TECHNICAL MEMORANDUM X-53532

PROPELLANT FEED DUCTING AND ENGINE GIMBAL LINES FOR THE SATURN VEHICLES

By

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ABSTRACT N67-13161

The propellant feed system concepts and configurations used on the Saturn V vehicle to convey propellants from the tank to the engine are described. In addition, the engine gimbal lines that provide flexibility for engine gimbaling and, therefore, vehicle control are described from the original concepts used on the Jupiter vehicle through the Saturn I to the more sophisticated systems of the Saturn V.

Design and development of propellant feed systems for future vehicles will be based on the Saturn V feed system technology.

author

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PROPULSION AND VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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SUMMARY

The propellant feed system concepts and configurations of the S-IC, S-II, and S-IVB stages of the Saturn V launch vehicle are described in detail. The design concepts of the flexible ducting for these stages are presented. A description of the engine gimbal lines used on the Jupiter and Saturn I vehicles is presented as background information for the advanced concepts used on the Saturn V vehicle.

The propellant feed system is designed to deliver propellants to the engine pump inlets at the correct conditions (temperature and pressure) for proper pump operation. This system must deliver the propellants as efficiently as possible; that is, with minimum weight and pressure drop. Correctly designed propellant feed systems are essential for proper vehicle operation.

Design and development of propellant feed systems for future vehicles will be based on the Saturn V feed system technology.

INTRODUCTION

The Saturn V vehicle is often described as the earth-escape launch vehicle for Project Apollo manned lunar landing. This vehicle is comprised of the S-IC (first stage), the S-II (second stage), the S-IVB (third stage), an Instrument Unit and the Apollo spacecraft. The propellant feed system transfers propellant from the tanks to the engine while providing the correct pressure and temperature for proper pump start and operation. Propellant feed ducting, in addition to transferring propellant from the tank to the engine, must allow for installation tolerances, structural and thermal deflections, and engine gimbaling.

A fuel and oxidizer are required for the engines on all three stages. The fuels used are RP-1 in the S-IC stage and liquid hydrogen in the S-II and S-IVB stages. Liquid oxygen is the oxidizer in all three stages.

The propellant feed system concept is based on two important considerations, mechanical design and thermodynamic design. The thermodynamic concept of the propellant feed system is presented in detail sufficient only to support the mechanical design that is covered in greater detail. The various ducting design concepts and problem areas that comprise the mechanical portion of the propellant feed systems are discussed later in this report.

The basic approach for ducting design is to provide maximum flexibility (minimum terminal reaction loads) within the limitations imposed by pressure drop and envelope requirements. The combined conditions of thermal contraction, tolerance stackup, fluid momentum, internal pressure, structural deflection and vehicle acceleration will result in extreme terminal reaction loads if proper ducting design principles are not followed.

S-IC STAGE OF SATURN V

The overall S-IC stage is shown in Figure 1. The S-IC stage has five F-1 engines with LOX tank forward and the fuel tank aft. The LOX system consists of a LOX tank 33 feet in diameter by 64 feet long and five 36-feet long suction lines with inside diameters varying from 21 to 17 inches. There are two fuel feed lines and one LOX feed line for each of the five F-1 engines.

Fuel System

Figure 2 is a schematic of the RP-1 fuel system for the S-IC stage. At the outlet of the fuel tank are two 12-inch diameter prevalves used to shut down the engine in the event of engine valve failure or rupture of a line downstream of the prevalves. Prior to fuel tank pre-pressurization, nitrogen is bubbled into each fuel feed line to prevent temperature stratification of the fuel in the tank and the feed lines.

LOX System

A schematic of the LOX system for the S-IC stage is shown in Figure 3. The LOX feed lines are routed from the lower bulkhead of the LOX tank through tunnels in the fuel tank to the engine turbopump inlets. Each LOX feed line consists of a long suction duct, a prevalve, and a pressure-volume compensator. The prevalve and the pressure-volume compensator are described in detail below.

The five suction lines are connected by four-inch diameter interconnect lines. The suction line interconnect junction is located below the prevalves on the outboard suction lines and above the prevalve on the inboard suction line. A six-inch diameter LOX drain line is terminated in the inboard suction line immediately above the prevalve to drain the suction ducting. The two six-inch diameter primary tank fill-and-drain lines are terminated in the aft bulkhead.

LOX Interconnect System

The LOX interconnect system for the S-IC stage is shown in Figure 4. These interconnect lines are required to maintain LOX conditions (temperature and pressure) at the turbopump inlets that will prevent geysering during loading or standby and pump cavitation during engine start. The required LOX conditions are maintained by circulating LOX from the tank through the down-flow feed lines into the interconnect lines and up another feed line. One circulation system consists of engine No. 2 feed line for down-flow with engine No. 1 feed line for up-flow. The other system consists of feed lines of engine Nos. 4 and 5 for down-flow and the engine No. 3 feed line for up-flow. At the start of LOX circulation, helium is bubbled into the up-flow lines until the LOX tank is about 5 percent full. At this time, circulation can be sustained by thermal pumping. LOX conditions required to prevent geysering can be maintained by circulation due to thermal pumping. The thermal pumping system is augmented by helium bubbling about 10 minutes before launch to maintain LOX temperature at the engine pump inlet below the redline value of -275°F.

Ducting

The S-IC engine gimbal line concepts are different from those used on earlier stages. On the Jupiter missile (FIG 5), the engine turbopump was mounted to the stage, and the thrust chamber was gimbaled for missile attitude control. Two sections of braided hose, one in the pitch plane and the other in the yaw plane of the engine gimbal system, were contained in the high-pressure discharge lines between the pump and thrust chamber. These flex-hoses were located to provide all the necessary flexibility for engine gimbaling. The use of external braid on a bellows has long been the accepted method of providing bellows restraint. The tendency of the bellows to elongate axially under the pressure-separating force is counteracted by the external braid, which acts as a mechanical linkage. Without the braid, the bellows would be expanded axially; so little or no flexibility would be available for gimbaling. The primary advantages of braided bellows are low cost, simplicity of fabrication and small space envelope. The main disadvantage is that the angular deflection of the line is restricted by the braid, which results in high load requirements for engine gimbaling. These lines should be designed so that rubbing contact between the braid and the end convolutions is minimized.

The arrangement of the engine gimbal lines for the S-IB stage of the Saturn IB vehicle is shown in Figure 6. On the S-IB stage, the turbopump assembly is mounted piggy-back on the H-1 engine, and engine gimbaling is provided for in the low-pressure feed system. An oxidizer line and a fuel line are provided for each engine. A three-gimbal system is used in this design. Two gimbals are located in the horizontal plane, one in the pitch axis and the other in the yaw axis. The third gimbal is located in the vertical plane to eliminate the torque from engine gimbaling. When three gimbals are installed as indicated, lateral deflection can be absorbed, as can angular motion. For a given angular rotation of the individual gimbal joints, the amount of lateral deflection that can be absorbed is directly proportional to the distance between the joints. The primary advantage of gimbal joints is that higher angular deflections can be provided with smaller actuating loads than with braided bellows.

The S-IC stage LOX and fuel system propellant feed ducting is shown in Figure 7. Two tie rods are located at the upper end of the outboard and inboard LOX suction ducts to accommodate the offset between the LOX tank outlet and the fuel tunnel opening. Two gimbal joints are located on the lower end to provide flexibility between the fuel tunnel outlet and the thrust structure. In addition to the gimbal joints, a sliding joint is installed to provide axial motion capability for deflection, manufacturing tolerances and thermal contractions. A 40-feet long seamless tube is welded between the upper and lower ends.

The inboard and outboard fuel suction lines consist of two gimbal joints and a sliding joint. All relative motions between the tank and thrust structure are accommodated by the gimbals and sliding joint. The pressure-volume compensators are connected to the thrust structure on the upper end and the engine on the lower end.

Figures 8, 9, and 10 are typical component parts of the LOX and fuel suction ducts used on the S-IC stage. One of two ball strut assemblies used at the upper end of the LOX suction duct to accommodate the offset between the LOX tank outlet and the fuel tunnel opening is shown in Figure 8. The ball strut assembly is limited to absorbing angular motion in any plane by the internal struts. This type of joint is similar to the tie-rod joint and the gimbal joint, and this particular design is capable of 12 3/4° angulation. The ball strut joint is deflected about a ball that is seated in spherical sockets in the centerline of struts that join the duct ends. The bearing stress of the ball is approximately 1/4 that in the comparable tie-rod design. As a result, a much smaller and lighter package is possible for high-pressure lines.

Figure 9 shows a gimbal joint similar in function to the ball strut assembly described above. The main difference is that an internal or external universal joint is used in the gimbal joint to prevent elongation of the bellows under the pressure-separating force while allowing angular motion in any plane. The primary advantage of gimbal joints is that high angular deflections are possible at lower actuating loads. The main disadvantage is that the gimbal ring is heavy because the full, pressure-area load must be carried by the gimbal ring.

Figure 10 shows the sliding joint used in the fuel feed line of the S-IC stage. Axial motion capability is provided by the sliding joint to compensate for structural deflections, manufacturing tolerances and thermal contractions. Essentially, a sliding joint consists of a bellows to absorb axial motion and a guide to prevent angular motion of the bellows. The sliding joint will be elongated by the pressure-separating force of the bellows area unless the joint is properly restrained by the missile structure.

Pressure-Volume Compensator

The LOX pressure-volume compensator used in the S-IC stage is shown in Figure 11. The main functions performed by the compensator are:

a. Transfer of propellant from the tank to the inlet of the engine,

b. Flexibility for gimbaling of the engine,

c. Reduction of the force required for engine gimbaling,

d. Volume compensation to eliminate pressure fluctuations when engines are gimbaled.

The importance of pressure compensation is shown in Figures 12 and 13. The LOX and fuel pump inlets on the F-1 engine are shown in Figure 12. The three pump inlets, two fuel and one oxidizer, on the F-1 engine are located on the same side of the engine 50 inches from the engine gimbal center. The pressure balancing function of the compensator is shown schematically in Figure 13. The F-1 engine gimbal point is also indicated. The PA (pressure area) downward load on the pump is balanced with an equal and opposite load in the compensator, which reduces the total PA load on the engine to zero. This reduction in force allows smaller engine actuators to be used and provides constant angular engine acceleration during gimbaling. The F-1 engine LOX PA load is 39,000 lb, and the two fuel pump PA loads are 14,300 lb for a total of 53,300 lb. This 53,300 lb must be reacted in the pump and pump supports if a pressure compensator is not installed. The moment about the engine gimbal point is 53,000 lb times the radius of 50 inches, which results in a moment of 2,665,000 in-lb without a pressure compensator. Without a compensator, this large moment must be overcome by the engine actuators. Therefore, a pressure volume compensator is a definite requirement for gimbaled engines when all the pump inlets are on the same side of the engine.

The pressure-volume compensator has a nominal I. D. of 17 inches, an overall length of 80 inches and a weight of 900 lbs. The pressure-volume compensator is made of three main sections, two gimbal joints (one at each end) and a compensating section. Only angular motion is absorbed by each gimbal joint. Provision is made for lateral and angular offset by placing the two gimbal joints in series. The compensator section is constructed to permit ±9 inches axial motion resulting from engine gimbaling and manufacturing tolerances. The compensator also provides for pressure and volumetric compensation. In the particular design shown, a pressure-balancing chamber is installed between the main duct bellows. This chamber is open to internal duct pressure and has the correct cross-sectional area to create an axial force equal and opposite to the pressure-separating force of the main duct bellows. The axial stroke of the primary bellows is equal to the stroke of the secondary so that this volume remains constant when the engine is gimbaled. Without a compensator, duct volume changes would be created at the pump inlet resulting in variations in engine thrust.

A bellows used in the LOX pressure-volume compensator is shown in Figure 14. This bellows is typical of many used in the missile industry. The ability of a joint to deflect axially is predicated upon the flexibility of the bellows. Flexibility is dependent upon the modulus of elasticity and thickness of the material, the diameter of the bellows, and the size, shape, and number of convolutions. If the size of convolutions and wall thickness are constant, flexibility is directly proportional to the number of convolutions per given length. Flexibility is also a function of the number of plys. Therefore, many bellows for missile use are fabricated from two-to-five plys. A bellows support is usually installed, as indicated in Figure 14, to prevent excessive deformation of the end convolution. Material thickness of each ply in a multi-ply bellows is from .005 to 0.020 inches.

An alternate design for the pressure-volume compensator is shown in Figure 15. The main difference between this and the compensator depicted in Figure 11 is the method of secondary bellows support. In Figure 11 the secondary bellows is supported externally; while in the alternate configuration, the bellows is supported internally. When using long-length bellows, a support is needed to prevent buckling. Bellows can become unstable when pressurized internally and will buckle in a manner similar to that of a column buckling. In some design situations, where a long bellows is required for axial stroke, adding a support point in the middle provides bellows stability by effectively reducing the bellows length by one-half.

The burst test results of an inboard fuel pressure-volume compensator are shown in Figure 16. The secondary bellows has squirmed to a high degree when a pressure of 405 psi was applied to the duct. This test was terminated at 405 psi without rupture of the bellows. The design burst pressure of this compensator is 135 psi, and the bellows became unstable at 180 psi pressure. It should be noted that after the bellows has squirmed and ceased to function as a bellows, there was no rupture even when a much higher pressure was applied.

In Figure 17, a fuel pressure-volume compensator is shown in the simulated corners of the engine gimbal pattern during life-cycle testing. The +Y position is the maximum compressed position of the compensator and is indicated by the maximum extension of the secondary bellows. The -Y position is the maximum extended position of the compensator, indicated by the maximum compressed position of the secondary bellows. The +X and -X positions are intermediate between compression and extension. The nominal length of the secondary bellows for the fuel pressure volume compensator is 17.35 inches. This bellows is compressed approximately 9.15 inches in the -Y position and extended 9.40 inches in the +Y position. This design results in a 50 percent plus stroke of the bellows, which is a major advance in bellows technology. Conventional bellows are normally designed for a 20 percent stroke. The major advantage of a high-stroke bellows is the resultant decrease in length required for the same axial stroke.

The tolerances and deflections used in the design of the outboard LOX and fuel pressure-volume compensator for the S-IC stage are summarized in Figure 18. The various tolerances are a result of manufacturing tolerances, engine alignment tolerances and misalignments. The deflections are caused by static and dynamic loading and shrinkage caused by thermal conditions.

The engine gimbal pattern of the outboard engines used for guidance control of the S-IC stage of the Saturn V vehicle is shown in Figure 19. The necessary ducting flexibility for this gimbal pattern must be provided by the pressure-volume compensator.

The centerline diagram used to conduct a motion study for the design of the LOX and fuel pressure-volume compensator is shown in Figure 20. The various tolerances, deflections, and engine gimbal angles shown in the previous figures were combined as indicated so that the motion of the gimbal joints and the compensator section could be determined. Because of the numerous combinations of tolerances, deflections and engine gimbal angles, a kinematic analysis was conducted using an IBM 7040 data processing system. A NASA Technical Memorandum describes the motion study of the suction ducting used on the S-IC stage (Ref. 1).

Prevalves

Emergency shutoff capability for the S-IC stage feed system is provided by prevalves. The requirement to include a prevalve in the S-IC ducting was determined by a need to protect the vehicle, test stand and launch equipment during static firing and prelaunch operations should a malfunction of the engine valve occur. Each of the five F-1 engines is served by one oxidizer and two fuel prevalves. The prevalves are located in the thrust-structure area upstream of the engine turbopumps. The LOX and fuel prevalves, which are normally-open type, are held in the fully open position by spring force and a positive latch mechanism. The LOX prevalve is shown in Figure 21. This arrangement satisfies the requirement for use on a man-rated vehicle. The prevalve is closed when 750 psig pneumatic pressure (gauge) is applied to the prevalve actuator cylinder that retracts the latch and overrides the spring force to close the valve and stop propellant flow to the engines. A spherical closure element, termed a "visor", and an integral flowmeter are contained in the prevalve. When opened, the prevalve becomes an unobstructed tube. The visor is moved completely out of the propellant flow stream to minimize flow losses through the prevalve. Visor position indication is provided continuously over the full range of travel by a potentiometer and, at the fully opened and closed positions, by switches.

S-II STAGE OF SATURN V

There are five J-2 engines on the S-II stage (FIG 22). The liquid hydrogen tank is forward; the LOX tank is aft. There is a LOX and an LH_2 feed line for each J-2 engine. All feed lines, except the short center engine LOX feed line, are vacuum jacketed to prevent excessive boiling of the propellant in the lines before ignition of the engines. Each fuel feed line is 8 inches in diameter and is composed of a prevalve, a suction duct and a scissors duct. The suction duct runs from the prevalve near the LH_2 tank outlet to the scissors duct that is attached to the engine turbopump inlet. The five LH_2 tank outlets are spaced around the base of the LH_2 tank. The LOX feed line for each engine is routed from a sump on the LOX tank lower bulkhead to the inlet of the engine turbopump. A prevalve, suction duct and scissors duct are contained in each 8-inch diameter feed line. The suction duct runs from the prevalve at the LOX tank sump to the scissors duct that is attached to the inlet of the engine turbopump inlet.

Liquid Hydrogen System

A schematic of the LH_2 system for the S-II stage is shown in Figure 23. A recirculation system is provided to maintain LH_2 temperature at the turbopump below about -422° F to prevent pump cavitation during engine start. LH_2 is circulated to the engine through a separate system for each engine with a common return line. Each system is composed of a recirculation pump in the LH_2 tank, a recirculation valve and a two-inch diameter duct from the recirculation pump to the fuel feed line downstream of the prevalve. The recirculation system outlets of each engine are manifolded together, and the LH_2 is routed through one 3-inch diameter recirculation return duct to the LH_2 tank from the engine area.

Operation of the LH_2 recirculation system is initiated during tank filling and is continued until 5 to 10 seconds before engine ignition. When the recirculation system is operated, the normally-open prevalves are closed, the recirculation valves and return valve are opened, and the recirculation pumps are started to circulate LH_2 through the engine pumps. Circulation of LH_2 is continued until the system is shut down by stopping the recirculation pumps, opening the prevalves, and closing the recirculation valves and the return valve.

Liquid Oxygen System

The LOX temperature at the turbopump is maintained below about -295° by the LOX recirculation system (FIG 24) to prevent pump cavitation during engine start. The LOX circulation path is from the tank through the engine feed lines to the turbopump, and from the turbopump to the LOX tank through the uninsulated 3-inch-diameter LOX recirculation return lines. LOX flow in the recirculation system is maintained by thermopumping, the LOX absorbs heat in the uninsulated LOX return lines. Provisions were made for injecting gaseous helium into the return lines to establish LOX circulation in case thermopumping is not self-induced. The LOX prevalves are open during recirculation. The two-inch diameter recirculation valves are closed near the end of S-IC boost to stop the recirculation flow.

S-IVB STAGE OF SATURN V

The arrangement of the S-IVB propellant feed system (FIG 25) is similar to that of the S-II system. One J-2 engine is used on the S-IVB stage. The liquid hydrogen tank is forward and the LOX tank is aft. The 10-inch suction duct is routed from the prevalve at the LH_2 tank outlet to the scissors duct that is attached to the engine turbopump inlet. The LOX suction duct runs from the bottom of the LOX tank to the scissors duct attached to the turbopump inlet.

Liquid Hydrogen System

The LH_2 system for the S-IVB stage of Saturn V, shown schematically in Figure 26, is composed of a pump mounted inside the LH_2 tank, a recirculation control valve, a 2-inch diameter duct from the pump outlet to the LH_2 feed line downstream of the prevalve and a 2-inch diameter LH_2 return line from the engine to the LH_2 tank.

Operation of the LH_2 recirculation system is initiated by closing the normally-open LH_2 prevalve and starting the LH_2 recirculation pump. The LH_2 circulation path is from the recirculation pump through the recirculation valve, engine pump and return line to the LH_2 tank. Shortly before the recirculation system is stopped, the LH_2 prevalve is opened and LH_2 is pumped through the prevalve into the LH_2 tank. In this way, any bubbles that may have accumulated under the antivortex screen will be removed. The recirculation system is shut down before engine start command by closing the recirculation control valve and stopping the pump.

LOX System

The LOX system is shown in Figure 27. The LOX recirculation system is composed of a recirculation pump mounted on the lower bulkhead of the LOX tank, a recirculation control valve, 2-inch diameter ducting from the pump to the LOX feed line downstream of the LOX prevalve and a 2-inch diameter return line from the engine to the LOX tank.

Operation of the LOX recirculation system is initiated by closing the normally-open LOX prevalve and starting the LOX recirculating pump. The LOX recirculation path is from the recirculation pump through the recirculation valve, engine pump, and return line to the LOX tank. Shortly before the recirculation system is stopped, the LOX prevalve is opened and LOX is pumped through the prevalve into the LOX tank. In this way, any bubbles that may have accumulated under the antivortex screen will be removed. The recirculation system is shut down before engine start command by closing the recirculation control valve and stopping the pump.

Scissors Ducts

The J-2 LOX scissors duct used on the S-II, S-IVB stages is shown in Figure 28. The J-2 inlet line is required to duct fluid from the vehicle stage to the engine while undergoing relatively large movements of displacement and rotation. Included in the movement caused by engine gimbaling are $\pm 4\ 1/2$ inches axial travel, and a twisting rotation of 3/4 degree. In addition to the motions caused by gimbaling, there are installation misalignments that must be added to the duct movements. The scissors duct is composed of a linkage to stabilize the bellows by providing an intermediate lateral support. As a secondary function, the ends of the bellows are oriented by the linkage into a position that minimizes the bellows strain for any particular line movement. The linkage is much more rigid than the bellows; hence, the movements of the ends of the bellows are dependent upon the positioning of the linkage.

The LOX and LH_2 scissors ducts mounted to the J-2 engine are represented in Figure 29. The LOX and fuel pump are mounted on opposite sides of the engine gimbal point and at the same distance from the gimbal point. The pressures in the LOX and LH_2 ducts are approximately equal. As a result, the pressure-area loads are balanced about the gimbal point and the resulting moment is balanced, eliminating the loading on the engine actuators. This balancing of loads eliminates the requirement for a pressure-volume compensator with the J-2 engine.

CONCLUSIONS

The adequacy of the design of the propellant feed system used on the Saturn V vehicle has been demonstrated by static firing. Gimbaling tests during static firing have demonstrated the design of the engine gimbal lines.

As a result of engine pump and actuator loading, a pressure compensated duct is required for the F-1 engine and is not required for the J-2 engine.

Problems such as pressure loading of engine turbopumps and actuators, maintaining required propellant temperature and pressure at the turbopump inlets, and vehicle safety can be reduced or eliminated by properly designed propellant feed systems.

The technology that has been developed for the present propellant feed systems will provide a sufficient base for the design of future systems.

REFERENCE

1. Fursdon, H. E.: Motion Study of the Suction Ducting on the S-IC Stage of the Saturn V Vehicle. NASA TM X-53471, June 1966.

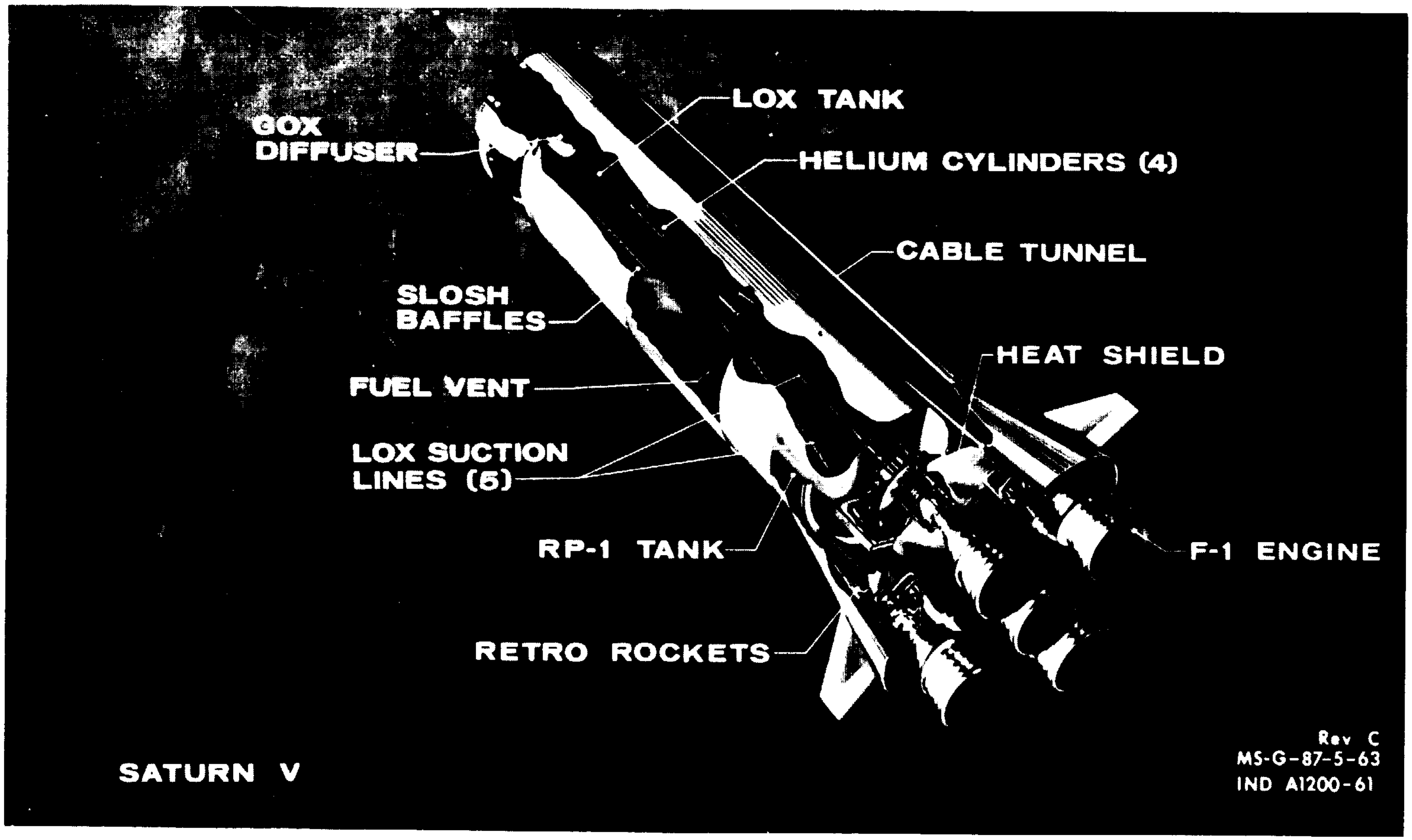


FIGURE 1. S-IC STAGE, SATURN V

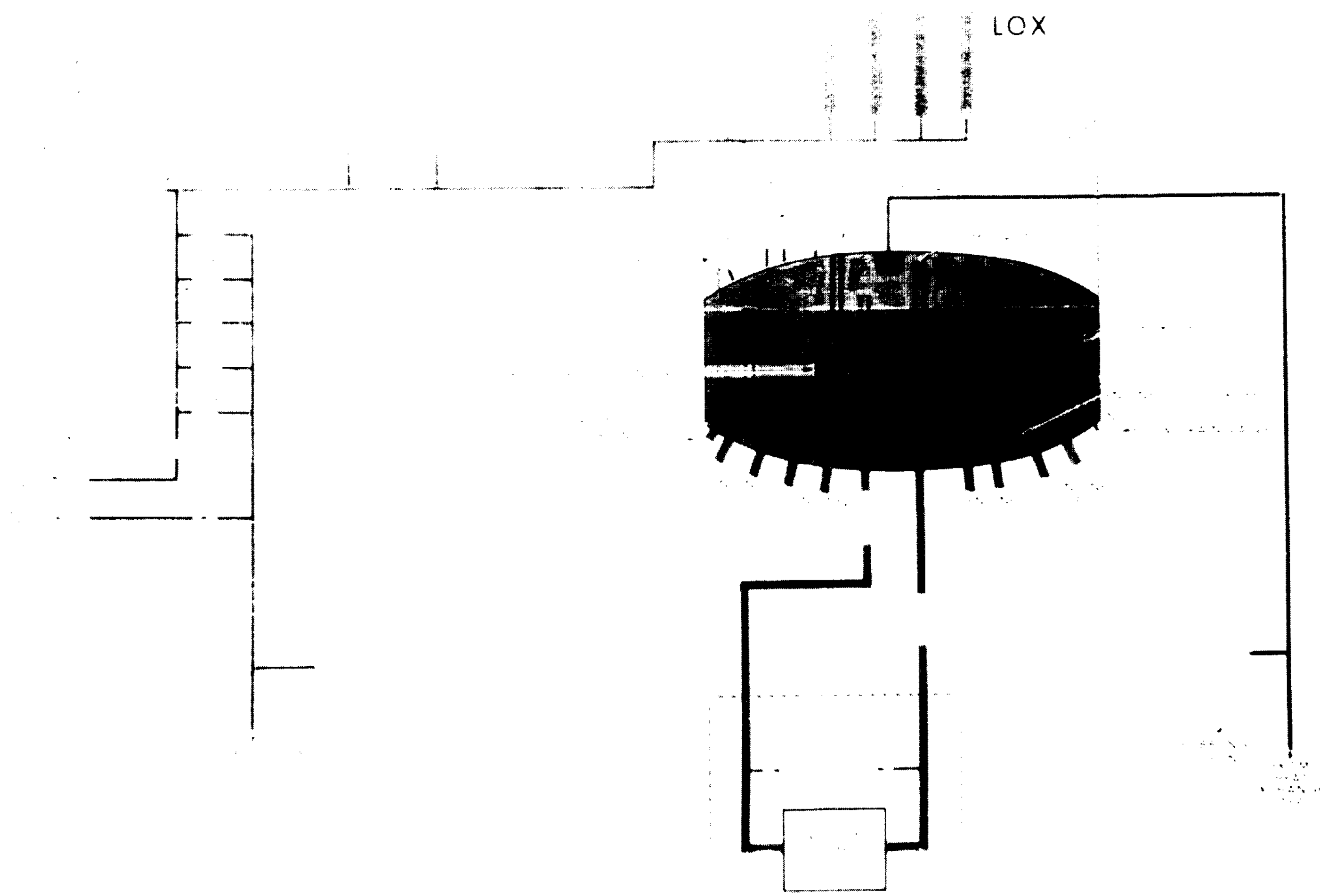


FIGURE 2. FUEL SYSTEM SCHEMATIC, S-IC STAGE

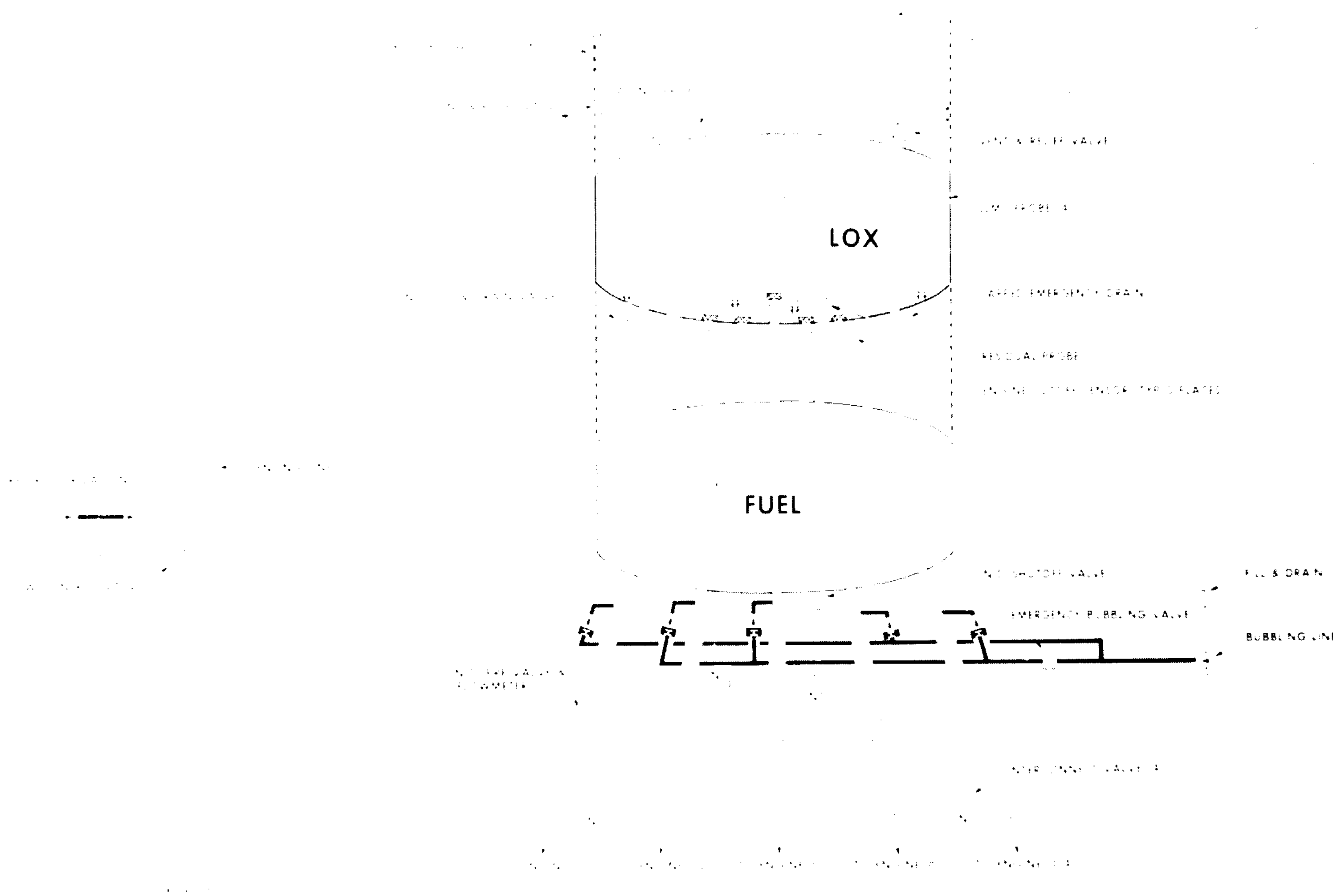


FIGURE 3. LOX SYSTEM SCHEMATIC, S-IC STAGE

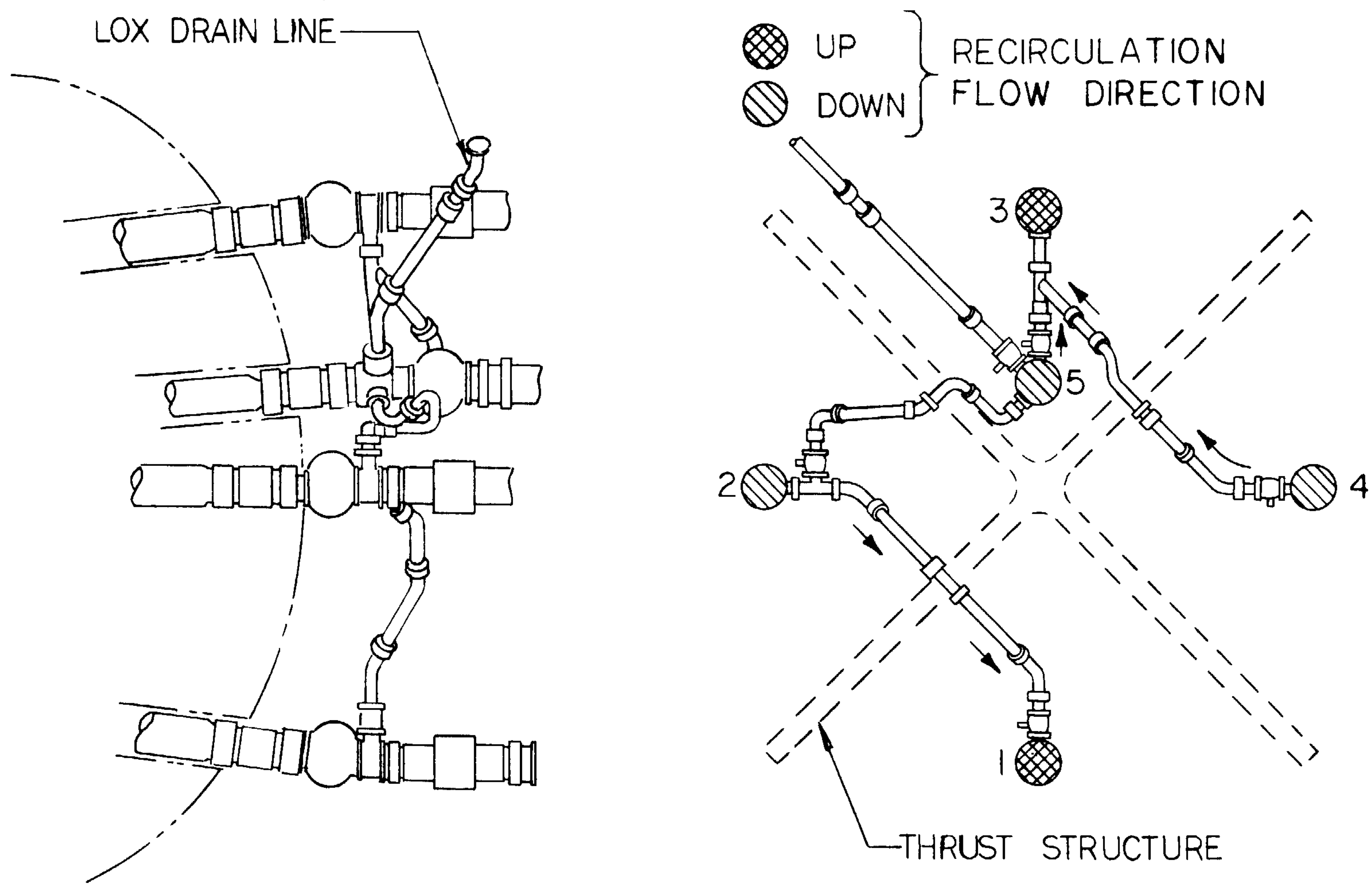


FIGURE 4. S-IC LOX INTERCONNECT SYSTEM

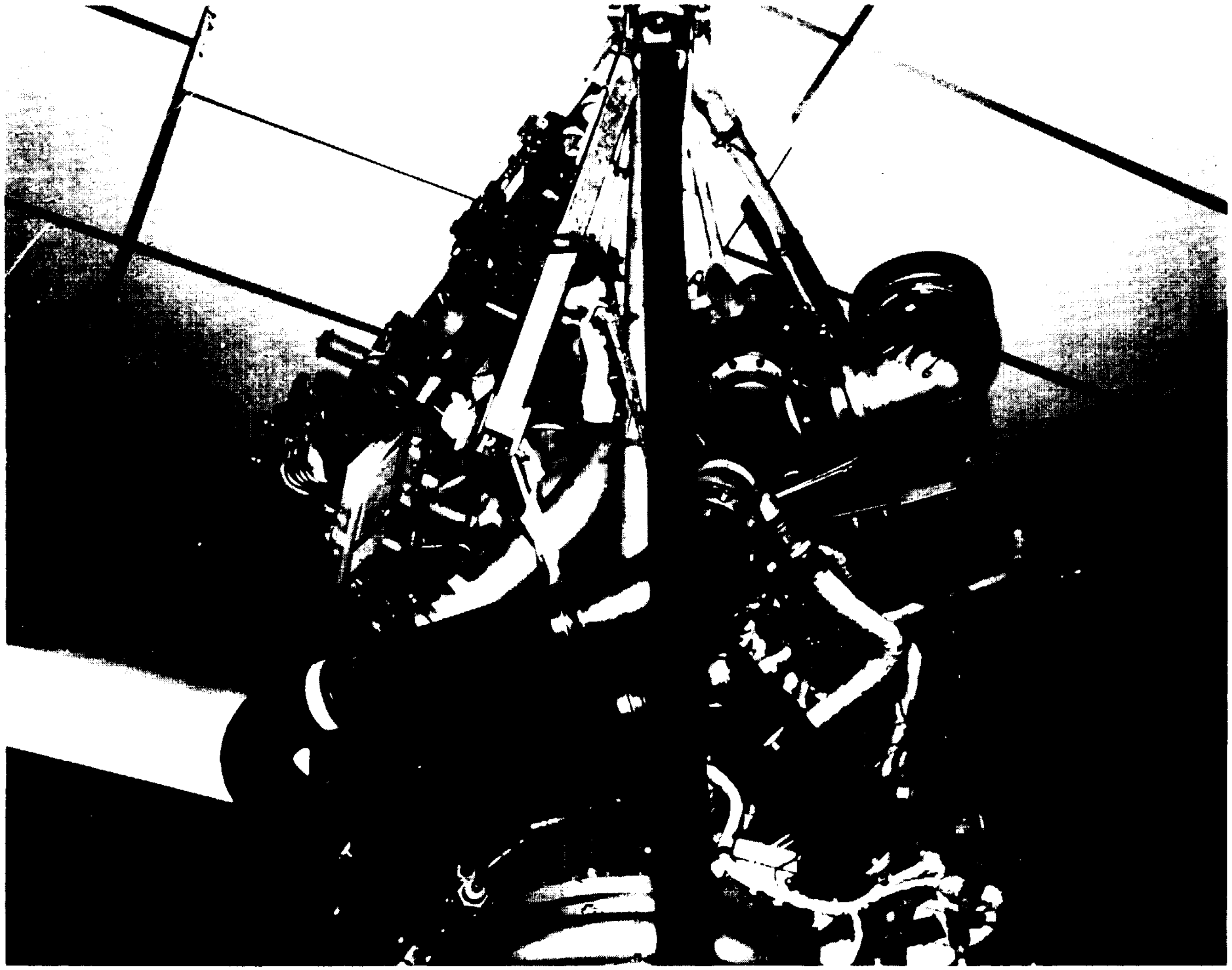


FIGURE 5. S-3D ENGINE GIMBAL LINES, JUPITER

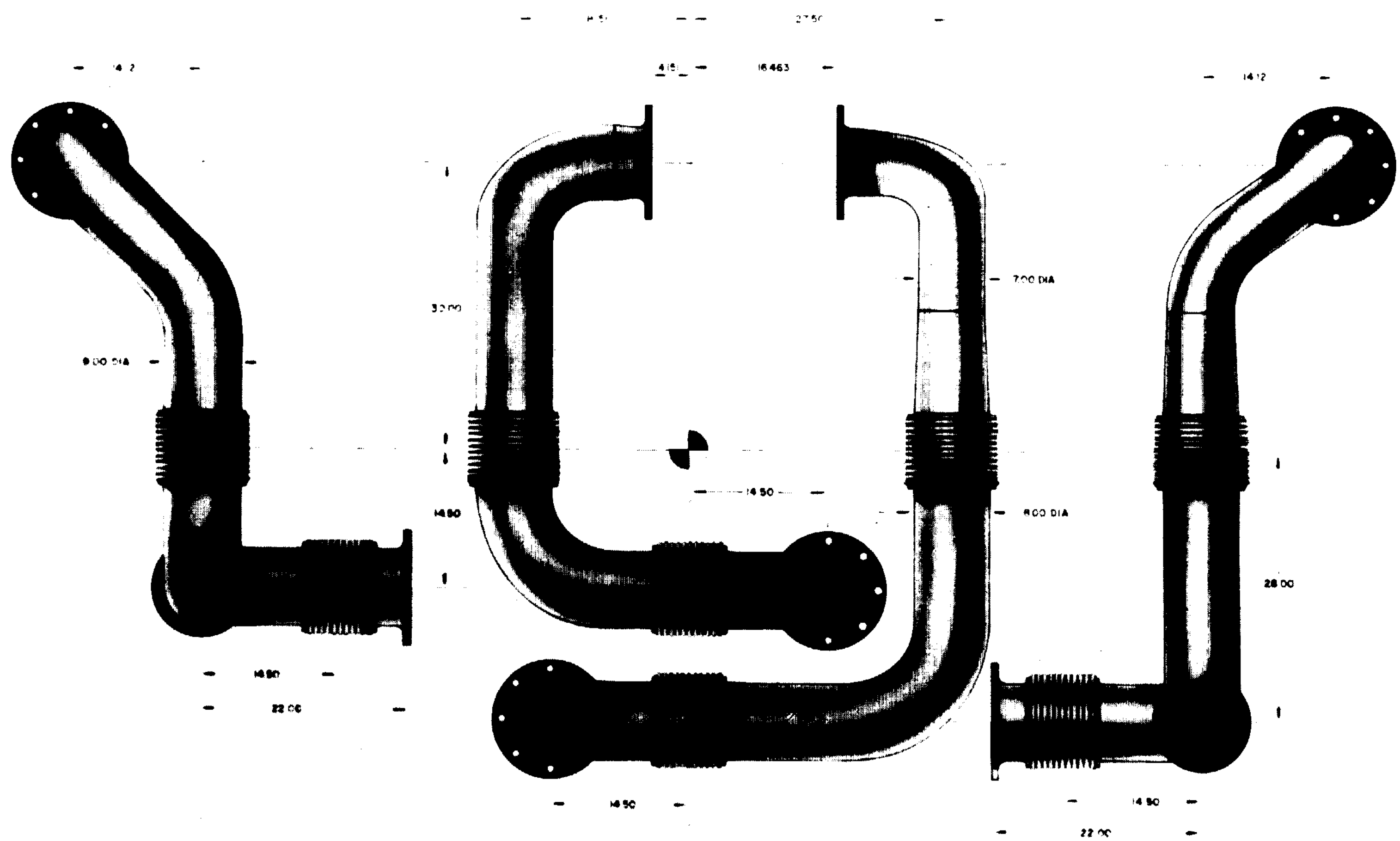


FIGURE 6. INLET DUCTING, S-IB

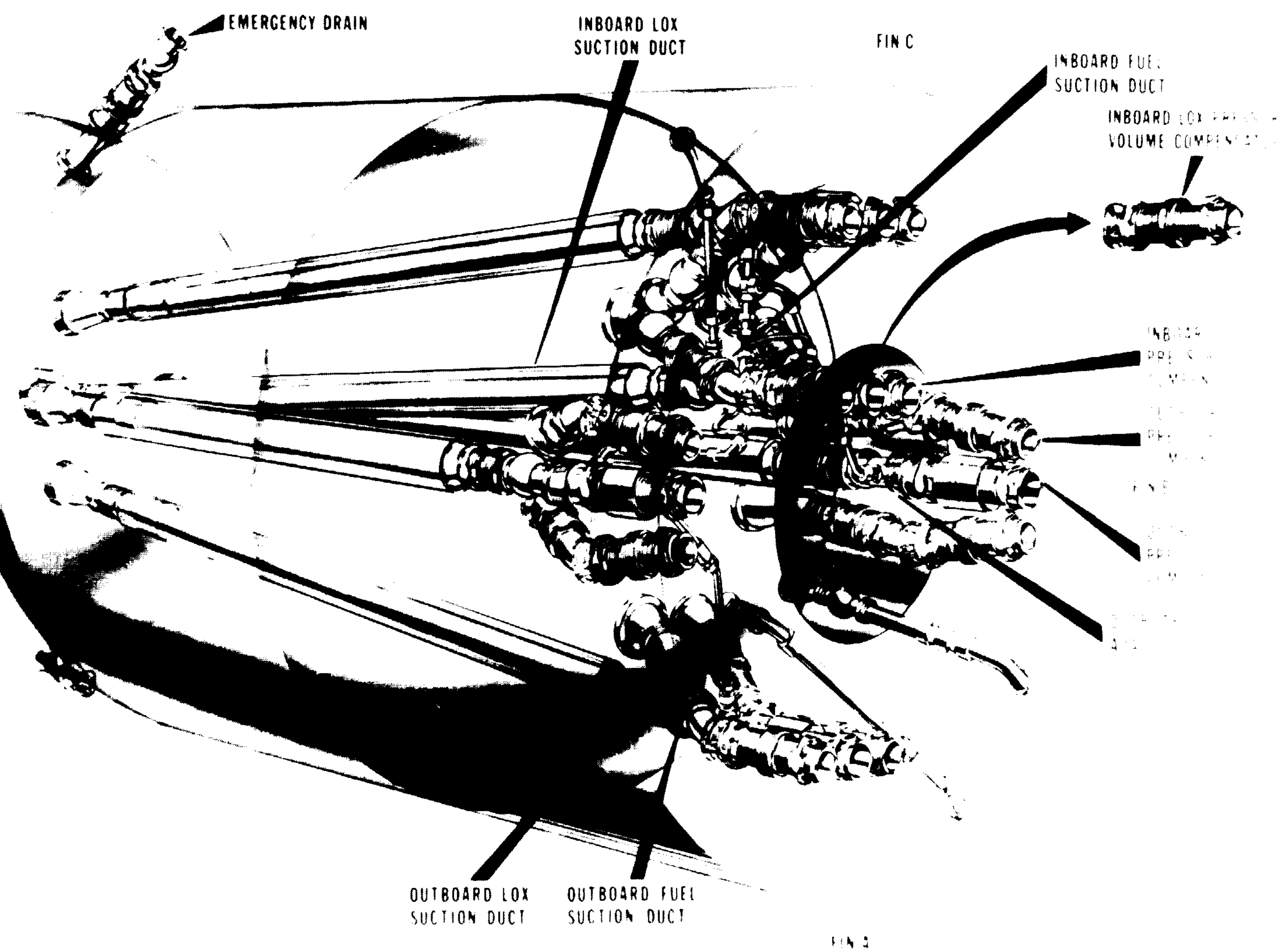
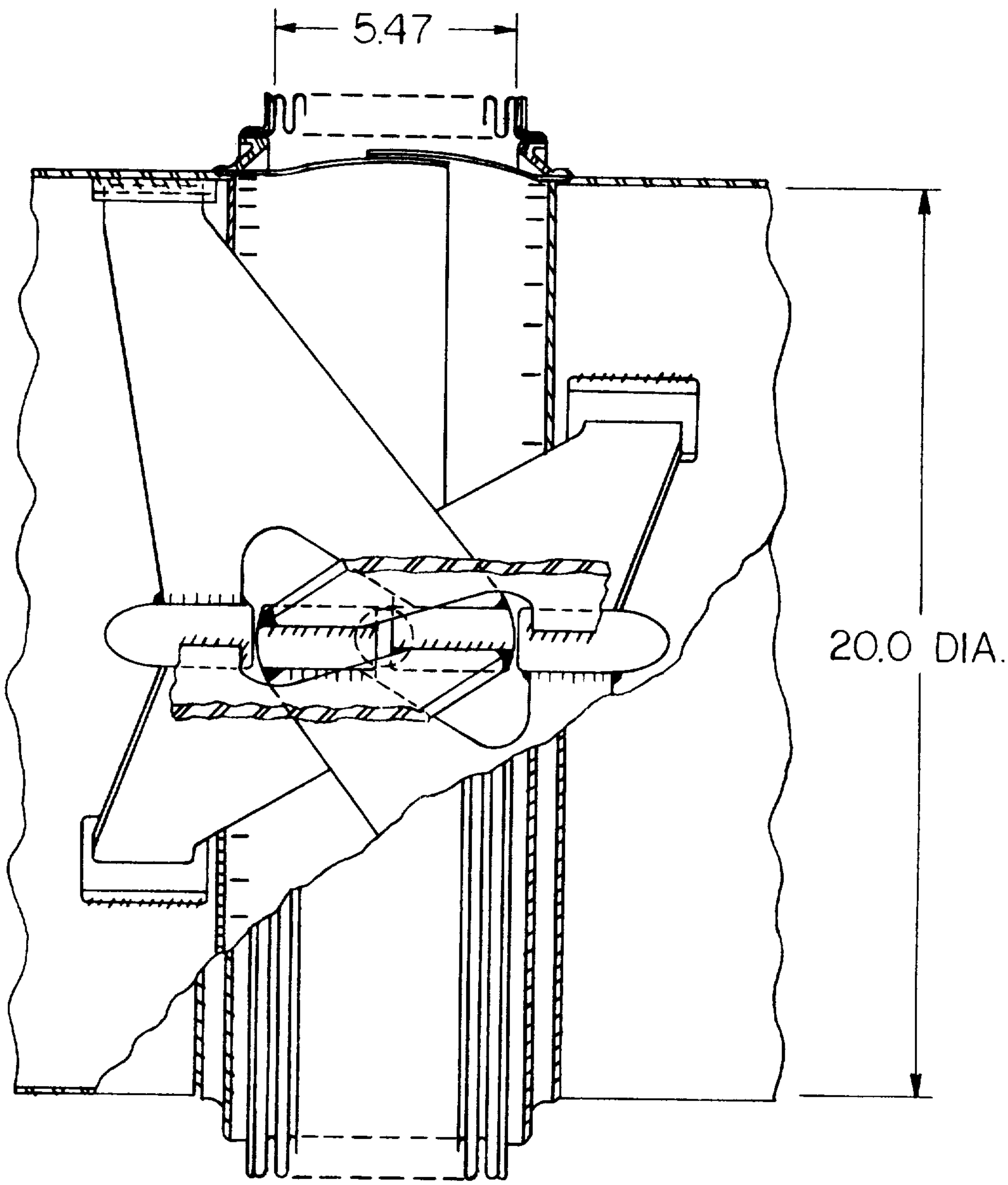
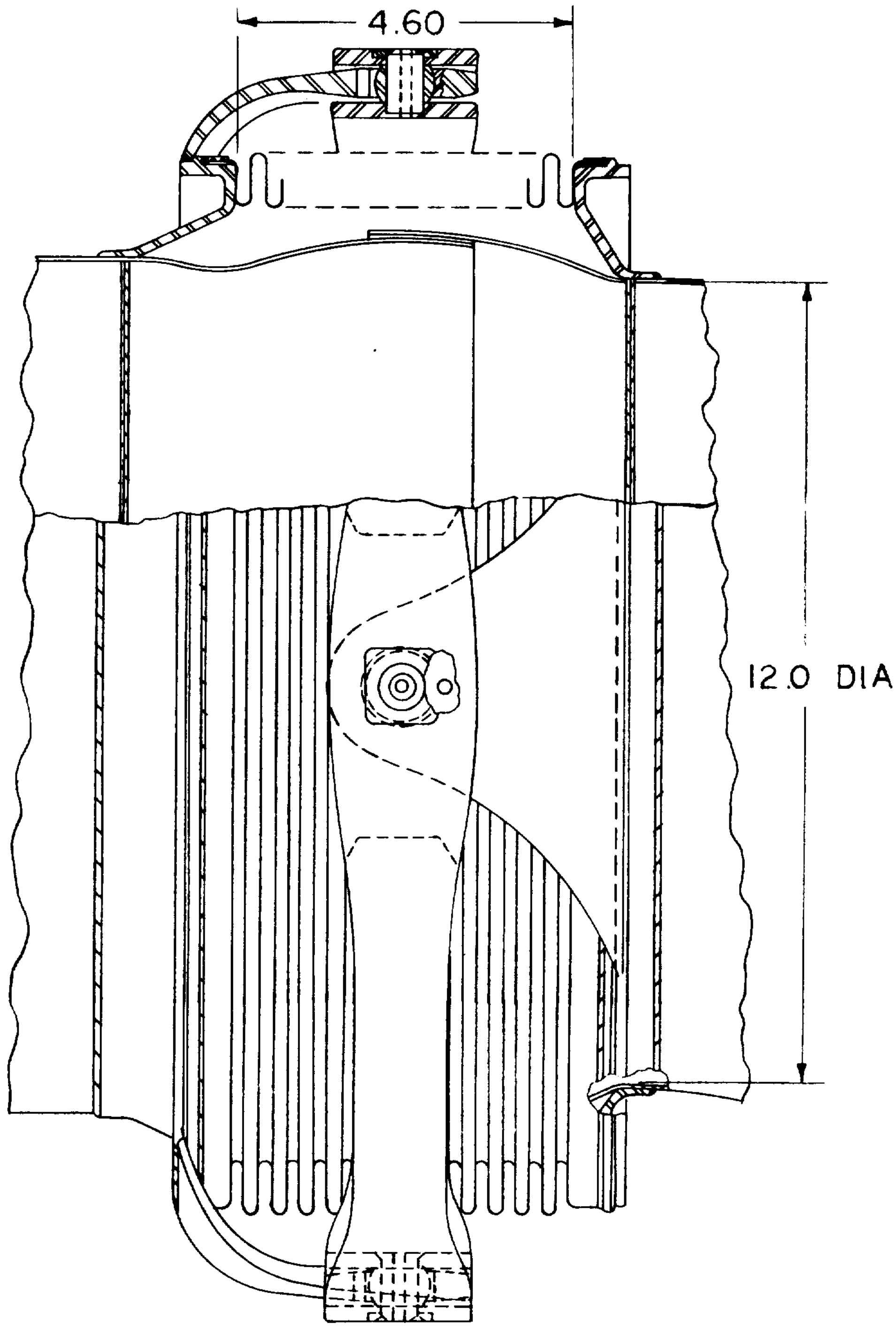


FIGURE 7. LOX AND FUEL DUCTING, S-IC STAGE



BALL STRUT ASSEMBLY
(MOTION REQUIREMENT 12° 45')

FIGURE 8. GIMBAL, BALL STRUT



GIMBAL JOINT

(MOTION REQUIREMENT 16° 45′)

FIGURE 9. GIMBAL, EXTERNAL

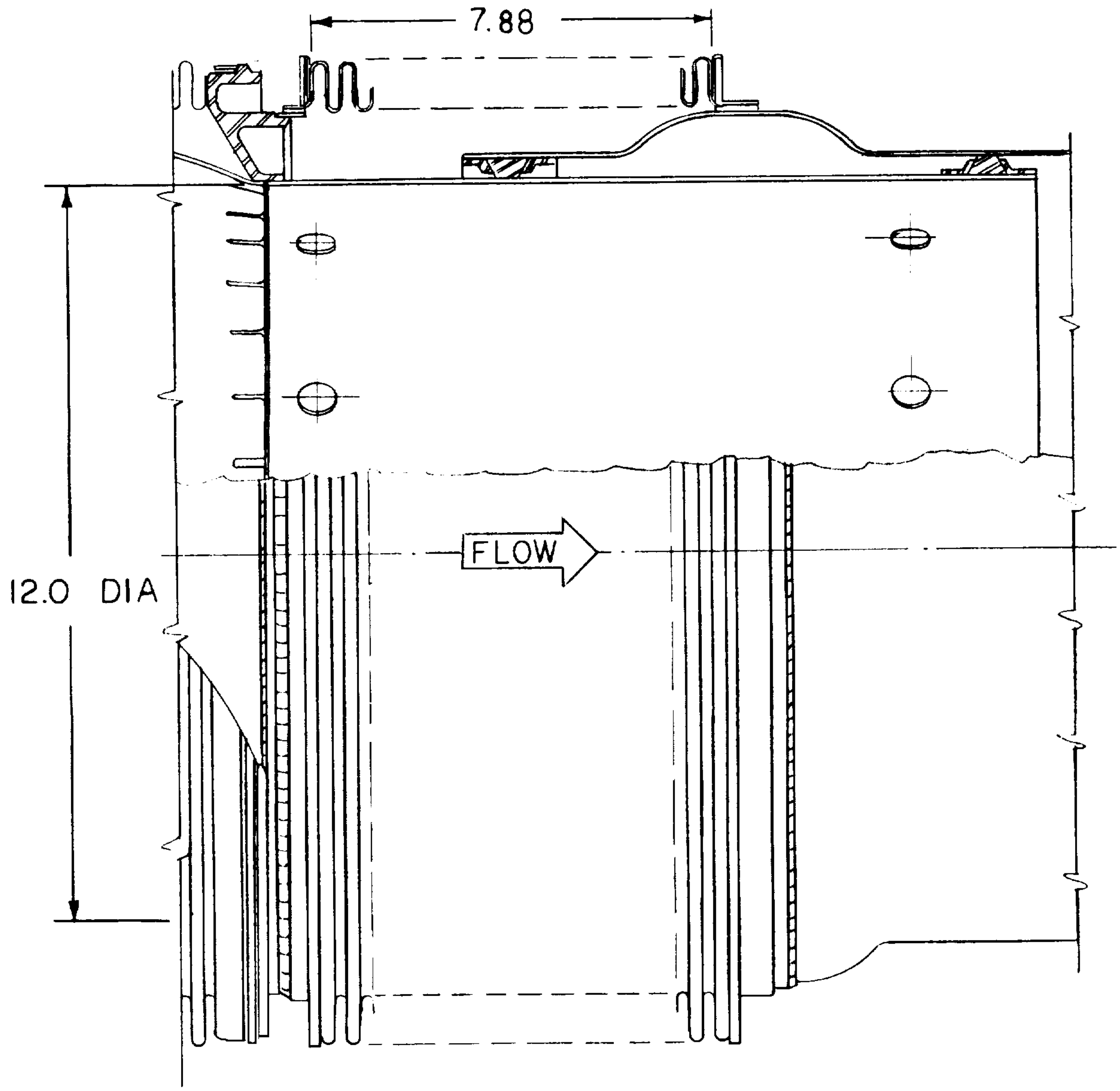


FIGURE 10. SLIDING JOINT

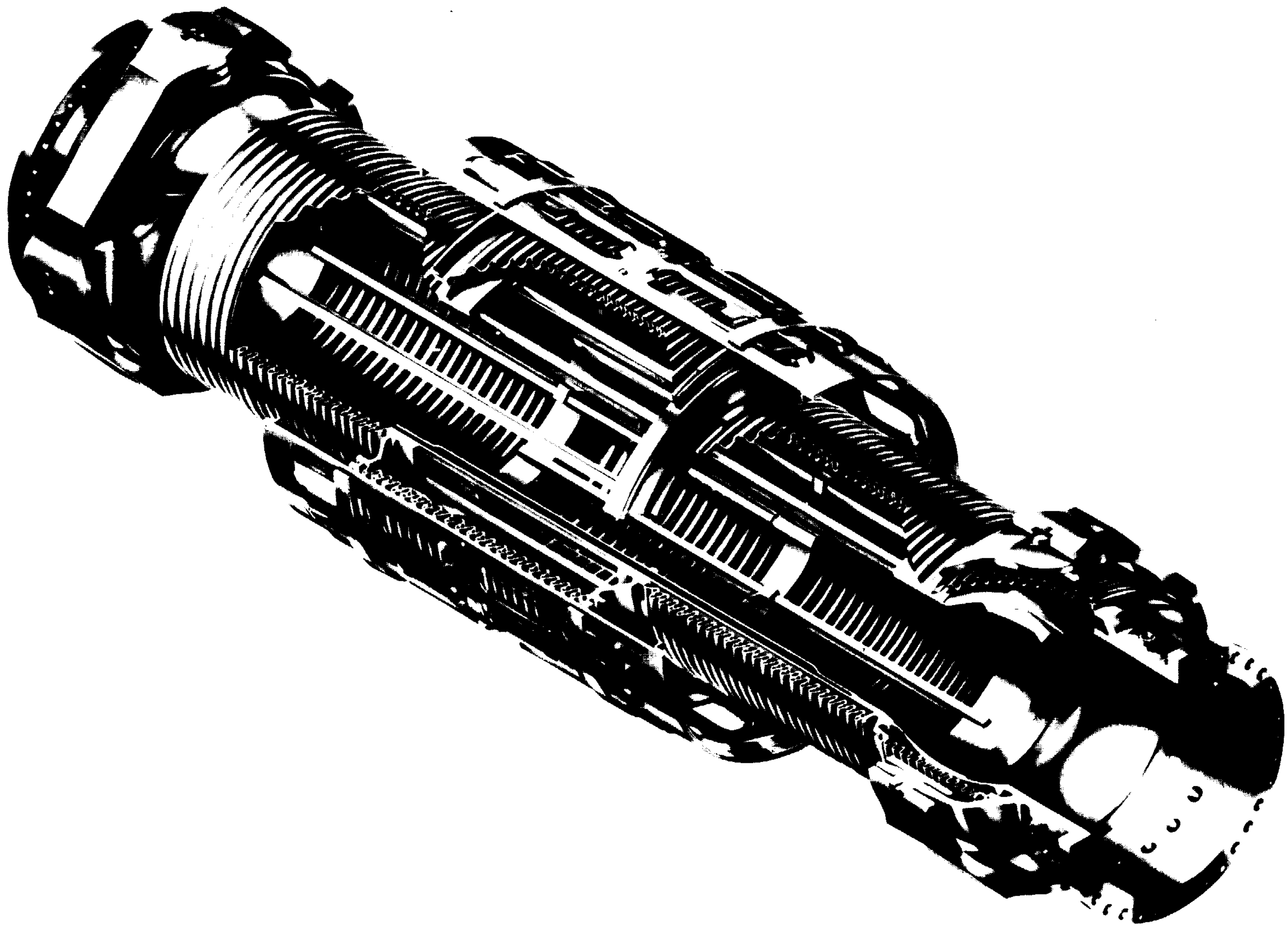


FIGURE 11. DUCT, PRESSURE VOLUME COMPENSATING (PVC), OUTBOARD LOX, EXTERNAL BELLOWS SUPPORT

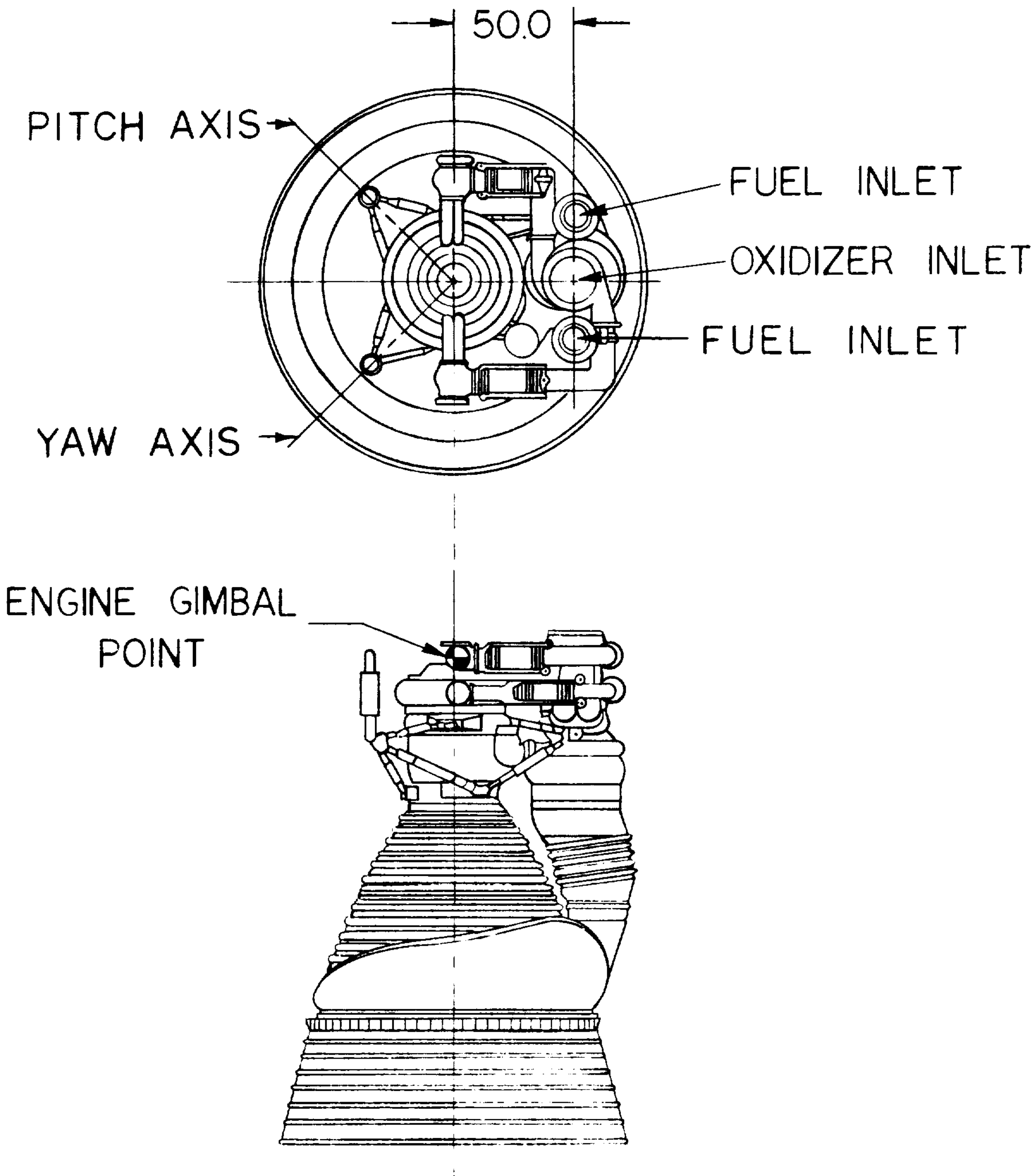
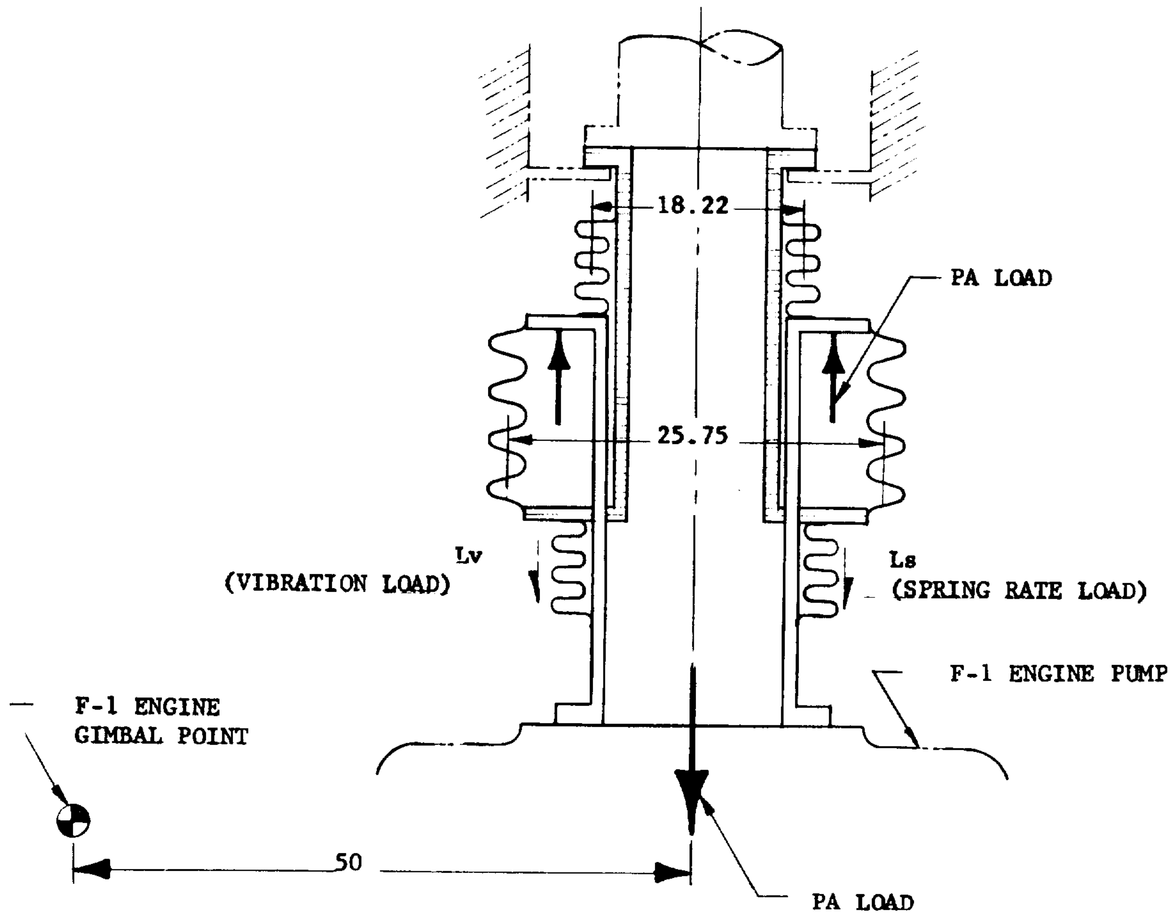


FIGURE 12. F-1 ENGINE CONFIGURATION

PRESSURE VOLUME COMPENSATOR



F-1 ACTUATOR MOMENT

COMPENSATOR $M_A = (Ls + Lv)R$

SLIP JOINT $M_A = (Ls + Lv + PA)R$

ADVANTAGE OF COMPENSATOR IS ELIMINATION OF PA LOAD

LOX PA LOAD = 39,000 LB   M = 53,300 LB x 50. IN.

FUEL PA LOAD = <u>14,300 LB</u>   M = 2,665,000 IN. - LB

53,300 LB

FIGURE 13. PVC LOAD BALANCE DIAGRAM

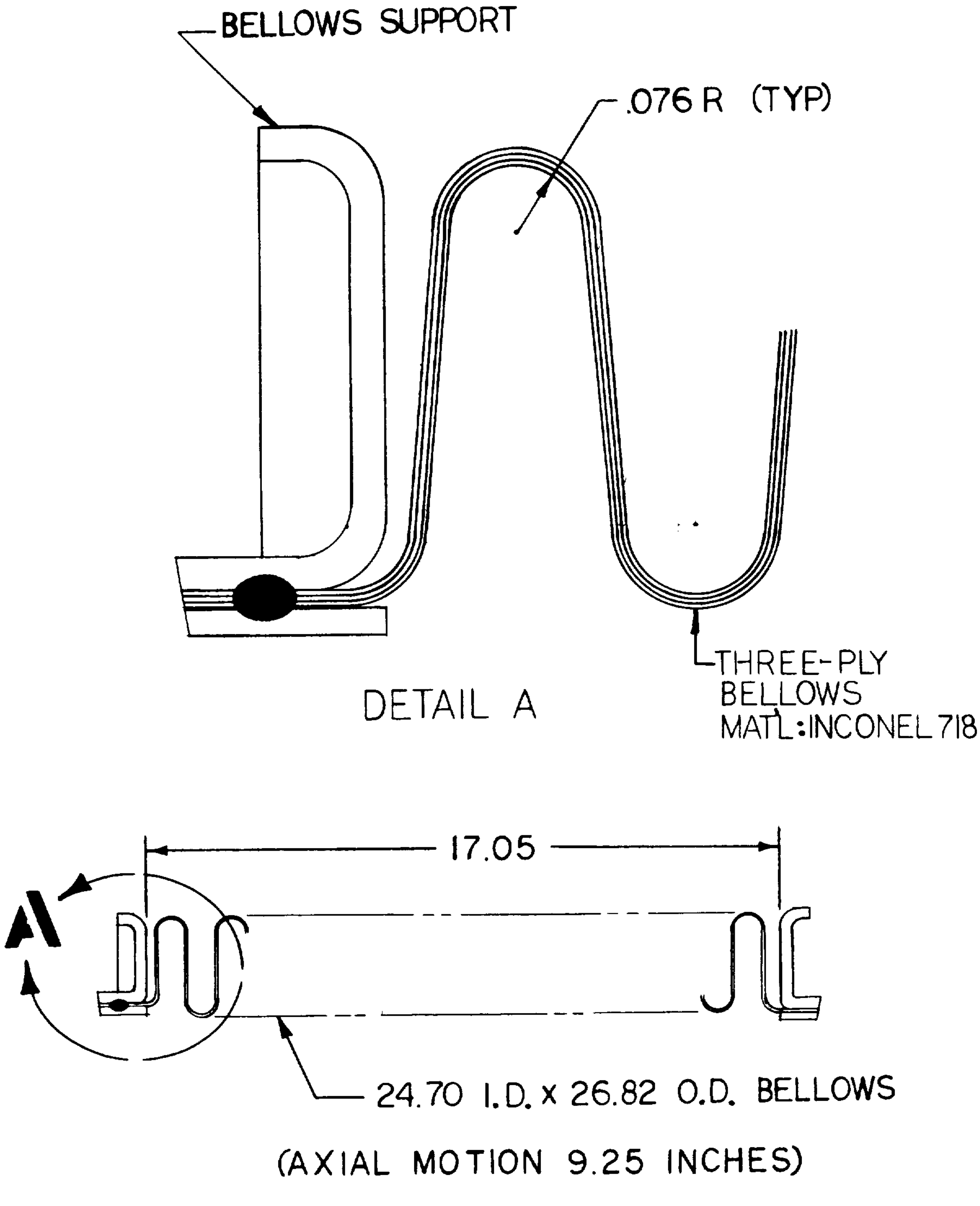


FIGURE 14. BELLOWS CONFIGURATION

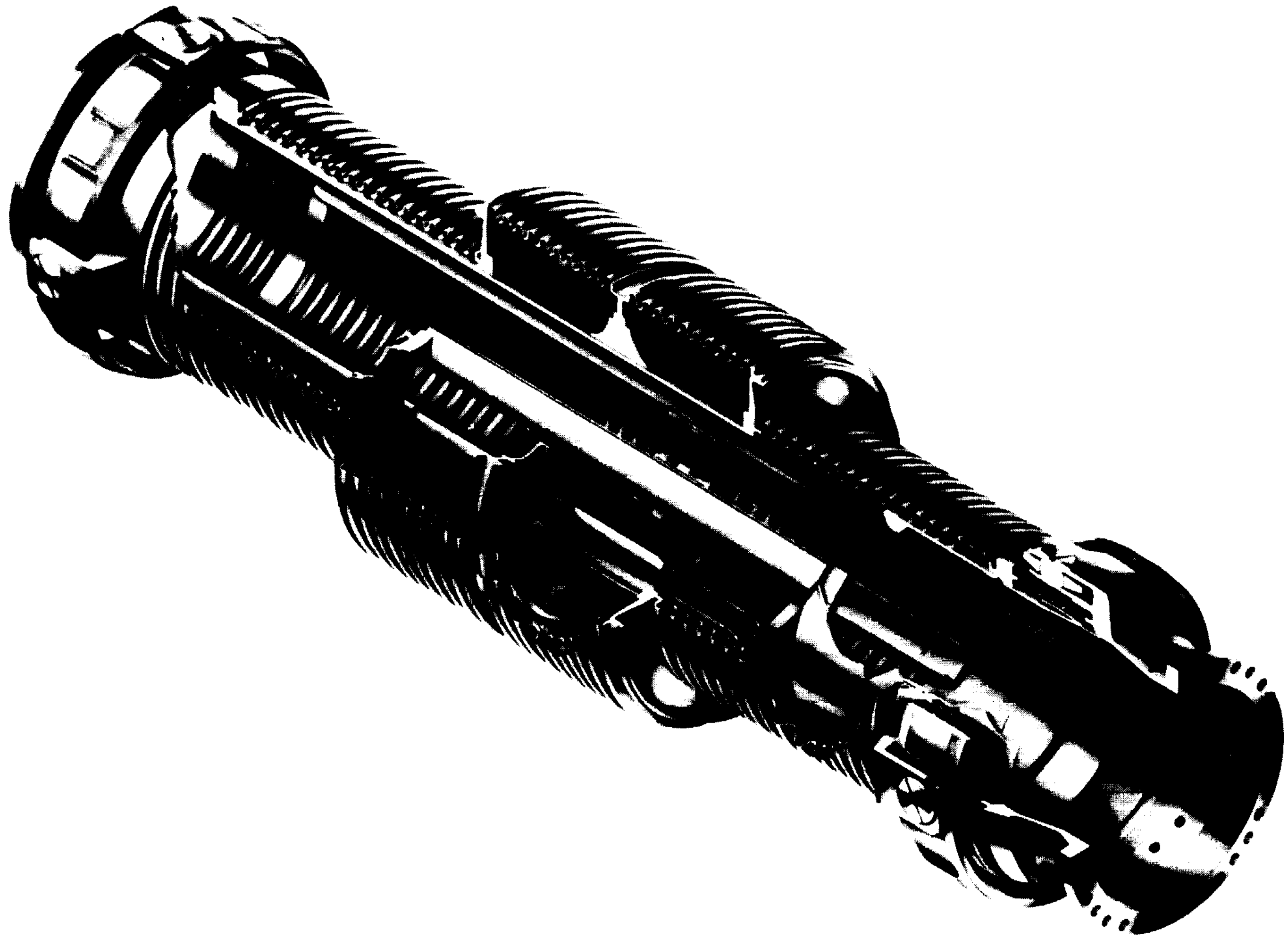


FIGURE 15. DUCT, PRESSURE VOLUME COMPENSATING, OUTBOARD LOX, INTERNAL BELLOWS SUPPORT

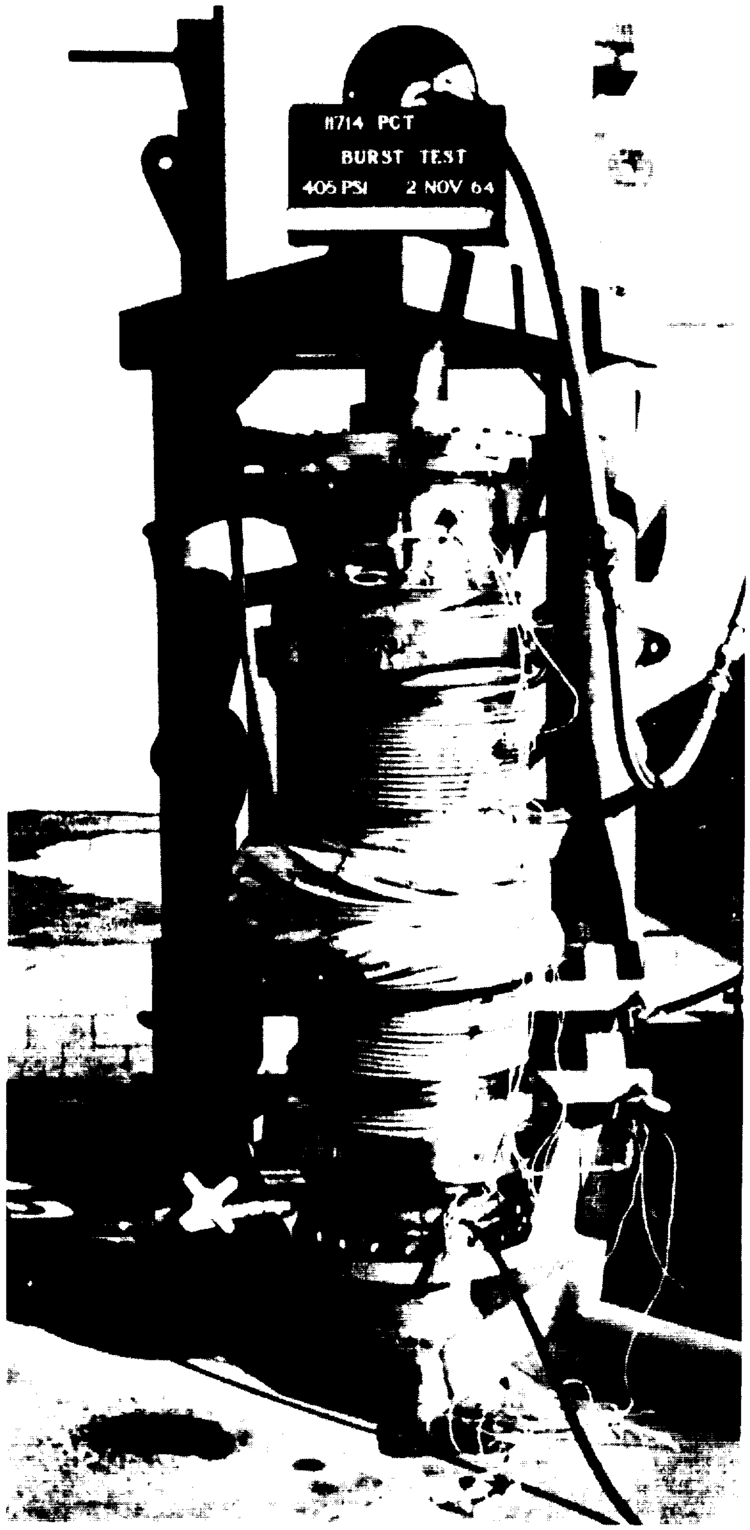
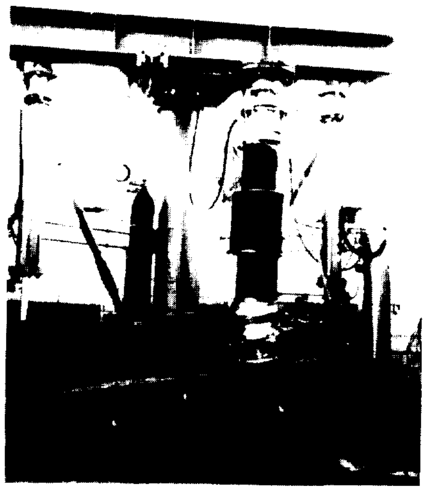
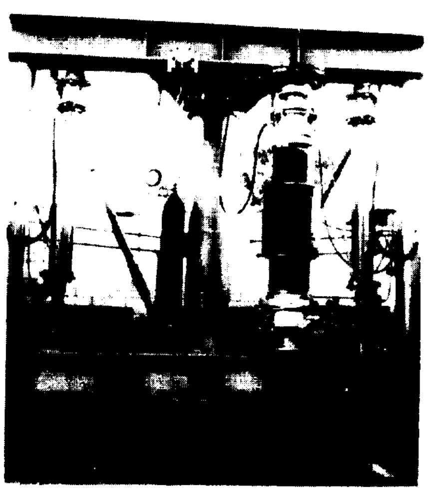


FIGURE 16. PVC BURST TEST WITH BELLOWS SQUIRM

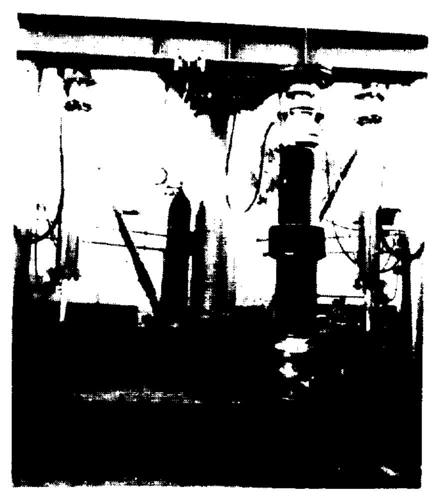


POINT 6 + X AXIS

POINT 2 - X AXIS

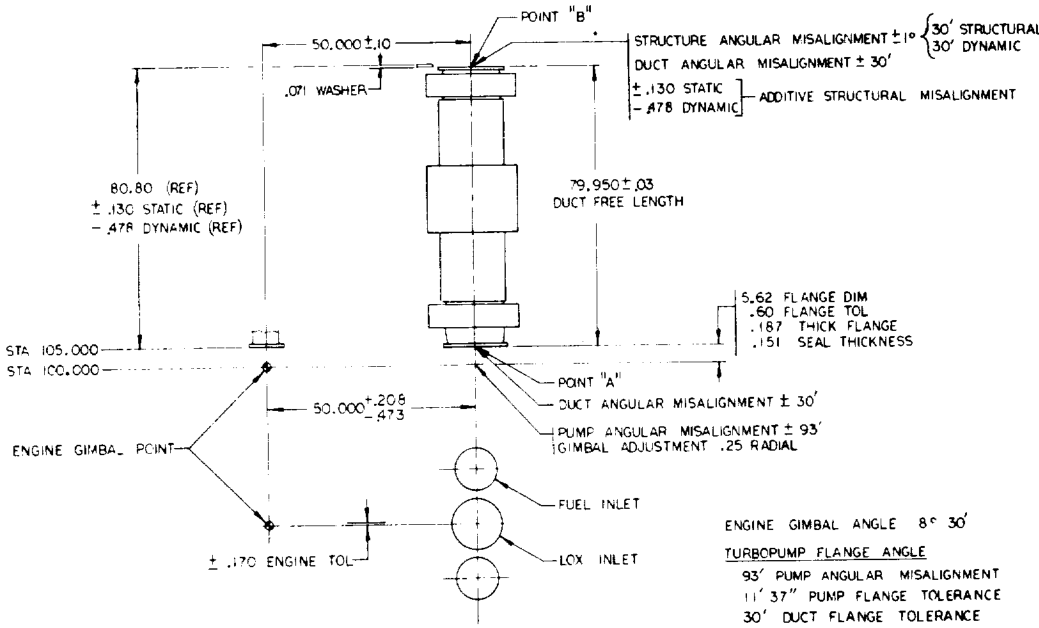


POINT 8 + Y AXIS



POINT 4 - Y AXIS

FIGURE 17. 20M02001 DUCT, OUTBOARD FUEL PVC LIFE CYCLE TEST POSITIONS



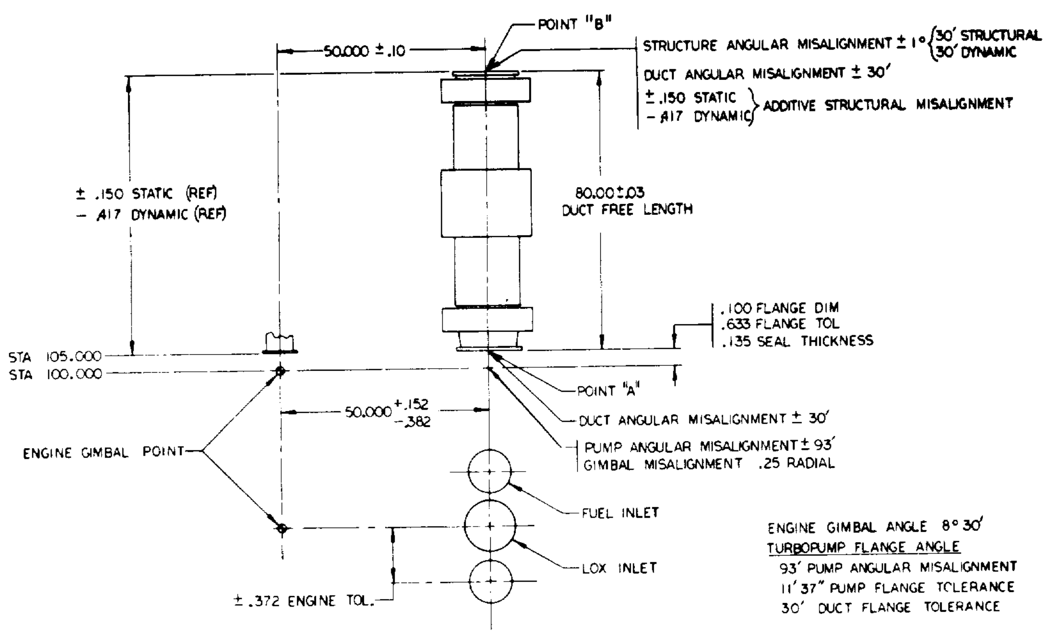


FIGURE 18. PVC OUTBOARD LOX AND FUEL TOLERANCES AND DEFLECTIONS

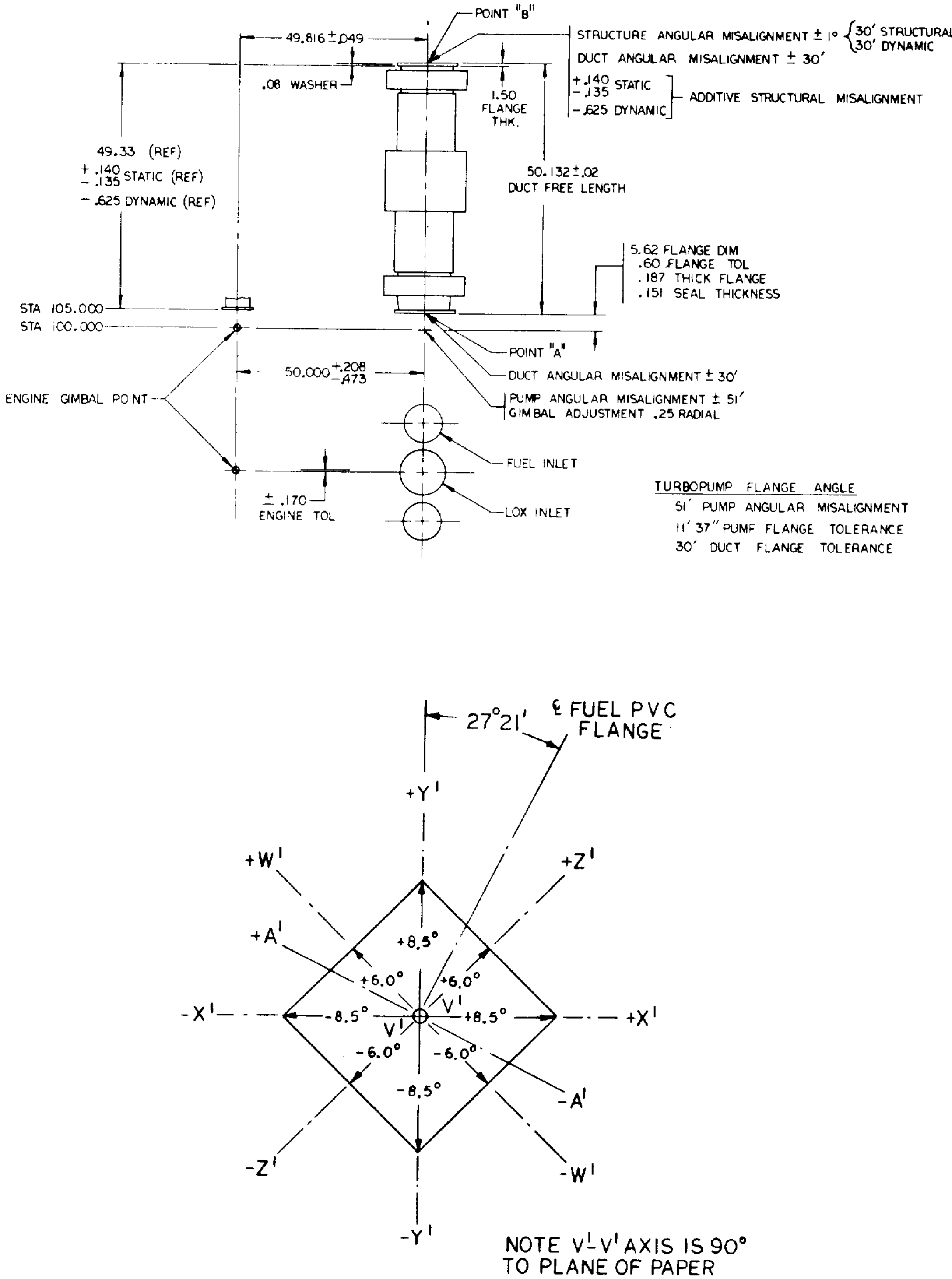
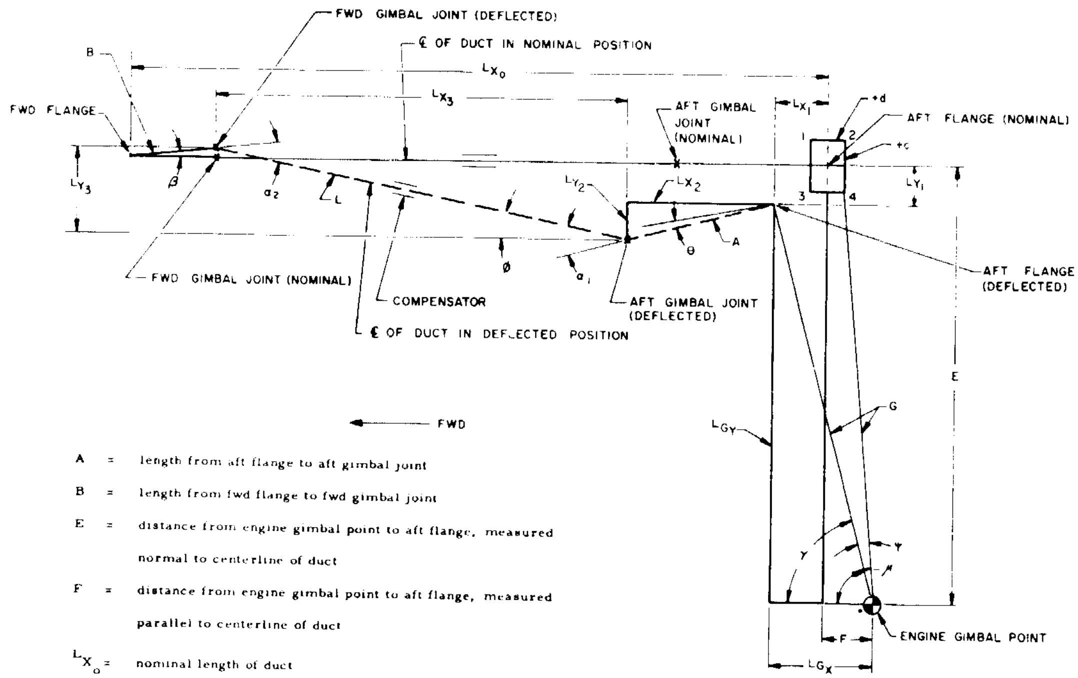


FIGURE 19. PVC INBOARD LOX TOLERANCES AND DEFLECTIONS, AND ENGINE GIMBAL PATTERN



FWD

A = length from aft flange to aft gimbal joint

B = length from fwd flange to fwd gimbal joint

E = distance from engine gimbal point to aft flange, measured normal to centerline of duct

F = distance from engine gimbal point to aft flange, measured parallel to centerline of duct

L_{X_o} = nominal length of duct

c = radial misalignment at aft flange

d = axial misalignment at aft flange

θ = angular misalignment at aft flange

β = angular misalignment at fwd flange

ψ = engine gimbal angle

α_1 = aft gimbal angle

α_2 = fwd gimbal angle

ΔL = change in length of compensator

μ = $\arctan\left[(E + c)/(F - d)\right]$

γ = $\mu - \psi$

G = $\sqrt{(E + c)^2 + (F - d)^2}$

$L_{G_Y} = G \sin \gamma$

$L_{G_X} = G \cos \gamma$

$L_{Y_1} = E - L_{G_Y}$

$L_{X_1} = L_{G_X} - F$

$L_{X_2} = A \cos(\psi + \theta)$

$L_{Y_2} = A \sin(\psi + \theta)$

$L_{X_3} = L_{X_o} - B \cos \beta - L_{X_1} - L_{X_2}$

$L_{Y_3} = L_{Y_1} + L_{Y_2} + B \sin \beta$

$\phi = \arctan(L_{Y_3} / L_{X_3})$

$L = \sqrt{L_{Y_3}^2 + L_{X_3}^2}$

$\alpha_1 = \phi + \psi + \theta$

$\alpha_2 = \phi + \beta$

$\Delta L = L - L_{X_o} - A - B$

FIGURE 20. CENTERLINE DIAGRAM FOR PVC DUCTS

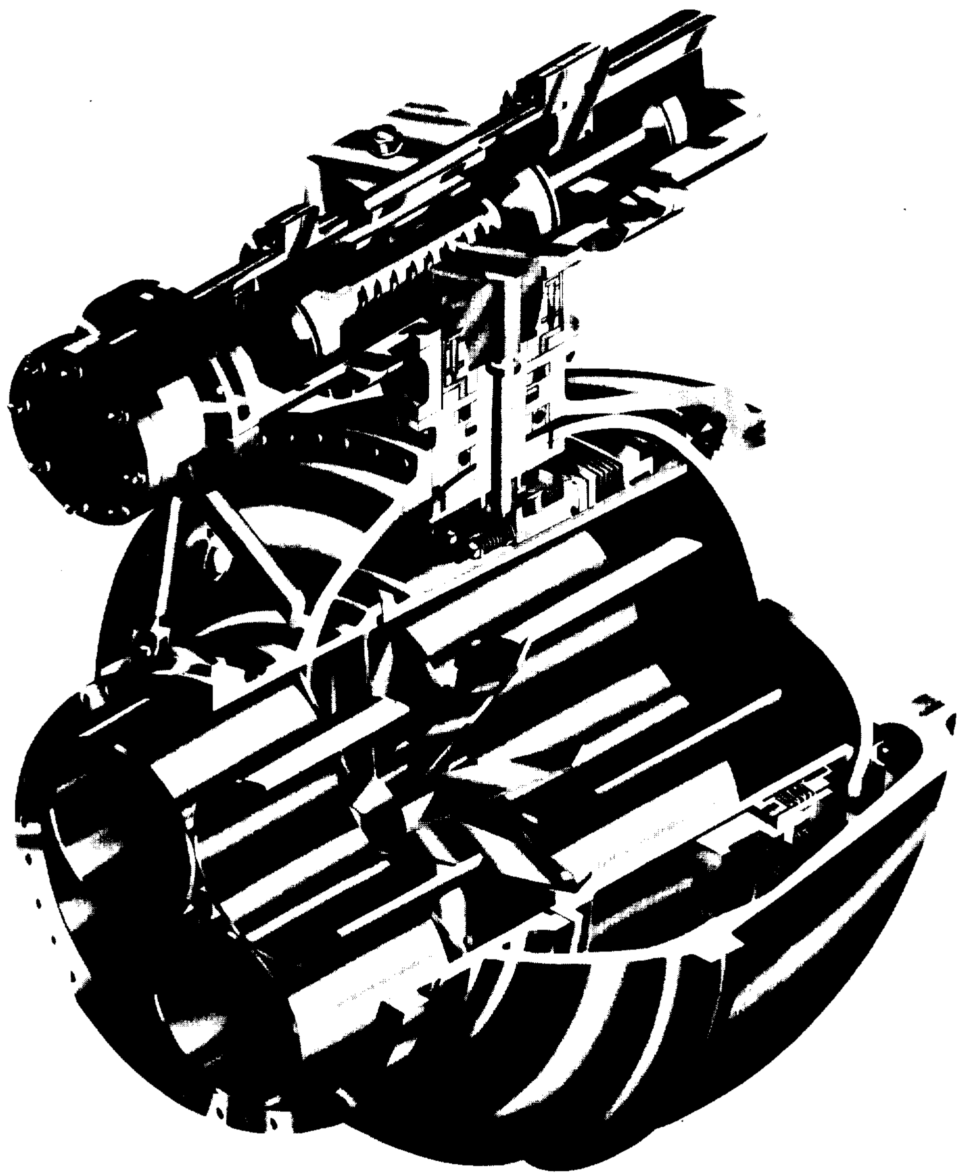


FIGURE 21. LOX PREVALVE, S-IC

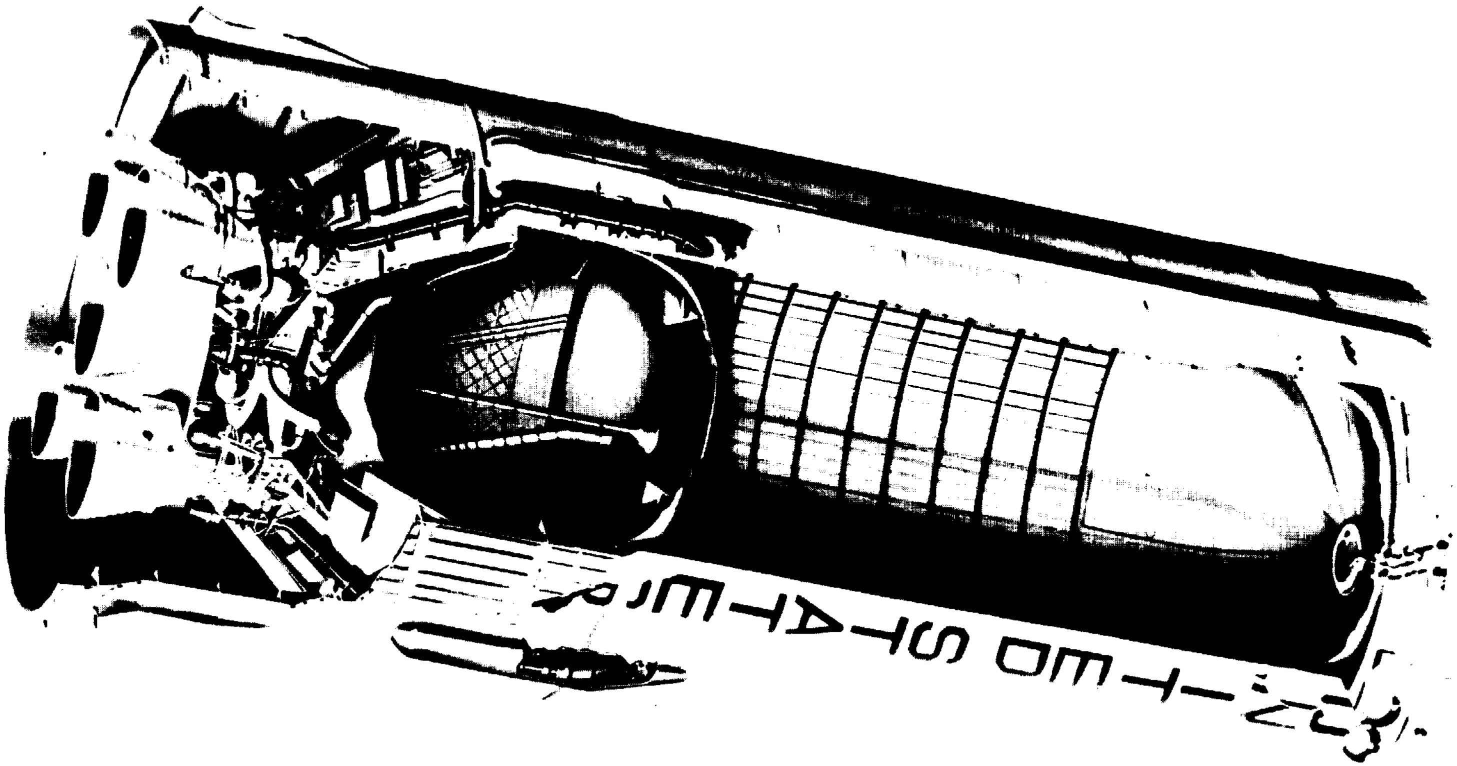


FIGURE 22. S-II STAGE

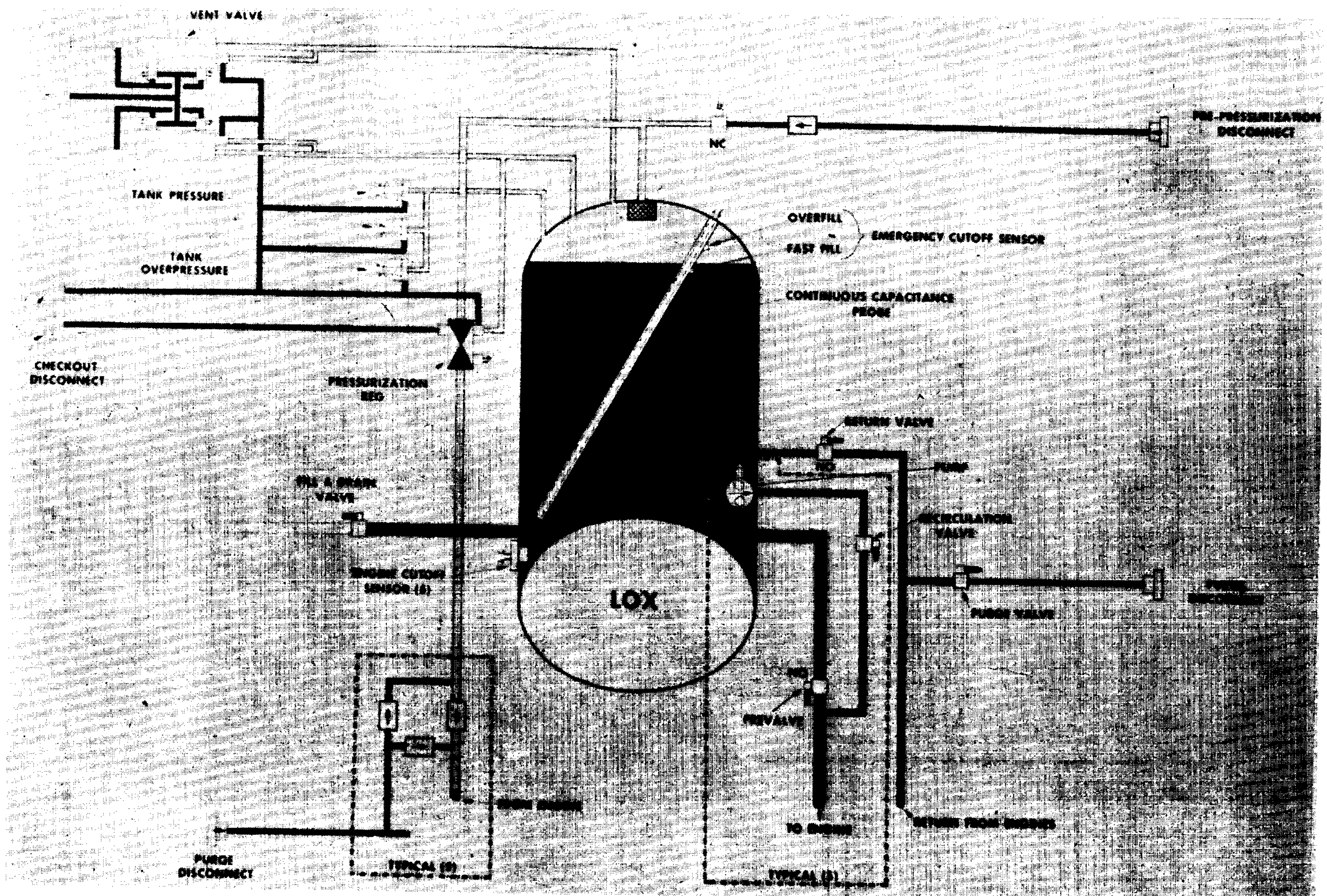


FIGURE 23. LH_2 SYSTEM SCHEMATIC, S-II STAGE

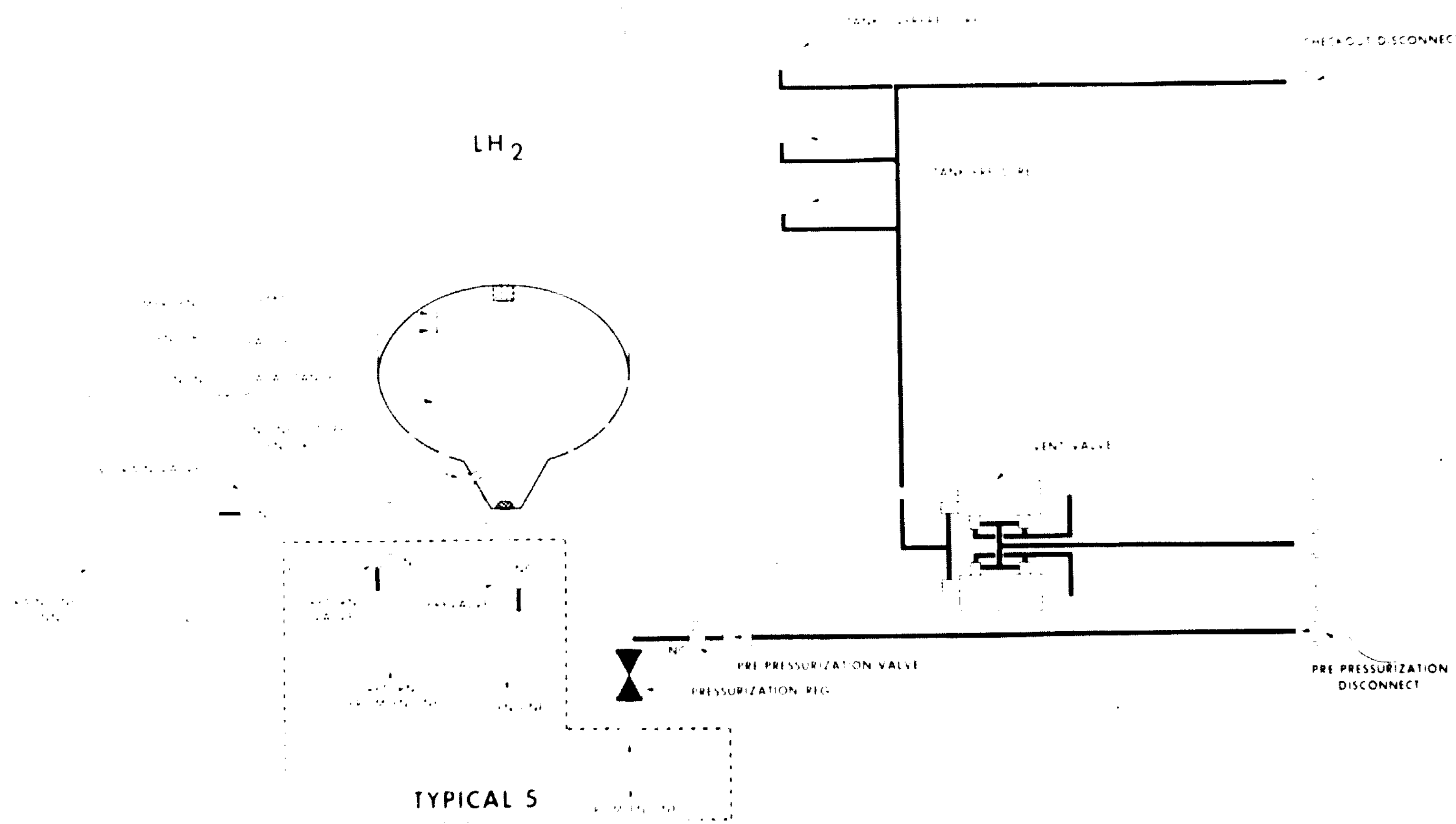


FIGURE 24. LOX SYSTEM SCHEMATIC, S-II STAGE

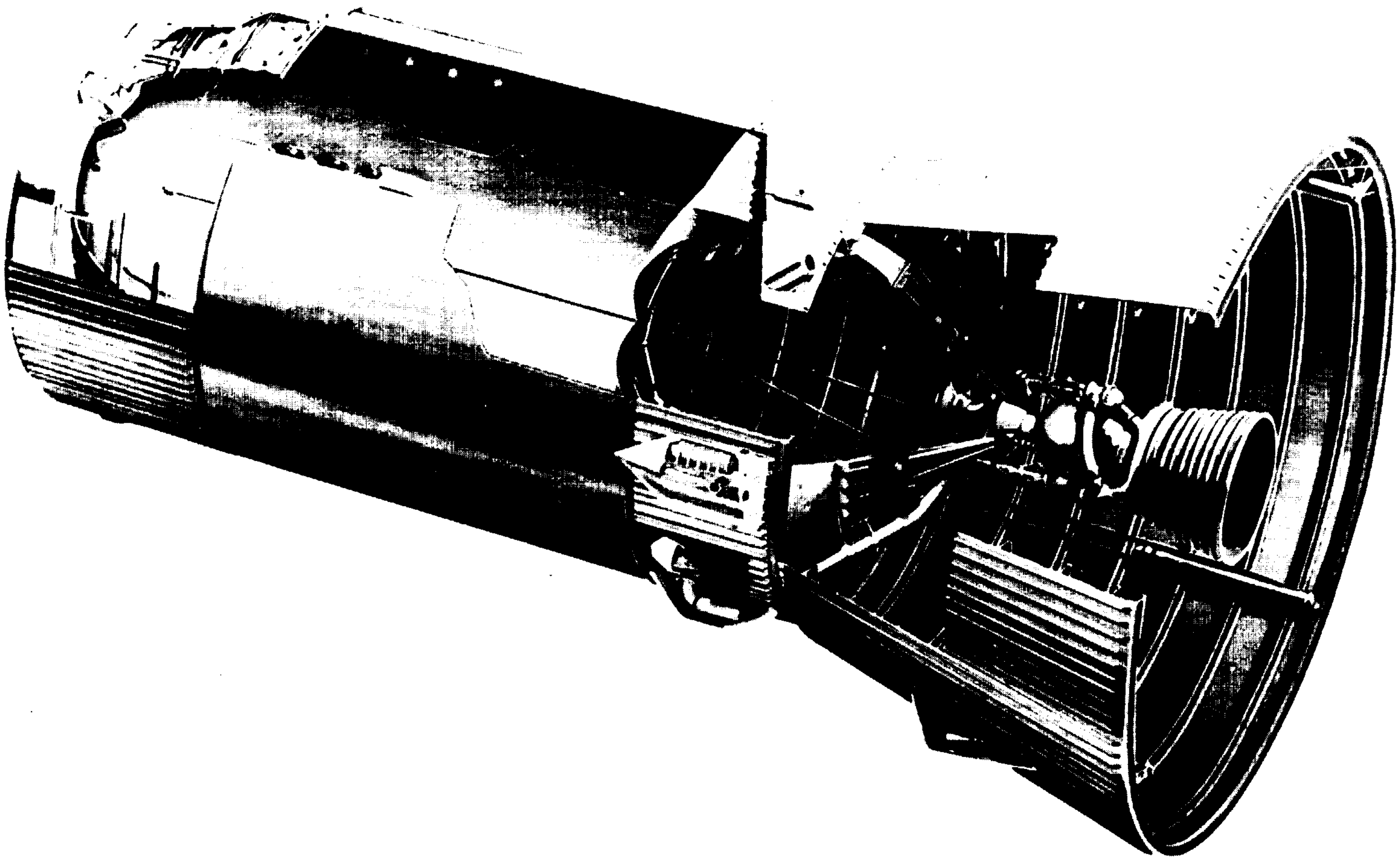


FIGURE 25. S-IVB STAGE

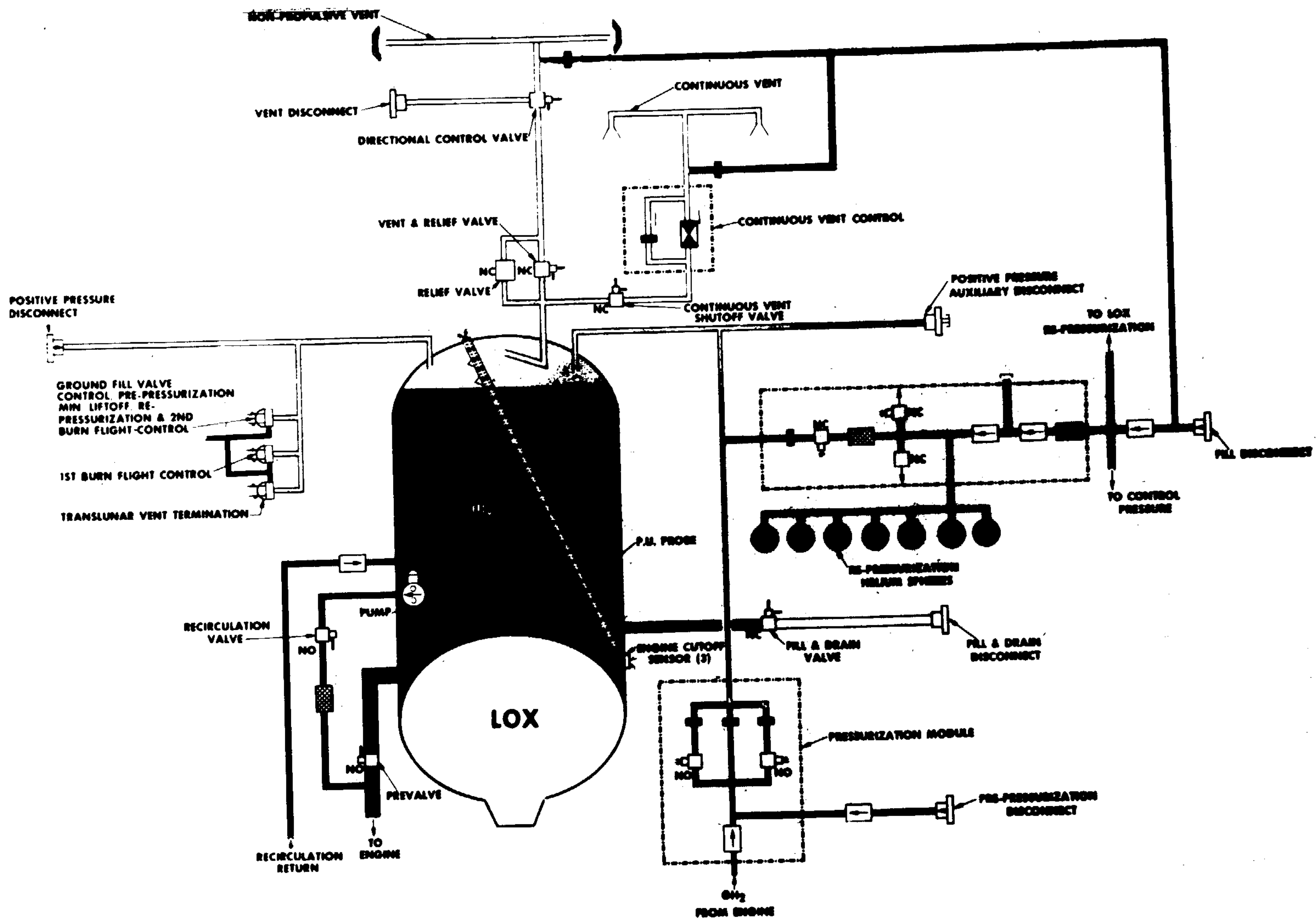


FIGURE 26. LH_2 SYSTEM SCHEMATIC, S-IVB STAGE

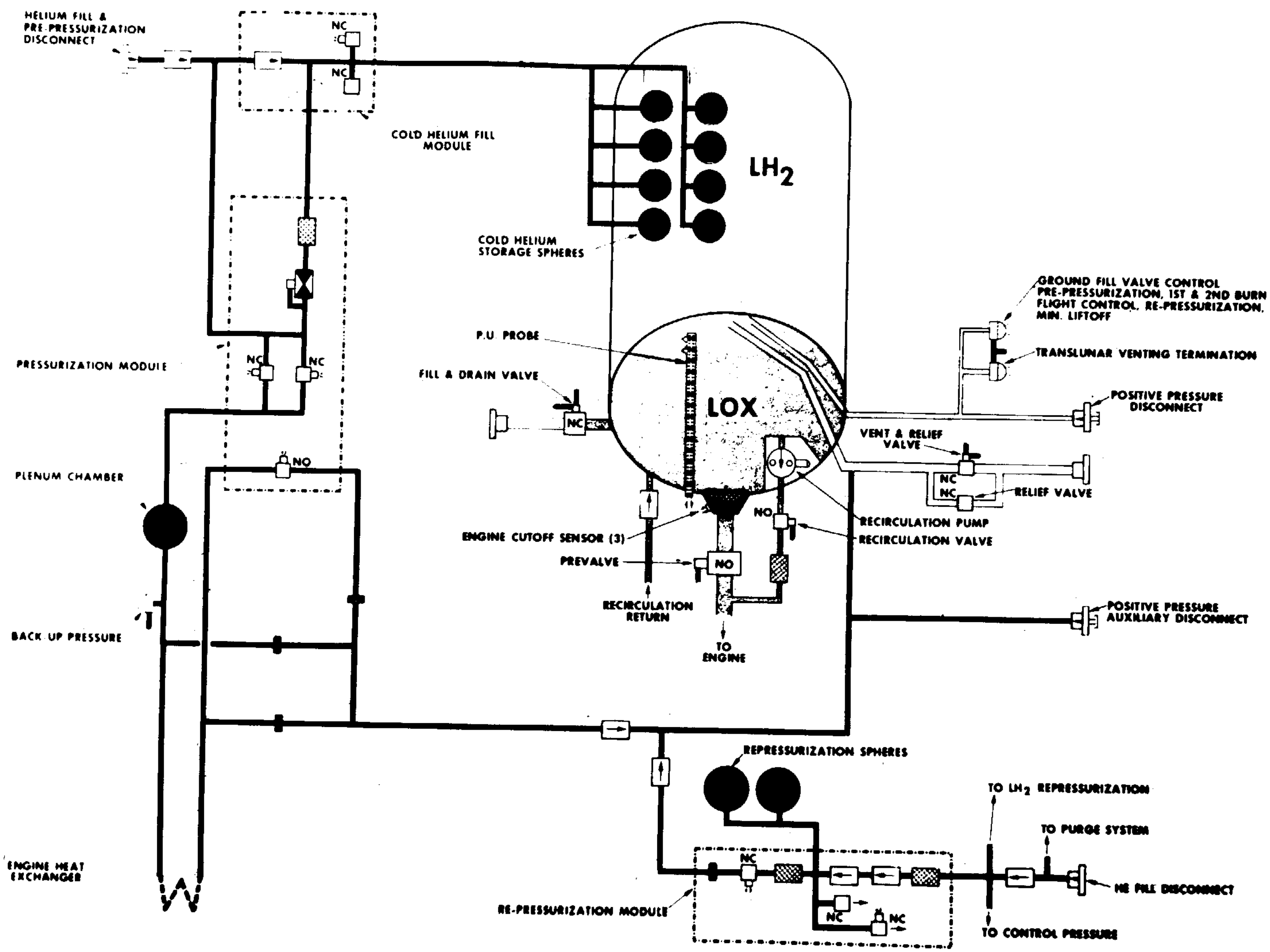


FIGURE 27. LOX SYSTEM SCHEMATIC, S-IVB STAGE

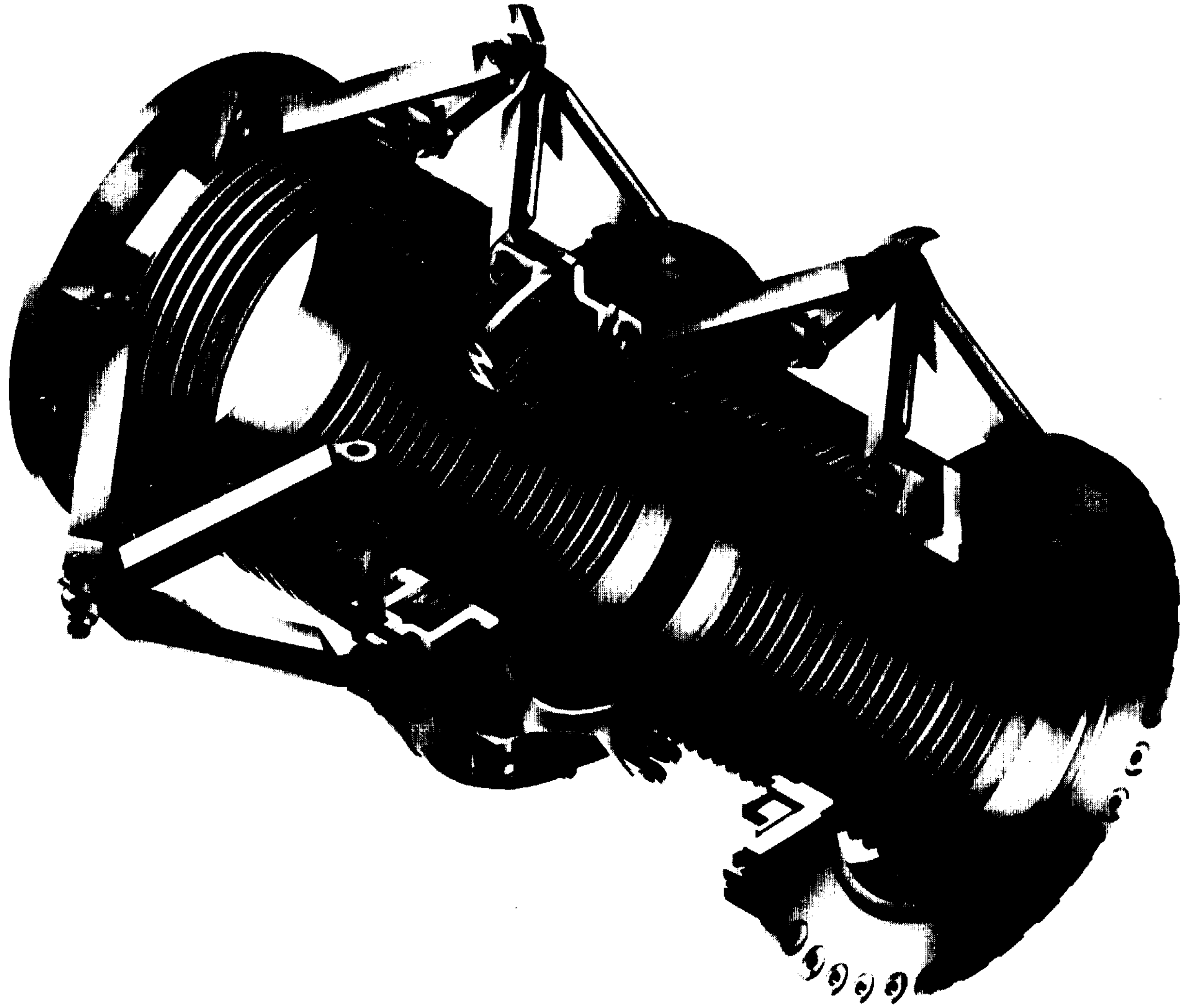


FIGURE 28. J-2 LOX SCISSORS DUCT

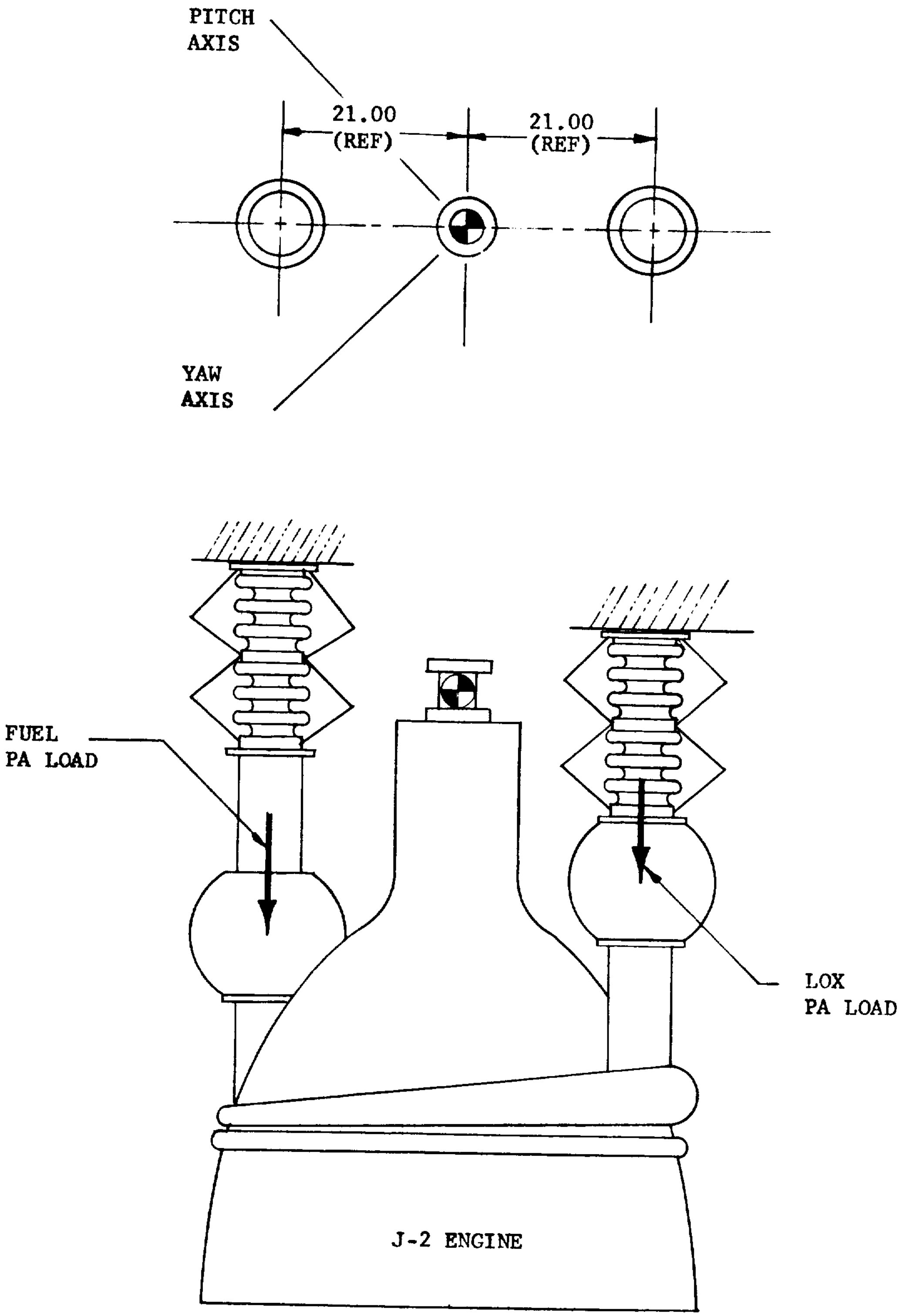


FIGURE 29. J-2 ENGINE, LOAD BALANCE DIAGRAM

November 4, 1966 APPROVAL TM X-53532

PROPELLANT FEED DUCTING AND ENGINE GIMBAL LINES FOR THE SATURN VEHICLES

By P. L. Muller, Jr.

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This document has also been reviewed and approved for technical accuracy.

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