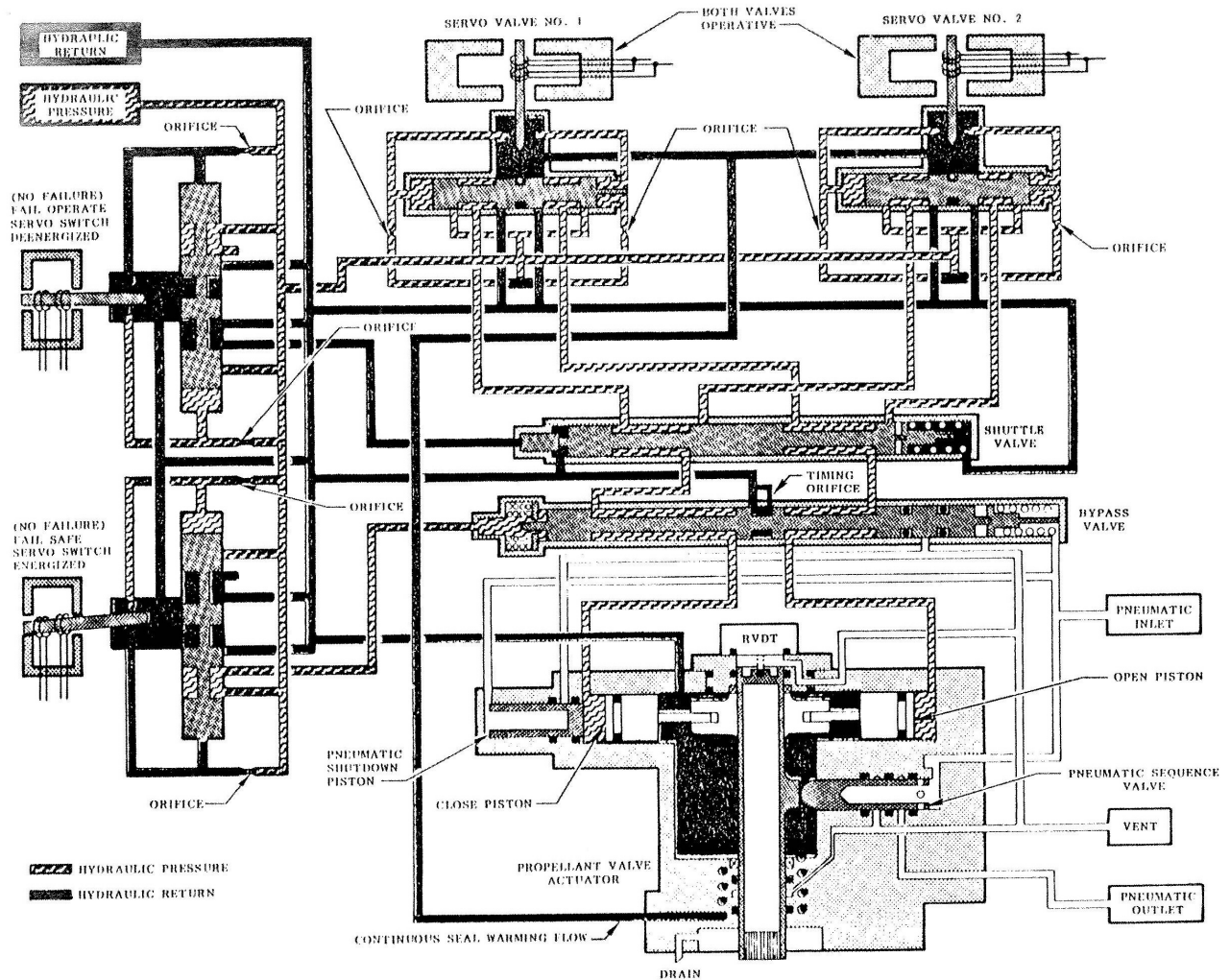


Figure 1.4-II - Preburner and CCV valve servoactuator (normal operation)

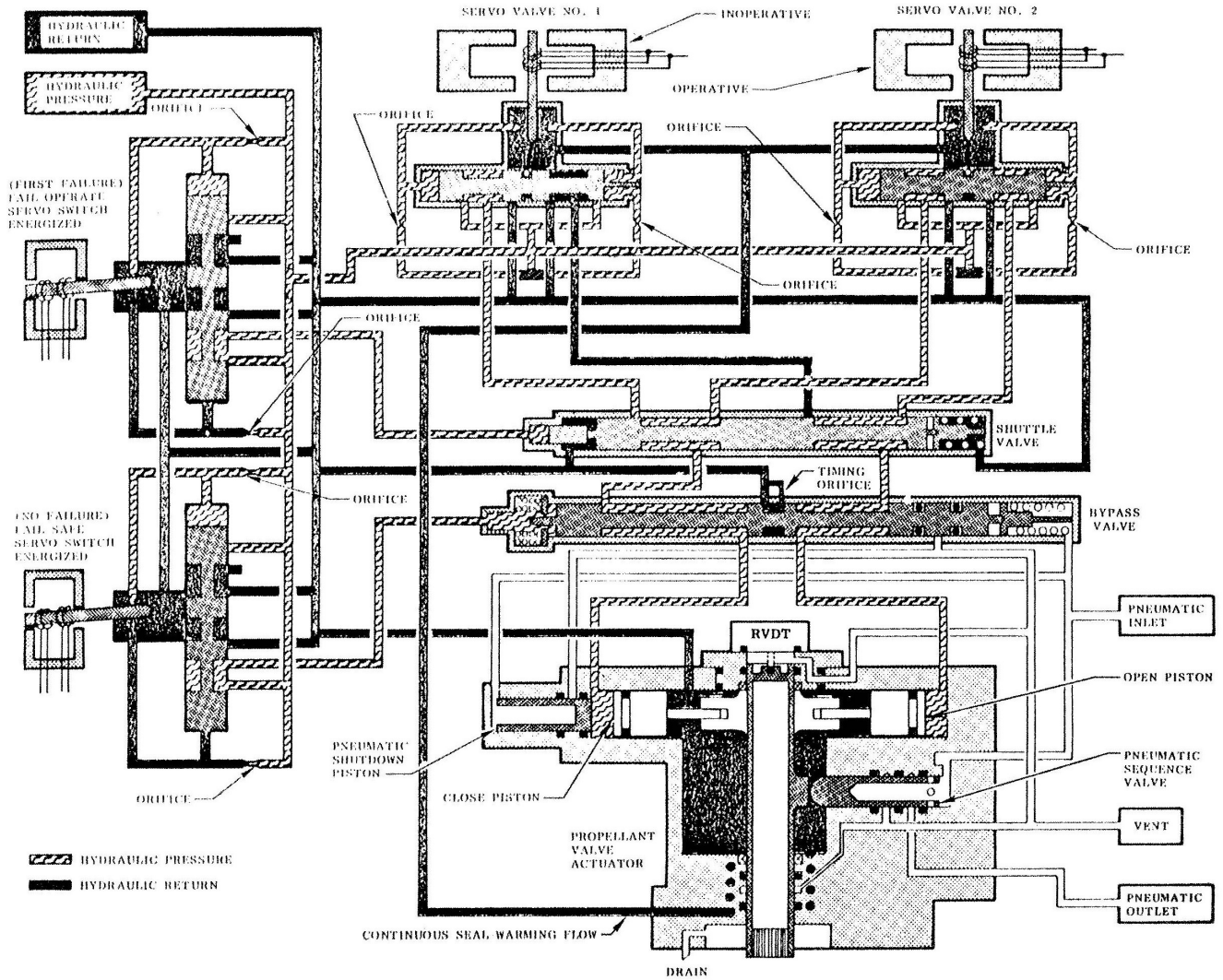


Figure 1.4-III - Preburner and CCV valve servoactuator (fail-operate configuration)

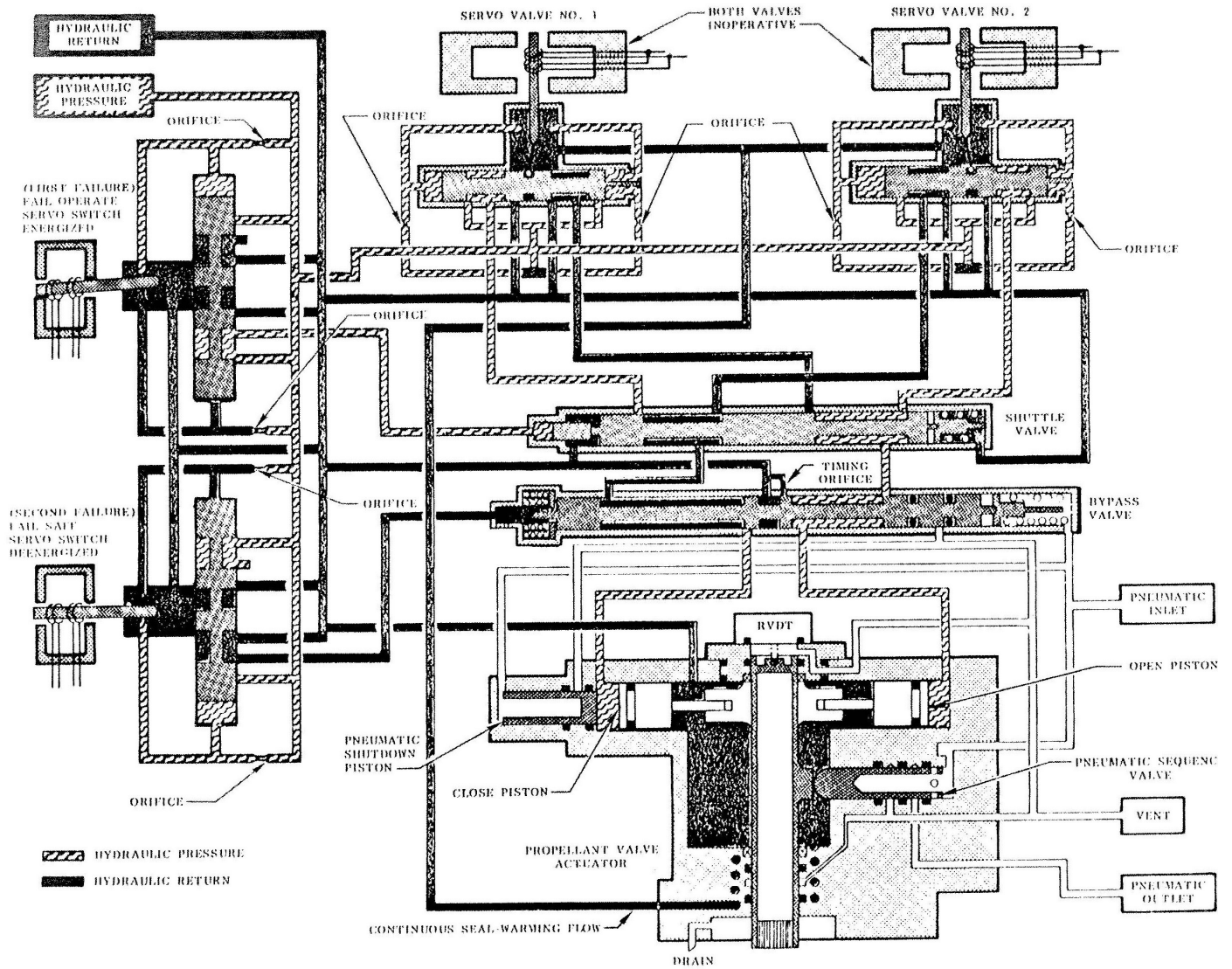


Figure 1.4-IV - Preburner and CCV valve servoactuator (fail-safe configuration)

<u>Engine</u>	<u>Date</u>	<u>Lockup power level</u>	<u>Time in lockup, sec</u>	<u>Mix ratio shift %</u>	<u>PC drift %</u>
0105	Oct. '79	100	255	+2.50	-1.2
0007	Nov. '80	65	420	-0.78	-2.8*
0007	Dec. '80	100	170	+0.32	-0.8
0007	Feb. '81	91 (Up-throttle)	10	-3.33	-
2005	STS-3	82 (3g throttle)	22	-	-
2106	May '87	104	190	+0.25	-0.5
2105	May '87	104	190	+2.50	-1.3
2105	June '87	104	190	+0.33	-0.4
2105	June '87	104	636	+11.9	-4.0
2106	June '97	104	107	0	-1.3
2106	July '87	104	184	0	-
0211	Apr. '88	104	500	+5.32	-3.0
0211	June '88	104	500	+4.33	-2.7
0211	Oct. '88	104	280	+1.25	+1.2
0523	Mar 96	104	305	+0.08	-0.42

*Percent of RPL PC.

Figure 1.7-V - Hydraulic lockup testing

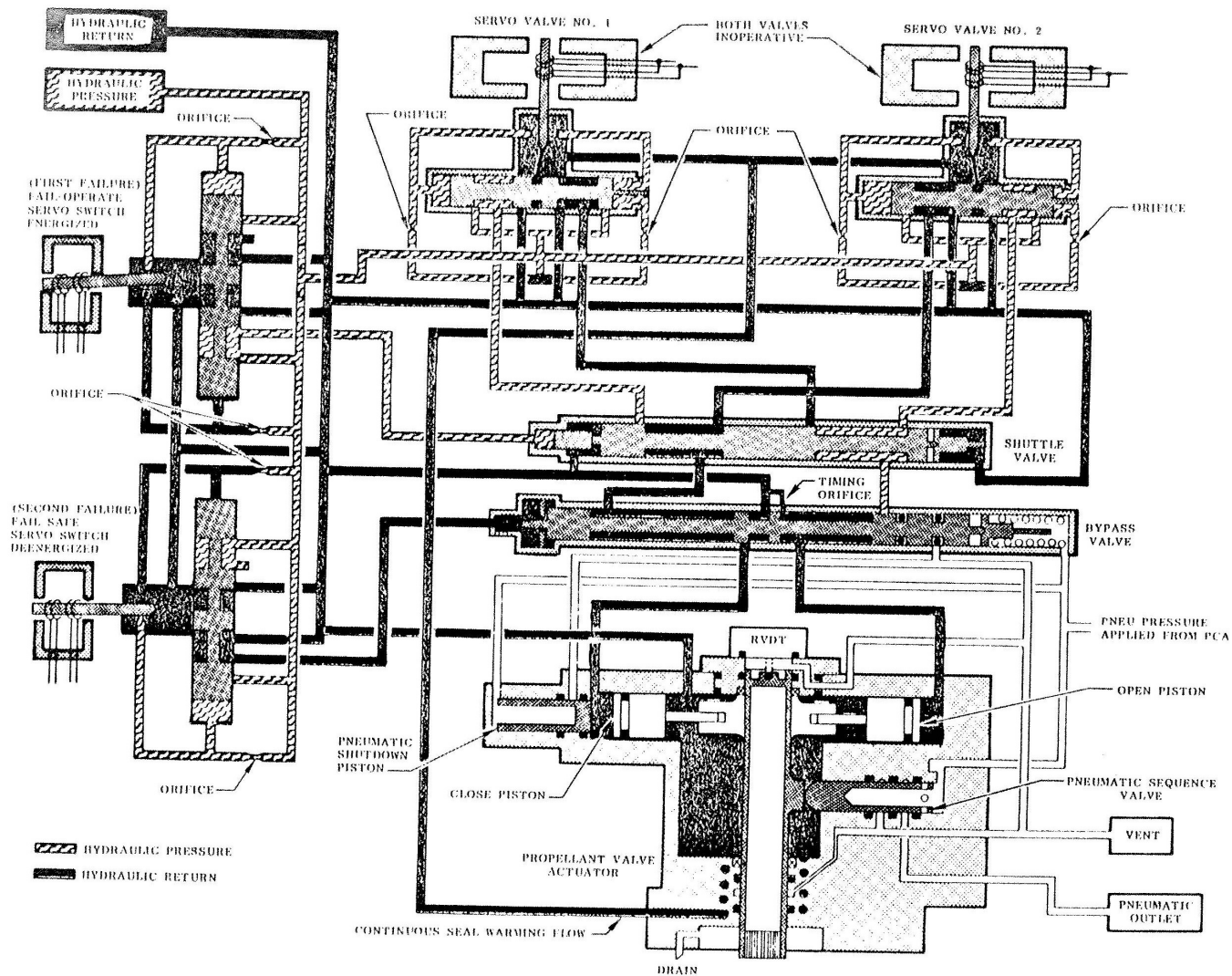


Figure 1.4-VI - Preburner and CCV valve servoactuator (pneumatic shutdown configuration)

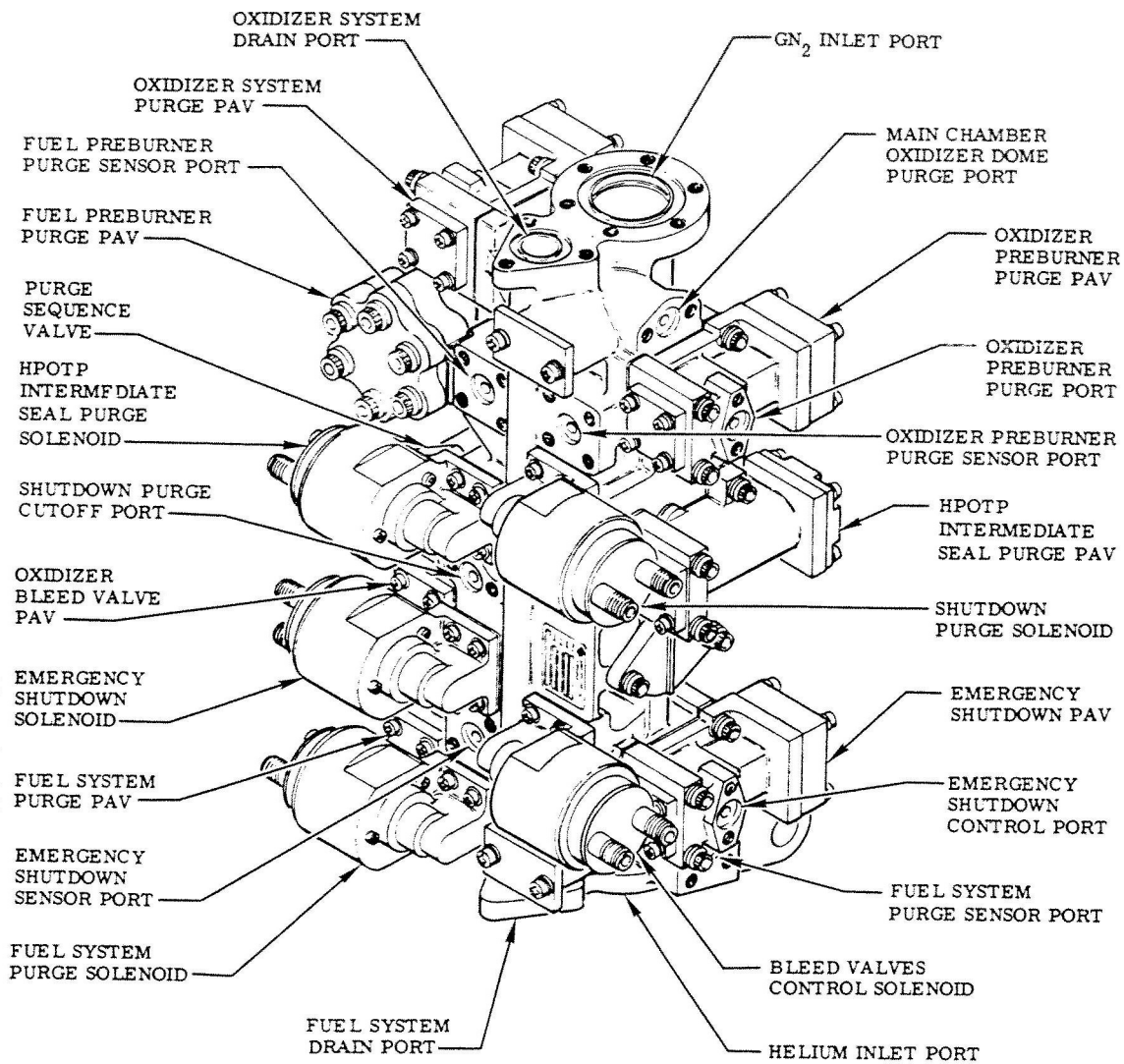
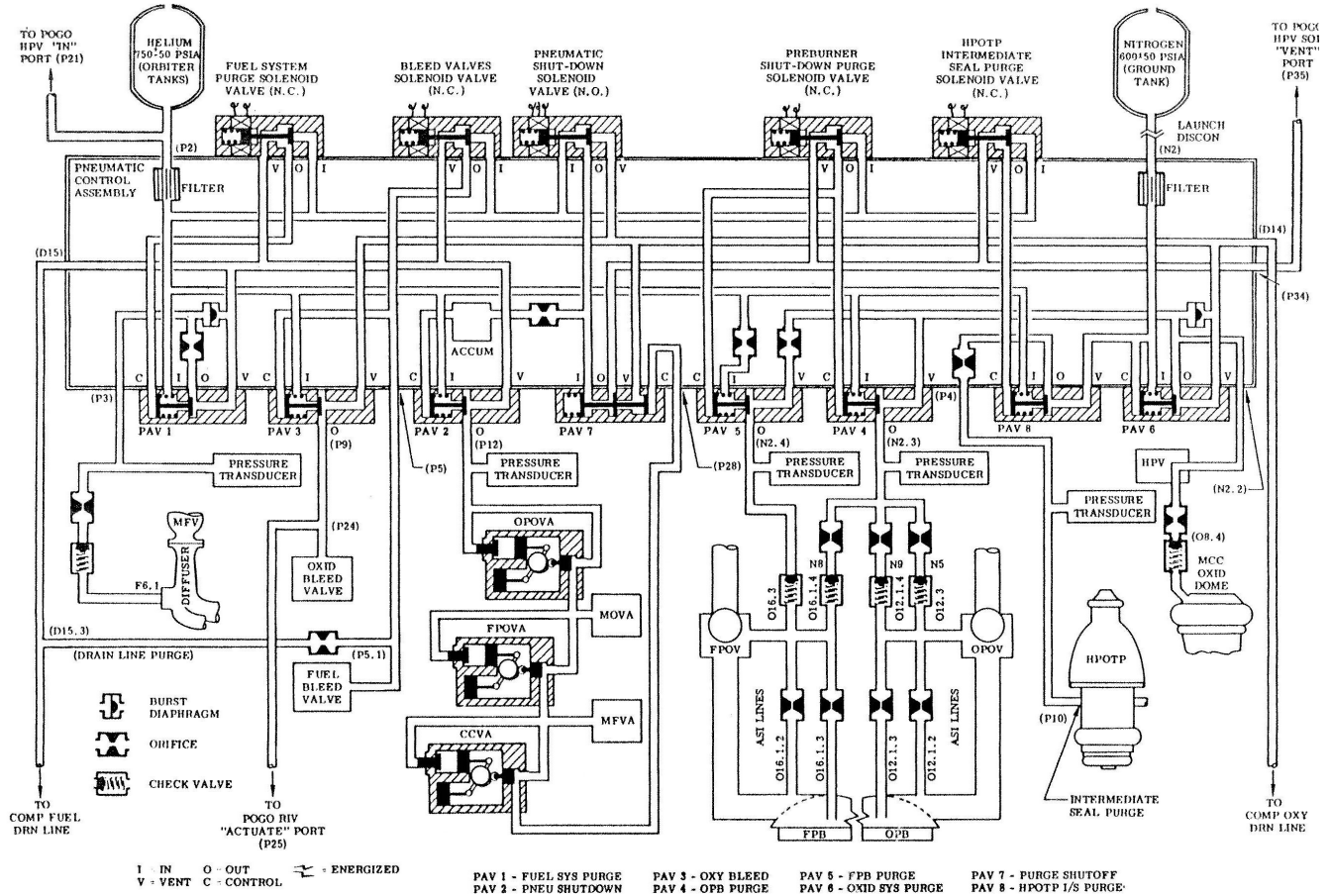
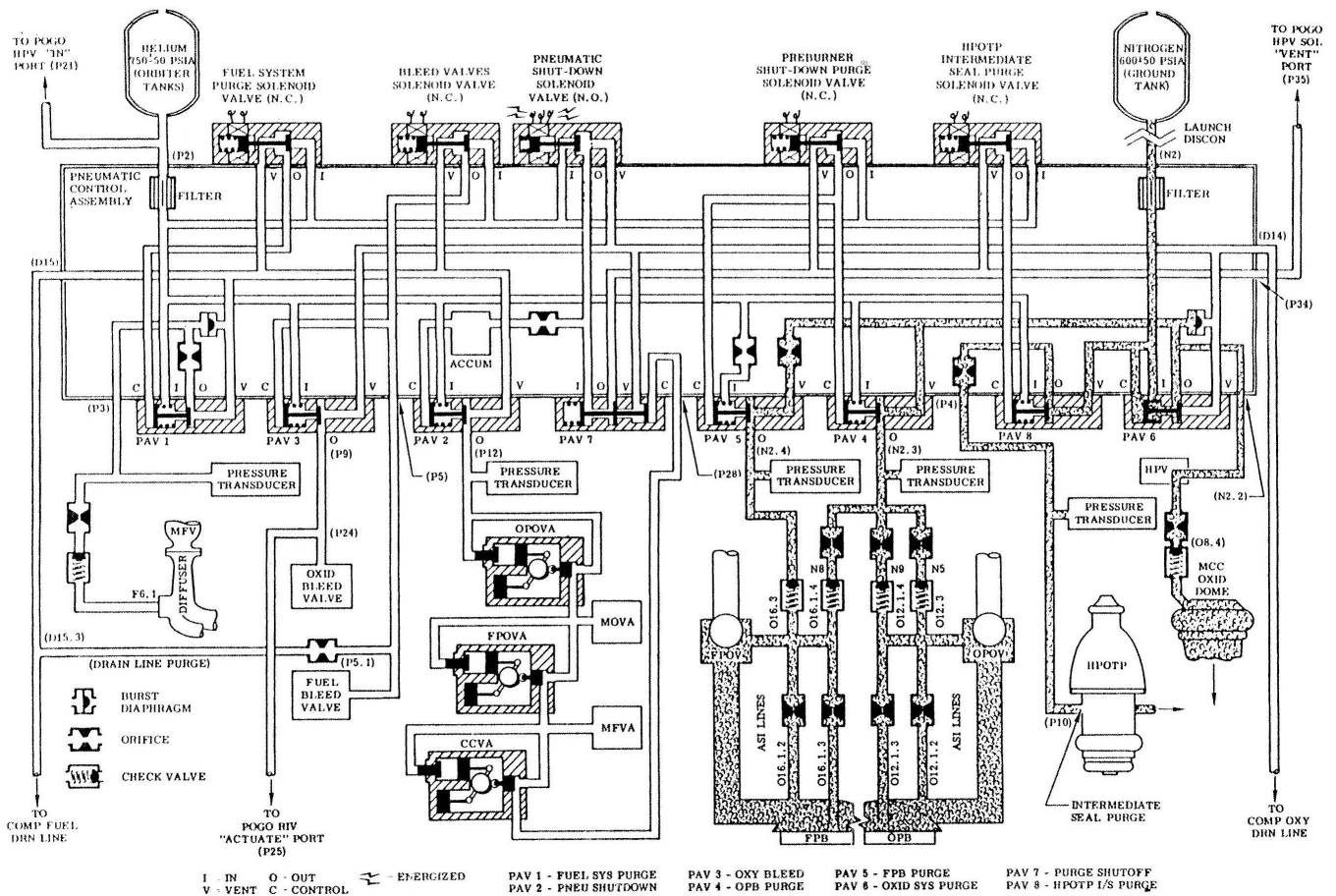


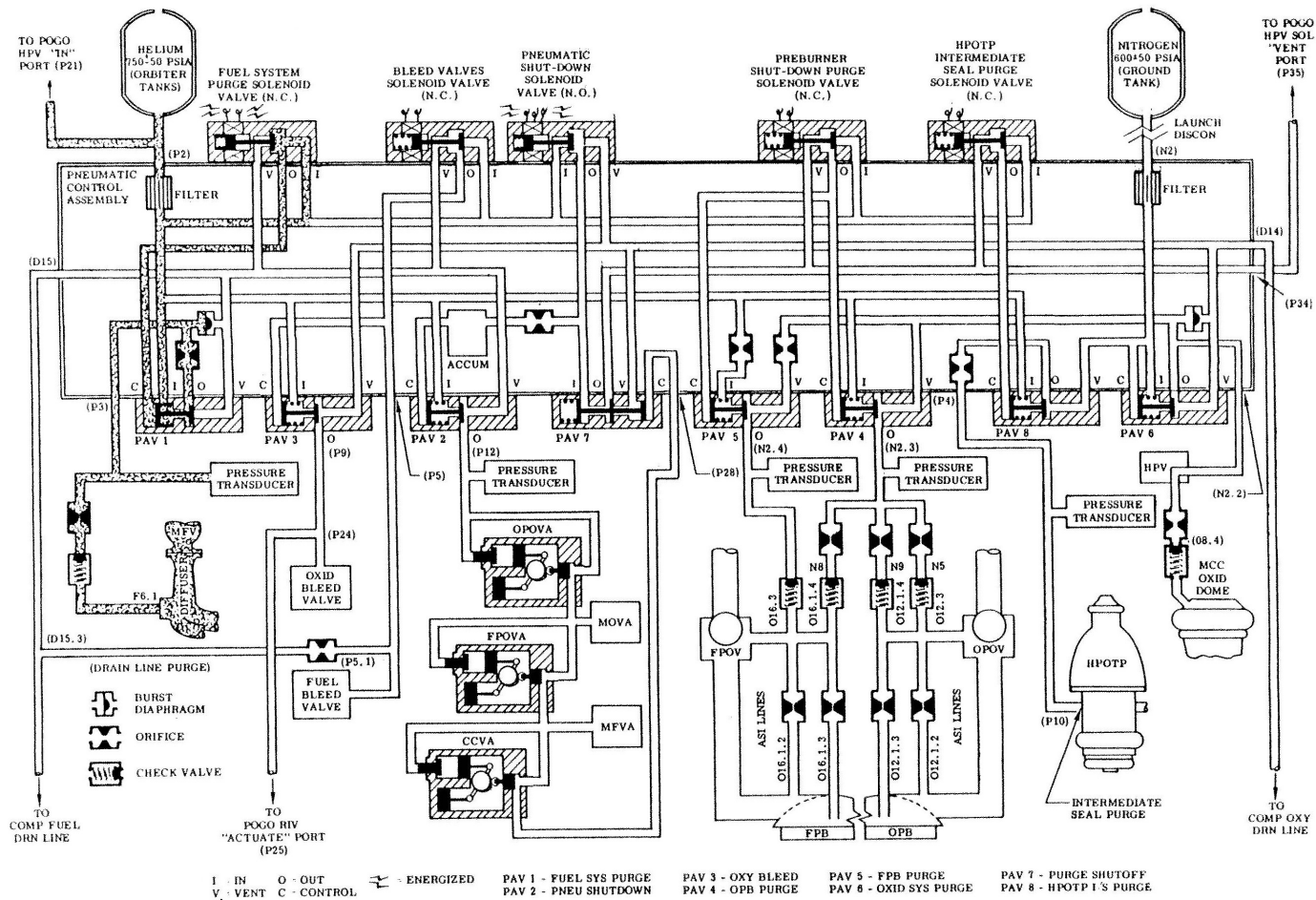
Figure 1.4-VII - Pneumatic control assemble flight configuration



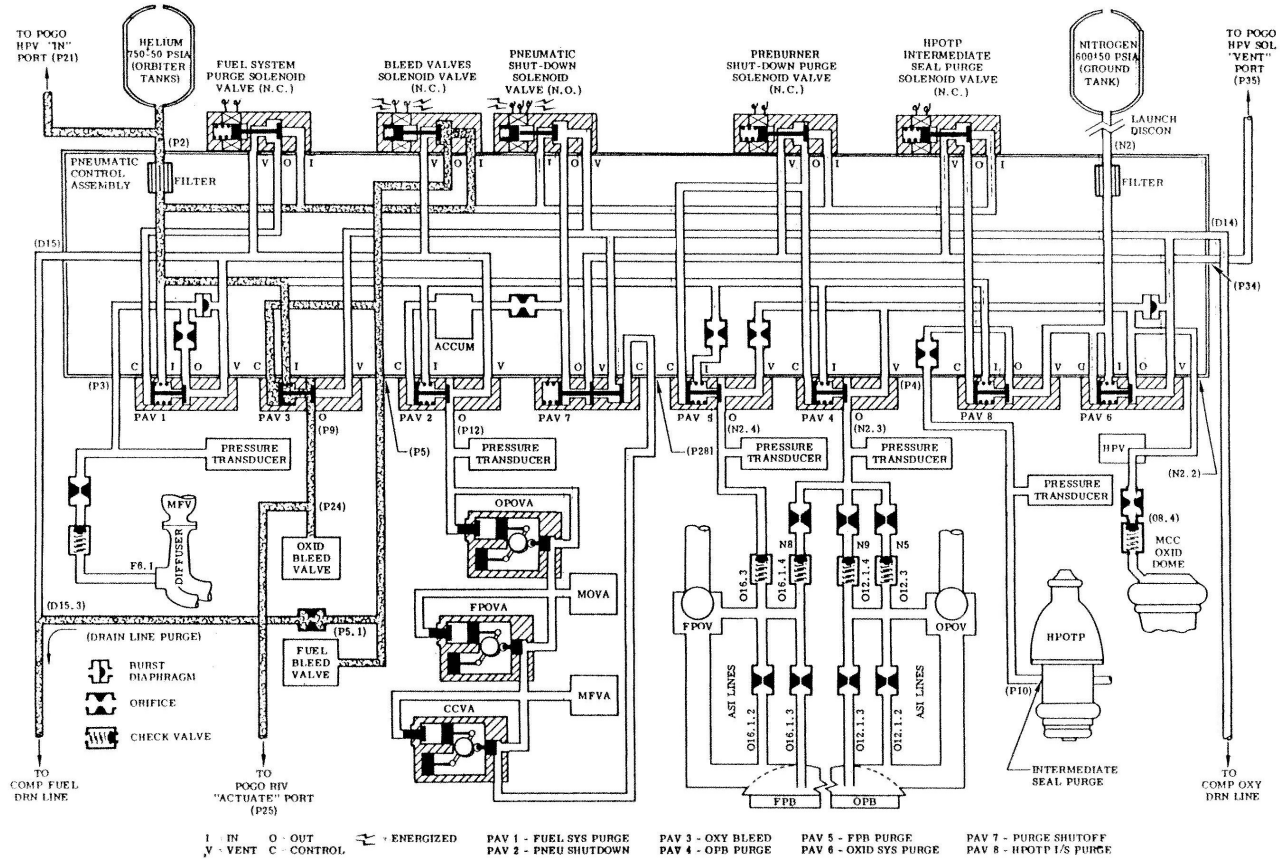
(a) No power -no pressure applied
Figure 1.4-VIII - SSME pneumatic schematic (1 of 12)



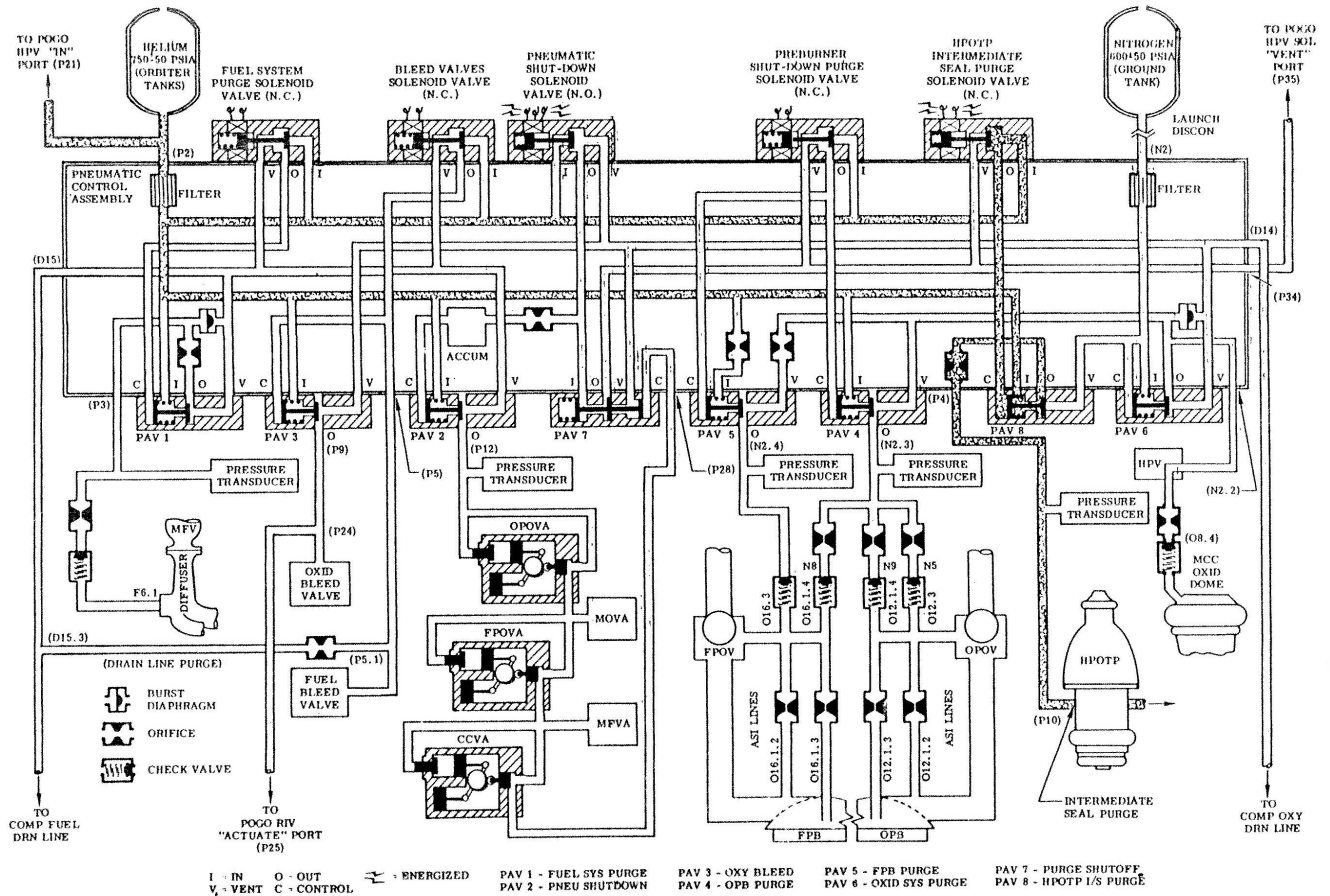
(b) Ground controlled GN₂ purge
Figure 1.4-VIII- Continued (2 of 12)



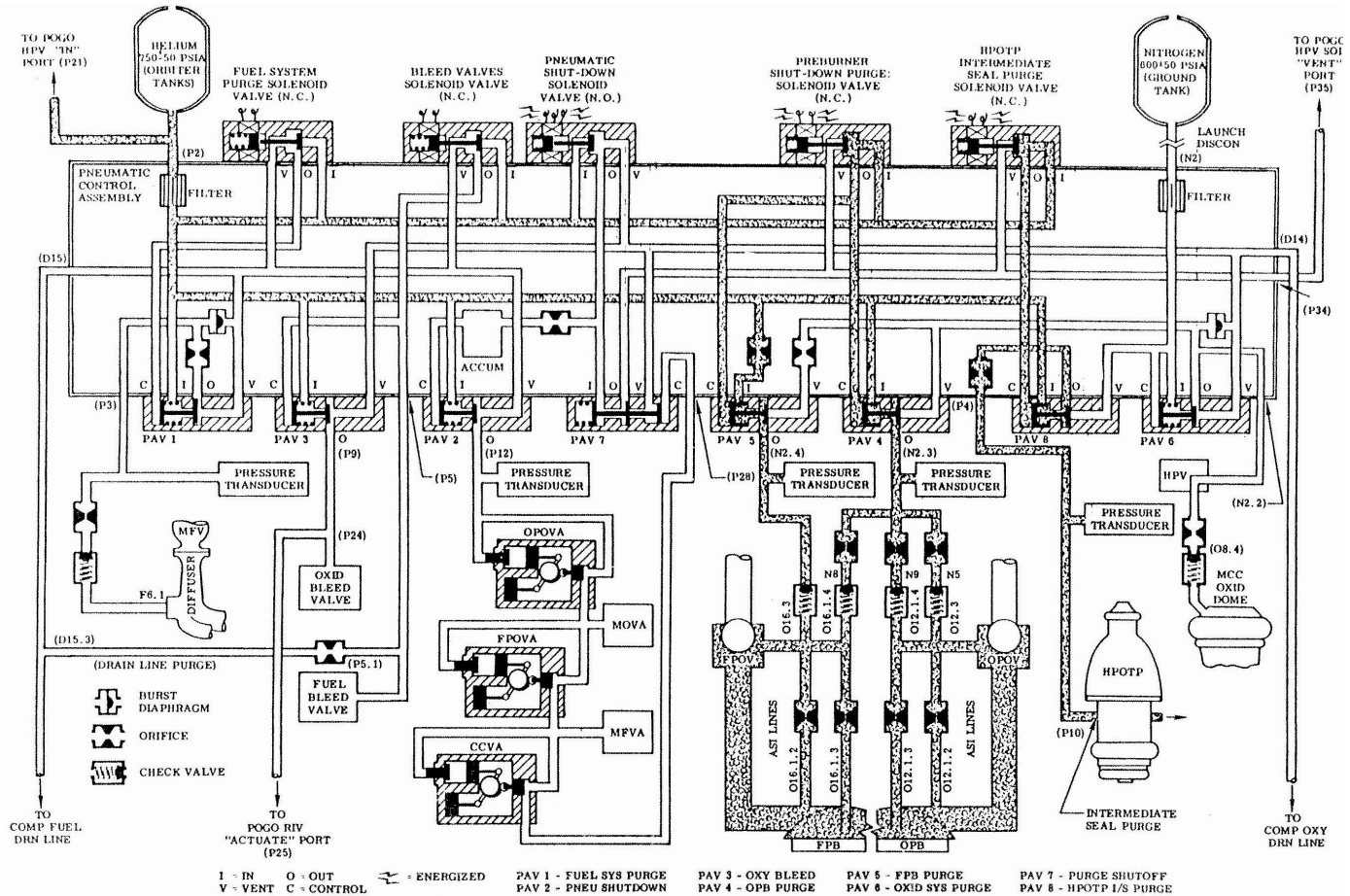
(c) Fuel system purge
Figure 1.4-VIII - Continued (3 of 12)



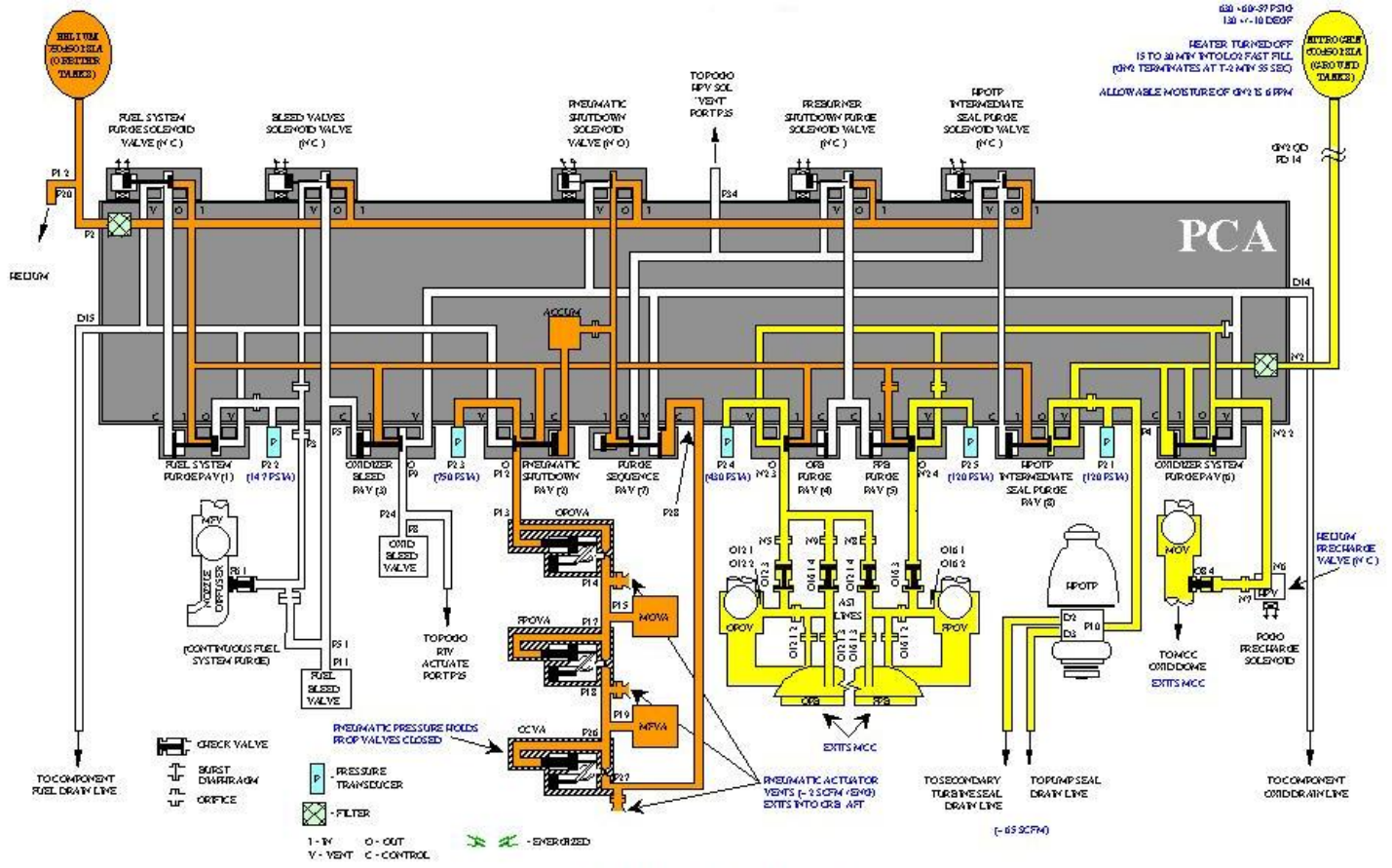
(d) Bleed valves open
Figure 1.4-VIII - Continued (4 of 12)



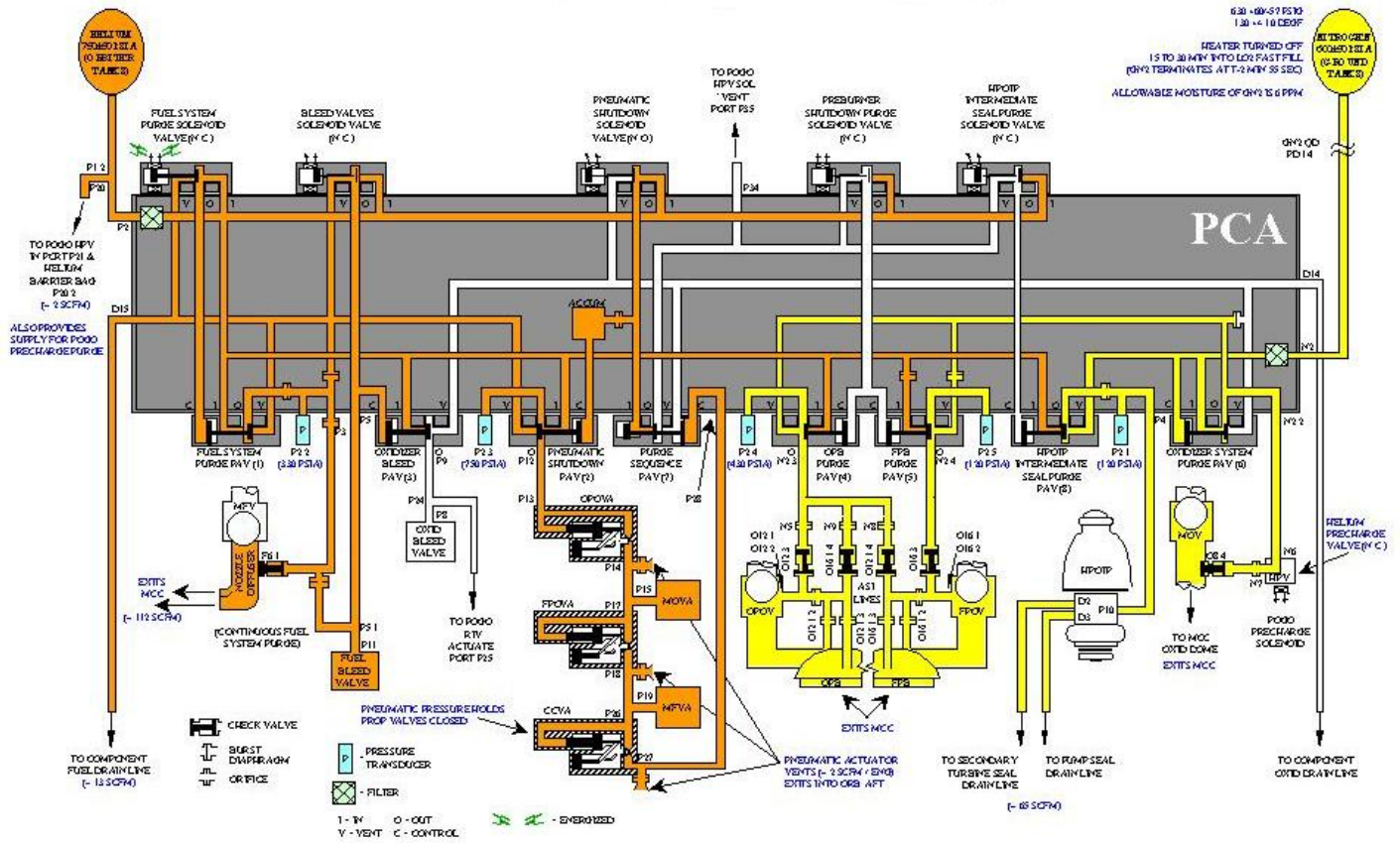
(e) HPOTP I/S purge (engine run configuration)
Figure 1.4-VIII - Continued (5 of 12)



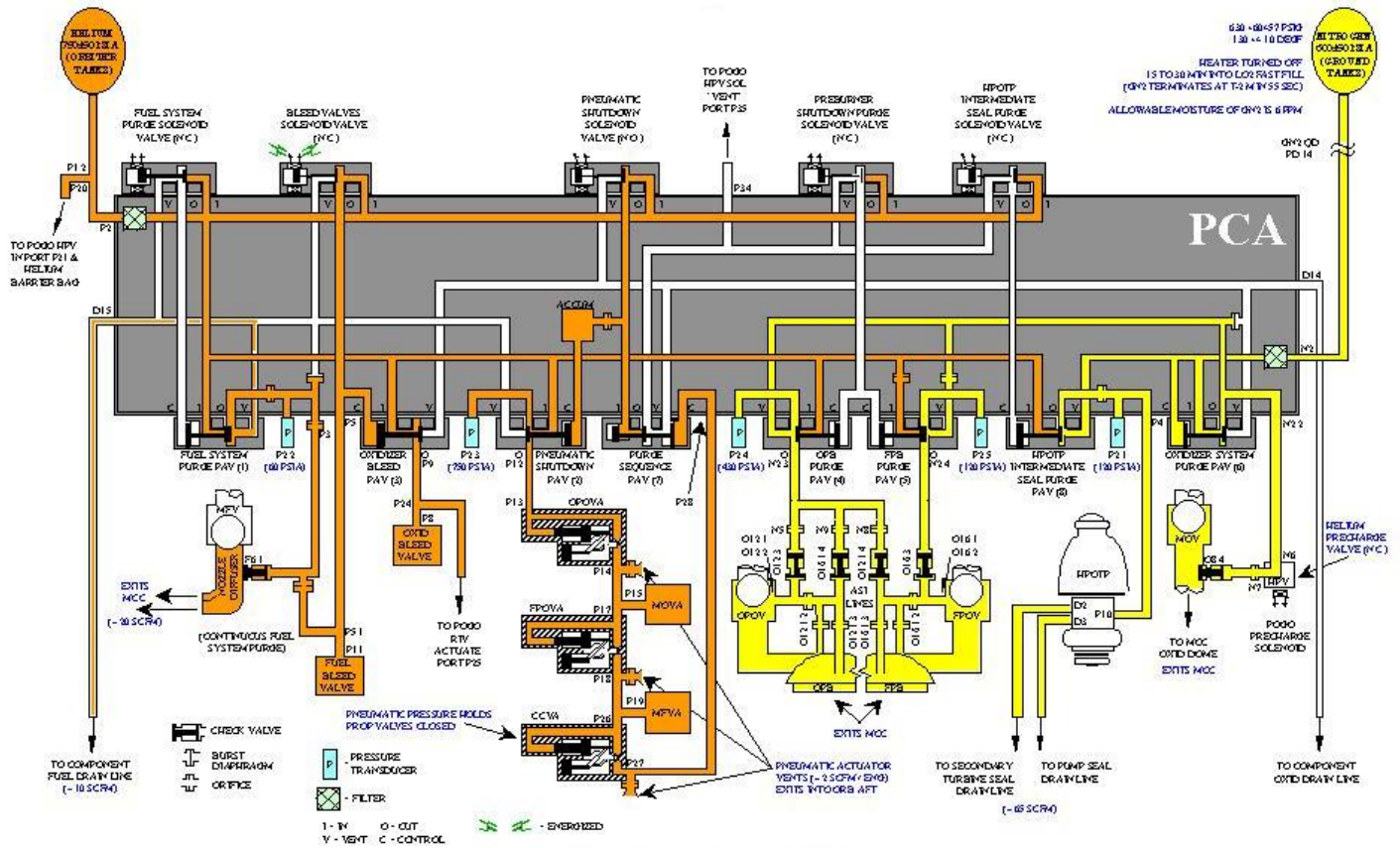
(f) Preburner purge (normal shutdown)
Figure 1.4-VIII - Continued (6 of 12)



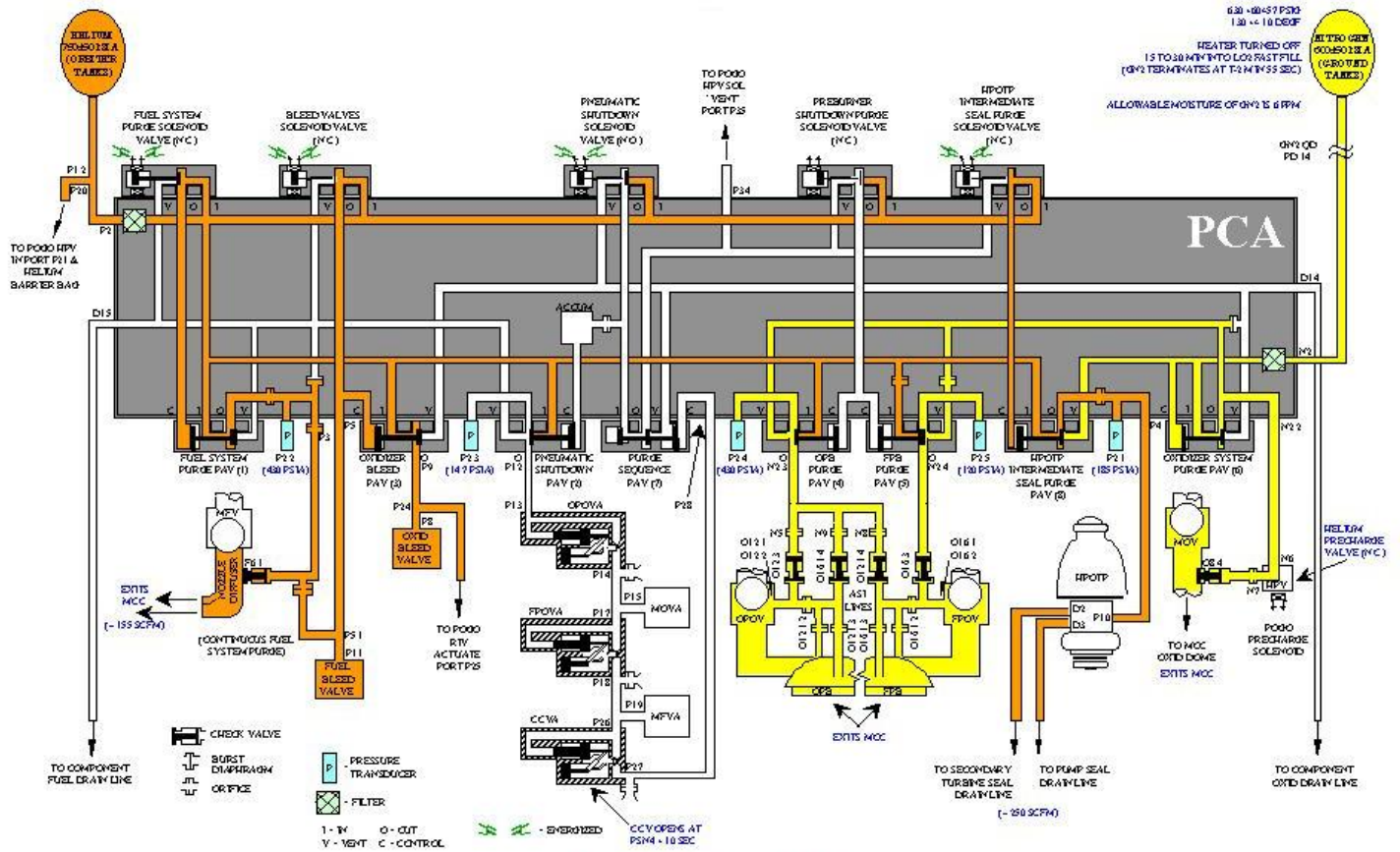
(g) Purge sequence no. 1 configuration
Figure 1.4-VIII - Continued (7 of 12)



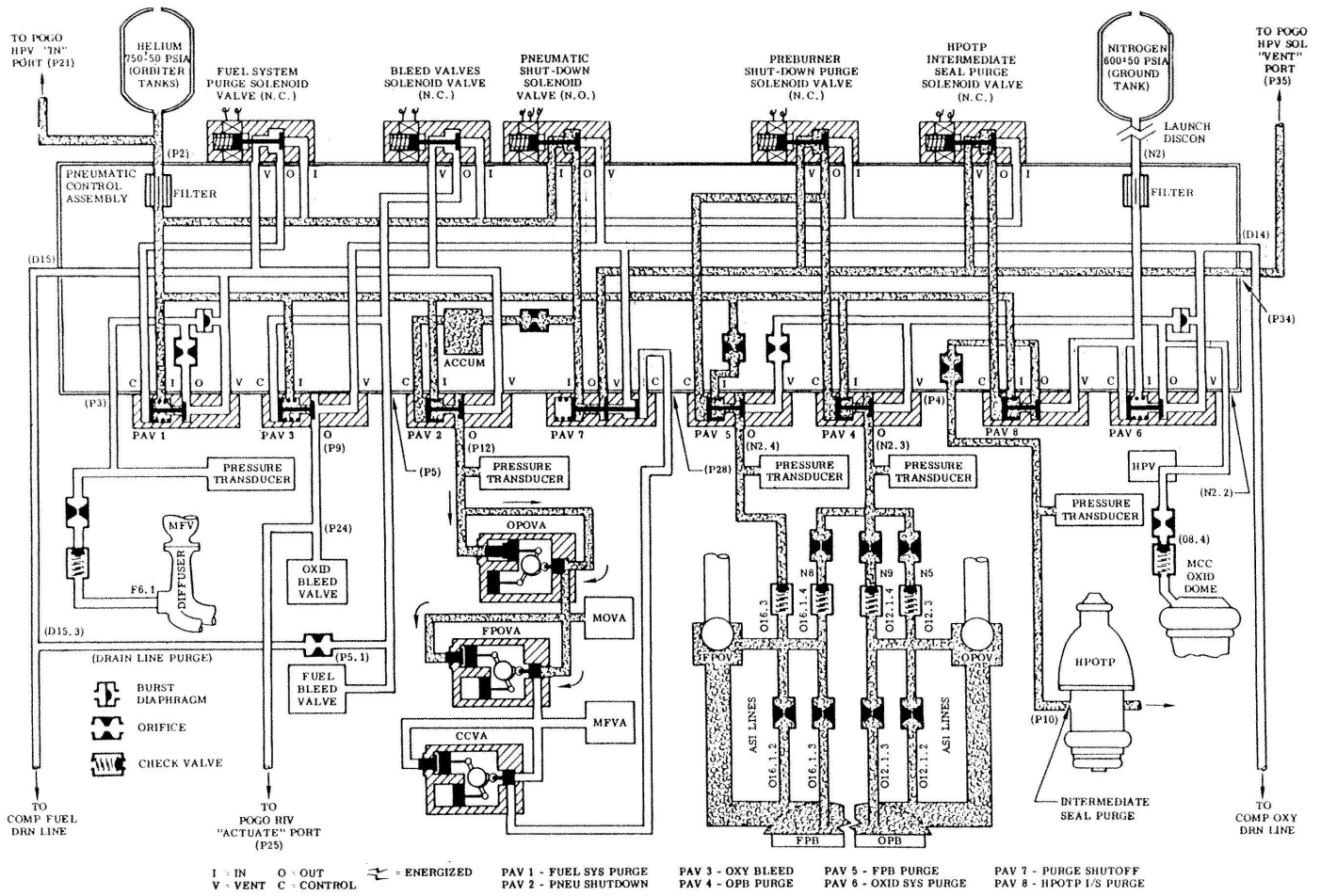
(h) Purge sequence no. 2 configuration
Figure 1.4-VIII - Continued (8 of 12)



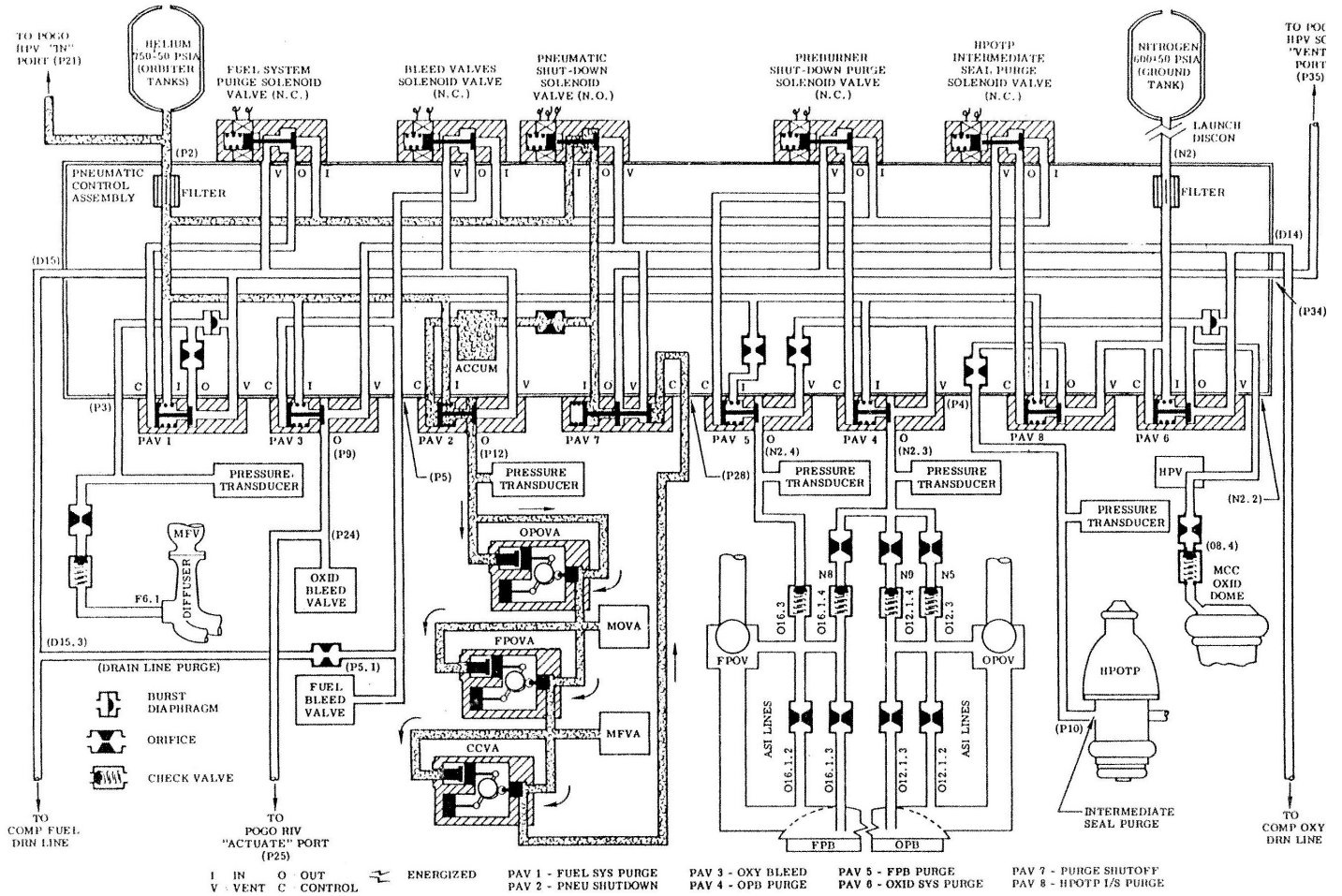
(i) Purge sequence no. 3 configuration
Figure 1.4-VIII - Continued (9 of 12)



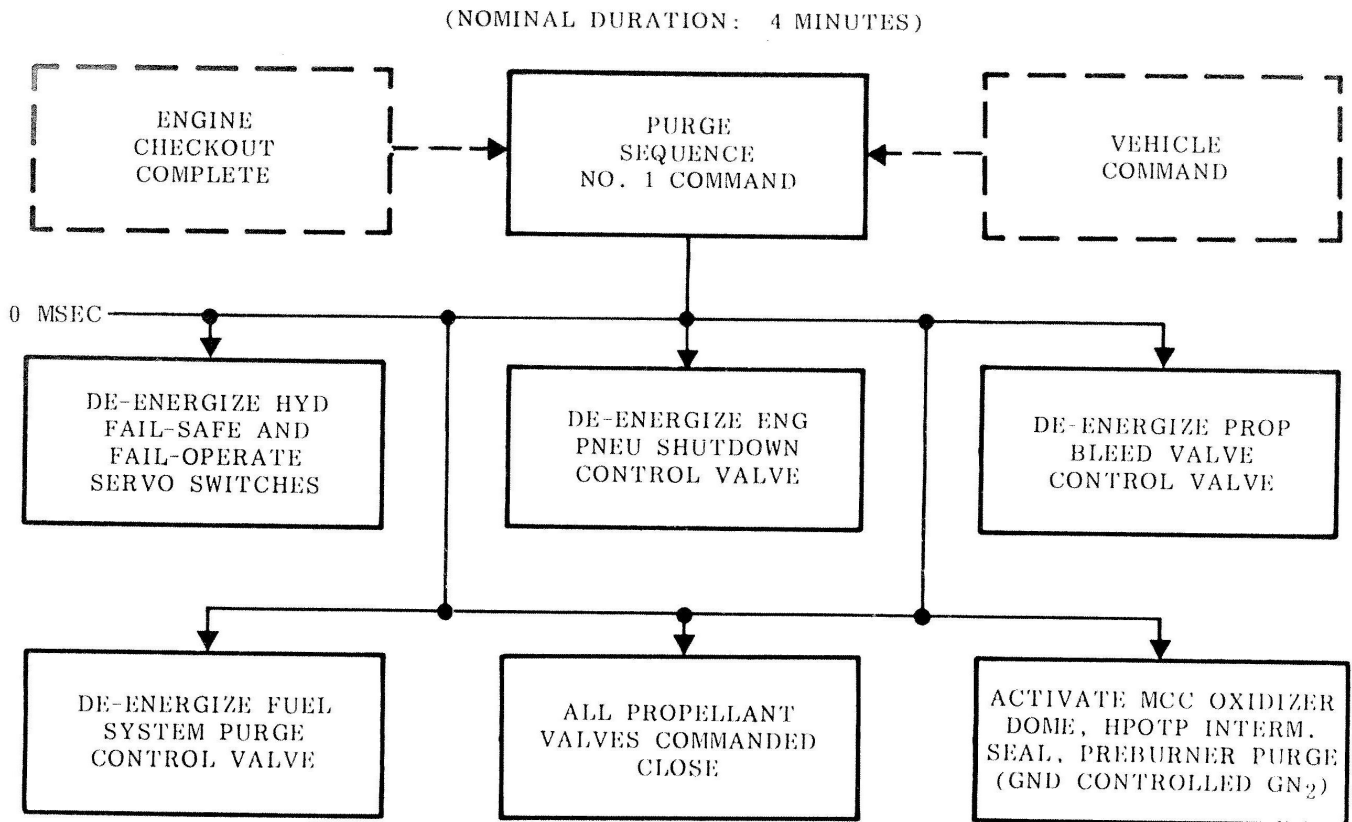
(j) Purge sequence no.4 configuration
Figure 1.4-VIII - Continued (10 of 12)



(k) Pneumatic shutdown; prop valves closing, purges on
Figure 1.4-VIII - Continued (11 of 12)

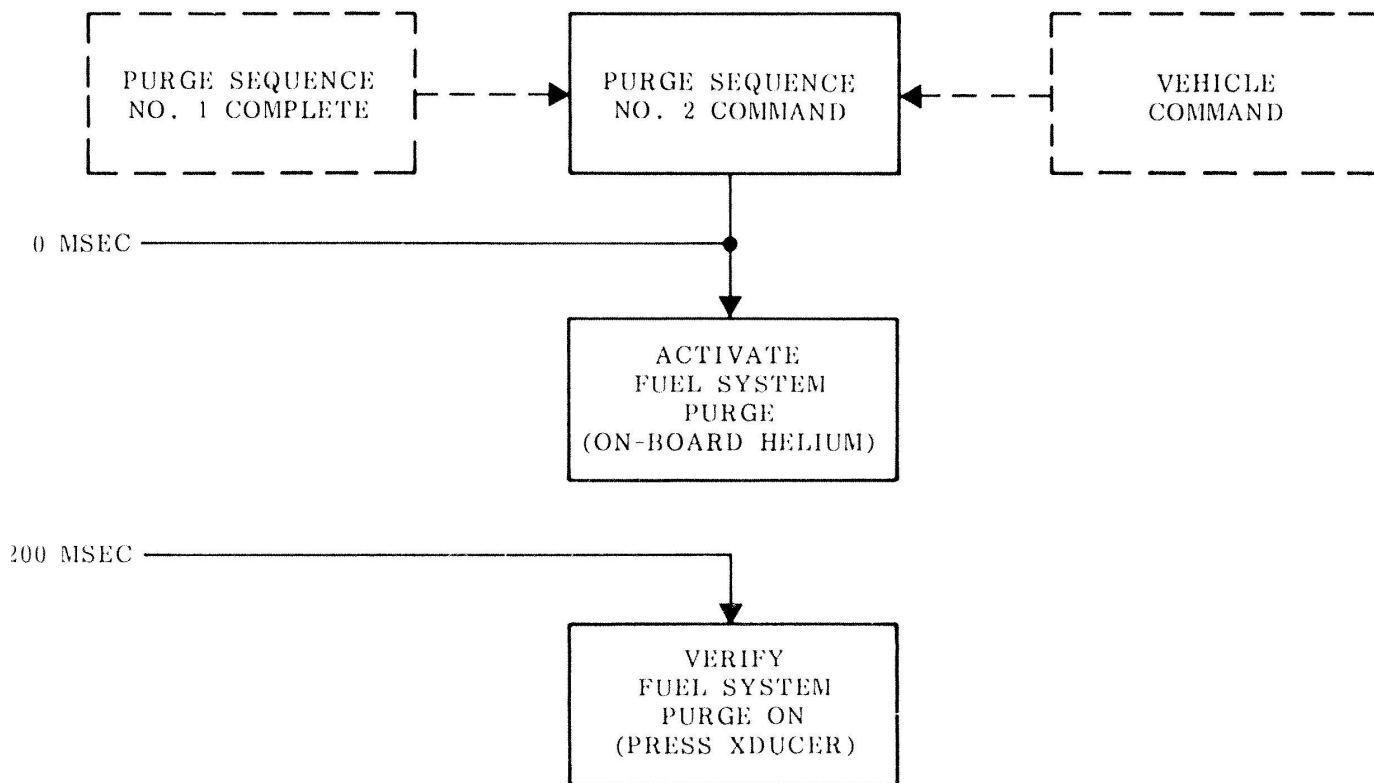


(1) Pneumatic shutdown; prop valves closed, purges off
Figure 1.4-VIII - Continued (12 of 12)

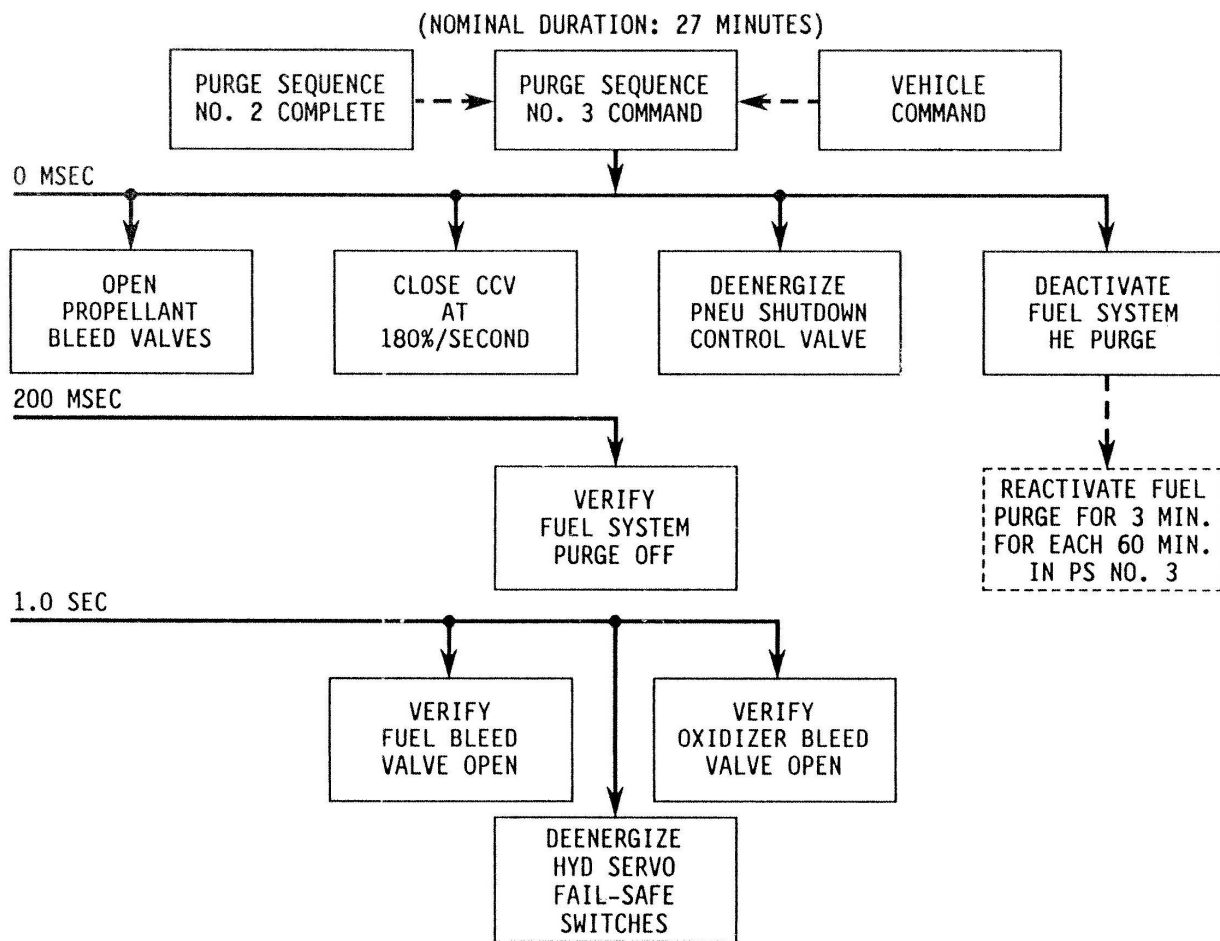


(a) purge sequence no. 1
Figure 1.4-IX - Start preparation

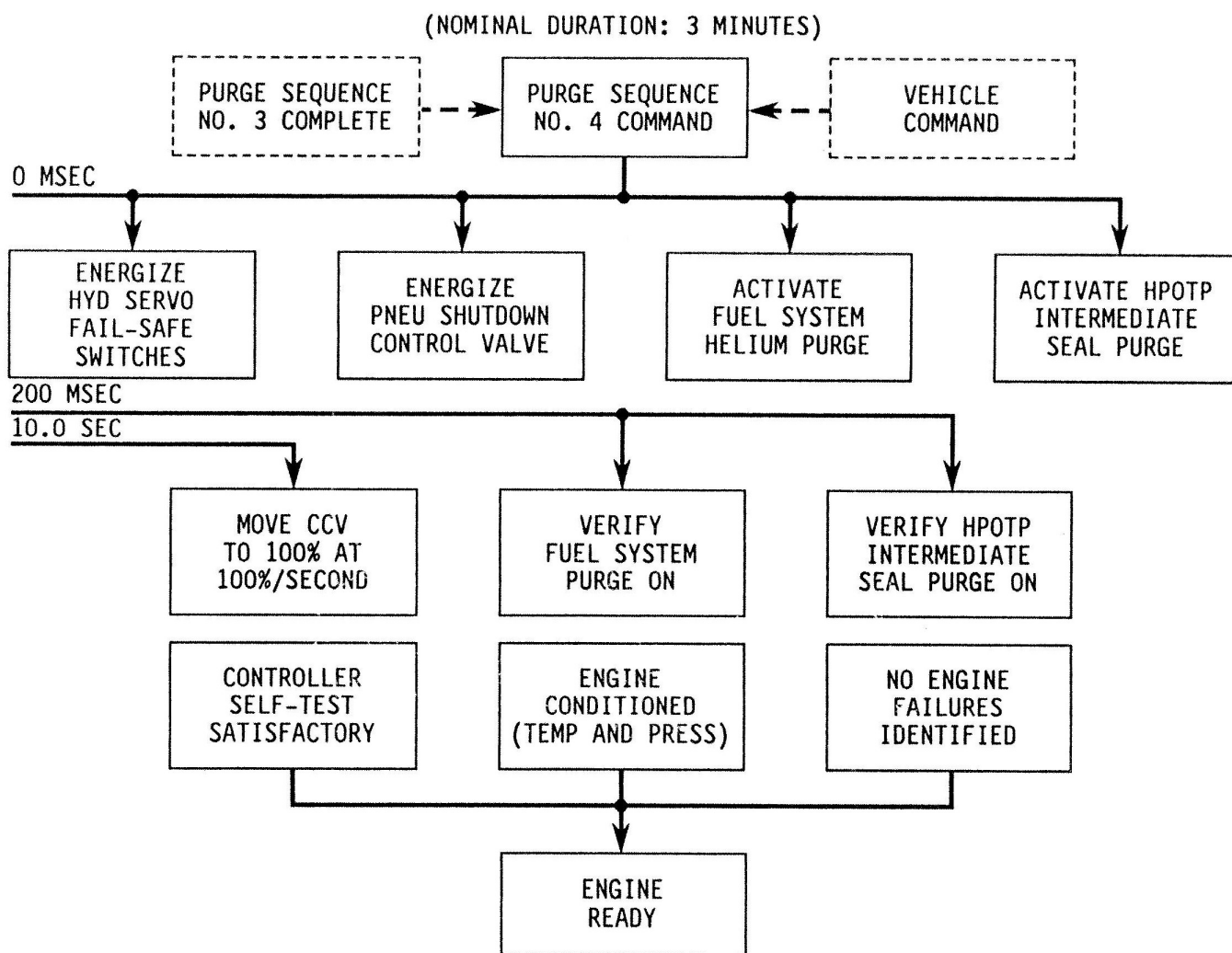
(NOMINAL DURATION: 3 MINUTES)



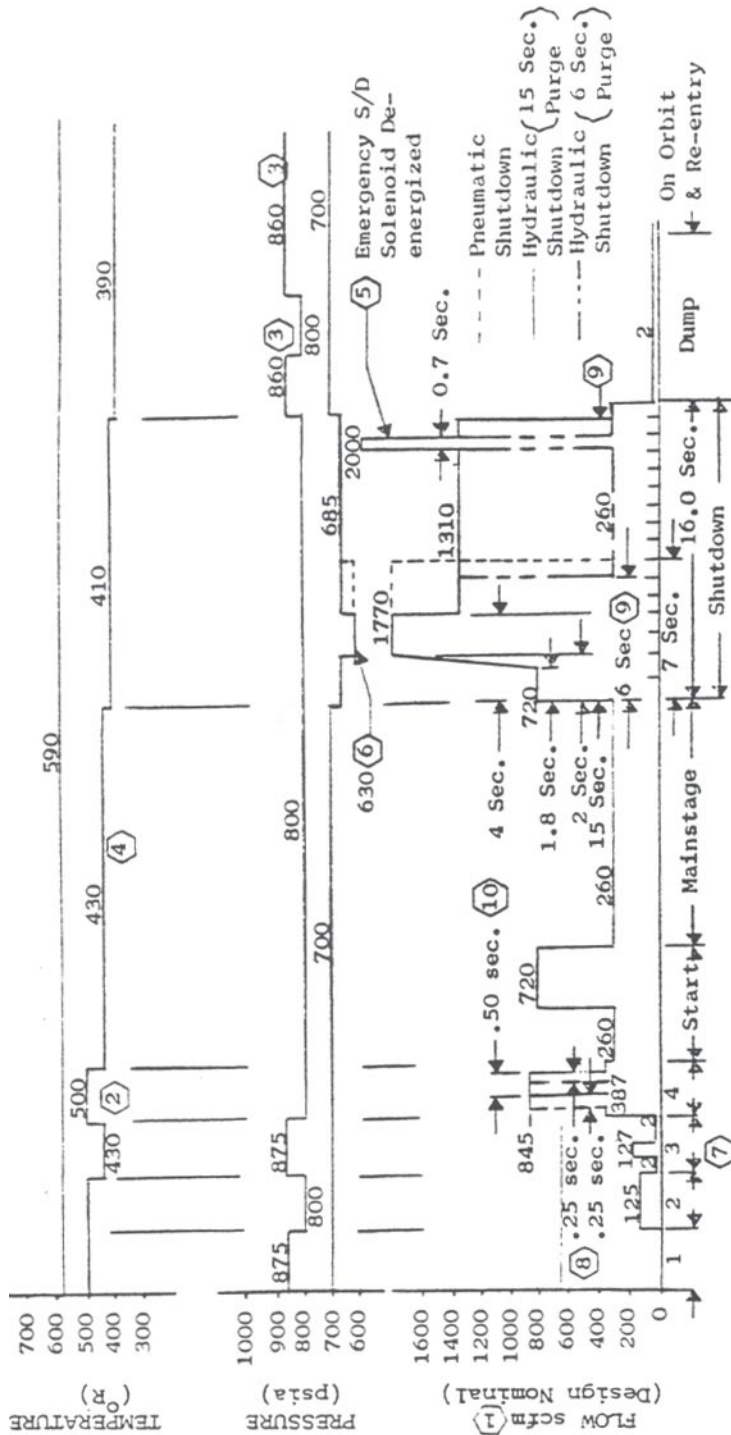
(b) purge sequence no. 2
Figure 1.4-IX - Continued



(c) purge sequence no. 3
Figure 1.4-IX - Continued

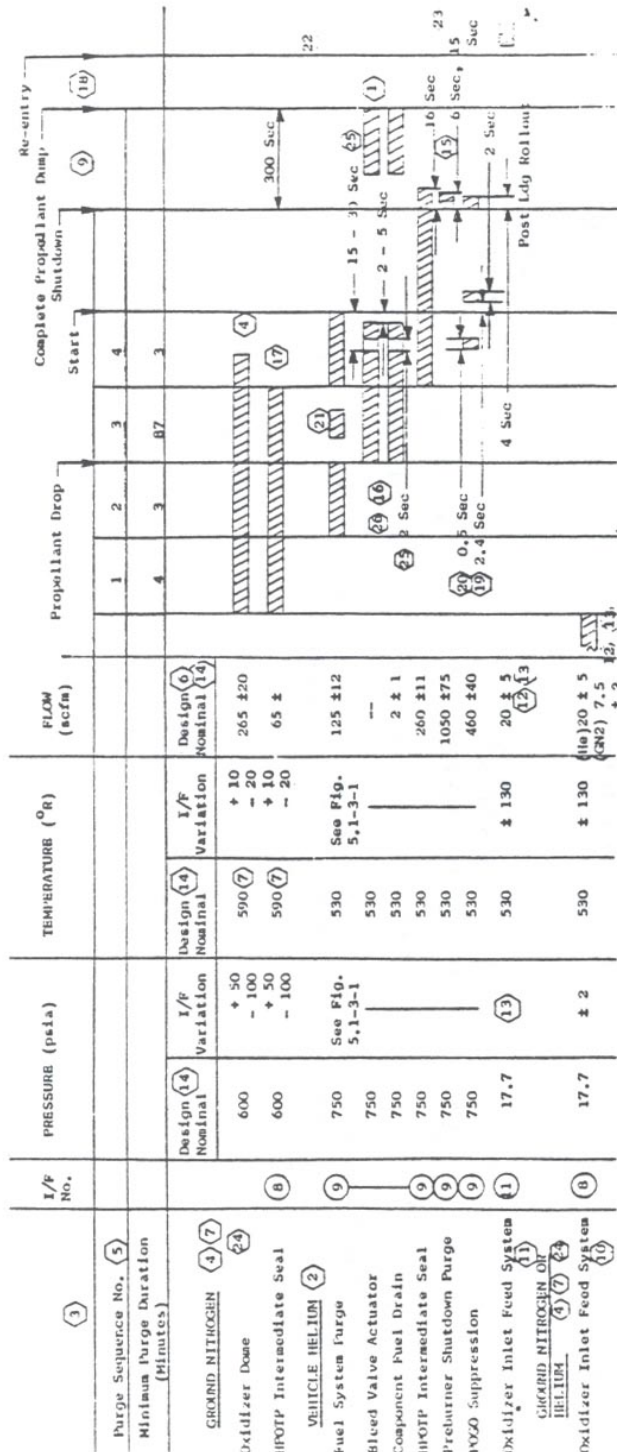


(d) purge sequence no. 4
Figure 1.4-IX - Concluded



- NOTES:
- ① Flow is Design Nominal and does not correlate with pressure temperature I/F variations.
 - ② Temperature requirements of 430°R maintained through the first 30 seconds of purge sequence No. 4.
 - ③ For ground shutdown pressure values may reach 875 psia.
 - ④ For RTLS abort the minimum Helium temperature is 395°R and the minimum pressure is 685 psia from Engine Start +600 seconds through Engine Shutdown.
 - ⑤ The I/F pressure and flow requirement are not applicable during this transient.
 - ⑥ When pressure drops to 630 psia there is a corresponding decrease in flow.
 - ⑦ Fuel System Purge on for 3 minutes each 60 minutes in Purge Sequence No. 3.
 - ⑧ POGO precharge at Engine Start signal minus 15-30 seconds and 2-5 seconds (bleed valve cycle) prior to engine start signal. (STS-1 thru -4)
 - ⑨ Six (6) second preburner purge shall be effective for STS-1 thru -15; Fifteen (15) second preburner purge shall be effective for STS-6 and Subs.
 - ⑩ POGO precharge is on at "Start Enable" which occurs 2-5 seconds prior to engine start. (STS-5 and Subs)

Figure 1.4-X - Engine pneumatic requirements (helium)



NOTES:

- Bleed Valves opened at post shutdown standby for duration of propellant dump sequence.
- Engine Helium consumption shall include additional helium per Figure 5.1-3-1 for each time the emergency shutdown solenoid is de-energized.
- The engine pneumatic requirements during FRT are identical to the operation requirements except for purge sequence duration requirements.
- The 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 seconds after receipt of this command. Deactivation of GN2 purge shall be such that the pressure requirements of Fig. 5.1-4 are met.
- See Paragraph 5.1.
- Includes the effects of SSME hardware tolerances.
- Nitrogen purge heater operation must be "ON" prior to PSN-2 to insure the purge gas temperature is 590 +10 °R at the start of PSN-2. A minimum of 30 continuous minutes of heated purge is required, of which 15 +15 minutes, shall be during that period -20 after the start of LOX fast fill, and must be left blank intentionally.
- Post static firing and pad abort purge requirements are specified in Figure 5.1-3-1.
- Oxidizer 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 IIVDP drains and throat chamber exit (or throat) are covered, or when the system is required to be vented to accomplish engine checkouts or maintenance activity, or when the vehicle is in a controlled atmosphere per paragraph 5.1.
- Start of oxidizer inlet feed system purge is required prior to reaching an altitude of 100,000 ft. during re-entry. This purge is not required for an RTLS mission.
- Flow is applicable at an ambient pressure of 14.7 psia.

Figure 1.4-X - Continued

NOTES: (Cont'd)

- 13 A purge flow of 4 SCFM Min, is required to ensure that the oxidizer feed system pressure is greater than local ambient pressure at all times. System pressure must not exceed a maximum of 50 psia.
- 14 Design nominal parameters define the Engine flow control equivalent orifice area.
- 15 Preburner shutdown purge is controlled by MEC and will not be applied during the period from start to start +2.0 seconds. For an RTLS the I/F conditions need to be met for 6.0 sec. only.
- 16 Bleed Valves closed and initiate POGO Precharge purge at start enable signal at 15-30 and 2-5 seconds before start. (STS-1 thru -4)
- 17 GN2 purge through the HPOTP intermediate seal is terminated by the SSME valves when the helium HPOTP intermediate seal purge is initiated.
- 18 Post Flight purge requirements are specified in Figure 5.1-9.
- 19 POGO Accumulator Post Charge is controlled by the MEC and will not be applied during the period from start, to start + 2.4 seconds.
- 20 POGO Prestart purge is on at "Start Enable" which occurs 2-5 seconds prior to engine start.
- 21 Fuel system purge on for 3 minutes each 60 minutes in purge sequence No. 3 (MEC controller).
- 22 Appropriate measures shall be taken to assure that the SSME propellant valves are maintained closed prior to re-entry and during SSME postland repositioning.
- 23 Six (6) seconds purge effective STS-1 thru -5. Fifteen (15) seconds purge effective at STS-6 and Subs.
- 24 The allowable moisture content of the GN₂ source gas at the SSME interface is 6 ppm maximum. STS-1 thru -4)
- 25 Bleed valves closed and initiate POGO precharge purge at "Start Enable" signal which occurs 2-5 seconds prior to engine start. (STS-5 and Subs)
- 26

Figure 1.4-X - Concluded

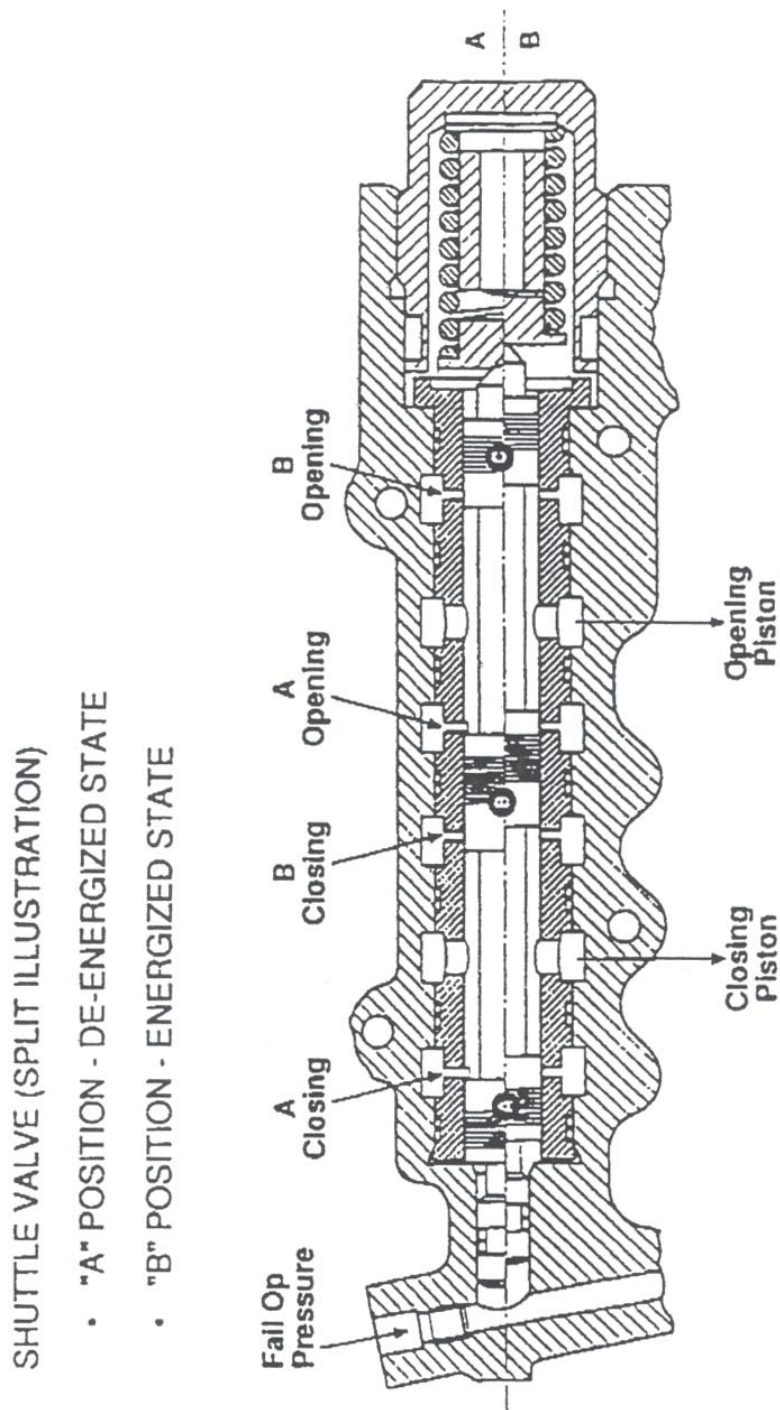


Figure 1.4-XI - Shuttle Valve

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1.5 LO2 PREVALVE CLOSURE AT SSME SHUTDOWN

1.5.1 General

Timed closing of the LO2 prevalves is critical for safe SSME shutdown. If the prevalves close too quickly, the LO2 manifold may overpressurize due to the water hammer effect. Conversely, if the valves close too slowly after a low level cutoff the High-Pressure Oxidizer Turbine Pump (HPOTP) may unload and overspeed causing a catastrophic shutdown.

When SSME shutdown occurs the LOX flowrate and consequently the LO2 Net Positive Suction Pressure (NPSP) in the HPOTP quickly decay to zero. Since the HPOTP was designed to operate with a minimum inlet pressure, a violation of the NPSP requirement will likely result in pump overspeed and catastrophic failure of the hardware. Several measures have been implemented in order to prevent pump cavitation while the SSME is shutting down. During the shutdown sequence, the SSME main fuel valve remains open 5 seconds longer than the main oxidizer valve. Secondly, the LO2 prevalves are closed 1.198 seconds after the shutdown commands are issued. This valve sequence allows a fuel rich flow to continue to drive the HPOT while LO2 flow to the HPOTP is slowly reduced. Finally, LO2 NPSP is maintained at the HPOTP inlet by pressurizing the inlet duct with MPS helium throughout the shutdown sequence.

1.5.2 LO2 Prevalve Timing

LO2 prevalve timing requirements were developed to protect against HPOT overspeed and LO2 manifold overpressurization. These requirements considered worse-case dispersions of orbiter avionics and SSME shutdown performance. The maximum allowable rotational speed for the HPOT is approximately 30,000 rpm. The burst speed is 38,000 rpm. The LO2 manifold proof pressure is 312 psia and the burst pressure is 390 psia. Based on the relationship between the time delay after SSME shutdown, HPOT speed and LO2 manifold pressurization, a target time delay was shown to be 1.198 seconds. This corresponds to an HPOT speed of about 20,000 rpm and an LO2 manifold pressure of 160 psia. The 1.198 second delay timer is for nominal MECO commanded shutdown. In the case of a pre-MECO shutdown, the close delay time is 4.62 seconds (4.62 sec = 4.5 sec I-load delay + 120 msec 3-cycle check). The OI-29 FSSR shows that the 4.5 second I-load delay is reset to the 1.078 K-load delay time in Step 17 if the MECO Command flag is set.

After STS-51L, there was concern that a single bit flip could possibly give an erroneous SSME phase indication, possibly leading to closure of a prevalve on a running engine. This resulted in establishment of the three-strike criteria for SSME shutdown verification. The GPC receives the shutdown or post-shutdown engine status word (ESW) from the SSMEC via the EIU, which may take 1 to 5 computing cycles (40-160 msec), and reads it three times for a total of 120 ms to make certain the command is legitimate. The GPC then sends the prevalve closure command to the orbiter Flight-Aft Multiplexer-Demultiplexers (FA-MDM). When the MECO status word is present and is read by the GPCs, the GPCs command the LO2 prevalves to the closed position at

a specified time. The LO2 prevalues close 1.198 seconds (1.078 sec K-load delay plus the 120ms three-strike check) after MECO during a nominal zero-g cutoff or 4.5 seconds after MECO for pad aborts and premature cutoff.

1.5.3 Prevalve Functional Redundancy

Electrically, closure of the LO2 prevalues is single-fault tolerant to the failure of electrical buses (APCs 4, 5 and 6) and two-fault tolerant of FA MDM failures. Each prevalue has four FA MDMs and two APC bus combinations in its circuit. Therefore, two APCs or three MDMs must be failed before the prevalues fail to close.

NOTE: Since the loss of two APCs cause the loss of LO2 prevalue close capability to one of the SSMEs, this engine MUST be shutdown pre-MECO. However, the pre-MECO shutdown will already be required since the same two APCs that cause the loss of LO2 prevalue close capability also cause the loss of the associated engine's electronic interface unit (EIU). The EIU failure will cause a command and data path failure. Command path failures must always be shutdown pre-MECO.

Mechanically, the prevalues are single fault tolerant. A pneumatic helium actuator is used to open and close the valve. The actuator is controlled by a series of four three-way solenoid valves. Two of these three-way valves are set-up in parallel on the closing pneumatic path of the actuator. Only one is needed to close the prevalue. On the opening pneumatic path of the actuator, there are two valves in series, which are both required to open the prevalue.

Helium supply to the prevalue actuators is redundant. The primary helium source for the prevalues is the orbiter MPS pneumatic helium tank. The system can also be interconnected to the left SSME helium supply tank through the left engine helium crossover valve. If necessary, the center and right engine helium systems can be interconnected to feed the left system. Additionally, there are 500 cubic inch accumulators downstream of the pneumatic helium regulators which have enough helium mass to close all LO2 and LH2 prevalues. The accumulators are typically charged with approximately 750 psia of helium, which is the outlet pressure of the upstream regulator. When the entire pneumatic tank supply is used to feed an engine system helium leak, and that engine shuts down pre-MECO, analysis shows that the accumulator pressure will drop to 708 psia. Therefore, there will be enough helium left in the accumulator to allow prevalue closure at MECO, since the requirement is 700 psia.

1.5.4 Prevalve Timing Issue

The Boeing letter 540-002 describes the prevalue timing issues associated with shutting down the last running SSME by the AC switches on panel R2. Until the release of this letter, it was believed that removing power from the last running SSME would result in erroneous prevalue timing and subsequent pump overspeed. However this letter describes a scenario where the last running SSME can be safely shutdown with the AC switches because MECO confirmed is set with 2 engine's main chamber combustion pressures are less than 30 psia and a datapath failure

on the third engine. This works in certain cases, when the MECO Command flag is set, because the MECO Command flag is the trigger that the software uses to initiate the prevalve closing process at MECO. More information can be found in SCP 2.1.4, Boeing letter 540-002, section 4.2.1 SSME Operation Sequence, and section 4.8.2 SSME SOP of the FSSR (Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements).

1.5.5 References

1. Space Shuttle System Handbook (SSSH), Drawing 10.8 - MPS HELIUM SYSTEM.
2. Space Shuttle System Handbook (SSSH), Drawing 10.11 - MAIN ENGINE LO2 SYSTEM.
3. Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements (FSSR), Book 26 – Sequencing; OI-28.
4. Boeing Letter 540-002 from Nelva W. Cary to M.F. Machula, March 15, 2000.
5. Booster Standard Console Procedures 2.1.4, Final, Rev-F, PCN-1

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1.6 SSME FASCOS SYSTEM (Block II Controller)

1.6.1 General Description

The flight accelerometer safety cutoff system (FASCOS) was designed to provide vibration redline capability for the high pressure oxidizer and fuel turbopumps. The FASCOS redlines protect against bearing, impeller, and turbine blade failures when the system is connected and the redline monitoring is enabled in the SSME controller.

FASCOS can operate in three modes: fully active, monitor only, or bypass. In fully active mode, vibration monitoring is performed, FASCOS will disqualify erroneous accelerometers, and FASCOS will also shutdown SSMEs if the vibration redline is exceeded. In monitor only mode, FASCOS will perform vibration monitoring and will generate report-only failure IDs (FIDs), but there will be no major component failures (MCFs) posted or SSMEs shut down. In bypass mode, all vibration channel qualifications and vibration redline monitoring will be bypassed even though data is being collected. No FIDs will be generated for any FASCOS related parameters. FASCOS is currently run in bypass for flights and no real-time data is available to the Mission Control Center.

FASCOS consists of six accelerometers, connecting cables, the SSME controller software, and the SSME controller hardware. The controller hardware is called the vibration system processing electronics (VSPE). The VSPE is on a single card internal to the SSME Block II controller. FASCOS is powered by three sources of 15 volt DC power. The power is provided by the controller digital computer unit's (DCU's) power supply. Accelerometers A1, B1, and C1 are on the HPFTP. Accelerometers A2, B2, and C2 are on the HPOT preburner boost pump (HPOT PBP). All accelerometers used for FASCOS are at the "pump end" of the turbopumps. There are also accelerometers at the "turbine end", however these are not part of the FASCOS system. Several turbine end accelerometers are available for use on ground tests. A single turbine end accelerometer on each pump is recorded on the Modular Auxiliary Data System recorder during flight. The radial positions of the pump-end accelerometers are different on the Pratt & Whitney pumps than they were on the Rocketdyne pumps. Table 1.6-I lists the accelerometer's channel, location, and MSID. The accelerometers are made of small piezoelectric crystals. These non-conducting crystals produce electrical output when subjected to mechanical stress.

Table 1.6-I – FASCOS Accelerometer Nomenclature and MSIDs

Accelerometer Location		Sensor Nomenclature	MSID (Center SSME)*
Rocketdyne Pump**	Pratt&Whitney**		
HPFTP 0°	HPFTP 21°	V1A	E41D1136D
HPFTP 174°	HPFTP 219°	V1B	E41D1138D
HPFTP 186°	HPFTP 231°	V1C	E41D1140D
HPOT PBP 45°	HPOT PBP 39°	V2A	E41D1137D
HPOT PBP 135° - 1	HPOT PBP 151°	V2B	E41D1139D
HPOT PBP 135° - 2	HPOT PBP 130°	V2C	E41D1141D

* Center, left, and right SSME MSIDs are 1136D, 2136D, and 3136D respectively (etc.).

** Phase II engines used Rocketdyne HPFTP and Rocketdyne HPOTP.
Block I, IA, and Block IIA engines used Rocketdyne HPFTP and P&W HPOTP.
Block II engines use P&W HPFTP and P&W HPOTP.

1.6.2 Accelerometer Data Flow

Raw accelerometer signals are sent to the VSPE. In the VSPE the signals are divided into three channels and are passed through an 800 Hz low pass and a 50 Hz high pass filter. The signals, now in the 50-800 Hz range, enter a root mean square (rms) converter which calculates the equivalent g_{rms} value. The processed signals leave the VSPE and enter input electronics A or B (IE A or IE B) for transmission to the DCU. The channel C data (V1C and V2C) is split into two additional flows V1CA/V1CB and V2CA/V2CB. This split allows the channel C data to be carried through both IE A and IE B. The data flow is shown in Figure 1.6-II.

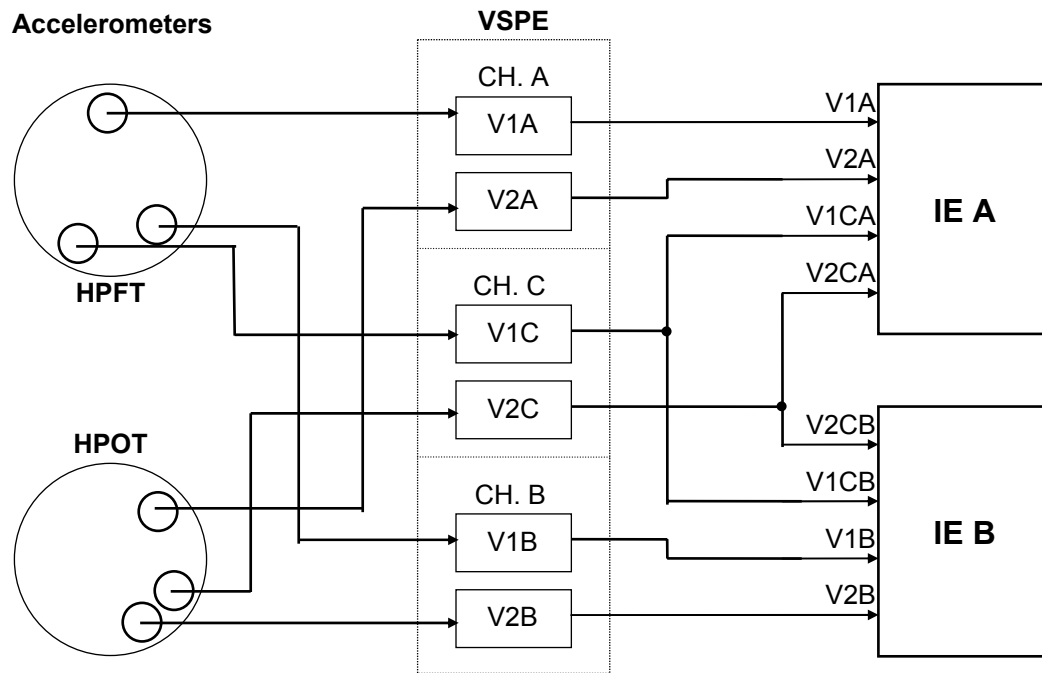


Figure 1.6-II – FASCOS Accelerometer Data Flow

The controller must “reconstitute” the V1C parameter into a single value by combing the input of V1CA from IE A and V1CB from IE B. If both V1CA and V1CB are qualified or both are disqualified, the controller sets V1C to the average of V1CA and V1CB. If either V1CA or V1CB is disqualified, the controller passes through the qualified parameter as the value for V1C. The exact same logic applies when the controller reconstitutes V2C from V2CA and V2CB (etc.).

1.6.3 Software Processing

If FASCOS is in the fully active or monitor only modes, the controller software determines if the accelerometer data is qualified using the logic discussed in the following section. If FASCOS is in fully active mode, the controller software uses the qualified accelerometer data to determine if an engine should be shutdown. The SSME limit shutdown switch on panel C3 enables and disables the FASCOS redlines like any other redline parameter if FASCOS is in fully active mode.

1.6.3.1 Qualification Logic (Fully Active or Monitor Only Modes)

Qualification checks are performed on the FASCOS accelerometers in both the fully active and monitor only modes. In fully active mode, the accelerometers must be qualified in order to be used in the shutdown logic. In monitor only mode, qualification checks are still performed, but the response is report-only FIDs (no MCFs will be generated).

During start prep, the measured acceleration must be less than or equal to 1.5 g_{rms} . An acceleration greater than 1.5 g_{rms} will cause the associated accelerometer to be disqualified. Loss of a single accelerometer causes a display-only FID 116 in the fully active and monitor modes. The loss of two accelerometers on any pump will cause a FID 016 in the fully active mode during the start prep phase. An MCF will also be generated if FASCOS is in the fully active mode.

During mainstage, the measured acceleration must be greater than or equal to 0.25 g_{rms} . A measured acceleration less than 0.25 g_{rms} will cause the associated accelerometer to be disqualified. Loss of two or more accelerometers on a given pump in the fully active mode will cause a loss of vibration redline protection for the associated pump. FIDs and MCFs will be generated as described above.

The only exception to these qualification checks is the V1CA and V1CB or V2CA and V2CB data shown in Figure 1.6-II. Since these outputs are provided by the same accelerometers (V1C or V2C), the parameters should be the same (V1CA should match V1CB and V2CA should match V2CB). In order for V1C to be disqualified, both V1CA and V1CB must be disqualified (likewise for V2C). Loss of only one input (say V1CA) will cause the channel output (V1C) to be equal to the other input (in this case, V1CB).

Power supply failures may also cause accelerometers to be disqualified. Loss of the power supply to a VSPE channel or IE will also cause the loss of the associated accelerometers.

1.6.3.2 Shutdown Logic (Fully Active Mode Only)

Logic to initiate shutdown requires votes from three of three qualified accelerometers. If one accelerometer is disqualified, two of two votes are required. If two or more accelerometers are failed on the HPOT PBP or HPFTP, FASCOS protection is unavailable for the associated pump. To vote for shutdown, all qualified accelerometers (at least two) on a given pump must exceed the redline limit (16 g_{rms} for HPFTP and 11 g_{rms} for HPOT PBP) simultaneously for five continuous major cycles (20 msec/cycle). If the accelerometer output drops below the redline threshold, the counter is reset, and five continuous cycles of redline violation are again required for the logic to initiate a shutdown. If a shutdown is initiated, a FID 017 is generated.

If less than all qualified accelerometers vote for shutdown, a FID 117 is generated, and the engine status word will indicate MCF. If all qualified accelerometers (at least two) vote for

shutdown with limits inhibited, FID 117 appears, the engine status word indicates engine limit exceeded, and the engine does not shut down.

Enabling and disabling the FASCOS limit monitoring in the fully active mode is done with the SSME limit shutdown switch on panel C3. The FASCOS vibration redline limits respond to enable and inhibit commands like the other SSME redline limits.

1.6.4 History

As of 3/94 FASCOS had a total hotfire time of 587,831 seconds. FASCOS data was also available from 23,380 seconds of flight time. This run time included both the Block I and Block II controller versions of FASCOS (Block I FASCOS is not discussed in this systems brief).

FASCOS has detected 15 HPFTP and 17 HPOTP failures on the test stand. Of these failures, 3 HPFTP and 8 HPOTP failures would have been catastrophic without FASCOS active. However, in 7 of the detected pump failures (3 HPOTP and 4 HPFTP), the failure was catastrophic even with FASCOS active. The remaining pump failures would have shutdown safely by the other SSME redlines even if FASCOS had not been active.

FASCOS has also erroneously shutdown several SSMEs on the test stand for accelerometer or accelerometer cable failures. In addition, 3 accelerometer cable failures would have caused FASCOS to shutdown one SSME during flight (STS-32) if FASCOS had been active.

1.6.5 Conclusion

FASCOS is the only protection against machinery vibration. Analysis shows FASCOS prevents catastrophic failure modes and provides increased crew safety for any reasonable abort risk, but there is concern about using FASCOS. While FASCOS could shutdown an unhealthy engine prior to a catastrophic failure, it could also erroneously shutdown a healthy engine due to faulty electronics. The reaction time of the system is also in question; FASCOS might not shutdown the engine quickly enough to prevent catastrophic failures. Using FASCOS requires a choice between the risk of losing an engine due to vibration and the risk of losing a good engine unnecessarily.

Engineering management was hesitant to use the newly designed system for STS-26. The young system, especially the sensors, had not yet demonstrated that it was fail-safe. There is a history of shutdown votes caused by faulty instrumentation. The previous 25 flights had 6 sensors in which 1 of 3 accelerometers voted to shutdown the engine. Therefore, in May 1988, it was decided not to use FASCOS in flight for redline monitoring. The electrical connectors for the FASCOS redline threshold outputs are not connected to the SSME controllers.

In 1999, a new system, AHMS (Advanced Health Management System) began development with the intent to detect new engine failure signatures. The leading mode of detection, and the first to

be implemented, will be a pump-end synchronous vibration redline using the same accelerometers currently used by FASCOS. The new system will perform real-time Fast-Fourier Transformation of accelerometer data, converting it to a frequency domain. Signal conditioning in the frequency domain can discern sensor and wiring failures from actual high vibration loads. Phase I of AHMS, with functional vibration redline sensing ability, is scheduled to be flight ready by mid 2004. It will fly in a passive “monitor only” mode for some period of time before being made fully active.

1.7 SSME AUTO SHUTDOWN REDLINES AND REASONABLENESS TESTS

1.7.1 Start Confirm Redlines

There are certain parameters, known as start confirm redlines, that are monitored by the main engine controller to ensure a safe SSME start. If there is a redline violation during start phase, the engines will be shut down and a limit exceeded flag will be set in the Redundant Set Launch Sequence (RSLS). However, the SSME controller is prevented from issuing a shutdown command between 0.8 and 1.5 seconds after ignition to prevent component damage during shutdown. This was established after an investigation following a SSME ground test failure determined that during the time frame from engine start plus 0.8 seconds to engine start plus 1.5 seconds, the pressure deltas across the oxidizer preburner oxidizer valve (OPOV) are great enough to prevent the OPOV from responding to the shutdown commands. Since the OPOV would stay open while the engine was shutting down, oxidizer would continue to flow into the oxidizer preburner (OPB), potentially causing engine damage.

The start confirm redline parameters and their associated values are presented in Table 1.7-I. Eight start confirm redlines are discussed: MCC Pc, High Pressure Fuel Turbopump (HPFTP) shaft speed, antiflood valve position, fuel preburner purge pressure, oxidizer preburner purge pressure, pogo precharge pressure, HPFT turbine discharge temperature, and High Pressure Oxidizer Turbine (HPOT) turbine discharge pressure. However, the SSME Controller Specifications Part I (Ref. 1) lists only MCC Pc, HPFTP shaft speed, and antiflood valve position as true “ignition confirmation” parameters. Pogo precharge pressure is defined as a “pogo/GOX flow check”, and all other parameters are defined as “engine shutdown (redline) limits.” This information is discussed in detail in the chapters on Control Parameter Qualification, Ignition Confirmation, and Shutdown Limit (Redline) Monitoring (3.2.3:4.2.2, 3.2.3:5.2, and 3.2.3:5.3 respectively) of the SSME Part I Spec (Ref. 1). All parameters are discussed as “ignition confirm” parameters in this Systems Brief because Rocketdyne defines them that way in the SSME Flight Operations Handbook (Ref. 2).

1.7.1.1 Main Combustion Chamber Pressure (MCC Pc)

The MCC Pc is a direct indication of SSME power level. The Pc limits are set to ensure that engine thrust is ramping up properly for launch at 100 percent ($P_c = 2747$ psia for the Block II/IIA SSME). Launching with an engine not delivering adequate thrust (low Pc) could require that an abort be performed. Engine thrust (Pc) is controlled by varying the amount that the OPOV is opened. The engine mixture ratio is maintained by the fuel preburner oxidizer valve (FPOV).

The overall average chamber pressure is used as the redline measurement. This is the average of two channels. During the redline activation time, if either qualified channel violates the start confirm redline the SSME will shut down and cause a pad abort. The redline values are listed in Table 1.7-I.

TABLE 1.7-I. – IGNITION (START) CONFIRM REDLINES (Ref. 1)
(Block II/IIA SSMEs)

Parameter	Redline Activation time (sec)	Reasonableness		Redlines	
		Min.	Max.	Min.	Max.
Main combustion chamber pressure (psia)	Start +1.94 Start +2.3 to 2.34	Same as flight values (see Table 1.7-II)		265 610	-- 1000
HPFTP shaft speed (rpm)	Start +1.40	500	12500	4600	--
Antiflood valve position (%)	Start +2.3 to 2.34	-10 to 40 ¹	60 to 110 ¹	80	--
Fuel preburner purge pressure (psia)	Start to start +5.02 Start +5.04 to 5.08	0	1200	-- --	715 100
Oxidizer preburner purge pressure (psia)	Start to start +5.02 Start +5.04 to 5.08	0	1200	-- --	715 100
Pogo precharge pressure (psia)	Start +4.94 to 4.98	0	1600	800	1425
HPFT turbine discharge temperature (deg R)	Start to 5.78	Same as flight values (see Table 1.7-II)		--	1760
HPOT turbine discharge temperature (deg R)	Start to 3.98 Start +4.0 to 5.78	Same as flight values (see Table 1.7-II)		-- 720	1460 1460

¹Minimum and maximum reasonableness values correspond to transducer limits for a closed or open valve. Transducer value must be between -10% and 40% OR between 60% and 100% to be qualified for ignition confirm monitoring.

Low MCC chamber pressures can be caused by an augmented spark igniter (ASI) failing to ignite, the failure of the OPOV to move, or an erroneous RVDT signal to the controller, which may prevent the OPOV from moving. Low chamber pressures may also be caused by an early priming of the Fuel Preburner (FPB) (causing low mixture ratios), which can prevent MCC and OPB ignitions. In these cases, the lower HPOTP turbine discharge temperature redline will be violated (refer to paragraph 1.7.2.3 for this redline).

Partial HPOTP cavitation will also be reflected in the chamber pressure redline exceedance. This can occur if the pogo relief isolation valve (RIV) fails to maintain proper gas/liquid level in the pogo accumulator.

TABLE 1.7-II - SSME QUALIFICATION (REASONABLENESS) AND REDLINE SHUTDOWN LIMITS CUE CARD (Ref. 4)

PARAMETER	QUALIFICATION LIMITS (Note 1)	REDLINE LIMITS (Note 2)	
		Phase II	Block I
HPOP/IMSL PR Ch A, B	$0 \leq A(B) \leq 650$ psia	A (B) < 170 psia	A (B) < 159
HPOP SEC SL PR Ch A, B (Phase II only)	$4 \leq A(B) \leq 300$ psia	A (B) > 100 psia	N/A
HPFP CL LNR PR Ch A, B (Phase II, Block I, and Block IIA)	$1800 \leq A(B) \leq 4500$ psia	(Note 3) A (B) > 2436 psia @ 67% A (B) > 3543 psia @ 100% A (B) > 3677 psia @ 104% A (B) > 3846 psia @ 109%	(Note 3) A (B) > 2447 psia @ 67% A (B) > 3559 psia @ 100% A (B) > 3694 psia @ 104% A (B) > 3862 psia @ 109%
HPOT DS TMP Ch A2, A3, B2, B3	(Note 4) $A2(A3, B2, B3) \leq 2650$ °R $ A2-A3 \geq 50$ degR (D/Q lwr of two) $ B2-B3 \geq 50$ degR (D/Q lwr of two) If down to 1 on either/both: $((Bavg+Delta)-Ax) \geq 150$ degR (D/Q Ax) or $(Aavg-(Bx+Delta)) \geq 150$ degR (D/Q Bx) or $ Ax-(By+Delta) \geq 150$ degR (D/Q lwr of two)	A (B) < 720 °R A (B) > 1760 °R	A (B) < 720 °R A (B) > 1660 °R
HPFT DS TMP Ch A2, A3, B2, B3	Same as HPOT DS TMP	A (B) > 1960 °R	A (B) > 1860 °R
MCC Pc Ch A, B	$1000 \leq A1(A2, B1, B2) \leq 3500$ psia $ A1-A2 \leq 125$ psia $ B1-B2 \leq 125$ psia	(Note 5) A (B) < (PcRef - 200) During steady state. A (B) < (PcRef - 400) During Throttling or PL < 75 %.	

- Sensor is qualified if it is within specified limits.
- Sensor is voting for shutdown if it meets the specified criteria.
- HPFP Coolant Liner Pressure Redline Limit = $188.3 + 1.1161 (MCC Pc_{Avg})$ psia where $MCC Pc_{Avg} = AVG(Pc_A + Pc_B)$.
- Delta = 0 for both HPOT & HPFT DS TMP, but could be modified (especially on the HPFT DS TMP is Ch A & B redlines are not set to same value, in which case $Delta = (Ch_{Arl} - Ch_{Brl})$)
- Block II SSME does not have HPFP CL LNR PR transducer and redline. For SIM, SMS does have Block II SSME which does have HPFP CL LNR PR transducer, but is not hidden using the Limit Manager.
- $PcRef = PcRef_{100} * PL_CMD / 100$. Phase II => $Pc_Ref_{100} = 3006$; Block I => $Pc_Ref_{100} = 3020$; and Block III/IA => $Pc_Ref_{100} = 2747$
- RVDYDT Blue Line Limits: HPOT DT BL = 50 °R above lower R/L and 50 °R below upper R/L
HPFT DT BL = 50 °R below upper R/L
- HPOT DT Start Upper R/L = 1560 °R (Ph-II & Blk-I), or 1460 °R (Blk-III/IA)
- HPFT DT Start Upper R/L = 1820 °R (Ph-II), 1860 °R (Blk-I), or 1740 °R (Blk-III/IA)

S:\Private\BCH\Main Engine\SSME_Qual_RL_SD_Limits Ref. SSMEC SWY, Part I Spec, Vol. I MPP - 07/30/98 Rev. A
SSME Flight OPS HB (White Book)

1.7.1.2 High Pressure Fuel Turbopump Shaft Speed

This redline was implemented to ensure the HPFTP speed is adequate to provide the proper output for engine start and operation. This redline uses two sensors. If either qualified sensor violates the start confirm redline during the redline activation time, the SSME will shut down and cause a pad abort.

If the HPFTP speed is reduced, its output is reduced, which will cause the amount of LH₂ supplied to the main injector to decrease, resulting in the mixture ratio being higher than required. This can occur if there is leakage past the FPOV purge check valve. In this instance, oxidizer will be vented through the drain line causing a degradation of the ASI mixture ratio. The energy required to obtain adequate speed of the HPFT will not be generated resulting in a redline violation. A similar scenario can also occur for the FPOV's ASI failing to ignite (or outputting a low spark rate) or if the FPOV fails to move properly and is not detected by the controller.

A reduction of turbine power output can also be caused by leakage of the fuel preburner (FPB) seals. This leakage results in reduced turbine speeds, flow, and discharge pressure. This leakage will also result in excessive HPFT turbine discharge temperatures.

The low pressure fuel turbopump (LPFTP), which is upstream of the HPFTP, has a definite effect on HPFTP performance. An energy loss at the LPFTP turbine inlet will result in a reduced power output from the LPFTP pump outlet to the HPFTP pump inlet. If the LPFT speed and output flow are decreased, and the pressure delivered to the HPFTP is reduced. The HPFTP shaft speed will not increase sufficiently for safe engine start and operation. This situation will also result in excessive HPFT turbine discharge temperatures.

1.7.1.3 Antiflood Valve (AFV) Position

Before engine start, the AFV is closed to prevent LO₂ from entering the heat exchanger (HEX). After engine start, the AFV will open when the HPOTP discharge pressure reaches a high enough pressure, thereby confirming that the LO₂ system is operational. Once the AFV is open, LO₂ will flow into the HEX. At this time, sufficient heat is available to gasify the liquid oxygen, which is used to pressurize the LO₂ tank. If the AFV fails to open at engine start, there will be no flow into the HEX and no pressurization of the ET. Pressurization of the ET is required to maintain the structural integrity of the tank and to satisfy LO₂ NPSP requirements.

There are two AFV position sensors. If either qualified sensor violates the start confirm redlines during the redline activation time, the SSME will shut down and cause a pad abort.

1.7.1.4 FPB, OPB, and Pogo Pressures

There are three other parameters that are commonly referred to as start confirm redlines. These are the fuel preburner (FPB) purge pressure, the oxidizer preburner (OPB) purge pressure, and

the pogo precharge pressure. Each of these parameters is monitored by two transducers. These parameters are not explicitly defined as 'start confirm' redlines in the software. However, if any of the qualified sensors violates the redline described in Table 1.7-I during the redline activation time, the associated SSME will be shut down and cause a pad abort. A brief discussion of these measurements is presented in the following paragraphs.

FPB and OPB Purge Pressures - The chamber pressures of the fuel and oxidizer preburners are controlled by the FPOV and the OPOV, respectively (refer to Booster Systems Brief 1.2; Ref. 3). During the start phase, the FPB and the OPB are purged with gaseous helium that is routed from the pneumatic control assembly (PCA) through a check valve for each preburner. The check valve and the purge are present to prevent oxidizer from entering the PCA, which would rupture the burst diaphragm and vent oxidizer into the oxidizer drain line resulting in contained engine damage. Also, if leakage is adequate to depress the ASI mixture ratio, it is possible that the HPFTP shaft speed redline would be violated (refer to paragraph 1.7.1.2.).

Pogo Precharge Pressure - The pogo precharge supplies helium pressure to the pogo accumulator during engine start until gaseous oxygen is available from the heat exchanger. Helium is routed from the pneumatic control assembly through the pogo helium precharge valve, which controls the precharge pressure.

1.7.1.5 HPFT and HPOT Turbine Discharge Temperatures

The HPFT and HPOT turbine discharge temperatures are discussed in paragraphs 1.7.2.2 and 1.7.2.3 respectively.

1.7.2 Flight Redlines

Redline parameters are monitored to assure that the engine is performing within safe operating conditions. Limits are set to guard against uncontained SSME damage and are based on test stand data, flight experience, and engineering analysis. Refer to Table 1.7-II for a summary of the redline shutdown limits. Flight Rule A5.1.1-2, Space Shuttle Main Engine Out (Ref. 5), gives additional information on the derivation of flight redlines.

1.7.2.1 Main Combustion Chamber Pressure

The MCC Pc redline was developed in an attempt to protect against hardware failures that cause a decrease in Pc well below the commanded value. An uncommanded decrease in main combustion chamber pressure may be caused by a drop in HPOTP efficiency, reduced HPOTP turbine inlet flow, loss of inducer/impeller head rise, drifting propellant valves, or sensor problems.

A large drop in Pc could cause the engine to reach unstable power levels (less than 67 percent rated power level). To prevent this, the controller shuts the engine down when the average

chamber pressure is 200 psi (400 psi during throttling or $PL < 75\%$) less than reference P_c (P_c REF). P_c REF is the chamber pressure the controller uses in the control loop as the commanded power level (reference SB 1.17, SSME Performance Cases).

Background

The addition of the MCC P_c redline was prompted by a failure that occurred in the OPB during a test of engine 2106 on July 1, 1987. The failure was caused by a crack in an OPB interpropellant baffle pin braze joint. The effect was a hot streak in the OPB, which eroded through the HPOTP turbine housing causing approximately 20 percent of the hot gas to bypass the turbine and flow directly into the hot gas manifold. This bypass flow caused a massive drop in MCC P_c . The test was terminated due to a ground test criteria violation. The damage to engine 2106 was contained; however, it is not known if the failure would have been contained if the engine had continued to run. The original redline limit of 400 psi below the commanded P_c was chosen based upon the amount of damage sustained by the engine's HPOT at the time the engine was shut down by a facility redline. This value was chosen because it equates to the engine 2106 HPOT hot gas bypass flow. The MCC P_c redline was updated for STS-89 and subsequent flights to 200 psi below the commanded P_c during steady state operations, while retaining the 400 psi during throttling when the power level is less than or equal to 75 percent RPL. This update was based upon the amount of damage sustained by engine 0524, which experienced a nozzle failure and uncontained shutdown during test 901-933. Therefore, an engine will be shutdown if all qualified P_c pair averages have dropped 200 (400) psi below P_c REF.

Updates were made to the MCC P_c controller software following STS-91 to include MCC P_c discriminator logic (RCN-6503, 6524). During ascent on STS-91, the center SSME MCC P_c Channel A failed its qualification check for engine control during throttling in the thrust bucket (IFA No. STS-91-01). The failed main combustion chamber (P_c) on the center engine continued to drift higher in pressure reaching a maximum pressure of 3150 psia (should have been 2870 @ 104.5% RPL). Since the P_c was disqualified for control, the drift did not have any impact to performance, but because it was still qualified for redline processing, it would have never voted for shutdown if it was needed (i.e. other channel voting). The pressure rise was due to the trapped gas in the P_c sense line heating up. Post-flight inspections revealed rubber contamination in the bore of the Lee-Jet expander pin, which was later determined to be from an adapter plate used during leak checks of the Lee-Jets. Rocketdyne believed the Lee-Jet (trickle purge orifice) was completely blocked during the mission, which allowed the hot steam combustion products in the MCC to enter the P_c sense line and form an ice blockage. Ice can form in the sense line because of its close proximity to the MCC coolant discharge manifold which is around 0 degrees F. This icing resulted in the disqualification of the Center MCC P_c Channel A sensors. The discriminator logic was added to ensure that a channel would be disqualified for both control and redline should a similar situation occur in the future, and that that decision would be based on actual performance as determined by the HPOT and/or HPFT discharge pressure(s).

1.7.2.2 High Pressure Fuel Turbopump Discharge Temperature

Excessive HPFTP turbine discharge temperatures may be caused by a drop in inlet pressure, distorted flow, or leakage past the preburner seals (static, rotor tip, platform, pump interstage seals) into the hot gas manifold. For these cases, the excessive temperatures are caused when the main engine controller increases FPB flow after it senses the reduced output, or flow. If not detected, this will cause uncontained engine damage.

Rubbing of the components can also cause excessive HPFTP temperatures. An increase in head pressure is required at the inlet of the HPFTP so that rotor imbalance and reduced turbopump output do not occur. Any type of imbalance, shaft movement, or vibration may result in the rubbing of components. This rubbing will degrade the performance of the turbopump, which will be sensed by the controller. Subsequently, the controller will increase FPB flow, which will create excessive turbine discharge temperatures. Vibrations may also be caused by the failures of the turbine-end and/or pump-end bearings. These bearings are required to support the rotating assembly.

The LPFTP, which is upstream of the HPFTP, has a definite effect on HPFTP performance. An energy loss at the LPFTP inlet will result in a reduced power output from the LPFTP to the HPFTP. The LPFTP speed and output flow are decreased and the pressure delivered to the HPFTP is reduced. The controller senses the increased demand by the HPFTP and will in turn increase FPB flow resulting in high turbine temperatures as previously described.

Off-nominal density of the fluid (LH_2) will also be reflected in the turbine temperature. Proper fluid density is needed to prevent cavitation of the turbopump, which will be reflected in increased temperatures. The fluid density will decrease if there is excessive leakage of GH_2 past the turbine seal in the LPFTP. The controller will increase FPB flow as before resulting in excessive turbine temperatures.

The upper redline limit was set at 1960°R for channels A and B for the Phase II and Block I SSMEs. This redline was created as a result of two engine failures (0204 and 2013). A discussion of these failures is presented in the background. Subsequent analysis determined that the maximum turbine blade root temperature is 2160°R for 109 percent power level. This root temperature equates to a turbine exhaust temperature of 2060°R . The 1960°R limit provided a 100°R margin. The channel A location on some HPFTPs may run cooler, thus necessitating a lower redline value (potentially as low as 1850°R). On some flights, these redlines may be revised to ensure that there is a comparable margin between the predicted nominal operating temperature and the redline value. Due to the reduced temperature environment facilitated by the large throat MCC, the redline for Block IIA and Block II SSMEs was reduced to 1860°R , which provides a 200°R margin.

Background

On October 7, 1981, engine 0204 failed during a test at 109 percent. The cutoff occurred after HPFTP accelerometer redline exceedance. The probable cause was a thrown turbine blade or broken turbine nozzle which jammed the pump. This caused the pump to seize, resulting in a pressure surge and rupture of the low pressure fuel duct. The shutdown was LOX-rich, and the damage was uncontained.

On April 7, 1982, engine 2013 failed during a certification test at 109 percent. The probable cause of the failure was the loss of one or more turbine blades caused by the following scenario. A new bearing heat shield (coolie hat) retainer nut assembly was used for the first time on that test. The geometry of the nut caused a direct hot gas leak path through the bearing heat shield that impinged on the bearing coolant cap (Kaiser hat). The bearing coolant cap then failed as a result of thermal stress and reduced structural properties. This failure allowed hot gas to enter the bearing coolant circuit and starve the bearing coolant flow. As a result, the bearings' stiffness decreased causing increased synchronous vibrations. Synchronous vibration continued to build up until bearing failure followed by large rotor displacement, severe blade rubbing, blade loss, turbine seizing, fuel flow stoppage, and rupture of the pump inlet assembly occurred. The resulting LOX-rich shutdown caused a severe fire.

Prior to these two engine failures, a HPFTP blade loss failure was thought to be a contained engine failure based on previous testing. The two engine failures prompted the development of a redline for the HPFTP. This redline is based upon the high temperature blade life. Since the engine 2013 failure occurred right before STS-4 (June 27, 1982), a ground observed redline was implemented for STS-4. Then on STS-5 and subs, the AUTO redline was implemented.

Development of the Alternate HPFTP (AHPFTP; "Pratt & Whitney Fuel Pump") was undertaken to improve safety margins, expand operational capabilities and reduce engine maintenance (Ref. 6). The AHPFTP is used on Block II engines and first flew on STS-104 in July 2001.

1.7.2.3 High Pressure Oxidizer Turbopump Discharge Temperature

A. Lower Limit

The lower limit of 720°R was designed to protect the engine from operating in an unstable region below 65 percent power level. This is due to the possibility of ice formation in the turbine, which can result from a 2 kHz clock failure in the SSME controller. If this clock fails, the output electronics (OE) would be disqualified, and the chamber pressure (MCC Pc) monitor function would be erroneously affected. The MCC Pc would be stuck at the value present at the time of the failure and could never be disqualified. The controller uses the OPOV to throttle the engines and measures thrust using the MCC Pc. In this case, the engine would have problems when throttle down commands are issued, because although the OPOV would start to close, the MCC Pc would not change. As a result, the valves would continue to close in an attempt to bring the MCC Pc down to the proper value and ice formation will occur. Once ice forms, the

pump could not function due to binding caused by the ice. The lower redline limit is designed to prevent this from occurring.

The lower limit may also be violated if the OPOV is prevented from opening properly. If the failure of the OPOV to open is not detected by the controller, adequate oxygen for combustion will not be present causing the lower temperature redline to be violated.

Background

This redline was created after the engine 0010 failure where two failures occurred that drove the engine to operate at 1800 psia chamber pressure and a mixture ratio of 3.4. The two failures consisted of a controller channel failure and a Pc sense line failure. First of all, a controller 400 Hz power glitch caused channel B of the controller to be disqualified. Therefore, the Pc B pair ceased to be monitored. Secondly, the measurement port of the remaining channel A Pc pair became plugged by a failed purge control orifice (leejet), and this Pc pair's pressure immediately stepped up to the purge supply pressure of 4300 psia. Since the controller uses the OPOV to throttle the engines and measures thrust using the chamber pressure, which is normally about 2871 psia (Block II/IIA at 104% RPL), the controller closed the OPOV to bring the erroneous Pc back to the reference value of 2871 psia. The resulting control point caused the engine to run at an actual chamber pressure of 1800 psia and a mixture ratio of 3.4 instead of the desired values of 2871 psia and 6.0, respectively. The HPOTP balance cavity function at this exotic engine balance point became inactive allowing the pump shaft to be jammed towards the preburner pump end of the assembly. The power balance coincidentally allowed the pump to run at or near its first critical shaft vibration resonance speed. This failure mode results in friction and/or bearing failure, which leads to an HPOTP detonation and an engine cutoff by the preburner pump accelerometer.

As a result of the engine failure, a hardware fix was made to the sense line, and the lower redline limit was added. The hardware fix was a leejet retention mod to prevent the leejet from plugging the sense line if the leejet breaks.

B. Upper Limit

The upper limit of 1760°R, for the Phase II and Block I SSMEs, was designed to protect the HEX from overheating and rupturing leading to uncontained engine failure. Engine analysis and testing indicate that the HPOTP could run at 1860°R for one flight with an acceptable safety factor. Above 1960°R the HEX could fail. The probability of failure is reduced at temperatures between 1860°R and 1960°R. Due to the reduced temperature environment facilitated by the large throat MCC, the redline for Block IIA and Block II SSMEs was reduced to 1660°R.

A decrease or loss of fuel to the OPB will result in oxygen rich operation causing an increase in turbine temperatures above the redline. Continued heating in this state will cause overheating of the turbine, which can result in uncontained engine damage. This decrease in fuel flow may be caused by internal fuel tube leaks.

Turbine temperatures will also be affected by turbopump inlet conditions. A reduction in turbine inlet flow or an energy loss in the inlet reduces the turbine power output. This results in reduced pump speed, flow, and discharge pressure, which will cause a degraded engine thrust or chamber pressure. The low P_c is sensed by the controller, which increases OPB oxidizer flow which results in excessive turbine temperatures. This reduced inlet condition can be caused by leakage of seals within the HPOTP (turbine blade tip seal, turbine interstage seal), OPOV/HPOTP seal, or excessive inlet flow distortion.

A loss of inducer/impeller head rise will also reduce engine thrust (MCC P_c) as previously discussed. This drop in MCC P_c is sensed by the controller, which will increase the oxidizer flow to the OPB, resulting in excessive turbine temperatures as previously discussed.

The Low Pressure Oxidizer Turbopump (LPOTP), which is located upstream of the HPOTP, has a definite effect on HPOTP performance. A loss of turbine power or head will reduce the output, which is delivered to the inlet of the HPOTP. The HPOTP discharge pressure is reduced and MCC P_c decreases. This decrease is detected by the controller, which attempts to correct the situation by increasing oxidizer flow by opening the OPOV. This will cause excessive turbine temperatures as before, resulting in uncontained engine damage if not detected.

1.7.2.4 HPOTP Intermediate Seal Purge (ISP) Pressure

Early in the development program, there were seal package failures that were uncontained. The seal packages were redesigned and redlines added.

For the Block II/IIA SSMEs, the HPOTP ISP pressure redline limit is set to 159 psia. This redline was derived from analysis to prevent LO_2 from the Alternate HPOTP pump combining in the purge cavity with H_2 from the fuel cooled roller and ball bearing package. This redline guards against excessive seal wear or loss of helium purge by ensuring that the HPOTP intermediate seal cavity pressure is greater than the HPOTP O_2 cavity and secondary H_2 cavity pressure by 10 psi during main stage under the worst seal gap condition.

1.7.2.5 HPOTP Secondary Seal Pressure

Redesign of the HPOTP led to the deletion of this sensor for Block I SSMEs and subs.

1.7.2.6 HPFTP Coolant Liner Pressure

Redesign of the HPFTP led to the deletion of this sensor for Block II SSMEs and subs.

1.7.3 Reasonableness Test

Each redline sensor is subjected to a reasonableness test (Ref. 4). This test is required to validate the sensor operation for application to the shutdown logic. The test is used to screen out a sensor(s), which may be outputting erroneous data (outside the normal operating range of the sensor). Refer to Table 1.7-I for a summary of the reasonableness test limits.

1.7.3.1 Start Confirm Redline Reasonableness

The reasonableness tests on all start confirm redlines are shown in Table 1.7-I. The disqualification of any single transducer (or channel for the MCC Pc redlines) during start will not cause a SSME shutdown. The disqualification of all of the transducers used for a given start confirm redline or two or more turbine discharge temperature transducers on a given pump will generate an MCF and cause an SSME shut down and pad abort prior to launch. Disqualification of any single transducer (or channel for MCC Pc) during SSME start will not cause a pad abort.

1.7.3.2 Flight Redline Reasonableness

Reasonableness tests are performed on each of the flight redlines. Disqualification of all of the transducers used to monitor a given flight redline leads to a loss of redline protection for that parameter.

Main combustion chamber pressure (Pc)

There are a total of four MCC Pc transducers per SSME, with two channels containing two MCC Pc sensors each. The sensors and channels are qualified for control and redline monitoring usage if they meet the reasonableness criteria. The first check is used to determine qualified transducers for control and crew display (used in VDT). This check consists of the (A) Intra-Channel Comparison and (B) Pc Ref Channel control loop reasonableness. If the first Pc channel fails the Pc REF check, then the (C) Pc Discriminator test is performed. If both channels are disqualified from control loop monitoring, the (D) individual sensor check is performed to determine which value will be used for crew display. Finally, a check is performed to determine the Pc that will be used for (E) redline monitoring. For further information on MCC Pc checks, refer to the chapter on Control Parameter Qualification (3.2.3:4.2.2) in the SSME Part I Spec (Ref. 1).

(A) Intra-Channel Comparison Test (Control Loop Reasonableness)

$$|A1 - A2| \leq 75 \text{ psi or } |B1 - B2| \leq 75 \text{ psi}$$

The Pc channel has the above intra-channel control reasonableness limit. If either channel violates this limit, then both sensors on the affected channel are disqualified from being used for control purposes.

(B) Pc REF Channel Reasonableness (Control Loop Reasonableness)

$$|\text{Channel} - \text{Pc REF}| \leq 75 \text{ psi or } |\text{Channel} - \text{Pc REF}| \leq 200 \text{ psi}$$

The average of each channel is compared to the expected Pc (Pc REF) and is expected to be within 75 psi. The only exception is during throttling or at rated power levels less than 75 percent. In these two cases, the reasonableness check for control becomes $|\text{Channel} - \text{Pc REF}| \leq 200$ psi. This relaxed check remains in effect for 50 major cycles after throttling. The control qualification check is done to prevent any large Pc shift performance cases. If both Pc channels fail control qualification, the engine enters electric lockup.

(C) Pc Drift Test Discriminator Logic

If the first Pc channel fails the Pc REF channel reasonableness (B) test, subsequent checking is needed to determine the failed component and failure response. If the A and B channels are within 50 psi (125 psi during throttling) of each other, then the offending channel will be permanently disqualified for control. If the A and B channel averages disagree by more than 50 psi (125 psi during throttling), then it is necessary to perform the Pc Discriminator Test to determine which is the bad channel.

For this check, the controller uses the HPFP and/or HPOP discharge pressure(s) to determine which direction the MCC Pc is drifting. Therefore, it will only be performed if either the HPFP or HPOP discharge sensors are qualified. The test calculates a Pc Discriminator Intercept, which is a function of Pc Average and either the HPFP or HPOP discharge pressure, which is then used to calculate the MCC Pc Discriminator. The discriminator is calculated using either the HPFP or HPOP-based intercepts, or takes an average of the two if both are qualified. The software then determines which channel more closely agrees with the discriminator and considers that channel to be the good channel. The channel that least agrees with the discriminator is considered bad and is then disqualified for both control and redline limit shutdown processing.

(D) Individual Sensor Redline Reasonableness

$$1,000 \text{ psia} \leq \text{Individual Pc Sensor} \leq 3,500 \text{ psia}$$

This test is performed if both the A and B pairs are disqualified from the control loop by checks A-C. Failure of both channels will result in electric lockup, and the initiation of this check to determine the value to be used for crew display. All Pc sensors meeting this check are averaged together and displayed. If no sensor meets these limits, Pc REF will be used.

(E) Shutdown Limit Monitoring Intra-Channel Comparison Test (Redline Reasonableness)

$$|A1 - A2| \leq 125 \text{ psi and } |B1 - B2| \leq 125$$

$$1000 \text{ psi} \leq (\text{Avg of A1 and A2}) \leq 3500 \text{ psi or } 1000 \text{ psi} \leq (\text{Avg of B1 and B2}) \leq 3500 \text{ psi}$$

The Pc channel also has an intra-channel redline reasonableness limit ($|A1 - A2| \leq 125$ psi and $|B1 - B2| \leq 125$) that protects against single-bridge failures. However, this test is only

performed if the individual sensors have passed their reasonableness checks. Failure of this test, disqualifies both sensors on the channel from redline monitoring. The lower of the two sensors is thrown out.

After this check, a second reasonableness check of: $1000 \text{ psi} \leq \text{Avg of A1 and A2} \leq 3500 \text{ psi}$ or $1000 \text{ psi} \leq \text{Avg of B1 and B2} \leq 3500 \text{ psi}$, is performed. If the channel fails this check, the channel is permanently disqualified. If both channels are disqualified, the remaining sensors between 1000 and 3500 psi are averaged and used for vehicle data table (VDT) reporting. If no sensors are within this reasonableness limit, then Pc REF is downlisted in the VDT. The channel average upper reasonableness limit protects against an off-scale high sensor pair or input electronics failure. The lower limit protects against a failed low sensor pair or input electronics failure.

HPOTP turbine discharge temperature

The upper reasonableness limit for this measurement is 2650°R. The upper limit guards against open circuits when the connector wire breaks (infinite resistance). There are two other forms of reasonableness checks, intra-channel and inter-channel, to protect for transducers that shift low.

(A) Intra-Channel Reasonableness Check

$$|A2 - A3| \geq 50 \text{ }^\circ\text{R} \text{ and } |B2 - B3| \geq 50 \text{ }^\circ\text{R}$$

The intra-channel check is performed when both of the sensors on a channel (A or B) are qualified. If the intra-channel limit is violated, then the lower of the two sensors is disqualified.

(B) Inter-Channel Reasonableness Check

$$A_{\text{avg}} - B_x \geq 150^\circ\text{R} \text{ or } B_{\text{avg}} - A_x \geq 150^\circ\text{R}$$

If one sensor has been disqualified on a channel, the controller begins an inter-channel check. The inter-channel check compares that single sensor to the average of the two good sensors on the other channel. If the inter-channel limit is violated, then the single sensor (A_x or B_x) will be disqualified. If both channels are down to one good sensor, then the inter-channel check will compare the two single sensors ($|A_x - B_y| \geq 150^\circ\text{R}$) and disqualify the lower of the two in case of a violation. The intra-channel and inter-channel checks protect against a short circuit or degraded sensor.

HPFTP turbine discharge temperature

This reasonableness criteria is the same as that of the HPOTP turbine discharge temperature sensors.

HPOTP ISP pressure

The reasonableness of this measurement is a minimum of 0 psia and a maximum of 650 psia. This represents the operating range of the transducer.

1.7.4 References

1. SSME Part 1 Spec, Volumes I and II, Rev. I, July 14, 2000.
2. SSME Flight Operations Handbook ("White Book"), STS-104, 2001.
3. Booster Cue Card Book (BCCB), Basic Rev A, PCN-12, January 10, 2003.
4. Space Shuttle Operational Flight Rules, NSTS-12820, Final 2002, PCN-1, November 21, 2002.
5. NASA SSME Project Flight Readiness Review, STS-104, May 18, 2001.

1.8 SSME EIU HARDWARE / USAGE

1.8.1 General EIU Hardware

One engine interface unit (EIU) is located in each of the aft avionics bays (avionics bays 4, 5, and 6) in the orbiter. Each EIU acts as the information transfer interface between a dedicated SSME controller (SSMEC) and four GPCs. The EIUs weigh approximately 20.6 lb and have physical dimensions of 16 3/8 by 6 by 7 inches. Figure 1.8-I is a perspective drawing of the EIU. Figure 1.8-II is a functional block diagram of the EIU. A summary of EIU functions follows:

- A. There is one EIU for each SSME. They are not interconnected, and they act completely independent of each other.
- B. Each EIU acts as an information transfer interface between a dedicated SSMEC, located on the SSME, and four GPCs located in the forward avionics bays of the orbiter.
- C. EIUs are used only during the prelaunch and launch phases of a flight. They are powered-up prior to SSMEC software loading and powered-off on-orbit (following OMS-2).
- D. Commands (both execute and transfer) and command data words (associated with the transfer command) are received from four GPCs over four flight-critical data buses of the computer data bus network. See Figure 1.8-III for a diagram of the execute and transfer commands. Execute commands consist of a single command word and cause an EIU internal function to occur; e.g., "response" execute command causes SSME status information to be sent to the GPC. A transfer command consists of a command word followed by two command data words which are formatted into a SSMEC command word and sent to the SSMEC over three redundant SSMEC data buses. See Figure 1.8-IV for GPC-to-EIU command and command data word formats. Figure 1.8-V shows the format of the EIU-to-SSMEC command words.
- E. SSME status data are transmitted back to the EIU from the SSMEC over two other redundant data buses. Upon GPC request by a "response" execute command, the EIU sends information back to the GPCs (only the first 32 words of the vehicle data table (VDT), Figure 1.8-VI) and automatically sends it (128 word VDT plus OIE overhead words, Figure 1.8-VII) through the EIU Operational Interface Element (OIE) to the:

1. Launch processing system (LPS) T-0 umbilical - Engineers at MSFC, KSC, JSC, and Rocketdyne/Canoga Park (RKD/CP) monitor the LPS data until the T-0 umbilical is pulled at liftoff.
 2. Maintenance and loop recorder number one - The data is recorded during ascent and the recorded data is dumped to Bermuda for review by MSFC and RKD/CP engineers.
 3. S-band FM telemetry system - None of the OIE data are available in real time to JSC flight controllers. Only the limited data (first 32 words) transmitted to the GPC and downlisted in the GNC telemetry stream are available real time to the flight controllers. S-band FM is transmitted to Merritt Island and Bermuda during ascent and relayed by ground link to MSFC and RKD/CP for real-time monitoring.
- F. Power is provided to each EIU from two of three redundant 28 volts main DC power buses.
- G. Cooling is provided by mounting each EIU on a coldplate.

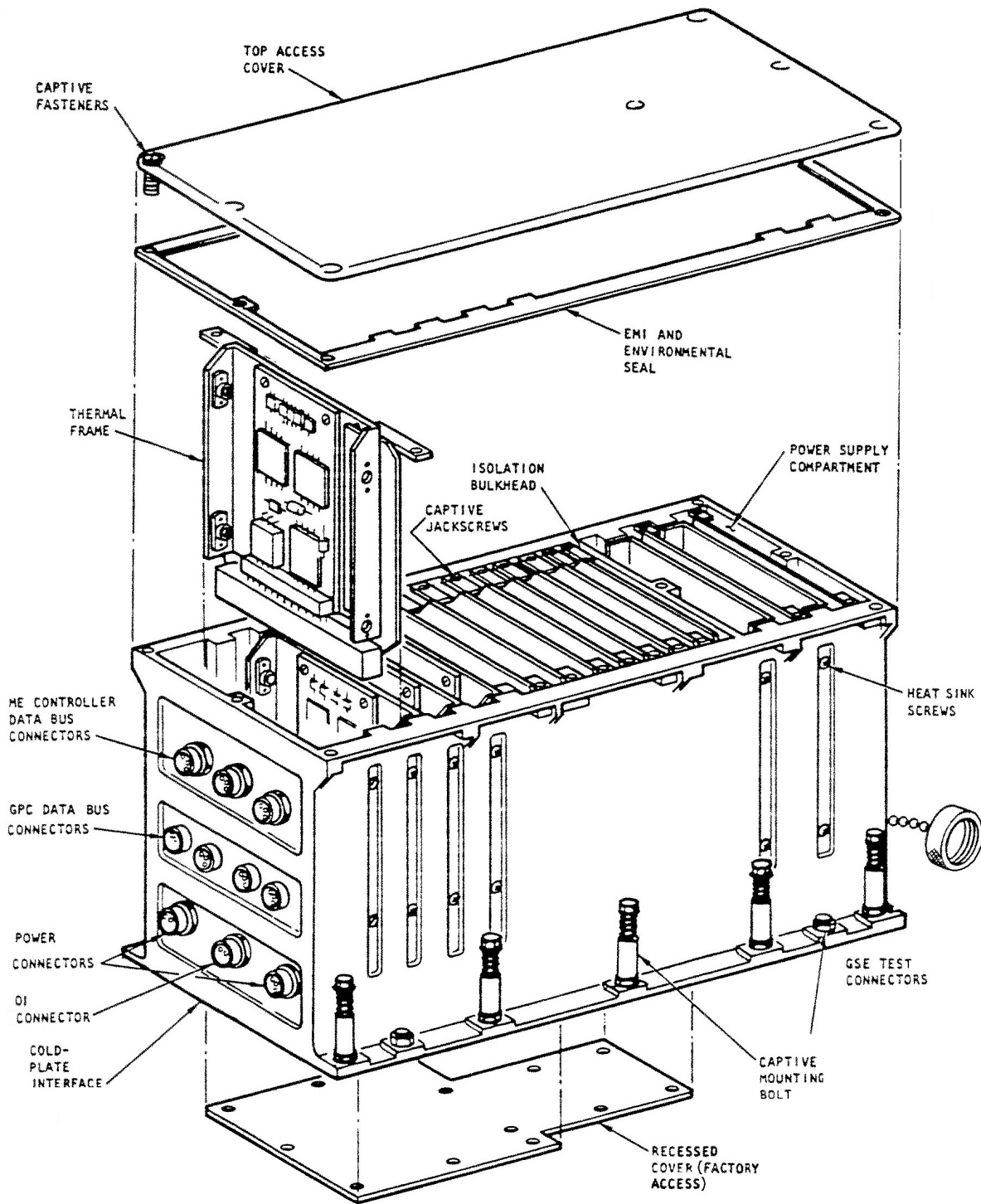


Figure 1.8-I - EIU perspective drawing.

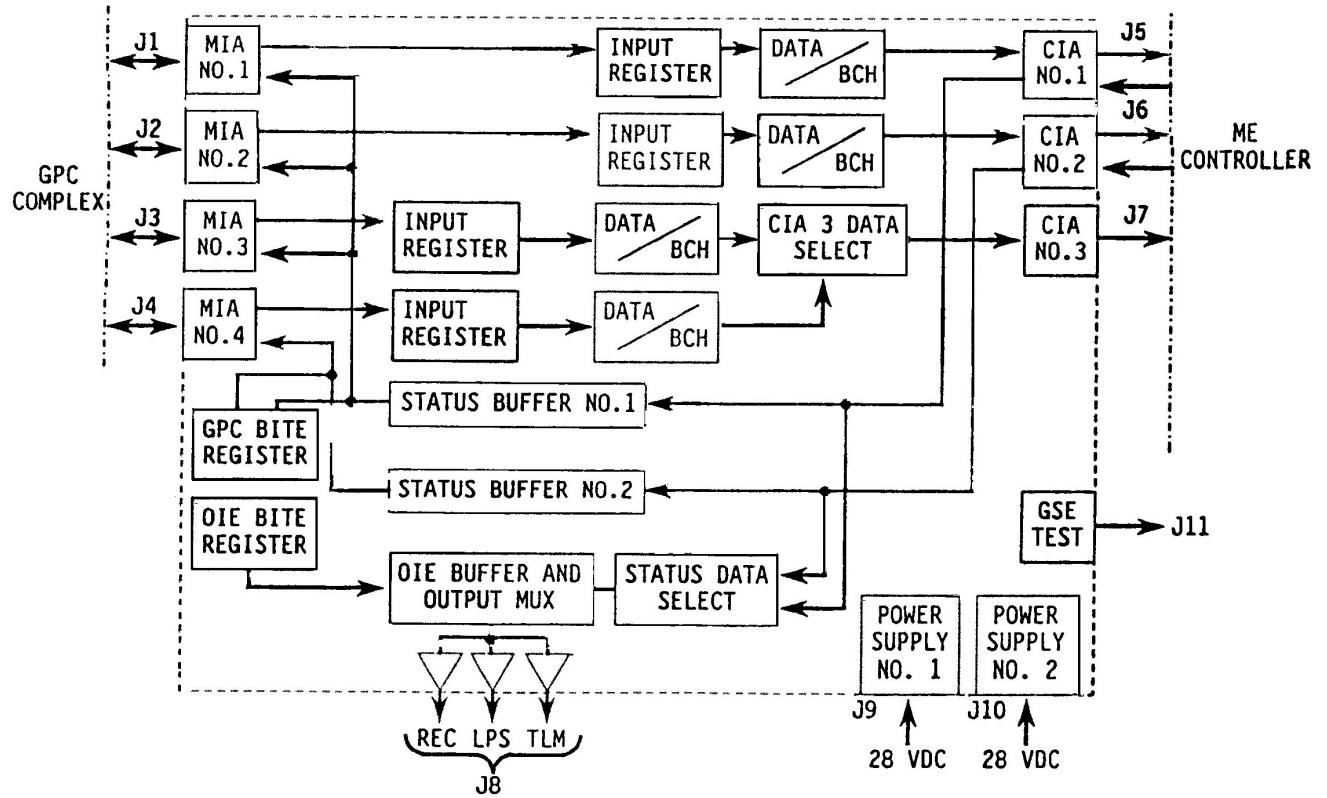
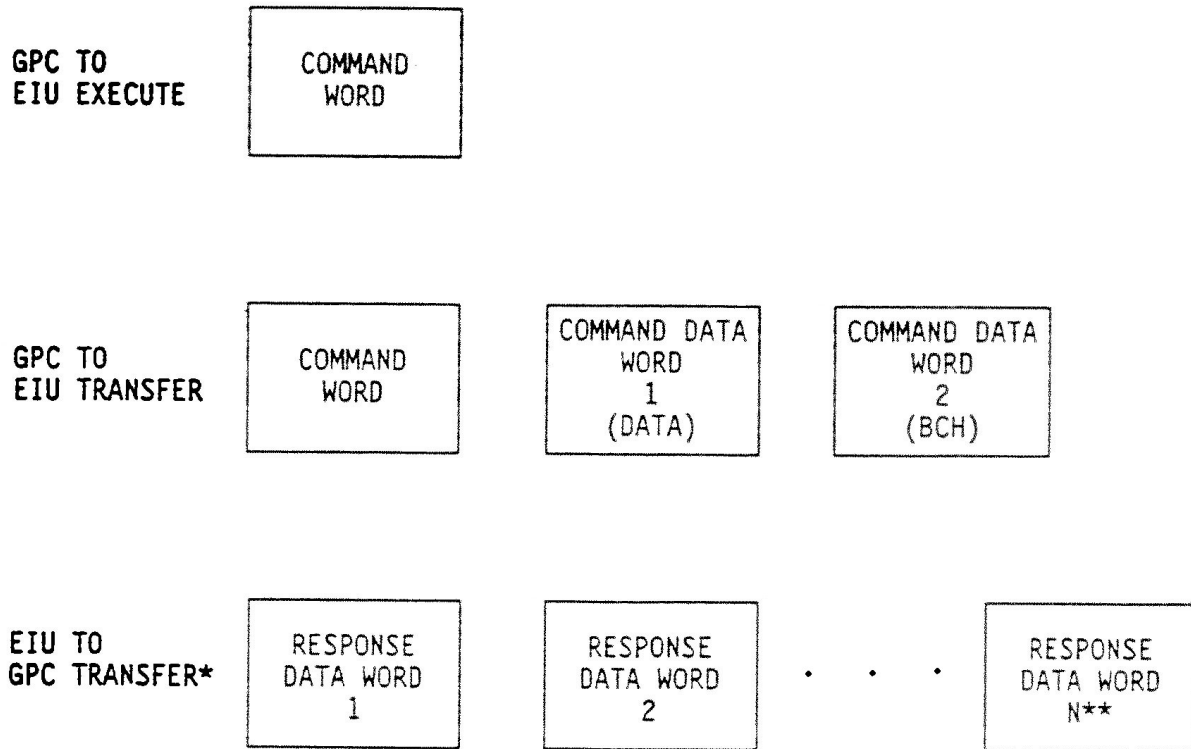
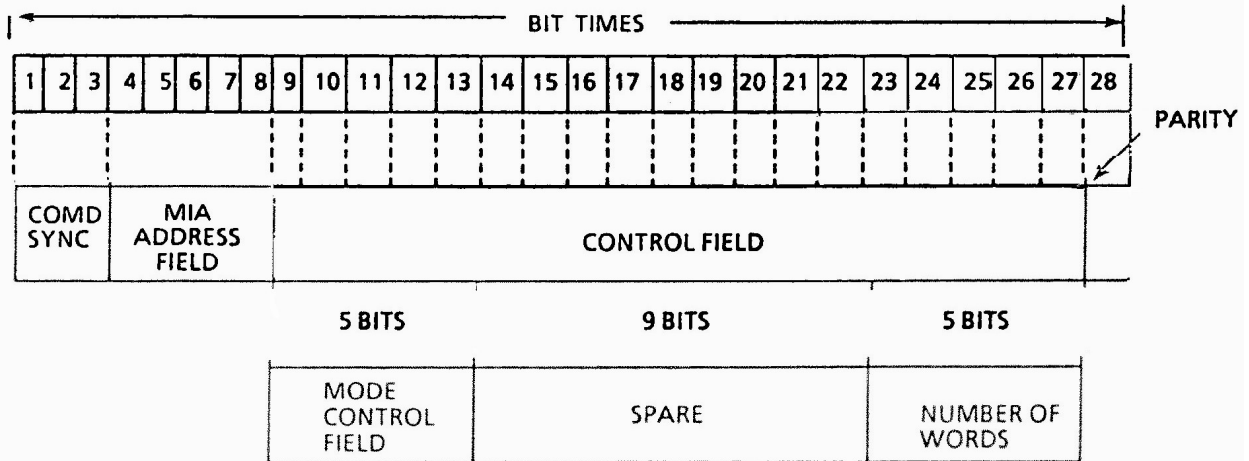


Figure 1.8-II - EIU block diagram.

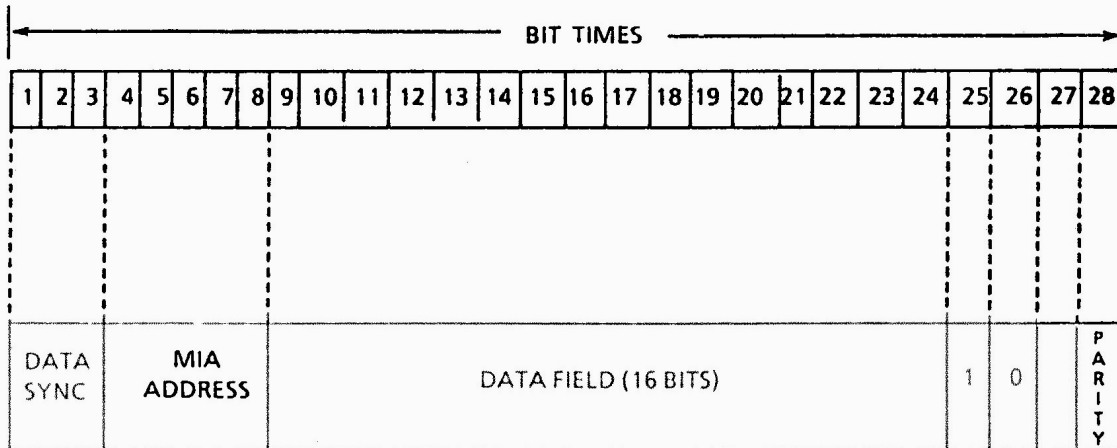


*IN RESPONSE TO AN EXECUTE COMMAND
**N EQUAL TO OR LESS THAN 32

Figure 1.8-III - MIA message formats.



Command Word Format (GPC to EIU)



Command Data Word Format (GPC to EIU)

Figure 1.8-IV - Command and command data word formats.

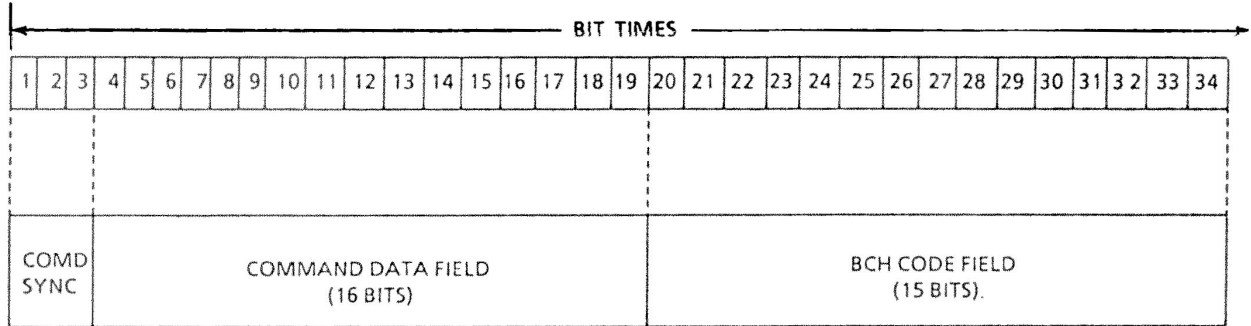


Figure 1.8-V - Command word format (EIU to SSMEC).

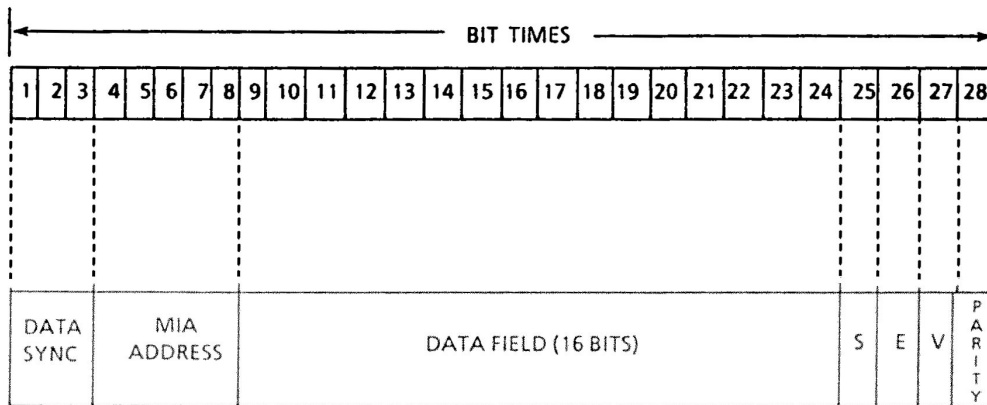


Figure 1.8-VI - Response data word format (EIU to GPC).

ID	ME CONTROLLER DATA STREAM	BITE	COLUMN PARITY
2 WORDS	128 WORDS	1 WORD	1 WORD

Figure 1.8-VII – OIE message format.

1.8.1.1 Functional Description

The three EIUs operate entirely under the control of the GPCs, except that status or memory dump data is continuously received from and automatically transmitted to the OIE. Each EIU accepts and decodes messages from up to four GPCs and transmits commands to its dedicated SSMEC when commanded by the GPCs. All signals entering and leaving the EIU are serial in nature and are encoded in the Manchester Bi-Phase format (non-synchronous). These non-synchronous signals have zero-to-one or one-to-zero transitions in the center of every data bit and this provides signal timing. Serial data transfer internal to the EIU is accomplished using the non return to zero (NRZ) format (synchronous). The EIU has an internal clock which it uses to synchronize NRZ transmissions. GPC control of the OIE data flow is limited to the selection of either the primary or secondary SSMEC status data channel.

The EIU is controlled by commands originated by the GPC and transmitted to the EIU over the digital data buses. The EIU is operational within 15 milliseconds after the application of power; however, messages containing words of all zeros are transmitted to the SSMEC until normal operations are initiated upon GPC command. OIE messages transmitted during the initial condition period will contain all zeros in the word count and data bits. The GPC must determine that an EIU is operational by transmitting a "return command" execute command and then checking the return message. The status of a unit is ascertained by the GPC through use of the "BITE" execute command.

1.8.1.2 EIU Major Components

The components of the EIU are shown in SSSH drawing 10.3. Each major component will be referenced to its location on that drawing (i.e. "A Z 1" is Zone A-1) and then its function will be briefly described.

A. Multiplexer interface adapters (MIA) 1-4 interface elements $O-TZ^{3-8}$

1. MIAs 1-4 TZ^{4-7}

The MIAs provide for bi-directional, serial, digital data flow between the EIU and the digital data bus network.

Each of the four MIAs within an EIU has the same address, which is established by the wiring of the five address bits in each MIAs data bus cable connector. The addresses are created by selectively connecting the address pins to a logic one or a logic zero which is supplied by the EIU. The MIAs in EIUs 1, 2, and 3 have addresses 17, 23, and 24, respectively. The address status overhead bits are generated in the EIU for transfer and execute command/data word address checking and for response data word address encoding.

Incoming data are transferred serially from the MIA to the MIA data register, and outgoing data are transferred serially to the MIA via the MIA interface element. Each MIAs receiver is always enabled, even while transmitting. This provides an immediate check on the transmitted word's MIA address validity.

Each MIA is supplied with the "SEV" status overhead bits which it includes in each response word to the GPC. The S bit is the power transient flag and is set to a logic 1 for all transmissions. The E bit is the serial channel error flag which is set by the CIA logic for errors in response word. The V bit is the validity flag and is set to 1 for all EIU to GPC responses.

2. MIA input register (1-4) $S^7 Z^7$

The 24-bit MIA input registers provide the serial-to-parallel message buffering needed for reception of command words and command data words from the GPC via the MIAs (see Figure 1.8-IV for command and command data word formats). Transfer and execute command words are broken apart and loaded into the MIA address compare, the command decoder, the timing control circuitry, 101 check pattern validity, and the message word counter. The first and second transfer command data words are loaded into the data transfer and BCH (Bose, Chaudhuri, Hocquenghem encoding) data registers in parallel for subsequent transmission to the CIA multiplexer (see Figure 1.8-V for the EIU-to-SSMEC command format). After receiving a "command return" execute command, the command word is serially transferred to the MIA interface element multiplexer for transmission to the GPC.

3. BCH and data transfer registers (data/BCH) $P-Q Z^7$

The EIU BCH/data transfer registers provide the message formatting and parallel-to-serial buffering needed for transmission of command and memory load words to the SSMEC.

The 16-bit data transfer register is loaded with the first command data word in a transfer command message. The 15-bit BCH register is loaded with the 15 most

significant bits (MSB) from the second command data word. The 31-bit message is then serially transferred to the CIA for transmission to the SSMEC.

BCH encoding is used by the SSMECs to determine if the command received is the same as the one transmitted by the EIU.

4. Word validation ^{S-R}**Z**⁴⁻⁶

The word validation circuitry looks for errors in the words recovered by the MIA including invalid Manchester data encoding, parity errors, or invalid bit counts in the input words.

5. Command decoder and timing control ^R**Z**⁴⁻⁶

The command decoder decodes the mode control bits which are transferred to it by the mode control command register in parallel. The time control provides the EIU internal logic with a 16-MHz clock signal which it uses to derive all other clock signals for synchronous data transfers between the EIU components. The time control also controls the timing (start and stop) of serial bi-directional data transfer between the MIA interface elements and the CIAs.

6. Interface element MUX (multiplexer) ^P**Z**⁴⁻⁶

The interface element MUX takes the serial data from the status registers and builds the MIA response data words by adding the MIA address and SEV bits to the 16-bit words. It then serially transmits these response words to the MIAs so that the MIAs can add sync and parity bits and transmit them to the GPCs.

B. CIA 3 data select ^{K-L}**Z**⁷⁻⁸

The CIA 3 data selection logic selects between the MIA 3 or MIA 4 transfer message (data/BCH represent SSMEC commands) to be transmitted over CIA 3 to the SSMEC. The logic selects the first channel to pass the MIA input validity checks for a three-word GPC-to-EIU transfer message. This function is also known as first-in/first-out buffering (FIFO). Once selection is achieved, it is maintained for 5 +/-1 milli-seconds to ensure acceptance of the command data words following the command word. If both channels have data present at the same time, only one channel is allowed to transmit.

C. Built-in test equipment $J-OZ_{1-3}$ 1. GPC BITE register $J-KZ_1$

The 16-bit GPC built-in test equipment (BITE) register provides storage for the GPC-oriented EIU BITE error signals. The register contents are transmitted to the GPC in response to the "BITE" execute command, and the majority of the register's bits are reset to zero. The "BITE" execute command is only exercised during prelaunch operations. The flags include MIA 2-MHz clock fail flags, CIA fail flags, status buffer fail flags, OIE buffer parity errors, power supply fail flags, format error flag, power-up sequence flag, and the status override flag. See Table 1.8-I for a breakdown of the GPC BITE response word format.

The first GPC channel that requests BITE data obtains access and the other three channels are kept from processing the BITE command for a period of 50 microseconds by the inhibit BITE flags.

2. Power supply fault detector OZ_{2-3}

This logic determines if power supply A or B's +12 V, -12 V, or +5 V DC voltages are within nominal operating ranges. If an out-of-tolerance condition is sensed, the power supply failure flags are set in both the GPC and OIE BITE words.

3. Power-up detector OZ_1

The power-up detection logic is used to initialize the circuitry of an EIU after initial power up or after the loss and recovery of one of its power supplies during operation; i.e., just Power Supply A or B. The power-up detection logic is used to clear GPC and OIE BITE flags (except the power-up sequence bit in the GPC BITE register) and EIU output words (EIU-to-GPC, EIU-to-SSMEC, and EIU-to-OIE). When an EIU power supply makes a transition from a low voltage to a high voltage (≥ 12 V DC), the power on reset signal associated with that power supply (A and/or B) is set to a logic 1 for approximately 100 microseconds. A power-on reset A will cause MIA port 1, MIA port 3, CIA port 1, Status Buffer 1, and the OIE to be initialized. A power on reset 0 will cause MIA port 2, MIA port 4, CIA port 2, and Status Buffer 2 to be initialized.

Power-up detection logic was redesigned between STS 51-L and STS 26-R to eliminate a single point failure of the power-up detector circuitry which could cause a command/data path failure on the SSME associated with the EIU. A failure in the

"OR" gate tied to the power on reset A and B signals could cause both of these signals to be tied to a 12 V DC source. This would assert these signals indefinitely and cause all of the MIA ports, CIA ports, OIE, and Status Buffers to be locked up in their initialization modes. All flights including STS 33-R and subsequent flights used the new configuration EIUs (dash 12 or later configuration).

By March of 1997, all EIUs in the fleet had been upgraded to the dash 13 configuration. This upgrade removed the one-shot circuit and changed the transient-detections circuit. This makes the EIUs less susceptible to noise, which is thought to cause Power On Resets (PORs). In addition, the dash 13 upgrade eliminated the 1.1 second delay circuit. This reduces the exposure window for dual PORs from 1.1 seconds to 144 msec. Note - SSME Controller OI-6 software (delivered in late 1993) eliminated the single POR Crit 1/1 concern.

TABLE 1.8-I – GPC BITE WORD BREAKDOWN

Bit Times	GPC bite word
1	Synch bit 1
2	Synch bit 2
3	Synch bit 3
4	Most significant address bit
5	Most significant address bit
6	Most significant address bit
7	Most significant address bit
8	Least significant address bit
9	MIA 1 FAIL FLAG
10	MIA 2 FAIL FLAG
11	MIA 3 FAIL FLAG
12	MIA 4 FAIL FLAG
13	CIA 1 FAIL FLAG
14	CIA 2 FAIL FLAG
15	CIA 3 FAIL FLAG
16	Status buffer 1 FAIL FLAG
17	Status buffer 2 FAIL FLAG
18	OIE buffer FAIL FLAG
19	OIE control FAIL FLAG
20	Power supply A FAIL FLAG
21	Power supply B FAIL FLAG
22	Power up sequence FLAG
23	Format FLAG
24	Status override activated FLAG
25	Check field bit 1 (always 1)
26	Check field bit 2 (always 0)
27	Check field bit 3 (always 1)
28	Parity bit

D. Controller interface adapters (CIAs) 1-3 ^{D-G}**Z**⁵⁻⁸

The CIAs provide for the simultaneous transmission and reception of data at a 1-MHz rate between the EIU and the SSMEC via the SSMEC data bus. In support of these primary functions, the CIA transmits dummy command words of all zeros when there are no commands to transmit to the SSMEC. It also performs verification checks for status words received from the SSMEC: e.g., Manchester validity checking.

Each of the three CIAs within the EIU are used to transmit commands to the SSMEC, only two (CIA 1, CIA 2) are used to receive data from the SSMEC. CIA 1 is the primary data channel and feeds data through status buffer 1 to MIA channels 1, 2, and 3. Although SSMEC data is available at MIAs 1, 2, and 3, only the GPC attached to MIA 1 reads primary data. CIA 2 is the secondary data channel and feeds data to MIA 4 through status buffer 2.

E. Power supply (A and B) and power source C ^{Q-S}**Z**¹⁻³

The dual power supplies (A and B) in each EIU receive 28 V DC from two of the three primary DC power buses as shown in Table 1.8-II.

Under normal operation, the dual power supplies share the EIU power requirements through three circuits, A, B, and C as shown in Table 1.8-II. A and B are two single supply circuits, and C is an “ORed” (A or B) supply source. The three supply circuits are distributed within the EIU so that a failure of one circuit will not prevent the EIU from processing communications between the GPCs and an SSMEC. Each power supply (A and B) contains over current and overvoltage protection, regulation, and ripple filtering. The DC voltages supplied are +5, +12, and -12. Circuit C is created from unregulated power from power supplies A and B that is “ORed” together and regulated. Power-up detection circuitry is located in the BITE circuitry (see paragraph 3.C.3 of this brief).

Whenever a power bus failure occurs, the power supplies are fed from the remaining bus. Interruption of both supplies for over 100 microseconds will cause the powerdown sequence to occur, shutting down the EIU until power is restored.

The maximum power consumption of the EIU at nominal main DC voltages, will be less than 50.6 Watts for all normal operating modes. Maximum power consumption occurs during MIA transmissions.

TABLE 1.8-II – POWER SUPPLY DISTRIBUTION

Power supply distribution to EIUs			
EIU	Power and control buses		
1	MN A APC4	MN B APC5	MN C APC6
2		MN B APC5	
3	MN A APC4		MN C APC6
1	CNTAB2	CNTCA2	CNTAB3
2		CNTBC1	
3	CNTBC1		CNTCA2
Power supply distribution within EIUs			
	Power Supply		
	A	B	A or B
	Source		
EIU logic description	A	B	C
MIA 1 interface assembly	X		
MIA 2 interface assembly		X	
MIA 3 interface assembly	X		
MIA 4 interface assembly		X	
CIA 1	X		
CIA 2		X	
CIA 3			X
Status buffer 1	X		
Status buffer 2		X	
OI buffer	X		
OI Control	X		
OI BITE	X		
GPC BITE			X

F. Operational Interface Element (OIE) ^{C-G}Z¹⁻⁵

1. OIE BITE shift register ^FZ³⁻⁴

The 16-bit OIE BITE register provides storage for the OIE-oriented BITE error signals. The register contents are serially transmitted to the OIE multiplexer to be included as part of the 132-word EIU-to-OIE message. The OIE includes MIA fail flags, CIA fail flags, power fail flags, secondary data flag, repeat flag, OIE buffer fail flag, and the OIE control fail flag. See Table 1.8-III for a breakdown of the OIE BITE data word format.

TABLE 1.8-III – OIE BITE WORD BREAKDOWN

Bit times	OIE BITE word
1	MIA no. 1 Flag
2	MIA no. 2 Flag
3	MIA no. 3 Flag
4	MIA no. 4 Flag
5	CIA no. 1 Flag
6	CIA no. 2 Flag
7	Power supply A fault
8	Power supply B fault
9	Power supply A or B fault
10	S (secondary)
11	R (repeat)
12	B (OIE buffer fail flag)
13	C (OIE control fail flag)
14	Logic "0"
15	Logic "0"
16	Logic "0"

2. Status override detector and status data select **GZ**¹⁻³

The status data select performs the function of passing either primary or secondary status channel data to the OIE buffer selection/status register/reset control. The normal selection will be the primary channel. The selection is changed to the secondary channel by the "status override" execute command. The status over-ride detector monitors for any of the MIA's status override commands to be set and sets the S input to the status data select which causes the data switchover. The selection is returned to normal by the "master reset" execute command or the power-on reset signal.

3. OIE Buffer selection/status register/reset control **E-FZ**³⁻⁴

The OIE buffer selection/status register/reset control provides a double-buffered serial-to-serial transfer point for two blocks of 128 16-bit words of SSMEC status or dump data. The messages, arriving on either the primary or secondary status channel, are loaded into the status register at a 1 MHz rate. Alternate messages are loaded into alternate buffers (A and B) and require about 2.3 milliseconds per message loaded. However, the SSMEC starts message transmission every 40 +/- 2 milliseconds except during memory loading.

Whenever a buffer is completely loaded, the VDT message (together with the two EIU identification words, BITE word, and column parity word) is transmitted to the three OIE output drivers at a 60 kHz rate. Each EIU-to-OIE message requires 35.2 milliseconds for transmission, which means each message is processed by the EIU over a 37.5-millisecond period.

Because of the asynchronous operation of the receive - transmit process, data protection logic is included in the OIE buffer selection/status register/reset control. If the SSMEC memory loading function has caused a status message transmission to the EIU to begin before all previous data blocks have been sent on to the OIE, the EIU logic discards the new data by asserting the reset signal. This prevents the loss of data in the OIE buffer.

If the EIU has not received a new message from the SSMEC, the last message is repeated at completion of the transmission of a message to the OIE and the repeat flag is set. When the alternate buffer is filled, the repeating message is terminated at the end of the block and transmission of the new message is begun and the R flag is cleared.

4. Identification word registers DZ^{1-2}

The identification word registers are two 16-bit parallel in/serial out registers used by the EIU to insert 32 bits of identification at the beginning of each EIU-to-OIE message. The first 24 bits form a fixed sync pattern. The remaining 8 bits contain the word count of the message received from the SSMEC. See Figure 1.8-VII for the OIE ID word formats.

BIT Times																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
111			110			101			111			001			1	First word
001			000			00			Word Count						Second Word	

Figure 1.8-VIII – OIE ID word formats.

5. OIE cycle control DZ^3

The 16-bit OIE cycle control provides the EIU-to-OIE message column parity word data. As each word of the message is transmitted to the OIE, the column parity generator maintains an odd parity bit for each bit position of the word. This is accomplished by processing each bit of generator data against each bit of each outgoing word, with the generator containing zeros at the start of each message.

The column parity word is transmitted to the OIE multiplexer as the last word of the EIU-to-OIE message and does not operate the parity generator.

6. OIE MUX (multiplexer)/Manchester encoder/OIE control failure detector and output drivers $C-DZ^{2-4}$

The OIE multiplexer provides the logic for combining the 128 Vehicle Data Table (VDT) words, the two OIE ID words, the OIE BITE word, and the column parity word. The Manchester encoder encodes the serial NRZ bits into Manchester bi-phase code, and drives the three isolated OIE outputs from a single data source at a 60 kHz rate.

As the bits for each word of a message are processed, the OIE column parity generator is signaled so that it can create the column parity word.

The three output drivers are designed to prevent a fault on one circuit from disrupting the message flow on the others.

G. Status buffers (1-2) ^{J-M}**Z**⁴⁻⁶

1. Status registers 1A, 1B, 2A, and 2B ^{K-L}**Z**⁴⁻⁵

The status registers in the status buffer 1 receive serial data from CIA 1 (primary status data) and subsequently transmit it to MIA 1, 2, or 3 upon receipt of a "response" execute command from the GPCs driving each respective MIA port. Although SSMEC data is available at each of MIA ports 1, 2, and 3, only the GPC attached to MIA 1 issues requests for data ("response" execute commands).

While data is transferred out of status register 1A, data is loaded into status register 1B and vice versa. The status registers in buffer 2 receive data from CIA 2 (secondary status) and transfer it to MIA 4 upon receipt of a "response" execute command from the GPC driving MIA 4.

The first 32 words of the 128-word SSMEC status/memory dump data stream are loaded into the status register at the CIA 1-MHz bit rate. At the same time, the validity (E) flag for each word is saved in its E flag bit. When a GPC issues a "response" execute command, the number-of-words field in it determines how many (1 to 32) words are to be transmitted from the status register to the GPC. Responses to requests from MIA 1, 2, or 3 (primary status channel) are available to all three MIAs, but only the requesting MIA can process the data. In practice, only MIA 1 is used to transmit primary SSMEC data. The response to a request from MIA 4 (secondary status channel) is available only to it.

2. Primary status channel/alternate buffer control/MIA/ CIA channel timing selection
^J**Z**⁵⁻⁶

This circuit controls the buffering of data in the two status registers within a status buffer. It tracks when the registers are full or empty and controls when these registers are loaded and emptied.

3. 32-bit E flag shift register/buffer ^L**Z**⁵⁻⁶

As each of the 16-bit data words is transferred into the status register from the CIA, the corresponding word valid bit is read into this buffer from the CIA error detection circuitry.

1.8.2 SSME Vehicle Data Table Description

The SSME VDT is transmitted from the DCU to the GPC through the EIU. This section provides information on the first 32 words of the VDT as seen by the flight controllers in the MCC via GPC downlist. This section also provides cue cards for decoding the engine status word (ESW). Information on the entire VDT is available in SSMEC S/W Part 1 Spec. Detailed information on data word 5, which contains the most recent failure identification word (FID) can be found in the Flight Operations Handbook. Information on the computation which provides syntax and flags for the FID words is available in SB 7.2.

Table 1.8.IV contains a listing of the first thirty-two of the 128 words output in the standard VDT used for flight which is provided by each SSME controller (SSMEC). The VDT is transmitted every 40 ms (every other controller cycle) over two controller data buses, called the primary and secondary data paths, to a dedicated engine interface unit (EIU) which provides the data to the GPC's and to the 60 kbit downlink. During normal operations, both controller data buses contain data from the controlling digital computer unit (DCU).

Usually the data source is DCU A since it is nominally the "in-charge" DCU. If a DCU switch over occurs due to a failure in DCU A, the data source will switch to DCU B since it would then be the in-charge DCU. A SWITCH VDT command issued by the GPC's can also change the source of the VDT without affecting which DCU is in charge (currently the GPC's only have the capability to command a switch from DCU A to DCU B; the Block II software capability to go back to DCU A data is not currently utilized). The SWITCH VDT command is issued if both the primary and secondary data paths have been disqualified for four consecutive cycles. This is an attempt by the GPC's to regain data if the cause of the data loss was a single point failure in the vehicle interface electronics (VIE) through which both channels of DCU A data must pass. For this special case the SWITCH VDT command, if successfully received by DCU A, will cause the data source to use a different hardware path which will bypass the failed circuit which caused loss of the data. Only in this case will a SWITCH VDT command be successful. However, since the data source is not the in-charge DCU, the VDT will not provide all of the same data as it normally does (e.g., sensor monitoring is not performed by the standby DCU). See reference 1 for more details on the standby DCU processing.

Additionally, the GPC SSME SOP sequence can switch the source of the SSME VDT when primary data is lost. On STS-93, an AC 1 power failure caused the ME 1 primary channel to send stale data to the CIA 1 in the EIU. Consequently, the ME 1 60 kb data was not sent to the ground or saved on-board. This change allows the SOP to force the EIU to accept the VDT from CIA 2 when a primary data path failure has been detected for 10 consecutive cycles (meaning that the primary data through CIA 1 has been lost). If primary data returns for 10 consecutive cycles, the SOP switches the EIU back to CIA 1 by issuing a Master Reset command.

The VDT contains 128 16-bit words. Only the first thirty-two words are available in the GPC downlist via the primary data path. Due to GPC I/O limitations, only the first six words of the VDT are requested from the secondary data path by the GPC's, even though all 128 are available.

The BFS only requests the first six words from both the primary and secondary data paths, but only three are available in the downlist (words 1, 2 and 5 are not downlisted). All 128 words, plus 4 EIU built in test equipment (BITE) words, are available in the 60 kbit data stream. The EIU's operational instrumentation (OI) section adds the four EIU BITE words to the 128 SSME words and ships it out to three sources: the FM downlink, the LPS T-0 umbilical, and to the Orbiter OPS Recorders. The MCC currently only has real-time access to the GPC-downlisted, first 32 words. The 60 kbit data is available in near real-time in the operational data recorder (ODRC). Plans are in-work to access the 60 kbit FM downlink data for real-time operations in the MCC.

The MML MSID's for the engine are the same for the three engines, with the exception being the fifth digit: a "1" is for the center engine, a "2" is for the left engine, and a "3" is for the right engine. For specific information on the vehicle interface and the formatting of the VDT, see reference 6.

TABLE 1.8-IV – SSME STANDARD VEHICLE DATA TABLE

VDT WORD NO. (1)	MML NO. (2)	PARAMETER NAME	FULL SCALE RANGE (4)	LCC SSID (6)	ENGINE READY PARAM. (7)	PERFORMANCE CONTROL (8)	SHUTDOWN REDLINE PARAM. (9)	NOTE (10)
1	E41M1001P	ID Word 1		RSLS-01				(10)
2	E41M1002P	ID Word 2		RSLS-01				(10)
3	E41M1003P (3)	Engine Status Word (ESW)		SSME-07 RSLS-01				(11)
4	E41W1004P (3)	Time Reference (Tref)	0-65535 mcc (20 msec)	RSLS-01				(12)
5	E41M1005P	Failure ID (FID)						
6	E41P1023B (3)	MCC Pc Avg.	0-3500 psia (± 2% FS)	RSLS-01				
7	E41R1021B	LH2 Flowrate Avg.	0-24000 gpm (± 1% FS)			YES		(8)
8	E41R1022B	LO2 Flowrate	0-7000 gpm			YES		(8)
9	E41P1018B	LPFT Discharge Pressure Avg.	0-300 psia (± 2% FS)		YES	YES		(8)
10	E41T1019B	LPFT Discharge Temperature Avg.	30-55 degR (± 2%)		YES	YES		(8)

TABLE 1.8-IV – SSME STANDARD VEHICLE DATA TABLE (continued)

VDT WORD NO. (1)	MML NO. (2)	PARAMETER NAME	FULL SCALE RANGE (4)	LCC SSID (6)	ENGINE READY PARAM. (7)	PERFORMANCE CONTROL (8)	SHUTDOWN REDLINE PARAM. (9)	NOTE
11	E41T1020B	PBP Discharge Temperature Ch A	160-23- degR (± 2%)	SSME-20 SSME-38	YES			
12	E41P1196B	MCC Liner Cavity Pressure CH A	0-300 psia (± 2% FS)	SSME-27			YES	(5)
13	E41P1197B	MCC Liner Cavity Pressure CH B	0-300 psia (± 2% FS)	SSME-27			YES	(5)
14	E41M1143P	HPFP ACCEL / HYD SOFT L/U Parent Word						
	E41D1144B	HPFP ACCEL 21 DEG CH 1	0-15.5 Grms (± 4% FS)				(13)	
	E41D1145B	HPFP ACCEL 219 DEG CH 2						
	E41D1146B	HPFP ACCEL 231 DEG CH 3						
	E41X1147B	HYD SYS SOFT LOCK ST	0 - 1 (N/A)					
15	E41M1148P	HPOP ACCEL / HYD REASONAB ST Parent Word						
	E41D1149B	HPOP ACCEL 39 DEG CH 1	0-15.5 Grms (± 4% FS)				(13)	
	E41D1157B	HPOP ACCEL 151 DEG CH 2						
	E41D1158B	HPOP ACCEL 130 DEG CH 3						
	E41X1159B	HYD SYS REASONAB ST	0 - 1 (N/A)					
16	E41M1621P	HPFT DT A Parent Word	150-2450 degR	SSME-24			YES	(12)
	E41T1622B	HPFT DT A2	(± 2%)					
	E41T1623B	HPFT DT A3						
17	E41M1624P	HPFT DT B Parent Word	150-2450 degR	SSME-24			YES	(12)
	E41T1625B	HPFT DT B2	(± 2%)					
	E41T1626B	HPFT DT B3						
18	E41M1627P	HPOT DT A Parent Word	150-2450 degR	SSME-25			YES	(12)
	E41M1628B	HPOT DT A2	(± 2%)					
	E41M1629B	HPOT DT A3						
19	E41M1630P	HPOT DT B Parent Word	150-2450 degR	SSME-25			YES	
	E41M1631B	HPOT DT B2	(± 2%)					
	E41M1632B	HPOT DT B3						

20	E41P1014B	HPOT Intermediate Seal Press Ch A	0-600 psia (± 2%)	SSME-3,10,& 26			YES	
21	E41P1015B	HPOT Intermediate Seal Press Ch B	0-600 psia (± 2%)	SSME-3, 10, & 26			YES	
22	E41P1016B	MCC Pc Ch A Avg.	0-3500 psia (± 2%)	SSME-31		YES	YES	
23	E41P1017B	MCC PcCh B Avg.	0-3500 psia (± 2%)	SSME-31		YES	YES	
24	E41H1024B	MFV Actuator Position	0-100 % (± 1% FS)	SSME-8, 34				
25	E41H1025B	MOV Actuator Position	0-100 % (± 1% FS)	SSME-8, 34				
26	E41H1026B	CCV Actuator Position	0-100 % (± 1% FS)	SSME-34				
27	E41H1027B	FPOV Actuator Position	0-100 % (± 1% FS)	SSME-8, 34		YES		
28	E41H1028B	OPOV Actuator Position	0-100 % (± 1% FS)	SSME-8, 34		YES		

TABLE 1.8-IV – SSME STANDARD VEHICLE DATA TABLE (concluded)

VDT WORD NO. (1)	MML NO. (2)	PARAMETER NAME	FULL SCALE RANGE (4)	LCC SSID (6)	ENGINE READY PARAM. (7)	PERFORMANCE CONTROL (8)	SHUTDOWN REDLINE PARAM. (9)	NOTE
29	E41P1029B	HPFT Discharge Pressure	0-9500 psia (± 2% FS)					
30	E41P1030B	HPOT Discharge Pressure	0-7000 psia (± 2% FS)					
31	E41P1031B	Fuel Preburner Chamber Pressure	0-7000 psia (± 2% FS)					
32	E41P1054B	Hydraulic Supply Pressure	0-4000 psia (± 2% FS)					

NOTES

(1) VDT Word Format:

15 14 13 12 11 10 09 08 07 06 05 04 03 02 01 00

MSB = most significant bit

LSB = least significant bit

Note: Block I SSME VDT word format was numbered 1 - 16 with bit 1 being the MSB and bit 16 being the LSB. In both controllers, the MSB is the left-most bit in the word.

(2) The MML number represents the center SSME only (engine 1). For the left SSME (engine 2), the fifth character changes to a 2 (E41_2_____). For the right SSME (engine 3), the fifth character changes to a 3 (E41_3_____).

(3) The BFS only downlists the ESW, TRef and PcAvg even though all six of the first thirty-two words are fetched from the primary data path. If the primary data path fails, PcAvg, the ESW, and TRef are available in the downlist via the secondary data path. PcAvg is only downlisted at 1 sample/sec as opposed to the 25 s/s available from the PASS. The BFS MSID's are listed below:

TABLE 1.8-V – BFS VDT PARAMETERS

VDT WORD No.	PARAMETER	MSID
3	ESW, C	V98M2200P
	R	V98M2220P
	L	V98M2240P
4	T ref., C	V98W1390C
	L	V98W1391C
	R	V98W1392C
6	Pc Avg., C	V98P2100C
	L	V98P2110C
	R	V98P2120C

- (4) Precision of data is in parenthesis.
- (5) Since there is no HPOT Secondary Cavity Seal Drain Purge Pressure measurements on the Block I or Block II SSME's, the data in these slots for either Block I or Block II engines is invalid. It is downlisted and typically bounces in the range of +/- 300 psia.
- (6) See reference 9, sections 20, 21, and 36 for complete information on LCC parameters.
- (7) Engine Ready mode is entered automatically from Purge Sequence Number Four (PSN4) by having no INHIBIT response in effect and satisfying the following criteria response:

TABLE 1.8-VI – ENGINE READY MONITORING

PARAMETER	ENGINE READY LIMITS		QUALIFICATION LIMITS	
	LOWER	UPPER	LOWER	UPPER
LPFT Disch T Ch A, B	37 °R	42 °R	35 °R	55 °R
LPFT Disch P Ch A, B	³ Block II SSME's 53 psia	60 psia	0 °R (monitor starts at PSN4 + 10 sec)	300 °R
PBP Disch T Ch A, B (HPOT Boost Stage Disch T)	-----	186.5 °R	160 psia	230 psia
LPOT Disch P Ch A	95 psia Memory	Max		
Emergency S/D P Ch A, B	-----	50 psia	0 psia (monitor starts at PSN4 + 2 sec)	1500 psia
FBP S/D Purge P	-----	50 psia	0 psia	1500 psia
OPB S/D Purge P	-----	50 psia	0 psia (monitor starts at PSN4 + 10 sec)	1500 psia
MOV Hydraulic T Ch A, B	450 °R	-----	360 °R	760 °R
MFV Hydraulic T Ch A, B	460 °R	-----	360 °R	760 °R

These parameters are monitored from PSN4 + 10 sec until Engine Ready is achieved and up until the START ENABLE command is received. The failure responses for this monitoring are the corresponding FID 12, a MCF, and an INHIBIT. These responses can be expected if the START ENABLE command is issued and the engine is not in Engine Ready, or if any of the above parameters fails once Engine Ready has been achieved. If failure occurs after Engine Ready mode has been entered, the controller will roll the engine back into PSN4 mode.

- (8) Performance control parameters which are available in the first 32 words of the VDT are MCC Pc Avg., MCC Pc Ch A Avg., MCC Pc Ch B Avg., LPFT Discharge Pressure Avg., LPFT Discharge Temperature Avg., and Fuel Flowmeter Average. The LPFT discharge pressure and temperature are used to derive a fuel density value which is used to determine volumetric flowrate in conjunction with the fuel flowmeter readings (see SCP 2.1.1 and references 1, 2, 7, and 8). The LO2 flowrate output in word 8 is a derived parameter and is a relic from the time when a hardware LO2 flowmeter was installed on the engine.

Shown in Table 1.8.VII are the reasonableness tests pertaining to control loop monitoring performed on the MCC Pc, LH2 fuel flowrate, and LPFT discharge temperature and pressure:

TABLE 1.8-VII – PERFORMANCE CONTROL PARAMETER QUALIFICATION MONITORING

PARAMETERS	REASONABLENESS TESTING (Mainstage Values)
MAIN COMBUSTION CHAMBER PRESSURE SENSORS A1, A2, B1 & B2 (psia)	$ A1-A2 < 75 \text{ psia}$ $ B1-B2 < 75 \text{ psia}$ $ CH \text{ Average} - PcRef \leq \Delta$ $\Delta = 200$ (i) During throttling & 50 major cycles thereafter (ii) During steady state if commanded power Level $\leq 75\%$ RPL (iii) For 50 major cycles after a Major Cycle Restart $\Delta = 75$ If none of the above conditions exist
LH ₂ FUEL FLOWMETER SENSORS A1, A2 B1 & B2 (gpm)	$Q_{ref}-1800 < A1(A2,B1,B2) < Q_{ref} + 1800$ $Q_{ref} = [(Pc + 14.5)/C2] * [1/(1 + MR)] * [448.8/Rho]$ where $Pc = MCC Pc (Pc \text{ Ref during thrust limiting})$ $C2 = \text{Calculated oxidizer flowrate coefficient}$ $MR = 6.011 \text{ (mixture ratio)}$ $Rho = \text{Calculated fuel density}$
	Pulse Rate Converter Self Test
LPFT DISCHARGE PRESSURE CH A & CH B (psia)	$140 < CH A < 300$ $140 < CH B < 300$
LPFT DISCHARGE TEMPERATURE CH A & CH B (° R)	$40 < CH A < 45$ $40 < CH B < 45$

- (9) A cue card with the SSME mainstage redlines and their qualification limits is shown in Figure 1.8-IX. For information regarding ignition confirmed and other start redlines, see references 1, 6 and 7.

PARAMETER	QUALIFICATION LIMITS (Note 1)	REDLINE LIMITS (Note 2)
		Block II
HPOP IMSL PR Ch A, B	$0 \leq A(B) \leq 650$ psia	A (B) < 159
HPOT DS TMP Ch A2, A3, B2, B3	(Note 3) $A2(A3, B2, B3) \leq 2650$ °R $ A2-A3 \geq 50$ degR (D/Q lwr of two) $ B2-B3 \geq 50$ degR (D/Q lwr of two) If down to 1 on either/both: $((B_{avg} + \Delta) - A_x) \geq 150$ degR (D/Q A_x) or $(A_{avg} - (B_x + \Delta)) \geq 150$ degR (D/Q B_x) or $ A_x - (B_y + \Delta) \geq 150$ degR (D/Q lwr of two)	(Note 4) A (B) < 720 °R A (B) > 1660 °R
HPFT DS TMP Ch A2, A3, B2, B3	Same as HPOT DS TMP	A (B) > 1860 °R
MCC Pc Ch A, B	$1000 \leq A1(A2, B1, B2) \leq 3500$ psia $ A1-A2 \leq 125$ psia $ B1-B2 \leq 125$ psia	A (B) < (PcRef - 200) During steady state. A (B) < (PcRef - 400) During Throttling or PL < 75 %

1. Sensor is qualified if it is within specified limits.
2. Sensor is voting for shutdown if it meets the specified criteria.
3. Delta = 0 for both HPOT & HPFT DS TMP, but could be modified (especially on the HPFT DS TMP is Ch A & B redlines are not set to same value, in which case Delta = (Ch A_{RL} - Ch B_{RL}))
4. RVDT Blueline Limits: HPOT DT BL = 50 °R above lower R/L and 50 °R below upper R/L
HPFT DT BL = 50 °R below upper R/L

Figure 1.8-IX – SSMEC Redline Shutdown Cue Card
Generic Flight With Thermocouples (TC's)

- (10) ID Word 1 Decoding (bit 15 = MSB): Bits 15-5 are only alterable by memory load. Bit 4 is loaded as 0 in both DCUs at memory load. DCU A remains zero and DCU B is set to one. Bits 3-0 are updated by software.

Bits 15-12: Nominal value (4 MSBs) = 1010

Bit 11: Designator for Development (05xx) or Flight Engine (20xx)

ENGINE	CODE
Development	0
Flight	1

Bits 10-5: Decimal Value identifies last two digits of Engine Number (00 - 63)

Bit 4: DCU Identifier (In-charge DCU or DCU outputting VDT)

DCU A = 0
DCU B = 1

Bits 3-0: Memory Configuration

CONFIGURATION	CODE
Not Used	0000
FRT-1	0001
Ground Checkout	0011
FRT-2	0111
PROM	1001
Reserved	1010
Flight Operation	1111
Not used	All Others

ID Word 2 is a bit by bit one's complement of ID Word 1 and is based on the same requirements as ID Word 1.

- (11) ESW Decoding:

Bit 15: Load Mode

Not in Load Mode = 0
Load Mode = 1 (only used by PROM)

Bits 14-13: Command status of last command received since last VDT transmission (per Table 4.1.1-V.) used by GPC software for command path fail logic.

No command received since last VDT transmission, or voted command is
the same as the last voted command = 00
Command failed voting = 01
Command voted but rejected, incompatible
with phase/mode, or invalid code = 10
Command accepted = 11

Bit 12: Command Channel 3 (Ch C) Status (per Table 1.8.IX)

Channel OK = 0
Channel Failed = 1

Bit 11: Command Channel 2 (CH B) Status (per Table 1.8.IX)

Channel OK = 0
Channel Failed = 1

Bit 10: Command Channel 1 (CH A) Status (per Table 1.8.IX)

Channel OK = 0
Channel Failed = 1

Bit 9: FRT Status

Normal Operation = 0
FRT Mode = 1

Bit 8: Limit Control Status

Limits Inhibited = 0
Limits Enabled = 1

Bits 7-5: Engine Phase

PHASE	CODE
Not used	000
Checkout	001
Start Prep (PSN1 - PSN4)	010
Start	011
Mainstage	100
Shutdown	101
Post-Shutdown	110
Reserved for PROM	111

Bits 4-2: Engine Operating Mode (depends on phase)

PHASE	MODE	CODE
Checkout	Hydraulic Conditioning	000
	Standby	001
	Actuator Checkout	010
	Engine Leak Detection	011
	Igniter Checkout	100
	Pneumatic Checkout	101
	Sensor Checkout	110
	Controller Checkout	111
Start Prep	Not Used	000
	Purge Sequence 1 (PSN1)	001
	Purge Sequence 2 (PSN2)	010
	Purge Sequence 3 (PSN3)	011
	Purge Sequence 4 (PSN4)	100
	Not Used	101
	Engine Ready	110
	Not Used	111
Start	Not Used	000
	Start Initiation	001
	Thrust Buildup	010
	Not Used	011
	Not Used	100
	Fixed Density	101
	Not Used	110
	Not Used	111
Mainstage	Not Used	000
	Normal Control	001
	Thrust Limiting	010
	Electrical Lockup	011
	Hydraulic Lockup	100
	Fixed Density	101
	Not Used	110
	Not Used	111
Shutdown	Not Used	000
	Not Used	001
	Throttling to Zero	010
	Propellant Vlvs Clsd	011
	Fail-Safe Pneumatic	100
	Not Used	101
	Not Used	110
	Not Used	111
Post - Shutdown	Not Used	000
	Standby	001
	Oxidizer Dump	010
	Not Used	011
	Not Used	100
	Not Used	101
	Not Used	110
	Terminate Sequence	111

Bits 1-0: Self-Test Status

Not Used = 00
 Engine OK = 01
 Major Component Failed (MCF) = 10
 Engine Limit Exceeded (ELE) = 11

ENGINE STATUS WORD: Bits 15-08						4/17/92, Rev. Y			
CH STATUS		LIMITS INHIBITED				LIMITS ENABLED			
		NO NEW CMD	VOTE FAIL	CMD REJ	CMD ACC	NO NEW CMD	VOTE FAIL	CMD REJ	CMD ACC
CHAN OK		00	20	40	60	01	21	41	61
CH(S)	1	04	24	44	64	05	25	45	65
WITH	2	08	28	48	68	09	29	49	69
M/CMPR	3	10	30	50	70	11	31	51	71
	1 & 2	0C	2C	4C	6C	0D	2D	4D	6D
	1 & 3	14	34	54	74	15	35	55	75
	2 & 3	18	38	58	78	19	39	59	79
	1, 2 & 3	1C	3C	5C	7C	1D	3D	5D	7D

ENGINE STATUS WORD: Bits 7-0		2/24/94		
PHASE / MODE		OK	MCF	ELE
CHECKOUT				
	HYDRAULIC CONDITIONING	21	22	--
	STANDBY	25	26	--
	ACTUATOR CHECKOUT	29	2A	--
	ENGINE LEAK DETECTION	2D	2E	--
	IGNITER CHECKOUT	31	32	--
	PNEUMATIC CHECKOUT	35	36	--
	SENSOR CHECKOUT	39	3A	--
	CONTROLLER CHECKOUT	3D	3E	--
START PREP				
	PURGE SEQUENCE 1	45	46	--
	PURGE SEQUENCE 2	49	4A	--
	PURGE SEQUENCE 3	4D	4E	--
	PURGE SEQUENCE 4	51	52	--
	ENGINE READY	59	--	--
START				
	START INITIATION	65	66	67
	THRUST BUILDUP	69	6A	6B
	FIXED DENSITY	75	76	77
MAINSTAGE				
	NORMAL	85	86	87
	THRUST LIMITING	--	8A	8B
	ELECTRICAL LOCKUP	--	8E	8F
	HYDRAULIC LOCKUP	--	92	93
	FIXED DENSITY	95	96	97
SHUTDOWN				
	THROTTLING TO ZERO THRUST	A9	AA	AB
	PROPELLANT VALVES CLOSED	AD	AE	AF
	F/S PNEUMATIC S/D	--	B2	B3
POST SHUTDOWN				
	STANDBY	C5	C6	C7
	OXIDIZER DUMP	C9	CA	CB
	TERMINATE SEQUENCE	DD	DE	DF

Figure 1.8-X – Engine Status Word Cue Card

- (12) These MSID's are used for thermocouple (TC) measurements and are in effect for STS-75 and subsequent flights. They are also in effect for all generic and flight specific simulations after 12/12/95.
- (13) Synchronous Vibration Redline can be in ACTIVE or MONITOR ONLY Mode.

TABLE 1.8-IX – COMMAND VOTING REQUIREMENTS

INPUT COMMAND WORD COMBINATIONS (1)	ESW COMMAND STATUS: ESW bits 14-13 (2)	ESW CMD CH STATUS: ESW bits 12-10 (2, 3)	VEH CMD ENTRY (VDT words 98-99)	OPERATIONAL RESPONSE (4)
No Change (No Vote)	00	000	No Entry	None
3 All Zero Cnds (Vote Fails)	01	111	No Entry	FID 042-101 & FID 042-102 & FID 042-103
2 All Zero, 1 Non-Zero Cmd (Vote Fails)	01	011 or 101 or 110 (0 Channel)	No Entry	FID 042-101 & FID 042-102 & FID 042-103
1 Zero Cmd & 2 Non-Zero Cnds (0 agree - Vote Fails)	01 (6)	001 or 010 or 100 (0 Channel)	No Entry	FID 042-101 & FID 042-102 & FID 042-103
1 Zero Cmd & 2 Non-Zero Cnds (2 Agree - Vote Fails) (5)	01 (6)	001 or 010 or 100	No Entry	FID 42-101 or FID 42-102 or FID 42-103 (On 0 Channel)
1 Zero Cmd & 2 Non-Zero Cnds (2 Agree - Vote OK)	10 or 11 (6, 7)	001 or 010 or 100 (0 Channel)	Voted Command (6)	Execute cmd & FID 042-101 or FID 042-102 or FID 042-103 (on 0 ch)
3 Non-Zero Commands (0 Agree - Vote Fails)	01	00	No Entry	FID 042-101 & FID 042-102 & FID 042-103
3 Non-Zero Commands (2 Agree - Vote Fails) (5)	01 (6)	001 or 010 or 100 (Out Voted Channel)	No Entry	FID 042-101 or FID 042-102 or FID 042-103 (Out Voted Channel)
3 Non-Zero Commands (2 Agree - Vote OK)	10 or 11 (6, 7)	001 or 010 or 100 (Out-Voted Channel)	Voted Command (6)	Execute cmd & FID 042-101 or FID 042-102 or FID 042-103 (Out-Voted)
3 Non-Zero Commands (3 Agree - Vote OK)	10 or 11 (6, 7)	000	Voted Command (6)	Execute Cmd
Single Command Ch Word Change (Vote OK) (8)	10 or 11 (7)	001 or 110 or 010 or 101 or 100 or 011 (unsuccessfully voted Channels)	Voted Command	Execute Cnds's & FID 41 for Channel (s) which accepted shutdown

NOTES:

- (1) The success of voting depends on the command indicated (see reference 1 or 2, 3.2.2:1.2).
- (2) Subsequent to VDT transmission, the command status field of the ESW will be initialized to indicate no command received since the last VDT transmission, and the channel status field of the ESW will be initialized to indicate all channels are OK.
- (3) Channel status bits are set to a logical 1 on the zero channels or the one whose command does not agree with the other two.
- (4) Execute = If command passes acceptance checks, then the commanded function will be performed.
FID 042-10# = VDT words 5 & 100-102 will indicate which command
(# = 1, 2, 3 channels are miscomparing or indicating zero(es)
for channels 1, 2, 3)
- No command voting failures (FID 42) will be reported in the first major cycle following a Major Cycle Restart or anytime following a permanent channel power loss.
- (5) All three command channels must agree to accept either the START or START ENABLE command to successfully pass command voting.
- (6) Indicated entry is not updated if two or more significant channels agree and are the same as the last voted command.
- (7) Command status code depends on outcome of command acceptance check (see reference 1 or 2, 3.2.2:1.2)
- (8) A command channel value is either Shutdown, Enabled or Shutdown, the Single Channel Shutdown Enable timer has expired, and no Shutdown Limit Control Inhibit has been in effect since the last Controller Reset command.
- (9) TRef is based on the number of major cycle counts (mcc) since the last major cycle reset. The counts are 16 bit unsigned integers and each count is equivalent to 20 msec. Therefore, the range of 0 - 65535 mcc corresponds to 0 - 1310.7 seconds. TRef is reset at PSN1, Start, Shutdown/Pneumatic Shutdown, and at LO2 dump sequence initiation and termination.
- (10) The ESW has several parameters derived from its contents which are used in the LCC. These parameters and their MSIDs are listed below:

TABLE 1.8-X – ESW DERIVED PARAMETERS

MSID	PARAMETER DESCRIPTION	LCC SSID
E41J#512B (# = 1, 2, 3 for C, L, R)	PHASE IN EFFECT	SSME-07
E41J#513B (# = 1, 2, 3 for C, L, R)	OPERATING MODE	SSME-07
V95X119#X (# = 4, 5, 6 for C, L, R)	ELECTRICAL LOCKUP MODE	RSLS-01
V95X1###X (# = 198, 199, 200 for C, L, R)	HYDRAULIC LOCKUP MODE	RSLS-01
V95X123#X (# = 0, 1, 2 for C, L, R)	MAJOR COMPONENT FAIL	RSLS-01
V95X119#X (# = 0, 1, 2 for C, L, R)	ENGINE LIMIT EXCEEDED	RSLS-01
V95X118#X (# = 2, 3, 4 for C, L, R)	ENGINE READY INDICATOR	RSLS-01
V95X115#X (# = 5, 6, 7 for C, L, R)	SHUTDOWN PHASE	RSLS-01
V95X116#X (# = 0, 1, 2 for C, L, R)	POST SHUTDOWN PHASE	RSLS-01
V95X119#X (# = 6, 7, 8 for C, L, R)	CHANNEL FAIL	RSLS-01

- (11) The FID enunciated in word 5 is used as a backup monitor or as a confirming cue by the LCC (e.g., DPS-18, SSME-05, and RSLS-01).
- (12) The GPC's convert the MCC Pc from psia to percent throttle level. The following MSIDs are the MCC Pc's calculated by the GPCs which are used by the RSLs for verification that all three engines have achieved enough thrust for liftoff (SRB ignition) to be commanded.

MSID	PARAMETER NAME
V95X1160X	MPS Engine 1 Percent Ch Press
V95X1161X	MPS Engine 2 Percent Ch Press
V95X1162X	MPS Engine 3 Percent Ch Press

- (13) ID words 1 and 2 and TRef are used in the validation of the data paths performed by the SSME SOP. If either the primary or secondary data paths are failed prelaunch, the SSME SOP running in the PASS will announce a PAD DATA PATH FAIL flag. The RSLs will then cause either a launch scrub or a pad abort, depending on whether the engines have started or not. This is an LCC documented in SSID RSLS-01.
- (14) LCC SSID SSME-20 is the Engine Ready monitoring of the PBP discharge temperature. Both channels are required for Engine Ready. SSME-38 is the LCC SSID for hardware integrity monitor and both channels must be simultaneously failed to announce this failure.
- (15) If both channels of MCC Pc are disqualified for control loop control, the SSMEC software will run a VDT qualification test on all four Pc sensors. If any of the four are between 1000 and 3500 psia, then they will be used to derive a PcAvg for VDT output. If all four of the sensors have been disqualified for VDT reporting of words 6 and 39, then PcRef will be used instead. The SSME will issue a FID (020-004) if PcRef is substituted for PcAvg in the VDT.

- (16) Regardless of qualification status, the value output into VDT words 22 and 23 for the current values of MCC Pc Ch A and Ch B will be the actual values being read by the input electronics (IE's).

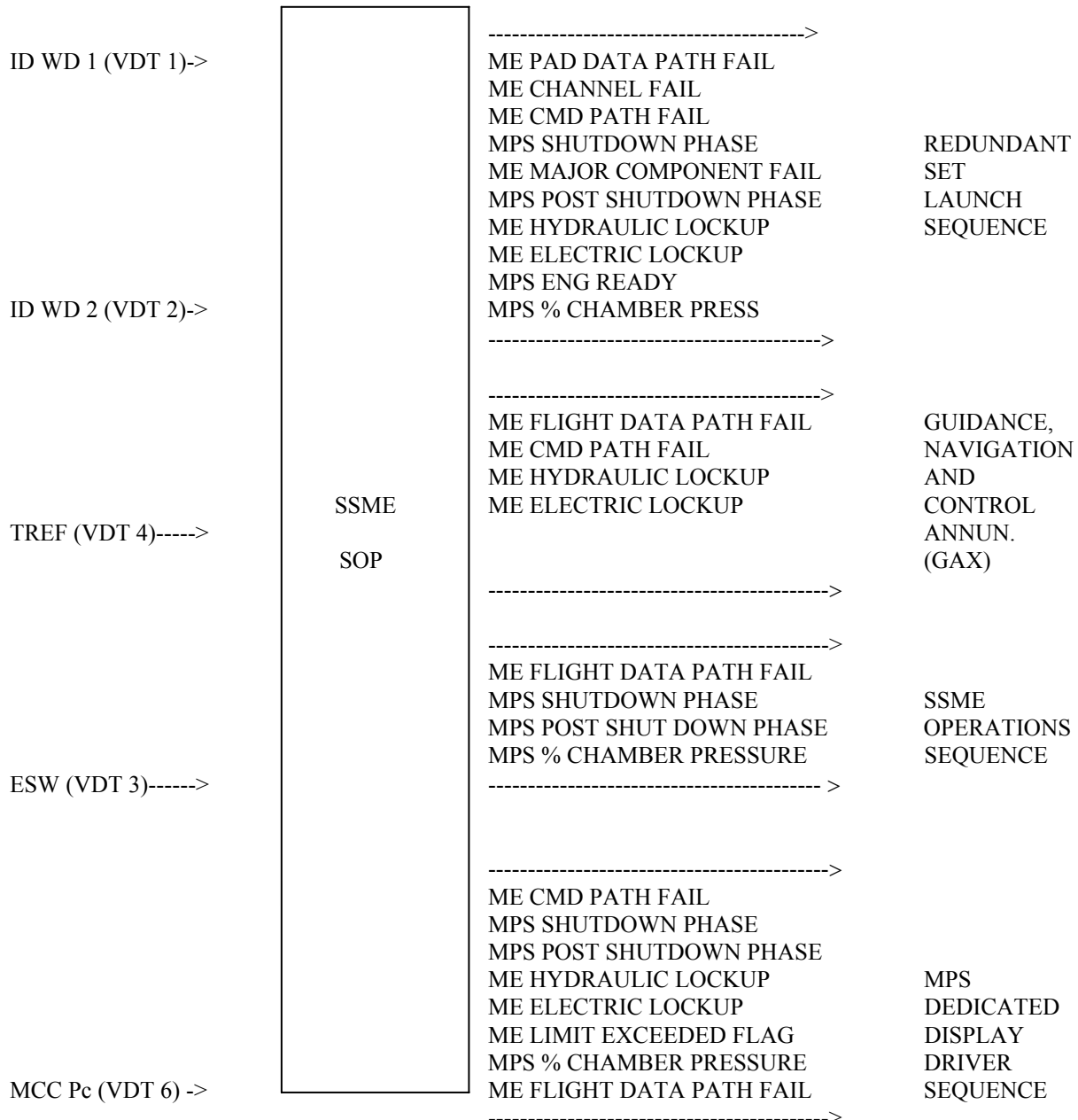


Figure 1.8-XI – PASS Uses of the VDT

1.8.3 OPS Recorder Usage for SSME Data

The purpose of this section is to document OPS-1 recorder usage for recording main engine data through the end of the MPS dump.

DESCRIPTION

During ascent, the OPS-1 recorder is configured to record main engine data and the OPS-2 recorder is configured to record orbiter data. For a nominal ascent and an ATO, the EIU 60 kbps data is recorded until a mission elapsed time (MET) of 25 minutes. An MET of 25 minutes nominally covers the timeframe that the SSME controllers (SSMECs) are powered ON. If the Booster console operator expects the crew to power OFF the SSMECs after 25 minutes MET, he/she must notify the INCO console operator that the OPS-1 recorder is required for additional time. The crew powers OFF the SSMECs at approximately 16 minutes MET. This is performed in the MPS PWRDN/ISOL procedure in the post OMS-1 procedures of the ascent checklist (for a nominal or ATO). For AOA, TAL, or RTLS aborts, the OPS-1 recorder is not stopped - SSME data is recorded until the end of the tape.

The OPS-1 recorder engine data is dumped within the first 24 hours of the mission. The engine data is dumped through the tracking and data relay satellite (TDRS) with the exception of mission-specific Ku-band constraints that would violate the 24 hour timeframe. In this case, the dump is completed via the continental United States (CONUS) ground station network. The engine data is not written over until MSFC verifies that the quality of the received data is good.

If the OPS-1 recorder fails prelaunch, the launch is not scrubbed (ref. LCC INS-02) because one of two recorders is required. The real-time FM downlink of the EIU 60 kbps will be available for recording on the ground until the Bermuda ground station loss of signal (LOS). Bermuda LOS occurs at 11:30 MET for 28.5 degree inclination missions and occurs earlier for higher inclination missions. If the OPS-2 recorder fails prelaunch, the OPS-1 recorder is tape-limited to 20 minutes (due to a necessary speed change), which should meet all of the main engine requirements. If the OPS-1 recorder fails during ascent, the recorders are not reconfigured and the main engine data recording stops.

This concludes the discussion of major EIU components. Further description of their interfaces and the flow of data between the SSMECs and GPCs may be found in systems brief 1.11.

1.8.4 References

1. CP406R0008G, Part I (Vol I and II), Computer Program Contract End Item, Block II SSME Controller Operational Program, June 12, 1999.
2. "Orbiter/SSME Software Interface" briefing, D. Townsend (JSC), September 3, 1987.
3. "SSME Interface Processing" briefing, R. Dobson (IBM), September 3, 1987.
4. Space Shuttle Technical Manual, Controller and Software Reference Handbook, RKD RSS-8628, date unknown.
5. Space Shuttle Orbiter Vehicle/Main Engine Interface Control Document, ICD 13M15000, Rev. Z.
6. "SSME Flight Operations Handbook, Atantis STS-104", RKD, July 12, 2001.
7. NSTS Launch Commit Criteria, NSTS 16007.

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1.9 SSME START TIME DETERMINATION

1.9.1 Introduction

This systems brief documents the process used in determining the exact Greenwich Mean Time (GMT) for the start of each Space Shuttle Main Engine (SSME). The time tags assigned to the engine data by the Launch Processing System (LPS) are not the actual GMT occurrences, since they do not account for the inherent hardware and data transfer delays which vary from 60 to 115 milliseconds (ms). The following discussion will provide a brief overview of the SSME data flow process, concentrating on the SSME Controller-Engine Interface Unit (EIU)-LPS data path and a detailed review of the delays introduced by each of these elements.

1.9.2 SSME Data Flow Overview

The SSME data is comprised of 128 words which identify engine status, engine failure identification, orbiter commands, engine operational parameters, and some engine unique selectable entries. The first 32 words of the engine data are intended for ground display and real-time operations, and of those first 32, five are used by the Orbiter GPCs.

The 128 data words generated by the SSME Controller, referred to as the Vehicle Data Table (VDT), are transmitted to the EIU every forty milliseconds. This VDT update rate of 40ms coincides with the Orbiter's High Frequency Executive (HFE) fetch of the VDT's first six words. Although both the SSME Controller's VDT transmission and Orbiter' HFE fetch occur every 40ms, it is important to note that the two are asynchronous.

The Engine data this memo addresses is the 60 kilobits/sec (kbs) data, the destination of which includes the onboard maintenance recorder, S-Band FM Signal Processor Transmitter, and LPS via the T₀ umbilical as illustrated in Figure 1.9-I. The data originates from the SSME Controller which is mounted on the side of the engine, and from there data is sent to the EIU in the aft bay of the Orbiter. The EIU buffers the data in a slow down register before being transferred at 60kbs to the LPS via the T₀ to the FM-FM telemetry via the S-Band FM Signal Processor Transmitter, and saved by the onboard maintenance recorder.

1.9.3 SSME Data Acquisition Delays

There are several delays introduced by each of the major elements in the SSME Controller-EIU-LPS data flow processing as identified in Figure 1.9-II. The SSME Controller delays can be attributed to the major cycle staleness delays and the time required for the controller to EIU data transmission. The EIU introduces delays due to an internal slow down register which is used for data buffering, in addition to the delays required for EIU to LPS data transmission. The processing time required by the LPS is the final delay in the SSME Controller-EIU-LPS data flow processing that must be accounted for in determining an accurate GMT for the start of each main engine. The following sections will explain how the delay times are determined for each of these major elements.

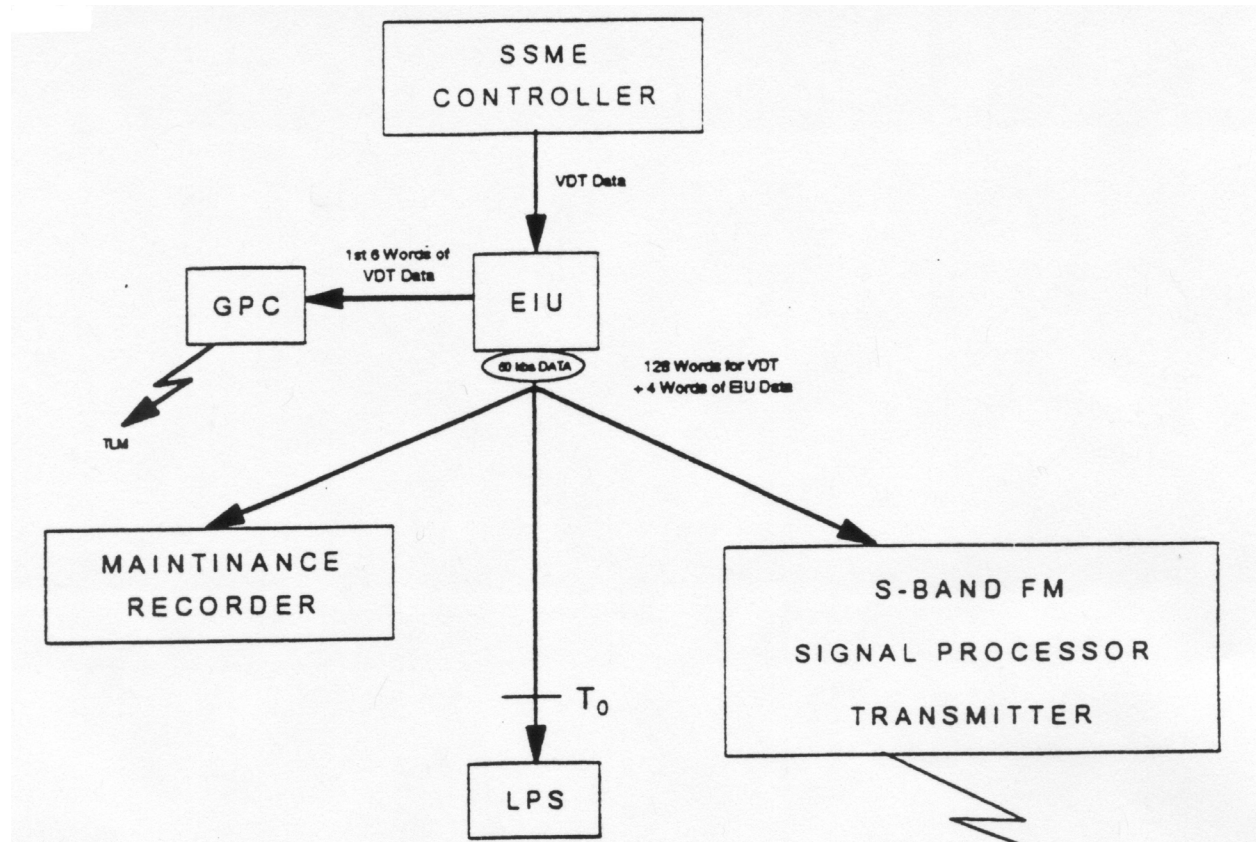


Figure 1.9-I - SSME Controller Data Destinations

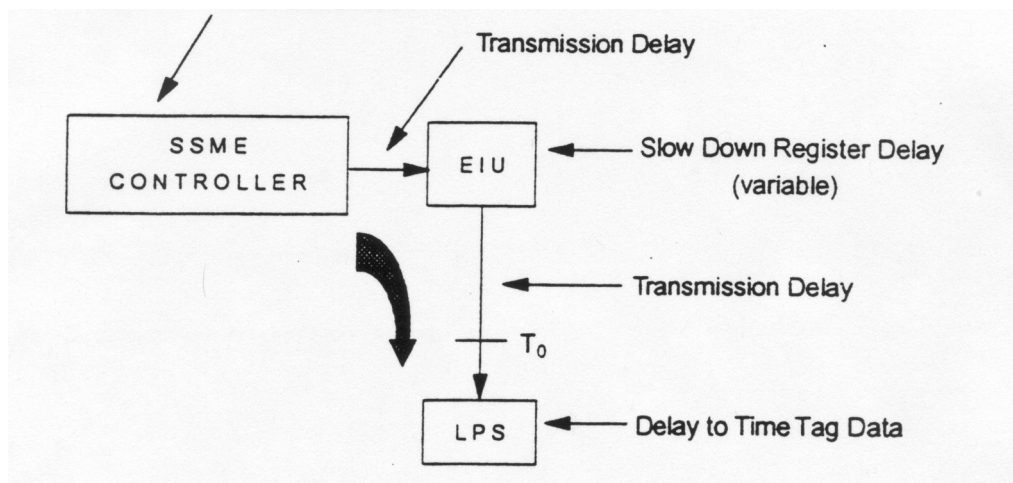


Figure 1.9-II - Delays in Data Time Tag

1.9.3.1 SSME Controller Delays

The SSME Controller introduces three different delays: Controller Staleness delays, non VDT Cycle delays, and Transmission delays. To better understand these delays, some background information on the operation of the SSMEC is needed.

The SSMEC operates on a 20ms major cycle comprised of four 5ms minor cycles. The SSME data, also referred to as the VDT, is transmitted to the EIU at the beginning of the fourth minor cycle, or approximately 15ms into the major cycle of the VDT major cycle (Figure 1.9-III). Although the engine data is recorded/processed every major cycle (20ms), the VDT is only transmitted to the EIU on alternate major cycles (40ms). This can be seen by examining data word three of the VDT, Time Reference Word (TRW). The TRW is a 16 bit counter that is incremented by 1 every major cycle, but only alternate counts of the TRW are seen in the VDT. This TRW is reset to zero for our purposes on the following two SSME events: start phase and shutdown phase. Since the TRW resets on the major cycle of Start Phase, a determination can be made whether the engine started on a VDT or Non-VDT major cycle.

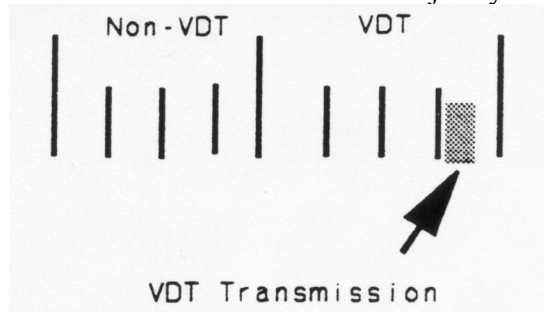


Figure 1.9-III - SSMEC Major Cycles

1.9.3.1.1 SSME Controller Non-VDT Cycle Delay

The Controller Non-VDT Cycle delay is due to the VDT being transmitted on alternate major cycles, as mentioned above. The major cycles that include the VDT transmission are VDT Cycles, and the others are Non-VDT Cycles. If an SSME enters Start Phase on a VDT cycle, the TRW will be reset to 0 and shipped out on the same major cycle. On the other hand, if an SSME enters the Start Phase on a Non-VDT cycle, the TRW is still reset to 0, and the first VDT indicating start is not shipped out until the next major cycle. If the TRW is 0, then there is no VDT cycle delay; however, if the TRW is 1, then there is a 20ms delay added to the time tag.

1.9.3.1.2 SSME Controller Staleness Delay

The Controller staleness time delay is attributed to the time between the engine moding to start phase and the VDT being transmitted to the EIU. This is because the VDT is shipped out in the fourth minor cycle. This delay is approximately 15.5ms (CP406R002, Part II Figure 1, SSME Controller Operational Program, Rocketdyne Division, Rockwell International).

1.9.3.1.3 SSME Controller Transmission Delay

The Controller transmission time delay is due to the time required to transmit the engine data (VDT) to the EIU. The VDT is comprised of 128 words, and each word of the VDT is 19 bits long (16 data bits, 2 sync bits, and one parity bit) with no gaps between words. The SSME Controller to EIU transmission rate is one megabit per second (1 microsecond/bit). As the following equation will show, the transmission of 128 words of 19 bits each at one megabit/second will result in a 2.43 millisecond (ms) transmission time delay.

$$\begin{aligned}
 \text{SSMEC-EIU} \\
 \text{VDT Transmission Time} &= \frac{\left[(16+2+1) \frac{\text{BITS}}{\text{WORD}} * 128 \text{ Words} \right]}{1 \times 10^{-6} \frac{\text{Bits}}{\text{Second}}} = .00243 \text{ SECONDS}
 \end{aligned}$$

Table 1.9-I summarizes the delays introduced by the SSMEC. The controller staleness and the SSMEC to EIU transmission delays are constant. The major cycle delay is dependent on which major cycle the Start Phase occurs and will be either 0 or 20 ms.

Table 1.9-I - SSMEC Timing Delays

Controller Staleness Delay	15.5ms	
VDT Cycle Delay	0/20ms	(VDT/Non-VDT cycle)
SSMEC - EIU Transmission Delay	2.43ms	

1.9.3.2 EIU Delays

The EIU introduces a transmission time delay and variable EIU downlink staleness. The EIU incorporates a double buffered serial-to-serial slowdown register which provides storage for two blocks of 128 sixteen bit words of SSMEC data. This data is continually loaded from the primary status channels (unless the secondary channel is selected) into the slowdown register at a 1 MHz rate with alternate blocks of data being loaded into alternate buffers.

1.9.3.2.1 EIU Transmission Delay

The EIU reformats the VDT into 132 sixteen bit words which include 128 words of the VDT plus 4 words of EIU data (EIU ID, BITE status, and parity words). At the EIU transmission rate of 60 KHz it will take 35.2 ms to transmit the 132 sixteen bit words as can be seen in the following equation.

$$\begin{array}{l} \text{EIU- LPS} \\ \text{VDT Transmission Time} \end{array} = \frac{\text{EIU 60 kbs} \\ \text{Transfer time for one frame of VDT} \\ \left[(128 \text{ WORDS} + 4 \text{ WORDS}) * 16 \frac{\text{BITS}}{\text{WORD}} \right]}{60 \times 10^3 \frac{\text{BITS}}{\text{SEC}}} = 35.2\text{ms}$$

The total transmission time for one frame of data is 35.2ms.

1.9.3.2.2 EIU Downlink Staleness

The EIU Downlink Staleness is due to the asynchronous EIU 60kbs input/output (I/O). The EIU receives an updated VDT every 40ms and transmits a complete, reformatted VDT (60kbs data) every 35.2ms (the transmission process lasts 35.2ms). This difference between incoming and outgoing SSMEC data results in a variable delay referred to as the EIU Downlink Staleness. Since the data is output faster than it is updated, some frames of data are retransmitted resulting in duplicate frames of data. A pattern is established based on this timing ratio that repeats every 880ms as illustrated in Figure 1.9-IV. There are 22 frames of input data within this 880ms ($880\text{ms}/40\text{ms} = 22$) and 25 frames of output data ($880\text{ms}/35.2\text{ms} = 25$). The three additional outgoing frames represent the duplicate frames. The transmission of the duplicate frames is a function of the data protection logic within the EIU. Transmission of a partially loaded buffer could result in an incomplete VDT frame. Therefore, if the EIU has not completely received a new block of data from the SMEC at the end of transmitting a block, the previous block of data is retransmitted. The LPS data recording process ignores the duplicate frame and therefore is detected in the recorded data by ~70ms time lapse between consecutive elements.

This 70ms time lapse is used to identify the pattern of new data frames and duplicate data frames. The pattern that results from this I/O timing ratio is 7 frames of new data followed by a duplicate data frame, 7 more frames of new data followed by a duplicate frame, and 8 frames of new data followed by a duplicate frame. This pattern repeats ad infinitum and is referred to as the 7-7-8 Pattern. Depending on the starting reference, this can also be viewed as an 8-7-7 or a 7-8-7 pattern. The important point here is that there are 3 different groups of data; a group of 7 frames before the group of 8, and a group of 7 frames following the group of 8. This periodic pattern can be seen in Figure 1.9-IV.

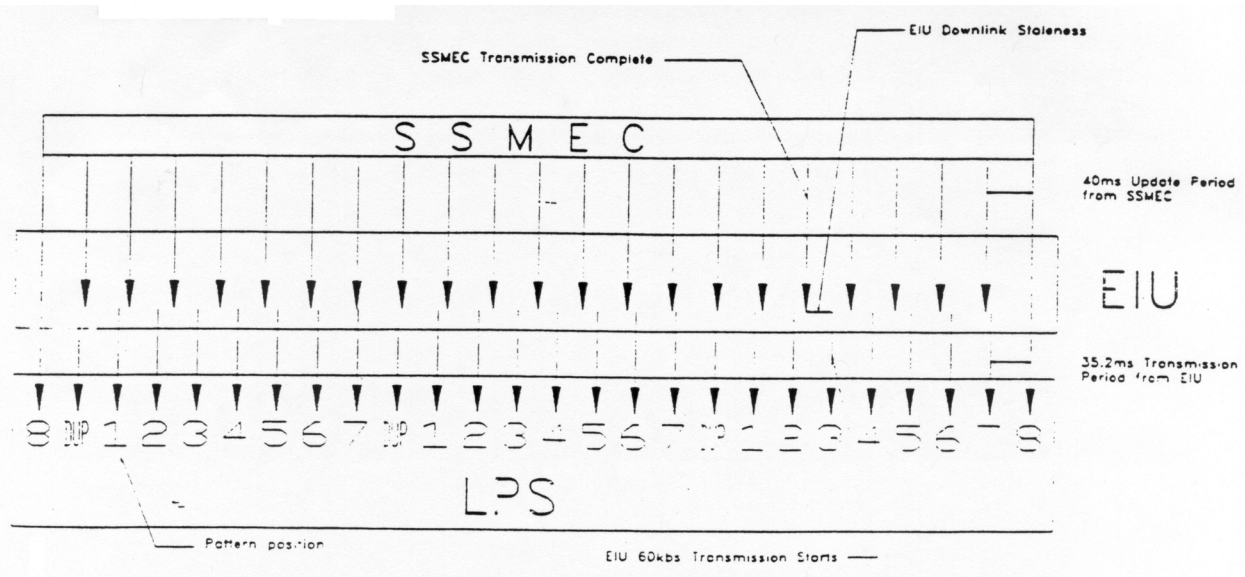


Figure 1.9-IV - Periodic Pattern

The EIU Downlink Staleness is defined as the amount of time a new block of SSME data sits in the slowdown register within the EIU before it is transmitted to the LPS. Because of the asynchronous operation, this delay is different for each frame of new data within the 880ms 7-7-8 pattern (depending on the position in the defined pattern) as illustrated in Figure 1.9-V. For each position in the pattern (22 total 7+7+8), the delay is always the same.

For example, if the fourth frame of data in the second series of 7 has an EIU Downlink Staleness of 18.4ms, then every fourth frame of data in the second series of 7 for the repeated patterns will have the same staleness. The EIU Downlink Staleness Factors (Figure 1.9-VII) are the delays in the slowdown register for a given pattern position and are determined once a pattern is defined.

In order to derive the delays associated with each position in the 7-7-8 pattern, the initial time skew between the 35.2ms VDT shipment and the 40ms VDT update rate from the SSMEC must be known. The time skew or starting point is arbitrary, and for our purposes the pattern definition is such that the starting point has no staleness and consequently the ending point has no staleness. That is, at some point a complete VDT is received by the EIU just as a 60kbs frame of data is ready for transmission; therefore, there would be no delay in the slowdown register in the transmission of that frame. The pattern definition establishes the delay for each position within the pattern, thereby identifying the slow down register delays.

The smallest delay for any position of this pattern definition is 1.6ms, assuming there was any delay at all in the slowdown register. According to the pattern definition established and as seen from Figures 1.9-V & 1.9-VI (VDT "H"), no delay can exist greater than 1.6ms and continue to maintain the defined pattern. If the delay of VDT "H" was greater than 1.6ms, the defined pattern would no longer exist. A delay of more than 1.6ms would cause a duplicate pattern in position 6 of the first set of seven, and that would violate the pattern definition. Therefore, by definition of the pattern, the resulting slowdown register delays do not vary more than 1.6ms in

addition to the defined values outline in Figure 1.9-V. The corresponding EIU Downlink Staleness Factors are established such that the accuracy reflects this unknown of 1.6ms. A bias (skew of the pattern definition) of .8ms is added into slowdown register values of Figure 1.9-V so that the midpoint of the unknown is selected. As a result, the EIU Downlink Staleness Factors used in determining engine start time (Figure 1.9-VII) have an accuracy of $\pm .8$ ms.

EIU Downlink Staleness (PATTERN DEFINITION)

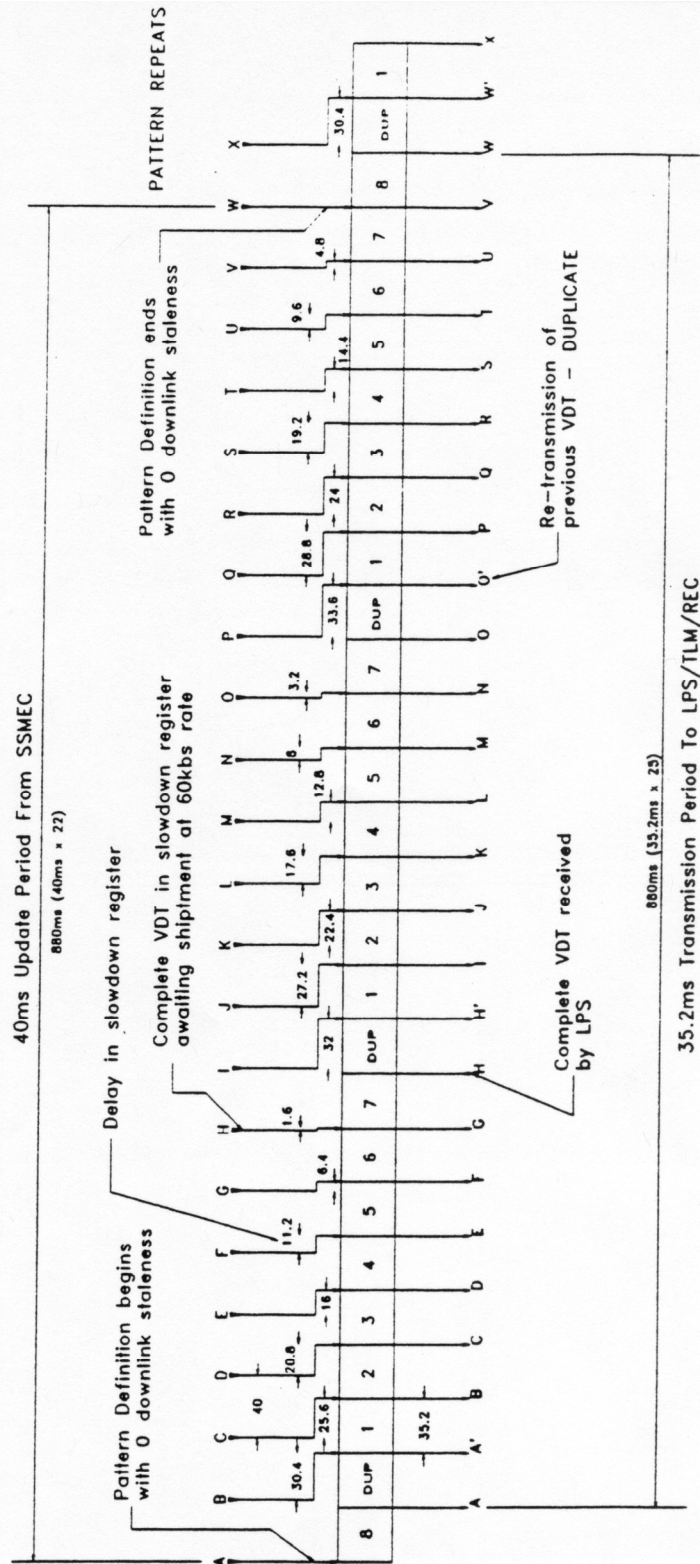


Figure 1.9-V

ACCURACY DETERMINATION FOR EIU STALENESS FACTORS

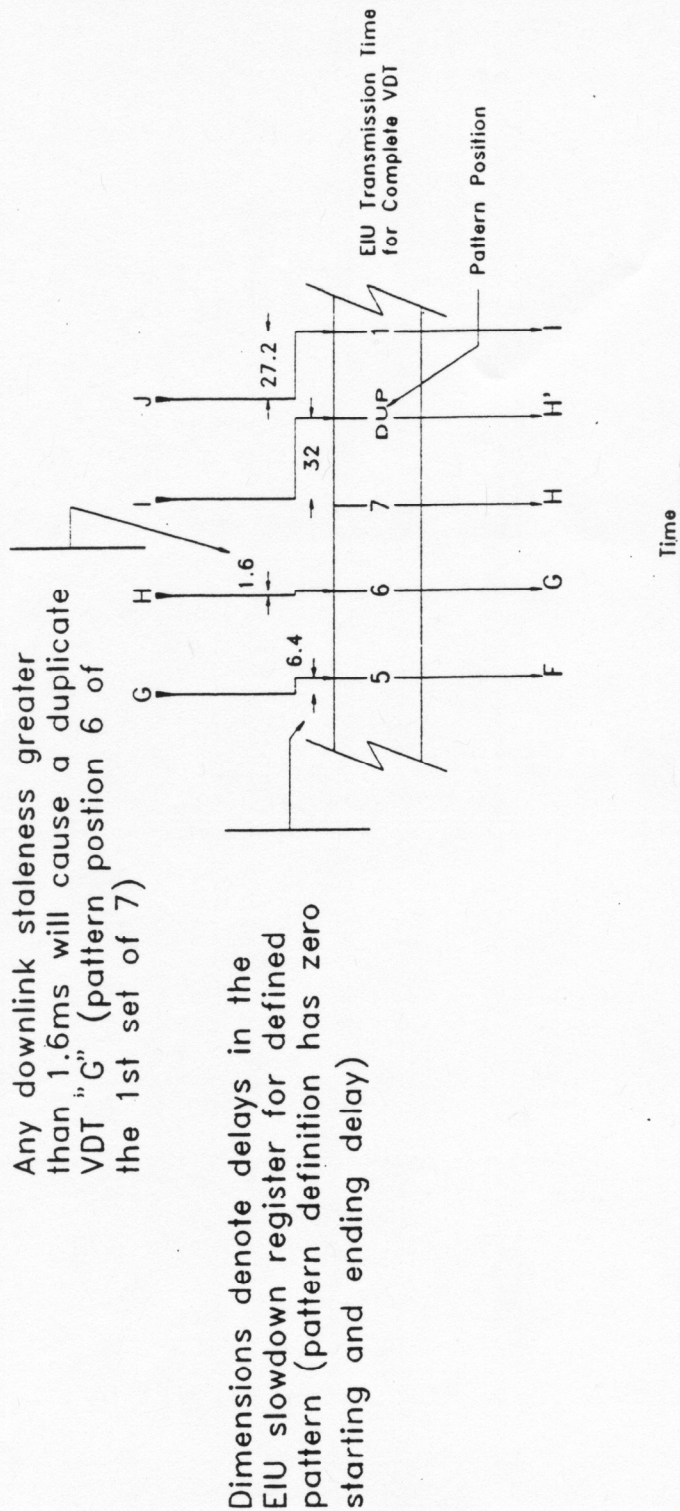


Figure 1.9-VI

EIU Staleness Factor ($\pm .8$ ms)	
Pattern Position	Staleness (ms)
DUPLICATE	
1	31.2
2	26.4
3	21.6
4	16.8
5	12.0
6	7.2
7	2.4
DUPLICATE	
1	32.8
2	28.0
3	23.2
4	18.4
5	13.6
6	8.8
7	4.0
DUPLICATE	
1	34.4
2	29.6
3	24.8
4	20.0
5	15.2
6	10.4
7	5.6
8	0.8

Figure 1.9-VII

1.9.3.3 LPS Delays

The remaining delays are associated with the LPS. The LPS delays are defined to be the processing time required to time tag the data (LPS buffer time is included in the EIU transmission delay). The delays acquired from KSC to time tag the data come from the front end processor (FEP), which are about 7.6ms. The buffer time used by FEP of 35.2ms is accounted for in the EIU transmission delay.

1.9.4 Start Time Determination Procedure

Two variables must be determined from the flight data in order to determine engine start time. The two indicators used from flight data are the TRW, which indicates whether the engine started on a VDT cycle, and secondly the time tag of the data which identifies a pattern from which a staleness of the slow down register can be deduced.

The flight data is obtained from the Central Data Subsystem (CDS) located at KSC; the access is achieved through the Secure Access Control System (SACS).

The first step after signing on and obtaining the correct data set is to retrieve the Engine Status Word (ESW) for all three engines during a time span of a few seconds around engine start. Record the GMT time tag of each engine when the command accept bits are set for the start command (ESW bits 3 & 4 are "11").

The next step is to retrieve the TRW of each engine for a time span of about one second on either side of engine start, recorded above. The pattern is recognizable with this time span. Figures 1.9-VIII and 1.9-IX show a sample of engine one and two for STS-48 data retrieved through CDS/HI-TRX. The check was added to denote the first frame in start phase; the numbers to the left, above and below the check were inserted to illustrate the pattern position. The pattern is detected by the time tag deltas between elements of approximately 70ms. Once the pattern is recognized, a staleness factor is determined from Figure 1.9-X. For example, Figure 1.9-VIII illustrates engine one going into start phase on the fourth position in the set of eight. The staleness associated with the EIU 1 slow down register for this engine is 20ms and started on a NON-VDT cycle. Figure 1.9-IX illustrates engine two going into start phase on the second position in the first set of seven. The staleness associated with the EIU 2 slow down register is 26.4ms and started on a VDT cycle.

The last step is to sum up all the delays. The following is an Engine Start Time Determination - Procedure example of the two engines for STS-48 previously mentioned. The asterisks denote variables.

Engine #1

LPS GMT @ engine start 91:255:23:10:57.8000 *

Delays:

20ms delay for NON-VDT cycle -0.0200 *

SSME Controller Staleness -0.0155

SSMEC-EIU Transfer delay -0.0024

EIU Staleness -0.0200 *

EIU Transmission\LPS Buffer delay -0.0352

LPS FEP delay -0.0076

~"TRUE" Engine #1 Start 91:255:23:10:57.6774

Engine #2

LPS GMT @ engine start 91:255:23:10:57.6580 *

Delays:

20ms delay for NON-VDT cycle -0.0000 *

SSME Controller Staleness -0.0155

SSMEC-EIU Transfer delay -0.0024

EIU Staleness -0.0264 *

EIU Transmission\LPS Buffer delay -0.0352

LPS FEP delay -0.0076

~"TRUE" Engine #2 Start 91:255:23:10:57.5490

The GMT times determined from this method have an accuracy of ± 0.8 ms.

SLC SA048A1,E41W1004D3;231057.000,231059.000,091291										
SA048A1		SCROLLED SINGLE MEAS CHGS LIST					19:37:11			09/12/91
09/12/91		23:10:57.000 - 23:10:58.996								
E41W1004D3		ME-1 TIME REFERENCE					DW 4			
HHMMSS.MSS	DEC		HHMMSS.MSS	DEC		HHMMSS.MSS	DEC			
231057.000	+ 8715		231057.800	+ 1	4 ✓	231058.609	+ 41			
231057.025	+ 8717		231057.835	+ 3	5	231058.644	+ 43			
231057.061	+ 8719		231057.870	+ 5	6	231058.680	+ 45			
231057.131	+ 8721	1	231057.905	+ 7	7	231058.715	+ 47			
231057.166	+ 8723	2	231057.940	+ 9	8 -	231058.750	+ 49			
231057.201	+ 8725	3	231058.011	+ 11	1	231058.785	+ 51			
231057.236	+ 8727	4	231058.046	+ 13	2	231058.820	+ 53			
231057.272	+ 8729	5	231058.081	+ 15	3	231058.891	+ 55			
231057.307	+ 8731	6	231058.117	+ 17	4	231058.926	+ 57			
231057.342	+ 8733	7 -	231058.152	+ 19	5	231058.961	+ 59			
231057.412	+ 8735	1	231058.187	+ 21	6	231058.996	+ 61			
231057.448	+ 8737	2	231058.222	+ 23	7 -					
231057.483	+ 8739	3	231058.292	+ 25	1					
231057.518	+ 8741	4	231058.328	+ 27	2					
231057.553	+ 8743	5	231058.363	+ 29	3					
231057.588	+ 8745	6	231058.398	+ 31	4					
231057.624	+ 8747	7 -	231058.433	+ 33	5					
231057.694	+ 8749	1	231058.468	+ 35						
231057.729	+ 8751	2	231058.504	+ 37						
231057.765	+ 8753	3	231058.574	+ 39						

Figure 1.9-VIII - CDS Data for STS-48 ME-1 Time Reference Word

```

# 24311 S7KCR
SLC SA048A1,E41W2004D3;231057.000,231059.000,091291

SA048A1 SCROLLED SINGLE MEAS CHGS LIST 19:38:13 09/12/91
09/12/91 23:10:57.000 - 23:10:58.995
E41W2004D3 ME-2 TIME REFERENCE DW 4
HHMMSS.MSS DEC HHMMSS.MSS DEC HHMMSS.MSS DEC
231057.000 + 8198 231057.763 + 6 5 231058.573 + 46
231057.024 + 8200 231057.798 + 8 6 231058.608 + 48
231057.059 + 8202 231057.834 + 10 7 - 231058.643 + 50
231057.094 + 8204 231057.904 + 12 1 231058.679 + 52
231057.130 + 8206 231057.939 + 14 2 231058.714 + 54
231057.165 + 8208 231057.975 + 16 3 231058.784 + 56
231057.200 + 8210 231058.010 + 18 4 231058.819 + 58
231057.235 + 8212 231058.045 + 20 5 231058.855 + 60
231057.306 + 8214 1 231058.080 + 22 6 231058.890 + 62
231057.341 + 8216 2 231058.115 + 24 7 - 231058.925 + 64
231057.376 + 8218 3 231058.186 + 26 1 231058.960 + 66
231057.411 + 8220 4 231058.221 + 28 2 231058.995 + 68
231057.447 + 8222 5 231058.256 + 30 3
231057.482 + 8224 6 231058.291 + 32 4
231057.517 + 8226 7 231058.326 + 34 5
231057.552 + 8228 8 - 231058.362 + 36 6
231057.622 + 8230 1 231058.397 + 38 7
231057.658 + 0 2 ✓ 231058.432 + 40 8 -
231057.693 + 2 3 231058.502 + 42 1
231057.728 + 4 4 231058.538 + 44 2
    
```

Figure 1.9-IX - CDS Data for STS-48 ME-2 Time Reference Word

1.9.5 Summary

The time tags assigned to the engine data by the LPS are not the actual GMT occurrences. The LPS does not account for the inherent hardware and data transfer delays discussed. These delays range from 60 to 115 milliseconds which vary on a periodic basis. Figure 1.9-X summarizes all the delays in the LPS time tag of 60kbs engine data.

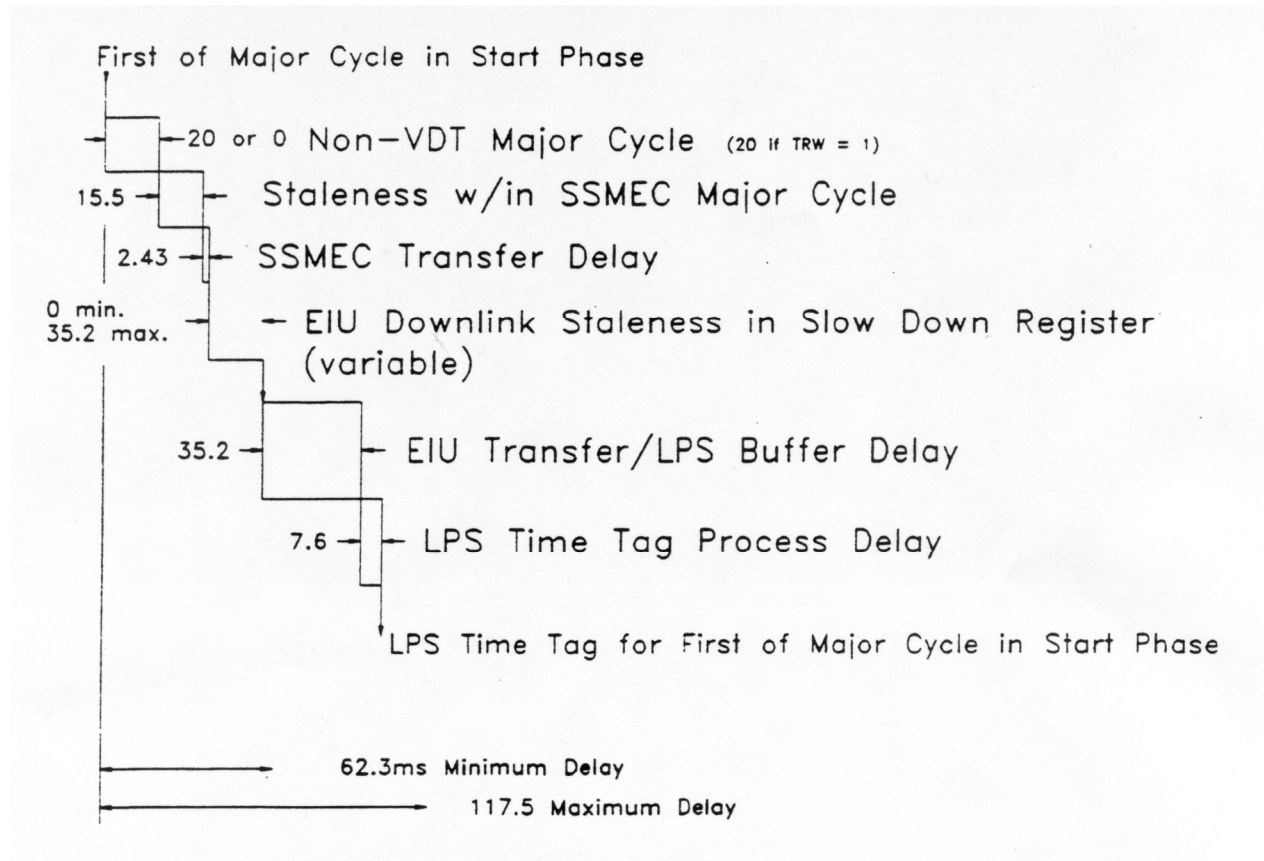


Figure 1.9-X - Time Tag Delay Summary

1.9.6 References

The complete contents of this Systems Brief have been duplicated and adapted from Broyles, K.C., Space Shuttle Main Engine Start Time Determination, Lockheed Engineering and Science Company Memorandum No. 92-030-NCAD, March 19, 1992.

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1.10 SSME CREW CONTROLS AND CAUTION & WARNING SYSTEMS

General

Crew control of the SSME system is provided via cockpit switches, pushbuttons, meters, and status lights. The function and contingency usage of crew control devices is provided in the following sections.

The first section of this Systems Brief provides a general description of the crew controls. References to associated Systems Briefs and Standard Console Procedures (SCPs) are offered to provide additional data and detail as required. The second section of this Systems Brief describes the crew Caution and Warning (C&W) system and which SSME failures are sensed by it.

1.10.1 Crew Controls

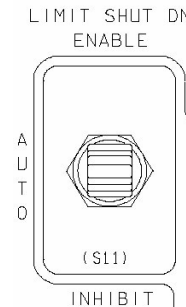
Component Name: MAIN ENGINE LIMIT
SHUT DN switch

Configuration and Nomenclature:

Panel Location: C3

Component No.: S11

Function:



In the INHIBIT position, the GPC issues a limit shutdown inhibit command to each main engine controller. The GPC cannot issue the enable command while in the INHIBIT position. On receipt of the inhibit command, the controller inhibits its internal limit shutdown logic. This action forces the SSME limits to be in “Hard Inhibit.” This prohibits SSMEs from automatically shutting down if the redline limits are violated.

In the AUTO position, the GPC automatically performs the inhibit function (as described above) on the remaining two engines after one engine shuts down prematurely, or after a data path failure occurs during mainstage operations. Refer to SCP 2.1.3 for more information.

In the ENABLE position, the GPC issues a limit shutdown enable command to each controller. The GPC cannot issue the inhibit command while in the ENABLE position. The controller, on receipt of the enable command, enables its internal limit shutdown logic. This action forces the SSME limits to be in “Hard Enable.” This will allow multiple SSMEs to fail if the redline limits are violated.

Nominal Usage:

None. Switch is in AUTO.

Contingency Usage:

There are numerous contingencies where the limit switch is manipulated. For details on the various failure scenarios and limit switch actions, refer to Flight Rule A5-103. Also, for details regarding the limit switch software, refer to Systems Brief 1.16.

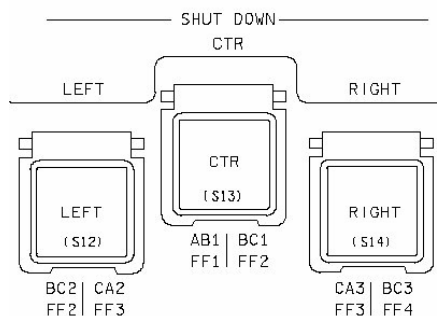
Component Name: MAIN ENGINE SHUTDOWN
pushbuttons

Configuration and Nomenclature

Panel Location: C3

Component No.: S12, S13, S14

Function:



Each main engine has a guarded shutdown pushbutton that is used to issue the SSME shutdown and safing commands. These commands are issued only if both contacts are operational and no switch miscompare has been detected by switch redundancy management (RM). If one of the contacts is commfaulted, only the safing command can be sent. For additional details on shutdown and safing commands, see Systems Brief 6.2 and the MPS DDD sequence requirements. For additional details on the switch RM, see SCP 2.1.12 and the GNC Switch RM requirements.

Nominal Usage:

Typically, there is no nominal usage; however, some crews depress all three shutdown pushbuttons immediately following MECO in order to manually back-up MECO Confirmed.

Contingency Usage:

There are numerous contingencies where the shutdown pushbuttons are manipulated from shutting down SSMEs, moding guidance (i.e. safing) and setting MECO Confirmed. For details on the various failure scenarios, refer to Flight Rules A5-105, A5-106, A5-108, A5-109, A5-113 and A5-153.

Component Name: MPS ENGINE POWER
switches

Configuration and Nomenclature

Panel Location: R2

Component No.: S4, S3, S5,S7, S6, S8

Note: AC ϕ A, B, C, ENGINE C, L,
R circuit breakers (panel L4)
provide circuit protection
(18 circuit breakers).

Function:

These switches turn SSME Controller power “ON” and “OFF.” There are two AC power supplies to each engine controller and the SSME will operate with either supply (redundant power supplies).

Nominal Usage:

The switches will be in the “ON” position from prior to the start of the countdown until the completion of the MPS propellant dump when the power will be turned OFF.

Contingency Usage:

An SSME will shut down pneumatically if the controller power switches are turned “OFF” while the SSME is still running. Therefore, the switches provide a means of shutting down an engine if the normal shutdown command path has failed.

For significant Pc sensor shifts and corresponding mixture ratio shifts, the affected controller channel may be power cycled (i.e. turned OFF then ON) to disqualify the erroneous sensors and return the engine to nominal performance. This procedure is only used when the predicted vehicle performance indicates that an ATO cannot be achieved and when doing so will not cause the SSME to shut down or go into hydraulic or electrical lockup.

See Flight Rules A5-106 and A5-110 for additional details regarding Engine Power switches.

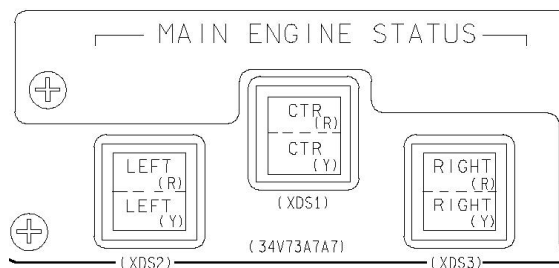
Component Name: MAIN ENGINE STATUS
lights

Configuration and Nomenclature

Panel Location: F7

Component No.: XDS1, XDS2, XDS3

Function:



The SSME Status Lights are used to alert the crew to certain SSME faults. The red SSME Status Light is an indication of an SSME shutdown (provided that controller data is valid) or that an SSME redline limit is being exceeded on all qualified channels with limits inhibited. The crew will also receive a corresponding SSME FAIL fault summary message for the first case of SSME shutdown with valid data but will not receive a fault message for all qualified redline sensors exceeding redline limits with limits inhibited. The amber SSME Status Light is indicative of Electrical Lockup, Hydraulic Lockup, Data Path Failure, or Command Path failure on an SSME. The crew will also receive a corresponding fault summary message for each of these four failures.

Nominal Usage:

The illumination of the all three SSME red status lights, simultaneously, indicates MECO. These red lights extinguish at external tank separation.

Component Name: ENGINE AC circuit breakers

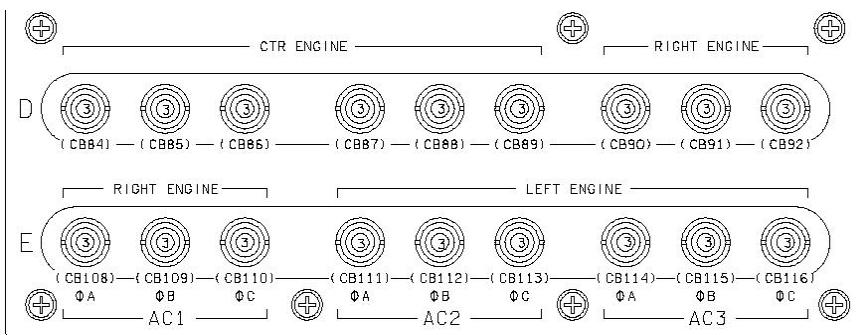
Configuration and Nomenclature:

Panel Location: L4

Component No.:

cb 84, 85, 86, 87, 88, 89,
90, 91, 92, 108, 109, 110
111, 112, 113, 114, 115, 116

Function:



The SSME Alternating Current (AC) circuit breakers provide circuit protection for SSME controllers. AC power is routed from the AC bus (powered by the main bus and FPC sub-bus) to the panel L4 circuit breakers to the panel R2 Engine Power switches to the SSME controllers in the aft compartment. Loss of a single phase causes loss of the associated controller channel (e.g., loss of controller redundancy). The loss of a single phase on two ac buses will shut down an SSME.

Nominal Usage:

The SSME AC circuit breakers remain IN from SSME Controller Power Up (prelaunch) through the entire flight.

Contingency Usage:

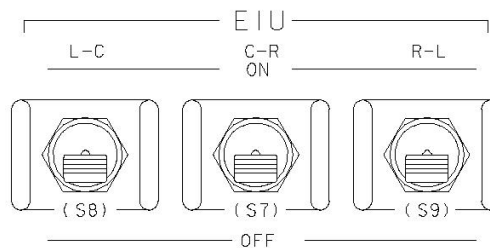
Circuit breakers will trip (OUT) upon detection of high circuit load.

Component Name: EIU switches

Configuration and Nomenclature

Panel Location: O17

Component No.: S8, S7, S9



Function:

These switches provide power to or remove power from the EIUs. Although each EIU is redundantly powered, the loss of all power to an EIU would cause a data path and command path failure on the associated SSME.

Nominal Usage:

These switches are positioned "ON" during prelaunch operations and are positioned "OFF" at a Mission Elapsed Time (MET) of approximately 1 hour in the Post Insertion timeframe.

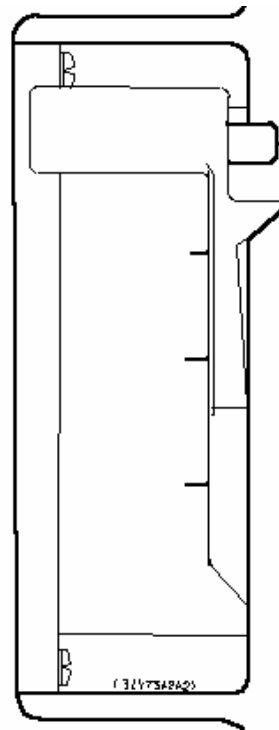
Contingency Usage:

Although not an SSME related contingency use, certain powerdown configurations specify early power OFF of the EIUs to conserve on-board power.

Component Name: Speed Brake Throttle
Controller

Configuration and Nomenclature

Panel Location: C3



Function:

The speed brake/throttle controller (SBTC) performs different functions during ascent than during entry. During ascent, the SBTC enables the Pilot to manually throttle the SSMEs. Although there are two SBTCs in the cockpit (one for the Commander and one for the Pilot), only the Pilot's SBTC functions during ascent. During entry, the both SBTCs enable the crew to manually open and close the Speed Brake.

Nominal Usage:

None.

Contingency Usage:

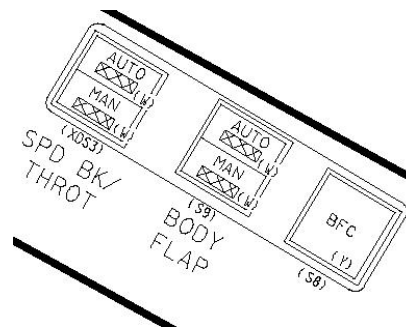
Various cases requiring the crew to perform manual SSME throttling are documented in Flight Rules A5-109, A5-112, A5-155 and A8-61. For a detailed description of how to engage manual throttles and the SBTC scale, see SCP 2.1.13.

Component Name: SPD BK/ THROT
pushbutton indicators

Configuration and Nomenclature

Panel Location: F2, F4

Component No.: S8



Function:

The pushbutton is used to change the SSME throttle control from manual to automatic. As an indicator, it identifies the throttle control mode.

The white AUTO light indicates that the throttle control is automatic. The white MAN light indicates that the throttle control is manual.

Nominal Usage:

None

Contingency Usage:

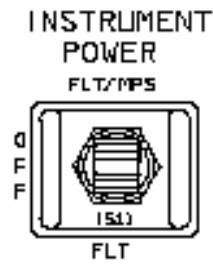
Refer to the SBTC description for cases where manual throttling is required.

Component Name: INSTRUMENT POWER
switch

Configuration and Nomenclature

Panel Location: F6

Component No.: S1



Function:

In the FLT/MPS position, power is supplied to the SSME Chamber Pressure (Pc) meter, the LH2 Manifold Pressure (ENG MANF) meter, the HELIUM meter on panel F7, and the flight critical dedicated displays on panels F6 and F7.

Power is removed from the dedicated meters and displays when the Instrument Power Switch is in the “OFF” position.

Power will be supplied to the flight critical dedicated displays on panels F6 and F7 but will not be supplied to the MPS meters, when the Instrument Power Switch is in the “FLT” position. This is performed on-orbit to save power.

Nominal Usage:

The Instrument Power Switch is in FLT/MPS position during ascent.

Contingency Usage:

None.

Note:

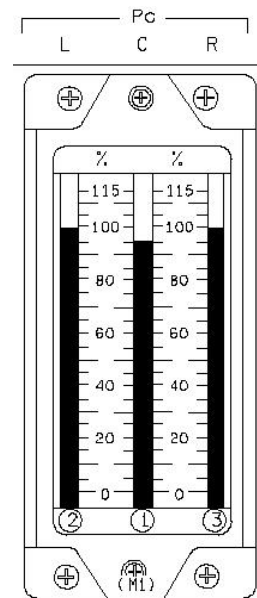
This component no longer exists on MEDS vehicles. See SB 6.6, “MEDS”, for details on this system.

Component Name: MPS PRESS Pc meters

Configuration and Nomenclature

Panel Location: F7

Component No.: M1



Function:

The SSME Pc meter displays the SSME Main Combustion Chamber Pressure (Pc) in percent power level. The average of the Pc sensors A and B pairs is computed in the controller and routed to the GPC, which scales it appropriately to drive the meters for each of the SSMEs.

Nominal Usage:

The SSME Pc meters verify proper SSME operation, especially during throttling periods.

Contingency Usage:

The SSME Pc meters are used for confirmation of SSME shutdowns. Note that the affected SSME Pc meter will be driven to zero when the SSME has a Data Path failure. For a stuck throttle condition (hydraulic lockup, electrical lockup, or command path failure), the affected engine Pc meter will remain static and not change with the other two engine Pc meters during engine throttling.

Note:

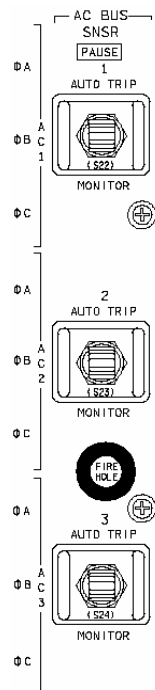
This component no longer exists on MEDS vehicles because it is displayed on the MEDS OMS/MPS display. See SB 6.6, "MEDS", for details on this system.

Component Name: AC BUS SNSR switches

Configuration and Nomenclature

Panel Location: R1

Component No.: S22, S23, S24



Function:

The AC bus sensor switches control caution and warning protection against an AC bus over/undervoltage. In the AUTO TRIP position an overloaded or underloaded AC bus will be tripped off-line. In the OFF position this protection and annunciation is disabled. In the MONITOR position, caution and annunciation is provided for a faulty bus, but the bus is not tripped off-line if a fault is detected.

Nominal Usage:

Nominally, the AC bus sensor switches are in the MONITOR position during ascent. The switches are cycled to OFF then AUTO TRIP during the post OMS-1 procedures.

Contingency Usage:

The AC bus sensor switches are taken to OFF when the loss of a single phase of an AC bus will result in engine shutdown. Since there are single point failures in the AC bus sensor electronics that can result in ac bus loss, taking the sensors to OFF protects against such scenarios. Reference flight rule A5-111, "AC Bus Sensor Electronics Control" for a list of the applicable cases.

The AC bus sensors can be taken from OFF to MONITOR during ascent, but the EGIL operator (not the Booster operator) would normally request this.

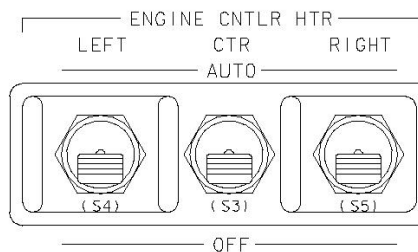
Component Name: MPS ENGINE CNTLR HTR
switches

Configuration and Nomenclature

Panel Location: R4

Component No.: S4, S3, S5

Function:



The SSME Controller Heaters are no longer active, although the switches still remain.

Nominal Usage:

None. Switches are is OFF.

Contingency Usage:

None.

1.10.2 Caution and Warning / SM Alert System / SSME Faults

1.10.2.1 *C&W Alerts (Hardware C&W)*

The only SSME fault that drives a hardware C&W class 2 alert is the SSME FAIL. In addition to the SSME FAIL fault message, the red BACKUP C/W ALARM light is illuminated. Refer to Systems Brief 3.8 for additional hardware C&W details.

1.10.2.2 *SM Alerts (Software C&W)*

The systems management (SM) alert is a class 3 alert activated when the BFS software has determined that a parameter has exceeded limits as sensed by the BFS GAX (GN&C annunciator interface) program. When one of these conditions is detected, the SM system sounds the SM alert tone, lights the blue SM alert light, and sends a fault message to a CRT (see Table 1.10.2-I). Then the digital readout can be checked on the BFS GNC SYS SUM 1 display.

Table 1.10.2-I – SM Alert Parameters

	Fault Message	Low Limit	High Limit
	MPS H2 OUT P C (L,R)	1050	-
	MPS O2 OUT T C (L,R)	125	-

The MPS H2 outlet pressure and O2 outlet temperature warn of an SSME shutdown prior to guided MECO.

1.10.2.3 *SSME Faults*

The SSME fault messages (Table 1.10.2-II) and status lights are used to alert the crew of problems with the main engines during ascent. The messages and lights are driven by the PASS when active and by the BFS when engaged.

Table 1.10.2-II – SSME Fault Messages

Fault Message	Cause	Status Light
ME SHDN SW C (L,R)	Switch contacts disagree	-
MPS CMD C (L,R)	Command path fail	Amber
MPS DATA C (L,R)	Data path fail	Amber
MPS ELEC C (L,R)	Electric lockup	Amber
MPS HYD C (L,R)	Hydraulic lockup	Amber
SSME FAIL C (L,R)	Premature main engine shutdown	Red

With the exception of the SSME FAIL fault message, the remaining fault messages listed in Table 1.10.2-II are class 3 alerts that turn on the blue SM alert light and sound the SM tone (in addition to the fault message displayed on the CRT). The SSME FAIL fault message is a class 2 alert that turns on the Master Alarm light and sounds the class 2 audible tone (in addition to the fault message and the BACKUP C/W ALARM hardware C&W light). Refer to Systems Brief 3.7 for additional class 2 alert details.

1.10.3 References

Flight Data File – Reference Data, Rev E PCN-6, August 16, 2002.

Flight Data File – Data Processing System Dictionary, Rev J PCN-11, August 21, 2002.

Space Shuttle Systems Handbook, Section 20, Rev G, November 15, 2002.

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1.11 SSME AVIONICS INTERFACES

1.11.1 General

The exchange of command messages and performance data between the Orbiter's General Purpose Computers (GPCs) and the SSMEs takes place through a network of avionics equipment as depicted in Figure 1.11-I. The major components in this network between the GPCs and SSMEs are flight-critical data buses, Engine Interface Units (EIUs), and SSME controllers. Although they are not avionics, the SSME interfaces with the Orbiter hydraulic systems are also covered in this Systems Brief.

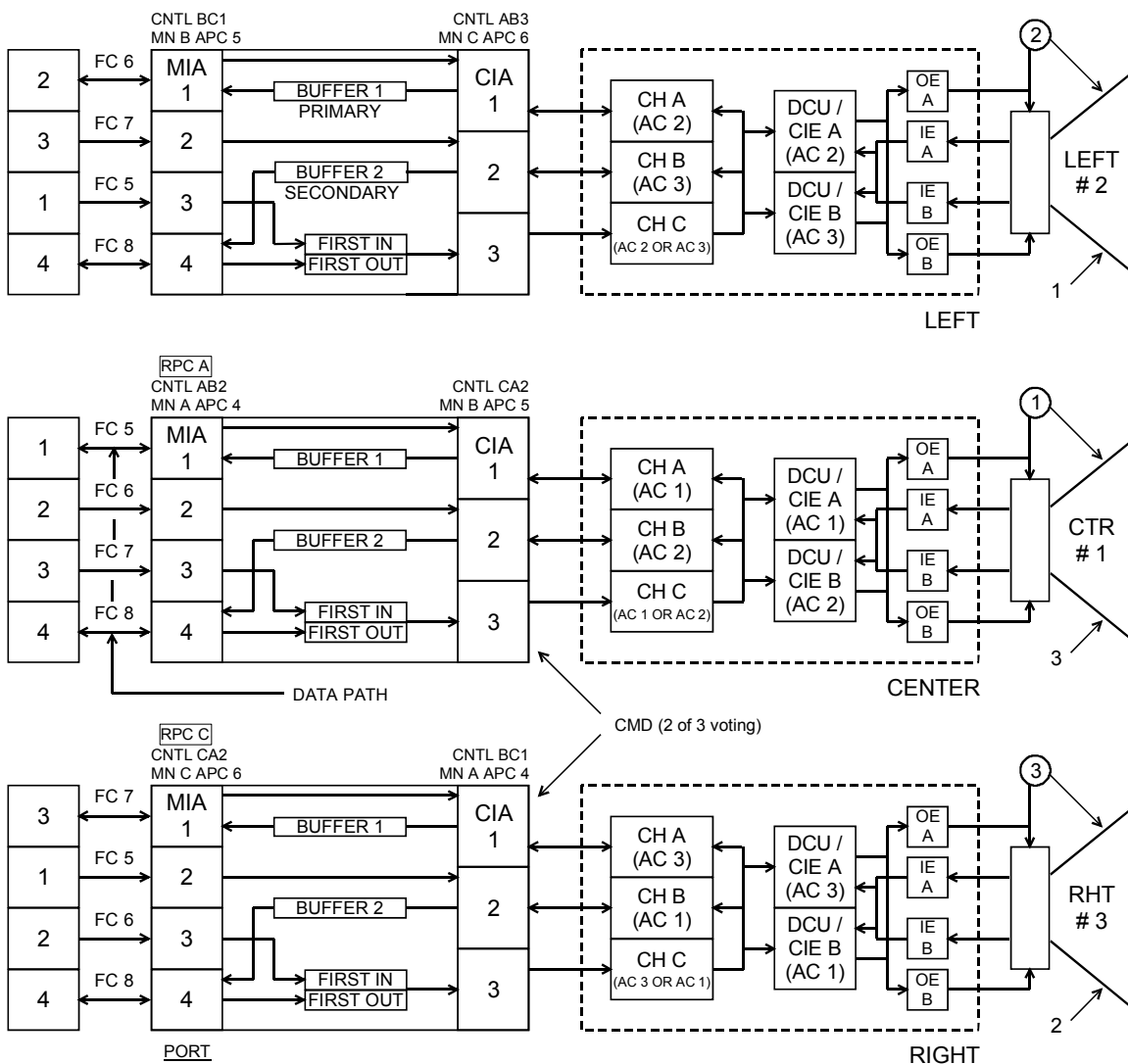


Figure 1.13-I - SSME avionics interfaces (Ref. 1)

1.11.2 Functional Description

1.11.2.1 Command Flow

Each SSME has an EIU, which is independent of the other EIUs, to act as a data transfer interface between the dedicated SSME controller and the GPCs. The EIU uses four Multiplexer Interface Adapter (MIA) ports to interface with the GPCs. Each of the four GPCs in the primary avionics software system (PASS) transmits SSME commands over a flight-critical (FC) data bus to a corresponding MIA port. The MIAs check the commands for proper sync, the correct number of bits, and odd parity. Commands that are not validated are dead-ended in the MIAs. The validated commands from MIAs 1 and 2 are sent to Controller Interface Adapters (CIAs) 1 and 2, respectively. The validated commands from MIAs 3 and 4 pass through a first-in/first-out logic box. The first valid command that enters the logic box is transmitted to CIA 3; the other is dead-ended. From CIAs 1, 2, and 3, the validated commands are transmitted to command channels A, B, and C, respectively, in the SSME controller. In the controller, the Vehicle Interface Electronics (VIE) checks for transmission errors and then sends the commands to Digital Computer Unit (DCU) A and B. If the new transmission fails the checks, an all-zero word is entered in the respective input command register and remains unchanged until a transmission word has been received and validated by the hardware. DCU A is normally in control; DCU B assumes control if DCU A fails. If DCU B subsequently fails, power will be removed from the fail-safe solenoids and a pneumatic shutdown of the SSME occurs.

The DCU that is in control compares the three commands received from the VIE. These commands must pass a two of three command agreement voting logic. Two of the three commands must agree exactly bit for bit.

All SSME commands are “absolute” commands. One SSME command that could be confused to be a “variable” command is the MAIN CHAMBER PRESSURE LEVEL. This command sets the SSME main chamber pressure level, which is variable from 65 percent to 109 percent power level in 1 percent increments – but each power level is its own individual command. The remaining SSME commands are more clearly “absolute” commands such as START ENABLE, START, LIMIT CONTROL INHIBIT, LIMIT CONTROL ENABLE, SHUTDOWN ENABLE, SHUTDOWN, DUMP START, and DUMP STOP.

If only two of the three commands agree, or if none of them agree, a failure will be reported by changing the SSME status word to major component failure and by setting FID 042. No more than one FID 042 per command channel will be posted after SSME start. Refer to Systems Brief 7.2 (Ref. 2) for more information on FIDs.

If two of the commands agree, and the commands are not START ENABLE or START, then the vote is defined as successful. If only two of the commands agree, and the commands are START ENABLE or START, the vote is defined as unsuccessful.

Single command channel shutdown logic in the SSME controller will process the SHUTDOWN ENABLE followed by SHUTDOWN command on a single command channel if a flight specific timer has expired (the predicted MECO time in MET plus the time from the last SSME start (6.36 seconds) minus 3 sigma dispersions of 5.5 seconds) and the limit inhibit command has not been processed since the last controller reset. The intent of this logic is to protect the vehicle and crew from exposure to an Orbiter/SSME command path failure occurring too close to MECO for manual action (catastrophic). When the SHUTDOWN command from a single command channel is accepted, a FID 041 is reported for that channel.

After the voting is passed, the DCU channel determines whether the voted command is valid for the phase of SSME operation. If the command is valid, the controller will send its own control signals to the various SSME components in response to the GPC-commanded function.

Command path failure results from the failure of the GPCs or flight-critical data buses assigned to MIAs 1 and 2, the failure of MIAs 1 and 2, the failure of any two of the three CIAs, failure of any two of the three VIE channels, a complete EIU failure, or the failure of any two controller channels. The loss of command capability to an SSME will mean that the SSME will not respond to throttle commands, limit inhibit/enable commands, GPC shutdown commands (both guided cutoff and manual shutdown pushbutton), and MPS dump commands. That SSME must be shutdown manually via the AC switches and shutdown pushbutton.

If a command is sent and voting is passed but the command is not valid for the current SSME operating mode, the controller sets a COMMAND REJECT status bit in the Engine Status Word. This is received by the GPCs and a command path failure message is annunciated. For example, when the GPC dump stop command is sent after an SSME has experienced a pneumatic shutdown, a COMMAND REJECT will be set and a command path message will be annunciated to the crew and ground because the engine was unable to get into Oxidizer Dump mode and the Dump Stop command is only valid in this mode.

1.11.2.2 Data Flow

SSME data is arranged into a Vehicle Data Table (VDT) in the controller. The controller transmits the VDT, consisting of 128 words, from command channel A and B to CIAs 1 and 2, respectively. The data transmitted to CIA 1 is called primary data, and the data transmitted to CIA 2 is called secondary data. In the EIU, the first 32 words of the VDT are loaded into a status register for transmission upon request by the GPCs. The remaining words of the VDT are not available real-time in the Mission Control Center. Upon GPC request, the 32 words are transmitted from MIA 1 and the first 6 words of the 32 words are transmitted from MIA 4. The MIA interface adds a sync pulse, address, and check pattern to each word. The primary data path is through MIA 1, and the secondary data path is through MIA 4.

Loss of CIA 1, MIA 1, VIE channel A, or the associated string (FC data bus or GPC) will cause loss of primary data. Secondary data (Main Combustion Chamber Pc (MCC Pc), Engine Status

Word (ESW), Failure Identifier (FID), Time Reference (TREF), ID Word 1 and 2) will still be available to monitor SSME status.

A data path failure, which is total loss of data (both Primary and Secondary Data) from the SSMEs to the GPCs, results from the failure of the GPCs or flight critical data buses assigned to MIAs 1 and 4, the failure of MIAs 1 and 4, the failure of CIAs 1 and 2, the failure of VIE channels A and B, a complete failure of the EIU, or the failure of controller channels A and B.

The command and data flow for the Backup Flight Software (BFS) is the same for the PASS, with the exception that all of the flight-critical data buses are assigned to GPC 5. Only VDT words 1-6 are available in BFS, but only three words are available in the downlist (MCC Pc, ESW, and TREF). The FID Word, and ID Words 1 and 2 are not downlisted by the BFS. If two PASS GPCs are lost, the resulting command or data path failure can be recovered by engaging the BFS, or by re-stringing the data buses to a good GPC. See Flight Rules Sections 2 and 7 for criteria on restringing during ascent (Ref. 4).

The GPC and SSME controller base time oscillators are not synchronized, which can occasionally result in omission of a VDT frame. If the missed frame contains the Command Accept bit, an erroneous Command Path message will be annunciated. This anomaly actually occurred 6.75 seconds into the STS-75 ascent.

1.11.2.3 EIU Power Supply

The power interface for each EIU was changed during the post STS-51-L SDRI review. The Orbiter wiring was changed such that a single switch failure will not power down an EIU, which would have resulted in a Command and Data Path Failure on an SSME. The current wiring is shown in Figure 1.11-II. The power supply to each EIU is single-failure tolerant.

1.11.2.4 SSME Controller Power Supply

Each of the SSME controller Power Supply Electronics (PSE) is powered by a different AC bus, as shown in Table 1.11-I.

Table 1.11-I - AC BUS CHART

SSME	DCU channel	AC bus
Center	A	AC1 Φ A, B, C
	B	AC2 Φ A, B, C
Left	A	AC2 Φ A, B, C
	B	AC3 Φ A, B, C
Right	A	AC3 Φ A, B, C
	B	AC1 Φ A, B, C

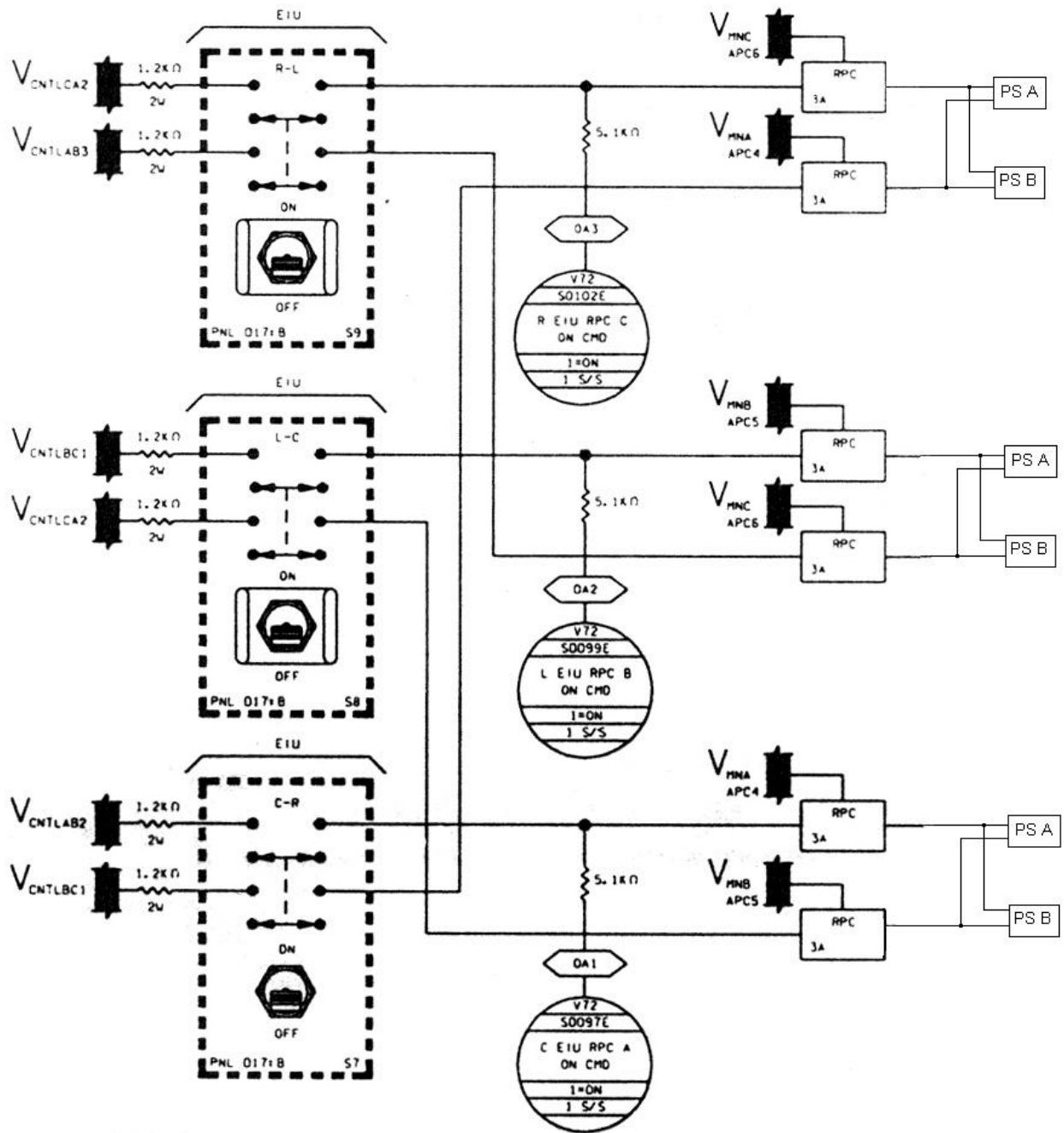


Figure 1.11-II - Orbiter switch wiring (Ref. 3)

The power supplies are dedicated to controller channels, that is PSE A supplies power to DCU A, Input Electronics (IE) A, Output Electronics (OE) A, and command channel A and PSE B supplies DCU B, IE B, OE B, and command channel B. Power to command channel C is supplied by both PSE A and B. This is to ensure there are at least two valid command channels in case of a single PSE failure.

Each AC bus has three phases (Φ). The loss of one or more phases in a bus causes channel failure, resulting in the loss of the corresponding PSEs and loss of redundancy in the controller. If no other failures occur, loss of redundancy has no adverse affect on continued SSME operation. If, however, there are additional failures affecting that SSME controller, SSME shutdown may occur. In particular, two failure scenarios deserve further examination.

- A. If a shutdown sensor(s) assigned to the remaining channel fail above or below its shutdown limit but within the disqualification limit, that controller channel will command a hydraulic shutdown of the SSME if the shutdown limits are enabled.
- B. If the remaining channel subsequently fails, power will be removed from the fail-safe pneumatic solenoid valve and a pneumatic shutdown of the SSME will occur.

There is an exception to the SSME having a pneumatic shutdown for the second controller failure. This is operationally transparent and only included here as background information. In this scenario, the SSME controller channel A power failure causes disqualification of DCU A during mainstage and DCU B to take over control. At MECO, DCU B accepts shutdown enable followed by shutdown command from the GPCs and starts the normal hydraulic shutdown sequence. When DCU B reports "shutdown" phase in the ESW, the GPCs discontinue sending the shutdown enable/shutdown commands. During shutdown, the SSME controller channel B power fails or DCU B halts, and the SSME modes to pneumatic shutdown. If DCU A power were to return at this point (0.3 to 0.6 second window), it can resume control and return the SSME to "mainstage" phase if the oxidizer preburner oxidizer valve has not changed position by more than 3.4% since the initial DCU A failure. With DCU A returning the SSME to "mainstage" phase and the GPCs thinking the SSME is in "shutdown" phase, there was a concern that the GPCs would close the LO₂ prevalve on a running engine. A GPC Software Change Request (SCR 90991) was initiated to eliminate this concern by having GPCs continuously send the shutdown enable/shutdown commands until the SSME controller reports "post-shutdown" phase in the ESW (MECO + 16 sec). After the initial preparation of the SCR, it was determined that the "shutdown" phase was not latched in the GPCs. When the DCU A reports "mainstage" phase in the ESW, the GPCs will eventually start resending the shutdown enable/shutdown command. The SCR 90991 was still accepted and incorporated into the OI-26A. This SCR still provided a benefit by minimizing the impact to the delay between the SSME shutdown and the LO₂ prevalve closure by 80 to 200 msec over current GPC logic.

1.11.2.5 Transient Power Failure in the SSME Controller

If the SSME controller channel were to have a transient (> 60 msec) power failure or if an MPS engine power switch (panel R2) were to be power cycled, the SSME controller would disqualify the respective DCU, IE, OE, and command channel even though the power had been restored. When the power is restored to the IE, the data from the engine sensors are received by the SSME controller and transmitted back in the VDT, but the SSME controller will still consider these sensors disqualified. Also since the power has been restored to the command channel, it will accept commands and transmit data. These two points are illustrated in the following two examples.

Example 1: There is a transient power failure on left SSME PSE A. The left SSME controller would report FID "001-001", DCU A disqualified due to channel power. During the power loss, command channel A will have failed (loss of primary data), and all the channel A sensors will be disqualified on the left SSME. When power is recovered, the primary data would be recovered and the channel A sensor data will be downlisted. If, subsequently, the High Pressure Oxidizer Turbopump Intermediate Seal Pressure (HPOT IMSL P) on channel B only were to exceed redline on left SSME with limits enabled, the controller would shutdown this engine.

Example 2: Center SSME has a performance case, MCC Pc shift high actual low, due to a shift in MCC Pc channel A sensor. Next, GPC 2 fails to halt. The performance case is bad enough to cause loss of uphill (Abort To Orbit) capability. According to the Flight Rule A5.1.3-9 (Ref. 4), the SSME controller channel with the bad sensor will be power cycled. Turning off the center SSME AC1 will disqualify MCC Pc channel A, and the SSME will rebalance based on the good MCC Pc sensor. This will also cause loss of primary data and everything on that controller channel to be disqualified. Now, with the GPC 2 failure and command channel A disqualified, there is a command path failure (see section 1.11.2.1) on the center SSME. Restoring the power to the controller in this case regains primary data to verify the performance case has cleared and the command capability on command channel A. Normally, the center SSME would have to be manually shutdown prior to MECO, but this is avoided since the AC1 switch is turned on again.

1.11.2.6 Hydraulics

Each SSME has one Auxiliary Power Unit (APU) to actuate the SSME valves. APUs 1, 2, and 3 operate valves on the center, left, and right SSMEs, respectively. Therefore, the loss of one APU will result in hydraulic lockup on one SSME.

Table 1.11-II - HYDRAULICS

SSME	TVC (APUs)	Valve (APUs)
Center	1 & 3	1
Left	1 & 2	2
Right	2 & 3	3

As seen above, the failure of two APUs will result in the hydraulic lockup and loss of Thrust Vector Control (TVC) capability on one SSME, hydraulic lockup and loss of TVC redundancy on another SSME, and loss of TVC redundancy on the third SSME.

1.11.3 References

1. Booster Cue Card Book (BCCB), Basic Rev A, PCN-6, July 12, 2001
2. Space Shuttle Systems Handbook (SSSH), JSC 11174, Basic Rev F, DCN-4, Dwg. 10.3, March 1, 2000
3. STS Operational Flight Rules, Volume A, All Flights, JSC-12820, Final 2002, PCN-1, November 21, 2002
4. Interface Control Document - 13M15000, Revision AC, Increment 14, July 9, 2001
5. Functional Subsystem Software Requirements - System Interface
6. Computer Program Contract End Item Spec - CP 406R0008, Revision H, September 13, 2000

1.12 SSME CONTROLLER HARDWARE

1.12.1 General

The controller is a single, integral electronics package mounted on the SSME. The controller is specifically designed to operate in conjunction with engine sensors, valves, actuators, spark ignitors, harnesses, and the operational computer program to provide a self-contained system for engine checkout, control, and monitoring. The size of the controller is 24.0 by 14.5 by 17.3 in., and it weighs 205 lb. The controller is mounted to the powerhead, by the MCC. See Figure 1.12-I for a view of an actual SSME with the controller installed, Figure 1.12-II for a controller overview, and Figure 1.12-III for controller physical characteristics. The controller is packaged in a sealed, pressurized chassis with cooling provided by convective heat transfer through pin fins as part of the main chassis. The electronics are distributed on functional modules having special provisions for thermal and vibrational protection. The main features of the controller are:

- a. Design flexibility - The controller is easily reprogrammed to allow for design flexibility and growth potential. The controller's digital computer unit (DCU) allows modification of engine control equations and constants by changing the stored program. The DCU updates instructions to the engine control elements every 20 milliseconds (50 Hz). The DCU uses 16-bit computations, 12-bit input/output resolution, and self calibrating analog-to-digital conversion to achieve precise closed-loop engine control.
- b. Onboard checkout - Onboard checkout and monitoring minimizes electronic ground support equipment (GSE). In-flight diagnostic service and engine redline limit monitoring are provided. Data acquisition for operation and maintenance are also provided.
- c. Sequencing - The controller verifies that the engine is ready to start. The sequences for starting and shutdown are provided by the controller.
- d. Closed loop control - Thrust and mixture ratio are controlled independently by two main valves. The OPOV controls thrust and the FPOV controls mixture ratio.
- e. Fail operational/fail safe design - Engine reliability is enhanced by a redundant control system. The redundancy management design provides fully operational avionics after the first failure. This design ensures a safe engine shutdown after the second failure. High reliability parts are used throughout the controller.

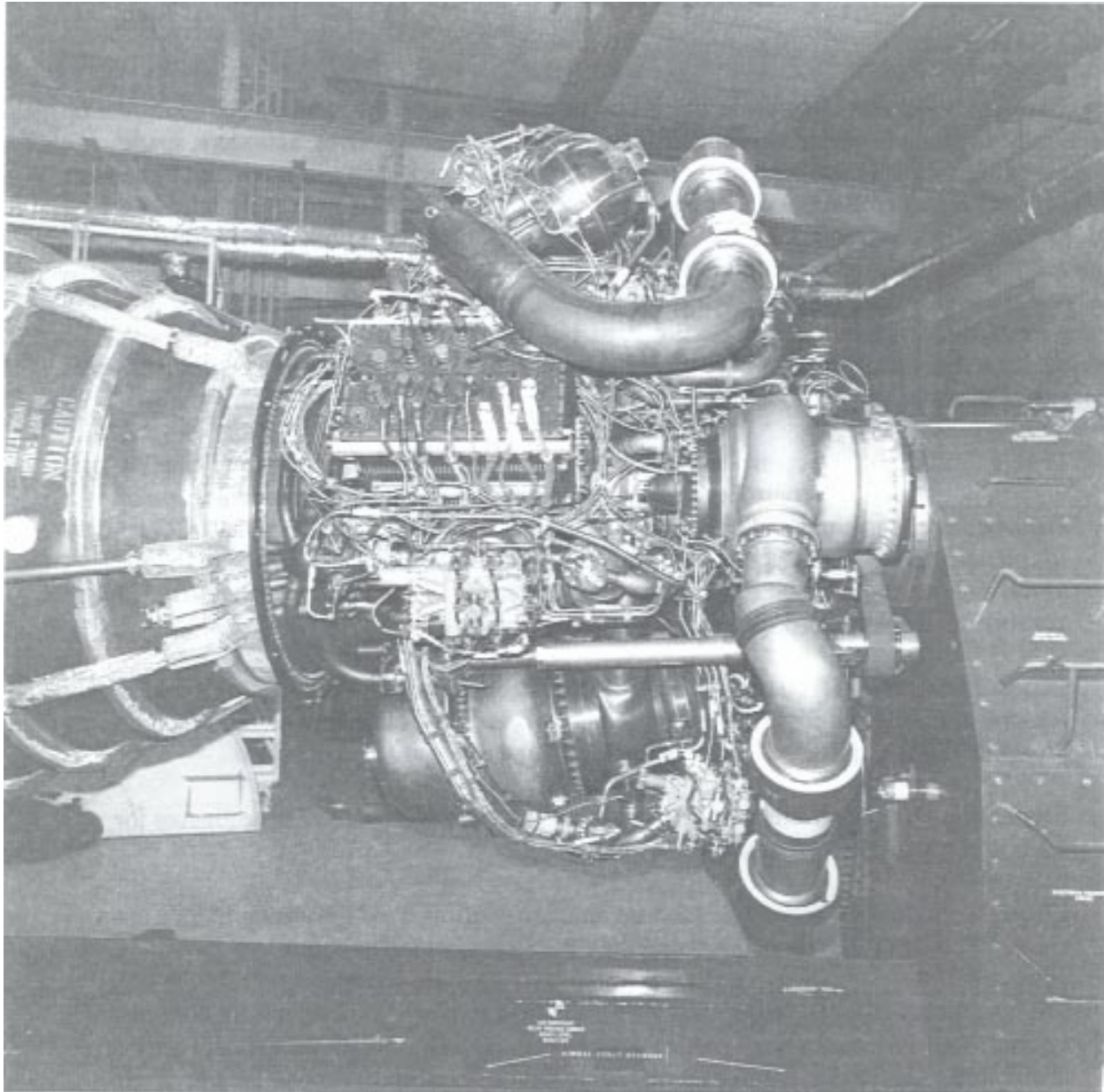


Figure 1.12-I – SSME

CONTROLLER OVERVIEW

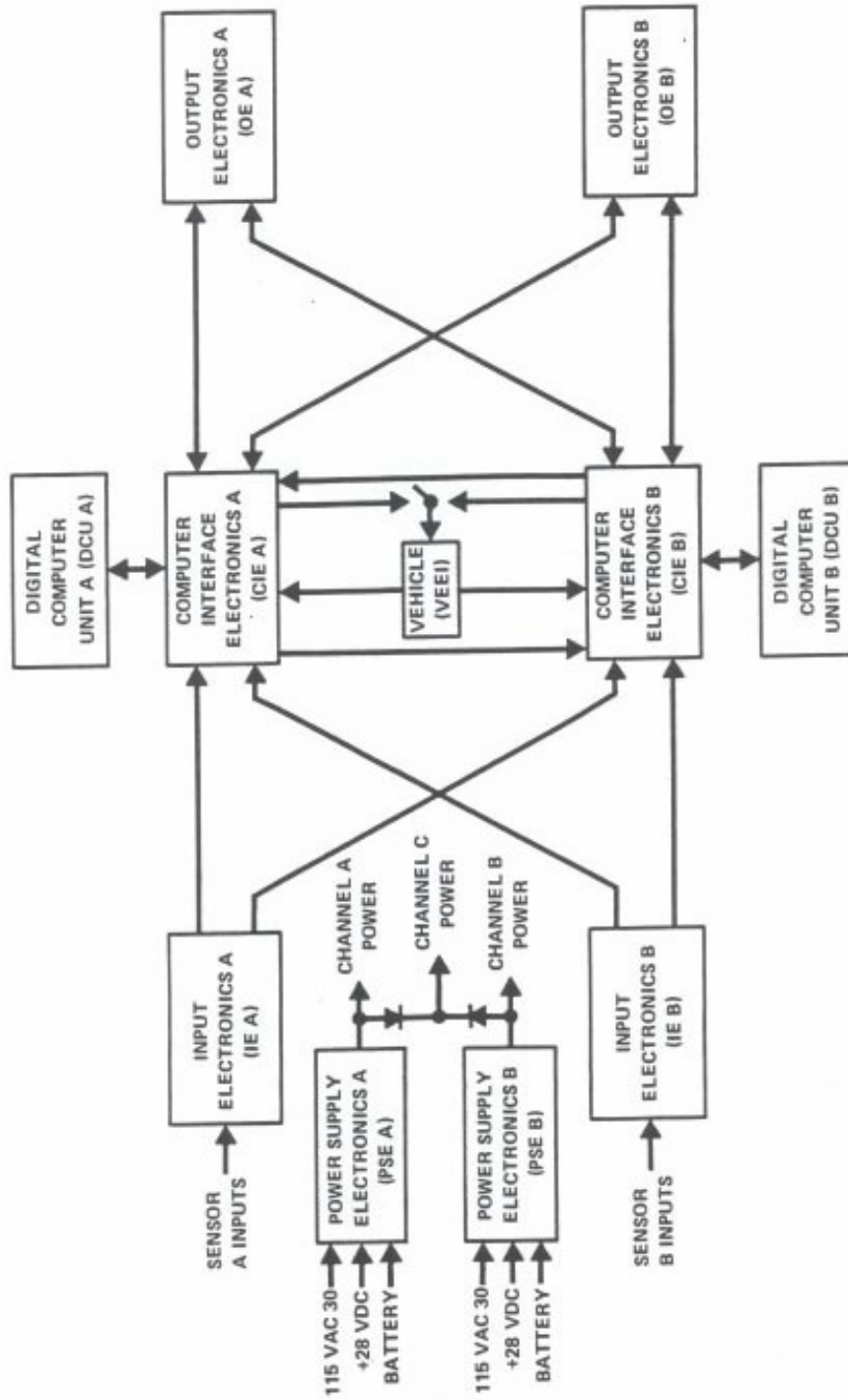
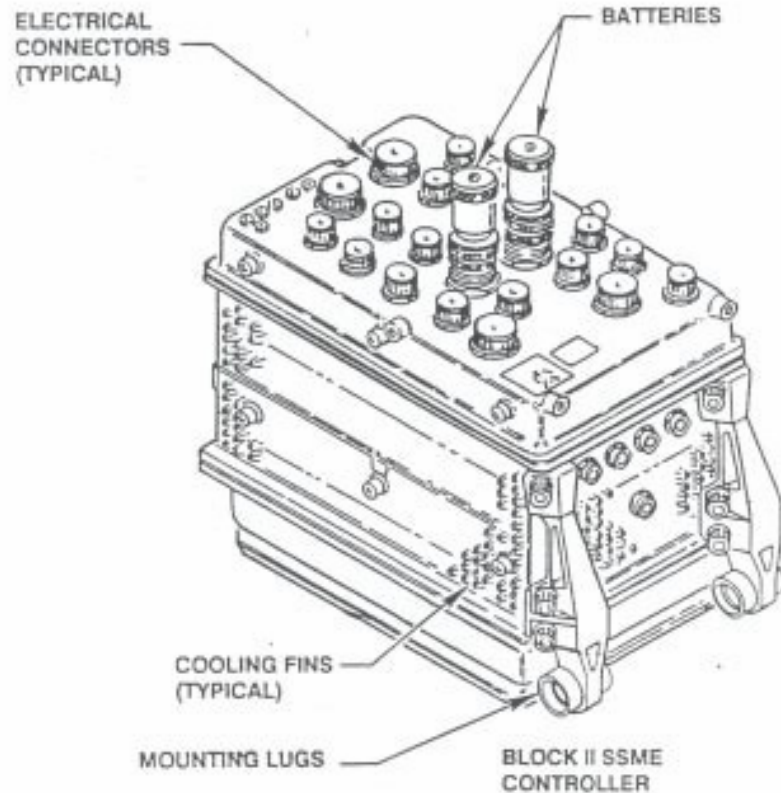


Figure 1.12-II – Controller Overview



* Size	24.0 x 14.5 x 17.3 in.
* Weight	205 lb
* Input power	115 +/- 5 , 400 Hz, Mainstage: 400 watts
* Heat transfer	Ground: Forced air cooling Flight: Convection cooling
* Design qualification temperature environment	Operating: -50° to +100° F Non operating: -220° to +200° F
* Vibration qualification environment (steady state)	X-axis: 27.64 Grms Y,Z-axis - 33.06 Grms
* Mounting isolators	Four point vibration

Figure 1.12-III – Controller Physical Characteristics

1.12.2 Functional Organization

The controller is divided into five subsystems. Each of the five subsystems is duplicated to provide dual-redundant capability. See Figures 1.12-IV and 1.12-V. Reference SSSH drawing 10.4 (Ref. 1) for an overview of the controller.

1.12.2.1 Input Electronics (IE)

The primary purpose of the input electronics is to acquire raw engine performance data from all engine sensors. Engine control sensors and redline sensors are at least dual redundant. Maintenance data sensors are not redundant. The IE conditions the signals from the sensors and converts them into digital values. The IE multiplexes that data and transfers it for processing by both DCUs. Each data transfer initiated by the software is controlled by dual port memory logic in the computer interface electronics (CIE). In addition the IE provides the interface for the DCUs monitoring of power supply voltages and BITE signals within the controller. The output of each IE is sent to redundant channel dual port memories. Reference SSSH drawing 10.19 (Ref. 1) for a schematic of the IE. Figure 1-12-VI shows a simplified version of the IE.

The input electronics consists of two major sections: the redundant sensor electronics, and the dual-redundant input interface electronics:

1.12.2.1.1 Sensor electronics

The sensor electronics provides interface with the engine sensors and the necessary sensor channel checkout provisions. The two electronics channels are isolated and obtain their operating voltages from the separate channels in power supply electronics. Sensor electronics Channel A and Channel B outputs are processed by the respective A and B channels in the input interface electronics. A pair of the four outputs from the fuel flowmeters is processed by each input electronics channel.

1.12.2.1.2 Input interface electronics

The IE input interface electronics converts all engine and controller DC analog sensor data, all output electronic sensor data and all voltage monitor DC analog data to digital format. Each channel interfaces with its dedicated computer via the interface buffer. Data is routed to the interface buffer by logic signals which are derived from the information contained in an 8-bit address word received from computer interface electronics associated with the controlling computer.

1.12.2.2 Output Electronics (OE)

The output electronics convert the computer digital control commands into voltages suitable for powering the following types of engine controls: spark igniters, the on/off solenoid valves, and the hydraulic servoactuators for the propellant valves and servoswitches. Reference SSSH drawing 10.20 (Ref. 1) for a schematic of the OE. Figure 1.12-VII shows a simplified schematic of the OE.

The OE consists of two identical channels, each of which is dedicated to an associated channel of spark igniters, solenoid valve coils, servovalves, servoswitches and actuator position transducers. Either OE channel is capable of operation with either CIE channel. A watchdog timer signal, received from the CIE channel, determines which CIE channel is controlling the OE. Each OE channel receives electrical power from its own power supply electronics channel. The OE receives and thus decodes commands issued by the CIE and thus determines which igniter, solenoid coil, or servovalve is to receive the command. The OE also provides sensor checkout control signals to the IE, contains provision for analog closed-loop control of actuator position, and provides built-in test data to the CIE and IE.

1.12.2.3 Computer Interface Electronics (CIE)

The primary purpose of the CIE is to provide control of communication between all units within the controller, and to control the flow of data within the controller. The CIE controls input data to the DCU, and DCU output commands to the OE. The CIE provides the controller interface to the orbiter vehicle through the engine interface unit (EIU). Vehicle commands and requests for data are received through the vehicle/engine electronics interface (VEEI). The controller receives engine commands from the vehicle over triple-redundant channels. The controller transmits engine status and data to the vehicle over dual-redundant channels. Reference Systems Brief 1.11 (Ref. 2). The CIE also includes watchdog timers whose function is to determine which part of the dual-redundant system is in control. Reference SSSH drawing 10.18 (Ref. 1) for a schematic of the CIE. Figure 1.12-VIII shows a simplified schematic of the CIE.

The CIE consists of the vehicle interface electronics (VIE) and two identical computer input/output interface electronics channels.

The VIE provides the digital communication link between the DCU and the VEEI.

Each of the dual input/output interface electronics channels is dedicated to the associated computer in the DCU. In addition, each channel interfaces with the VEEI, IE, OE, and the power supply electronics. Power to the computer input/output interface electronics channels is supplied by the respective channels in the power supply electronics (PSE). An interface between the two electrical output channels is the watchdog timer, which reports the operational status of the other computer.

Each CIE channel also contains a failure data recorder that stores up to 2048 words of monitor processor data bus, address bus, and control signal data. This failure data recorder was added to help determine the failure cause if multiple failures occurred on the controller, which lead to a loss of data.

1.12.2.4 Digital Computer Unit (DCU)

The controller consists of two identical general purpose digital computers, which are independent of each other (see Figure 1.12-IX for a simplified DCU drawing). Each DCU provides the computational capability necessary for all engine control functions. Each DCU receives sensor data, vehicle commands, and vehicle data request through its dedicated CIE channel. Each DCU performs computations necessary for full-authority closed-loop control of engine thrust and mixture ratio, and each DCU stores data until requested by the vehicle. Normally, one DCU is in control and issues commands while the other DCU is in operational standby. Each DCU tests all control system components once per major cycle. The operation of the IE, OE, PSE, and dedicated CIE are continuously monitored. Thus, each computer has knowledge of the operational status of the controller and engine. Upon detection of an engine or controller failure, automatic corrective action is initiated by the controlling DCU. When in control, either DCU is capable of issuing commands to the engine control elements through either OE channel.

Each DCU consists of a Motorola MC68000 16 bit microprocessor and a 64 K static RAM. Typical computer instruction times are 2 microseconds for add and 9 microseconds for multiply. The total engine major cycle time is 20 milliseconds (50 Hz).

1.12.2.5 Power Supply Electronics (PSE)

The primary purpose of the PSE is to convert the 115 + 5 V, three-phase, 400-Hz vehicle input AC power into the individual DC power supply voltage levels required by the controller subsystems. The controller receives AC power from two vehicle AC sources (reference Figure 1-12-X). The PSE consists of two identical channels each capable of deriving full power from one of the AC input power buses. Each channel supplies power to one channel of IE, OE, DCU, and CIE. Operating voltage for CIE channel C vehicle interface electronics is derived from the other two PSE channels. The PSE monitors the input AC power and the power supply operation. The PSE will initiate controller shutdown if the voltages are not within satisfactory limits. This is implemented by the PSE issuing a power failure sense (PFS) signal to the DCU if a failure of both input power busses or switching regulators occurs. Reference Systems Brief 1.11 (Ref. 2).

Originally there was a heater on the PSE for the Block I controller. This was removed on the Block II controller. There is a switch located on panel R4 but it is not connected to anything. For all STS flights the switch is left in the "off" position.

1.12.3 Fail-Operational/Fail-safe Design Features

Normal controller operation is under DCU A control. This DCU receives inputs from both IE A & B, and sends commands through both OE A & B. DCU B is operating and tracking DCU A. If DCU A fails (non-power fail), DCU B takes control, and would still receive inputs from IE A & B, and send commands through OE A & B (if DCU A fails with power then DCU B would take over but only receive input from IE B and send commands through OE B). This provides fully operational avionics after the first failure. Engine control is transferred to the standby computer without impairing engine operation. If DCU B were to subsequently fail, the engine would perform a pneumatic shutdown sequence, ensuring a safe engine shutdown after the second failure. See Figure 1.12-XI for a pictorial of controller redundancy.

During operation, the IE and OE are tested by the DCU and will be disqualified by the DCU if failed. A safe pneumatic shutdown will occur if both IEs or OEs fail. The power supplies are dedicated to controller channels, that is PSE A supplies DCU A, IE A, and OE A, PSE B supplies DCU B, IE B, and OE B. A safe pneumatic shutdown will occur if both PSEs fail.

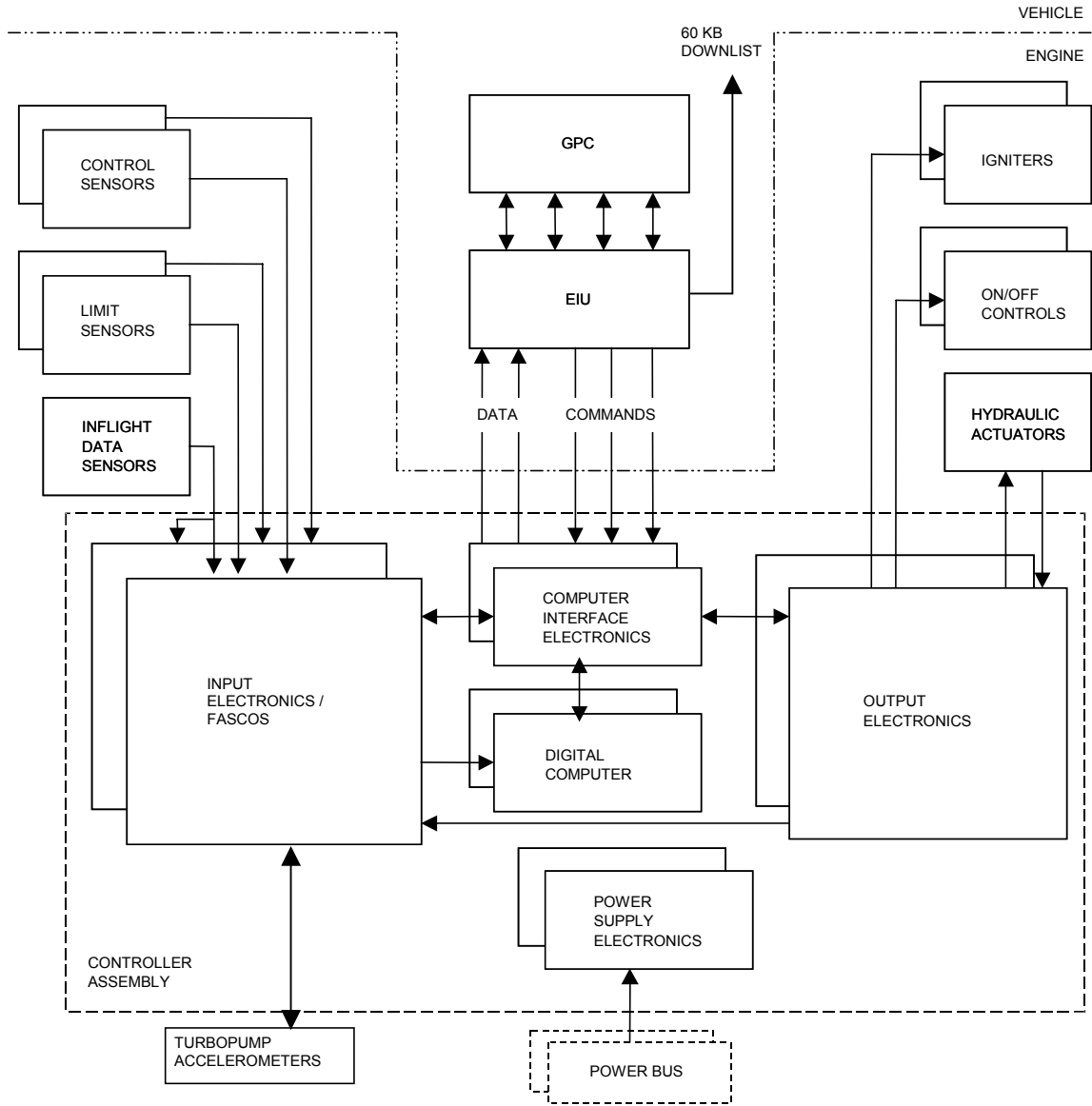


Figure 1.12-IV – Controller Organization

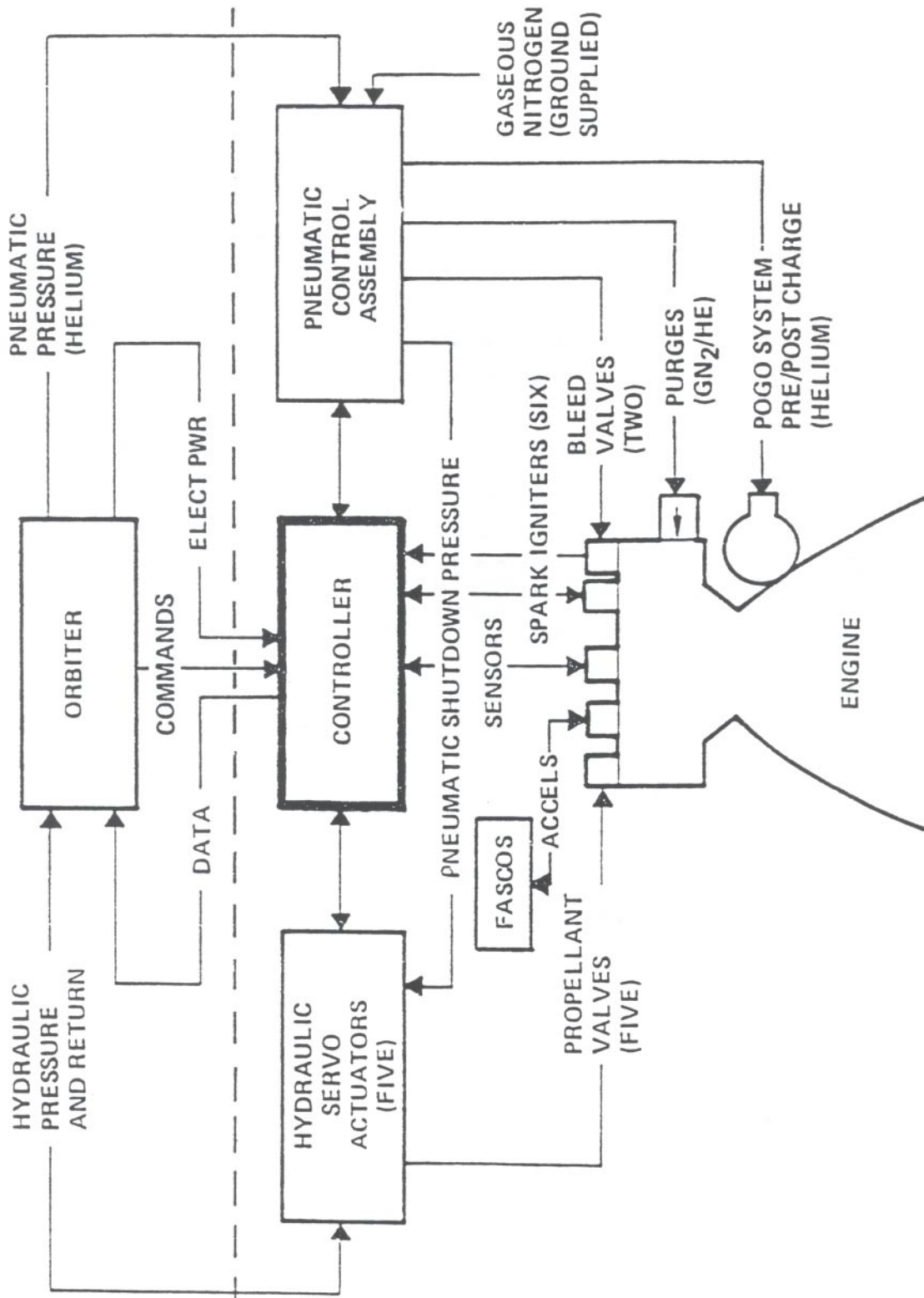


Figure 1.12-V – SSME Controller Functions

INPUT ELECTRONICS

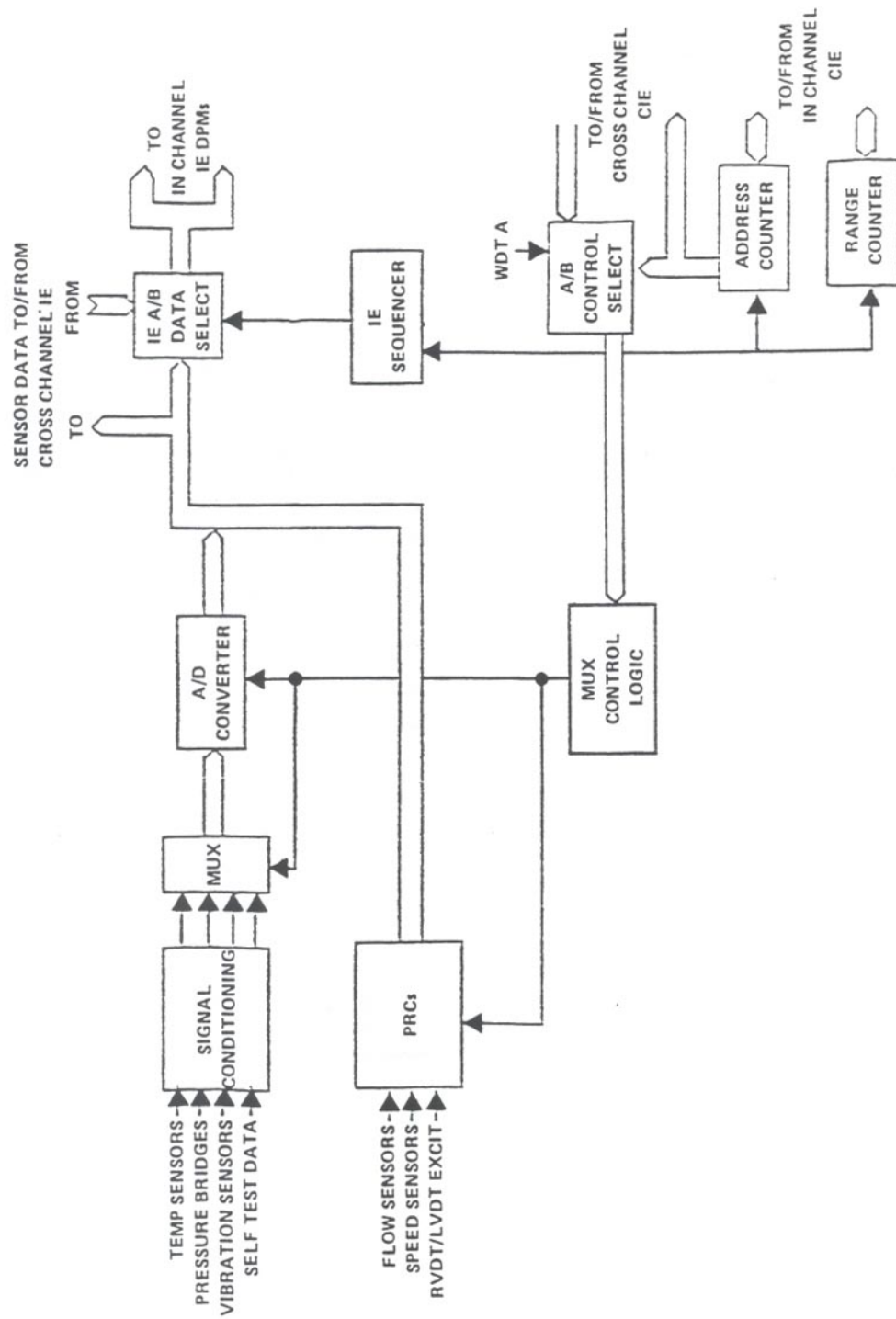


Figure 1.12-VI – Input Electronics

OUTPUT ELECTRONICS

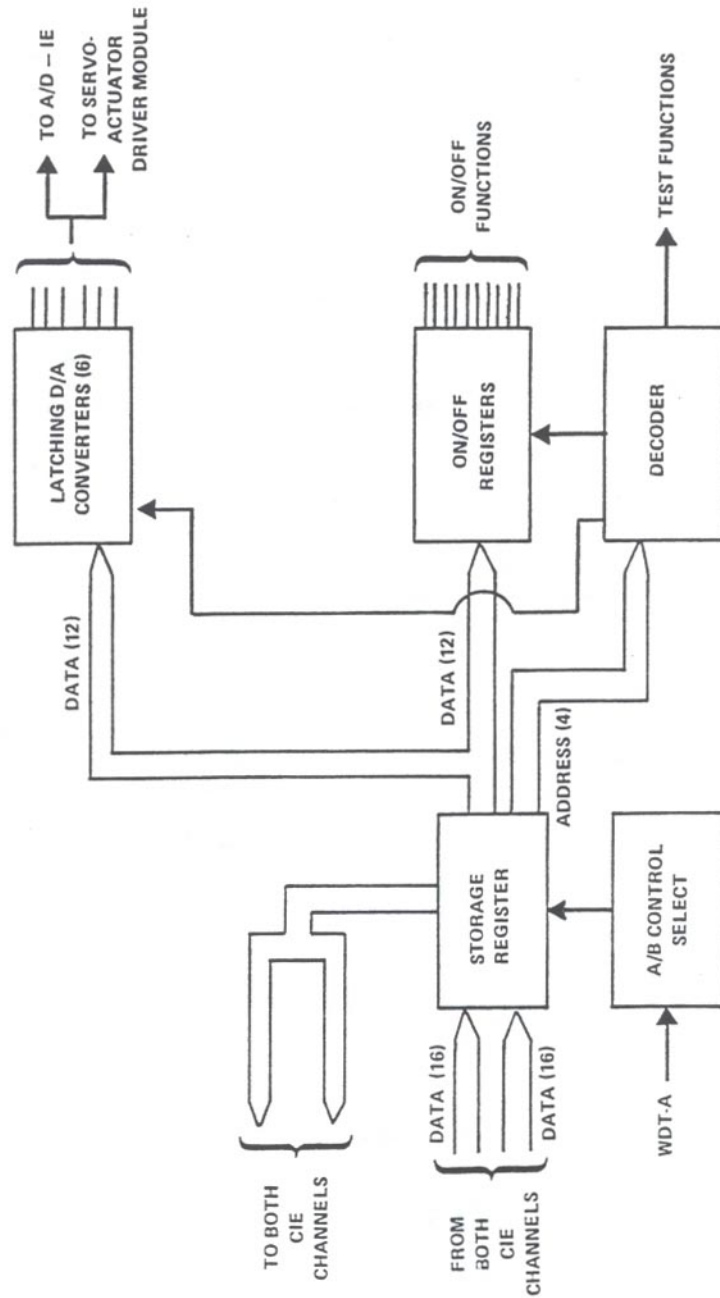


Figure 1.12-VII – Output Electronics

COMPUTER INTERFACE ELECTRONICS

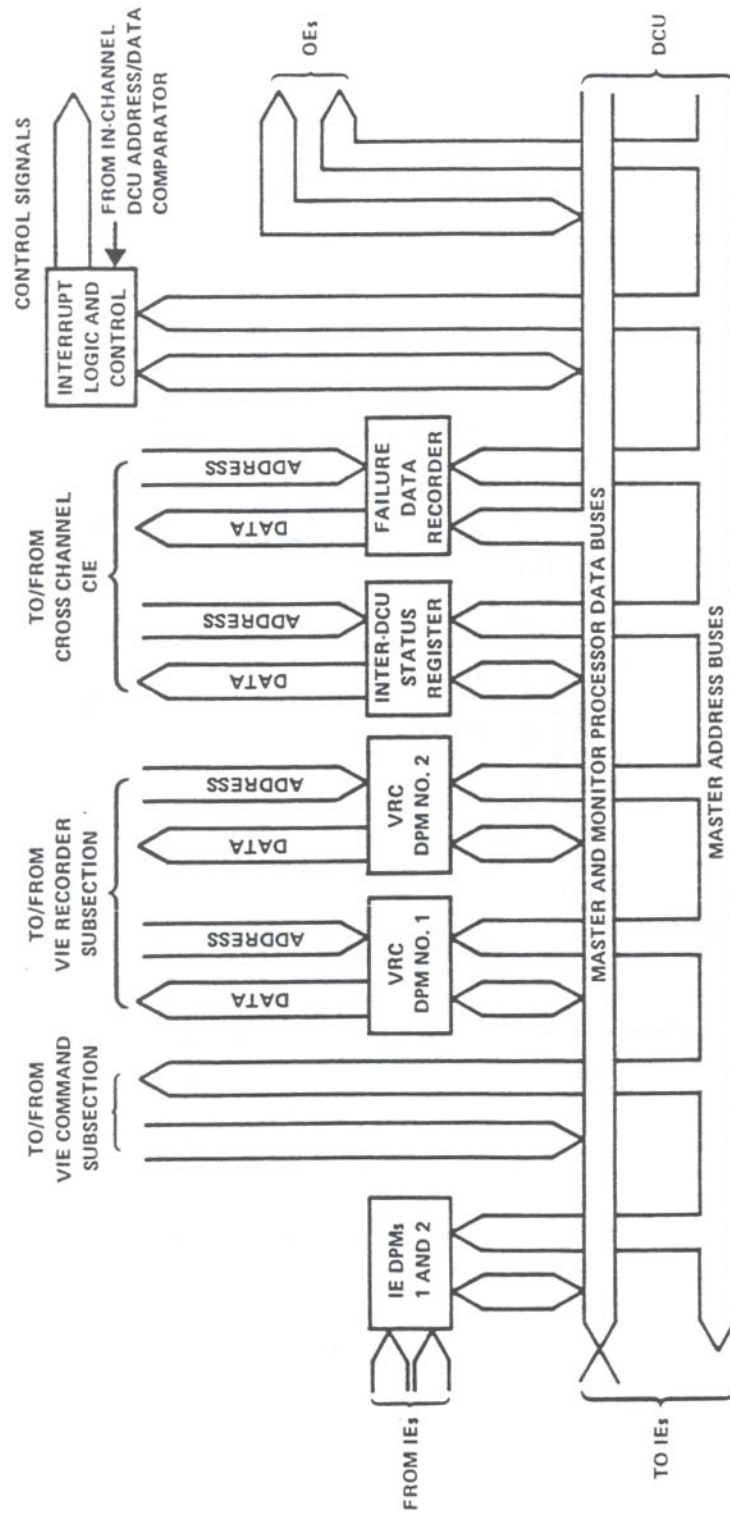


Figure 1.12-VIII – Computer Interface Electronics

DIGITAL COMPUTER UNIT

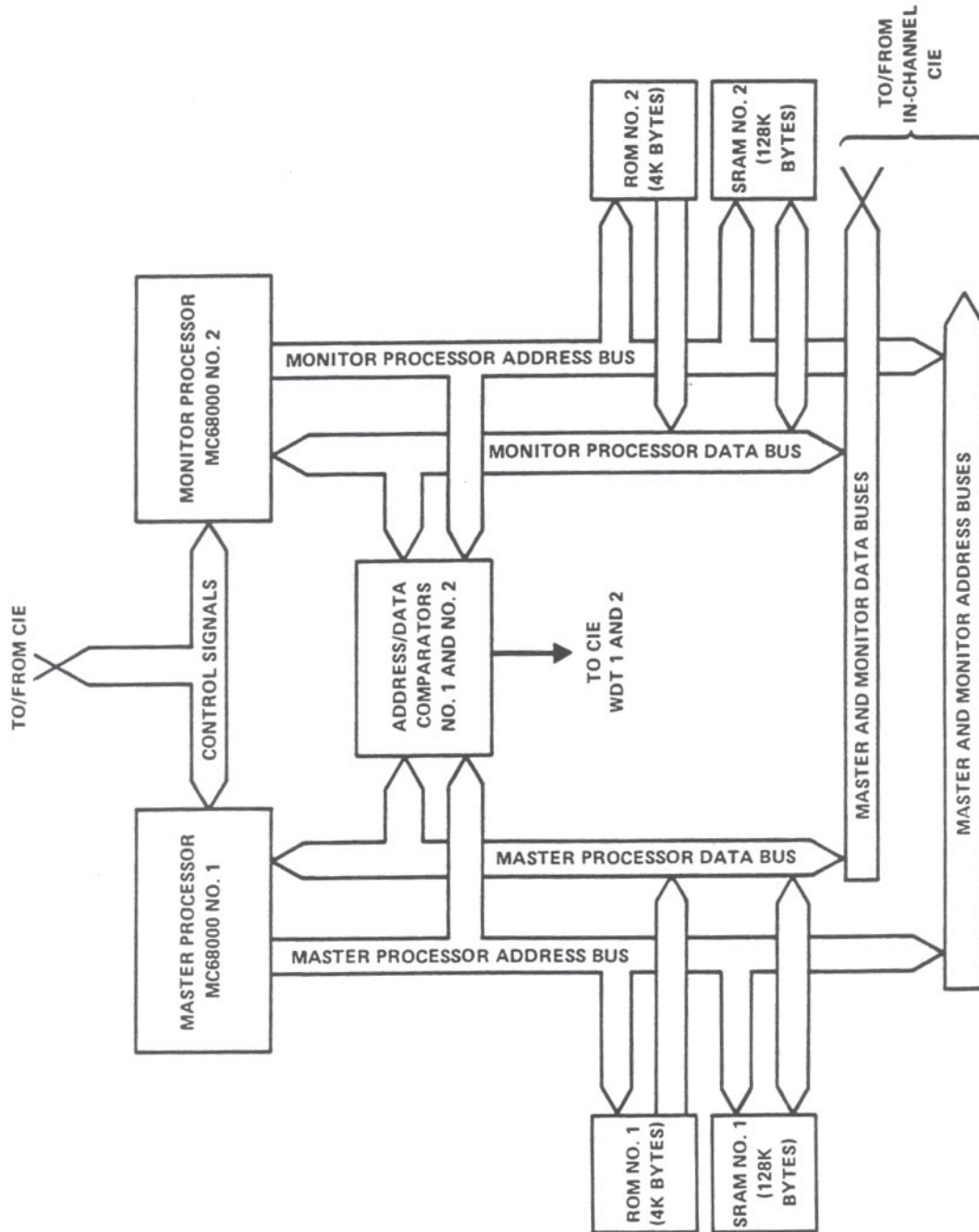


Figure 1.12-IX – DCU

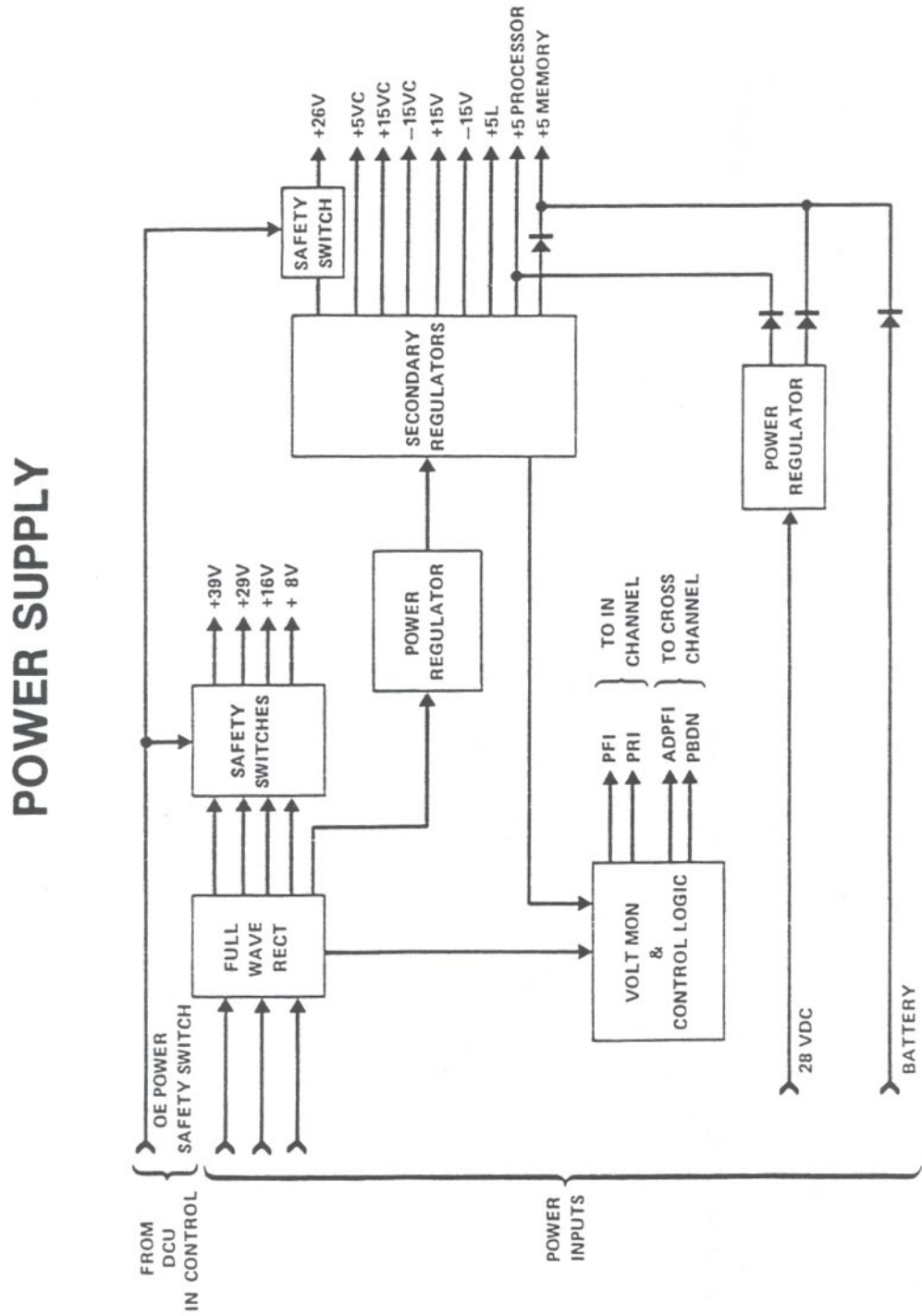


Figure 1.12-X – Power Supply

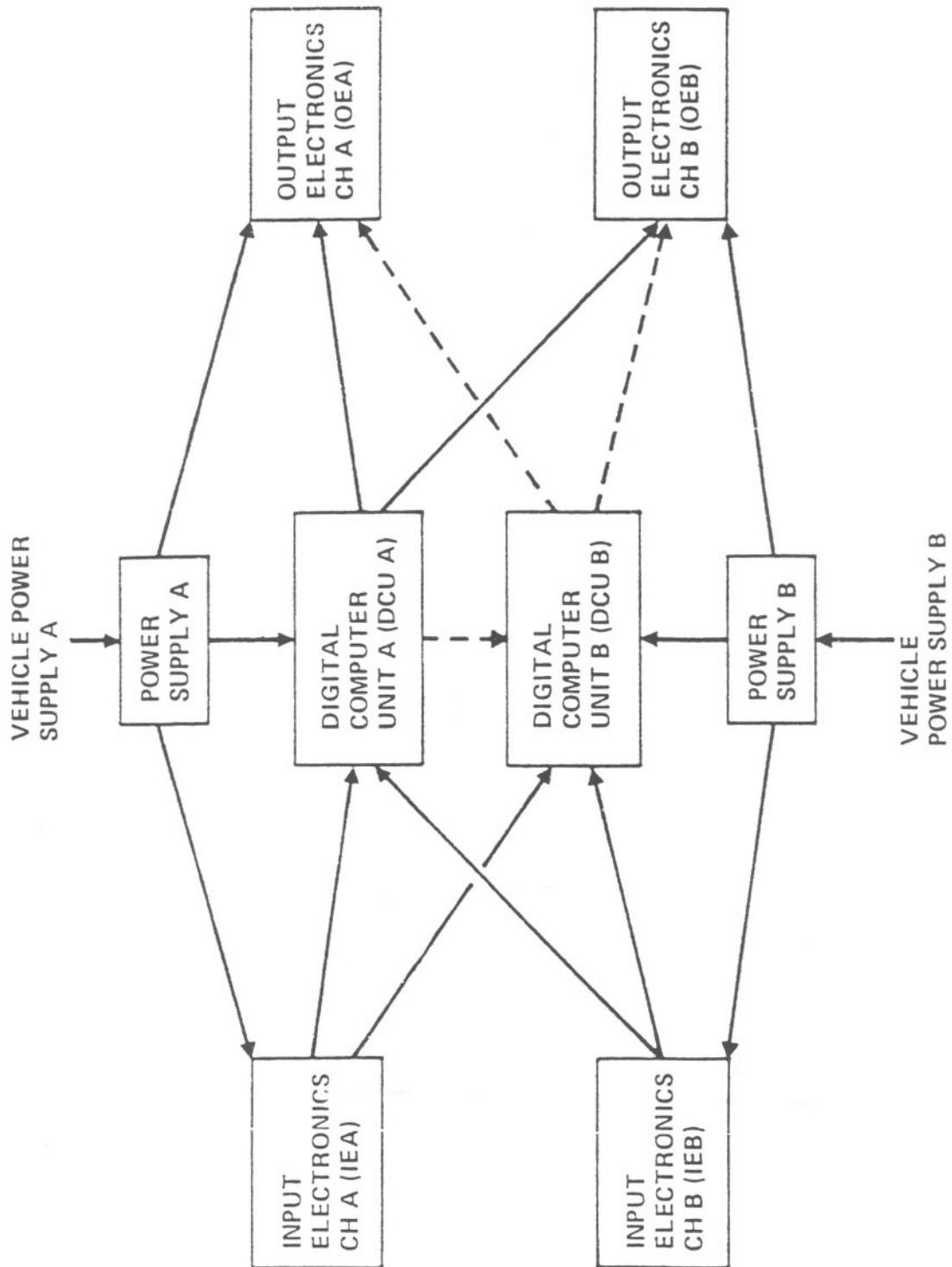


Figure 1.12-XI – Controller Redundancy

1.12.4 References

1. Space Shuttle Systems Handbook (SSSH), JSC 11174, Basic Rev. G, November 15, 2002.
2. SSME Operation, Rocketdyne course no. ME-110(A) RIR
3. SSME Description & Operation, Rocketdyne no. RSS-8559-1-1-1
4. SSME Block II Controller Reference Manual

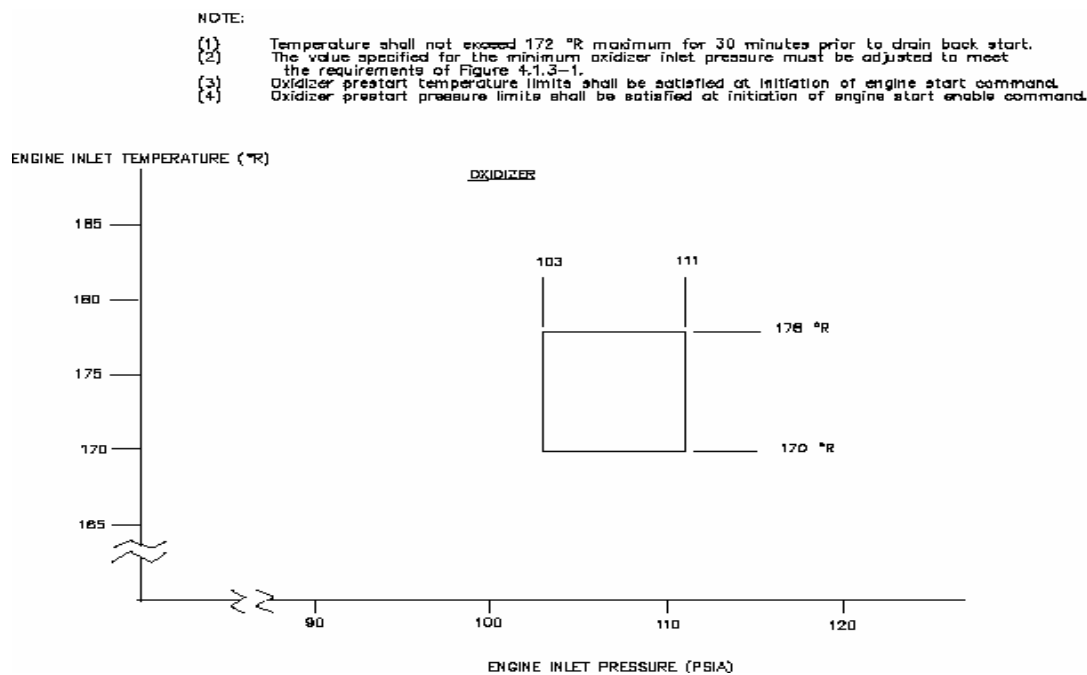
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1.13 SSME STARTBOX VIOLATION AND TURNAROUND REQUIREMENTS

A startbox violation refers to the condition in which LO2 or LH2 engine inlet temperatures and/or pressures are outside the range required for proper engine start. This systems brief describes the startbox and its associated constraints and discusses the minimum turnaround time required after an engine startbox violation. Achieving the LO2 inlet temperature constraint is operationally more complex than the others, so it will be described first.

1.13.1 LO2 Startbox

The SSME LO2 startbox is defined in the Space Shuttle Orbiter Vehicle / Main Engine Interface Control Document (ICD-13M1500) Figure 4.1-3.1 reproduced below as Figure 1.13-I.



186.5 °R = -273.2 °F – Launch Commit Criteria (LCC) SSME-20, maximum PBP Disch T, T-3:50 to T-0:09.5, RSLs-01 (PBP warmer than interface)

178.0 °R = -281.7 °F – Interface Control Document (ICD) maximum Engine LO2 Inlet T at Engine Start command

172.0 °R = -287.7 °F – LCC MPS-24, maximum MPS LO2 in T, T-34:55 to T-4:55 (MPS LO2 in T colder than interface)

170.5 °R = -289.2 °F – LCC MPS-25, minimum MPS LO2 in T, T-0:75 to T-0:31 (0.5 °R is for cool-off from T-31 to Start)

170.0 °R = -289.7 °F – ICD minimum Engine LO2 Inlet T at Engine Start command

111 psia = 96.3 psig – ICD maximum Engine LO2 Inlet P at Engine Start Enable command

103 psia = 88.3 psig – ICD minimum Engine LO2 Inlet P at Engine Start Enable command

95 psia = 80.3 psig – LCC SSME-19, minimum LPOT Disch P, T-3:50 to T-0:09.5, RSLs-01

37.2 psia = 22.5 psig – LCC ET-06, maximum LO2 Ullage Pressure
(= ~107.5 psia = ~92.8 psig at LPOT Disch P location), T-2:13 to T-0:10 (this covers the ICD)

34.0 psia = 19.3 psig – LCC ET-06, minimum LO2 Ullage Pressure
(= ~104.3 psia = ~89.6 psig at LPOT Disch P location), T-2:13 to T-0:10 (this covers the ICD)

Figure 1.13-I - LO2 Pre-start Propellant Conditions (Startbox)
(Figure 4.1-3.1 from ICD-13M15000)

1.13.1.1 LO2 Startbox Temperature Constraints

- a. For the 30 minutes prior to LO2 Terminate Replenish (drainback start) at T-4 minutes, 55 seconds:

During this time the ET LO2 tank is in stable replenish. Facility LO2 enters the Orbiter through the 8-inch LO2 fill-drain line and flows into the MPS LO2 manifold. Engine LO2 prevalves are open at this time. Thus, engine LO2 inlets are exposed to facility LO2.

A maximum LO2 inlet temperature limit of 172.0°R or -287.7° F (continuously monitored per LCC MPS-24) ensures proper propellant conditioning and bleed flow. This limit ensures that bubbles will not form in the LO2 flowing from the facility, through the engine, and out the overboard bleed valve. This limit in the colder portion of the start box also ensures that the engine is able to tolerate warmer LO2 from the ET LO2 downcomer without producing bubbles in the LO2 after drainback is initiated. Bubbles in the LO2 system have the potential to produce catastrophic geysers during replenish or drainback and pump overspeeds during engine start.

- b. Subsequent to LO2 Terminate Replenish (drainback start) at T-4 minutes, 55 seconds, until T-31 seconds:

LO2 stable replenish is terminated at drainback start (closure of the LO2 Inboard Fill/Drain Valve). Liquid oxygen then begins to travel from the ET, through the downcomer, through the main engines, and then out of the Orbiter through the overboard bleed valve.

The LO2 in the downcomer is warmer and less dense than that in the ET because a greater surface area (relative to the quantity of LO2) is exposed to ambient temperatures, and the bulk temperature of the LO2 in the ET does not change a great deal over time. At drainback start, this warmer LO2 from the downcomer raises the engine inlet temperature. The minimum temperature limit of 172.0°R or -287.7° F maintained prior to drainback start ensures that the LO2 inlet temperature remains within the startbox during this temperature rise. The timing of the events also gives a small amount of hold time after the planned T-zero prior to the entrance of the colder LO2 into the SSME and violation of the lower temperature requirement. The hold time estimate is documented in OMRSD File II , Volume 1, S00E00.125.

The lower temperature limit of the engine startbox is violated when the LO2 inlet temperatures fall below 170.5 °R or -289.2° F (per LCC MPS-25). This situation will occur after the warm LO2 in the downcomer drains away and is replaced by cooler fluid from the ET. This limit is monitored until T-31 seconds and ensures that the ICD minimum allowable SSME LO2 inlet temperature limit of 170.0 °R or -289.7° F is satisfied at engine start command. Violation of this temperature limit indicates the LO2 has become too cold and dense. In this case, the increased density of the LO2 entering the SSME may

result in a large increase in the preburner mixture ratio. If the preburner mixture ratio is too high, turbine inlet temperature limits can be exceeded and the pump can overspeed with catastrophic results.

- c. During the time period of T-3 minutes, 50 seconds (SSME purge sequence 4 +10 seconds) and until T-9.5 seconds (SSME Start Enable):

The SSME LO2 Preburner Boost Pump (PBP) Discharge Temperature is monitored for a maximum value of 186.5 °R or -273.2 °F by LCC SSME-20. This limit verifies that proper quality (sub-cooled) propellant is supplied to the engine to ensure that the start will occur properly. The limit is derived from maximum acceptable temperature based on anti-geyser line removal simulation test experience. If this limit is violated, a FID and MCF are posted and Engine Start inhibited on second redline violation – FID 012-005 “ENGINE READY – PBP DISCH TA” and 012-006 “ENGINE READY – PBP DISCH TB”. The MCF causes the RSLs to invoke a hold (LCC RSLs-01). No FID or inhibit occurs until after Engine Ready is obtained or Start Enable command is given without Engine Ready.

1.13.1.2 LO2 Startbox Temperature Constraints Turnaround Requirements

Consult Figure 1.13-II for the following discussion. The following outlines the time required for countdown resumption subsequent to a launch hold due to an LO2 startbox temperature violation occurring after drainback start.

- (1) An estimated 30 minutes are required to reestablish MPS valve configuration, to revert to LO2 stable replenish, and to reestablish LO2 inlet temperatures.
- (2) A minimum of 60 minutes in stable replenish is required before re-initiation of drainback start (reference LCC MPS-24). This ensures that engine inlet temperatures are maintained within limits (LO2 inlet temperatures less than 172.0°R or -287.7° F) and ensures that the engine is properly conditioned thermally so that startbox conditions are met for engine start. The 60 minute requirement is based on SSME test stand experience.
- (3) An allotment of 4 min 55 sec from drainback start to launch is required.

Note: With 90 minutes of stable replenish (as in a nominal count – reference LCC MPS-24), approximately 4 to 5 minutes of hold capability can be established (reference OMRSD File II, Volume 1, S00E00.125).

Since the clock will revert to T-20 minutes due to a SSME startbox violation, it may be re-started approximately 35 minutes after the initiation of stable replenish. Alternatively, the clock can also be resumed any time before this and held at T-5 until 60 minutes of stable replenish has been established.

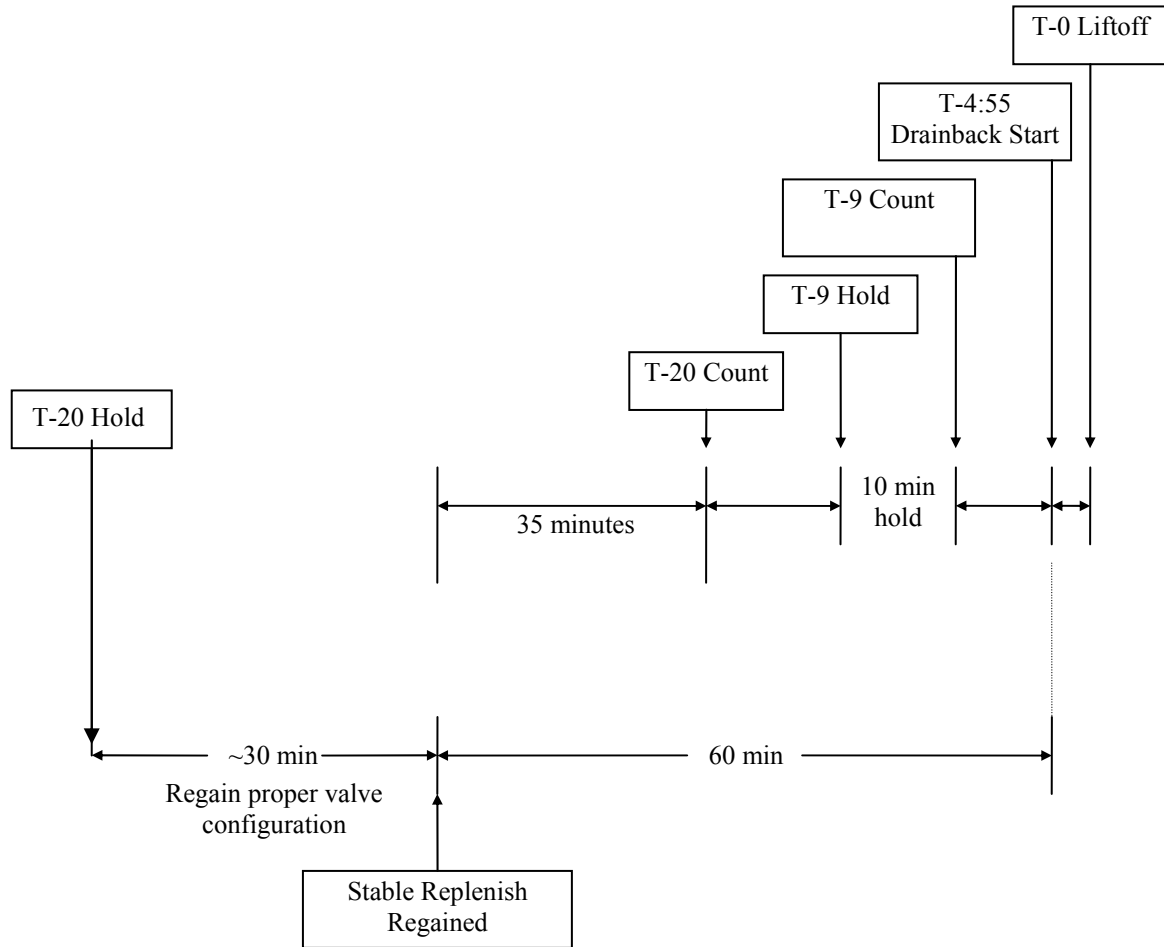


Figure 1.13-II - Launch Turnaround Timetable

Illustration of the shortest possible timeline in the event of a launch recycle due to an LO2 startbox temperature violation after drainback start.

1.13.1.3 LO2 Startbox Pressure Constraints

- a. During the time period of T-3 minutes, 50 seconds (SSME purge sequence 4 +10 seconds) until T-9.5 seconds (SSME Start Enable):

The SSME LO2 Low Pressure Oxidizer Turbopump (LPOT) Discharge Pressure is monitored for a minimum value of 95 psia by LCC SSME-19. This limit verifies proper SSME propellant feed system pressure to ensure that SSME start will occur properly. If this limit is violated, a FID and MCF are posted and Engine Start inhibited on second redline violation – FID 012-007 “ENGINE READY – LPOT DISCH PA” and FID 012-010 “ENGINE READY – LPOT DISCH PB”. The MCF causes the RSLs to invoke a hold (LCC RSLs-01). No FID or inhibit occurs until after Engine Ready is obtained or Start Enable command is given without Engine Ready.

- b. During the time period of T-2 minutes, 13 seconds until T-10 seconds (Go For SSME Start):

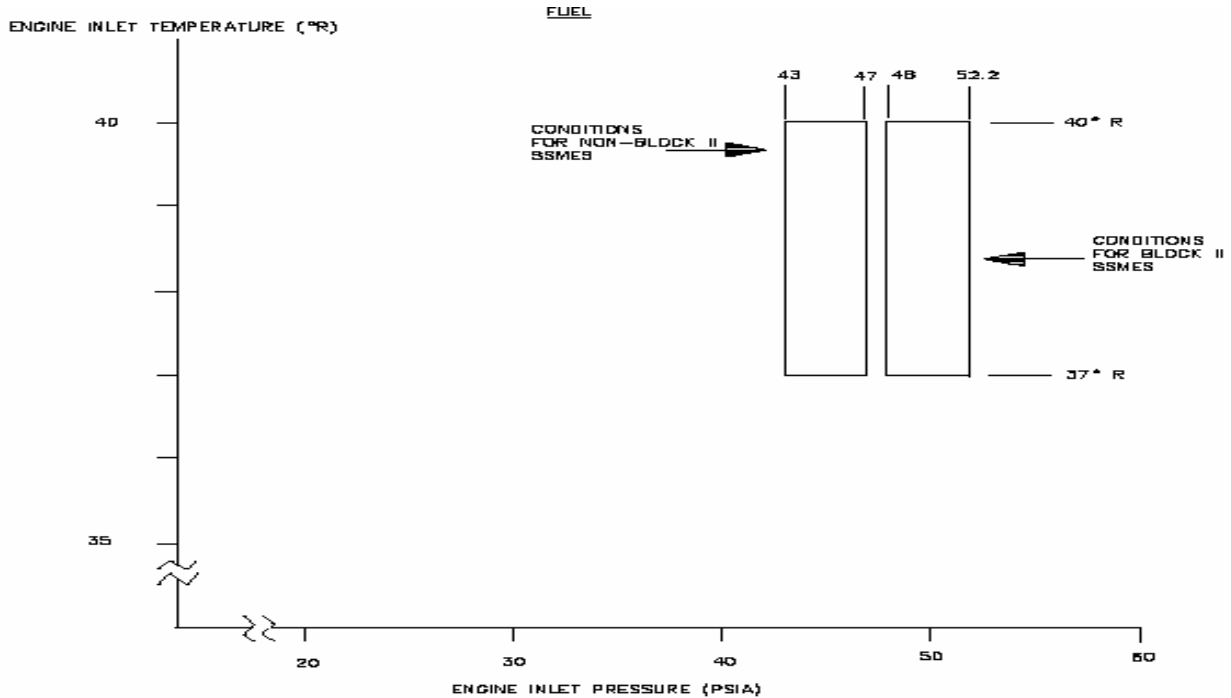
The ET LO2 Ullage Pressure is monitored to be between 34.0 and 37.2 psia (19.3 to 22.5 psig) by LCC ET-06. This limit verifies proper SSME propellant feed system pressure to ensure that SSME start will occur properly (covers the ICD) as well as ensuring that the ullage pressure is within LO2 ET structural design limits during prepress.

1.13.1.4 LO2 Startbox Pressure Constraints Turnaround Requirements

There are no preplanned contingency procedures for LO2 startbox pressure constraint violations.

1.13.2 LH2 Startbox

The SSME LH2 startbox is defined in the Space Shuttle Orbiter Vehicle / Main Engine Interface Control Document (ICD-13M1500) Figure 4.1-1.1 reproduced below as Figure 1.13-III.



- 44.7 °R = -415.0 °F – LCC MPS-11, max. LH2 High Point Bleed T (backup measurement), T-0:75 to T-0:31 (protects database)
- 42.0 °R = -417.7 °F – LCC SSME-18, max. Low Pressure Fuel Pump (LPFP) Disch T, T-3:50 to T-0:09.5, RSLs-01 (LPFP is warmer than interface)
- 40.7 °R = -419.0 °F – LCC MPS-11, maximum LH2 17 inch disc T, L-30:00 to T-0:31 (protects database)
- 40.0 °R = -419.7 °F – ICD maximum Engine LH2 Inlet T for three minutes prior to Engine Start.
- 37.0 °R = -422.7 °F – ICD minimum Engine LH2 Inlet T for three minutes prior to Engine Start.
- 37.0 °R = -422.7 °F – LCC SSME-18, minimum LPFP Disch T, T-3:50 to T-0:09.5, RSLs-01 (same as interface)

3 Block II SSMEs:

- 60.0 psia – LCC SSME-17, maximum LPFP Disch P, T-3:50 to T-0:09.5, RSLs-01 (pressure is higher here than at inlet)
- 53.0 psia – LCC SSME-17, minimum LPFP Disch P, T-3:50 to T-0:09.5, RSLs-01 (pressure is higher here than at inlet)
- 52.2 psia – ICD maximum Engine LH2 Inlet P at Engine Start Enable command.
- 48.0 psia – ICD minimum Engine LH2 Inlet P at Engine Start Enable command.

Less than 3 Block II SSMEs:

- 55.0 psia – LCC SSME-17, maximum LPFP Disch P, T-3:50 to T-0:09.5, RSLs-01 (pressure is higher here than at inlet)
- 48.0 psia – LCC SSME-17, minimum LPFP Disch P, T-3:50 to T-0:09.5, RSLs-01 (pressure is higher here than at inlet)
- 47.0 psia – ICD maximum Engine LH2 Inlet P at Engine Start Enable command.
- 43.0 psia – ICD minimum Engine LH2 Inlet P at Engine Start Enable command.

Figure 1.13-III - LH2 Pre-start Propellant Conditions (Startbox)
(Figure 4.1-1.1 from ICD-13M15000)

1.13.2.1 LH2 Startbox Temperature Constraints

Thirty minutes of continuous LH2 recirculation is required prior to LH2 tank prepress at T-1:57 (per LCC MPS-33, see also OMRSD File II, Volume 1, S00E00.576) for SSME temperature stabilization. This prevents the formation of bubbles in the fuel lines that could cause SSME fuel pump cavitation and hardware damage during SSME ignition. The LH2 engine inlet temperature constraints are shown in Figure 1.13-III above.

- a. During the time period of L-30 minutes to Go For RSLs Start (T-31 Seconds):

LCC MPS-11 requires the MPS LH2 17 inch Feedline Manifold Disconnect Temperature to be a maximum of 40.7 °R or -419.0 °F. A backup measurement is the GSE High Point Bleed Temperature with a maximum of 44.7 °R or -415.0 °F from T-75 seconds to Go For RSLs Start (T-31 seconds). These values protect the database - see LCC MPS-11 for specific details.

- b. During the time period of T-3 minutes, 50 seconds (SSME purge sequence 4 +10 seconds) until T-9.5 seconds (SSME Start Enable):

The SSME LH2 LPFP (also known as the Low Pressure Fuel Turbopump – LPFT) Discharge Temperature is monitored for a minimum value of 37.0 °R or -422.7 °F and a maximum value of 42.0 °R or -417.7 °F by LCC SSME-18. This limit verifies proper quality (sub-cooled) propellant is supplied to the engine to ensure that the start will occur properly. If this limit is violated, a FID and MCF are posted and Engine Start inhibited – FID 012-003 “ENGINE READY – LPFT DISCH TA” and FID 012-004 “ENGINE READY – LPFT DISCH TB”. All qualified sensors must meet Engine Ready limits - see LCC SSME-34 for qualification limits. The MCF causes the RSLs to invoke a hold (LCC RSLs-01). No FID or inhibit occurs until after Engine Ready is obtained or Start Enable command is given without Engine Ready.

1.13.2.2 LH2 Startbox Temperature Constraints Turnaround Requirements

LH2 recirc interruptions of less than one minute duration are acceptable from L-30 to T-5 minutes. Between T-5 minutes and T-1:57, interruptions of less than one minute duration are acceptable provided that launch is delayed to provide at least 3.5 minutes of continuous recirc prior to terminate LH2 replenish at T-1:57. After T-1:57, interruptions of any duration are not acceptable (reference LCC MPS-33 – monitored from L-30 minutes to T-75 seconds). After T-75 seconds and until T-9.5 seconds (Start Enable), LCC SSME-17 (SSME LPFP Discharge Pressure Engine Ready Anomaly) will detect loss of LH2 recirculation.

The redline ensures adequate engine conditioning for nominal start sequence/performance when orbiter recirculation pump interruption is preceded by a normal hydrogen loading profile. All engine starts during ground testing are preceded by at least one hour of continuous LH2 conditioning at less than nominal orbiter recirculation pump flow rate. Thirty minutes of orbiter

recirculation pump operation is considered equivalent to this ground test experience. Testing indicates that engine temperatures will recover within 5 minutes after a one minute interrupt.

LH2 recirculation pump termination occurs at T-9.4 seconds. There is no impact to the LH2 system if a scrub occurs for a problem in another system prior to this time because the recirculation pumps will remain "ON" maintaining the LH2 in a sub-cooled state. Due to the LH2 recirculation system and the short LH2 17 inch feedline, there are no significant temperature excursions or geyser concerns in the LH2 system as there are in the LO2 system.

The external Long Throw Hydrogen Igniters (the "sparklers") are ignited at T-10 seconds to burn off any free hydrogen prior to SSME ignition. Free hydrogen in the SSME nozzle area can result in unstable ignition events ("pops") that can damage engine hardware. Replacement of the external Long Throw Hydrogen Igniters typically requires a 48 hour scrub since 22 hours are required to boil off ET propellants, and Engine Servicing Platforms must be installed.

1.13.2.3 LH2 Startbox Pressure Constraints

- a. During the time period of T-3 minutes, 50 seconds (SSME purge sequence 4 +10 seconds) until T-9.5 seconds (SSME Start Enable):

The SSME LH2 LPFT Discharge Pressure is monitored for a minimum value of 53.0 psia and a maximum value of 60.0 psia (for three Block II SSMEs) or a minimum value of 48.0 psia and a maximum value of 55.0 psia (for less than three Block II SSMEs) by LCC SSME-17. These limits verify proper SSME propellant feed system pressure to ensure that SSME start will occur properly.

If one of these limits are violated, a FID and MCF are posted and Engine Start inhibited on second redline violation – FID 012-001 "ENGINE READY – LPFT DISCH PA" and FID 012-002 "ENGINE READY – LPFT DISCH PB". The MCF causes the RSLs to invoke a hold (LCC RSLs-01). No FID or inhibit occurs until after Engine Ready is obtained or Start Enable command is given without Engine Ready.

1.13.2.4 LH2 Startbox Pressure Constraints Turnaround Requirements

The LH2 startbox pressure constraints turnaround requirements are identical to those for the LH2 startbox temperature constraints – see section 1.13.2.2 above.

1.13.3 Summary

MPS LO2 inlet temperatures must be maintained at or below -287.7 °F prior to drainback start (LCC MPS-24) and at or above -289.2 °F from T-0:75 to T-0:31 (LCC MPS-25). The SSME LO2 Preburner Boost Pump (PBP) Discharge Temperature must be maintained at or below 186.5 °R from T-3:50 to T-0:09.5 (LCC SSME-20).

ET LO2 ullage pressure must be maintained at or between 19.3 psig and 22.5 psig from T-2:13 to T -0:10 (LCC ET-06).

The minimum turnaround time for LO2 inlet temperature violations from the “go for turnaround” call to drainback start is 90 minutes. The minimum turnaround time from the “go for turnaround” call to launch is 95 minutes.

The MPS LH2 17 inch disconnect temperature must be maintained at or below -419.0 °F (LCC MPS-11) from L-30:00 to T-0:31. The SSME LPFP Discharge Temperature must be maintained at or between 37.0 °R and 42.0 °R from T-3:50 to T-0:09.5 (LCC SSME-18).

The SSME LPFP Discharge Pressure must be maintained at or between 53.0 and 60.0 psia from T-3:50 to T-0:09.5 for 3 Block II SSMEs, and at or between 48.0 and 55.0 psia from T-3:50 to T-0:09.5 for less than 3 Block II SSMEs (LCC SSME-17).

For proper engine thermal conditioning, only short interruptions (less than one minute) are allowed in LH2 recirculation pump operation down to T-5 minutes (around T-6 minutes taking into account cutoff length). From around T-6 minutes to T-9.4 seconds no interruptions in LH2 recirculation pump operation are allowed.

1.13.4 Appendix – nominal prelaunch data from STS-108

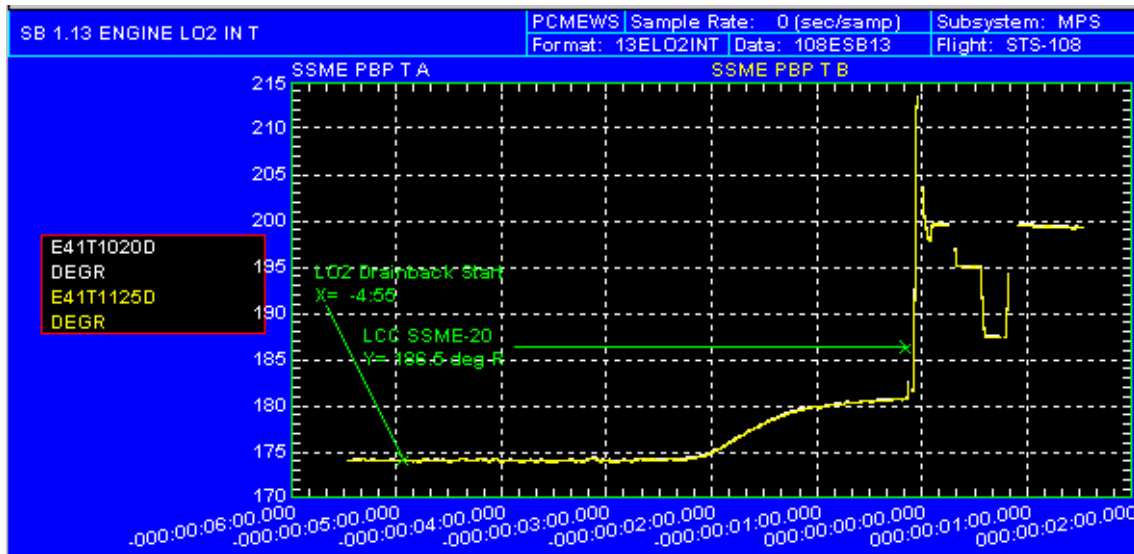


Figure 1.13-IV - LCC SSME-20 Nominal SSME LO2 PBP Discharge Temperature Data

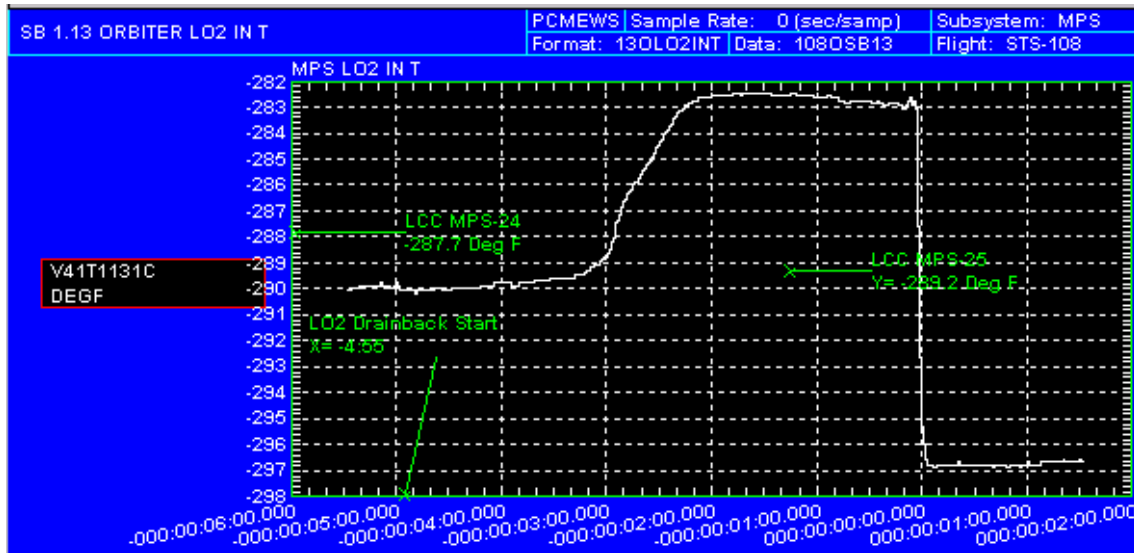


Figure 1.13-V - LCC MPS-24/25 Nominal MPS LO2 Inlet Temperature Data

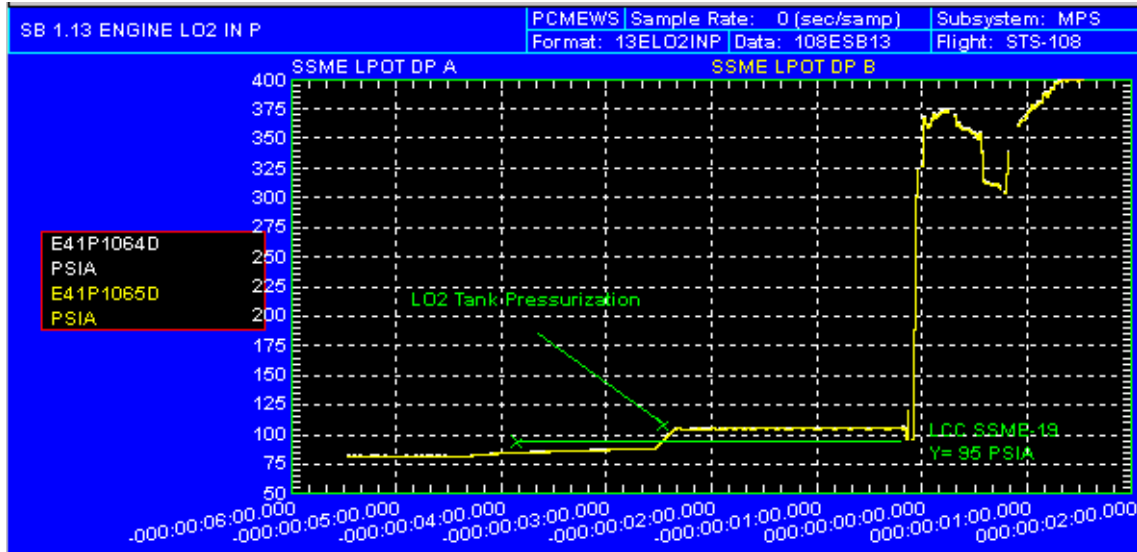


Figure 1.13-VI - LCC SSME-19 Nominal SSME LO2 LPOT Discharge Pressure Data

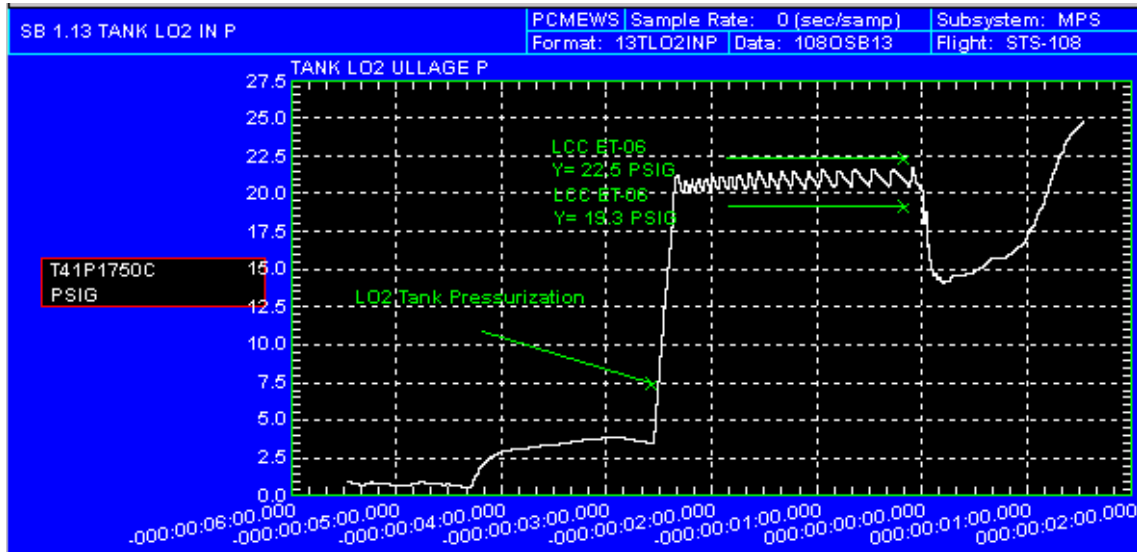


Figure 1.13-VII - LCC ET-06 Nominal ET LO2 Pressure Data

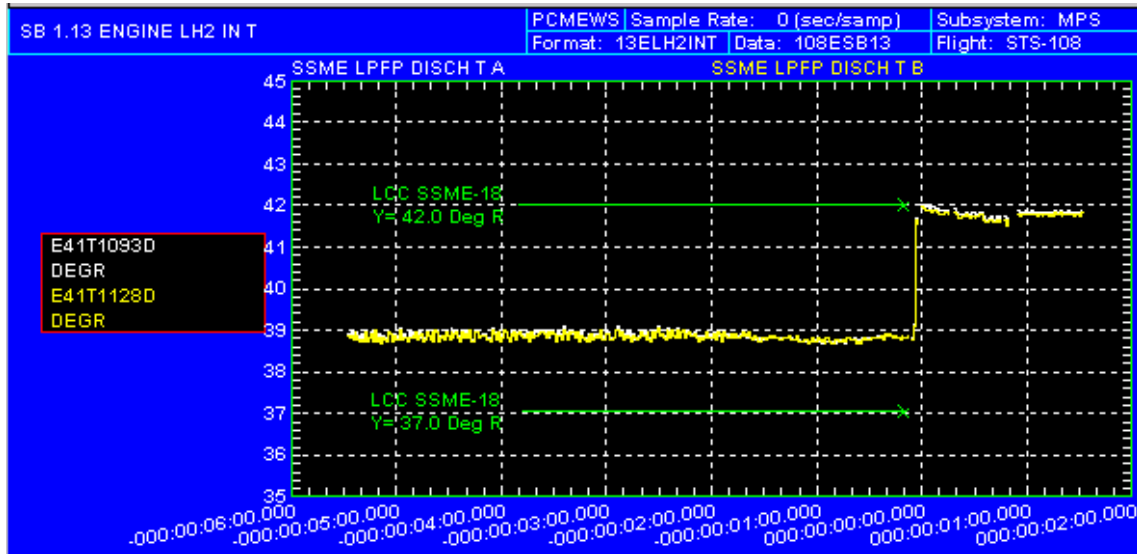


Figure 1.13-VIII - LCC SSME-18 Nominal SSME LH2 LPFP Discharge Temperature Data

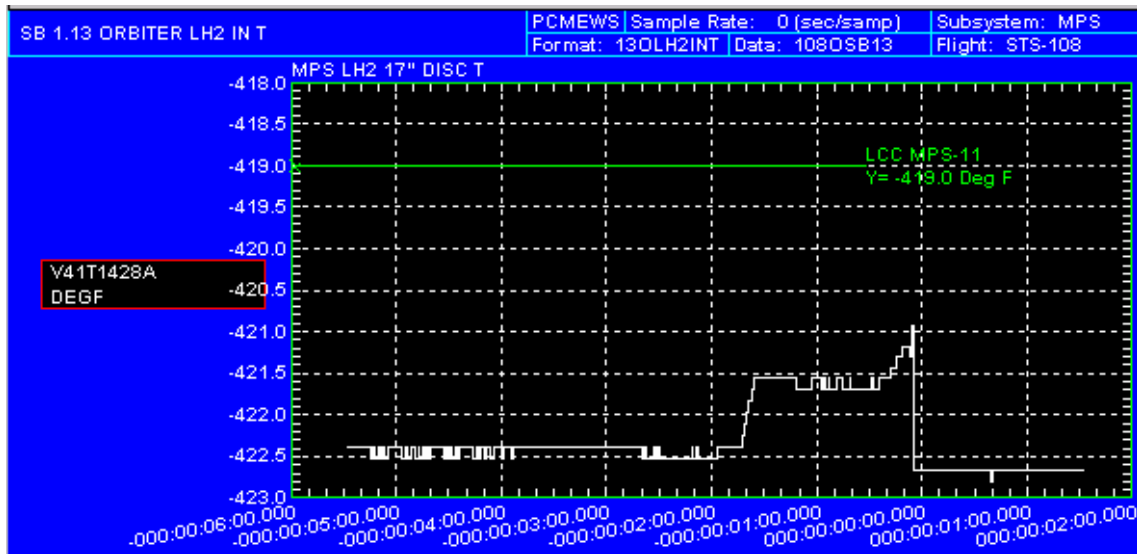


Figure 1.13-IX - LCC MPS-11 Nominal MPS LH2 Disconnect Temperature Data

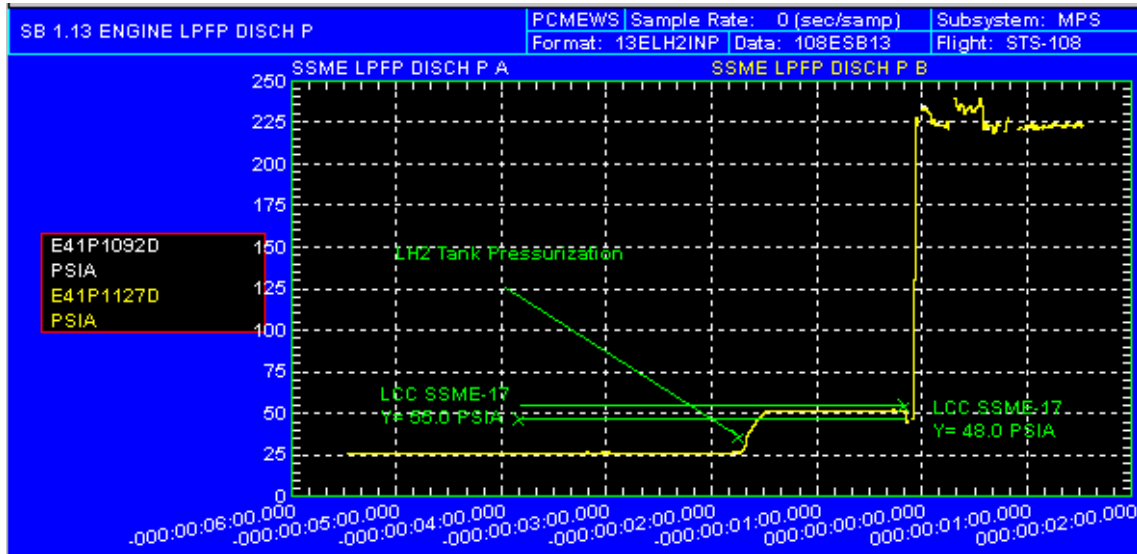


Figure 1.13-X - LCC SSME-17 Nominal SSME LH2 LPFP Discharge Pressure Data (Less Than 3 Block II SSMEs)

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1.14 SSME POGO SUPPRESSION SYSTEM

1.14.1 Introduction

Pogo is a longitudinal vehicle instability due to closed-loop coupling of the vehicle structure (including payload), engines, and propellant delivery system. Low-frequency (5-20 Hz) propellant flow and pressure oscillations affect the performance of the propellant pumps (primarily the head rise). Propellant pump exit pressure oscillations affect the combustion process in the main combustion chamber (MCC), which results in a positive feedback into the propellant, feed system. Propellant pumps act as amplifiers in this process. The end result is that

the crew is bounced around like they are riding a Pogo stick. The Jupiter, Thor, Thor-Delta, Atlas, Titan II - Gemini, and Saturn programs all suffered to varying degrees the affects of Pogo.

A simplified example of Pogo is as follows: In a Saturn S-II stage, as LO2 pump inlet pressure rises, more liquid oxygen (LO2) is sent to the main combustion chamber (MCC) of each of the 5 J-2 engines. More LO2 in the MCC means a higher chamber pressure (P_c) which means more thrust. As thrust increases, the pressure drop across the injector face increases, which decreases LO2 flow into the MCC. The increased thrust also has structural effects on the vehicle. As the LO2 flow decreases, the P_c goes down, which lowers the thrust and the LO2 pump inlet pressure. Due to the structural lag effects and since the vehicle is under acceleration, the LO2 pump inlet pressure rises again thus starting the cycle over.

If this oscillation in P_c is near the natural frequency of vehicle (several cycles per second - but varies as propellants are consumed), then Pogo can be a major problem.

Pogo suppression systems were added to the above-mentioned vehicles to damp out pressure surges in the propellant feed systems. Pogo damper systems have typically included a gas bubble or piston which acts like a shock absorber to damp out fluid pressure and flow oscillations. The Titan II originally added a contained gas accumulator system (standpipe) on the oxidizer feedline then additionally included a spring/piston system on the fuel feedline as well. In the S-I stage, Pogo on the F-1 engines was effectively controlled using a helium precharge after LO2 tanking (but prior to tank pressurization) in an annular volume in the LO2 valve housings of the four outside engines. The precharge was combined with a small helium trickle purge into the LO2 feedlines initiated at engine start (to maintain the valve housing helium charge). The center engine used no helium precharge or trickle purge since analysis showed this would cause a Pogo problem at a higher frequency.

The Saturn S-II stage originally used no Pogo suppression - but Pogo was discovered late during the second stage burn on the first manned flight: AS-503. The AS-503 Pogo was caused mostly by the center engine of the 5 engine J-2 cluster. The first remedy attempt was to simply increase the LO2 tank pressure - this did not eliminate Pogo on flight AS-504. The next remedy was to cutoff the center engine 75 seconds early and burn the remaining engines longer with a slight

drop in performance. The early cutoff method was used for flights AS-505 through AS-508, but continuing Pogo concerns with both the S-II and S-IV-B stages resulted in the implementation of a helium-bleed toroidal Pogo suppressor - also known as an overflow gas accumulator. The Pogo suppressor was installed on the oxidizer feedline of both the S-II and S-IV-B stages for all subsequent flights. This solved Saturn Pogo problems.

The early design of the space shuttle main engine (SSME) had to eliminate Pogo to ensure vehicle stability from the beginning of the program since vibration and overall G limits on the vehicle were more confining than any previous space vehicle - and there were to be no unmanned test flights. The SSME uses an engine mounted spherical Pogo accumulator located between the low pressure and high-pressure LO₂ pumps. With special test equipment, the Pogo suppression system could be tested on engine test stands before the vehicle ever flew. Like the Saturn, the SSME uses an overflow gas accumulator, but it uses gaseous oxygen (GO₂) instead of helium. GO₂ is a condensable gas in LO₂. The concern was that accumulator overflow of a non-condensable gas, such as helium (in LO₂), would result in pump cavitation and catastrophic overspeed of the high-pressure oxidizer turbopump (HPOTP).

It is not clear that a Pogo suppression system is really needed on the Space Shuttle. Unlike previous vehicles, the SSME has a closed loop thrust control system that operates into the Pogo frequency range. The SSME controller operates at 50 Hz, Pogo is found at 5 to 20 Hz. The Space Shuttle also has a different engine to vehicle structural configuration. SSMEs are offset from the vehicle centerline - which tends to avoid vehicle natural frequency coupling. However, since the SSME Pogo system exists, this systems brief will describe how it works by describing the sequence of events that take place from just prior to engine start until just after engine shutdown.

1.14.2 Pre-Launch

Refer to Figures 1.14-I, 1.14-II, and 1.14-III. During prelaunch, the entire engine liquid oxygen (LO2) system upstream of the main combustion chamber is chilled down. LO2 flows through the open LO2 prevalve, the low-pressure oxidizer turbopump (LPOTP), and the high-pressure oxidizer turbopump (HPOTP) down to the main oxidizer valve (MOV), oxidizer preburner oxidizer valve (OPOV), and fuel preburner oxidizer valve (FPOV), which are closed. Heat "soaks" into the engine and vaporizes the LO2. LO2 vapor is collected and is bled overboard through the open SSME oxidizer bleed valve (OBV). The orbiter Pogo recirculation isolation valves (POGOs) and engine recirculation isolation valve (RIV) are closed to ensure that this is the only path for LO2 vapor since an open Pogo suppression system would short circuit the bleed path.

1.14.3 Engine Start

During engine start, the anti-flood valve (AFV) is closed to prevent LO2 from flowing into the heat exchanger (HEX) until sufficient heat is present in the HPOTP turbine exhaust to vaporize the LO2 into GO2. "Sufficient heat" is indirectly determined by HPOTP LO2 exit pressure. Once the HPOTP LO2 exit pressure in the duct is between 200 and 300 PSI delta, the AFV is opened by this pressure. The open AFV allows LO2 to flow into the heat exchanger to form GO2. The GO2 then flows to the flow control valves (FCV) to pressurize the ET LO2 tank and also to the GO2 control valve (GCV) to pressurize the Pogo accumulator. Since Pogo suppression is desired during engine start before GO2 is flowing out of the heat exchanger, the Pogo accumulator is pre-charged with helium from the helium precharge valve (HPV). The helium precharge provides an ullage bubble in the Pogo bottle for the GO2 to flow into when the AFV opens. Without the helium precharge, it would take two to three seconds to pressurize the Pogo accumulator with GO2 from the heat exchanger. Just prior to liftoff, the Pogo recirculation isolation valves are opened, and the SSME oxidizer bleed valve and orbiter overboard bleed valves are closed.

The GCV and HPV are operationally interconnected. When the HPV solenoid (in the SSME pneumatic control assembly - the PCA) is energized, helium from the HPV is routed up to the GCV to close the GCV. The GCV opens when the HPV solenoid is turned off and if there is sufficient GO2 pressure from the heat exchanger. The RIV is spring loaded to open, but the GO2 that opens the GCV also ensures that the RIV opens. The RIV is pneumatically closed. The pneumatic pressure that closes the RIV opens the SSME oxidizer bleed valve.

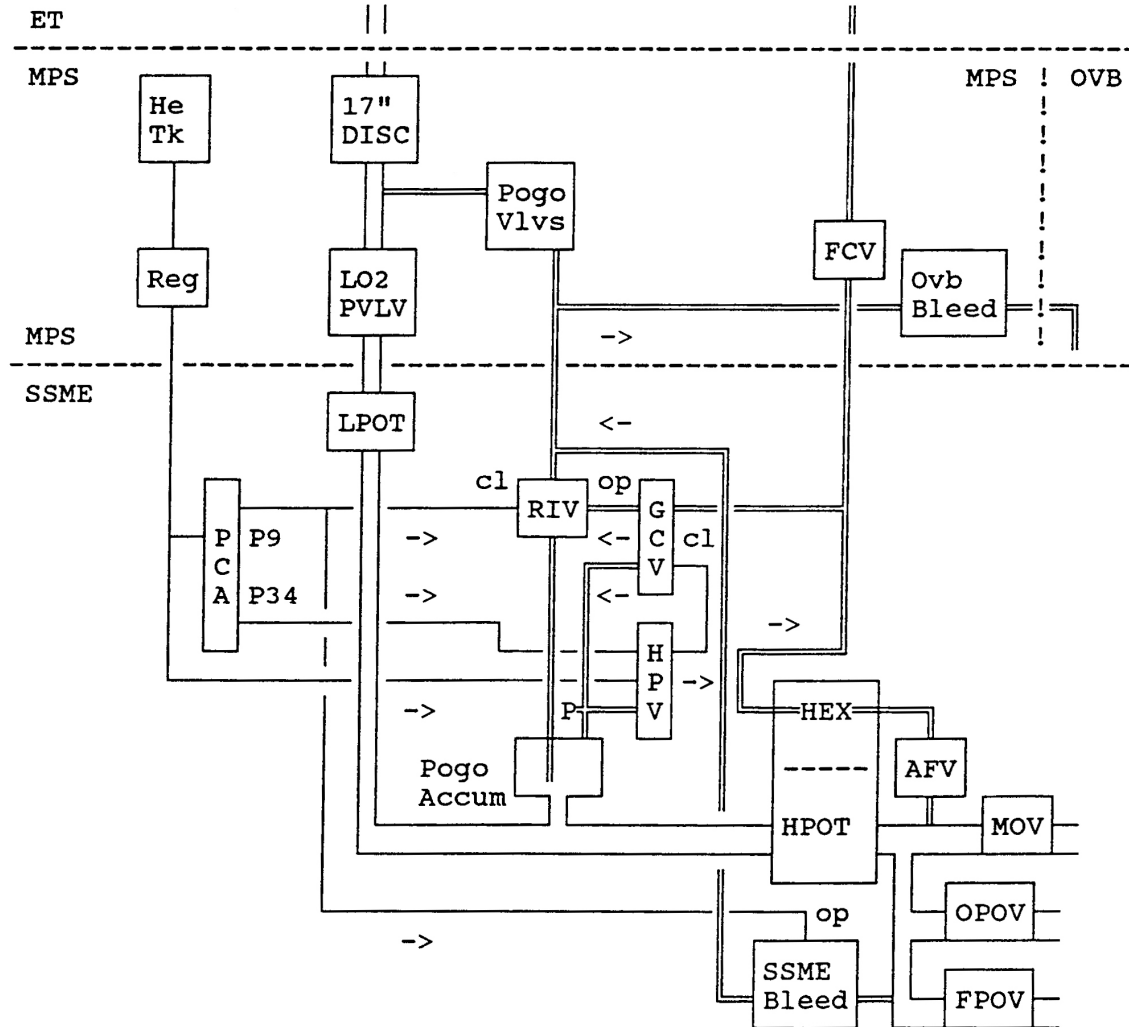
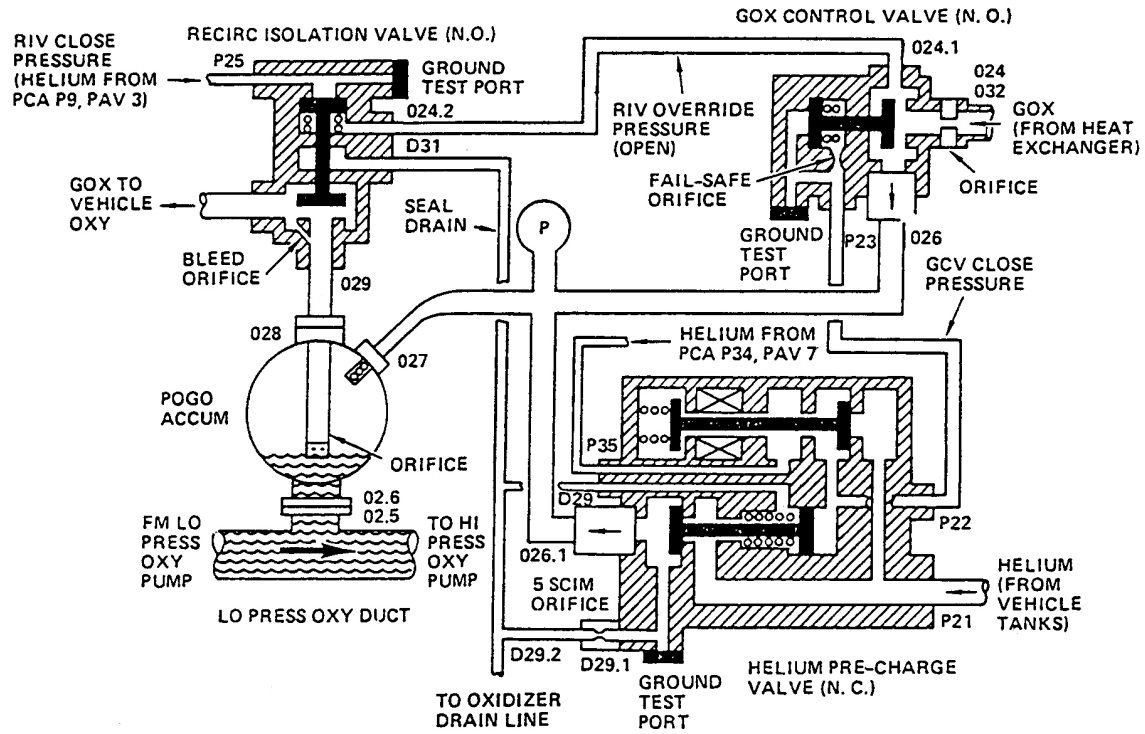


Figure 1.14-I - Pogo Suppression System

POGO ACCUM PRESSURIZING SYSTEM



LSS-ES-T-327D

Figure 1.14-II - Pogo Accumulator Pressurization System

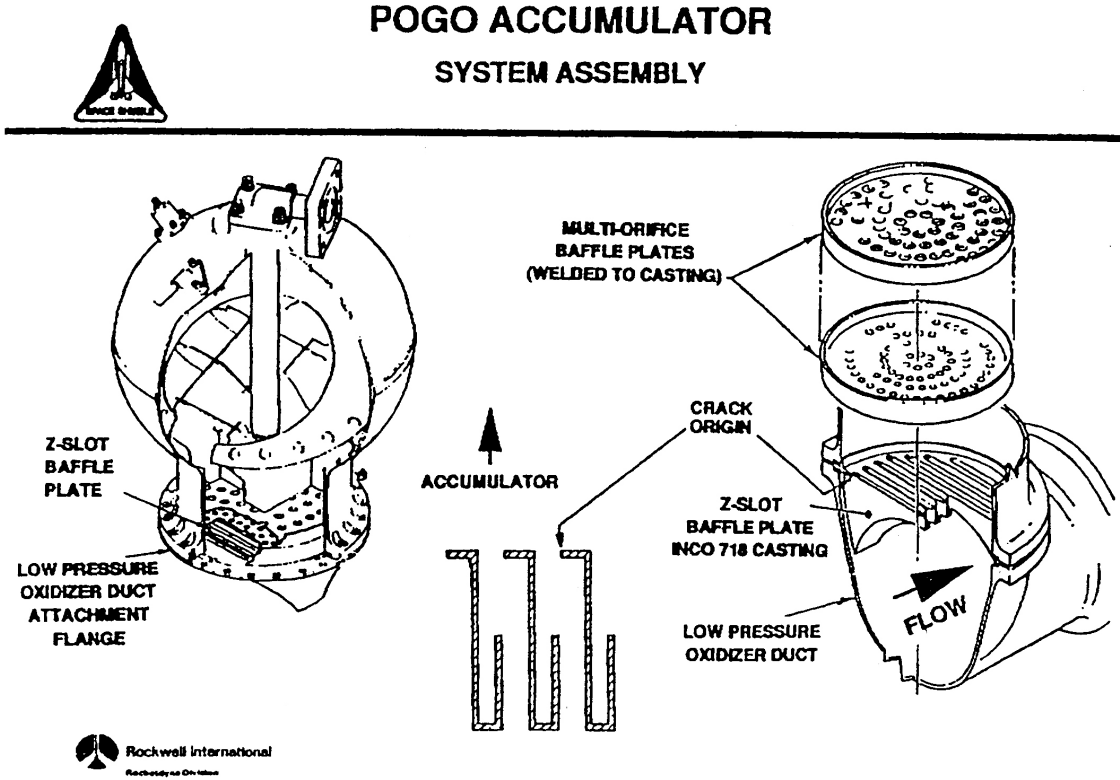


Figure 1.14-III - Pogo Bottle Detail

1.14.4 Mainstage

GO2 is supplied at a constant rate to the Pogo accumulator. The liquid/gas interface is regulated when excess GO2 pushes the liquid interface below the level of the standpipe (overflow tube) which has six small exit holes at the bottom. The GO2 overflow goes through the RIV and POGO valves and enters the LO2 system upstream of the pre valve, where it is condensed back into liquid. GO2 overflow is routed through the bleed system to minimize amount of plumbing which reduces weight and the number of MPS/engine interfaces. GO2 overflow is routed into the LO2 feedline near the 17" disconnect to maximize the time available for GO2 to collapse / condense before entering the LPOT.

GO2 is supplied to the Pogo bottle by an inlet diffuser that breaks up the incoming stream of gas. There is a pressure transducer upstream of the diffuser to monitor the precharge pressure during start and shutdown. The Pogo accumulator liquid interface has cruciform and ring baffles to reduce sloshing of the LO2 in the feed line between the pumps (see Figure 1.16-III). Z-slot and multi-orifice baffle plates prevent surface turbulence and gas ingestion by the HPOTP.

1.14.5 Software Sequencing

1.14.5.1 Prelaunch

During tanking, the engine is in the start prep mode. This is known as purge sequences 1, 2, 3, and 4. The Pogo precharge pressure transducer qualification limits are 0 to 1600 PSIA. These are the only limits in effect on the Pogo pressure in the prelaunch timeframe. The transducer range is 0 to 1500 PSIA with a 2% of full scale accuracy. Qualification limits detect transducer failures such as open or short circuits that cause the pressure to go off-scale high or low. There is one transducer for each controller channel (A and B). Failure identification word (FID) number

FID 111-701:

1ST SEN CH DQ-
POGO PRCHG PA

or

FID 111-702:

1ST SEN CH DQ-
POGO PRCHG PB

will be posted if one transducer channel violates the qualification limit while in start prep. A resumable major component failure (MCF) and a start inhibit will be issued for one transducer failing the qualification limit. The RSLs sees the MCF and issues an RS Hold.

For a second transducer failing qualification during the start prep to start initiate,

FID 011-701:

RDNT SEN FAIL-
POGO PRCHG PA

or

FID 011-702:

RDNT SEN FAIL-
POGO PRCHG PB

is posted. A non-resumable MCF and start inhibit are now issued. These are in addition to those originally posted for the first disqualification.

During prelaunch, the Pogo precharge pressure transducer also has engine controller monitored purge and ancillary limits. From start prep to start enable (approximately T-9 seconds) a

FID 014-001:

PGE & ANC SYS-
POGO PRCHG PA

or

FID 014-002:

PGE & ANC SYS-
POGO PRCHG PB

and a resumable MCF are issued if one pressure transducer rises above 1425 PSIA. For a second failure the MCF is non-resumable. These limits are essentially a tighter qualification range. The MCF causes an RS Hold (pad abort).

1.14.5.2 Engine Start

If one transducer fails the 0 to 1600 PSIA qualification limit from engine start +2.40 seconds to start +4.40 seconds, the controller issues a report only

FID 111-701:

1ST SEN CH DQ-
POGO PRCHG PA

or

FID 111-702:

1ST SEN CH DQ-
POGO PRCHG PB

No MCF is issued for either of these FIDs in this case.

If a second transducer fails the qualification limits during start +2.40 seconds to start +4.40 seconds, the controller issues a

FID 011-701:

RDNT SEN FAIL-
POGO PRCHG PA

or

FID 011-702:

RDNT SEN FAIL-
POGO PRCHG PB

with a non-resumable MCF.

At start enable, the HPV is energized for 440 milliseconds (ms). This is known as the pre-charge. 120 ms after the HPV is energized, the Pogo pressure is required to be above 600 PSIA and stay above 600 PSIA until start enable +440 ms (320 ms duration). At 200 ms after the HPV is de-energized, the pressure is required to drop below 150 PSIA and stay below 150 PSIA until engine start. The HPV is energized to check out the Pogo suppression system before engine start. The limits verify the HPV can be energized and de-energized. If the HPV is not de-energized, helium would overflow the accumulator and be ingested by the HPOT. This would cause pump cavitation and overspeed. A

FID 014-001:

PGE & ANC SYS-
POGO PRCHG PA

or

FID 014-002:

PGE & ANC SYS-
POGO PRCHG PB

and a resumable MCF are issued if one Pogo pressure transducer violates these limits. The MCF causes an RS Hold (pad abort). A second failure results in a non-resumable MCF.

From 2.30 to 2.34 seconds after engine start, it is required that sufficient HPOTP outlet pressure (200 - 300 PSI delta) be available to open the AFV. This is an ignition confirm test. During this time, if one AFV linear variable differential transducer (LVDT) indicates that the valve is not open more than 80%, or both LVDTs are disqualified, a

FID 013-007:

LIMIT SD -
IGNC-AFV POS A

or

FID 013-010:

LIMIT SD -
IGNC-AFV POS B

is issued and the engine shuts down pneumatically. This causes a pad abort.

Qualification limits on the LVDT from 2.30 to 2.34 seconds after engine start are between -10% and 40% open or between 60% and 110% open.

FID 111-505:

1ST SEN CH DQ-
IGNC-AFV POS A

or

FID 111-506:

1ST SEN CH DQ-
IGNC-AFV POS B

or

FID 011-505:

RDNT SEN FAIL-
IGNC-AFV POS A

or

FID 011-506:

RDNT SEN FAIL-
IGNC-AFV POS B

will be issued for the first (top two FIDs) and second (bottom two FIDs) disqualifications, respectively. If both LVDT transducers are disqualified for all three controller major cycles of this ignition confirm test, shutdown is performed with FID 013-007 or FID 013-010 being annunciated (see above).

At 2.40 seconds after engine start, the HPV is energized for 2.00 seconds. This is known as the pre-charge. 120 ms later and during the remainder of the 2.00 second pre-charge, the accumulator pressure is required to be above 600 PSI.

FID 014-001:

PGE & ANC SYS-
POGO PRCHG PA

or

FID 014-002:

PGE & ANC SYS-
POGO PRCHG PB

and a non-resumable MCF are issued if a single transducer is below 600 PSIA.

When the HPV is de-energized, the GCV is required to open and start supplying GO2 to the accumulator. 4.94 seconds after engine start, a one time check (40 ms) is made to see if the GO2 is flowing through the GCV. This check is accomplished by verifying that the accumulator pressure is above 800 PSIA and below 1425 PSIA. This is called the Pogo GO2 flow check. A

FID 014-025:

PGE & ANC SYS-
POGO PRCHG PA

or

FID 014-026:

PGE & ANC SYS-
POGO PRCHG PB

and an MCF are issued if one pressure transducer violates these limits. The MCF causes a pad abort.

Qualification limits during the Pogo GO2 flow check are 0-1600 PSIA. No MCF is issued for the first failure:

FID 111-601:

1ST SEN CH DQ-
POGO PRCHG PA

or

FID 111-602:

1ST SEN CH DQ-
POGO PRCHG PB

But a second failure does cause an MCF and the resulting pad abort:

FID 011-601:

RDNT SEN FAIL-
POGO PRCHG PA

or

FID 011-602:

RDNT SEN FAIL-
POGO PRCHG PB

1.14.5.3 Engine Shutdown

Late in the development stage of the Shuttle, a main engine cutoff (MECO or zero-g) low SSME LO2 net positive suction pressure (NPSP) concern was discovered. One way of eliminating this concern is to inject helium into the LO2 feedline to raise the static pressure and thus the NPSP. The Pogo system was already there. A quick software fix that energized the HPV for a Pogo accumulator post-charge was implemented to eliminate the concern. At 0.02 seconds after shutdown, the HPV is energized for 3.98 seconds. The pressure is monitored and a

FID 014-030:

PGE & ANC SYS-
BD PG/POGO P

will be generated (no MCF) if the pressure is less than 600 PSIA or greater than 1500 from shutdown +0.12 to shutdown +4.00 seconds.

Since this is a critical purge, the emergency shutdown solenoid is de-energized if FID 014-030 occurs. The resulting fail-safe pneumatic shutdown routes helium around the HPV solenoid to post-charge the accumulator. This is known as the back-door purge. Only the HPV solenoid has redundancy. If the post-charge fails due to the check valve sticking closed, or the accumulator inlet is obstructed, there is no way to get helium into the LO2 duct to raise the NPSP.

Purge and ancillary limits from shutdown +0.14 seconds to shutdown +4.00 seconds are a lower limit of 600 PSIA and no upper limit.

FID 014-001:

PGE & ANC SYS-
POGO PRCHG PA

or

FID 014-002:

PGE & ANC SYS-
POGO PRCHG PB

will be issued with no MCF for the first failure. For the second failure an MCF will be issued.

Qualification limits from shutdown +0.02 seconds to shutdown +4.00 seconds are a lower limit of 0 PSIA and an upper limit of 1600 PSIA.

FID 111-701:

1ST SEN CH DQ-
POGO PRCHG PA

or

FID 111-702:

1ST SEN CH DQ-
POGO PRCHG PB

will be issued with no MCF for the first disqualification. For the second disqualification,

FID 011-701:

RDNT SEN FAIL-
POGO PRCHG PA

or

FID 011-702:

RDNT SEN FAIL-
POGO PRCHG PB

will be issued with an MCF.

Purge and ancillary limits from post shutdown to the end of post shutdown are no lower limit and an upper limit of 1425 PSIA.

FID 014-001:

PGE & ANC SYS-
POGO PRCHG PA

or

FID 014-002:

PGE & ANC SYS-
POGO PRCHG PB

will be issued if these limits are violated. No MCF is issued for the first failure. An MCF will be issued for the second failure in this timeframe.

1.14.6 References

1. SSME Orientation, Rocketdyne, June 15, 1989.
2. STS-78 Sensor Monitoring package.
3. Booster Real Time Software - Version 11.04 - Failure Identifier Code - October 3, 1996.
4. Space Shuttle Technical Conference, NASA CP-2342, Part 2.
5. POGO, Jim Fenwick, Rocketdyne "Threshold", spring, 1992.

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1.15 SSME CONFIGURATION SUMMARY

Table 1.15-I, below, summarizes the differences between the Phase II, Block I, Block IIA, and Block II engines. Only the Block II engines are currently flown.

TABLE 1.15-I - SSME CONFIGURATION SUMMARY

<u>ENGINE TYPE</u>	<u>HARDWARE CONFIGURATION</u>	<u>WEIGHT</u>	<u>SPECIFIC IMPULSE</u> <u>@ 104/104.5%</u>
Phase II Last Flown STS-93, July 1999	<ul style="list-style-type: none"> • 3-Duct Powerhead • Main Injector Baffles • Rocketdyne High Pressure Pumps • Standard Throat MCC • Bifurcated Heat Exchanger • Block II controller 	7029 lbm (Total Engine)	452.86 sec (Nominal)
Block I Last Flown STS-88, Dec. 1998	Phase II engine with: <ul style="list-style-type: none"> • 2-Duct Powerhead (Phase II+ Powerhead) • Baffleless Main Injector • Enlarged Boundary Layers Coolant Holes • ATD HPOT • Single Coil Heat Exchanger • Start Sequence Mods • Miscellaneous Systems Hardware 	+171 lbm +161 lbm +19 lbm 7380 lbm (Total Engine)	+1.00 sec -0.24 sec -0.19 453.44 sec (Predicted)
Block IIA Last Flown STS-109, Mar. 2002	Block I engine with: <ul style="list-style-type: none"> • Resized Boundary Layer Coolant Holes • LPFT (insulation, bearings, L/O seal) • LPOT (inducer mod, ceramic bearing) • Large Throat MCC (LTMCC) 	+150 lbm 7530 lbm (Total Engine)	+1.24 sec -1.70 sec 452.7 sec (Predicted)

TABLE 1.15-I - SSME CONFIGURATION SUMMARY Continued

<u>ENGINE TYPE</u>	<u>HARDWARE CONFIGURATION</u>	<u>WEIGHT</u>	<u>SPECIFIC IMPULSE</u> @ 104/104.5%
Block II	Basic Block IIA with: <ul style="list-style-type: none"> • ATD HPFT • Continuous Helium Purge • Revised Liquid Air Insulation • Main Fuel Valve (MFV) redesign • OPOV flowcheck and process changes • Pump-to-Powerhead flange (G-6) mods • Eliminated HPFTP Coolant Liner measurement 	+218 lbm	
		7748 lbm (Total Engine)	452.2 sec (Predicted)

References

1. Space Shuttle Main Engine Flight Operations Handbook, Atlantis STS-104, 2001
2. Power Balance Model, Rocketdyne, June 1997 (Blk-IIA ISP) & December 2000 (Blk II ISP)
3. Fax Transmission from NASA MSFC/D. Wilson to DF55 / J. Reding, dated July 30, 1997.

1.16. SSME LIMIT SWITCH SOFTWARE

1.16.1 Introduction

This Systems Brief offers a detailed discussion of orbiter software logic used to process the inputs provided by the SSME limit shutdown switch. It is intended to be a supplement to the discussion of the function and usage of the limit switch offered in Systems Brief 1.10, “SSME Crew Controls.”

1.16.2 Overview

The limit switch is a three contact switch, which will produce three discrete outputs if in the auto, enable, or inhibit positions. This single switch controls the limits for all three SSMEs.

1.16.3 Differences between PASS and BFS limit switch software

Limit switch software used in the Primary Avionics Software System (PASS) differs from the limit switch software used in the Backup Flight System (BFS). Since the Backup Flight System (BFS) does not use internal counters like the PASS, limit switch logic in the BFS does not allow limits to be reenabled with the switch in “AUTO” after a data path failure or an engine shutdown. The more complex PASS logic is discussed in section 1.16.4. Refer to section 1.16.5, “BFS Limit Switch Software” for discussion of limit switch logic used in the BFS.

The discussion below assumes that the proper voting logic and processing has been applied to the three discrete outputs to determine the switch position. In the case of the PASS, the switch discretely are processed by GN&C Redundancy Management (RM) software (Ref. 1). In the case of the BFS, two of three available discretely must be recognized before a function is recognized.

1.16.4 PASS Limit Switch Software

Crew inputs made using the limit switch are processed in the SSME OPS software sequence (Ref. 2) operating in the orbiter PASS GPCs. The sequence monitors SSME shutdown phase flags, data path fail flags, and limit switch position in order to set enable and inhibit limit flags (Table 1.16-I). These limit flags are processed by the SSME SOP (SSME Subsystem Operating Program). The SSME SOP then issues enable or inhibit commands to the appropriate SSME controller (Ref. 2).

Again, it is the SSME SOP sequence and not the SSME OPS sequence which sends commands to the SSME controller. The SSME OPS sequence only generates flags to be interpreted by the SSME SOP and does not send commands to the SSMEs. The SSME OPS sequence does not initialize redline limit monitoring to enable. This is accomplished by the controller at power-up.

The SSME SOP sequence is executed before the SSME OPS sequence in the PASS software sequencing. Thus, any flags set by the SSME OPS sequence are not processed by the SSME SOP until the next GPC cycle.

TABLE 1.16-I: SSME OPS sequence internal INHIBIT/ENABLE flags

<u>INTERNAL FLAG</u>	<u>MSID</u>
MPS E1 LIMIT CNTL ENA	V90X8573X
MPS E1 LIMIT CNTL INH	V90X8570X
MPS E2 LIMIT CNTL ENA	V90X8574X
MPS E2 LIMIT CNTL INH	V90X8571X
MPS E3 LIMIT CNTL ENA	V90X8575X
MPS E3 LIMIT CNTL INH	V90X8572X

1.16.4.1 SSME OPS Sequence

Logic flow of the portion of the SSME OPS sequence responsible for setting limit flags is provided in Figure 1.16-I. A key detail of this logic flow is the use of counters to force limit commands to be issued for multiple GPC cycles. Although data is transmitted between the GPCs and engine controller in 40 ms data frames, the beginning of a data frame in a GPC may not necessarily correspond with the beginning of a data frame in the SSME controller. Thus, the controller and GPC are considered asynchronous and limit commands are transmitted for three frames, or 120 ms, to ensure good commanding. This is accomplished by incrementing the appropriate counter from zero to three when limit flags (Enable and Inhibit) are set and read by the SSME SOP.

A listing of counters and initial values is provided in Table 1.18-II. Note that the engine auto-enable counters (C, E, G) are initialized to three to allow the limits to be inhibited on two SSMEs should an SSME fail during the first three passes of the SSME OPS sequence. Initializing the C, E, and G counters to three also prevents enable flags from being set unnecessarily in the case where three SSMEs are operating nominally.

TABLE 1.16-II: SSME OPS sequence limit counters

Counter	Name	Value at OPS software at initialization
A	MANUAL ENABLE COUNTER	0
B	MANUAL INHIBIT COUNTER	0
C	E1 AUTO-ENABLE COUNTER	3
D	E1 AUTO-INHIBIT COUNTER	0
E	E2 AUTO-ENABLE COUNTER	3
F	E2 AUTO-INHIBIT COUNTER	0
G	E3 AUTO-ENABLE COUNTER	3
H	E3 AUTO-INHIBIT COUNTER	0

Limit switch software in the SSME OPS uses the following logic sequence. First, the logic evaluates limit switch position. If the switch is in “INHIBIT” or “ENABLE”, the appropriate limit flag is output to the SSME SOP sequence for three OPS sequence cycles (software “passes,” 120 msec). If the limit switch is in the “AUTO” position, the software individually checks status flags from each engine (reference Figure 1.16-II). If an engine is in shutdown phase or if a data path flag is latched, inhibit limit flags on the other two engines are set to inhibit for three GPC cycles. Thus, when the limit switch is in “AUTO” and an SSME enters the shutdown phase or experiences a data path failure, the SSME OPS software sets the appropriate inhibit flags and passes these flags to the SSME SOP sequence. The SSME SOP sequence then sends commands that inhibit redline shutdown logic on the other two engines.

If the limit switch is in the “AUTO” position and the fail status flags (shutdown and data path flags) for that engine are not set, limit control enable flags for that engine are set to enable if the auto-enable counter (C, E, or G) for that engine is less than three. At software initialization, the auto-enable counters are set to three. Therefore, for nominal, uphill flight, the SSME OPS sees the limit switch in “AUTO” but does not change controller limits.

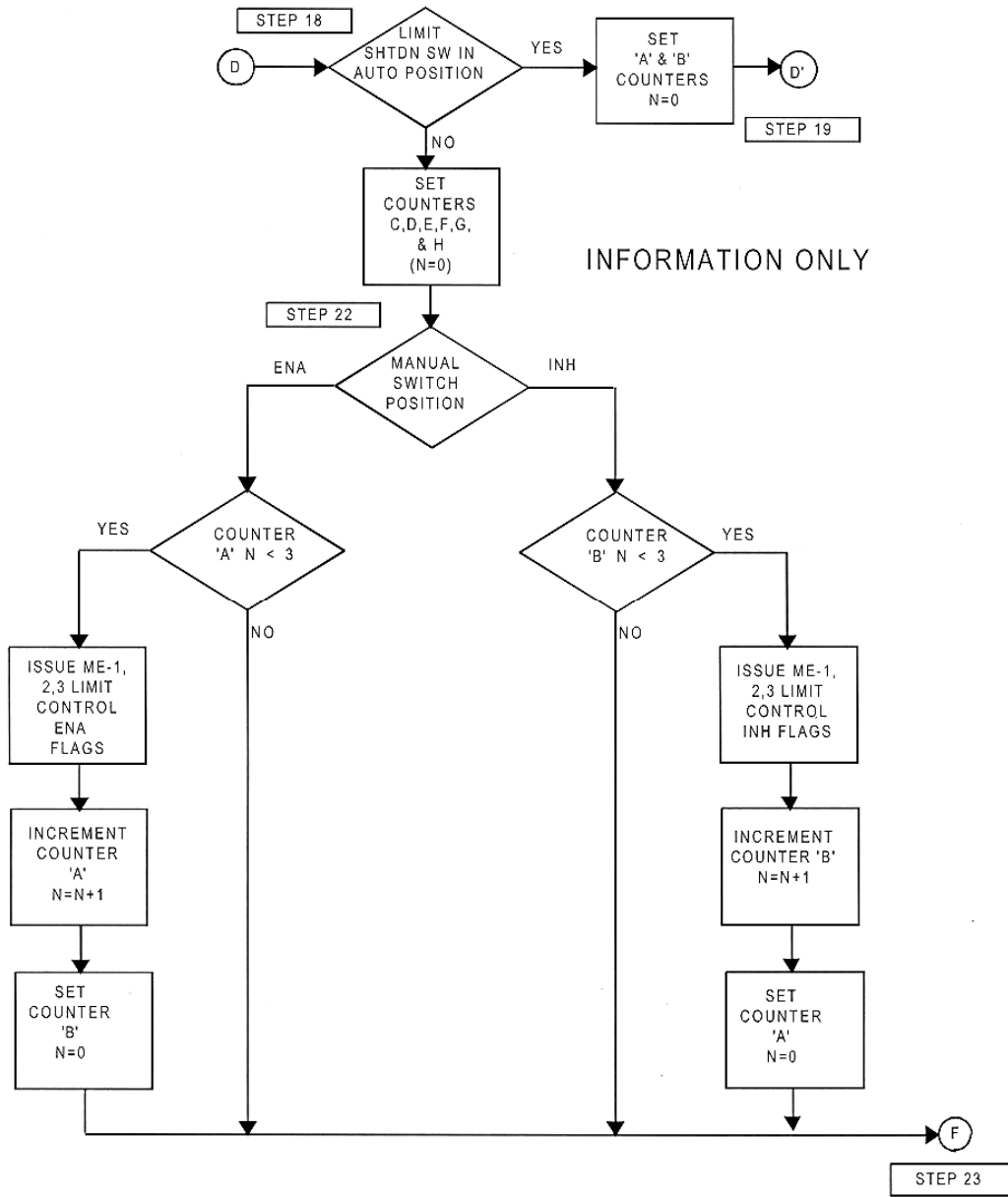


Figure 1.16-I - SSME OPS sequence limit switch logic. (Ref. 2)

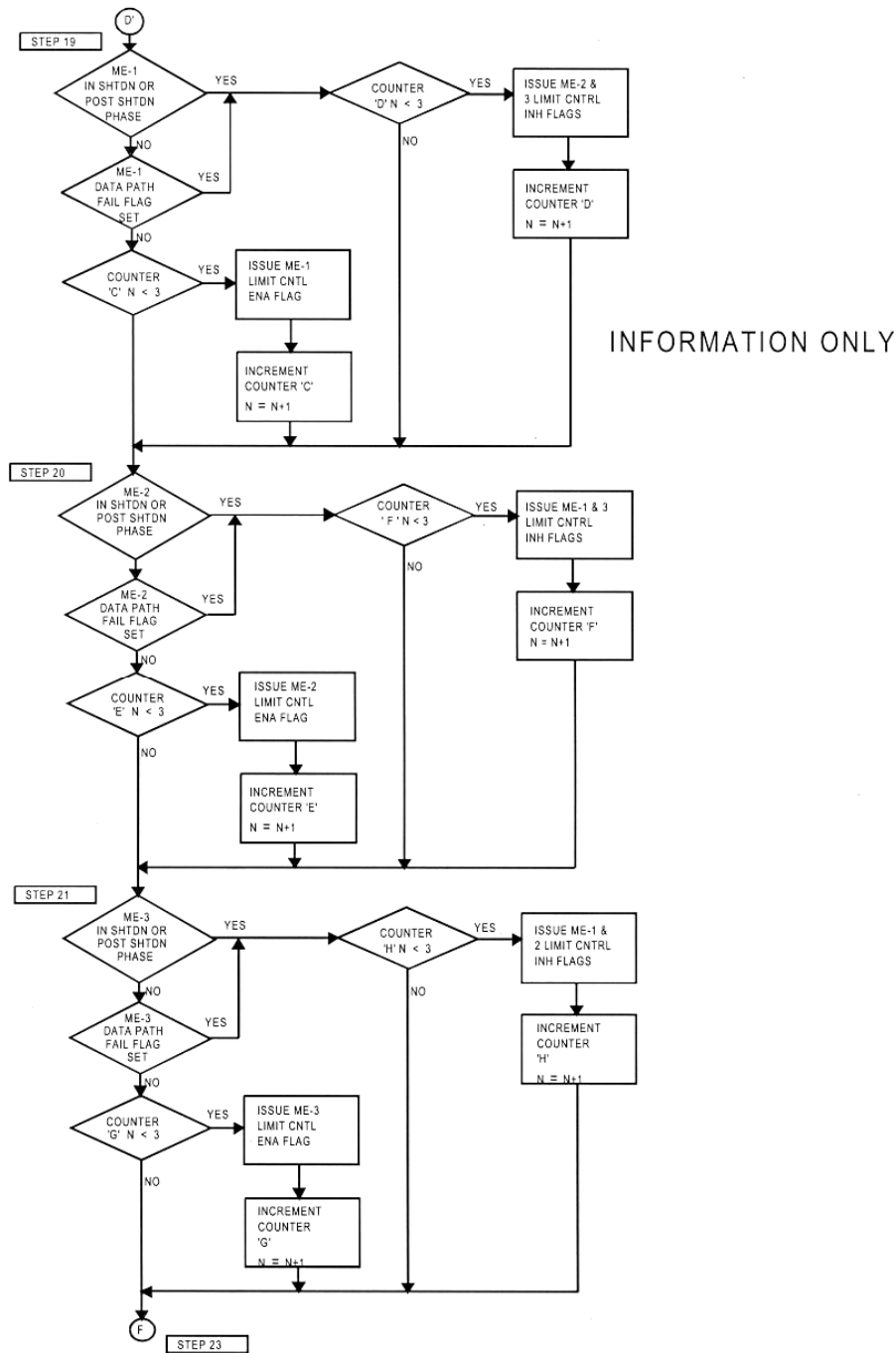


Figure 1.16-II - SSME OPS sequence limit switch logic (continued). (Ref. 2)

1.16.4.2 SSME SOP Sequence

The SOP may receive inhibit and enable flags which are associated with the same SSME, within the same 40 ms GPC cycle (i.e. Logic in the OPS has set both the inhibit and enable flags for the same engine to on at the same time.). The SSME SOP logic flow (Figure 1.16-III) manages this situation by prioritizing the evaluation of inhibit/enable flags. If the inhibit flag for an engine is set, the logic turns that inhibit flag off and sends the limit inhibit commands to that SSME. No processing of the enable flag occurs and the enable flag remains set for three passes through the SSME SOP sequence. Thus, limits will be commanded to enable during the next pass through the SOP. Limits are commanded to enable only if an enabled flag is present and an inhibit flag is not present.

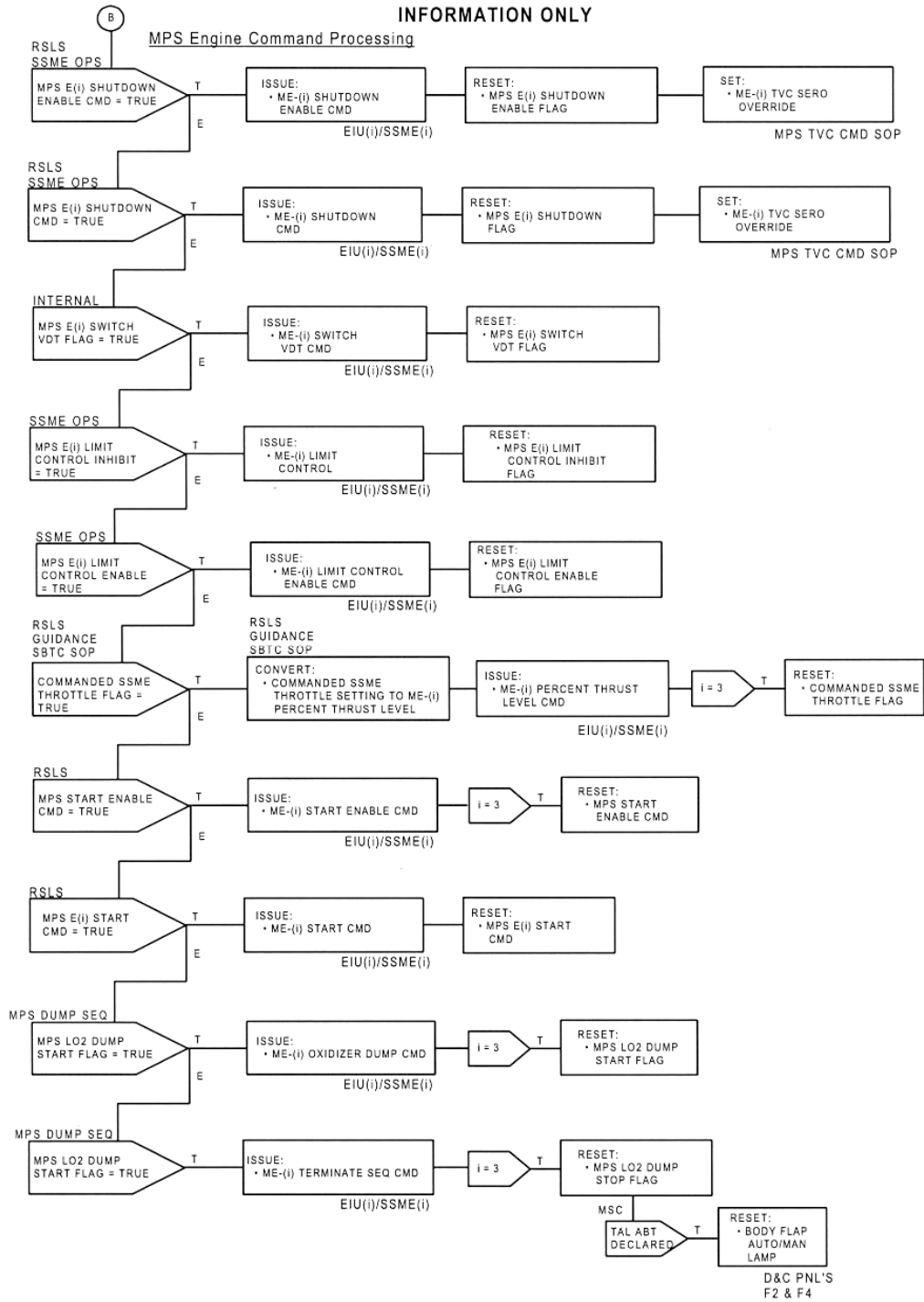


Figure 1.16-III - SSME SOP sequence limit switch logic. (Ref. 2)

1.16.4.3 PASS Limit Switch Input processing example

Table 1.16-III illustrates the processing of failures and limit switch commands by SSME OPS and the SSME SOP software. In the example shown, a data path is annunciated on the center SSME (the SSME is running). This results in limits being inhibited on the left and right SSMEs. Subsequently, limits are reenabled by moving the limit switch to enable and then back to auto based on the MCC “limits enable/auto call.” (reference Flight Rule A5.1.3-4, Ref. 3)

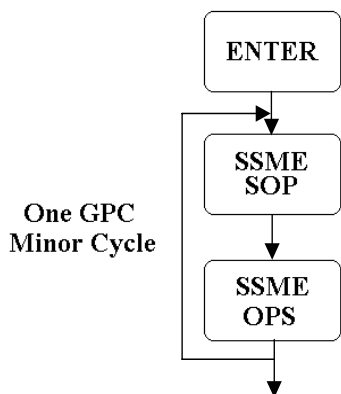
The prioritized processing of inhibit/enable flags in the SSME SOP, together with the counter setup in the SSME OPS, allows limits for each engine to be reenabled after the data path failure on the center engine occurs. Moving the switch to enable sets all internal counters to zero and results in the enable command being sent to each engine controller. When the switch is returned to the auto position, the latched data path flag on the center engine results in the inhibit flags being reset for the left and right engines. Limit enable flags for the left and right engines are also set during the same GPC cycle because the logic has no failure flags for these engines. Therefore, for three GPC cycles (120 ms), the SSME SOP processes the following flags: Left SSME Inhibit, Left SSME Enable, Right SSME Inhibit and Right SSME Enable. The SSME SOP clears the limits inhibit flag subsequent to commanding limits to inhibit. The limits enabled flag is not cleared during the first three cycles because the limits inhibit flag is processed prior to the limits enable flag.

On the fourth cycle, enable flags on the left and right engine remain on. Inhibit flags are not reset because internal SSME OPS counters hold values that do not allow setting the inhibit flags. Since the enable flags for the left and right engines are latched during this cycle, the SSME SOP issues enable commands to the engine controller. Limits for the center engine were enabled when the limit switch was taken to ENABLE.

For additional information on operational use of the limits switch, refer to SCP 2.1.11 (Ref. 4)

Table 1.16-III – Counter Values For Data Path Failure On Center Engine
Followed By Limits-Enable-Auto Switch Sequence

EVENT	GPC CYCLE	COUNTERS								SOP COMMAND	SSME OPS FLAG SET	CONTROLLER LIMITS		
		A	B	C	D	E	F	G	H			1(C)	2(L)	3(R)
INITIALIZE	N/A											E	E	E
MM 102	1	0	0	3	0	3	0	3	0	NONE	NONE	E	E	E
DATA PATH	1	0	0	3	1	3	0	3	0	NONE	E2 INH, E3 INH	E	E	E
	2	0	0	3	2	3	0	3	0	E2 INH, E3 INH	E2 INH, E3 INH	E	I	I
	3	0	0	3	3	3	0	3	0	E2 INH, E3 INH	E2 INH, E3 INH	E	I	I
	4	0	0	3	3	3	0	3	0	E2 INH, E3 INH	NONE	E	I	I
	5	0	0	3	3	3	0	3	0	NONE	NONE	E	I	I
ENABLE	1	1	0	0	0	0	0	0	0	NONE	E1,E2,E3 ENA	E	I	I
	2	2	0	0	0	0	0	0	0	E1,E2,E3 ENA	E1,E2,E3 ENA	E	E	E
	3	3	0	0	0	0	0	0	0	E1,E2,E3 ENA	E1,E2,E3 ENA	E	E	E
	4	3	0	0	0	0	0	0	0	E1,E2,E3 ENA	NONE	E	E	E
	5	3	0	0	0	0	0	0	0	NONE	NONE	E	E	E
AUTO	1	0	0	0	1					NONE	E2 INH, E3 INH	E	E	E
						1	0				E2 ENA			
								1	0		E3 ENA			
	2	0	0	0	2					E2 INH, E3 INH	E2 INH, E3 INH	E	I	I
						2	0				E2 ENA			
								2	0		E3 ENA			
	3	0	0	0	3					E2 INH, E3 INH	E2 INH, E3 INH	E	I	I
						3	0				E2 ENA			
								3	0		E3 ENA			
	4	0	0	0	3	3	0	3	0	E2 INH, E3 INH	E2 ENA, E3 ENA	E	I	I
	5	0	0	0	3	3	0	3	0	E2 ENA, E3 ENA	NONE	E	E	E
	6	0	0	0	3	3	0	3	0	NONE	NONE	E	E	E



1.16.5 BFS Limit Switch Software

In addition to the PASS processing discussed above, crew inputs from the limit switch are also processed in the BFS SSME OPS software sequence (Figures 1.16-IV – VI) operating in the orbiter BFS GPC. The sequence monitors SSME shutdown phase flags, data path fail flags, and limit switch position in order to set enable and inhibit limit flags. These limit flags are processed by the BFS SSME HIP (Hardware Interface Program; see Figure 1.16-VII), which sends enable or inhibit commands to the appropriate SSME controller.

This scheme is analogous to the scheme used in the PASS. The BFS SSME OPS sequence is the analog of the PASS SSME OPS. The BFS SSME HIP is the analog of the PASS SSME SOP. Like the PASS SSME SOP, it is the BFS SSME HIP which commands to the SSME controller.

1.16.5.1 BFS Limit Switch input processing

The BFS SSME OPS sequence logic processes inputs from the limit switch as follows. If the limit switch is in “AUTO,” and there are no engine failures or data paths, limits are commanded to enable for three BFS GPC cycles (software “passes”) after BFS engage (Figure 1.16-IV). If the limit switch is in “AUTO,” and an engine has shutdown or has a latched data path failure, all enable flags are terminated and inhibit flags are set for the remaining two engines. No limit flags or commands are ever issued for a shutdown engine (Figure 1.16-V).

If the limit switch is in “ENABLE”, the logic terminates all inhibit flags and sets enable flags for processing by the BFS SSME HIP. Conversely, if the limit switch is in “INHIBIT,” the logic terminates all enable commands and sets inhibit flags for processing by the HIP (Figures 1.16-IV & VII).

Unlike the PASS system, BFS limit switch logic does not allow enable and inhibit flags to be set for the same engine at the same time. This fact has two implications. First, any enable or inhibit flag set by the BFS SSME OPS sequence results in limits for the associated engine controller being enabled or inhibited by the HIP. Secondly, the switch sequence “limits-enable-auto” will not reenable limits after failure of a single engine because an inhibit flag does not remain set on the fourth pass through the logic after the switch sequence is executed (as in the PASS).

For the case in which limits on two engines are inhibited due to a data path failure on the third engine, limits on the two good (non-data path) engines may be reset to enable ONLY by putting the limit switch into hard “ENABLE” (Ref. 3).

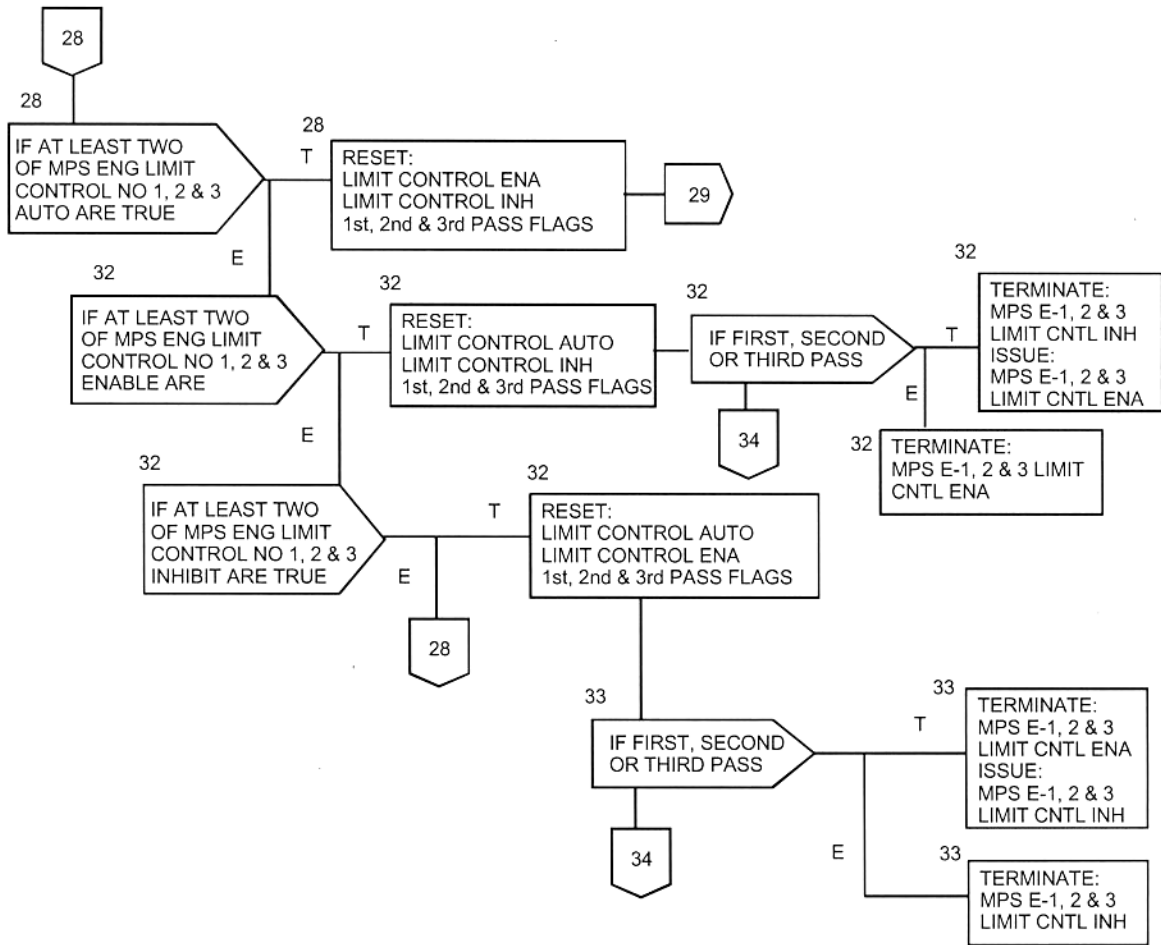


Figure 1.16-IV - BFS SSME OPS sequence limit switch logic. (Ref. 5)

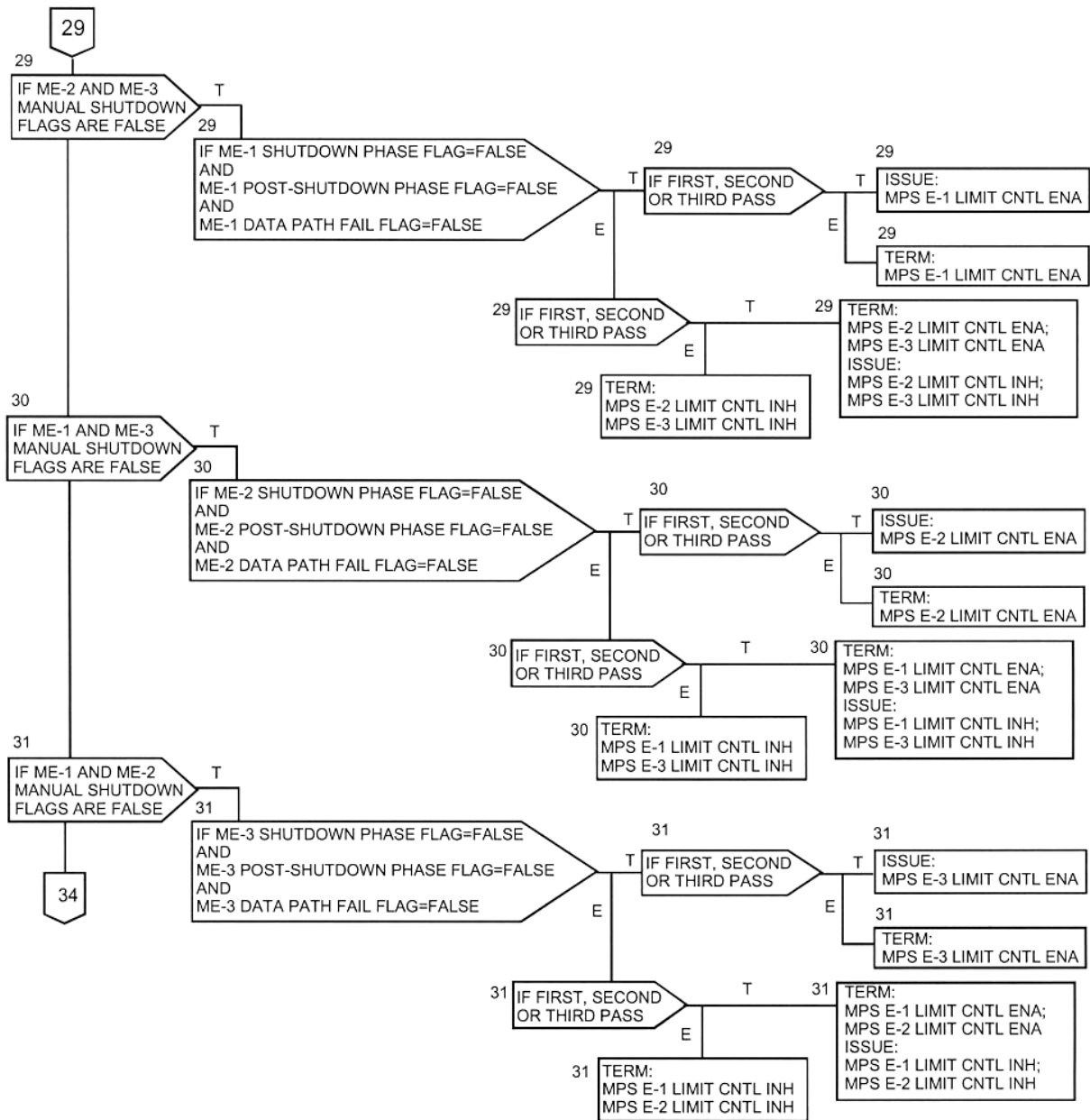


Figure 1.16-V - BFS SSME OPS sequence limit switch logic (continued). (Ref. 5)

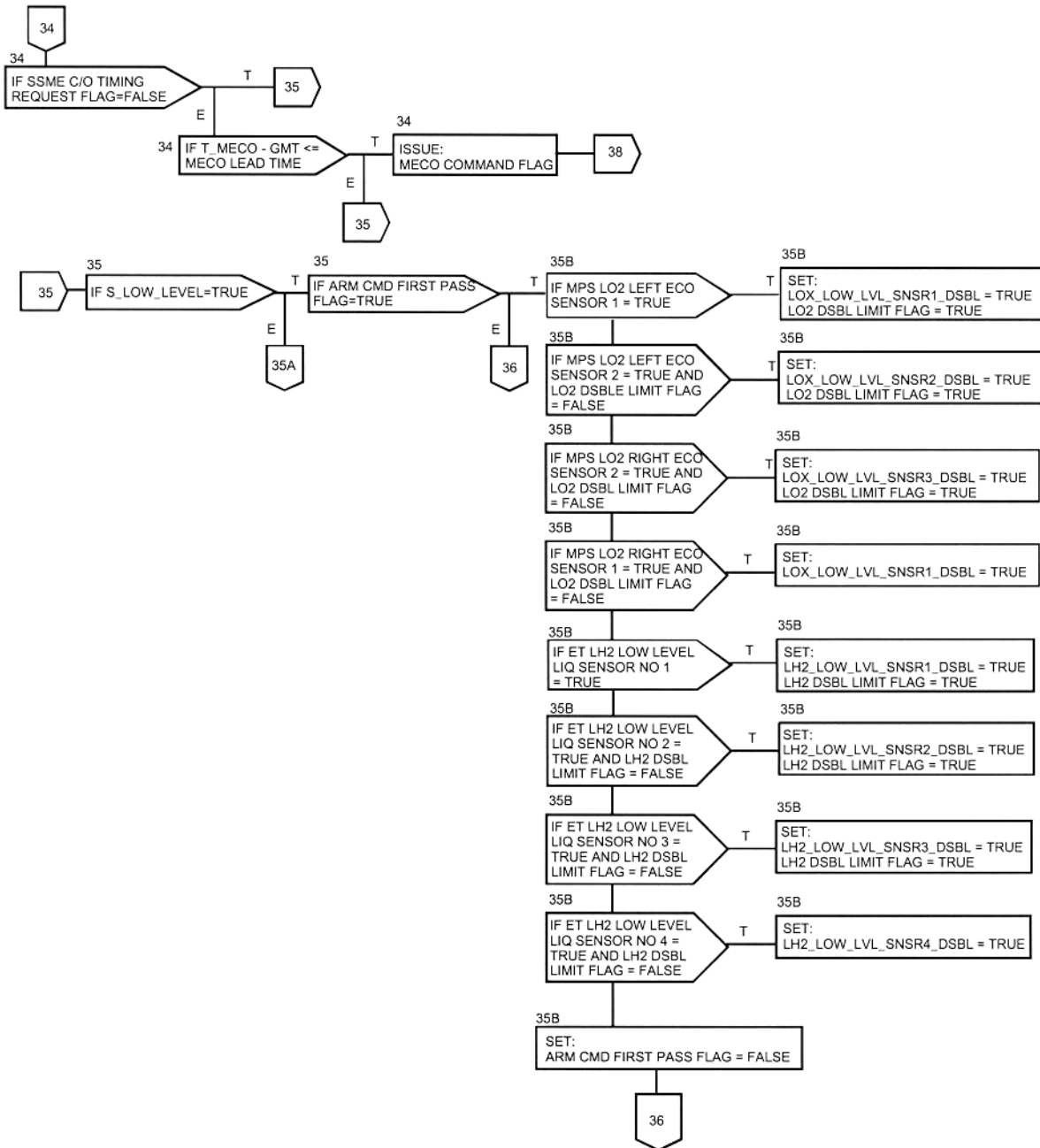


Figure 1.16-VI - BFS SSME OPS sequence limit switch logic (concluded). (Ref. 5)

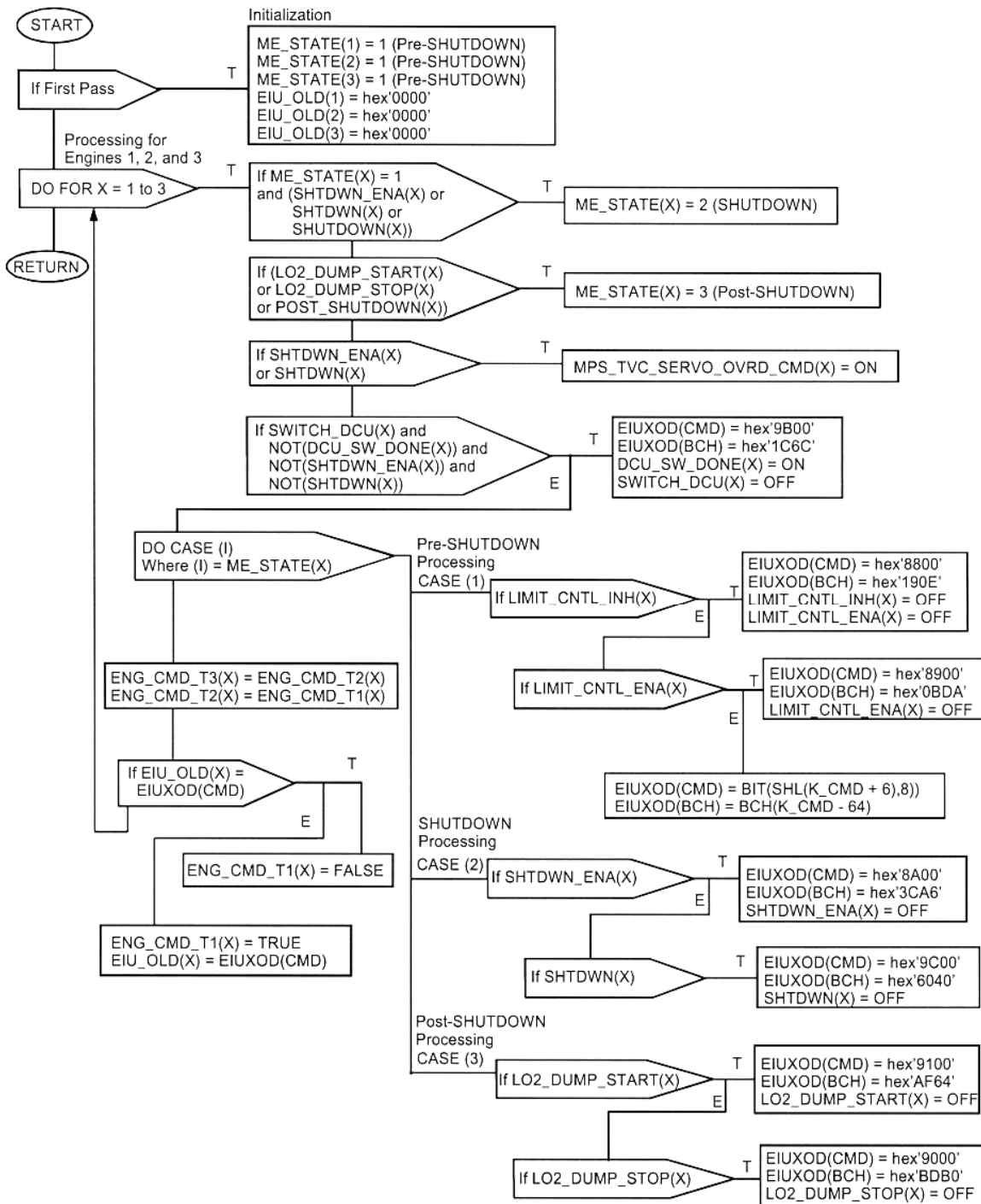


Figure 1.16-VII - BFS SSME HIP limit switch logic. (Ref. 5)

1.16.6 References

1. Functional Subsystems Software Requirements (FSSR) GNC, Redundancy Management; April 30, 1998 (OI-28)
2. Functional Subsystems Software Requirements (FSSR) GNC, Sequence Requirements; April 30, 1998 (OI-28)
3. STS Operational Flight Rules, All Flights, Volume A, NSTS-12820; Final PCN-11, December 7, 2000; Section 5 Booster
4. Booster Standard Console Procedures (SCP), Basic Rev F
5. BFS Program Requirements Document (PRD), Sequencing; June 30, 1998 (OI-28)

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1.17 SSME PERFORMANCE CASE DESCRIPTIONS

1.17.1 General

This System Brief (SB) provides detailed descriptions and impacts of the seven quantifiable Space Shuttle Main Engine (SSME) performance cases currently covered by the Booster Systems Group. Rocketdyne identifies many other unique performance cases, but the most significant ones are the seven used by the Booster Group, and they are presented in this SB.

1.17.2 SSME Performance Parameters

A number of SSME parameters are used to determine SSME performance. The most significant of these parameters are the Main Combustion Chamber Pressure (MCC Pc), the High Pressure Oxidizer Turbopump Pump Discharge Pressure (HPOT DP), and Turbine Discharge Temperature (HPOT TDT), the High Pressure Fuel Turbopump Pump Discharge Pressure (HPFT DP) and Turbine Discharge Temperature (HPFT TDT), the Fuel Preburner Oxidizer Valve (FPOV) position, and Oxidizer Preburner Oxidizer Valve (OPOV) position. The ensuing paragraphs discuss how each SSME parameter is used to monitor the SSME performance. For a performance case, in general, several of the following parameters will diverge from their nominal operating values.

1.17.2.1 MCC Pc

The SSME main combustion chamber pressure is an important parameter in the SSME thrust and mixture ratio control loop. The MCC Pc is proportional to SSME thrust. Specific power level commands (67% to 109%) from the General Purpose Computers (GPCs) are translated into a reference Pc value by the SSME controller. The MCC Pc varies linearly with respect to the SSME throttle range, and the GPC commanded power level is converted into a reference MCC Pc value ranging from 1840.5 psia at 67% to 2994.2 psia at 109%. Once the SSME controller receives a throttle command, the OPOV and FPOV are commanded open or closed to maintain the desired thrust and mixture ratio, respectively. The thrust is controlled by a loop function in the SSME controller by measuring MCC Pc and comparing it to a reference MCC Pc value. Simultaneously, the MCC Pc is being used to calculate the LO2 flowrate that is used by the SSME mixture ratio control loop. The calculated mixture ratio is then compared to a reference value to control to the desired mixture ratio.

The Booster Main Engine display lists the MCC Pc Average and Pc Channel A and B values, with the corresponding commanded and actual power level values. If the commanded power level is known, then the commanded reference Pc value is also known.

1.17.2.2 HPOT DP

The HPOT DP is probably the single most important parameter used to recognize and confirm off-nominal SSME performance. Since the thrust control of each SSME is accomplished by varying the level of LO2 in the combustion chambers, variation in the HPOT DP is indicative of SSME thrust or mixture ratio variations. The HPOT DP is also a very important cue for the evaluation of performance dispersions, because there is little variation in this measurement with varying LO2 inlet pressure (LO2 inlet pressure varies proportionally with changes in vehicle acceleration). Consequently, if the HPOT DP at a particular power level is higher or lower than expected, the SSME is potentially operating off-nominally.

1.17.2.3 HPFT DP

The HPFT DP is also a very important parameter used to recognize and confirm off-nominal SSME performance. Like the HPOT DP pressure, the HPFT DP does not vary significantly with changes in vehicle acceleration. Therefore, an operator does not have to apply gain factors to this parameter when the vehicle acceleration is not at 1g. This parameter is also important because it is very sensitive to a fuel flowmeter shift, which is one of the hardest cases for the Main Engine operator to quantify. The HPFT Discharge Pressure is three times as sensitive to a fuel flowmeter shift as the HPOT DP. The HPFT DP, therefore, should be monitored closely for a significant delta from the predicted value, as this may be indicative of SSME performance dispersions.

1.17.2.4 HPOT TDT

Similar to the HPOT DP, the HPOT TDT is a good indication of the oxidizer turbopump performance. Like the HPOT DP, the HPOT TDT is expected to be within a certain range for nominal SSME operation at a given thrust level. Unlike the Discharge Pressure, the Discharge Temperature is a turbine versus pump discharge parameter. If the HPOT TDTs are higher/lower than predicted, then the mixture ratio in the HPOT preburner is off-nominal. A high preburner mixture ratio would cause the turbine exhaust temperature to increase. Similarly, a low preburner mixture ratio would cause the temperature to decrease. Either condition is indicative of an SSME performance dispersion. It should also be noted that the HPOT DP should vary proportionally with HPOT Discharge Temperature, assuming the High Pressure Oxidizer Pump is not the cause of the high turbine temperatures.

1.17.2.5 HPFT TDT

The HPFT TDT can be used as an indication of turbopump health and engine performance. The power applied to the pump and the resulting turbine exhaust temperature is directly related to changes in the SSME mixture ratio (because the SSMEC controls the mixture ratio of the engine by throttling the HPFT). This parameter will not vary as greatly as the HPOT TDTs, which are directly related to MCC Pc and vary more greatly when a performance case is present. Some, but not all off-nominal engine performance problems will result in significantly elevated or depressed HPFT turbine temperatures, so this cue is not as unilaterally helpful as HPOT turbine temperature variances. Usually, the direction, not necessarily the magnitude of a HPFT TDT shift is more useful as a secondary cue for determining a performance case.

1.17.2.6 OPOV Position

The OPOV is the valve that controls the flow of LO2 into the high-pressure oxidizer turbopump preburner. As the valve opens, the increased LO2 flow raises the preburner mixture ratio and the total mass flowrate into the preburner combustion chamber. The resultant high pressure and temperature gas imparts more energy into the downstream turbine blades and increases the output of the turbine shaft thereby increasing the output of the axially attached high-pressure pump. The increased pump pressure and mass flowrate raises the MCC Pc and overall SSME thrust. Closing the OPOV has an opposite affect on SSME thrust. In either case, an OPOV position that is significantly different than predicted for the desired power level is indicative of an off-nominal operating condition in the SSME.

Do not be confused about which valve is used to control SSME thrust. If a change in SSME power level is commanded by the GPCs or detected by the SSME controller, the controller will command the OPOV, not FPOV, to open/close. The OPOV controls SSME thrust. It is important to note that the controller responds to the thrust update by commanding the FPOV open/closed in order to maintain a constant MCC propellant mixture ratio at all times. It should be pointed out that even though the controller will attempt to maintain a proper mixture ratio at all times, most performance cases will result in an off-nominal mixture ratio.

1.17.2.7 FPOV Position

The FPOV controls the flow of oxidizer to the high-pressure fuel turbopump preburner, and this controls the overall mixture ratio of the engine. Since the mixture ratio in the fuel preburner controls the HPFT speed, variations in the FPOV position change the mixture ratio in the MCC. If the FPOV is commanded open, the increased oxidizer flow increases the preburner mixture ratio and consequently increases the output of the HPFT turbine. The reverse holds true if the FPOV is commanded closed. Since the FPOV indirectly controls the fuel flowrate to the MCC, an off-nominal FPOV position at a particular power level is indicative of an off-nominal MCC propellant mixture ratio.

1.17.3 Quantifiable SSME Performance Cases

1.17.3.1 Main Combustion Chamber Pressure (MCC Pc) Sensor Shifts

The MCC contains four pressure-sensing transducers. These four transducers are divided into two channels, two sensors on each channel. Each of these channels is on one pressure port connected to the SSME main combustion chamber. Therefore, there are two pressure ports connected to the main combustion chamber, each of which having two sensors. SSME Pc average is an overall average (measured MCC Pc) of both Pc pairs, channel A and channel B. This average is used in the SSME thrust control loop. Upon receipt of a new GPC thrust command or in response to variations in the MCC Pc, the SSME controller commands the oxidizer preburner oxidizer valve (OPOV) open/closed to raise or lower the chamber pressure, respectively.

1.17.3.1.1 Single Pc Channel Shift Low Actual High - High Mixture Ratio Case

An MCC Pc channel shift low, actual high case is caused by a one of the two MCC Pc sensor pairs erroneously shifting low, thus indicating a lower MCC pressure value than the other sensor channel (shifts of both Pc pairs will be discussed in Section 1.17.3.1.4). Although this will typically be caused by a shift low of a single transducer, there is no way for the flight controller to determine if the shift is caused by a single transducer.

When a single sensor shifts low, or if both sensors on one channel shift low, the associated average of both Pc pairs will also be lower. This reduced average Pc is lower than the reference Pc, so the OPOV is commanded to open and the LO2 flowrate increases. Nominally the combustion in the oxidizer preburner (OPB) is fuel rich (the mixture ratio is approximately 0.76), so the increased LO2 flow allows more combustion to take place. The greater amount of combustion increases the shaft power of the turbine that in turn increases the volumetric output of the high-pressure oxidizer pump, causing more LO2 to be injected into the MCC. This increases the actual MCC Pc to a value above what it should be for normal operation. The following example describes the failure effect of a Pc shift low, actual high. If the SSME is operating nominally at a steady state condition at 104.5 percent power level, the Pc average will equal 2870.6 psia. If one pair shifts low by 50 psia, the average Pc will be:

$$(2870.6 + 2820.6)/2 = 2845.6 \text{ psia}$$

The Pc average is below Pc reference by 25 psia or one-half the sensor pair shift. Since the Pc average is below the reference Pc, the controller will command the OPOV to open further. As the OPOV opens, the output from both Pc sensor pair increases. When the Pc average reaches 2870.6 psia the good pair will indicate 2895.6 psia ($2870.6 + 25 = 2895.6$) and the bad pair will indicate 2845.6 psia ($2820.6 + 25 = 2845.6$). The Pc average now is at its expected value of 2870.6 ($(2895.6 + 2845.6)/2 = 2870.6$).

Although the MCC Pc average is 2870.6, the actual Pc is 2895.6. This equates to a power level of approximately 105.6 percent. Since a MCC Pc shift low results in disproportionate LOX usage, the case is considered to have a higher than normal mixture ratio.

NOTE: A good rule of thumb when evaluating MCC Pc sensor shifts is that the good Pc pair, HPOT DP, OPOV position, HPOT TDT, MR, and power level will all shift in the same direction. In the case of a Pc shift low actual high all these cues will shift up (“actual high”).

1.17.3.1.2 Single Pc Channel Shift High Actual Low - Low Mixture Ratio Case

An MCC Pc channel shift high, actual low is caused by a shift high of one of the two MCC Pc sensor pairs (shifts of both Pc pairs is discussed in the next section). This case is essentially the opposite of the “shift low, actual high” case. In the case of a Pc pair shift high, the average Pc is higher than the commanded Pc, so the controller commands the OPOV to close and the LO2 flowrate decreases. Nominally the combustion in the OPB is fuel rich (mixture ratio is approximately 0.8), so the decreased LO2 flow allows less combustion to take place. The reduced amount of combustion decreases the shaft power of the turbine that in turn decreases the volumetric output and pressure of the high pressure oxidizer pump causing less LO2 to be injected into the MCC. This decreases the actual MCC Pc. For the Pc shift high actual low case the MCC mixture ratio and power level are lower than normal.

The following example describes the failure effect of a Pc shift high, actual low. If the SSME is operating nominally at a steady state condition at 104.5 percent power level, the Pc average will equal 2870.6 psia. If one pair shifts high by 50 psia, the average Pc will be:

$$(2920.6 + 2870.6)/2 = 2895.6 \text{ psia}$$

Notice that Pc average is above Pc reference by 25 psia or one-half the sensor pair shift. Since the Pc average is above the reference Pc, the controller will command the OPOV to close further. As the OPOV closes, the output from both Pc sensor pair decreases. When the Pc average reaches 2870.6 psia, the bad pair will indicate 2895.6 psia ($2920.6 - 25 = 2895.6$) and the good pair will indicate 2845.6 psia ($2870.6 - 25 = 2845.6$). The Pc average now is at the expected value of 2870.6 ($(2895.6 + 2845.6)/2 = 2870.6$).

Although the MCC Pc average is 2870.6, the actual Pc is 2845.6. This equates to a power level of approximately 103.4 percent. BOSS will calculate the power level, but it can also be read from the Main Engine Tables (MET). This type of Pc shift is a low mixture ratio case and the values for MR and power level are lower than nominal. The low mixture ratio is due to the decreased LO2 usage caused by a decrease in the OPOV position.

NOTE: A good rule of thumb when evaluating MCC Pc sensor shifts is that the good Pc pair, HPOT DP, OPOV position, HPOT TDT, MR, and power level will all shift in the same direction. In the case of the Pc shift high actual low all these cues will shift low.

1.17.3.1.3 Actions to Remove the Single Pc Channel Shift

For the shift high actual low case, the Shuttle's performance can be degraded to the point that uphill capability is lost (loss of ATO capability). This is due to the nature of the "shift high, actual low" case. When in a low mixture ratio case, an LO2 imbalance will be created due to the lower usage of LO2. This lower usage results in more oxygen remaining in the ET at MECO, basically becoming payload. This hurts overall vehicle performance (due to the additional LO2 weight) and may inhibit the Shuttle's ability to achieve orbit. If FDO determines that performance has degraded to this point, a call may be made to power cycle (off for 1 second and back to on) to the controller channel with the bad Pc pair (the pair that has shifted high). Turning off the channel will disqualify the bad Pc channel and leave only the good Pc pair in control so the SSME performance should return to nominal. When the power is turn back on, the DCU, IE and OE associated with that controller channel will remain disqualified, but the associated command channel will start to receive and transmit data. The bad channel will not be powered off if this will cause the SSME to shutdown, or go into electric or hydraulic lockup. Causing the SSME to go into lockup would not improve performance because all valves will remain at their current values and the SSME will stay at the degraded Pc level.

Creating a momentary command path failure by power cycling the bad controller channel is acceptable to regain nominal SSME performance. This is acceptable due to the way the internal control loop of the SSME controller works. Prior to turning off the bad channel, the controller has a valid command within its registers. If a command path occurs when the bad channel is powered off, the last valid command is still present and therefore the controller will use its internal control loop to maintain the proper mixture ratio and Pc. Thus the SSME is operating at the nominal Pc and mixture ratio even though there is a command path failure. In more simple terms, the SSME thrust and mixture ratio control loop is handled internal to the SSME controller and is not dependent on external inputs from the GPCs for the control of thrust and mixture ratio.

It is very important provide the proper switch nomenclature of the bad controller channel to avoid turning off the good channel. If the good channel is powered off, then the case level will double (i.e. a 25 psia shift becomes a 50 psia shift because only the bad Pc is then being used in the control loop).

1.17.3.1.4 Dual MCC Pc (channel A&B) Shift High or Low

The previous sections discussed one of two Pc pairs shifting. However, it is possible for both Pc pairs to shift in the same direction, or one Pc pair to shift when only one Pc pair is qualified. The failure signature for this “dual” Pc shift is the same for the single Pc shift except that the HPOT DP is the best cue available for determining power level and level number. For the shift high actual low case the HPOT TDT, HPOT DP, HPFT DP, and OPOV will all shift low. For the shift low actual high the HPOT TDT, HPOT DP, HPFT DP, and OPOV will all shift high.

With nominal operations, the Channel Pc A pair and the Channel Pc B pair will both read approximately 2870.6 psia for a power level of 104.5 percent. Then, if the Pc A pair shifts 60 psia high and the Pc B pair shifts 40 psia high, the Pc A pair will equal 2930.6 psia and the Pc B pair will equal 2910.6. This will cause the controller to see a Pc of 2920.6 psia (Pc avg). Since the main engine controller sees the average Pc above the Pc reference of 2870.6, it will close the OPOV to bring the Pc average to 2870.6 psia. When it does this, the A Pc pair will read 2880.6 psia and the Pc B pair will read 2860.6, but actual Pc will be 2820.6. Although the shift looks like only a difference of 20 psia between the two, the HPOT DP will show that the actual shift in Pc is much worse. If this case exists, the impacts of the actual shift of the engine are the same as those listed above.

A dual Pc shift case cannot be called until the Pc error is greater than 37.5 psi. This is to protect against erroneously calling the case due to prediction errors, and their reliably to differentiate this case from other cases that have similar SSME temperature and pressure movements.

It should be noted that the dual Pc shift case due to sensor errors is highly unlikely to be called due to the type and number of failures required, and the sensor checks designed to limit the impact of sensor shifts. Aside from one channel shifting with one channel disqualified, two failures must occur simultaneously for a dual pc shift to exist. One way this happens is if one sensor on each channel shifts in the same direction. In order for this to be an impact, though, both bad sensors would have to shift 74 psi high (if they shifted 75 psi high, they would be disqualified by the Pc intrachannel check, which is a delta of 75 between the sensors). With two channel averages reading 37 psi high, this is close enough to the 37.5 psi minimum dual Pc shift threshold to call the case. Obviously, since two sensors have to shift into a very small window below the disqualification threshold for this case to be called, the odds of this case occurring is very low.

Another way this case can occur is for ice to build up in the PC sense port inside the engine and cause blockage that could affect the sensor reading. This scenario is seen occasionally on flights, but is typically immediately melted away or blown out. When this blockage occurs, both sensors on the same channel are likely to be biased at the same rate, nullifying the Pc intrachannel check (delta of 75 between the sensors). If icing conditions exist, though, it is possible for both sense ports to become blocked, messing with the pc sensors on both channels. If this happens to two channels, it is possible that both channels would experience bias in the same direction, and they

1.17.3.2 Fuel Flowmeter Sensor Shifts

Similar to the MCC Pc logic, the LH2 flowmeter logic uses the average of all qualified sensors (A1, A2, B1, B2) in the mixture ratio control loop. However, there are no intrachannel qualification limits. The qualification of each sensor is measured by comparing the number of pulses per second the sensor picks up to a reference number for a given engine operating condition. The fuel flowmeter sensor picks up each fuel flowmeter blade pass as a pulse, and the number of pulses per second (pps) is directly proportional to the fuel flowrate. Therefore, the SSMEC compares the number of pulses per second acquired by the sensor to a reference value determined using the equation shown below. The qualification limit is Nref-50 pps to Nref+50 pps from start + 3.5 sec to start + 4.98 sec, and Nref-25 pps to Nref+25 pps from start + 5.0 sec to the end of mainstage. The 25-pulse per second qualification range corresponds to an 1800 GPM fuel flow error.

$$N_{ref} = N0 + [N1 * P_c] + \left[\left(\frac{P_c}{RPL} \right) * (MR_i - MR_{ref}) * 25.2 \right] * [(\rho_{fd} - \rho) * 51.4]$$

Where:	P_c	=	MCC Pc (Pc ref during Thrust Limiting)
	RPL	=	2747 (Block IIA & Block II)
	N0	=	0 pps
	N1	=	0.82 pps/psi (Block IIA & Block II)
	MR_i	=	6.0 (ICD Mixture Ratio Value)
	MR_{ref}	=	6.032 (Reference Mixture Ratio)
	ρ_{fd}	=	4.323 (Fixed Density Default Value)
	ρ	=	Calculated Fuel Density = f(P,T), lb/ft ³

1.17.3.2.1 LH2 Flowmeter Shift Low Actual High - Low Mixture Ratio Case

If one or more of the fuel flowmeter sensors are biased low, a fuel flowmeter shift low actual high case exists. The actual fuel flowrate is higher than the average of the sensors (since one or more of the sensors is erroneously reading low). In this case the controller mixture ratio calculation will be erroneously high. Therefore, the controller will compensate by increasing the fuel flowrate. This is accomplished by opening the FPOV. When the FPOV position increases, the HPFT turbine discharge temperatures will also increase. With the FPOV opening more there will be greater LO2 flow into the fuel preburner causing increased the turbine power and pump discharge. The additional fuel discharge from the HPFP will slightly increase the MCC Pc. The main engine controller will decrease the OPOV open position to reduce the MCC Pc back to the desired value. This action will cause the HPOT discharge pressure and temperatures to decrease. Although the ISP will go up in this case, the power level goes down since total flowrate into the MCC is decreased by a factor greater than the increase in ISP. This is a low mixture ratio case since the fuel flowrate is greater than nominal and the total oxidizer flow is less.

1.17.3.2 Fuel Flowmeter Shift High Actual Low - High Mixture Ratio Case

If one or more of the flowmeter sensors shifts high, a fuel flowmeter shift high actual low case exists. The flowrate is actually lower than the sensor average, but the controller will erroneously calculate the mixture ratio to be low. The controller compensates for this by decreasing the FPOV position. This in turn will cause a decrease in the HPFT turbine power and pump discharge. Next, the MCC Pc will drop and the controller will compensate by opening the OPOV. The increase in OPOV position will increase both the HPOT discharge temperature and pump pressure.

This case is essentially the opposite of the “shift low, actual high” case in that a flowmeter sensor shifts up instead of down.

For this case the ISP will go down, but the power level goes up since total flowrate is increased. This is because the thrust decrease due to ISP is proportionally less than the flow rate increase. This is a high mixture ratio case since the fuel flowrate is less than nominal and the total oxidizer flow is greater.

1.17.3.3 Electric Lockup

Electric lockup occurs when all four fuel flowmeter sensors, or both MCC Pc pairs are not available to the controller for mixture ratio or thrust control. This can occur due to individual disqualification of the sensors by failing disqualification limits, or through controller failures such as loss of a DCU or IE, which also disqualifies the sensors. When lockup occurs, the controller initiates lockup by deactivating the mixture ratio and thrust control loops. The SSME valve actuators are actively controlled to maintain the last valid command position. Actively holding this last position minimizes valve drift and performance dispersions. However, when an SSME operates in electrical lockup, variations in SSME performance can occur due to the effects of vehicle acceleration and thermal stabilization. Thermal stabilization is a secondary effect while vehicle acceleration is a much greater impact to drifting performance. The LO2 inlet pressure will increase or decrease with changes in acceleration. These pressure changes will impact the HPOT DP, HPFT DP, HPFT TDT, FPOV, OPOV, and HPOT TDTs. However, if the SSME is in electrical lockup, the OPOV and FPOV cannot change to compensate for changes in LO2 inlet pressure. For example, if the vehicle goes into electric lockup soon after SRB SEP, the LO2 inlet pressure will start to increase and the OPOV will not be able to decrease as it normally would (normally it decreases because the LO2 inlet pressure steadily increases post SRB SEP so the HPOT does not have to do as much work to increase the pressure to an appropriate level). It should be noted that the SSME performance might have already been degraded (prior to the lockup) due to a slow fuel flowmeter or the chamber pressure transducer sensor shifts that might have caused performance dispersions before the sensors were disqualified. In these cases, the mixture ratio, thrust, and Isp may be locked at off-nominal values since the valve positions will not change after the SSME enters into Electric Lockup.

1.17.3.4 Hydraulic Lockup for SEII

The SSME valves (MOV, MFV, OPOV, FPOV, and CCV) are hydraulically actuated valves. The controller receives valve position information for each valve expressed in terms of percent open (channels A and B). If the valve is not at the position it is supposed to be, the controller will attempt to move the valve to the correct position. If this is unsuccessful (or only partially successful), the controller will log the percent error between the actuator model position and the indicated actuator position. Each major cycle, the controller will cumulatively add to the valve's percent error. When this cumulative error reaches 6%, the controller will announce a "Servoactuator Error Indication Interrupt" (SEII) on the "A" side of the actuator, and the "B" side will be placed in control. If the B side then registers a 10% cumulative error, the controller will issue an SEII on the B side as well and will assume that it has lost control over the valves. In order to prevent a catastrophic failure (due to actuator malfunctions), the controller hydraulically locks all five SSME valves at their current position. This is accomplished by closing the fail-safe servo-switch on the actuator, which effectively eliminates the in/out flow of hydraulic oil through the valve actuator. This is called a hydraulic lockup, and when an SSME is in a hydraulic lockup, it can only be shut down using the pneumatic backup system. Note that the greater error percentage allowed for a "B" actuator SEII is due to the potential errors that may occur during the A to B swap.

Whether the valve is not moving correctly due to actual valve/actuator problem, a controller valve model problem, or due to the loss of hydraulic pressure (if an APU goes down) the controller will log the cumulative percent error and the SSME will be placed in hydraulic lockup if the limits of 6% (Ch A) and 10% (Ch B) are reached.

In the case of an APU failure, the valve error can take up to 60 seconds to exceed limits during non-throttling periods. During throttling, the error limits will be violated nearly instantaneously.

Similar to electric lockups, the SSME controller will announce a hydraulic lockup in the engine status word and will not accept new throttle commands from the GPC. Unlike electric lockups, the SSME will not actively control the SSME valves at their last commanded positions. Therefore, the SSME valve(s) can drift while the engine is in hydraulic lockup. Several hot-fire tests were conducted with the SSME in hydraulic lockup. This testing demonstrates that significant valve drift in the locked state is possible. The valve most susceptible to drifting during testing was the FPOV. Mixture ratio changes up to 0.72 were seen during testing.

The following table shows the expected drift of the SSME's five actuators per 100 seconds, and the resulting shift in mixture ratio and power level (in terms of MCC Pc). Additionally, the valves are expected to drift this amount whether the SSME is at 104.5% PL or at 67% PL.

Table 1.17-I: SSME Actuator Drift Rates

	DRIFT RATES PER 100 SECS				
	ECP 1261 Actuators				
	901-859	901-860	901-862**	901-863	Average
OPOV	-0.11%	-0.07%	0.00%	-0.06%	-0.06%
FPOV	-0.10%	-0.11%	-0.01%	-0.18%	-0.10%
MFV	*	*	-0.18%	-0.25%	-0.22%
MOV	-0.18%	-0.18%	-0.16%	-0.22%	-0.19%
CCV	-0.24%	-0.21%	0.00%	-0.28%	-0.18%
Mixture Ratio	0.000	0.000	0.017	0.017	0.008
MCC Pc (psia)	-5	-2	-2	-8	-4

With the BFS engaged, the ESW will show Hydraulic Lockup, but a mixture ratio cannot be calculated, because the fuel flowrate is not downlisted. Therefore, the console operator cannot determine a level.

1.17.3.4.1 Hydraulic Lockup for RVDT Miscompare

An RVDT (Rotational Variable Differential Transducer) is the device placed on each hydraulic actuator that physically measures the actuator (and therefore, the valve's) position expressed in percent open. Each actuator has two RVDTs, and they should always read approximately the same value. If they differ, however, then an RVDT problem may be occurring. When the delta percent error between the two RVDTs surpasses $\pm 3\%$, the controller will declare an RVDT miscompare on that valve.

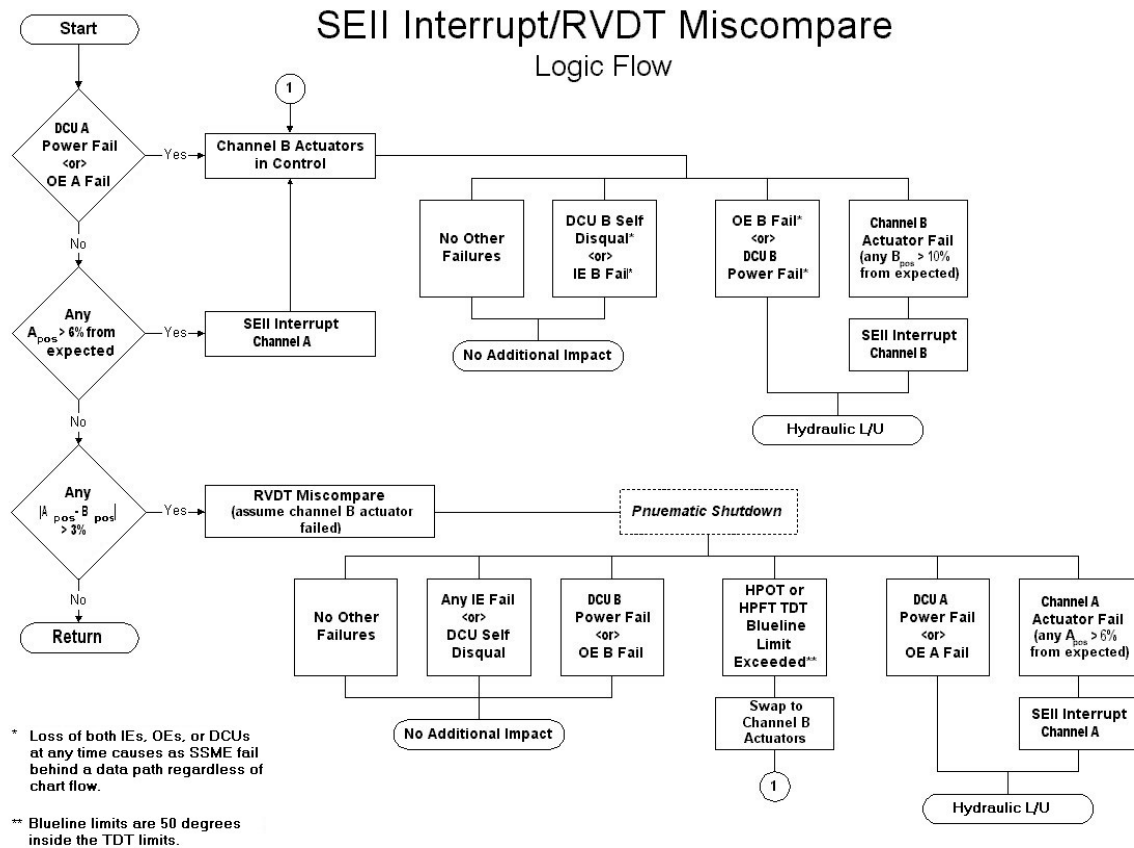
At this point, the controller is in a dilemma, because the devices informing the controller of the valve's position are in question, and the controller may not be getting the proper information. This is a potentially dangerous situation, and with little information the controller will do two things: first, the controller sets a flag so that whenever the engine needs to shutdown (commanded or redline) it will be a pneumatic shutdown; and second, the controller will assume that the B channel has failed, and will continue to control to the A channel's RVDT. Since the controller cannot trust the information it is receiving from the RVDTs, it does not want to attempt a shutdown using the questionable RVDTs; therefore the pneumatic shutdown method is the safest solution. The controller assumes that the OE B RVDTs are failed until this assumption is proven incorrect by the HPOT or HPFT turbine exhaust temperatures failing their "Blueline Limits". These limits are 50° inside the redline limits (both upper and lower). If all qualified sensors on either turbopump's exhaust temperature are beyond a blueline limit, but not all beyond the associated redline limit, the controller will believe that its original assumption (that the OE B channel was bad) was incorrect, and will swap over control to the OE B channel actuators. Note that regardless of the actuator switchover, the SSME will still experience a pneumatic shutdown. It should also be noted that RVDT miscompares are not valve specific like

SEIIs. When RVDT miscompares are experienced, the controller makes blanket assumptions about the entire OE A or OE B. If a miscompare is experienced on the OPOV, for example, the controller assumes that OE B is suspect.

Since the OE B channel is assumed failed when an RVDT miscompare is announced, any failure occurring on the B controller will not have any additional impact (other than the loss of redundancy). If OE-A fails for any reason, however, the controller will enter into hydraulic lockup because it previously assumed that the B channel RVDT had failed. This OE-A failure could be due to a DCU-A power failure, an OE-A failure, or if an SEII interrupt occurs on any OE-A valve. The DCU-A (or IE-A) may self-disqualify without sending the SSME into hydraulic lockup, because the DCU-B will simply take over and the OE-A still has power.

If the upper or lower blueline is violated, then the controller assumes that the A channel RVDTs were actually failed, and it will swap control to the B channel RVDTs. At this point any failure on the A controller, a DCU B Self Disqualification, or an IE B failure may be experienced without causing further complications (except, of course, loss of redundancy). The SSME will enter into hydraulic lockup if the DCU-B experiences a power failure, if OE-B fails, or if any channel B actuator experiences an SEII.

Figure 1.17-I is available in the Booster Cue Card Book, and outlines the logic flow that causes an RVDT miscompare and resulting hydraulic lockups.



RLMS:\Divisions\DR\Private\DF55\Internal Documentation\CueCards...Seii.jpg

Ref. SSME S/W Part 1 Spec Vol. 1

1/23/02 Rev. B

Figure 1.17-I – SEII Interrupt/RVDT Mismatch Logic Flow

1.17.3.5 Thrust Limiting (OPOV Limiting)

Any time the MCC P_c drops below the reference P_c , the SSME controller increases the OPOV open position to increase the P_c to the proper value. This action causes the HPOT turbine discharge temperatures to increase. If the OPOV position increased enough, the HPOT TDTs could exceed their redline limit. In an attempt to prevent a redline shutdown, OPOV limiting (also called thrust limiting) was developed. During the SSME start sequence the controller calculates the maximum open position the OPOV is allowed to achieve for a given power level. Currently this limit is approximately 4.21 percent greater than the nominal position (for more on how this value is calculated refer to the Block II Controller Operational Program Book). When this limit is reached, the SSME enters what is called OPOV limiting and the engine status word will change to 8A or 8B. When this occurs, the OPOV will not be commanded to open any further and the reference P_c is substituted in for the MCC P_c average to maintain the FPOV at its last commanded position. If the performance case worsens after thrust limiting is initiated, the SSME performance may continue to decay since the OPOV is not allowed to open any further. This will cause the MCC P_c and SSME thrust to drop.

If the SSME is commanded to a lower power level, the SSME may get out of OPOV limiting because the controller commands the OPOV to close to accommodate the new power level and the valve may not be at its limit for the new power level.

Thrust Limiting is not a performance case unto itself. Thrust limiting is simply a condition that the SSME can get into as the result of a HPOT efficiency case or a large Nozzle Leak (both of which are discussed later in this systems brief).

1.17.3.6 Nozzle Leak - High Mixture Ratio Case

A nozzle leak is defined as any fuel leak downstream of the fuel flowmeter (not necessarily a leak in the engine nozzle). Nozzle leaks, therefore, are transparent to the controller (since the flowmeter measurement remains constant). Fuel leaks upstream of the fuel flowmeter are quantified as ullage leaks or losses of net positive suction pressure (NPSP) and are discussed in SB 3.4. The SSME controller uses flow rate, as measured by the fuel flowmeter, to calculate the mixture ratio. Therefore, when a nozzle leak occurs, the controller calculated mixture ratio does not change and the FPOV is not opened to compensate for the leak. Since fuel flow into the MCC is decreased, the MCC P_c will also decrease. In response, the controller commands the OPOV to open further. This action increases the HPOT TDTs and the oxidizer flow. This leads to a higher than nominal mixture ratio, and higher thrust.

Again, a nozzle leak does not have to be in the nozzle itself but can be anywhere downstream of the LH2 flowmeter. There were several cases of nozzle leaks early in the program and hence the term nozzle leak was adopted. Due to the number of early “true” nozzle leaks, tube walls were thickened. Note that in the nozzle leak case, there is a severe degradation in Isp.

1.17.3.6.1 Nozzle Leak – Pre-Thrust Limiting

A pre-thrust limiting nozzle leak is defined as a fuel leak large enough to cause significant performance impact, but not so large as to cause the OPOV to reach its limit (i.e. thrust limiting). Pre-thrust limiting nozzle leaks can be declared at leak rates of 7 lb/sec. Thrust limiting occurs at leak rates of approximately 13.6 lb/sec. The cues used to identify a pre-thrust limiting nozzle leak are increase in HPOT TDT, HPFT TDT, and OPOV position and a decrease in HPFT DP.

1.17.3.6.2 Nozzle Leak – Post Thrust Limiting

If a fuel leak is severe enough, OPOV limiting may be reached. After OPOV limiting occurs, HPOT TDTs will continue to increase, but at a lower rate than before the OPOV limit value was reached (when the OPOV is in the process of opening, the temperatures rise quickly). The HPOT TDT's continue to rise because the SSME is burning oxidizer rich. A secondary impact causing the temperature increase is the possibility that there is less fuel available for the coolant jacket in the HPOT.

If the leak continues to worsen, the engine will not be able to compensate (because it is in thrust limiting) and will eventually violate the HPOT TDT redline.

If the BFS is engaged, the ESW will indicate OPOV limiting but there is no data that can indicate if the limiting is caused by the nozzle leak or an HPOT efficiency loss.

1.17.3.7 HPOT Efficiency Loss - Low Mixture Ratio Case

A reduction in HPOT efficiency reduces output from the turbopump and thus the MCC Pc will decrease. The SSME controller responds by commanding the OPOV to open further to increase the mixture ratio in the HPOT preburner which in turn increases both the HPOT discharge temperature and pump pressure. Once OPOV limiting is reached, however, the MCC Pc will begin to decrease assuming the efficiency loss increases or the OPOV had not yet reached a position that would compensate for the reduction in HPOT efficiency.

The HPOT efficiency loss can only be quantified after the SSME enters OPOV limiting. Subsequent to OPOV limiting, the HPOT TDTs will start to decrease if the case continues to get worse. The inefficient HPOT pumps less LO₂, which results in a low mixture ratio case in the preburner.

If the HPOT efficiency worsens, the engine will not be able to compensate (due to the thrust limiting). In this case, the MCC Pc can violate the control qualification limit (enter electric lockup) and subsequently violate the lower Pc redline (200 below PcRef or 400 below when throttling).

With the BFS engaged, the ESW will show OPOV limiting but without the HPOT TDTs, the console operator cannot tell what caused the SSME to go into thrust limiting. The crew has no insight into this failure in either the PASS or BFS.

1.17.3.8 Low Pressure Fuel Pump Discharge Temperature (LPFT DT) Shift Low - High Mixture Ratio Case

The main engine controller uses the LPFT discharge temperature sensor on each SSME to calculate the fuel density. This density is used in the calculation of the fuel mass flowrate, which in turn is used in the mixture ratio calculation. The qualification limits for this sensor are 40 deg R minimum and 45 deg R maximum. If the transducer is outside this range, the sensor will be disqualified, and the SSME will enter fixed density mode when both LPFT discharge temperature sensors are disqualified. The actual in flight average LPFT discharge temperature is 42.22 deg R. For more on how the controller calculates density and flowrate refer to the Block II Space Shuttle Main Engine Controller Operational Program Book Volume I.

There is no credible scenario that would cause the LH2 temperature to decrease; therefore, a LPFTP discharge temperature sensor shifting low is most likely a sensor problem (since the source propellant all comes from the same external tank). A shift low is understood as an indication of a sensor problem.

The LPFT discharge temperature shifting low causes the value of the calculated fuel density to increase. This increase causes the value of the calculated fuel flowrate to increase, and the controller calculated fuel flowrate would be greater than the actual flowrate (the controller thinks that the mixture ratio is lower than it actually is). If the controller senses a mixture ratio that is lower than expected, the controller will decrease the FPOV position. This causes the fuel flowrate to decrease, the mixture ratio to go up, and the MCC Pc will go down. In response to this decrease in MCC Pc, the controller opens the OPOV to increase the MCC Pc back to the reference Pc. The increase in the OPOV position will also cause the HPOT discharge pressure and HPOT discharge temperature to increase. The result is that the SSME returns to a nominal power level, but the mixture ratio is high.

If the LPFT discharge temperature on an SSME is higher than the other two SSMEs, no console action is taken. A higher temperature could be indicative of either a transducer failure or a real SSME problem. Since the SSME project believes that a high transducer reading is much more likely a real hardware problem than a transducer shift, no action is taken. An example would be if the LPFT pump efficiency were low, more work than normal to the pump would be required, thus raising the LPFT pump discharge temperature on that engine. Since the LH2 temperature has actually increased, the FFM will measure the adjusted fuel flow rate and thus use the actual, decreased LH2 density in the Mixture Ratio equation. Although the fuel volumetric usage will be increased to compensate for the lower density, since all sensor values are accurate, the engine will operate at a nominal MR and MCC Pc.

1.17.4 References

1. Booster Standard Console Procedures, JSC-17239, Final, Rev. F, PCN-3, November 12, 2002.
2. "SSME Flight Operations Handbook, Atlantis STS-104", RKD, July 12, 2001.
3. CP406R0008G, Part I (Vol. I and II), Computer Program Contract End Item, Block II SSME Controller Operational Program, June 12, 1999.
4. Space Shuttle Operational Flight Rules, NSTS-12820, Final 2002, PCN-1, November 21, 2002.

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