SPACE TRANSPORTATION SYSTEM
TRAINING DATA

SSME ORIENTATION (PART A — ENGINE)

COURSE NO. ME-110(A)RIR

ROCKWELL INTERNATIONAL CORPORATION
ROCKETDYNE DIVISION
02602

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REPLACEMENT NOTICE

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FOREWORD

This manual is the supporting handout material to a lecture presentation on the Space Shuttle Main Engine called the SSME Orientation Course. The SSME Orientation Course is a technically oriented discussion of the SSME, designed for personnel at any level who support SSME activities directly or indirectly (ie, warehouse, spares, supervisory, administration, technician, quality assurance, etc). This manual is updated and improved as necessary by the Publications and Training unit of SSME Logistics, department 579-410. To request copies, call Canoga 710-5678 or 710-4705. To obtain information on classes, call Canoga 710-5678.

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

Page

TURBOPUMPS

POGO SUPPRESSION SYSTEM

HYDRAULIC VALVES

SENSORS

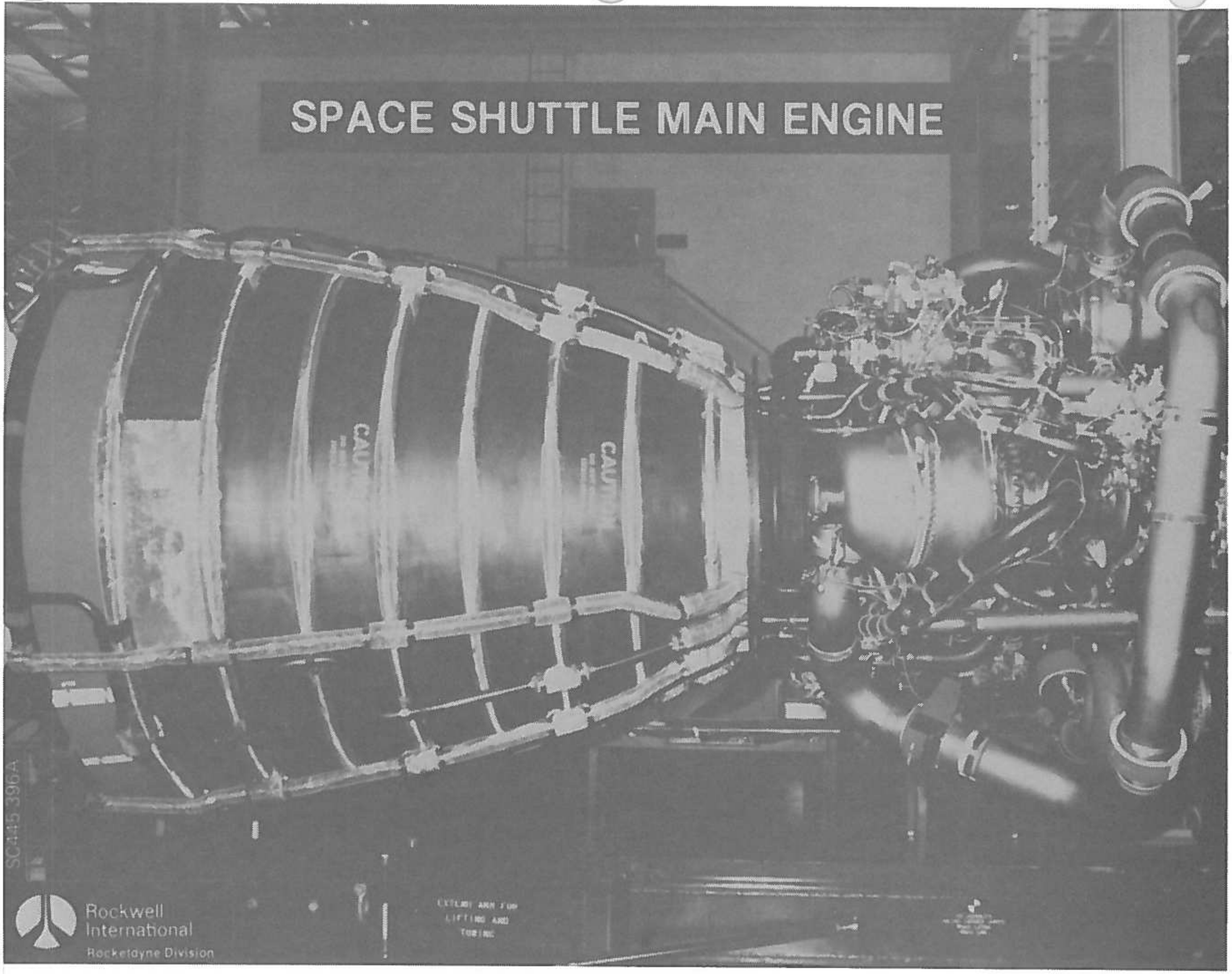
IGNITION SYSTEM

CONTROL SYSTEM

TABLE OF CONTENTS
(continued)

ENGINE OPERATION

SPACE SHUTTLE MAIN ENGINE



SHUTTLE PROPULSION SYSTEM

The space shuttle propulsion system consists of two large booster motors, three space shuttle main engines (SSMEs), two orbital maneuvering system (OMS) engines, and 44 reaction control system (RCS) thrusters.

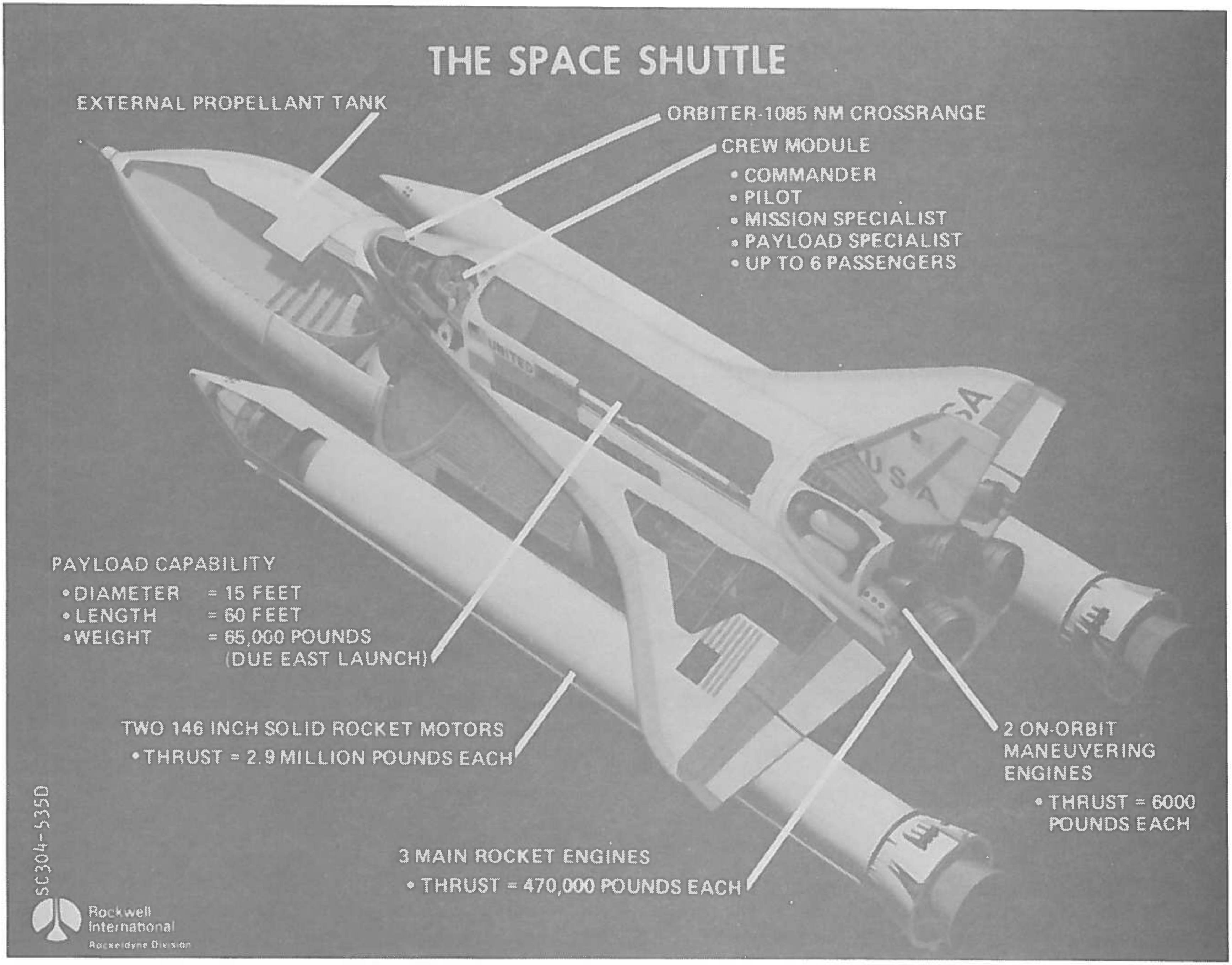
Each booster measures 12 feet by 150 feet, weighs 1.3 million pounds, and generates approximately 2.9 million pounds of thrust. The boosters also serve as launch pad mounts for the entire vehicle and are ignited at launch after all three SSMEs are producing at least 90-percent thrust. The solid propellant consists of a cast mixture of ammonium perchlorate (oxidizer, 69.93 percent by weight), aluminum (fuel, 16 percent), iron oxide (catalyst, 0.07 percent), polymer (binder, 12.04 percent), and epoxy (curing agent, 1.96 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 three SSMEs burn liquid hydrogen (LH) and liquid oxygen (LOX) from the external tank, and are sequentially started at launch. Engine thrust is throttleable. Throttle-down is necessary during initial ascent to prevent excessive aerodynamic loading of vehicle structure and during final ascent to limit vehicle acceleration to three g's. Each engine is gimbaled through two planes for vehicle pitch, yaw, and roll control. The SSMEs steer and accelerate the vehicle to the desired preorbit position, and shut down. The empty external tank is then jettisoned and falls into the ocean. The OMS engines are then fired to accelerate the orbiter to the velocity necessary to inject it into the desired orbit.

The two OMS engines are mounted in pods on either side of the orbiter vertical stabilizer. Each pod also contains the engine propellant tanks and a tank of pressurizing helium. 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, and transfer, and for deorbit. The pods are detachable. They 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 pitch, yaw, and roll control. It includes 38 primary thrusters (870 pounds thrust each), and six vernier thrusters (24 pounds 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 or deorbiting (if the OMS fails), translating, station keeping, and nulling out delta velocities. After the orbiter is established in reentry attitude, the forward thrusters are deactivated. At 10 psi on the ailerons, the aft roll thrusters are deactivated. At 20 psi on the elevons, the aft pitch thrusters are deactivated. At 45,000 feet, the aft yaw thrusters are deactivated.

THE SPACE SHUTTLE



EXTERNAL PROPELLANT TANK

ORBITER-1085 NM CROSSRANGE

CREW MODULE
- COMMANDER
- PILOT
- MISSION SPECIALIST
- PAYLOAD SPECIALIST
- UP TO 6 PASSENGERS

PAYLOAD CAPABILITY
- DIAMETER = 15 FEET
- LENGTH = 60 FEET
- WEIGHT = 65,000 POUNDS (DUE EAST LAUNCH)

TWO 146 INCH SOLID ROCKET MOTORS
- THRUST = 2.9 MILLION POUNDS EACH

3 MAIN ROCKET ENGINES
- THRUST = 470,000 POUNDS EACH

2 ON-ORBIT MANEUVERING ENGINES
- THRUST = 6000 POUNDS EACH

SC304-535D

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SSME INTRODUCTION

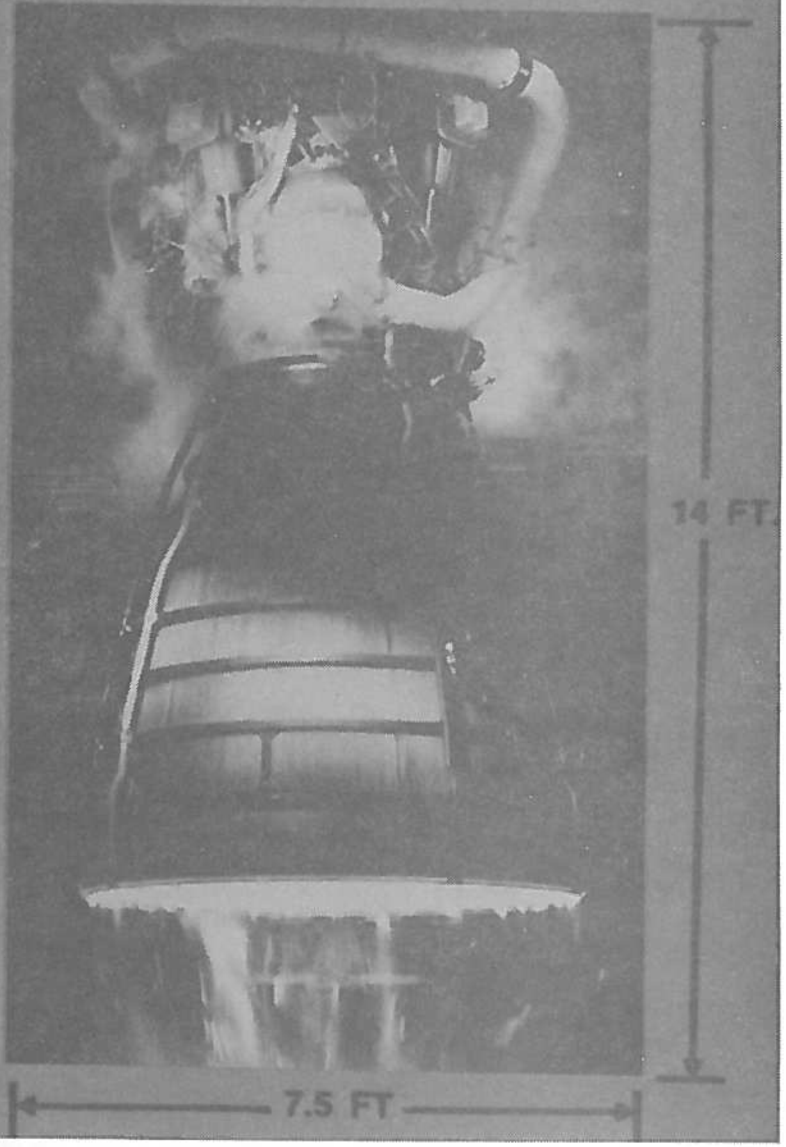
The Space Shuttle Main Engine is a preburner-type engine that burns liquid hydrogen and liquid oxygen, both cryogenic. The identifying feature of a preburner engine is that most of the fuel flow (except for a small coolant flow) and a small amount of the oxidizer flow are "preburned" in a preburner(s) at an extremely fuel-rich mixture. The resulting fuel-rich gas is used to power the turbopump(s) turbine(s), 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 470,000 pounds thrust (100 percent) in vacuum or 375,000 pounds at sea level. It is throttleable from 305,000 pounds (65 percent) to 512,300 pounds (109 percent) in 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 MCC pressure is approximately 3,200 psia 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 77.5 to 1 (throat area versus nozzle exit area) is required to fully expand the very high pressure gas in the MCC. Specific impulse in vacuum is 453.5 seconds (ie, 453.5 pounds of thrust is generated for each pound of propellant burned per second).

In order to start, the SSME needs only the 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 gimbaled through the Y and Z planes by hydraulic actuators for vehicle pitch, yaw, and roll control.

SSME IS FIRST REUSABLE LARGE LIQUID ROCKET ENGINE

■ PROPELLANTS	OXYGEN/ HYDROGEN
■ RATED POWER LEVEL (RPL) 100%	470,000 LBS
■ FULL POWER LEVEL (FPL) 109%	512,300 LBS
■ CHAMBER PRESSURE	3200 PSIA
■ SPECIFIC IMPULSE AT ALTITUDE	453.5 SECONDS
■ THROTTLE RANGE	65 TO 109%
■ WEIGHT	7000 LBS
■ DESIGN LIFE	27,000 SECONDS 55 STARTS
■ FULL POWER LEVEL	14,000 SECONDS



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SSME HIGHLIGHTS

- PREBURNER-TYPE ENGINE:
  - 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
  - TURBOPUMP FED BY TWO HIGH-PRESSURE AND TWO LOW-PRESSURE (BOOST) PUMPS
  - MAIN COMBUSTION PROPELLANT RATIO--6.026 LB OXYGEN TO 1 LB HYDROGEN

- VARIABLE THRUST:
  - FULL POWER LEVEL (FPL)------------109% (512,300 LB)
  - RATED POWER LEVEL (RPL)-----------100% (470,000 LB)
  - MINIMUM POWER LEVEL (MPL)--------- 65% (305,500 LB)
  - VARIABLE IN 1% INCREMENTS--------- 1% (4,700 LB)

- HIGH EFFICIENCY--SPECIFIC IMPULSE APPROXIMATELY 453.5 SECONDS:
  - TWO-STAGE COMBUSTION APPROXIMATELY 99.96% EFFICIENT
  - MAIN CHAMBER PRESSURE APPROXIMATELY 3,200 PSIA AT FPL
  - DIRECT DRIVE TURBOPUMPS (NO REDUCTION GEARS)
  - HIGH EXPANSION RATIO (77.5 TO 1) (NOZZLE EXIT AREA VS. THROAT AREA)

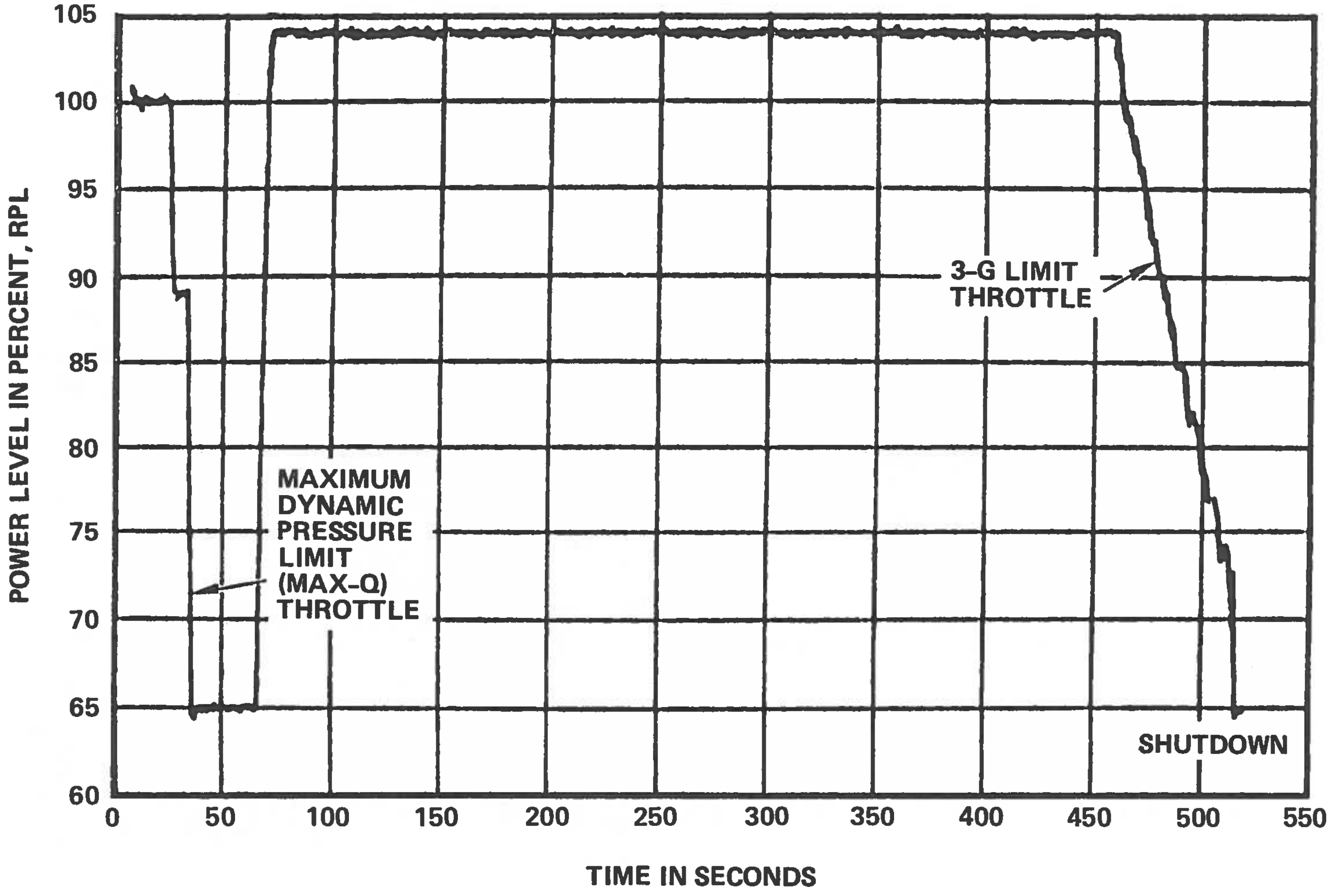
- SIMPLE START SYSTEM:
  - TANK HEAD PRESSURE STARTS PROPELLANT FLOW
  - SPARK IGNITERS INITIATE COMBUSTION
  - NO START TANKS, TURBINE SPINNERS, PYROTECHNICS, PRESSURE LADDERS, ETC

- ON-BOARD CONTROLLER:
  - THROTTLING, MIXTURE RATIO CONTROL, MONITORING, START, STOP, ETC

- HYDRAULICALLY-DRIVEN PROPELLANT VALVES (PNEUMATIC BACKUP FOR CLOSING)

- POGO SUPPRESSION SYSTEM (PRESSURIZED ACCUMULATOR IN LOX FEED SYSTEM)

SSME TYPICAL THROTTLING PROFILE



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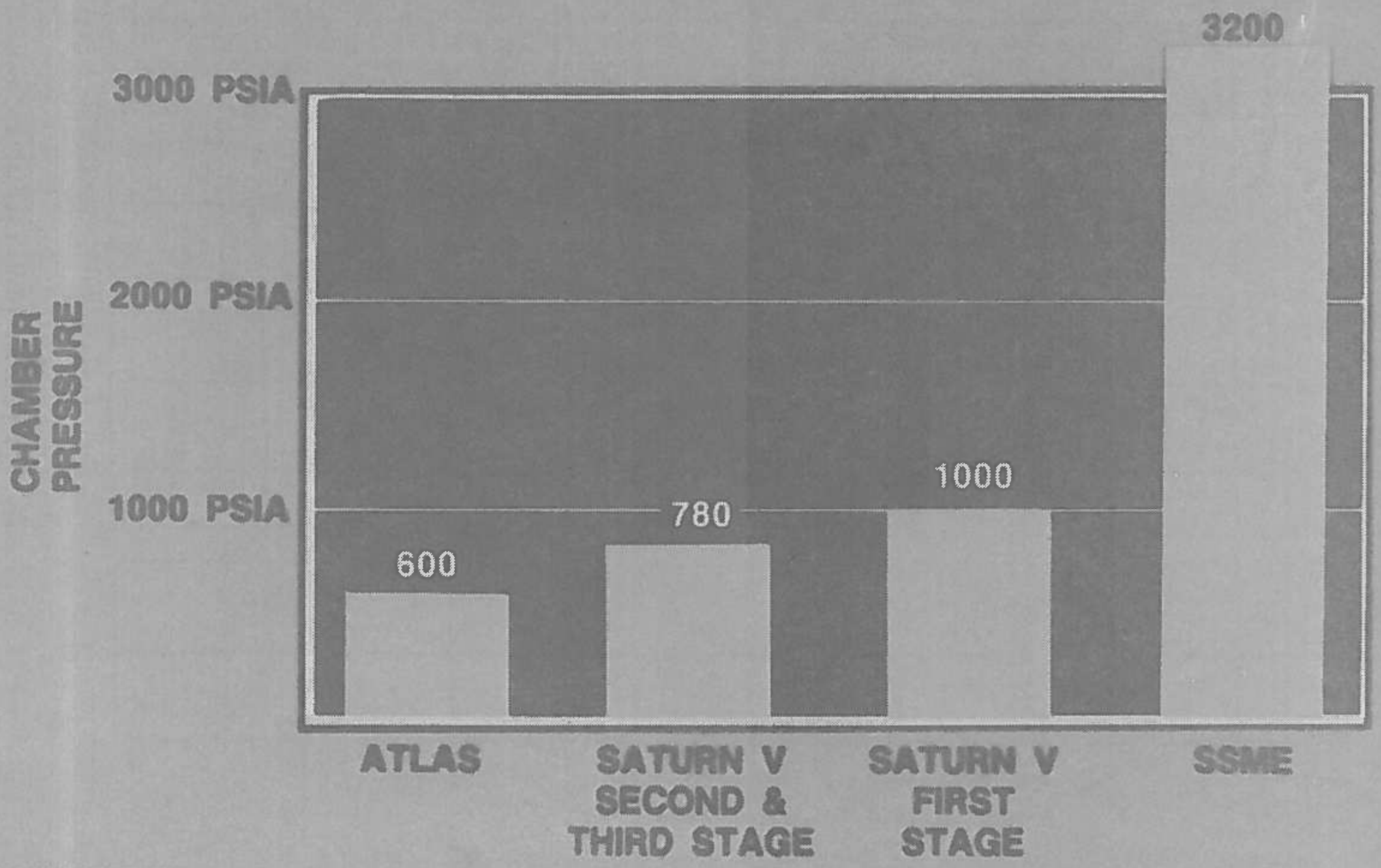
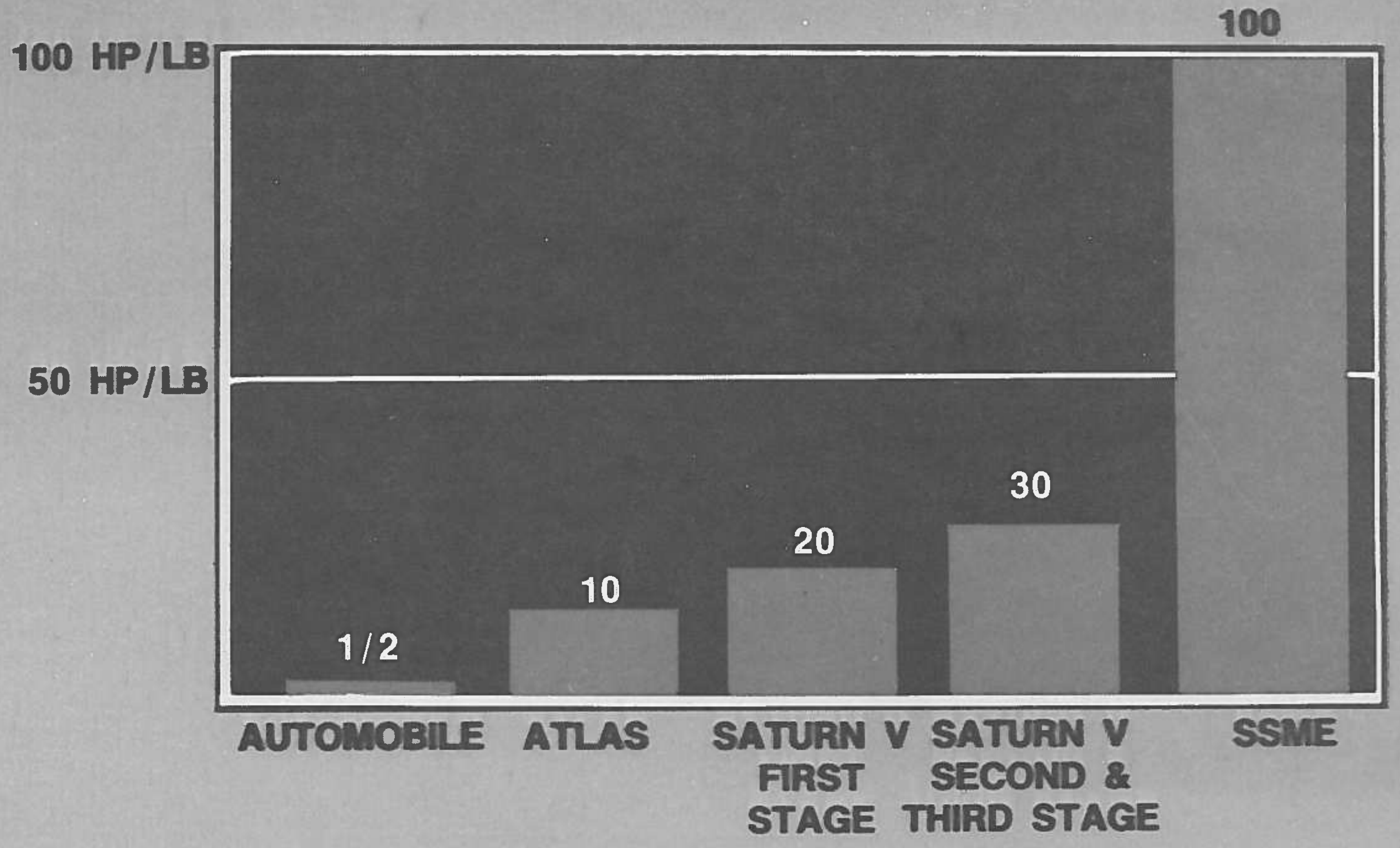
HIGH PRESSURE OPERATION REDUCES ENGINE ENVELOPE



SC430-503C

HIGH TURBOMACHINERY POWER DENSITY RESULTS IN MINIMUM WEIGHT



SC430-505A

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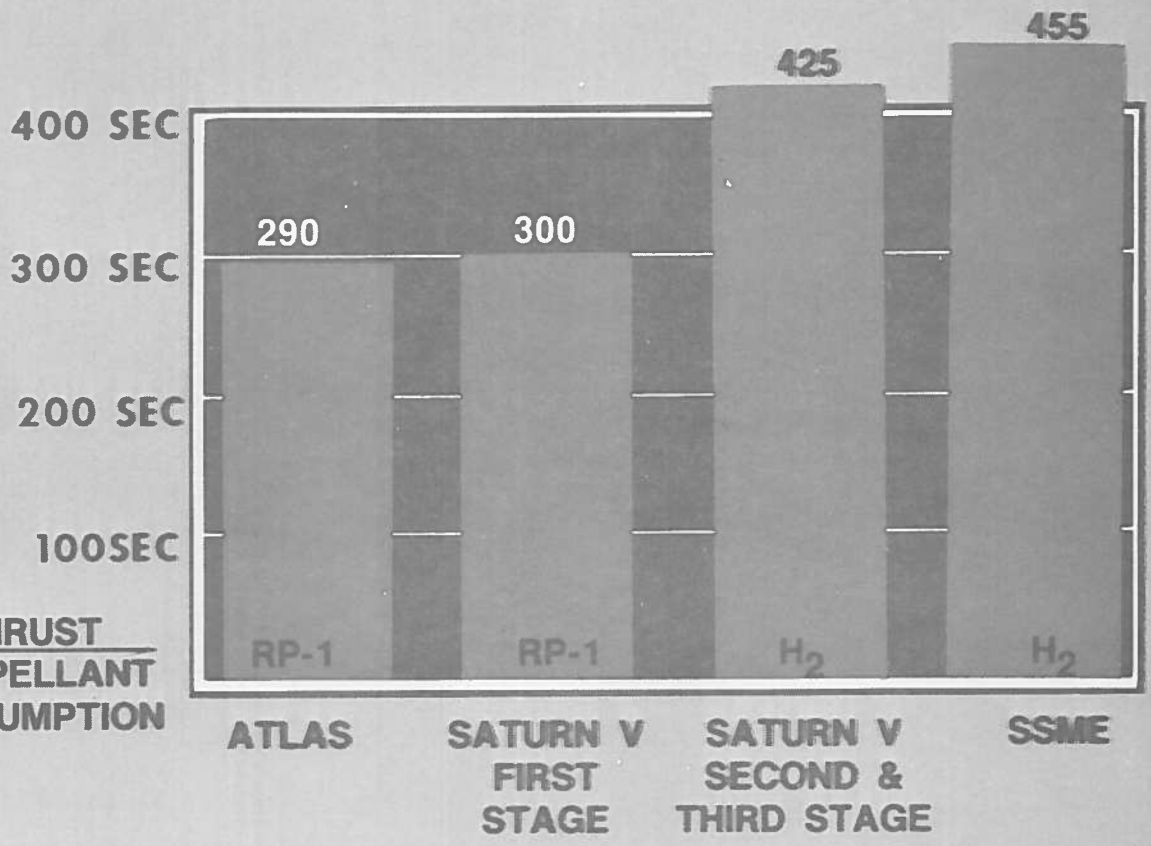
HIGH SPECIFIC IMPULSE REDUCES PROPELLANT CONSUMPTION



$$\text{SPECIFIC IMPULSE} = \frac{\text{THRUST}}{\text{PROPELLANT CONSUMPTION}}$$

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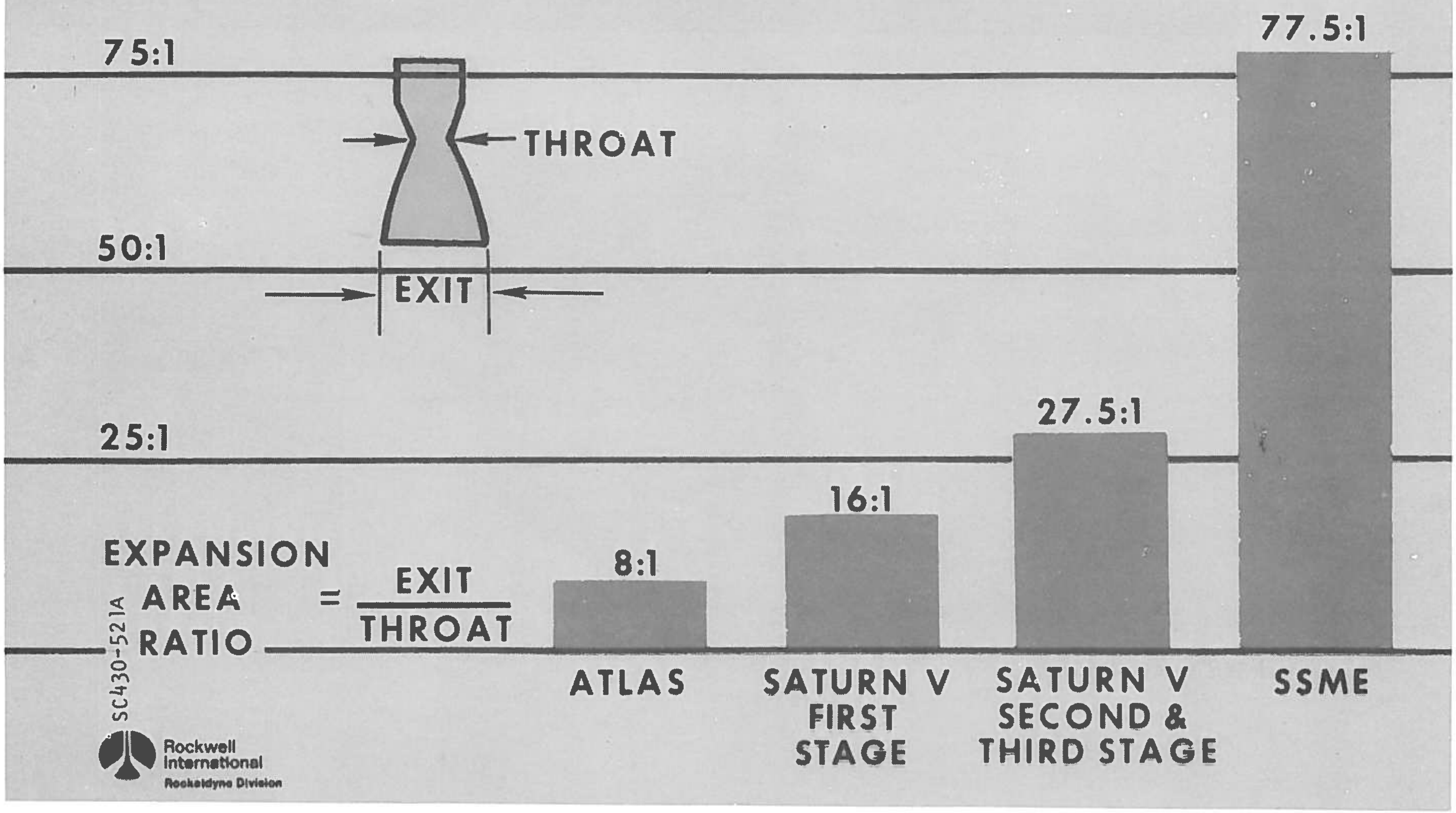
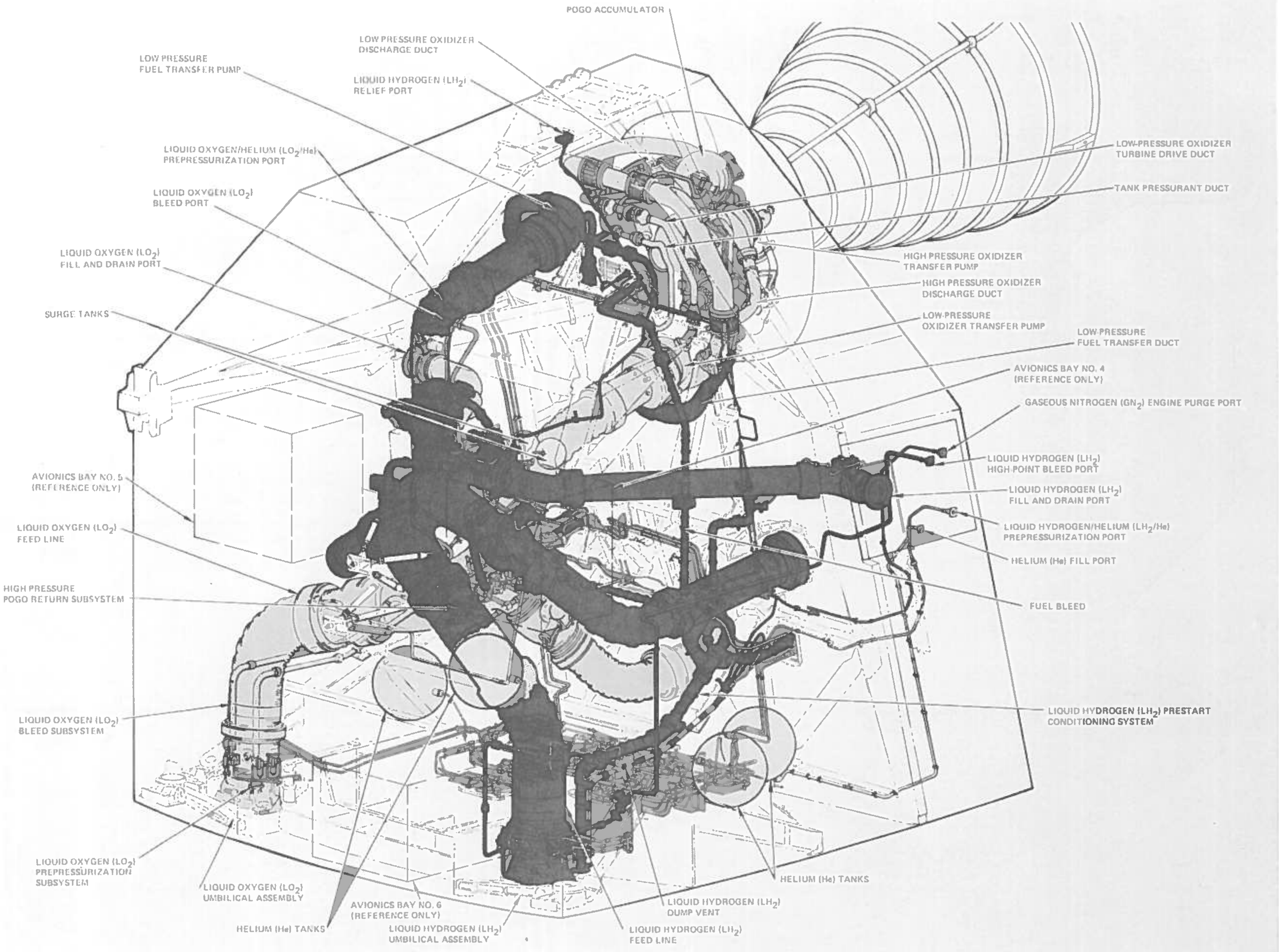
HIGH AREA RATIO NOZZLE INCREASES EFFICIENCY



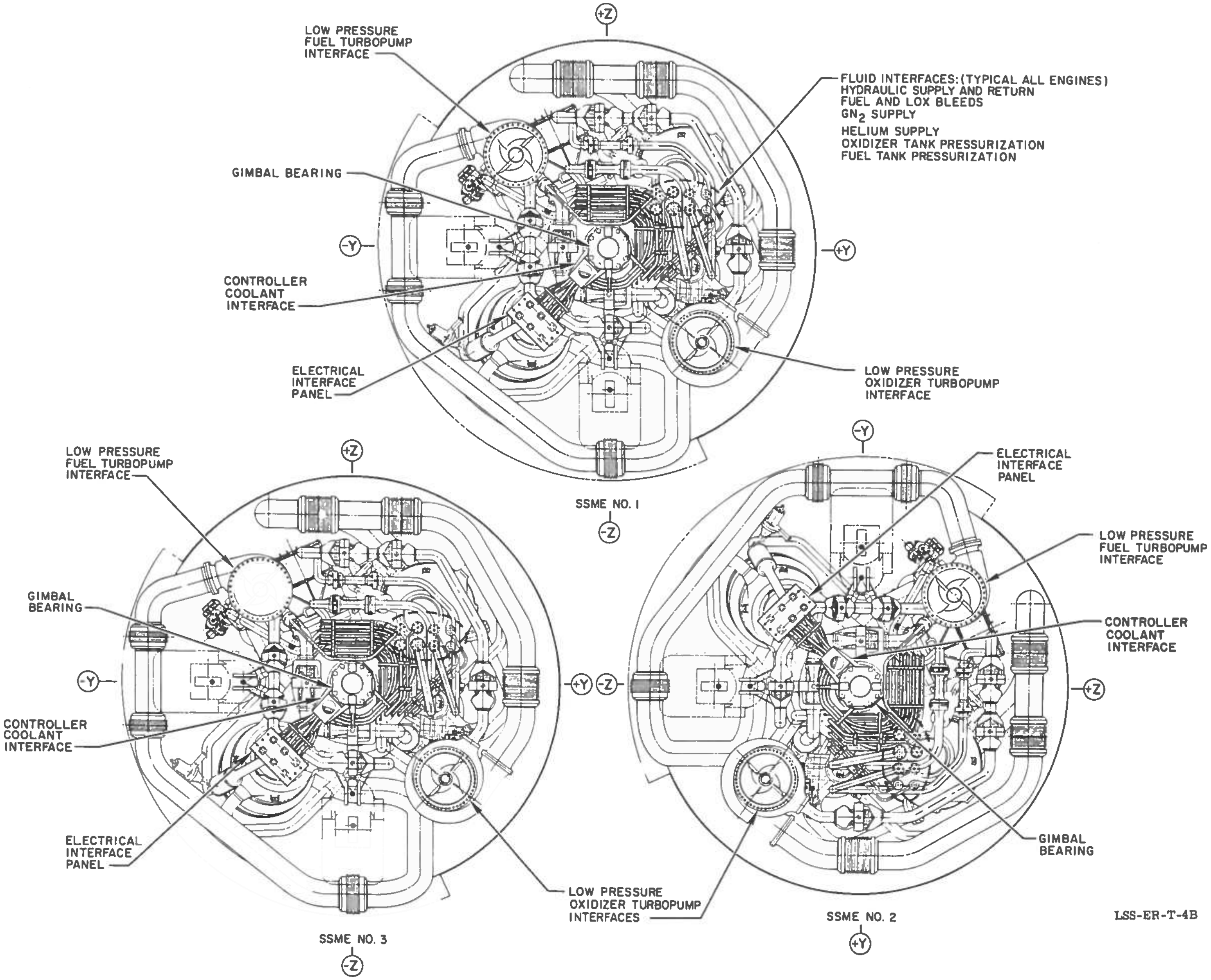
$$\text{EXPANSION AREA RATIO} = \frac{\text{EXIT}}{\text{THROAT}}$$


POGO ACCUMULATOR
LOW PRESSURE OXIDIZER DISCHARGE DUCT
LOW PRESSURE FUEL TRANSFER PUMP
LIQUID HYDROGEN (LH2) RELIEF PORT
LIQUID OXYGEN/HELIUM (LO2/He) PREPRESSURIZATION PORT
LIQUID OXYGEN (LO2) BLEED PORT
LIQUID OXYGEN (LO2) FILL AND DRAIN PORT
SURGE TANKS
AVIONICS BAY NO. 5 (REFERENCE ONLY)
LIQUID OXYGEN (LO2) FEED LINE
HIGH PRESSURE POGO RETURN SUBSYSTEM
LIQUID OXYGEN (LO2) BLEED SUBSYSTEM
LIQUID OXYGEN (LO2) PREPRESSURIZATION SUBSYSTEM
LIQUID OXYGEN (LO2) UMBILICAL ASSEMBLY
HELIUM (He) TANKS
AVIONICS BAY NO. 6 (REFERENCE ONLY)
LIQUID HYDROGEN (LH2) UMBILICAL ASSEMBLY
LIQUID HYDROGEN (LH2) FEED LINE
LIQUID HYDROGEN (LH2) DUMP VENT
HELIUM (He) TANKS
LOW-PRESSURE OXIDIZER TURBINE DRIVE DUCT
TANK PRESSURANT DUCT
HIGH PRESSURE OXIDIZER TRANSFER PUMP
HIGH PRESSURE OXIDIZER DISCHARGE DUCT
LOW-PRESSURE OXIDIZER TRANSFER PUMP
LOW PRESSURE FUEL TRANSFER DUCT
AVIONICS BAY NO. 4 (REFERENCE ONLY)
GASEOUS NITROGEN (GN2) ENGINE PURGE PORT
LIQUID HYDROGEN (LH2) HIGH POINT BLEED PORT
LIQUID HYDROGEN (LH2) FILL AND DRAIN PORT
LIQUID HYDROGEN/HELIUM (LH2/He) PREPRESSURIZATION PORT
HELIUM (He) FILL PORT
FUEL BLEED
LIQUID HYDROGEN (LH2) PRESTART CONDITIONING SYSTEM

LSS-VS-T-1

SSME INSTALLATION ORIENTATION AND INTERFACES

(LOOKING AFT)



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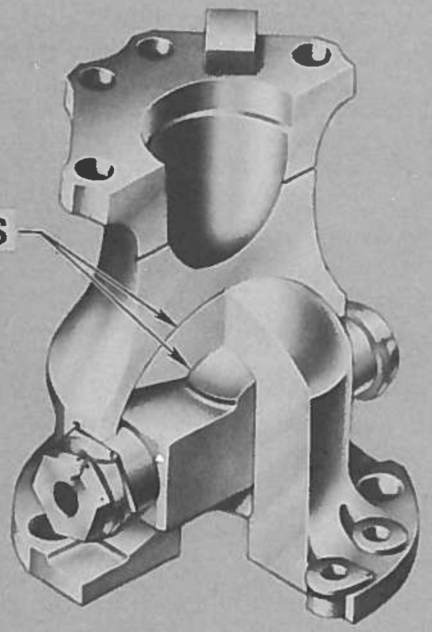
GIMBAL BEARING HIGHLIGHTS

The gimbal bearing provides a means of attaching the engine to the vehicle while allowing the engine to be pivoted (gimbaled) around its Y and Z 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 7,000 pounds of engine 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. The bearing is installed during engine assembly, using offset bushings to aline it to the engine. It measures approximately 11 by 14 inches, weighs about 105 pounds, and is made of titanium alloy.

GIMBAL BEARING ASSEMBLY DESIGN AND PERFORMANCE REQUIREMENTS

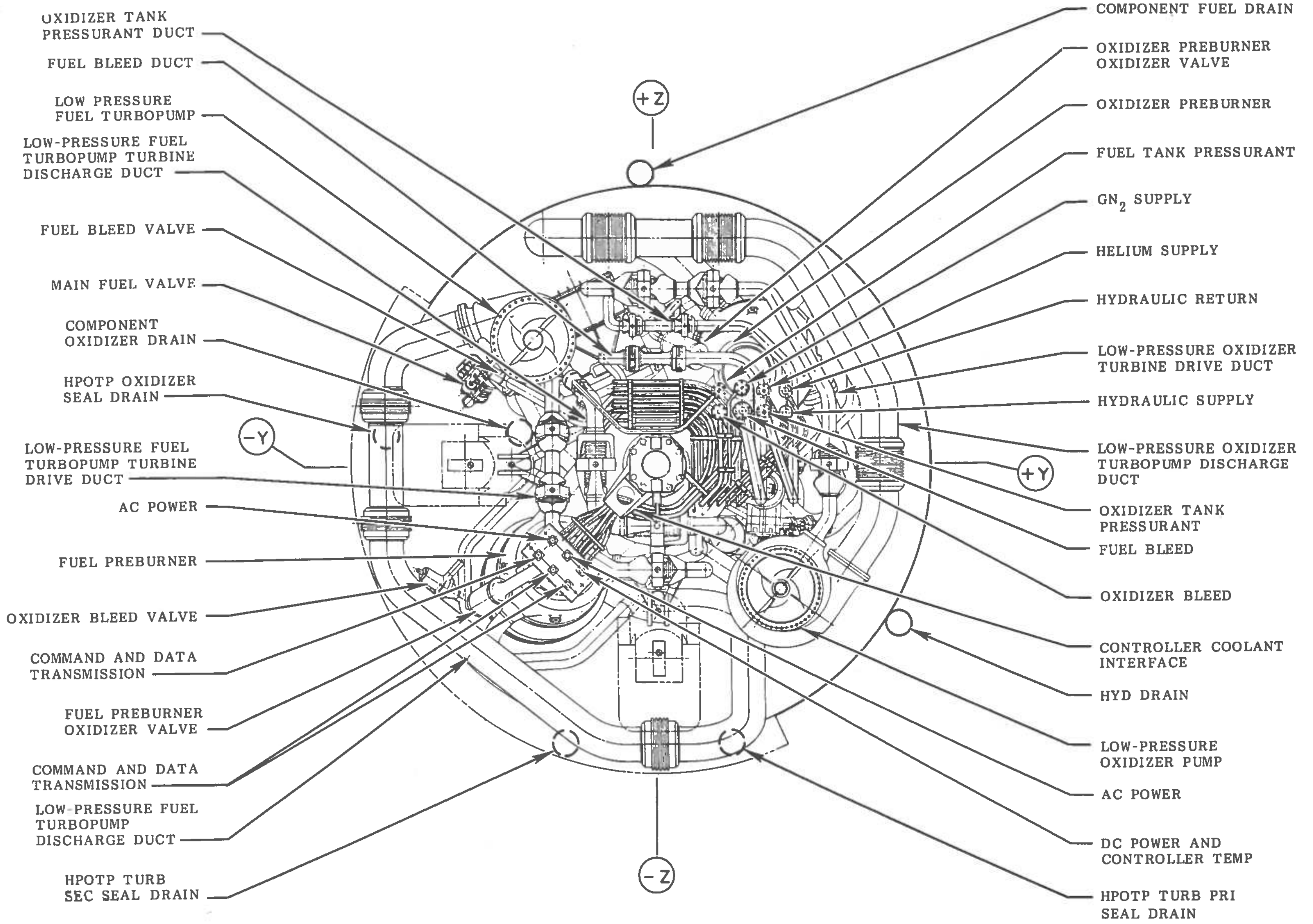


MATERIAL -
6AL-6V-2Sn
TITANIUM ALLOY

- ■ ANGULATION CAPABILITY ± 12.5 DEGREES ABOUT EACH OF TWO AXES. THIS INCLUDES:
  - ■ 0.5 DEGREE FOR SNUBBING
  - ■ 0.5 DEGREE FOR ANGULAR ALIGNMENT
  - ■ 6 MINUTES OVER-TRAVEL VECTOR ADJUSTMENT
  - ■ 0.7 DEGREE FOR GIMBAL ATTACH POINT TOLERANCE
- ■ ACCELERATION – 30 RAD/SEC^2 MAX.
- ■ ANGULAR VELOCITY – 20 DEGREES/SEC MAX.
- ■ LATERAL ADJUSTMENT – ±.25 INCH MAX.
- ■ GIMBAL DUTY CYCLE ABOUT EACH AXES
  - ■ OPERATIONAL – 200 CYCLES TO 10.5 DEGREES
  - ■ NON-OPERATIONAL – 1400 CYCLES TO 10.5 DEGREES
- ■ COEFFICIENT OF FRICTION – 0.01 TO 0.20 OVER TEMPERATURE RANGE OF 160 TO 610°R

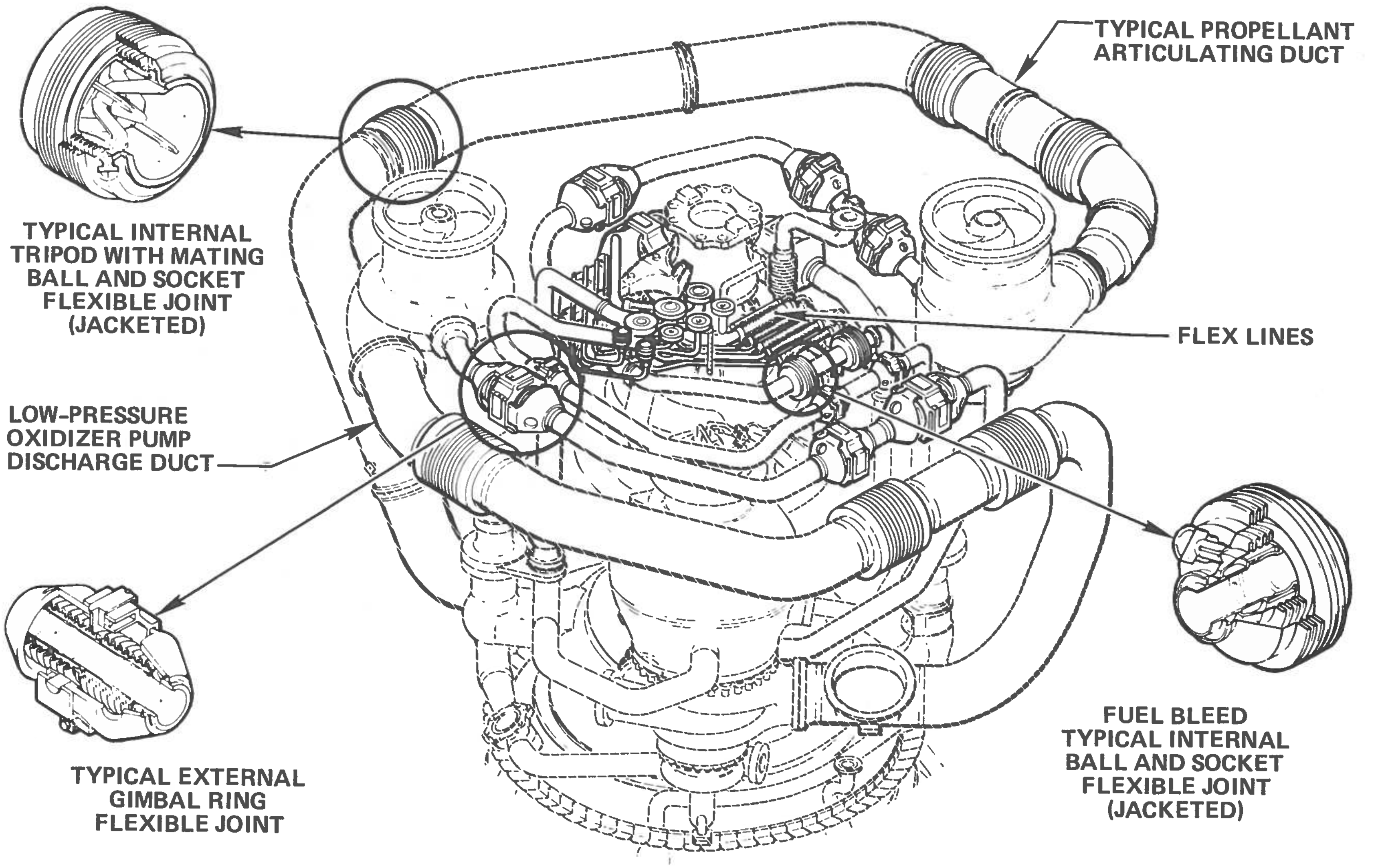
SSME COMPONENT LOCATION

(LOOKING AFT)



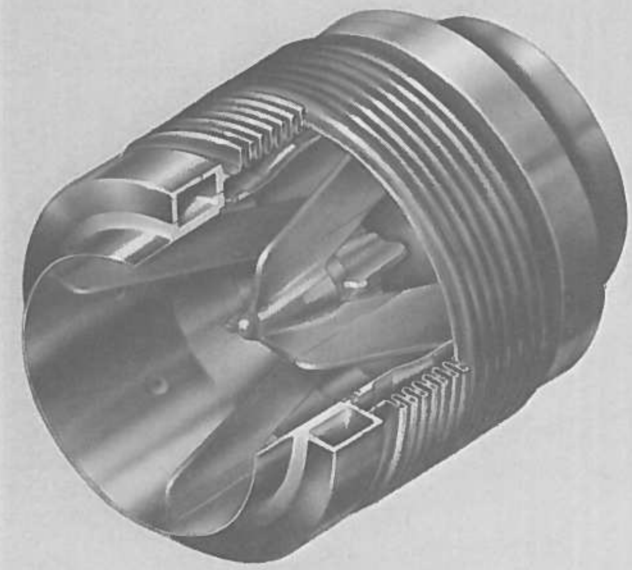
LSS-ER-T-3D

TYPICAL FLEX BELLOWS APPLICATIONS



LSS-EC-T-135C

INTERNALLY TIED FLEX JOINTS



OPERATING PRESSURE	300 TO 600 PSIA
TEMP.	-290F
I.D.	6.3 INCH LINER
ANGULAR DISPLACEMENT	±13°
LIFE	200 OPERATIONAL 1400 NON-OPERATIONAL FULL DEFLECTION CYCLES
MATERIAL	INCONEL 718 ARMCO 21-6-9
TYPICAL OF	LPOP DISCH.

LC308-182A

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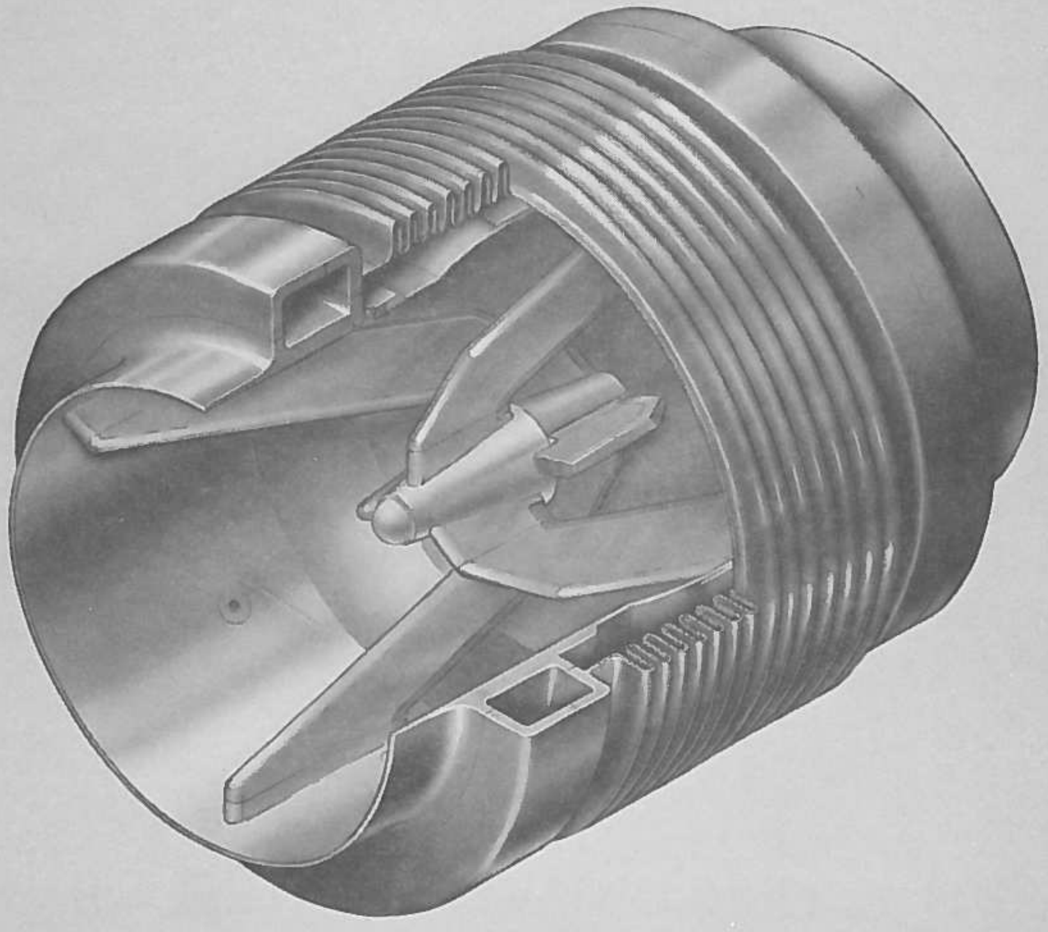
OXIDIZER PUMP DISCHARGE FLEX JOINT



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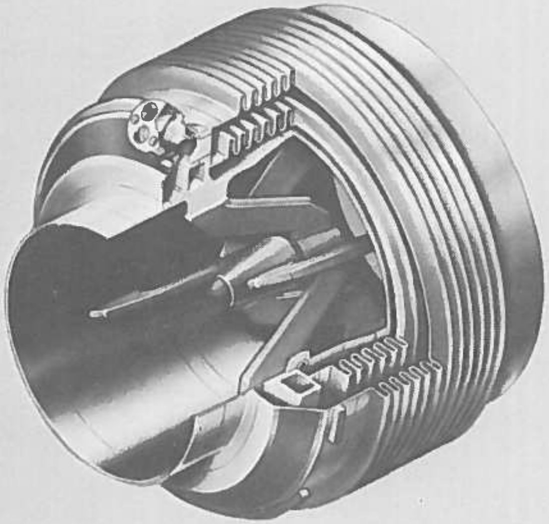
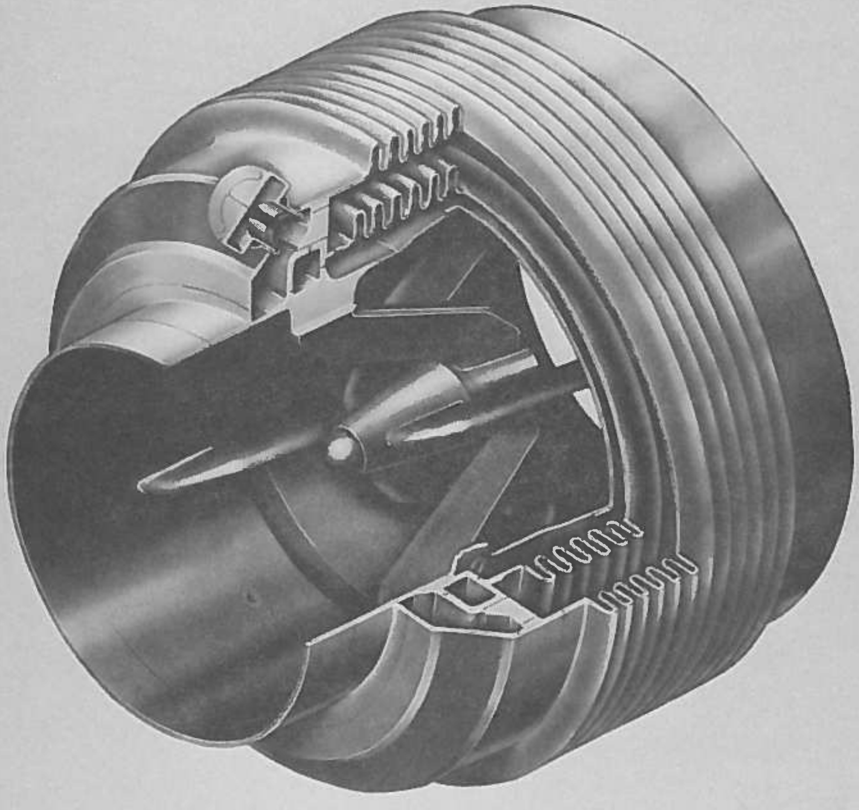
INTERNALLY TIED WITH INSULATING JACKET FLEX JOINTS



OPERATING PRESSURE	280 TO 300 PSIA
TEMP.	-420F
I.D.	5.20 INCH LINER
ANGULAR DISPLACEMENT	±11.5°
LIFE	200 OPERATIONAL 1400 NON-OPERATIONAL FULL DEFLECTION CYCLES
MATERIAL	INCONEL 718 ARMCO 21-6-9
TYPICAL OF	LPFP DISCH.

LPFP DISCHARGE FLEX JOINT



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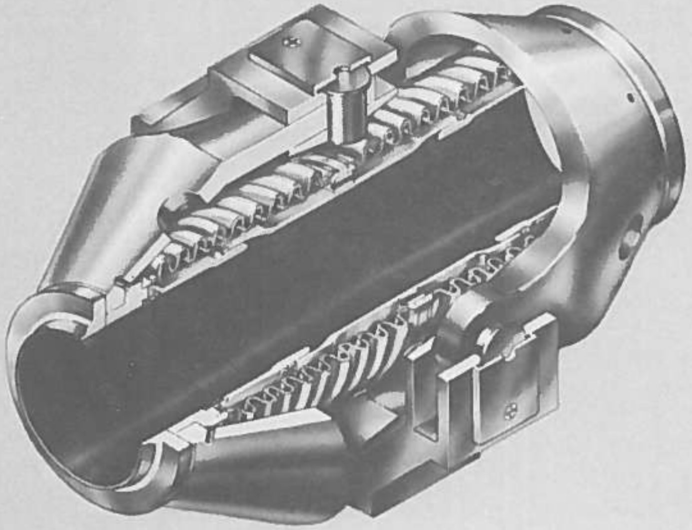
EXTERNAL GIMBAL RING (LONG) FLEX JOINTS



OPERATING PRESSURE	4000 TO 6000 PSIA
TEMP RANGE	AMB. TO 670F
I.D.	.75 TO 2.70 INCH LINER
ANGULAR DISPLACEMENT	±13.25°
LIFE	200 OPERATIONAL 1400 NON-OPERATIONAL FULL DEFLECTION CYCLES
MATERIAL	INCONEL 718 INCONEL 903 TITANIUM

TYPICAL OF

- LPOP TURBINE DRIVE
- OXID TANK PRESSURANT
- LPFP TURBINE DRIVE
- LPFP TURBINE DISCH.

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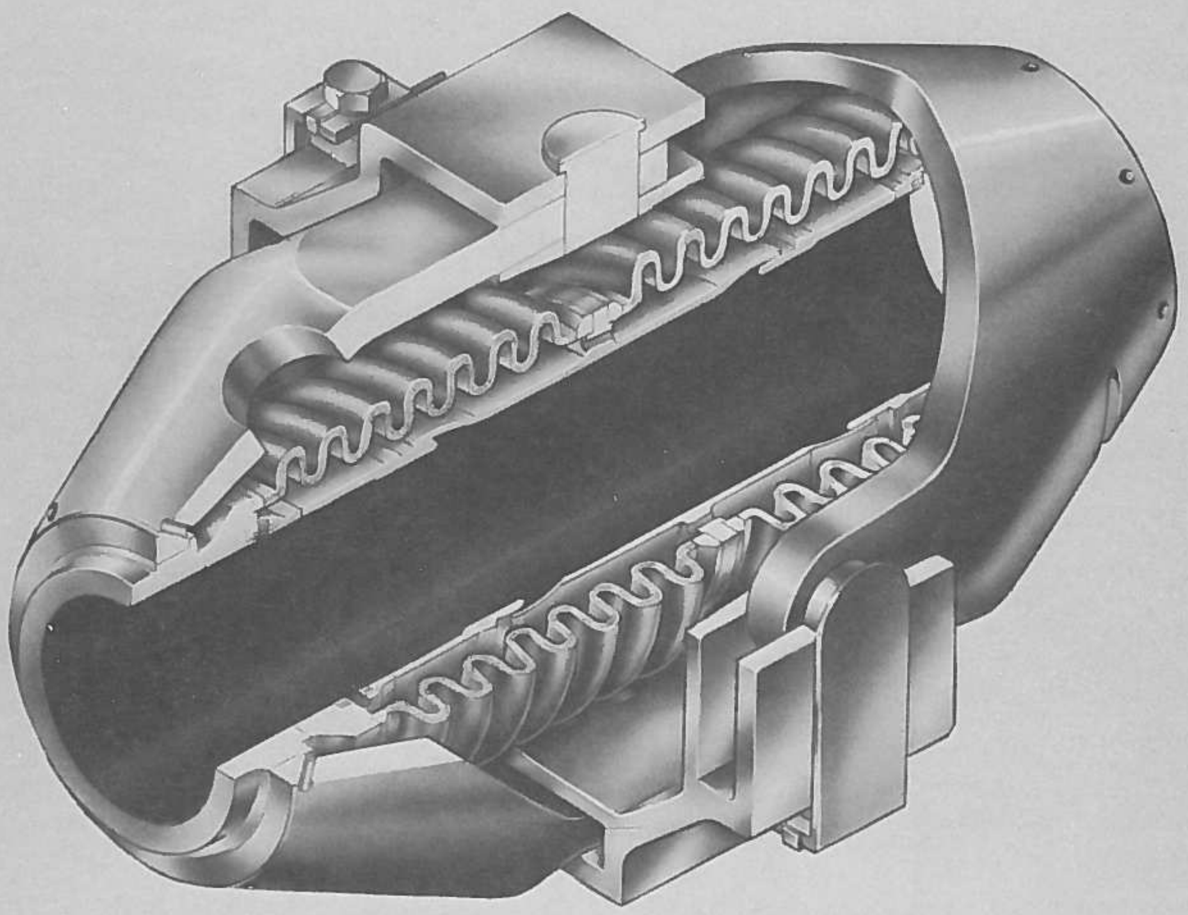
LPFP TURBINE DISCHARGE FLEX JOINT



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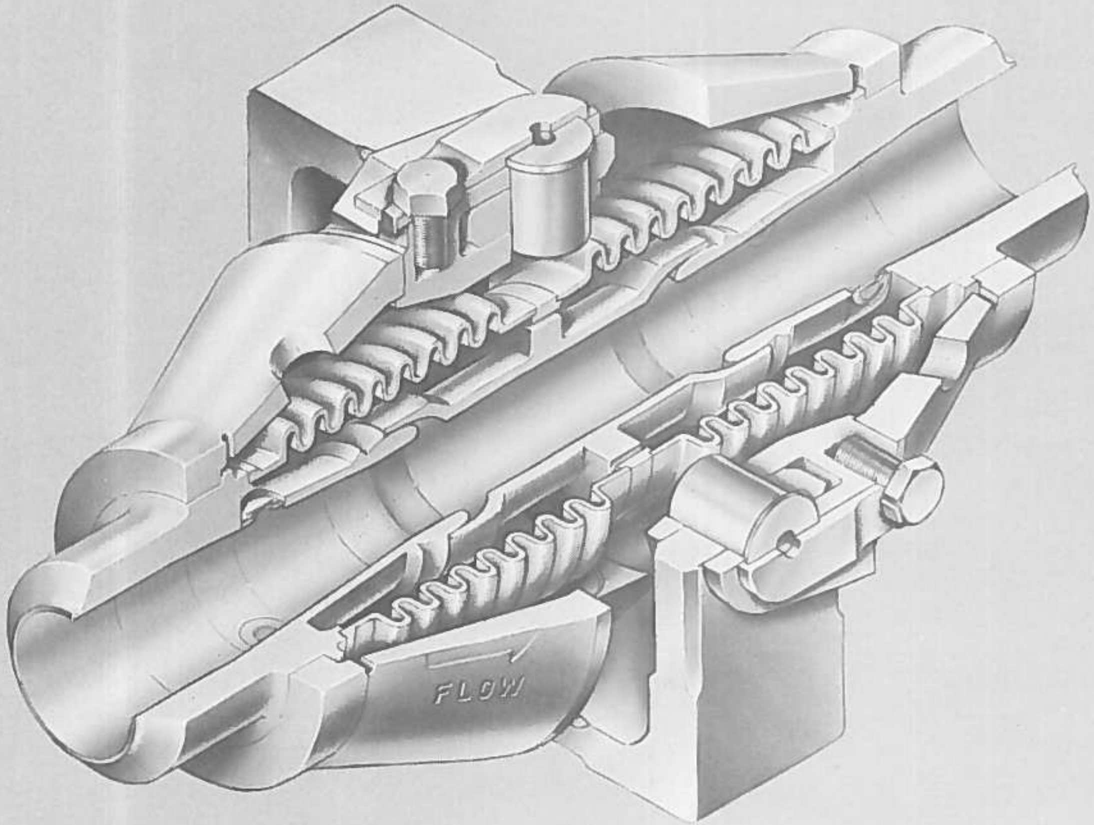
OXIDIZER TANK PRESSURIZATION DUCT FLEX JOINT



OPERATING PRESSURE --- 4819 PSIA
TEMP. RANGE -------- AMB TO 940F
I.D. ------------ 0.75 INCH LINER
ANGULAR DISPLACEMENT --- ±11.33°
LIFE ---- 200 OPERATIONAL
1400 NON-OPERATIONAL
FULL DEFLECTION CYCLES
MATERIAL ------------- INCO 718
TYPICAL OF ---------- OTP (SHORT)
OTP (LONG)

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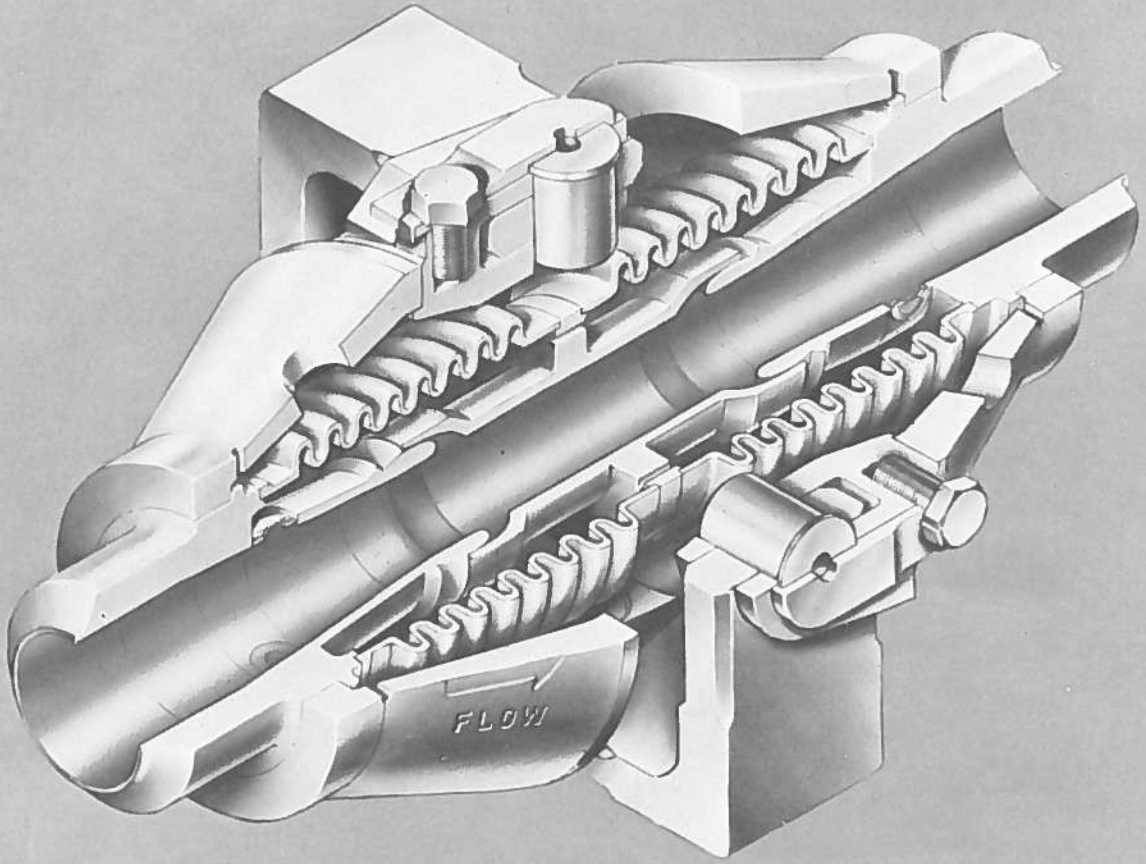
OXIDIZER TANK PRESSURIZATION DUCT FLEX JOINT



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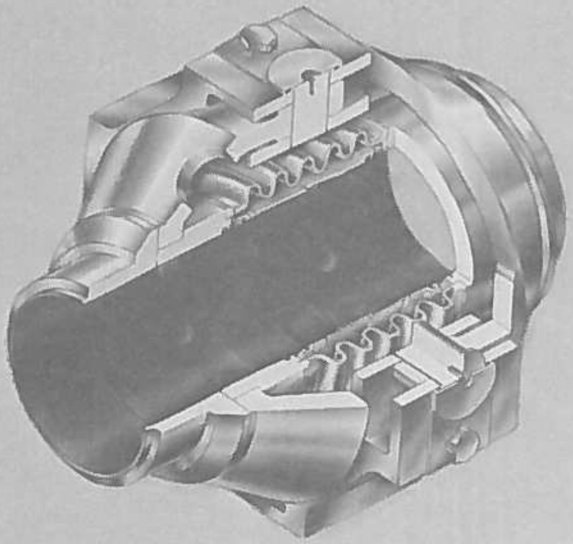
EXTERNAL GIMBAL RING (SHORT) FLEX JOINT



OPERATING PRESSURE	4000 TO 4500 PSIA
TEMP. RANGE	AMB. TO 260F
I.D.	2.70 INCH LINER
ANGULAR DISPLACEMENT	±3°
LIFE	200 OPERATIONAL 1400 NON-OPERATIONAL FULL DEFLECTION CYCLES
MATERIAL	INCONEL 718 INCONEL 903 TITANIUM
TYPICAL OF	LPFP TURBINE DISCH.

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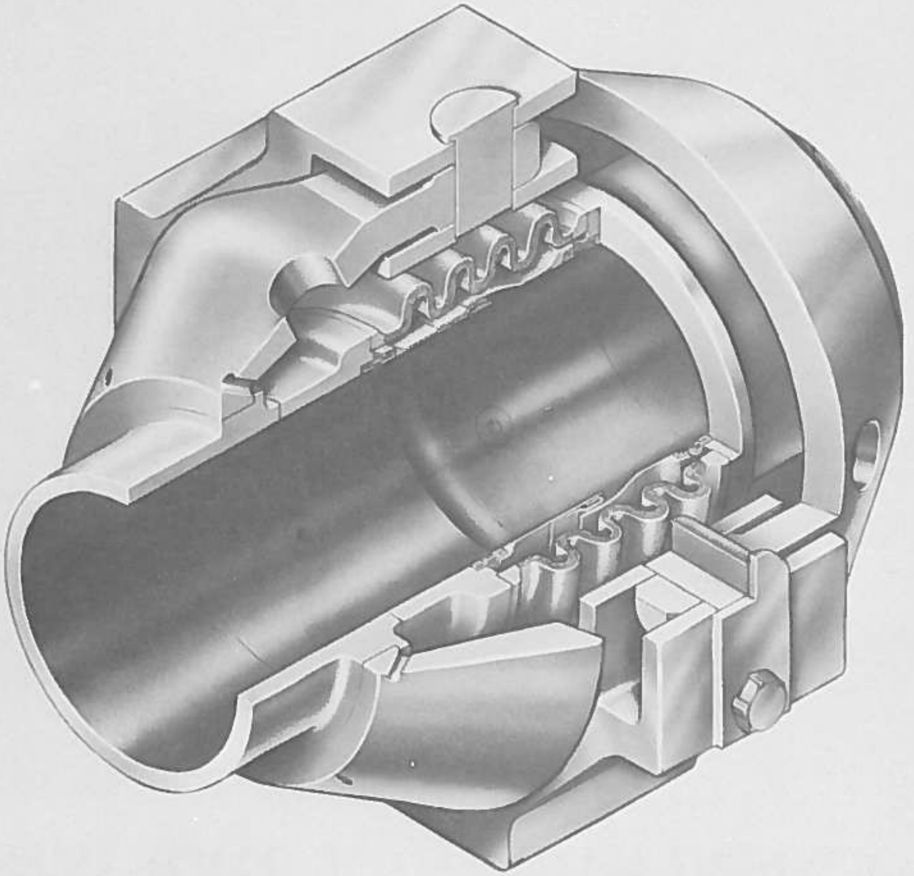
FUEL PUMP TURBINE DISCHARGE (SHORT) FLEX JOINT



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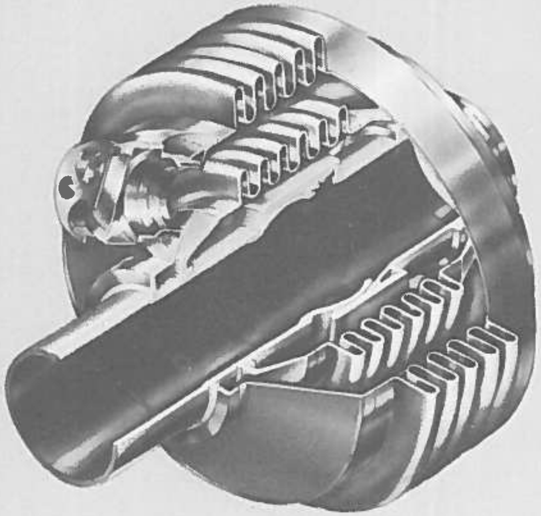
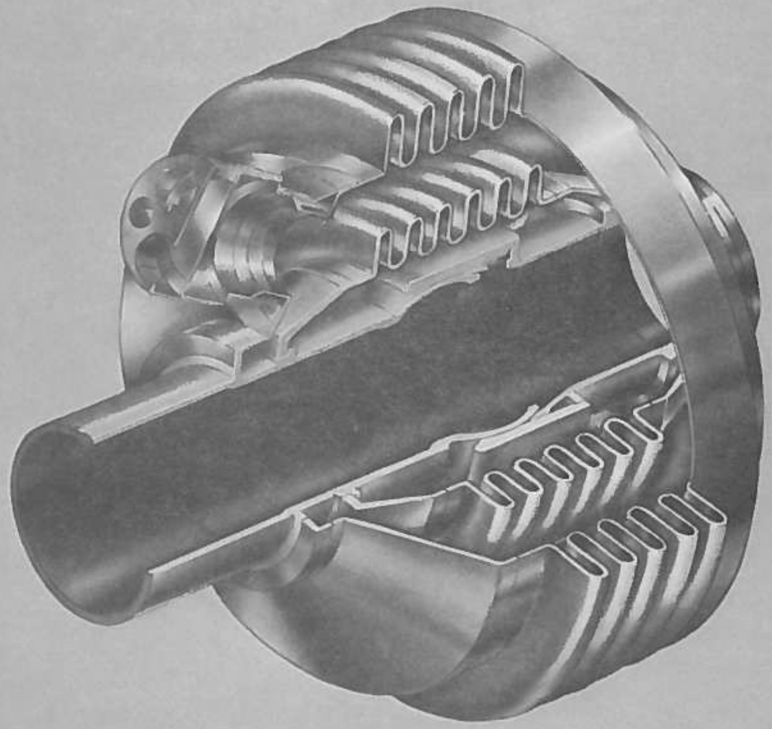
INTERNAL BALL JOINT WITH INSULATING JACKET



OPERATING PRESSURE	AMB. TO 300 PSIA
TEMP.	-420F
I.D.	1.18 INCH LINER
ANGULAR DISPLACEMENT	±12.75°
LIFE	200 OPERATIONAL 1400 NON-OPERATIONAL FULL DEFLECTION CYCLES
MATERIAL	INCONEL 718 ARMCO 21-6-9 HAYNES 188 INCONEL 625
TYPICAL OF	FUEL BLEED

FUEL BLEED LINE FLEX JOINT



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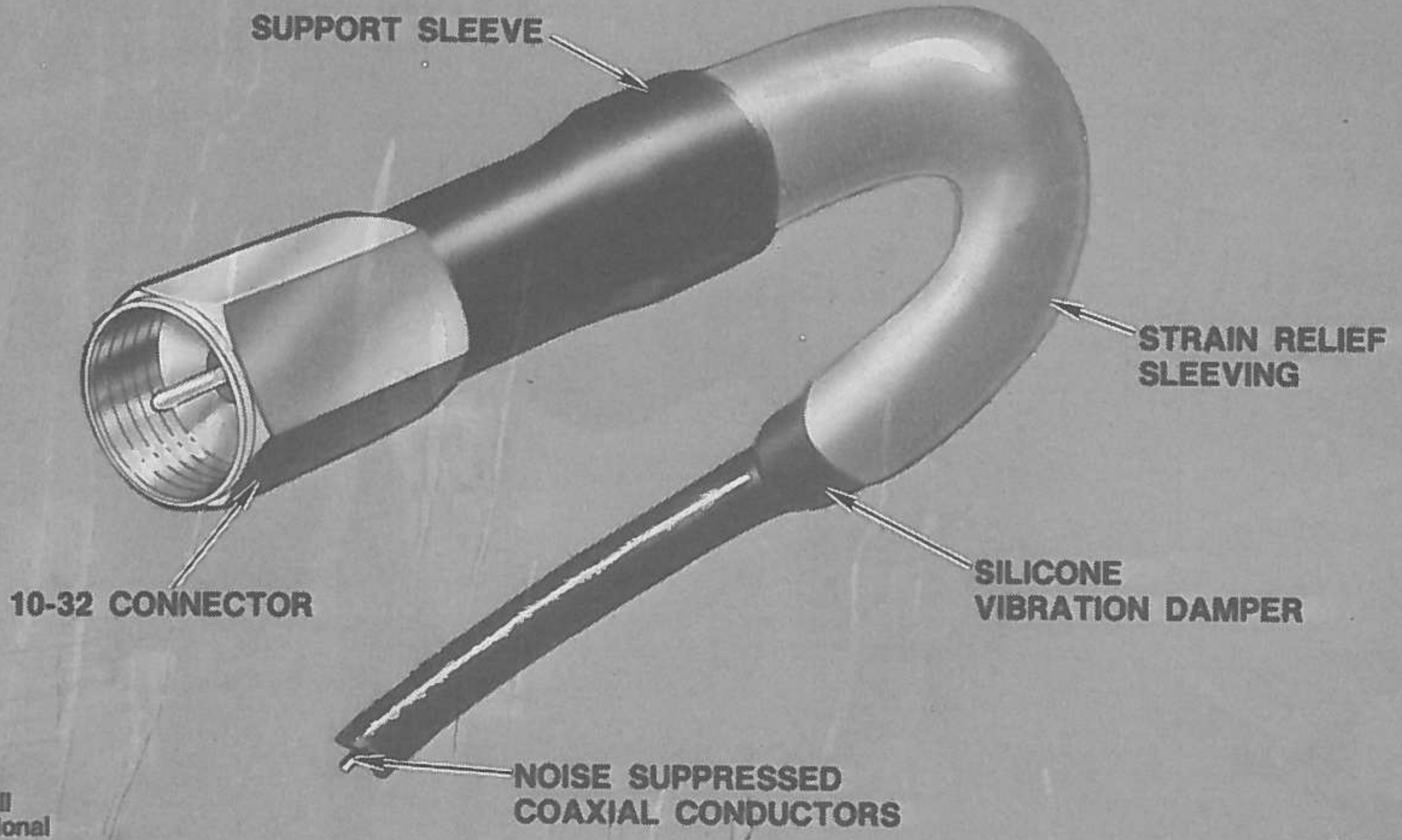
SSME ELECTRICAL HARNESS DESIGN FEATURES

- HARNESS PROTECTION
  - ARMOR BRAIDING ON ORBITER INTERFACE HARNESSES
  - LIGHTNING BRAIDING ON INSTRUMENTATION HARNESSES
  - CONVENTIONAL CONSTRUCTION ON IGNITER AND VALVE ACTUATOR HARNESSES
- CONNECTOR ENGAGEMENT PROVISIONS
  - BAYONET COUPLING ON CONTROLLER AND ORBITER INTERFACE CONNECTORS
  - THREADED COUPLINGS ON INSTRUMENTATION, IGNITER, AND VALVE ACTUATOR HARNESSES

COAXIAL CABLE



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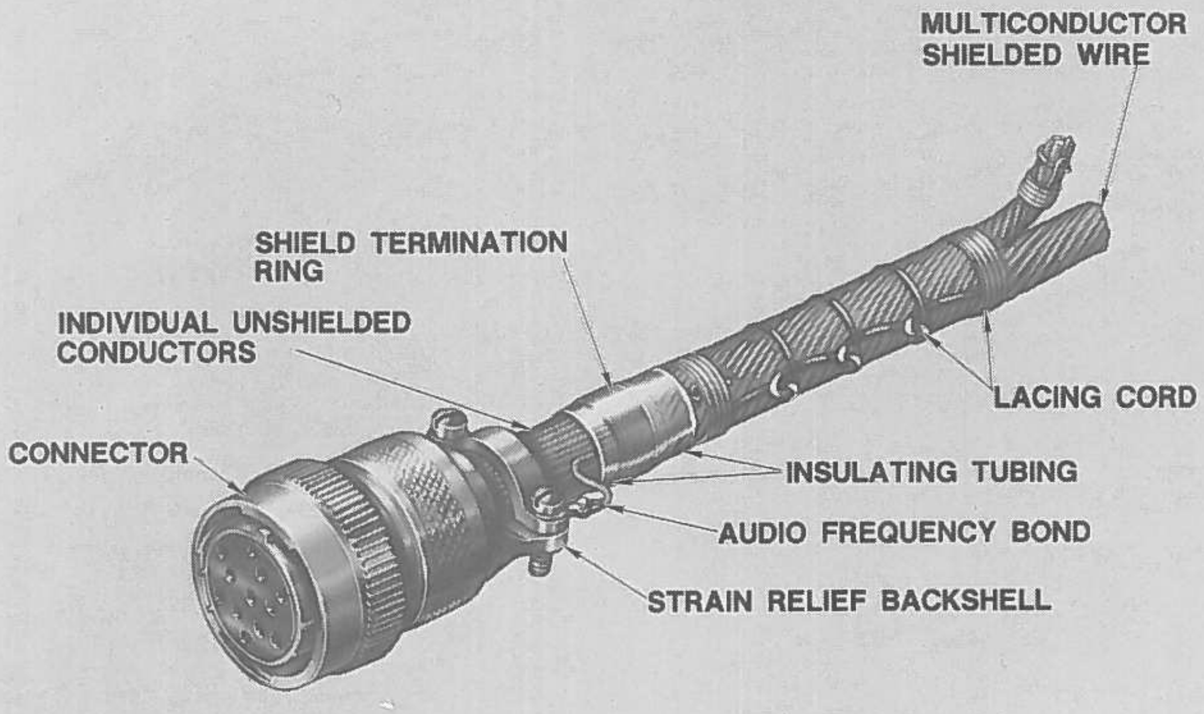
1904m/1

CONVENTIONAL HARNESS COMPONENT



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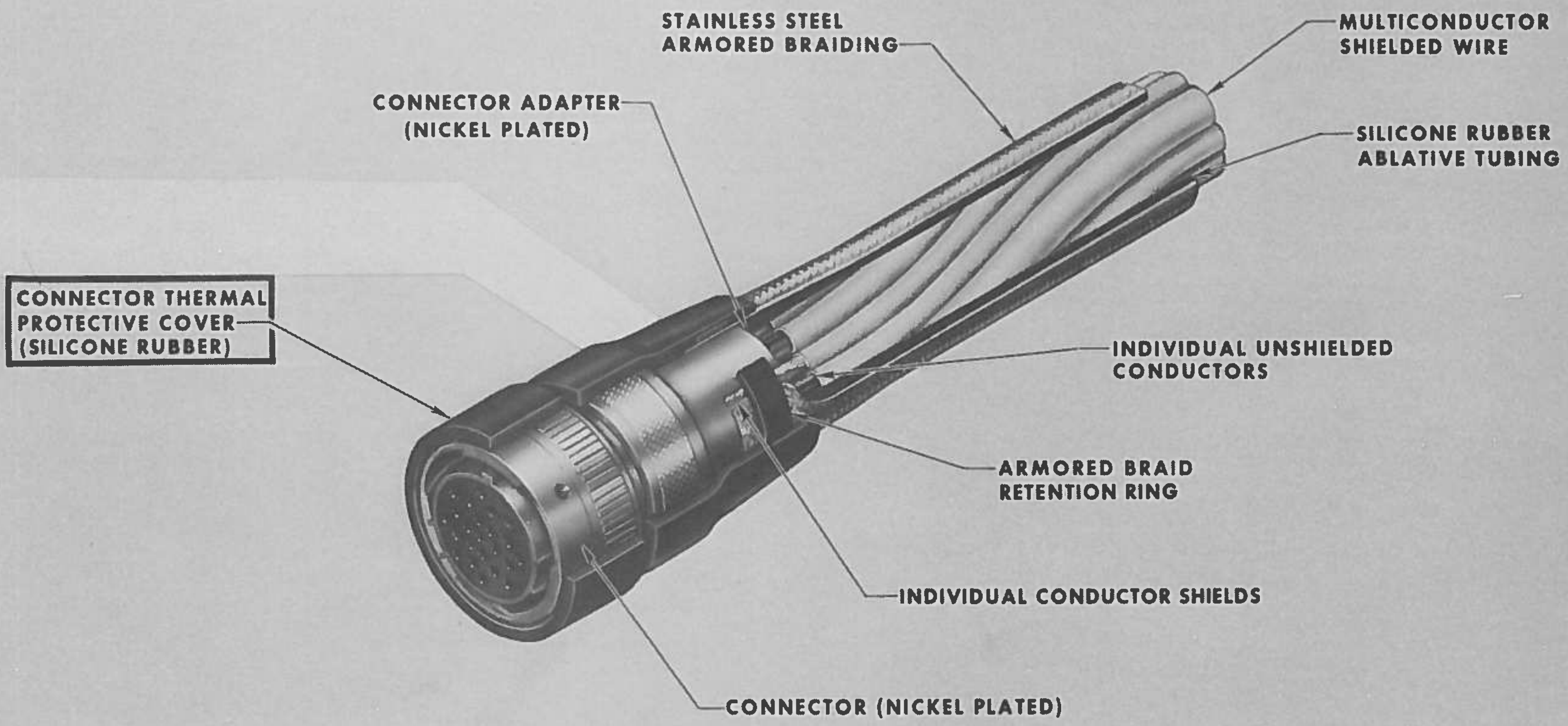
1904m/2

FLEXIBLE ARMORED HARNESS



LC303-181D

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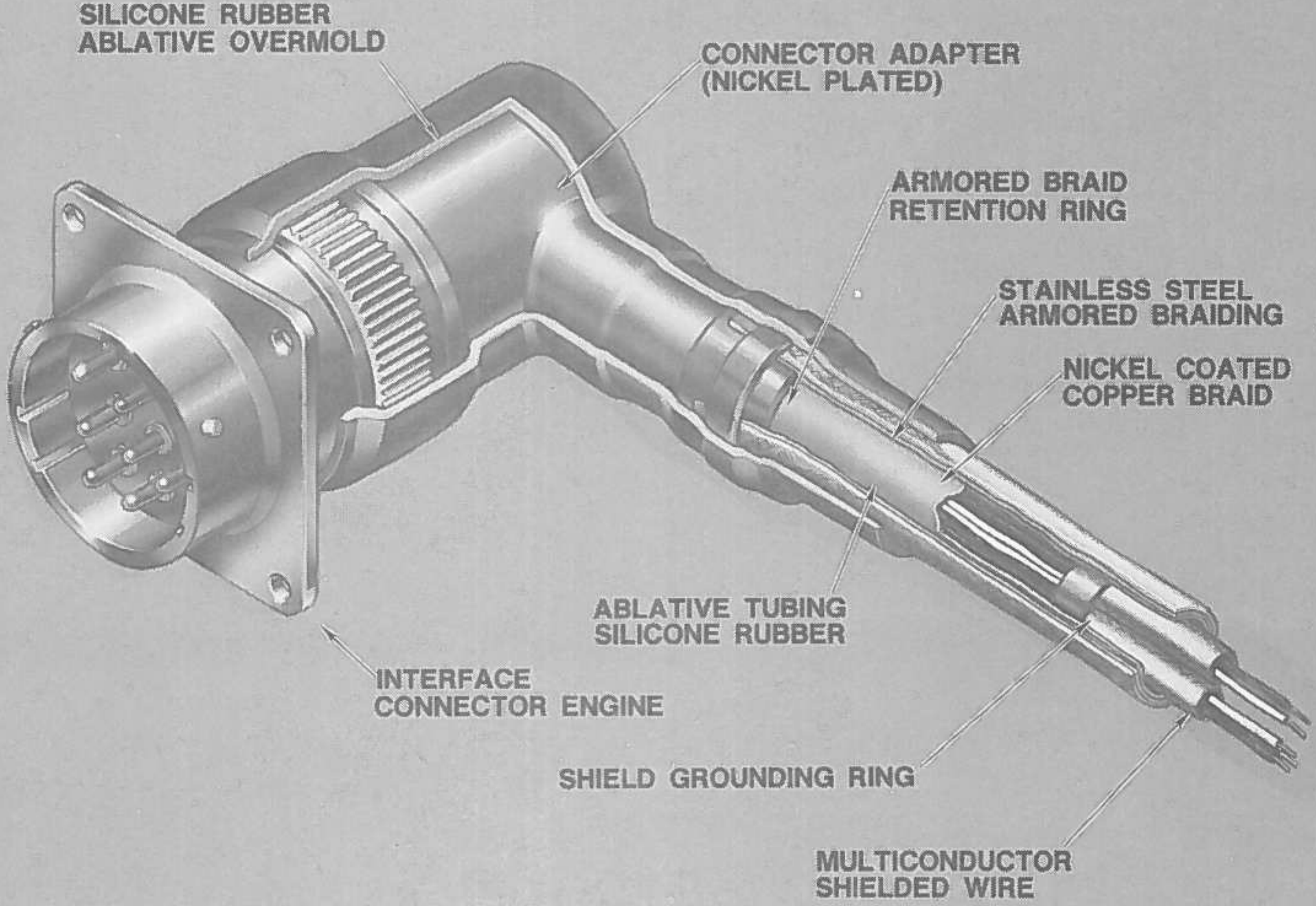
ARMOR BRAIDED HARNESS ENGINE INTERFACE CONNECTOR



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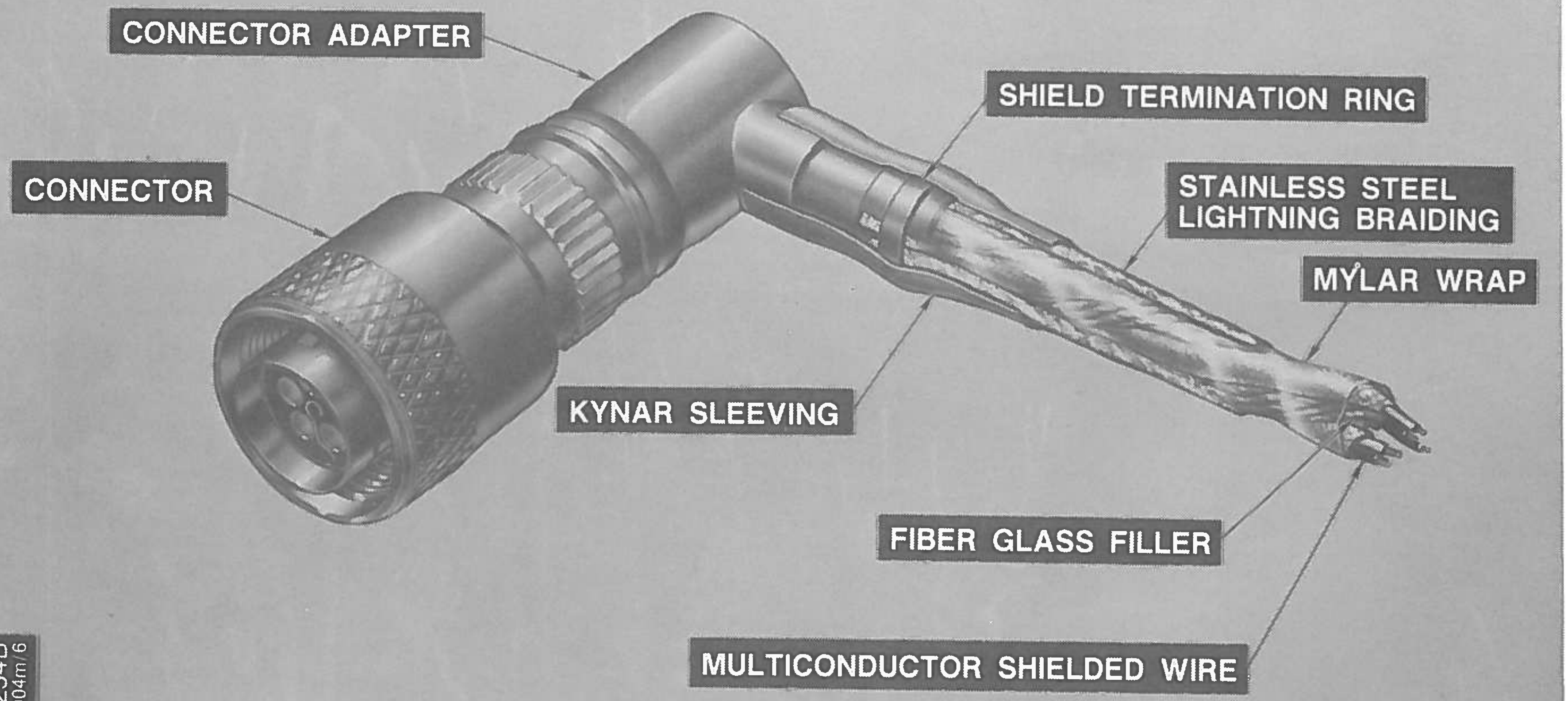
LC434-997A
1904m/4

LIGHTNING BRAIDED HARNESS COMPONENT



SC305-254B
1904m/6

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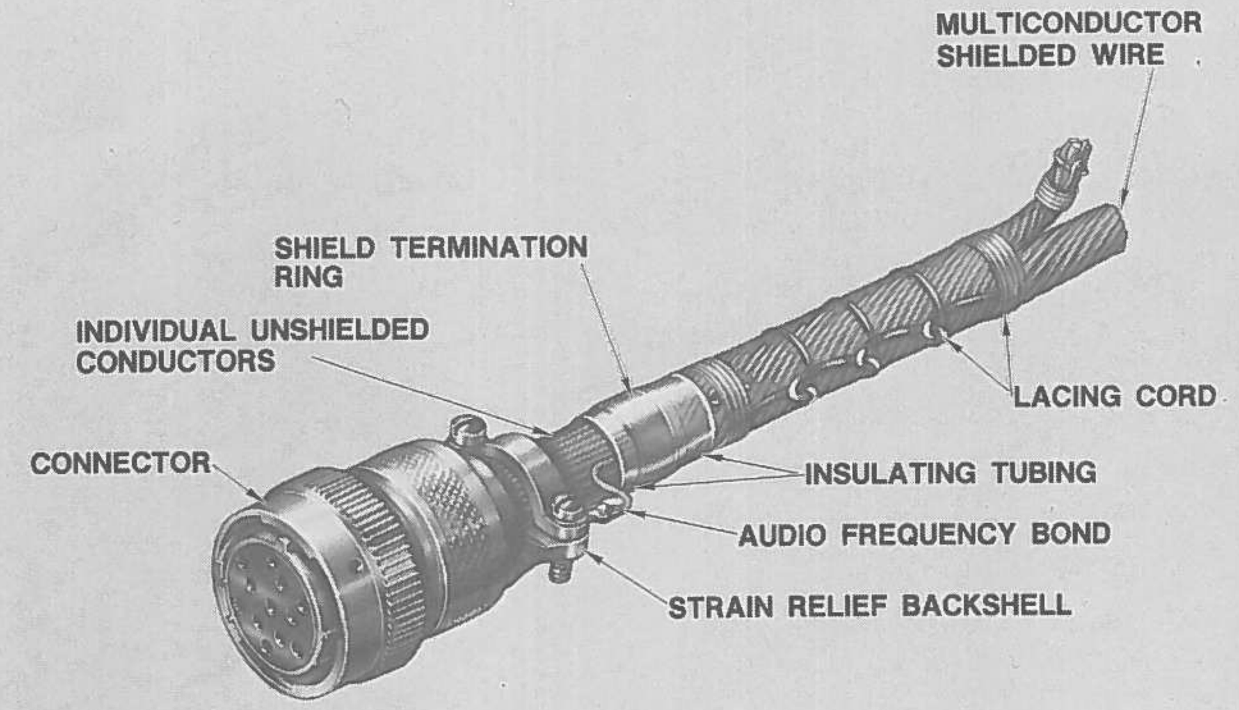
CONVENTIONAL HARNESS CONTROLLER



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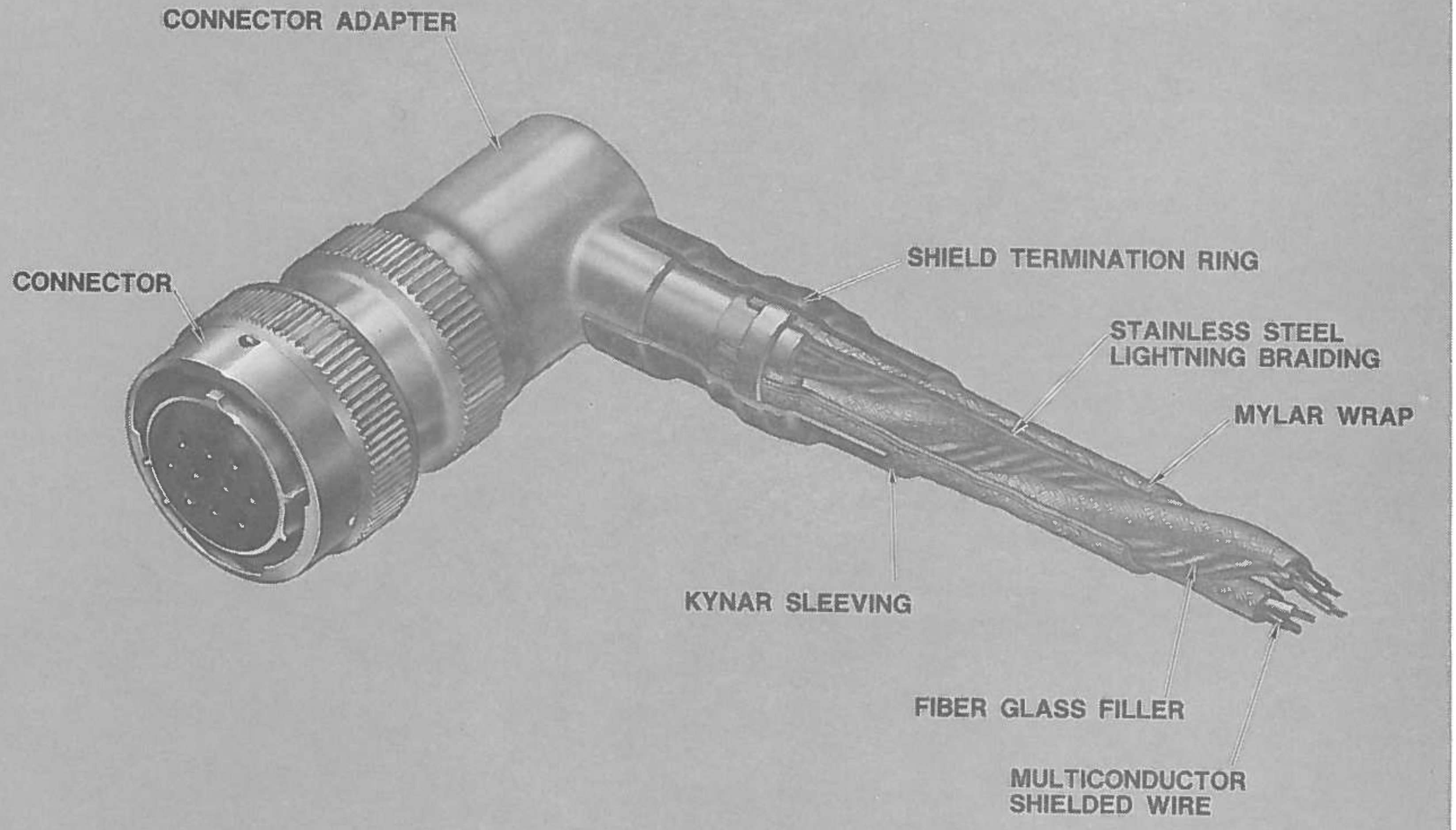
LC303-182B
1904m/3

ARMOR / LIGHTNING BRAIDED HARNESS CONTROLLER CONNECTOR



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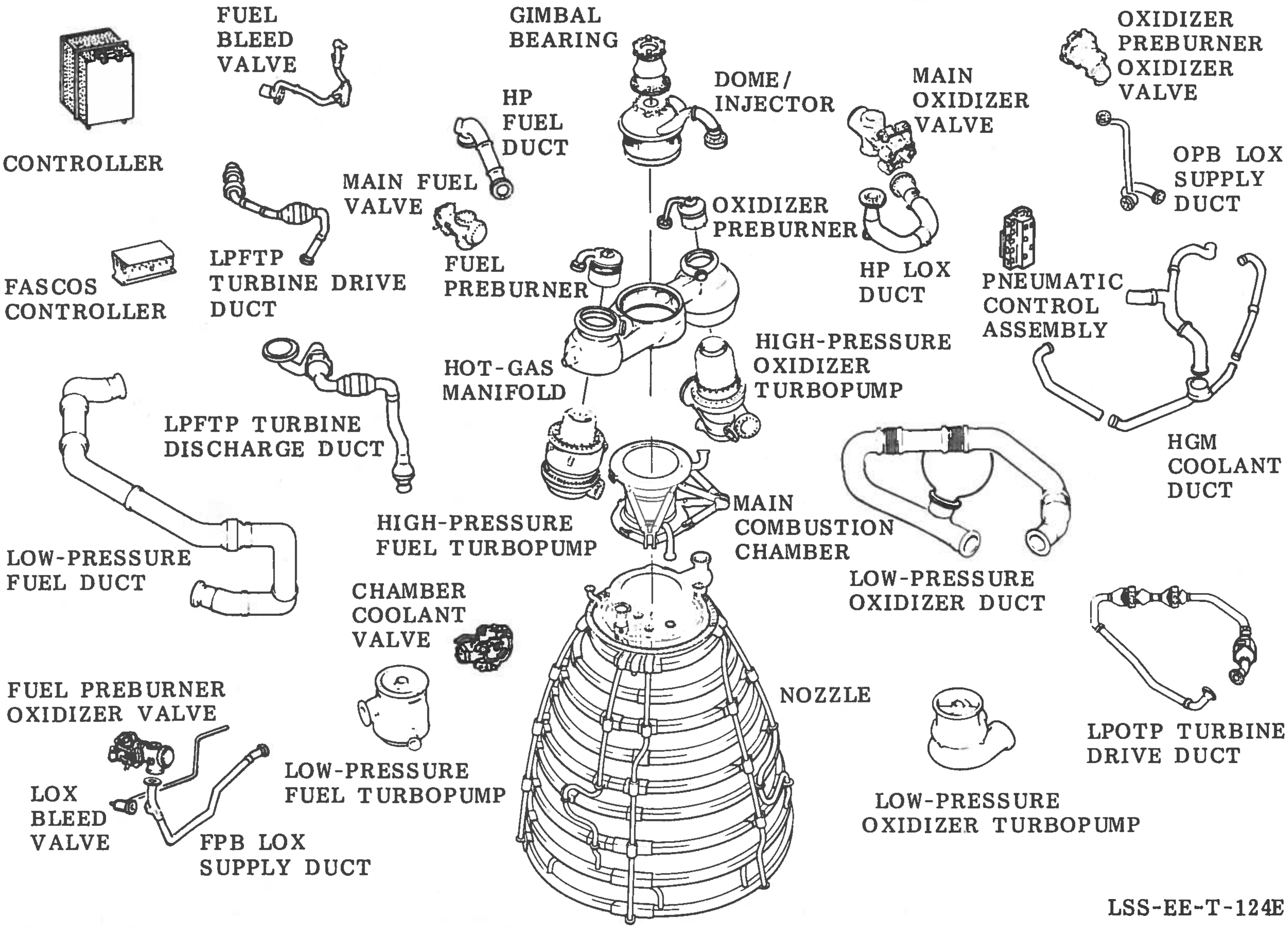
LC435-189A
1904m/5

SSME MAJOR COMPONENTS



LSS-EE-T-124E

ROCKET ENGINE TYPES - COMPARED

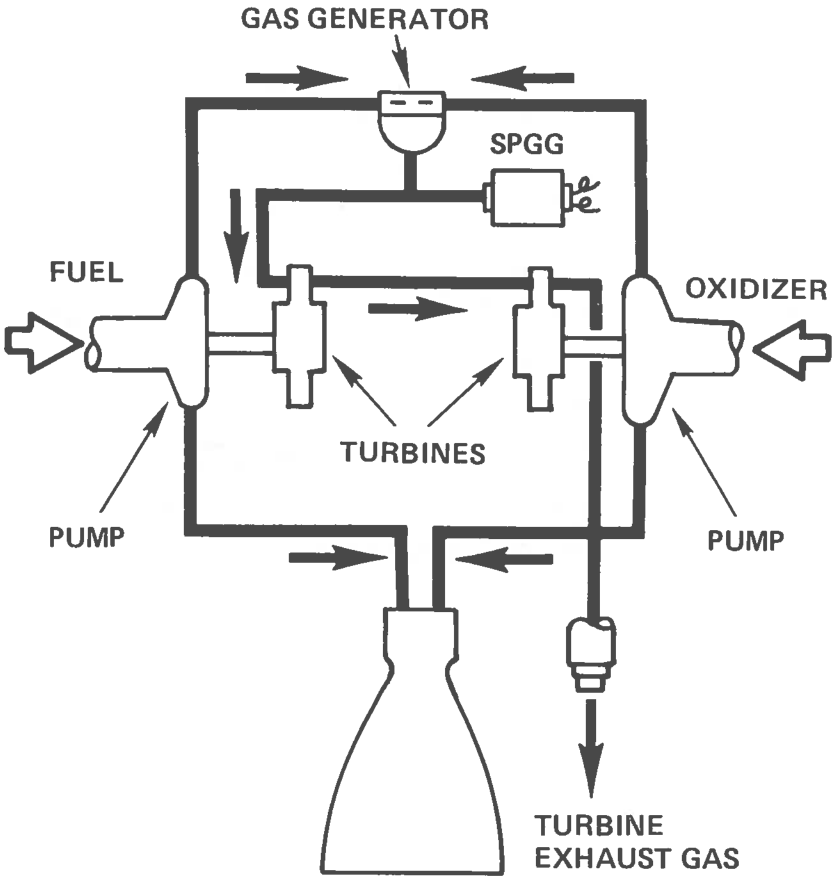
A major requirement for operating any large liquid propellant rocket engine is driving the turbopumps. The method by which this is accomplished categorizes the engine as an expander, a gas generator, or a preburner.

In an expander engine (not shown), the cryogenic liquid fuel is heated (expanded) by using it to cool the MCC and nozzle. The resulting gas is used to drive the turbopump(s) turbine(s). The gas is then injected into the combustion chamber to be burned.

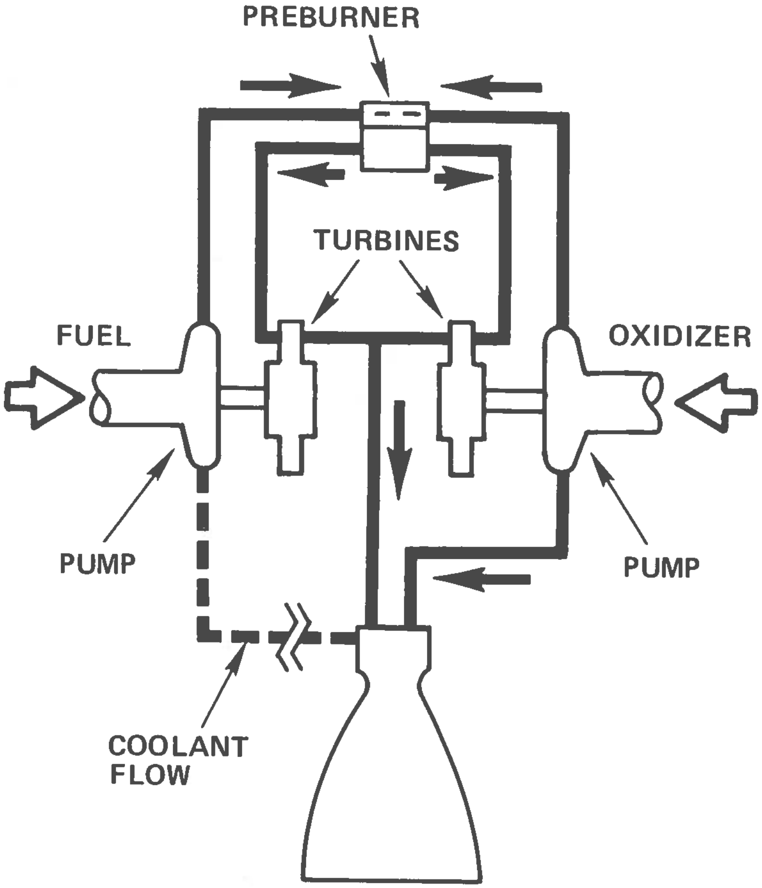
In a gas generator engine, small quantities of fuel and oxidizer are burned in the gas generator. The resulting high-pressure gas is expanded through the turbopump turbine(s) to, typically, the atmosphere. This arrangement requires the turbopump(s) to supply GG flow as well as main combustion chamber flow. On the positive side, the pump(s) need only develop sufficient pressure to ensure injection. Past and present Rocketdyne gas generator engines include: Redstone, Jupiter, Thor, Atlas, H-1, F-1, J-2, RS-27, and XLR-132.

In a preburner engine, most of the fuel (except for a minor coolant flow) and a small quantity of the oxidizer are "preburned" in a gas-generator-like device called a preburner. The extremely fuel-rich, high-pressure gas emanating from the preburner is first expanded through the turbopump(s) turbine(s) and then injected into the combustion chamber (along with the coolant flow and the remaining oxidizer) to be "final-burned". Although the pumps are not required to supply additional flows for a gas generator, they must develop very high pressures in order to drive the preburner injector, the pump turbines, and the main combustion chamber injector, which have delta pressure requirements that are additive. The SSME is an example of a modern preburner engine that uses two preburners to individually drive and control its two high-pressure turbopumps.

GAS GENERATOR/PREBURNER COMPARISON



GG ENGINE



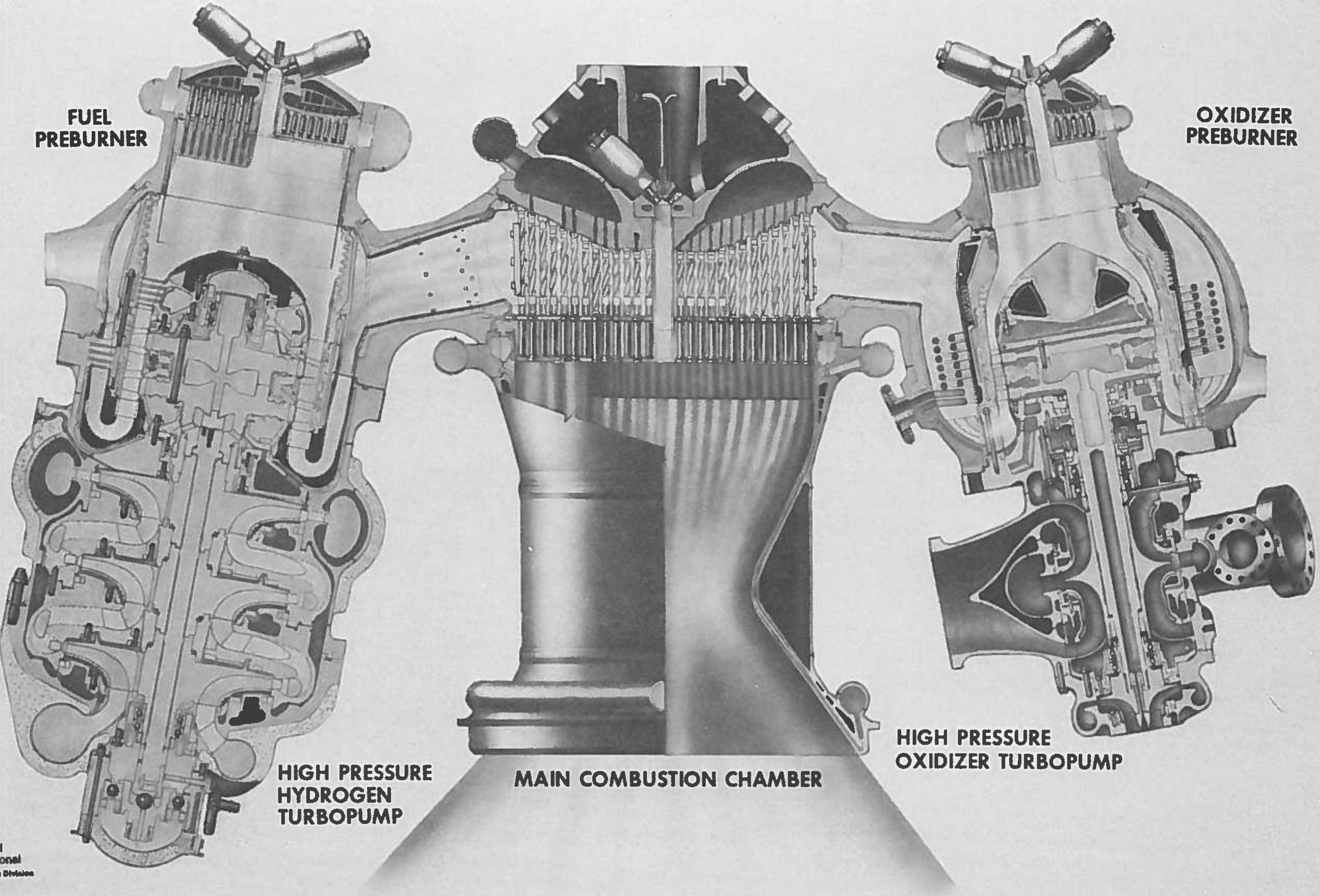
PREBURNER ENGINE

LSS-ES-T-51A

SSME 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 remaining oxidizer, into the 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 ignition system. The chamber is cooled by fuel flowing through 390 channels cut into its liner and is strengthened by a throat collar. The high-pressure fuel pump 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 liquid air (-320° F) from forming on the pump. The high-pressure oxidizer pump 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



LC300-266N

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SSME PROPELLANT FLOW ANALYSIS (1 of 3)

GENERAL

The SSME utilizes a two-stage combustion process. In the first (or preburn) stage, about 80 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 one pound of LOX to one pound of LH. (A normal ratio is about 6 to 1.) The resulting two hydrogen-rich gas streams first drive their respective high-pressure turbopumps and then merge to be injected into the MCC, along with the coolant fuel (about 17 percent) and the remaining oxygen (about 88 percent). Second (or final) stage combustion occurs in the MCC at a carefully controlled mixture ratio of 6.026 to 1.

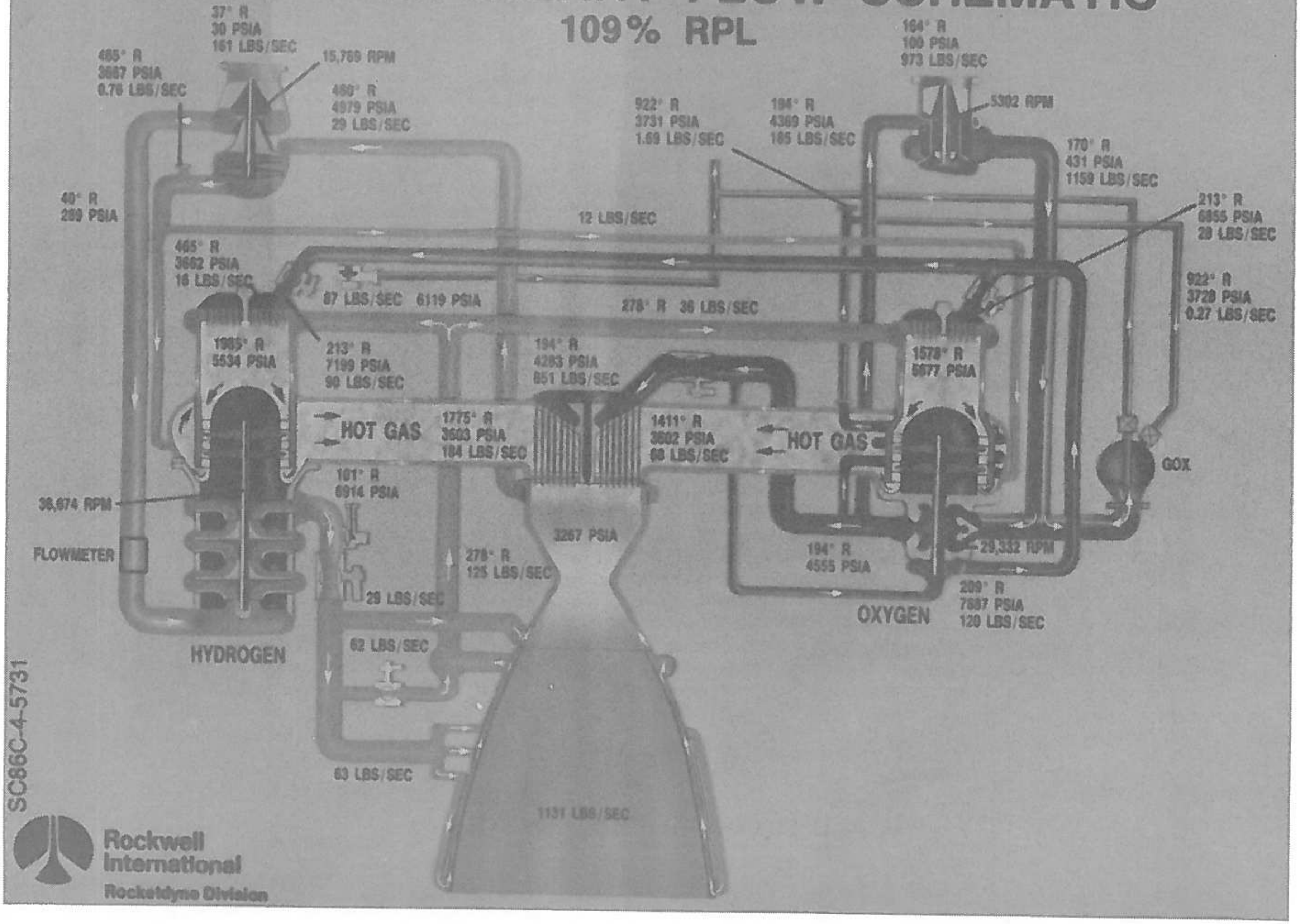
The two low-pressure turbopumps serve as boost pumps for the two high-pressure turbopumps. This arrangement allows lower ullage pressures to be used in the propellant tanks and higher pump speeds.

A pogo suppression system accumulator is attached to the oxidizer low-pressure duct. When pressurized with gaseous oxygen (GOX) from the heat exchanger coil, the accumulator dampens oxidizer feed system pressure oscillations. Oscillations can cause unstable combustion by disturbing the injection process. GOX flow into the accumulator exits 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.

PHASE I

SSME PROPELLANT FLOW SCHEMATIC

109% RPL



SC86C-4-5731

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SSME PROPELLANT FLOW ANALYSIS (2 of 3)

OXIDIZER FLOW

LOX enters at the low-pressure oxidizer turbopump (LPOTP). It flows through the low-pressure duct and the high-pressure oxidizer turbopump (HPOTP), and then splits into a main flow and several branch flows. The main flow (about 88 percent) continues on through the main oxidizer valve (MOV) and the main injector (MI), into the main combustion chamber (MCC). One branch supplies LOX back to the LPOTP to drive the turbine. (The turbine exhaust is merged with the pump output, since they are both liquid oxygen.) A second branch supplies LOX to the heat exchanger coil to be gasified and used to pressurize the oxidizer tank 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 its oxidizer to about 8,000 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 6.026 to 1 mixture ratio in the MCC.

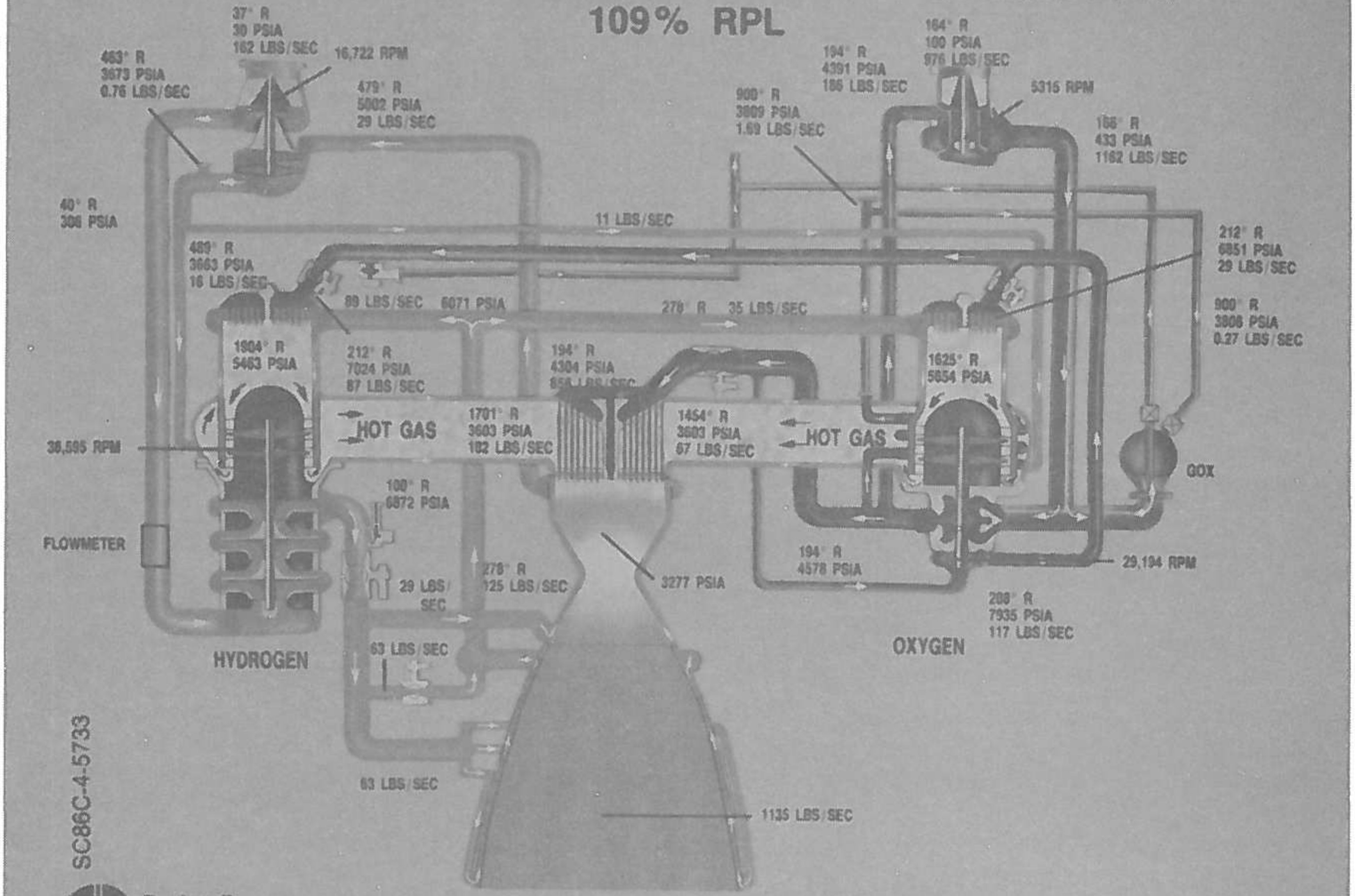
FUEL FLOW

LH enters at the low-pressure fuel turbopump (LPFTP). It flows through the low-pressure duct, the high-pressure fuel turbopump (HPFTP), and the main fuel valve (MFV). Beyond the MFV, the fuel system is no longer insulated. Therefore, the hydrogen gasifies, splitting into three paths. The first path (20 percent) leads upward through the 390 MCC coolant channels and then on to drive the LPFTP. Emerging from the turbine, the gas flow is tapped for fuel tank pressurizing and 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 (40 percent) passes upward through the 1,080 nozzle tubes, joining the third path (40 percent), which bypasses the nozzle through the chamber coolant valve (CCV). (The relative amounts flowing through the nozzle and the CCV vary in accordance with thrust.) This combined flow then splits to feed the preburners, with the fuel preburner receiving, by far, the larger share.

PHASE II

SSME PROPELLANT FLOW SCHEMATIC

109% RPL



SC86C-4-5733

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SSME PROPELLANT FLOW ANALYSIS (3 of 3)

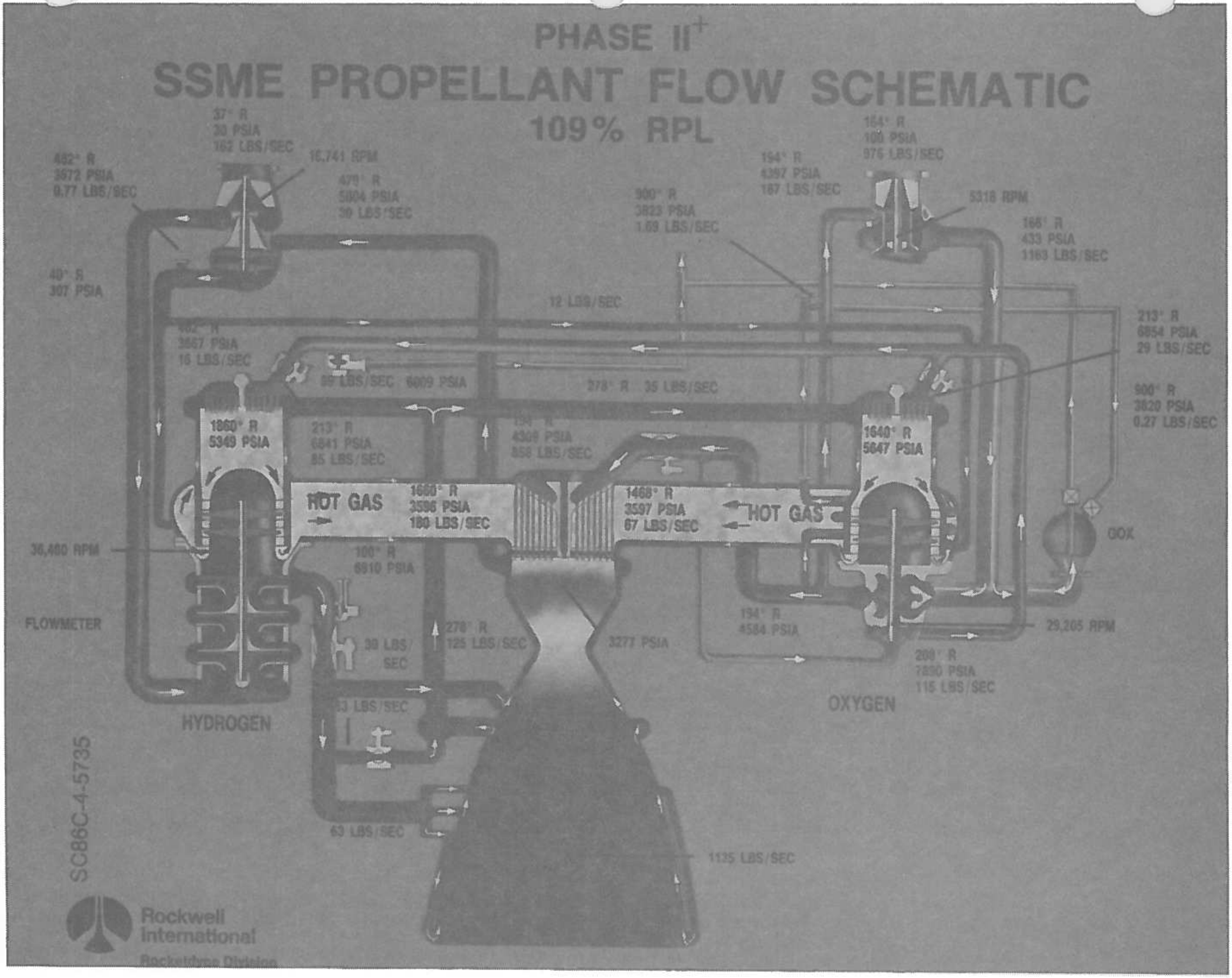
ENGINE CONTROL

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.

During the engine start phase, all five valves operate in scheduled modes; ie, their actions are predetermined. These start schedules ensure a smooth, positive start by establishing a fuel lead; ie, the fuel arrives in the combustion chambers ahead of the oxidizer. This lead creates a controlled, fuel-rich start environment.

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 operation. 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 65 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 valves, and the transducers that sense flowrates and MCC pressure; ie, thrust.

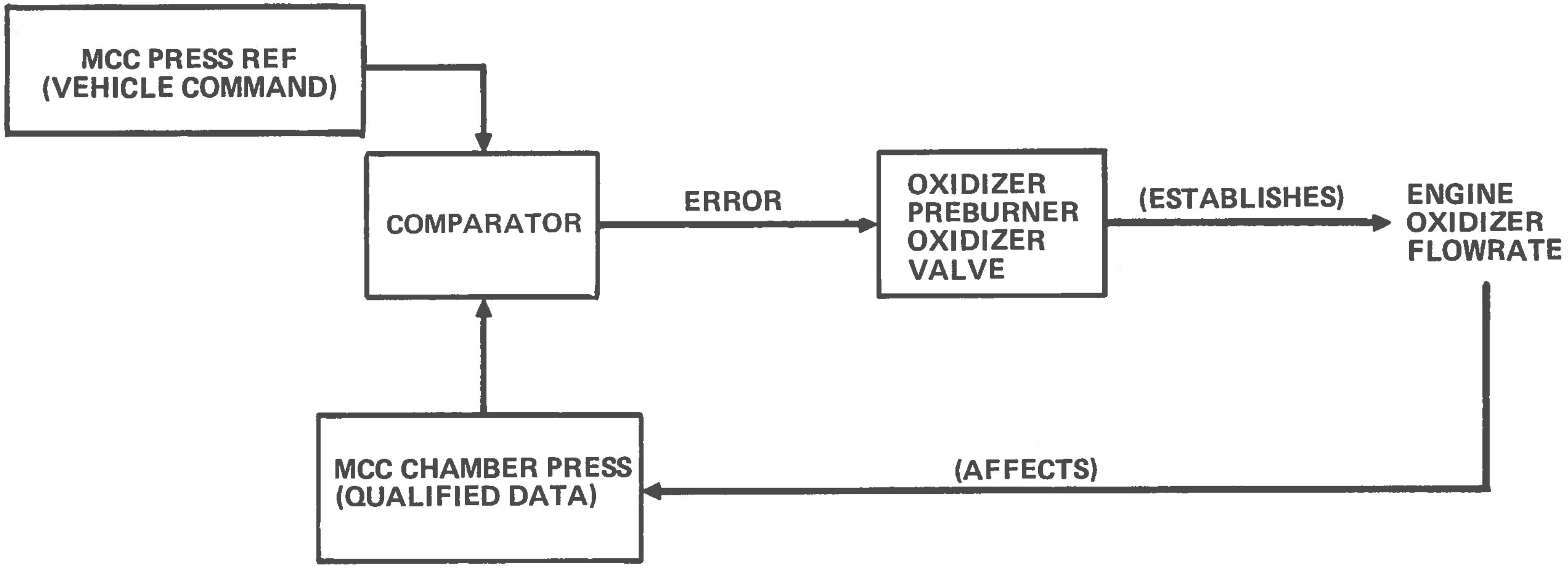
During the engine shutdown phase, all five valves are switched to shutdown schedules. These schedules ensure a smooth, safe shutdown by establishing a fuel lag; ie, the oxidizer departs the combustion chambers ahead of the fuel. This lag creates a fuel-rich, cool shutdown environment.



PHASE II+
SSME PROPELLANT FLOW SCHEMATIC
109% RPL

SSME MCC PRESSURE (THRUST) CONTROL

THRUST CONTROL LOOP



MCC PRESS REF
(VEHICLE COMMAND)

COMPARATOR

ERROR

OXIDIZER
PREBURNER
OXIDIZER
VALVE

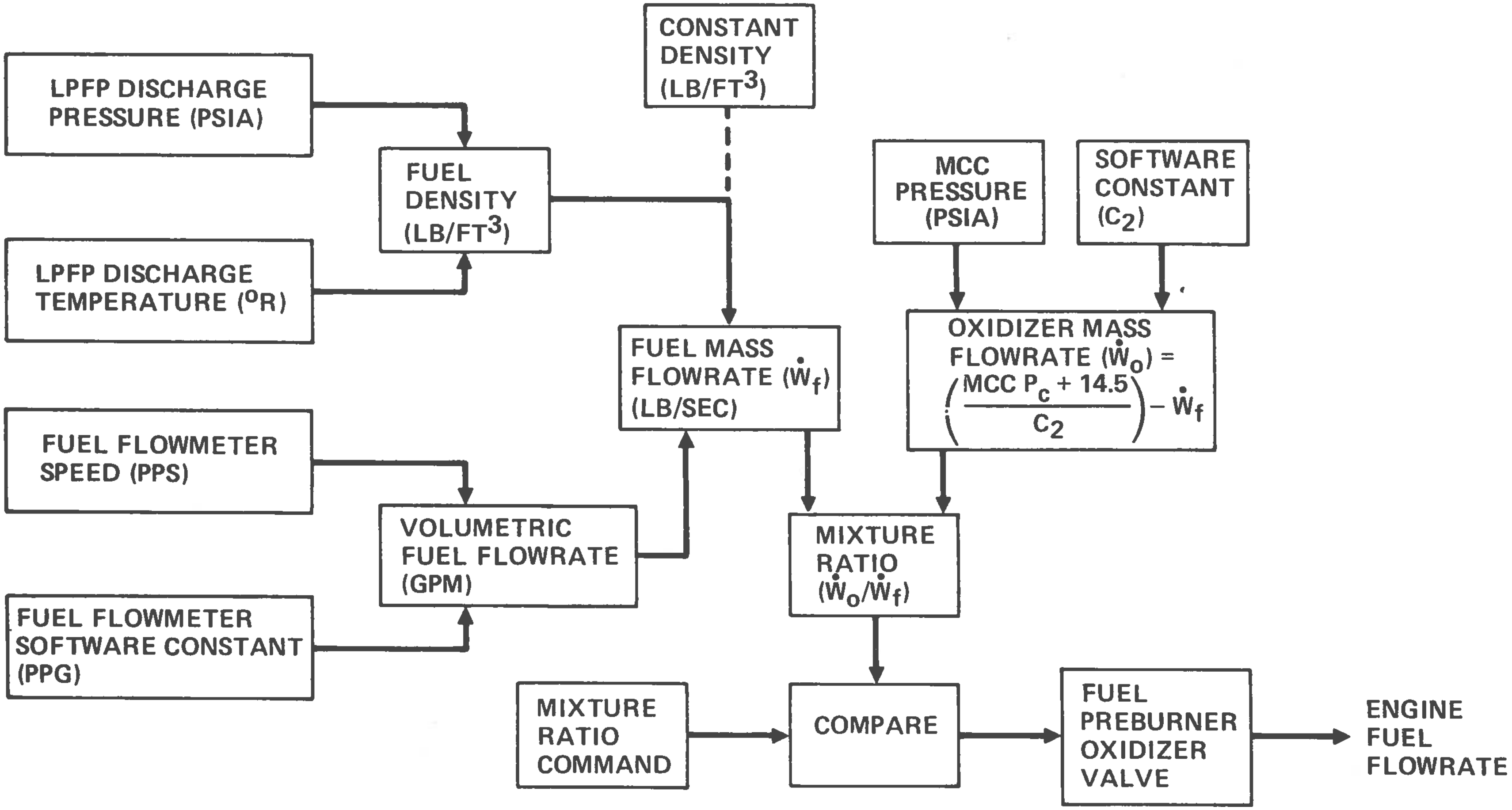
(ESTABLISHES)

ENGINE
OXIDIZER
FLOWRATE

(AFFECTS)

MCC CHAMBER PRESS
(QUALIFIED DATA)

SSME MCC MIXTURE RATIO CONTROL



LPFP DISCHARGE PRESSURE (PSIA)

LPFP DISCHARGE TEMPERATURE (^oR)

FUEL DENSITY (LB/FT^3)

CONSTANT DENSITY (LB/FT^3)

FUEL FLOWMETER SPEED (PPS)

FUEL FLOWMETER SOFTWARE CONSTANT (PPG)

VOLUMETRIC FUEL FLOWRATE (GPM)

FUEL MASS FLOWRATE ($\dot{W}_f$) (LB/SEC)

MCC PRESSURE (PSIA)

SOFTWARE CONSTANT (C_2)

OXIDIZER MASS FLOWRATE ($\dot{W}_o$) = $\left(\frac{MCC\ P_c + 14.5}{C_2}\right) - \dot{W}_f$

MIXTURE RATIO ($\dot{W}_o/\dot{W}_f$)

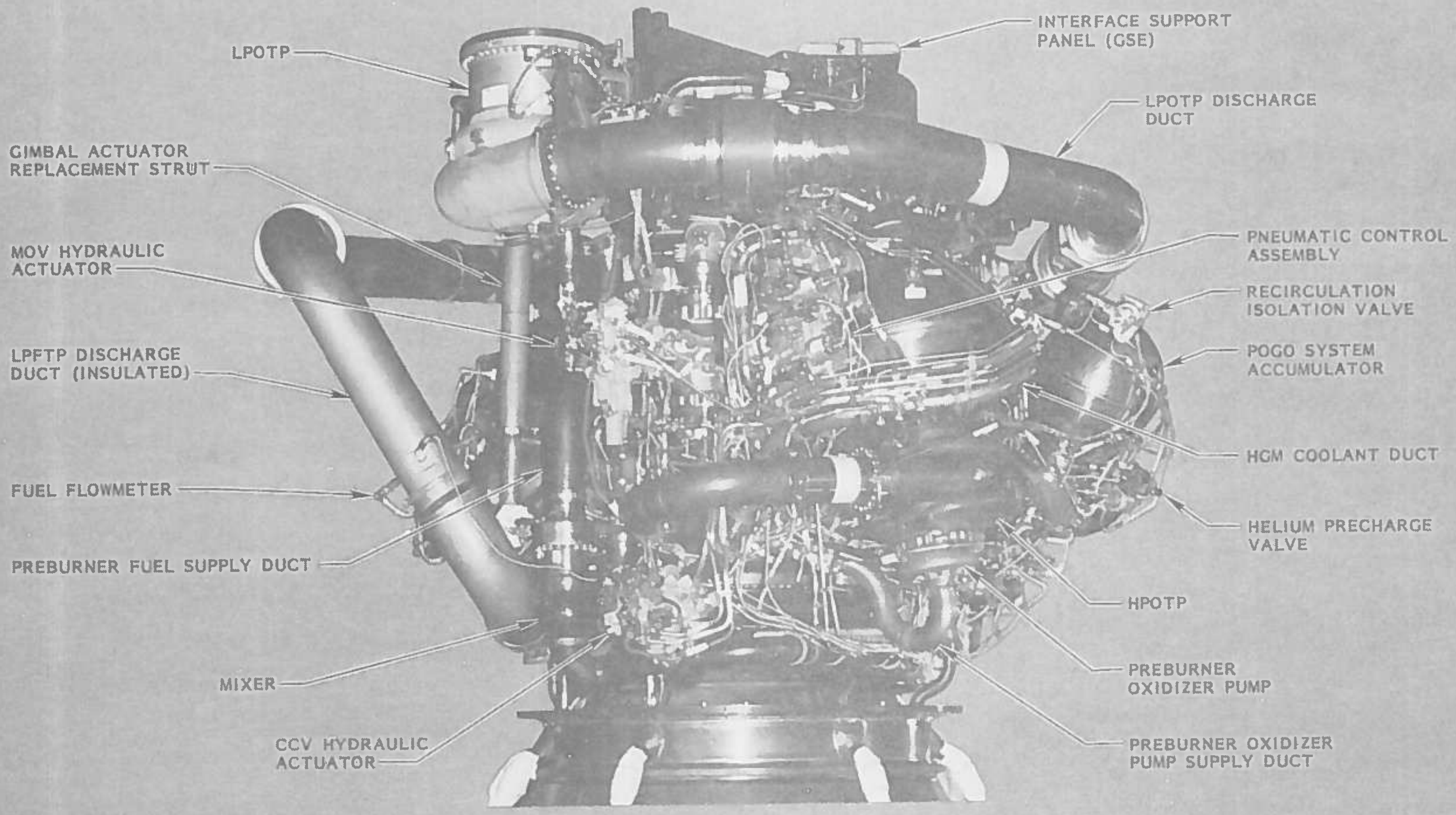
MIXTURE RATIO COMMAND

COMPARE

FUEL PREBURNER OXIDIZER VALVE

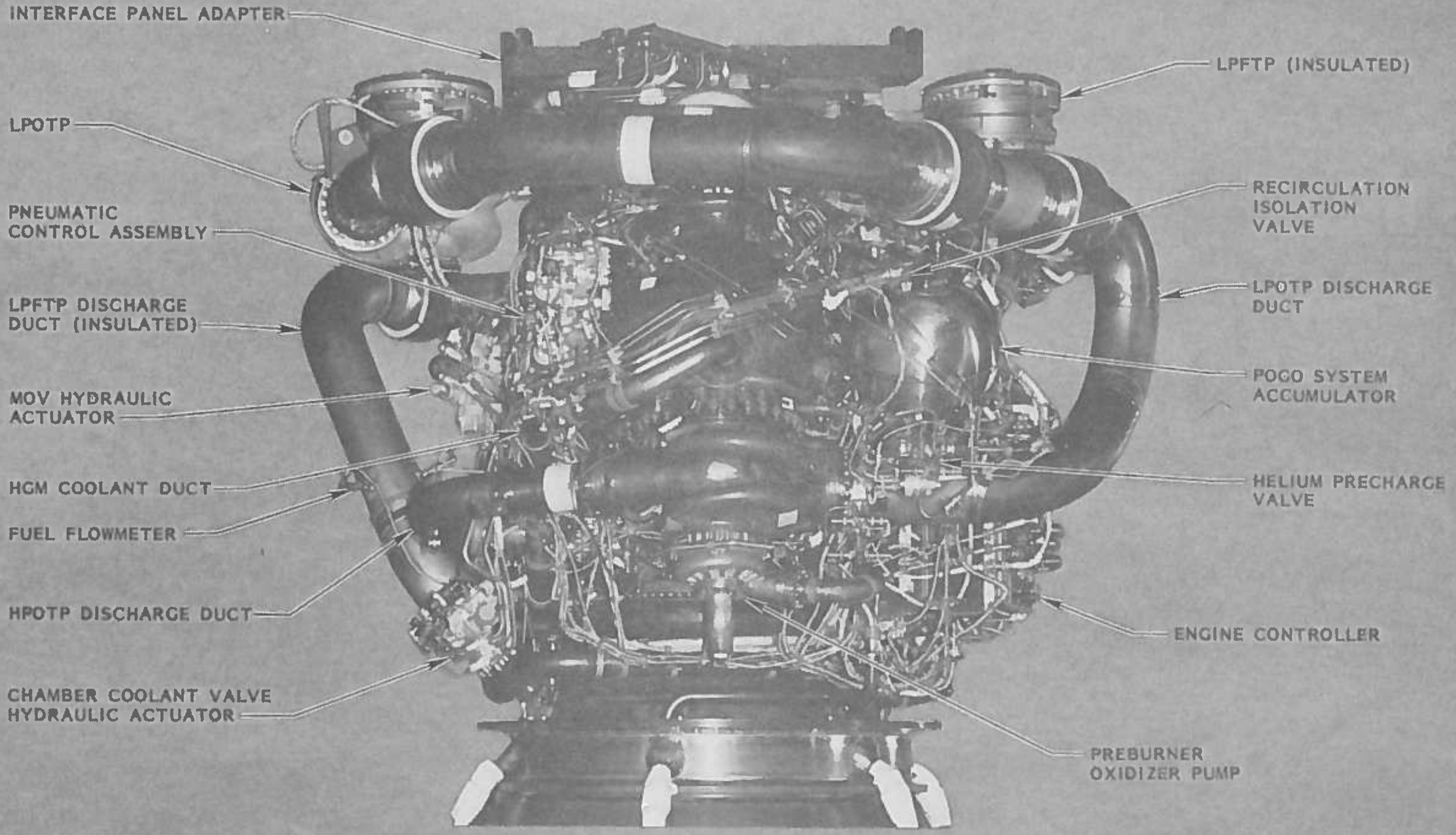
ENGINE FUEL FLOWRATE

TYPICAL SSME-VIEW 1



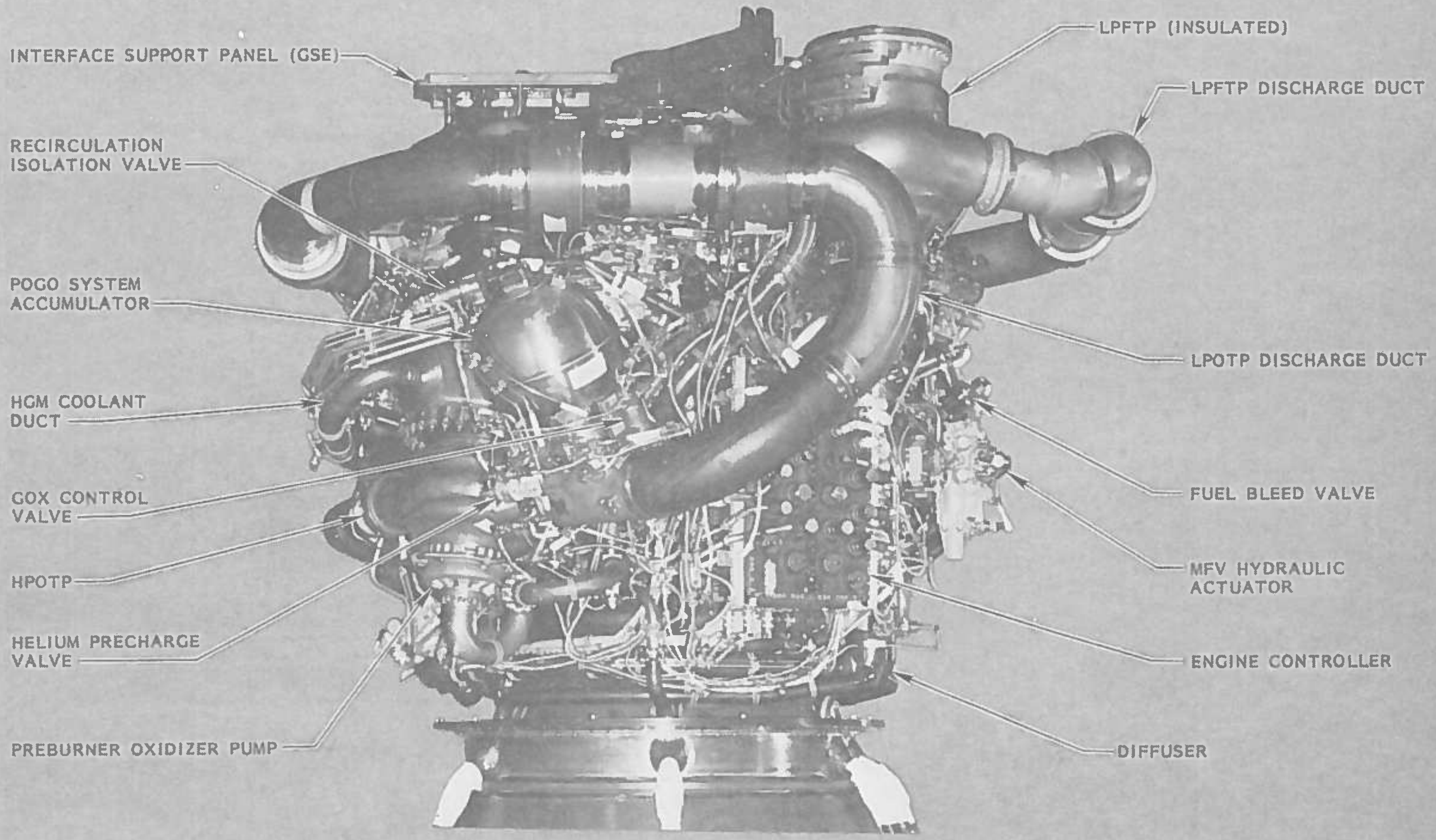
LSS-ER-T-24C

TYPICAL SSME-VIEW 2



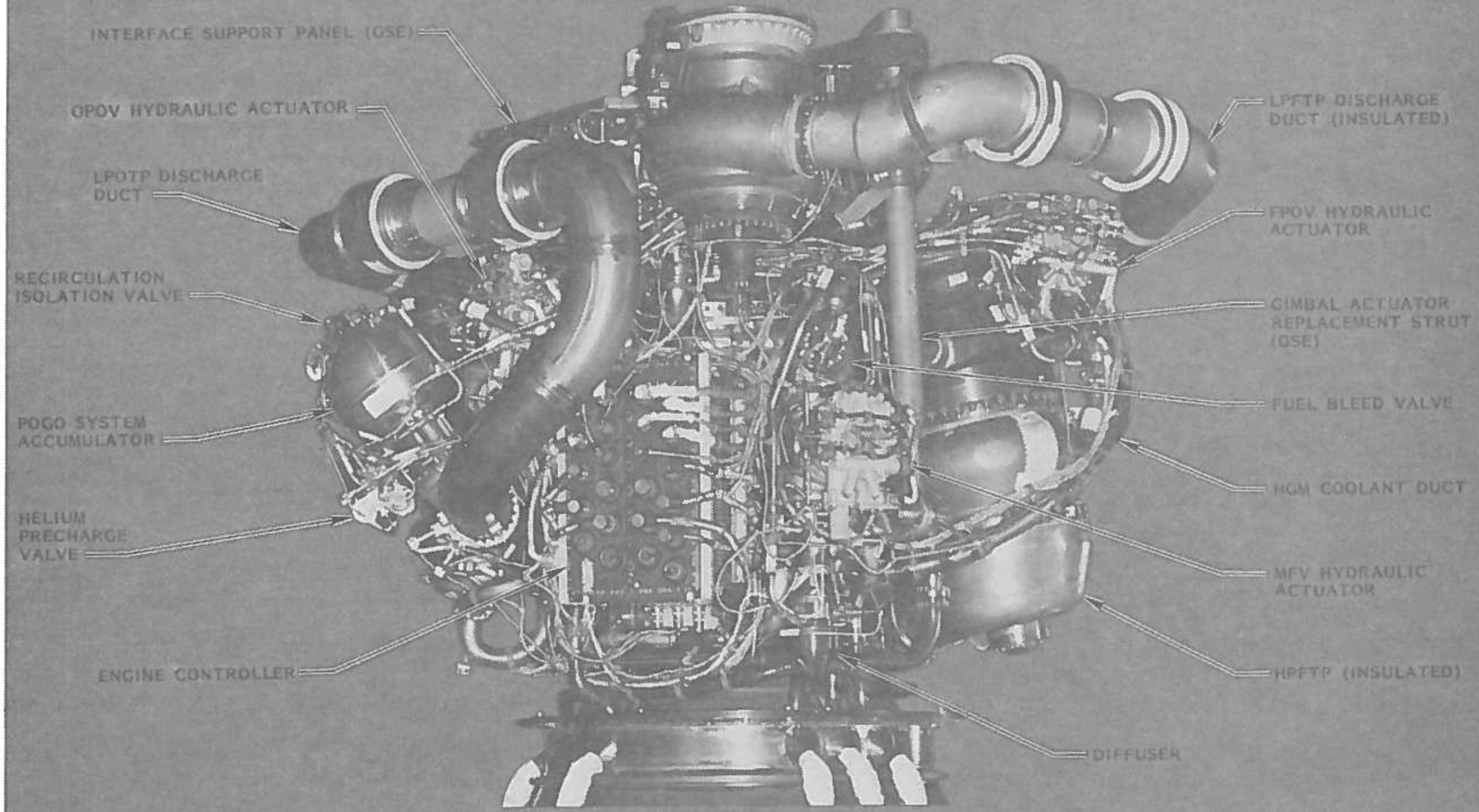
LSS-ER-T-25C

TYPICAL SSME-VIEW 3



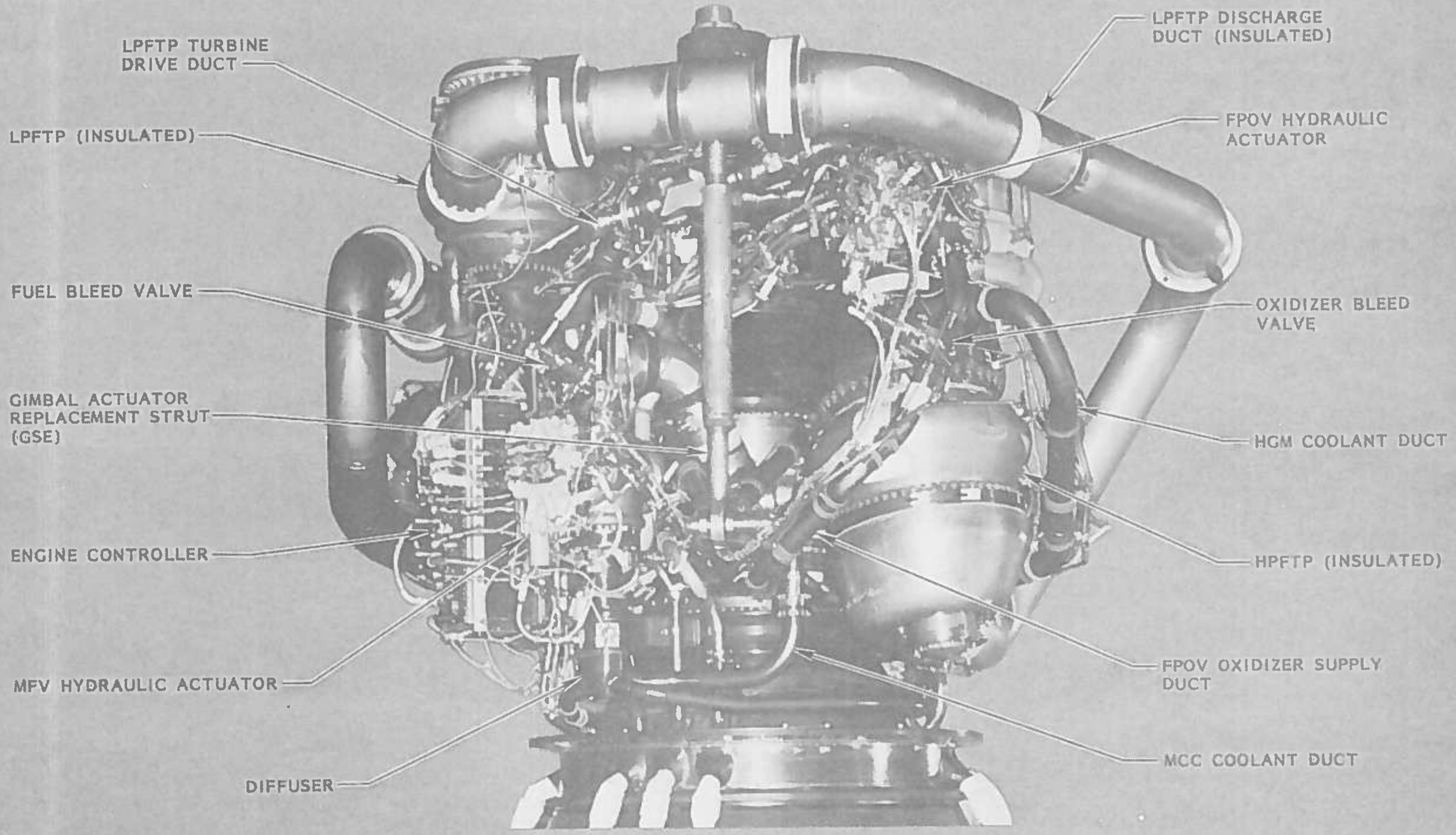
LSS-ER-T-26D

TYPICAL SSME-VIEW 4



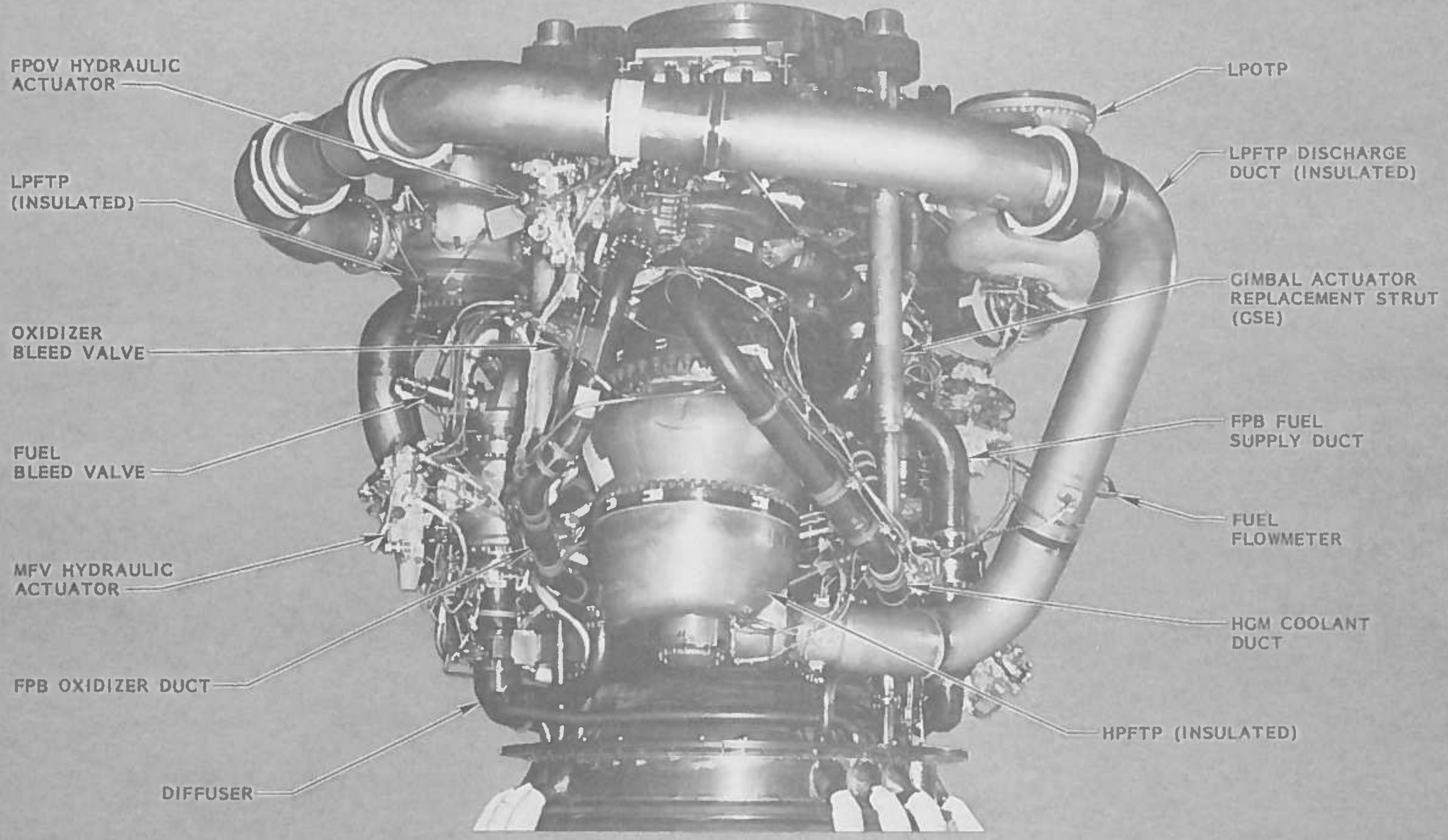
LSS-ER-T-27D

TYPICAL SSME-VIEW 5



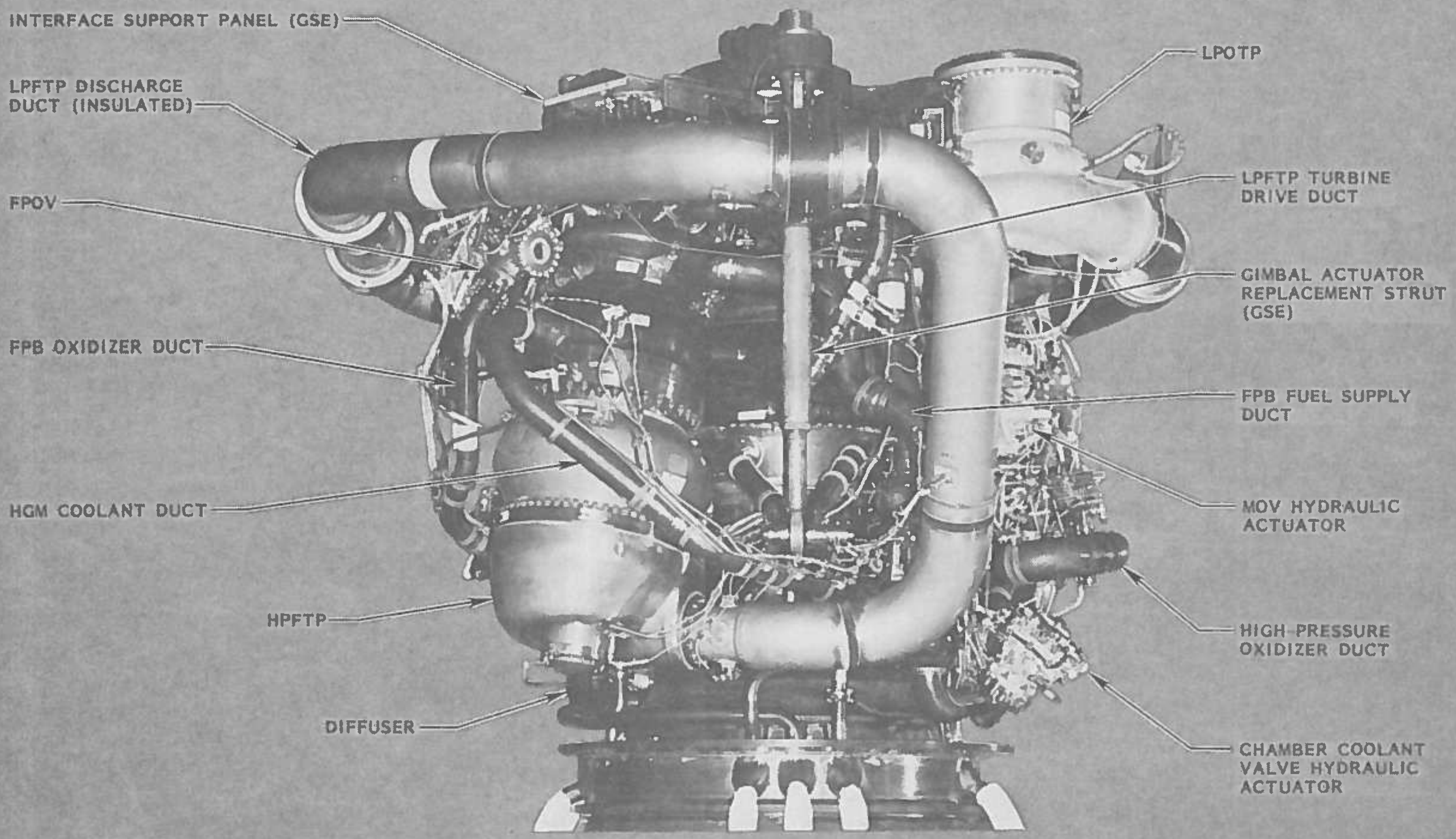
LSS-ER-T-28A

TYPICAL SSME-VIEW 6



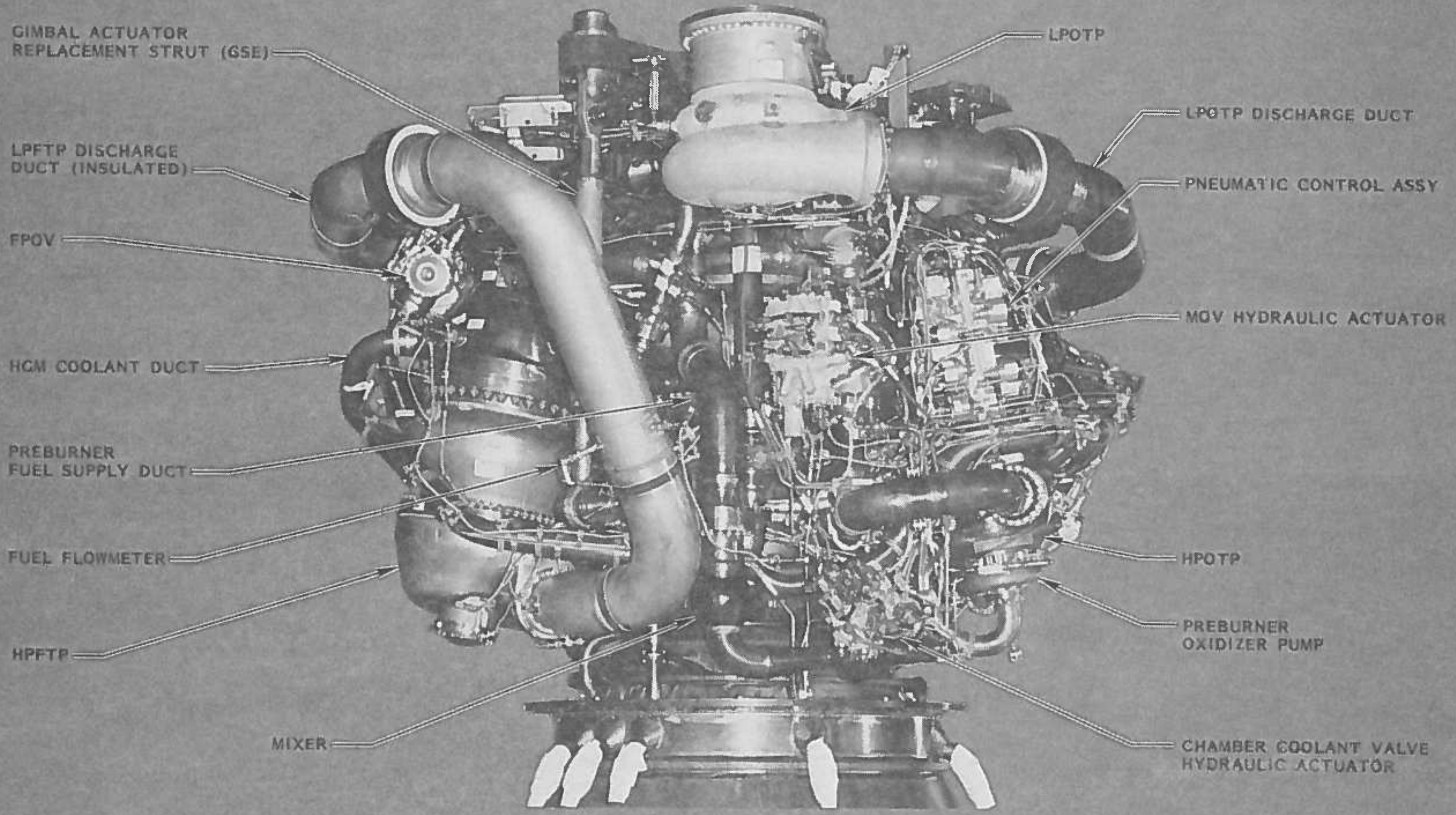
LSS-ER-T-29A

TYPICAL SSME-VIEW 7

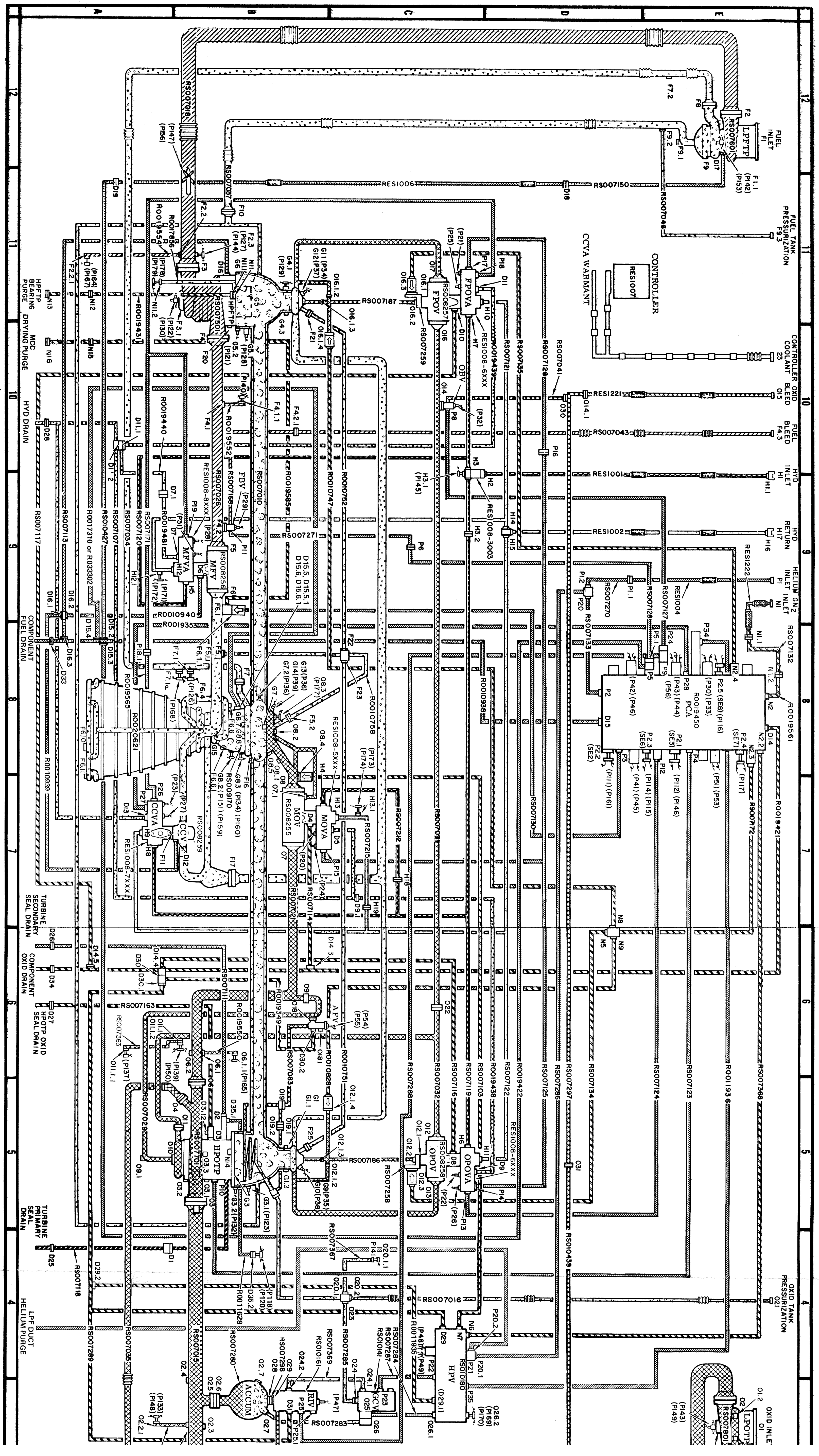


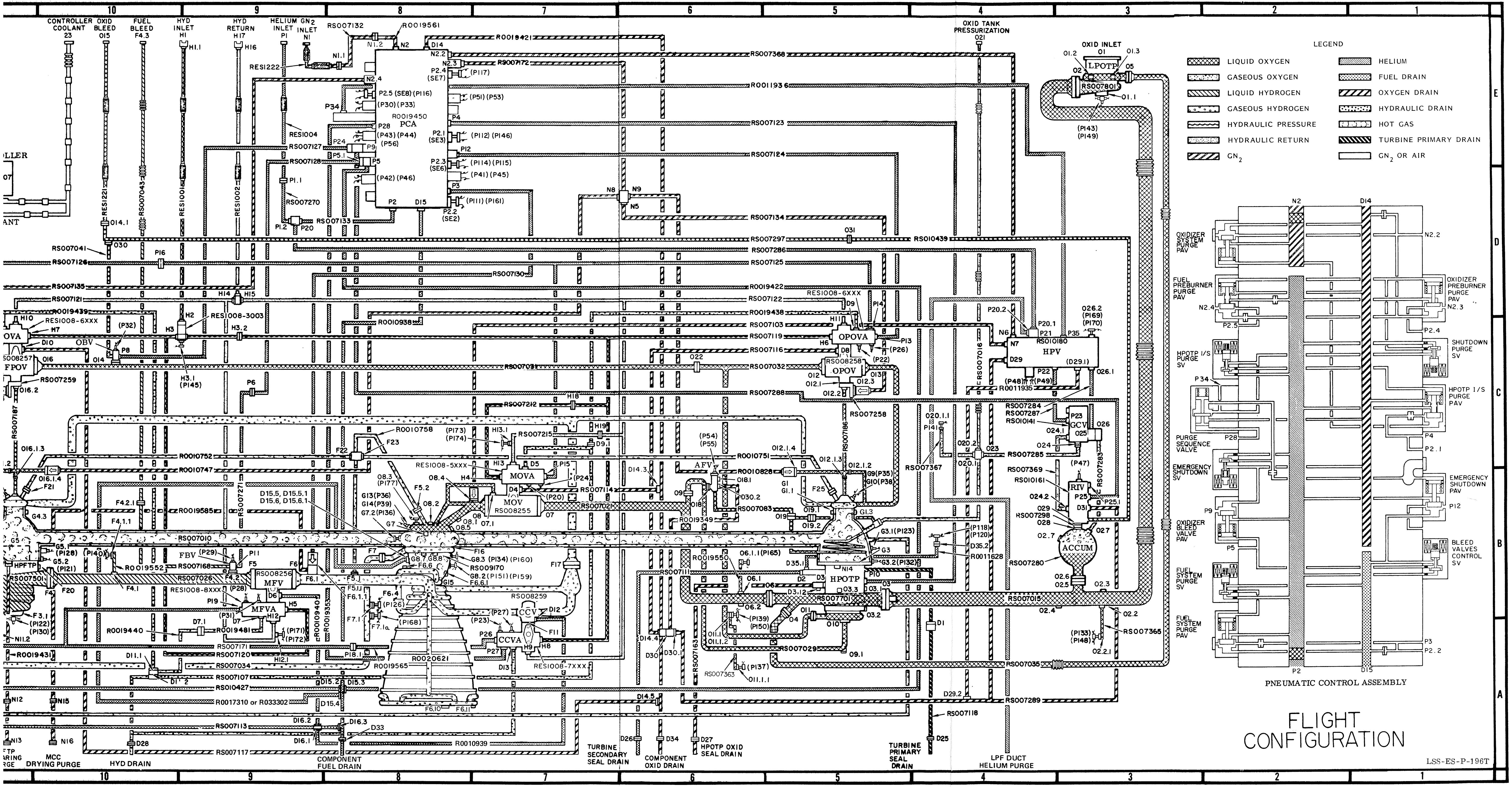
LSS-ER-T-30A

TYPICAL SSME-VIEW 8



LSS-ER-T-31A

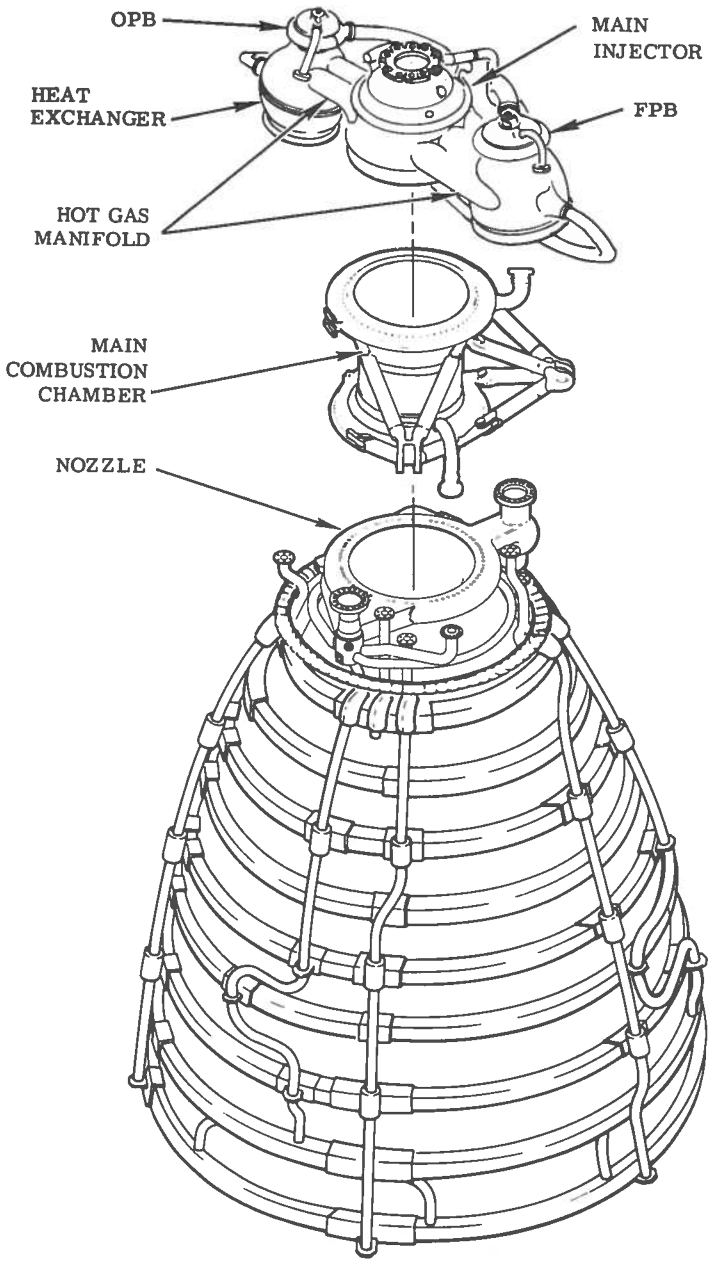

FUEL INLET F1
LPFTP
FUEL TANK PRESSURIZATION F3
CONTROLLER
RES1007
CCVA WARMANT
CONTROLLER COOLANT
OXID BLEED D15
FUEL BLEED F4.3
HYD INLET H1
HYD RETURN H17
HELIUM INLET N1
GN2 INLET
PCA
HPFTP
FPOVA
FPOV
OBV
FBV
MFVA
MFV
MOVA
MOV
CCVA
CCV
AFV
HPOTP
OPOVA
OPOV
HPV
ACCUM
RIV
GCV
LPOTP
OXID INLET O1
OXID TANK PRESSURIZATION O21
HPFTP BEARING PURGE
MCC DRYING PURGE
HYD DRAIN
COMPONENT FUEL DRAIN
TURBINE SECONDARY SEAL DRAIN
COMPONENT OXID DRAIN
HPOTP OXID SEAL DRAIN
TURBINE PRIMARY SEAL DRAIN
LPF DUCT HELIUM PURGE
A
B
C
D
E
12
11
10
9
8
7
6
5
4



FLIGHT
CONFIGURATION

LSS-ES-P-196T

SSME COMBUSTION DEVICES



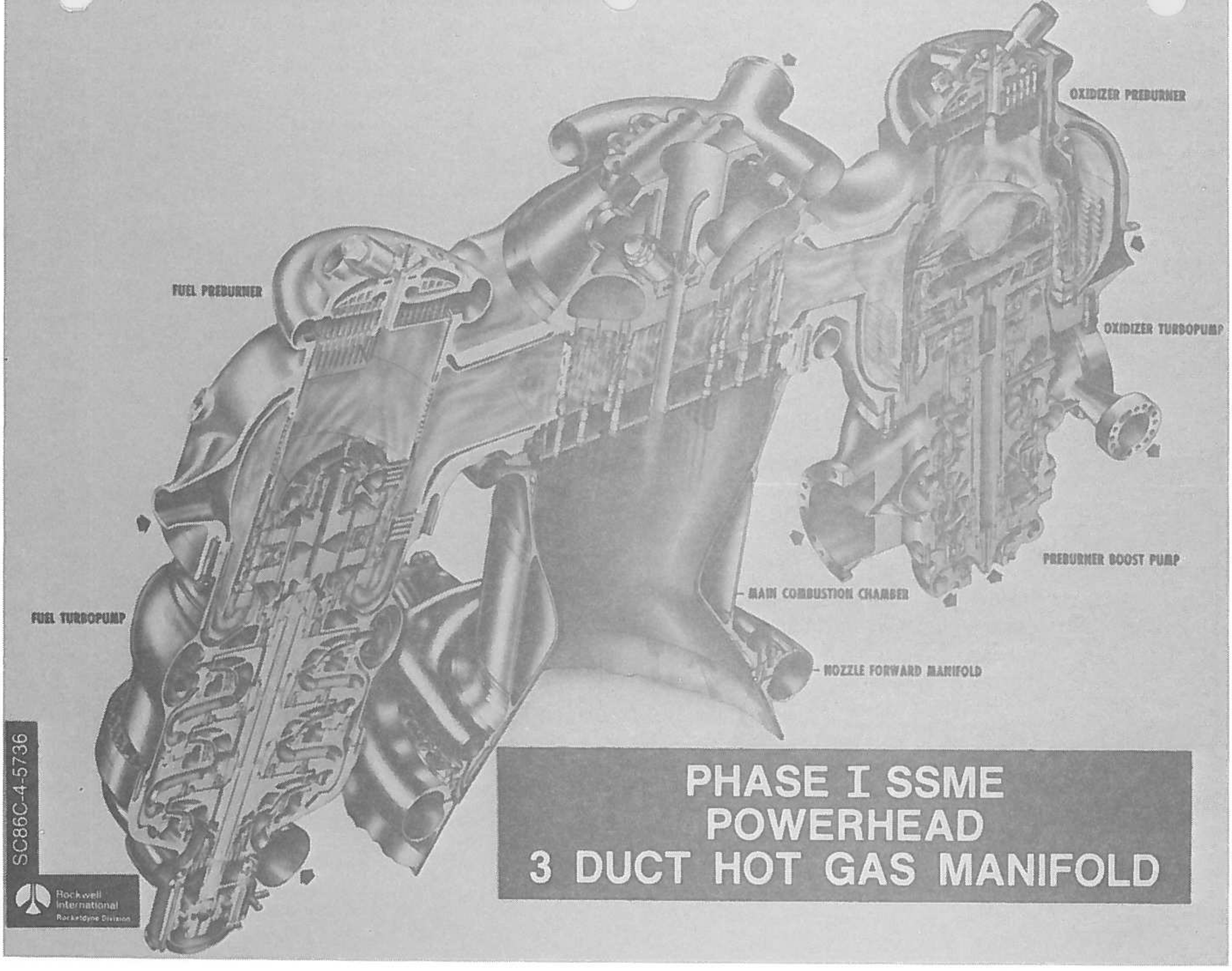
LSS-EE-T-149C

SSME 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 (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 very close-coupled to the preburners, and duct lengths and losses are held to a minimum. Both turbopumps are canted from vertical to facilitate removal.

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 the secondary plates. The coolant gas flows (permeates) through the porosity of the rigimesh plates, cooling them. It also flows through the 75 baffle tips and through a peripheral ring of small holes in the primary plate, which forms a cooling curtain along the MCC walls; ie, film cooling. (This coolant gas has previously flowed through the 390 coolant channels in the MCC liner and driven the LPFTP.)

PHASE I SSME POWERHEAD 3 DUCT HOT GAS MANIFOLD



SC86C-4-5736

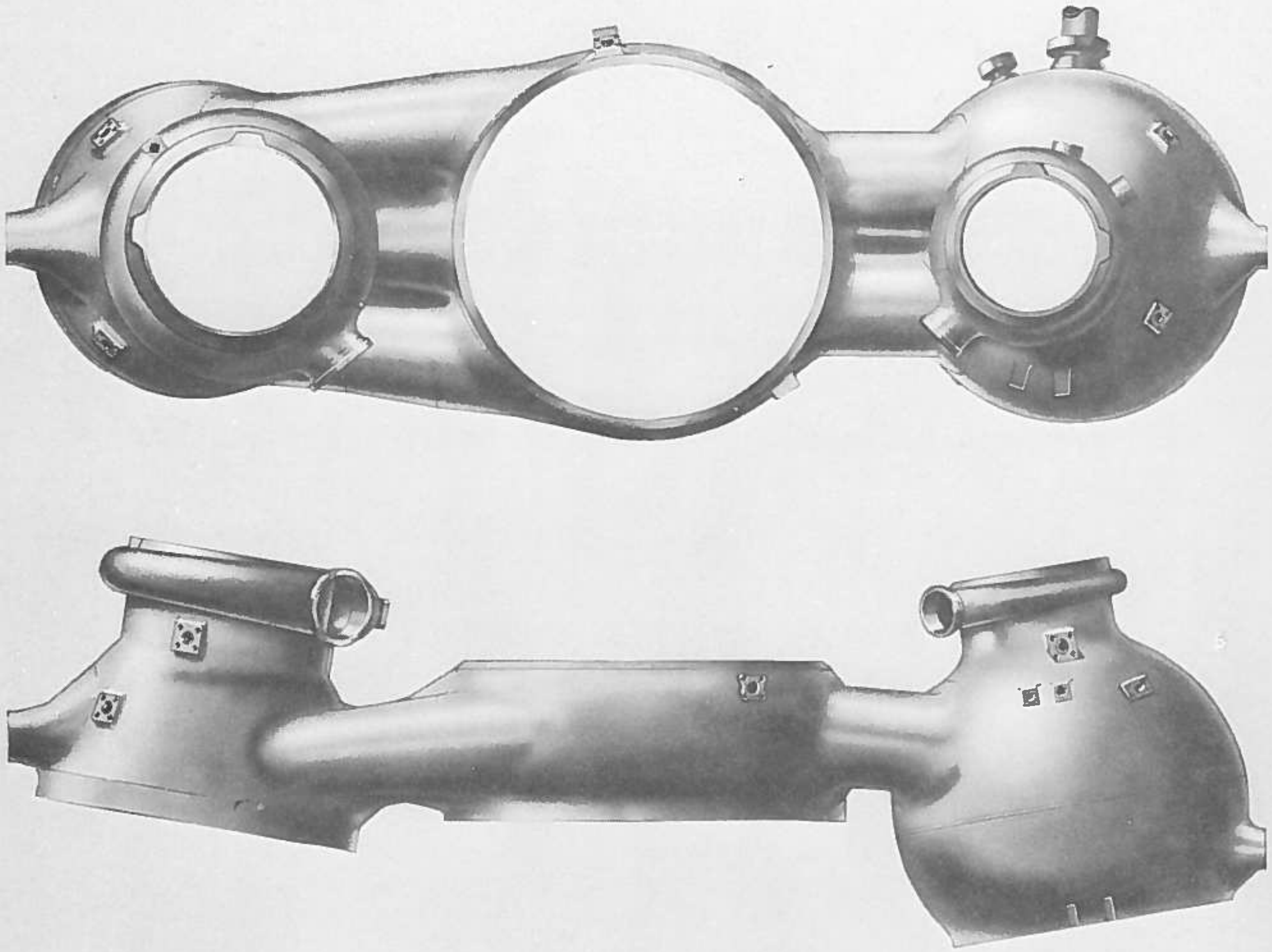
Rockwell International
Rocketdyne Division

SSME 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).

SSME HOT GAS MANIFOLD



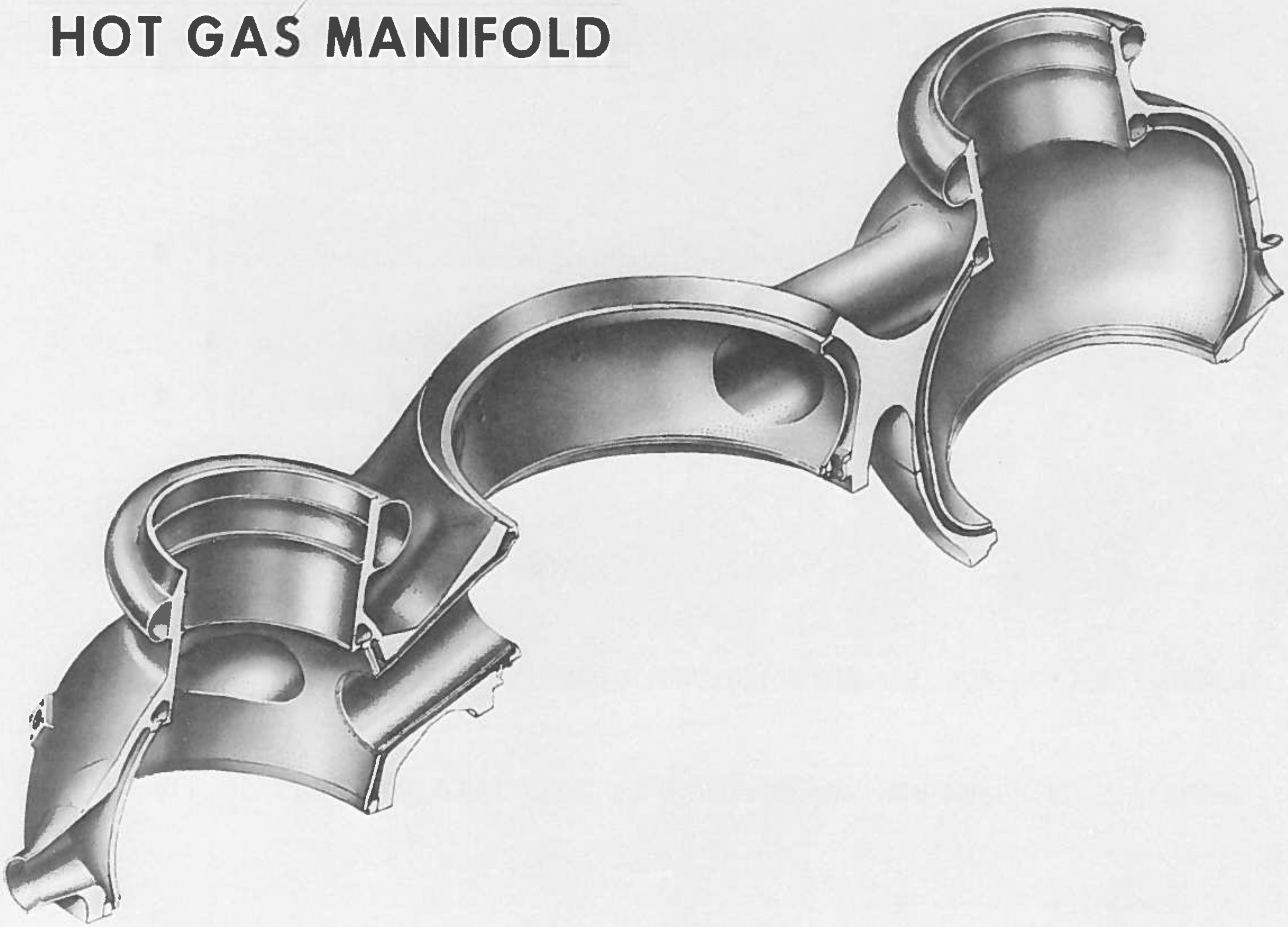
LC301-961B

Rocketdyne Division
Rockwell International

HGM STRUCTURAL FEATURES

- MATERIAL: INCONEL 718
  - HIGH-STRENGTH CORROSION-RESISTANT MATERIAL
  - HEAT-TREATED FOR MAXIMUM STRENGTH
  - MAXIMUM TEMPERATURE IS LIMITED TO MAINTAIN STRENGTH
  - NICKEL ALLOY IS SUSCEPTIBLE TO A HYDROGEN EMBRITTLEMENT ENVIRONMENT (HEE)
    - STRAINS IN MATERIAL EXPOSED TO H_2 ARE KEPT BELOW THE HEE RANGE OR ARE PROTECTED WITH AN OVERLAY OF INCOLOY 903

HOT GAS MANIFOLD



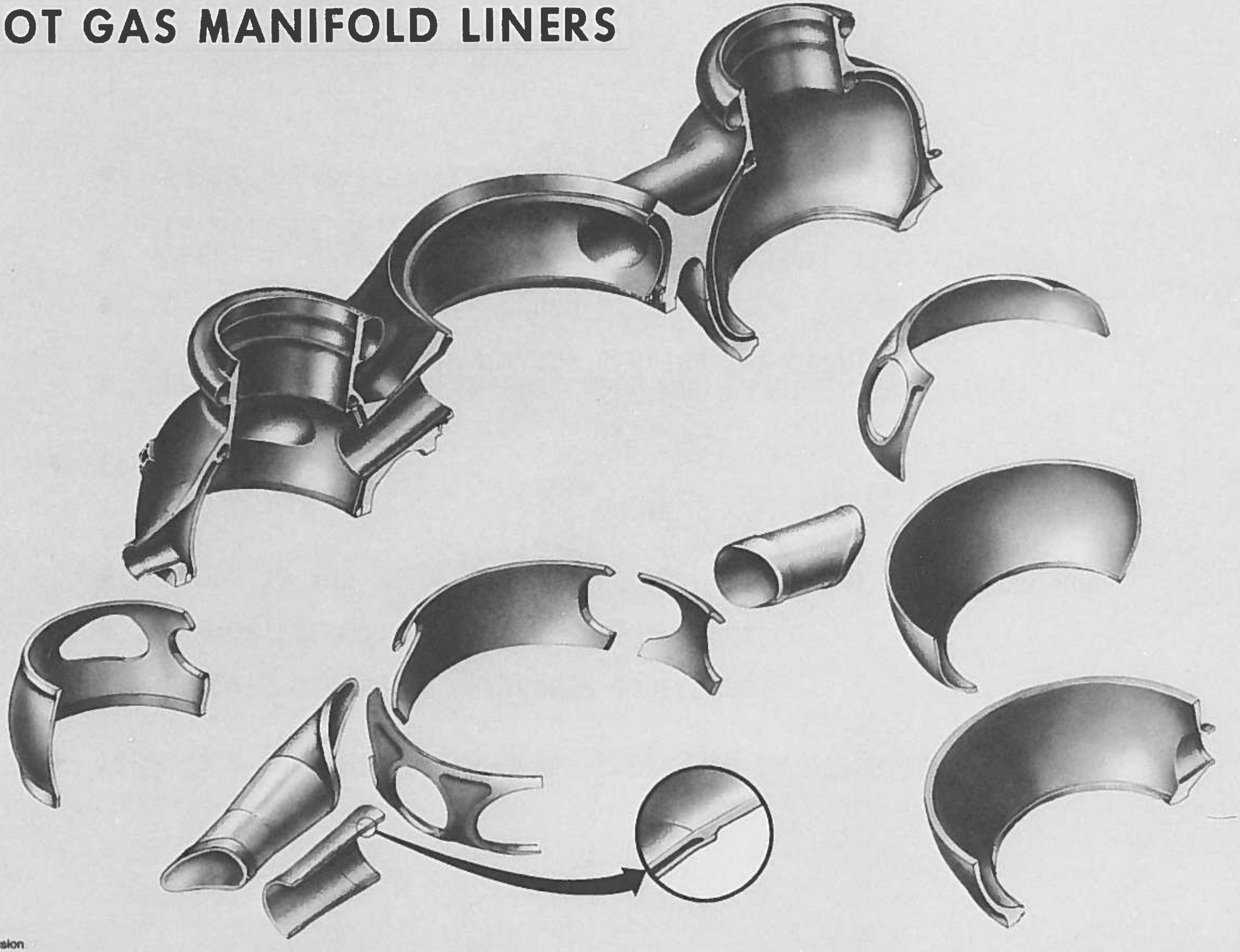
LC301-960

Rocketdyne Division
Rockwell International

HGM COOLING TECHNIQUE

- ALL OF STRUCTURE KEPT COOL TO MAINTAIN MAXIMUM MATERIAL STRENGTH
- LINERS SEPARATE COOLANT AND STRUCTURE FROM THE HOT-GAS ENVIRONMENT
  - MATERIAL: INCOLOY 903
  - NOT SUSCEPTIBLE TO HEE
  - HAS A LOW COEFFICIENT OF THERMAL EXPANSION
    - REDUCE THERMALLY-INDUCED LOADS
  - TRANSFER TUBE LINERS REQUIRE DOUBLE WALLS TO FURTHER REDUCE THERMAL EXPANSION

HOT GAS MANIFOLD LINERS



LC301-960C

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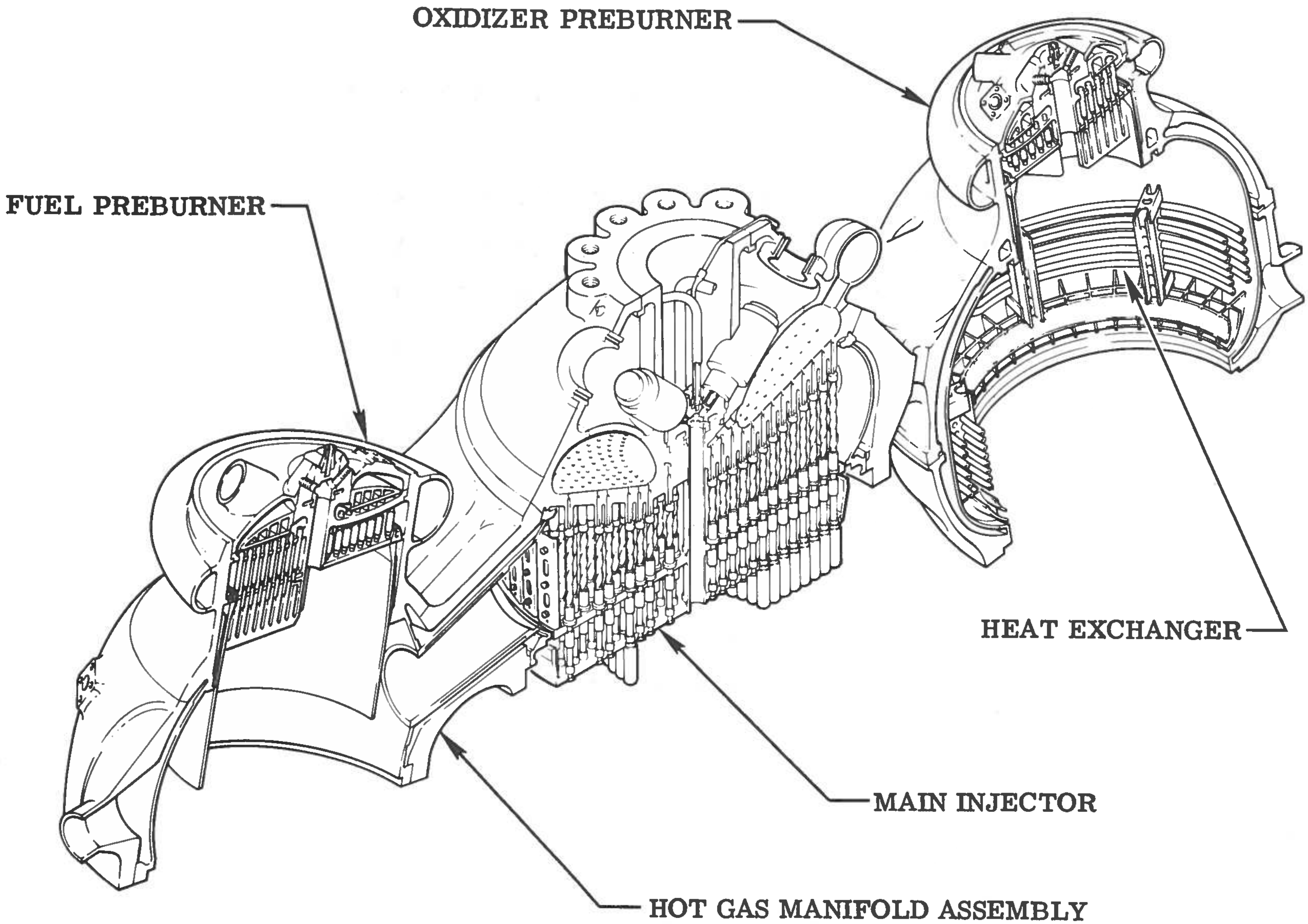
HGM STRUCTURAL ENTITIES

- PREBURNER COMBUSTION CHAMBERS - FUEL AND OXIDIZER SIDES
    - SUPPORTS WELDED-IN PREBURNER INJECTORS
    - CYLINDRICAL FOR EFFICIENT PRESSURE VESSEL
    - WELDED TO AND BECOMES AN INTEGRAL PART OF THE COLLECTOR BOWL

- COLLECTOR BOWLS
    - SUPPORTS THE HIGH-PRESSURE FUEL AND OXIDIZER TURBOPUMPS
        - COLLECTS THE EXHAUST GAS LEAVING THE TURBINE
    - SUPPORTS PREBURNER COMPONENTS
    - SPHERICAL SHAPE FOR MOST EFFICIENT PRESSURE VESSEL VOLUME PER UNIT OF WEIGHT
    - OXIDIZER SIDE COLLECTOR ALSO HOUSES THE HEAT EXCHANGER

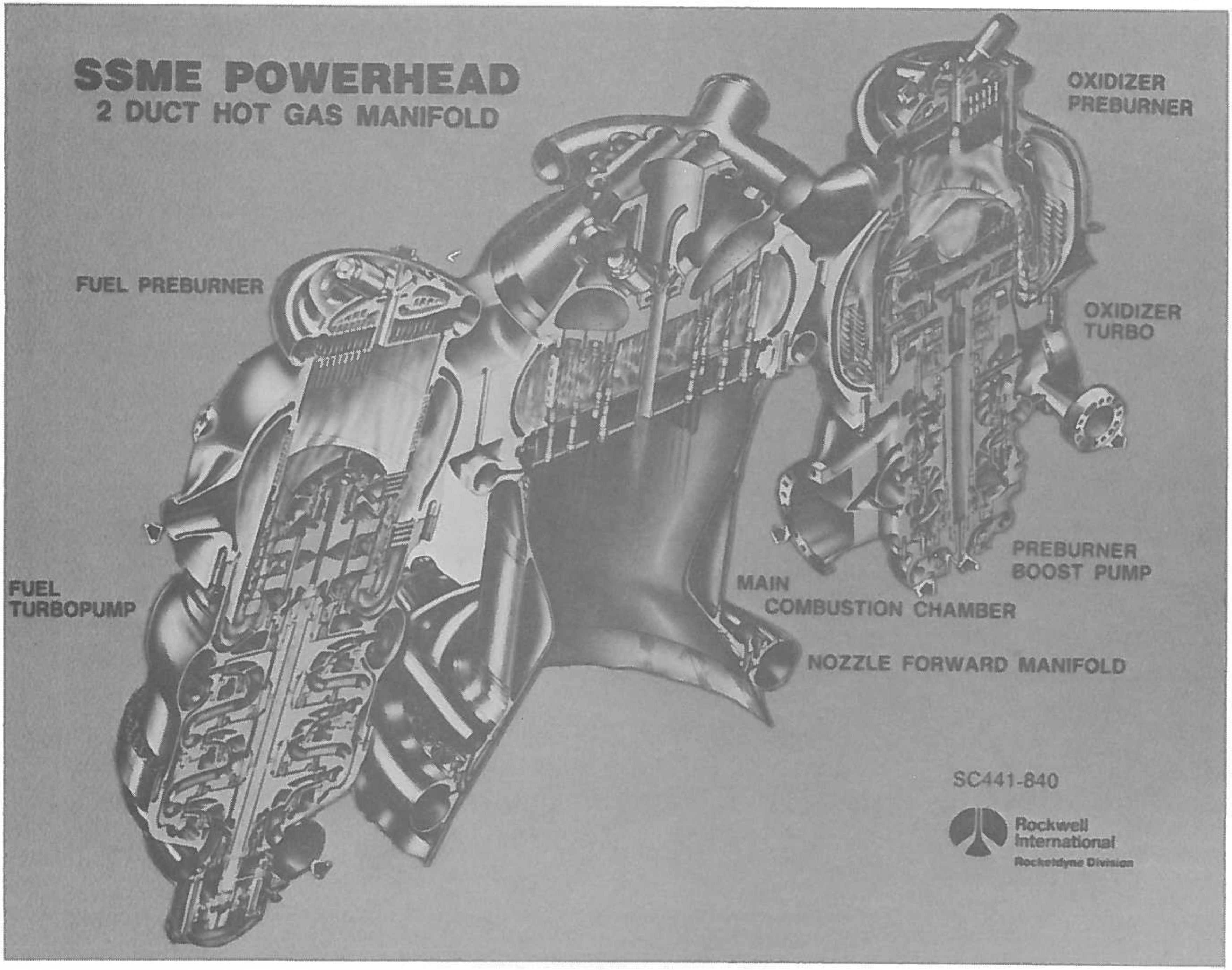
HGM/INJECTOR ASSEMBLY



LSS-EC-T-112B

HGM FLOW IMPROVEMENT PROJECT

- GOALS
  - REDUCE FLOW-BACK PRESSURE
  - REDUCE FLOW VELOCITY
  - REDUCE FLOW TURBULENCE
  - REDUCE DYNAMIC LOAD ON LOX POSTS
- CHANGES TO ACHIEVE GOALS
  - INCREASE FUEL COLLECTOR AREA
  - ELIMINATE CENTER TRANSFER TUBE
  - INCREASE TRANSFER TUBE TOTAL FLOW AREA
  - INCREASE MAIN INJECTOR TORUS FLOW AREA
- MAINTAIN ALL MAJOR INTERFACES



SSME POWERHEAD

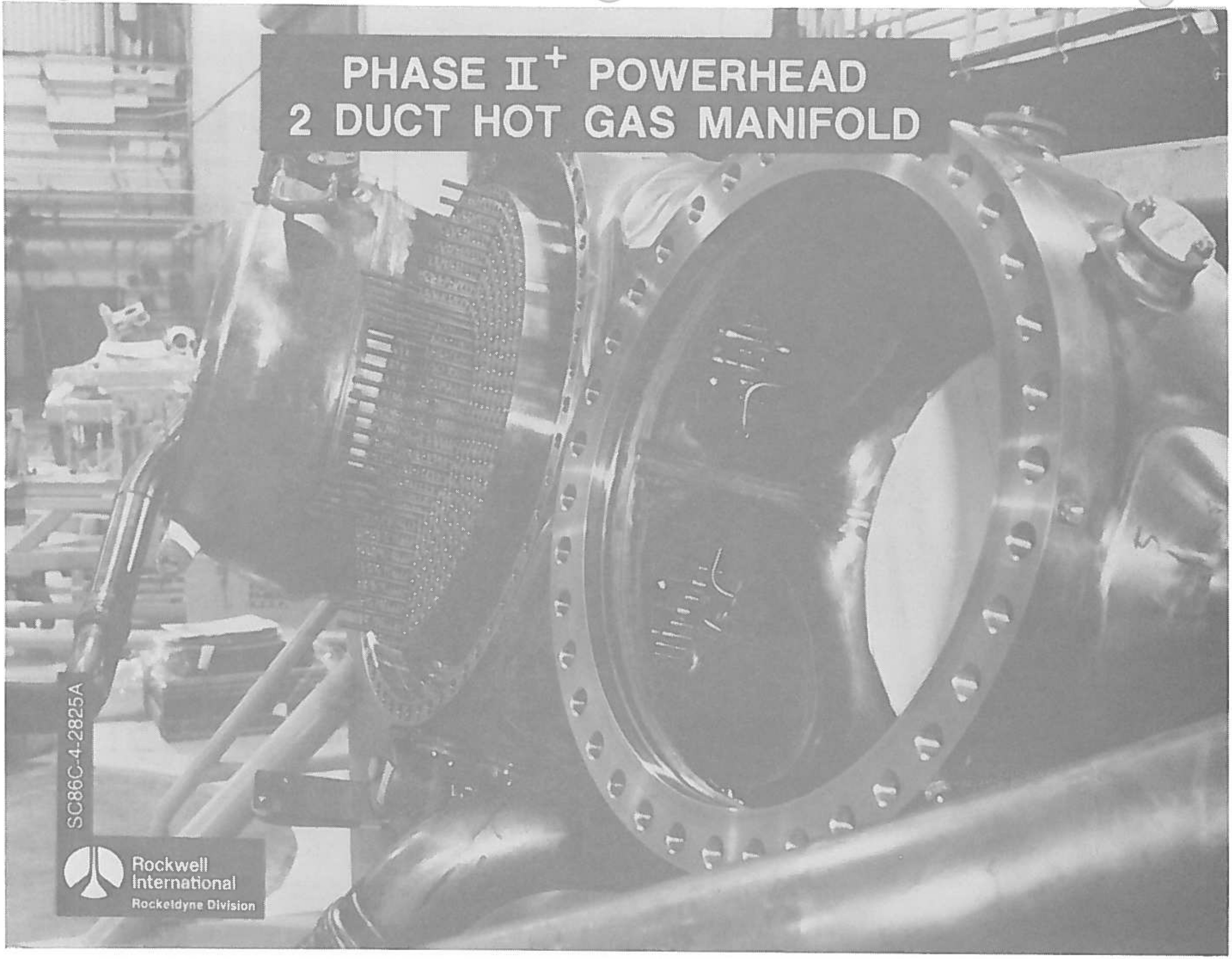
2 DUCT HOT GAS MANIFOLD

SSME IMPROVED FLOW HGM

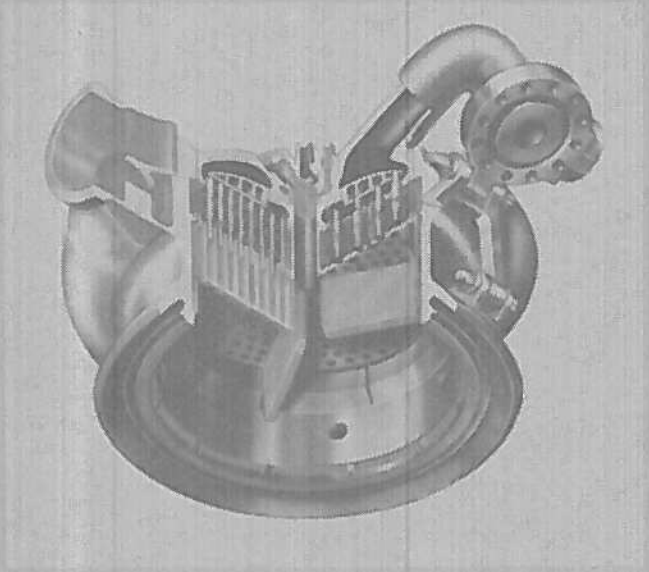
- TWO DUCT PHASE II^+ DESIGN
  - TWO LARGE ELLIPTICAL FUEL SIDE TRANSFER TUBES
  - LARGER TORUS FLOW AREA
  - FUEL BOWL IS MAXIMUM FEASIBLE WHILE RETAINING HPFTP INTERFACES
  - OXIDIZER SIDE RETAINS HEAT EXCHANGER BOWL STRUCTURES AND TRANSFER TUBE STRUCTURE WHILE INCORPORATING THE NEW TORUS CROSS SECTION AND INCREASING TRANSFER TUBE HOT GAS FLOW AREA

	NEW DESIGN	PRODUCTION	% CHANGE
● FUEL TRANSFER TUBE AREA	66. $IN.^2$	36 $IN.^2$ INLET 51 $IN.^2$ OUTLET	83% 29%
● TORUS FLOW AREA	12.9 $IN.^2$	9.5 $IN.^2$	36%
● FUEL BOWL FLOW AREA	15.7 $IN.^2$	6.05 $IN.^2$	160%
● HPFTP INTERFACE DIAMETER	15.5 IN.	15.5 IN.	----
● OXIDIZER TRANSFER TUBE AREA	30.4 $IN.^2$	24.4 $IN.^2$	25%

PHASE II$^+$ POWERHEAD 2 DUCT HOT GAS MANIFOLD



FUEL PREBURNERS



GEOMETRY	
• INTERNAL DIAMETER	10.43 IN.
• COMBUSTOR LENGTH	4.37 IN.
• INCO 625 FACEPLATE	
• INJECTOR CONFIGURATION	CONCENTRIC ORIFICE
• NUMBER OF ELEMENTS	264
• BAFFLE LENGTH	2.25 IN.
MATERIAL	NARLOY-A

PHASE II OPERATING PARAMETERS (RPL, MR-6.026)	100%	109%
• INJECTOR END PRESSURE (PSIA)	4868	5462
• COMBUSTION TEMPERATURE (°R)	1794	1904
• HOT GAS MIXTURE RATIO (O/F)	0.9152	0.9813
• OXIDIZER FLOWRATE (INCLUDING IGNITER) (LB/SEC)	75.80	87.97
• FUEL FLOWRATE (INCLUDING IGNITER) (LB/SEC)	82.83	89.64

LC308-56D

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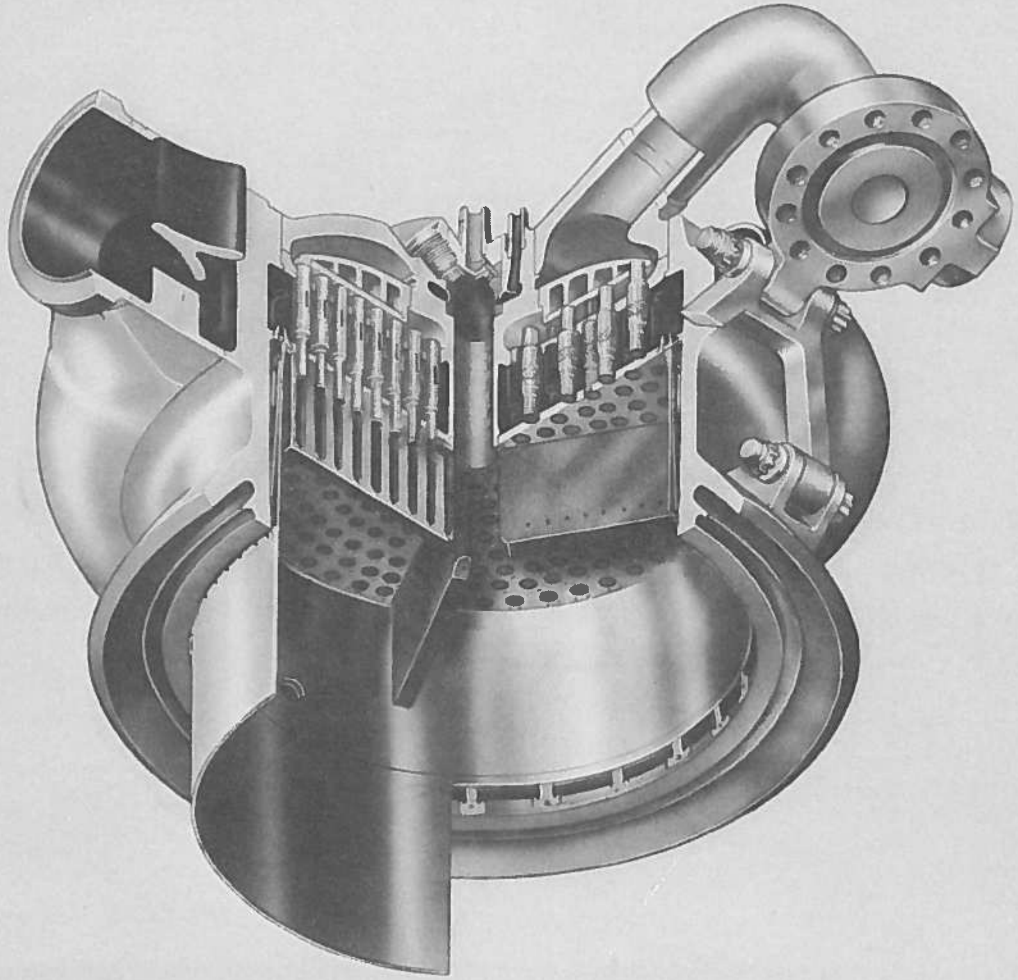
Rocketdyne Division

FUEL PREBURNER



LC303-154D

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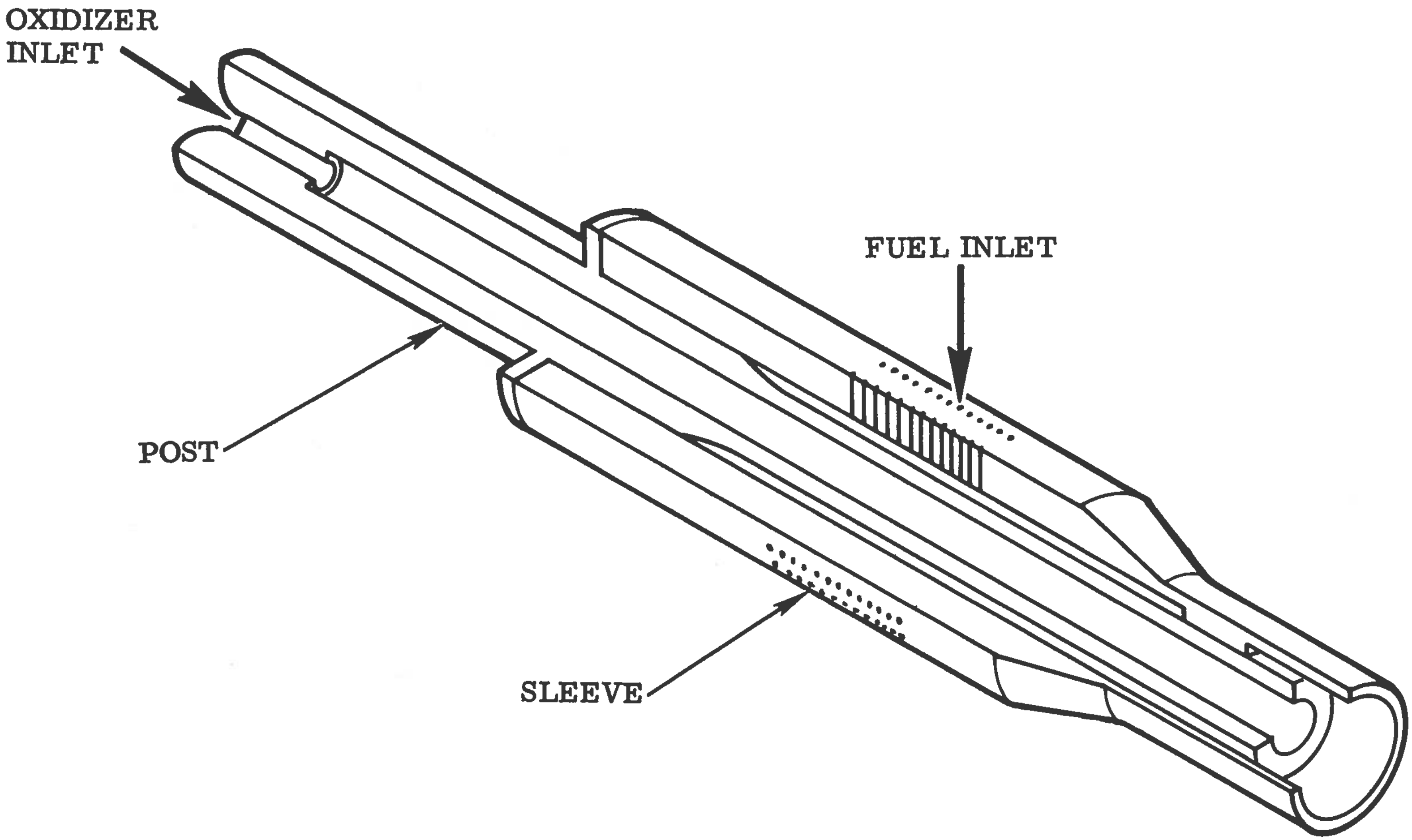
PREBURNER INJECTION ELEMENT

Each SSME preburner injector consists of many individual coaxial injector elements arranged to produce a showerhead spray pattern (no impinging streams). Each basic coaxial element consists of a tube within a tube. The center tube carries heavy, slow-moving liquid oxygen, while the outer tube (annulus) carries light, fast-moving gaseous hydrogen. The relative velocities and differing densities cause a stripping and mixing action to occur at the tip, precluding any need for angled, impinging streams. The fuel shroud around the heavy, slow-moving oxidizer stream also helps to isolate it from combustion disturbances. The basic element design is sometimes modified to adapt it to specific requirements.

PREBURNER INJECTOR ELEMENT



LSS-EC-T-120

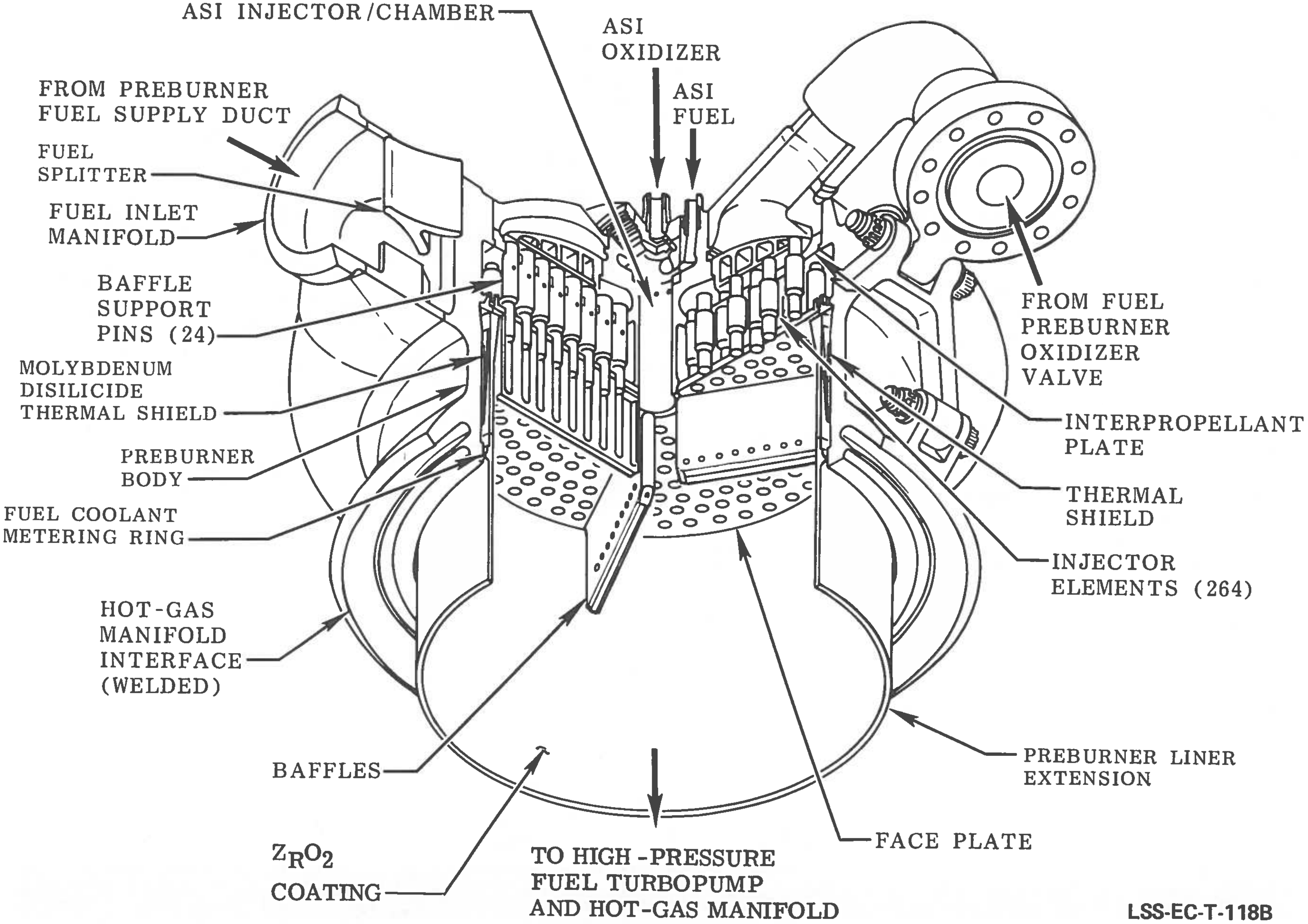
FUEL PREBURNER

The fuel preburner combusts hydrogen and oxygen at an extremely fuel-rich mixture ratio, and thus supplies hot gas to drive the high-pressure fuel turbopump. 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 elements, 24 of which 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.

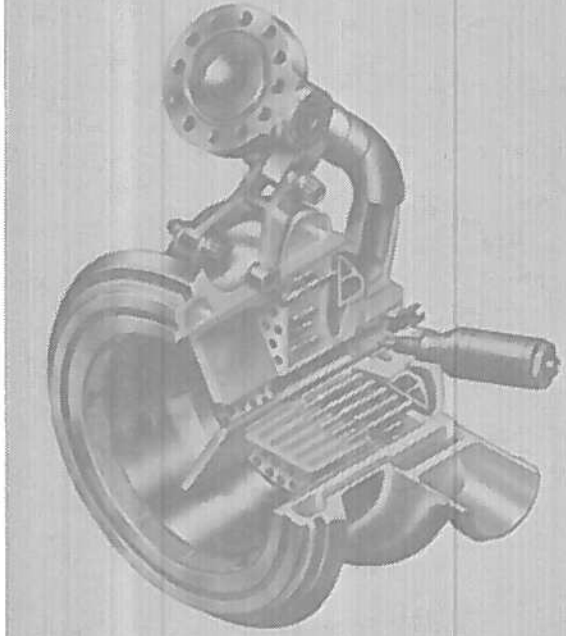
An augmented spark igniter (ASI) chamber is located in the center of the injector. Small quantities of hydrogen and oxygen are continuously injected into this chamber, and are initially ignited by two spark igniters located therein. This flame then ignites the propellants flowing through the injector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

FUEL PREBURNER



LSS-EC-T-118B

OXIDIZER PREBURNER



GEOMETRY

• INTERNAL DIAMETER	7.43 IN.
• COMBUSTOR LENGTH	4.25 IN.
• INCO 625 FACEPLATE	
• INJECTOR CONFIGURATION	CONCENTRIC ORIFICE
• NUMBER OF ELEMENTS	120
• BAFFLE LENGTH	2.25 IN.
• MATERIAL	NARLOY-A

PHASE II OPERATING PARAMETERS (RPL, MR-6.0)

	100%	109%
• CHAMBER PRESSURE (PSIA)	5039	5654
• COMBUSTION TEMPERATURE (°R)	1522	1625
• HOT GAS MIXTURE RATIO (O/F)	0.7453	0.8051
• OXIDIZER FLOWRATE (INCLUDING IGNITER) (LB/SEC)	25.11	29.21
• FUEL FLOWRATE (INCLUDING IGNITER) (LB/SEC)	35.16	37.92

LC308-55D

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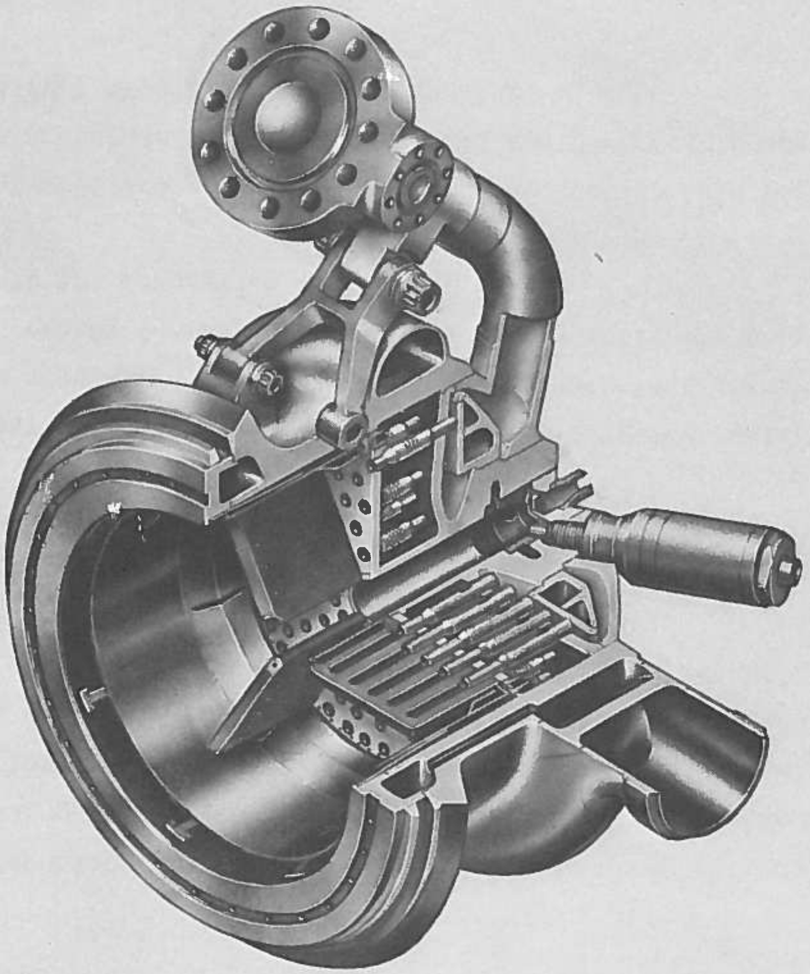
OXIDIZER PREBURNER



LC301 339D

OXIDIZER PREBURNER

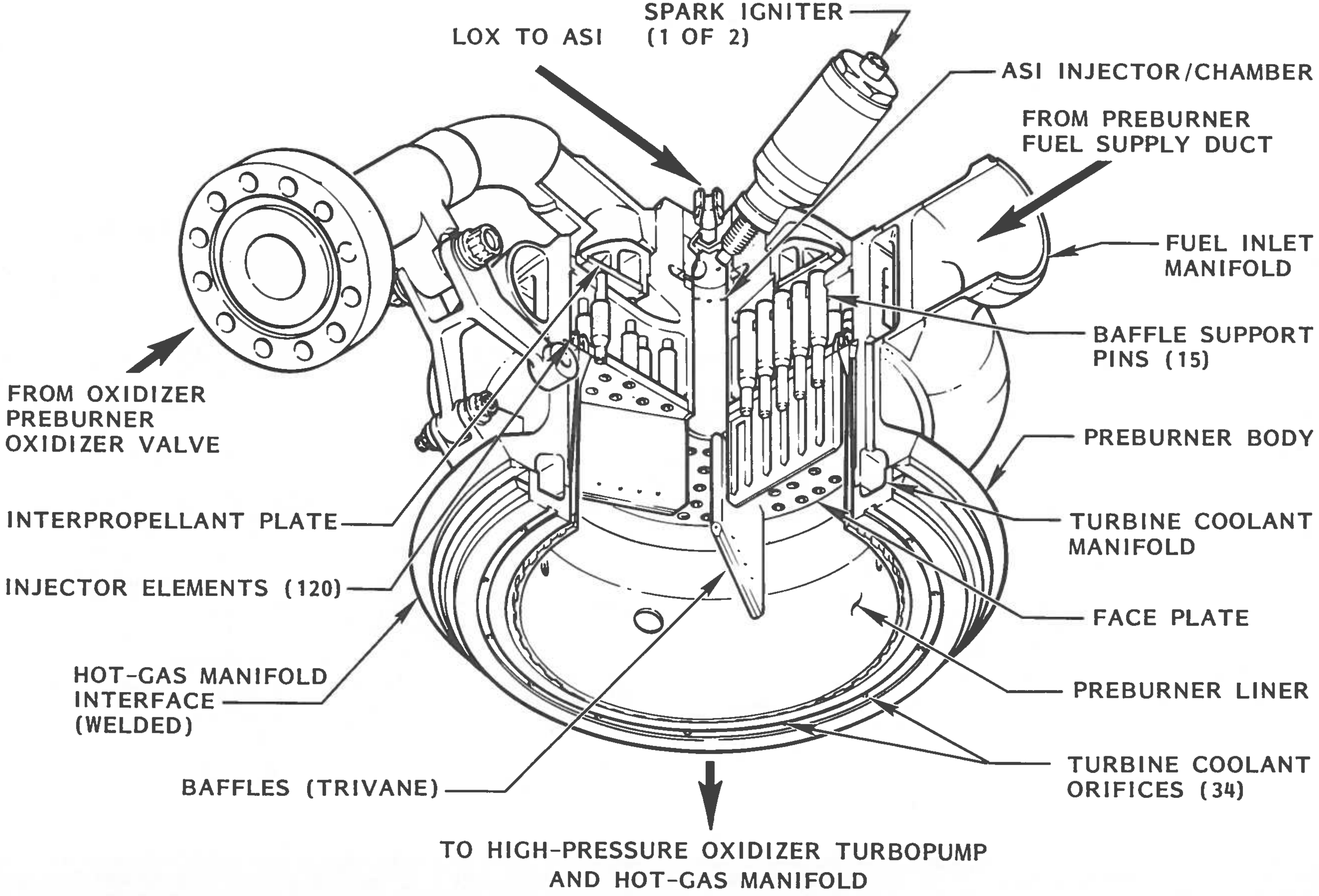
The oxidizer preburner combusts hydrogen and oxygen at an extremely fuel-rich mixture ratio, and thus supplies hot gas to drive the high-pressure oxidizer turbopump. Welding the injector into the top of the HGM forms the combustion area and places it immediately above the pump turbine. Injector diameter is about 7.5 inches. The injector is made up of 120 elements, 15 of which 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 igniter (ASI) 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 area.

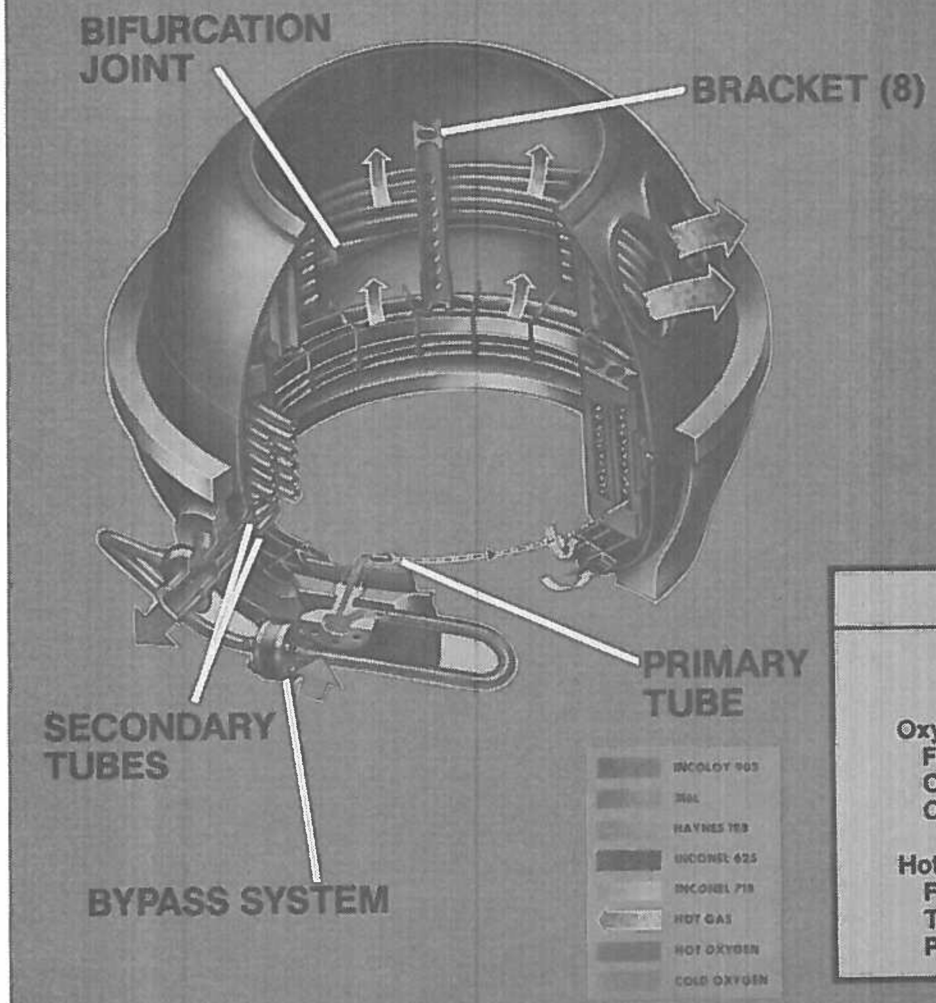
Because the high-pressure oxidizer turbopump does not contain fuel to cool its turbine, fuel is tapped from the preburner fuel inlet manifold and directed through a turbine coolant manifold down to the high-pressure oxidizer turbopump turbine.

OXIDIZER PREBURNER



LSS-EC-T-119B

SSME Heat Exchanger Assembly



Features

- Supplies hot oxygen for external tank pressurization and pogo accumulator
- Heated by high pressure oxidizer turbopump turbine exhaust
- 316L CRES tubing
  - Primary – .215 OD x .0125 w x 2.6 ft
  - Secondaries – .382 OD x .0265 w x 25.8 ft

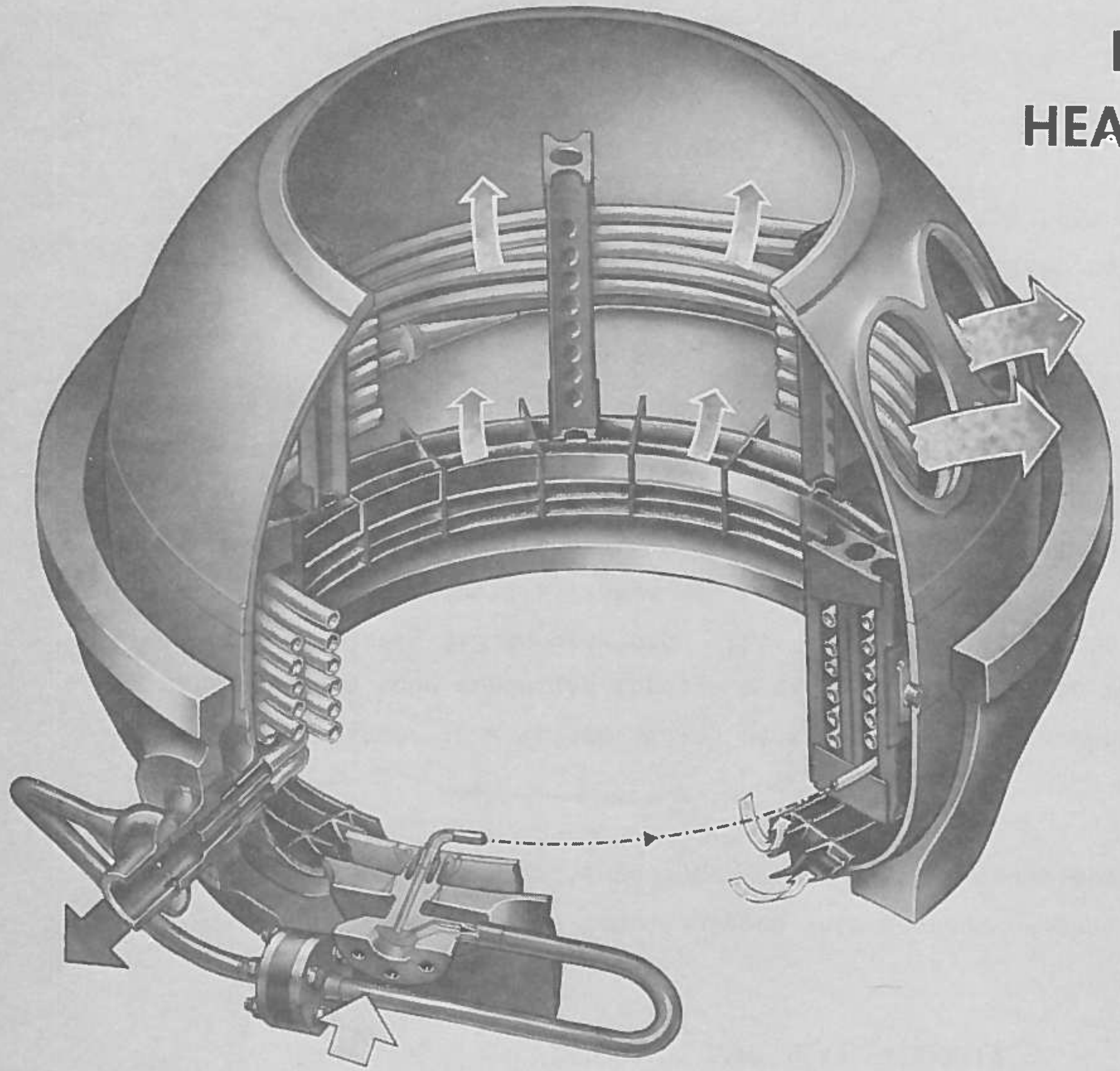
Key Performance Parameters

	RPL (100%)	FPL (109%)
Oxygen		
Flowrate (lb/s)	1.1, 2.35	1.2, 2.45
Outlet temp. (°R)	835	880
Outlet press (psia)	3700, 3300	4100, 3700
Hot gas		
Flowrate (lbs)	60	67
Temperature (°R)	1370	1450
Pressure (psia)	3300	3600

Rockwell International
Rockeldyne Division

LC308-60C

LOX TANK PRESS
HEAT EXCHANGER ASSY



- INCOLOY 903
- 316L
- HAYNES 188
- INCONEL 625
- INCONEL 718
- ⇦ HOT GAS
- HOT OXYGEN
- COLD OXYGEN

Rocketdyne Division
Rockwell International

LC301-394D

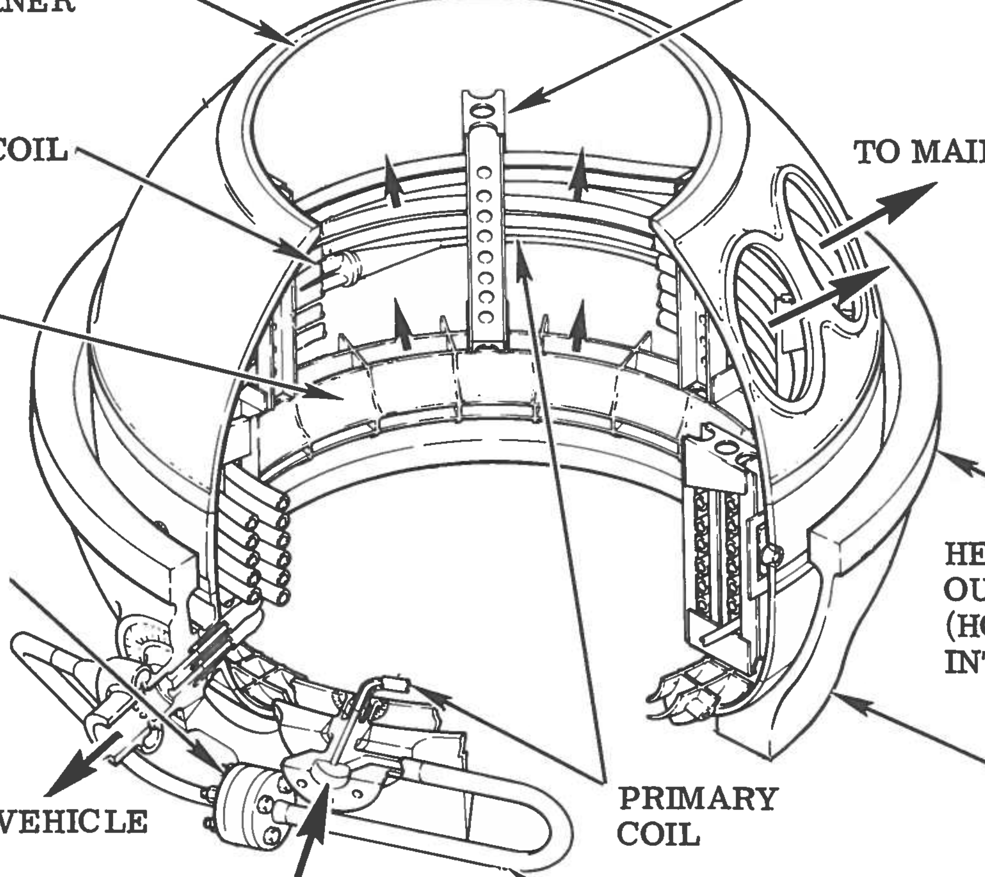
SSME HEAT EXCHANGER

The heat exchanger converts liquid oxygen into gaseous oxygen, to be used for vehicle oxygen tank pressurization and pogo suppression system accumulator pressurization.

The heat exchanger is a coiled tubing pack consisting of approximately 30 inches of a smaller single tube connected through a bifurcation joint to two larger parallel tubes, each approximately 310 inches long. This allows 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 flows over the coils, providing the heat necessary to change the liquid oxygen to gas.

SSME HEAT EXCHANGER



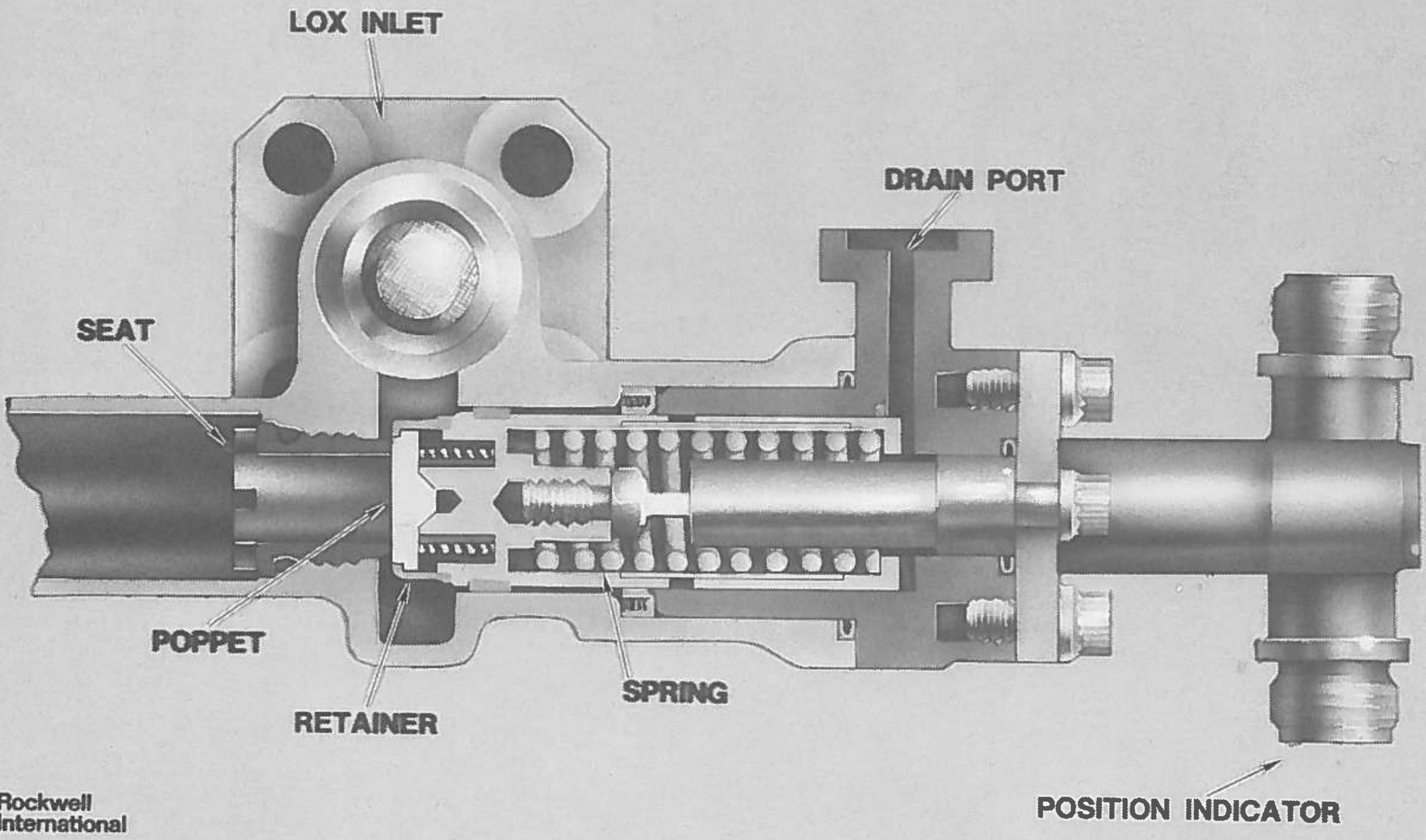
LSS-EC-T-117C

HEAT EXCHANGER ANTI-FLOOD VALVE

The anti-flood valve (AFV) prevents liquid oxygen from entering (flooding) the heat exchanger coil until sufficient heat is available at engine start to convert the LOX to GOX.

The AFV is a spring-loaded-closed, LOX pressure-opened, poppet-type valve. The metal poppet is self-alining to its metal seat. A linear variable differential transducer is used to indicate poppet position. The AFV is flange-mounted to the LOX high pressure duct at the outlet of the HPOTP, and feeds directly into the heat exchanger coil. LOX pressure of 200-300 psig acting on the poppet face opens it, permitting LOX flow to the heat exchanger.

ANTI-FLOOD VALVE



LC87C-4-1904

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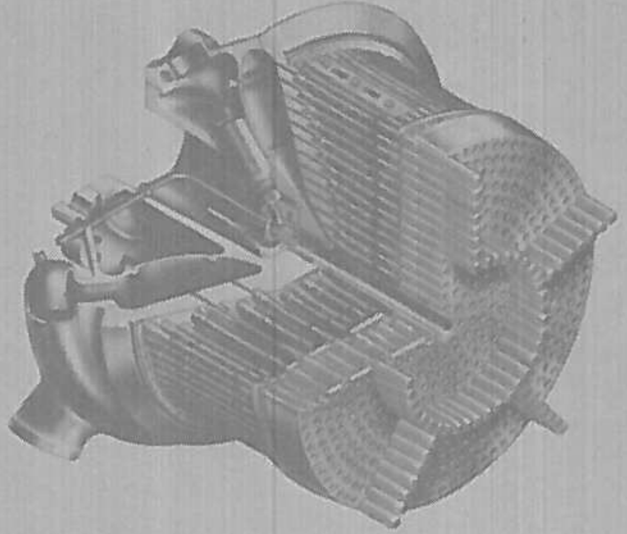
Rocketdyne Division

MAIN INJECTOR



GEOMETRY

• 347 CRES RIGIMESH FACEPLATES	
• DUAL SPARK IGNITER	
• FACE DIAMETER	17.74 IN.
• INJECTOR CONFIGURATION	CONCENTRIC ORIFICE
• NUMBER OF ELEMENTS	525
• NUMBER OF FLOW SHIELDS	42
• NUMBER OF BAFFLE ELEMENTS	75
• BAFFLE ELEMENT LENGTH	2 IN.

PHASE II OPERATING PARAMETERS (RPL, MR-6.026)

	100%	109%
• CHAMBER PRESSURE (PSIA)	3006	3277
• OXIDIZER FLOWRATE (LB/SEC)	792.4	856.1
• HOT GAS FLOWRATE (LB/SEC)	225.8	252.4
• COOLANT FLOWRATE (LB/SEC)		
• PRIMARY FACEPLATE	4.3	5.0
• SECONDARY FACEPLATE	2.9	3.4
• BAFFLES	16.5	18.5

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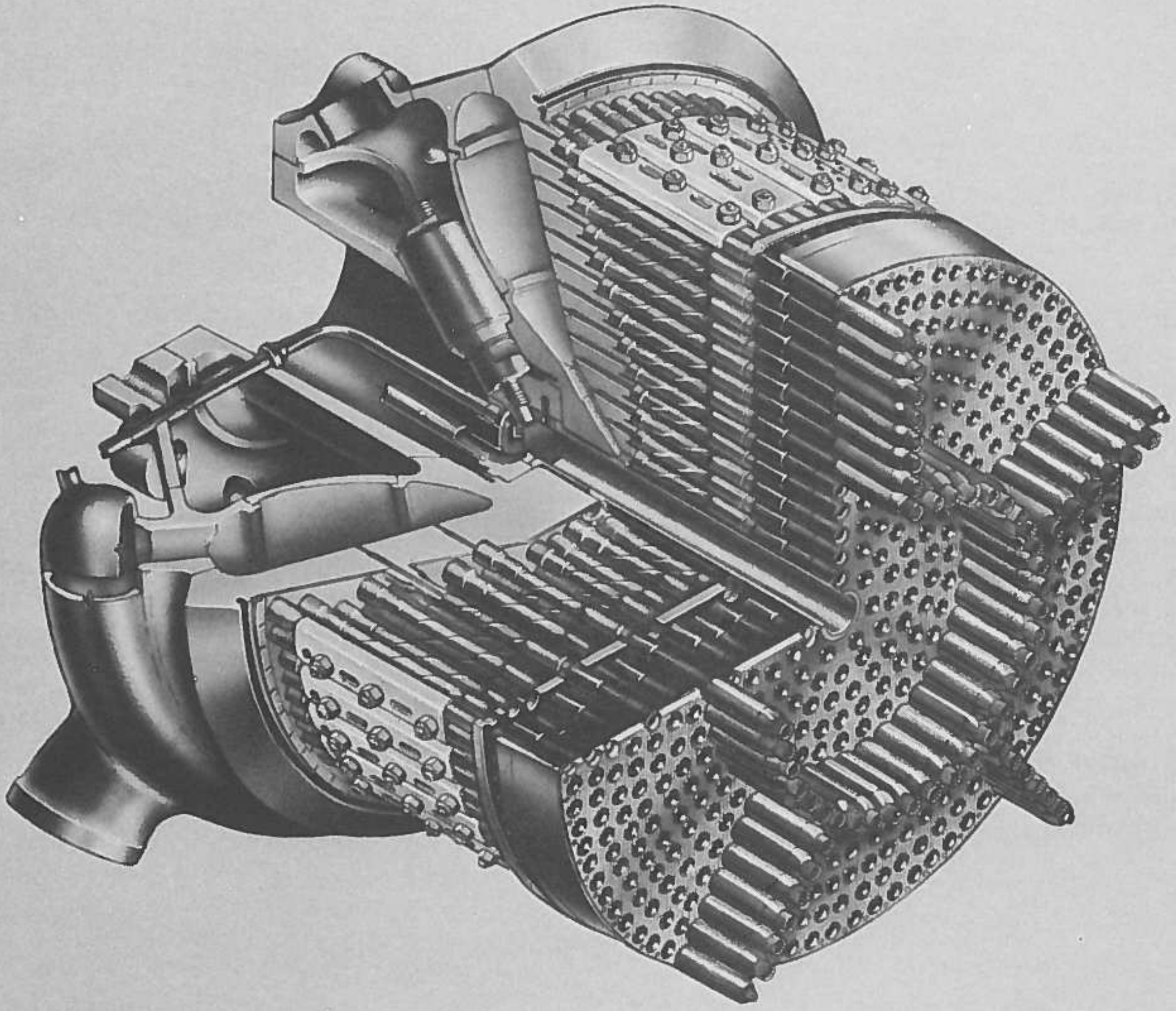
Rocketdyne Division

LC306-57F

MAIN INJECTOR ASSEMBLY



LC301-386C

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Rocketdyne Division

SSME MAIN INJECTOR

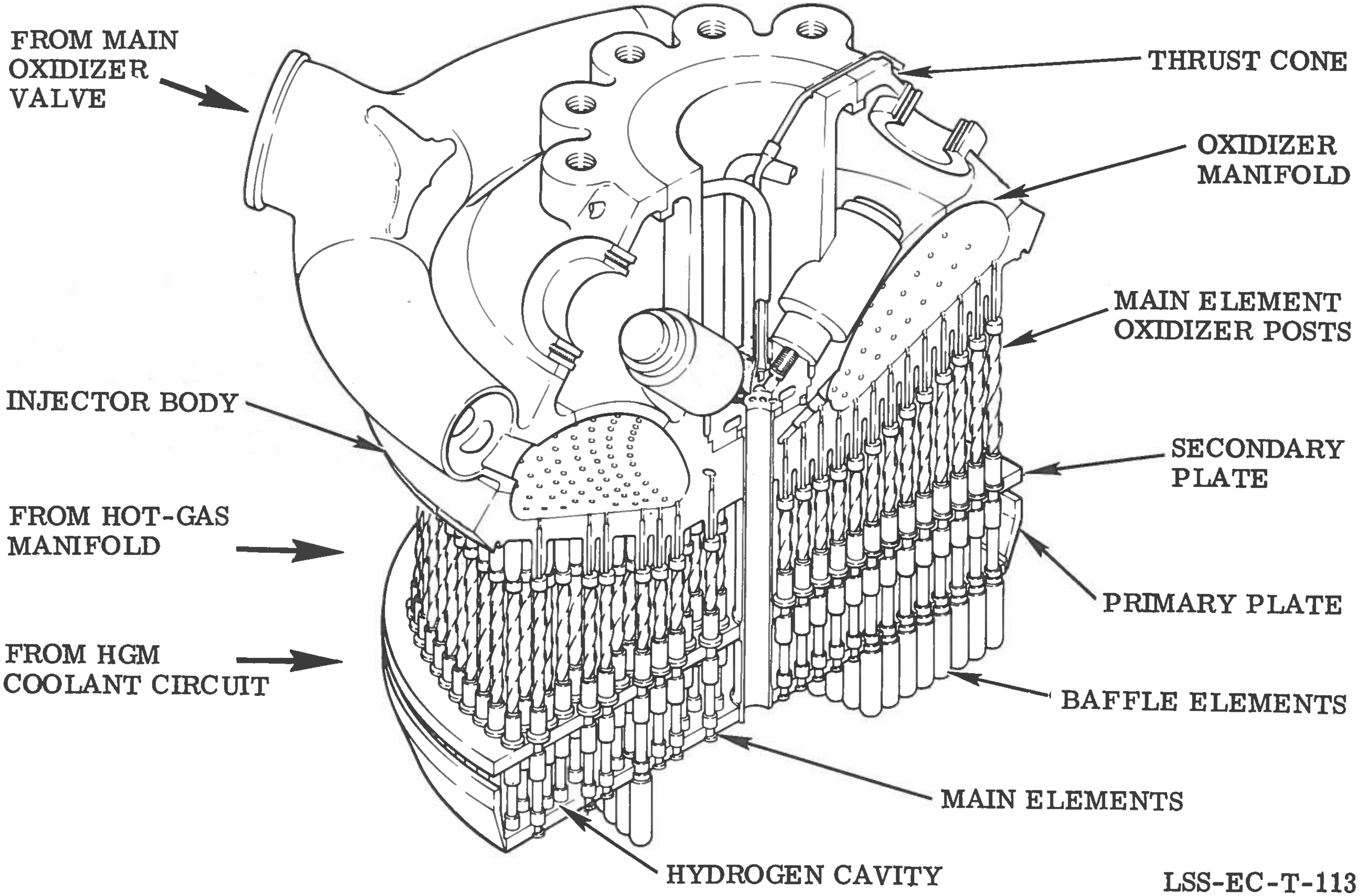
The main injector injects into the main combustion chamber a combination of hot, fuel-rich gas from the two preburners, cold hydrogen gas from the cooling circuits, and cold liquid oxygen from the HPOTP. By welding the injector into the center of the HGM, passageways are formed for these fluids to enter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

The injector includes 600 coaxial elements, 525 of which are main elements, and 75 of which are baffle elements. The baffle elements have 2-inch extensions that form the combustion chamber baffles. All 600 elements inject liquid oxygen from the oxidizer manifold through their center posts. The 525 main elements inject, through the annulus, the hydrogen gas entering the cavity between the heat shield and the secondary plate. The 75 baffle elements inject, and are cooled by, the cold hydrogen gas entering 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. The flow shields bolted to the elements help protect them from damage and erosion from the high-velocity gas.

An augmented spark igniter (ASI) 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 combusion chamber.

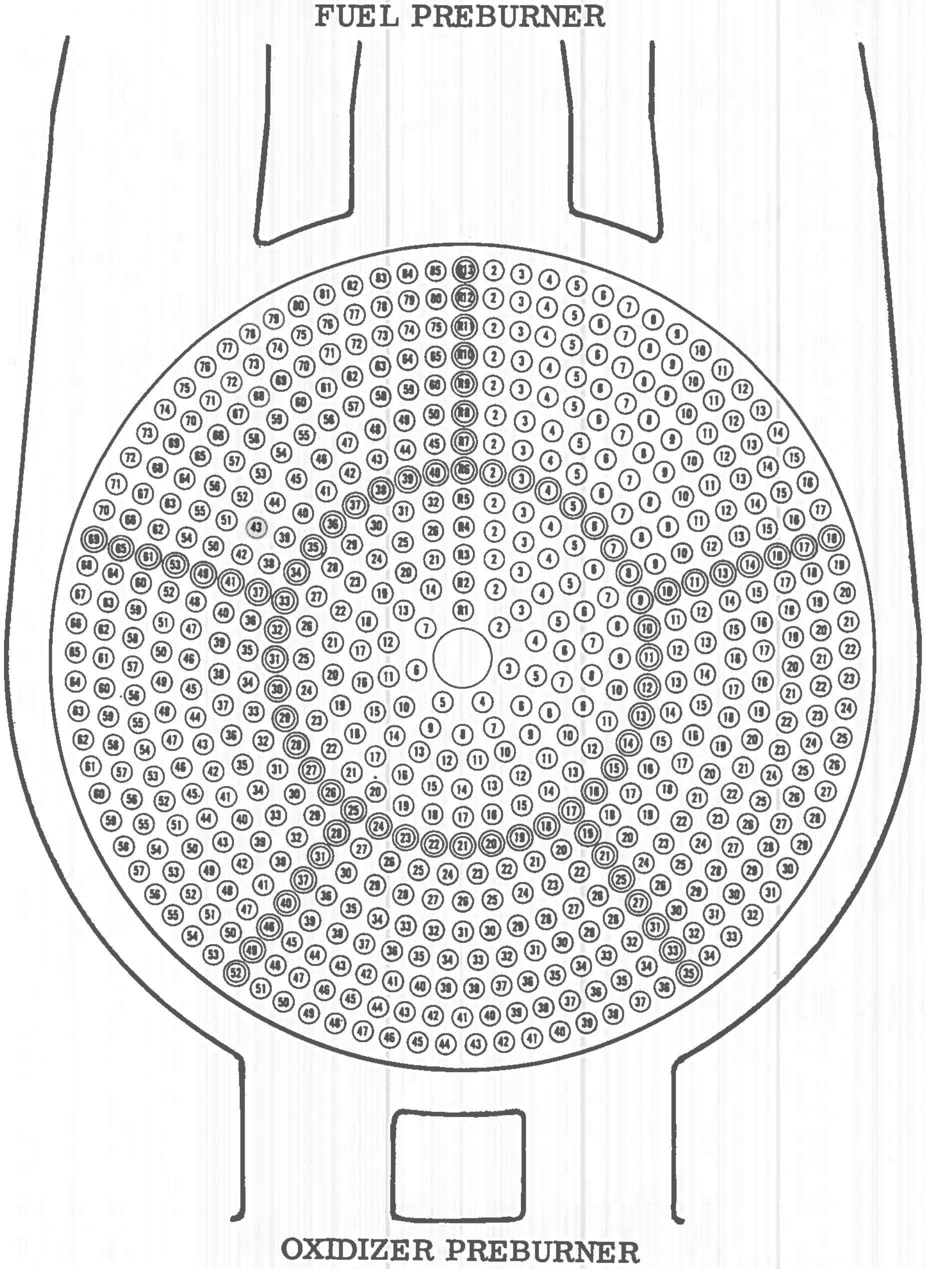
The thrust cone is a mounting pad for the gimbal bearing which, in turn, attaches the engine to the vehicle.

MAIN INJECTOR ASSEMBLY

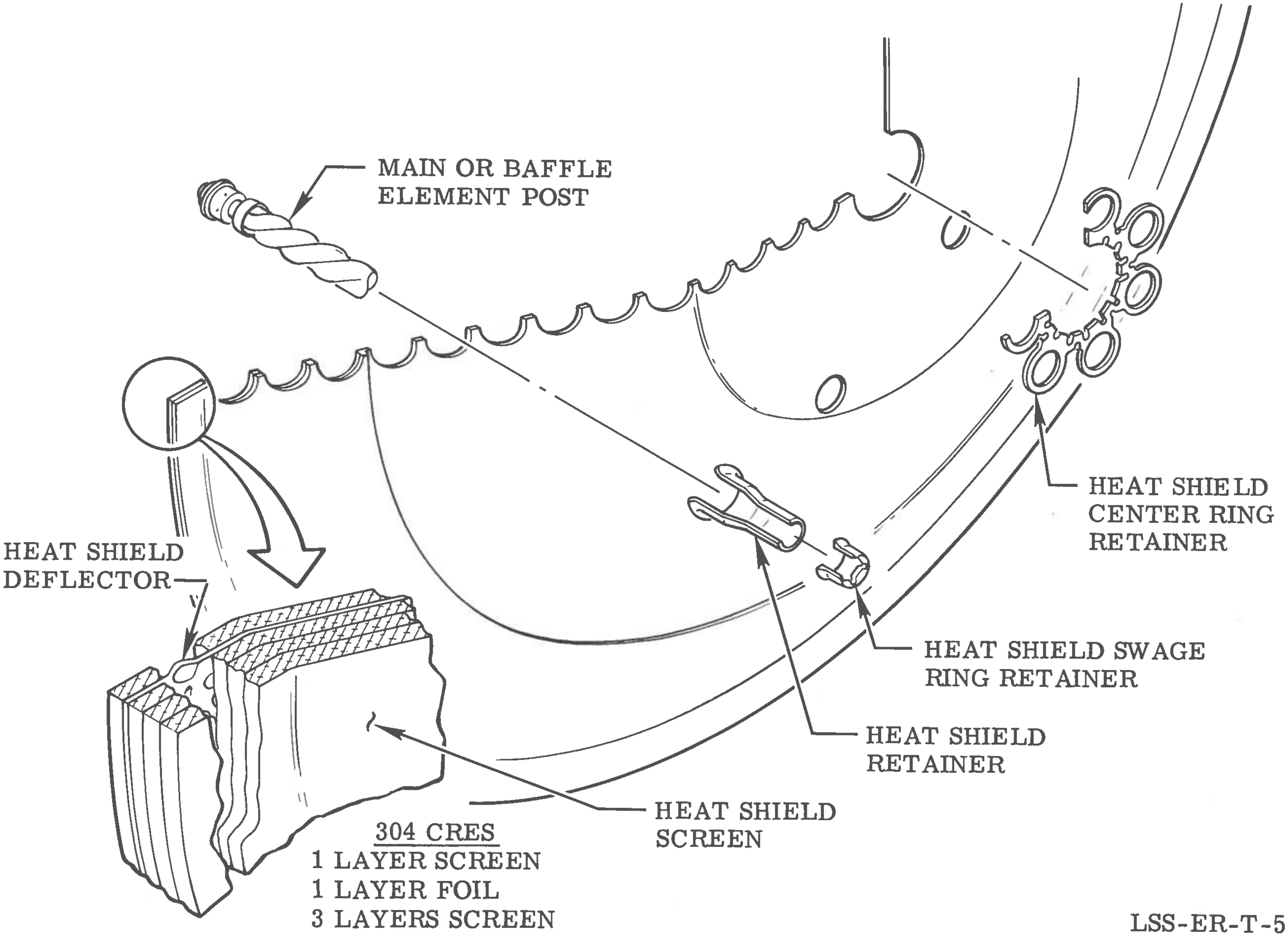


LSS-EC-T-113

HGM/MAIN INJECTOR POST RELATIONSHIP



MAIN INJECTOR HEAT SHIELD

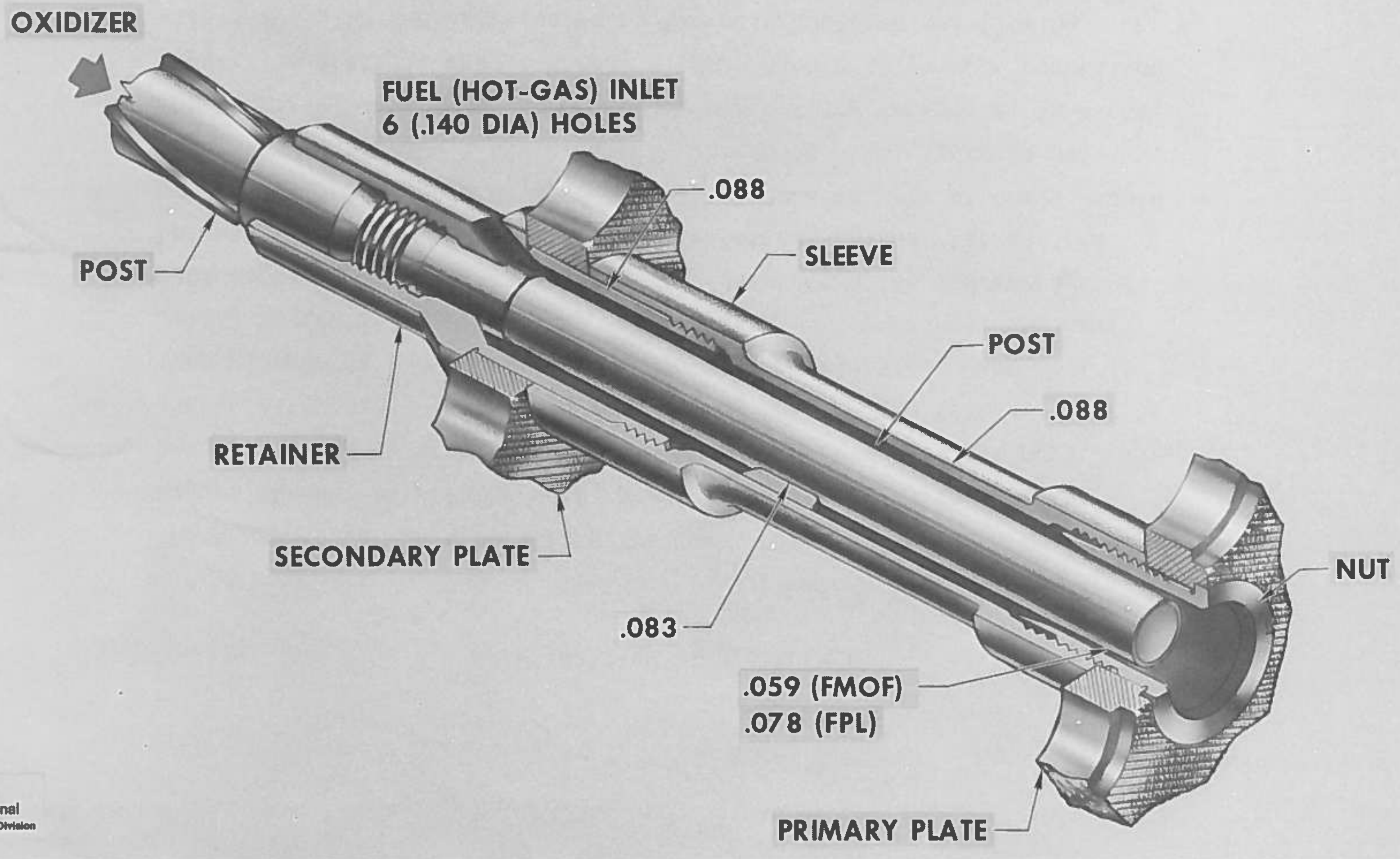


LSS-ER-T-59

MAIN INJECTOR MAIN ELEMENT

There are 525 coaxial main elements in the main injector. They carry liquid oxygen through the center post and hot hydrogen gas through the annulus formed by screwing the retainer and sleeve onto the post. The sleeve also clamps the secondary plate in place. The primary plate is then clamped to the sleeve with a faceplate nut. Each post is welded to the injector body by inertia welding (spinning), and has four machined-on helical spoilers to reduce vibration induced by the hot gas flowing around them. Each element establishes the desired propellant injection condition of a slower moving core of heavy liquid oxygen surrounded by a faster moving shroud of light hydrogen gas.

MAIN INJECTOR ELEMENT



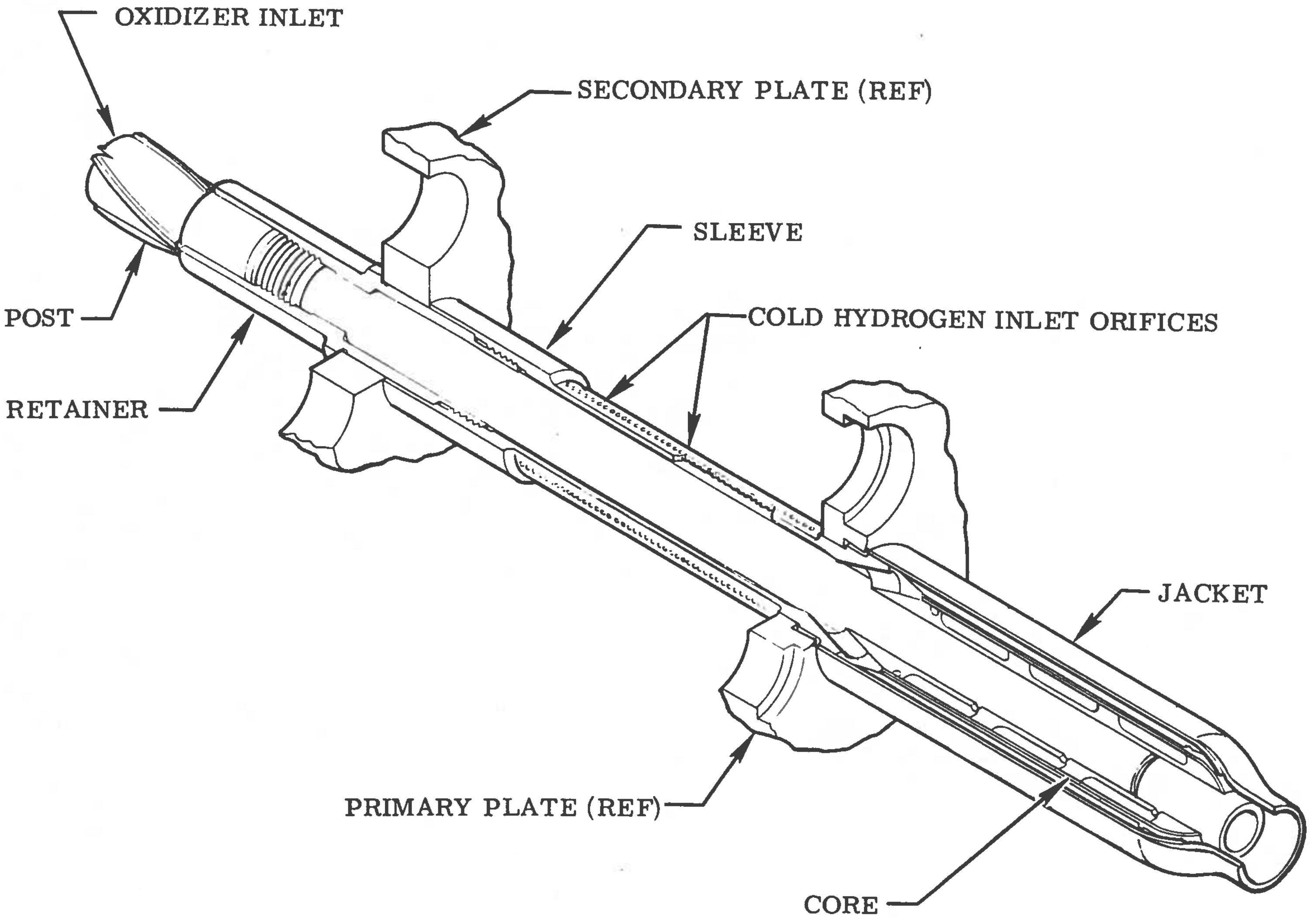
LC301-472F

Rockwell International
Rocketdyne Division

MAIN INJECTOR BAFFLE ELEMENT

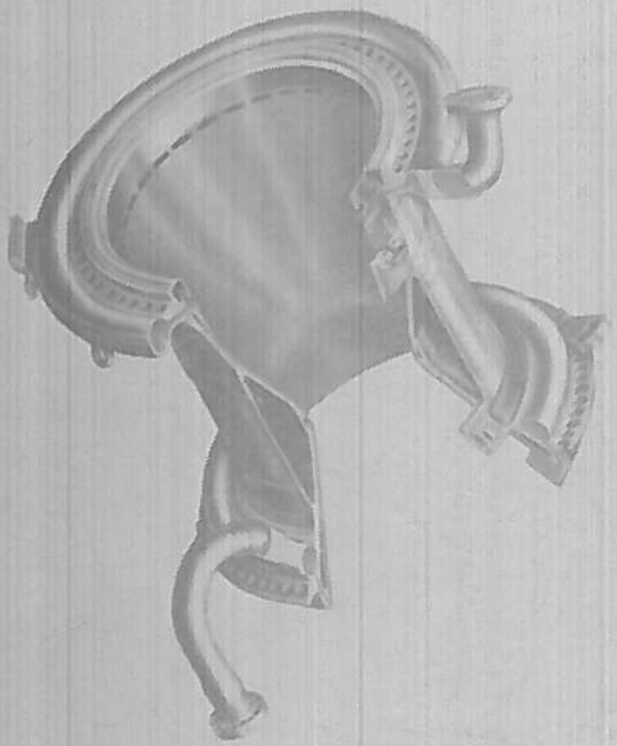
There are 75 baffle elements in the main injector. They carry liquid oxygen through the center post, and cold hydrogen gas through the annulus formed by screwing the retainer and sleeve onto the post. The sleeve also clamps the secondary plate in place. The primary plate is then clamped to the sleeve with the 2-inch baffle tip. Each post is welded to the injector body by inertia welding (spinning), and has four machined-on helical spoilers to reduce vibration induced by the hot gas flowing around them. Each element establishes the desired propellant injection condition of a slower moving core of heavy liquid oxygen surrounded by a faster moving shroud of light hydrogen gas. The baffle tips extend 2 inches below the primary faceplate, in a configuration that divides it into six compartments to promote combustion stability. The tips are cooled by the cold hydrogen gas flowing through them.

MAIN INJECTOR BAFFLE ELEMENT



LSS-EC-T-115A

MAIN COMBUSTION CHAMBER



GEOMETRY	
• NARLOY Z LINER + EDCu BARRIER + EDNi CLOSEOUT + INCO 718 STRUCTURE SHELL	
• NUMBER OF SLOTS	390
• NUMBER OF ACOUSTIC CAVITIES	30
• INJECTOR END DIAMETER	17.74 IN.
• THROAT AREA	83.41 IN.^{2}
• INJECTOR END TO THROAT LENGTH	14.00 IN.
• CONTRACTION RATIO	2.96:1
• EXPANSION RATIO	5.0:1

PHASE II
OPERATING PARAMETERS (RPL, MR-6.0)

	100%	109%
• THROAT STAGNATION PRESSURE (PSIA)	3010	3282
• COOLANT INLET PRESSURE (PSIA)	5978	6718
• COOLANT INLET TEMPERATURE (°R)	95	101
• COOLANT EXIT PRESSURE (PSIA)	4756	5315
• COOLANT EXIT TEMPERATURE (°R)	493	479
• COOLANT FLOWRATE (LB/SEC)	26.09	29.46
• HOT GAS WALL TEMPERATURE AT THROAT (°F)	1000	1000

LC308-54E

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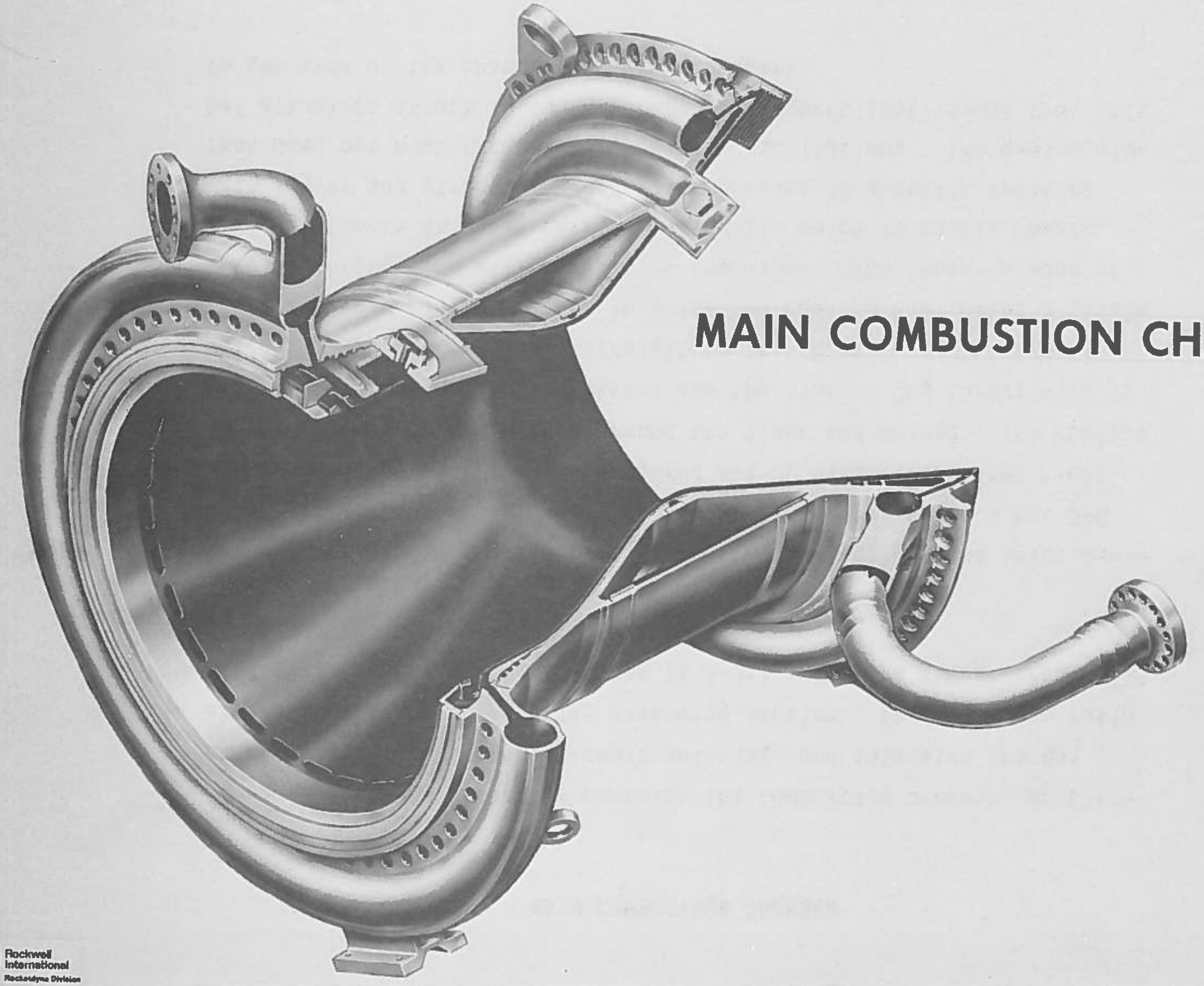
Rocketdyne Division

MAIN COMBUSTION CHAMBER



LC301-38IC

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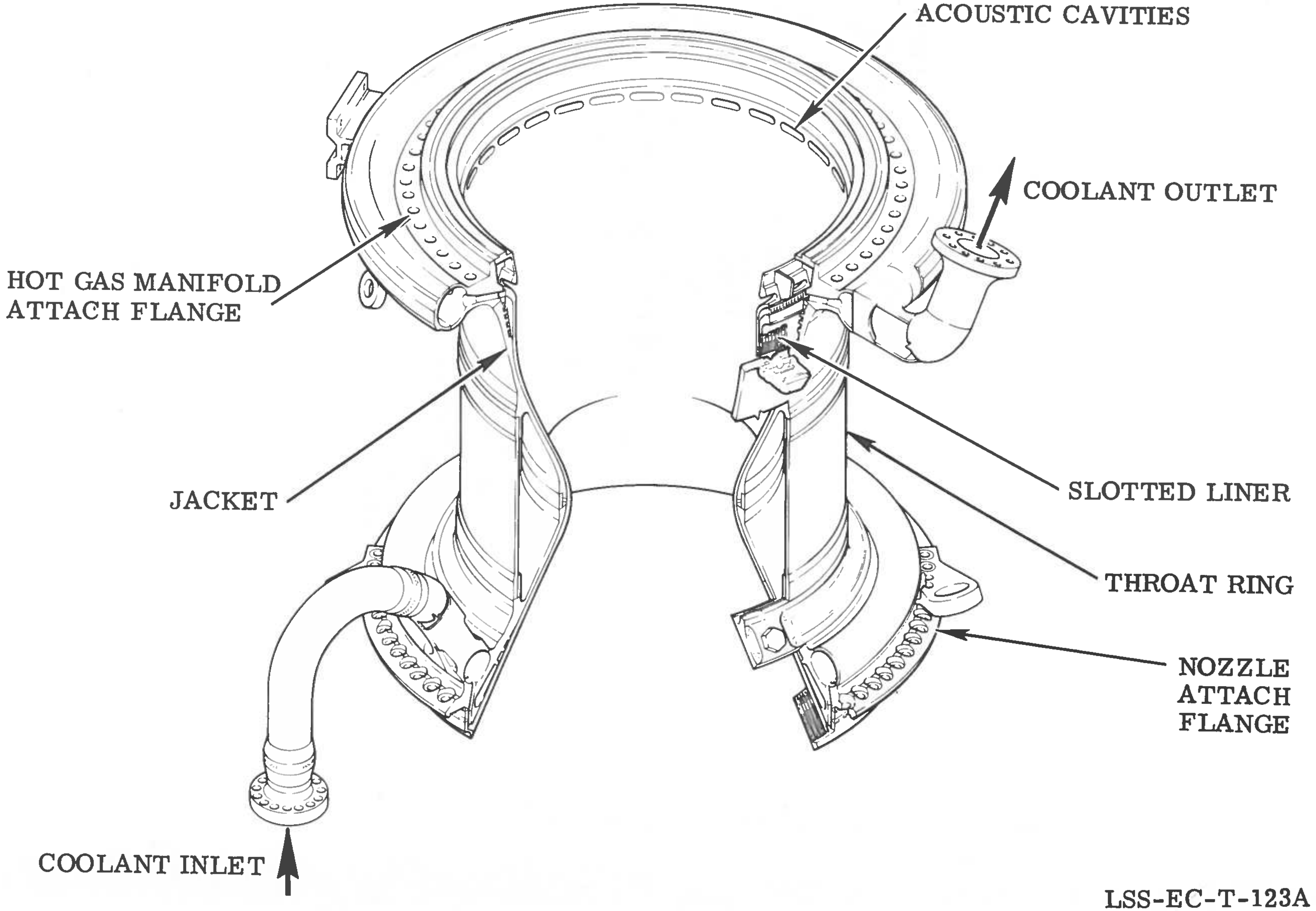
MAIN COMBUSTION CHAMBER

The main combustion chamber 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 5.0:1, with the throat area being 83.41 square inches.

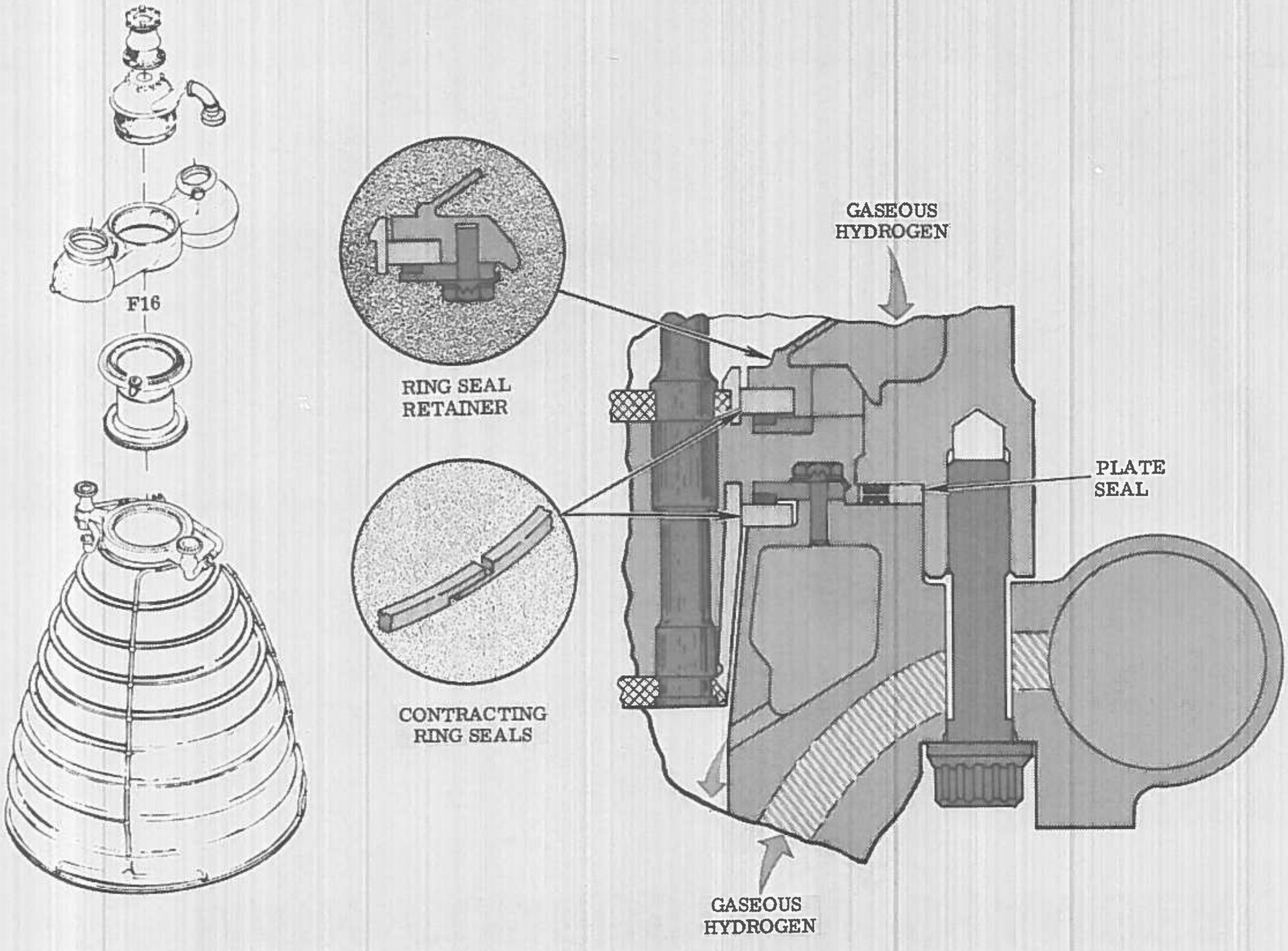
The chamber includes a liner, jacket, throat ring, coolant inlet manifold, and coolant outlet manifold. The liner outer surface has 390 vertical milled slots that are closed out by electrodeposited nickel. The jacket halves are placed around the liner and welded. The coolant manifolds are welded to the 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. It contains 30 acoustic cavities that damp out high-frequency combustion oscillations. The engine gimbal actuators attach to two quadruped outriggers (not shown) that bolt to the side of the chamber, 90 degrees apart.

MAIN COMBUSTION CHAMBER



LSS-EC-T-123A

MCC-POWERHEAD JOINT (F16) DETAILS



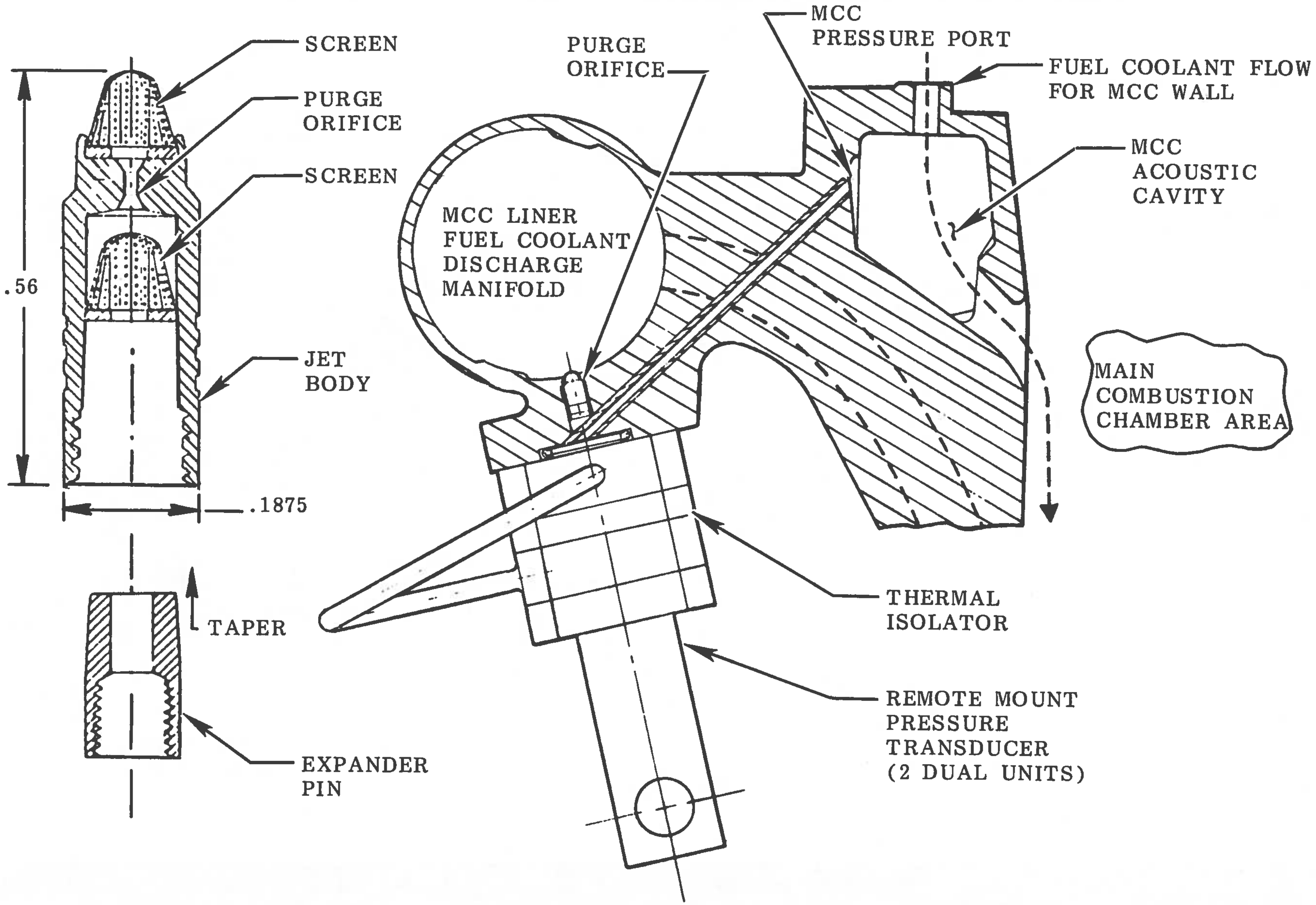
LSS-EC-T-79B

MAIN COMBUSTION CHAMBER

MCC PRESSURE SENSING

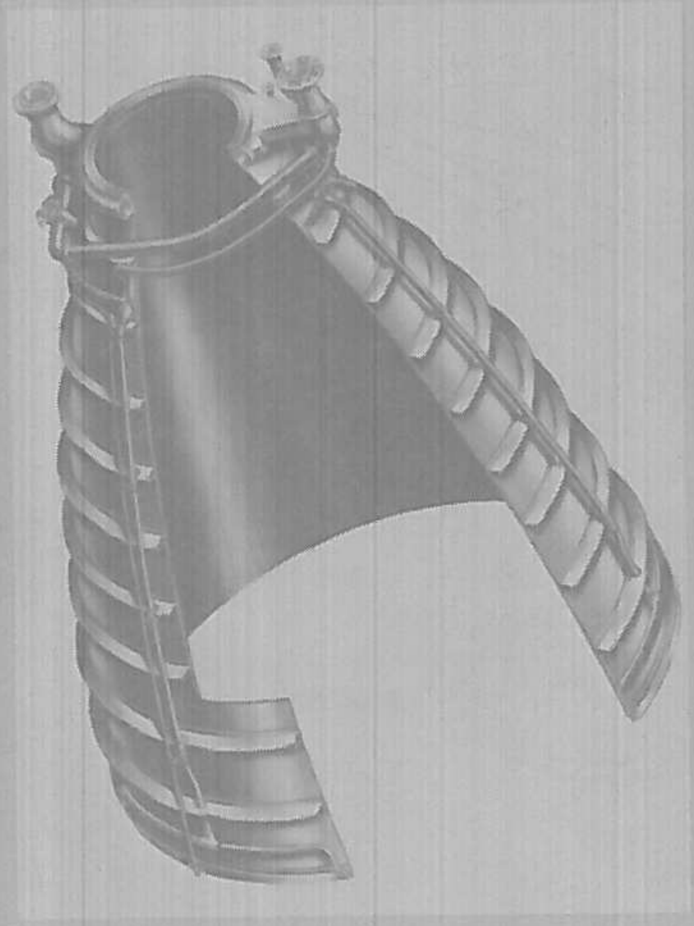
Measuring engine thrust directly on a flight vehicle is impractical. Therefore, thrust chamber combustion pressure, which is directly proportional to thrust, is measured instead. This is accomplished with pressure transducers. Since quadruple redundancy is desired for this important parameter, two dual units are used. (Should one or more signals fail to properly work, they will be cancelled out in the controller.) The transducers are thermally isolated from their mounting pads, since they can be affected by heat. The pad incorporates a minuscule purge orifice that has two functions. During engine purging, it provides a flowpath for purge gas, to help dry the transducer area. During engine run, it permits cooling hydrogen to flow from the discharge manifold (in which the pressure is always higher than combustion pressure) through the MCC pressure port passage, acoustic cavity, acoustic port, and into the combustion chamber.

MAIN CHAMBER PRESSURE SENSOR



LSS-EC-T-8A

NOZZLE



GEOMETRY	
• ATTACH POINT AREA RATIO	5.0:1
• EXIT AREA RATIO	77.5:1
• LENGTH (THROAT TO EXIT)	121 IN.
• EXIT DIAMETER (INSIDE/OUTSIDE)	90.7/94 IN.
• NUMBER OF TUBES	1,080
• NUMBER OF FEED DUCTS	3

PHASE II OPERATING PARAMETERS (RPL)		
	100%	109%
• INLET PRESSURE (PSIA)	5999	6741
• DISCHARGE PRESSURE (PSIA)	5460	6110
• COOLANT FLOWRATE (LB/SEC)	54	63
• MAX HOT GAS WALL TEMP (°F)	880	880

LC308-52E

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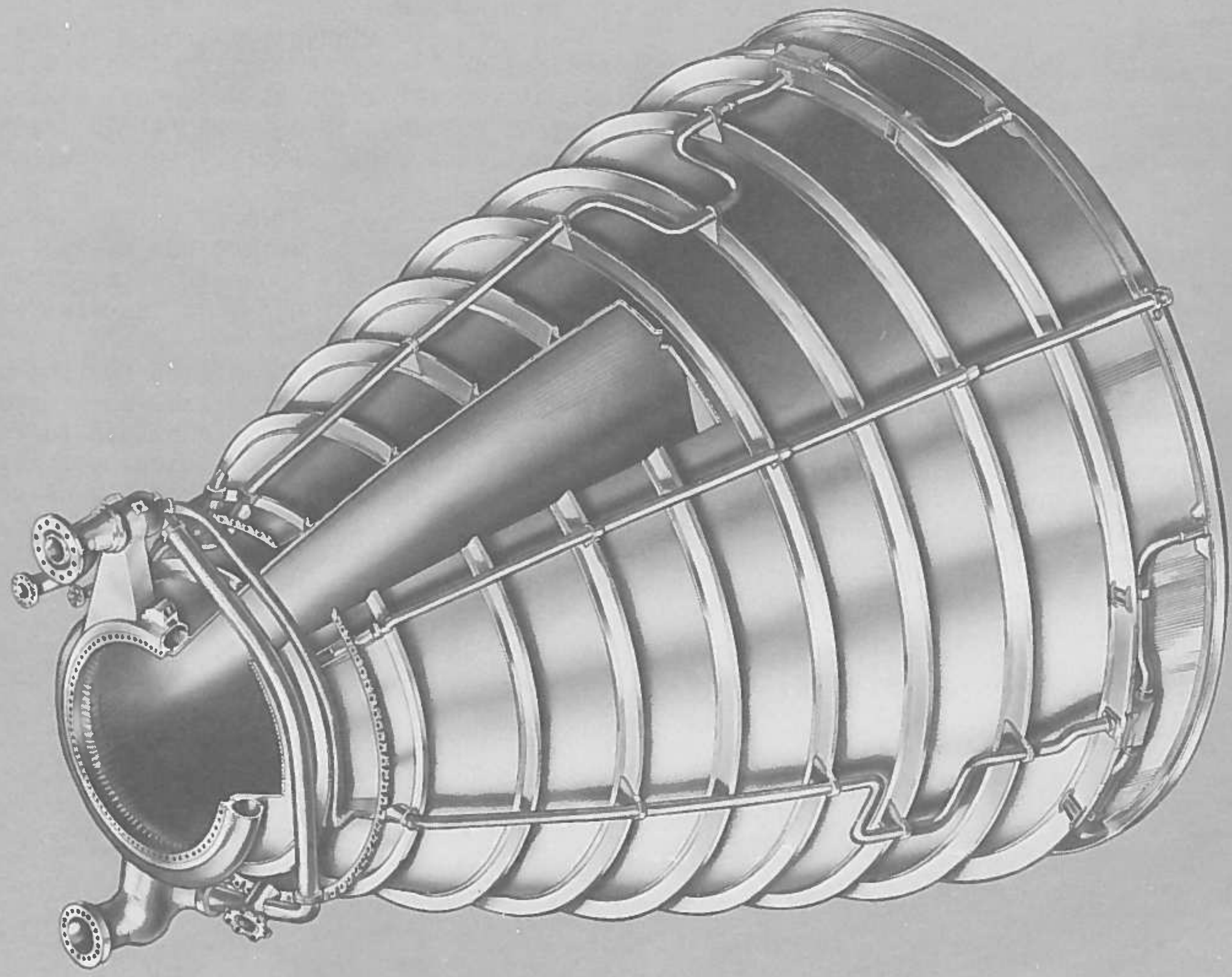
Rocketdyne Division

NOZZLE ASSEMBLY



LC301-382F

Rockwell International
Rocketdyne Division

SSME FLIGHT NOZZLE

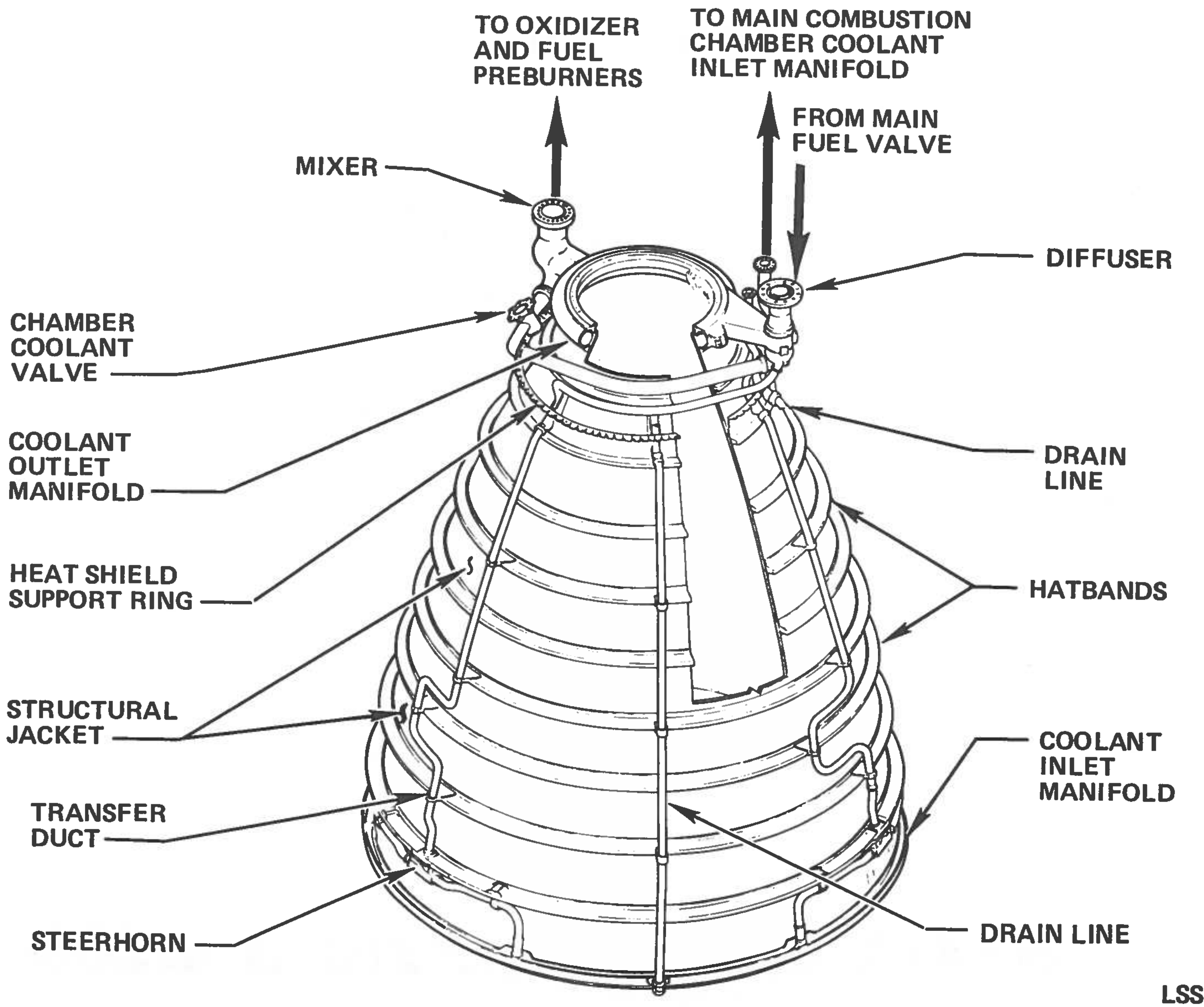
A rocket engine de Laval nozzle (ie, converging-diverging) increases the velocity of the exhaust gas stream by controlling its expansion and attendant pressure reduction.

Optimum expansion (and maximum thrust) exists when gas pressure at the nozzle exit plane equals ambient pressure. Nozzle shape (cone or bell), length, and area ratio (throat plane versus exit plane), combine with chamber pressure to determine at what altitude optimum expansion occurs. This is the design altitude of the engine. Below this altitude, overexpansion usually exists; above, underexpansion. Both produce less than maximum thrust. Since the SSME operates mostly in space where ambient pressure is zero, it needs a somewhat large area ratio of 77.5:1 to fully expand the exhaust gas. The nozzle is an 80.6 percent bell nozzle, which means that it is only 80 percent as long as a conical nozzle would be with the same area ratio.

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.

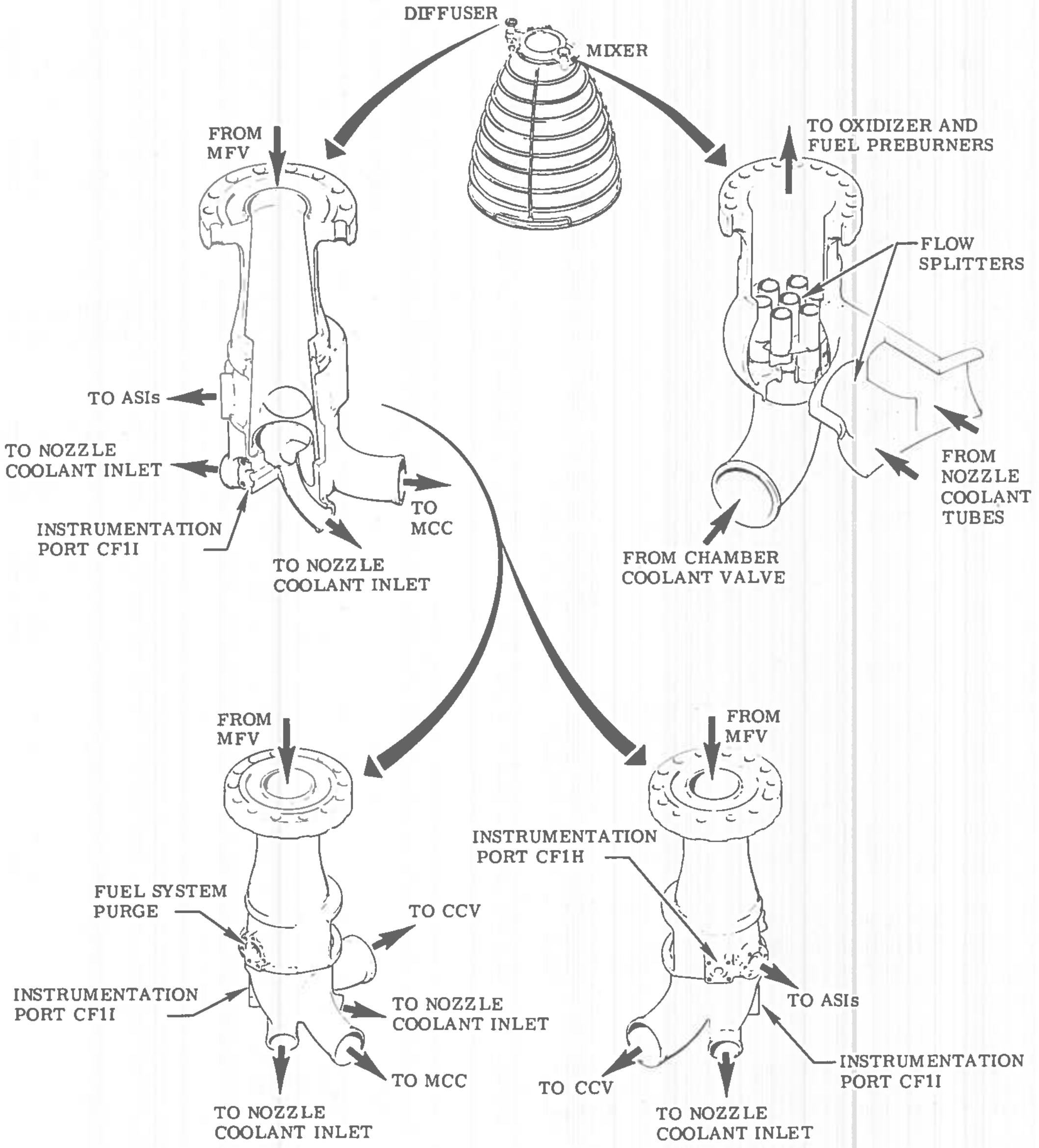
Nozzle cooling is as follows: Fuel entering the diffuser splits to flow to the MCC, to the three fuel transfer ducts, and through the CCV to the mixer. Fuel flowing through each transfer duct splits at each steerhorn to enter the nozzle coolant inlet manifold at six points. The fuel then makes a single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

SSME FLIGHT NOZZLE



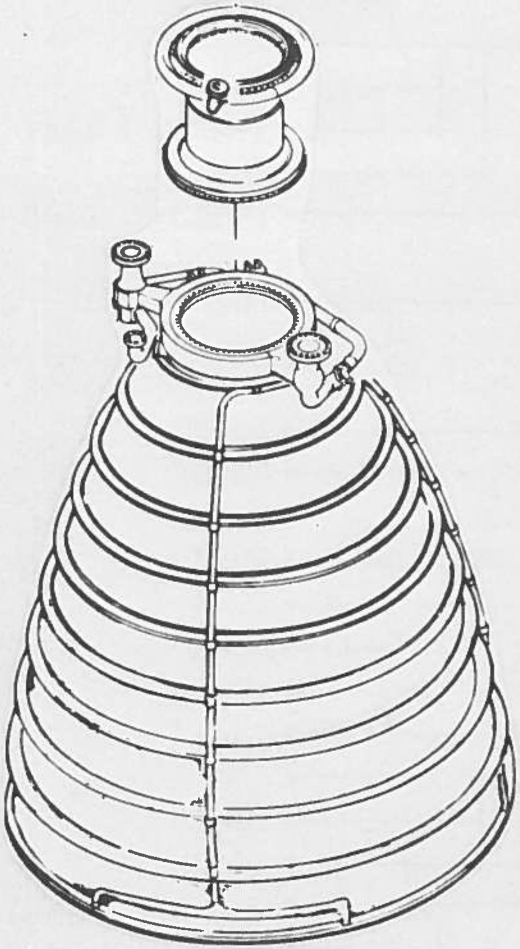
LSS-EC-T-124B

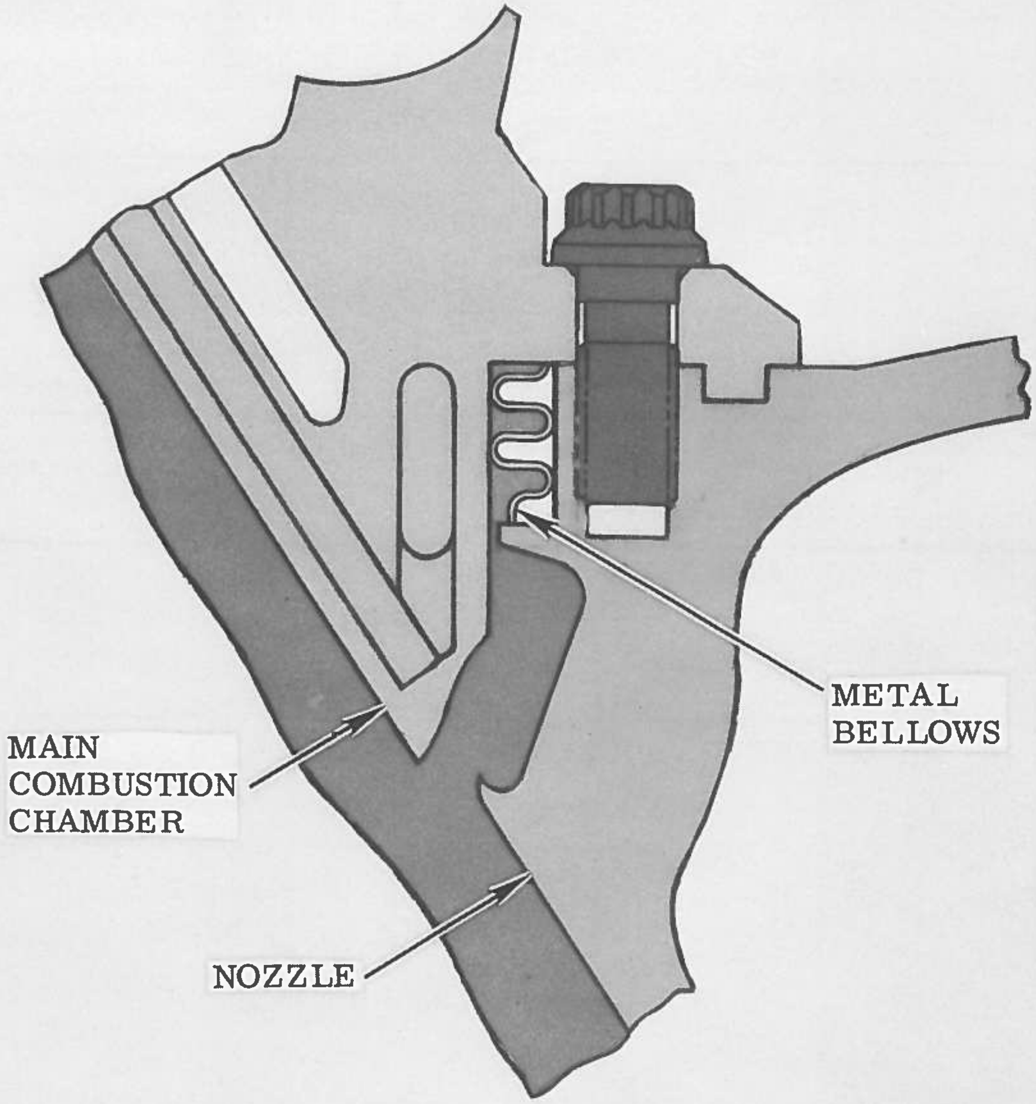
NOZZLE DIFFUSER AND MIXER



LSS-EC-T-127

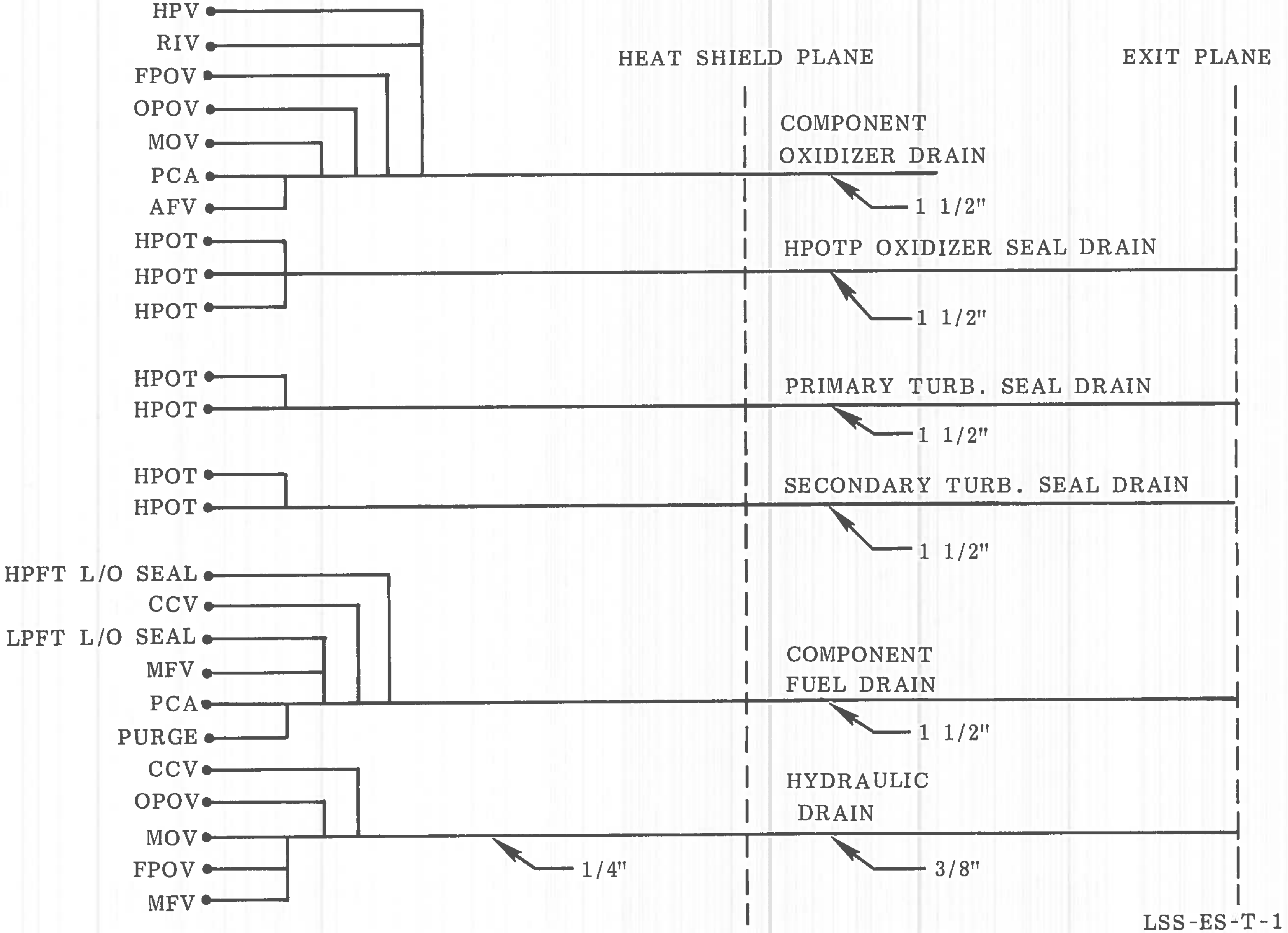
MCC-NOZZLE JOINT (GI5) DETAILS





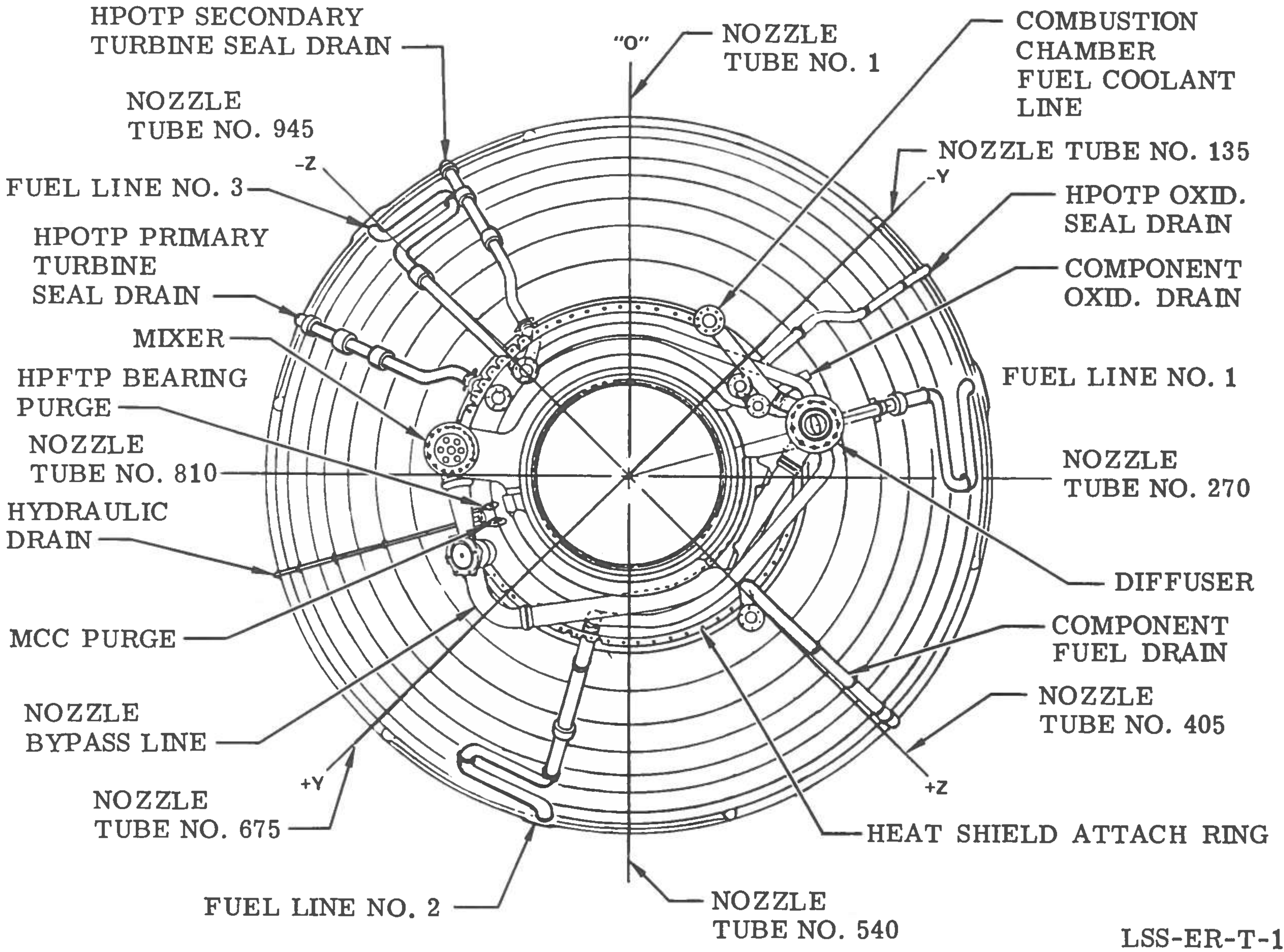
LSS-EC-T-77C

SSME DRAIN LINE SCHEMATIC



LSS-ES-T-1

FLIGHT NOZZLE FEATURES



LSS-ER-T-1B

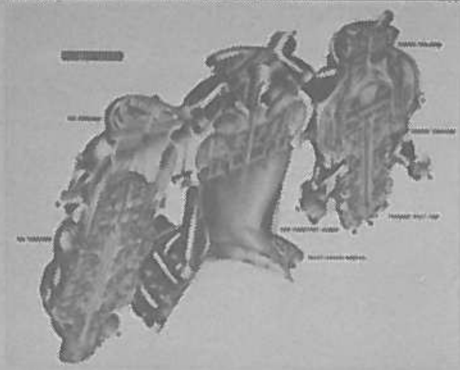
FOUR SSME PHASES EXTEND LIFE AND MARGINS

PHASE I

- PRODUCTION
- LAUNCH SUPPORT

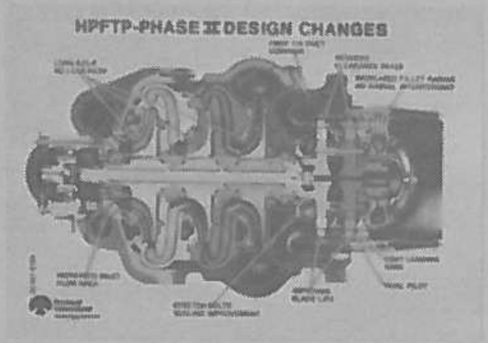
PHASE II⁺

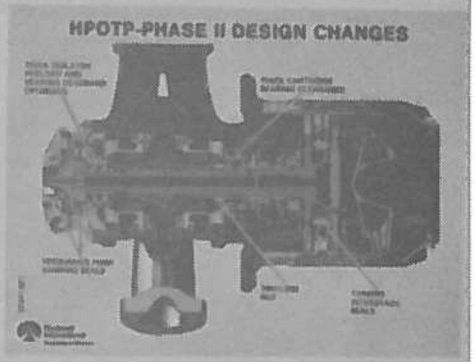
- INCREASE ENGINE OPERATING MARGIN BY IMPROVING HOT GAS SYSTEM FLOW ENVIRONMENT



PHASE II

- EXTEND HIGH PRESSURE PUMP LIFE TO 10 FLIGHTS @ 109%
- EXTEND FLIGHT CERTIFICATION TO 25 FLIGHTS





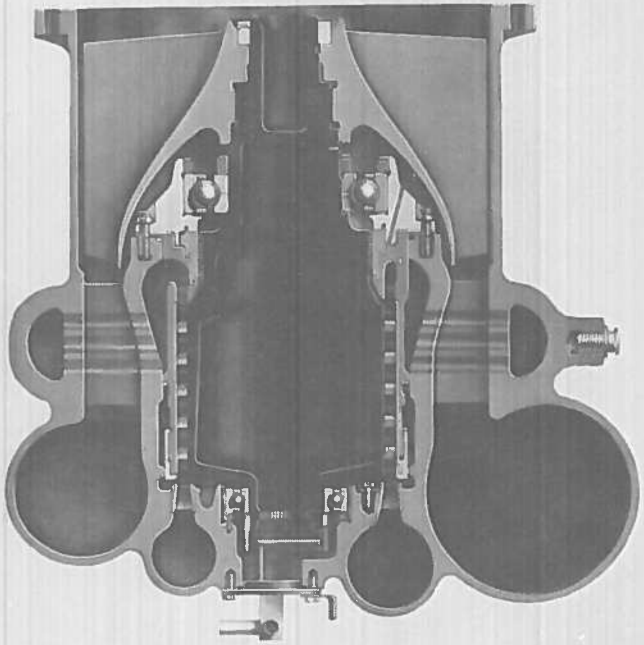
TECHNOLOGY TESTBED PRECURSOR

- EVALUATE CHANGES WITH SIGNIFICANT MARGIN GAIN POTENTIAL FOR POSSIBLE FUTURE INCORPORATION

Rockwell International
Rocketdyne Division

LC441-885D

LOW PRESSURE OXYGEN TURBOPUMP

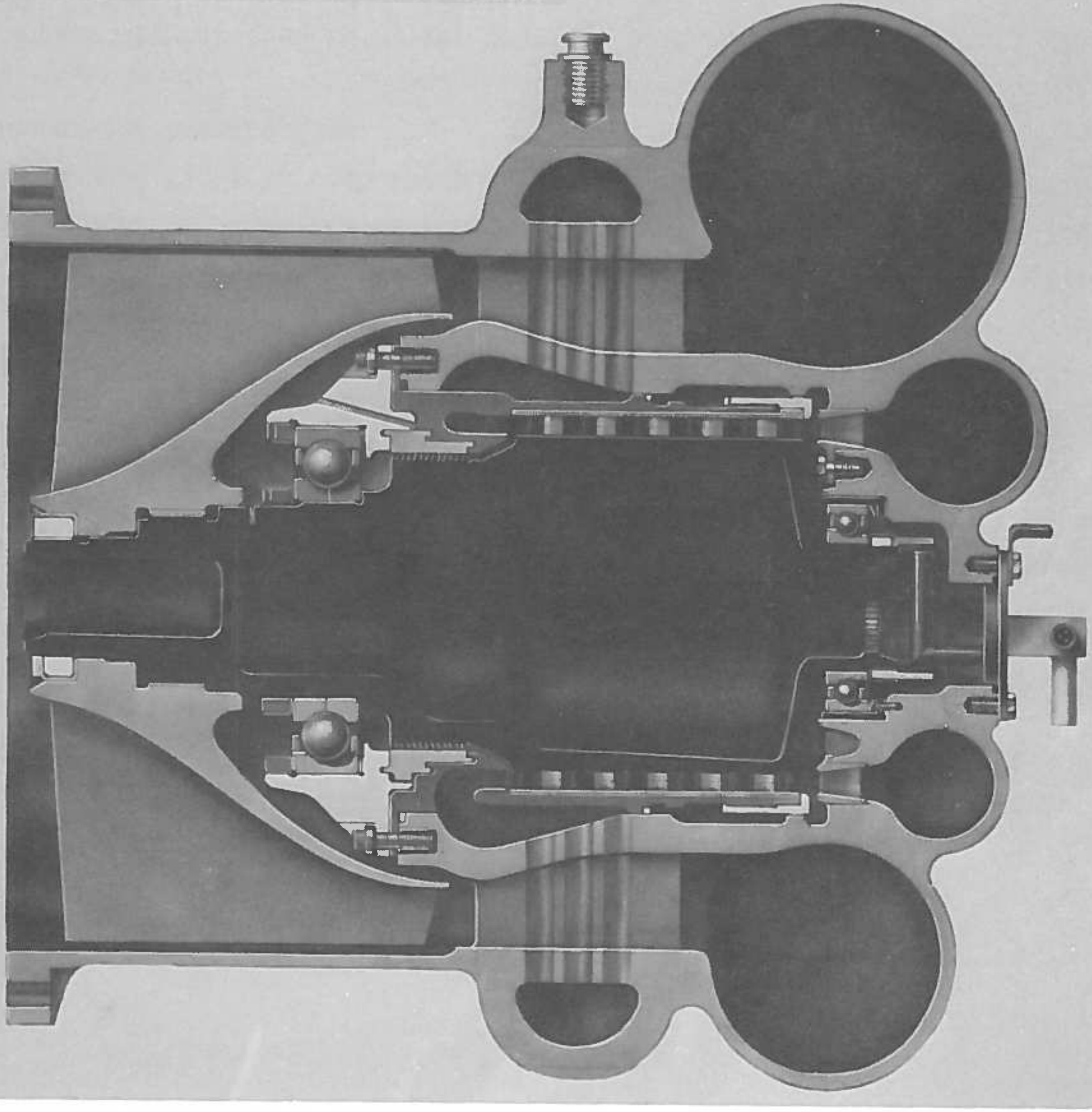


PHASE II KEY PERFORMANCE PARAMETERS	100%	109%
PUMP INLET FLOWRATE (LB/SEC)	895.8	975.1
PUMP INLET PRESSURE (PSIA)	100.0	100.0
PUMP DISCHARGE PRESS (PSIA)	414.2	432.7
PUMP EFFICIENCY	.689	.671
TURBINE FLOWRATE (LB/SEC)	176.3	186.4
TURBINE INLET PRESSURE (PSIA)	3951.1	4390.9
TURBINE INLET TEMP (°R)	190.2	193.5
TURBINE PRESSURE RATIO	–	–
TURBINE EFFICIENCY	.649	.649
TURBINE SPEED (RPM)	5042.1	5814.6
TURBINE HORSEPOWER	1504.8	1782.0

LC308-51E

Rockwell
International
Rocketdyne Division

LOW PRESSURE OXYGEN TURBOPUMP



LC301-379C

Rockwell International
Rocketdyne Division

SSME LOW-PRESSURE OXIDIZER TURBOPUMP

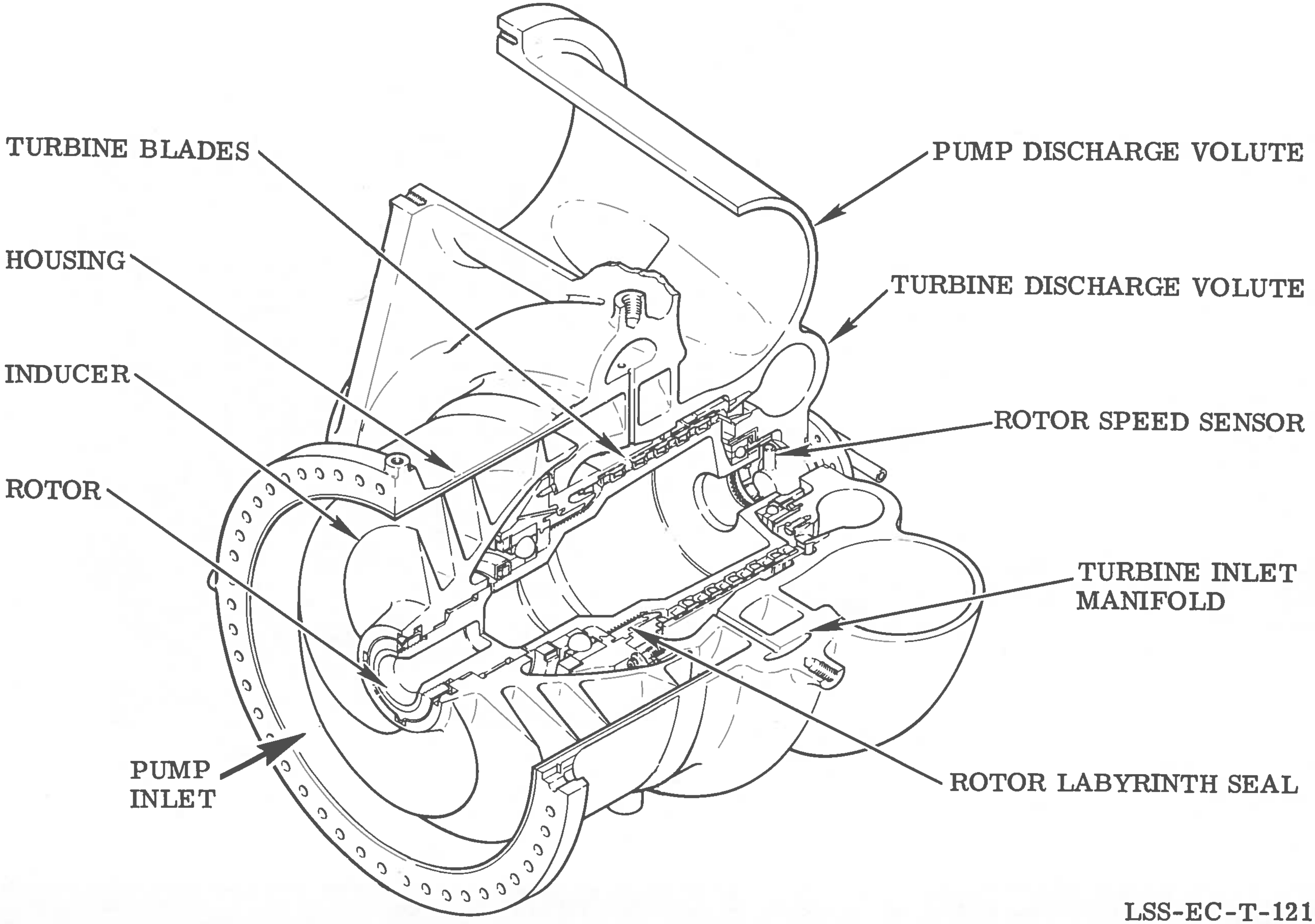
The low-pressure oxidizer turbopump (LPOTP) raises the pressure of the liquid oxygen to approximately 430 psi, so that the oxidizer tank ullage pressure can be lower, and the HPOTP can be run at a faster speed.

The LPOTP is an axial-flow pump with an inducer-type pumping element. It is directly driven with a six-stage, axial-flow, hydraulic turbine powered with liquid oxygen tapped from the HPOTP. The turbine exhausts into the turbine discharge volute and then through a port into the pump discharge volute.

The bearings are cooled by internal flow of oxygen from a point of higher pressure to a point of lower pressure. Coolant source for the inducer-end 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 join the inducer-end bearing flow.

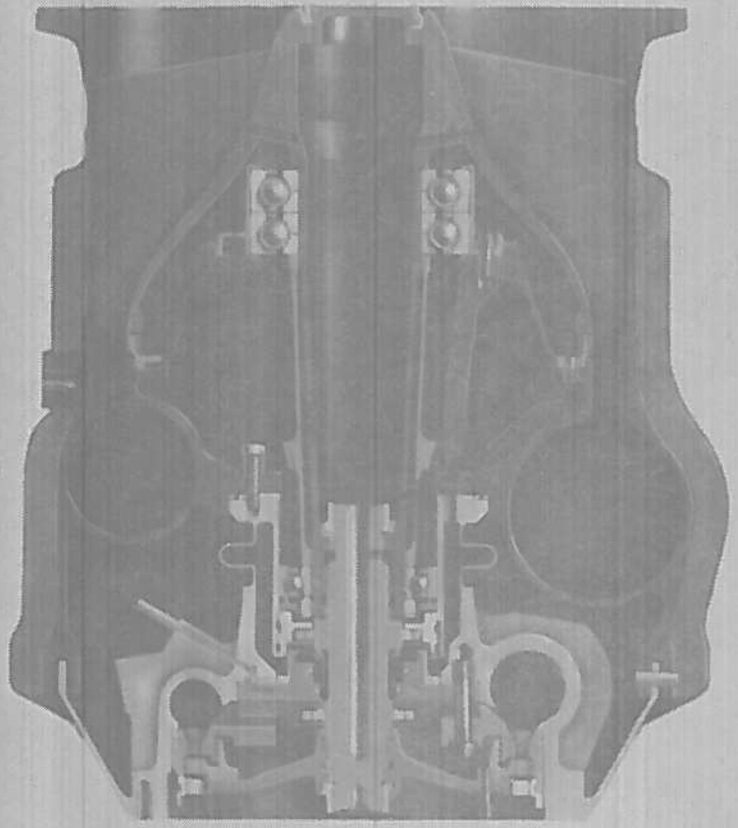
Extensive seals are unnecessary in the LPOTP, the only one being the labyrinth shaft seal. A triple-redundant, magnetic-type, pump speed transducer is located on the turbine end of the pump.

LOW-PRESSURE OXIDIZER TURBOPUMP



LSS-EC-T-121

LOW PRESSURE FUEL TURBOPUMP



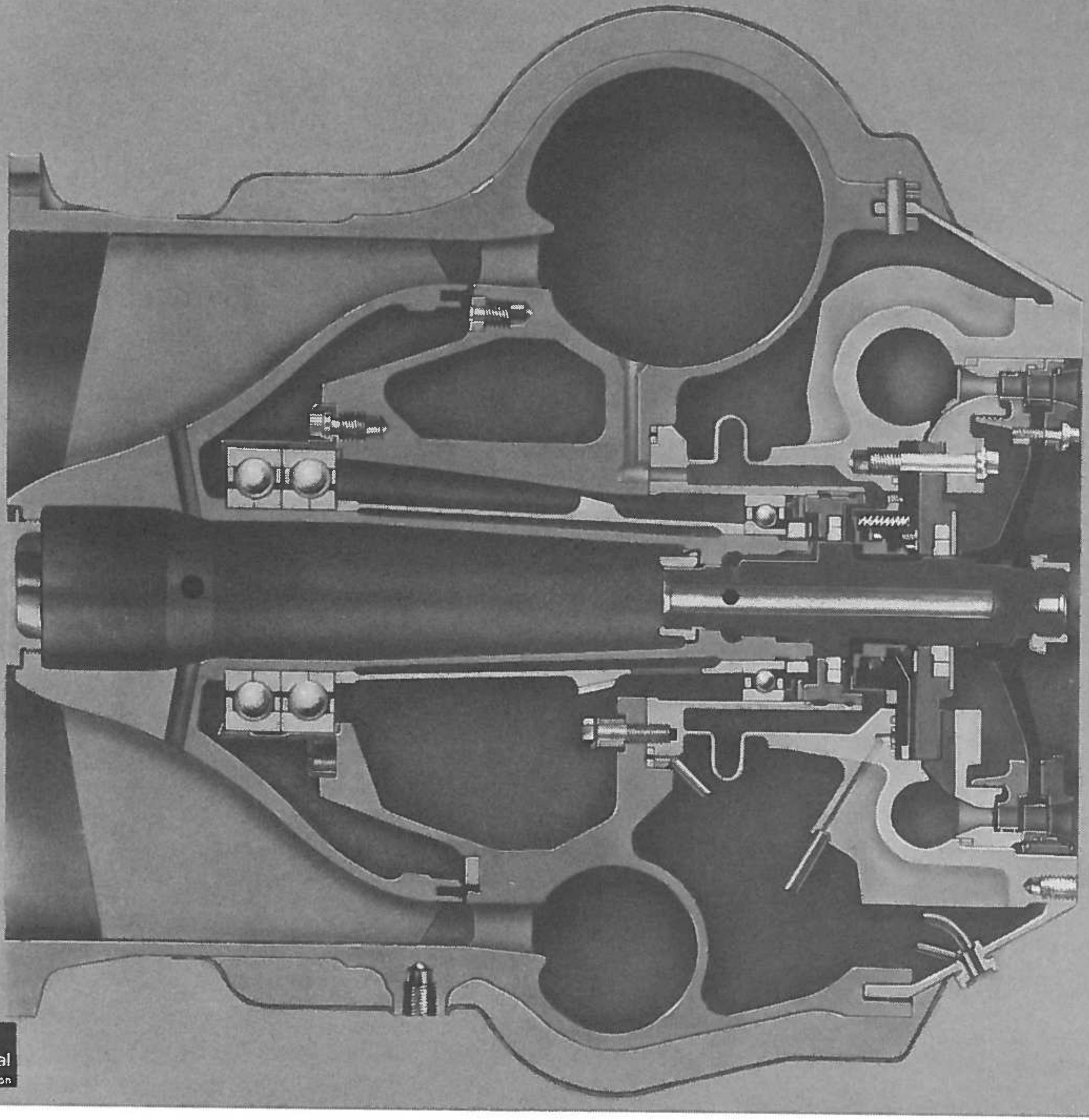
PHASE II
KEY PERFORMANCE PARAMETERS

	100%	109%
PUMP INLET FLOWRATE (LB/SEC)	148.6	161.9
PUMP INLET PRESSURE (PSIA)	30.0	30.0
PUMP DISCHARGE PRESS (PSIA)	280.5	306.3
PUMP EFFICIENCY	.774	.749
TURBINE FLOWRATE (LB/SEC)	26.1	29.5
TURBINE INLET TEMP (°R)	493.4	479
TURBINE PRESSURE RATIO	1.32	1.34
TURBINE EFFICIENCY	.519	.523
TURBINE SPEED (RPM)	15765	16722
TURBINE HORSEPOWER	2950	3518

LC308-53E

Rockwell International

LOW PRESSURE FUEL TURBOPUMP



LC301-377J
4-87

Rockwell International
Rocketdyne Division

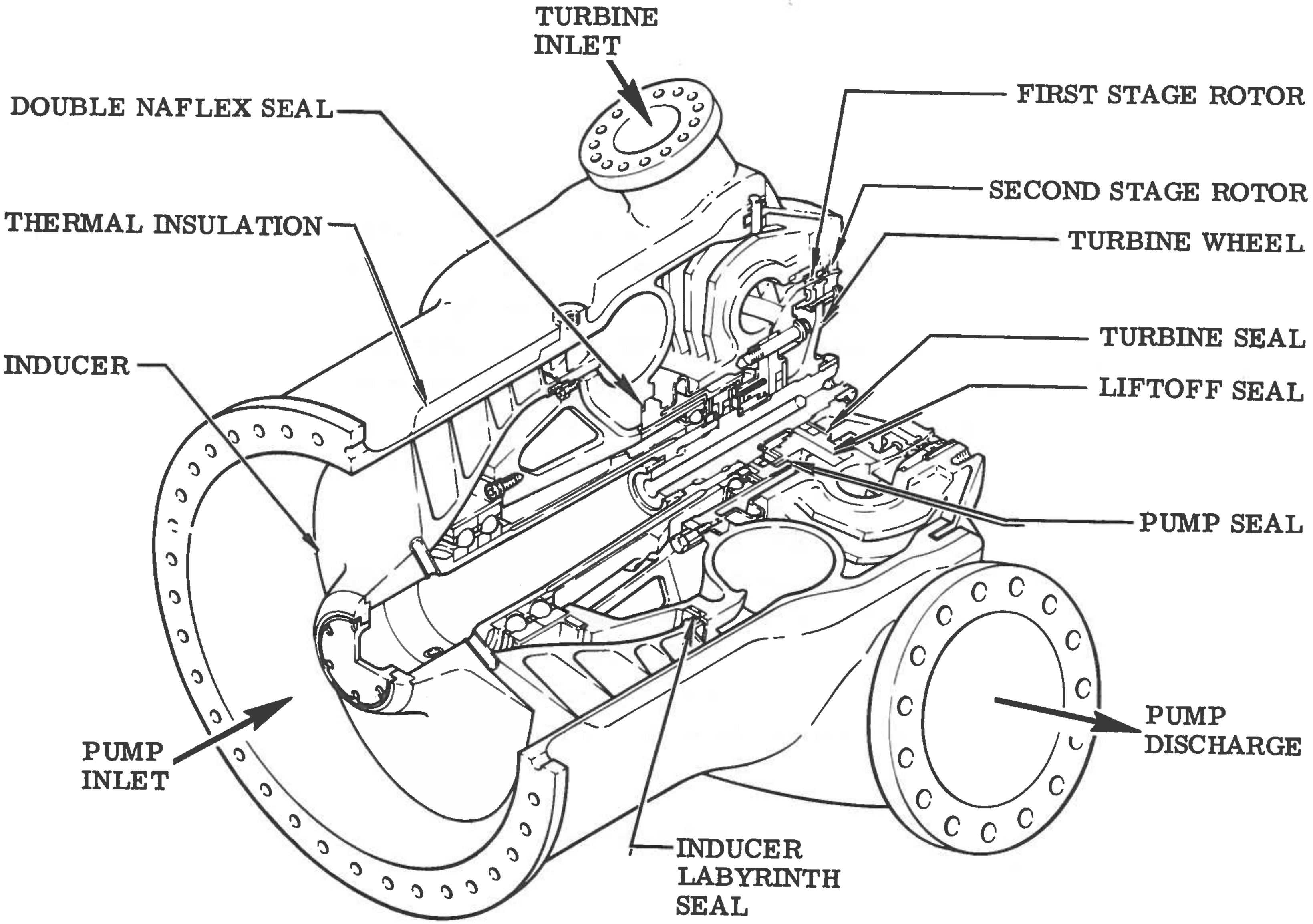
SSME LOW-PRESSURE FUEL TURBOPUMP

The low-pressure fuel turbopump (LPFTP) raises the pressure of the liquid hydrogen to approximately 300 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 liquid 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 internal flow of hydrogen from a point of higher pressure to a point of lower 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.

LOW-PRESSURE FUEL TURBOPUMP

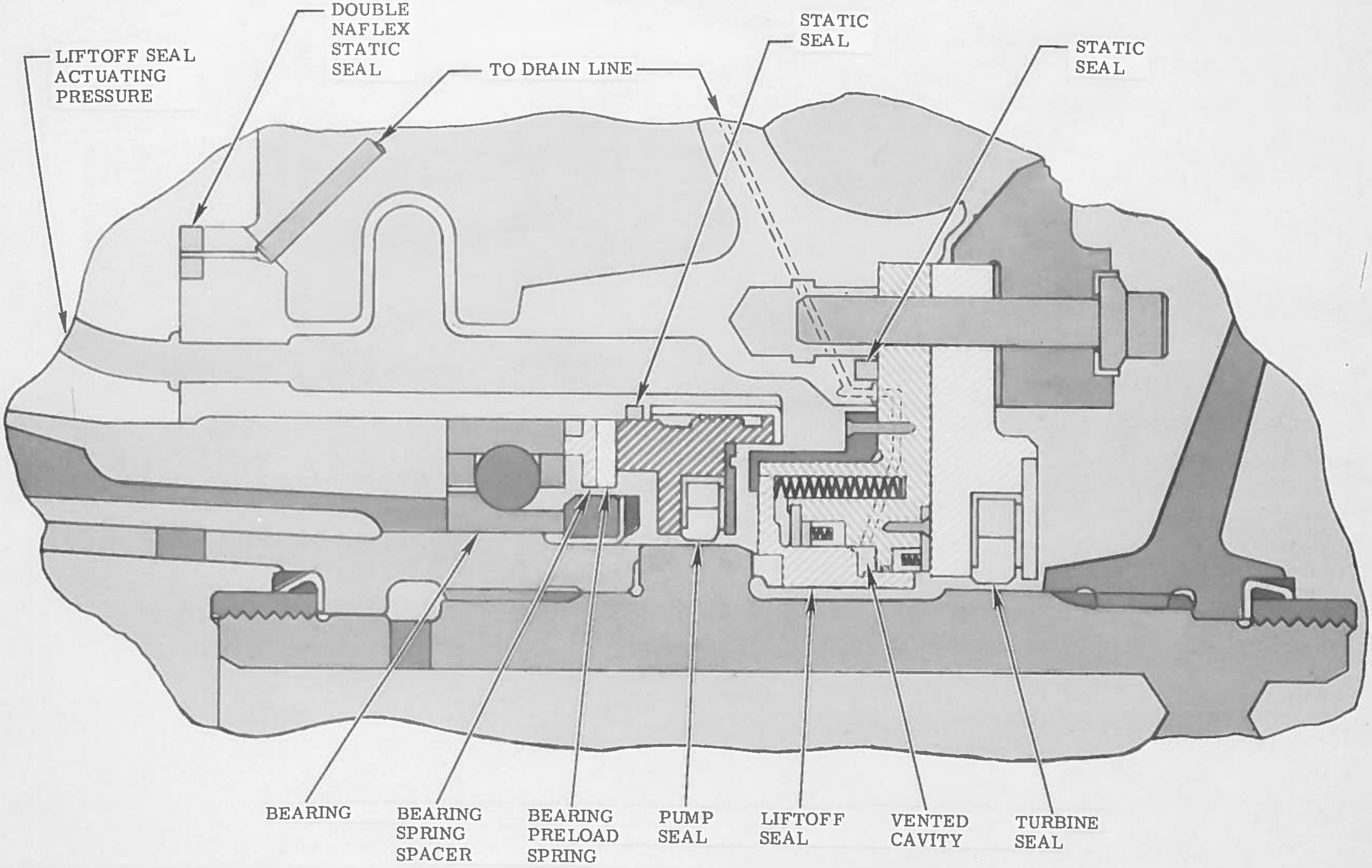


LSS-EC-T-122A

SSME LPFTP SHAFT SEALS

Prior to engine start, hydrogen leakage along the pump shaft into the turbine area (and, therefore, overboard) is prevented by a liftoff ring seal that is spring-loaded against a mate ring on the pump shaft. At engine start, pump pressure from the pump discharge volute pushes the seal away from the mate ring. Shaft sealing is then assumed by a floating, controlled-gap ring seal placed on either side of the liftoff seal (usually called a pump seal and a turbine seal, respectively). The gap between the ring and the shaft is maintained relatively constant within the pump temperature environment by using materials with compatible thermal characteristics.

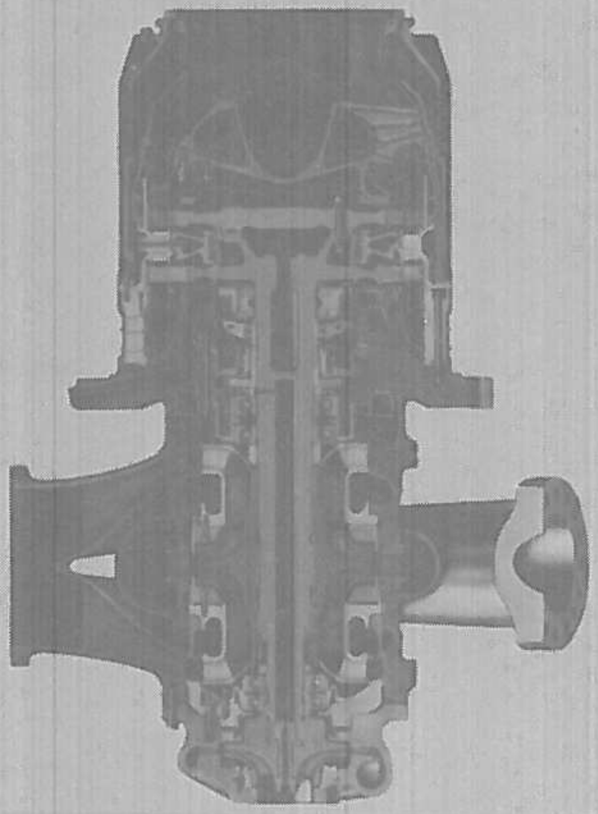
LPFTP SEAL GROUP



LSS-EC-T-80B

PHASE II

HIGH PRESSURE OXYGEN TURBOPUMP



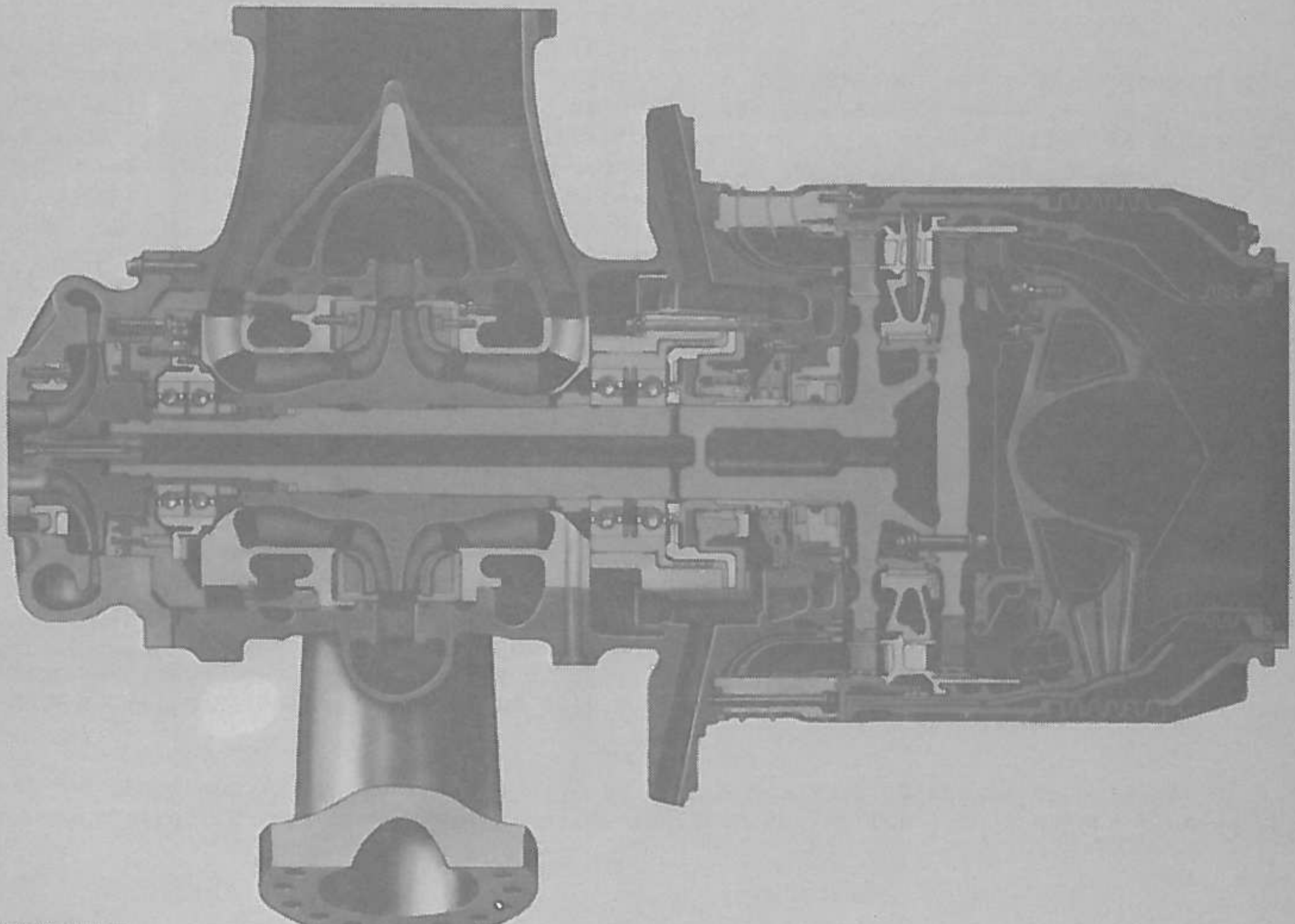
PHASE II
KEY PERFORMANCE PARAMETERS

	100%		109%	
	MAIN	BOOST	MAIN	BOOST
PUMP INLET FLOWRATE (LB/SEC)	1072.1	109.1	1162.5	125.8
PUMP INLET PRESS (PSIA)	379.9	3992.2	392.3	4428.7
PUMP DISCHARGE PR (PSIA)	4118.4	7210.9	4578.2	7935.9
PUMP EFFICIENCY	.686	.808	.681	.805
TURBINE FLOWRATE (LB/SEC)	58.8		65.49	
TURBINE INLET PR (PSIA)	5020.0		5631.6	
TURBINE INLET TEMP (°R)	1522.5		1625.4	
TURBINE PRESS RATIO	1.513		1.547	
TURBINE EFFICIENCY	.759		.769	
TURBINE SPEED (RPM)	27,263		29,194	
TURBINE HORSEPOWER	23,068		28,229	

LC308-56E

Rockwell International
Rocketdyne Division

PHASE II
HIGH PRESSURE OXYGEN TURBOPUMP



LC30I-330P

Rockwell
International
Rocketdyne Division

SSME 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.

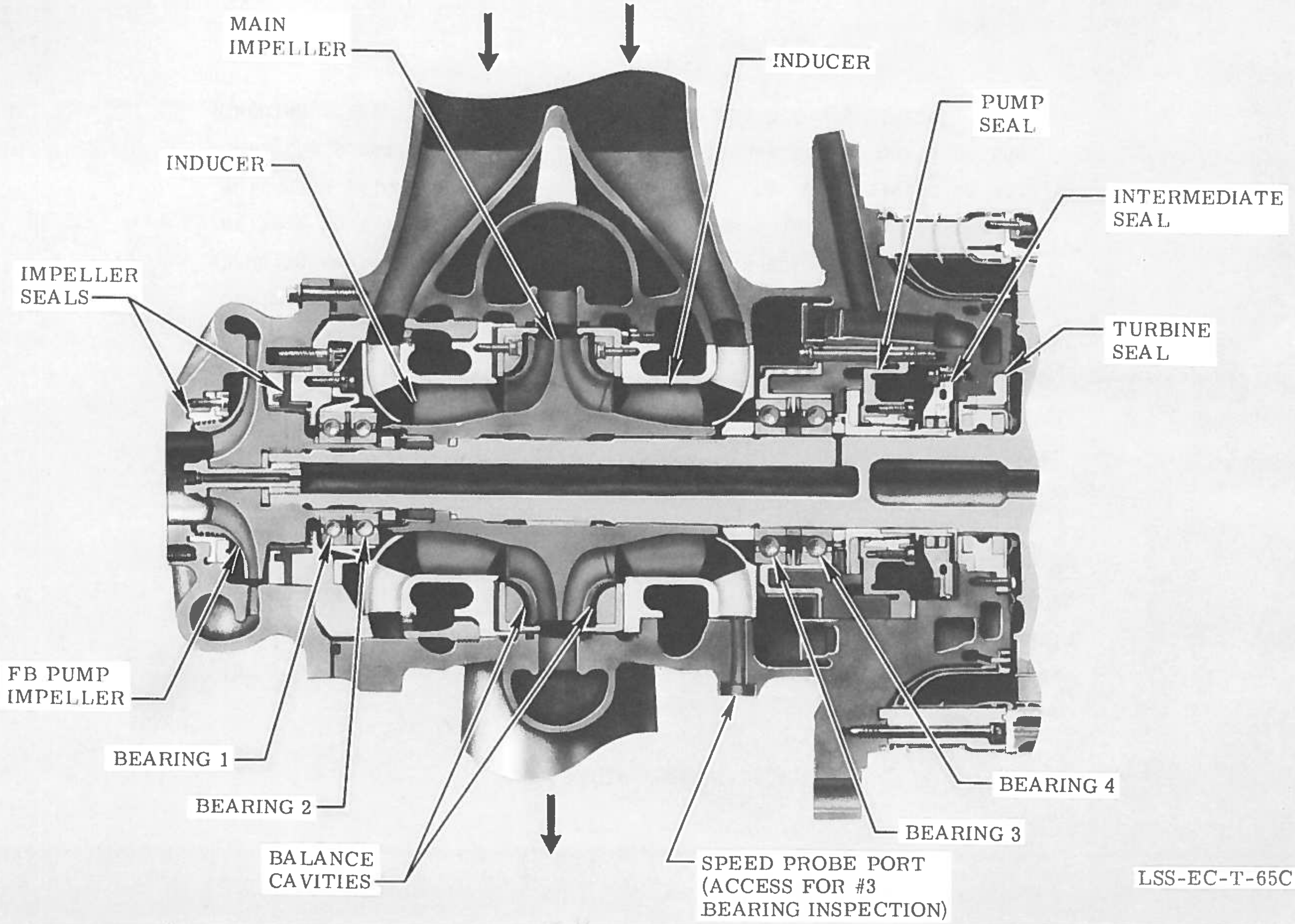
The HPOTP is a centrifugal pump that contains both a double-entry main impeller and a single-entry preburner oxidizer boost impeller. The oxidizer input is split 50-50 into the main impeller, where it is raised to approximately 4,600 psi. Built-in inducers on both sides of the impeller help boost the input pressure. A portion of the output flow is ducted into the boost impeller to be raised to approximately 8,000 psi for preburner injection.

The pump bearings are cooled by two internal flows of oxygen from points of higher pressure to points of lower pressure. Coolant source for bearings 1 and 2 is at the output of the preburner pump impeller. Oxygen flows down the back face of the impeller, through the impeller hub seal, the bearings, and into the input of the left-hand inducer. Coolant source for bearings 3 and 4 is at the input of the preburner pump impeller. Oxygen flows through the hollow retaining bolt, the hollow shaft, the bearings, and into the input of the right-hand inducer.

The bearings consist of two matched pairs of angular-contact ball bearings whose inner races are clamped and whose outer races are preloaded. Excessive axial loads are reacted by two balance cavities (not by the bearings). These cavities lie between the front faces of the 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 cavities and 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.

A pump speed transducer is not presently used on this pump. The port is used for No. 3 bearing inspection.

HPOTP PUMP SECTION



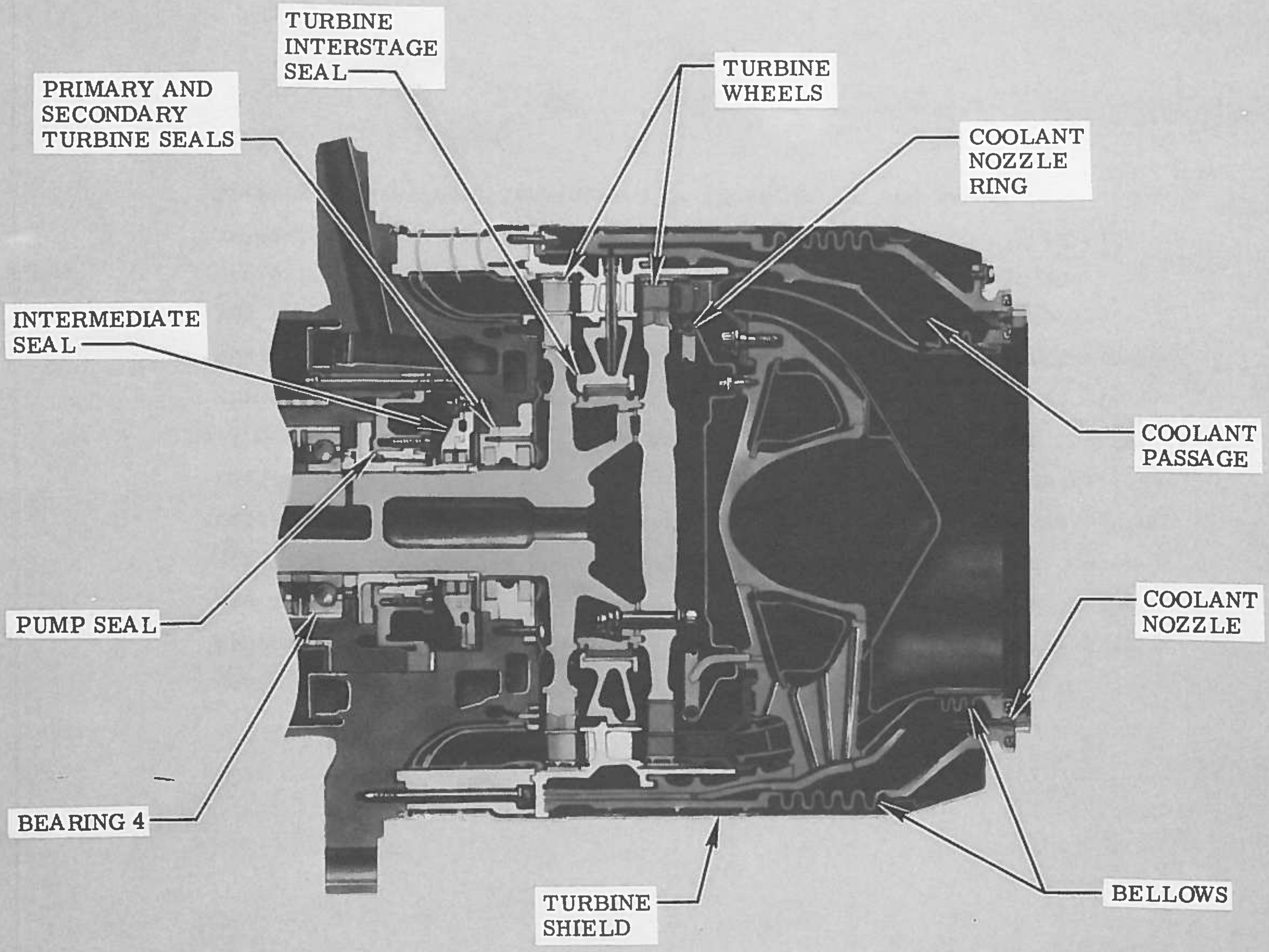
LSS-EC-T-65C

SSME HPOTP TURBINE SECTION

The high-pressure oxidizer turbopump (HPOTP) turbine is a two-stage, cantilevered turbine powered with hot, hydrogen-rich gas generated in the oxidizer preburner. Hot gas, guided by the sheet metal structure, is nozzled into and through the first- and second-stage blades and is discharged into the HGM.

The second-stage turbine wheel is made integral with the pump shaft, and the first-stage wheel is bolted to the second-stage wheel with a curvic coupling. The 11-inch turbines are shrouded, each blade tip contributing a small portion of the total shroud. Lands on the outer perimeter of the shrouds run against circular seals for blade-to-housing sealing. Turbine-to-OPB sealing is accomplished by two bellows that load two seals in the turbine inlet flange to the OPB. This also allows cooling fuel from the PB fuel manifold to be nozzled into the space between the bellows and thence to all parts of the turbine. The fuel then discharges into the hot-gas stream.

HPOTP TURBINE SECTION



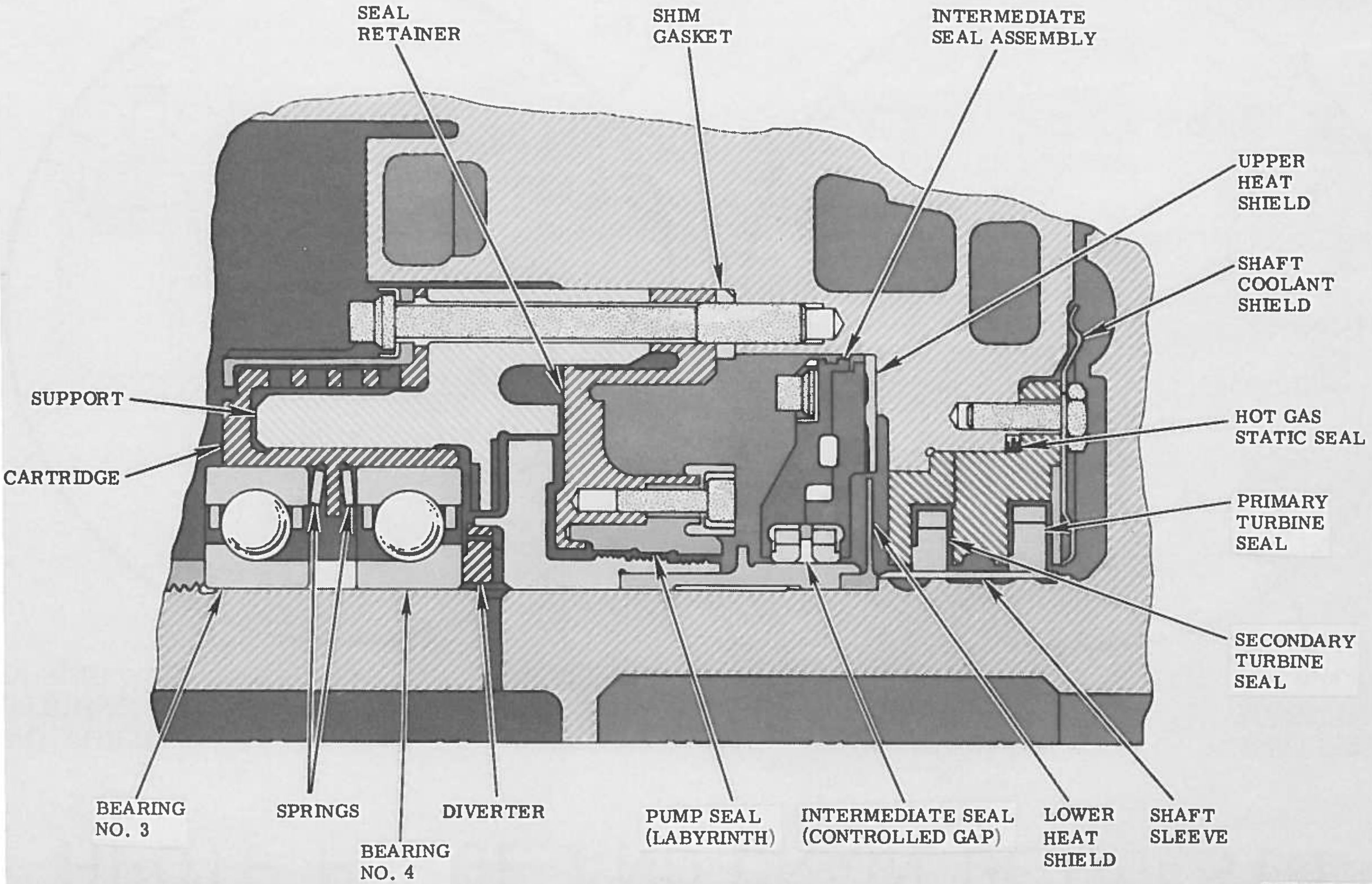
LSS-EC-T-62B

SSME HPOTP SHAFT SEALS

Because the HPOTP pumps liquid oxygen and is powered by hot, hydrogen-rich gas, extensive shaft seals are needed between the pump and its turbine. The seal area of the shaft contains a three-step labyrinth pump seal; a double-element, controlled-gap, purged, intermediate seal; and a double-element, controlled-gap, turbine seal. The cavity between the primary turbine seal and the secondary turbine seal is drained; the cavity between the secondary turbine seal and the intermediate seal is drained; and the cavity between the intermediate seal and the pump seal is drained. In addition, the cavity between the two elements of the intermediate seal is purged 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 hydrogen and oxygen.

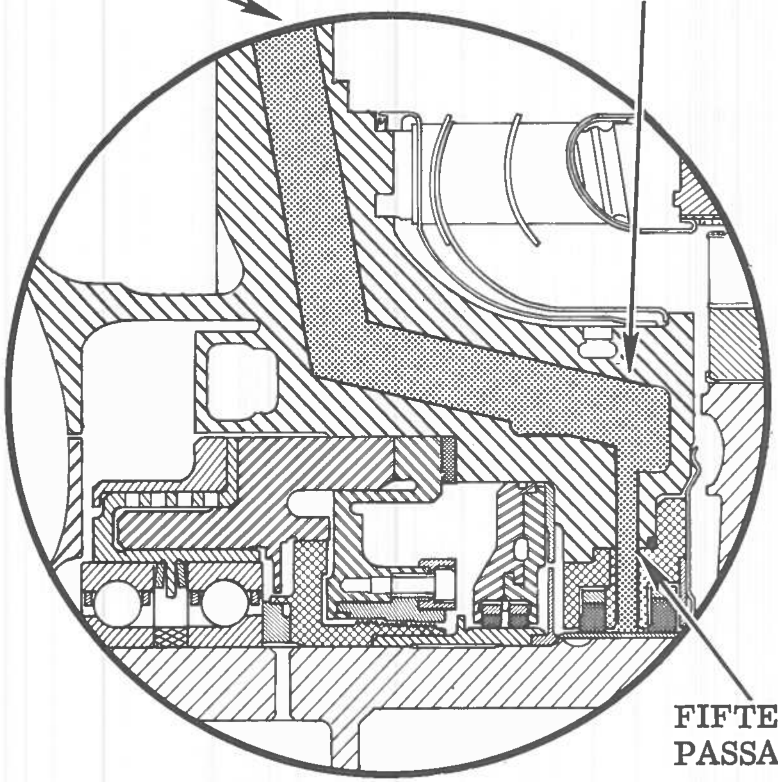
HPOTP SEAL GROUP

(ENGINES 2004 AND SUBSEQUENT)

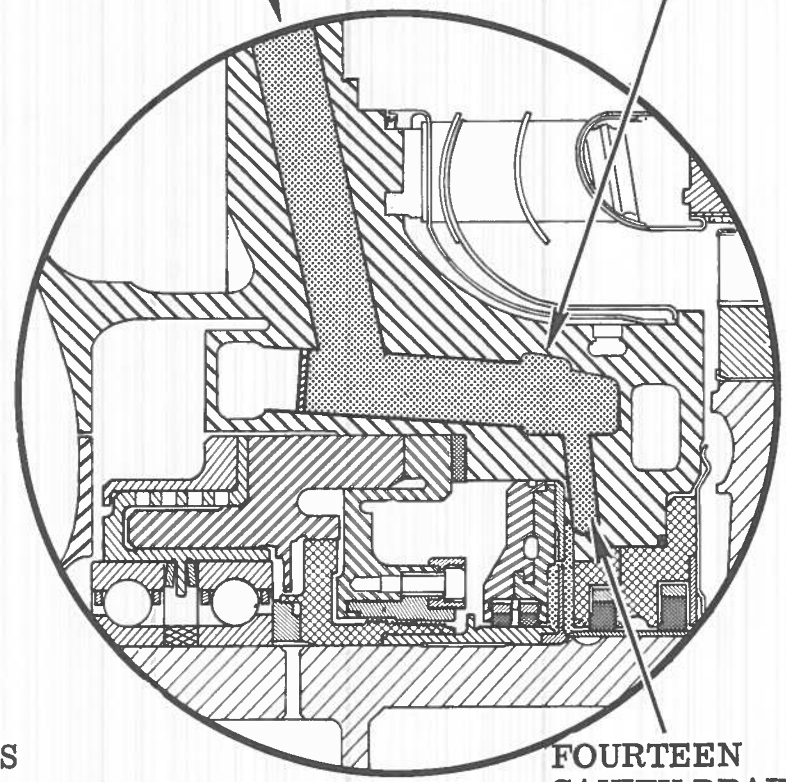


LSS-EC-T-102A

HPOTP PURGE AND DRAIN DETAILS (1)

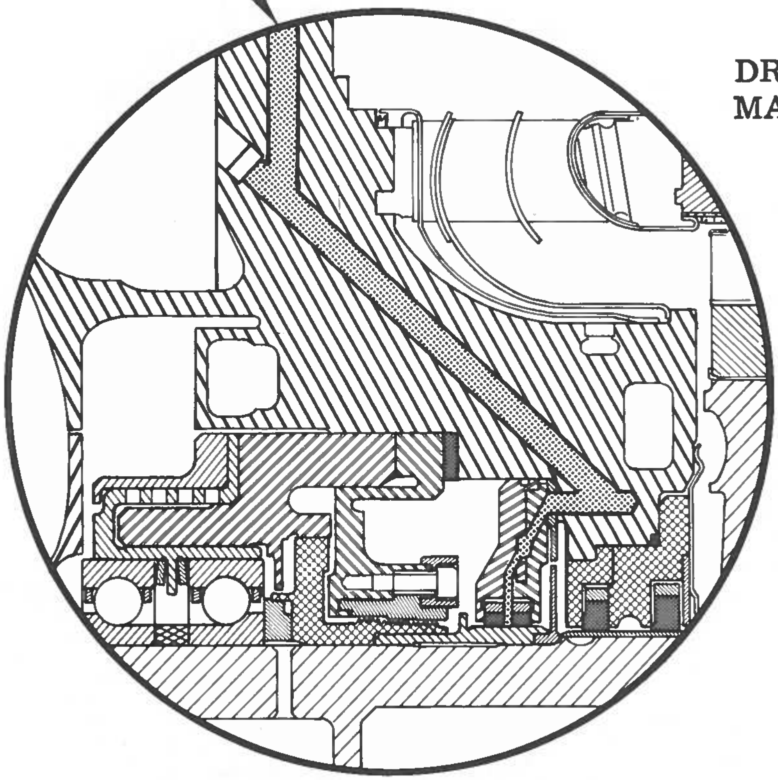


PRIMARY TURBINE SEAL PURGE AND DRAIN

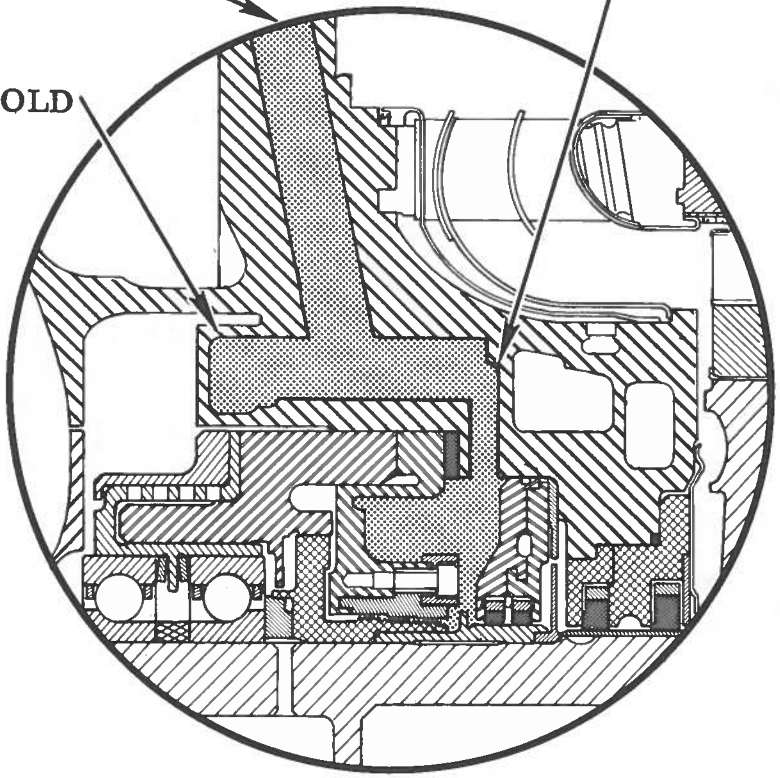


INTERMEDIATE SEAL AND SECONDARY TURBINE SEAL DRAIN

HPOTP PURGE AND DRAIN DETAILS (2)



INTERMEDIATE SEAL PURGE

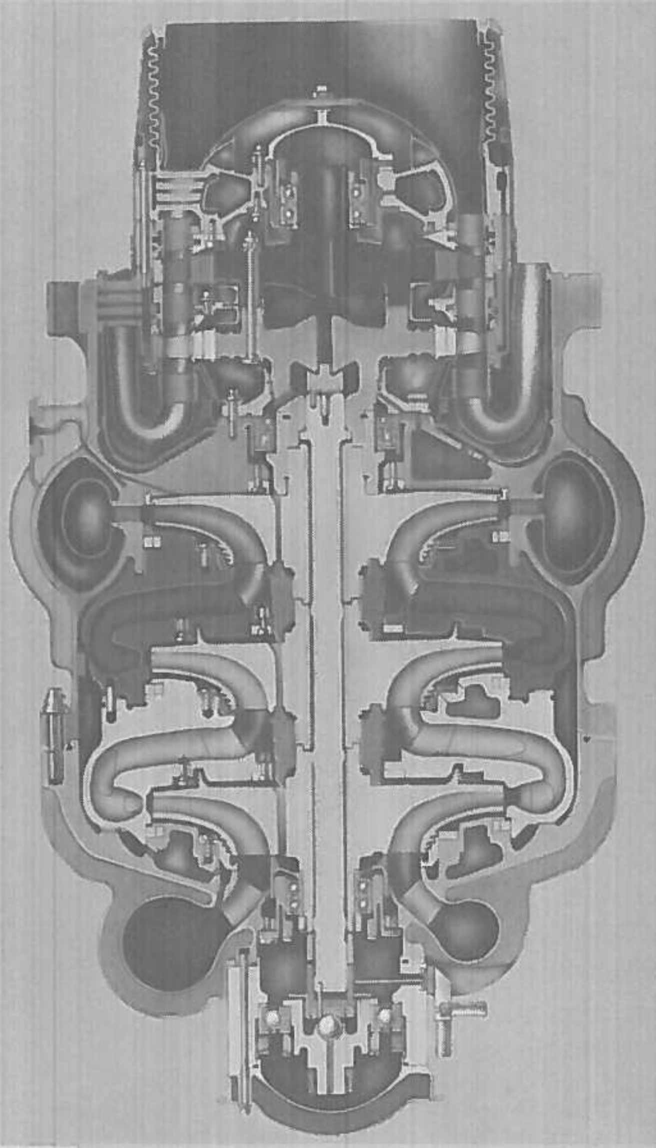


OXIDIZER CAVITY DRAIN
(FOR PUMP AND INTERM. SEALS)

LSS-EC-T-82C

PHASE II

HIGH PRESSURE FUEL TURBOPUMP



KEY PERFORMANCE PARAMETERS

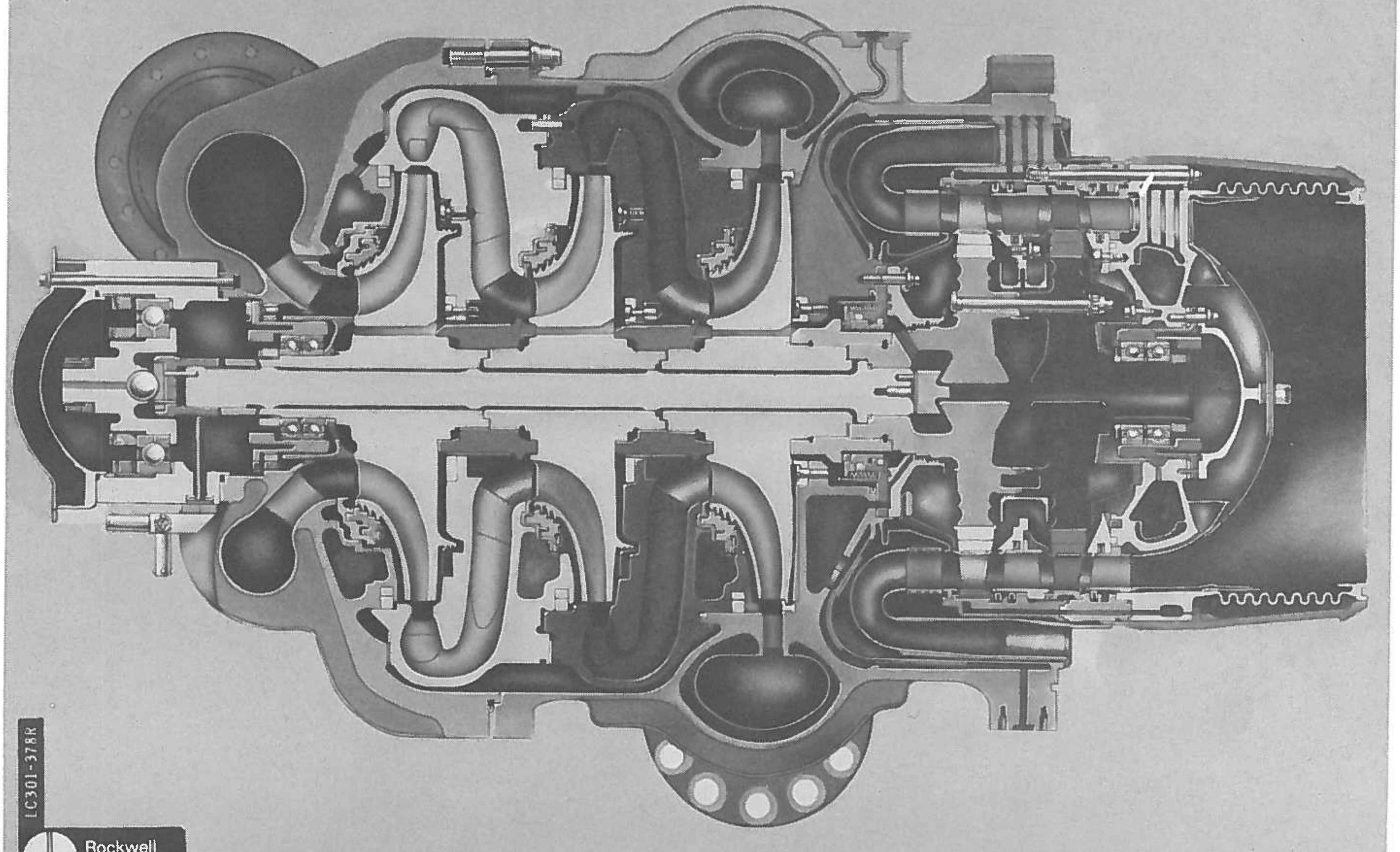
	100%	109%
PUMP INLET FLOWRATE (LB/SEC)	149.1	162.5
PUMP INLET PR (PSIA)	222.4	237.5
PUMP DISCH PR (PSIA)	6110.4	6871.7
PUMP EFFICIENCY	.763	.760
TURBINE FLOWRATE (LB/SEC)	158.6	177.6
TURBINE INLET TEMP (°R)	1794.5	1903.7
TURBINE PRESSURE RATIO	1.411	1.440
TURBINE EFFICIENCY	.839	.842
TURBINE SPEED (RPM)	34,386	36,595
TURBINE HORSEPOWER	61,402	74,928

LC308-59D

Rockwell International
Rocketdyne Division

PHASE II

HIGH PRESSURE FUEL TURBOPUMP



LC301-378R

Rockwell International
Rocketdyne Division

SSME HPFTP PUMP SECTION

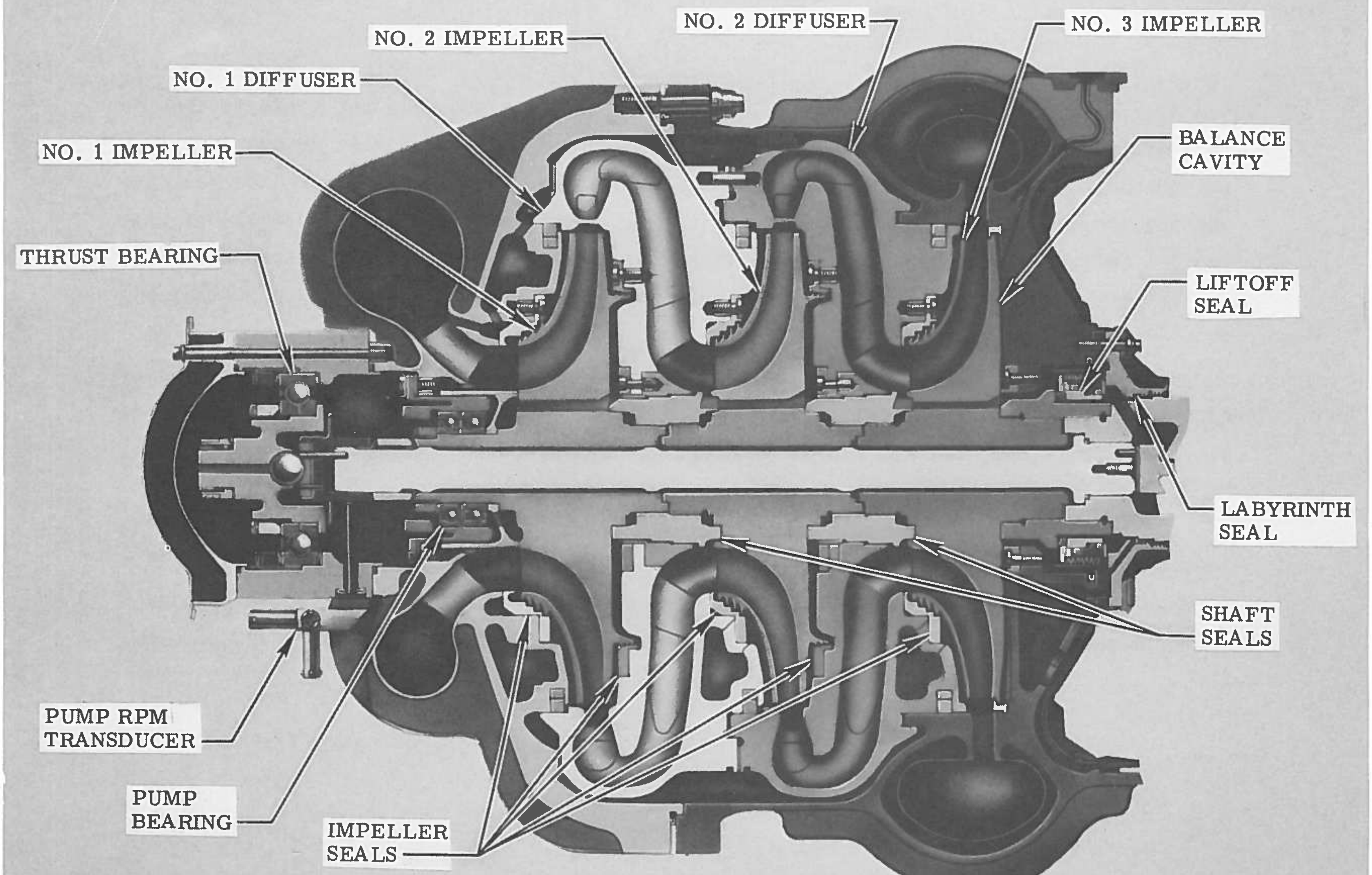
The high-pressure fuel turbopump (HPFTP) raises the pressure of the hydrogen flowing to the engine combustion chambers sufficiently to ensure positive injection of hydrogen at all thrust levels.

The HPFTP is a three-stage centrifugal pump that uses two interstage diffusers to pass the hydrogen from one stage to the next. Liquid hydrogen enters the sheet metal discharge volute at approximately 6,900 psi. The discharge volute is built inside the pump housing. Each impeller has front and back face labyrinth seals except No. 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 points of higher pressure to points of lower pressure. Coolant source for the pump-end bearings, including the thrust bearing, is the output of No. 1 impeller. Hydrogen flows down the back face of the impeller, through the holes in the hub, through the bearings, and into the No. 1 impeller input. The bearing inner races are clamped to the shaft with the bearings free to slide axially within the bearing cartridge.

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

HPFTP PUMP SECTION



LSS-EC-T-61C

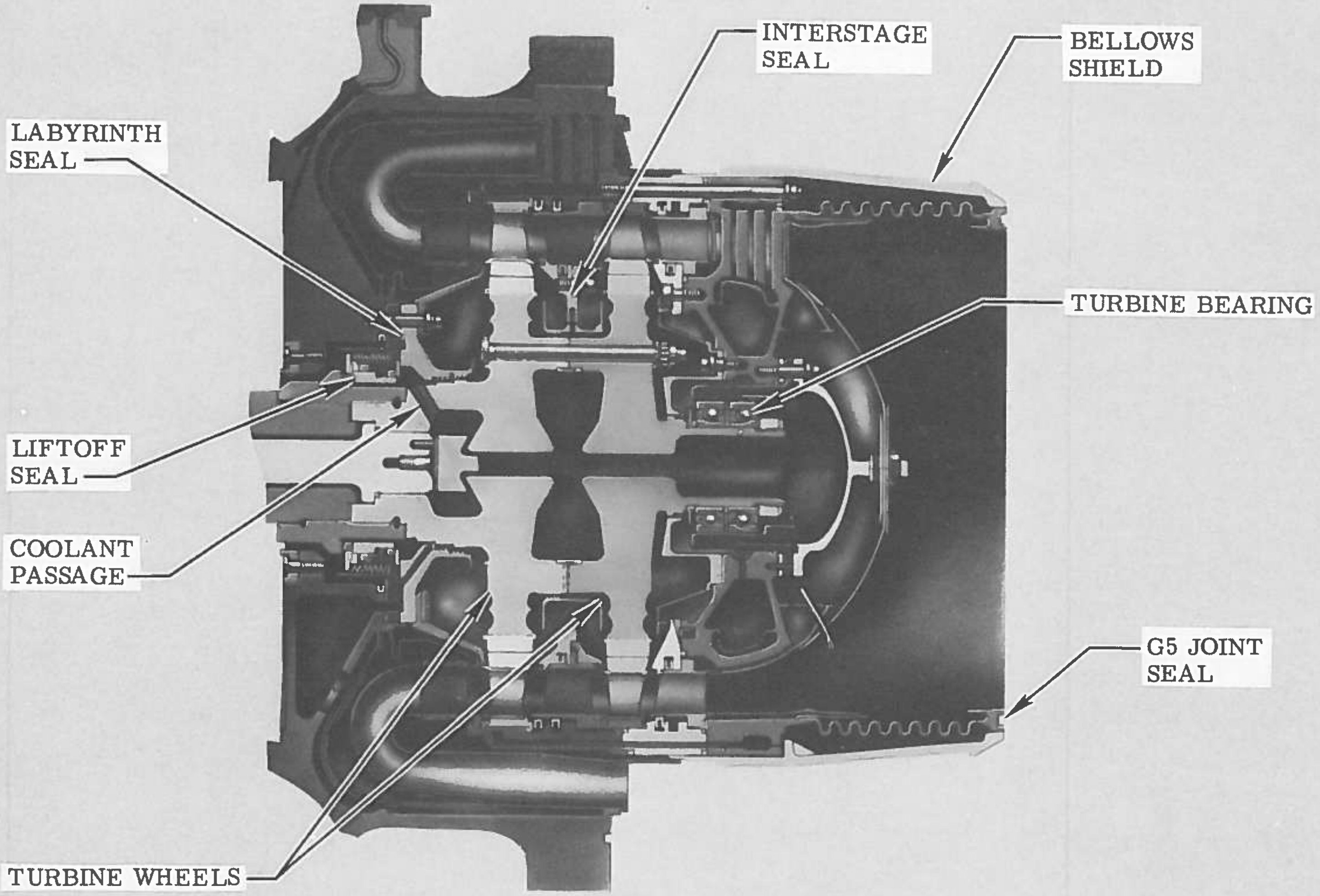
SSME HPFTP TURBINE SECTION

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 sheet metal structure, is nozzled into and through the first- and second-stage blades, and is discharged into the HGM.

The second-stage wheel is spline-coupled to the pump shaft, and the first-stage wheel is bolted to the second-stage wheel with a curvic coupling. Turbine-to-FPB sealing is accomplished by a bellows that loads a seal at the turbine inlet flange (G5) to the FPB.

The turbine and turbine bearings are cooled by extracting fuel from the fuel pump itself. When fuel pressure has lifted the liftoff 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. The bearings are clamped to the shaft and are free to slide axially within the bearing cartridge.

HPFTP TURBINE SECTION

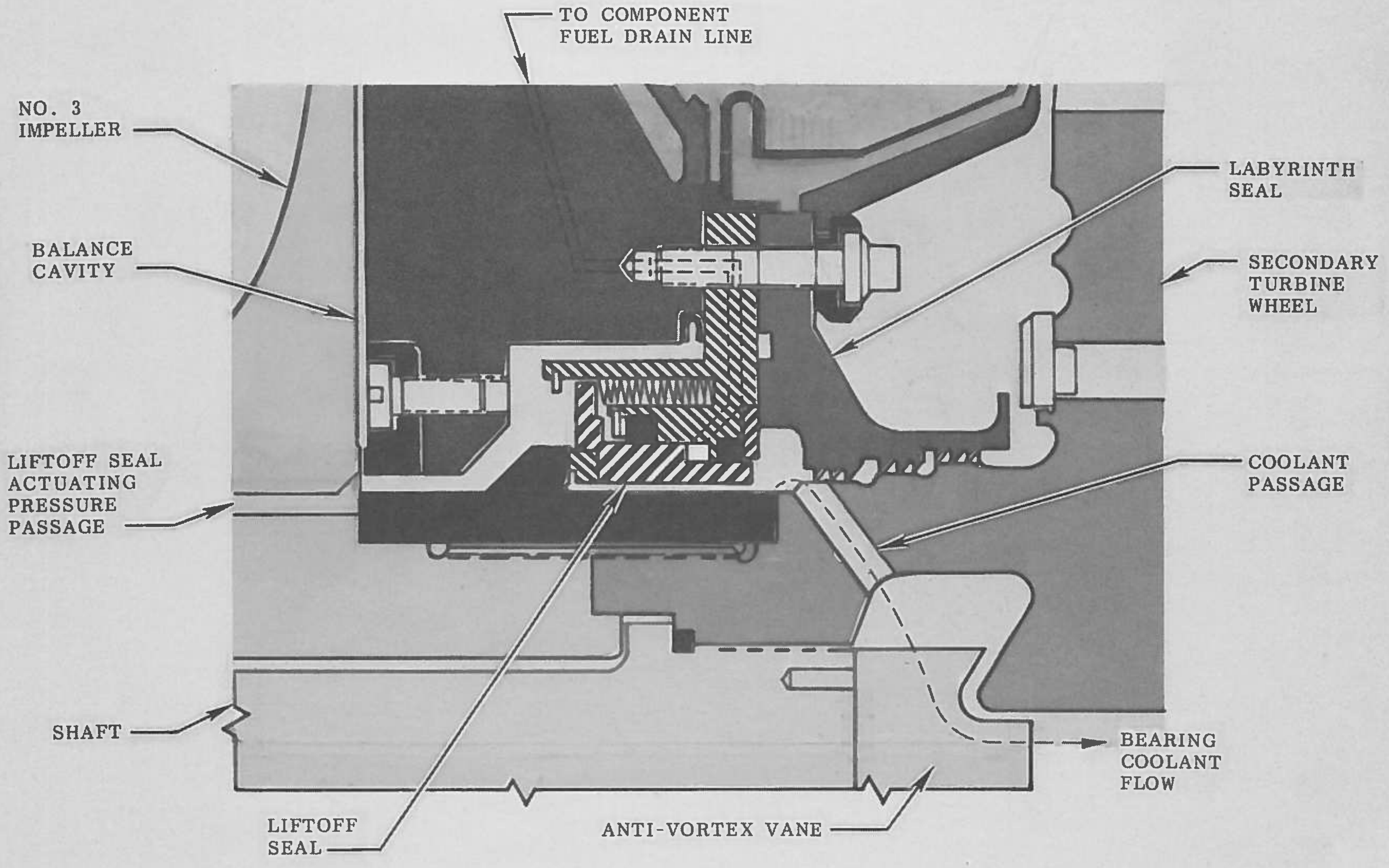


LSS-EC-T-66D

SSME HPFTP SHAFT SEALS

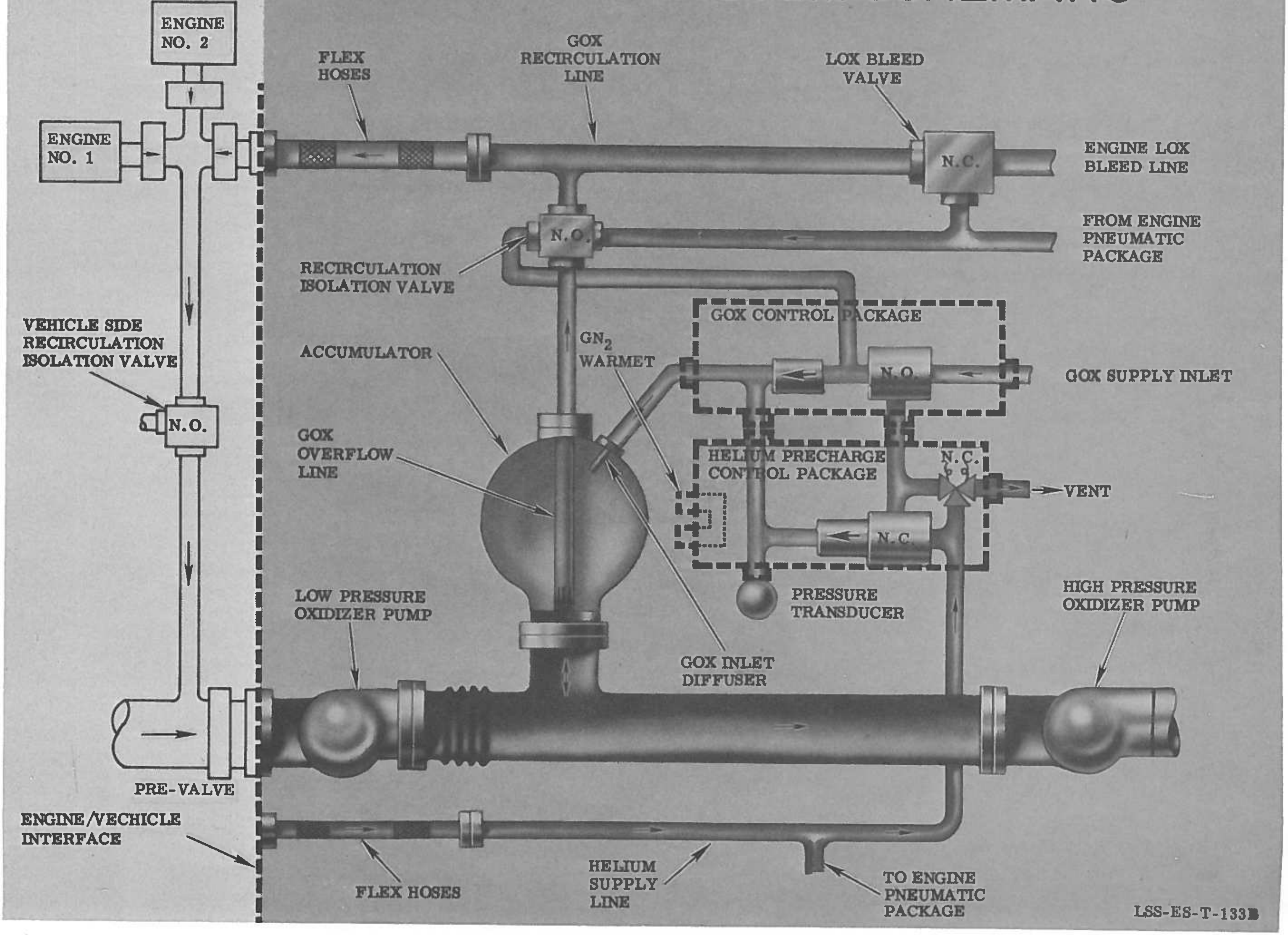
Prior to engine start, hydrogen leakage into the turbine end (and, therefore, overboard) is prevented by a liftoff seal spring-loaded against a shaft mate ring. At engine start, pump pressure from the hub area of No. 3 impeller lifts the seal from the mate ring. Shaft sealing is then assumed by a three-step labyrinth seal adjacent to the liftoff seal. The antivortex vane solved an early problem involving a vortex plug that had been partially blocking the bearing coolant flow.

HPFTP SEAL GROUP



LSS-EC-T-15A

POGO SUPPRESSION SYSTEM SCHEMATIC



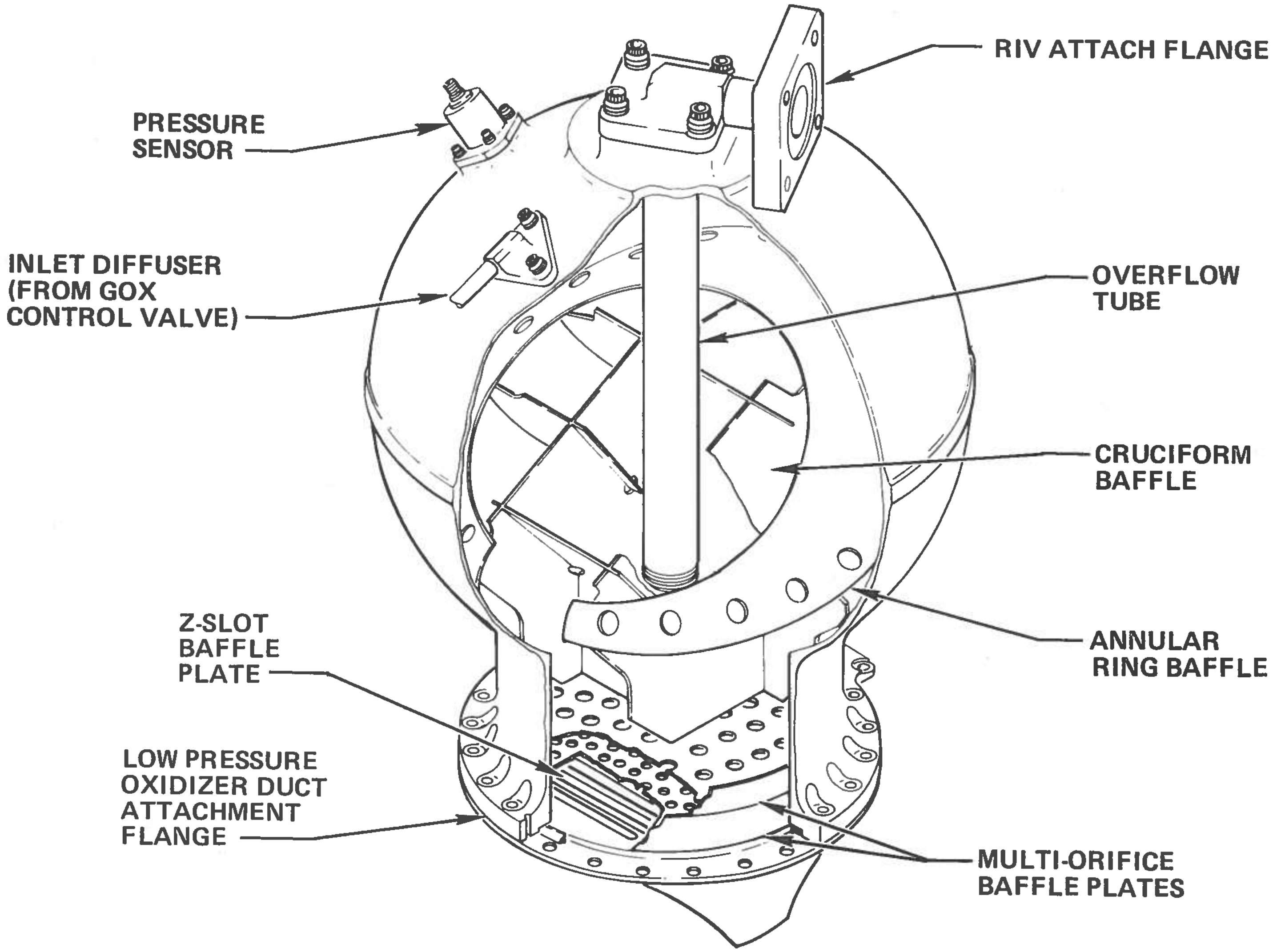
POGO SUPPRESSION SYSTEM ACCUMULATOR

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 inlet diffuser turns and breaks up the incoming stream of pressurizing gas. The overflow tube (standpipe) has only six small exit holes at the bottom. The cruciform and ring baffles reduce LOX sloshing. The Z-slot and multi-orifice baffle plates prevent surface turbulence and, therefore, gas ingestion.

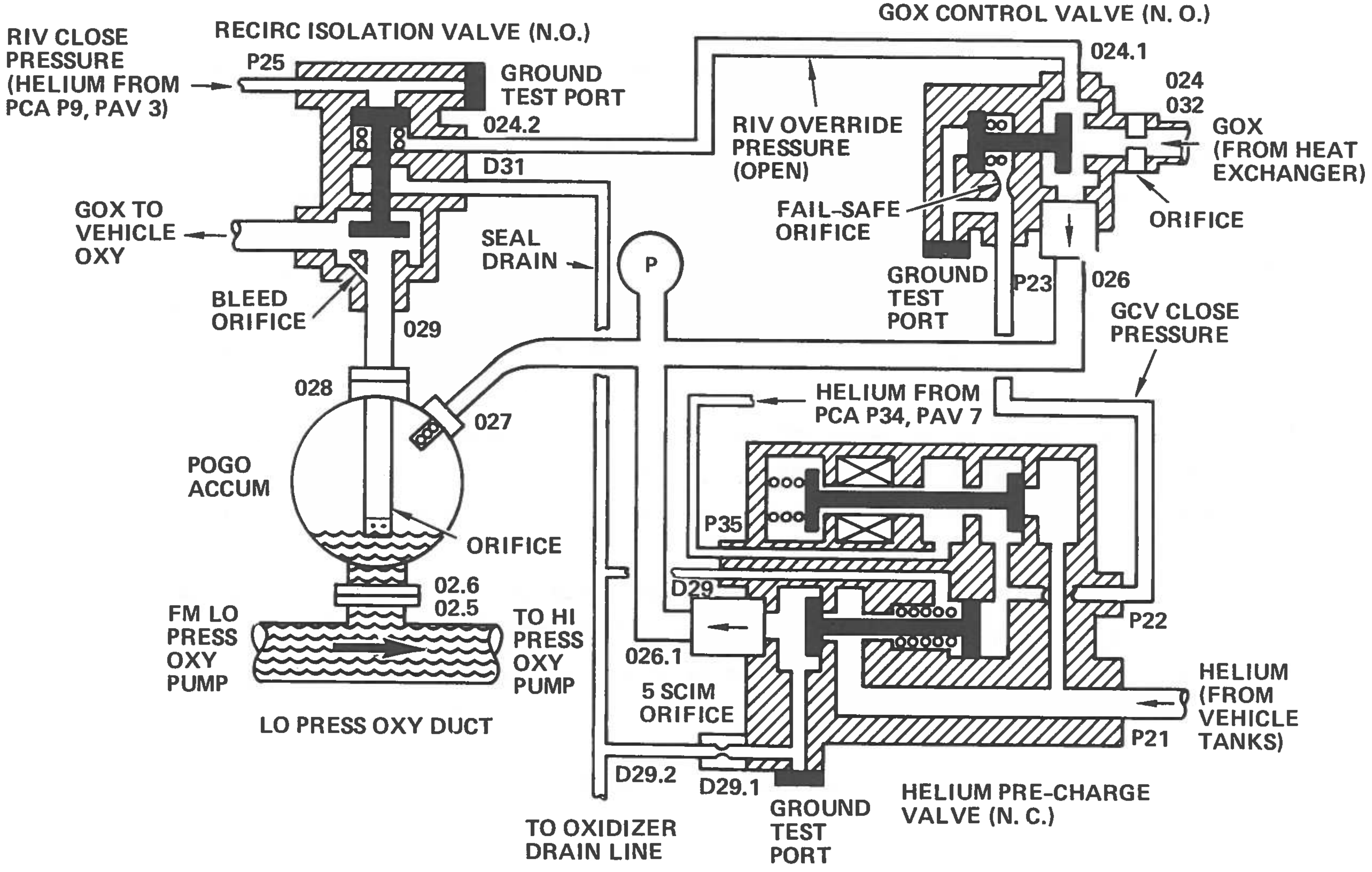
POGO SUPPRESSION ACCUMULATOR



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 an inverted standpipe, and returns to the vehicle system to be recondensed. Restrictors in the flowpath 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 flow stops and the 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. When the HPV is open, the GOX 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 short 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 (024.1) is applied to the RIV (024.2) to ensure that it opens at engine start.

POGO ACCUM PRESSURIZING SYSTEM



LSS-ES-T-327D

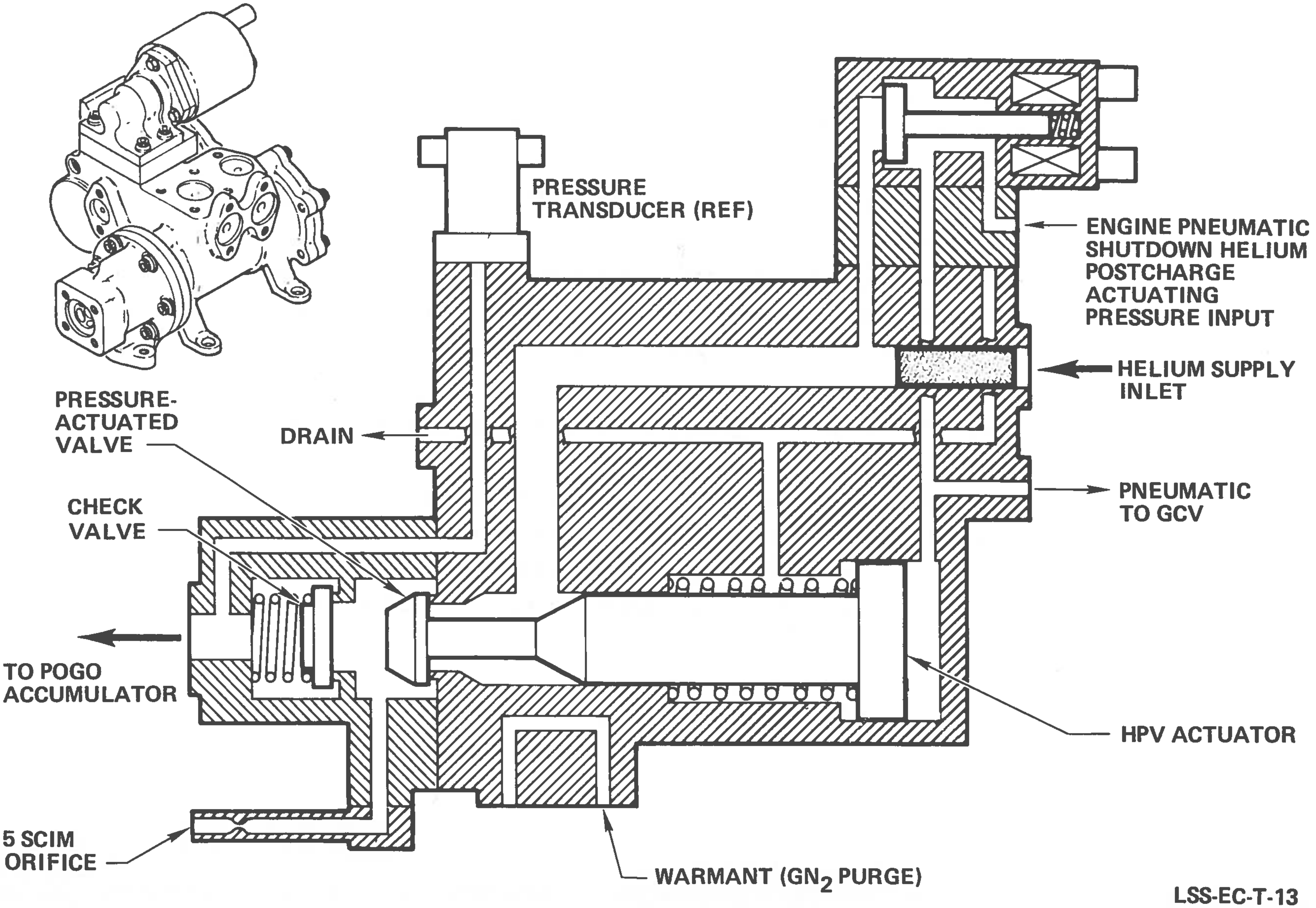
POGO SYSTEM HELIUM PRECHARGE VALVE

The helium precharge valve (HPV) controls the flow of helium to the pogo accumulator. The accumulator needs to be pressurized at engine start before sufficient GOX is available, and at engine shutdown after GOX pressure decays.

The HPV is a spring-loaded-closed, pneumatically-opened poppet valve. Pressure to open the poppet is tapped from the helium input, and is applied to the poppet by energizing the solenoid pilot valve. The same pressure is routed to the GOX control valve (not shown) to close it. The helium inlet is filtered by a 15-micron absolute filter. The poppet cavity is vented through a 5-scim orifice to pressure-relieve it. During engine preparation, the engine oxidizer dome GN_2 purge is routed through the HPV body to warm it.

In the event of an engine pneumatic shutdown, helium pressure from the PCA (not shown) is routed to the HPV to open the poppet for the postcharge function. The poppet actuating pressure is routed through the solenoid valve in the deenergized position, on the assumption that it cannot be energized.

POGO SYSTEM HELIUM PRECHARGE VALVE



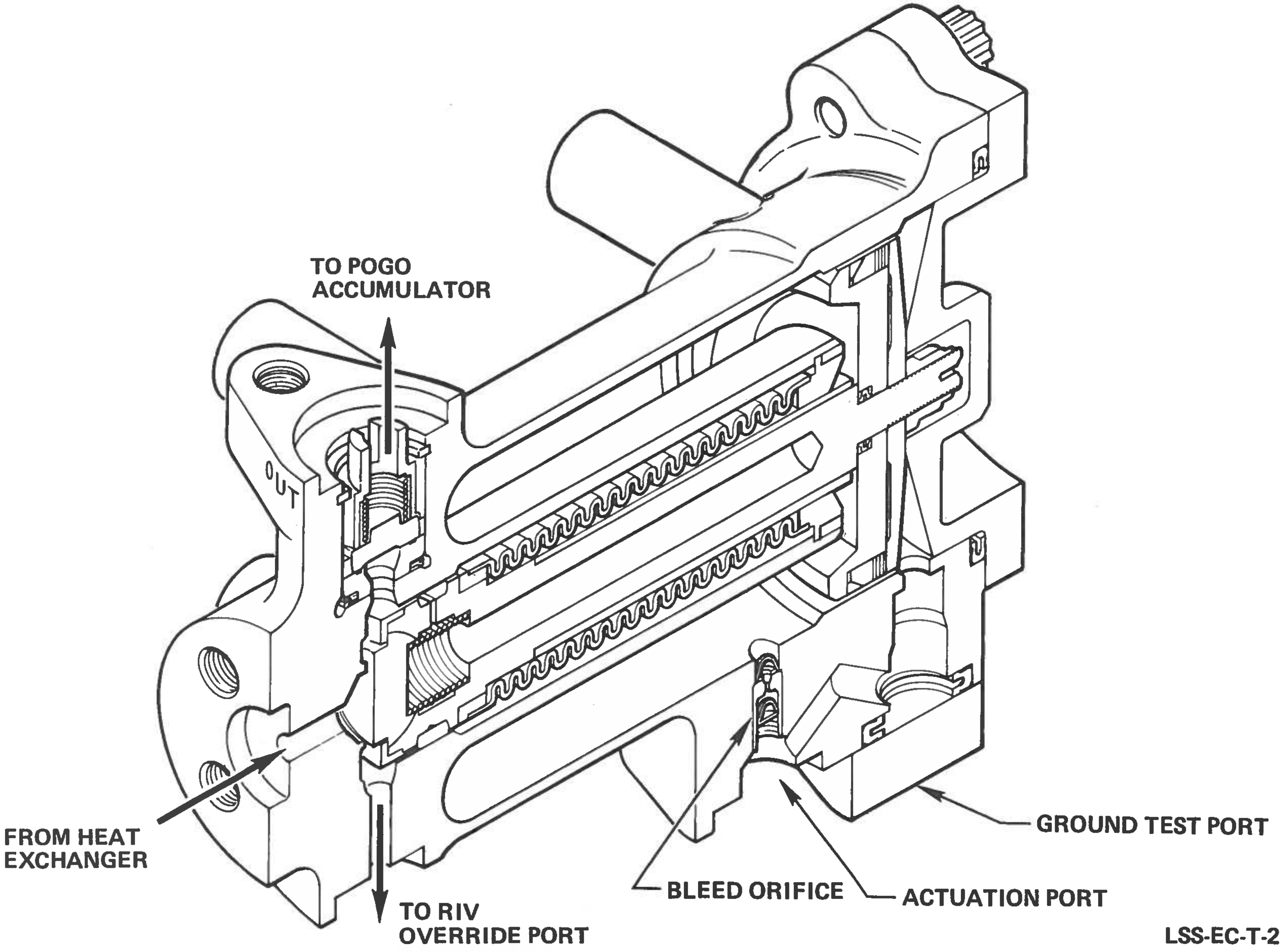
LSS-EC-T-13

POGO SYSTEM GOX CONTROL VALVE

The GOX control valve (GCV) controls the flow of GOX to the pogo accumulator. It is normally open, but pressurized closed for 0.44 seconds at start enable (pre-precharge), 2 seconds during start phase (precharge), and 0 to 4 seconds at shutdown (postcharge).

The GCV is a bellows opened, pneumatically closed poppet valve. Pressure applied to the top of the piston pushes the poppet against its seat and stretches the bellows. Pressure to close the valve is controlled by the same pilot valve that controls the helium control valve. To ensure that the GCV will open even if close pressure is not removed, close pressure is simultaneously applied to the underside of the piston through a small bleed orifice. When the pressure equalizes on both sides of the piston (4 seconds), the stretched bellows pulls the poppet from its seat. When open, the GCV also applies pressure to the recirculation isolation valve override port, to ensure that it also opens.

POGO SYSTEM GOX CONTROL VALVE



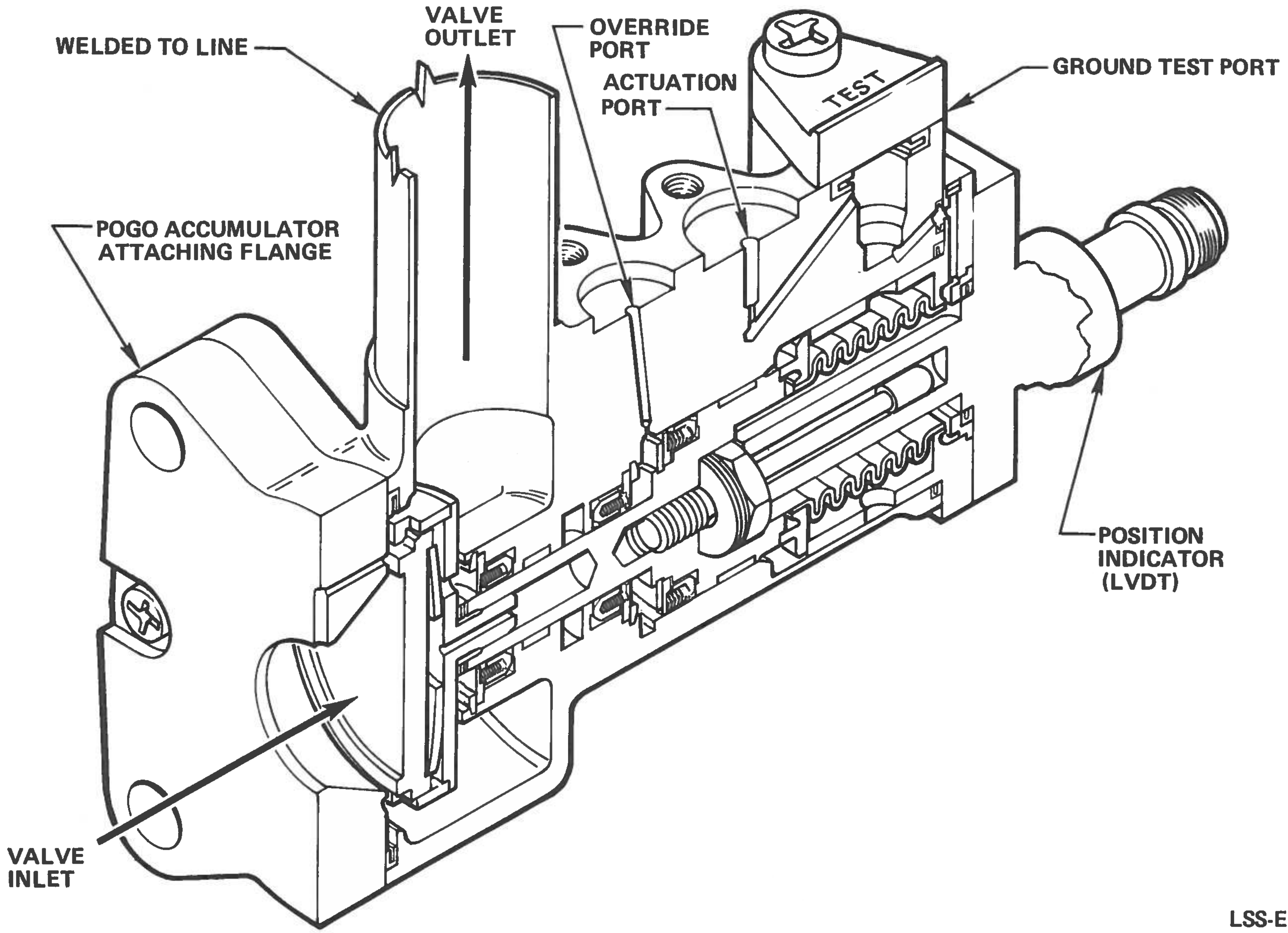
LSS-EC-T-21

POGO SYSTEM RECIRCULATION ISOLATION VALVE

The recirculation isolation valve (RIV) blocks the pogo accumulator exit standpipe, to remove a short-circuit flowpath for oxidizer recirculation during the engine preparation phase. All recirculation must pass through the oxidizer bleed valve (OBV).

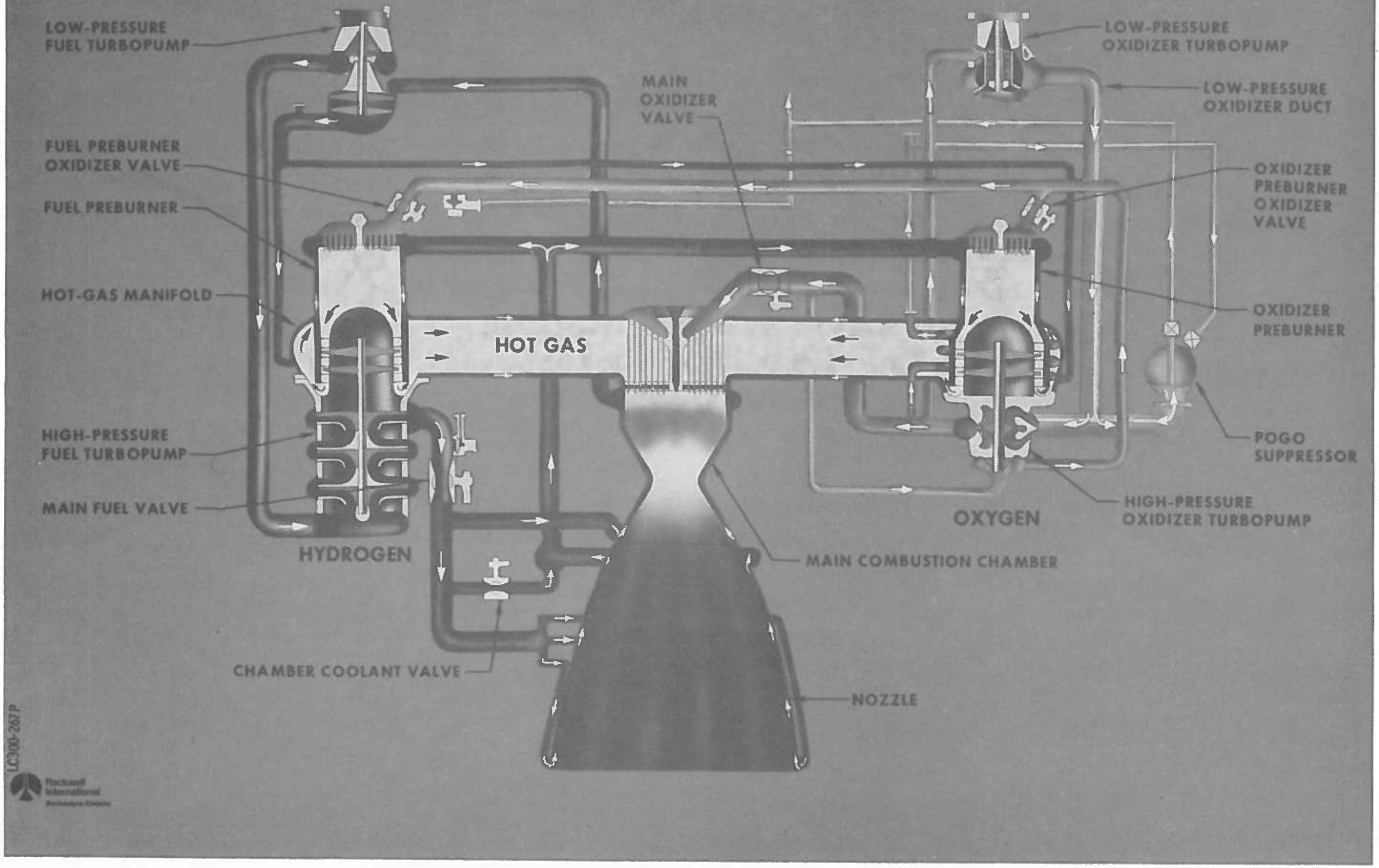
The RIV is a bellows-opened, pneumatically-closed poppet valve. Pressure applied to the top of the piston pushes the poppet against its seat and stretches the bellows. Pressure to close the RIV is the same as that which opens the OBV. This pressure is controlled by the pneumatic control assembly (PCA). To ensure that the RIV opens when the GOX valve opens, GOX pressure from the GOX valve is routed to the RIV override port. This assists the bellows in pulling the poppet open. The poppet seat contains a small drilled orifice to permit oxidizer to rise to the accumulator standpipe when the poppet is closed during oxidizer recirculation. A linear variable differential transducer (LVDT) is used to indicate poppet position.

POGO SYSTEM RECIRCULATION ISOLATION VALVE



LSS-EC-T-26

SSME PROPELLANT FLOW SCHEMATIC

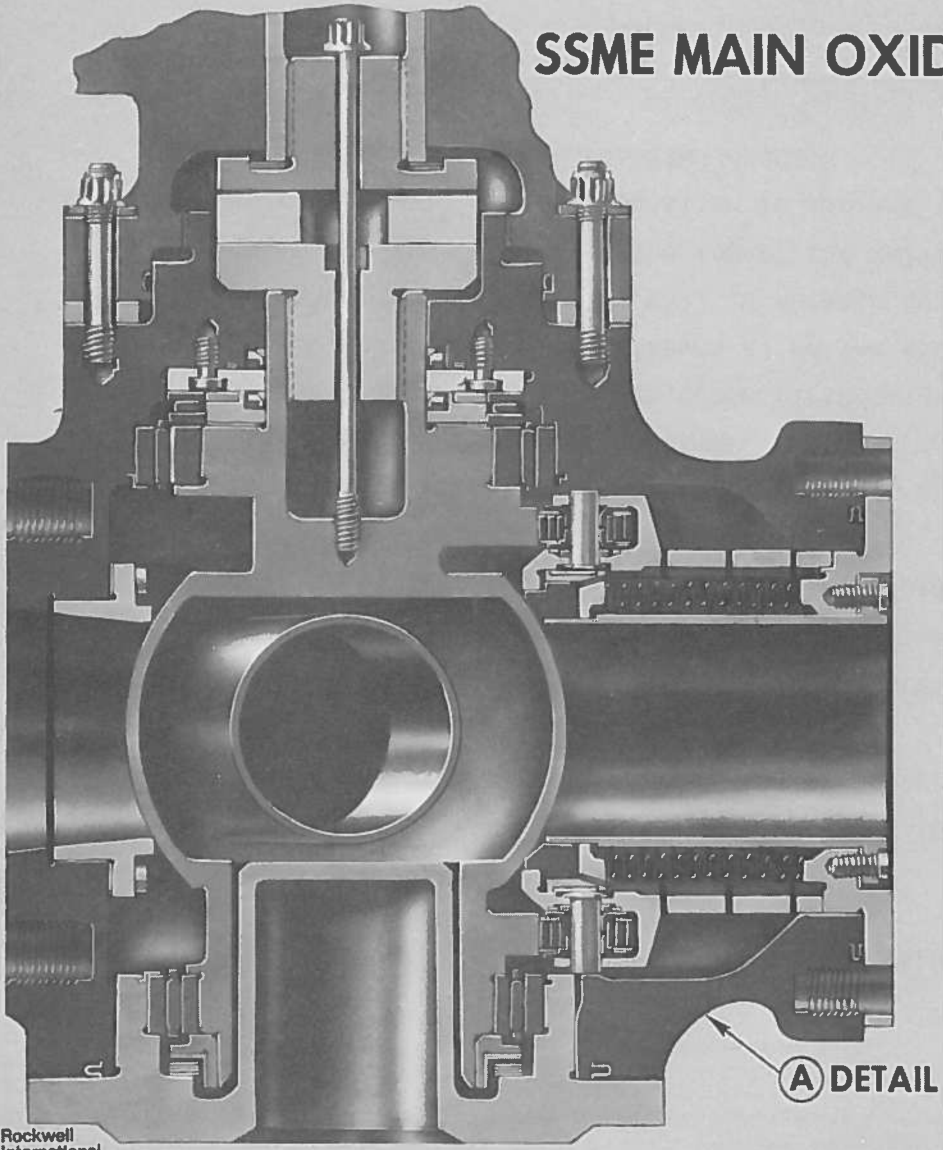


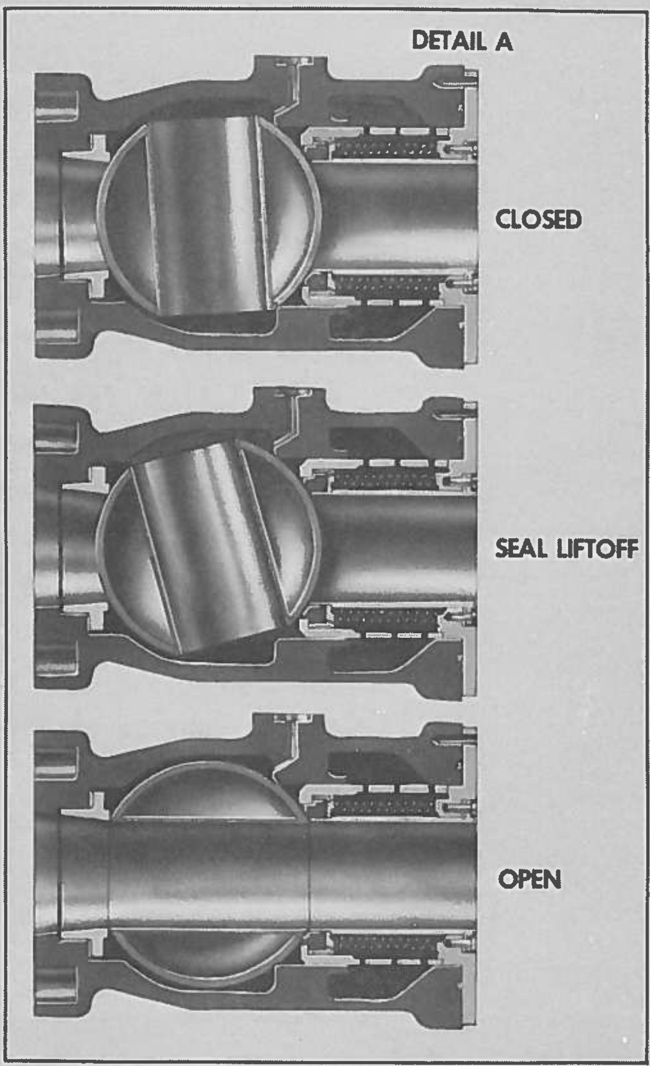
SSME MAIN OXIDIZER VALVE

The main oxidizer valve (MOV) permits or stops the flow of oxidizer to the main injector oxidizer dome and initiates oxidizer flow to the MCC augmented spark ignition (ASI) system chamber.

The MOV is a ball-type valve with an integral ball and shaft. The hollow ball is approximately 5 inches in diameter with a 2.5-inch tubular passage. The ball seal is a machined-plastic ring, bellows-loaded against the inlet side of the ball. Two cams machined on the shaft lift the seal from the ball within the first several degrees of ball rotation. Inlet and outlet sleeves aline the flow with the ball to minimize turbulence. The MCC ASI oxidizer is tapped from the back of the valve housing, and flows as soon as the liftoff seal is lifted. The ball is rotated by a hydraulic actuator (not shown) spline-coupled to the top of the valve.

SSME MAIN OXIDIZER VALVE ASSEMBLY



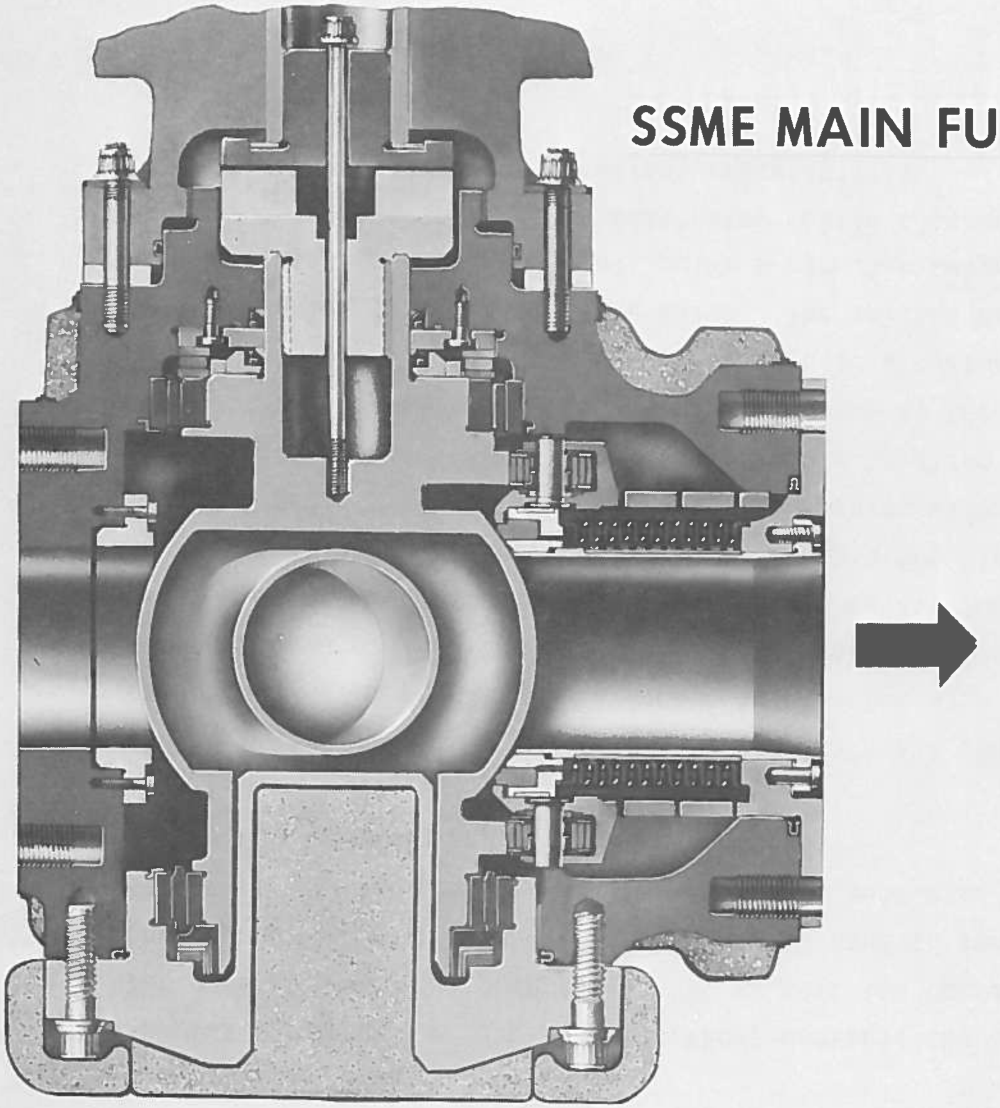


SSME MAIN FUEL VALVE

The main fuel valve (MFV) permits or stops the flow of fuel to the several cooling circuits and to the preburners.

The MFV is a ball-type valve with an integral ball and shaft. The hollow ball is approximately 5 inches in diameter with a 2.5-inch tubular passage. The ball seal is a machined-plastic ring, bellows-loaded against the outlet side of the ball. Placing the seal on the outlet side of the ball allows hydrogen to enter the valve housing, which reduces the cooldown time. Two cams machined on the shaft lift the seal from the ball within the first several degrees of ball rotation. Inlet and outlet sleeves aline the flow with the ball to minimize turbulence. The ball is rotated by a hydraulic actuator (not shown) spline-coupled to the top of the valve. The valve housing is insulated with molded insulation to prevent the formation of liquid air and to assist the cooldown process.

SSME MAIN FUEL VALVE ASSEMBLY



LC303-167D

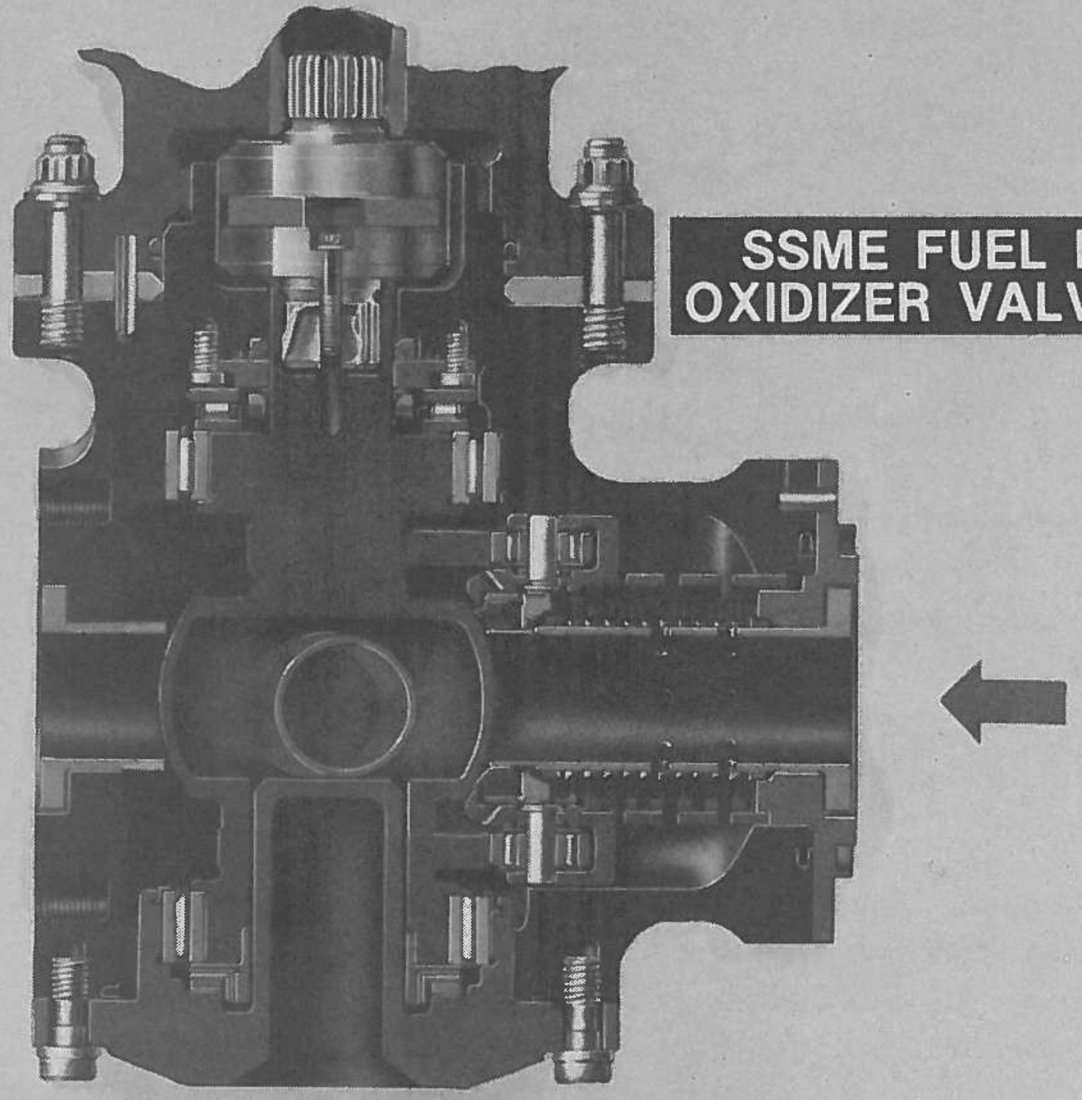
Rockwell International
Rocketdyne Division

SSME FUEL PREBURNER OXIDIZER VALVE

The fuel preburner oxidizer valve (FPOV) controls the amount of oxidizer entering the fuel preburner (FPB) so that its operating level (horsepower output) can be varied. This is done to control engine thrust and MCC mixture ratio. The FPOV also initiates oxidizer flow to the FPB ASI chamber.

The FPOV is a ball-type valve with an integral ball and shaft. The hollow ball is approximately 3 inches in diameter with a 1-inch tubular passage. The ball seal is a machined-plastic ring that is bellows loaded against the inlet side of the ball. Two cams machined on the shaft lift the seal from the ball within the first several degrees of ball rotation. Inlet and outlet sleeves aline the flow with the ball to minimize turbulence. The FPB ASI oxidizer is tapped from the back of the valve housing and flows as soon as the liftoff seal is lifted. The ball is rotated by a hydraulic actuator (not shown) spline-coupled to the top of the valve. The splined coupling is a zero-backlash device; ie, a bolt pulls a circular wedge into each spline, spreading them. This eliminates spline clearance, giving precise valve control and excellent repeatability.

SSME FUEL PREBURNER OXIDIZER VALVE ASSEMBLY



LC303-162E

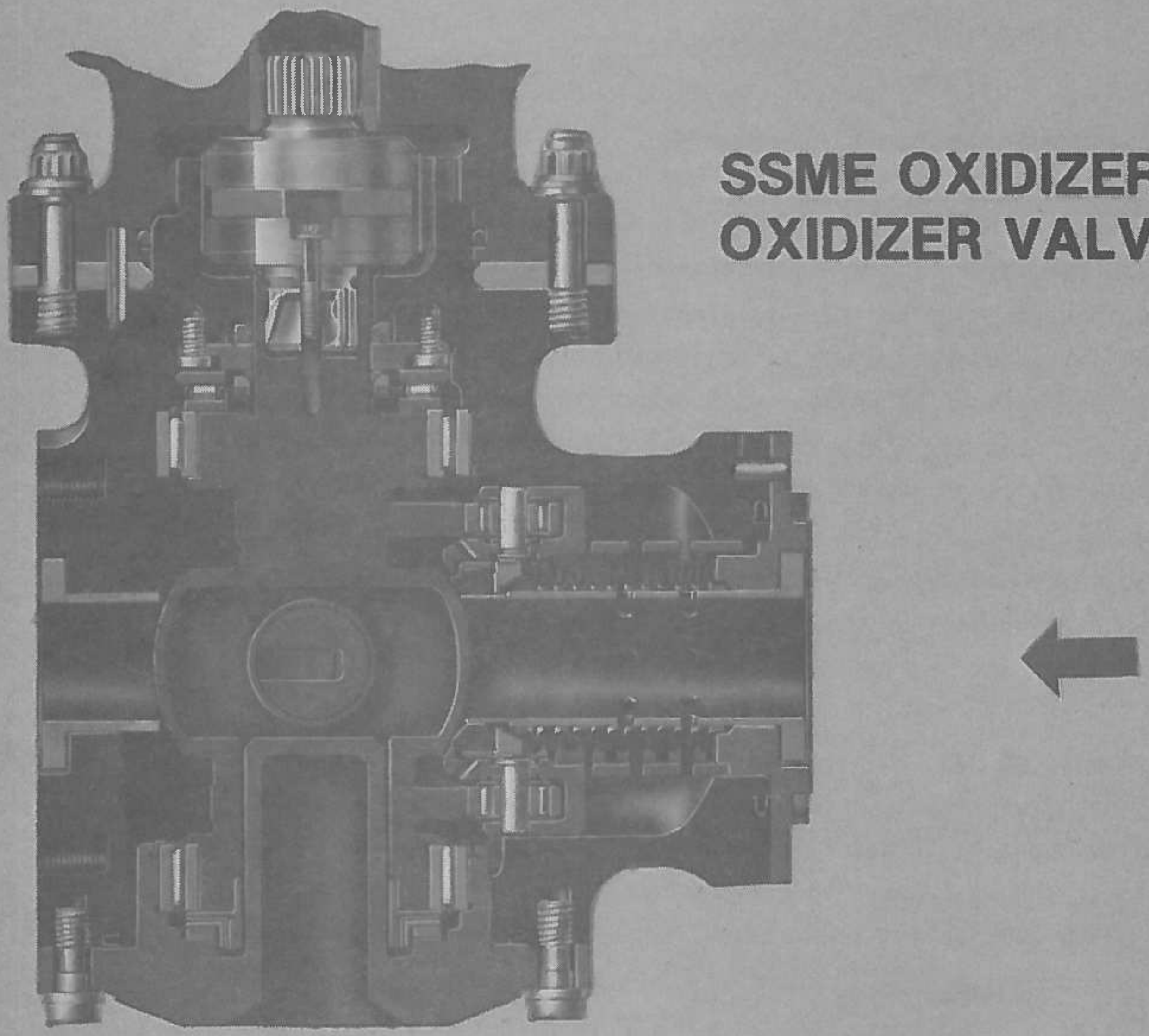
Rockwell International
Rocketdyne Division

SSME OXIDIZER PREBURNER OXIDIZER VALVE

The oxidizer preburner oxidizer valve (OPOV) controls the amount of oxidizer entering the oxidizer preburner (OPB) so that its operating level (horsepower output) can be varied. This is done to control engine thrust. The OPOV also initiates oxidizer flow to the OPB ASI chamber.

The OPOV is a ball-type valve with an integral ball and shaft. The hollow ball is approximately 3 inches in diameter and its slot passage is approximately 1.0 by 0.4 inch. A slot (instead of a hole) makes flow-opening versus ball rotation a linear function. This is desirable, since the OPOV is the engine throttle valve. Two cams machined on the shaft lift the seal from the ball within the first several degrees of ball rotation. Inlet and outlet sleeves aline the flow with the ball to minimize turbulence. The OPB ASI oxidizer is tapped from the back of the valve housing and flows as soon as the liftoff seal is lifted. The ball is rotated by a hydraulic actuator (not shown) spline-coupled to the top of the valve. The splined coupling is a zero-backlash device; ie, a bolt pulls a circular wedge into each spline, spreading them. This eliminates spline clearance, giving precise valve control and excellent repeatability.

SSME OXIDIZER PREBURNER OXIDIZER VALVE ASSEMBLY



SC87C-4-2043

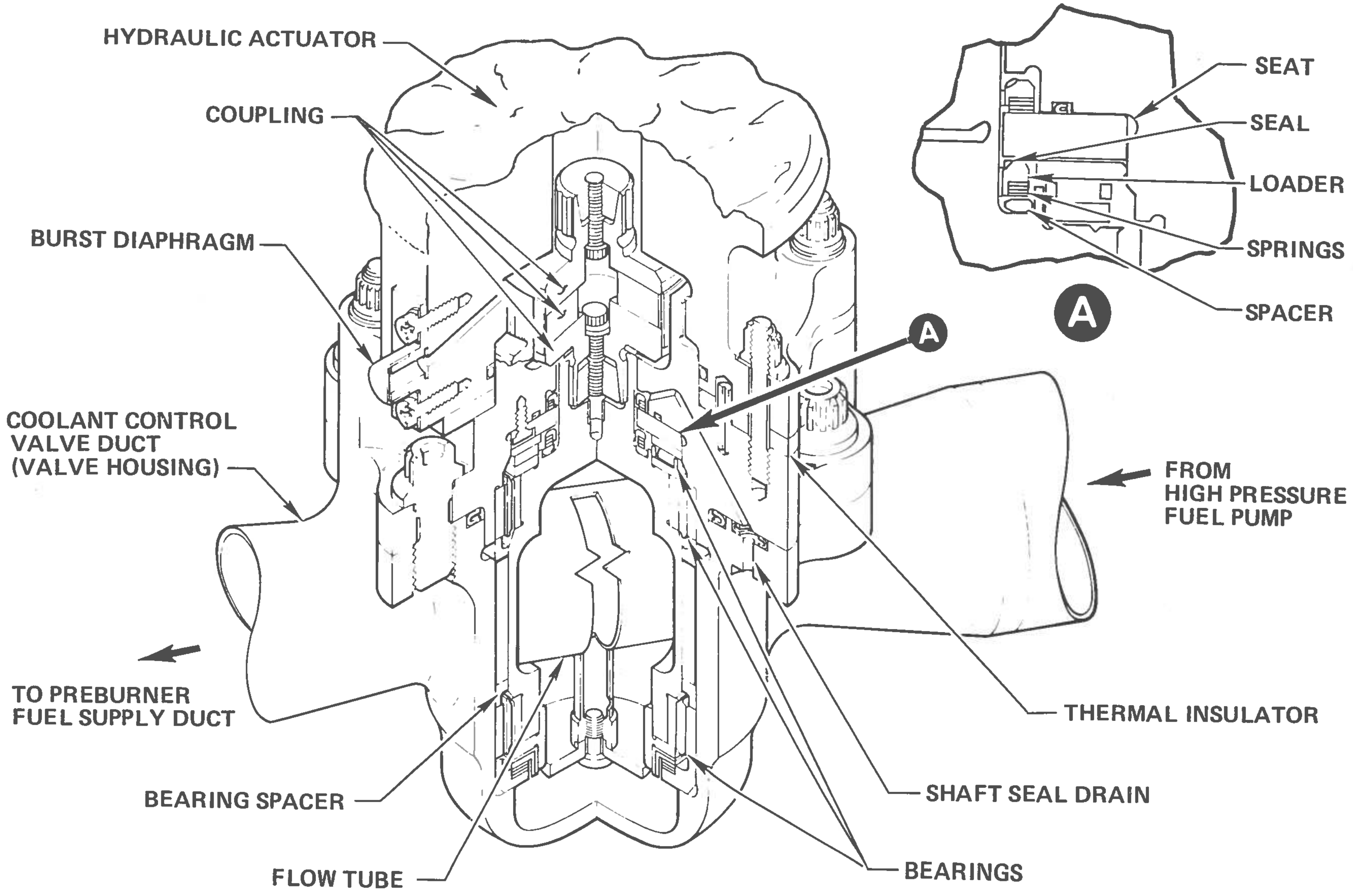
Rockwell International
Rocketdyne Division

SSME CHAMBER COOLANT VALVE

The chamber coolant valve (CCV) establishes the desired three-way split ratio of fuel to the MCC coolant passages, the nozzle coolant tubes, and the preburners. By gradually opening from one-half to full between MPL and RPL, it also allows the additional fuel required for higher thrust levels to bypass the nozzle tubes and go directly to the preburners.

The CCV is a rotating-tubular-gate valve. The tubular gate has a diameter of 2.5 inches and a flow passage of 1.6 inches. Since it is a bypass control valve and not a shutoff valve, it needs no gate seal. The valve is mounted in a fuel line that is welded to the top of the nozzle and bypasses the nozzle coolant tubes. The body of the valve is welded into the line; however, the operating portion can be removed from the body. The gate is rotated by a hydraulic actuator (not shown) spline-coupled to the top of the valve. The splined coupling is a zero-backlash device; ie, a bolt pulls a circular wedge into each spline, spreading them. This eliminates spline clearance, giving precise valve control and excellent repeatability.

SSME CHAMBER COOLANT VALVE



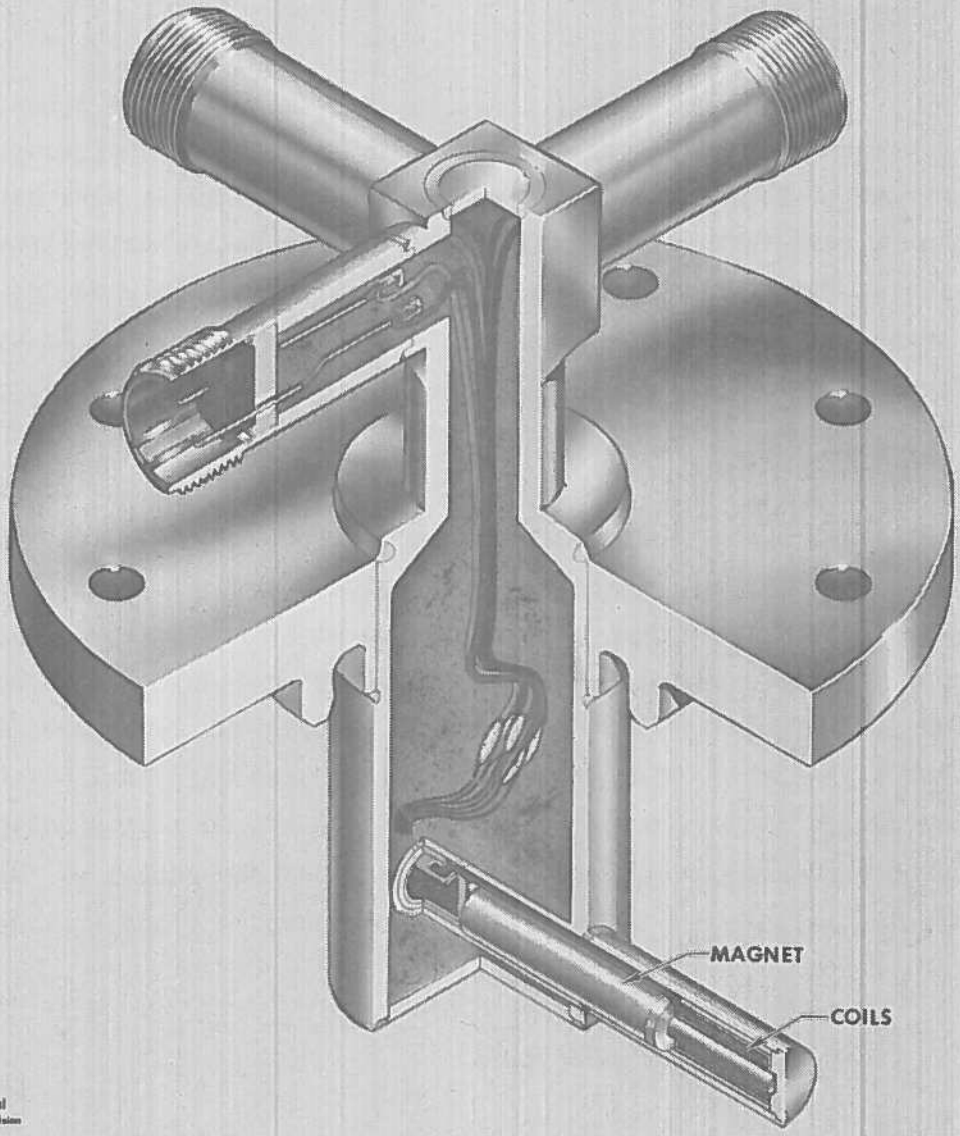
LSS-EC-T-38A

SSME SPEED AND FLOW SENSORS

Magnetic-type transducers are used to sense and monitor turbopump shaft speed and fuel flow. A transducer contains sensing coils wound around a magnetic core, which produces induced output pulses when stimulated by rotation of a ferromagnetic body adjacent to the sensing tip. The coils are encapsulated in a hermetically sealed, machined housing and the lead wires are brought out through an electrical connector that provides a moisture-proof seal. The transducer connects through the electrical harness to the controller, which contains the pulse rate counters. Checkout is performed by inducing a voltage at known frequency into one coil and monitoring the output, produced by transformer coupling, in the other coils. The speed sensors contain three sensing coils and the flow sensors contain two.

The fuel flowmeter measures the volumetric flowrate of the fuel. The fluid flows past a rotor with helical blades. The speed of rotation of the blades is essentially proportional to the fluid velocity. Each time a blade tip passes an externally mounted transducer, a small alternating voltage is induced in the transducer's magnet and coil assembly. The pulse rate is directly proportional to the volumetric flowrate. Accuracy is obtained by calibration, accounting for variations caused by tolerances in the fabrication of the assembly and the duct in which it is installed.

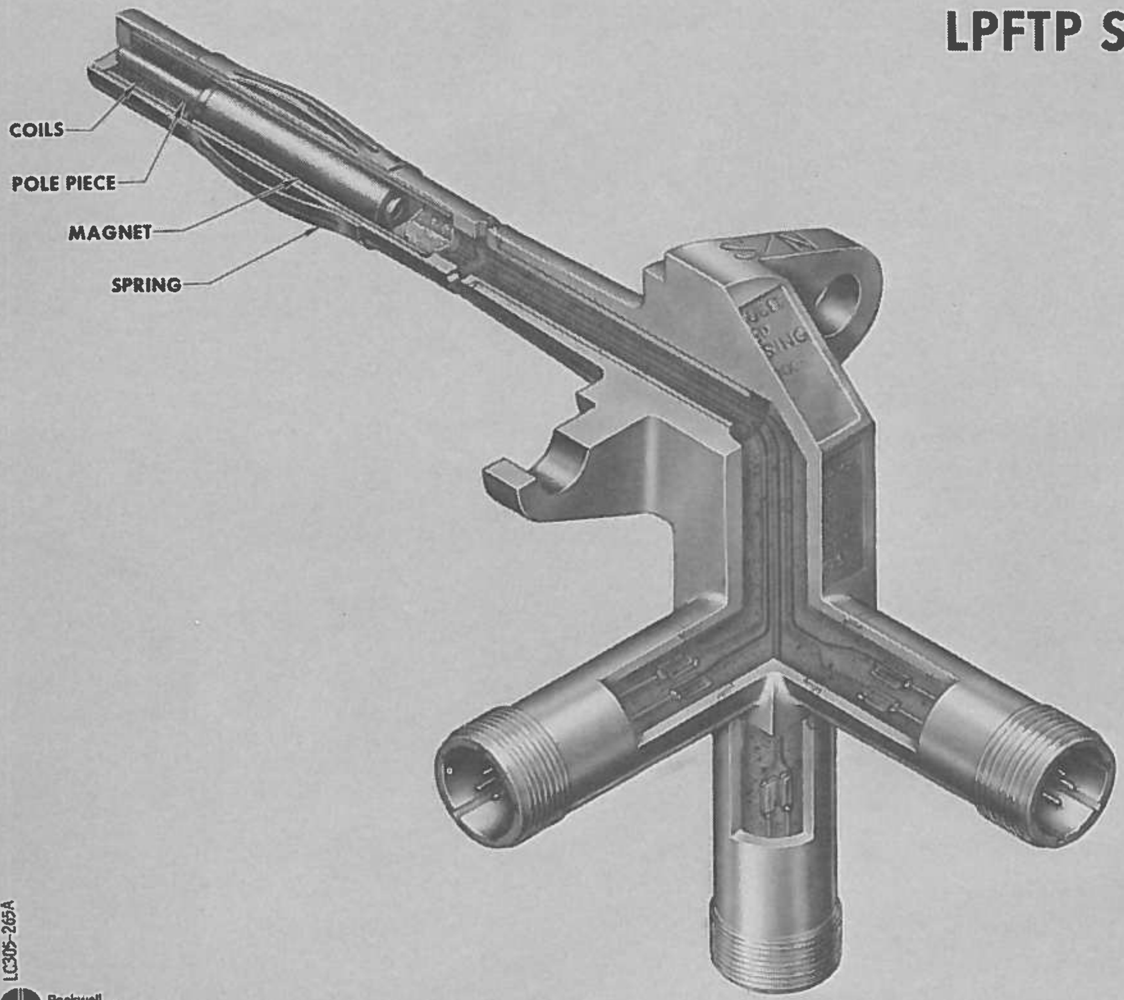
LPOTP
SPEED SENSOR



LC305-257B

Rockwell International
Rocketdyne Division

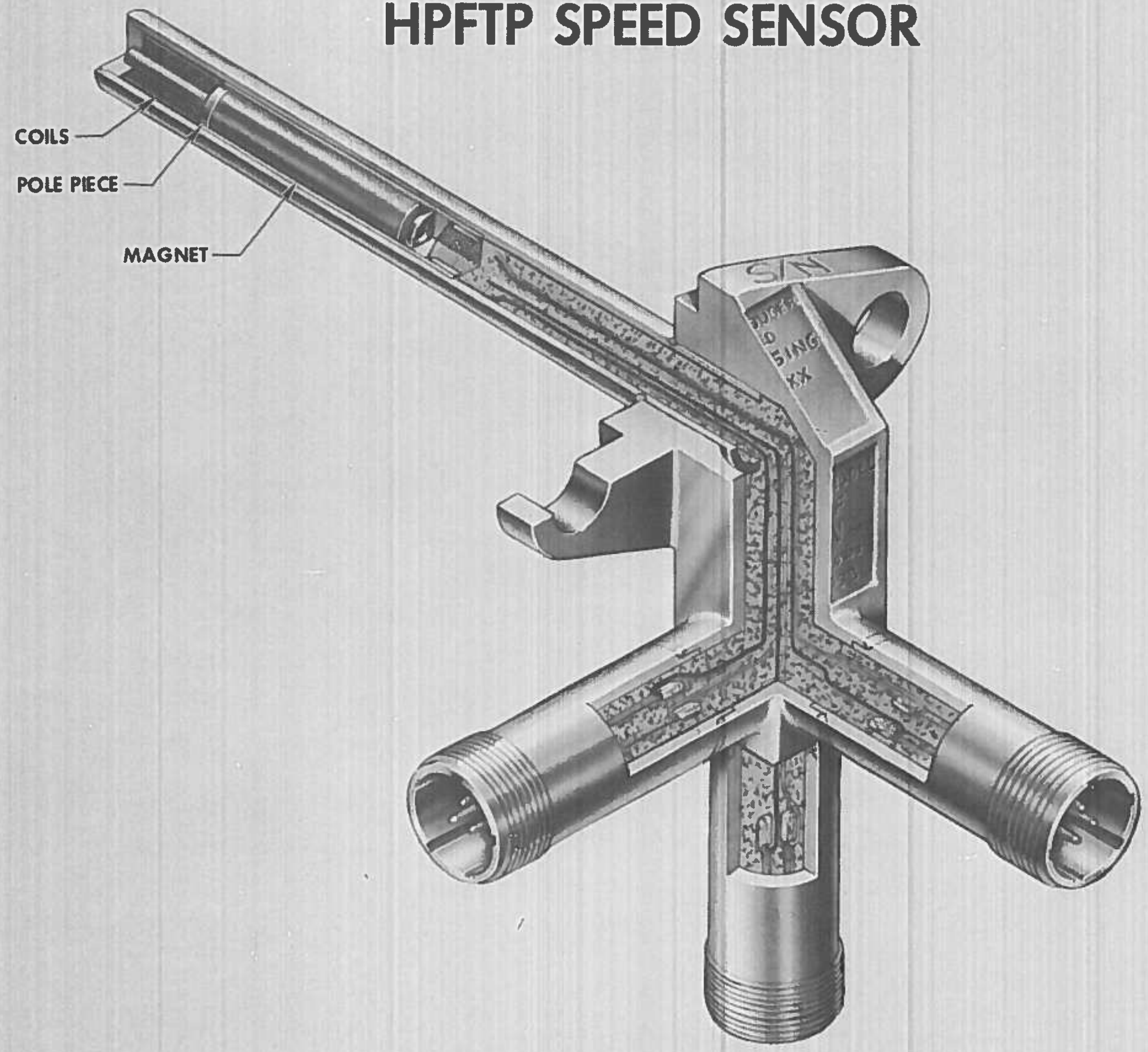
LPFTP SPEED SENSOR



LC305-265A

Rockwell International
Rocketdyne Division

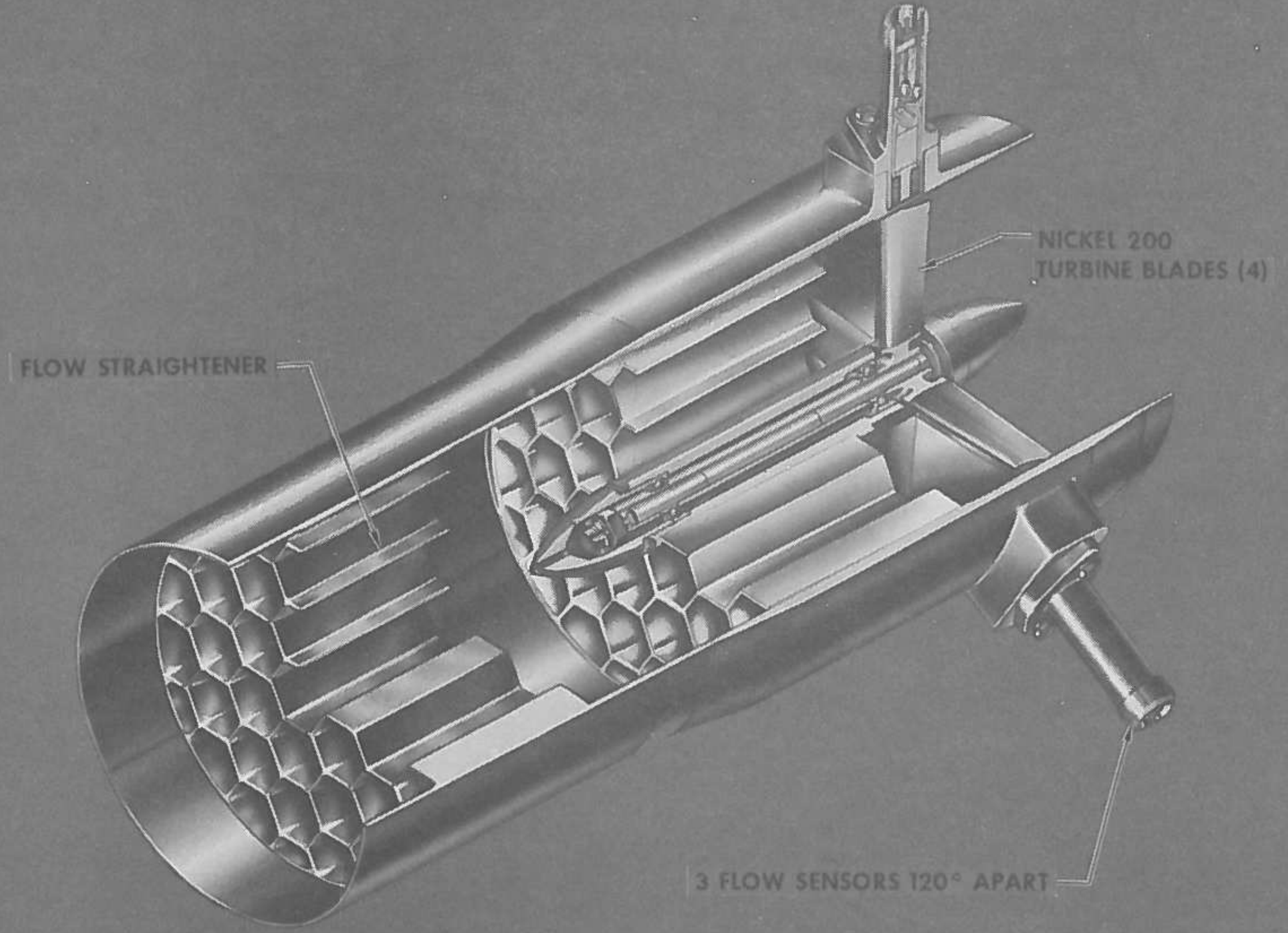
HPFTP SPEED SENSOR



LC305-264A

Rockwell International
Rocketdyne Division

SSME FUEL FLOWMETER



LC303-183C

Rockwell
International
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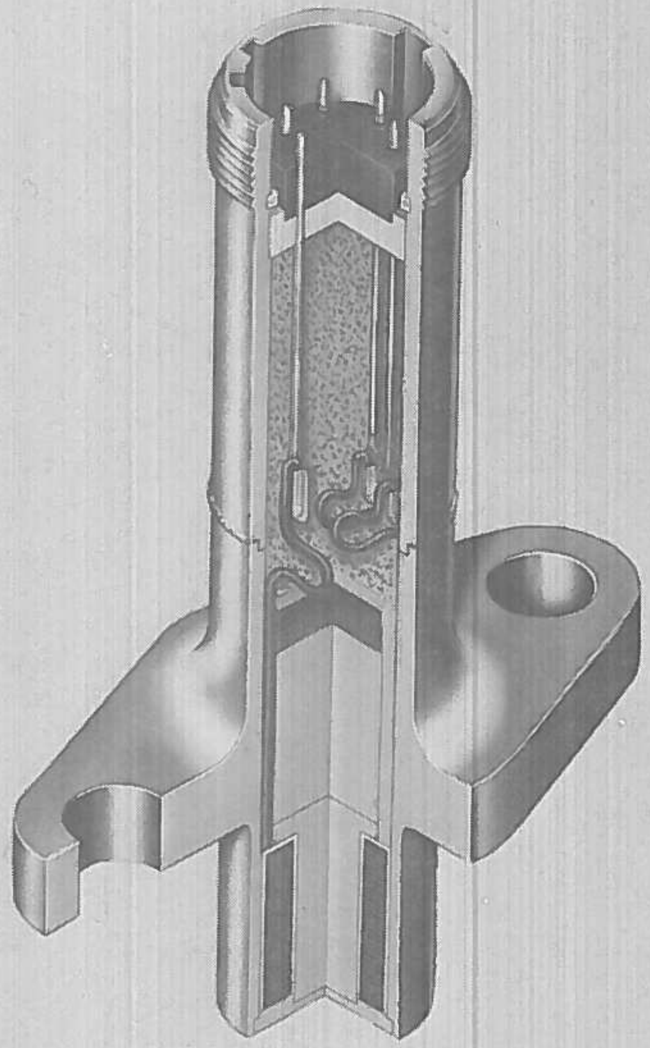
FLOW SENSOR



LC305-258B

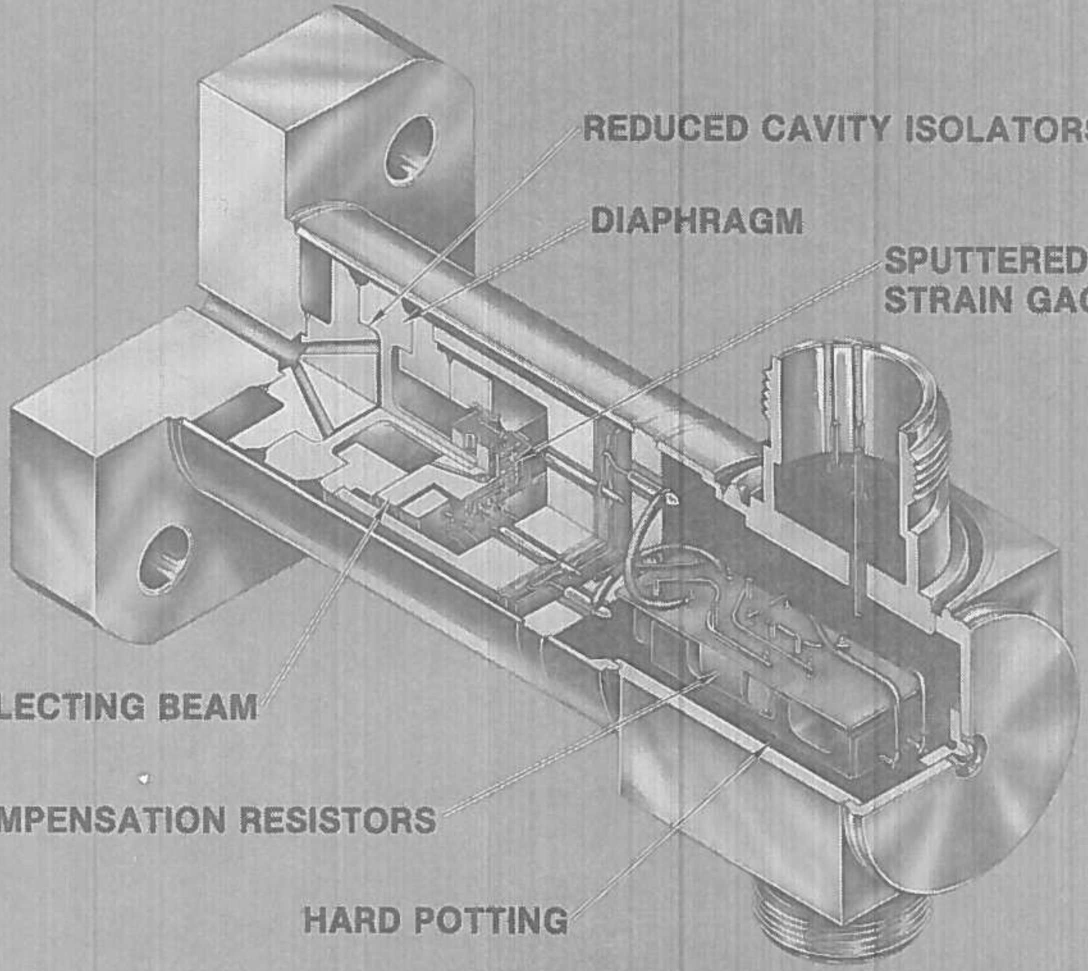
Rockwell International
Rocketdyne Division

SSME PRESSURE TRANSDUCER

The transducer uses strain gages, electrically connected to form Wheatstone bridge circuits, to produce dual-output signals proportional to the pressure applied. A set of resistors in each bridge provides for electrical checkout. The electrical networks are connected to separate electrical connectors. The transducer and the electrical receptacles are hermetically sealed in a flanged mounting case. The transducer is mounted at the point of measurement and connected through electrical harnesses to the controller, which contains the signal conditioning and checkout switching electronics.

SSME PRESSURE TRANSDUCER

(MANUFACTURED BY STATHAM)



REDUCED CAVITY ISOLATORS

DIAPHRAGM

SPUTTERED THIN FILM STRAIN GAGES

DEFLECTING BEAM

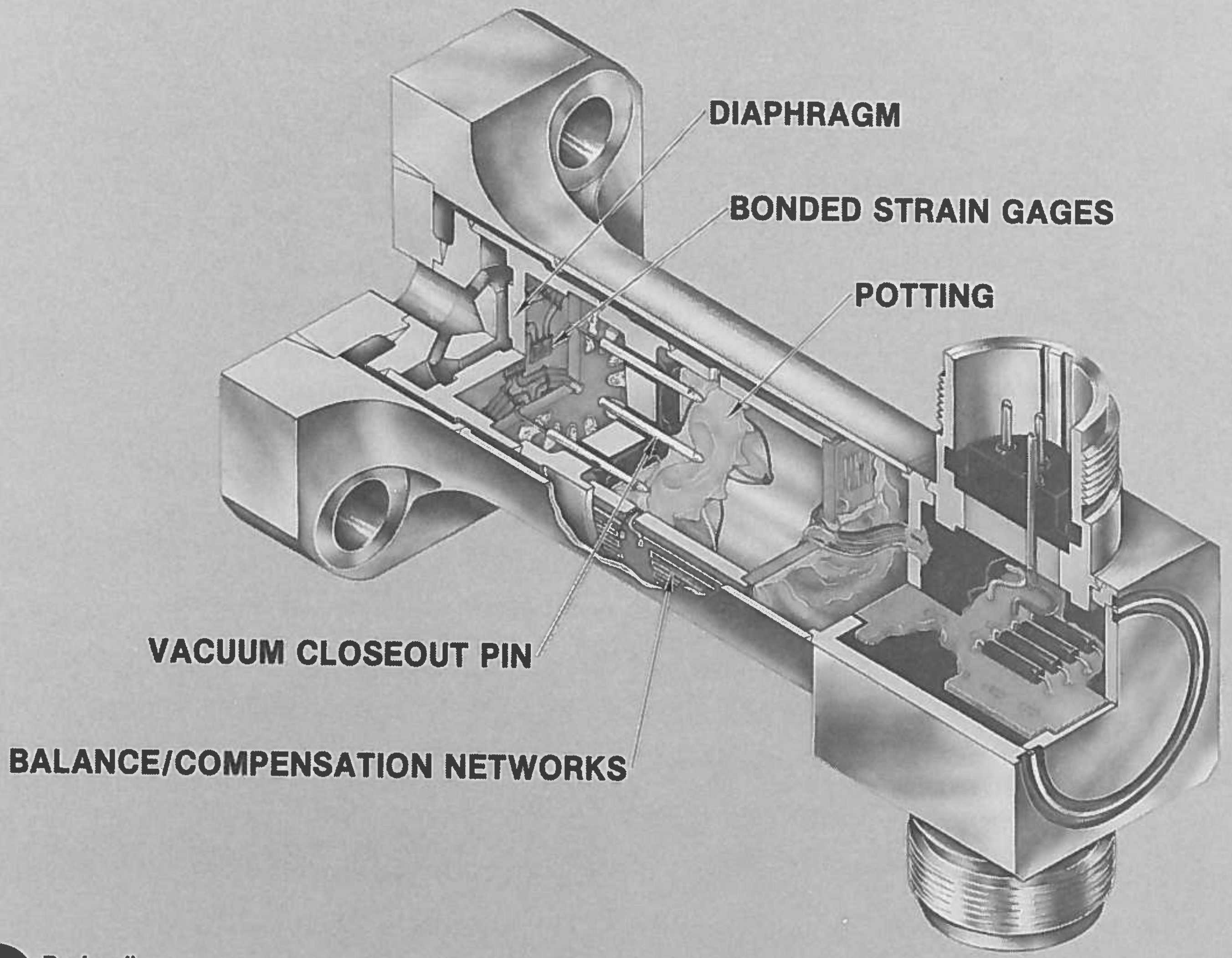
BALANCE/COMPENSATION RESISTORS

HARD POTTING

LC303-187C

Rockwell International
Rocketdyne Division

SSME PRESSURE TRANSDUCER
(MANUFACTURED BY C.C.C.)



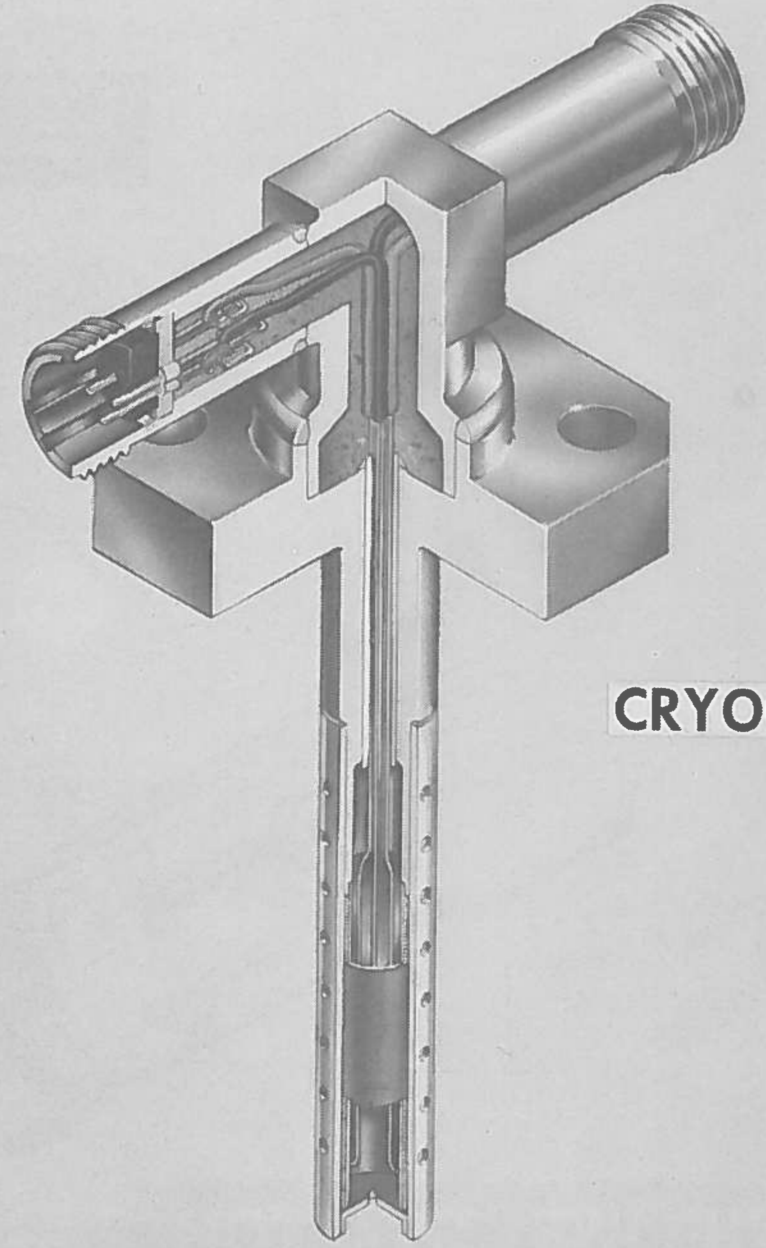
LG308-247

Rockwell
International
Rocketdyne Division

SSME TEMPERATURE SENSORS

A temperature sensor output signal is a temperature-dependent change in electrical resistance. A temperature sensor employs a platinum wire element that is electrically connected in a Wheatstone bridge configuration. The platinum wire element is mounted on a strain-free support and protected by a shield. The element assembly is brazed into a machined housing of Inconel 625. The lead wires are brought out through an electrical connector that provides a moisture-proof seal. This design provides protection for the sensing element during handling, installation, and service. The resistors for completing the bridge and the electronics for signal conditioning and checkout are located in the controller. A hot-gas sensor employs a single element while a cryogenic sensor employs dual elements.

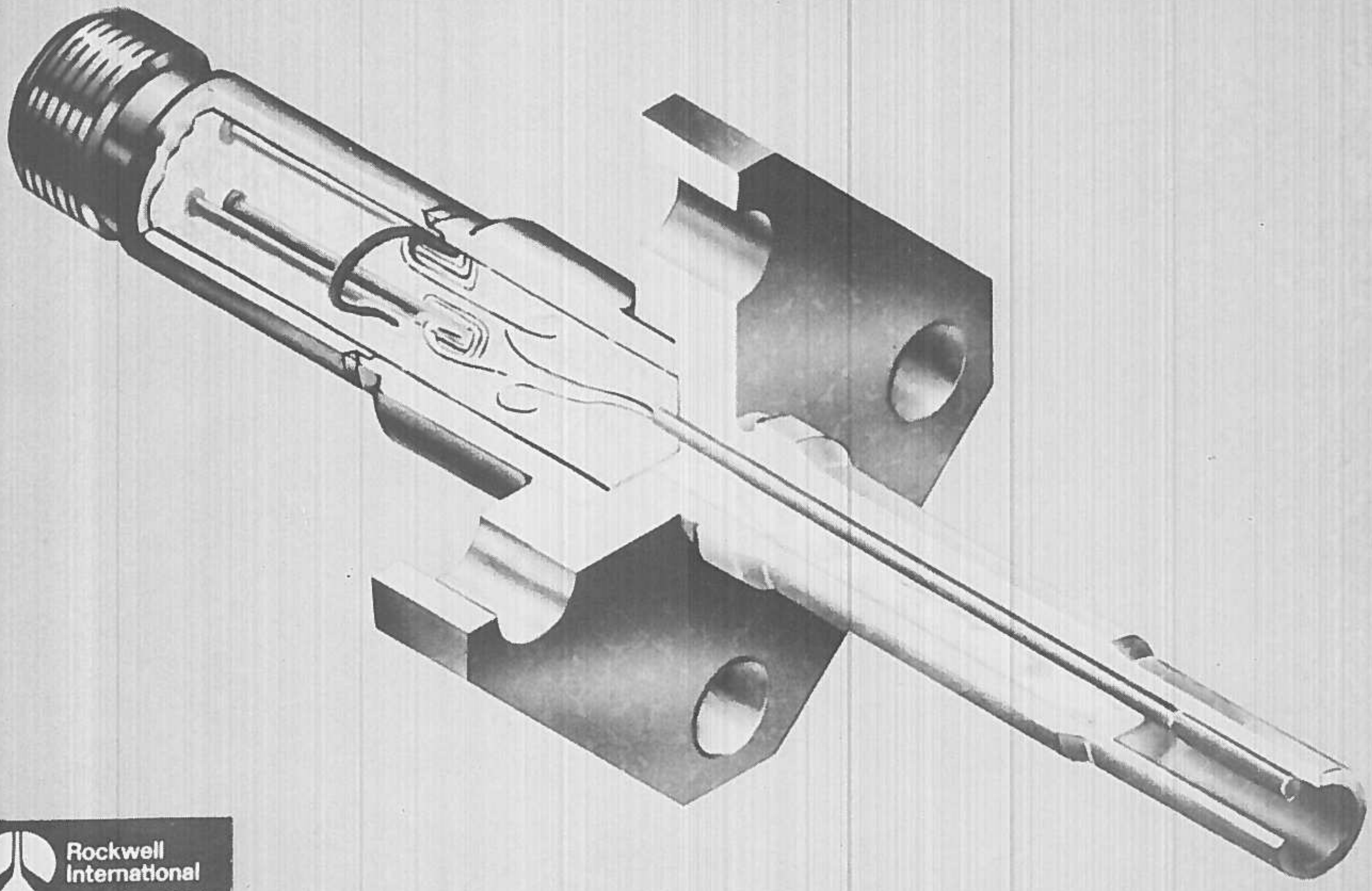
CRYOGENIC TEMPERATURE SENSOR



LC305-262B

Rockwell International
Rocketdyne Division

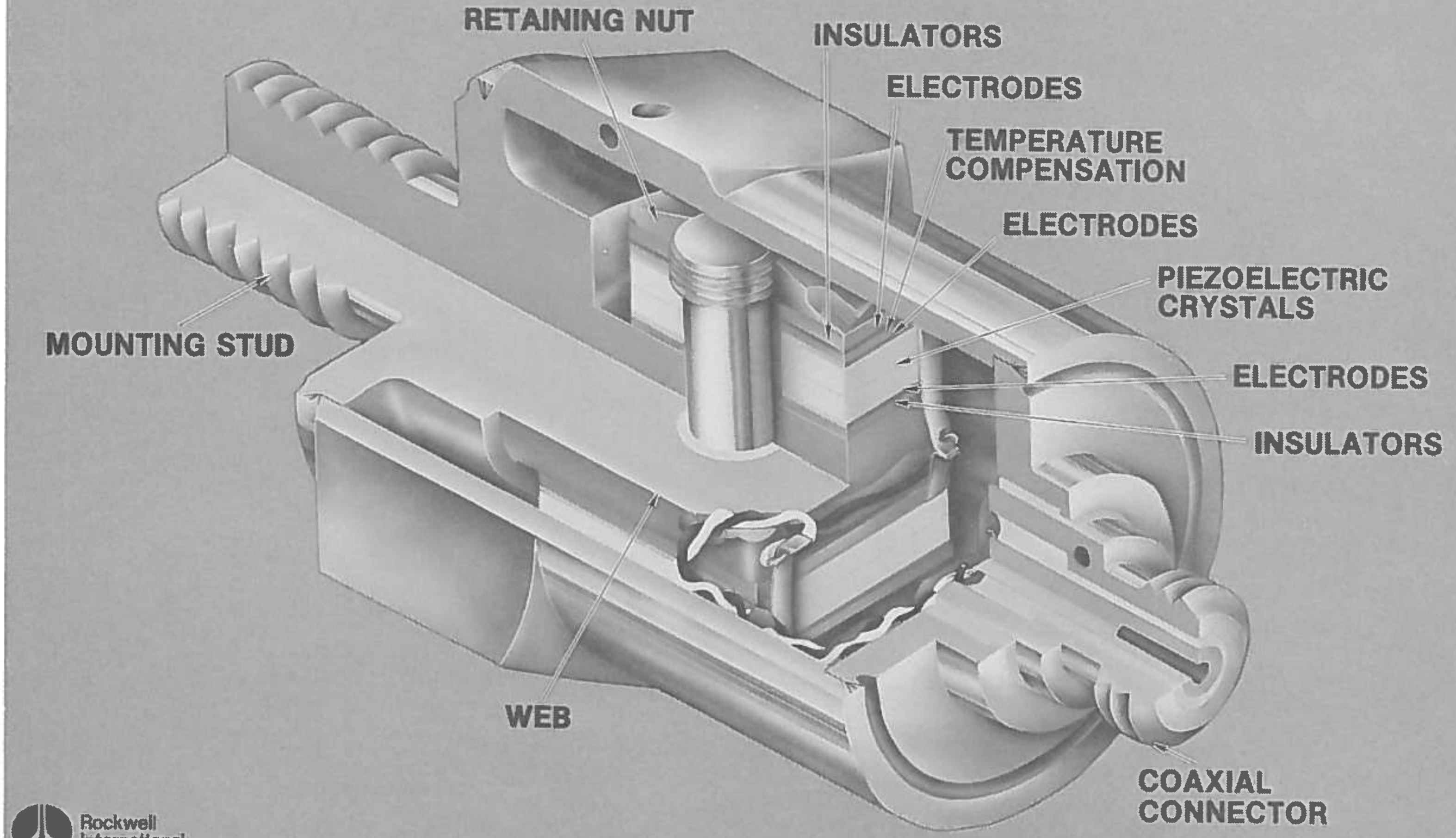
HOT GAS TEMPERATURE SENSOR



Rockwell International
Rocketdyne Division

SC87C-4-1479C

FLIGHT ACCELEROMETER



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Rocketdyne Division

LC446-640A

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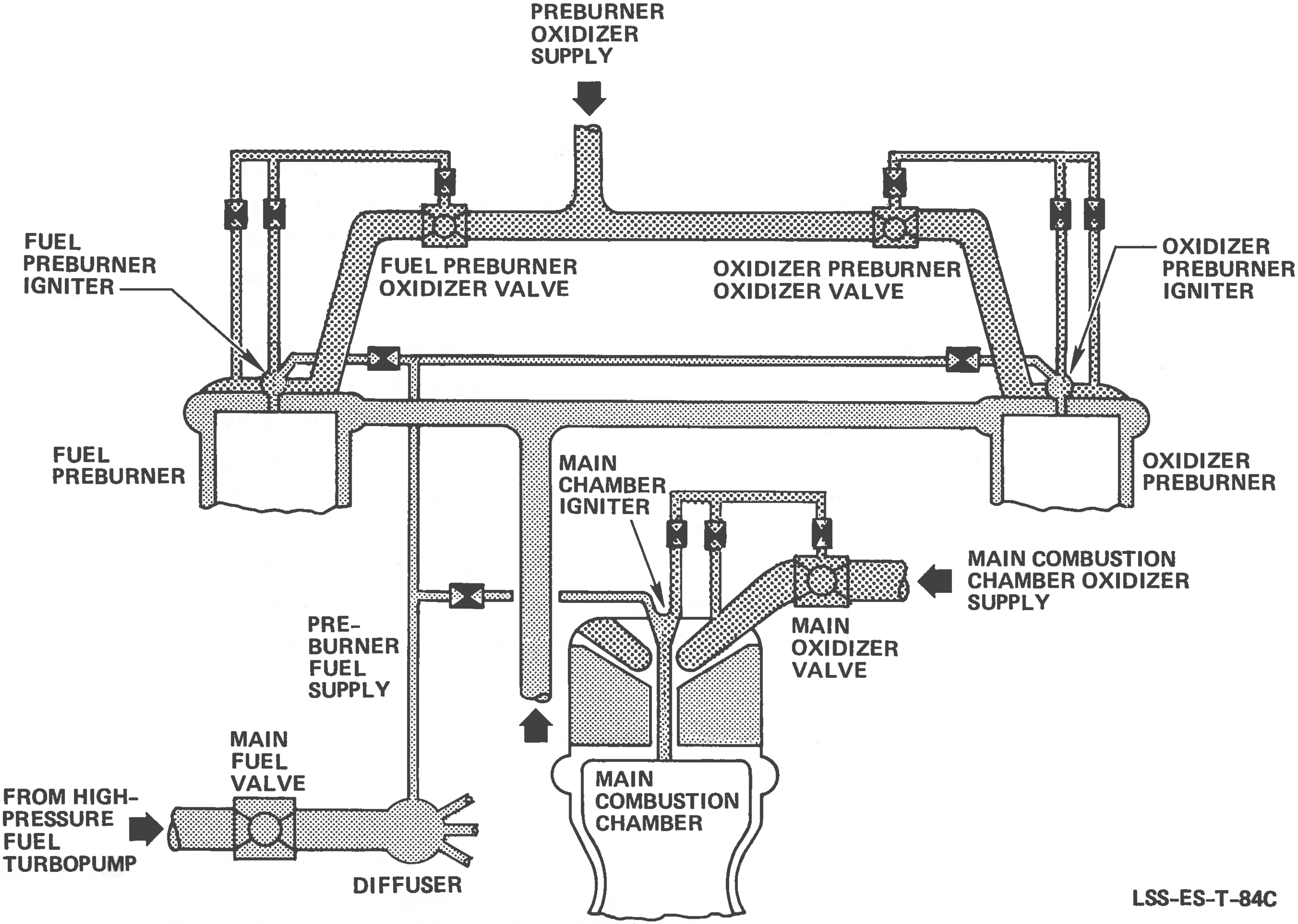
SSME IGNITION SYSTEM

The SSME ignition system ensures a smooth, safe, and predictable engine start.

The method of initiating propellant combustion in the SSME MCC and two preburners is called an augmented spark ignition (ASI) system. Two (redundant) spark igniters are mounted at each location, but not directly in the combustion chambers. Rather, they are mounted in a small ASI chamber in the center of each injector. The amount, ratio, and timing of propellants injected into these three ASI chambers is very precisely controlled. The fuel source is directly downstream of the MFV, which is the first valve to open. Therefore, fuel reaches the ASI chambers before oxidizer. This is called a fuel lead. The initial source of oxidizer is from the housings of the MFV, OPOV, and FPOV (when the liftoff seals are lifted). Before these valves rotate open and allow the oxidizer domes to fill, flow will occur from a housing, through two restrictors, and into an empty dome. The reduced pressure between the restrictors (approximately one-half) is the temporary driver of flow to an ASI chamber. When the oxidizer domes fill and pressure equalizes, they become the sources. This arrangement results in oxidizer being added to the fuel in the ASI chambers in a controlled manner without the use of complex valves and timing systems. The resulting flames injected into the three combustion chambers ignite the main propellants; hence the name augmented spark ignition. Although the spark igniters are turned off after 2.5 seconds, ASI combustion is allowed to continue so that ASI chamber environment can be controlled.

IGNITION SYSTEM SCHEMATIC

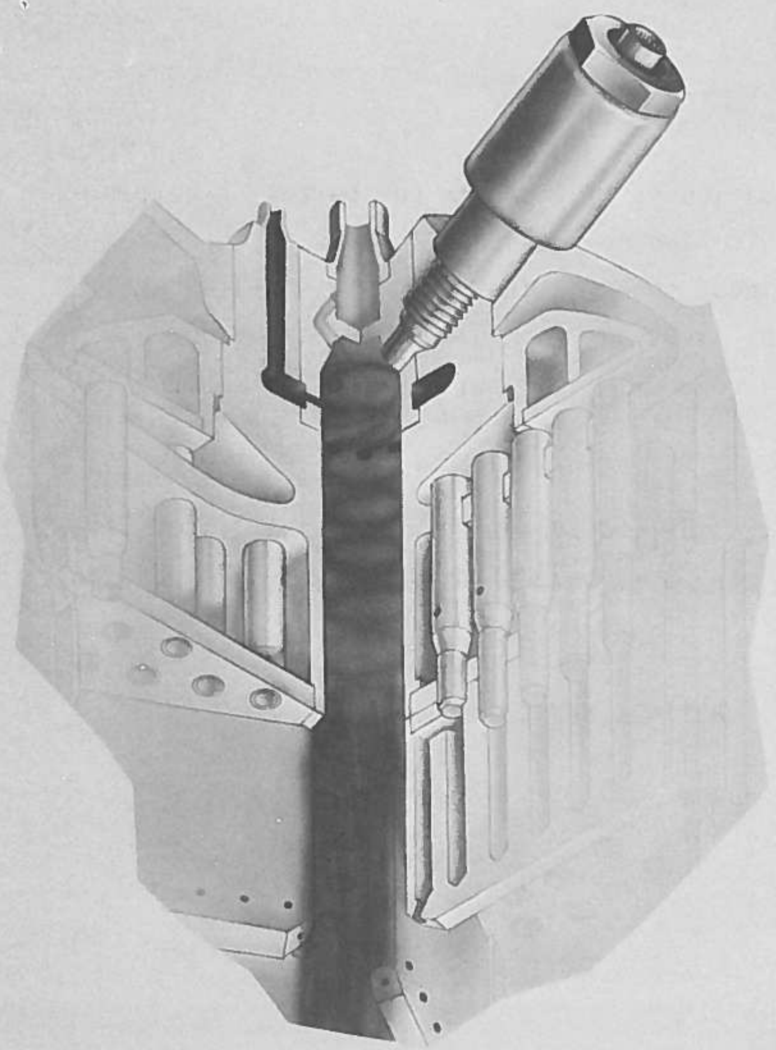


LSS-ES-T-84C

SSME ASI INJECTOR/COMBUSTION CHAMBER

Two (redundant) spark igniters are installed at the top of each ASI chamber. The fuel and oxidizer are injected into the chamber in a very precise manner to establish specific, desirable conditions; eg, maximum oxidizer-rich at the point of ignition, a fuel-rich cooling shroud along the walls, or 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 (71 lb/cu ft), slow-moving liquid, which tend toward the center of the chamber. The fuel is injected from the side as eight tangential streams of light (4.5 lb/cu ft), 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 2 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



LC301-964

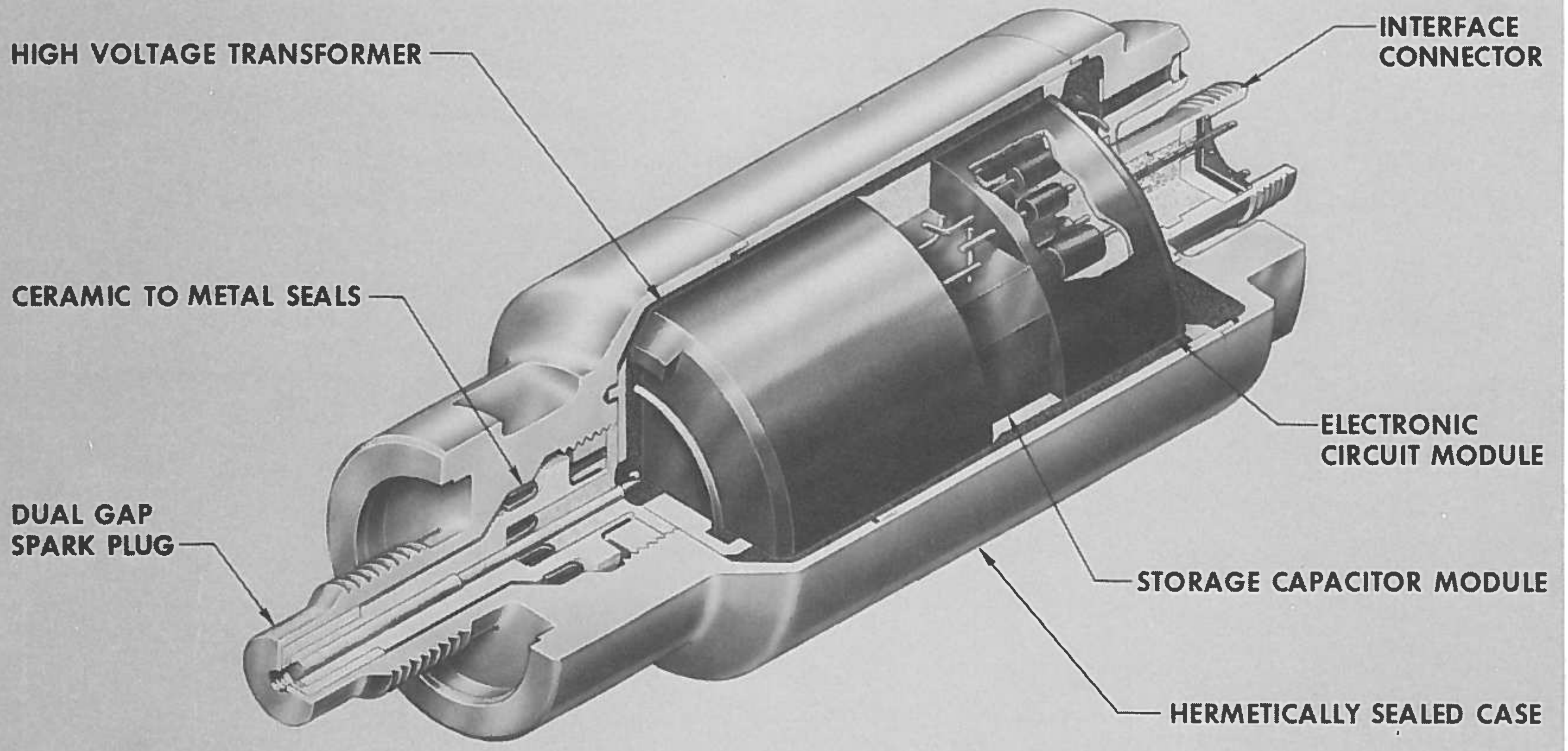
Rockwell International
Rocketdyne Division

SSME ASI SPARK IGNITER

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

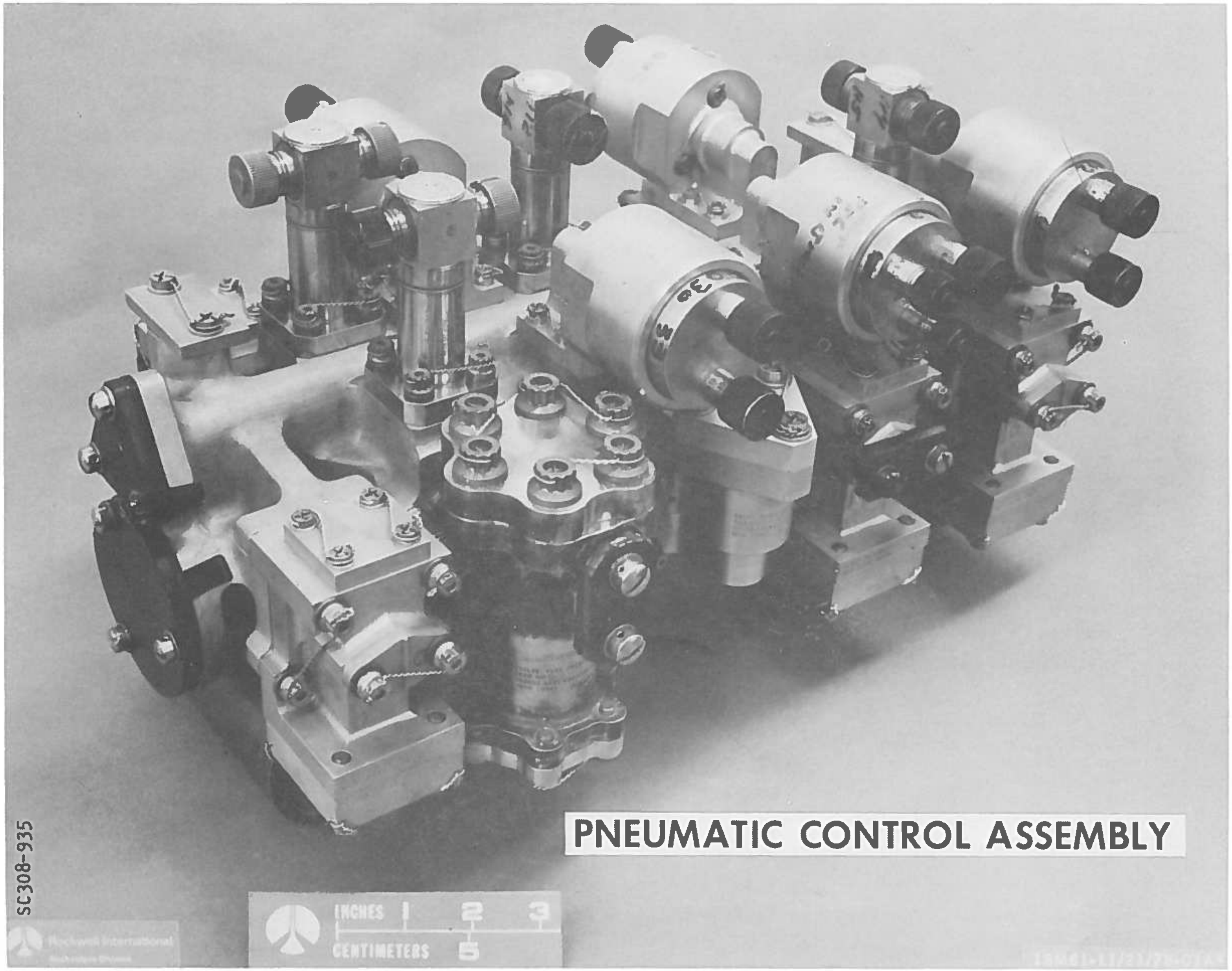
Six igniters are used on the SSME, two each (for redundancy) in the MCC and both preburners. The spark igniter is completely self-contained in that a 28-vdc input results in a 10-kilovolt, 50 sparks per second output. The igniter is hermetically sealed and welded. It is not repairable in the field.

SPARK IGNITER



LC303-188A

Rocketdyne Division
Rockwell International



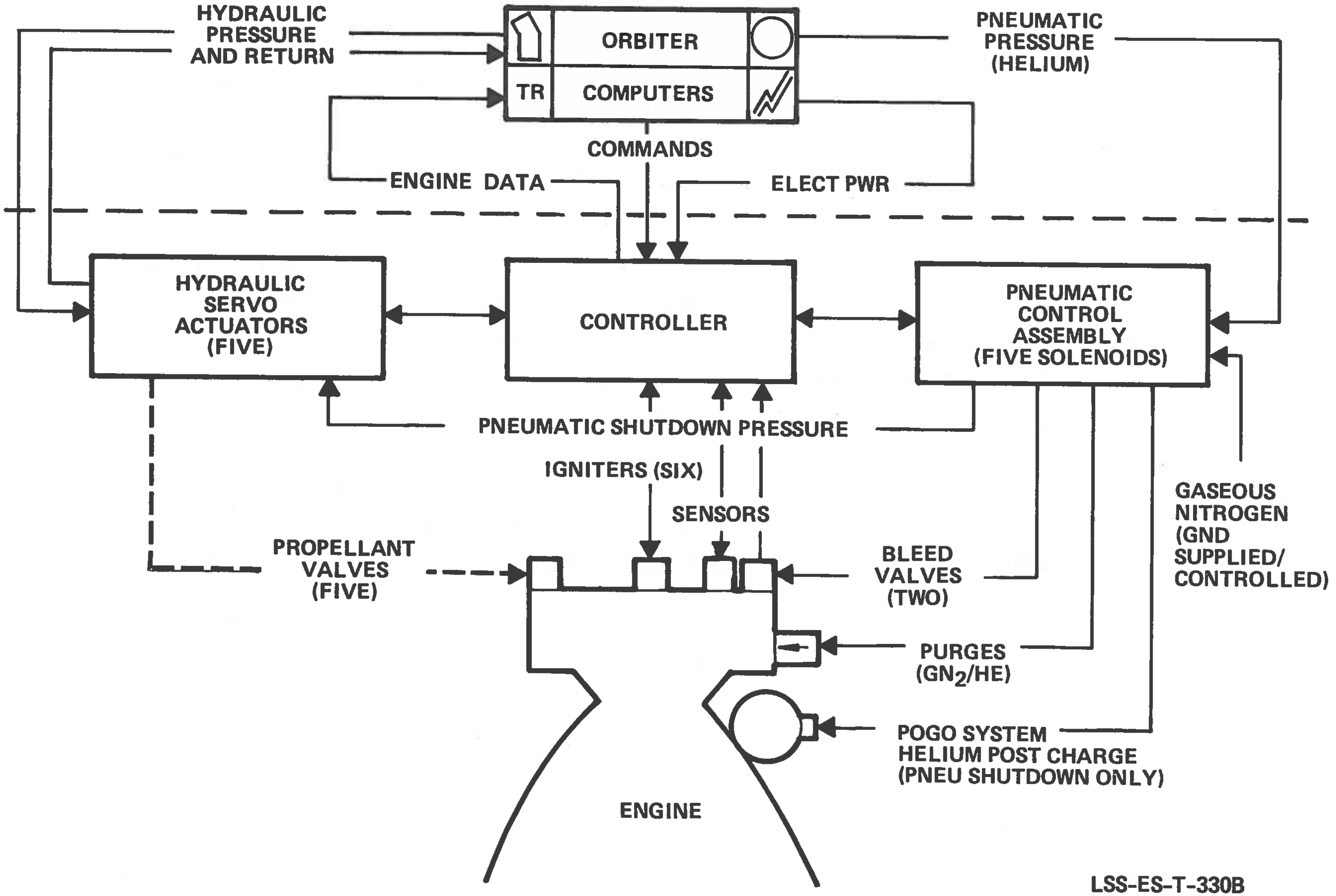
PNEUMATIC CONTROL ASSEMBLY

SSME CONTROL SYSTEMS INTERFACES

The orbiter, with its three hydraulic power systems (one for each engine), 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 storage spheres in the thrust section. Commands to prepare, start, throttle, and stop the engine are issued from the orbiter, while a table of engine data (the vehicle data table) is periodically transmitted to the orbiter for recording.

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 pressures, temperatures, pump speeds, flowrates, and valve positions from the sensors. The controller also can effect an engine pneumatic shutdown by signalling the PCA to pressurize a pneumatic "close" piston in each of the five propellant valve hydraulic actuators.

SSME CONTROL SYSTEMS INTERFACES



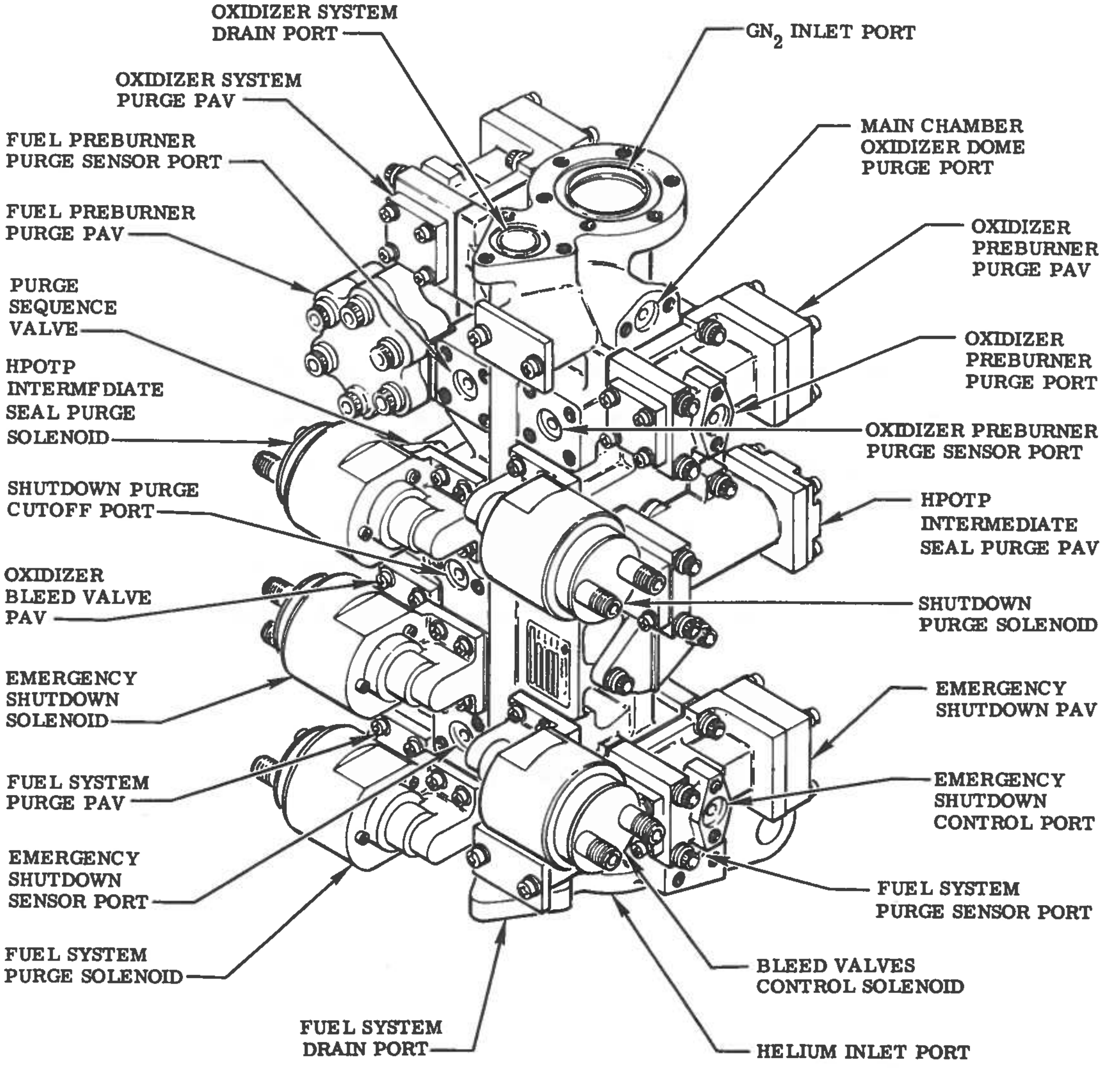
LSS-ES-T-330B

SSME PNEUMATIC CONTROL ASSEMBLY

The pneumatic control assembly (PCA) provides central control of all pneumatic functions; ie, 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) combined into one body, but not interconnected. Five solenoid valves, eight pneumatic-actuated valves (PAV), and five pressure transducers (not shown) 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. These 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 obtained from storage spheres on board the vehicle and is vented to the fuel system drain port; ie, the engine fuel components drain line. Nitrogen is obtained from a ground source and is vented to the oxidizer system drain port; ie, the engine oxidizer components drain line.

PNEUMATIC CONTROL ASSEMBLY
FLIGHT CONFIGURATION



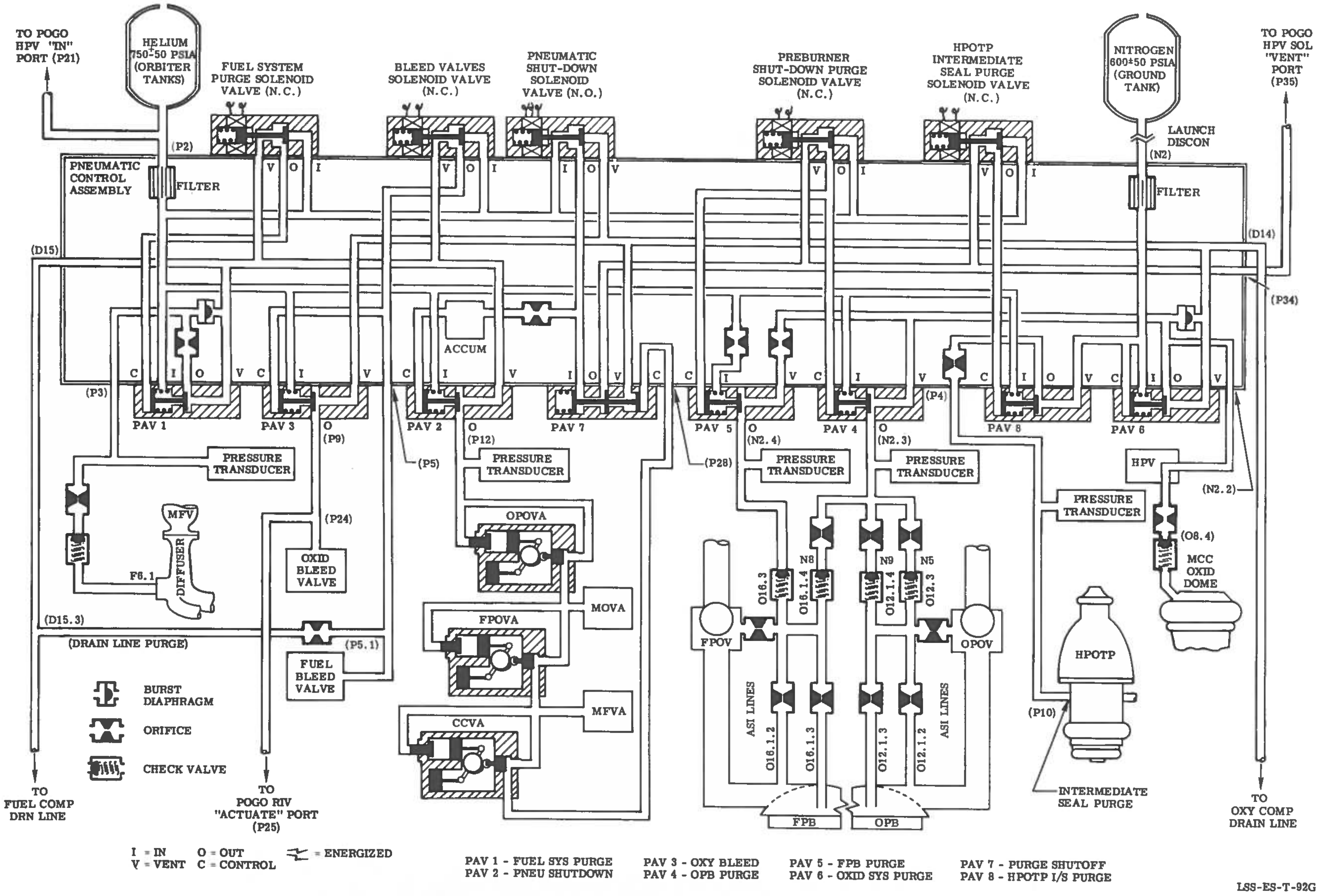
LSS-ER-T-48

SSME PNEU SCHEMATIC (1/14)
NO POWER OR PRESSURE APPLIED TO PCA

This is a baseline schematic. No solenoid valves are energized. Four NC solenoid valves are closed (I to O blocked, V to O open). One NO solenoid valve (pneu shutdown) is open (I to O open, V to O blocked). No PAVs are pressurized at port C. Seven NC PAVs are closed. One NO PAV (No. 7) is open.

SSME PNEU SCHEMATIC (1/14)

DEPICTS: NO POWER OR PRESSURE APPLIED TO PCA



LSS-ES-T-92G

SSME PNEU SCHEMATIC (2/14)
GROUND CONTROLLED GN_2 PURGE FUNCTION

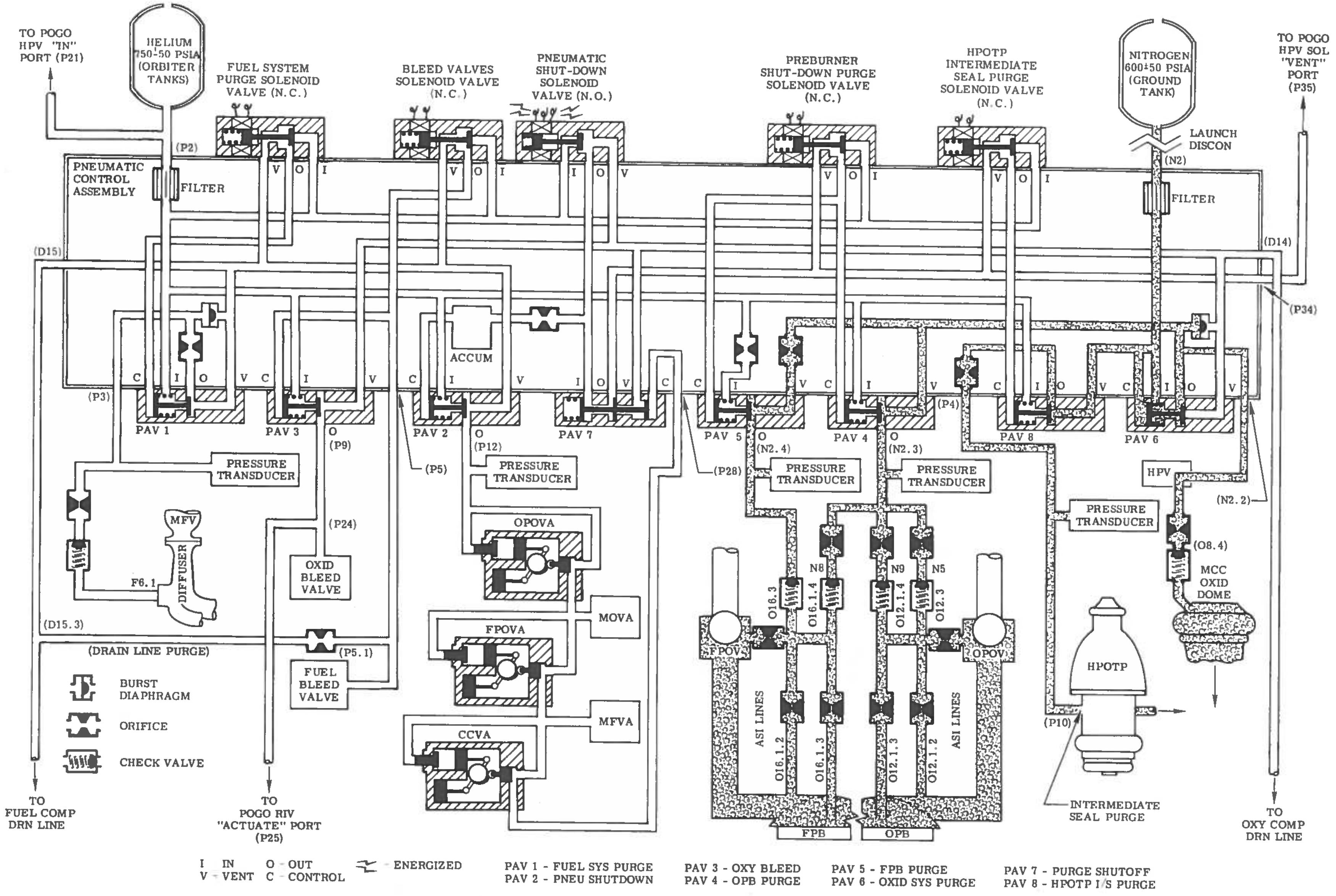
With heated GN_2 supplied directly to the PCA from a ground system:

1. A reverse flow (V to O) purge occurs through PAV 8 to the HPOTP intermediate seal.

2. Pressure at port C opens PAV 6, permitting a normal flow (I to O) purge through PAV 6 to the MCC oxidizer dome and also to the ASI lines and preburners by reverse flow (V to O) through PAV 4 and PAV 5.

SSME PNEU SCHEMATIC (2/14)

DEPICTS: GROUND CONTROLLED GN$_2$ PURGE FUNCTION



LSS-ES-T-332F

SSME PNEU SCHEMATIC (3/14)
FUEL SYSTEM PURGE FUNCTION

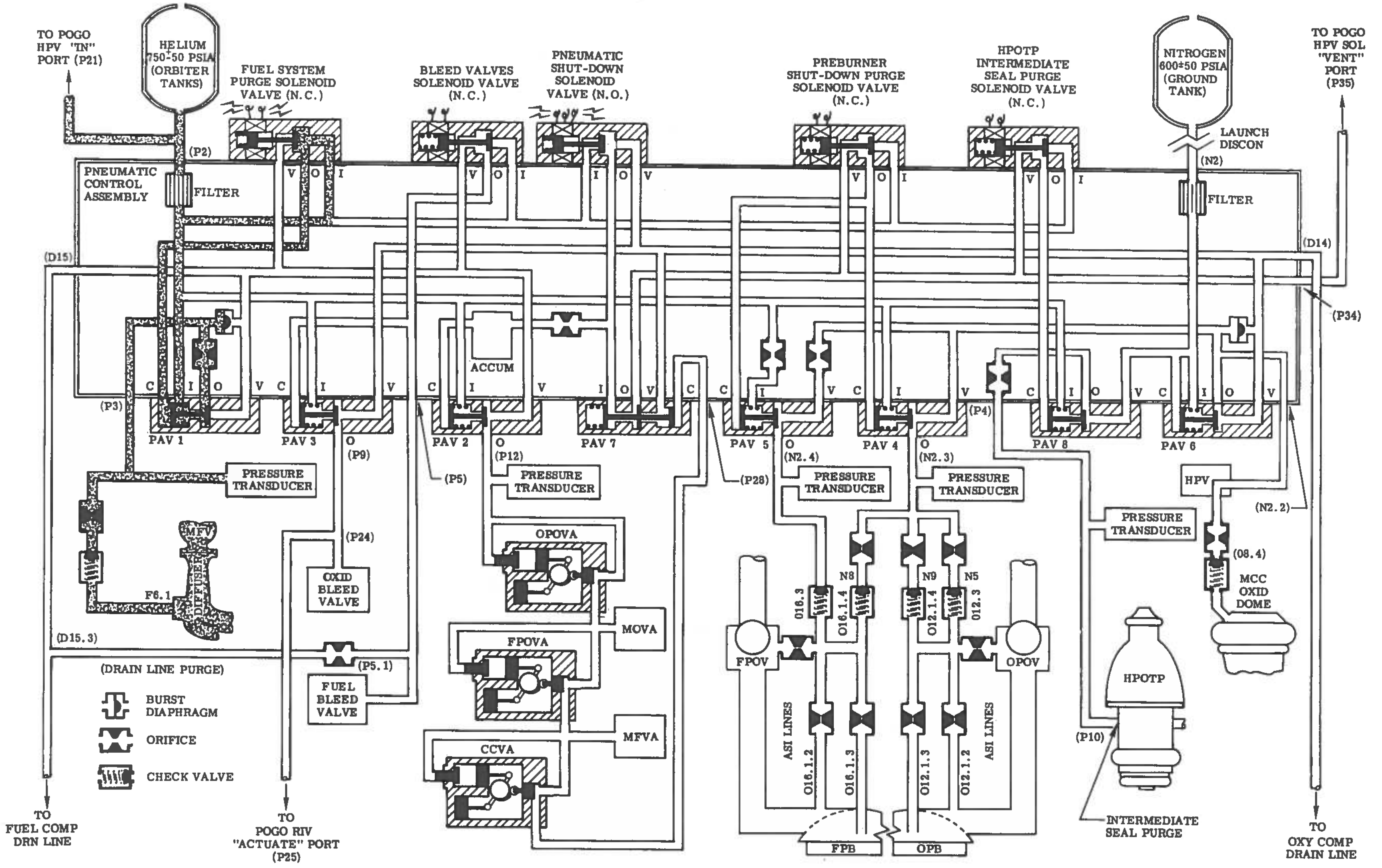
With helium from storage spheres on the orbiter supplied to the PCA:

1. Energizing the fuel system purge solenoid valve pressurizes port C on PAV 1.

2. Purge flow occurs through PAV 1 (I to O) to the entry point on the diffuser and through all parts of the fuel system downstream of the MFV.

SSME PNEU SCHEMATIC (3/14)

DEPICTS: FUEL SYSTEM PURGE FUNCTION



I = IN O = OUT
V = VENT C = CONTROL

⚡ = ENERGIZED

PAV 1 - FUEL SYS PURGE
PAV 2 - PNEU SHUTDOWN

PAV 3 - OXY BLEED
PAV 4 - OPB PURGE

PAV 5 - FPB PURGE
PAV 6 - OXID SYS PURGE

PAV 7 - PURGE SHUTOFF
PAV 8 - HPOTP I/S PURGE

LSS-ES-T-333F

SSME PNEU SCHEMATIC (4/14)
BLEED VALVES OPEN FUNCTION

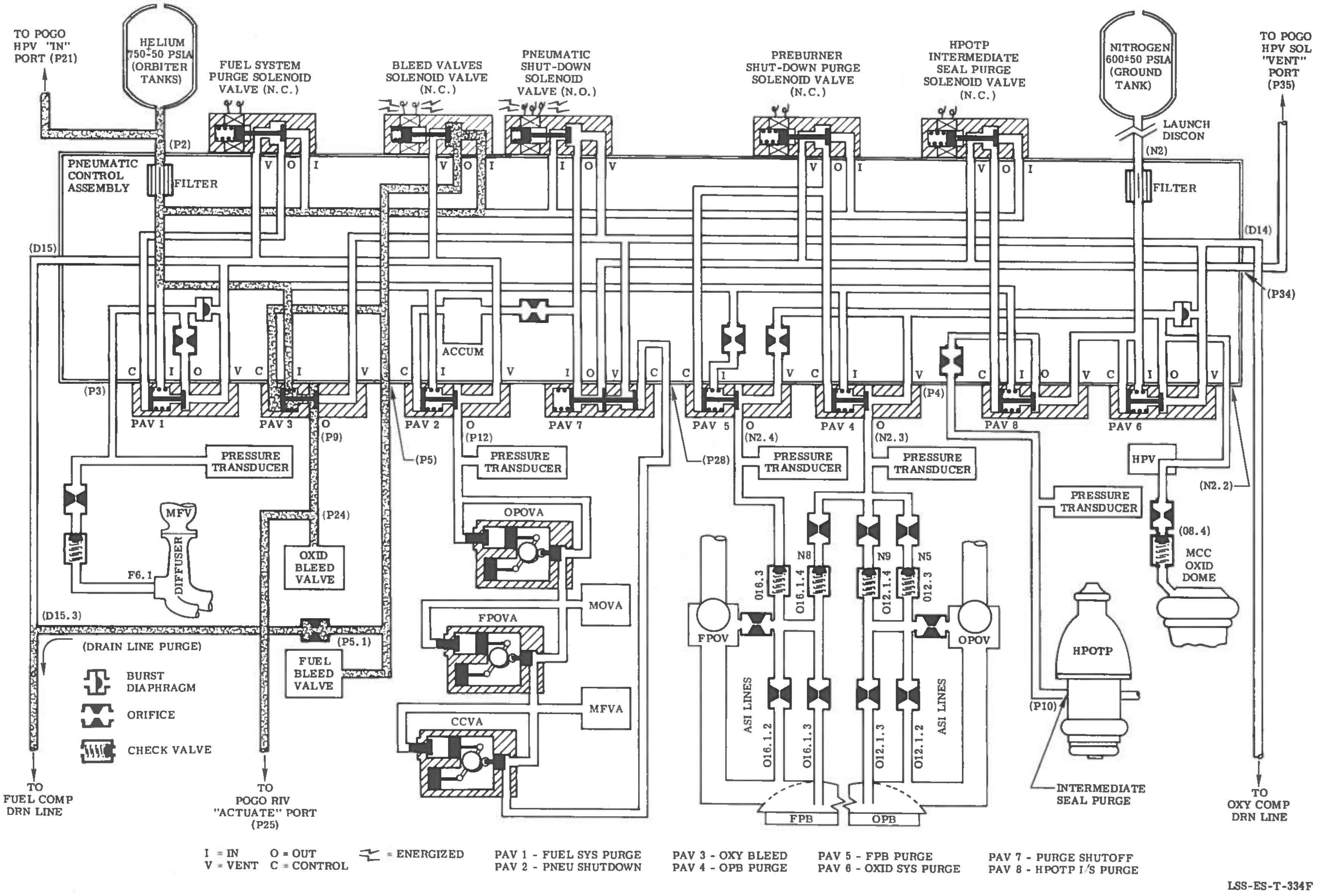
With helium from storage spheres on the orbiter supplied to the PCA:

1. Energizing the bleed valves solenoid valve pressurizes port C on PAV 3, pressurizes (opens) the fuel bleed valve directly, and (through an orifice) purges the fuel components drain line.

2. Opening PAV 3 pressurizes (opens) the oxidizer bleed valve and pressurizes (closes) the recirculation isolation valve in the pogo suppression system.

SSME PNEU SCHEMATIC (4/14)

DEPICTS: BLEED VALVES OPEN FUNCTION



SSME PNEU SCHEMATIC (5/14)
PREBURNER PURGE FUNCTION

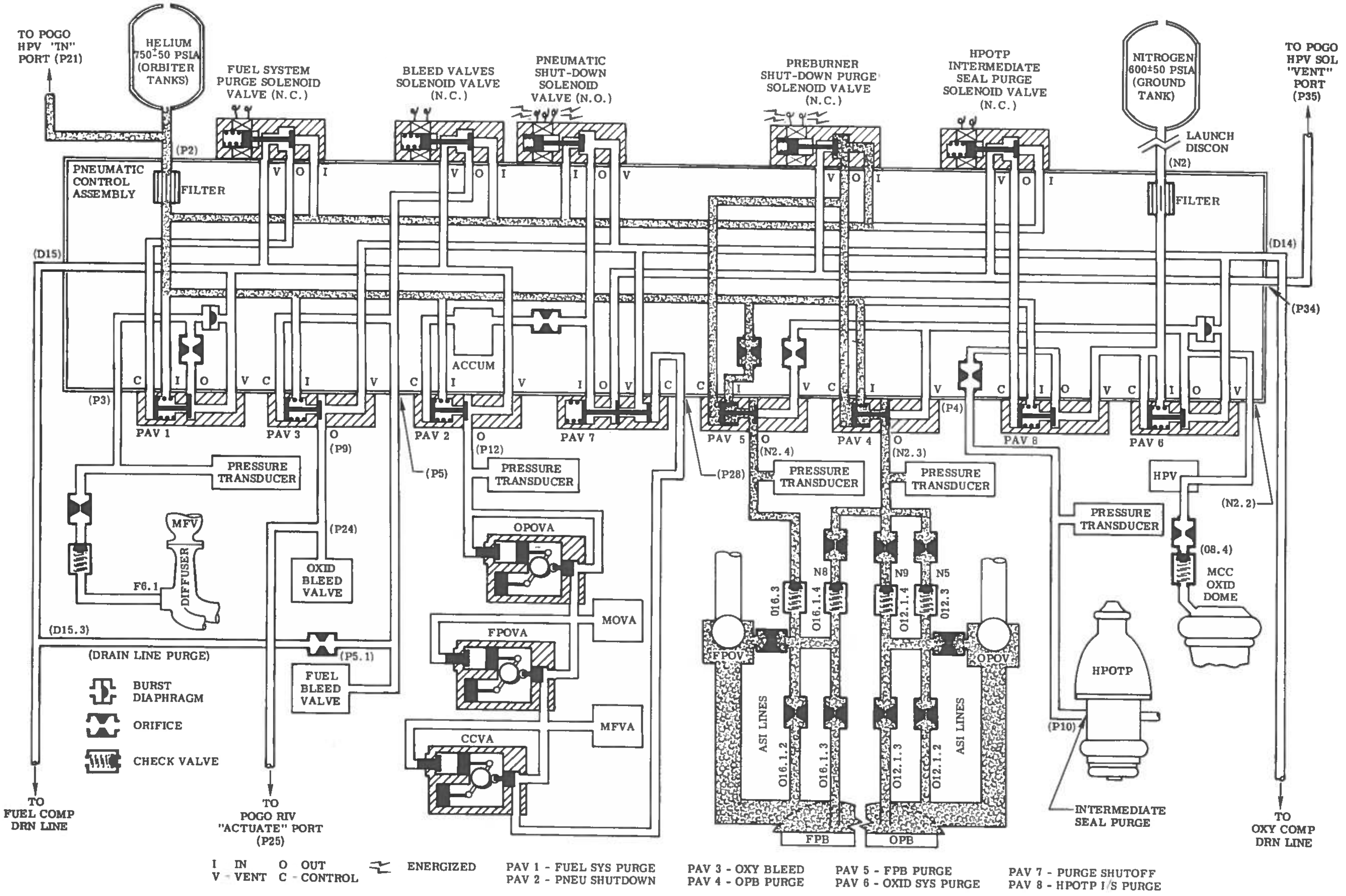
With helium from storage spheres on the orbiter supplied to the PCA:

1. Energizing the preburner shutdown purge solenoid valve pressurizes port C on PAV 4 and PAV 5.

2. Purge flow occurs through PAV 4 and PAV 5 (I to O) to the preburner area, entering through the ASI system oxidizer lines.

SSME PNEU SCHEMATIC (5/14)

DEPICTS: PREBURNER PURGE FUNCTION



LSS-ES-T-344

SSME PNEU SCHEMATIC (6/14)
HPOTP INTERMEDIATE SEAL PURGE FUNCTION

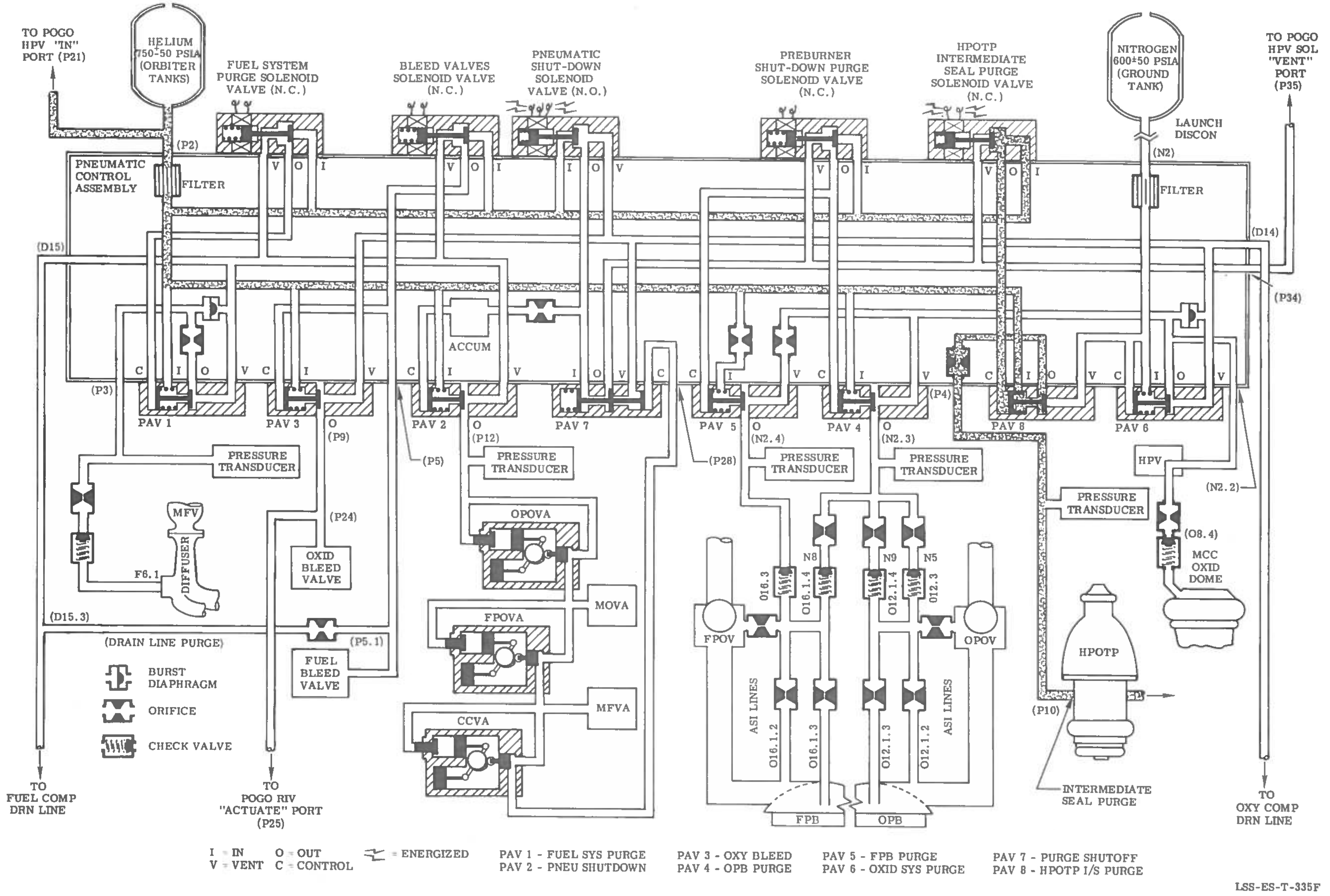
With helium from storage spheres on the orbiter supplied to the PCA:

1. Energizing the HPOTP intermediate seal purge solenoid valve pressurizes port C on PAV 8.

2. Purge flow occurs through PAV 8 (I to O) to the intermediate shaft seal inside the HPOTP.

SSME PNEU SCHEMATIC (6/14)

DEPICTS: HPOTP I/S PURGE FUNCTION



LSS-ES-T-335F

SSME PNEU SCHEMATIC (7/14)
ENGINE PNEUMATIC SHUTDOWN - PART 1 OF 2
(OPOV CLOSED - FPOV CLOSING - PURGES ON - POGO POST-CHARGING)

With helium from storage spheres on the orbiter supplied to the PCA:

1. Deenergizing the pneumatic shutdown solenoid valve pressurizes port C on PAV 2. The restrictor and accumulator act similar to a resistor/capacitor in an electrical circuit to delay actuation of PAV 2.

2. Opening PAV 2 applies pressure to a pneumatic piston (and a sequence valve) in the OPOV hydraulic actuator, closing the OPOV.

3. At 40 percent open, the OPOVA sequences the pressure to a pneumatic piston (and a sequence valve) in the FPOVA and to a pneumatic piston in the MOVA, closing the FPOV and the MOV.

4. At 40 percent open, the FPOVA sequences the pressure to a pneumatic piston (and a sequence valve) in the CCVA and to a pneumatic piston in the MFVA, closing the CCV and the MFV.

5. Pressure is also applied through PAV 7 (I to O) to, and in reverse, through the preburner and the intermediate seal solenoid valves (V to O) to the C ports of PAV 4, 5, and 8.

6. PAV 8 will sustain the intermediate seal purge and PAV 4 and 5 will initiate the preburner shutdown purge.

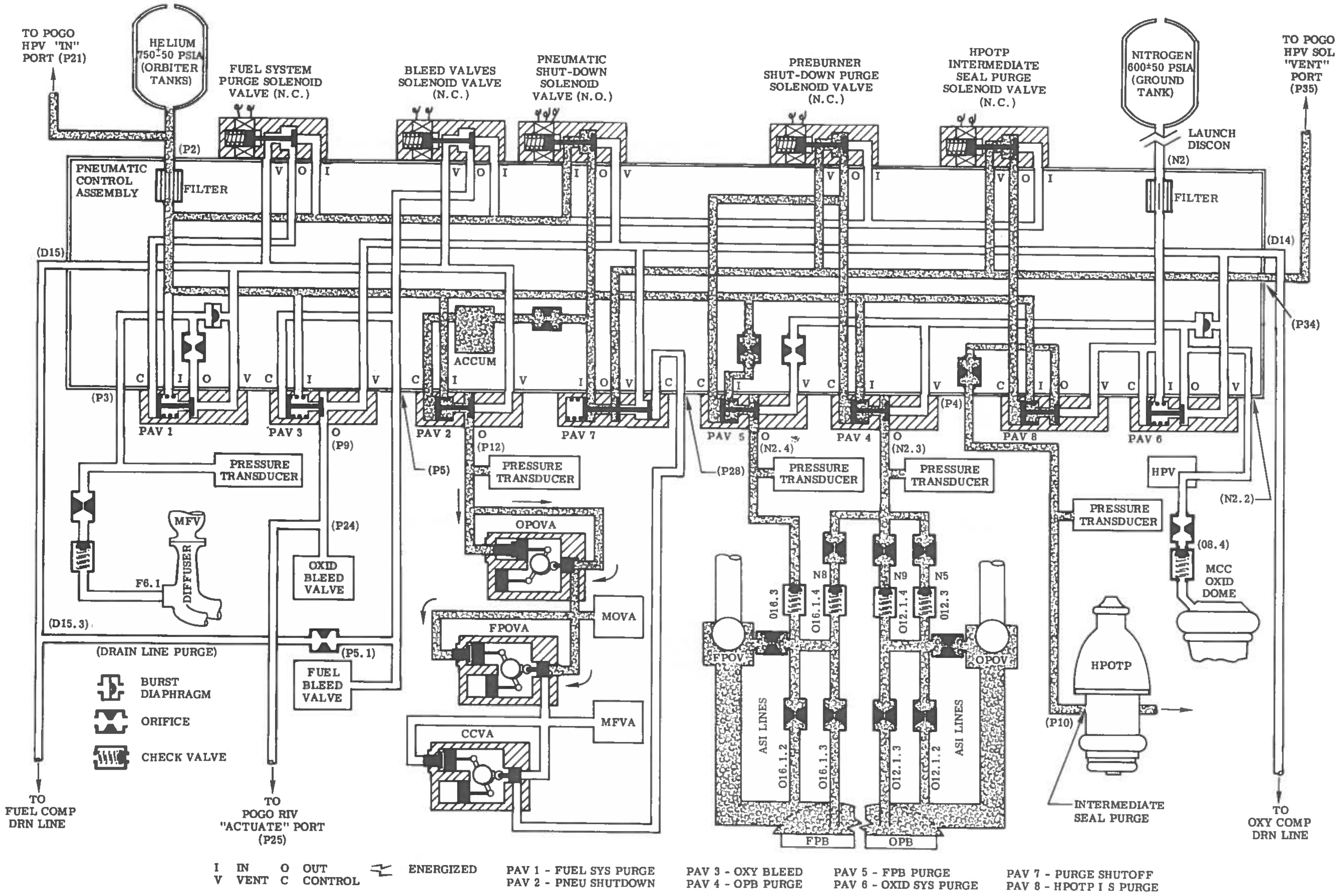
7. Pressure is also sent out P34 to the HPV to post-charge the pogo accumulator.

(See part 2 of 2.)

SSME PNEU SCHEMATIC (7/14)

DEPICTS: PNEU SHUTDOWN FUNCTION-PART 1

(OPOV CLOSED, FPOV CLOSING, PURGES ON, POGO POST CHG)



LSS-ES-T-337F

SSME PNEU SCHEMATIC (8/14)
ENGINE PNEUMATIC SHUTDOWN - PART 2 OF 2
(PROPELLANT VALVES CLOSED - PURGES OFF)

With helium from storage of spheres on the orbiter supplied to the PCA:

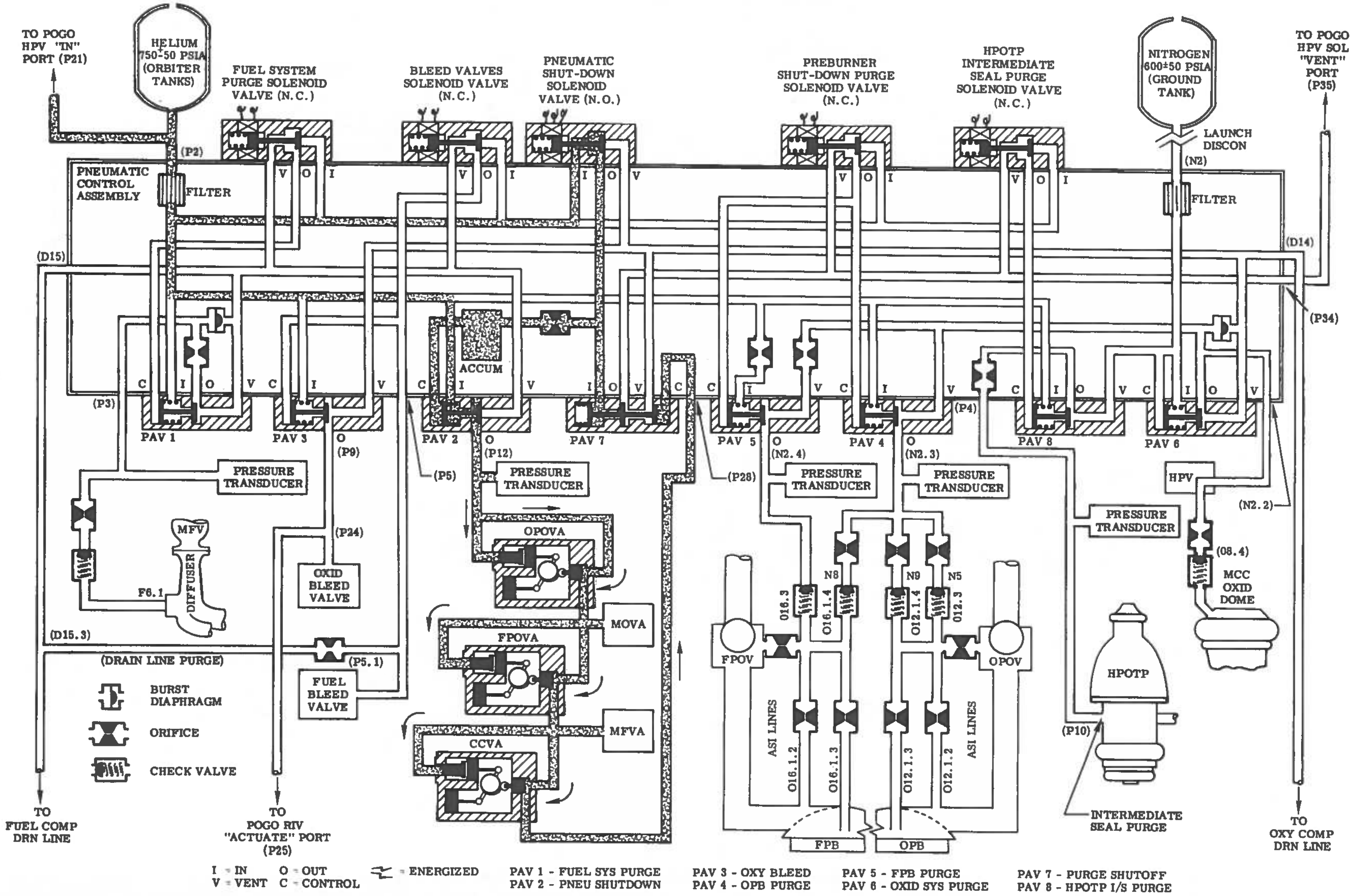
1. Deenergizing the pneumatic shutdown solenoid valve long enough to pressurize the accumulator and open PAV 2 results in a sequential closing of the engine propellant valves. As with a normal engine shutdown, a preburner shutdown purge is initiated, the intermediate seal purge is continued, and the pogo accumulator is postcharged. (See part 1 of 2.)

2. At 10 percent open, the CCV sequences pressure to port C on PAV 7. PAV 7 closes, stopping the postcharge and removing pressure from port C on PAV 4, 5, and 8, which terminates the preburner shutdown purge and the intermediate seal purge.

SSME PNEU SCHEMATIC (8/14)

DEPICTS: PNEU SHUTDOWN FUNCTION-PART 2

(PROP VALVES CLOSED, PURGES OFF)

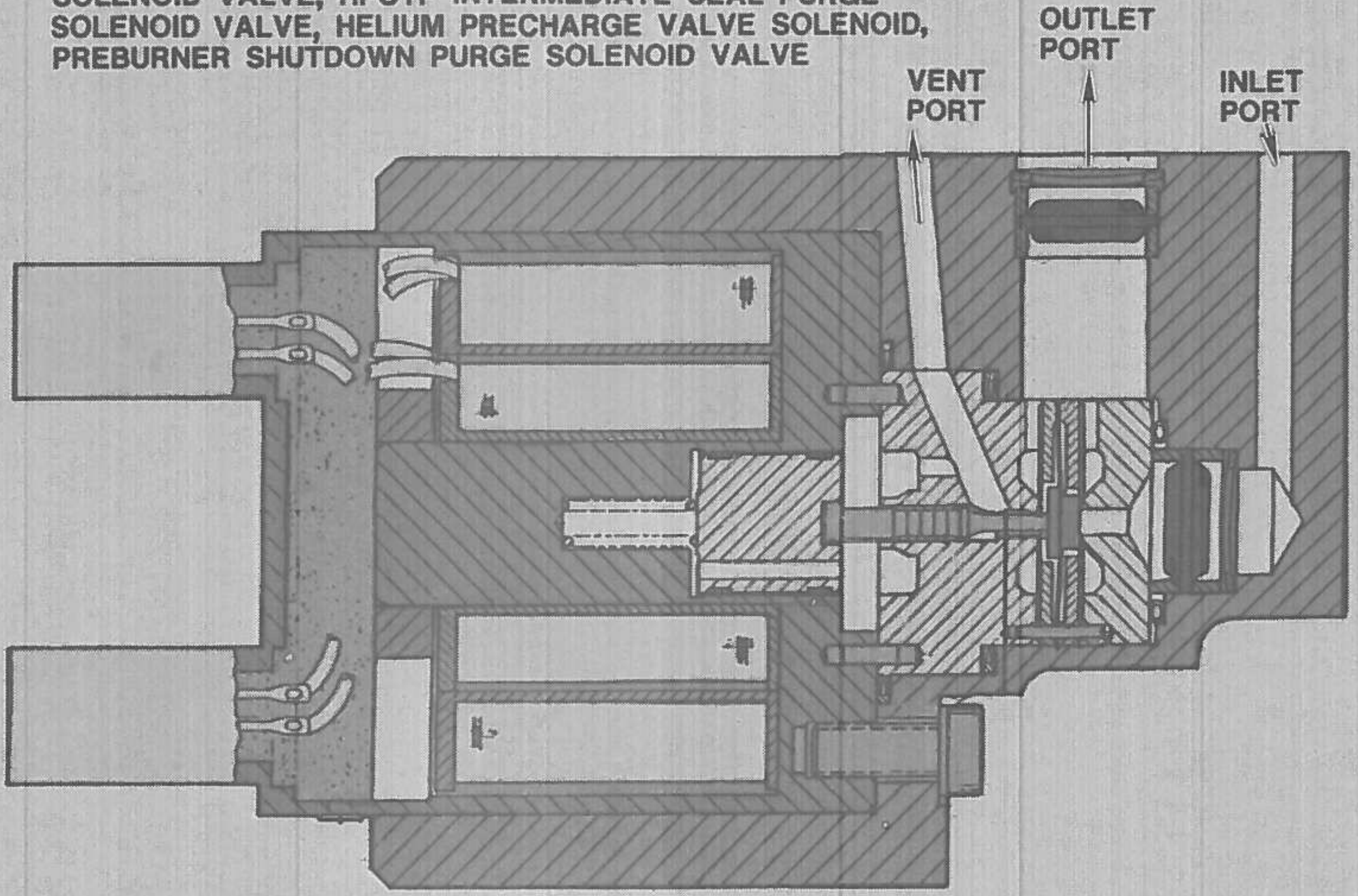


LSS-ES-T-338F

SOLENOID VALVE
RS010341

NORMALLY CLOSED

BLEED VALVES SOLENOID VALVE, FUEL SYSTEM PURGE SOLENOID VALVE, HPOTP INTERMEDIATE SEAL PURGE SOLENOID VALVE, HELIUM PRECHARGE VALVE SOLENOID, PREBURNER SHUTDOWN PURGE SOLENOID VALVE

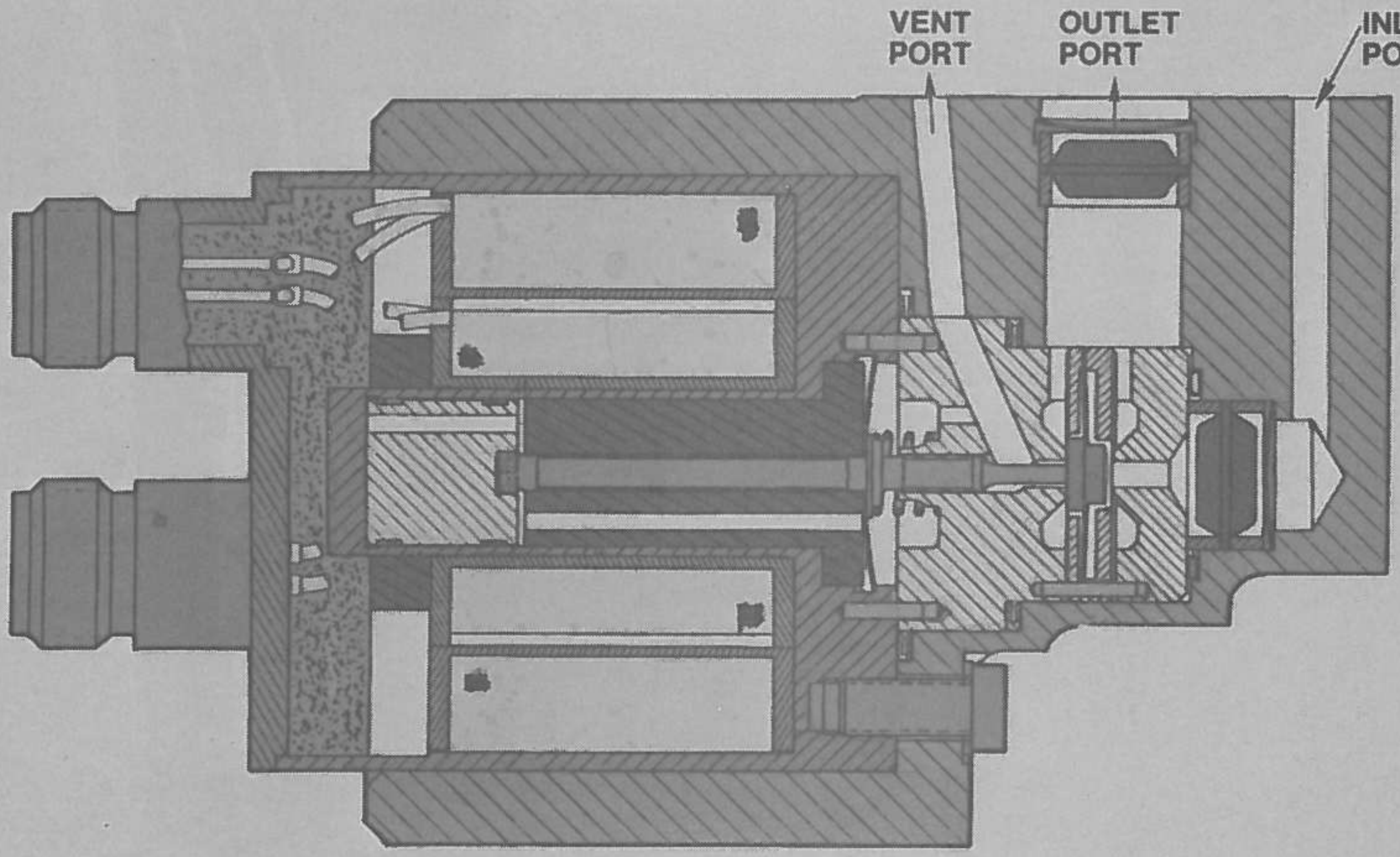


SC87C-4-952

Rockwell International
Rocketdyne Division

EMERGENCY SHUTDOWN SOLENOID VALVE
R0010725

NORMALLY OPEN



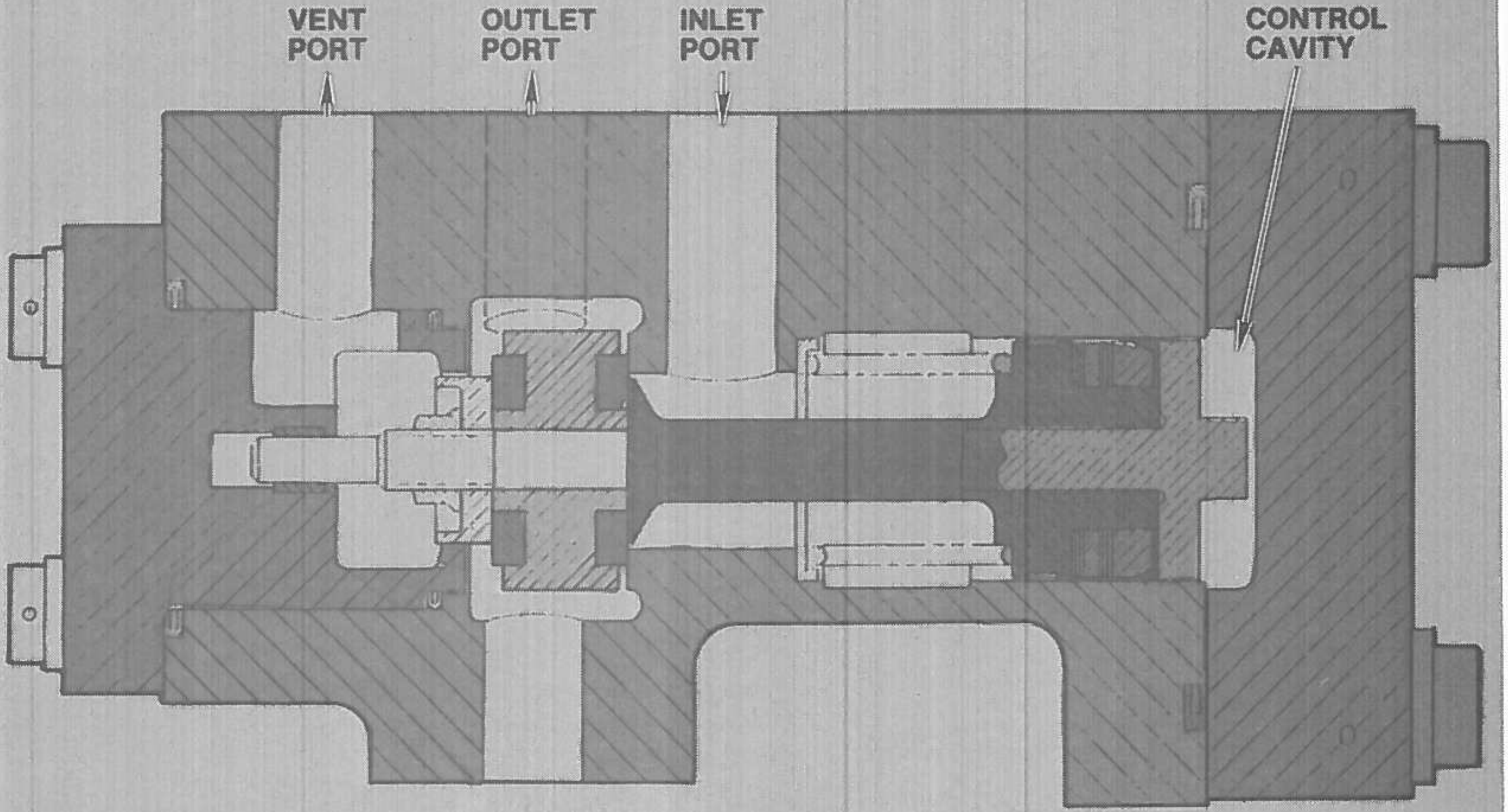
SC87C-4-951

Rockwell International
Rocketdyne Division

PRESSURE ACTUATED VALVE
RS008021

EMERGENCY SHUTDOWN PURGE PAV, FUEL SYSTEM PURGE PAV, OXIDIZER BLEED VALVE PAV, OXIDIZER PREBURNER PURGE PAV, OXIDIZER SYSTEM PURGE PAV

NORMALLY CLOSED



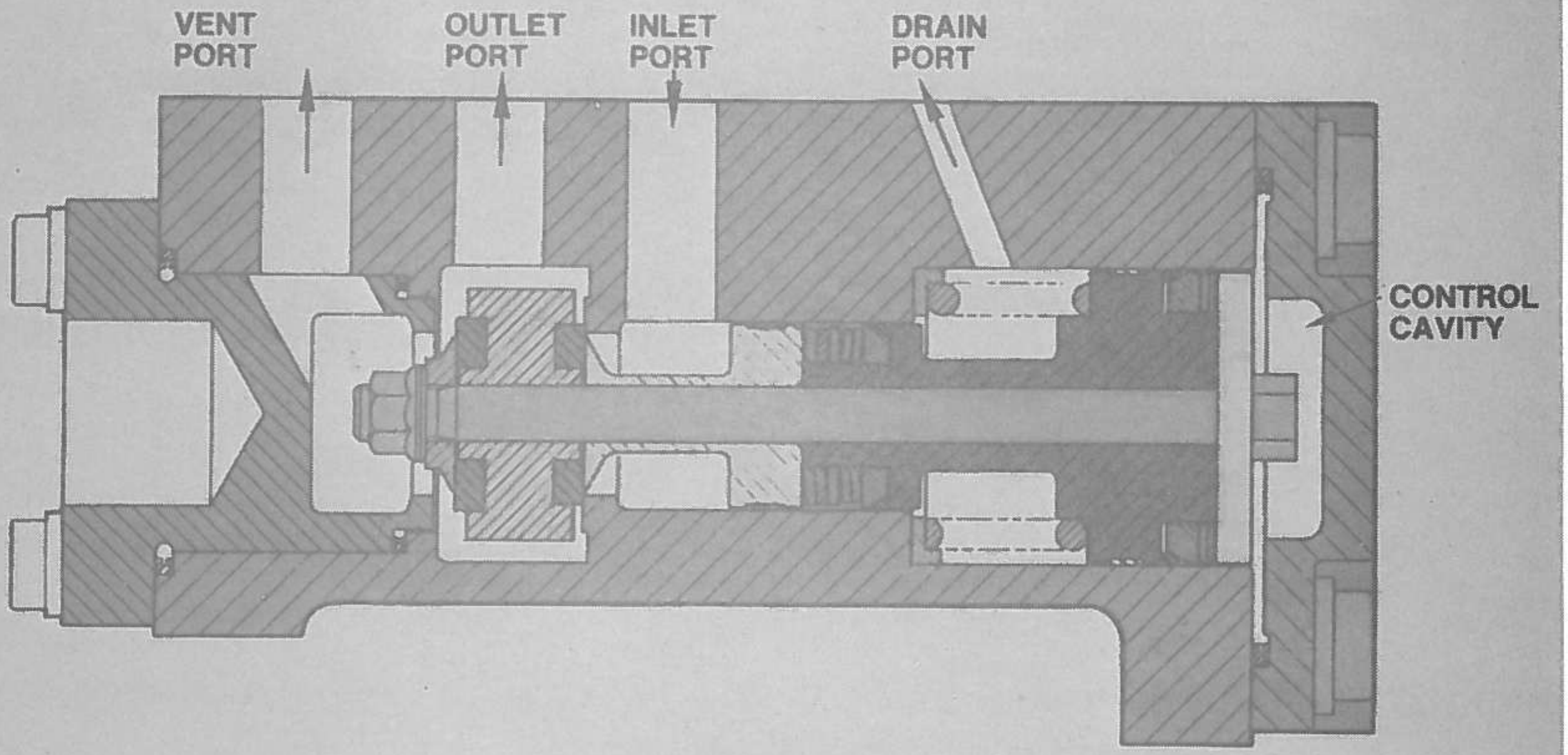
SC87C-4-948

Rockwell International
Rocketdyne Division

HPOTP INTERMEDIATE SEAL PURGE PRESSURE ACTUATED VALVE (PAV)

R0011040

NORMALLY CLOSED



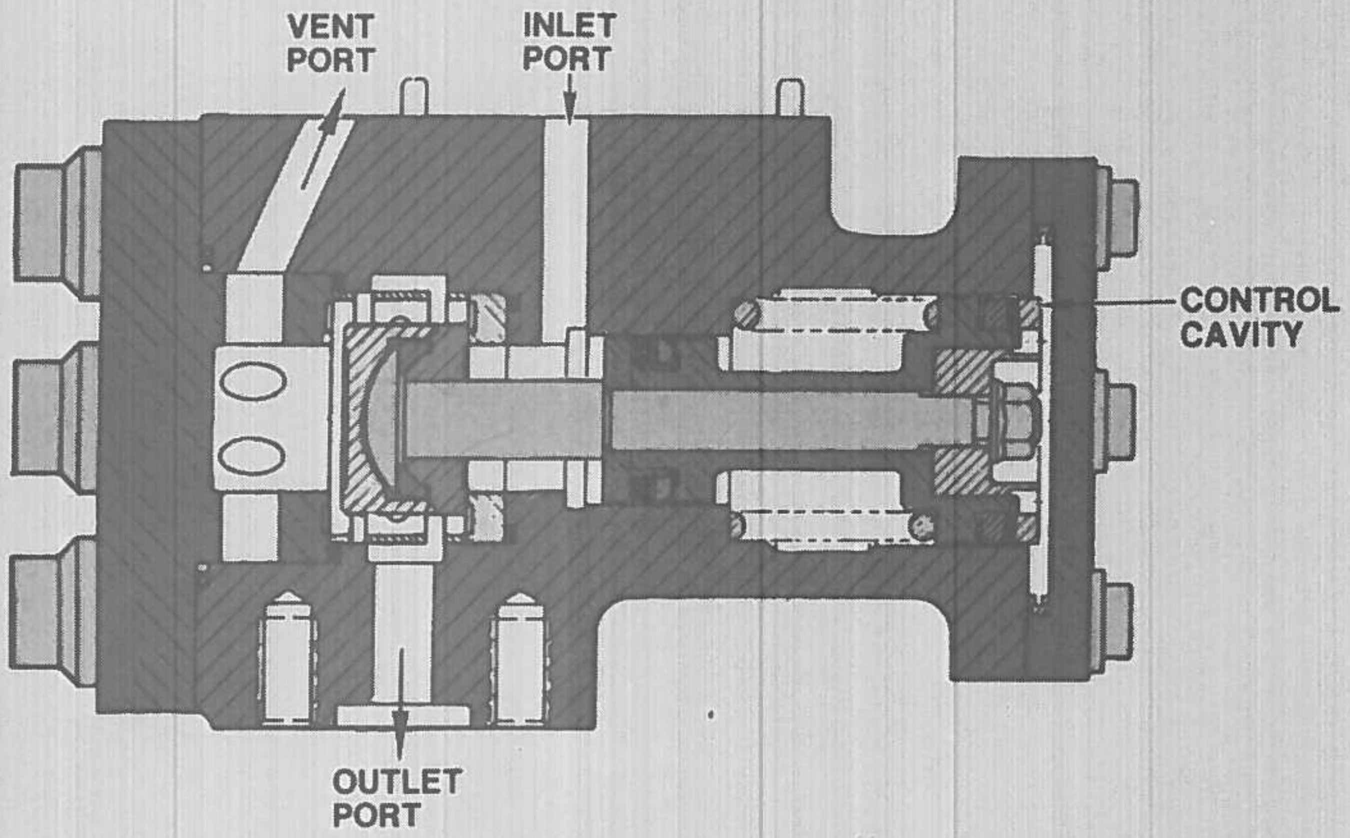
SC87C-4-946

Rockwell International
Rocketdyne Division

FUEL PREBURNER PURGE PRESSURE ACTUATED VALVE (PAV)

R0010984

NORMALLY CLOSED



SC87C-4-947

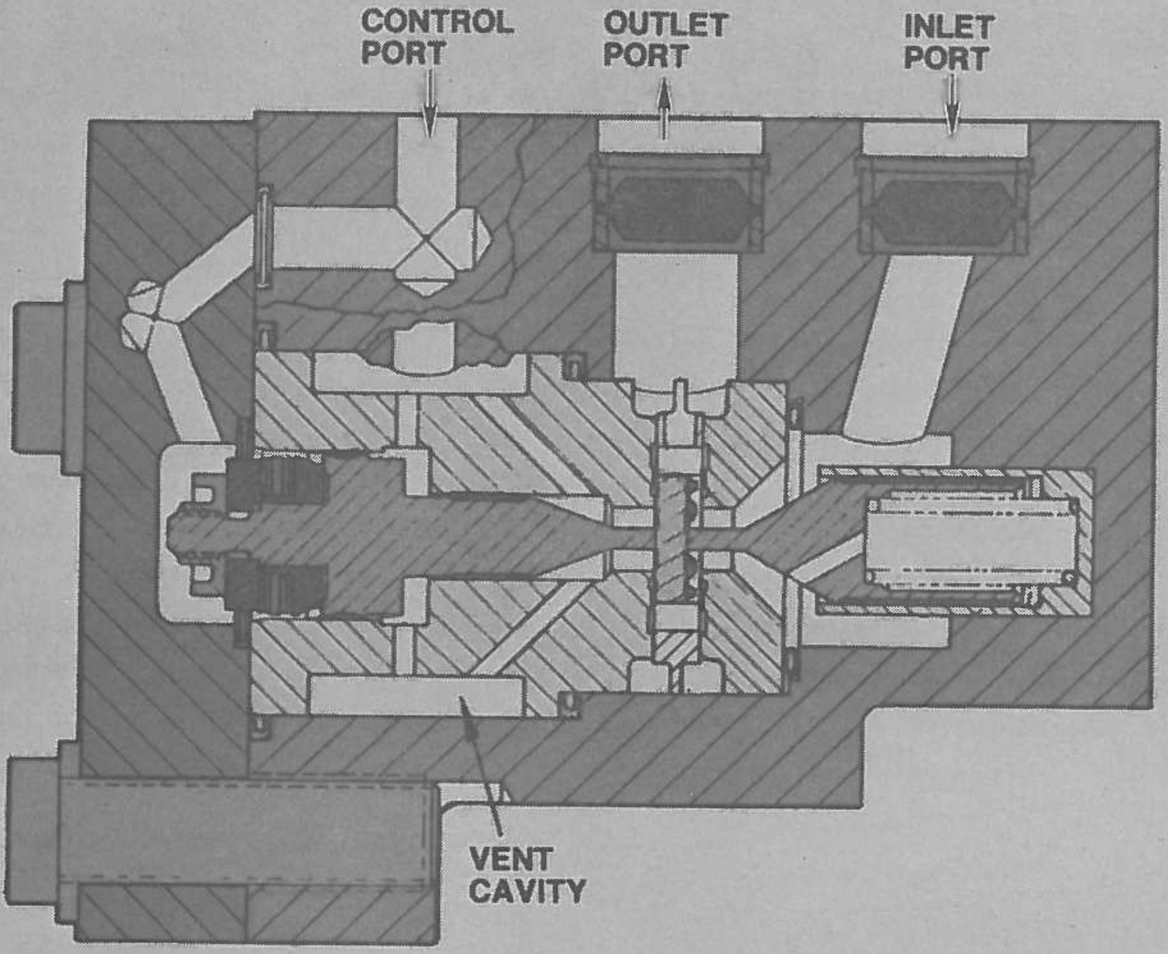
Rockwell International

Rocketdyne Division

PURGE SEQUENCE PRESSURE ACTUATED VALVE (PAV)

R0019401

NORMALLY OPEN



SC87C-4-949A

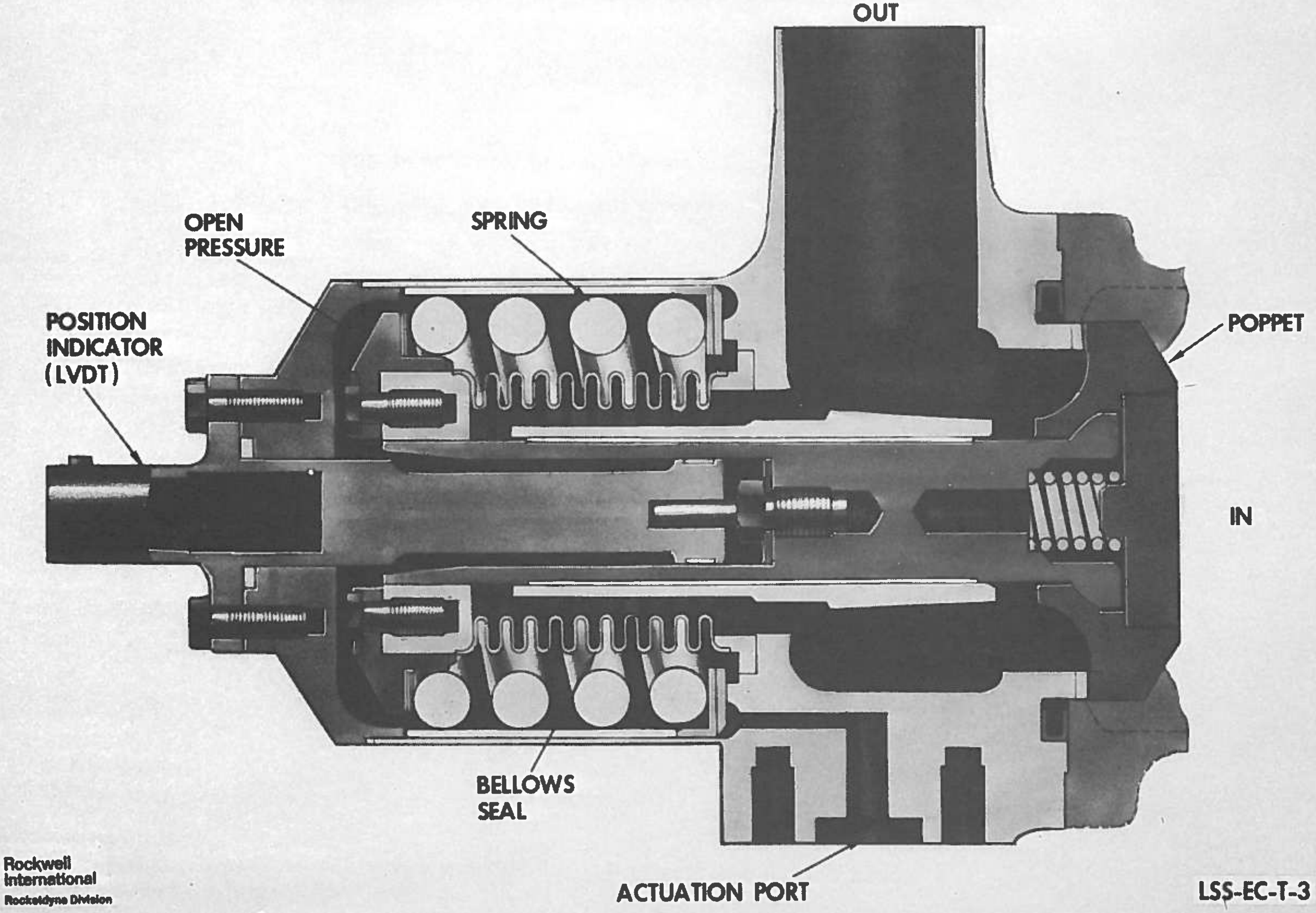
Rockwell International
Rocketdyne Division

PROPELLANT BLEED VALVES

The oxidizer bleed valve (OBV) and fuel bleed valve (FBV) are spring and bellows loaded closed, pneumatically actuated open, metal-to-metal seat, poppet valves. The valves are opened by pneumatic pressure from the pneumatic control assembly (PCA) during engine start preparation. This provides a recirculating flow of propellants through the engine to ensure that the propellants and 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 pressure acting on the unbalanced area poppet, combined with spring and bellows forces, can overcome the actuation pressure. The valves have linear variable differential transducers (LVDT) for full-open or full-closed position indication.

The OBV inlet is flange-mounted to the preburner oxidizer supply duct adjacent to the fuel preburner oxidizer valve (FPOV). The oxidizer bleed duct is welded to the valve outlet. The FBV inlet is flange-mounted to the fuel high-pressure duct adjacent to the HPFTP. The fuel bleed duct is welded to the valve outlet.

PROPELLANT BLEED VALVE



LC301-920A

Rockwell International
Rocketdyne Division

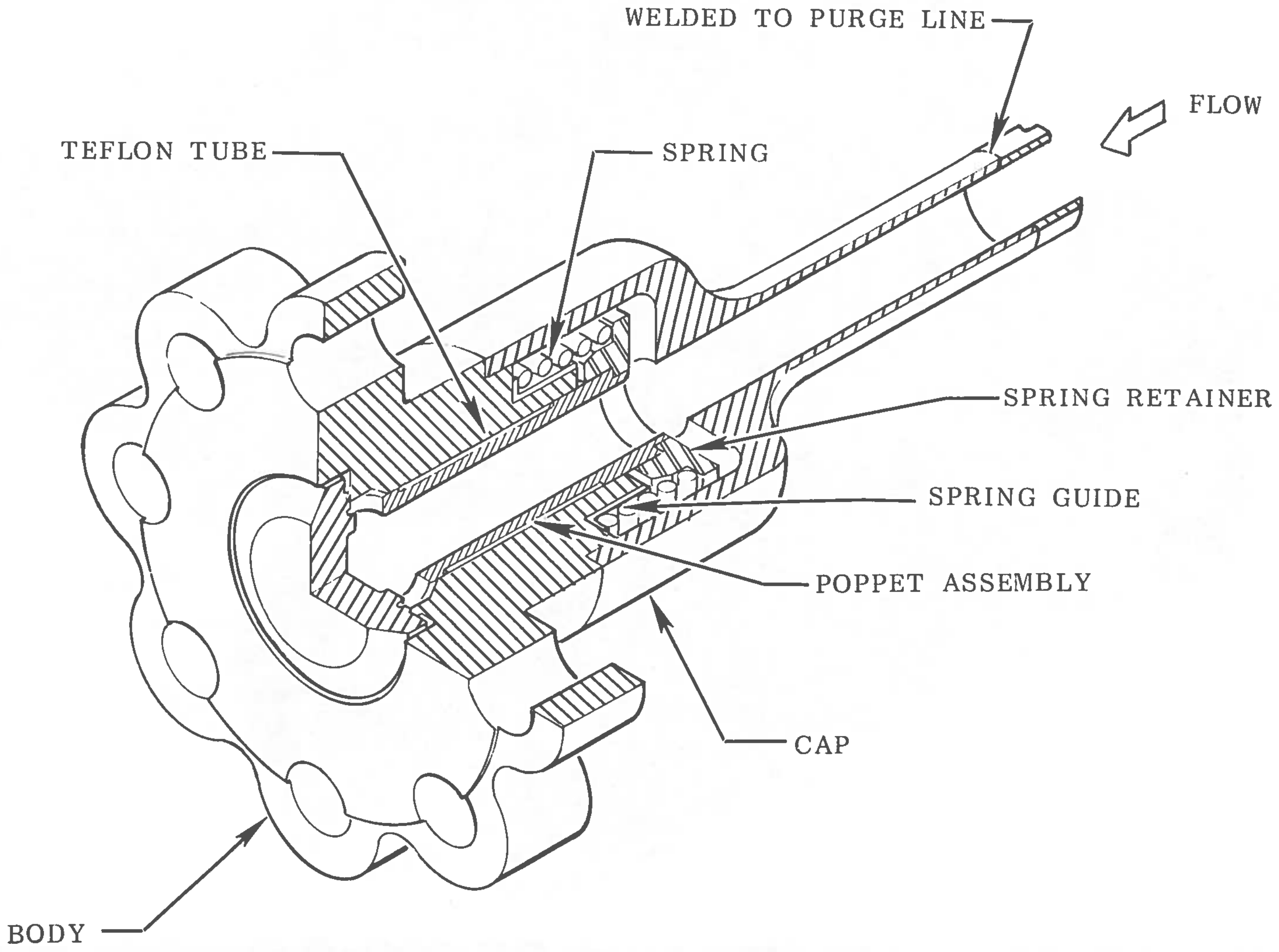
LSS-EC-T-3

SSME PURGE CHECK VALVE

The purge check valve (PCV) permits purge gas to enter the engine systems while preventing propellants from entering the purge systems.

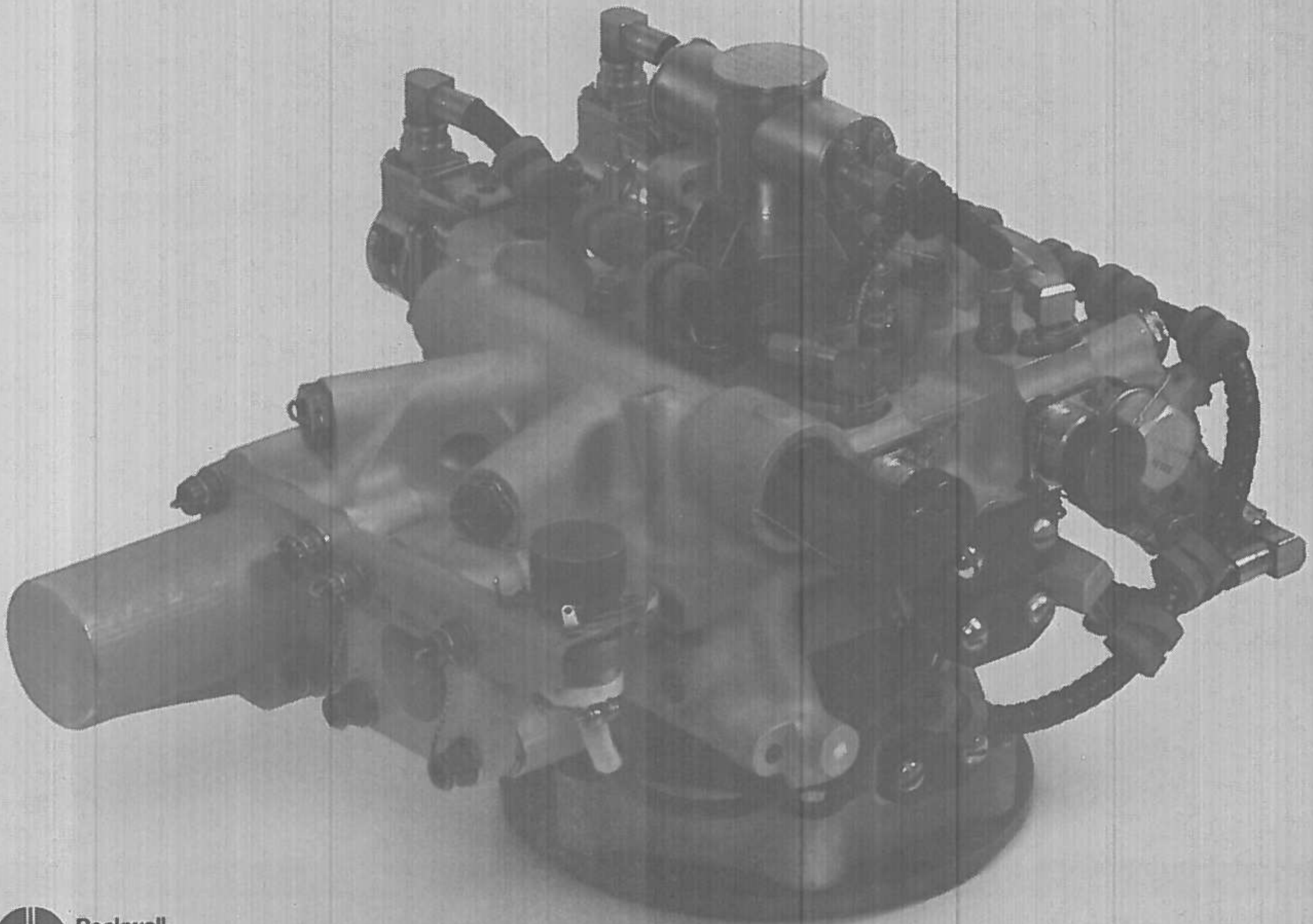
A PCV is a spring-loaded-closed, purge-pressure-opened, poppet-type valve with a metal-to-metal seat. There are six on the engine: one each for the fuel and oxidizer systems purges, and four on the preburner purge system.

PURGE CHECK VALVE



LSS-EC-T-126A

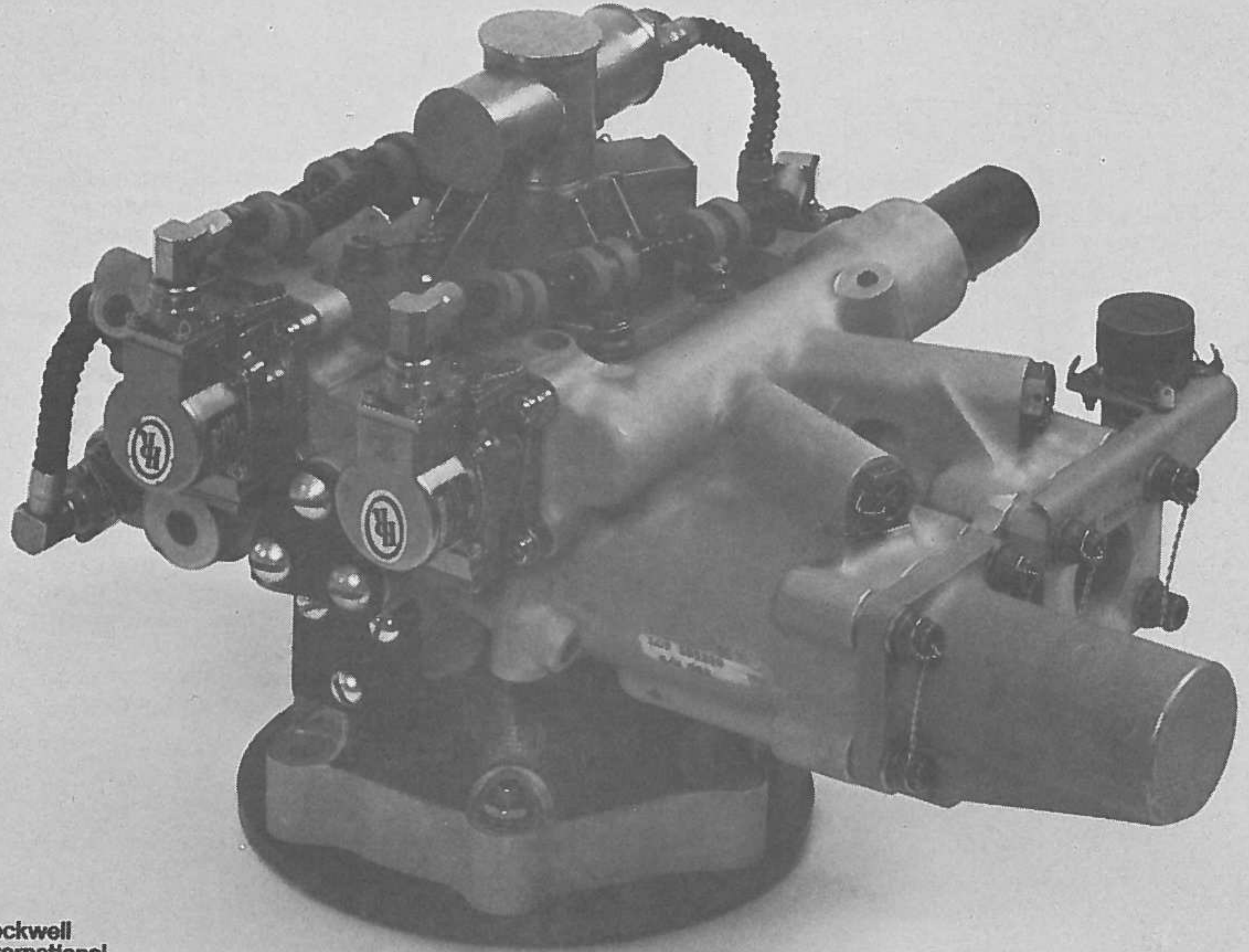
HYDRAULIC ACTUATOR



Rockwell
International
Rocketdyne Division

SC87C-4-3372
1908m/1

HYDRAULIC ACTUATOR



Rockwell
International
Rocketdyne Division

SC87C-4-3373
1908m/2

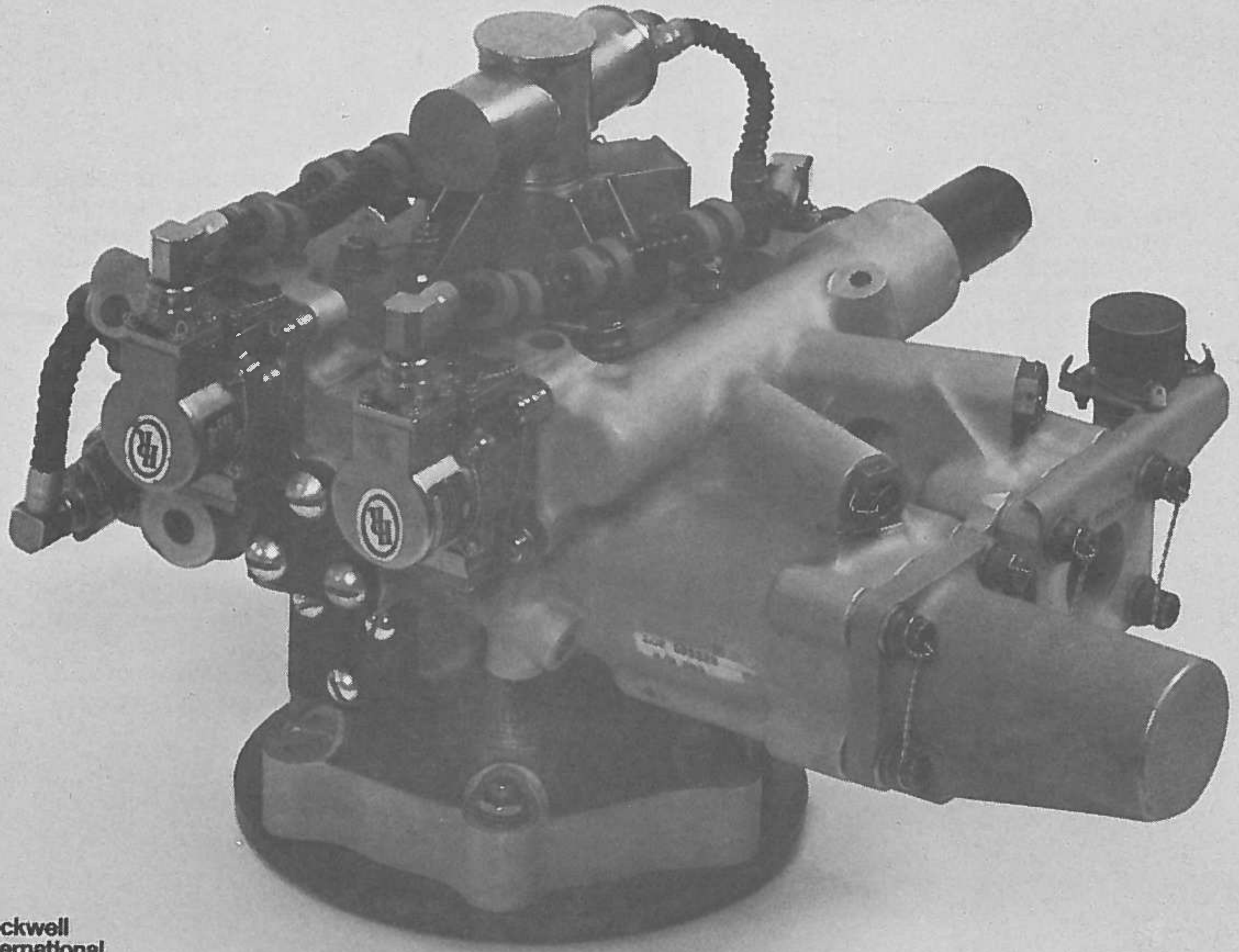
SSME PROPELLANT VALVE HYDRAULIC ACTUATOR

A hydraulic actuator rotates the valving element of a propellant valve in two directions at varying rates.

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

The brains consist of two servovalves (channel A and channel B). The servovalves convert input signal polarity into shaft rotation direction, and amplitude into rate. Channel A servovalve is normally in control. The fail-operate servoswitch, when signaled by the controller, switches control to channel B servovalve. The fail-safe servoswitch, when signaled by the controller, 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 rotary variable differential transducer (RVDT). A blanket heater is installed on only the MFV actuator neck, to maintain the required hydraulic fluid temperature.

HYDRAULIC ACTUATOR



Rockwell
International
Rocketdyne Division

SC87C-4-3373
1908m/2

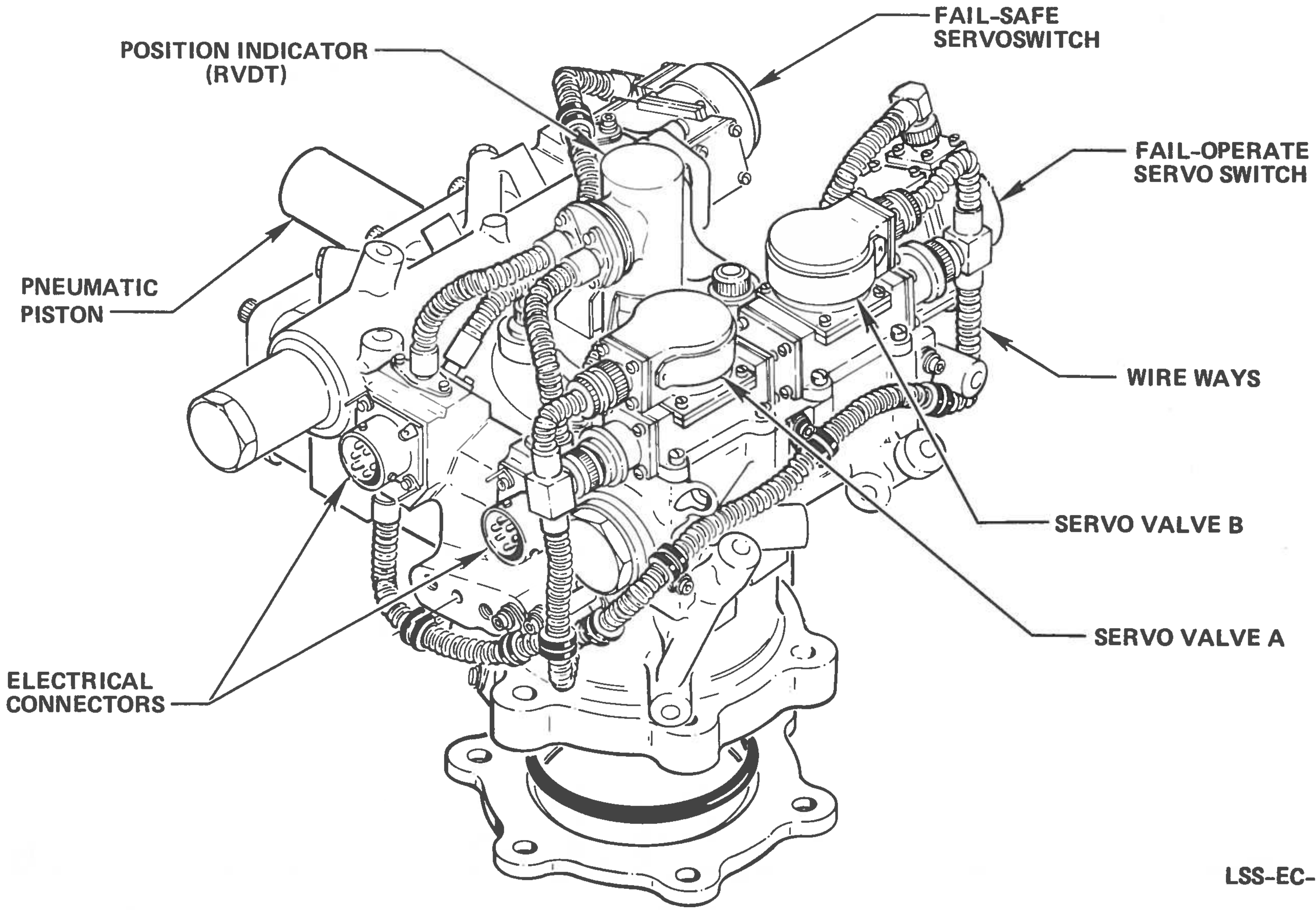
SSME PROPELLANT VALVE HYDRAULIC ACTUATOR

A hydraulic actuator rotates the valving element of a propellant valve in two directions at varying rates.

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

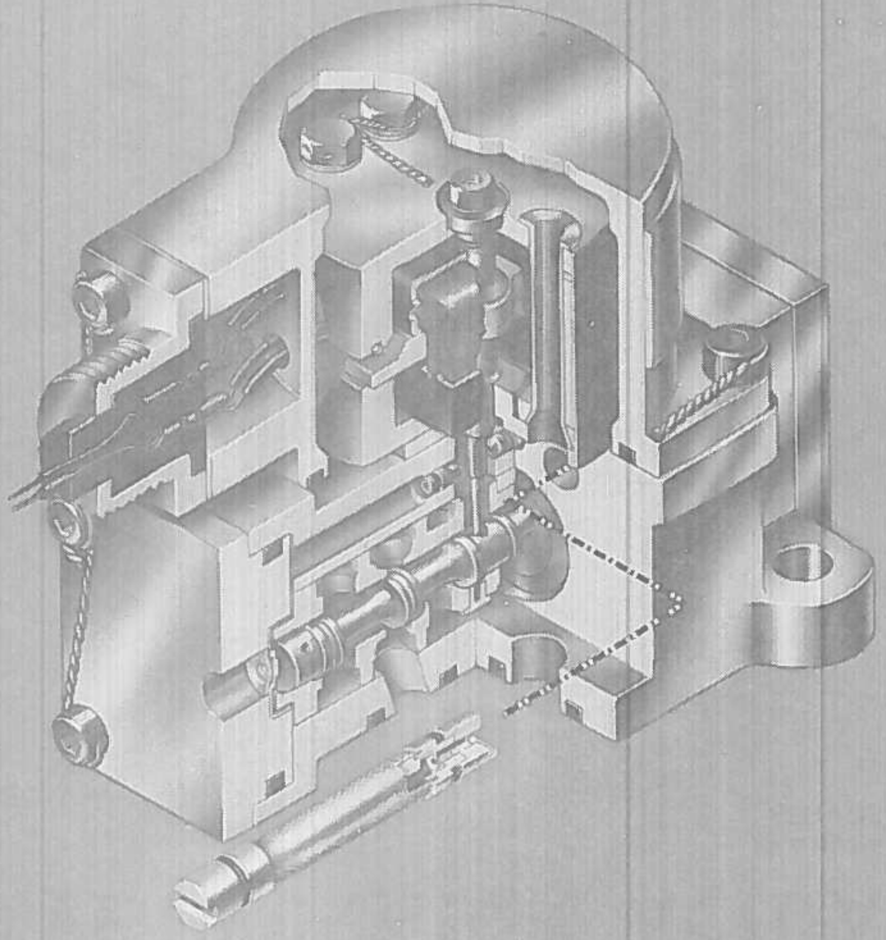
The brains consist of two servovalves (channel A and channel B). The servovalves convert input signal polarity into shaft rotation direction, and amplitude into rate. Channel A servovalve is normally in control. The fail-operate servoswitch, when signaled by the controller, switches control to channel B servovalve. The fail-safe servoswitch, when signaled by the controller, 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 rotary variable differential transducer (RVDT). A blanket heater is installed on only the MFV actuator neck, to maintain the required hydraulic fluid temperature.

SSME PROPELLANT VALVE HYDRAULIC ACTUATOR



LSS-EC-T-39

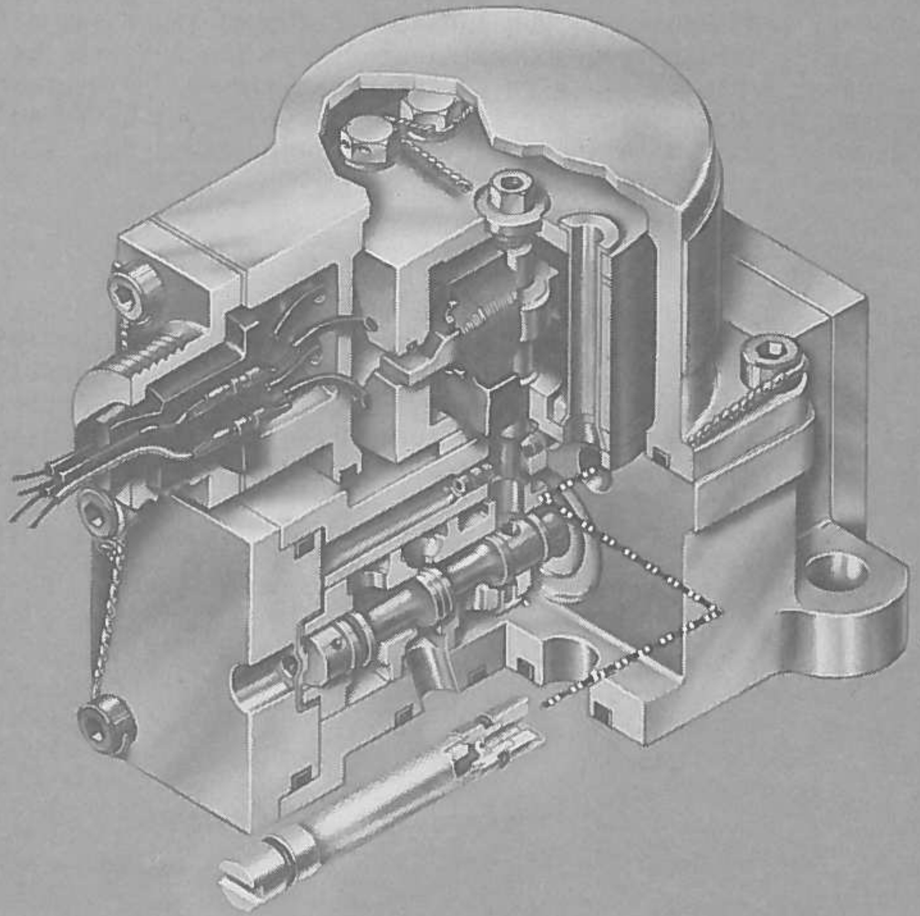
SERVOVALVE ASSEMBLY



LC430-666B

Rockwell International
Rocketdyne Division

SERVOSWITCH ASSEMBLY



LC430-665A

Rockwell International
Rocketdyne Division

HYDRAULIC SERVOVALVE OPERATION

1. Control Circuit

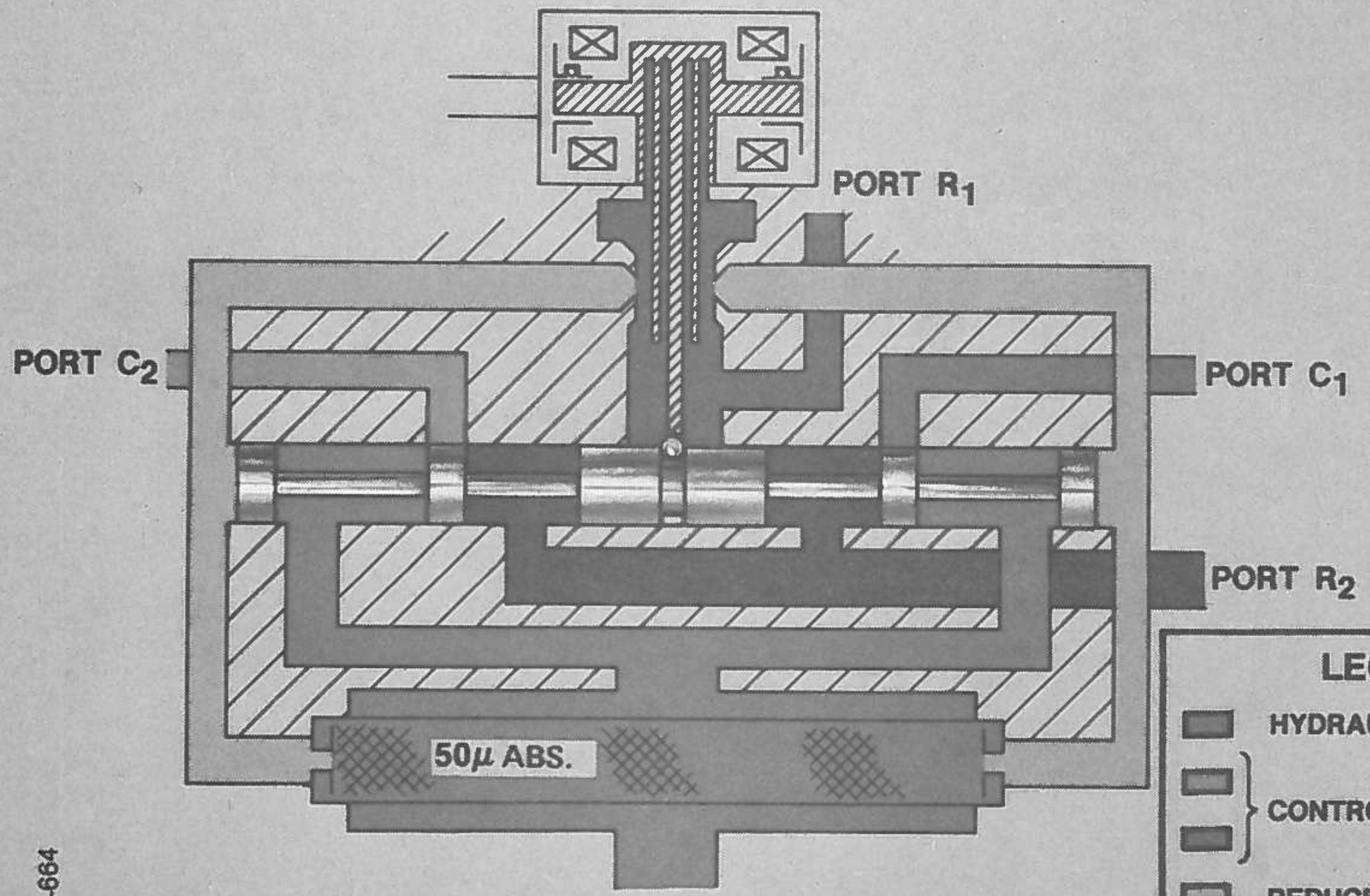
When the torque motor tilts (in response to input signal polarity and amplitude), it increases the flow restriction at one nozzle and decreases it at the other. These variable restrictors are paired with constant restrictors at the ends of the filter, forming two matched pressure dividers. Therefore, the pressures applied to the ends of the sliding poppet can be varied, being equal at null and not equal otherwise. The resulting poppet offset is opposite to torque motor tilt and is fed back to the torque motor via the springy connecting rod.

2. Actuating Circuit

Because of clearance at the poppet lands, constant flows occur from the poppet input cavities, past the poppet lands (and ports C1 and C2), and into hydraulic return at port R2. Therefore, the intermediate pressures established at ports C1 and C2 (and at the actuating pistons) are equal at null and not equal otherwise. Poppet 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 SCHEMATIC

NORMAL FLIGHT CONDITION (NULL POSITION)



LEGEND

▨ HYDRAULIC PRESSURE

▨ ▨ CONTROLLED PRESSURE

▨ REDUCED PRESSURE

▨ HYDRAULIC RETURN

▨ SERVOVALVE LEAKAGE

SC446-664

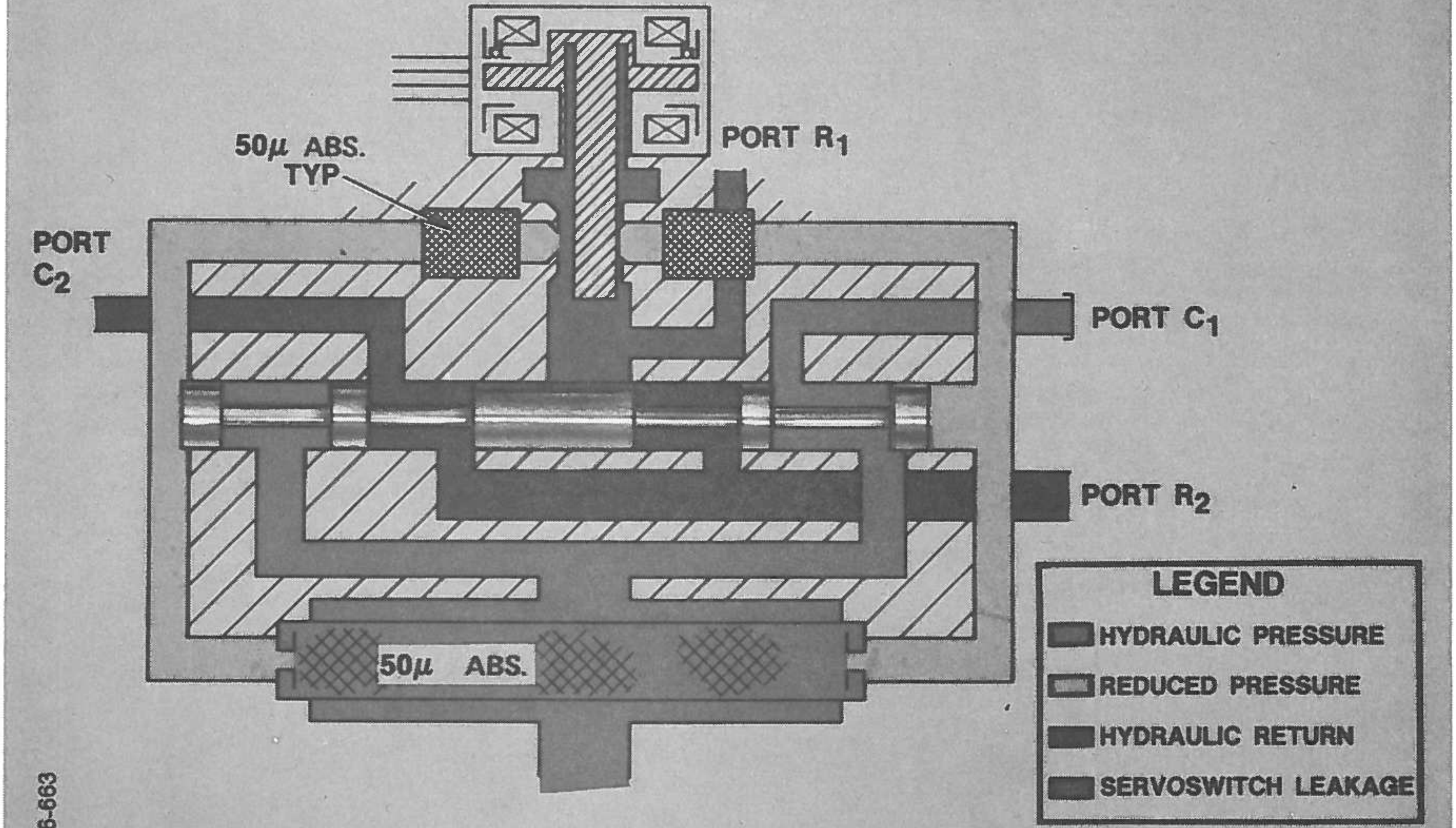
Rockwell International
Rocketdyne Division

HYDRAULIC SERVOSWITCH OPERATION

Servoswitch operation is similar to servovalve operation except that a servoswitch is built or signal-biased to always block one nozzle. This keeps the sliding poppet offset to one side, establishing a pressurized output (eg, port C1) and a nonpressurized output (eg, port C2). By energizing or deenergizing the servoswitch, the states of these ports can be switched.

FAIL-OPERATE SERVOSWITCH SCHEMATIC

NORMAL FLIGHT CONDITION (DE-ENERGIZED)



LEGEND

- ▨ HYDRAULIC PRESSURE
- ▨ REDUCED PRESSURE
- ▨ HYDRAULIC RETURN
- ▨ SERVOSWITCH LEAKAGE

SC446-663

Rockwell International
Rocketdyne Division

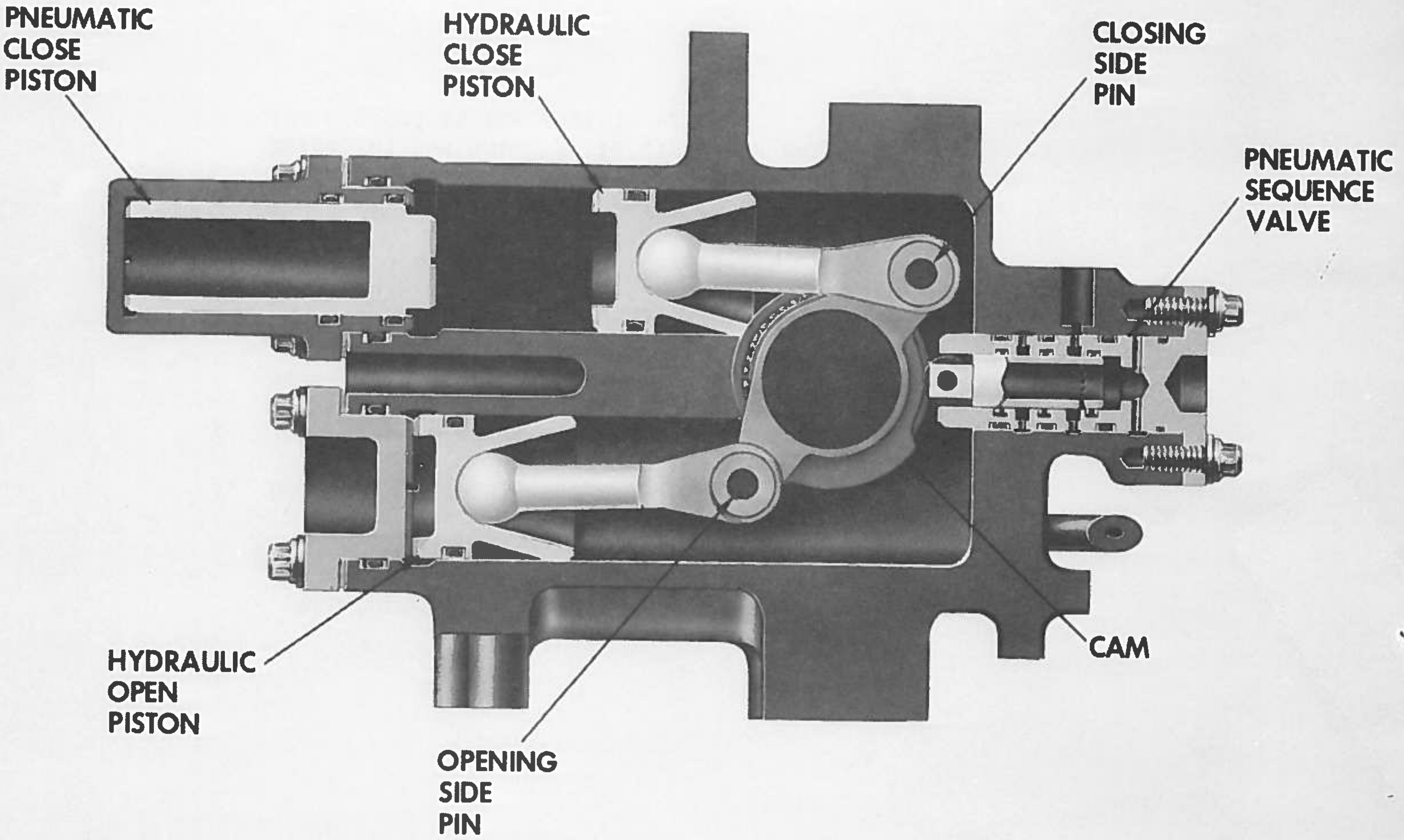
SSME PROPELLANT VALVE HYDRAULIC ACTUATOR PISTON CONFIGURATION

A hydraulic actuator rotates the valving element of a propellant valve in two directions at varying rates.

There are five similar actuators on the SSME: one each for the MFV, MOV, FPOV, OPOV, and CCV. 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) the valve. The pressure then proceeds to the next actuator.

PREBURNER VALVE ACTUATOR



LC254-407C

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Rocketdyne Division

LSS-EC-T-4

HYDRAULIC ACTUATOR SCHEMATIC NORMAL CONFIGURATION

1. Both servovalves are operational.

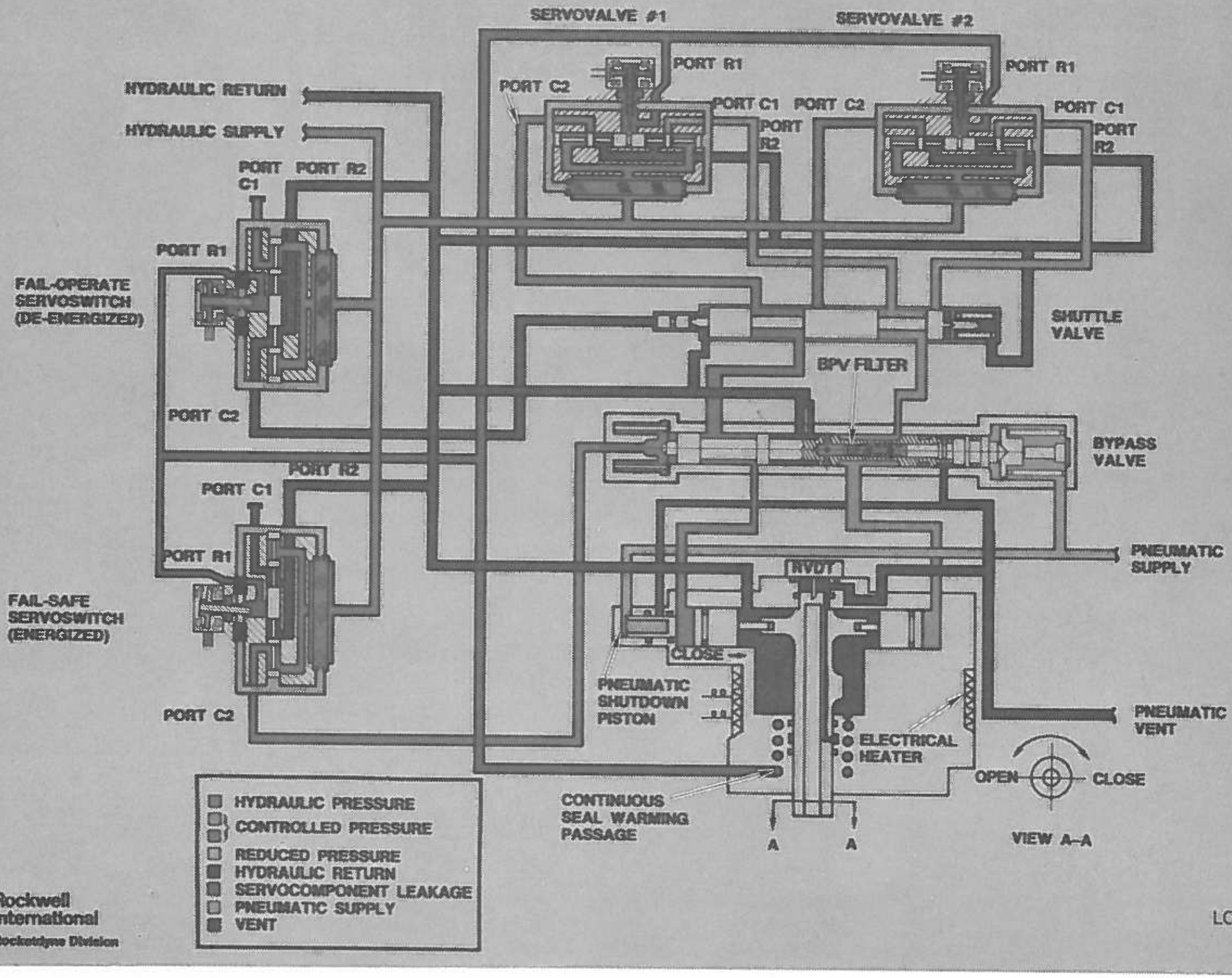
2. The fail-operate servoswitch is deenergized. Port C2 and the shuttle valve are depressurized. The shuttle valve is spring-loaded to the left and:

3. The fail-safe servoswitch is energized. Port C2 and the bypass valve are pressurized. The bypass valve is displaced to the right. Therefore:

4. Ports C1 and C2 on servovalve No. 1 are connected through the shuttle valve and the bypass valve to the actuating pistons. Ports C1 and C2 on servovalve No. 2 are blocked at the shuttle valve.

MAIN FUEL VALVE HYDRAULIC ACTUATOR (MFVA) SCHEMATIC

NORMAL FLIGHT CONDITION



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Rocketdyne Division

LC87C-4-4268
1312m/15

HYDRAULIC ACTUATOR SCHEMATIC
FAIL-OPERATE CONFIGURATION (CHANNEL B)

1. Failure in command channel A, therefore:

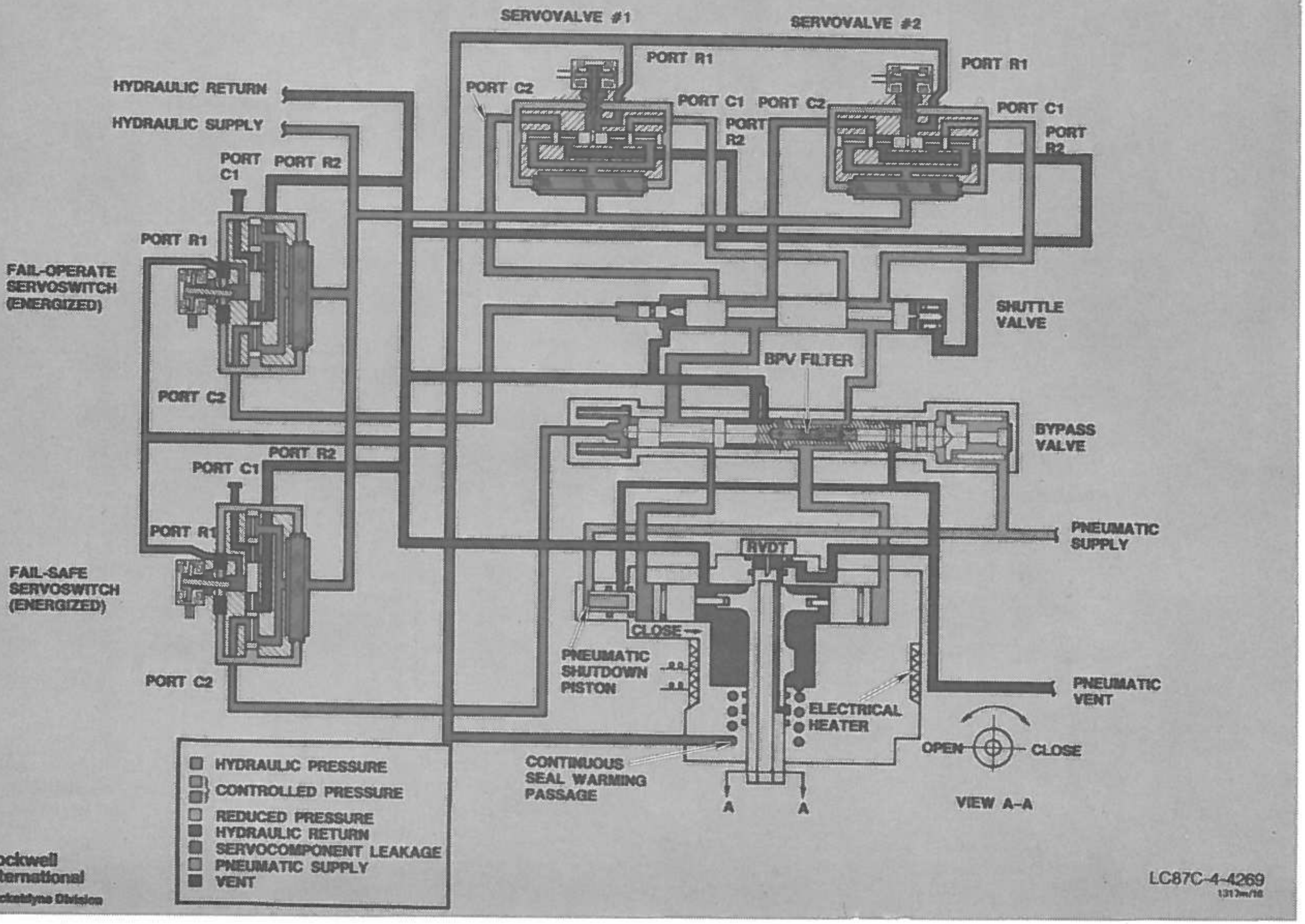
2. The fail-operate servoswitch is energized. Port C2 and the shuttle valve are pressurized. The shuttle valve is displaced to the right, and:

3. The fail-safe servoswitch remains energized. Port C2 and the bypass valve remain pressurized. The bypass valve remains displaced to the right. Therefore:

4. Ports C1 and C2 on servovalve No. 1 are blocked at the shuttle valve. Ports C1 and C2 on servovalve No. 2 are connected through the shuttle valve and the bypass valve to the actuating pistons.

MAIN FUEL VALVE HYDRAULIC ACTUATOR (MFVA) SCHEMATIC

CHANNEL B OPERATION



Rockwell International
Rocketdyne Division

LC87C-4-4269
1317m/16

HYDRAULIC ACTUATOR SCHEMATIC
FAIL-SAFE CONFIGURATION (HYDRAULIC LOCKUP)

1. Both command channels have failed and/or hydraulic pressure has failed. Therefore:

2. The state of the fail-operate servoswitch and shuttle valve is ambiguous and unimportant.

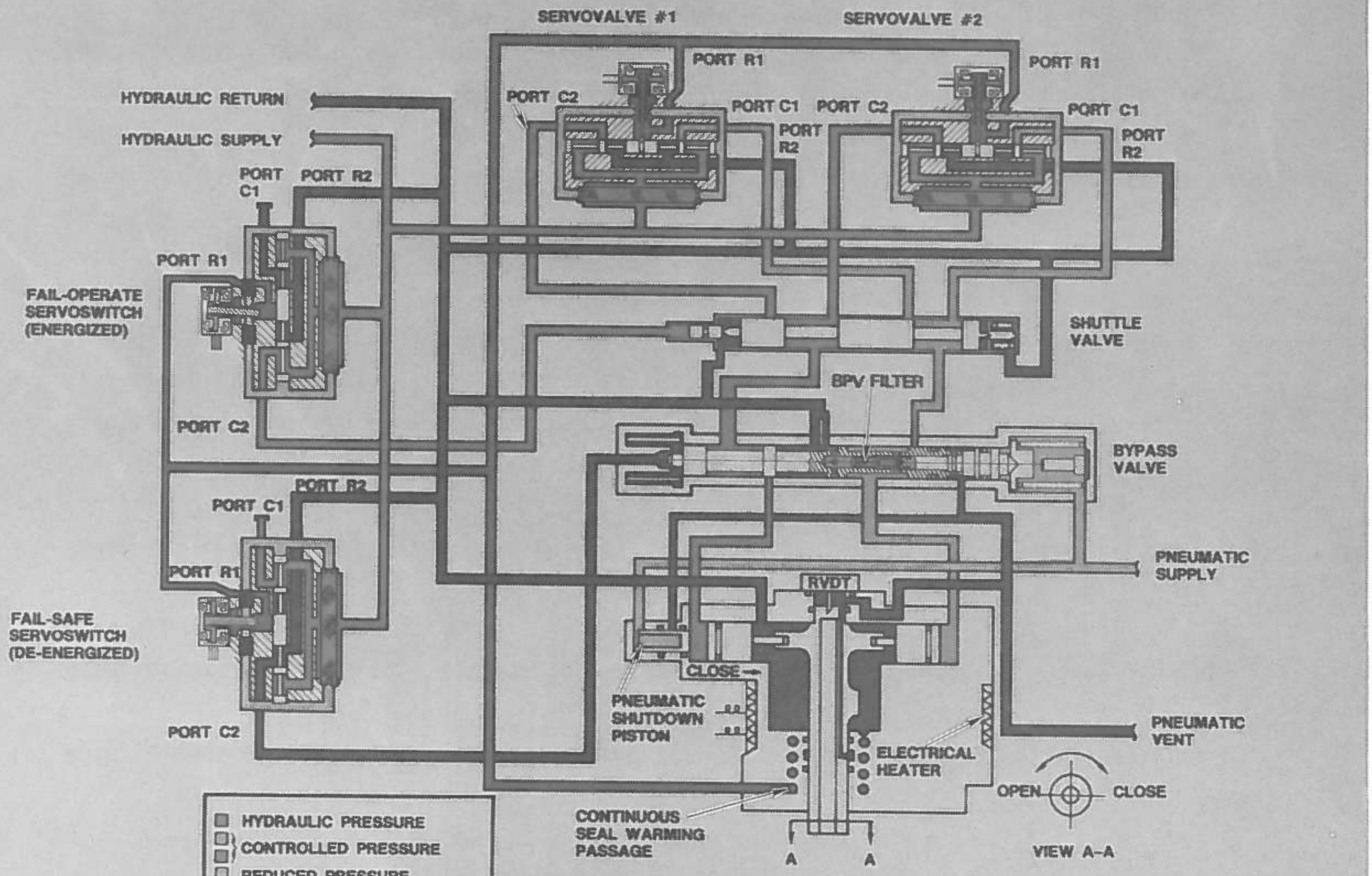
3. The fail-safe servoswitch is then deenergized. Port C2 and the bypass valve are depressurized. The bypass valve is positioned to its center position by spring-loaded stops at both ends.

4. The oil passage to the close actuating piston is blocked at the land on the bypass valve. The oil passage to the open actuating piston is blocked in the bypass valve filter cavity.

5. The actuator (and propellant valve) are hydraulically locked and cannot rotate except for an infinitesimal drift due to actuator internal leakage.

MAIN FUEL VALVE HYDRAULIC ACTUATOR (MFVA) SCHEMATIC

LOCKUP CONDITION



- ▨ HYDRAULIC PRESSURE
- ▨ } CONTROLLED PRESSURE
- ▨
- ☐ REDUCED PRESSURE
- ■ HYDRAULIC RETURN
- ■ SERVOCOMPONENT LEAKAGE
- ▨ PNEUMATIC SUPPLY
- ■ VENT

Rockwell International
Rocketdyne Division

LC87C-4-4270
1317m/17

HYDRAULIC ACTUATOR SCHEMATIC
PNEUMATIC SHUTDOWN CONFIGURATION

1. Both command channels have failed and/or hydraulic pressure has failed. Therefore:

2. Both servovalves and servoswitches are in the fail-safe configuration. (See previous page.)

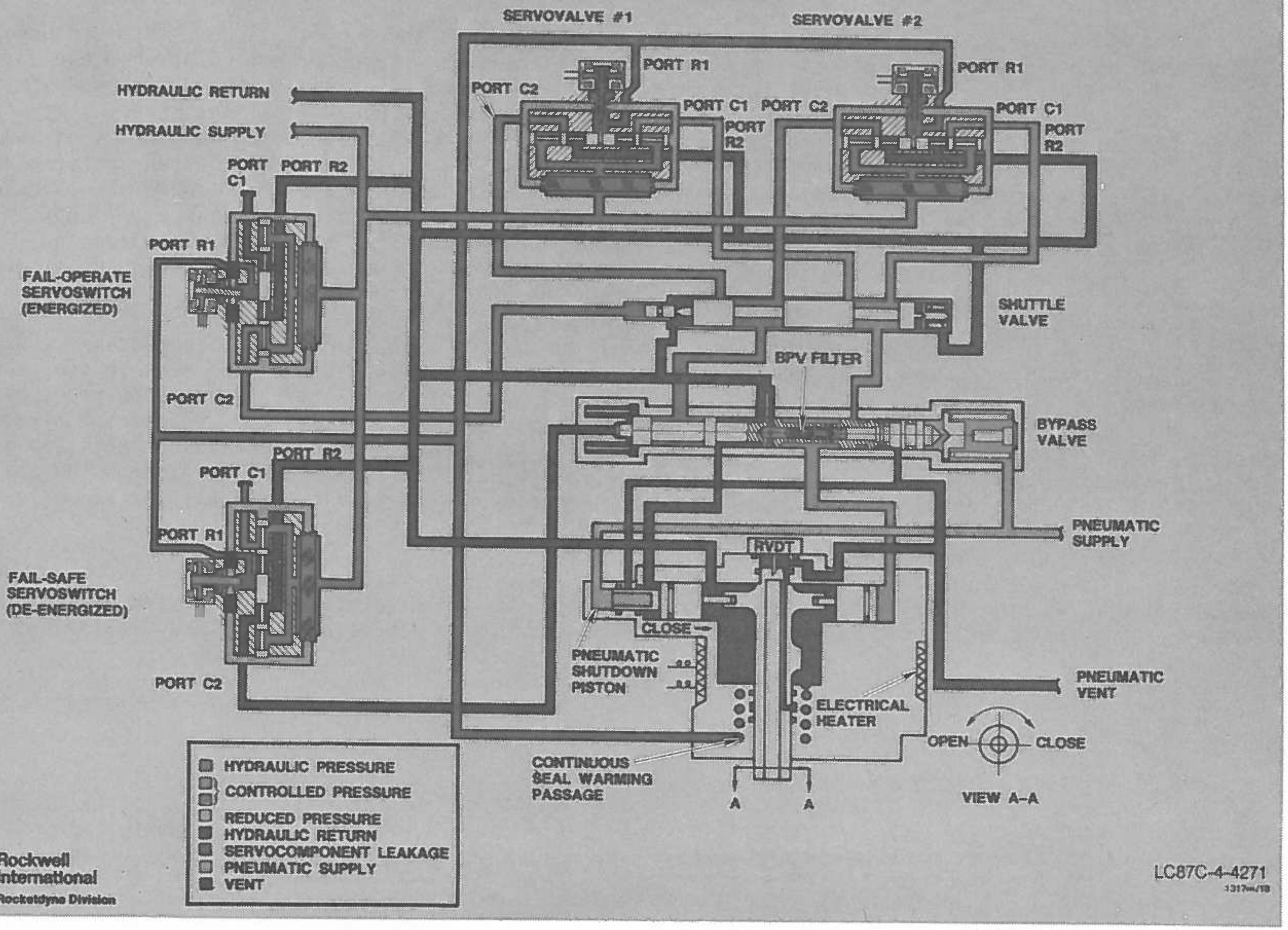
3. Pneumatic pressure applied to the pneumatic supply input is ported to the pneumatic shutdown piston, which contacts the hydraulic close piston to close the valve.

4. Pneumatic pressure is also applied to the right-hand cavity of the bypass valve, displacing it to the left. This connects the bypass valve filter cavity (and the passageway to the hydraulic open piston) to hydraulic return through a small bleed passageway. This unlocks the actuator and controls the rate at which the oil can exit and, therefore, how fast the valve can be pneumatically closed.

5. On an actuator that incorporates a sequence valve (OPOV, FPOV, and CCV), pneumatic shutdown pressure is also directed to and waits within the valve until the actuator closes and permits the sequence valve to open, passing the pneumatic pressure on to the next actuator in the closing sequence.

MAIN FUEL VALVE HYDRAULIC ACTUATOR (MFVA) SCHEMATIC

PNEUMATIC SHUTDOWN CONDITION



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Rocketdyne Division

SSME CONTROLLER

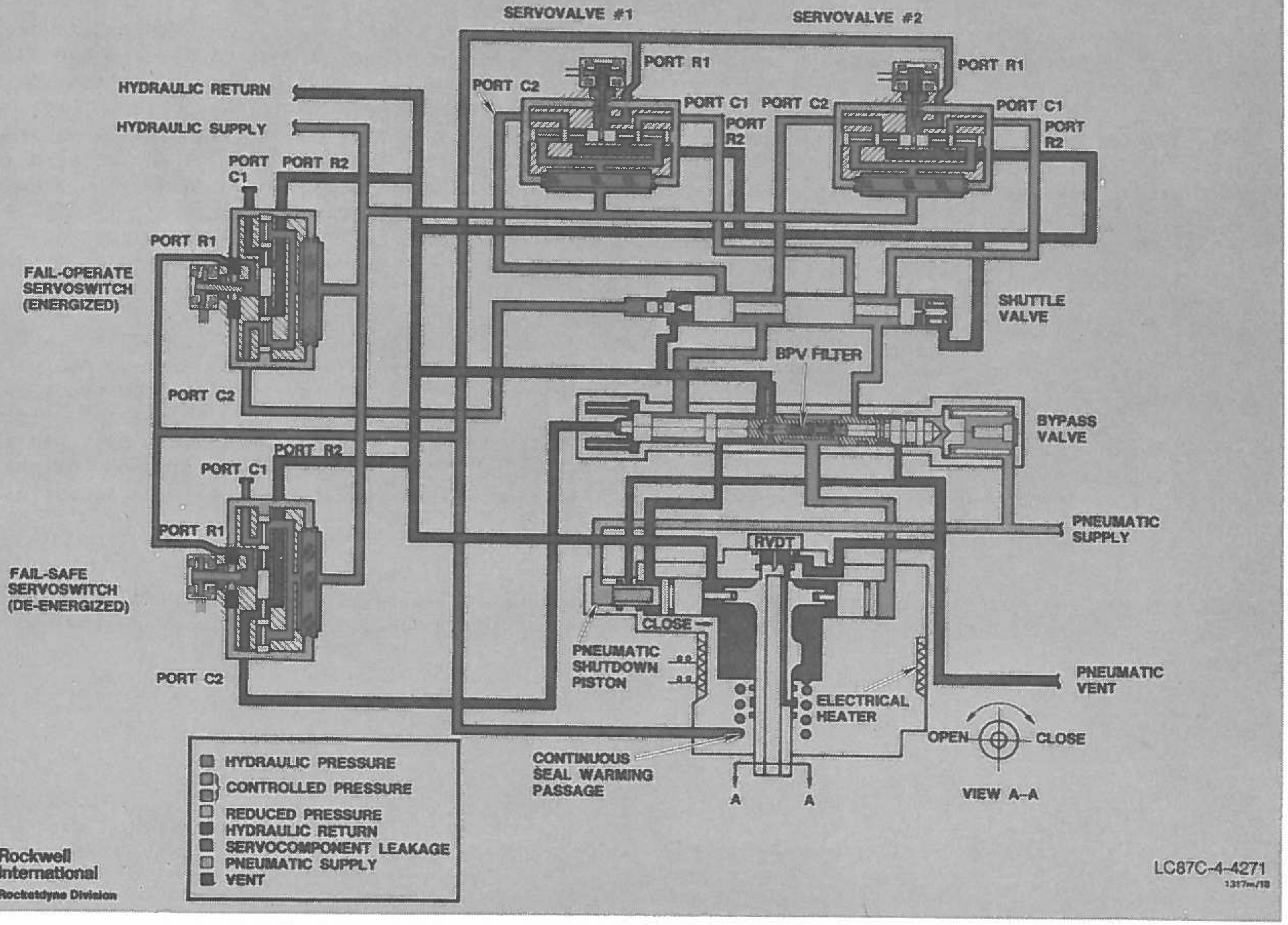
The SSME controller provides complete and continuous monitoring and control of engine operation. In addition, it performs maintenance and start preparation checks, and collects data for historical and maintenance purposes.

The controller is an electronic package that contains five major sections, ie, power supply, input section, output section, computer interface section, and digital computer. 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 gives 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 is suspended, and the engine is subsequently shut down 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 module boards inside a sealed, pressurized chassis that is cooled by heat convection through pin fins.

MAIN FUEL VALVE HYDRAULIC ACTUATOR (MFVA) SCHEMATIC

PNEUMATIC SHUTDOWN CONDITION



Rockwell International
Rocketdyne Division

LC87C-4-4271
1317m/18

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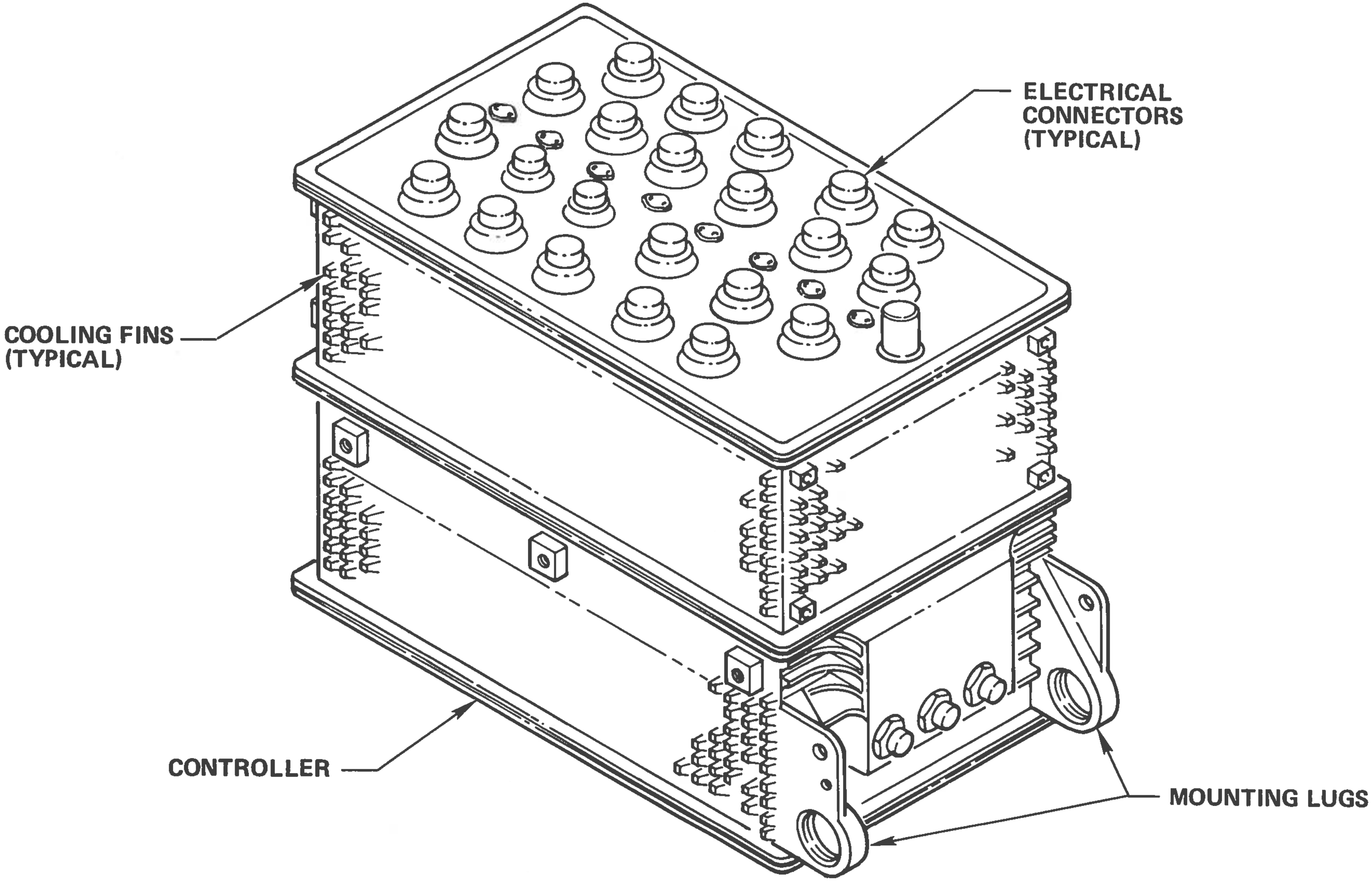
SSME CONTROLLER



LSS-EC-T-40

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 (ie, valve positions, pressures, temperatures, flowrates, and pump speeds) from the engine sensors. Converts data from existing 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.

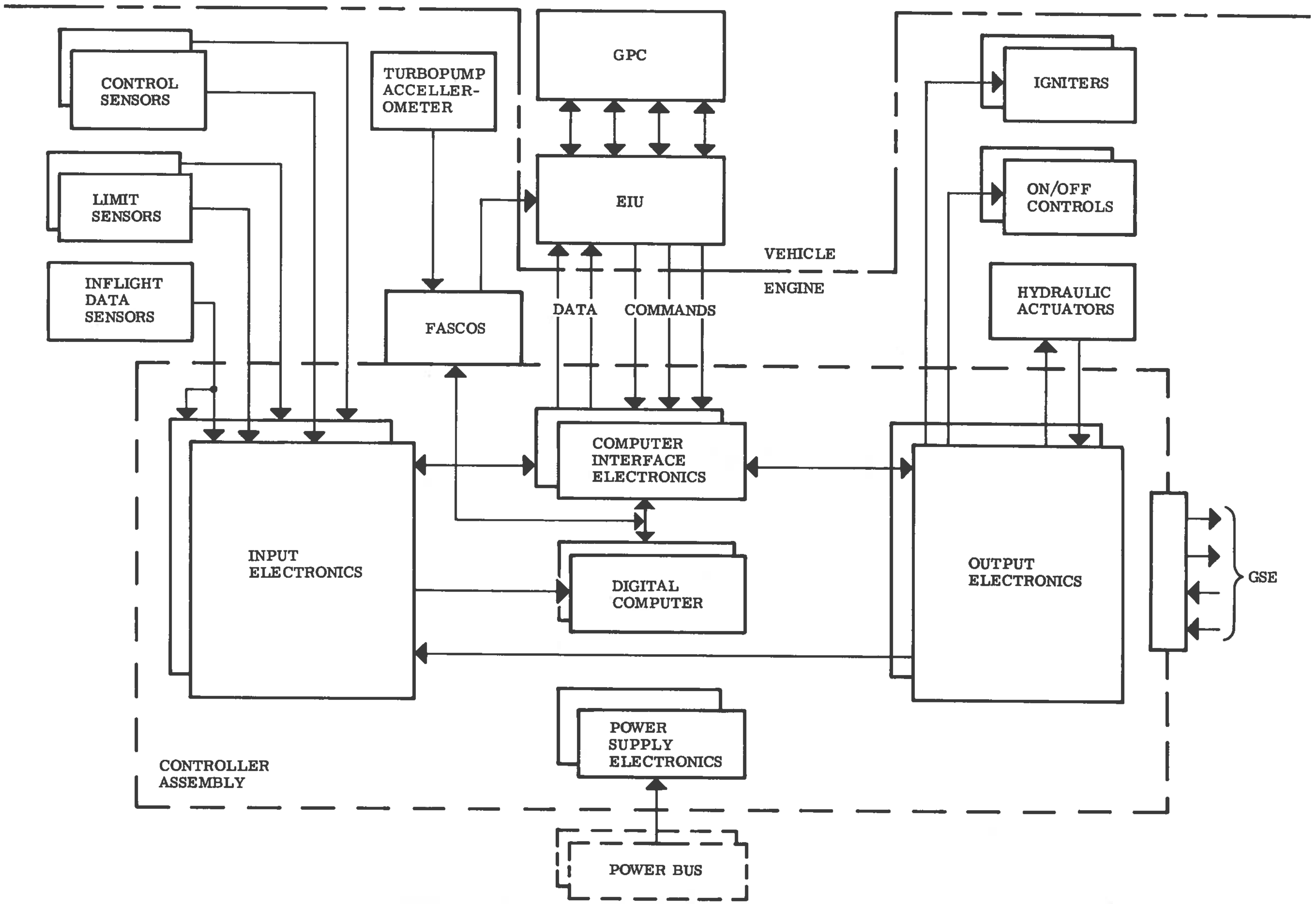
3. Digital Computer: Provides the computations necessary for all engine control functions. The 2-mil, plated-wire memory has a nondestructive readout and a storage capacity of 16,384 17-bit data and instruction words. Typical instruction times are 2 microseconds add and 9 microseconds multiply. Major cycle time is 20 milliseconds and includes four 5-millisecond minor cycles.

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 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 preset time.

CONTROLLER ORGANIZATION



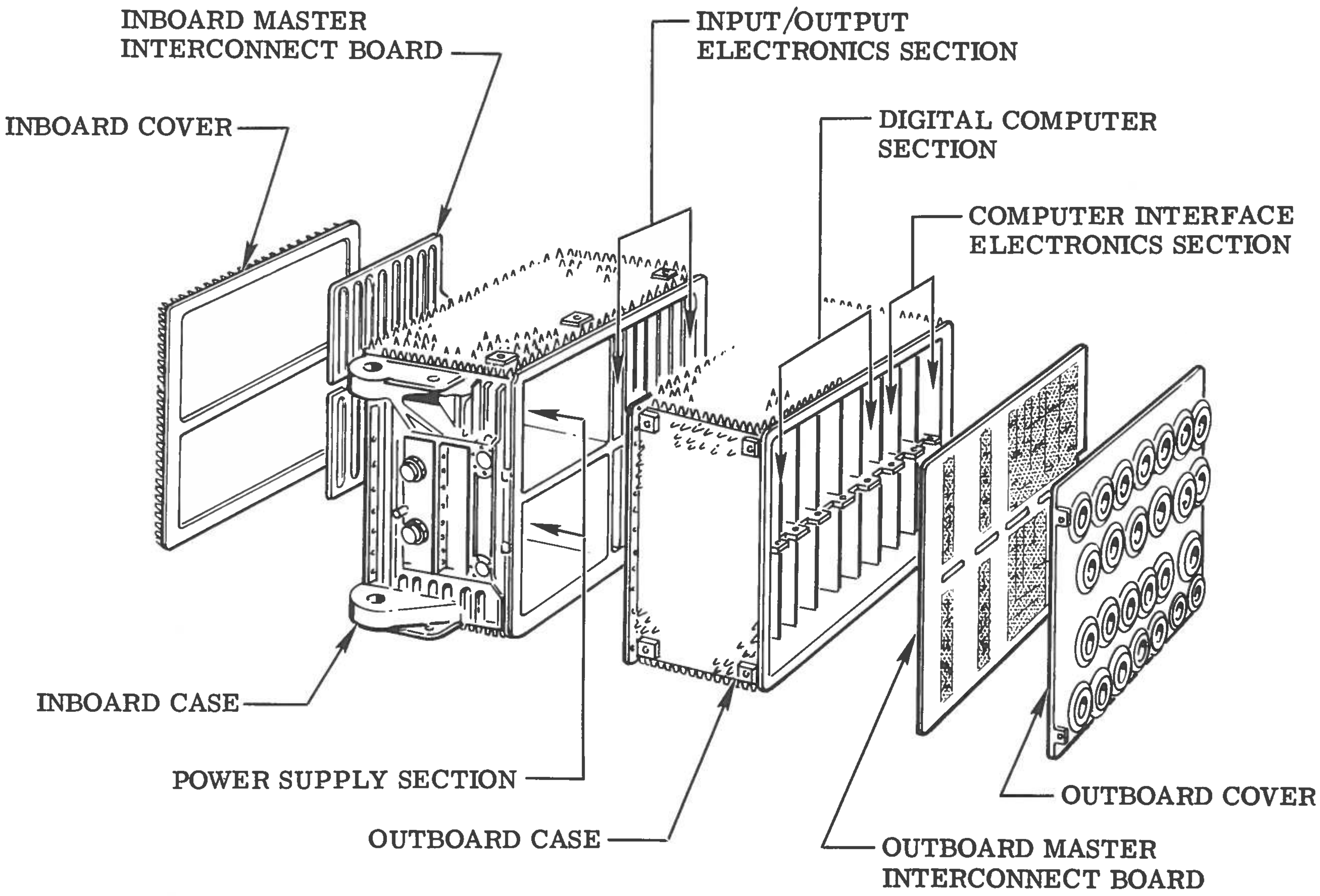
LSS-ES-T-125C

CONTROLLER PHYSICAL CHARACTERISTICS

● SIZE	23.5 X 14.5 X 17.0 INCHES
● WEIGHT	211 POUNDS
● INPUT POWER	490 WATTS (STANDBY) 600 WATTS (MAINSTAGE)
● HEAT TRANSFER	FORCED AIR COOLING (GROUND) CONVECTIVE COOLING (FLIGHT)
● MOUNTING	FOUR-POINT VIBRATION ISOLATORS
● TEMPERATURE ENVIRONMENT	OPERATIONAL -50° TO +150° F NONOPERATIONAL -200° TO +200° F

T122A

SSME CONTROLLER



LSS-EE-T-221A

SSME OPERATIONAL PHASES AND MODES

- CHECKOUT PHASE
  - STANDBY MODE
  - COMPONENT CHECKOUT MODE
- START PREPARATION PHASE
  - PURGE SEQUENCE NO. 1 MODE
  - PURGE SEQUENCE NO. 2 MODE
  - PURGE SEQUENCE NO. 3 MODE
  - PURGE SEQUENCE NO. 4 MODE
  - ENGINE READY MODE
- START PHASE
  - START INITIATION MODE
  - THRUST BUILDUP MODE
  - ELECTRICAL LOCKUP MODE
  - HYDRAULIC LOCKUP MODE
  - FIXED DENSITY MODE
- MAINSTAGE PHASE
  - NORMAL CONTROL MODE
  - THRUST LIMITING MODE
  - ELECTRICAL LOCKUP MODE
  - HYDRAULIC LOCKUP MODE
  - FIXED DENSITY MODE
- SHUTDOWN PHASE
  - THROTTLING TO ZERO THRUST MODE
  - PROPELLANT VALVES CLOSED MODE
  - FAIL-SAFE PNUEMATIC SHUTDOWN MODE
- POST-SHUTDOWN PHASE
  - STANDBY MODE
  - OXIDIZER DUMP MODE
  - TERMINATE SEQUENCE MODE

T83D

SSME CHECKOUT PHASE MODE DEFINITIONS

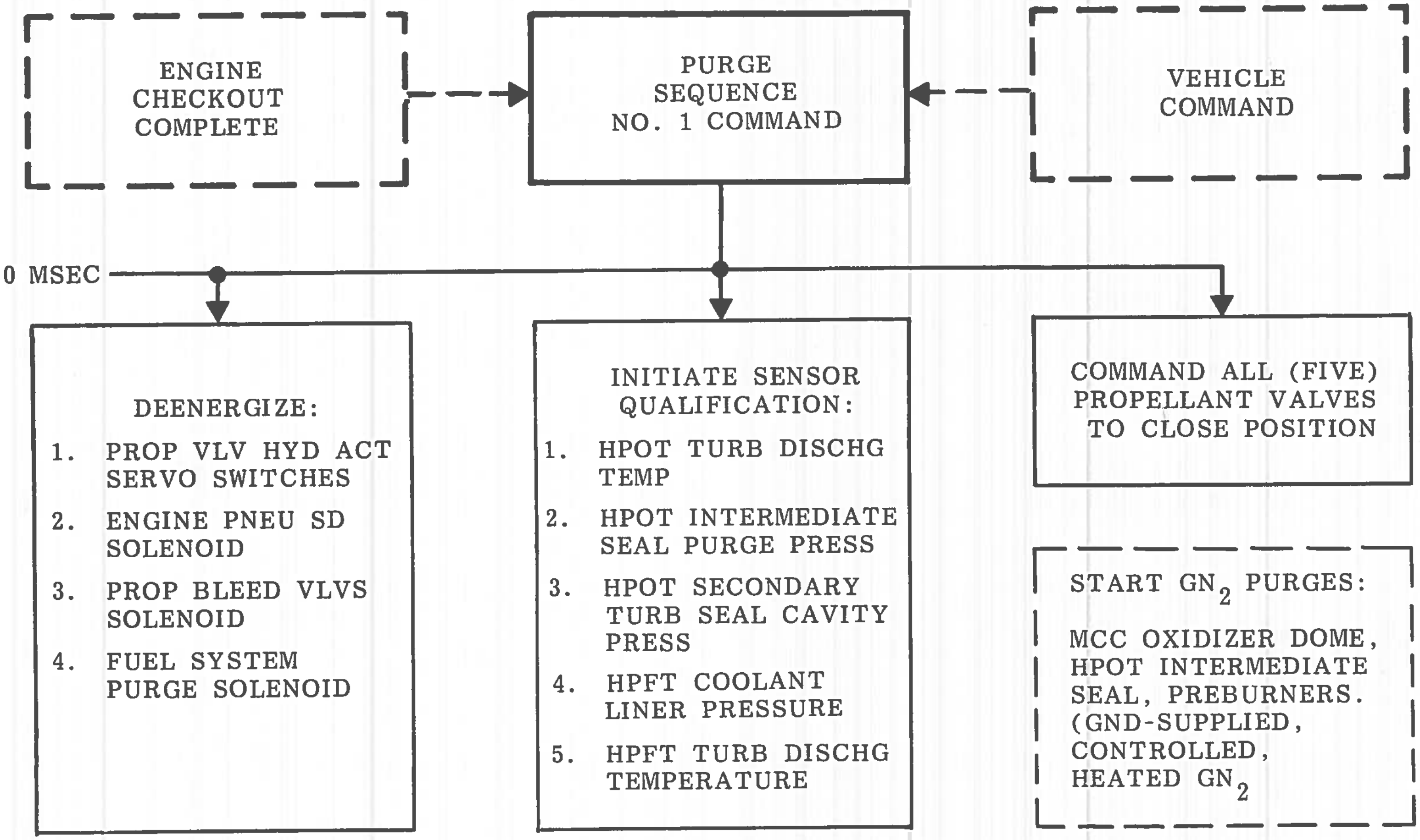
- CHECKOUT PHASE: CONTROLLER OPERATIONAL PROGRAM IS INITIATED TO BEGIN ACTIVE CONTROL, MONITORING, OR CHECKOUT.
  - STANDBY MODE: A WAITING MODE DURING WHICH ACTIVE CONTROL SEQUENCE OPERATIONS ARE NOT IN PROCESS. MONITORING FUNCTIONS THAT DO NOT AFFECT ENGINE HARDWARE COMPONENT STATUS ARE CONTINUALLY ACTIVE. SUCH FUNCTIONS INCLUDE PROCESSING OF VEHICLE COMMANDS, STATUS UPDATE, AND CONTROLLER SELF-TEST. DURING CHECKOUT PHASE, DATA AND INSTRUCTIONS CAN BE LOADED INTO COMPUTER MEMORY. THIS PERMITS UPDATING OF SOFTWARE PROGRAM AND DATA AS NECESSARY TO PROCEED WITH ENGINE FIRING OPERATIONS OR CHECKOUT OPERATIONS.
  - COMPONENTS CHECKOUT MODE: A CHECKOUT OR ENGINE LEAK TEST IS BEING PERFORMED ON AN INDIVIDUAL ENGINE SYSTEM COMPONENT USING OVERLAY MODULES.
  - SENSOR CALIBRATION AND CHECKOUT
  - PNEUMATIC CHECKOUT
  - HYDRAULIC ACTUATOR CHECKOUT
  - REDUNDANCY VERIFICATION I AND II
  - FLIGHT READINESS TEST (FRT-1 + FRT-2)

SSME START PREPARATION PHASE MODE DEFINITIONS

- SSME START PREPARATION PHASE: ENGINE SYSTEM PURGES AND PROPELLANT CONDITIONING ARE BEING PERFORMED.
  - PURGE SEQUENCE NO. 1 MODE: FIRST PURGE SEQUENCE OF START PREPARATION PHASE IS IN PROGRESS. GROUND-SUPPLIED GN_2 PURGE OF PREBURNERS, OXIDIZER DOME, AND HPOTP INTERMEDIATE SEAL IS INITIATED. PROPELLANT VALVE POSITIONS ARE VERIFIED.
  - PURGE SEQUENCE NO. 2 MODE: SECOND PURGE SEQUENCE OF START PREPARATION PHASE IS IN PROGRESS. ON-BOARD HELIUM PURGE OF FUEL SYSTEM IS INITIATED. GN_2 PURGES INITIATED IN PURGE SEQUENCE NO. 1 ARE CONTINUED.
  - PURGE SEQUENCE NO. 3 MODE: THIRD PURGE SEQUENCE OF START PREPARATION PHASE IS IN PROGRESS. PROPELLANT RECIRCULATION (BLEED VALVES OPENED) IS INITIATED. FUEL SYSTEM HELIUM PURGE IS SUSPENDED. (NOTE: DURING PURGE SEQUENCE NO. 3, FUEL SYSTEM HELIUM PURGE IS REAPPLIED FOR 3 MINUTES EACH 60-MINUTE PERIOD AND PROPELLANT VALVE HYDRAULIC ACTUATORS ARE EXERCISED.) GN_2 PURGES INITIATED IN PURGE SEQUENCE NO. 1 ARE CONTINUED.
  - PURGE SEQUENCE NO. 4 MODE: FOURTH PURGE SEQUENCE OF START PREPARATION PHASE IS IN PROGRESS. FUEL SYSTEM HELIUM PURGE IS REINSTATED. ALL FAIL-SAFE SERVOSWITCHES ARE ENERGIZED. GN_2 PURGES INITIATED IN PURGE SEQUENCE NO. 1 ARE CONTINUED.
  - ENGINE READY MODE: PROPER THERMAL AND PRESSURE CONDITIONS FOR START HAVE BEEN ATTAINED AND OTHER CRITERIA FOR START HAVE BEEN SATISFIED. ALL PURGES ON IN PURGE SEQUENCE NO. 4 ARE CONTINUED.

SSME START PREPARATION PHASE PURGE SEQ. NO. 1 MODE (SIMPLIFIED)

(NOMINAL DURATION: 4 MINUTES)



ENGINE CHECKOUT COMPLETE

PURGE SEQUENCE NO. 1 COMMAND

VEHICLE COMMAND

0 MSEC

DEENERGIZE:

1. PROP VLV HYD ACT SERVO SWITCHES
2. ENGINE PNEU SD SOLENOID
3. PROP BLEED VLVS SOLENOID
4. FUEL SYSTEM PURGE SOLENOID

INITIATE SENSOR QUALIFICATION:

1. HPOT TURB DISCHG TEMP
2. HPOT INTERMEDIATE SEAL PURGE PRESS
3. HPOT SECONDARY TURB SEAL CAVITY PRESS
4. HPFT COOLANT LINER PRESSURE
5. HPFT TURB DISCHG TEMPERATURE

COMMAND ALL (FIVE) PROPELLANT VALVES TO CLOSE POSITION

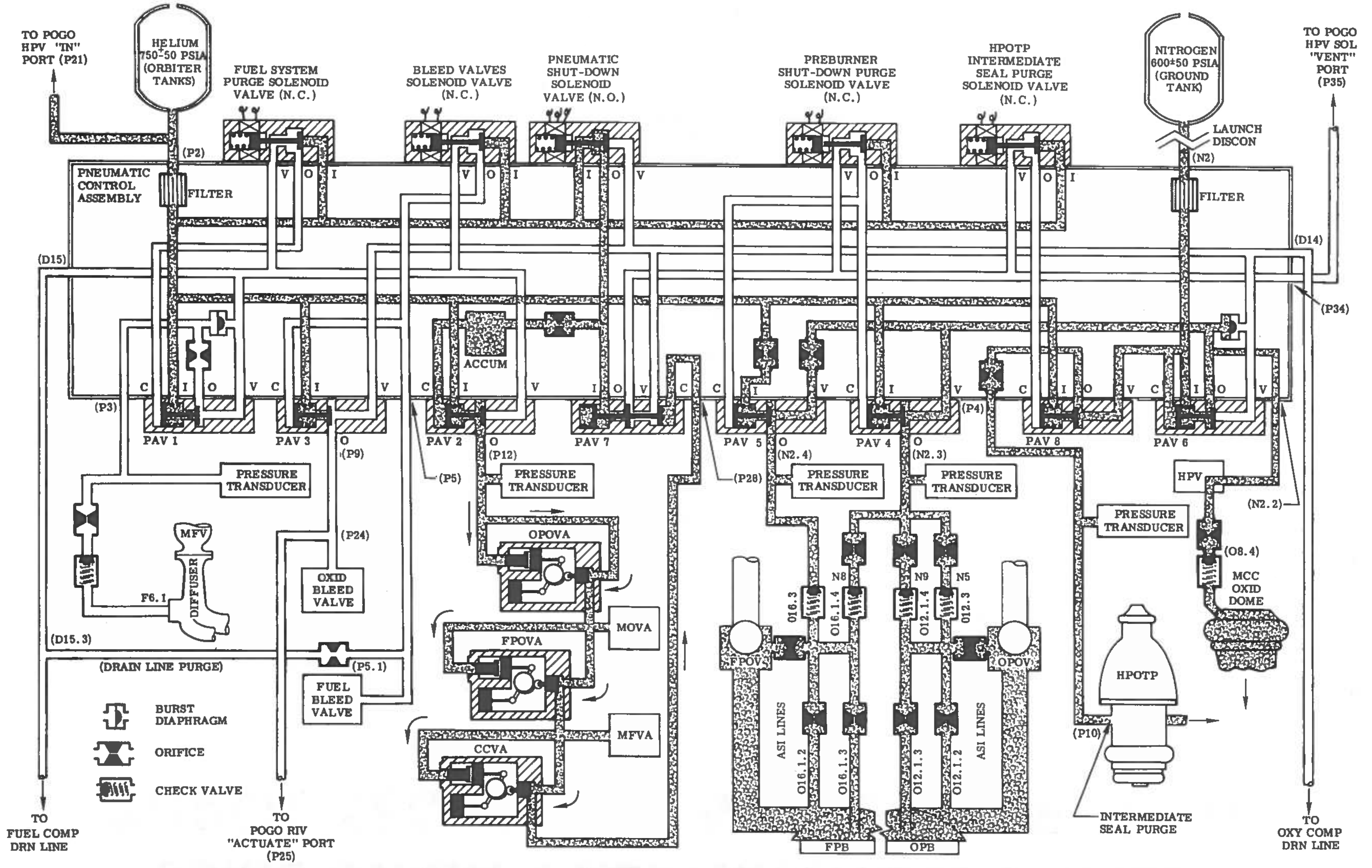
START GN_2 PURGES:

MCC OXIDIZER DOME, HPOT INTERMEDIATE SEAL, PREBURNERS. (GND-SUPPLIED, CONTROLLED, HEATED GN_2

LSS-ES-T-93F

SSME PNEU SCHEMATIC (9/14)

DEPICTS: PURGE SEQUENCE NO. 1 MODE



I = IN O = OUT
V = VENT C = CONTROL

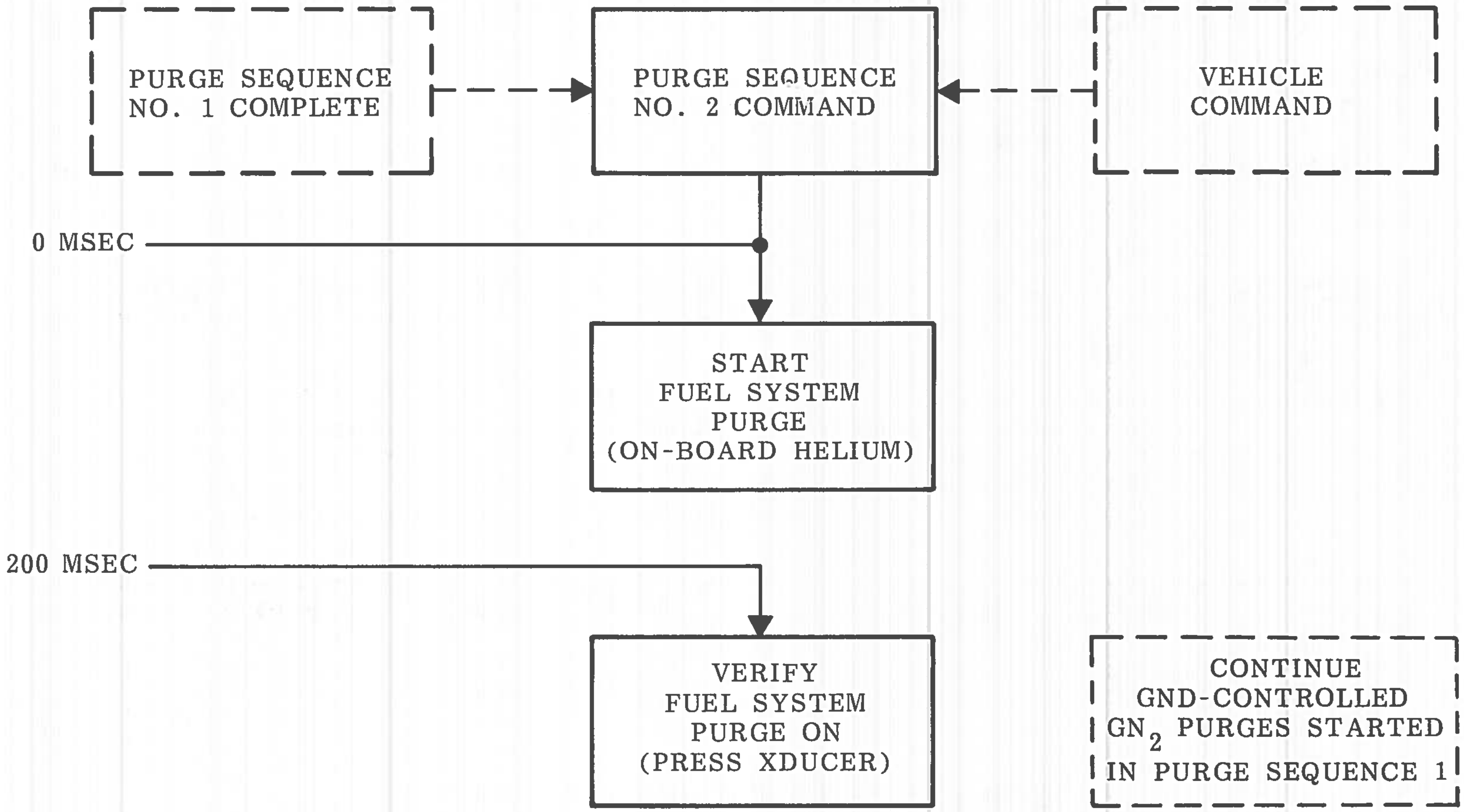
⚡ = ENERGIZED

PAV 1 - FUEL SYS PURGE
PAV 2 - PNEU SHUTDOWN
PAV 3 - OXY BLEED
PAV 4 - OPB PURGE
PAV 5 - FPB PURGE
PAV 6 - OXID SYS PURGE
PAV 7 - PURGE SHUTOFF
PAV 8 - HPOTP I/S PURGE

LSS-ES-T-339D

SSME START PREPARATION PHASE PURGE SEQ. NO. 2 MODE (SIMPLIFIED)

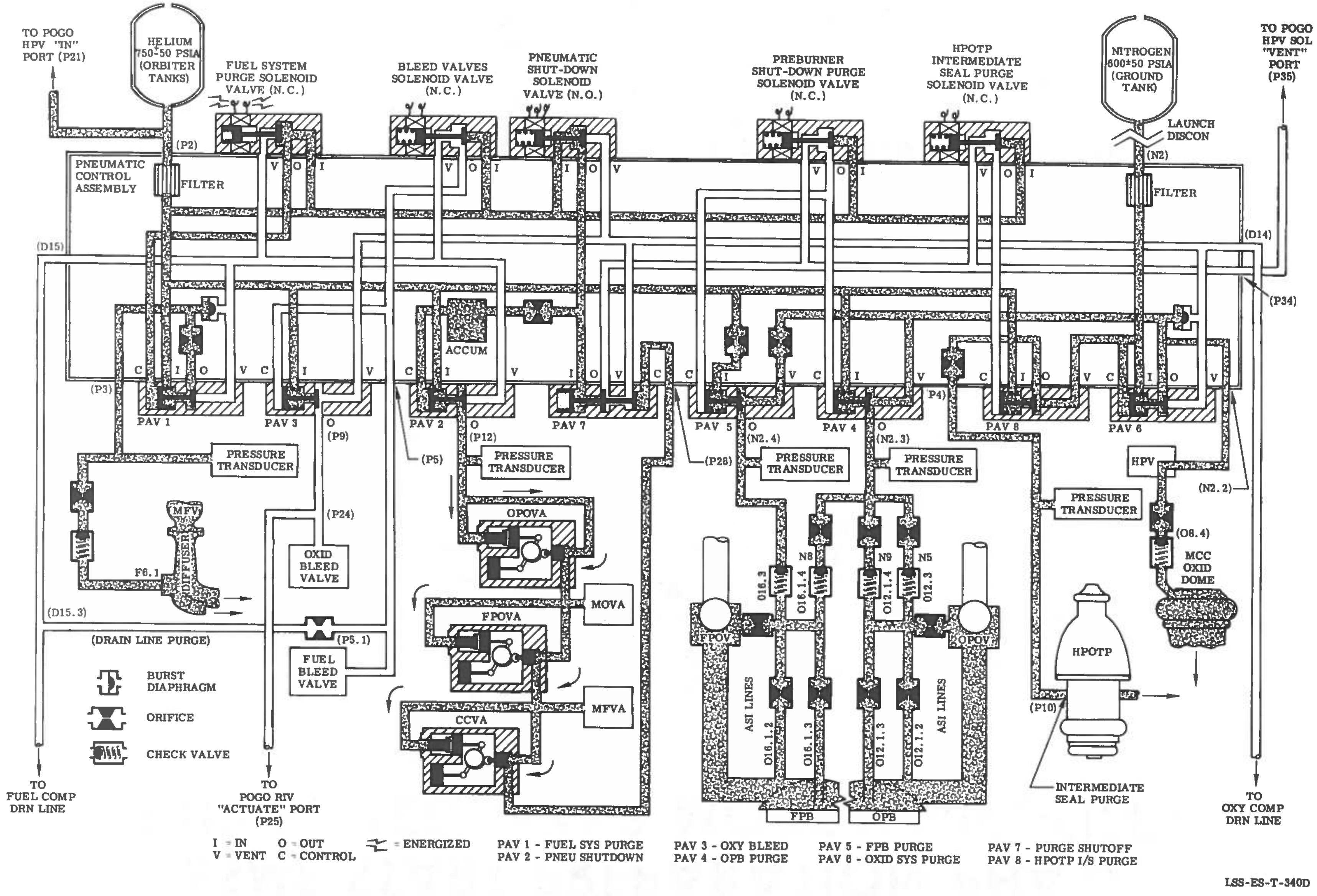
(NOMINAL DURATION: 3 MINUTES)



LSS-ES-T-94E

SSME PNEU SCHEMATIC (10/14)

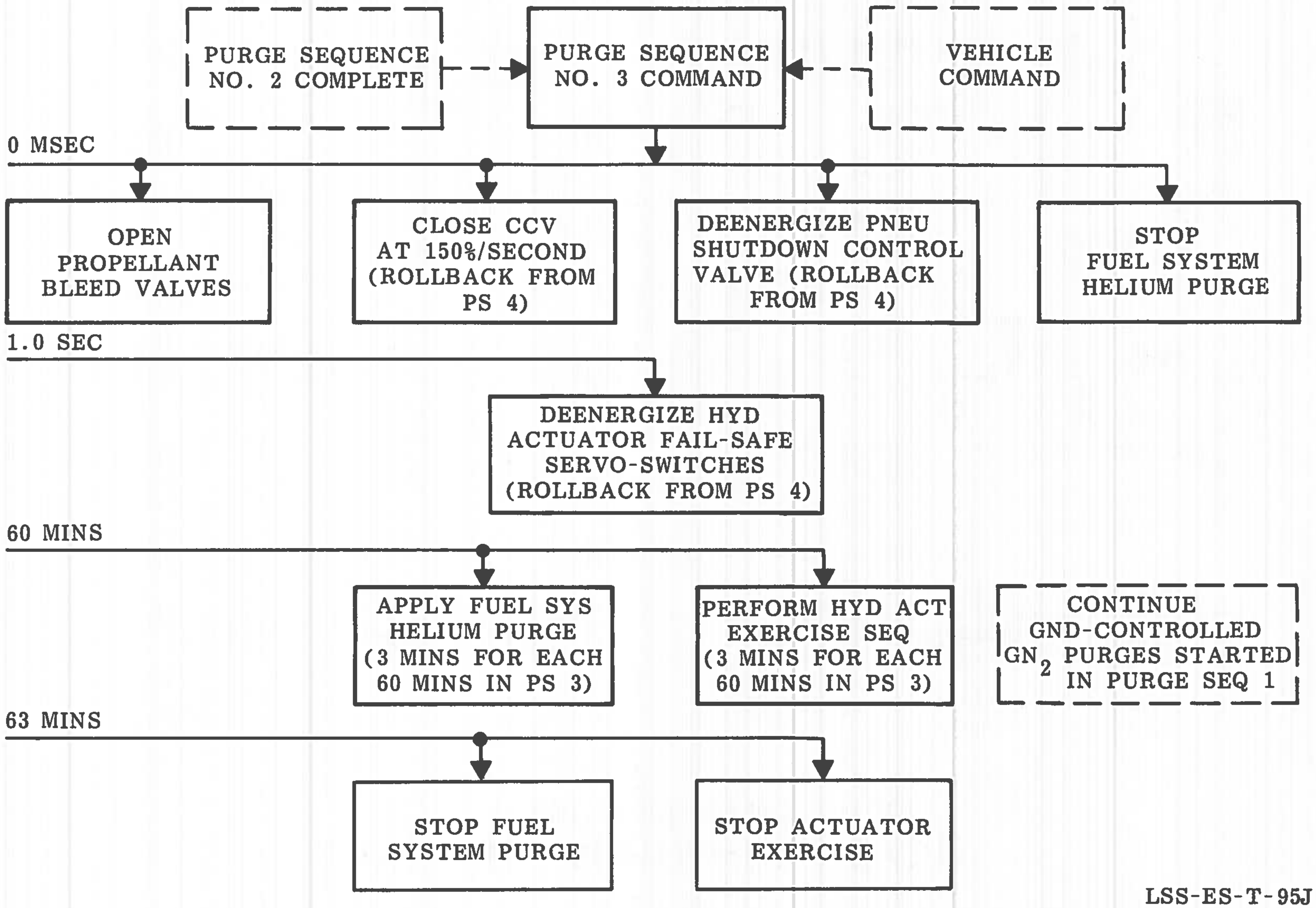
DEPICTS: PURGE SEQUENCE NO. 2 MODE



LSS-ES-T-340D

SSME START PREPARATION PHASE PURGE SEQ. NO.3 MODE (SIMPLIFIED)

(DURATION: VARIES WITH ENGINE COOLDOWN RATE)



PURGE SEQUENCE NO. 2 COMPLETE

PURGE SEQUENCE NO. 3 COMMAND

VEHICLE COMMAND

0 MSEC

OPEN PROPELLANT BLEED VALVES

CLOSE CCV AT 150%/SECOND (ROLLBACK FROM PS 4)

DEENERGIZE PNEU SHUTDOWN CONTROL VALVE (ROLLBACK FROM PS 4)

STOP FUEL SYSTEM HELIUM PURGE

1.0 SEC

DEENERGIZE HYD ACTUATOR FAIL-SAFE SERVO-SWITCHES (ROLLBACK FROM PS 4)

60 MINS

APPLY FUEL SYS HELIUM PURGE (3 MINS FOR EACH 60 MINS IN PS 3)

PERFORM HYD ACT EXERCISE SEQ (3 MINS FOR EACH 60 MINS IN PS 3)

CONTINUE GND-CONTROLLED GN_2 PURGES STARTED IN PURGE SEQ 1

63 MINS

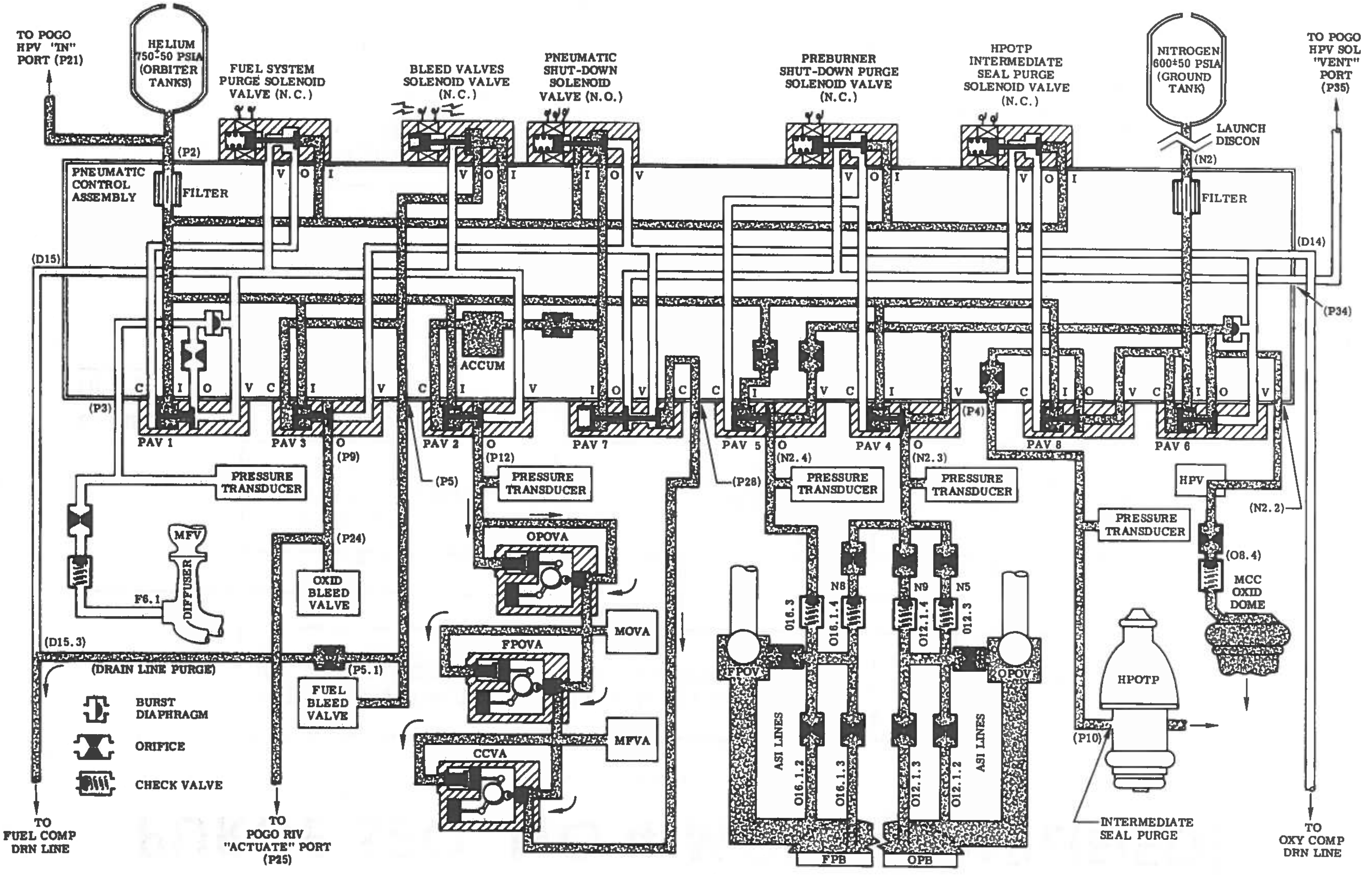
STOP FUEL SYSTEM PURGE

STOP ACTUATOR EXERCISE

LSS-ES-T-95J

SSME PNEU SCHEMATIC (11/14)

DEPICTS: PURGE SEQUENCE NO. 3 MODE



I IN O OUT
V VENT C CONTROL

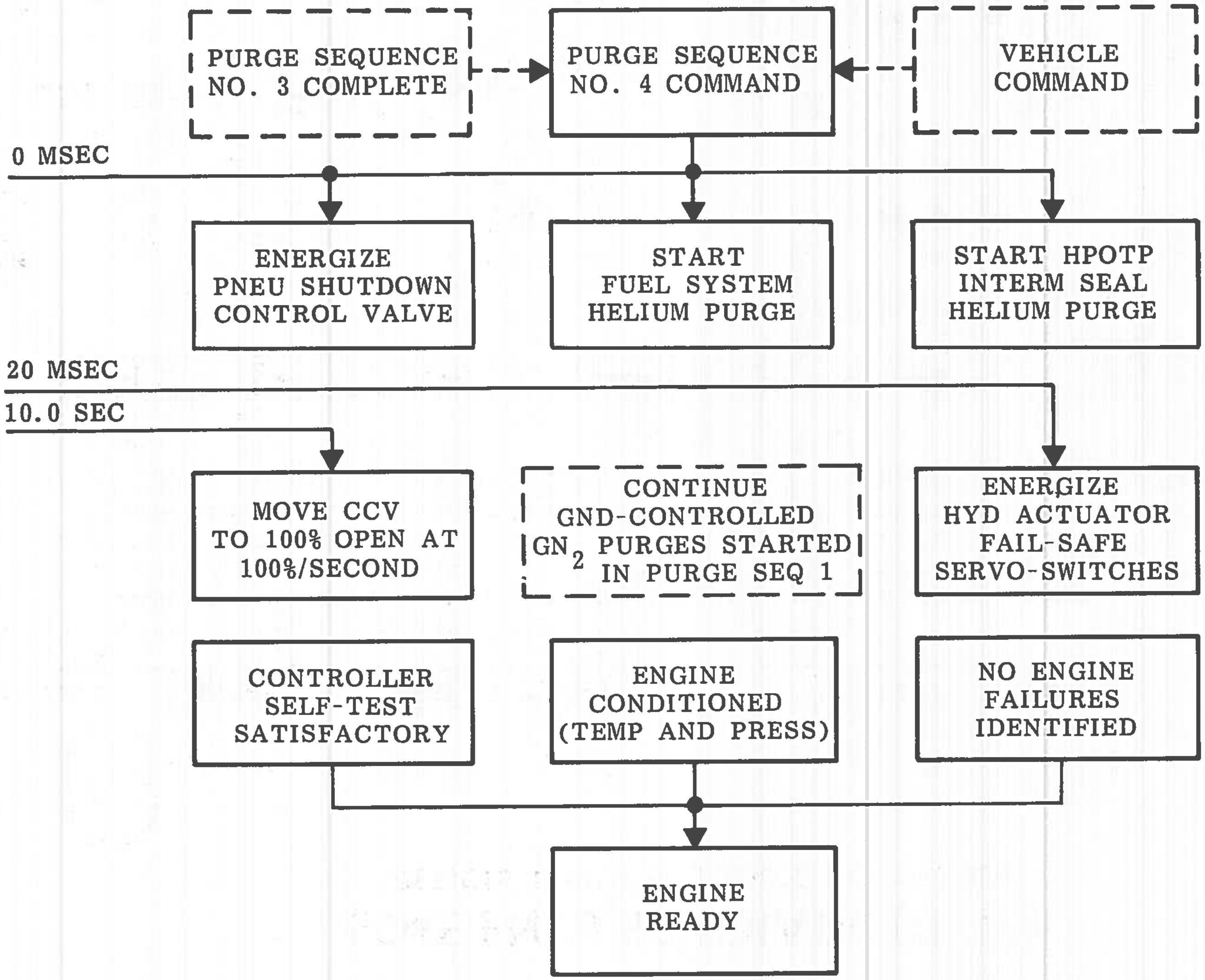
ENERGIZED

PAV 1 - FUEL SYS PURGE
PAV 2 - PNEU SHUTDOWN
PAV 3 - OXY BLEED
PAV 4 - OPB PURGE
PAV 5 - FPB PURGE
PAV 6 - OXID SYS PURGE
PAV 7 - PURGE SHUTOFF
PAV 8 - HPOTP I/S PURGE

LSS-ES-T-341E

SSME START PREPARATION PHASE PURGE SEQ. NO.4 MODE (SIMPLIFIED)

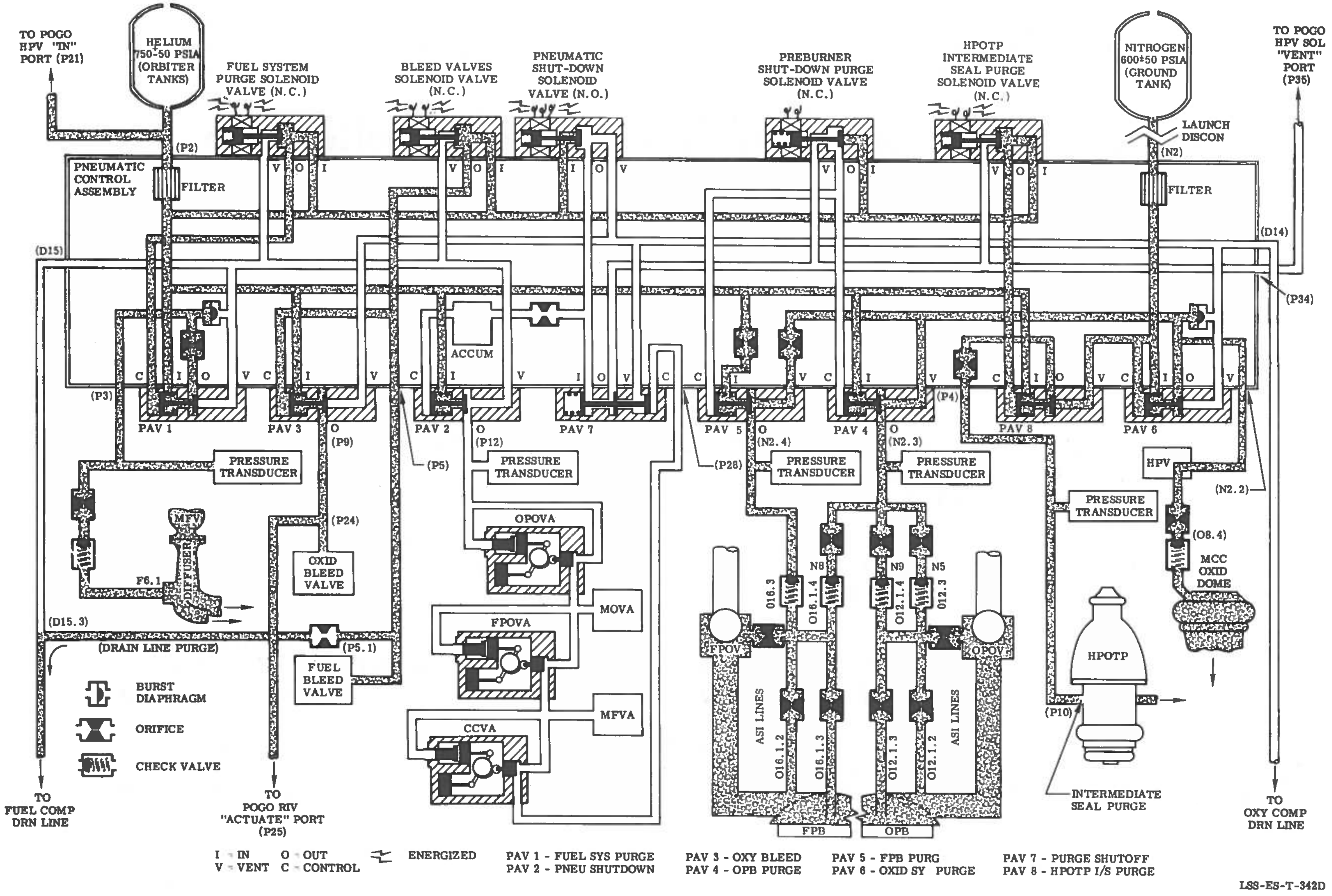
(NOMINAL DURATION: 3 MINUTES)



LSS-ES-T-96F

SSME PNEU SCHEMATIC (12/14)

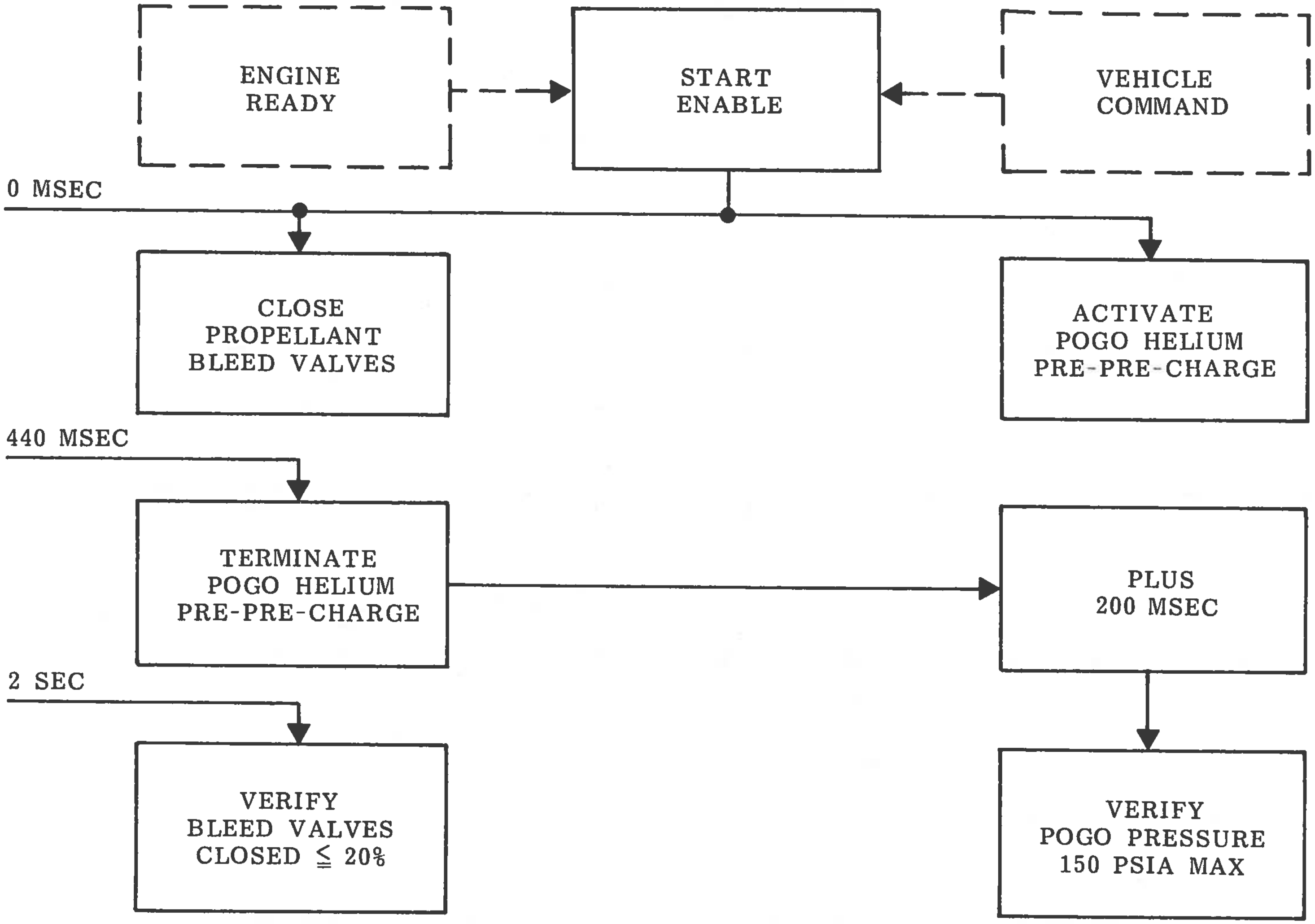
DEPICTS: PURGE SEQUENCE NO. 4 MODE



SSME START PHASE MODE DEFINITIONS

- START ENABLE PHASE: INTERIM PERIOD BETWEEN ENGINE READY AND START WITHIN WHICH, IF ALL CONDITIONS FOR ENGINE READY EXIST, THE BLEED VALVES WILL BE CLOSED AND VERIFIED AND THE POGO ACCUMULATOR WILL BE PRE-PRECHARGED AND VERIFIED.
- START PHASE: OPERATIONS FOR PROPELLANT IGNITION AND THRUST BUILDUP ARE IN PROGRESS, BEGINNING WITH SCHEDULED (OPEN-LOOP) OPERATION OF ALL FIVE PROPELLANT VALVES.
    - START INITIATION MODE: INITIAL FUNCTIONS PRIOR TO IGNITION CONFIRMED ARE IN PROGRESS. ALL PURGES OFF AND VERIFIED. IGNITERS ENERGIZED AND VERIFIED. THRUST CONTROL LOOP IS CLOSED.
    - THRUST BUILDUP MODE: IGNITION HAS BEEN DETECTED BY MONITORING VARIOUS EVENTS AND PARAMETERS AND CLOSED-LOOP THRUST BUILDUP IS IN PROGRESS. MIXTURE RATIO CONTROL LOOP IS CLOSED. POGO SUPPRESSION ACCUMULATOR IS HELIUM PRECHARGED FOR 2 SECONDS.
- START PHASE ANOMALY MODES:
    - ELECTRICAL LOCKUP MODE: ENGINE PROPELLANT VALVES ARE ELECTRICALLY HELD IN A FIXED CONFIGURATION AS EXISTED AT INITIATION OF THIS MODE. ENGINE LIMITS AND ACTUATORS ARE BEING MONITORED. ALL CONTROL LOOP COMPUTATIONS ARE SUSPENDED. MODE EXIT WILL BE TO HYDRAULIC LOCKUP MODE OR NORMAL SHUTDOWN.
    - FIXED DENSITY MODE: ENTERED DURING START AS A RESULT OF FAILURE OR DISQUALIFICATION OF BOTH CHANNELS OF LPFP DISCHARGE PRESSURE OR TEMPERATURE. COMPUTATIONS OF PROPELLANT DENSITY VALUES MUST BE SUSPENDED.
    - HYDRAULIC LOCKUP MODE: ALL FAIL-SAFE SERVOSWITCHES ARE DEENERGIZED TO HYDRAULICALLY HOLD PROPELLANT VALVES IN A FIXED CONFIGURATION AS EXISTED AT INITIATION OF THIS MODE. ENGINE LIMITS AND ACTUATORS ARE BEING MONITORED. ALL CONTROL LOOP COMPUTATIONS ARE SUSPENDED. MODE EXIT WILL BE TO PNEUMATIC SHUTDOWN.

SSME START ENABLE PHASE



ENGINE
READY

START
ENABLE

VEHICLE
COMMAND

0 MSEC

CLOSE
PROPELLANT
BLEED VALVES

ACTIVATE
POGO HELIUM
PRE-PRE-CHARGE

440 MSEC

TERMINATE
POGO HELIUM
PRE-PRE-CHARGE

PLUS
200 MSEC

2 SEC

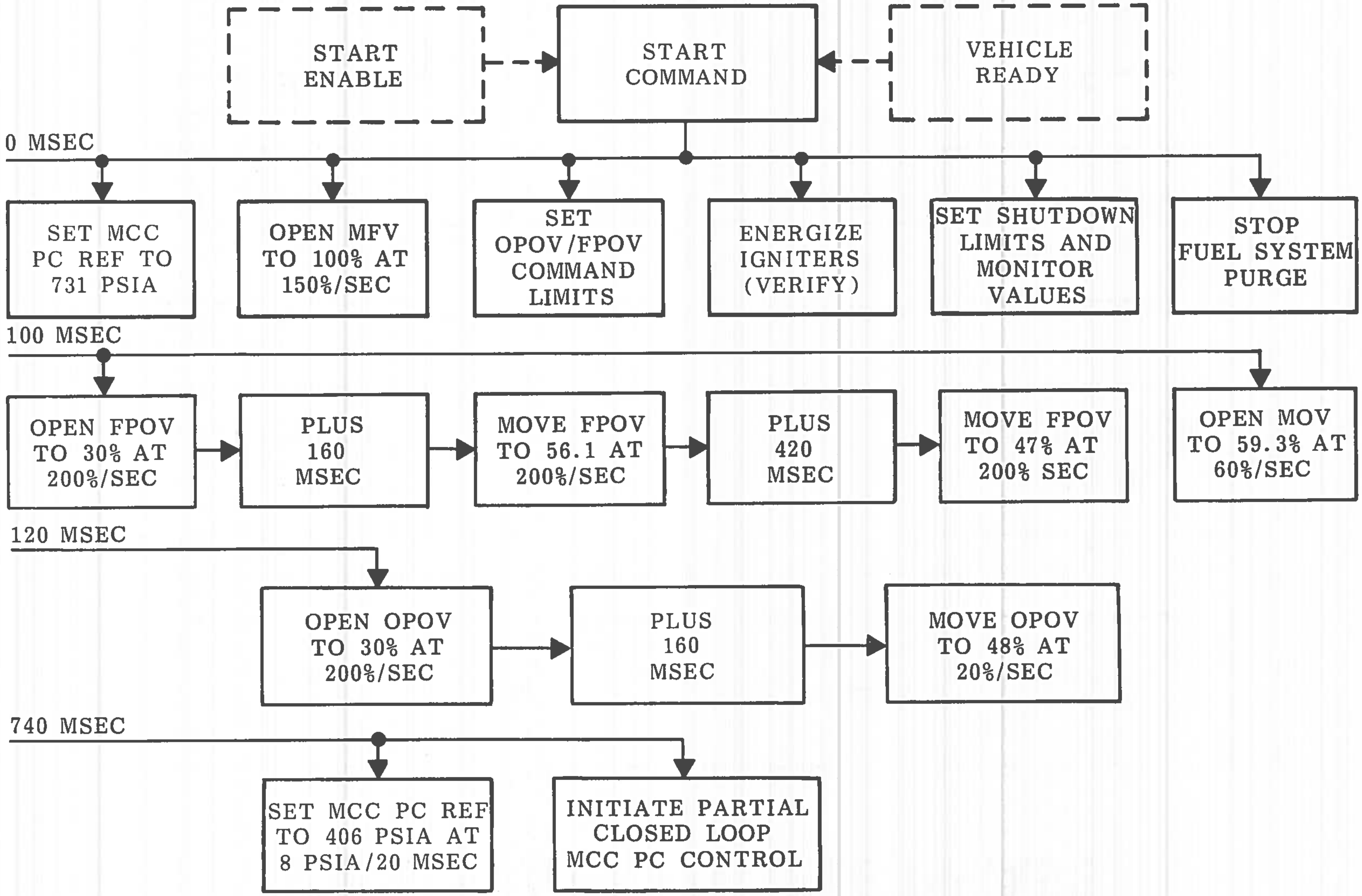
VERIFY
BLEED VALVES
CLOSED ≦ 20%

VERIFY
POGO PRESSURE
150 PSIA MAX

LSS-ES-T-98

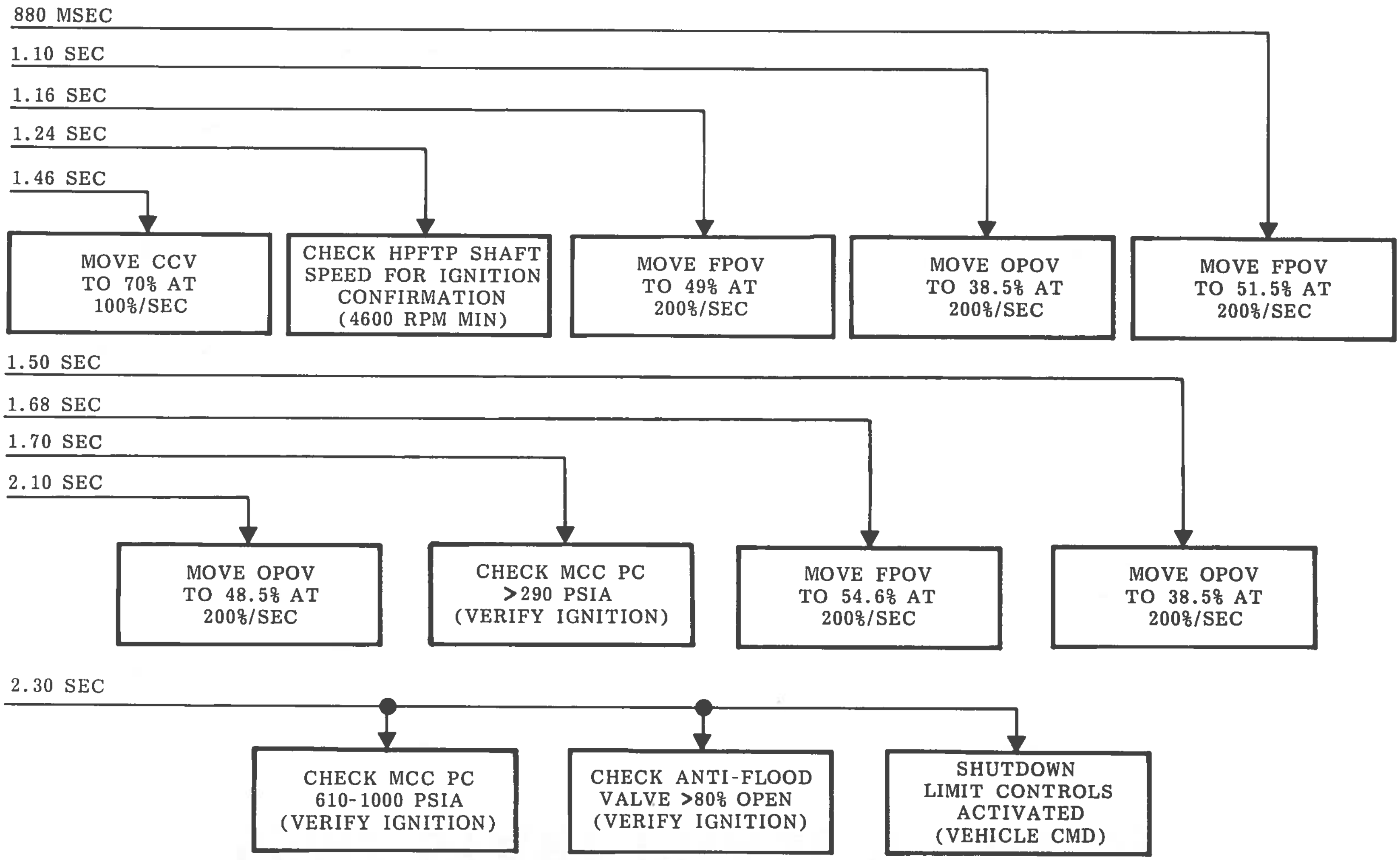
SSME START PHASE (PAGE 1)

START INITIATION MODE (NOMINAL DURATION: 2.4 SEC)



SSME START PHASE (PAGE 2)

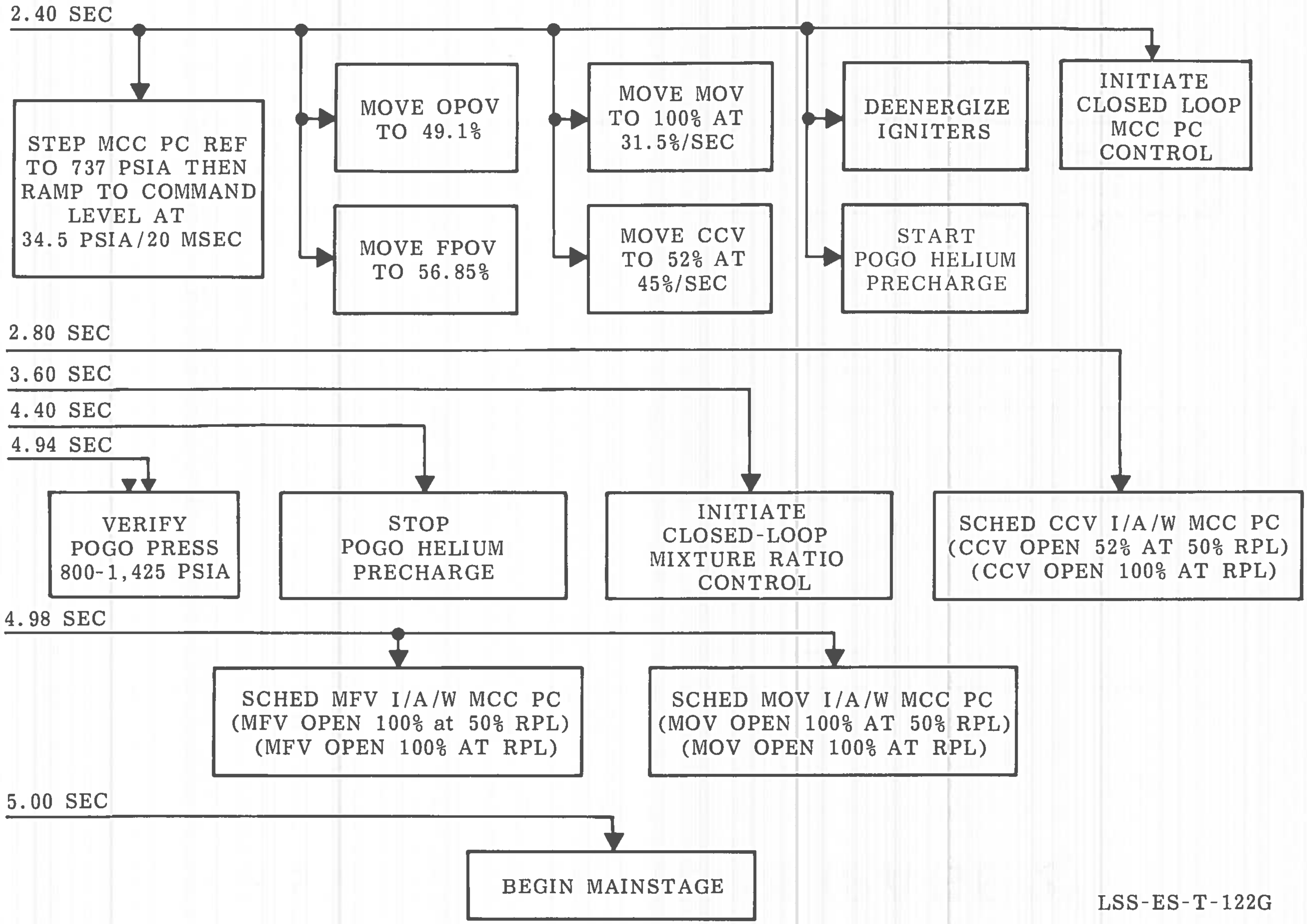
START INITIATION MODE (CONTINUED) NOMINAL DURATION: 2.4 SEC



LSS-ES-T-121F

SSME START PHASE (PAGE 3)

THRUST BUILDUP MODE (NOMINAL DURATION: 2.6 SECONDS)



2.40 SEC

STEP MCC PC REF TO 737 PSIA THEN RAMP TO COMMAND LEVEL AT 34.5 PSIA/20 MSEC

MOVE OPOV TO 49.1%

MOVE FPOV TO 56.85%

MOVE MOV TO 100% AT 31.5%/SEC

MOVE CCV TO 52% AT 45%/SEC

DEENERGIZE IGNITERS

START POGO HELIUM PRECHARGE

INITIATE CLOSED LOOP MCC PC CONTROL

2.80 SEC

SCHED CCV I/A/W MCC PC (CCV OPEN 52% AT 50% RPL) (CCV OPEN 100% AT RPL)

3.60 SEC

INITIATE CLOSED-LOOP MIXTURE RATIO CONTROL

4.40 SEC

STOP POGO HELIUM PRECHARGE

4.94 SEC

VERIFY POGO PRESS 800-1,425 PSIA

4.98 SEC

SCHED MFV I/A/W MCC PC (MFV OPEN 100% at 50% RPL) (MFV OPEN 100% AT RPL)

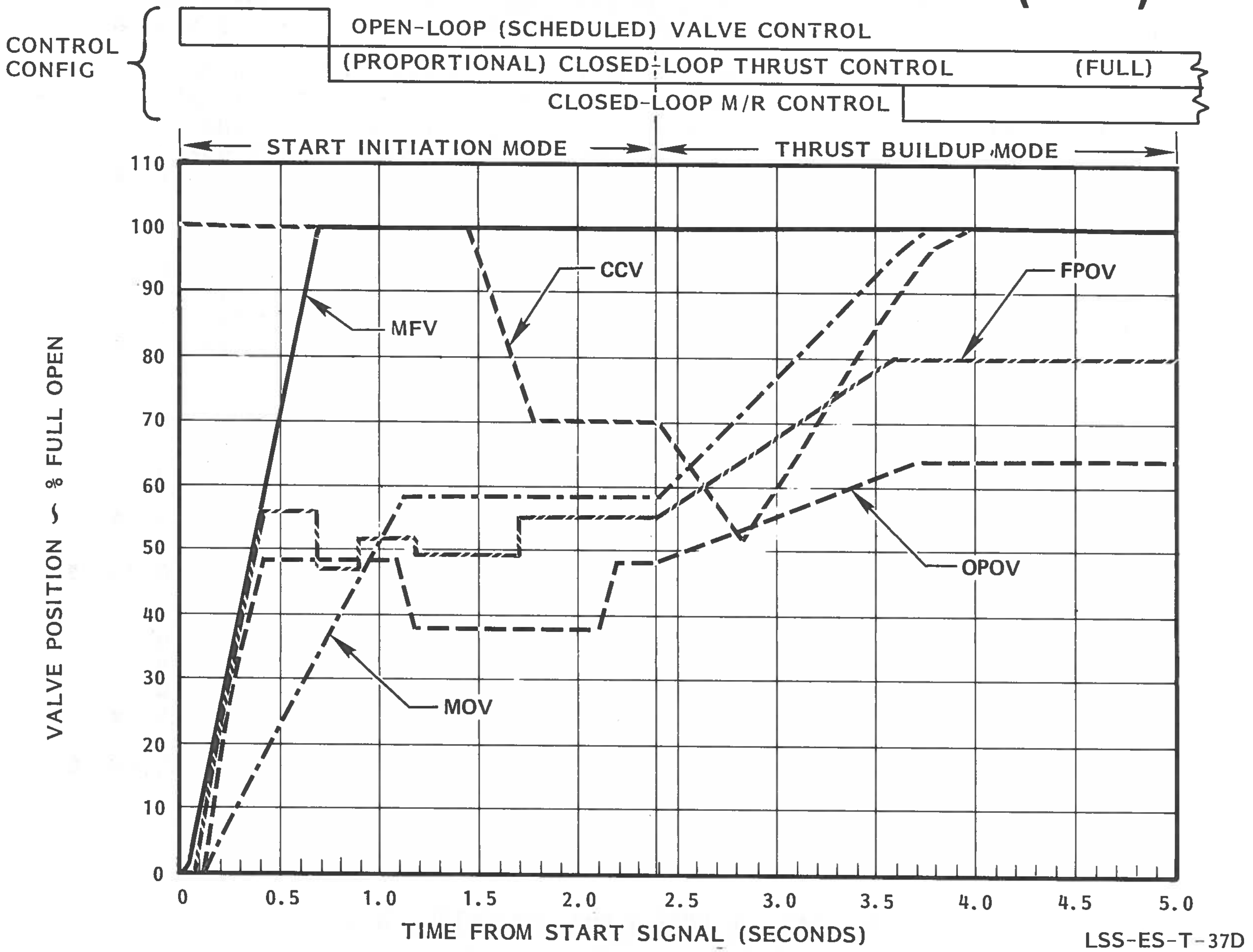
SCHED MOV I/A/W MCC PC (MOV OPEN 100% AT 50% RPL) (MOV OPEN 100% AT RPL)

5.00 SEC

BEGIN MAINSTAGE

LSS-ES-T-122G

ENGINE START VALVE SEQUENCE (TYP)



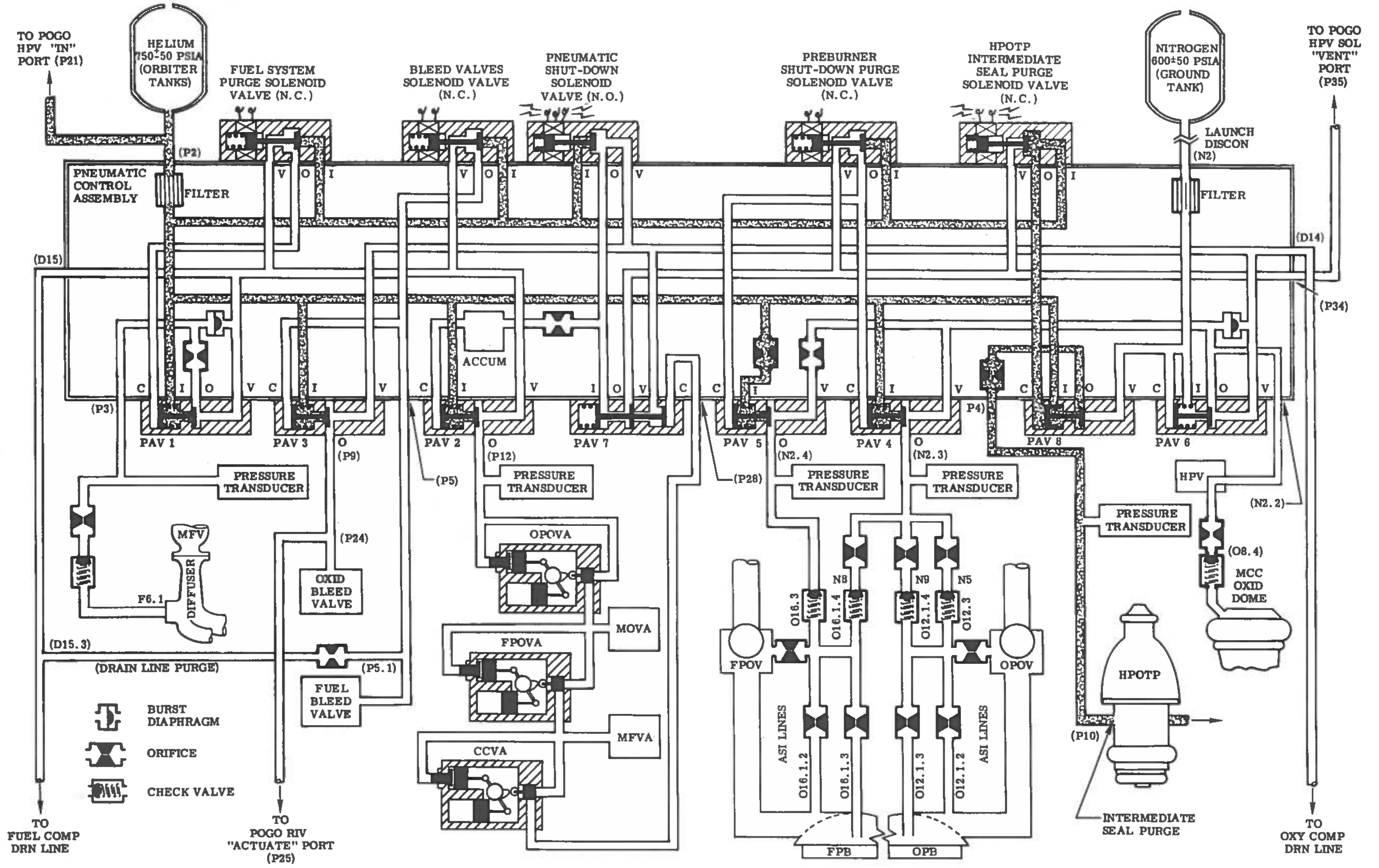
LSS-ES-T-37D

SSME MAINSTAGE PHASE MODE DEFINITIONS

- MAINSTAGE PHASE: AUTOMATICALLY ENTERED ON COMPLETION OF START PHASE.
  - NORMAL CONTROL MODE: THRUST (CHAMBER PRESSURE) AND PROPELLANT MIXTURE RATIO CONTROL FUNCTIONING NORMALLY VIA THE OPOV AND FPOV, RESPECTIVELY. MFV, MOV, AND CCV POSITIONS SCHEDULED IN ACCORDANCE WITH REAL TIME THRUST LEVEL.
- MAINSTAGE ANOMALY MODES:
  - ELECTRICAL LOCKUP MODE: ENGINE PROPELLANT VALVES ARE ELECTRICALLY HELD IN A FIXED CONFIGURATION AS EXISTED AT INITIATION OF THIS MODE. ENGINE LIMITS AND ACTUATORS ARE BEING MONITORED. ALL CONTROL LOOP COMPUTATIONS ARE SUSPENDED. MODE EXIT WILL BE TO HYDRAULIC LOCKUP MODE OR NORMAL SHUTDOWN.
  - HYDRAULIC LOCKUP MODE: ALL FAIL-SAFE SERVOSWITCHES ARE DEENERGIZED TO HYDRAULICALLY HOLD PROPELLANT VALVES IN A FIXED CONFIGURATION AS EXISTED AT INITIATION OF THIS MODE. ENGINE LIMITS AND ACTUATORS ARE BEING MONITORED. ALL CONTROL LOOP COMPUTATIONS ARE SUSPENDED. MODE EXIT WILL BE TO PNEUMATIC SHUTDOWN.
  - THRUST LIMITING MODE: INITIATED DURING MAINSTAGE NORMAL CONTROL OR FIXED DENSITY MODE WHENEVER THE OPOV POSITION COMMAND IS LIMITED FOR 3 CONSECUTIVE MAJOR CYCLES. ENGINE CONTROL WILL CHANGE FROM THRUST LIMITING MODE BACK TO NORMAL CONTROL OR FIXED DENSITY MODE WHEN THE OPOV POSITION COMMAND IS NOT LIMITED FOR 3 CONSECUTIVE MAJOR CYCLES.
  - FIXED DENSITY MODE: ENTERED DURING MAINSTAGE AS A RESULT OF FAILURE OR DISQUALIFICATION OF BOTH CHANNELS OF LPFP DISCHARGE PRESSURE OR TEMPERATURE. COMPUTATIONS OF PROPELLANT DENSITY VALUES MUST BE SUSPENDED.

SSME PNEU SCHEMATIC (13/14)

DEPICTS: ENGINE RUN PURGE MODE



I = IN O = OUT
V = VENT C = CONTROL
⚡ = ENERGIZED

PAV 1 - FUEL SYS PURGE
PAV 2 - PNEU SHUTDOWN
PAV 3 - OXY BLEED
PAV 4 - OPB PURGE
PAV 5 - FPB PURGE
PAV 6 - OXID SYS PURGE
PAV 7 - PURGE SHUTOFF
PAV 8 - HPOTP I/S PURGE

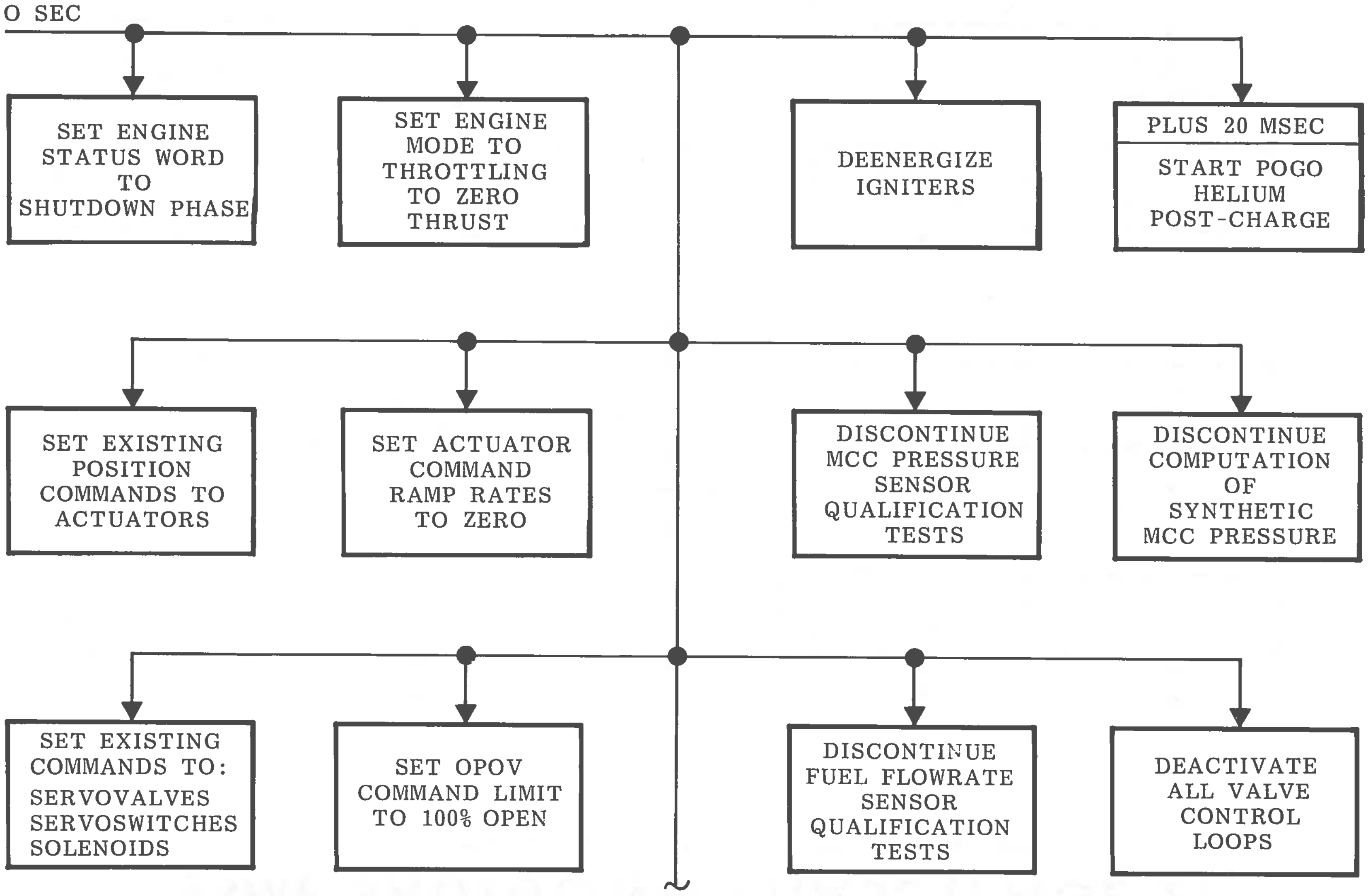
LSS-ES-T-343C

SSME SHUTDOWN PHASE MODE DEFINITIONS

- SHUTDOWN PHASE: OPERATIONS TO REDUCE ENGINE MCC PRESSURE AND DRIVE ALL VALVES TO EFFECT ENGINE SHUTDOWN.
  - THROTTLING TO ZERO THRUST MODE: SHUTDOWN IS IN PROGRESS AT A PROGRAMMED SHUTDOWN THRUST REFERENCE LEVEL. POGO POSTCHARGE AND SHUTDOWN PURGE ARE ACTIVATED.
  - PROPELLANT VALVES CLOSED MODE: THE SHUTDOWN SEQUENCE IS IN STAGE FOLLOWING CLOSURE OF ALL LIQUID PROPELLANT VALVES.
- SHUTDOWN ANOMALY MODE
  - PNEUMATIC SHUTDOWN MODE: ENGINE IS BEING SHUT DOWN PNEUMATICALLY DUE TO THE EXISTENCE OF HYDRAULIC LOCKUP OR VARIOUS OTHER SERIOUS ENGINE FAILURES.

SSME SHUTDOWN PHASE (PAGE 1)

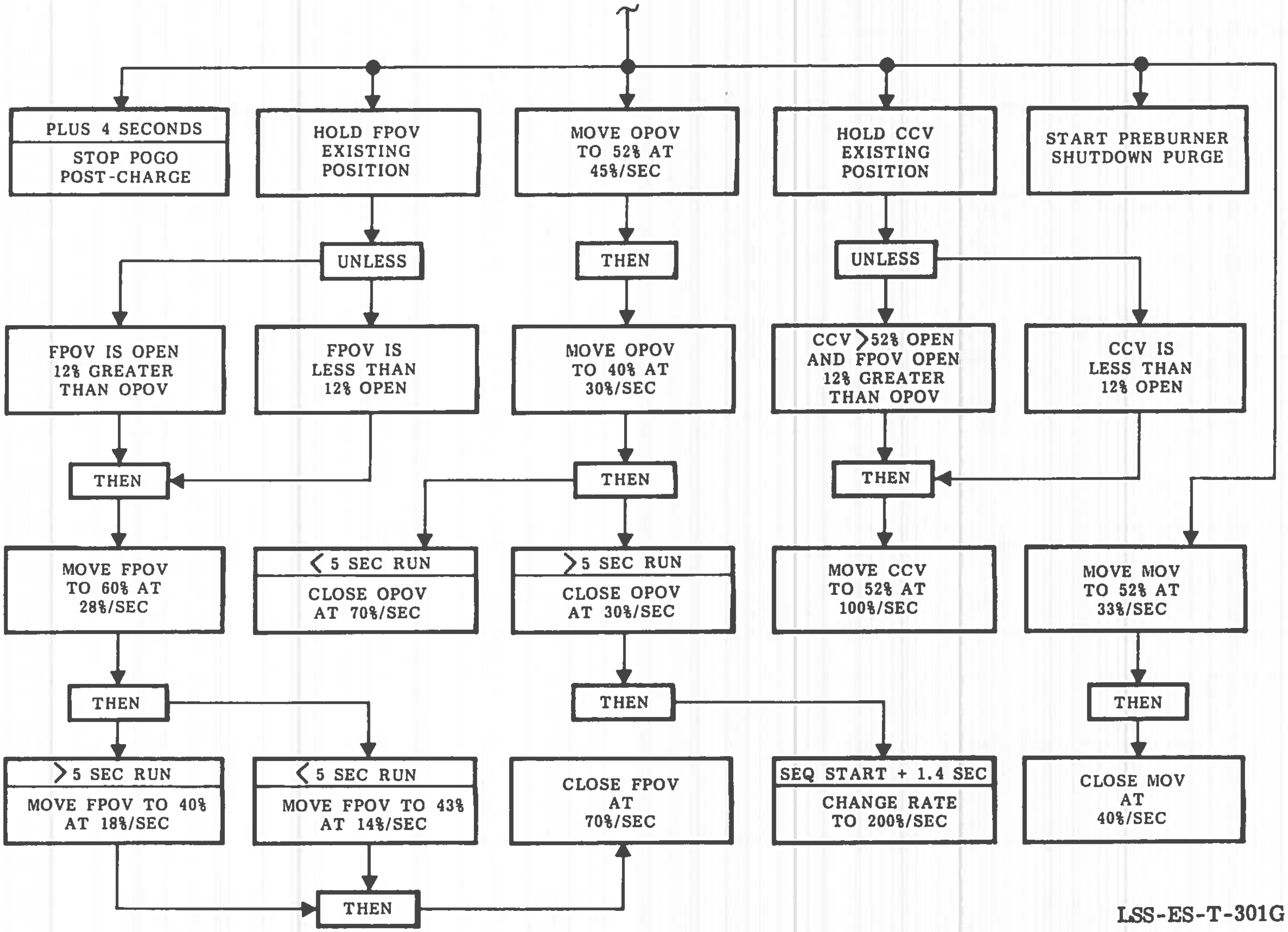
PART A: THROTTLING TO ZERO THRUST MODE



LSS-ES-T-300F

SSME SHUTDOWN PHASE (PAGE 2)

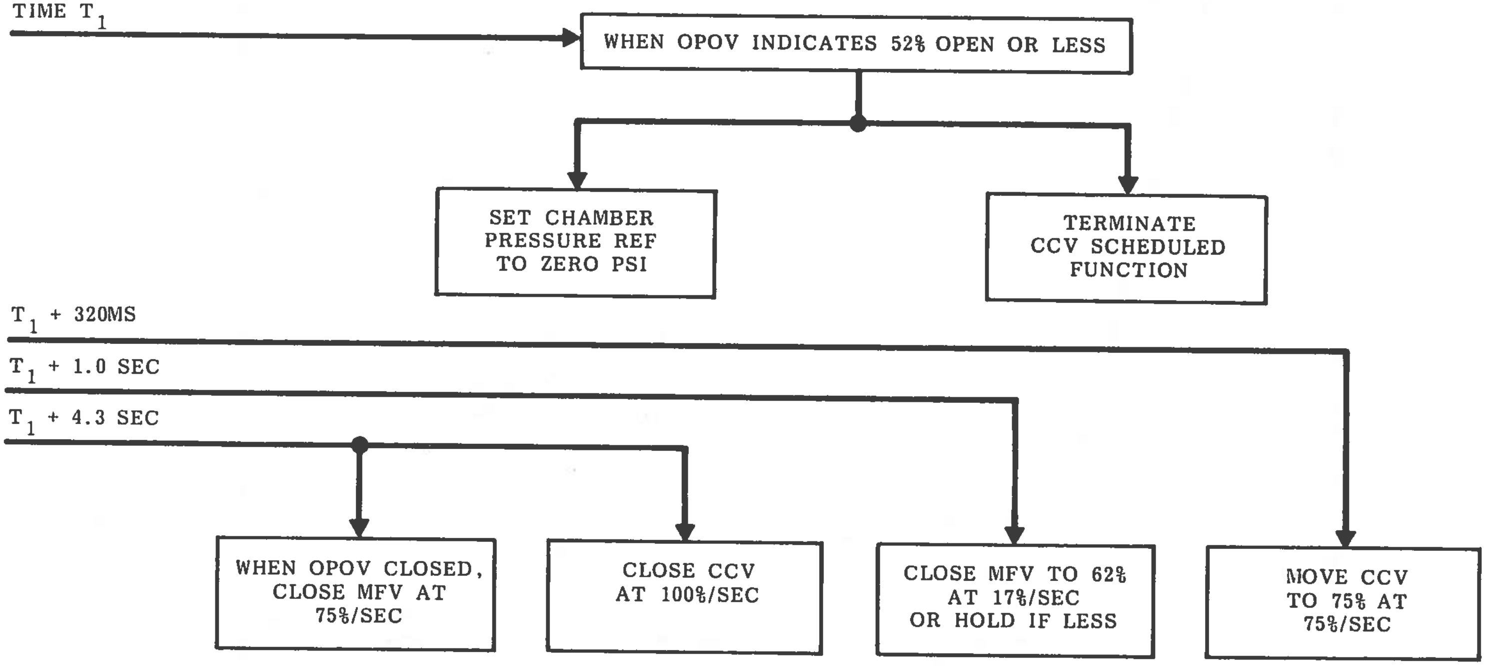
PART A: THROTTLING TO ZERO THRUST (SCHEDULED FUNCTIONS)



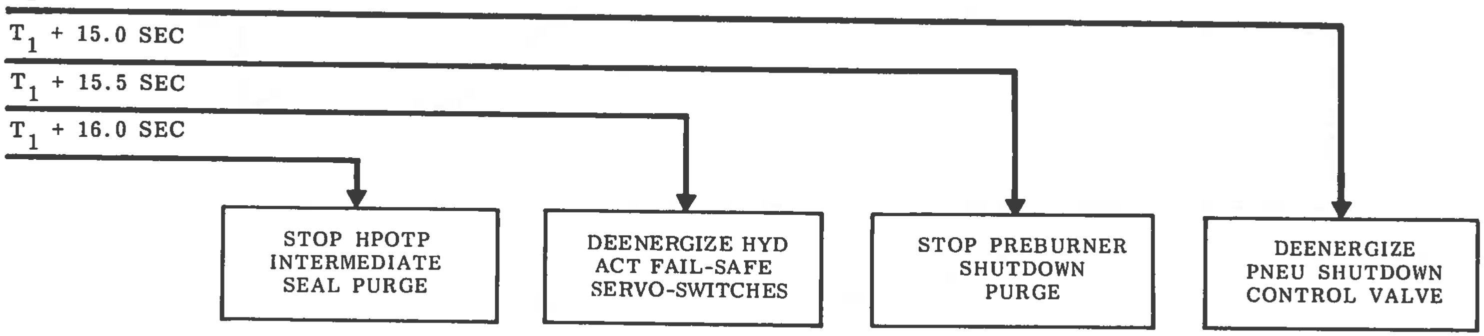
LSS-ES-T-301G

SSME SHUTDOWN PHASE (PAGE 3)

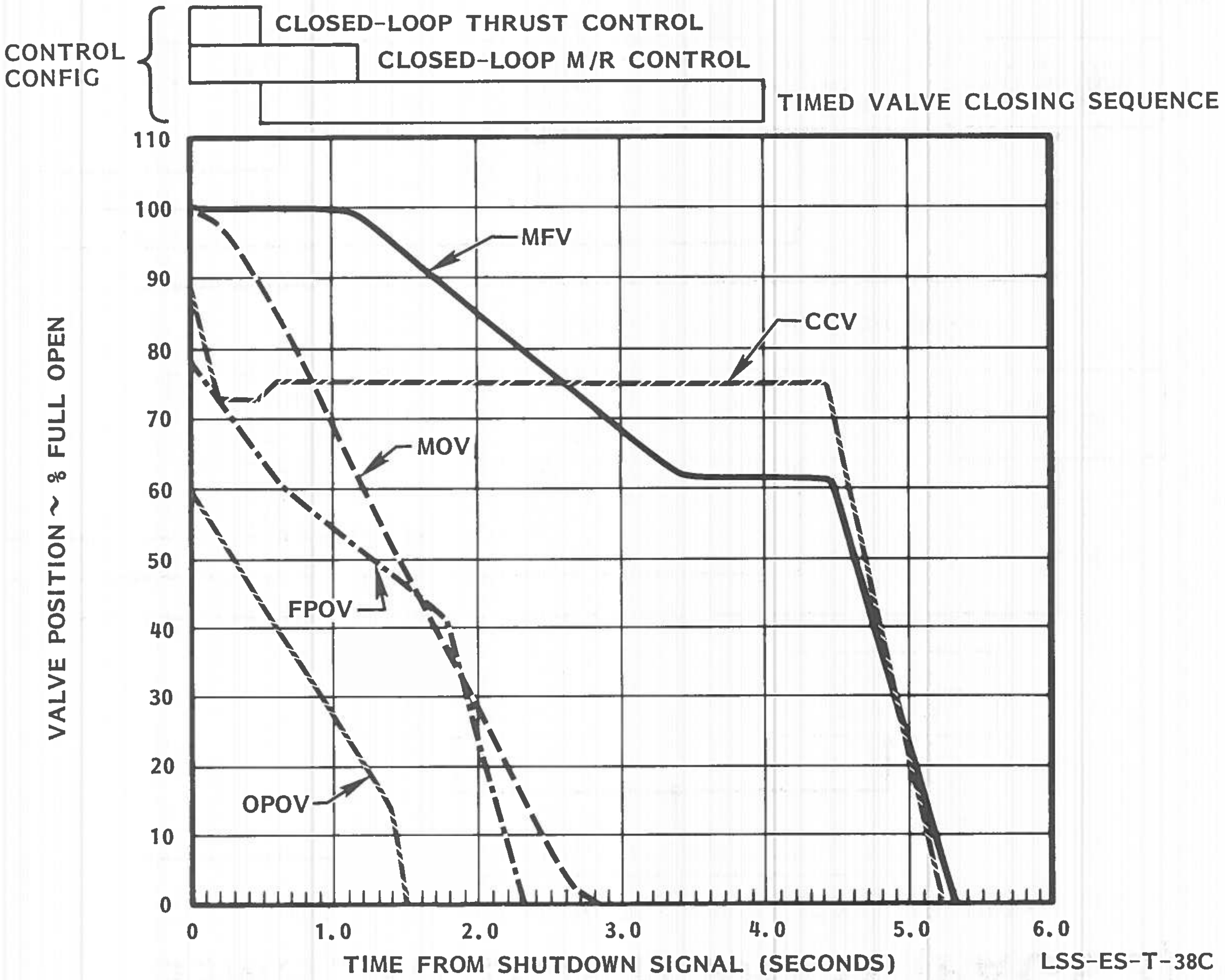
PART A: THROTTLING TO ZERO THRUST (TIMED FUNCTIONS)



PART B: POST PROP VALVES CLOSED FUNCTIONS



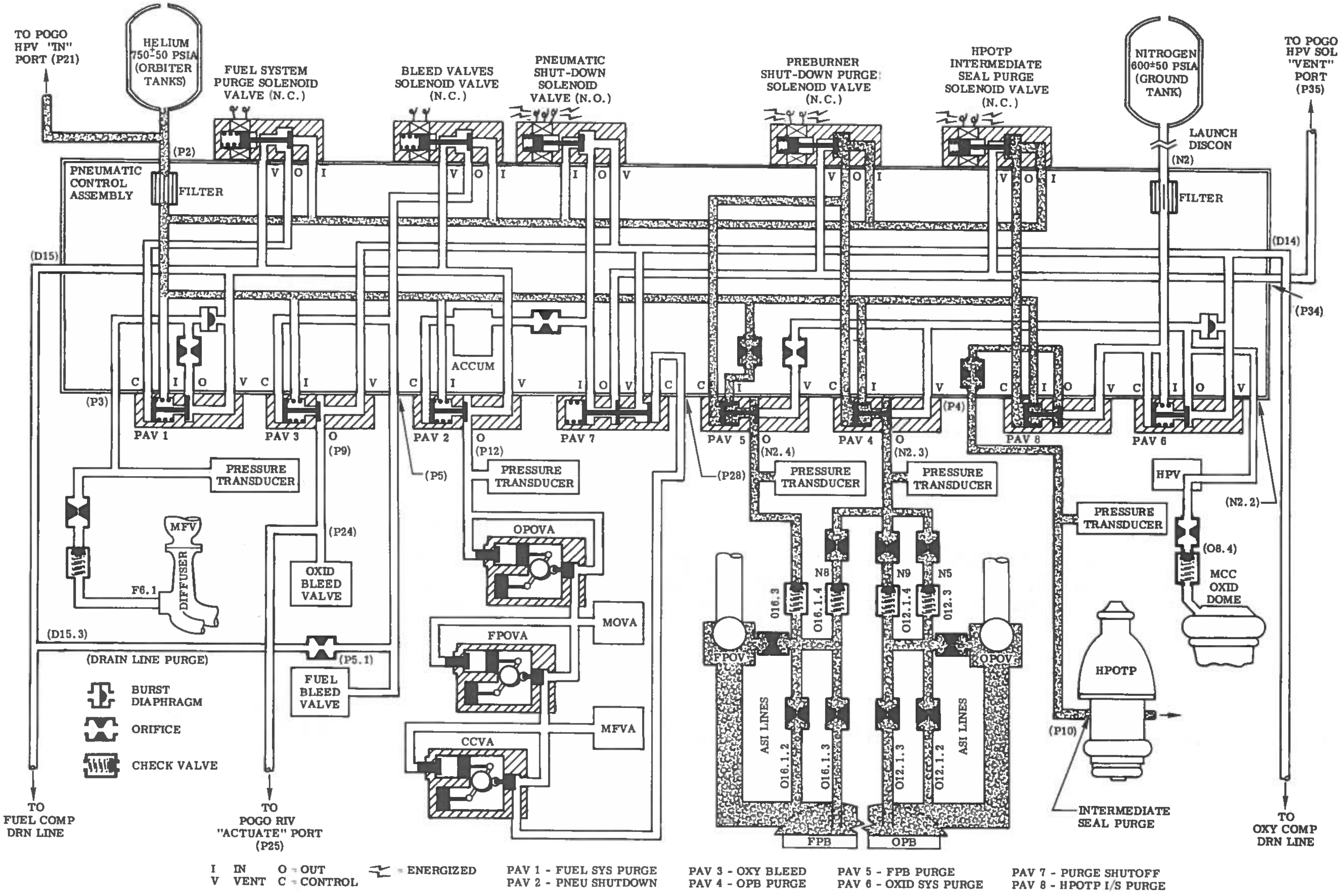
ENGINE SHUTDOWN VALVE SEQUENCE (TYP)



LSS-ES-T-38C

SSME PNEU SCHEMATIC (14/14)

DEPICTS: ENGINE SHUTDOWN PURGE MODE



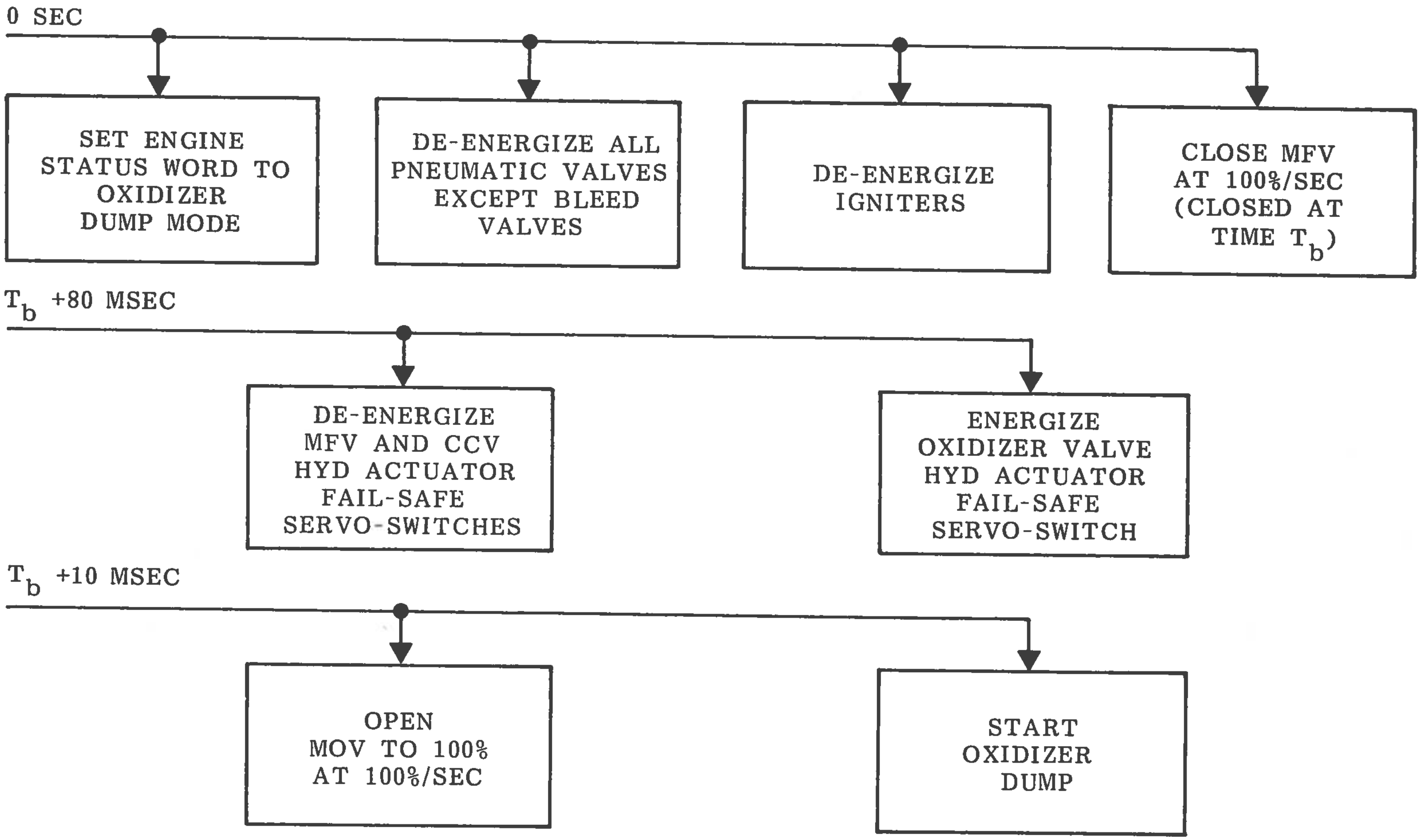
LSS-ES-T-336F

SSME POST-SHUTDOWN PHASE MODE DEFINITIONS

- POST-SHUTDOWN PHASE: STATE TO WHICH SSME AND MAIN ENGINE CONTROLLER (MEC) GO AT COMPLETION OF ENGINE FIRING.
  - STANDBY MODE: A WAITING MODE OF CONTROLLER OPERATIONS WITH FUNCTIONS IDENTICAL TO THOSE OF STANDBY DURING CHECKOUT. THIS IS NORMAL MODE OF POST-SHUTDOWN ENTERED AFTER COMPLETION OF SHUTDOWN PHASE OR INITIATION OF CONTROLLER OPERATION.
  - OXIDIZER DUMP MODE: OXIDIZER DUMP SEQUENCE BEING PERFORMED.
  - TERMINATE SEQUENCE MODE: TERMINATION OF A PURGE OR DUMP SEQUENCE BY A COMMAND FROM VEHICLE IS IN PROGRESS. ALL PROPELLANT VALVES ARE BEING CLOSED, AND ALL SOLENOID AND FAIL-SAFE SERVOSWITCHES ARE BEING DEENERGIZED.

SSME POST-SHUTDOWN PHASE

OXIDIZER DUMP MODE



0 SEC

SET ENGINE STATUS WORD TO OXIDIZER DUMP MODE

DE-ENERGIZE ALL PNEUMATIC VALVES EXCEPT BLEED VALVES

DE-ENERGIZE IGNITERS

CLOSE MFV AT 100%/SEC (CLOSED AT TIME T_b)

T_b +80 MSEC

DE-ENERGIZE MFV AND CCV HYD ACTUATOR FAIL-SAFE SERVO-SWITCHES

ENERGIZE OXIDIZER VALVE HYD ACTUATOR FAIL-SAFE SERVO-SWITCH

T_b +10 MSEC

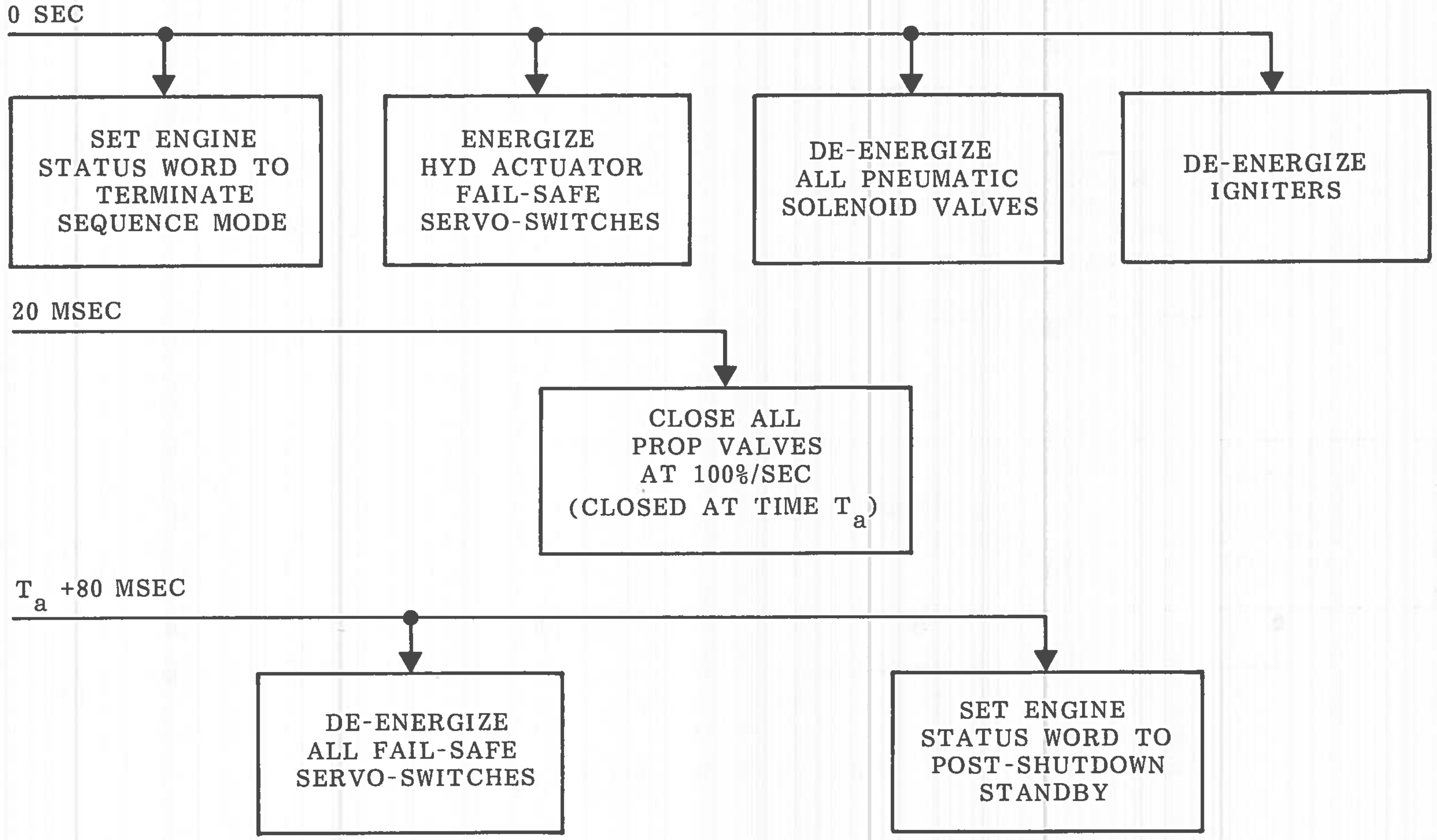
OPEN MOV TO 100% AT 100%/SEC

START OXIDIZER DUMP

LSS-ES-T-99

SSME POST-SHUTDOWN PHASE

TERMINATE SEQUENCE MODE



0 SEC

SET ENGINE STATUS WORD TO TERMINATE SEQUENCE MODE

ENERGIZE HYD ACTUATOR FAIL-SAFE SERVO-SWITCHES

DE-ENERGIZE ALL PNEUMATIC SOLENOID VALVES

DE-ENERGIZE IGNITERS

20 MSEC

CLOSE ALL PROP VALVES AT 100%/SEC (CLOSED AT TIME T_a)

T_a +80 MSEC

DE-ENERGIZE ALL FAIL-SAFE SERVO-SWITCHES

SET ENGINE STATUS WORD TO POST-SHUTDOWN STANDBY

LSS-ES-T-100