

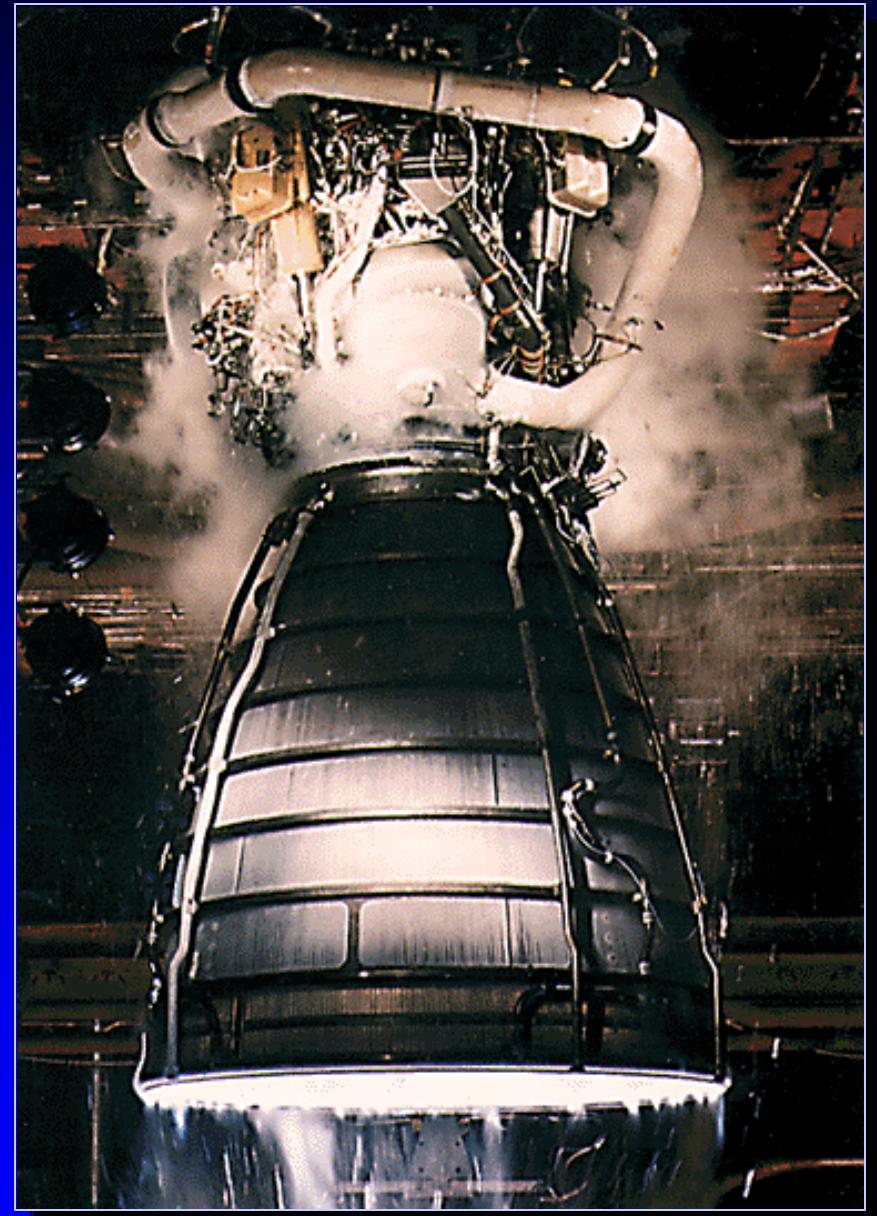
## Space Transportation System Training Data

# Space Shuttle Main Engine Orientation

June 1998

**Use this data for training purposes only**

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Propulsion & Power



## **FORWARD**

This manual is the supporting handout material to a lecture presentation on the Space Shuttle Main Engine called the Abbreviated SSME Orientation Course. This course is a technically oriented discussion of the SSME, designed for personnel at any level who support SSME activities directly or indirectly. This manual is updated and improved as necessary by Betty McLaughlin. To request copies, or obtain information on classes, call Lori Circle at Rocketdyne (818) 586-2213

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## ACRONYMS AND ABBREVIATIONS

AFV	Anti-Flood Valve	LRU	Line Replaceable Unit
ASI	Augmented Spark Igniter	LTMCC	Large Throat Main Combustion Chamber
CCV	Chamber Coolant Valve	LVDT	Linear Variable Differential Transformer
CCVA	Chamber Coolant Valve Actuator	MAX	Maximum
CRES	Corrosion Resistant Steel	MCC	Main Combustion Chamber
DC	Direct Current	MEC	Main Engine Controller
DCU	Digital Computer Unit	MFV	Main Fuel Valve
EDCu	Electrodeposited Copper	MFVA	Main Fuel Valve Actuator
EDNi	Electrodeposited Nickel	MI	Main Injector
EIU	Engine Interface Unit	MOV	Main Oxidizer Valve
ET	External Tank	MOVA	Main Oxidizer Valve Actuator
FASCOS	Flight Acceleration Safety Cutoff System	MPL	Minimum Power Level
FBV	Fuel Bleed Valve	MR	Mixture Ratio
FPB	Fuel Preburner	NC	Normally Closed
FPL	Full Power Level	NO	Normally Opened
FPOV	Fuel Preburner Oxidizer Valve	NPL	Normal Power Level
FPOVA	Fuel Preburner Oxidizer Valve Actuator	OBV	Oxidizer Bleed Valve
FRI	Flow Recirculation Inhibitor	OE	Output Electronics
GCV	GOX Control Valve	OMS	Orbital Maneuvering System
GG	Gas Generator	OPB	Oxidizer Preburner
GN <sub>2</sub>	Gaseous Nitrogen	OPOV	Oxidizer Preburner Oxidizer Valve
GOX	Gaseous Oxygen	OPOVA	Oxidizer Preburner Oxidizer Valve Actuator
GPC	General Purpose Computer	OV	Orbiter Vehicle
GSE	Ground Support Equipment	PAV	Pressure Actuated Valve
H <sub>2</sub>	Hydrogen	PEBB	Pump End Ball Bearing
HE(X)	Heat Exchanger	PB	Preburner
HEE	Hydrogen Embrittlement Environment	PCA	Pneumatic Control Assembly
HGM	Hot Gas Manifold	PSI	Pounds Per Square Inch
HPF	High-Pressure Fuel	RCS	Reaction Control System
HPFTP	High-Pressure Fuel Turbopump	PH	Right Hand
HPO	High-Pressure Oxidizer	RIV	Recirculation Isolation Valve
HPOTP	High-Pressure Oxidizer Turbopump	RPL	Rated Power Level
HPV	Helium Precharge Valve	RPM	Revolutions Per Minute
IE	Input Electronics	RVDT	Rotary Variable Differential Transformer
LH	Left Hand	SPGG	Solid Propellant Gas Generator
LH <sub>2</sub>	Liquid Hydrogen	SRB	Solid Rocket Booster
LO <sub>2</sub>	Liquid Oxygen	SSME	Space Shuttle Main Engine
LOX	Liquid Oxygen	TEBB	Turbine End Ball Bearing
LPF	Low-Pressure Fuel	TERB	Turbine End Roller Bearing
LPFTP	Low-Pressure Fuel Turbopump	VDC	Volts direct Current
LPO	Low-Pressure Oxidizer	WDT	Watchdog Timer
LPOTP	Low-Pressure Oxidizer Turbopump	ZRO <sub>2</sub>	Zirconium Oxide

# Space Shuttle Launch at Kennedy Space Center



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## SHUTTLE PROPULSION SYSTEM

The Space Shuttle propulsion system consists of two large solid rocket booster (SRB) motors, three space shuttle main engines (SSME), and an external propellant tank (ET), all used to boost the shuttle orbiter into space. In addition, the orbiter contains two orbital maneuvering system (OMS) engines, and 44 reaction control system (RCS) thrusters.

Each SRB measures 12 feet in diameter by 149 feet in height, weighs 1.3 million pounds, and generates approximately 3.3 million pounds of thrust. The SRBs also serve as launch pad mounts for the entire vehicle and are ignited at launch after all three SSMEs are producing at least 90-percent thrust. The solid propellant consists of a cast mixture of ammonium perchlorate (oxidizer, 69.93 percent by weight), atomized aluminum powder (fuel, 16.00 percent), polymer (binder, 12.04 percent), epoxy (curing agent, 1.96 percent), and iron oxide (catalyst, 0.07 percent). After burnout at approximately 150,000 feet, the spent cases separate from the vehicle, arcing up to approximately 220,000 feet before parachuting to the ocean for recovery and reuse.

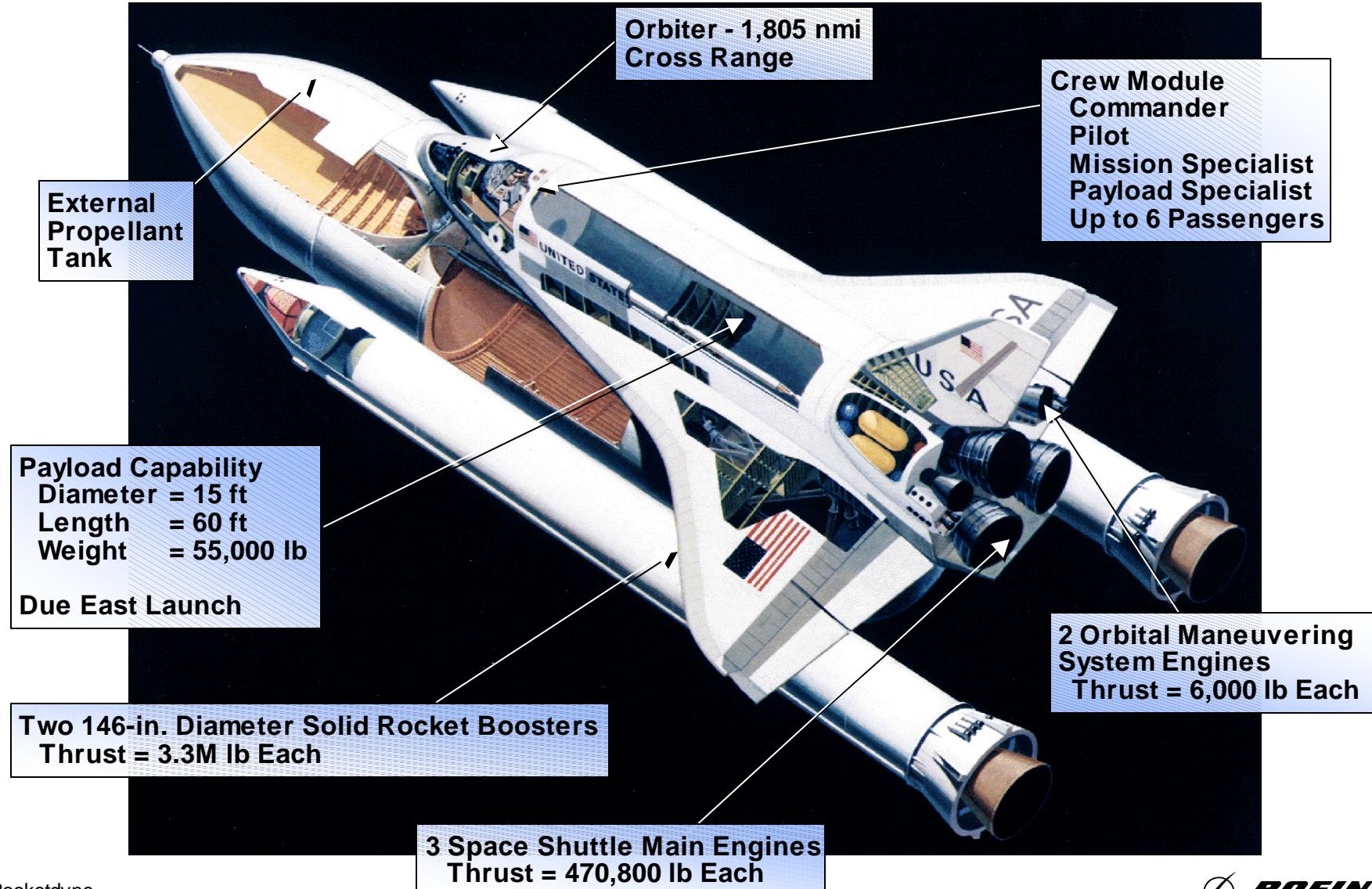
The External Tank, at 154 feet long by 27.5 feet in diameter is the largest element of the Space Shuttle. It serves as the backbone structure for attachment of the Orbiter and SRBs and also contains and delivers propellants under pressure to the three Orbiter main engines. The ET must accommodate the stresses created by its own weight, when loaded with propellants, and that of the Orbiter prior to launch. Then at launch the thrust generated by the Orbiter and the SRBs must be reacted by the ET structure. The ET has three major components: The forward liquid oxygen tank, the aft liquid hydrogen tank, and an unpressurized intertank that joins the two propellant tanks. After the SSMEs are shut down, the ET is jettisoned, enters the Earth's atmosphere, breaks up, and the pieces that survive reentry impact in a remote ocean area. It is the only element of the Space Shuttle that is not recovered.

The three SSMEs, which are sequentially started at launch, combust a mixture of propellants consisting of hydrogen and oxygen, which are stored and delivered in a cryogenic liquid state from the external tank (ET). Throttling-down of engine thrust is necessary early in the ascent to prevent excessive aerodynamic loading of vehicle structure and later in the flight to limit vehicle acceleration to no more than 3 times normal Earth gravity. Each engine is gimballed through two planes for vehicle pitch, yaw, and roll control. The SSMEs steer and accelerate the vehicle to the desired orbital position and velocity, and shut down.

The two OMS engines are mounted in pods on either side of the orbiter vertical stabilizer. Each pod also contains engine propellant tanks and helium tanks used for propellant tank pressurization. The propellants used are monomethylhydrazine (fuel) and nitrogen tetroxide (oxidizer), which are hypergolic (ignite on contact). Each engine produces 6,000 pounds of thrust in a vacuum. They are used together or separately to increase or decrease orbiter velocity for orbit insertion, circularization, transfer, and deorbit. The OMS pods, which are detachable, are serviced in a dedicated facility and reattached to the orbiter during ground turnaround activities. The pods also contain the aft group of reaction control system thrusters.

The reaction control system provides the capability for rotation and translation maneuvers of an orbiter in space. It includes 38 primary thrusters (870 pounds thrust each), and six vernier thrusters (24 pounds thrust each). The forward thruster group (in the orbiter nose) includes 14 primary and two vernier thrusters. Each OMS pod contains 12 primary and two vernier thrusters. Each thruster can fire a pulse as short as 800 milliseconds, using monomethylhydrazine (fuel) and nitrogen tetroxide (oxidizer), which are hypergolic. Typical RCS uses are: Attitude control as required, roll control during a one-OMS engine burn, orbiting and deorbiting (if the OMS fails), rendezvous and docking, and station keeping.

# Space Shuttle



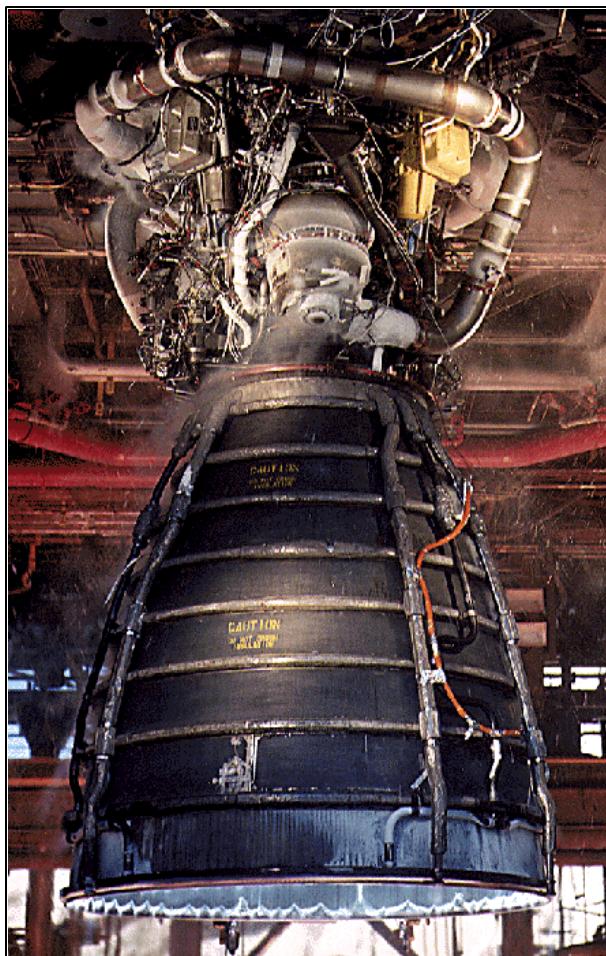
## SSME INTRODUCTION

The Space Shuttle Main Engine is a staged combustion cycle engine that burns a mixture of gaseous hydrogen and liquid oxygen. The identifying feature of a staged combustion engine is that most of the fuel flow (except for a small coolant flow) and a small amount of the oxidizer flow are “preburned” in a preburner at an extremely fuel-rich mixture. The resulting fuel-rich hot gas is used to power the turbopump turbine, and then injected into the main combustion chamber (MCC) along with the remaining oxidizer and the coolant fuel, all to be “final-burned”.

The SSME is rated at 470,800 pounds thrust (100 percent) in vacuum of 376,600 pounds at sea level. It is throttleable from 316,100 pounds (67 percent) to 512,900 pounds (109 percent) in approximately 4,700-pound (1-percent) increments. These three thrust levels are called rated power level (RPL), minimum power level (MPL), and full power level (FPL), respectively. Throttling is accomplished by varying the output of the preburners, thus varying the speed of the high-pressure turbopumps and, therefore, the propellant mass flowrates. The pressure of the burning propellants within the MCC is approximately 3,008 pounds per square inch (PSI) at FPL. The MCC propellant mixture ratio is approximately 6 pounds of oxygen to 1 pound of hydrogen, maintained by varying the fuel flowrate around the oxidizer flowrate. A large nozzle with a fairly high expansion ratio of 69 to 1 (nozzle exit area versus throat area) is required to fully expand the very high pressure gas in the MCC. Specific impulse in vacuum is 452 seconds (i.e., 452 pounds of thrust is generated for each pound of propellant burned per second).

In order to start, the SSME needs only propellant head for initial propellant flow and spark igniters to initiate combustion. It has an electronic controller to perform all checkout, start, run, monitoring, and shutdown functions. The engine is gimballed through two planes by hydraulic actuators for vehicle pitch, yaw, and roll control.

# SSME Is the First Reusable Large Liquid Rocket Engine



14 ft

• Propellants	Oxygen/ Hydrogen
• Rated power level (RPL) 100%	470,800 lb
• Nominal power level (NPL) 104.5%	491,900 lb
• Full power level (FPL) 109%	512,900 lb
• Chamber pressure (109%)	3,008 psia
• Specific impulse at altitude	452 sec
• Throttle range (%)	67 to 109
• Weight	7,480 lb
• Total program hot-fire time	> 2,660 starts > 832,500 sec

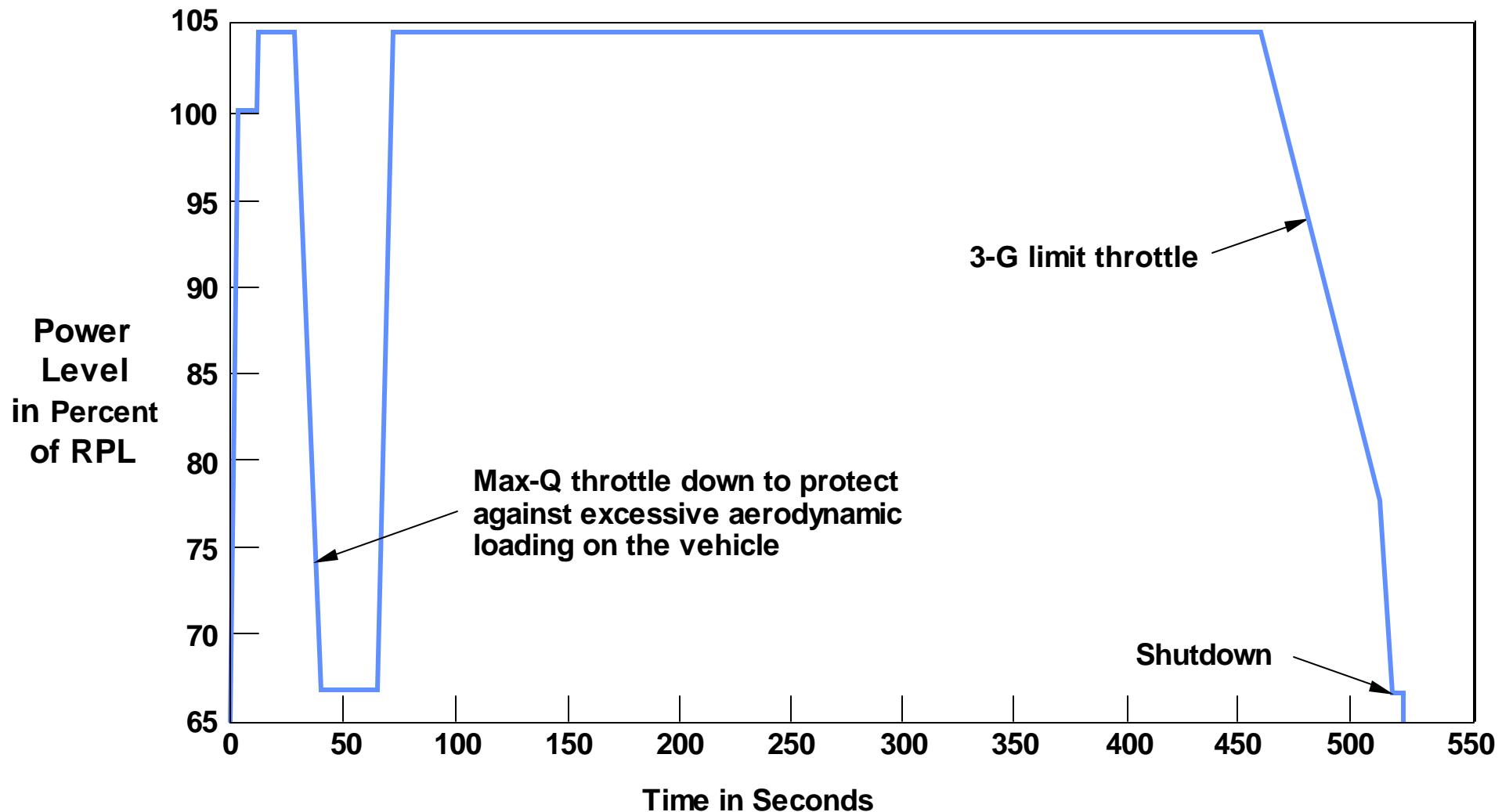
7.5 ft

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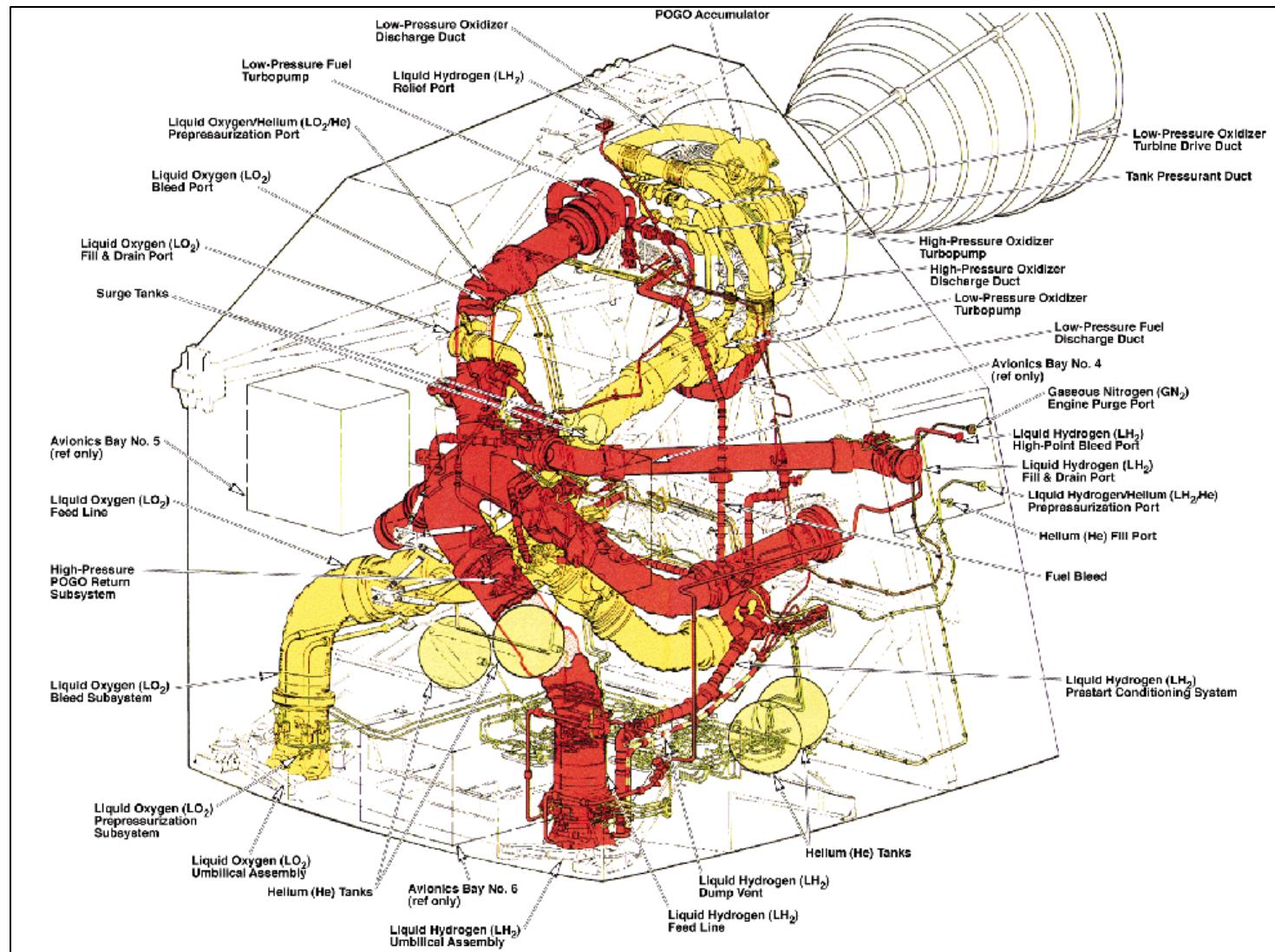
## SSME HIGHLIGHTS

- **Power cycle:**
  - Staged combustion. Fuel-rich combustion gas from two preburners drives two high-pressure turbopumps and then injects with oxidizer into main combustion chamber.
- **High-energy propellants:**
  - Liquid oxygen/liquid hydrogen
  - Delivered by two high-pressure and two low-pressure (boost) turbopumps
  - Main combustion propellant mixture ratio is 6.032 lbs oxygen to 1 lb hydrogen
- **Variable thrust:**
  - Full Power Level (FPL) ..... 109% (512,900 lbs)
  - Nominal Power Level (NPL)..... 104.5% (491,900 lbs)
  - Rated Power Level (RPL)..... 100% (470,800 lbs)
  - Minimum Power Level (MPL)..... 67% (316,100 lbs)
  - Variable in 1% increments..... 1% (~4,700 lbs)
- **High efficiency:**
  - Specific impulse approximately 452 seconds
  - Two-stage combustion approximately 99.6% efficient
  - Main chamber pressure approximately 3,008 psi at FPL
  - Direct drive turbopumps (no reduction gears)
  - High expansion ratio (69 to 1) (nozzle exit area vs. throat area)
- **Simple start system:**
  - Tank head pressure starts propellant flow
  - Spark igniters initiate combustion
  - No start tanks, turbine spinners, pyrotechnics, pressure ladders, etc.
- **On-board controller:**
  - Checkout, start, run, throttling, mixture ratio, monitoring, shutdown, etc.
  - Hydraulically-driven propellant valves (pneumatic backup for closing)
  - Pogo suppression system (pressurized accumulator in LOX feed system)
  - Gaseous Hydrogen and Oxygen tank repressurization system

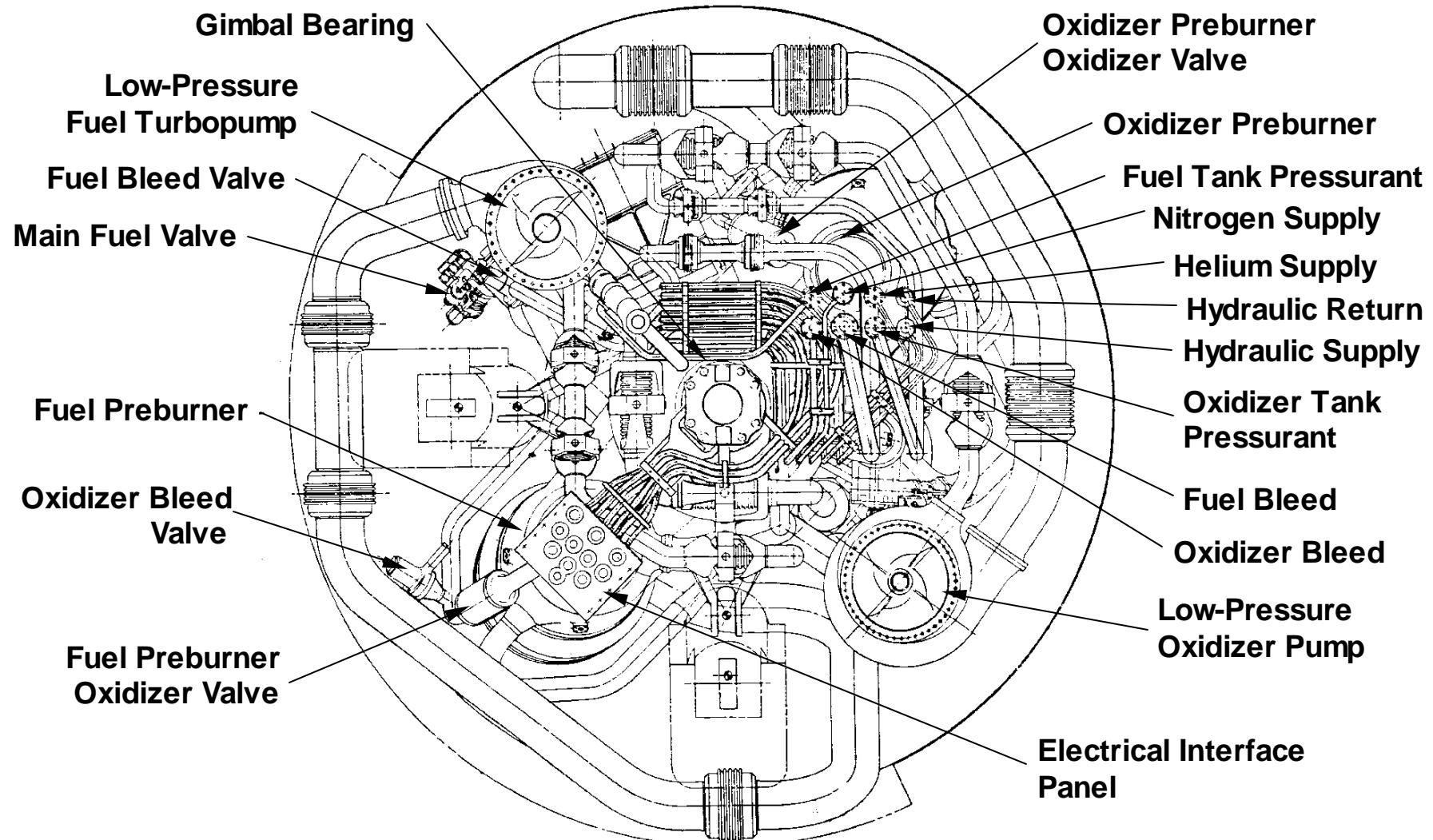
# SSME Typical Throttling Profile



# Main Propulsion System



# SSME Component Location Looking Aft

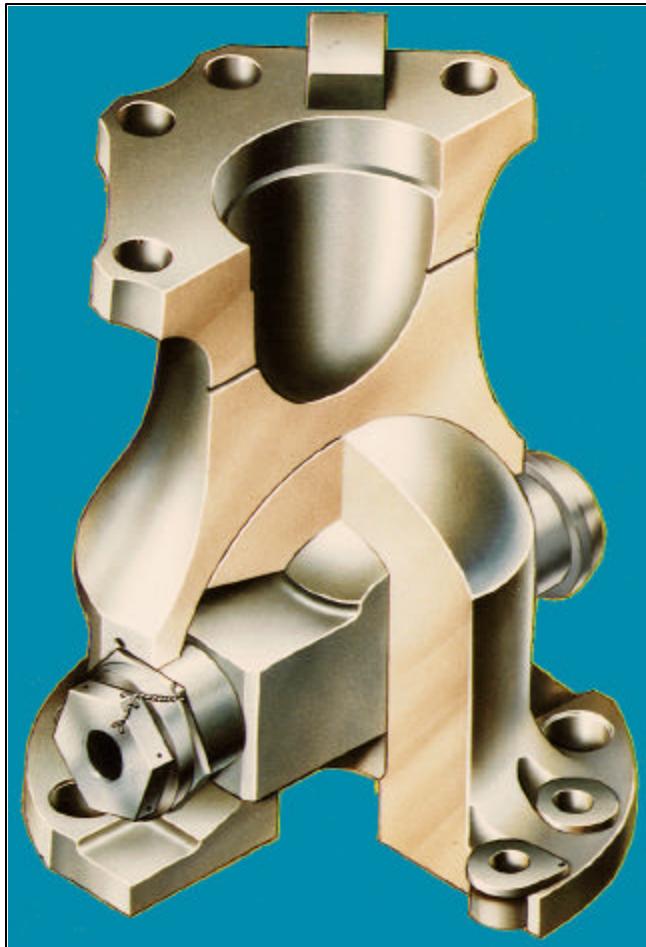


## GIMBAL BEARING

The gimbal bearing provides a means of attaching the engine to the vehicle while allowing the engine to be pivoted (gimballed) around its two axes. This is necessary in order to point the engine thrust vector for vehicle steering, in the manner of a ship's rudder.

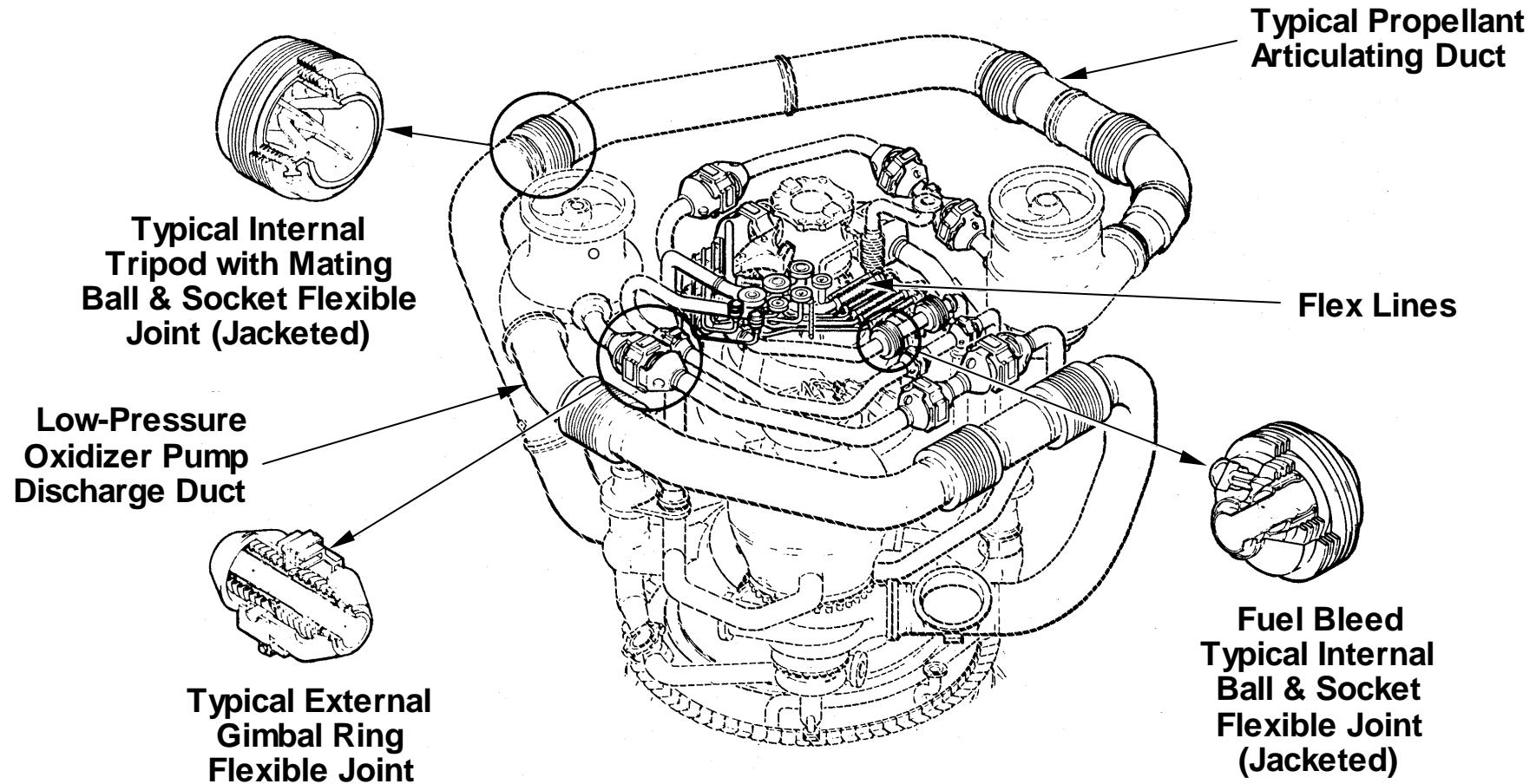
The gimbal bearing is bolted to the vehicle by its upper flange and to the engine by its lower flange. It supports 7,480 pounds of engine weight and withstands over 500,000 pounds of thrust. It is a ball-and-socket universal joint in which concave and convex spherical surfaces on the seat, body, and block intermesh. Sliding contact occurs between these surfaces as the bearing is angulated. Fabroid inserts located at the sliding contact surfaces reduce friction that occurs during gimbal bearing angulation. The bearing, which is installed during engine assembly, measures approximately 11 by 14 inches, weighs about 105 pounds, and is made of a titanium alloy.

# Gimbal Bearing Assembly Design & Performance Requirements

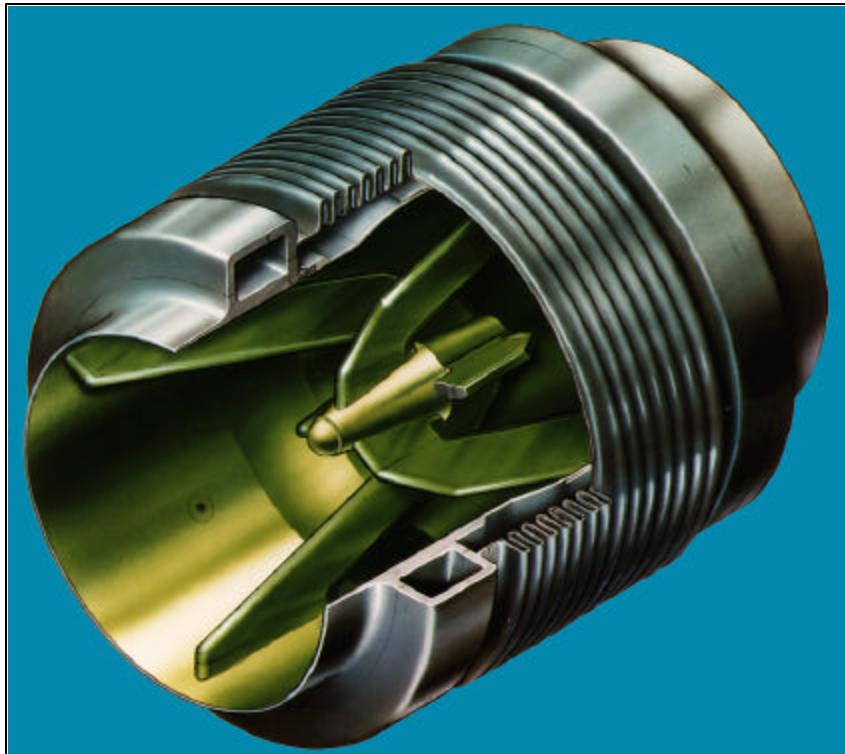


<b>Angular capability (°)</b>	<b>±12.5</b>
<b>Gimbal duty cycle</b> To 10.5°	<b>200 operational</b> <b>1,400 nonoperational</b>
<b>Material</b>	<b>6AL-6V-25n</b> <b>Titanium alloy</b> <b>Fabroid inserts</b>

# Typical Flex Bellows Applications



# Internally Tied Flex Joints



<b>Operating pressure (psia)</b>	423
<b>Temperature (°F)</b>	-294
<b>Inside diameter (in.)</b>	6.3
<b>Angular displacement (°)</b>	±13
<b>Life</b>	200 operational 1,400 nonoperational Full deflection cycles
<b>Material</b>	Inconel 718 ARMCO 21-6-9
<b>Typical use</b>	LPO discharge duct

## FLEXIBLE JOINTS

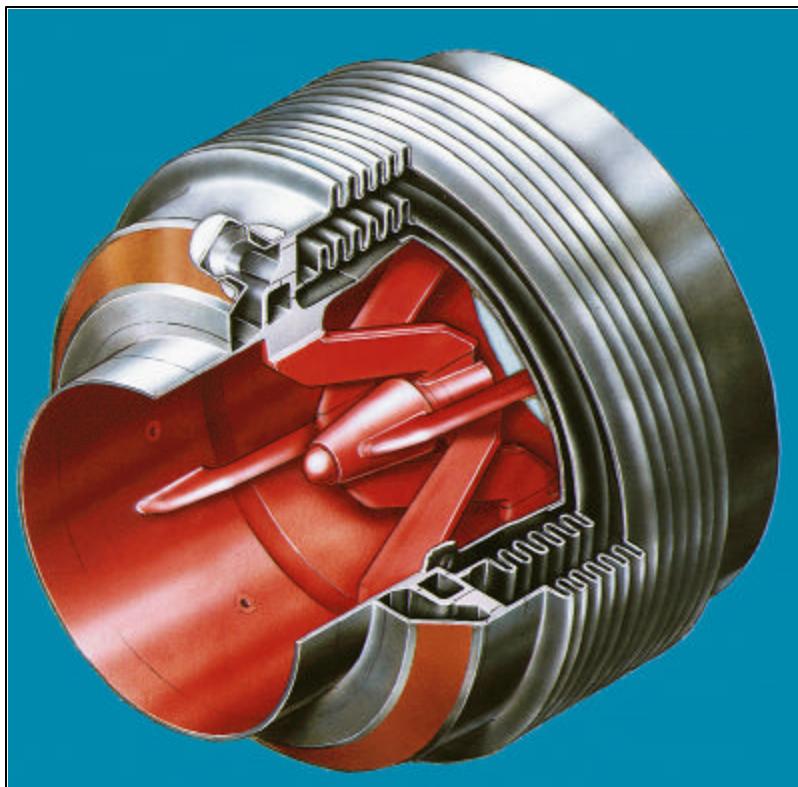
The flexible joints welded into the fluid interface lines, allow movement of the engine for vehicle steering, while maintaining the internal pressure and temperature environment of the lines. Since the fluid interface lines connect either between the engine (which gimbals) and the vehicle, or between the engine and a nongimballing component, they must be flexible.

A flexible metal bellows is used as the pressure vessel. With both ends welded into a section of fluid ducting, a continuous, leak proof pathway is provided. Instead of consisting of a single thick sheet, the bellows have several thin plies sandwiched together. This arrangement makes them more flexible while maintaining integrity against system pressure.

The ducts containing internally tied flex joints have a large enough internal diameter to allow an internal gimballed support. The internal support arrangement saves weight over an external support for a given duct, provided there is a sufficient internal diameter. If not for the gimbal joint holding both ends of the flexible bellows together, the normal internal operating pressure of the duct would expand the flexible bellows linearly in much the same way as an accordion. The joint of the internal gimballed support is of a ball and socket style universal configuration. Ducts with small internal diameters utilize an external gimbal ring to restrain the bellows. The ends of the flex joint are attached to the gimbal ring (which is centered over the bellows) at two points, forming a universal style joint.

The flexible joints contain an integral flow liner. This liner prevents the propellant flowing through the duct from impinging on the convolutions of the bellows which could cause flow turbulence, resulting in hardware vibration. The liner is made up of two or three overlapping pieces. The outside ends of the end pieces are welded into the flexible joint so as to form a continuous, smooth internal diameter when the flexible joint is itself welded into a duct. The overlapping portions of the liner are configured as a truncated ball and socket to allow movement of the flexible joint. The liner will allow propellant to fill the space between it and the bellows. Screened ports at the upstream ends of the flow liner provide a positive path for propellant to exit the space behind the liner after engine shutdown.

# Flex Joints with Insulating Jacket



<b>Operating pressure (psia)</b>	279
<b>Temperature (°F)</b>	-420
<b>Inside diameter (in.)</b>	5.2
<b>Angular displacement (°)</b>	±11.5
<b>Life</b>	200 operational 1,400 nonoperational Full deflection cycles
<b>Material</b>	Inconel 718 ARMCO 21-6-9
<b>Typical use</b>	LPF discharge duct

## POWERHEAD

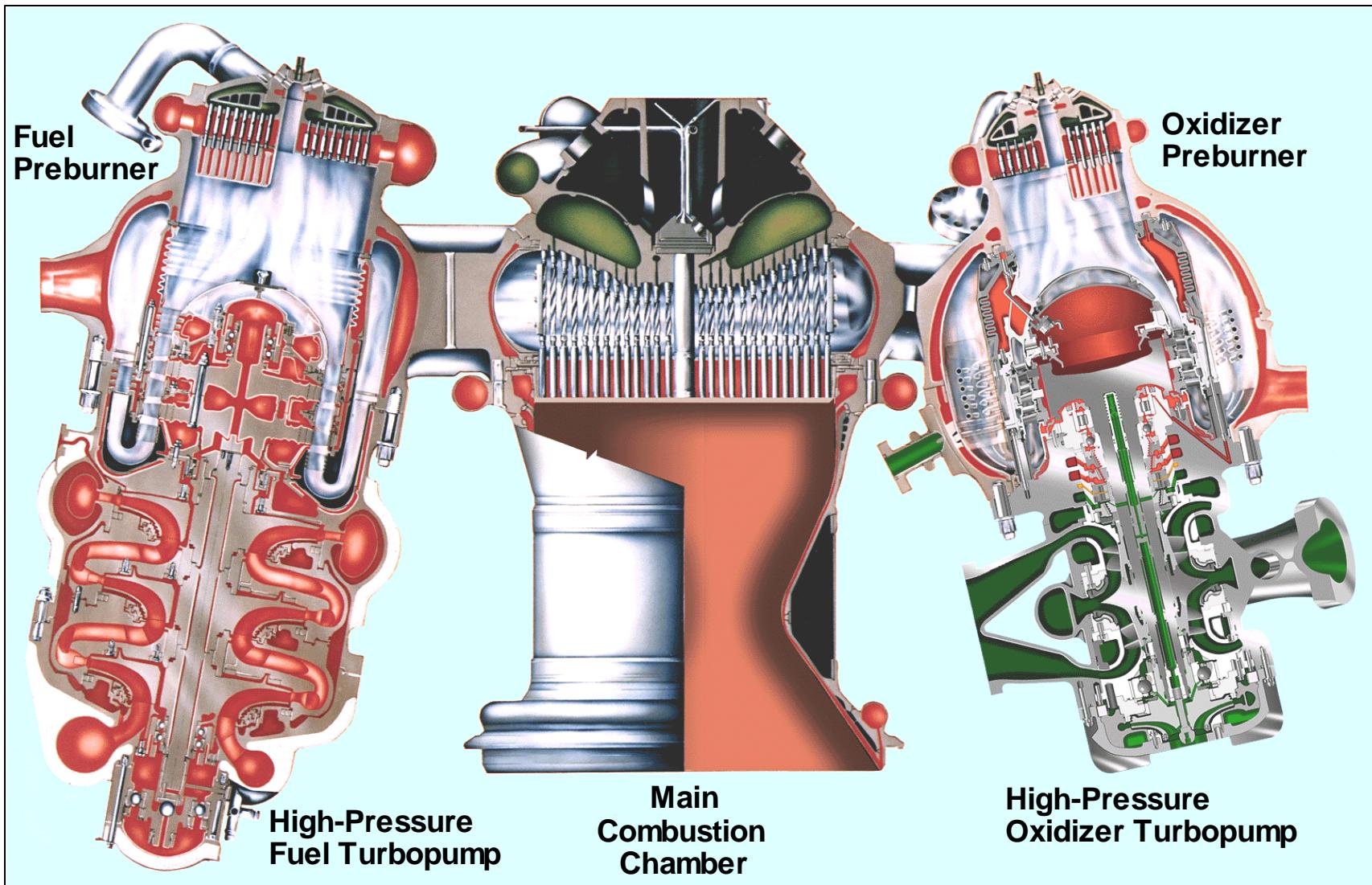
The powerhead is the heart of the SSME. Its central component is the hot gas manifold (HGM). The HGM ties together and structurally supports seven major components, forming a rigid, efficient package. The main injector and the two preburner injectors are welded into openings in the top. The two high-pressure turbopumps and the main combustion chamber are secured with bolts or studs on the bottom, making them readily replaceable. Each pump is individually driven by its own close-coupled preburner. The oxidizer side also incorporates a heat exchanger coil in which liquid oxygen is heated to gaseous oxygen. The two hot gas streams from the preburners, having driven their respective pumps, merge in the main injector and are injected, along with the majority of the oxidizer, into the main combustion chamber. Also injected is the coolant fuel that has migrated through the double walls of the HGM from both ends. Each injector includes a small "hole" in the middle and two spark igniters, which are components of the augmented spark igniter system.

The main combustion chamber, which contains the combustion process, is cooled by fuel flowing through 430 channels cut into its liner.

The high-pressure fuel turbopump is a three-stage centrifugal pump. It is completely insulated to reduce chilldown time, keep the hydrogen in a liquid state (-423°F), and prevent the formation of liquid air (-318°F) on the pump.

The high-pressure oxidizer turbopump is a double-entry, back-to-back twin impeller centrifugal pump that includes a small boost pump splined to the end of the shaft.

# SSME Powerhead Component Arrangement



## PROPELLANT FLOW ANALYSIS (1 of 3)

### General

The SSME utilizes a two-stage combustion process. In the first (or preburn) stage, 76 percent of the hydrogen flow and 11 percent of the oxygen flow are injected into two preburners to be preburned at the extremely fuel-rich mixture ratio of less than one pound of LOX to one pound of hydrogen. The resulting two hydrogen-rich gas streams first drive their respective high-pressure turbopumps and then merge to be injected into the main combustion chamber, along with the coolant fuel (about 19 percent) and the remaining oxygen (about 89 percent). Second (or final) stage combustion occurs in the main combustion chamber at a carefully controlled mixture ratio of 6.032 to 1.

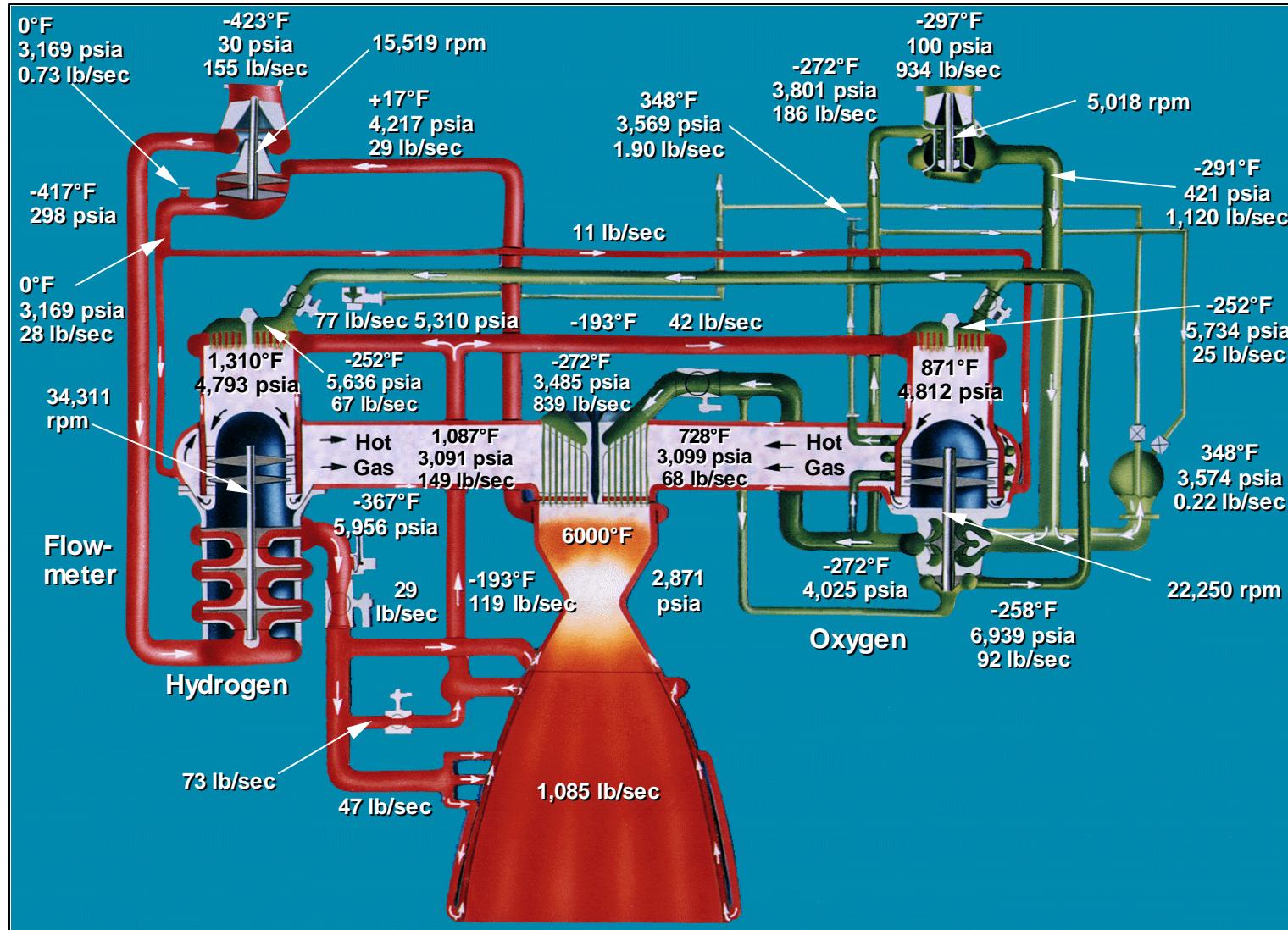
The two low-pressure turbopumps serve as boost pumps for the two high-pressure turbopumps. This arrangement allows lower ullage pressure to be used in the propellant tanks and higher pump speeds.

A pogo suppression system accumulator is attached to the low-pressure oxidizer duct. When pressurized with gaseous oxygen (GOX) from the heat exchanger coil, the accumulator dampens oxidizer feed system pressure oscillations. GOX flow into the accumulator exists through the end of an inverted standpipe, the length of which establishes the LOX/GOX interface plane. The exiting GOX is recondensed to LOX in the vehicle oxidizer feed system.

# Block II A

## SSME Propellant Flow Schematic

### *104.5% of RPL*



## PROPELLANT FLOW ANALYSIS (2 of 3)

### Oxidizer Flow

LOX enters at the low-pressure oxidizer turbopump (LPOTP). It flows through the low-pressure oxidizer duct and the high-pressure oxidizer turbopump (HPOTP), and then splits into a main flow and several branch flows. The main flow (about 89 percent) continues on through the main oxidizer valve (MOV) and the main injector, into the main combustion chamber (MCC). The first branch supplies LOX back to drive the LPOTP turbine. (The turbine discharge flow is merged with the pump output flow, bound for the HPOTP.) A second branch supplies LOX to the heat exchanger coil to be gasified and used to pressurize the oxidizer tank in the ET and the pogo accumulator. A third branch (11 percent) supplies the preburner oxidizer boost pump, located at the bottom of the HPOTP. This small pump increases the pressure of the oxidizer to about 6,970 PSI for injection into the preburners. The preburner oxidizer flows are controlled by the oxidizer preburner oxidizer valve (OPOV) and the fuel preburner oxidizer valve (FPOV). Acting together, they establish the thrust level. Acting alone, the FPOV maintains a 6.032 to 1 mixture ratio in the MCC. Additional branches downstream supplies LOX to the three augmented spark ignition systems.

### Fuel Flow

Liquid hydrogen enters at the low-pressure fuel turbopump (LPFTP). It flows through the low-pressure fuel duct, the high-pressure fuel turbopump (HPFTP), the high-pressure fuel duct, and the main fuel valve (MFV). Up to this point the fuel system has been insulated and downstream from here, without insulation, the hydrogen is allowed to warm and gasifies. The hydrogen now enters the diffuser where the flow splits into three paths. The first path (19 percent) leads upward through the 430 MCC coolant channels and then on to drive the LPFTP. Emerging from the LPFTP turbine, a branch supplies warm hydrogen gas to pressurize the fuel tank in the ET while the remainder is then split to enter both ends of the HGM. Both flows migrate through the HGM coolant spaces to enter a dedicated cavity in the main injector. From there, the gas is injected into the MCC. The second path (27.5 percent) passes upward through the 1,080 nozzle tubes, joining the third path (48.5 percent), which bypasses the nozzle through the chamber coolant valve (CCV). This combined flow then splits to feed the preburners, with the fuel preburner receiving, by far, the larger share (50 percent versus 26 percent).

## PROPELLANT FLOW ANALYSIS (3 of 3)

### Engine Control

SSME start, run, and shutdown characteristics are established by the combined actions of the main fuel valve (MFV), the main oxidizer valve (MOV), the oxidizer preburner oxidizer valve (OPOV), the fuel preburner oxidizer valve (FPOV), and the chamber coolant valve (CCV). These valves are powered by hydraulic actuators that receive positioning signals from the engine controller which utilizes performance data gathered by sensors located throughout the engine.

During the engine run phase, the MOV, MFV, and CCV are switched to run schedules, while the OPOV and FPOV are switched to closed-loop operations. The run schedules for the MOV and MFV cause them to simply remain fully open, whereas the run schedule for the CCV drives it between half open at 67 percent thrust (MPL) and fully open at 100 percent thrust (and above). This action maintains the appropriate flow relationships among the several parallel fuel flow paths as the HPFTP output pressure varies with thrust. During engine run, the OPOV and FPOV are used as control devices for thrust and mixture ratio. Manipulating these valves affects the output of the preburners, the speed of the turbopumps, and, therefore, the propellant flowrates. The FPOV is driven alone to maintain mixture ratio in the MCC, while the OPOV is driven with the FPOV to increase or decrease thrust while maintaining the mixture ratio. The control loops include the controller, the valve actuators, and the transducers that sense flowrates and MCC pressure; i.e., thrust.

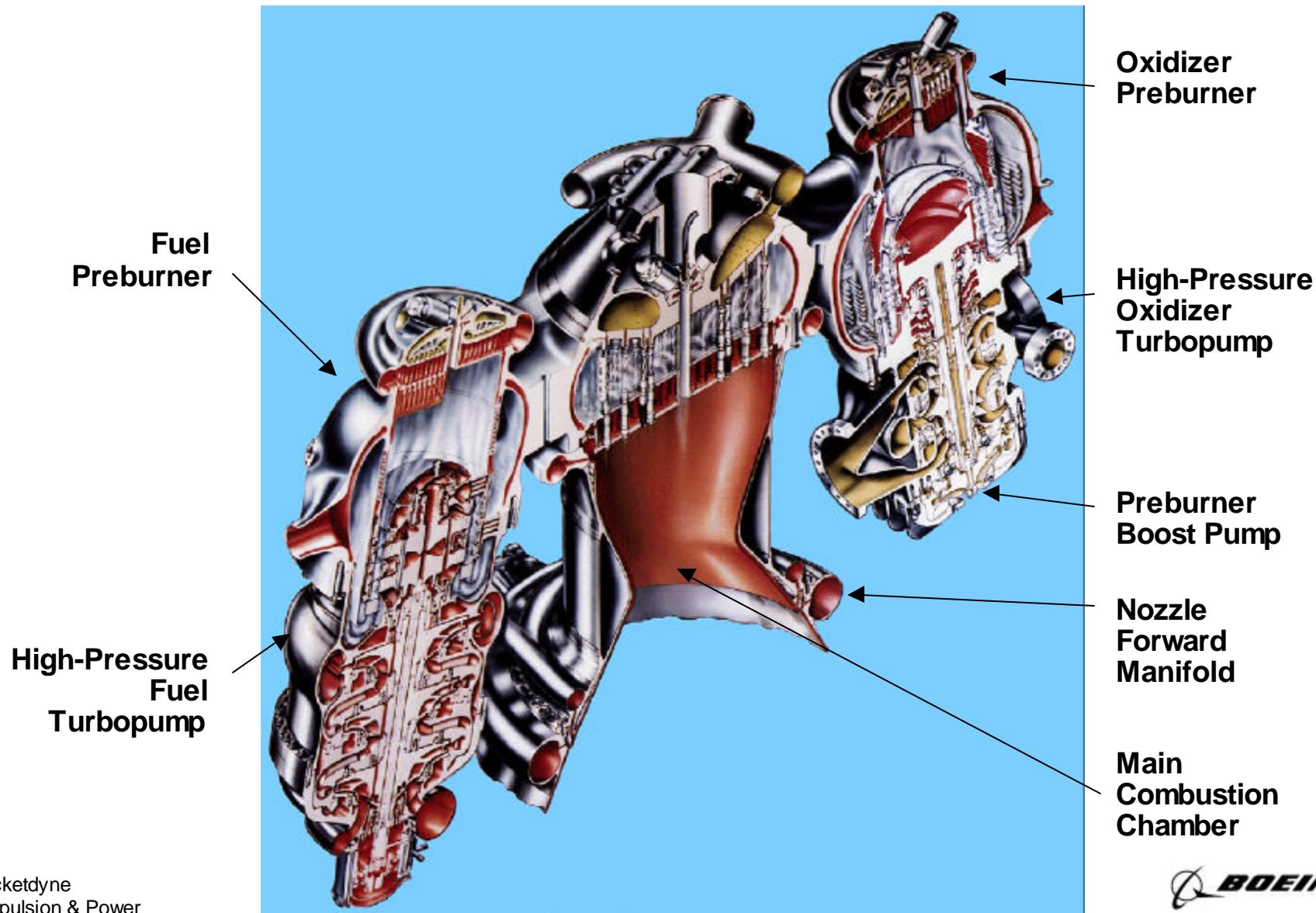
During the engine shutdown phase, all five valves are switched to shutdown schedules. These schedules ensure a smooth, safe shutdown by establishing a fuel lag; i.e., the oxidizer departs the combustion chambers ahead of the fuel. This lag creates a fuel-rich, cool shutdown environment.

## POWERHEAD

The SSME powerhead is an assembly of eight major units. One unit, the hot gas manifold (HGM), serves as a structural base for mounting the main injector, the two preburner injectors, and the heat exchanger coil (all by welding), and also the two high-pressure turbopumps and the main combustion chamber (by bolting). This creates a compact, efficient package wherein the pump turbines are close-coupled to the preburners, and duct lengths and losses are held to a minimum. Both turbopumps are canted from the vertical by 10 degrees to facilitate replacement.

Coolant (gaseous hydrogen) enters both ends of the HGM and migrates through the spaces between the outside structure and the liner. It then enters the narrow cavity in the main injector, formed between the primary and secondary plates. The coolant gas flows (permeates) through the porosity of the rigimesh plates, cooling them.

# Block II A Powerhead

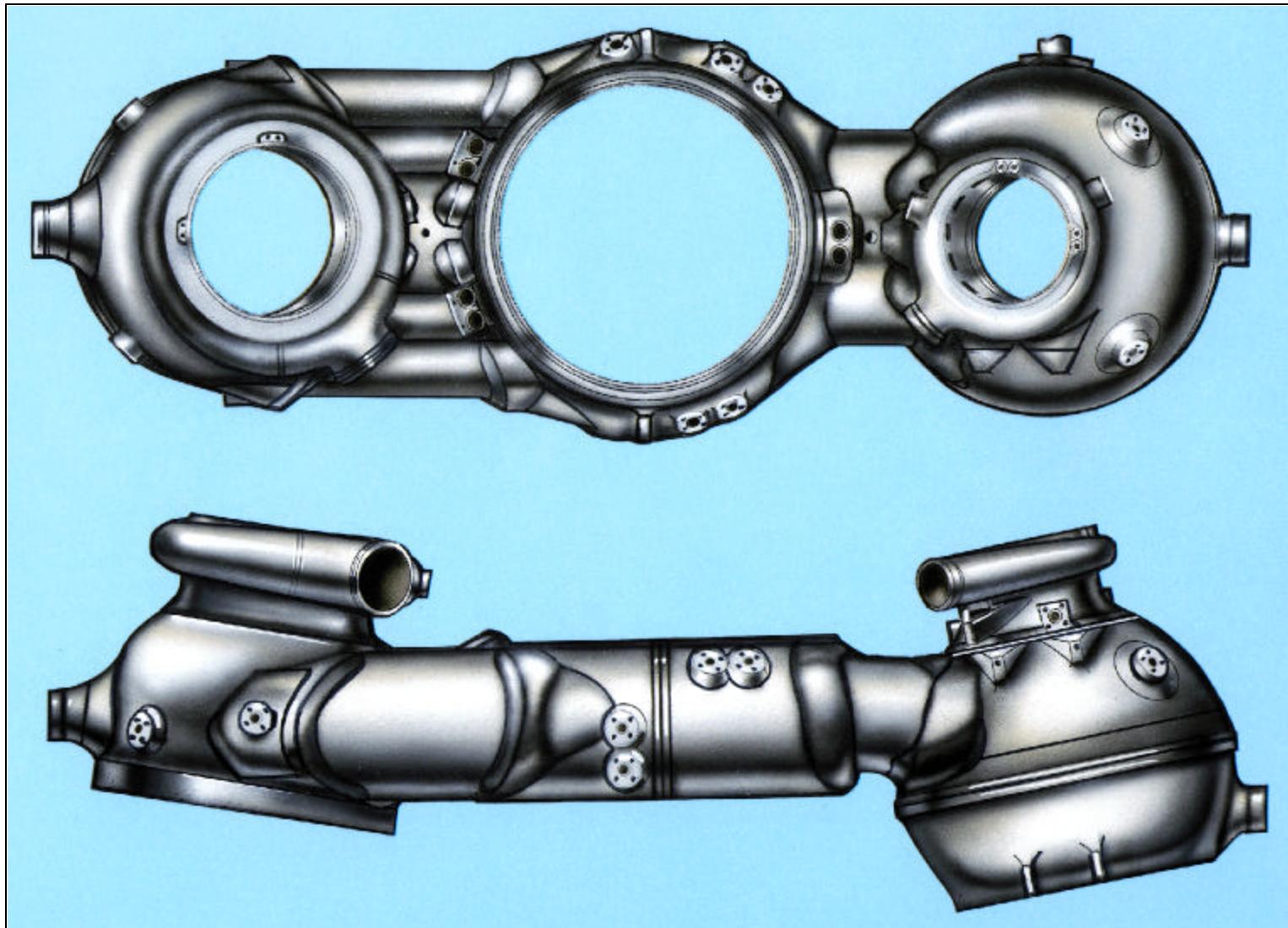


## HOT GAS MANIFOLD

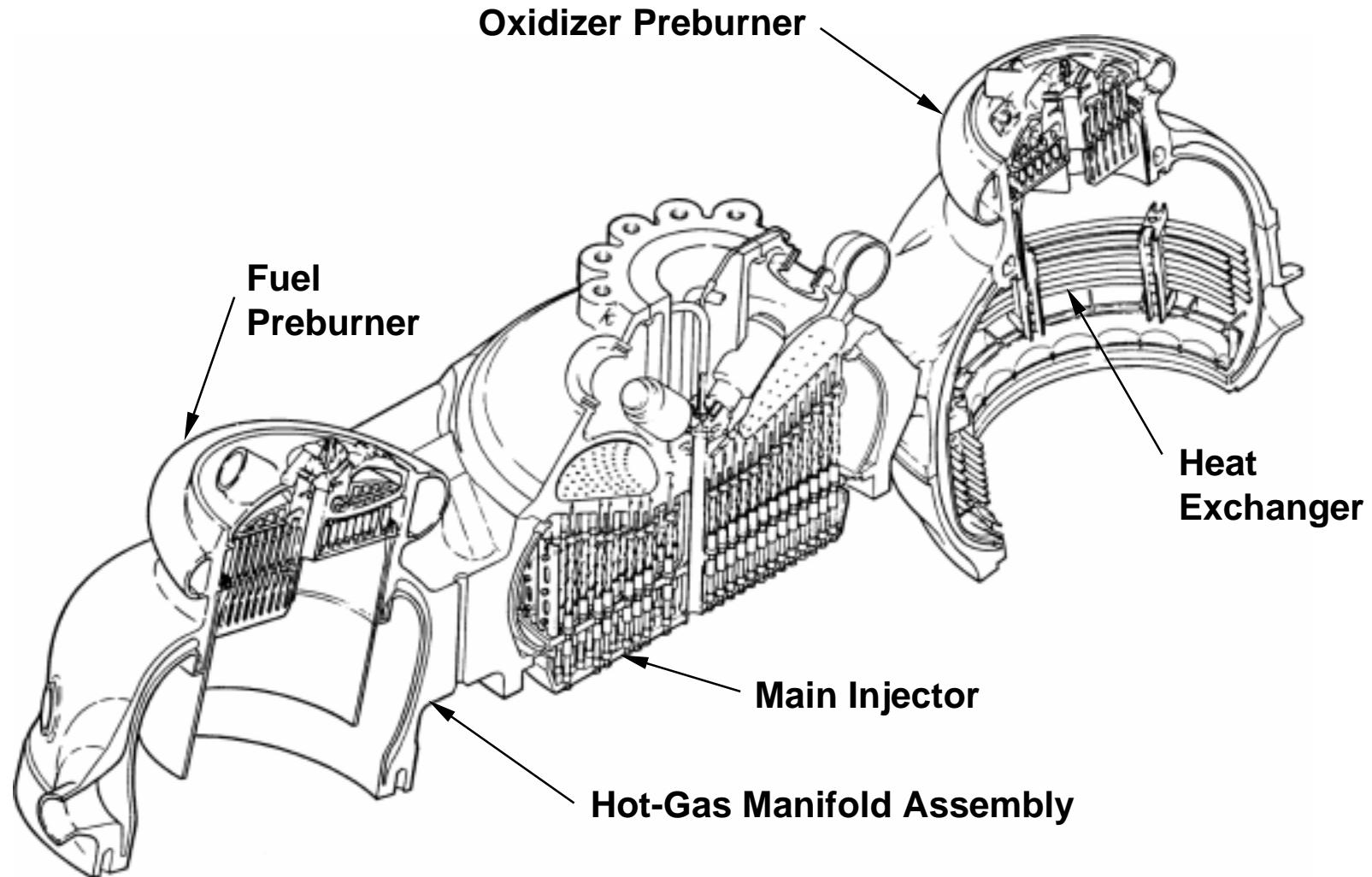
The hot gas manifold (HGM) serves as a structural support for seven main components of the engine, while also acting as a hot gas passageway from the high-pressure turbopump turbines to the MCC injector.

The HGM interconnects three injectors, two high-pressure turbopumps, a heat exchanger coil, and an MCC. It is double-walled and cooled by cold hydrogen gas entering both ends and migrating through the spaces toward the center to be injected into the MCC. The three injectors are welded into the top, while the pumps and the MCC are bolted to the bottom. The heat exchanger coil is secured with dimple brackets welded into the oxidizer pump side (large side).

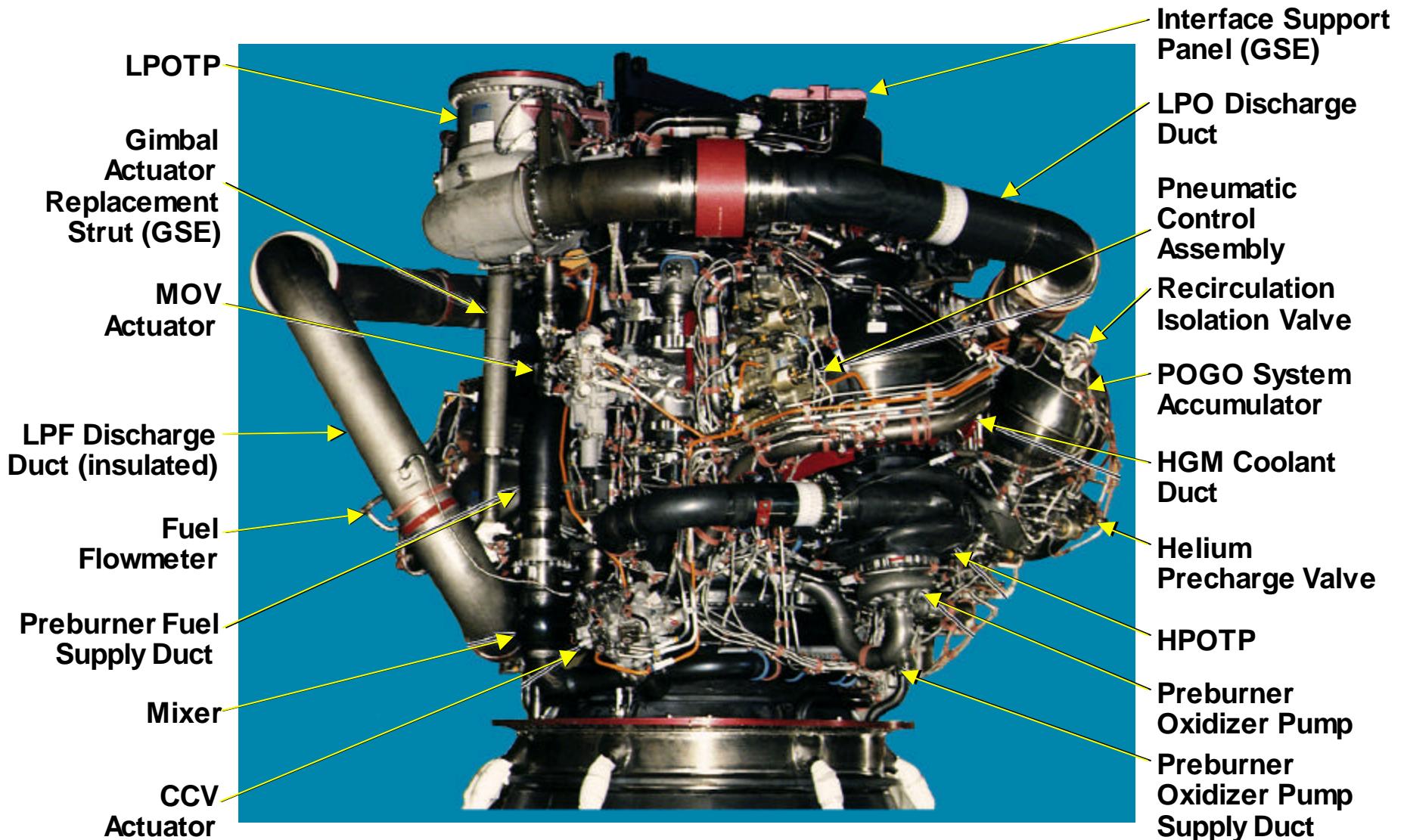
# Hot Gas Manifold



# HGM/Injector Assembly



# Typical SSME – View 1



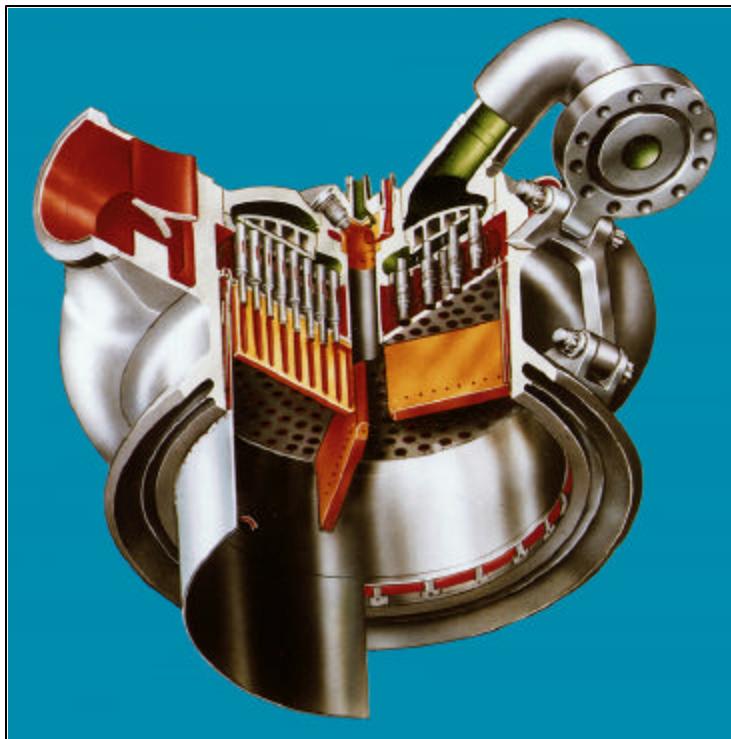
## FUEL PREBURNER

The fuel preburner combusts hydrogen and oxygen at an extremely fuel-rich mixture ratio, and thus supplies hot gas at variable rates to drive the high-pressure fuel turbopump. The operating level of the fuel preburner is controlled by regulating the oxidizer flowrate by means of the fuel preburner oxidizer valve. Welding the injector into the top of the HGM forms the combustion area and places it immediately above the pump turbine. Injector diameter is about 10.5 inches. The injector is made up of 264 coaxial injection elements, arranged in a concentric row pattern. Twenty-four of the elements support and cool the three baffles and do not carry oxygen. The baffles help to stabilize combustion.

The combustion area is bounded by a cylindrical liner that is cooled by gaseous hydrogen flowing downward between it and the HGM structural wall.

An augmented spark ignition (ASI) chamber is located in the center of the injector. Small quantities of hydrogen and oxygen are continuously injected into this chamber, and are initially ignited by two spark igniters located therein. This flame then ignites the propellants flowing through the injector elements into the combustion area.

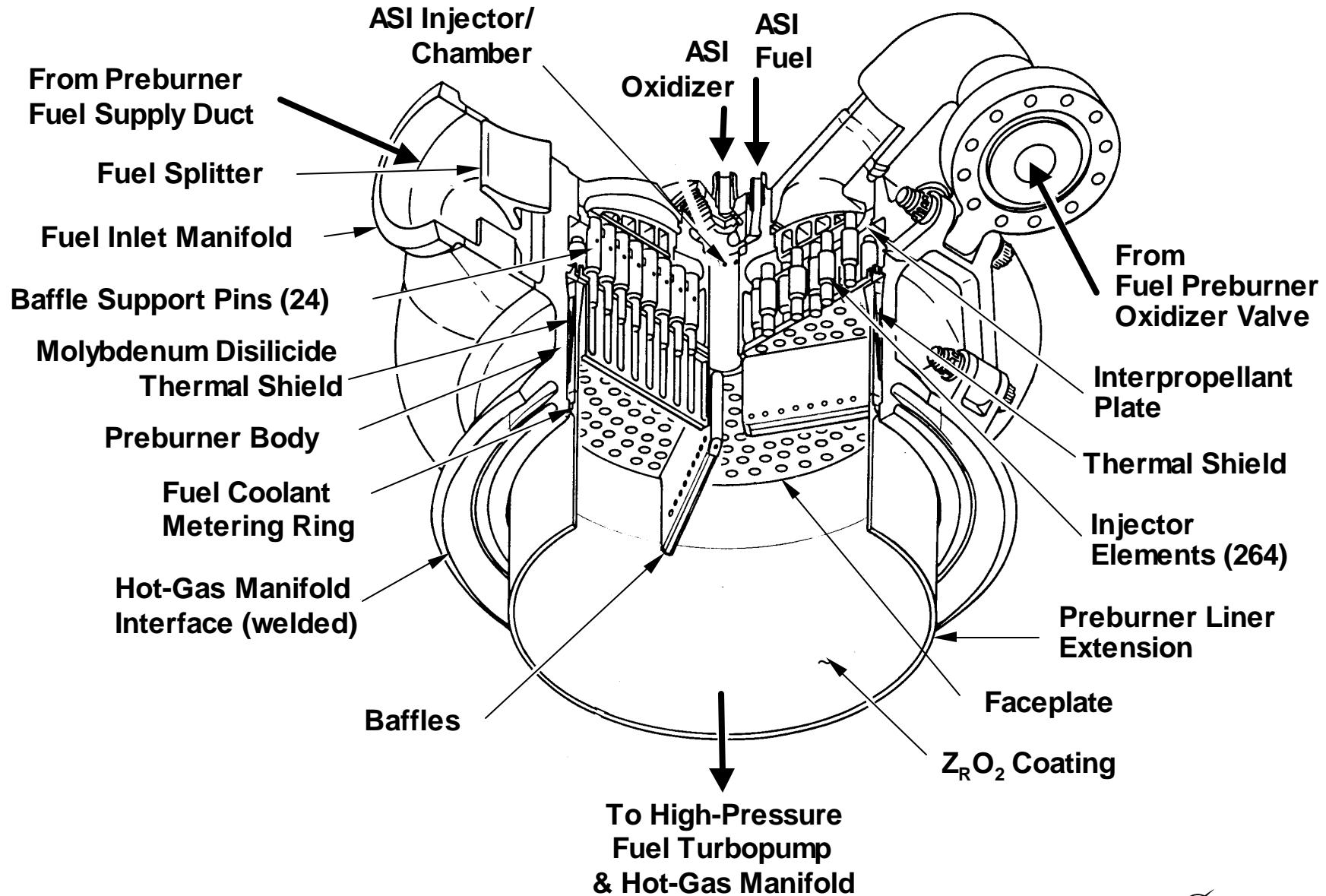
# Fuel Preburner



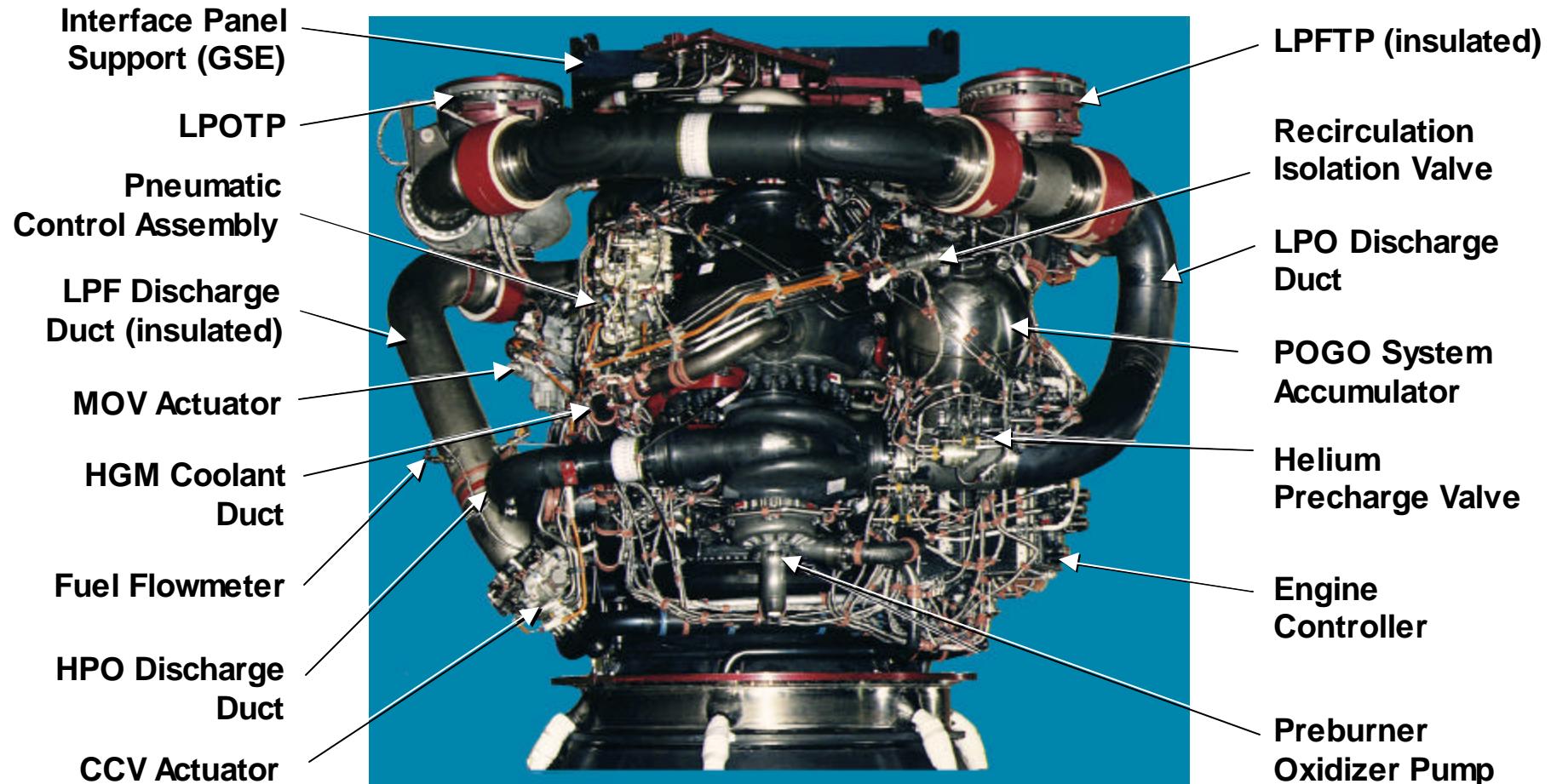
Geometry	
Internal diameter (in.)	10.43
Combuster length (in.)	4.37
Inconel 625 faceplate	
Injector configuration	Concentric orifice
Number of elements (in.)	264
Baffle length (in.)	2.25
Material	NARloy-A

Block IIA Operating Parameters	
	At 104.5% of RPL
Injector end pressure (psia)	4,793
Combustion temperature (°F)	1,310
Hot gas mixture ratio (O/F)	.86
Oxidizer flowrate (including igniter) (lb/sec)	66.9
Fuel flowrate (including igniter) (lb/sec)	77.7

# Fuel Preburner



# Typical SSME - View 2



## OXIDIZER PREBURNER

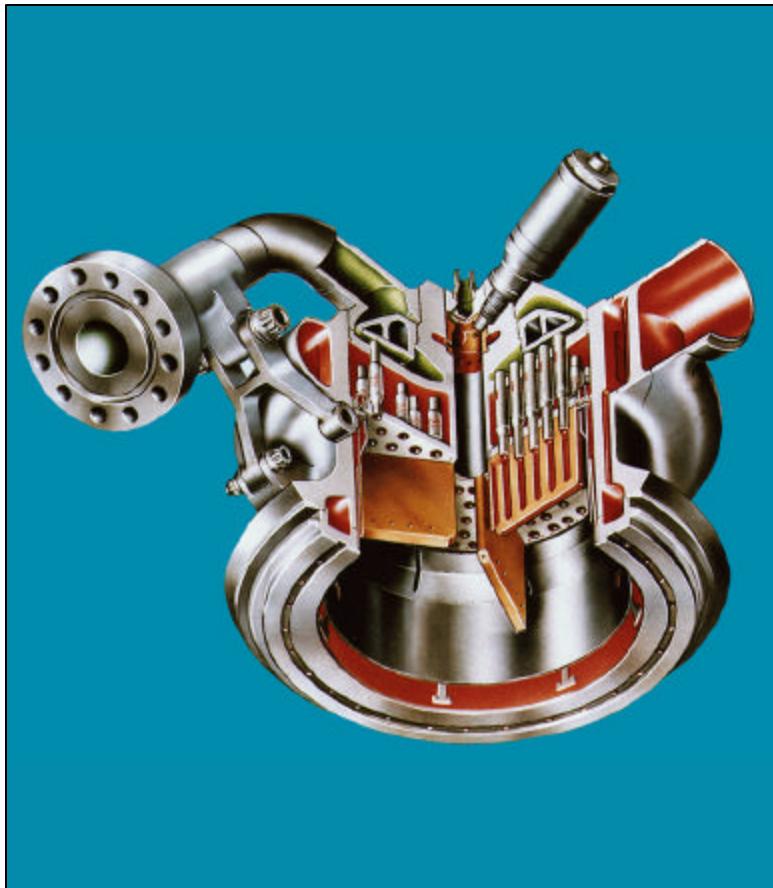
The oxidizer preburner combusts hydrogen and oxygen at an extremely fuel-rich mixture ratio, and thus supplies hot gas at variable rates to drive the high-pressure oxidizer turbopump. The operating level of the oxidizer preburner is controlled by regulating the oxidizer flowrate by means of the oxidizer preburner oxidizer valve. Welding the injector into the top of the HGM forms the combustion area and places it immediately above the pump turbine. Injector diameter is about 7.5 inches. The injector is made up of 120 coaxial injection elements, arranged in a concentric row pattern. Fifteen of the elements support and cool the three baffles and do not carry oxygen. The baffles help to stabilize combustion.

The combustion area is bounded by a cylindrical liner that is cooled by gaseous hydrogen flowing downward between it and the HGM structural wall.

An augmented spark ignition (ASI) chamber is located in the center of the injector. Small quantities of hydrogen and oxygen are continuously injected into this chamber, and are initially ignited by two spark igniters located therein. This flame then ignites the propellants flowing through the injector elements into the combustion area.

Because fuel is required to cool the turbine end of the high-pressure oxidizer turbopump, fuel is tapped from the preburner fuel inlet manifold and directed through a turbine coolant manifold down to the high-pressure oxidizer turbopump turbine.

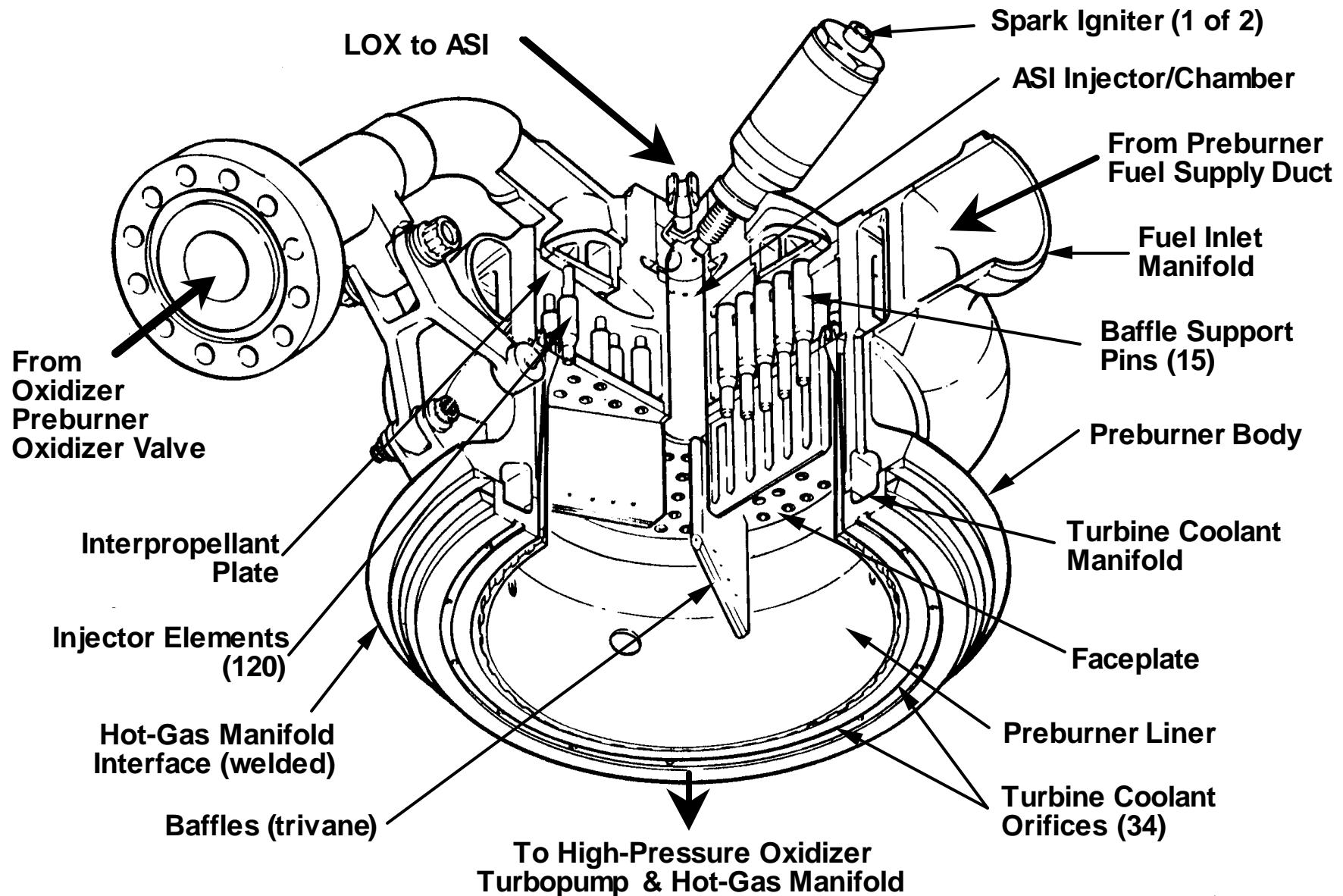
# Oxidizer Preburner



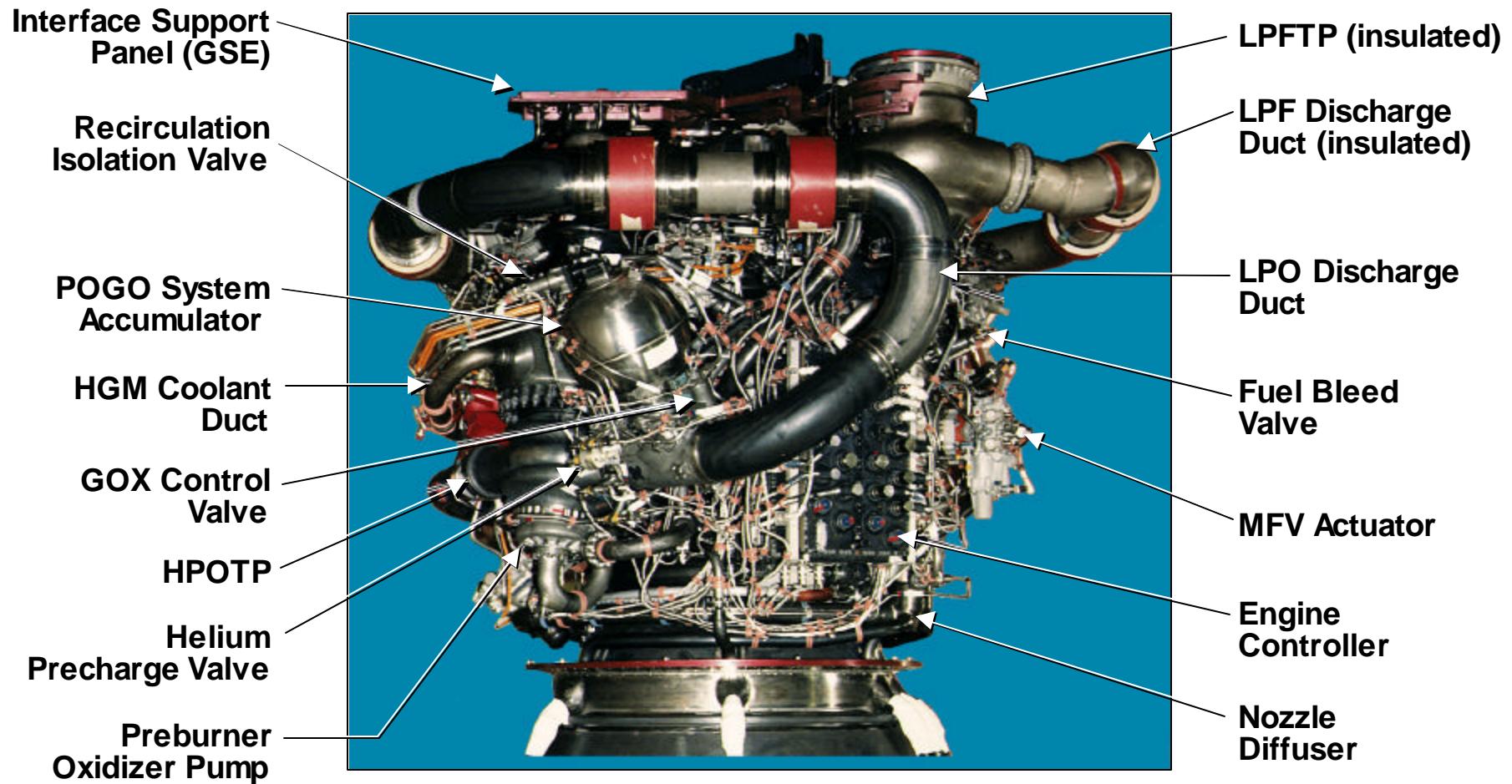
Geometry	
Internal diameter (in.)	7.43
Combustor length (in.)	4.25
Inconel 625 faceplate	
Injector configuration	Concentric orifice
Number of elements	120
Baffle length (in.)	2.25
Material	NARloy-A

Block IIA Operating Parameters	
	At 104.5% of RPL
Injector end pressure (psia)	4,812
Combustion temperature (°F)	871
Hot gas mixture ratio (O/F)	0.60
Oxidizer flowrate (including igniter) (lb/sec)	24.9
Fuel flowrate (including igniter) (lb/sec)	41.1

# Oxidizer Preburner



# Typical SSME - View 3



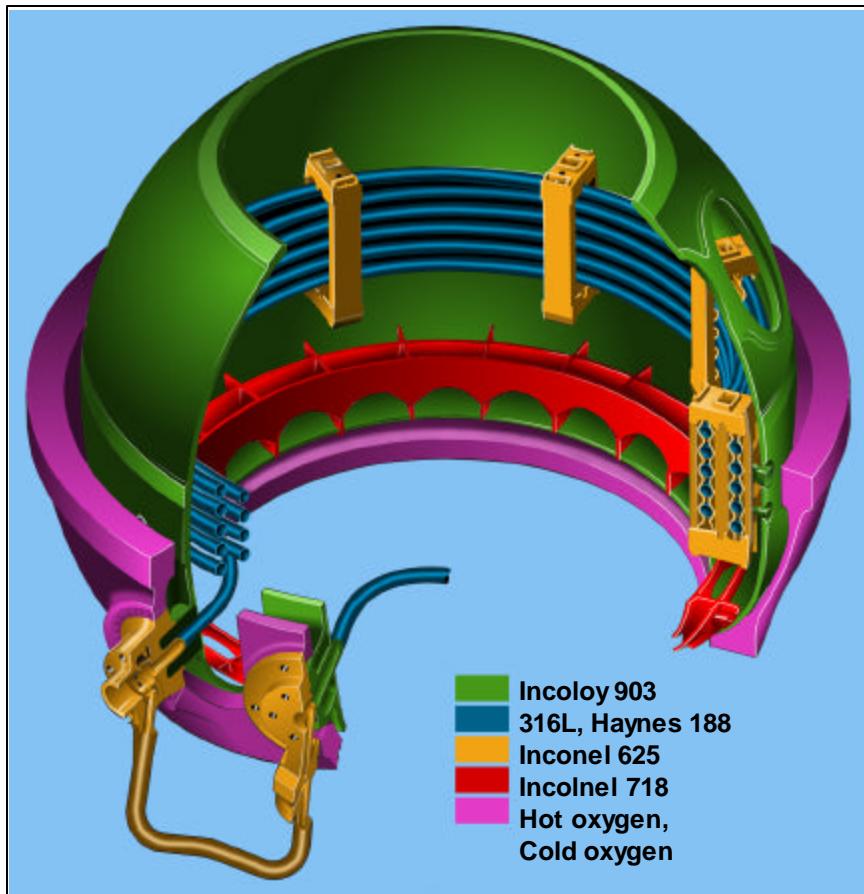
## **HEAT EXCHANGER**

**The heat exchanger converts liquid oxygen into gaseous oxygen, to be used for ET oxygen tank pressurization as well as pogo suppression system accumulator pressurization.**

**The heat exchanger is a coiled tubing pack, the tube being 496 inches long by 0.50 inch in diameter. The tube is sized to allow the oxygen to expand as it changes to a gas. A bypass line with a flange-mounted orifice allows cold liquid oxygen to bypass the heat exchanger coil, and then to mix with the coil effluent in a ratio determined by the size of the orifice. This establishes and maintains the temperature and pressure of the end product, even though the total mass flowrate through the system rises and falls with thrust changes.**

**The coils are loosely positioned in dimpled brackets welded to the inside of the HGM. The hot gas from the OPB, upon exiting the HPOTP turbine, flows over the coils providing the heat necessary to change the liquid oxygen to gas.**

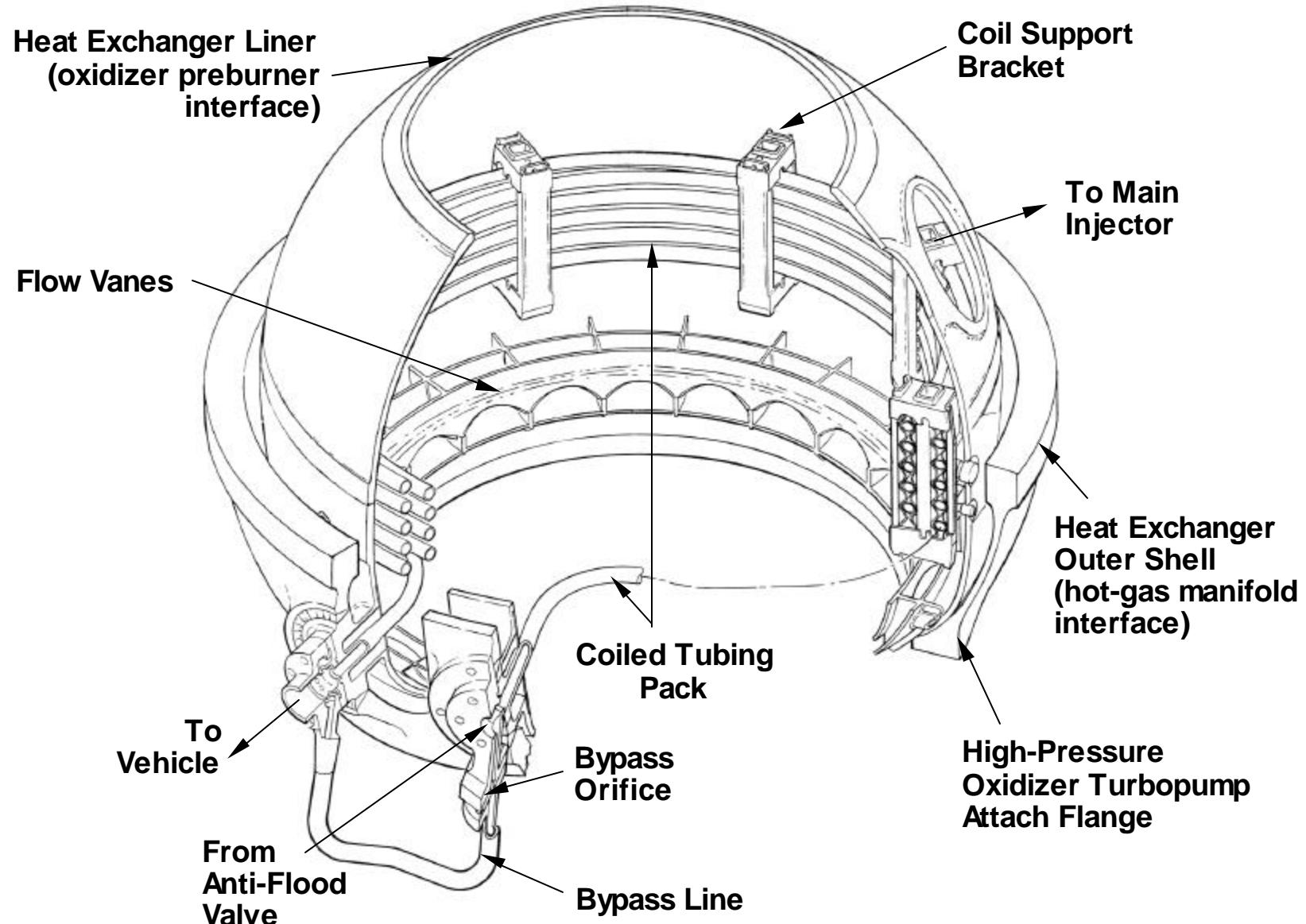
# SSME Heat Exchanger Assembly



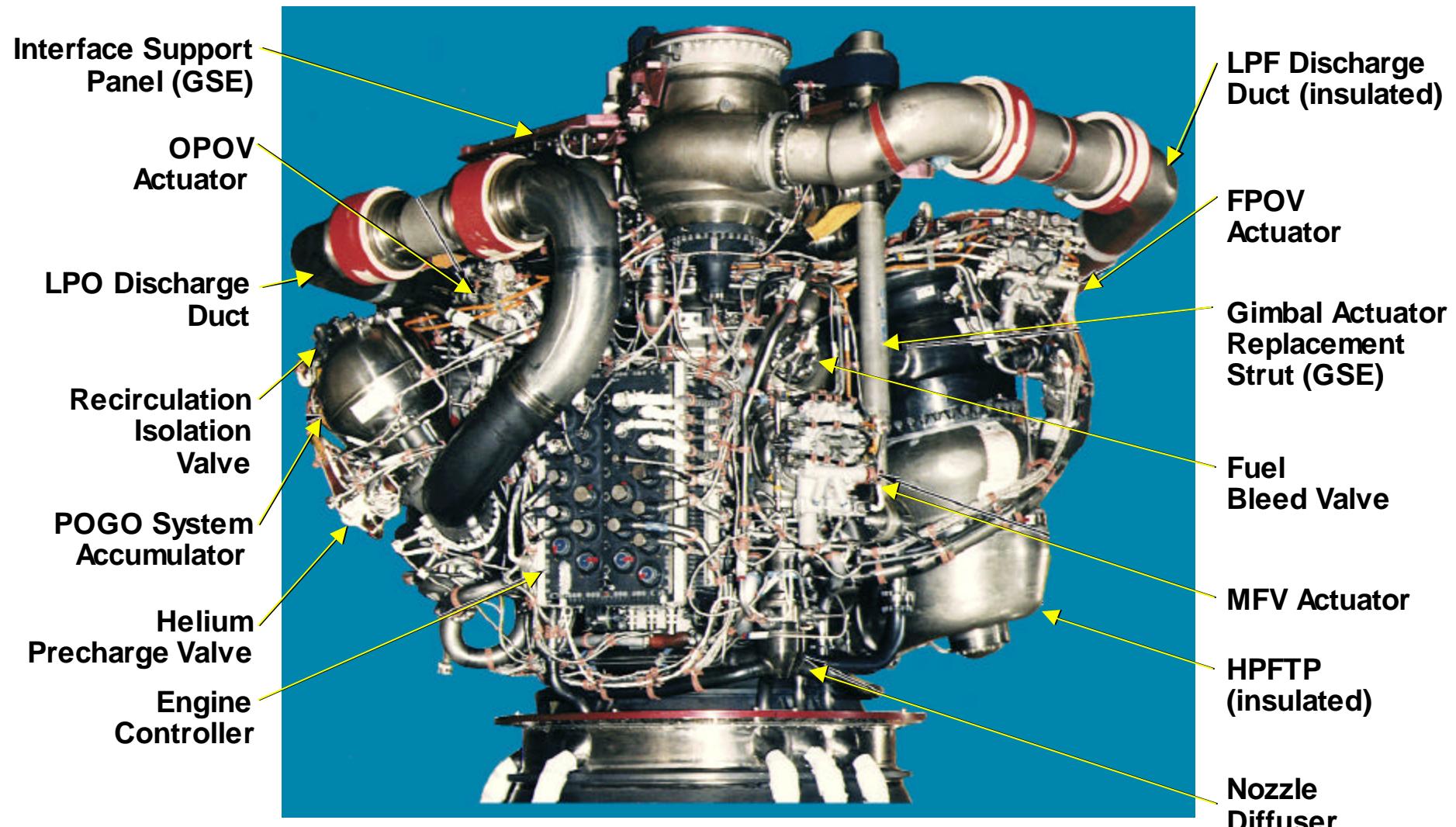
Geometry	
<b>Single Coil Tube</b>	
<b>Diameter-outer (in.)</b>	0.50
<b>Thickness (in.)</b>	0.032
<b>Length (ft.)</b>	41.3
<b>Material</b>	316L CRES

	Key Performance Parameters	
	At 104.5% of RPL	
Oxygen	Coil	Bypass
Flowrate (lb/sec)	1.50	0.63
Outlet temp (°F)	692	-273
Outlet press (psia)	3,580	3,580
Hot gas		
Flowrate (lb/sec)	67.8	
Temperature (°F)	730	
Pressure (psia)	3,105	

# SSME Heat Exchanger



# Typical SSME – View 4



## MAIN INJECTOR

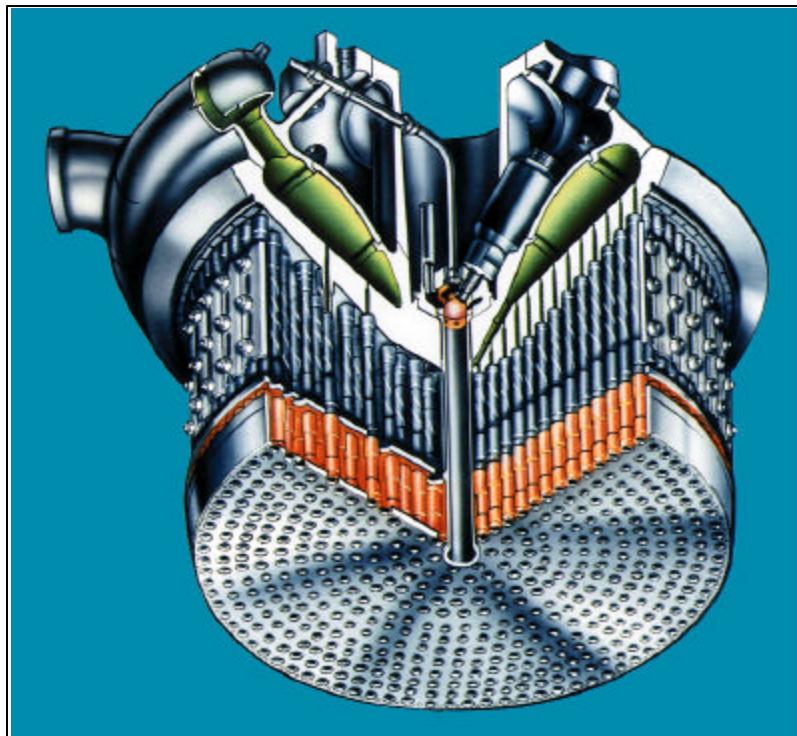
The main injector injects into the main combustion chamber a combination of hot, fuel-rich gas from the two preburners, cold hydrogen gas from the cooling circuits, and cold liquid oxygen from the HPOTP. By welding the injector into the center of the HGM, passageways are formed for these fluids to enter the proper cavities in the injector.

The injector includes 600 coaxial elements which inject liquid oxygen from the oxidizer manifold through their center posts. Each element also injects, through its annulus, the hot, fuel-rich gas entering the cavity between the heat shield and the secondary plate. Cold hydrogen gas, that had previously migrated through the double walls of the HGM, enters the slot between the secondary plate and the lip of the primary plate. Both plates are porous and are transpiration-cooled by the cold hydrogen gas as it flows through them. The flow shields, bolted to the outer row of elements, help protect them from damage and erosion from the high-velocity gas.

An augmented spark ignition (ASI) system chamber is located in the center of the injector. Small quantities of hydrogen and oxygen are continuously injected into this chamber, and initially ignited by two spark igniters located therein. This flame then ignites the propellants flowing through the injector elements into the combustion chamber.

The thrust cone is a mounting pad for the gimbal bearing which, in turn, attaches the engine to the vehicle.

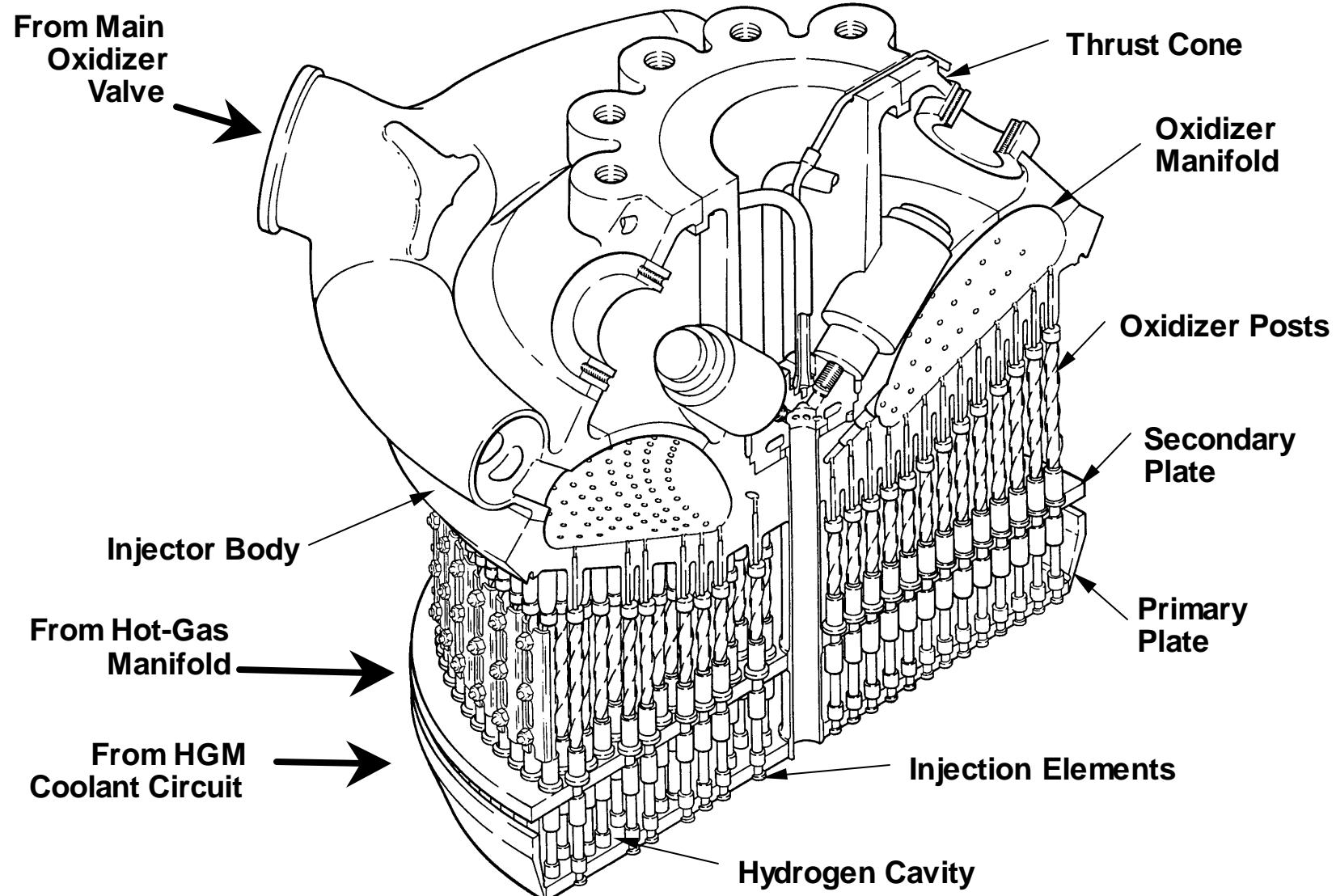
# Main Injector



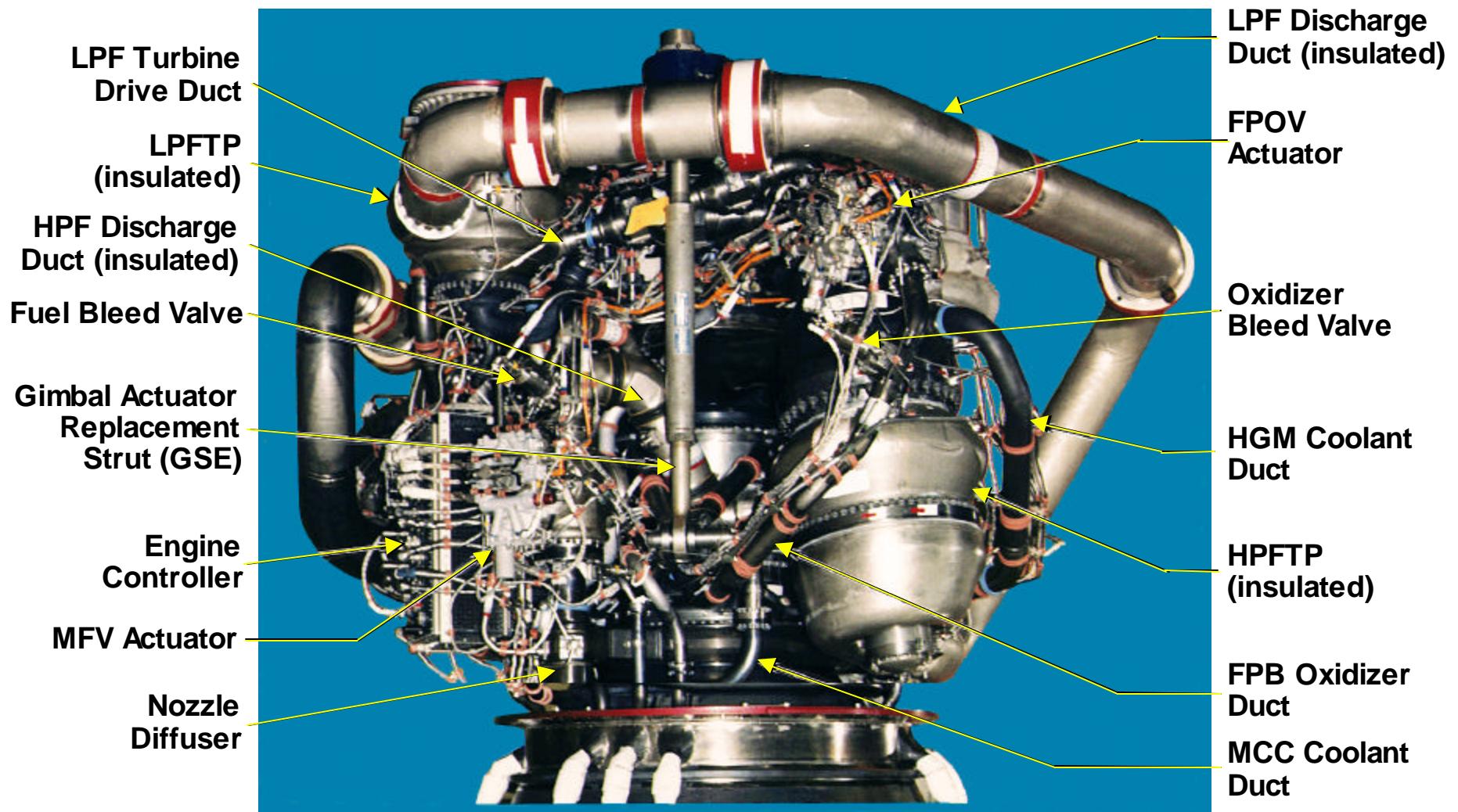
Geometry	
347 CRES rigimesh faceplates	17.74
Dual spark igniter	Coaxial elements
Face diameter (in.)	600
Injector configuration	42
Number of elements	
Number of flow shields	

Block IIA Operating Parameters	
	At 104.5% of RPL
Chamber pressure (psia)	2,865
Mixture ratio (O/F)	6.03
Oxidizer flowrate (lb/sec)	839
Hot gas flowrate (lb/sec)	239
Coolant flowrate (lb/sec)	27.9
Primary faceplate	2.5
Secondary faceplate	22.2
Fuel Sleeves	3.2

# Main Injector Assembly



# Typical SSME – View 5

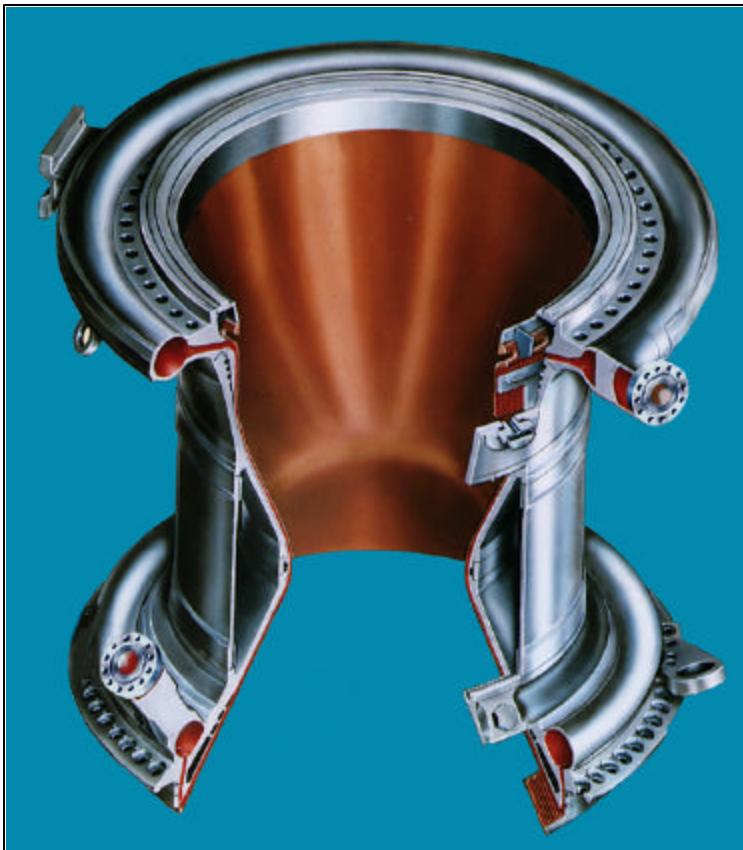


## MAIN COMBUSTION CHAMBER

The Main Combustion Chamber (MCC) contains the combustion process, accelerates the gas flow to throat sonic velocity, and initiates the gas expansion process through its diverging section. The expansion ratio of throat to nozzle attach flange is 4.48:1, with the throat area being 93.02 square inches.

The chamber includes a liner, jacket, throat ring, coolant inlet manifold, and coolant outlet manifold. The liner outer surface has 430 vertical milled slots that are closed out by electrodeposited nickel. The jacket halves are placed around the liner and welded. The coolant manifolds are welded to the jacket and the liner. The throat ring is welded to the jacket to add strength to the chamber. This creates a regeneratively-cooled chamber in which the cooling fuel makes a single up-pass through the milled slots of the liner. The liner is made of NARloy Z (North American Rockwell alloy Z), which is mostly copper, with silver and zirconium added. The engine thrust vector control actuators attach to two quadruped outriggers that bolt to the side of the chamber, 90 degrees apart.

# Main Combustion Chamber



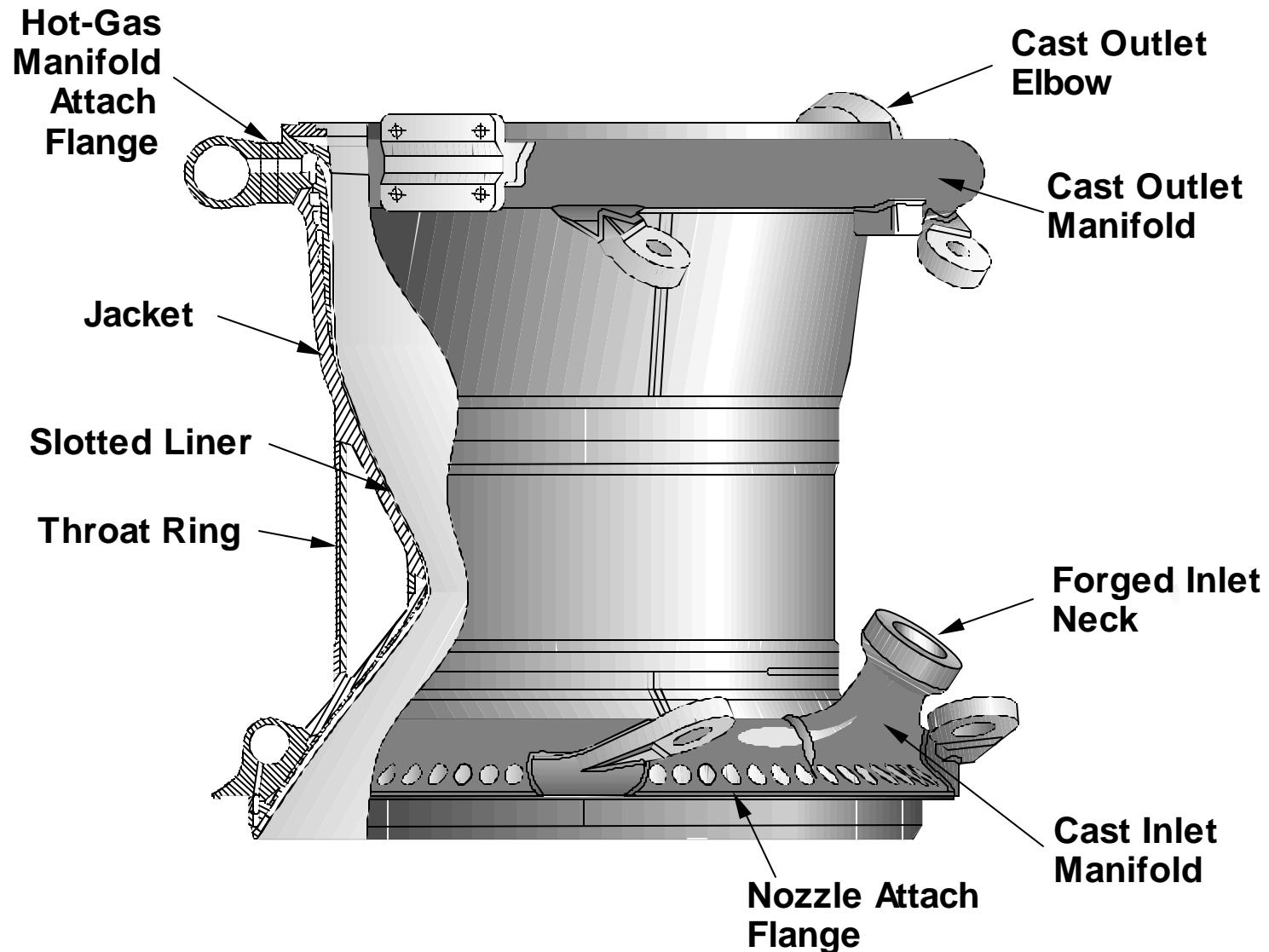
## Geometry

NARloy-Z liner + EDCu barrier + EDNi closeout + Inconel 718 structural Jacket + JBK-75 Cast Manifolds	
Number of slots	430
Injector end diameter (in)	17.74
Throat area (in <sup>2</sup> )	93.02
Injector end-to-throat length (in)	14.7
Contraction ratio	2.66:1
Expansion ratio	4.48:1

## Block IIA Operating Parameters

	At 104.5% of RPL
Throat stagnation pressure (psia)	2,865
Coolant inlet pressure (psia)	5,647
Coolant inlet temperature (°F)	-366
Coolant exit pressure (psia)	4,441
Coolant exit temperature (°F)	17
Coolant flowrate (lb/sec)	29
Max Hot gas wall temperature	1,000

# SSME Large Throat MCC



# Block II A Large Throat Main Combustion Chamber



## NOZZLE (1 of 2)

A rocket engine nozzle increases the velocity of the exhaust gas stream by controlling its expansion and attendant pressure reduction. Optimum expansion (and maximum thrust efficiency) exists when gas pressure at the nozzle exit plane equals ambient pressure. Nozzle shape (cone or bell), length, and area ratio (throat plane area versus exit plane area), combine with chamber pressure to determine at what altitude optimum expansion occurs. This is the design altitude of the engine. Below this altitude, overexpansion of the available exhaust gas occurs; above, underexpansion. Both produce less than maximum thrust efficiency. Since the SSME operates mostly in space where ambient pressure is zero, it needs the large area ratio of 69:1 to fully expand the exhaust gas.

The nozzle consists of 1,080 stainless steel tubes brazed to themselves and to a surrounding structural jacket. Nine hatbands are welded around the jacket for hoop strength. Coolant manifolds are welded to the top and bottom of the nozzle, along with three fuel transfer ducts and six drain lines.

Nozzle cooling is as follows: Fuel entering the diffuser splits to flow to the MCC, to the three fuel transfer ducts, and through the CCV to the mixer. Fuel flowing through each transfer duct splits at each steerhorn to enter the nozzle coolant inlet manifold at six points. The fuel then makes a single up-pass through the 1,080 tubes to the outlet manifold, and then to the mixer, to join the bypass flow from the CCV.

The flow recirculation inhibitor (FRI), a porous, ropelike barrier, prevents a recirculating flow of hot exhaust gas from reaching and damaging the bellows seal located at the joint between the MCC and nozzle.

# Nozzle



Geometry	
Attach point area ratio	4.5:1
Exit area ratio	69:1
Length (throat-to-exit) (in.)	121
Exit diameter (inside/outside ) (in.)	90.3/94
Number of tubes	1,080
Number of feed ducts	3

Block IIA Operating Parameters	
	At 104.5% of RPL
Inlet pressure (psia)	5,624
Discharge pressure (psia)	5,420
Coolant flowrate (lb/sec)	46.6
Max hot gas wall temp (°F)	950

## NOZZLE (2 of 2)

The FRI consists of a sleeve of braided Nextel 321 filled with Saffil batting. Both materials, which are composed of silica-glass ceramic fiber, can withstand working temperatures of up to 2,600°F. The materials, being flexible and compliant, provide the required resistance to flow.

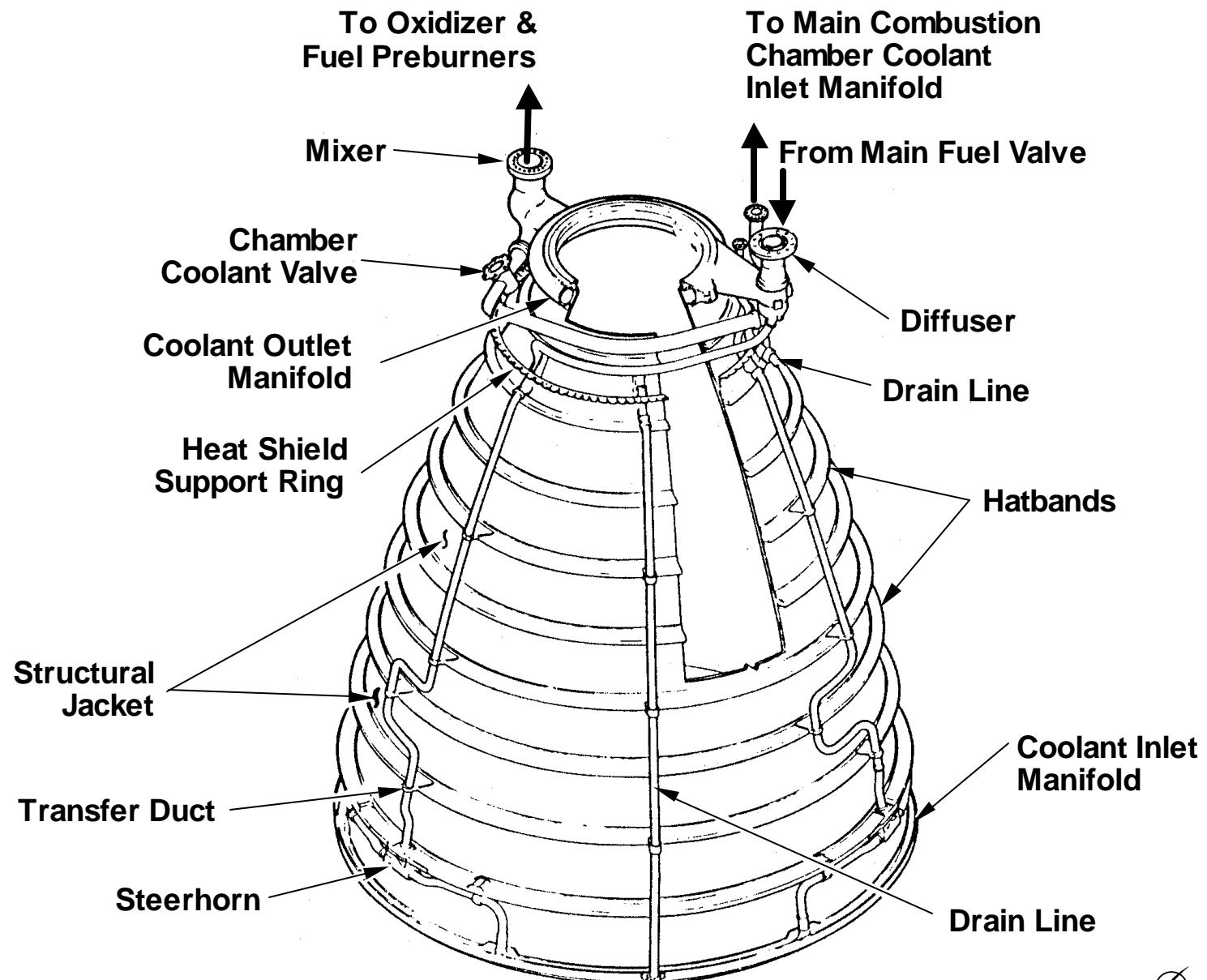
Thermal Protection System (TPS) insulation protects areas of the nozzle from high temperatures during launch and reentry. During the ascent phase, the three engine nozzles are subject to SSME plume radiation and convection, and SRB plume radiation. Reentry exposes the engine nozzles in positions 2 and 3 to high heat loads due to convective aeroheating.

The areas requiring protection are the hatbands, drainlines and their support brackets, fuel transfer ducts support brackets, and depending on the installed engine positions, aft portions of the fuel transfer ducts, portions of the aft manifold, and certain areas between the 8th and 9th hatbands and between the 9th hatband and the aft manifold.

The individual insulators consist of a core of Lytherm batting (high purity alumina-silica ceramic fibers formed into flexible sheets) contained by a layer of fine weave Nichrome screen. The batting is then covered by a layer of 2 mil thick Nichrome foil acting as a thermal shield, and this is closed out by a layer of fine weave Nichrome screen.

The insulators are produced in molded shapes to fit specific areas of the nozzle and are attached individually by resistance (spot) welding.

# Nozzle



## LOW-PRESSURE OXIDIZER TURBOPUMP

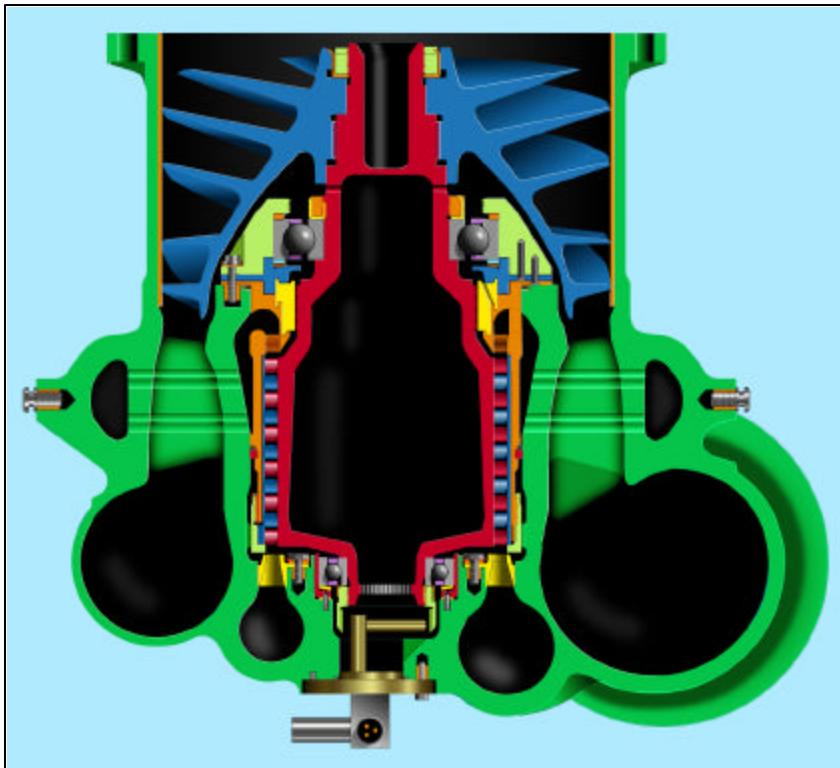
The low-pressure oxidizer turbopump (LPOTP) raises the pressure of the liquid oxygen to approximately 417 psi, so that the oxidizer tank ullage pressure can be lower, and the HPOTP can be run at a faster speed.

The LPOTP is an axial-flow pump with an inducer-type pumping element. The inducer leading edges have been optimized for performance in the large throat MCC operating environment. It is directly driven with a six-stage, axial-flow, hydraulic turbine powered with liquid oxygen tapped from the HPOTP discharge. The turbine exhausts into the turbine discharge volute and then through a port into the pump discharge volute.

The bearings are cooled by internal flows of oxygen from a source of high pressure. Coolant source for the inducer-end silicon nitride ball bearing is the turbine inlet. Oxygen flows through the labyrinth shaft seal and the bearing, and up the back face of the inducer to the inducer discharge. Coolant source for the turbine-end bearing is the last stage of the turbine. Oxygen flows through the bearing, the hollow rotor, and the radial holes to joint the inducer-end bearing flow.

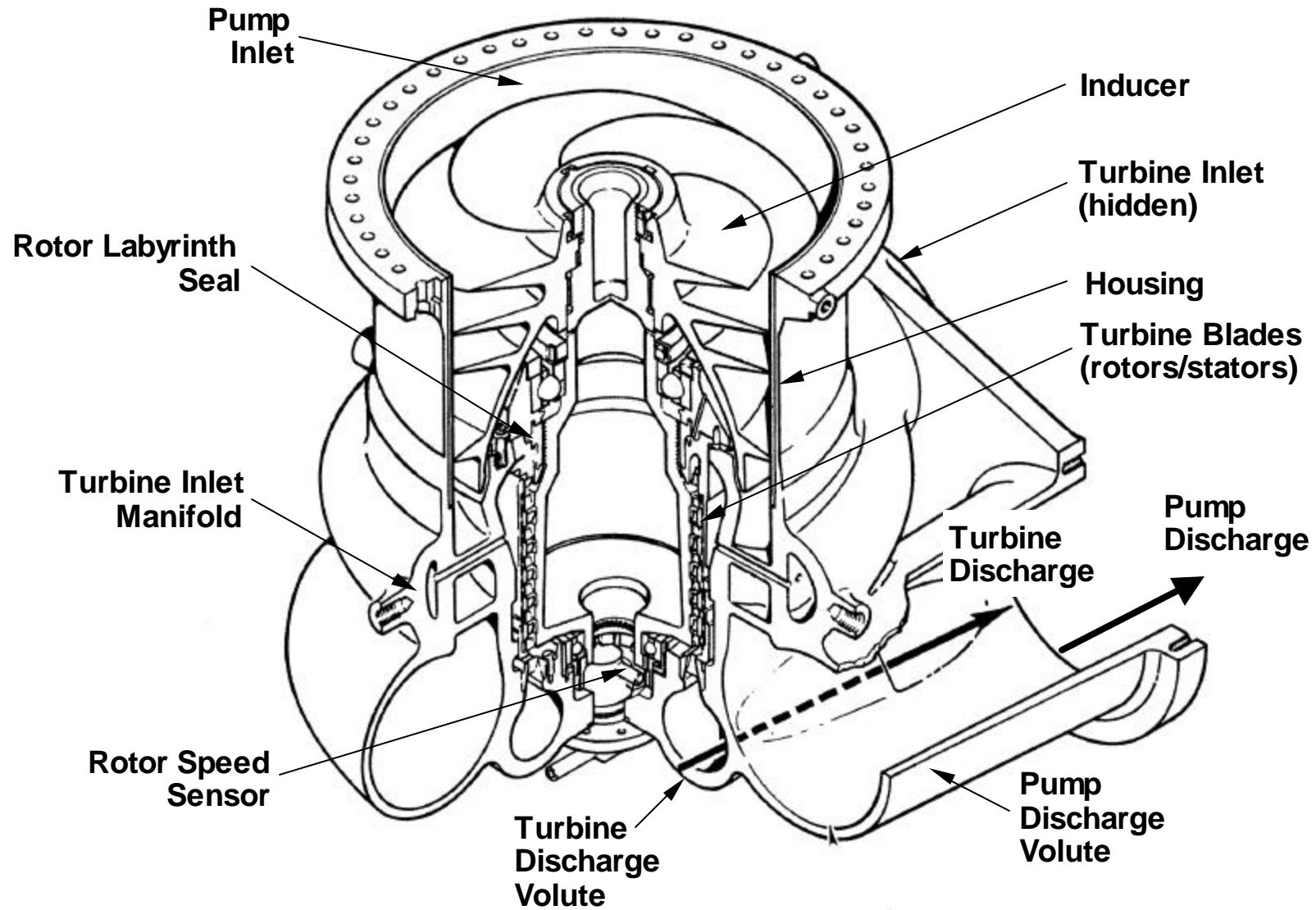
Extensive seals are unnecessary in the LPOTP, the only one being the labyrinth shaft seal. A triple-redundant, magnetic-type, pump speed transducer is located on the turbine end of the pump.

# Low-Pressure Oxidizer Turbopump

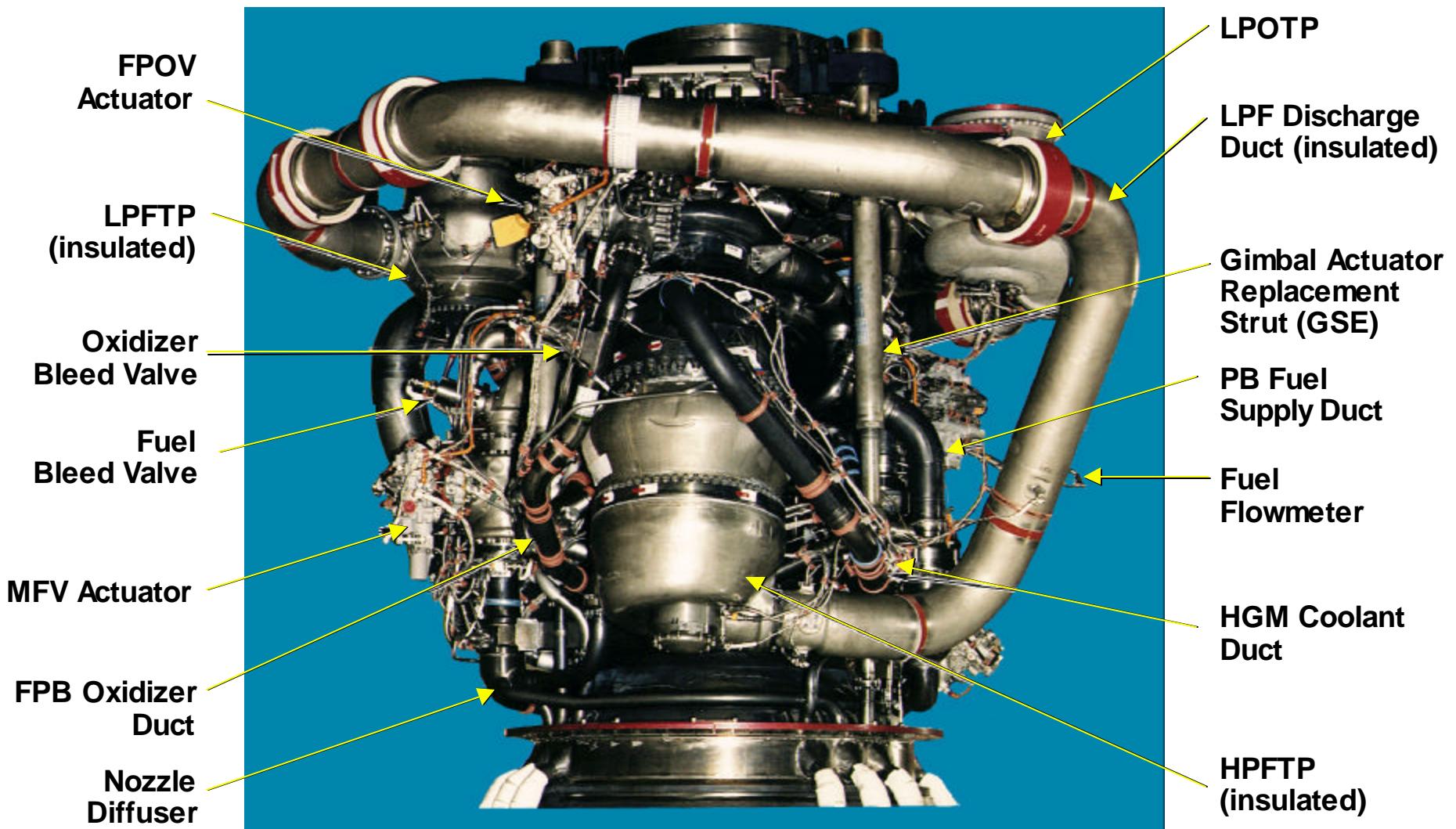


Block II A Key Performance Parameters	
	At 104.5% of RPL
Pump inlet flowrate (lb/sec)	935
Pump inlet pressure (psia)	100
Pump discharge press (psia)	417
Pump efficiency (%)	67.7
Turbine flowrate (lb/sec)	187
Turbine inlet pressure (psia)	3,819
Turbine inlet temp (°F)	-272
Turbine pressure ratio	—
Turbine efficiency (%)	67.7
Turbine speed (rpm)	5,050
Turbine horsepower	1,614

# Low-Pressure Oxidizer Turbopump



# Typical SSME – View 6



## LOW-PRESSURE FUEL TURBOPUMP

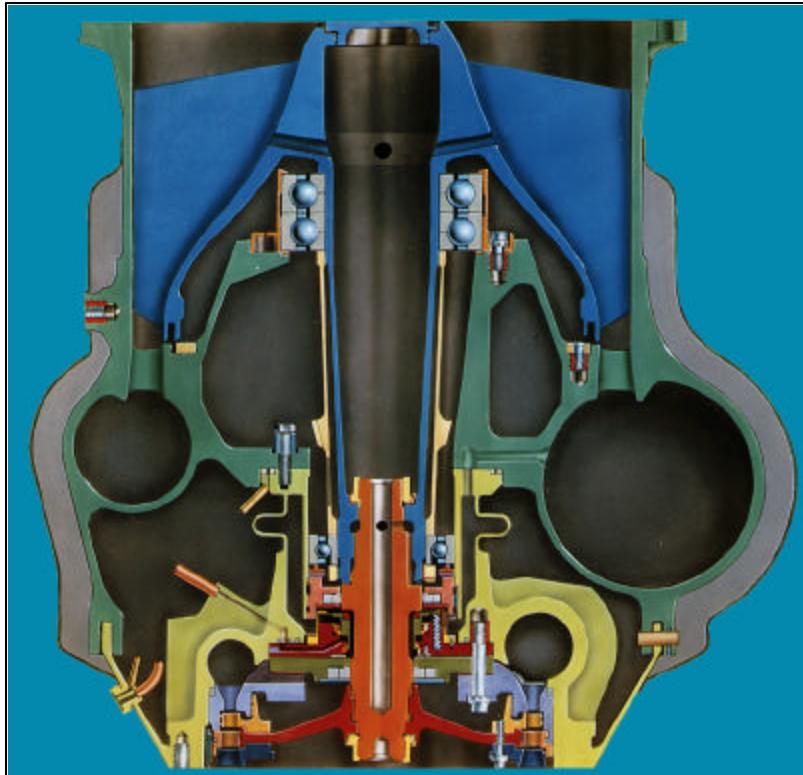
The low-pressure fuel turbopump (LPFTP) raises the pressure of the liquid hydrogen to approximately 290 psi so that the fuel tank ullage pressure can be lower and the HPFTP can be run at a faster speed.

The LPFTP is an axial-flow pump with an inducer-type pumping element. It is directly driven with a two-stage, axial-flow, gas turbine powered with gaseous hydrogen coming from the MCC cooling circuit. Since the pumped fluid is hydrogen, the turbine exhaust gas cannot be discharged into the pump discharge volute; in addition, it is still required for HGM cooling.

The bearings are cooled by an internal flow of hydrogen from a source of high pressure. The coolant source is the inducer discharge area. Hydrogen flows through the fishmouth seal at the trailing edge of the inducer, down the back face, through the inducer bearings, along the shaft, through the turbine bearing, down into the hollow shaft, through the radial holes, to the inducer input.

Thermal stabilization and the prevention of liquid air formation for the LPFTP is provided by foam insulation encased in a Kevlar jacket over the pump housing.

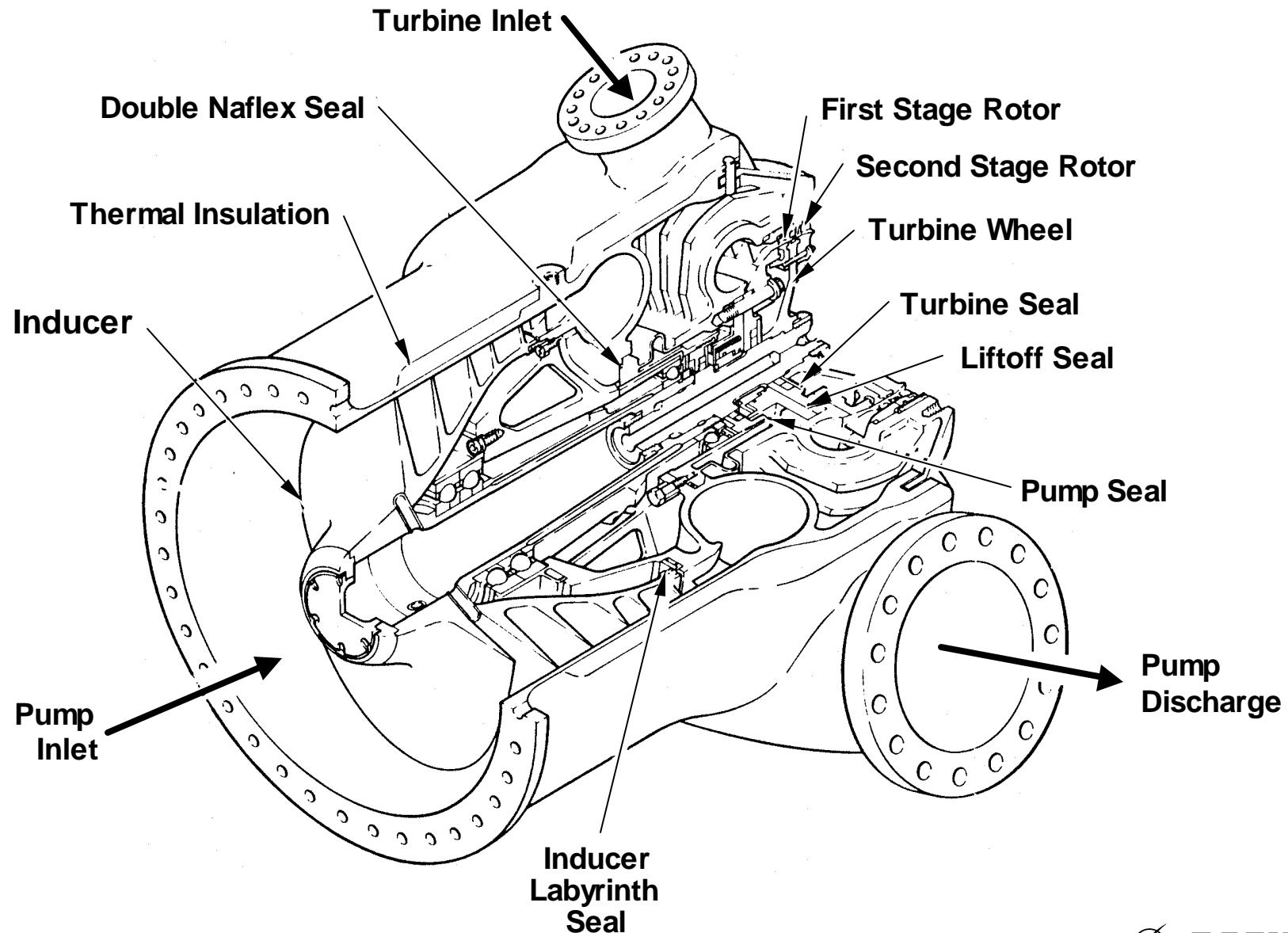
# Low-Pressure Fuel Turbopump



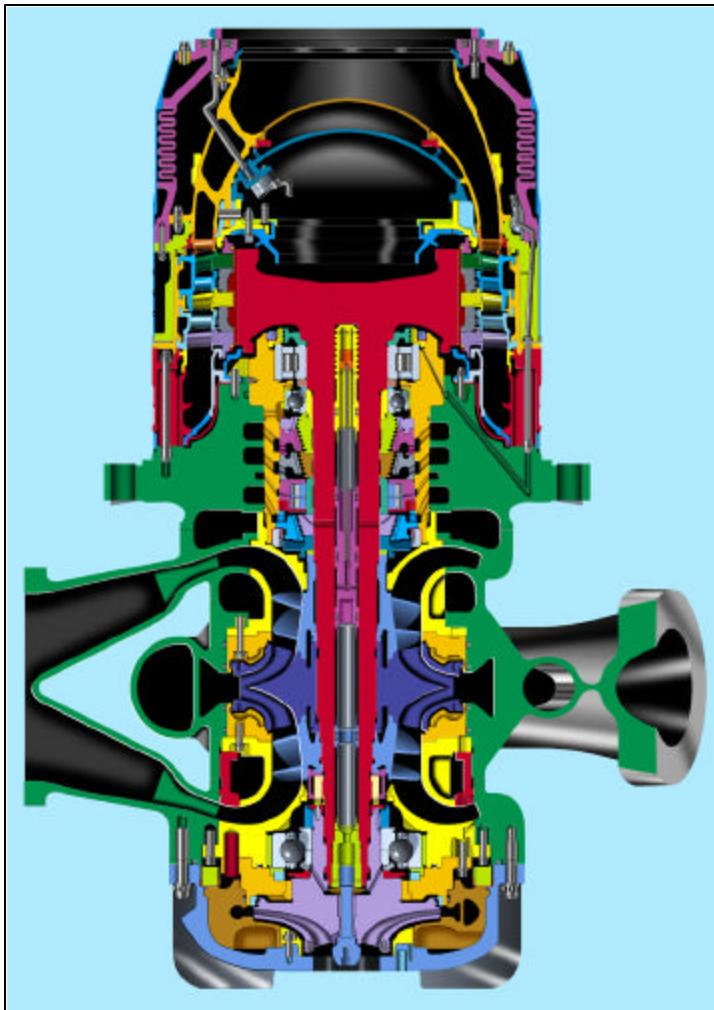
## Block IIA Key Performance Parameters

	At 104.5% of RPL
Pump inlet flowrate (lb/sec)	155
Pump inlet pressure (psia)	30
Pump discharge press (psia)	290
Pump efficiency (%)	71.3
Turbine flowrate (lb/sec)	29
Turbine inlet temp (°F)	-17
Turbine pressure ratio	1.30
Turbine efficiency (%)	58.0
Turbine speed (rpm)	15,400
Turbine horsepower	3,330

# Low-Pressure Fuel Turbopump



# High-Pressure Oxidizer Turbopump



Block IIA Key Performance Parameters		
	At 104.5% of RPL	
Pump inlet flowrate (lb/sec)	1,122	111
Pump inlet pressure (psia)	380	3,910
Pump discharge press (psia)	4,045	6,970
Pump efficiency (%)	71.8	75.8
Turbine flowrate (lb/sec)		62
Turbine inlet pressure (psia)		4,785
Turbine inlet temp (°F)		870
Turbine pressure ratio		1.53
Turbine efficiency (%)		74.6
Turbine speed (rpm)		22,220
Turbine horsepower		22,880

## HPOTP PUMP SECTION

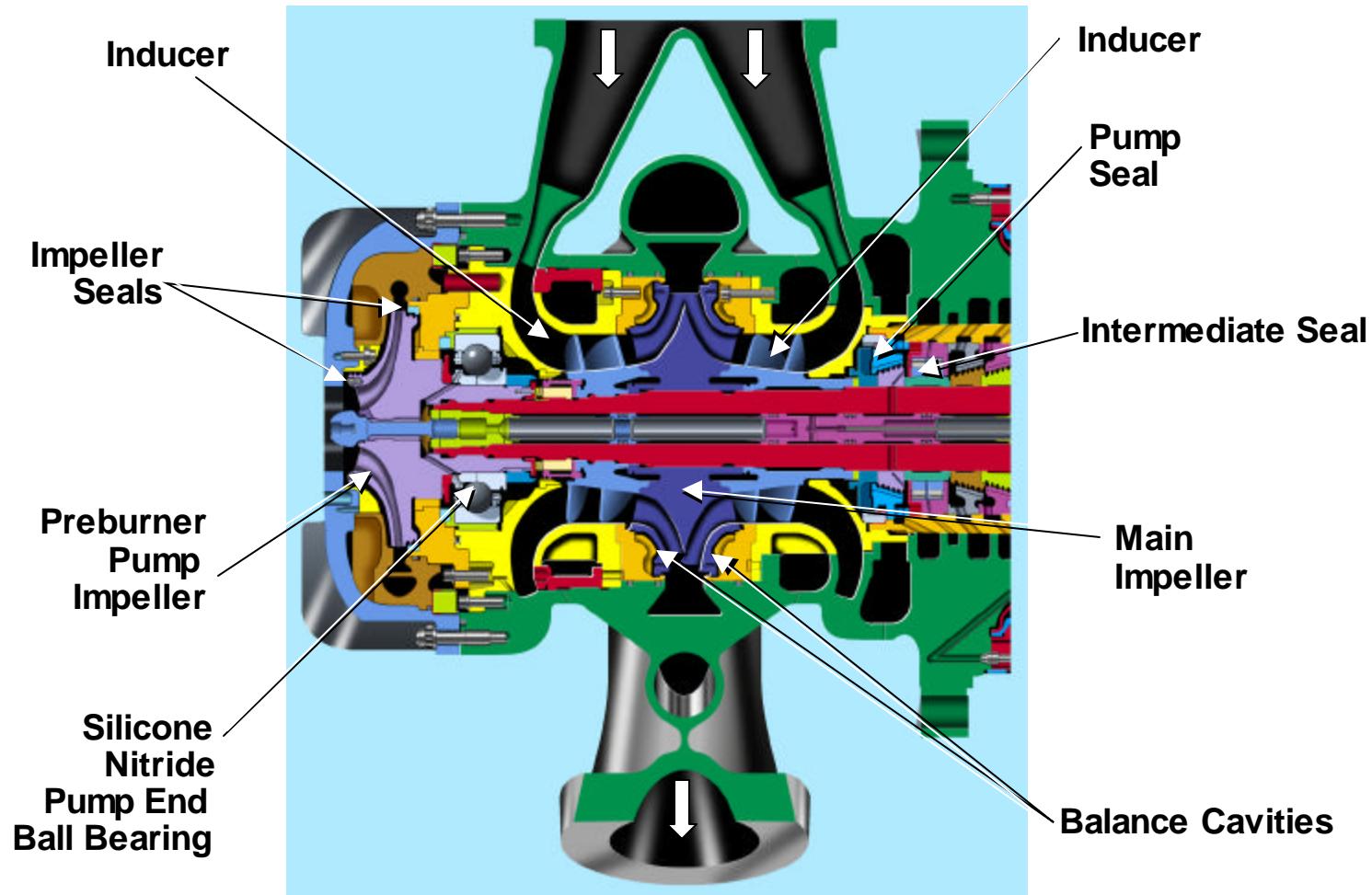
The high-pressure oxidizer turbopump (HPOTP) raises the pressure of the liquid oxygen flowing to the main injector and the preburner injectors sufficiently to ensure positive injection of oxidizer at all thrust levels.

The HPOTP is a centrifugal pump that contains both a double-entry, back-to-back main impeller and a single-entry preburner oxidizer boost impeller. The oxidizer input is split 50-50 to enter both ends of the main impeller, where inducers on both sides of the main impeller help improve suction performance. A portion of the output flow is ducted externally into the boost impeller where its pressure is raised for preburner injection.

The silicone nitride pump end ball bearing (PEBB) is cooled by two internal flows of liquid oxygen from a source of high pressure. Coolant sources for the PEBB are at the output of the preburner pump impeller and a passage along the preburner boost impeller tie bolt, directed at the bearing inner race. Oxygen flows down the back face of the impeller, through the impeller damper seal, the bearing, and joins the inner race coolant to flow into the input of the main pump left-hand inducer.

Excessive axial loads are reacted by two balance cavities (not by the bearings). These cavities lie between the front faces of the main impeller and the adjacent rings. Circular orifices formed at the impeller tips and hubs vary with axial shifting of the impeller. Reverse flow from the impeller outputs to inputs passes through the orifices, pressurizing the cavities equally. If, for example, the impeller is then loaded to the left, the LH "tip" orifice widens, decreasing its pressure drop, and the LH "hub" orifice narrows, increasing its pressure drop. As a result, LH cavity pressure increases to react the offending axial load. (RH cavity pressure decreases in a reverse manner.) The bearings, then, are spared these stressful loads. They do, however, react axial loading during pump spin-up and spin-down when the cavities are not fully effective.

# HPOTP Pump Section



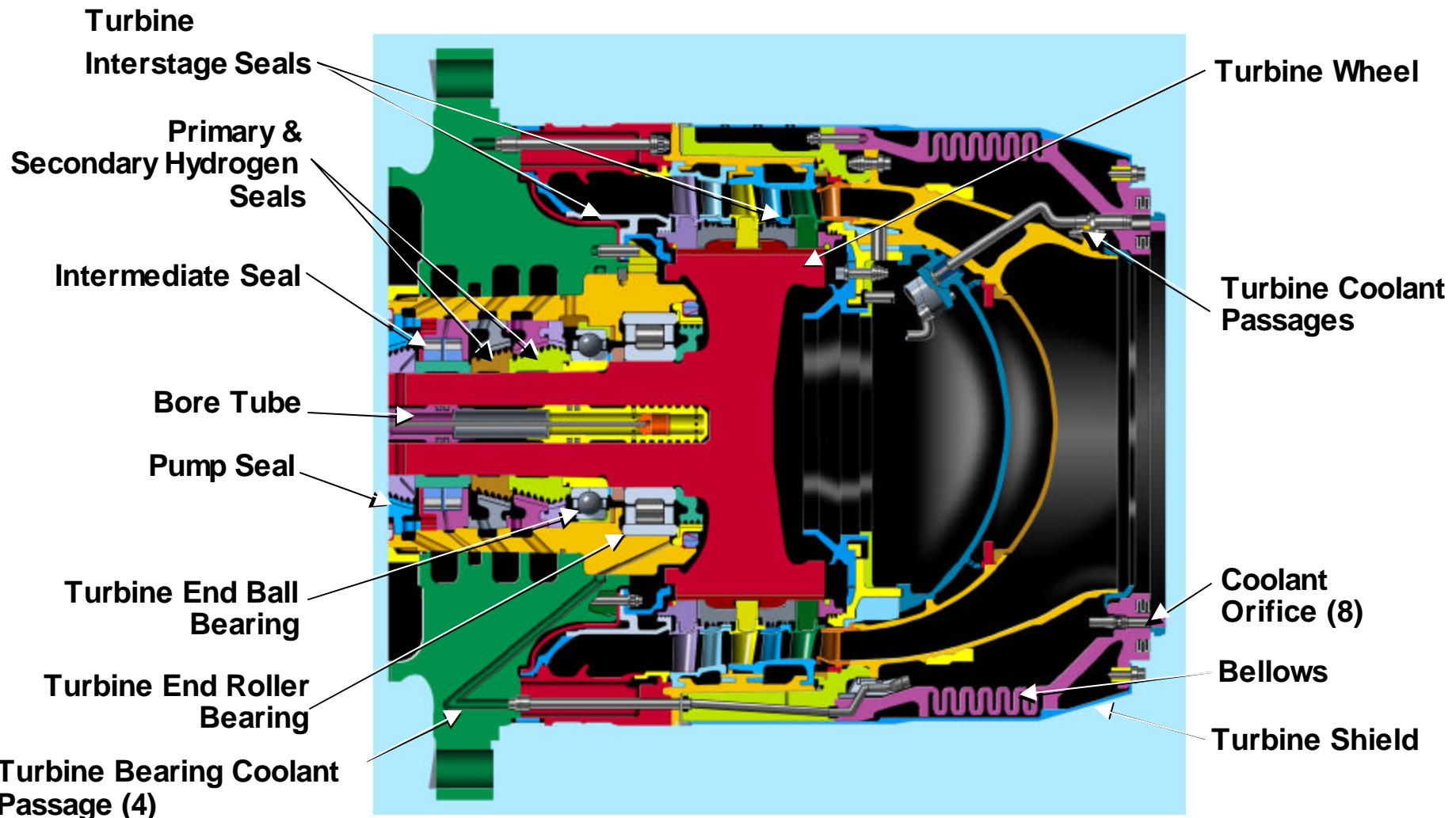
## HPOTP TURBINE SECTION

The HPOTP turbine is a three-stage, cantilevered turbine powered with hot, hydrogen-rich gas generated in the oxidizer preburner. Hot gas, guided by the cast inlet housing, is nozzleled into and through the first-, second-, and third-stage blades and is discharged into the HGM.

The steel turbine end roller bearing (TERB) and turbine end ball bearing (TEBB) are cooled by an internal flow of cold gaseous hydrogen from a source of high pressure. Coolant source for the TERB and TEBB is from the OPB fuel manifold. Hydrogen flows down four supply tubes through the outside of the turbine housing and up internal passages to a point above the TERB. The hydrogen flows across both bearings and exits through the primary and secondary hydrogen seal drain cavities, to be dumped overboard.

The single turbine wheel is made integral with the pump shaft, and retains all three stages of turbine blades. The blade tips operate at close clearances to the stationary circular seals for blade-to-housing sealing. Turbine-to-OPB sealing is accomplished by a bellows that load two seals in the turbine inlet flange to sealing surfaces in the OPB. This also allows cooling fuel from the OPB fuel manifold to be orificed into the turbine end of the pump and from there to various parts of the turbine. The turbine coolant then discharges into the hot gas stream.

# HPOTP Turbine Section



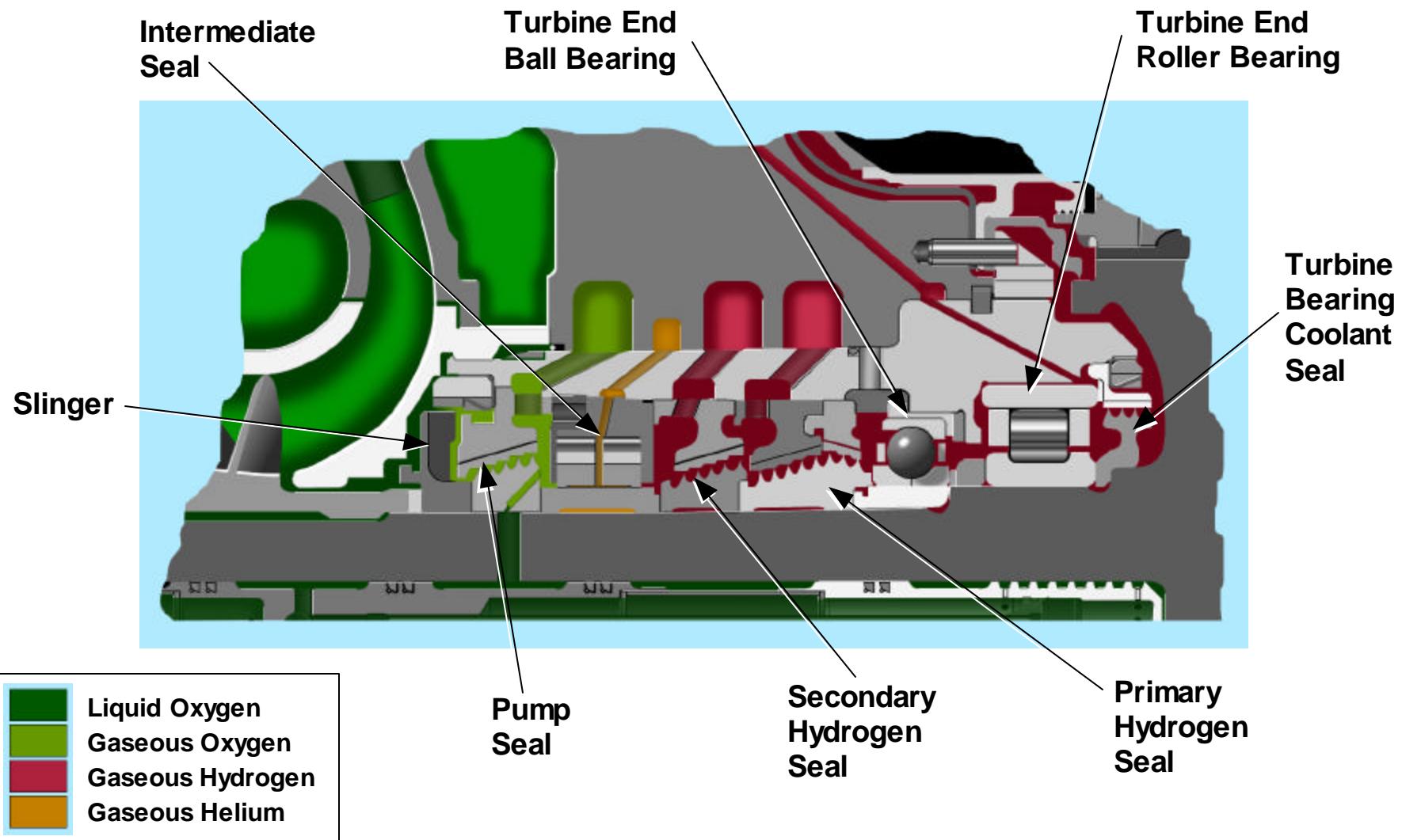
## HPOTP SHAFT SEALS

Because the HPOTP pumps liquid oxygen and the turbine end bearings are cooled by cold hydrogen gas, extensive shaft seals are needed to prevent the two fluids from meeting. The seal area of the shaft contains a slinger, three sets of labyrinth seals, and a double-element, controlled-gap, purged, intermediate seal.

The labyrinth seals contain rows of raised rings which ride closely to a mating half of the seal. Contact between the spinning and stationary halves does not occur and a positive clearance is always maintained. Each raised ring presents a restriction to the flow of fluid reducing the pressure as well as the flowrate. The more raised rings that are used the better the performance of the seal. However, leakage will always occur across a labyrinth seal.

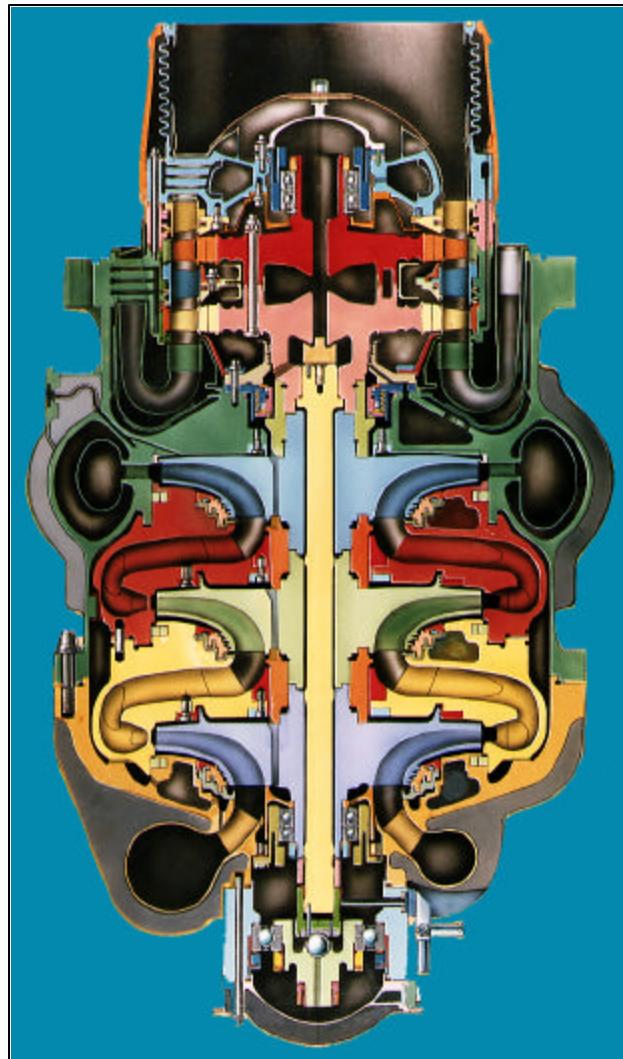
All three propellant seal cavities are drained overboard via dedicated drain lines. In addition, the cavity between the two elements of the intermediate seal is continuously purged with either gaseous nitrogen or helium before, during, and after engine run. The purge flow splits to flow through the intermediate seal gaps and out the cavity drain lines on either side, thereby preventing intermingling of the oxygen and hydrogen.

# HPOTP Seal Group



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# High-Pressure Fuel Turbopump



Block IIA Key Performance Parameters	
	At 104.5% of RPL
Pump inlet flowrate (lb/sec)	155
Pump inlet pressure (psia)	250
Pump discharge press (psia)	5,950
Pump efficiency (%)	75.0
Turbine flowrate (lb/sec)	145
Turbine inlet temp (°F)	1,330
Turbine pressure ratio	1.50
Turbine efficiency (%)	81.1
Turbine speed (rpm)	34,360
Turbine horsepower	63,080

## HPFTP PUMP SECTION

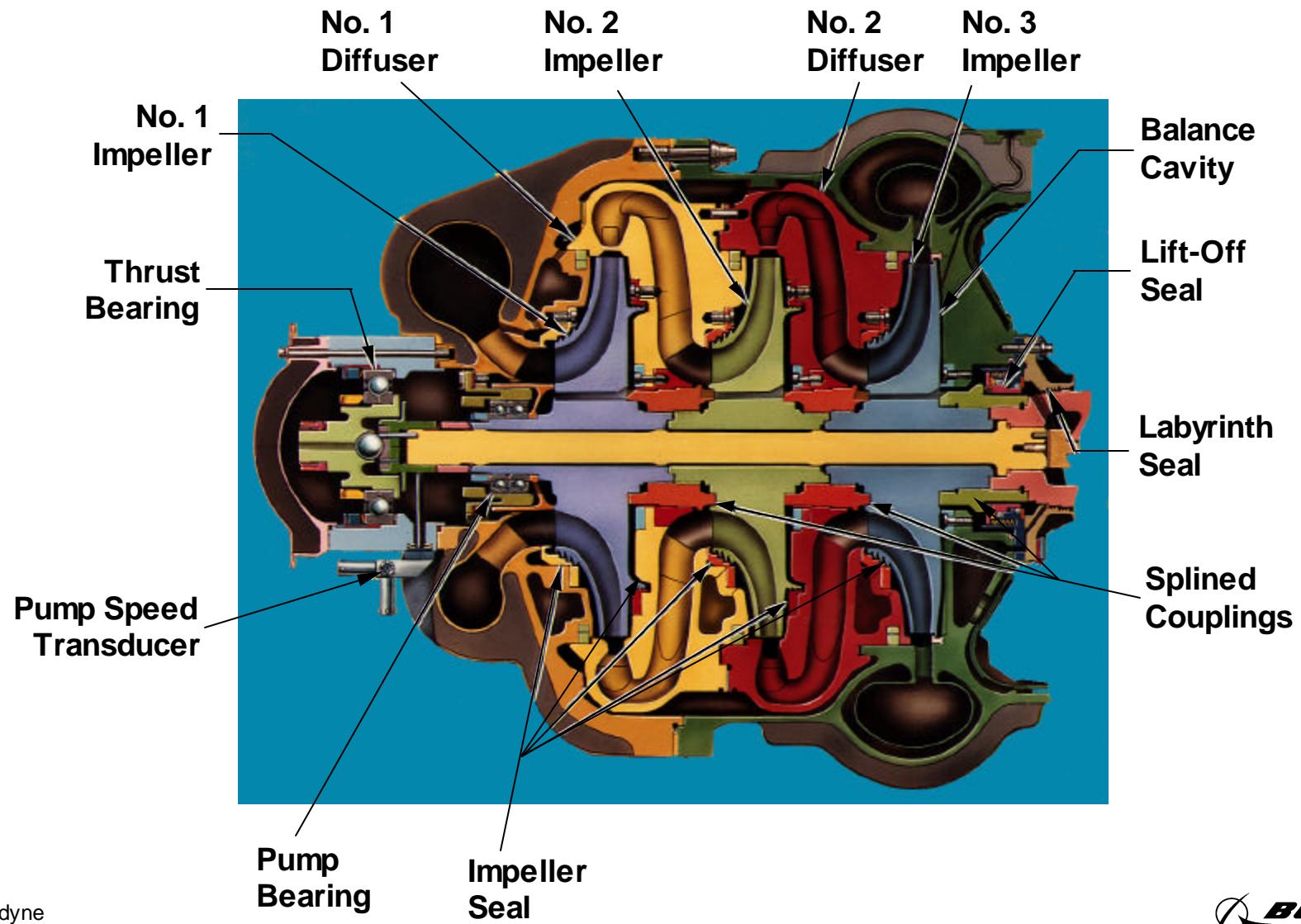
The high-pressure fuel turbopump (HPFTP) raises the pressure of the hydrogen flowing to the engine combustion chambers sufficiently to ensure positive injection of hydrogen at all thrust levels.

The HPFTP is a three-stage centrifugal pump that uses two interstage diffusers to pass the hydrogen from one stage to the next. Each impeller has front and back face labyrinth seals except number 3, which incorporates a balance cavity to react axial loads as follows: Circular orifices formed at the impeller tip and hub vary with axial shifting of the impeller. Reverse flow from the impeller output to the input passes through the cavity and the orifices, pressurizing the cavity. If, for example, the impeller is then loaded to the right, the tip orifice widens, decreasing its pressure drop, and the hub orifice narrows, increasing its pressure drop. As a result, the cavity pressure increases to react the offending axial load. If the impeller is loaded to the left, the entire process is reversed. Hence, the bearings need not sustain these loads.

The pump bearings are cooled by two internal flows of hydrogen from a source of high pressure. Coolant source for the pump-end bearings, including the thrust bearing, is the output of number 1 impeller. Hydrogen flows down the back face of the impeller, through the holes in the hub, through the bearings, and into the number 1 impeller input.

The HPFTP is completely insulated to retain the hydrogen in a liquid state and prevent the formation of liquid air on the pump. A redundant, magnetic-type, pump speed transducer is located adjacent to the thrust bearing.

# HPFTP Pump Section



## HPFTP TURBINE SECTION

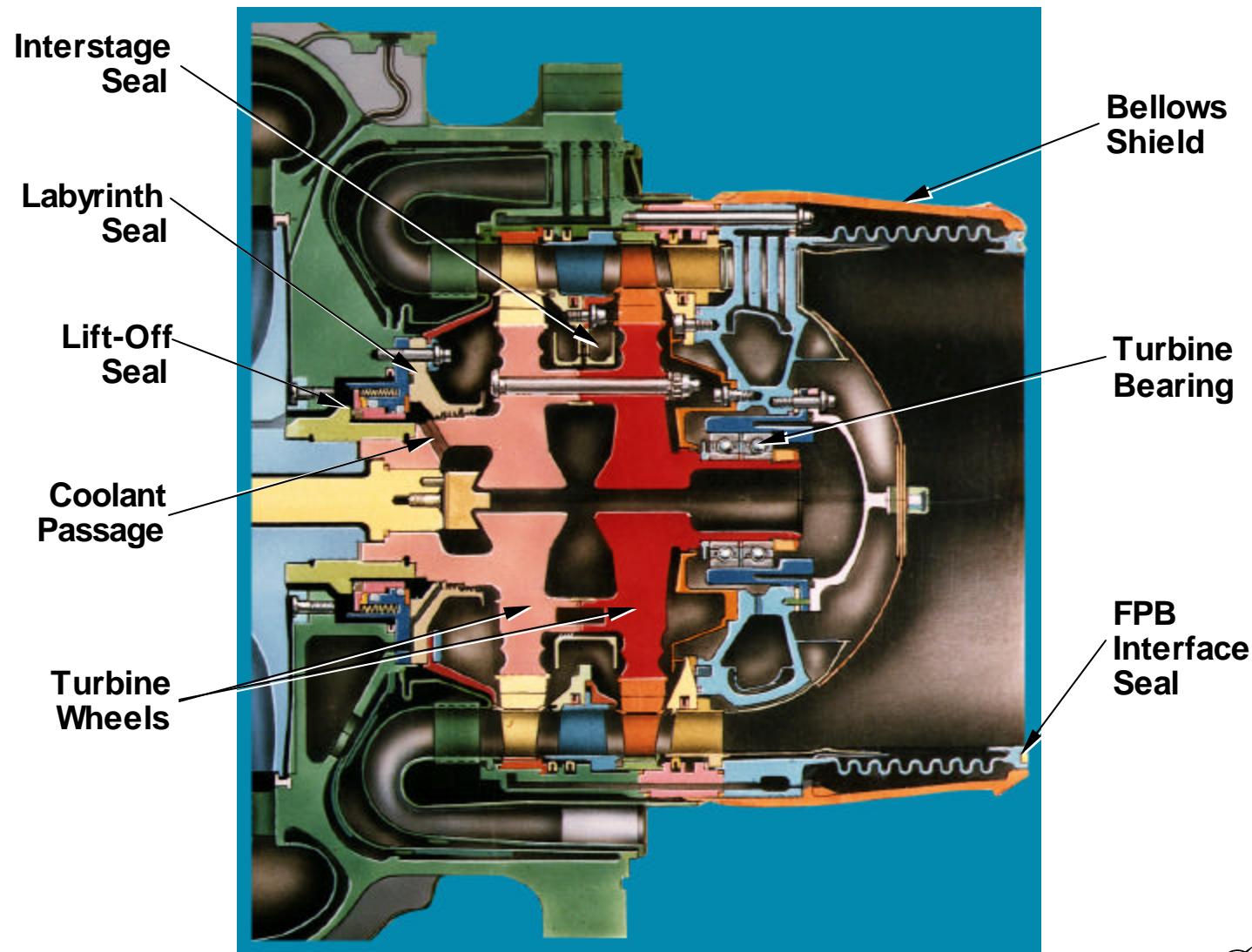
The high-pressure fuel turbopump (HPFTP) turbine is a two-stage turbine powered with hot, hydrogen-rich gas generated in the fuel preburner. Hot gas, guided by the one-piece inlet sheet metal structure, is nozzleed into and through the first- and second-stage blades, and is discharged into the HGM.

The second-stage wheel is spline-coupled to the third stage impeller, and the first stage wheel is bolted to the second-stage wheel through a curvic coupling. Turbine-to-FPB sealing is accomplished by a bellows that loads a seal at the turbine inlet flange to a sealing surface in the FPB.

Prior to engine start, leakage of liquid hydrogen from the pump into the turbine end is prevented by a lift-off seal. Springs load a carbon nose against a shaft mate ring, sealing the pump. When the pump starts, discharge pressure overcomes the spring tension and lifts the seal off of the shaft mate ring.

The turbine and turbine bearings are cooled by extracting fuel from the fuel pump itself. When fuel pressure has lifted the lift-off seal from the shaft mate ring, fuel will flow into the general area of the turbine. The flow first splits through the coolant passage and the labyrinth seal. Then, through several circuitous pathways, it flows through and over all turbine structure and the turbine bearings. The fuel then discharges into the hot gas stream.

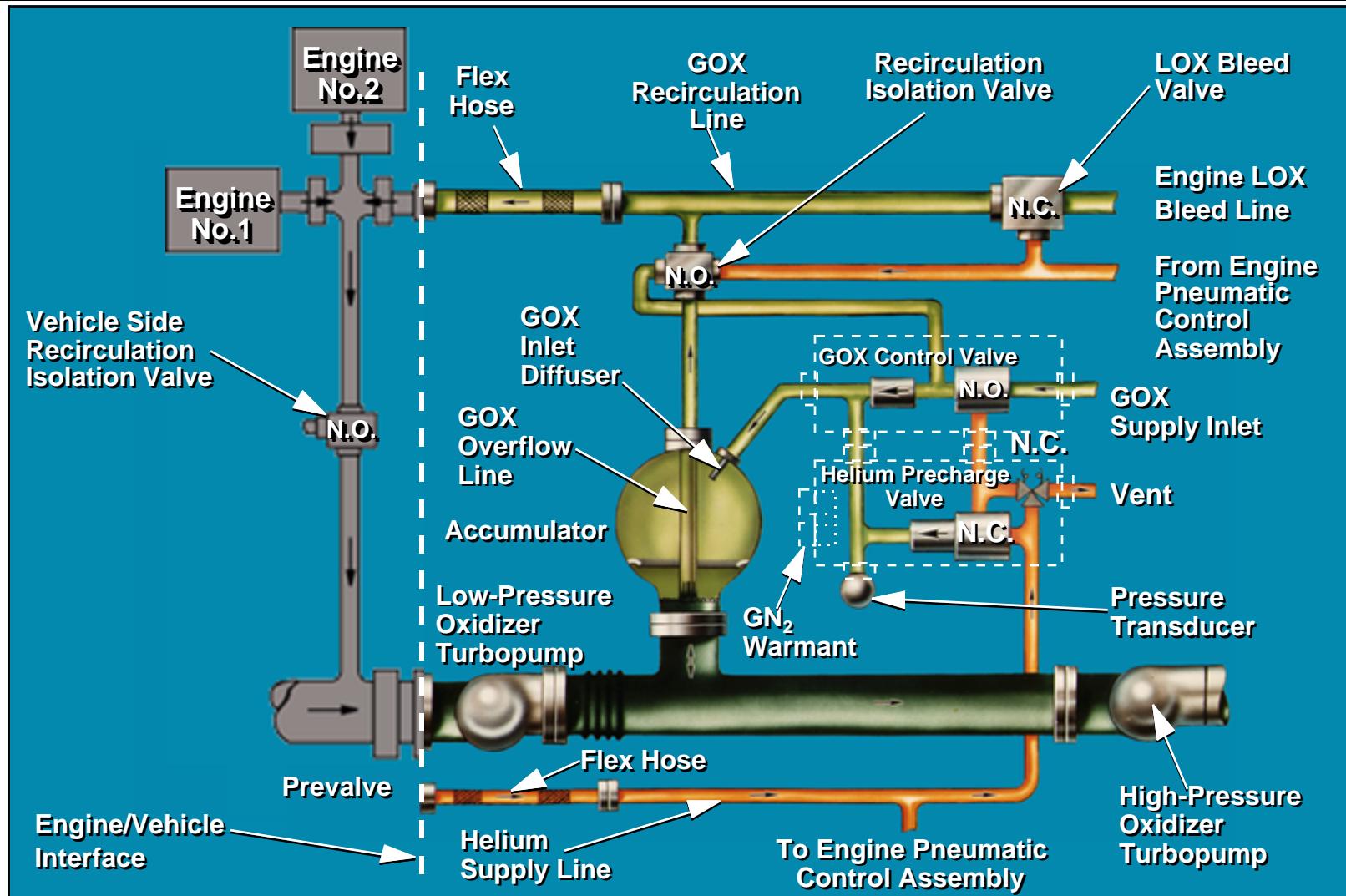
# HPFTP Turbine Section



## POGO ACCUMULATOR PRESSURIZING SYSTEM

The major component in the pogo accumulator pressurizing system is a 0.6-cubic-foot, hollow metal sphere (accumulator), flange-mounted to the low-pressure oxidizer duct. During engine operation, it is pressurized with gaseous oxygen. The gaseous oxygen, being a compliant medium in direct contact with the liquid oxygen, is able to smooth the oxidizer flow by absorbing delta pressures. Accumulator pressure is maintained by a constant flow of GOX into, through, and out of the accumulator. The GOX comes from the heat exchanger coil, flows through the GOX control valve into the accumulator, exits through the bottom of the inverted standpipe, and returns to the vehicle system to be recondensed. A restrictor in the GCV and the restricted standpipe outlet establish the proper GOX pressure in the accumulator. The liquid/gas interface location is established by the length of the standpipe since, if the liquid rises to block the gas exit holes, the gas pressure rises to block further incursion of liquid and drive it back down. Since pogo suppression is desired before and after sufficient GOX is available, a helium precharge and postcharge are necessary. Helium from the vehicle supply is used and is controlled by the helium precharge valve (HPV). When the HPV is open, the GOX control valve is closed, and vice versa. The remaining valve in the system is the recirculation isolation valve (RIV). One function occurring during engine preparation is propellant recirculation. To ensure that oxidizer entering the engine can exit only through the open bleed valve, the potential open circuit through the accumulator and standpipe is blocked by the RIV. The RIV is closed by the same helium pressure that opens the bleed valve. GOX pressure from the GOX control valve is applied to the RIV to ensure that it opens at engine start.

# POGO Suppression System Schematic



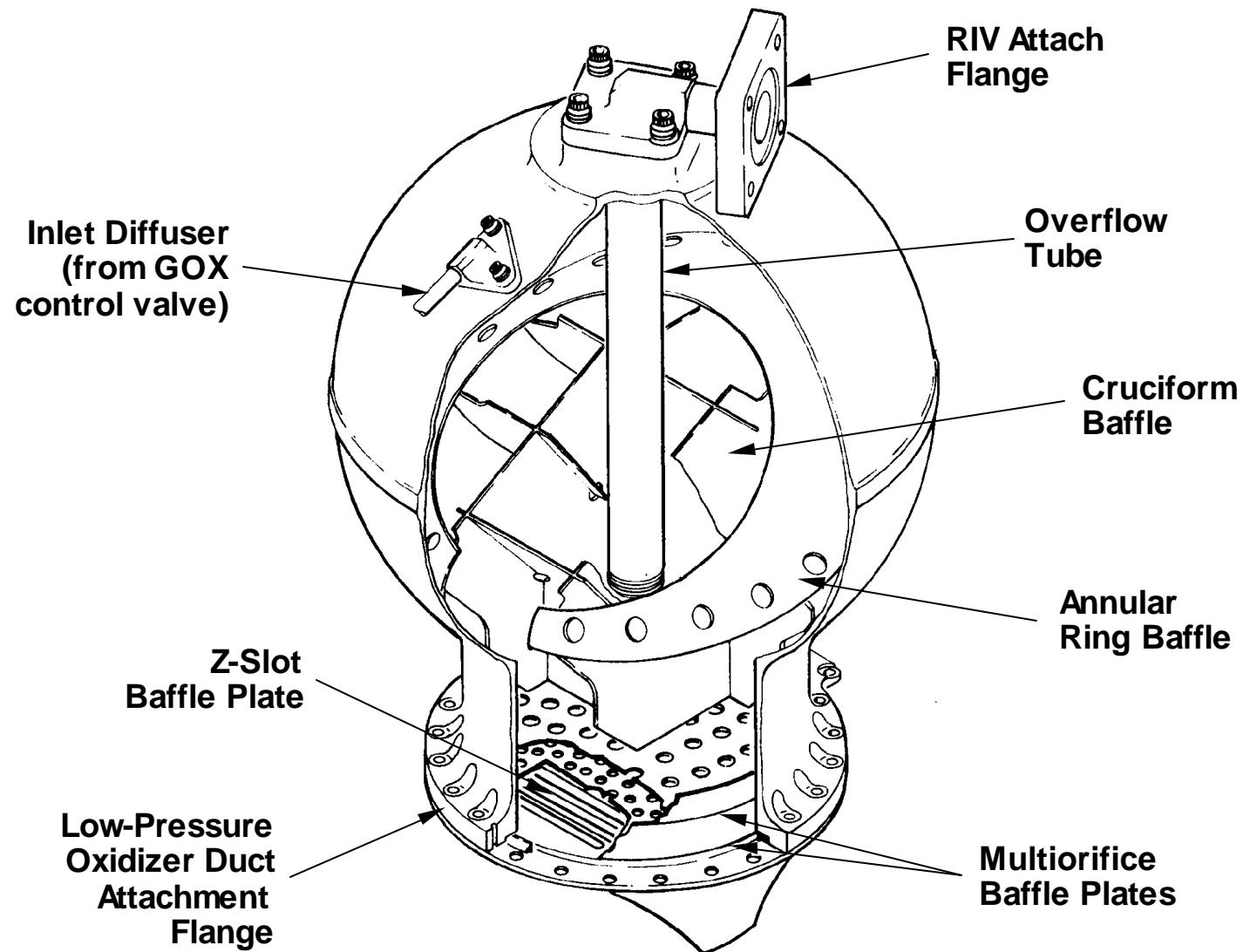
## POGO SUPPRESSION SYSTEM ACCUMULATOR

The pogo accumulator provides capacitance in the engine oxidizer system, which prevents low-frequency flow oscillations from affecting the combustion process.

During engine start and shutdown, it is precharged and postcharged with helium from vehicle spheres. During engine run, it is pressurized with GOX from the heat exchanger coil.

The overflow tube (standpipe) has only six small exit holes at the bottom. To ensure efficient operation of the accumulator in controlling the liquid/gas interface location, several devices are utilized. The inlet diffuser turns and breaks up the incoming stream of pressurizing gas which could cause surface turbulence. Cruciform and ring baffles reduce LOX sloshing. The Z-slot and multi-orifice baffle plates prevent surface turbulence and, therefore, gas ingestion by the HPOTP.

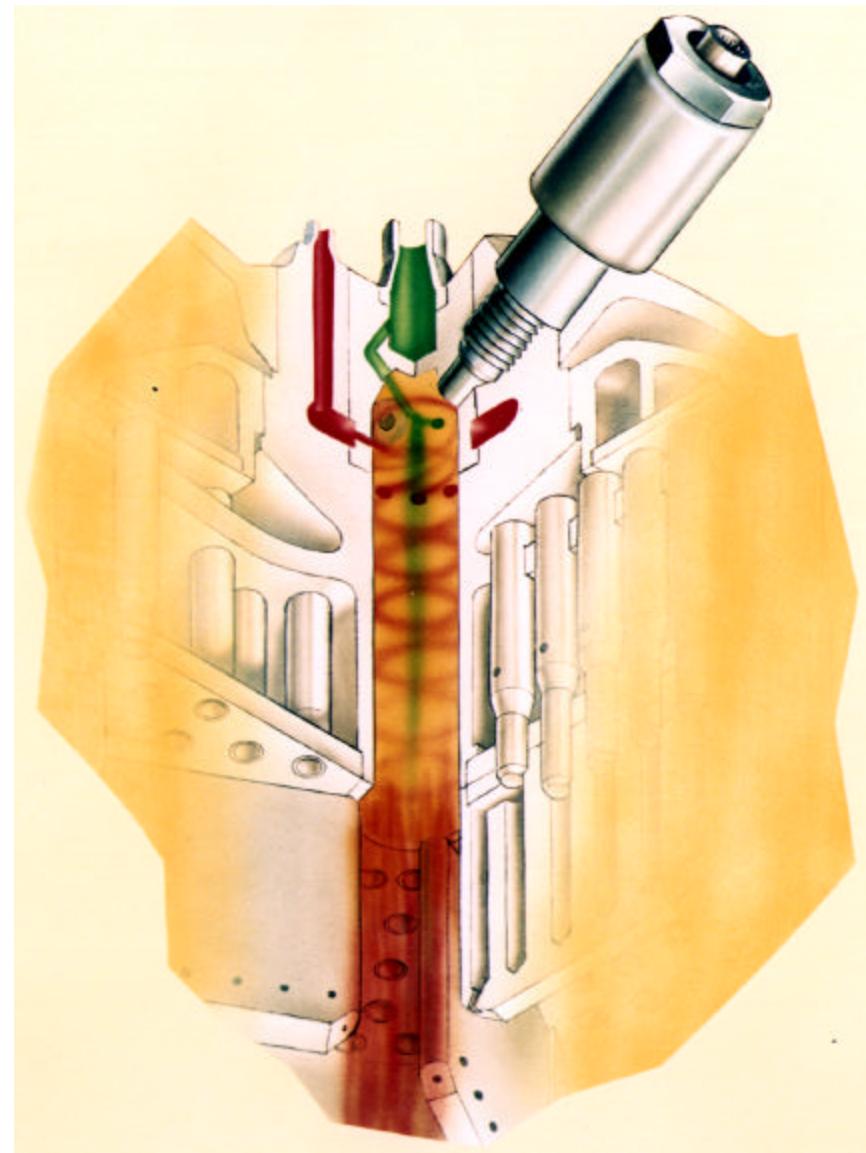
# POGO Suppression Accumulator



## ASI INJECTOR/COMBUSTION CHAMBER

Two (redundant) spark igniters are installed at the top of each augmented spark ignition (ASI) chamber. The fuel and oxidizer are injected into the chamber in a very precise manner to establish specific, desirable conditions; e.g., maximum oxidizer-rich at the point of ignition, a fuel-rich cooling shroud along the walls, and a propellant mixing action the length of the chamber. To these ends, the oxidizer is injected at the spark point as two impinging streams of heavy, slow-moving liquid, which tend toward the center of the chamber. The fuel is injected from the side as eight tangential streams of light, fast-moving gas, which whirlpool around the oxidizer. This geometry ensures a positive start, chamber protection(film cooling), and thorough propellant mixing. The igniters turn off after 4.4 seconds while the ignition flame continues in order to prevent intermittent and possibly damaging blowback from the main combustion area. This also keeps the system simple and reliable.

# Preburner ASI

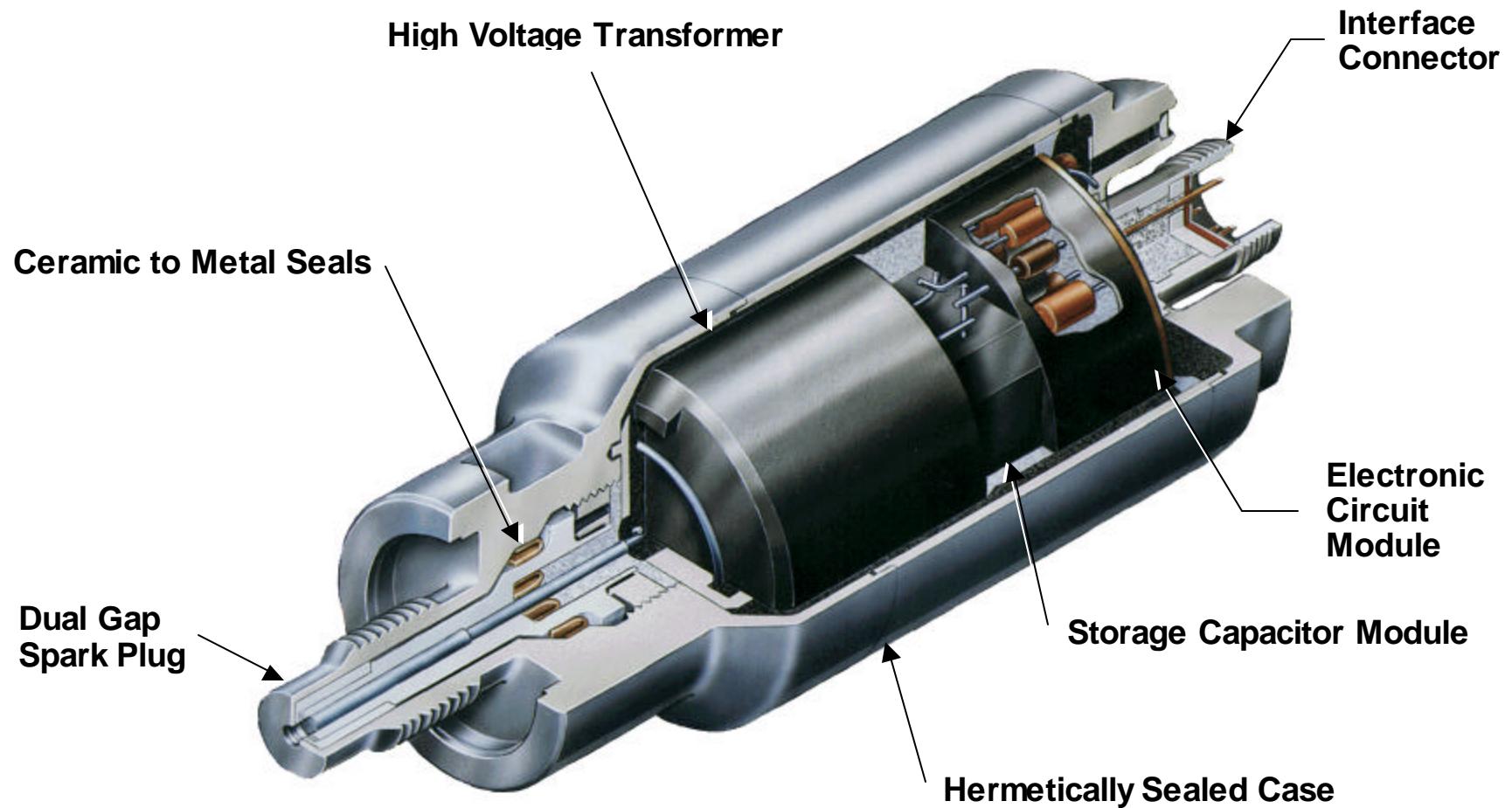


## **ASI SPARK IGNITER**

**The spark igniter generates sparks at a rate and energy level sufficient to ignite the propellants in the ASI chamber.**

**Six igniters are used on the SSME, two each (for redundancy) in the MCC and both preburners. The spark igniter is completely self-contained in that a 26-VDC input as provided by the controller, results in a 10-kilovolt, 50 sparks per second output. The igniter is hermetically sealed and welded.**

# Spark Igniter

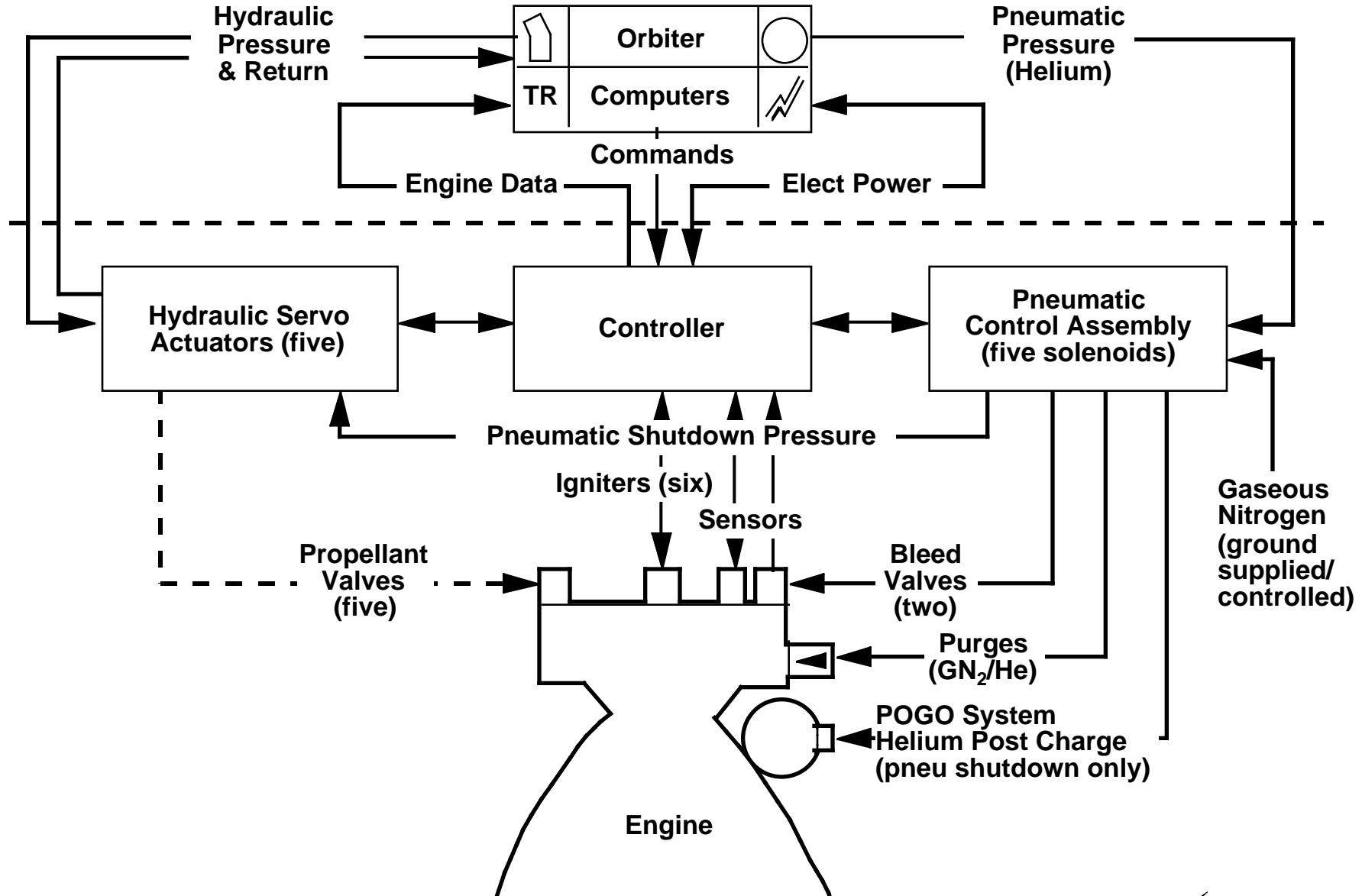


## CONTROL SYSTEM INTERFACE

The orbiter, with its three hydraulic power systems, supplies hydraulic pressure to drive five engine valve actuators, as well as its own flight controls, landing gear, etc. It also supplies electrical power to the controller and, hence, to the entire engine. Pneumatic pressure (helium) is furnished from high-pressure storage spheres located under the orbiter's cargo bay. Commands to prepare, start, throttle, and stop the engine are issued from the orbiter, while engine data is transmitted to the orbiter for transmission back to the ground.

The controller generates signals to position the five propellant valves and also to energize the five PCA solenoids, the six spark igniters, and the various sensors. It receives response and/or situation feedback signals representing pressure, temperatures, pump speeds, flowrates, and valve positions from the sensors. The controller also can effect an engine pneumatic shutdown by signaling the PCA to pressurize a pneumatic "close" piston in each of the five propellant valve hydraulic actuators.

# SSME Control Systems Interfaces

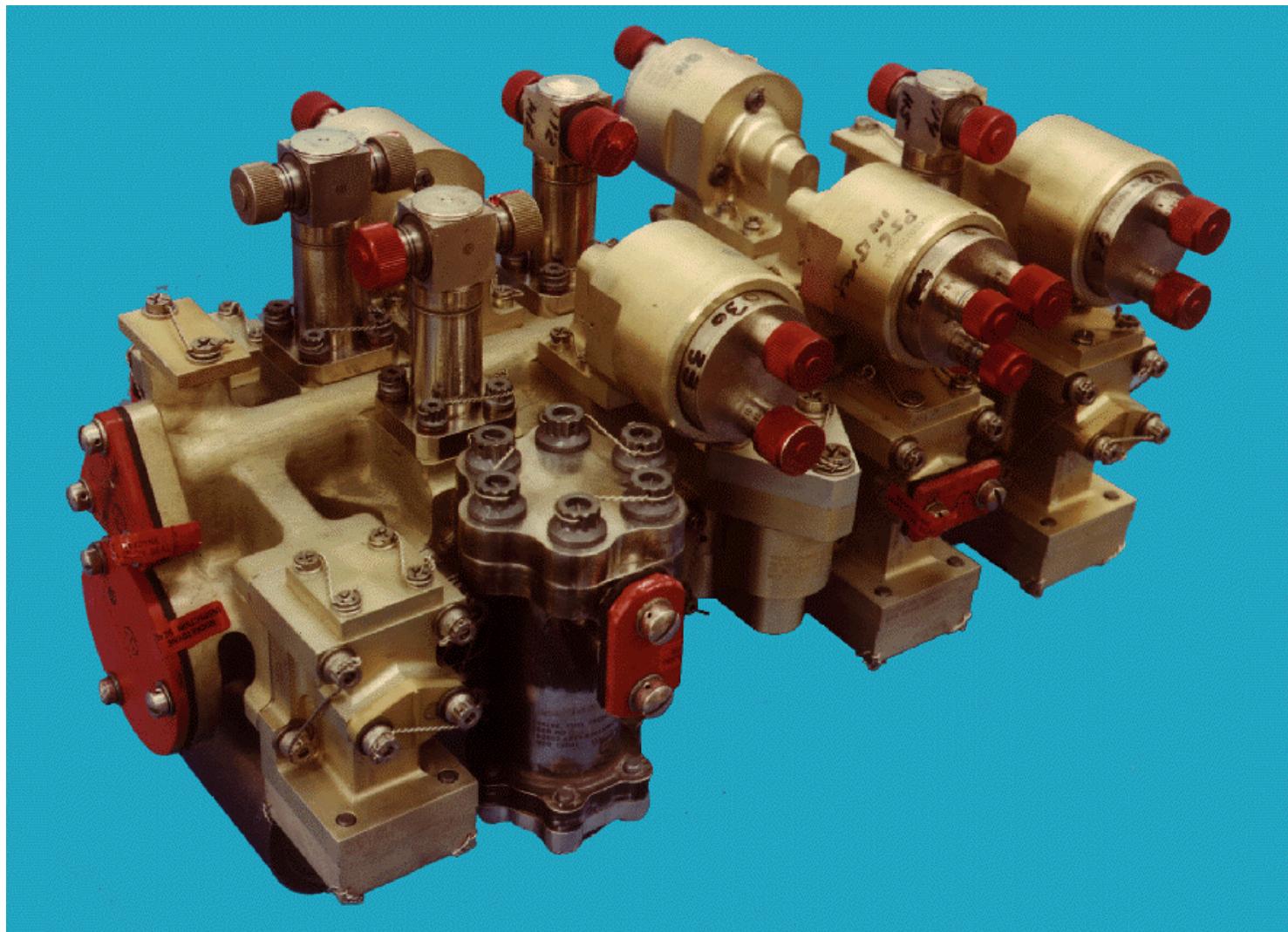


## PNEUMATIC CONTROL ASSEMBLY

The pneumatic control assembly (PCA) provides central control of all pneumatic functions; i.e., engine preparation and shutdown purges, bleed valve operation, and engine pneumatic shutdown (including pogo postcharge).

The PCA is a double manifold (one for helium, one for nitrogen) contained in one body, but not interconnected. The helium and nitrogen inlets incorporate 15-micron absolute filters to protect downstream systems from particulate contamination. Five solenoid valves, eight pressure-actuated valves (PAV), and five pressure transducers are mounted on the manifold to complete the assembly. As a general rule, a solenoid valve controls a PAV, which performs the desired function, while a pressure transducer confirms the function. The exceptions exist: One function does not require a PAV, one solenoid valve controls two PAVs, and one PAV does not require a solenoid valve. Helium is supplied by storage spheres on board the vehicle and is generally vented to the fuel system drain passage; i.e., the engine component fuel drain line. Nitrogen is supplied by a ground source and is generally vented to the oxidizer system drain passage; i.e., the engine component oxidizer drain line.

# Pneumatic Control Assembly



## PROPELLANT VALVE HYDRAULIC ACTUATOR

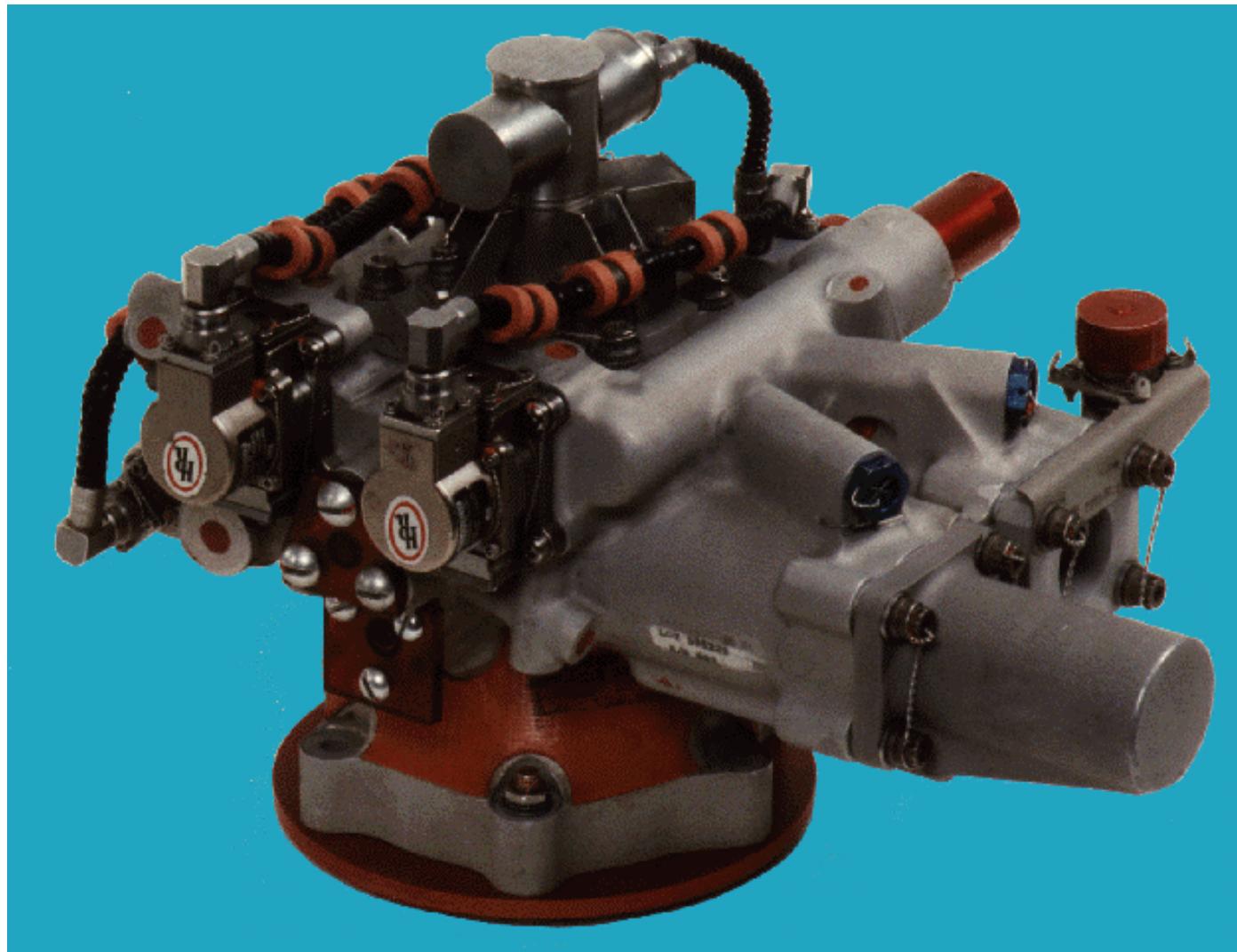
Hydraulic power is provided for operating valves in the propellant feed system. Hydraulic actuators are mounted to the valves and convert vehicle-supplied hydraulic fluid under pressure to rotary motion of the actuator shaft as a function of an electrical input command.

There are five similar actuators on the SSME: One each for the MFV, MOV, FPOV, OPOV and CCV.

Two servovalves (channel A and channel B) are mounted on each actuator and convert the electrical command signal from the engine controller to hydraulic flow to position the valve actuator. The servovalves convert input signal polarity into shaft rotation direction, and signal amplitude into rotation rate.

The servovalves provide redundancy that permits a single servovalve failure with no change in actuator performance. The fail-operate servoswitch controls actuation of the two-position shuttle valve and is used to select the servovalve which controls actuator operation. Channel A servovalve is normally in control. The fail-operate servoswitch when signaled by the controller, switches control to channel B servovalve. The dual-coil fail-safe servoswitch, when either signaled by the controller (due to a second failure), or upon loss of either electric or hydraulic power, places the actuator into hydraulic lockup, from which configuration it can only be pneumatically closed. Each actuator incorporates a pneumatic piston for this purpose. To pneumatically close the five engine valves in a manner similar to normal, the OPOV, FPOV, and CCV actuators also incorporate a sequence valve. The pneumatic close pressure is sequenced in series from the OPOV to the FPOV to the CCV. The MOV and MFV do not contain sequence valves and are closed in parallel with the foregoing action. Actuator (valve) position feedback to the controller is accomplished with a redundant rotary variable differential transformer (RVDT). A blanket heater is installed on only the MFV actuator neck, to maintain the required hydraulic fluid temperature.

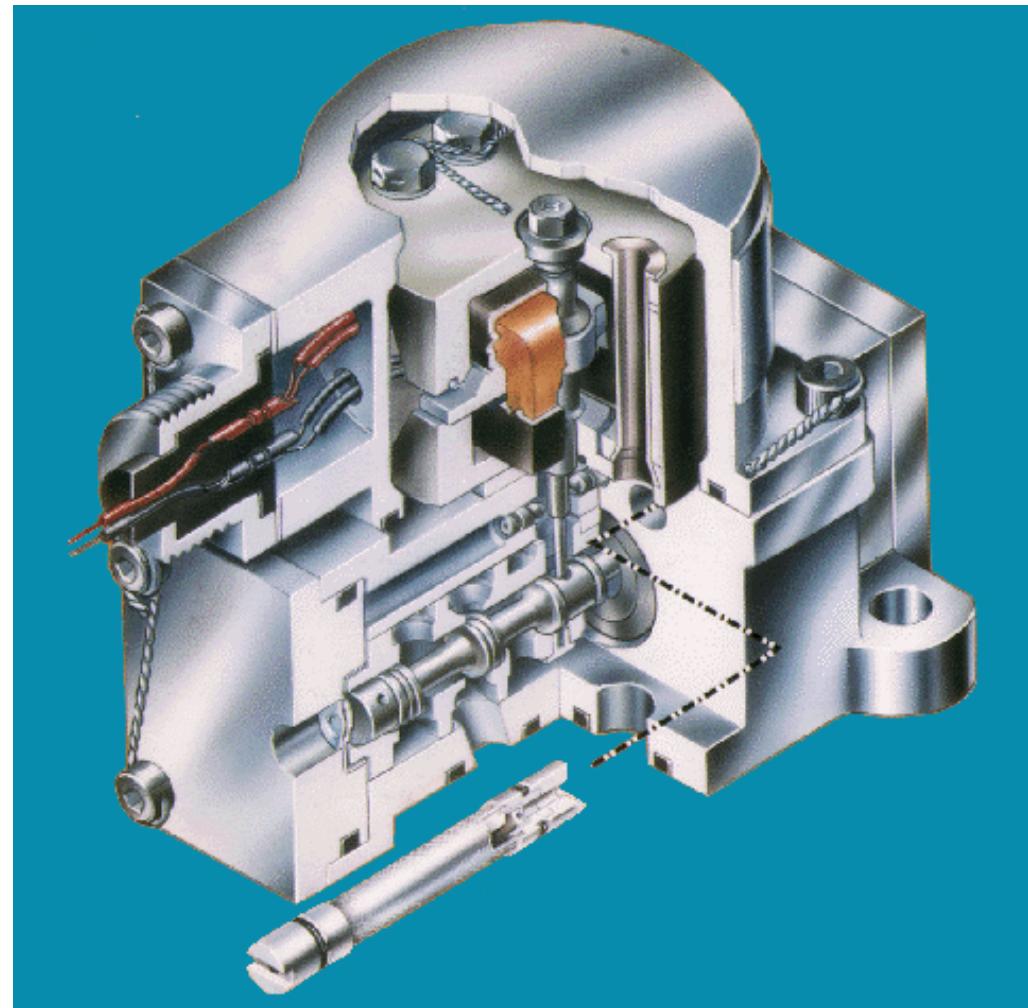
# Hydraulic Actuator



## HYDRAULIC SERVOVALVE OPERATION

When the torque motor tilts (in response to input signal polarity and amplitude), it increases the flow restriction at one nozzle and decreases it at the other. These variable restrictors are paired with constant restrictors at the ends of the filter, forming two matched pressure dividers. Therefore, the pressures applied to the ends of the second stage spool can be varied, being equal at null and not equal otherwise. The resulting spool offset is opposite to torque motor tilt and is fed back to the torque motor via the springy connecting rod thereby ensuring proportional control. Spool offset in effect simultaneously moves one port toward the input (higher) pressure and the other port toward the return (lower) pressure, driving the pistons. Therefore, signal polarity determines valve rotation direction; signal amplitude determines valve rotation rate.

# Servovalve Assembly

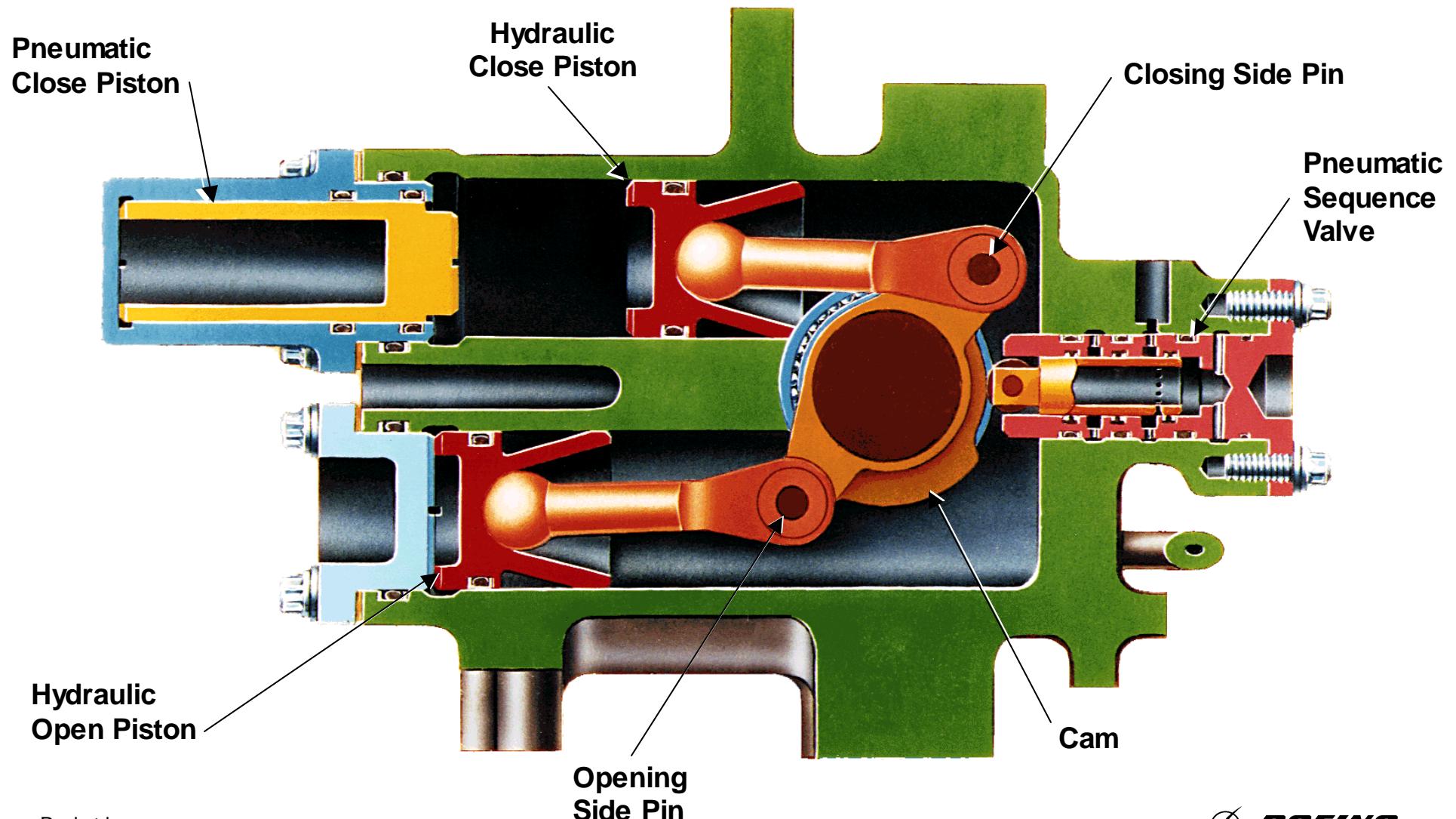


## HYDRAULIC ACTUATOR PISTON CONFIGURATION

The actuator muscle consists of two identical pistons lying parallel and connected to a double-clevis bellcrank splined to the output shaft. When hydraulic pressure is equal on both pistons, the shaft is held steady. When pressure is unequal, the shaft is rotated clockwise or counterclockwise, with the rate determined by the amount of pressure unbalance.

The pneumatic close piston contacts the hydraulic close piston and drives the valve closed (clockwise) during an engine pneumatic shutdown. The same pneumatic pressure is directed to and waits within the pneumatic sequence valve until passed through by the cam releasing (opening) at the valve. The pressure then proceeds to the next actuator.

# Preburner Valve Actuator



## CONTROLLER

The SSME controller provides complete and continuous monitoring and control of engine operation. In addition, it performs maintenance and start preparation checks, and collects data for historical and maintenance purposes.

The controller is an electronic package that contains five major sections; power supply section, input electronics section, output electronics sections, computer interface section, and digital computer unit. Pressure, temperature, pump speed, flowrate, and position sensors supply the input signals. Output signals operate spark igniters, solenoid valves, and hydraulic actuators. The controller is dual-redundant, which give it normal, fail-operate, and fail-safe operational mode capability. Fail-operate mode follows a first failure and is similar to normal mode but with a loss of some redundancy. Fail-safe mode follows a second failure. In this mode, engine throttling and mixture ratio control are suspended, the main propellant valves are held fixed in their last commanded position, and the engine is subsequently shutdown pneumatically.

The controller provides active, continuous control of engine thrust and MCC mixture ratio through closed-loop control. The controller reads MCC pressure (equivalent to thrust) and compares it to the existing thrust reference signal. It uses the error to drive the oxidizer preburner oxidizer valve, which adjusts the thrust and eliminates the error. For MCC mixture ratio, the controller reads the fuel flowmeter and drives the fuel preburner oxidizer valve to adjust the fuel flowing to the MCC, thus maintaining a mixture ratio of 6 pounds of oxidizer to 1 pound of fuel. In addition to these primary functions, the controller performs engine checkout, limit monitoring, start readiness verification, and engine start and shutdown sequencing. Controller instructions to the engine control elements are updated 50 times per second (every 20 milliseconds). The electronics are mounted on modular boards inside a sealed, pressurized chassis that is cooled by heat convection through pin fins.

# Block II Controller



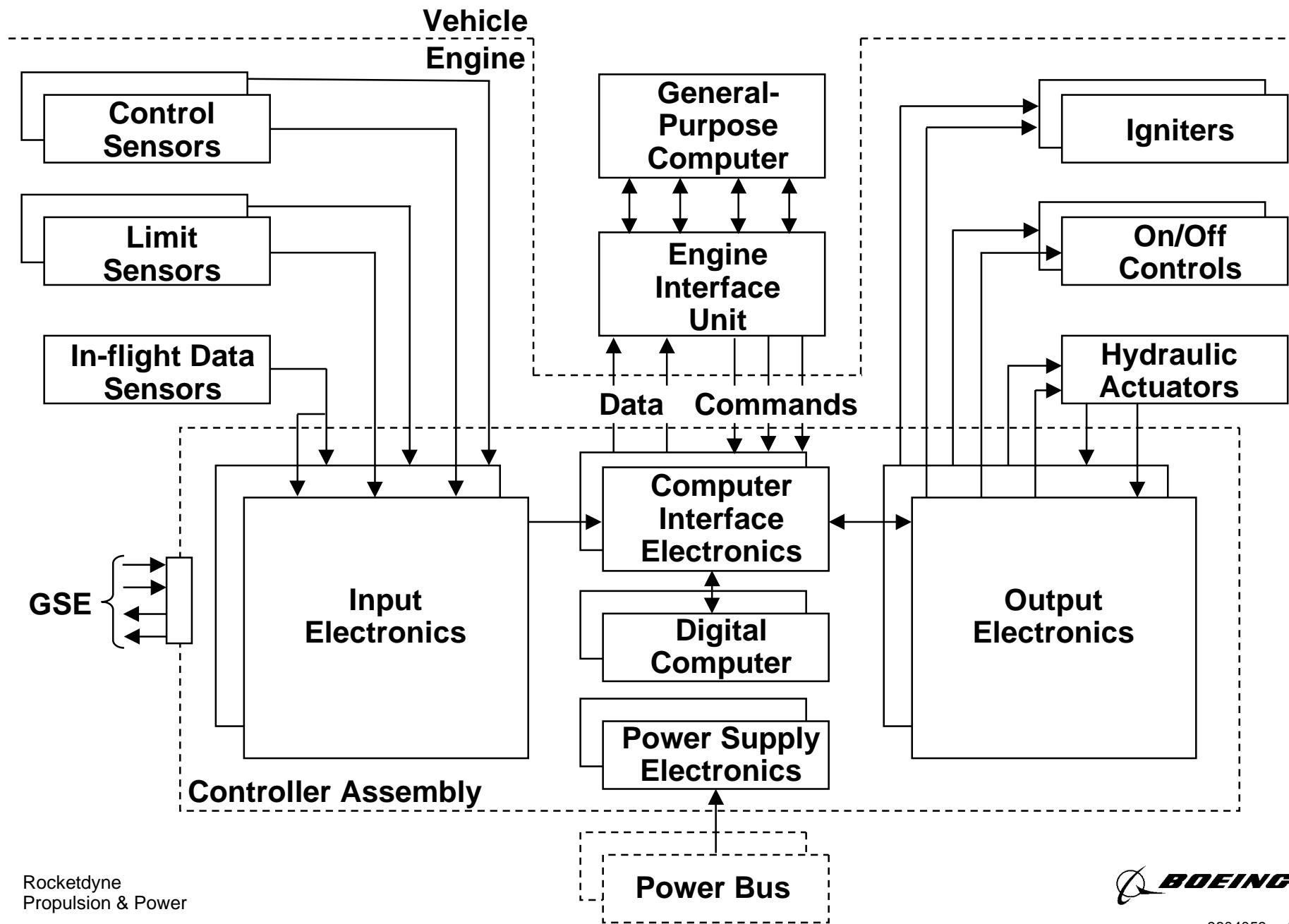
## CONTROLLER FUNCTIONAL ORGANIZATION

Controller operation is divided into five functional subsystems, each of which is duplicated to provide dual redundancy.

1. **Input electronics:** Receives and scales engine data (i.e., valve positions, pressures, temperatures, flowrates, and pump speeds) from the engine sensors. Converts data from its existing analog form to digital values. Multiplexes data to serial format for transmission to digital computer unit.
2. **Output electronics:** Converts the computer digital control commands into voltages suitable for powering the engine spark igniters, the solenoid valves, and the propellant valve hydraulic actuators.
3. **Digital computer:** Provides the computations and memory necessary for all engine control functions
4. **Interface electronics:** Controls the flow of data and commands within the controller. Provides an interface with the vehicle electronics interface unit for receiving triple-redundant engine commands from the vehicle and for transmitting dual-redundant engine data to the vehicle. Includes watchdog timers that switch channels when failures are sensed.
5. **Power supply electronics:** Converts the 115-volt, 3-phase, 400-Hz vehicle power to the various voltages required by the controller electronics and by the engine control devices. It also monitors the voltage levels to be within satisfactory limits.

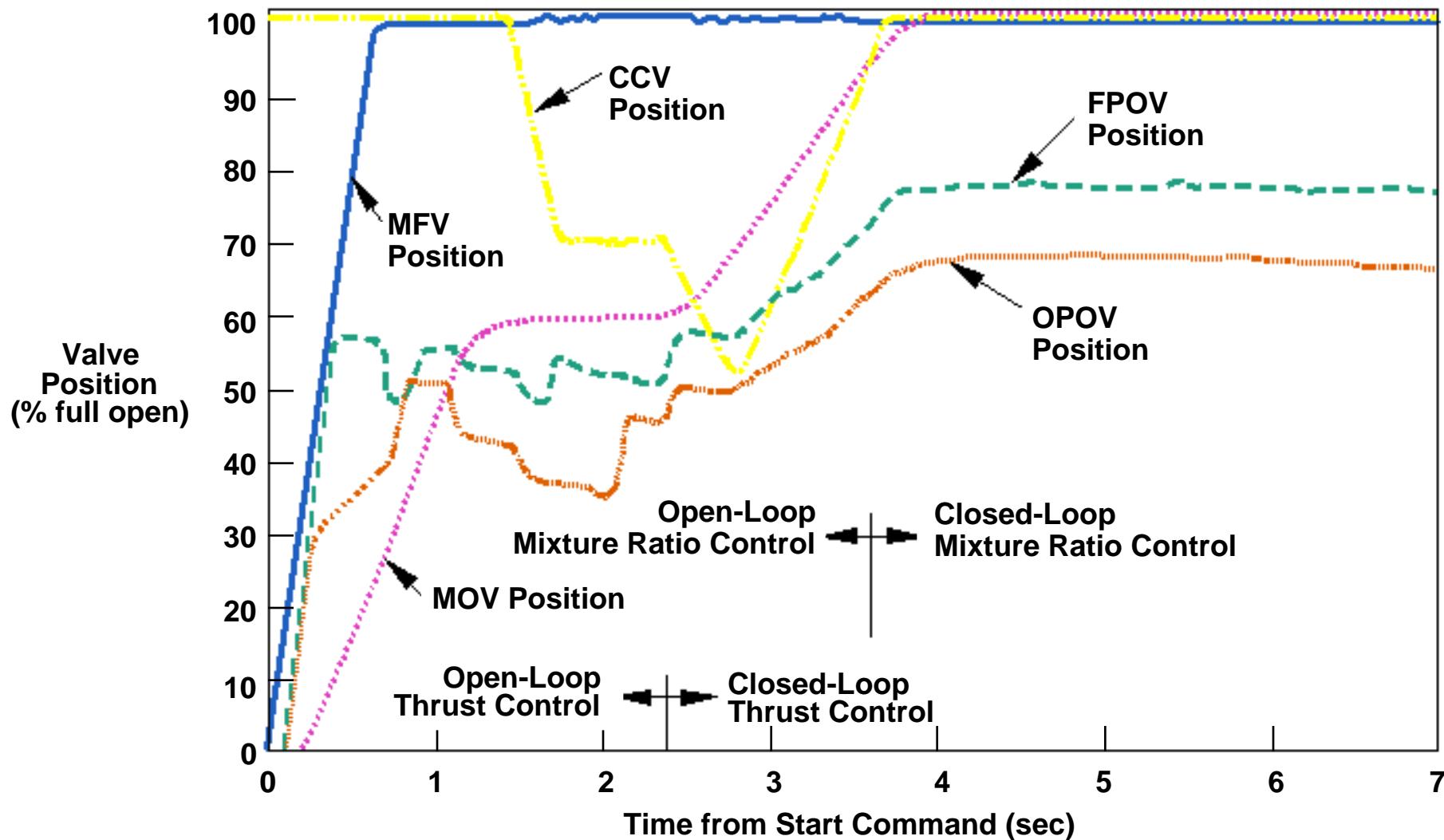
The flight acceleration safety cutoff system (FASCOS) controller uses input signals from accelerometers, mounted on the high pressure turbopumps, to cut off (if activated) the engine if certain vibrations exceed a preset amplitude for a present time. The FASCOS controller circuitry is contained within the input electronic section

# SSME Controller Organization



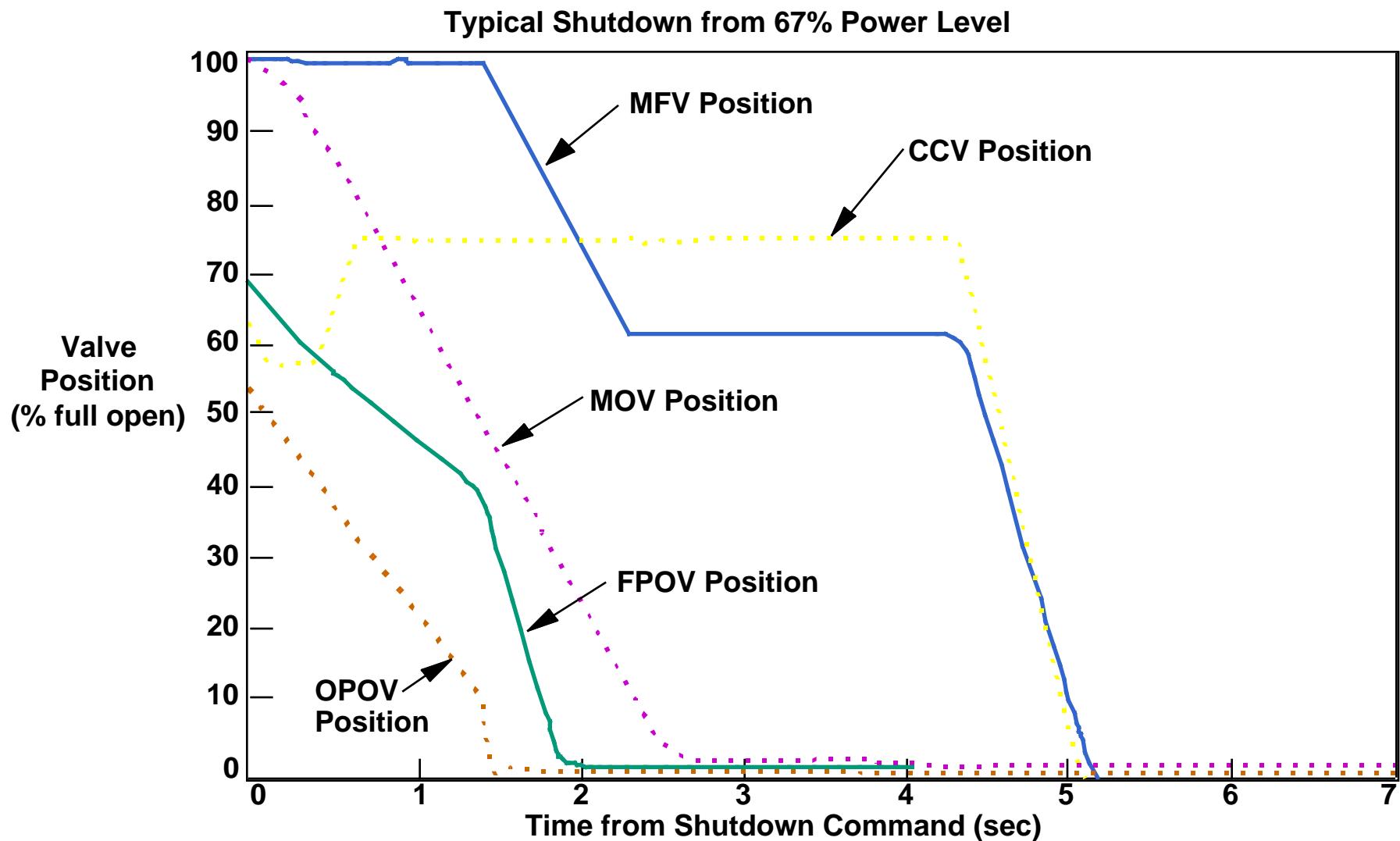
# SSME Start Sequence

## Main Valve Positions

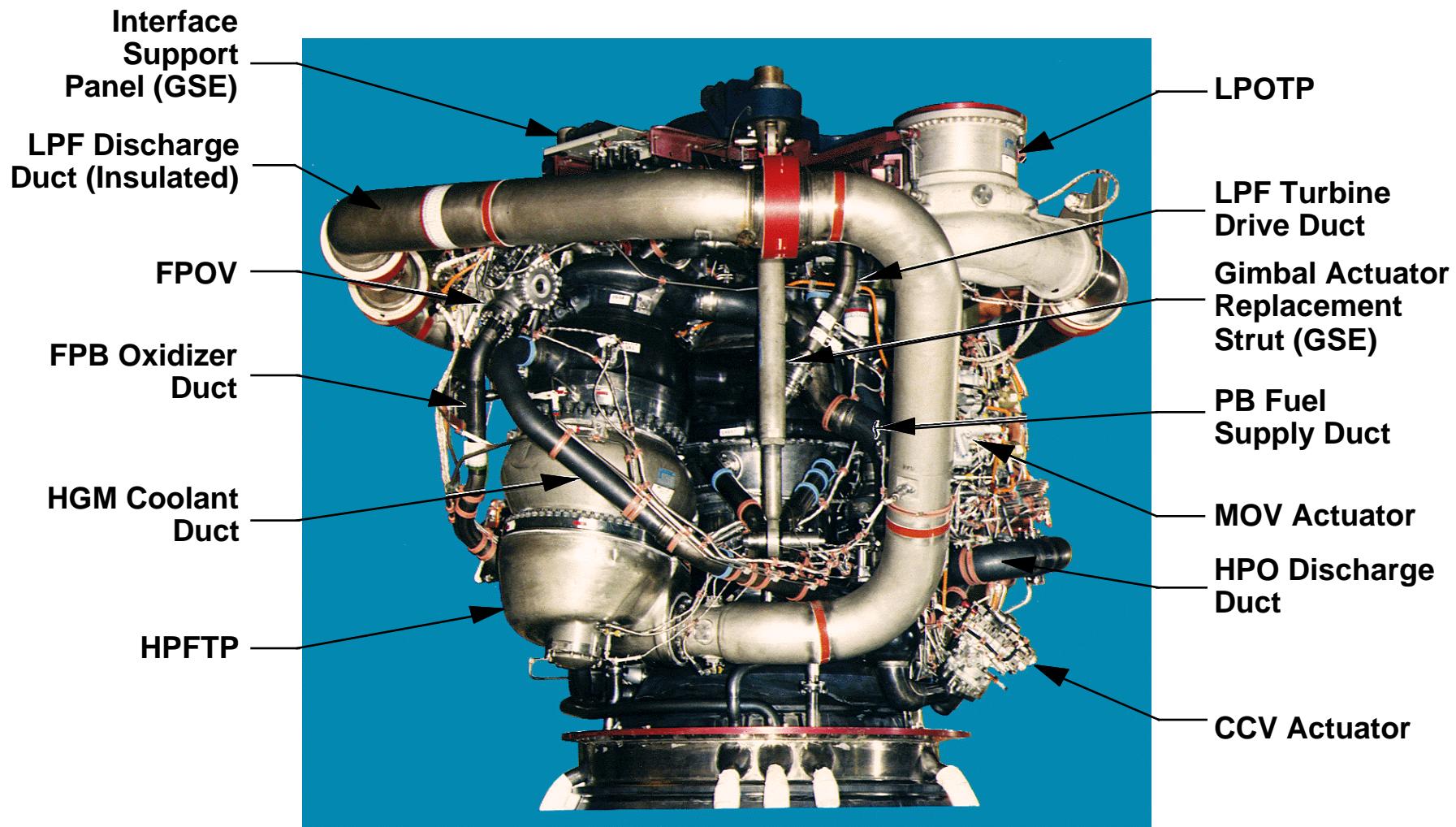


# SSME Shutdown Sequence

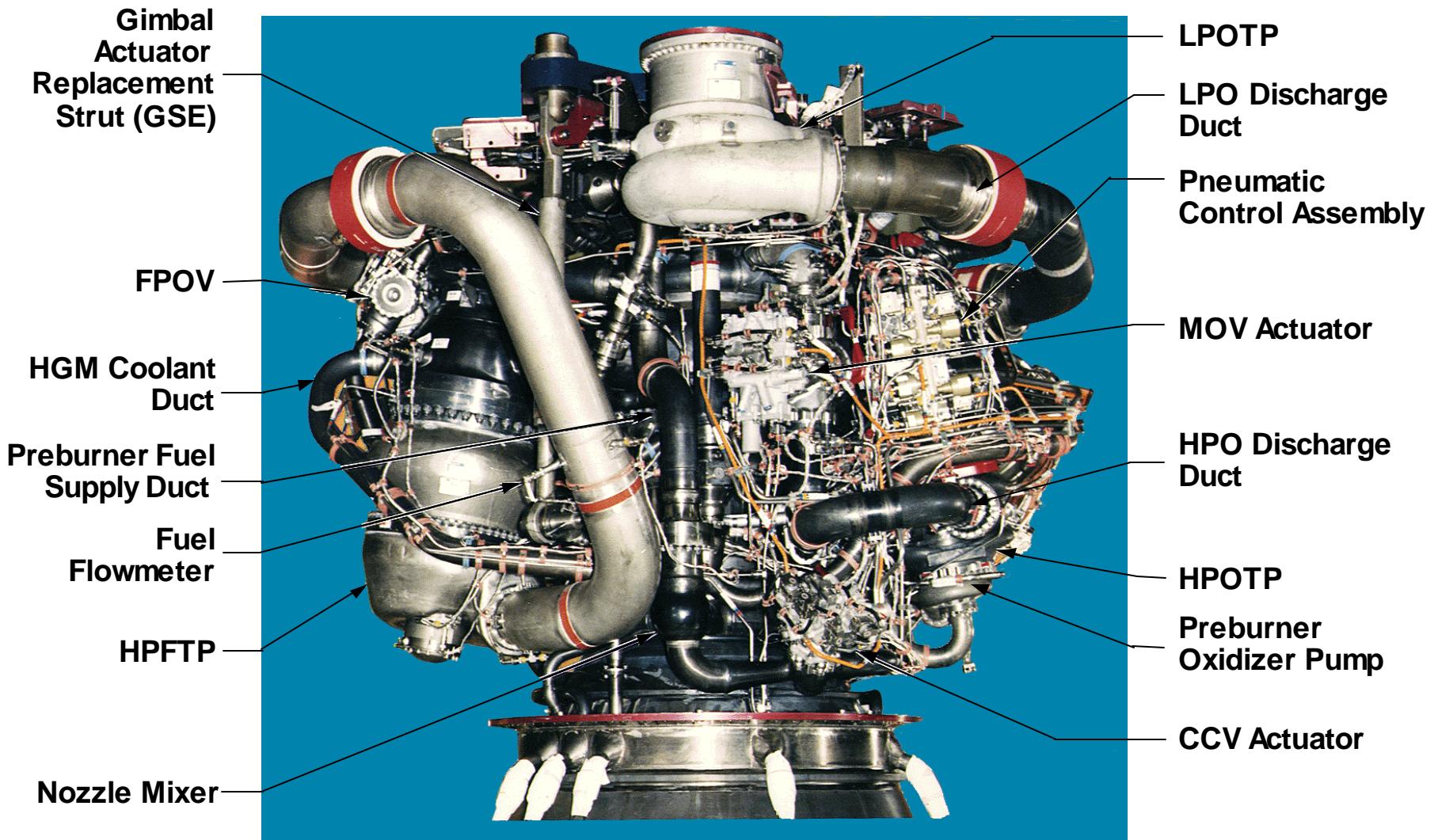
## Main Valve Positions



# Typical SSME - View 7



# Typical SSME - View 8



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