STUDENT STUDY GUIDE

AIR TRAINING COMMAND

MISSILE LAUNCH/MISSILE OFFICER (SM-65F)

PROPULSION SYSTEM

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COURSE OZR1821B/3121B-4

TECHNICAL TRAINING

FOR INSTRUCTIONAL PURPOSES ONLY

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PROPULSION SYSTEM

OBJECTIVE

To familiarize the student with the operation and inspection of the MA-3 propulsion system. To give an understanding of the launch control and checkout utilized on this system.

SECTION I

PRINCIPLES OF LIQUID PROPELLANT ROCKET ENGINES

INTRODUCTION

In order to have a basic understand of the propulsion system, the fundamentals of a rocket engine will be discussed briefly. People have been experimenting with propulsion as far back as the 15th century. There were many ideas presented, even though in a crude form as compared to our modern display of rocket engines. Several have been developed in the past, however, it was not until during World War II that the Germans developed the most advanced rocket for that time known as the V2. From the knowledge obtained through the experimental rockets over the past several hundred years we were able to develop the present propulsion systems now in use.

BASIC THRUST CHAMBER

Before attempting an analysis of a particular rocket engine, one should have a basic understanding of the rocket propulsion principle. Once the underlying principles are understood, it becomes relatively simple to make specific applications to any rocket engine system.

The fundamental principles upon which all propulsion is based (rotary, propellar, jet, or rocket) was brought out in 1686 by an Englishman, Sir Isaac Newton. In his third law of motion, Newton said, "For every action there is an equal and opposite reaction".

If we produced a hollow steel sphere, provided it with a spark plug (igniter), and charged it with a combustible mixture (gasoline and air), we would have a crude bomb. Upon igniting the mixture, hot gases under high pressure would be generated instantaneously. This action exerts an equal pressure in all directions. Pressure at any one point on the internal wall of the sphere will be exactly equal to the pressure applied at a point on the opposite wall. Rupture of the completely closed sphere would of course result. However, should we remove the plug at the same instant that the mixture was ignited, the combustion gases would rush out of the hole (Figure 1). This would produce an unbalance of forces resulting in movement of the sphere in the direction opposite of the opening. This force would be the product of the combustion pressure in pounds per square inch

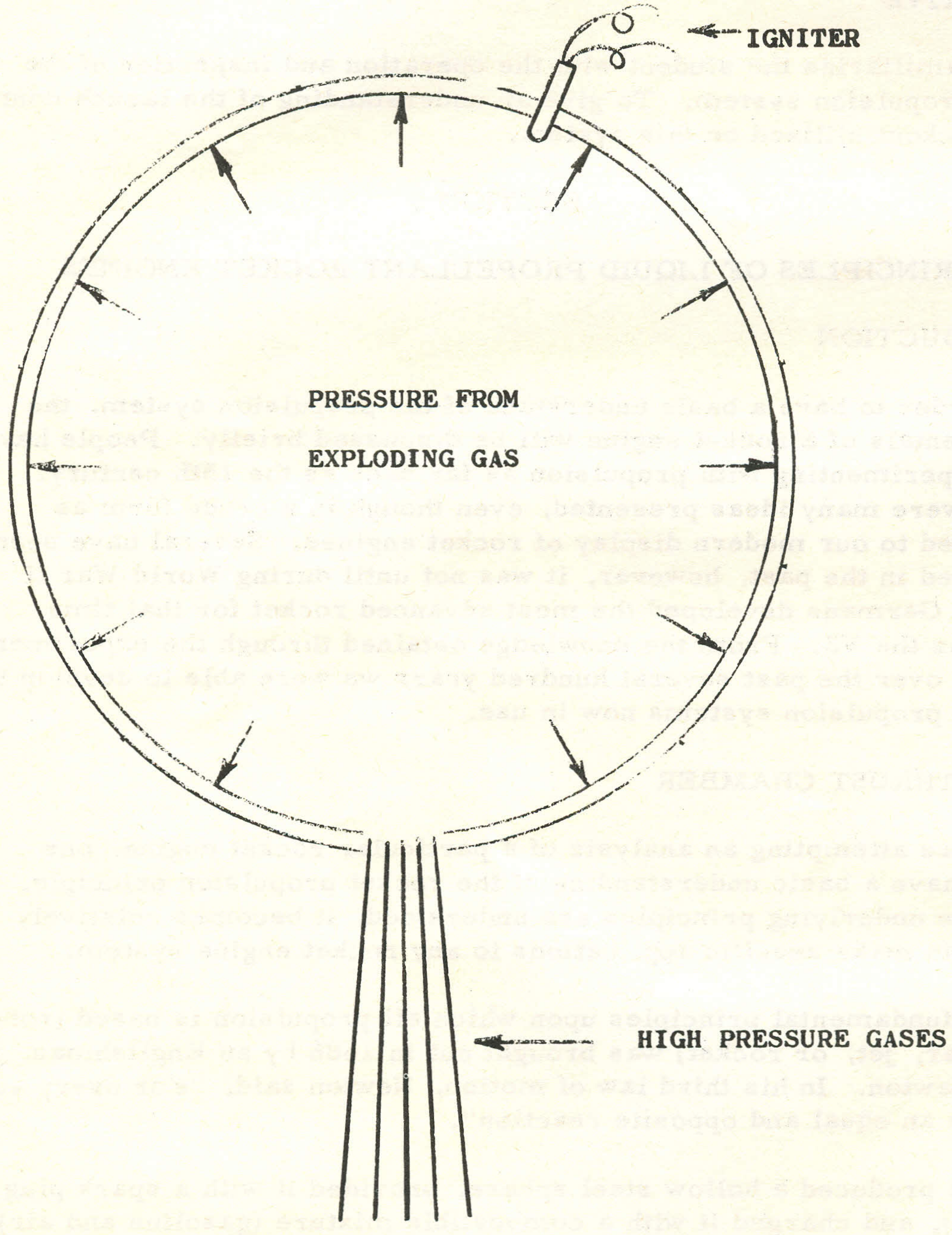


Figure 1 Crude Thrust Chamber

and the area in inches of the wall directly opposite of the opening.

With this theory in mind, to obtain continuous propulsion, the sphere (combustion chamber) must be provided with propellants. By attaching a thrust chamber to two propellant feed tanks, (one for fuel and one for oxygen) the propellants can be fed to the thrust chamber for continuous operation. In order to inject the propellants, the supply tank pressures must be greater than the combustion chamber pressure. A continuous stream of propellants is then delivered, preventing decay of the propulsive force.

The combustion chamber is an enclosure in which the transformation of energy from potential to kinetic form occurs. Simple geometric shapes such as the cylinder and sphere are most common in the design and manufacture of the chamber. The length and diameter must be such as to produce a chamber volume most suitable for complete and stable combustion. The chamber length and nozzle exit diameter are determined by the propellants to be used. The chamber and nozzle exit must be designed to produce the proper gas velocity and pressure at the nozzle exit when a given propellant is used. Depending upon the type of propellant used, the combustion chamber may also contain an injection system and ignition system.

The ignition system consists of a hypergolic fluid. A hypergol is a compound that is instantaneously combustible upon contact with oxygen. When the hypergolic fluid comes into contact with liquid oxygen, ignition is achieved.

The exhaust nozzle is a nonuniform chamber through which the gases generated in the combustion chamber flow to the outside. In the nozzle, the most important areas to be considered are the cross-section at the mouth, the throat, and the exit. These areas are indicated in Figure 2.

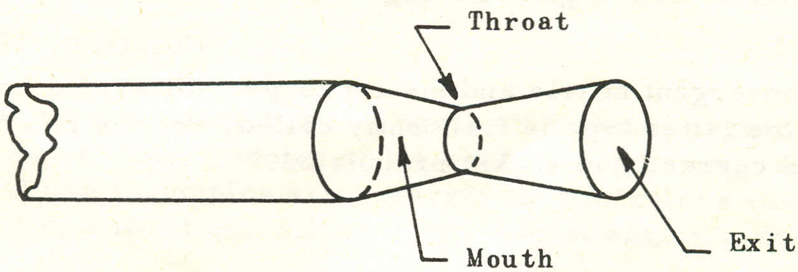


Figure 2 Exhaust Nozzle

The function of the nozzle is to increase the velocity of the gases under conditions of steady flow. The weight of the gases passing any cross-section in unit time is constant (Bernoulli's theorem); thus, in the case of subsonic flow, the velocity of the gases must increase if the cross-section is constricted at some point and the weight rate of flow stays constant. If the cross-section becomes wider, the velocity of the gases decreases. This relation of cross-section to velocity holds true for subsonic flow of gases but is not true for gases flowing at supersonic speeds.

To obtain a supersonic exhaust velocity, currently used rocket engines combine the convergent and divergent configurations. The exhaust nozzle first converges to bring the subsonic flow up to the local speed of sound, and then, at the right instant, the nozzle diverges, allowing the gases to expand. The expansion produces supersonic flow, as indicated in Figure 3.

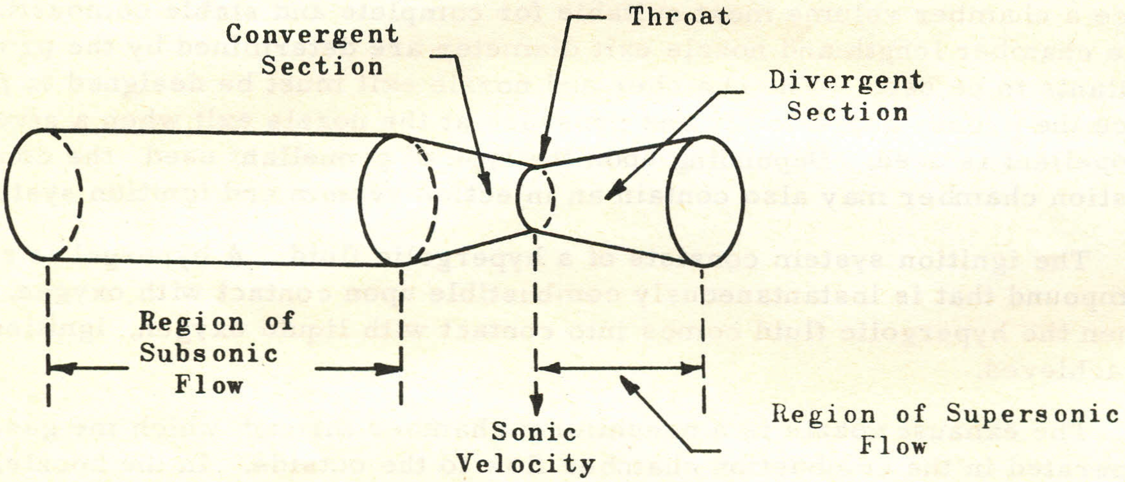


Figure 3 Convergent-Divergent Exhaust Nozzle (DeLavel)

The convergent nozzle and the convergent-divergent nozzle, or DeLavel as the latter type is frequently called, are the two main types of nozzles used currently in rocket propulsion.

SUMMARY

The basic thrust chamber consists of a combustion chamber, throat section, and thrust chamber exit. This is normally referred to as a convergent- divergent exhaust nozzle or DeLavel type. In the combustion chamber the gases reach a subsonic velocity, in the throat section a sonic velocity and in the exit they reach a supersonic velocity. Therefore, applying Newton's third law of motion, "For every action there is an equal and opposite reaction" the thrust chamber would be capable of lifting a mass.

QUESTIONS

1. What three sections make up a basic thrust chamber?

2. Explain Newton's third law of motion.

3. What type nozzle is the convergent-divergent nozzle?

4. What propellants must be present for a thrust chamber to perform?

5. What is the purpose of the divergent section of the exhaust nozzle?

SECTION II

BOOSTER ENGINES

INTRODUCTION

The booster rocket engines, LR89-NA-5 is a device used to provide thrust for accelerating a missile from launch to flight velocity. When its function is completed the engines will be separated from the missile.

The engines are a fixed-thrust, liquid bi-propellant engine, regeneratively cooled by its fuel, and embodies gimbaling capabilities for thrust vector control. The major components of the engine consists of a thrust chamber, a turbopump, a gas generator, and various control valves. Interconnection between these components consists of pneumatic lines, fuel control lines, propellant ducting, propellant lines, lube oil lines, and electrical cables.

The thrust chamber is independently attached to the booster structure with a gimbal support bracket. This bracket, in conjunction with a turbopump support arm, provides for support of one side of the turbopump and gives indirect support to the gas generator and the turbine exhaust duct. The turbopump receives support for its other side through an attach point at the missile structure.

Approximate overall dimensions of each booster is 133 by 48 inches. Dry weight of model A20 exhaust duct is 1,382 pounds and model A21 is 1,420 pounds.

The number one booster turbopump incorporates a vickers type hydraulic pump. It is a constant speed variable displacement pump. The only hydraulic operation in the booster system is powering thrust chamber gimbal actuators.

Each booster thrust chamber produces approximately 165,500 ±3% pounds of thrust at sea level for a total of 331,000 pounds of thrust. The maximum run time for the booster engines is 145 seconds. The boosters were designed to provide major thrust at launch and initial acceleration at low altitudes.

COMPONENTS

The booster engine structure and components will be discussed individually as to their structure, and purpose that each one serves in the system. Since both booster engines are identical in construction except for the heat exchanger on the number two booster, all references will be made on the number two booster.

Thrust Chamber

The thrust chamber (Figure 4) generates the thrust for which the engine is designed. The thrust chamber body consists of 292 nickel tubes with a wall thickness of .012 of an inch. The tubes are rectangular in shape and are joined together by silver brazing and reinforcement tension bands. They are fastened together so that their configuration makes up the bell shape of the thrust chamber. The thrust chamber can be divided into three sections for explanation. First is the combustion chamber where the propellants are ignited. Since this would be the hottest area, the outside of the combustion chamber is wrapped with a fiberglass winding. The second section is the throat area which develops the thrust to a sonic velocity. Also the external portion of the throat is used as a mount for the outriggers to which the hydraulic actuators are attached for gimbaling of the engines. Third is the skirt or expansion nozzle through which the combustion gases are expelled at supersonic velocities.

The tubular construction of the walls permit fuel cooling of the walls. Fuel from the fuel manifold flows down every other tube into a common manifold at the bottom of the thrust chamber. The fuel then returns through the alternate tubes to the injector and is then sprayed into the combustion chamber where it comes into contact with the oxidizer (LOX) for combustion. This circulation of fuel is known as regenerative cooling which results in higher efficiency, due to a lower heat loss from the system.

The booster thrust chambers are located in the thrust section attached to the aft end of the missile. The boosters are designed to be jettisoned during flight to lessen the weight of the missile.

There are fairings and nacelles with fiberglass exteriors around the booster section to protect the thrust chambers from aerodynamic loads and heating. On the aft end of the booster section is a heat radiation shield which protects the engine components from rocket engine exhaust.

Thrust Chamber Oxidizer Dome

The oxidizer dome receives oxidizer from the oxidizer inlet elbow and directs it into the injector. The dome is made of machined aluminum alloy and is bolted directly to the top of the thrust chamber. An oxidizer

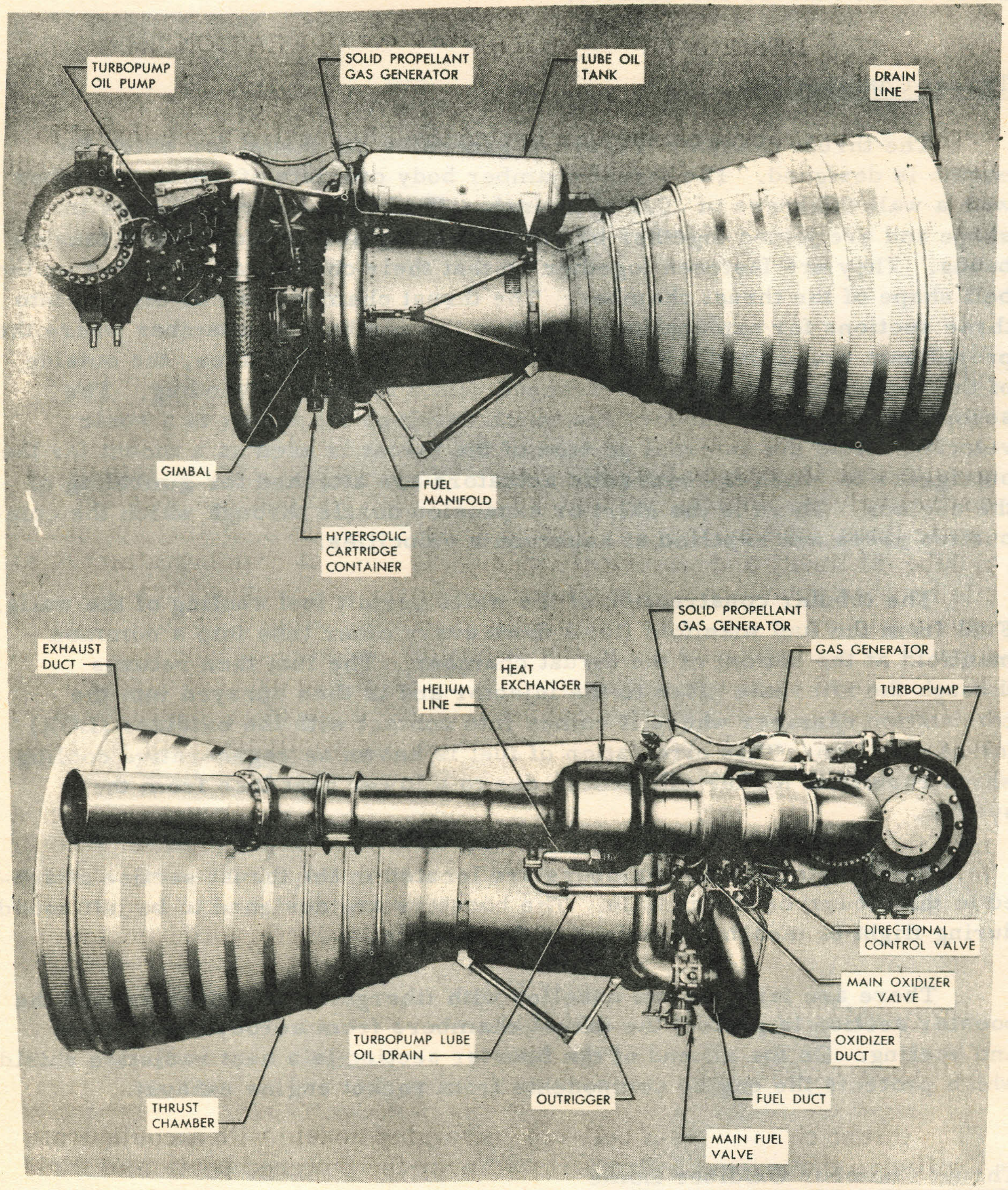


Figure 4 Booster Engine

flow straightener is located in the dome inlet and serves to distribute the oxidizer evenly to the injector. The dome also has a port for purging the oxidizer section of the thrust chamber.

Thrust Chamber Oxidizer Inlet Elbow

The oxidizer inlet elbow is a heavily reinforced bronze casting, stressed for large thrust loads. The elbow has two mounting flanges, one for bolting the elbow to the thrust chamber oxidizer dome and one for mounting the main oxidizer valve. The top of the elbow is machined to fit the gimbal bearing and is bolted to four integral lugs on each elbow. The inlet elbow directs the oxidizer from the oxidizer valve to the flow straightener in the center of the oxidizer dome. It will transmit the engine thrust load to the gimbal mount since the top surface of the elbow is machined to fit the thrust chamber gimbal.

Thrust Chamber Gimbal

The gimbal bearing is a cross-bearing journal type universal connection constructed of steel. It is located between the oxidizer inlet elbow and the missile structure. The gimbal transmits thrust loads from the thrust chamber to the missile and permits pivotal movement of the line of thrust for directional control. The maximum angle of displacement of the thrust vector from the normal through the planes of the gimbal axes is approximately 6.0 degrees. The gimbal is attached to the oxidizer inlet elbow with four bolts and to the gimbal support bracket with four bolts. The gimbal support bracket is, in turn, secured to the missile structure by six bolts.

Thrust Chamber Propellant Injector

The propellant injector (Figure 5) is constructed of steel and is nickel plated. It controls the entry of propellants into the combustion chamber and provides for the expulsion of propellants in impingement patterns for the most effective combustion. The impingement is in a like-on-like pattern which means fuel on fuel and oxidizer on oxidizer. Fuel and oxidizer are kept separated by distribution through alternate rings until impingement takes place. Propellants are passed through the injector via alternate fuel and oxidizer rings. Radial passages lead from the return tubes of the body to the fuel rings of the injector, while the oxidizer simply passes through the injector from the oxidizer dome area. The injector is held in place between the oxidizer dome and the fuel manifold by the same bolts which secure the oxidizer dome.

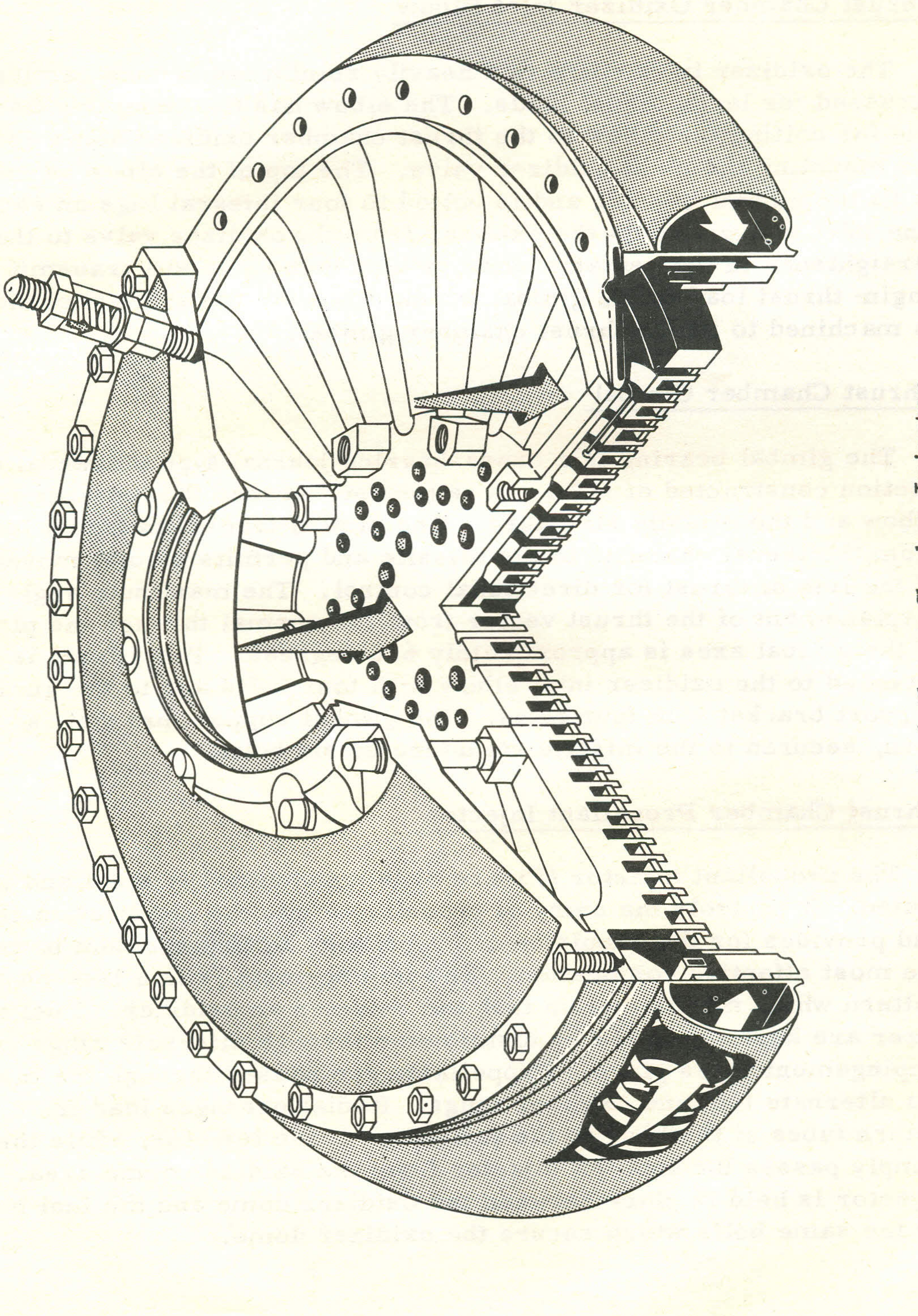


Figure 5 Typical Thrust Chamber Injector

Main Oxidizer Valve

The main oxidizer valve (Figure 6) is a four inch gate type valve. There are two functions of the main oxidizer valve. One, to control the oxidizer flow to the thrust chamber dome and the other to mechanically control the opening of the fuel ignition valve.

In the normal position, the valve is closed by spring action only. During ignition stage, fuel is routed to the opening port of the valve actuator. When the fuel pressure is sufficient, the valve will start opening. Due to cam action, the fuel ignition valve will begin to open as the main oxidizer valve reaches $74^{\circ} \pm 4^{\circ}$ from the closed position. During mainstage the main oxidizer valve remains open, and also holds the fuel ignition valve in the open position. At booster engine cutoff the opening fuel pressure is vented, and fuel pressure is applied to the closing side, forcing the valve closed, which will allow the ignition fuel valve to close. The main LOX valve blanket heater will be de-energized during standby, energized at the beginning of countdown, de-energized by electrical signal that starts the booster engines (Figure 18).

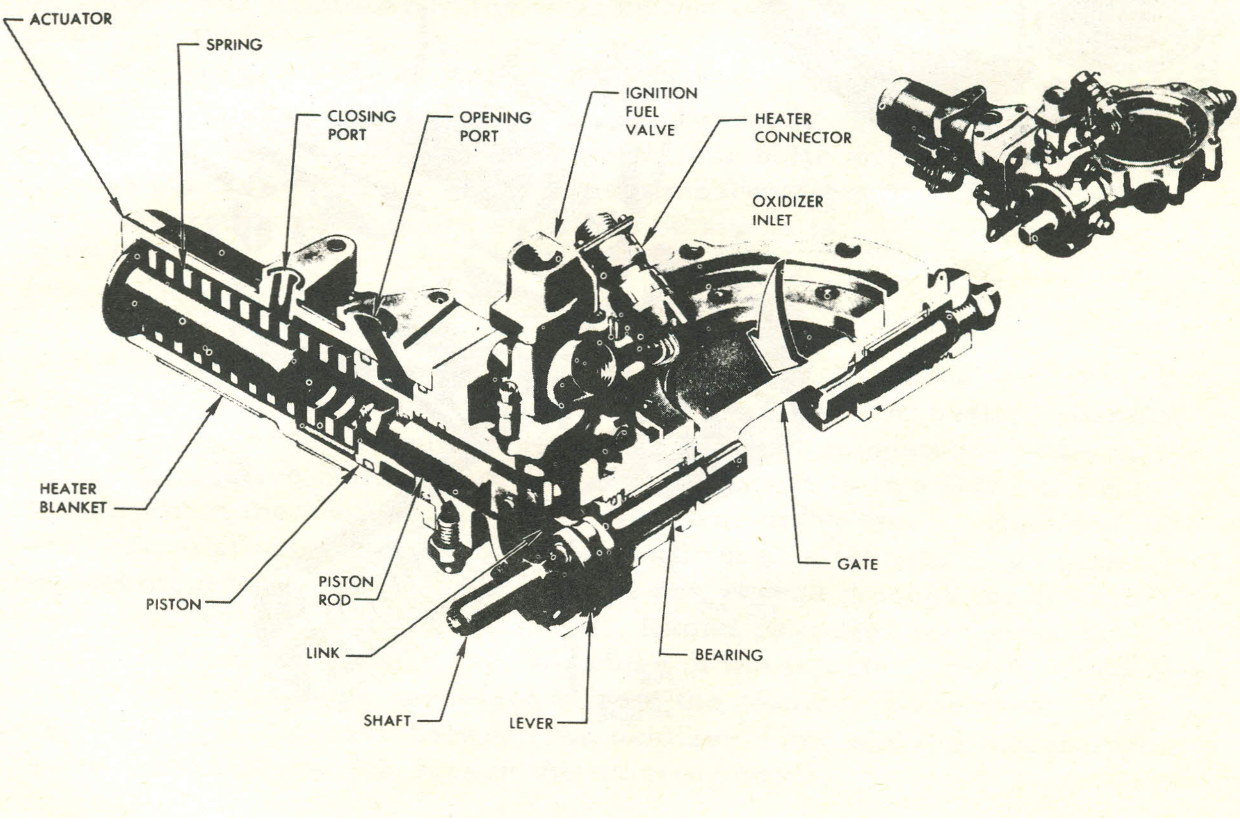


Figure 6 Main Oxidizer Valve

Main Fuel Valve

The main fuel valve (Figure 7) is a four inch butterfly gate-type valve installed on the flange of the thrust chamber fuel manifold inlet elbow and is connected to the turbopump with ducting. Its function is to control the fuel flow to the thrust chamber fuel manifold. In the normal position, the valve is closed and is held in the closed position by spring action only. During ignition stage, fuel pressure breaks the hypergol diaphragms and flow to the main fuel valve opening port. The fuel pressure drops as soon as the hypergolic diaphragms burst, then it builds up again on the opening side of the main fuel valve. When it has built up to sufficient pressure the valve is fully open

During mainstage the booster main fuel valve remains open. At booster engine cutoff, the main oxidizer valve closes allowing the ignition fuel valve to close, thus cutting off opening fuel pressure to the main fuel valve. As pressure depletes, the spring tension closes the main fuel valve.

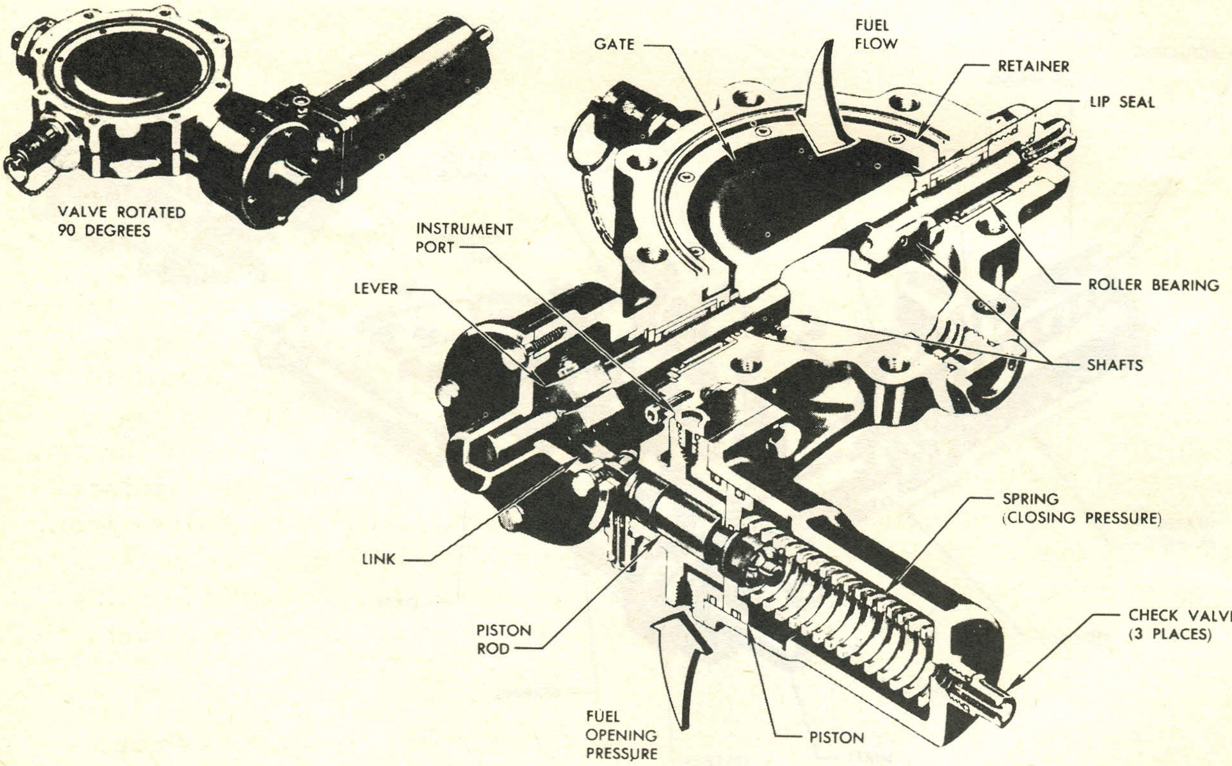


Figure 7 Main Fuel Valve

Liquid Propellant Gas Generator

The liquid propellant gas generator (Figure 8) provides the high pressure gases to drive the turbopump turbine. It consists of a gas generator oxidizer valve, a gas generator fuel valve, a gas generator propellant injector, and a gas generator combustor. The gas generator is joined to the turbine by an exhaust manifold which directs the hot gases to the turbine wheels.

The gas generator oxidizer valve is a normally closed poppet valve that controls the flow of oxidizer to the gas generator propellant injector.

The gas generator fuel valve is located on the gas generator manifold adjacent to the gas generator oxidizer valve. The valve housing contains a fuel inlet port, a poppet, and a spring to hold the poppet in a normally closed position. Fuel pressure directed into the inlet port forces the poppet against the spring to open the fuel valve. When the valve is opened, the fuel flows through the inlet port into the gas generator propellant injector. Due to mechanical linkage the fuel poppet when opened, will open the oxidizer poppet allowing the oxidizer to flow under pressure to the injector. When fuel pressure decays, spring pressure closes the fuel poppet and oxidizer poppet shutting off the gas generator.

The gas generator propellant injector is installed between the manifold housing body and the combustion chamber and incorporates propellant outlet passages spaced and angled so that propellants impinge within the combustion chamber. The passages are drilled in groups with fuel streams impinging on oxidizer streams. This is known as unlike impingement. There is an outer ring of fuel passages for cooling the combustion chamber wall. Oxidizer from the gas generator control valve, enters the injector through the oxidizer passage in the center of the gas generator manifold housing and the hollow mating cone of the injector. Fuel from the gas generator valve enters the injector through radially drilled holes in the injector at the perimeter of the cone base. Packing between the oxidizer manifold and the injector cone isolates and prevents fuel and oxidizer from contacting one another. Should any oxidizer or fuel leak past the packing it is vented to atmosphere through a vent passage in the manifold housing. The function of the injector is to bring fuel and oxidizer together at the proper place and ratio for ignition and burning.

The gas generator combustor is nearly teardrop in shape. Propellants flow through the injector into the combustion chamber where they are mixed and burned to furnish the hot gases for turbine operation. The exhaust manifold is joined to the combustor hot-gas outlet with the injector and fuel manifold housing bolted to the propellant inlet mounting flange.

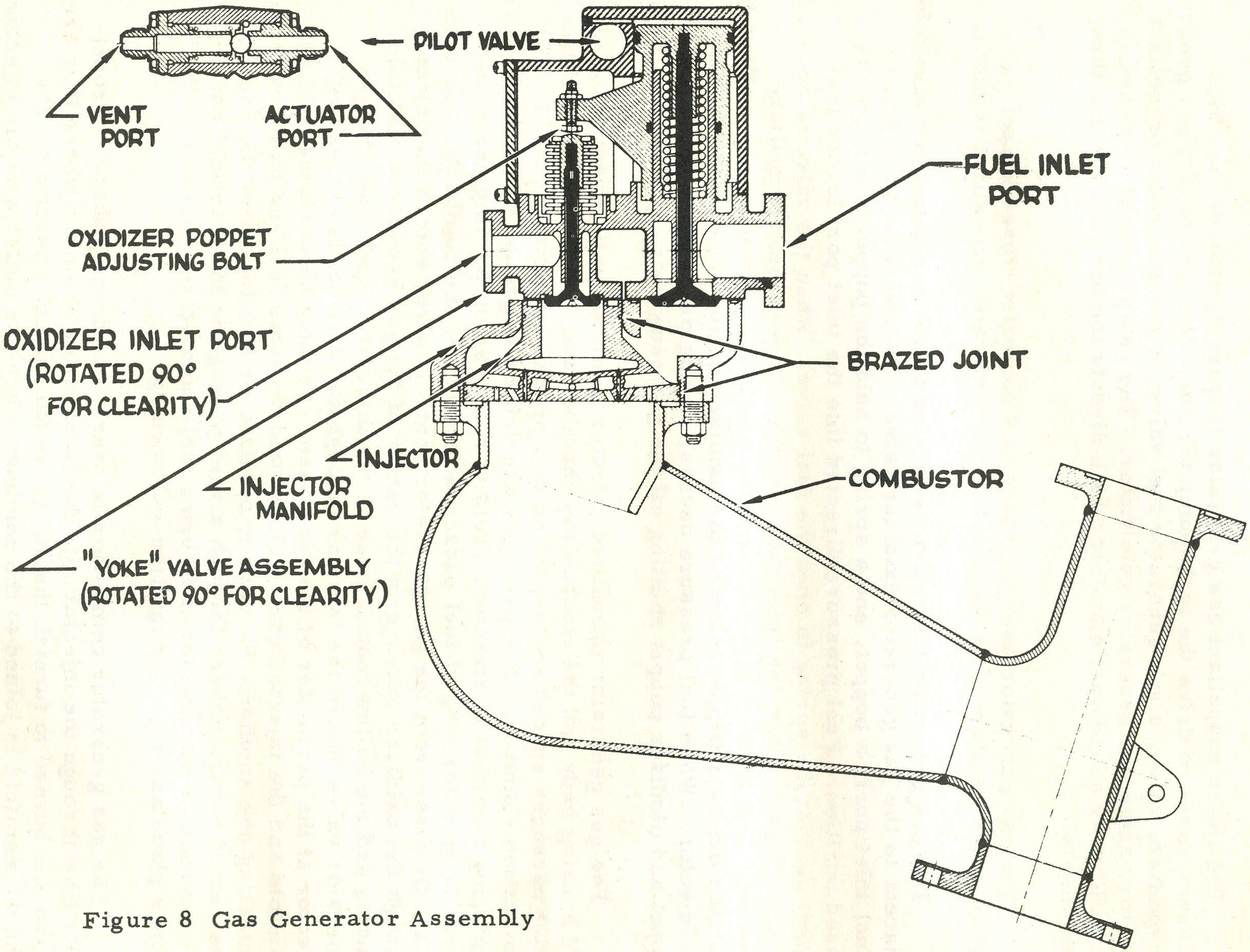


Figure 8 Gas Generator Assembly

Gas Generator Igniter

The gas generator igniter (Figure 9) is an electrical device used to initiate burning of the propellant mixture in the combustion chamber of the liquid propellant gas generator. This unit consists of a pyrotechnic squib and a pyrotechnic igniter. At the proper time, the squib is ignited by a 28V DC signal and the burning squib ignites the pyrotechnic igniter. The pyrotechnic burns from 3. 0 to 3. 5 seconds at 275 PSI. When the fuel and oxidizer enter the combustion chamber from the gas generator injector, they combine burning the igniter causing combustion to occur.

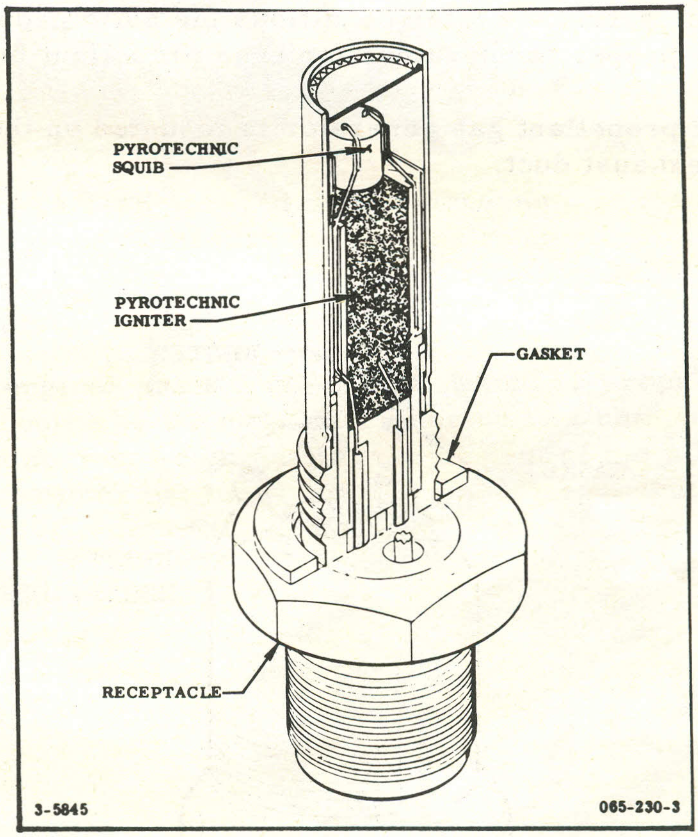


Figure 9 Gas Generator Igniter

Solid Propellant Gas Generator

The purpose of the solid propellant gas generator (Figure 10) is to generate hot gases for initially starting the turbopump turbines. The gas generator assembly incorporates a solid propellant cartridge, pyrotechnic igniter pellets, two initiators, a burst diaphragm and an electric heater. When the gas generator is sequenced into operation the initiators are fired which ignites the pyrotechnic pellets and in turn the pellets will ignite the solid propellant grain. As a result of the propellants burning there will be a pressure increase in the container and the diaphragm will rupture, allowing the hot gases to flow to turn the turbopump turbine. The turbine will be accelerated for 1.2 seconds by the solid propellant gas generator while in the meantime the liquid propellant gas generator will come into operation. The cartridge heater conditions the solid propellant by keeping the grain at the proper temperature for even propellant burning.

The solid propellant gas generator is mounted on the liquid propellant gas generator exhaust duct.

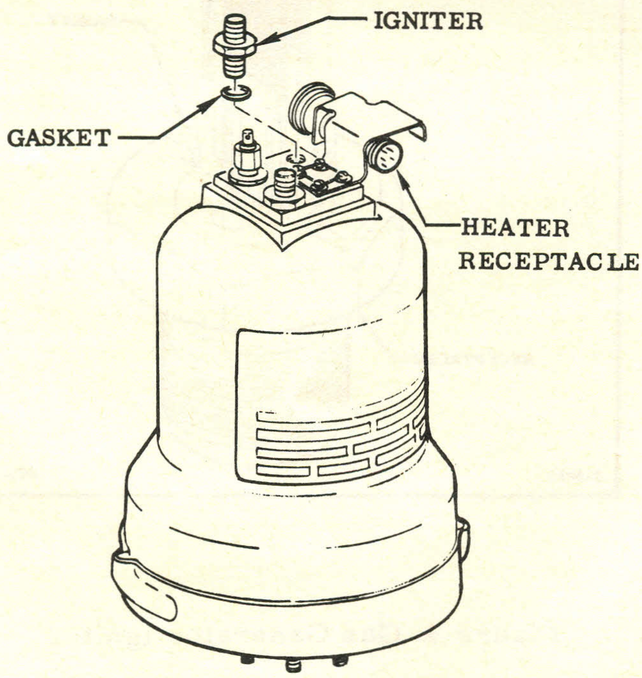


Figure 10   Booster Solid Propellant Gas Generator and Igniter

Turbopump

The purpose of the turbopumps is to supply propellants to the booster engines and liquid propellant gas generator during flight. The turbopump consists of two centrifugal pumps mounted on a common shaft. The turbopump turbine is driven by exhaust gases from the solid propellant gas generator and the liquid propellant gas generator.

The gas turbine is a 2-stage type with shrouded blades to reduce blade flexing.

The reduction gears are full cut, with a reduction ratio of 4.885 from turbine to pumps. The main gear train consists of 4 main gears mounted on 3 shafts. There is a takeoff from the intermediate shaft for driving the accessory driven units. The gearcase is pressurized by back pressure from the turbine exhaust, reflected back to the case through the lube oil overboard line, (approximately 5 PSI).

The oxidizer pump is a single entry, centrifugal-type impeller with a tapered inducer. The inducer takes the oxidizer inlet pressure of 50 PSI and increases it to prevent cavitation of the impeller. The impeller increases the oxidizer velocity and pressure, and slings it to the delivery volute. The outlet pressure is approximately 818 PSI. The shaft seal prevents oxidizer from mixing with the bearing lube oil. The seal cavity is purged overboard through a separate line by means of helium purge.

The fuel pump is the same type as the oxidizer and differs from it only in minor respects. From hub to the outside of the casing the fuel pump has the larger diameter with a small volute cross section. The oxidizer pump, on the other hand, has a small overall diameter and large cross section in the volute. The explanation for these differences is: the mixture ratio is 2.336 to 1 $\pm$15% therefore more oxidizer must be pumped; the fuel on the other hand must travel further (through the thrust chamber tubes for regenerative cooling) so it must have a greater initial velocity and pressure. The fuel pump inlet pressure is 73 PSI and outlet pressure is 872 PSI. Compare this with the oxidizer pump pressures. The fuel pump seals prevent fuel from mixing with the lube oil, however fuel and lube oil are both hydrocarbons and are compatible, so any fuel bypassing the seal passes into the gearcase and is pumped overboard with the lube oil.

Lube Oil Tank

The booster lube oil tank is steel with a capacity of 12.0 gallons.

The tank is filled to 11.75 gallons with lube oil MIL-L-25336 and the remaining 0.25 gallon is ullage space. The lube oil tank is pressurized to 63 PSI from the main missile fuel tank pressure line at the same time the fuel pressure is delivered by the fuel pump. The fuel pressure then overcomes spring pressure in the lube oil tank pressurizing valve and closes the vent, pressurizing the tank and closing the tank overflow drain. When the ullage space is pressurized it will force the oil through a stand pipe up to the lube oil pump which is a gear type pump, putting out a constant volume and pressure. The output rate is 4.5 GPM at 750 PSI. From the lube pump, the output goes to a manifold. The lube pump lags turbopump start by about .05 seconds. From the manifold the flow goes to lubricate the gears at 650 PSI on the unmeshing side, and bearings at 125 PSI on the inner race. This is a one shot lube oil system, in that the oil is not recycled. It is sprayed on once and then dumped overboard. The gearcase is pressurized slightly by back pressure from the turbine exhaust to prevent the lube oil from foaming and reducing its heat transfer ability.

Lube Oil Pressurizing Valve

The oil tank pressurizing valve, Figures 11 and 12, is a fuel pressure actuated valve located on top of the tank. The pressurization of the oil tank and the exit of lubrication oil from the tank is controlled by this valve. In the normal position the valve blocks the flow of pneumatic gas into the oil tank and blocks flow of oil from the oil tank. The valve is made in two parts, one for oil control and one for pneumatic control and is actuated by fuel pressure generated at engine start. The fuel pressure enters the fuel pressure inlet port to a passage common to both valves. One valve when actuated connects the pneumatic pressure inlet port to the pneumatic pressure outlet port and blocks off the vent port. This action pressurizes the oil tank and oil flows to the oil pump.

Directional Control Valve

The directional control valve (Figure 13) is a multiple valve package which will control the closing of the main oxidizer valve. It is a fuel-actuated selector valve that directs control pressure to the opening inlet pressure port of the main oxidizer propellant valve. When a solenoid is energized, a pilot valve incorporated in the package vents pressure on one side of the selector valve piston while it maintains pressure on the opposite side. This unbalanced condition results in the opposing force actuating the selector valve and changing the control pressure flow direction. With the pilot valve energized, pressure is vented from the main oxidizer propellant valve actuator opening port, and, simultaneously, pressure is directed to

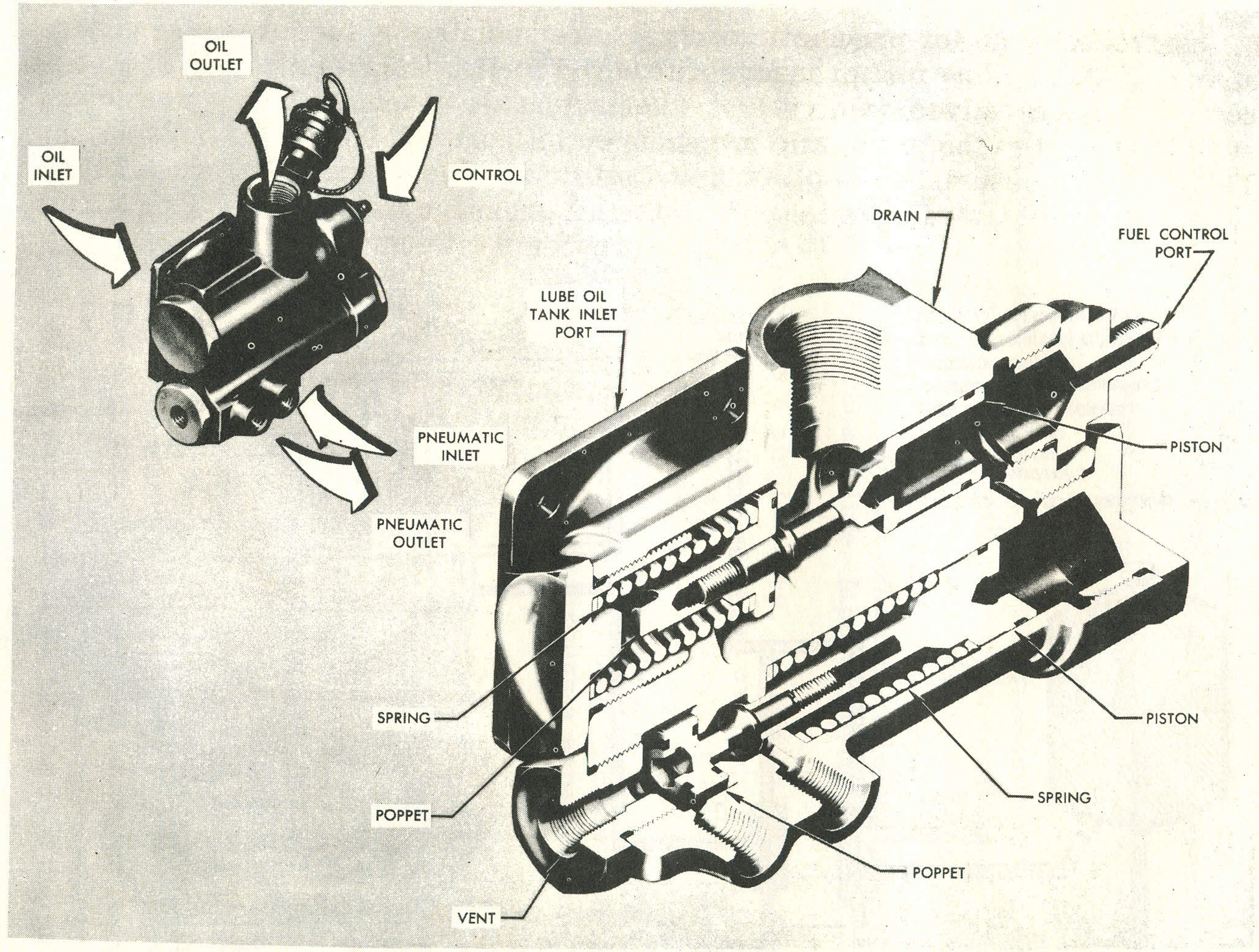


Figure 11 Turbopump Oil Tank Pressurizing Valve

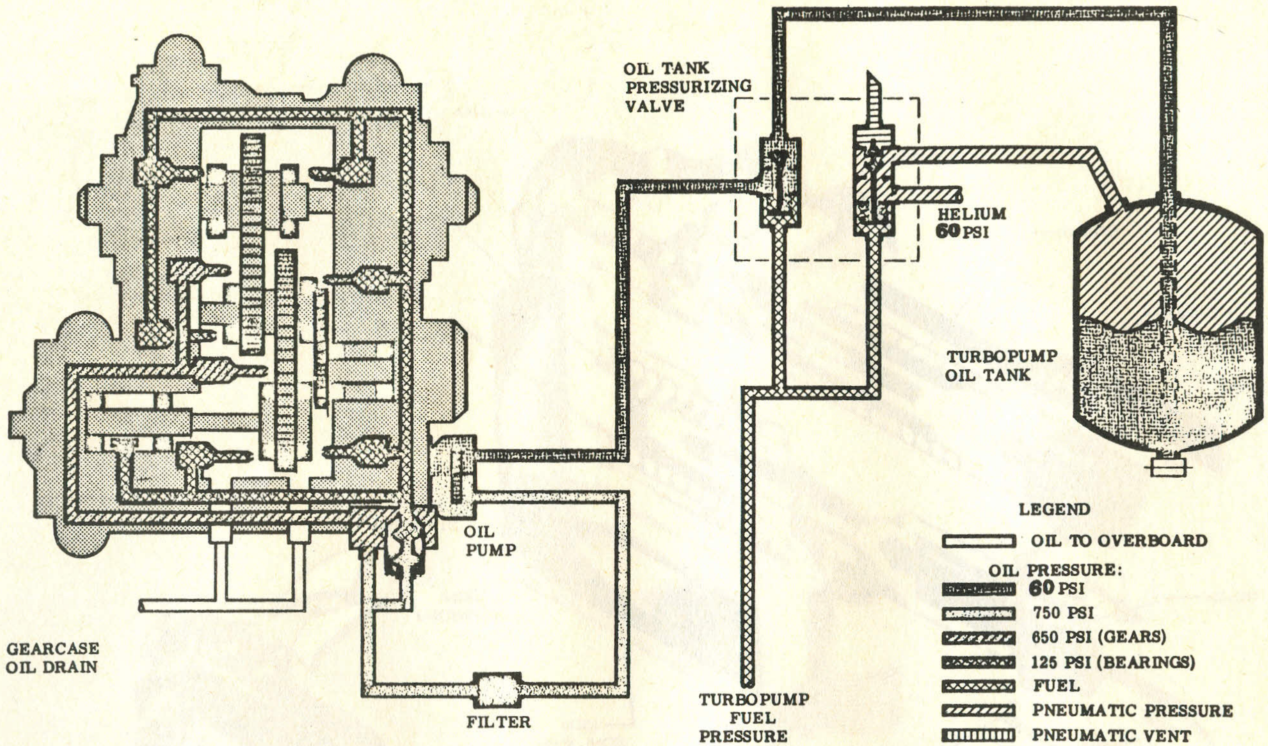


Figure 12 Turbopump Lube System

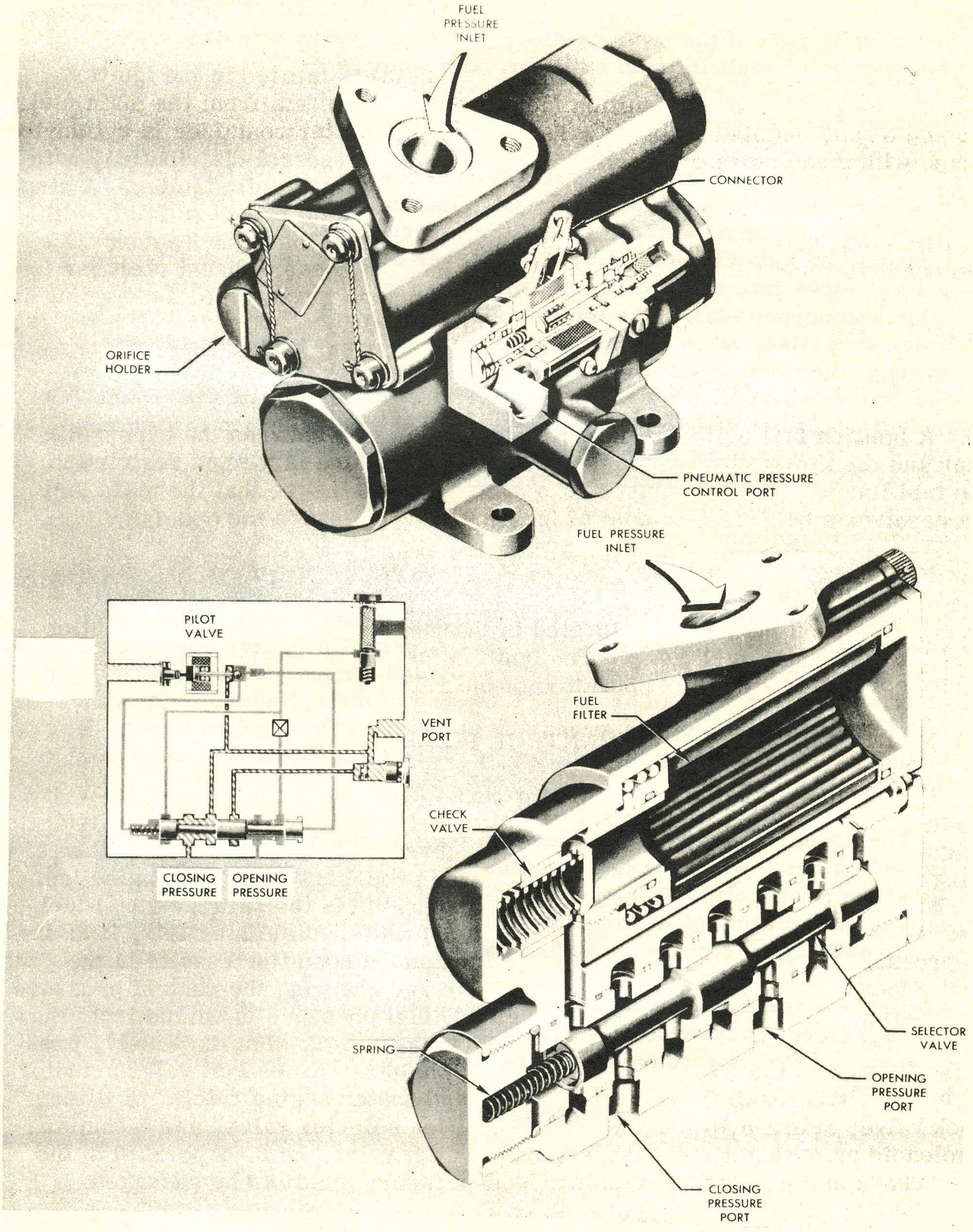


Figure 13 Directional Control Valve

the closing port of the main oxidizer propellant valve actuator. This function will result in main oxidizer valve shutoff.

Ignition Fuel Valve

The ignition fuel valve (Figure 14) controls the flow of fuel from the fuel turbopump, through the hypergolic igniter, to the opening port of the main fuel propellant valve, and the thrust chamber injector. The ignition fuel valve is opened by a cam lever on the main oxidizer propellant valve gate shaft which rotates and lifts the ignition fuel valve stem and poppet seat. The ignition fuel valve closes when the main oxidizer propellant valve closes, and the cam lever rotates to allow the spring in the fuel ignition valve to force the poppet closed. The ignition fuel valve incorporates a thermostatically controlled heater to insure proper operation and to prevent freezing of the valve due to low temperature of the adjoining main oxidizer valve. The thermostatic switch closes the heater circuit to heat the valve (Figure 18).

Hypergolic Igniter

The hupergolic igniter (Figure 15) is located in the ignition fuel line downstream of the ignition fuel valve and upstream from the main fuel valve and thrust chamber injector. The hypergolic igniter container is cylindrical in shape with three ports provided for propellant and hypergol distribution, and with an opening in one end of the cylinder for ignition fuel to enter and the opposite end allows fuel and hypergol to flow to the thrust chamber injector for ignition and also to the main fuel valve for opening pressure.

The hypergol materials are used in the ignition system for a more reliable start. When the ignition fuel valve opens, fuel pressure will burst the hypergol diaphragms allowing the hypergol to enter the injector for ignition and at the same time the pressure will be applied to the opening side of the main fuel valve.

The booster engines use Tri-ethyl-aluminum (TEA) as the hypergol. The hypergol reacts violently with water, acetone, alcohols, acids and chlorinated hydrocarbons, therefore it must be kept in an enclosed container.

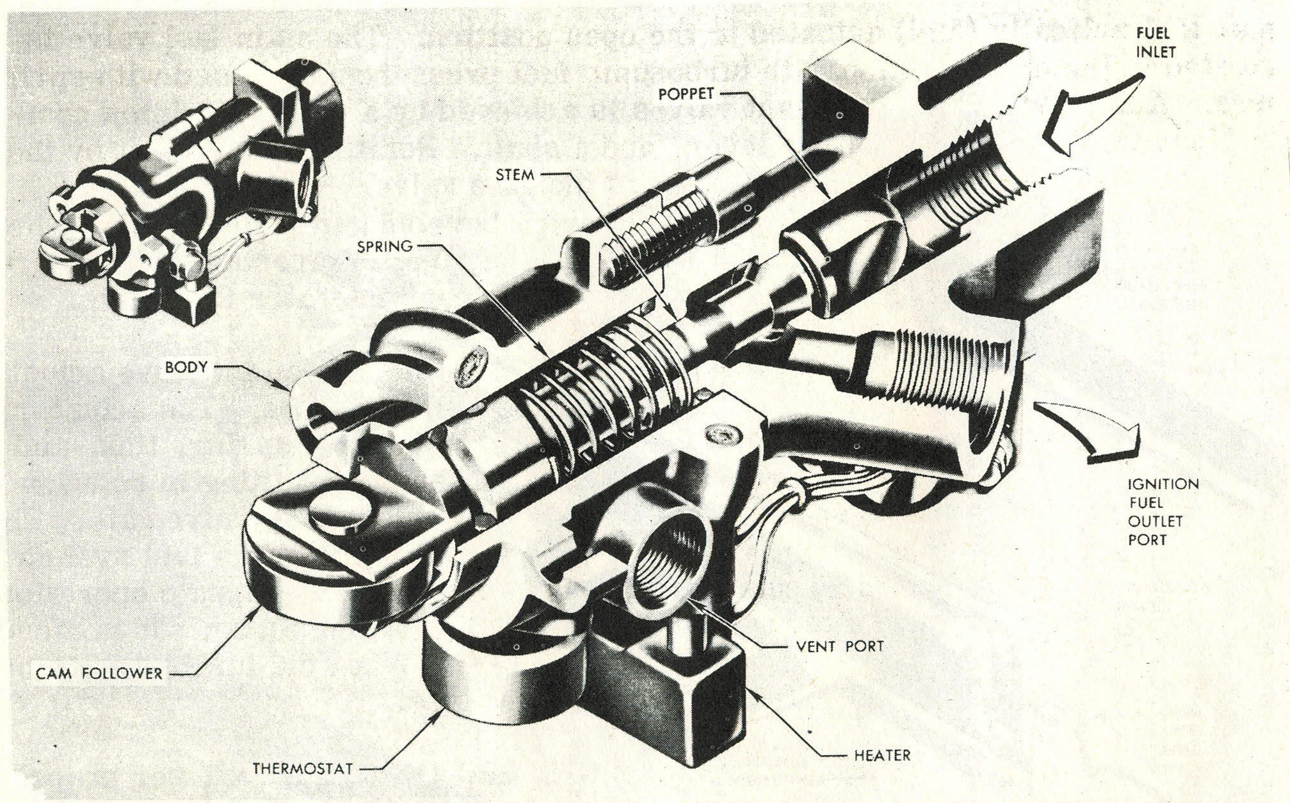


Figure 14 Ignition Fuel Valve

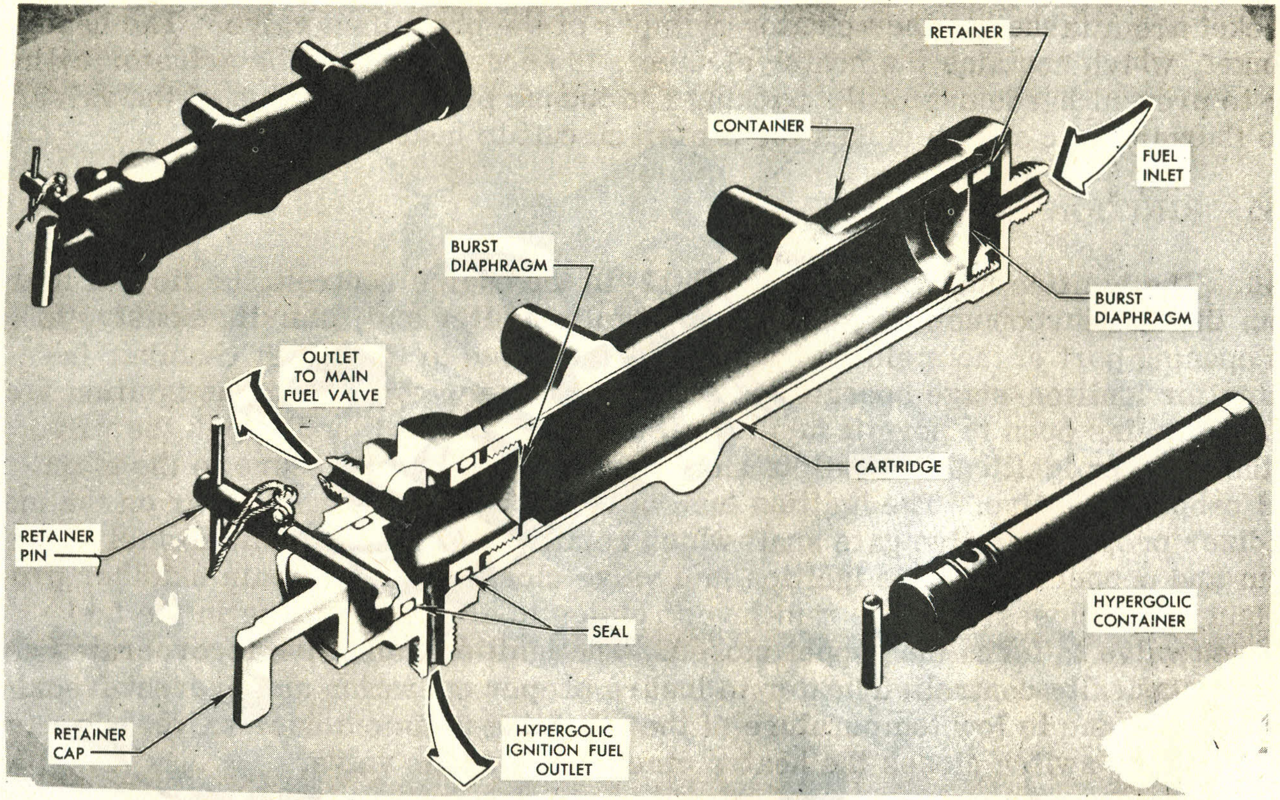


Figure 15 Hypergolic Igniter

Turbine Exhaust Duct and Heat Exchanger

The booster engine may be delivered with either of two exhaust duct configurations: Rocketdyne model A20 or A21. The Rocketdyne model A20 exhaust duct assembly is made up of a flanged elbow and two expansion bellows. The major difference between it and the Rocketdyne model A21 exhaust duct assembly is that the latter exhaust duct inforporates a heat exchanger (Figure 16). The heat exchanger (Figure 17) has a coil that allows a controlled amount of helium from the missile supply to enter the heat exchanger. Turbine gases heat the helium, increasing its volume, and the expanded gas flows from the heat exchanger coil to pressurize the missile propellant tanks.

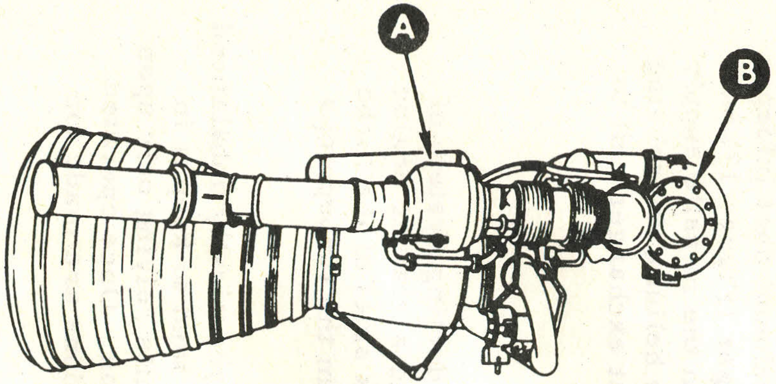
Fuel Prevalves

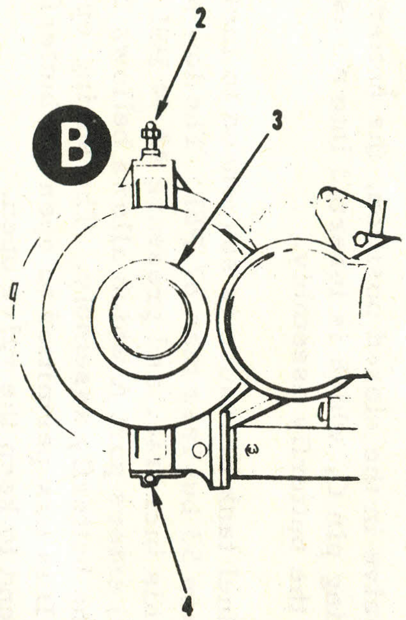
Fuel prevalves are installed in the low pressure ducting system of booster engine NO. 1, booster engine NO. 2, and the sustainer engine fuel lines. These valves are located upstream (tank side) of the turbopumps and serve the purpose of keeping the fuel from the turbopumps until the missile is readied for flight.

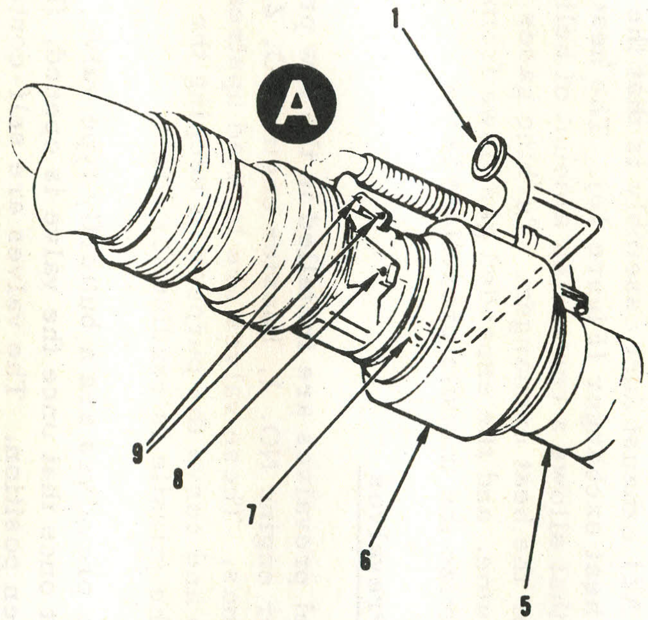
The prevalves are a butterfly type valve, hydrodynamically unbalanced so that once that once the valve is opened, flow will tend to keep it in the open position. The valves are self-contained units relying only upon missile fuel tank pressure buildup for their operation. Once operated they must be manually closed and reset. No provisions are made for automatic closing and reset capability.

In Figure 19 with the valve in the closed position, the butterfly is held from moving by locking pin C, which is inserted into a restraining pocket manufactured into the butterfly assembly.

During countdown the fuel tank pressure is sequenced to increase to flight pressure greater than 53 but less than 67 PSI. The low pressure fuel ducting also senses this increase, and pressure 42 ± 4 PSI from upstream (missile fuel tank) enters port A which allows bellows B to expand pulling pin C from the butterfly assembly. The spring-operated valve opener mechanism D is now permitted to open the butterfly assembly. Fuel flow will tend to keep the valve open.







1 HELIUM OUTLET
2 TURBOPUMP TO MISSILE MOUNT (REF)
3 TURBOPUMP FUEL INLET (REF)
4 TURBOPUMP TO SUPPORT PLATFORM ATTACH FITTING
5 NO. 2 BOOSTER EXHAUST DUCT
6 HEAT EXCHANGER
7 HELIUM INLET
8 EXHAUST DUCT LUG *(REF)*
9 EXHAUST DUCT TO MISSILE MOUNTS *(REF)*

Figure 16 Booster Engine and NR. 2 Booster Exhaust Duct

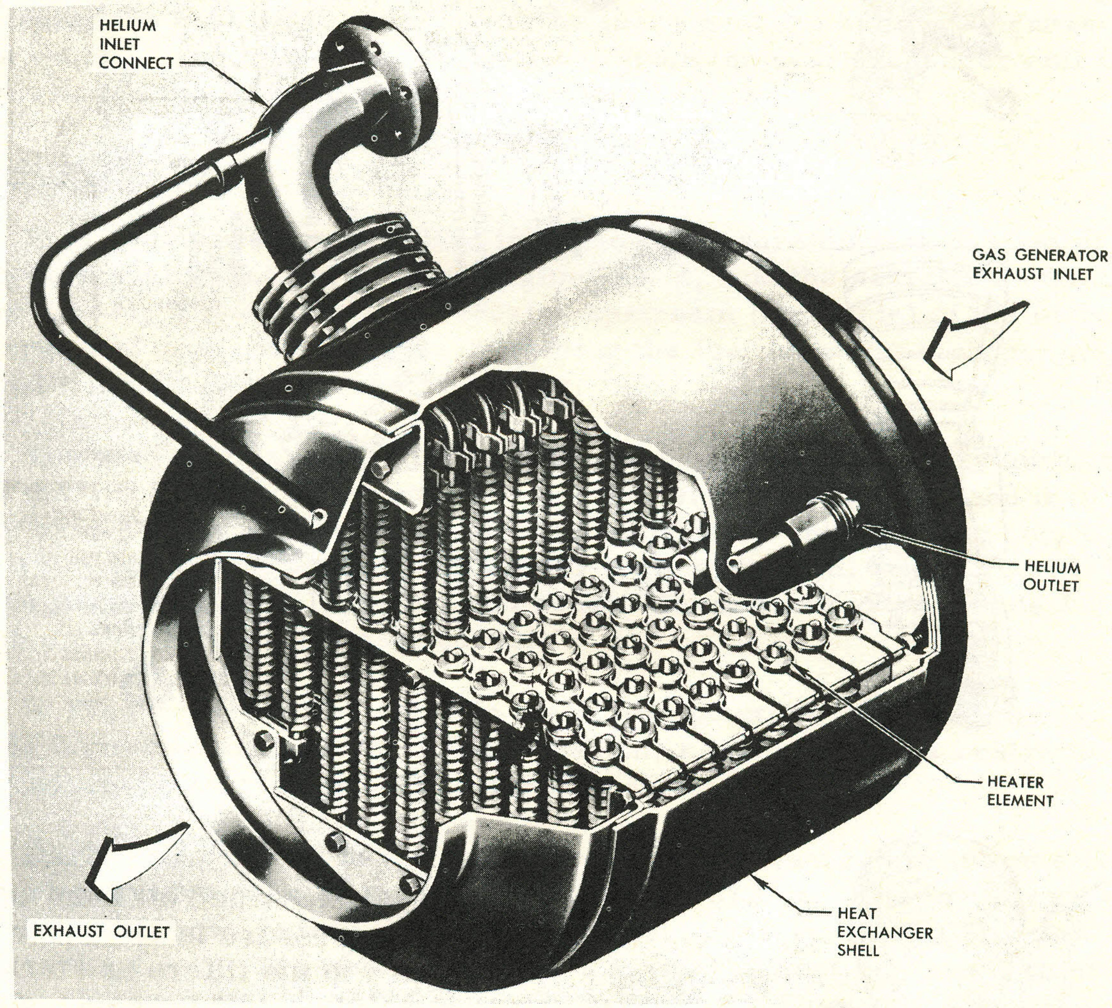


Figure 17 Heat Exchanger

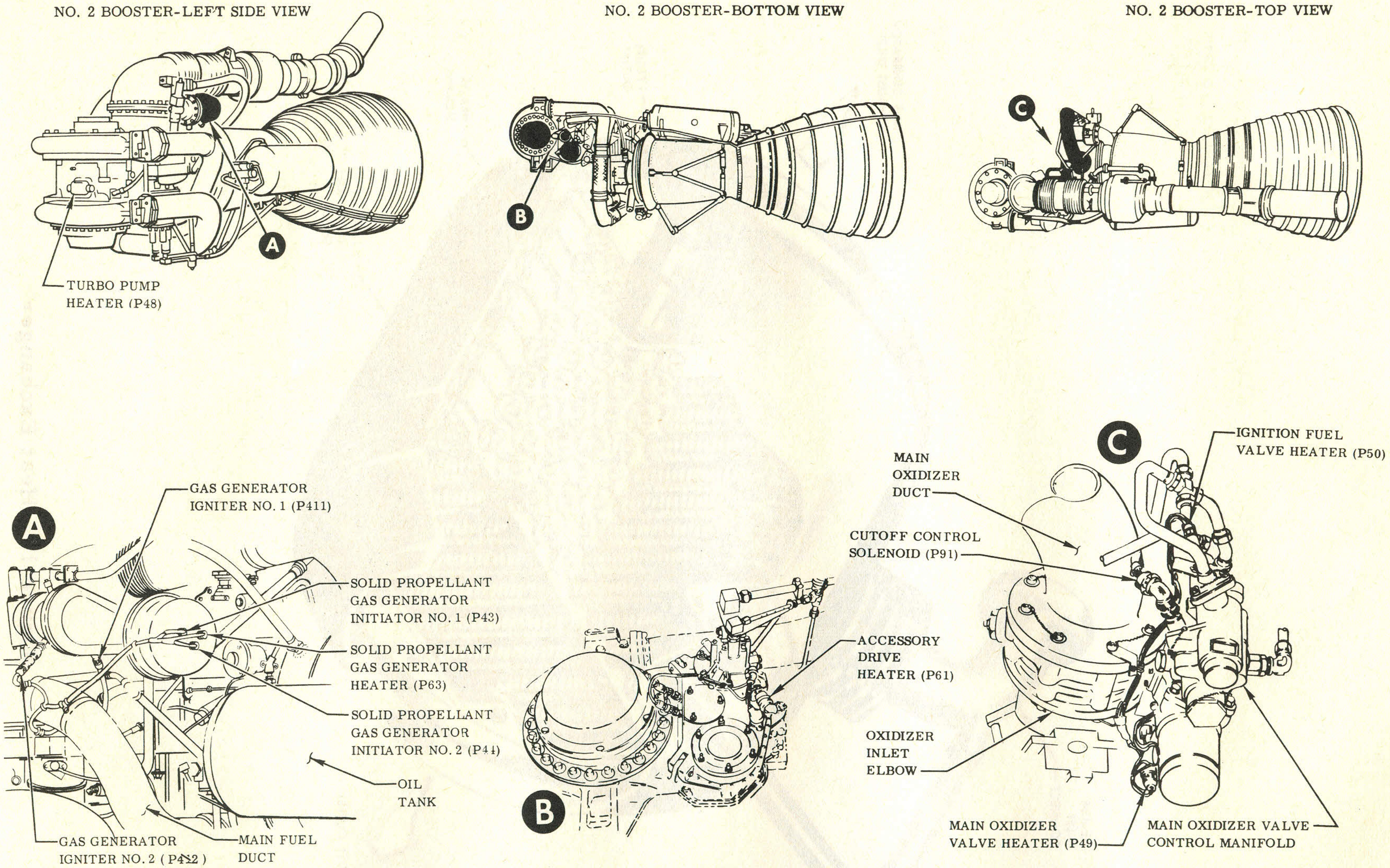


Figure 18 Booster Engine Electrical Connectors

OPERATION (Figure 49)

Preparation Stage

When the main missile fuel tank is brought up to flight pressure, the fuel pre-valves will be opened allowing fuel to enter the booster turbopumps. Under gravity flow the fuel will flow through the turbopump to the closed lube oil tank pressurizing valve, to the closed ignition fuel valve, through the directional control valve to the opening side of the main oxidizer valve to standby until pressure buildup, and to the closed main fuel valve. When oxidizer is loaded aboard the missile, it will flow through the turbopumps to the closed main oxidizer valve.

Helium is supplied from the main missile fuel tank pressurizing duct to the lube oil tank pressurizing valve to standby until the valve is energized.

Ignition Stage

The solid propellant gas generator initiators are fired, generating hot gases, initially starting the turbopump turbines. When fuel pressure builds up, the lube oil tank pressurizing valve will open allowing 60 PSI helium to pressurize the lube oil tank ullage space. This will force the lube oil to the lube oil pump which is now operating since it is driven off of the turbopump accessory drive pad. The pump will supply the turbopump gears and bearings with oil throughout booster operated. With fuel pressure applied to the opening side of the main oxidizer valve it will open and in turn cam open the ignition fuel valve. The ignition fuel valve had fuel standing by during the preparation stage so the fuel now under pressure will flow through the ignition fuel valve to the hypergolic cartridge. Fuel pressure will burst the hypergol diaphragms, and the fuel and hypergol will flow into the combustion chamber. When hypergol contacts the oxidizer in the combustion chamber, ignition is accomplished.

The pneumatics have been switched to airborne use just prior to engine start so therefore helium will be applied to the heat exchanger from the shrouded bottles. The helium will be routed through the heat exchanger and the turbine exhaust will heat the helium expanding it for pressurization purposes. Helium is also being supplied to the booster turbopumps for oxidizer shaft seal puge. The source of this helium is from the ambient helium bottle through the vernier pneumatic regulator to the booster turbopumps.

Main Stage

When fuel pressure breaks the hypergol diaphragms and fuel flows

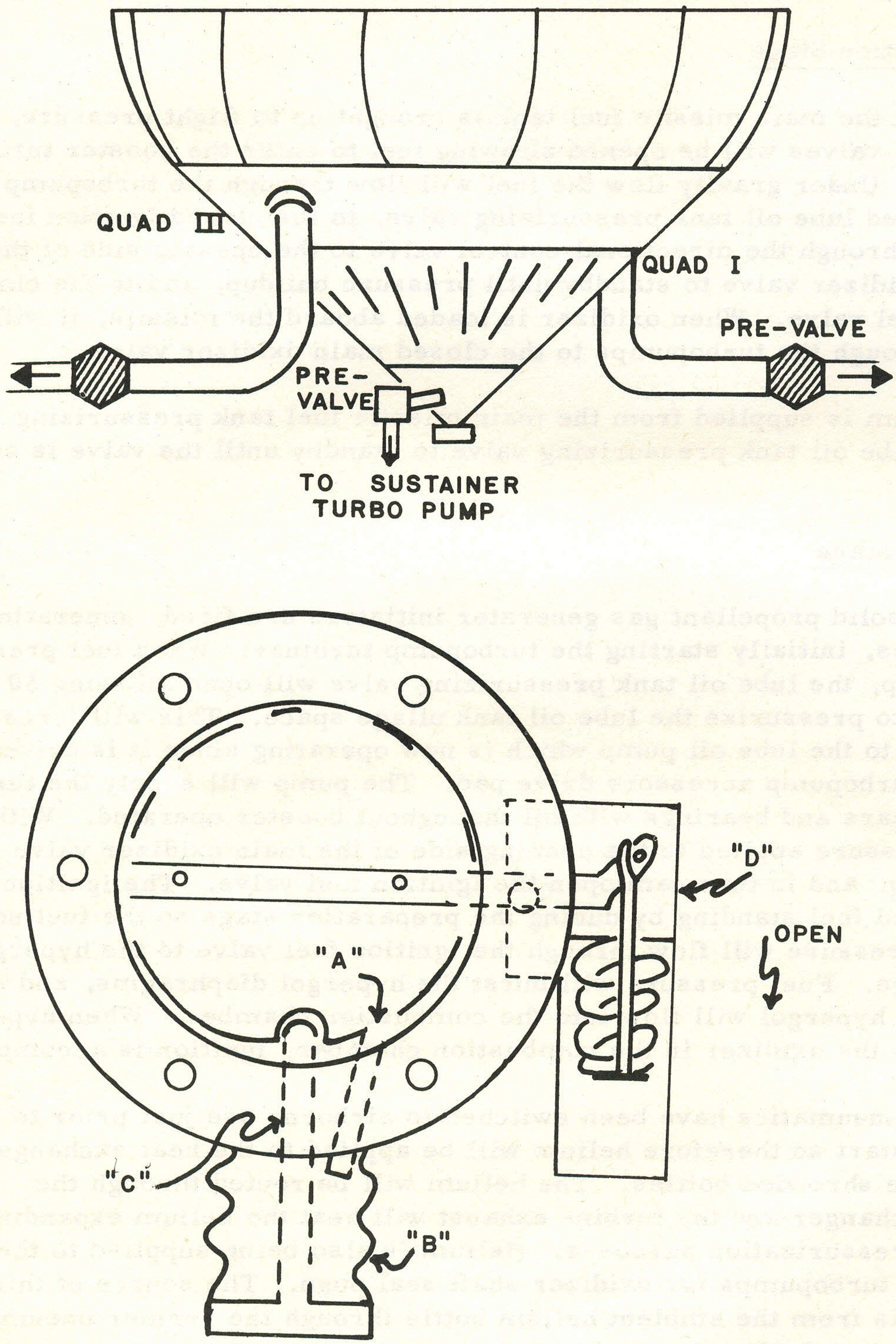


Figure 19 Alternate Type Prevalve

into the combustion chamber, it also will flow from the output of the hypergol container to the opening side of the main fuel valve. Since there was a pressure drop across the hypergol igniter, the main fuel valve will open as the pressure builds back up. With the main fuel valve open, the fuel will flow into the combustion chamber for combustion with the oxidizer. Downstream of the main fuel valve, a line is directed to the liquid propellant gas generator fuel poppet. The oxidizer is already standing by due to the main oxidizer valve being opened. When fuel pressure reaches the desired pressure, the fuel poppet will open and will mechanically open the oxidizer poppet allowing fuel and oxidizer to flow to the gas generator injector and combustion will occur. The liquid propellant gas generator will generate hot gases and keep the turbopump turbines turning for continued operation. The booster engines will now be in mainstage.

Helium will continue flowing to the heat exchanger throughout the complete booster operation.

Lube oil that has been sprayed on the turbopump gears and bearings will be routed overboard through the turbine exhaust.

SUMMARY

The booster engines are a fixed thrust, liquid bi-propellant engine, regeneratively cooled by its fuel. Each engine is a complete system within itself and operates completely independent of the other. Each booster thrust chamber produces 165, 000 pounds of thrust to aid in initial liftoff and velocity of the missile.

The booster solid propellant gas generator generates hot gases for the initial starting of the turbopump turbines. The output of the oxidizer turbopump flows to the closed main oxidizer valve and stands by until valve opening takes place. The output of the fuel turbopump flows to the closed lube oil tank pressurizing valve and through the directional control valve to the opening side of the main oxidizer valve. As soon as the fuel pressure has reached sufficient pressure the lube oil tank pressurizing valve opens allowing helium at 60 PSI to pressurize the lube oil tank ullage space, which in turn forces the oil to the lube oil pump on the turbopump accessory drive pad and then on into the gearcase. As soon as the fuel pressure increases the main oxidizer valve will open allowing oxidizer to enter the injector for ignition and also to flow to the liquid propellant gas generator oxidizer poppet. The opening of the main oxidizer valve will cam open the ignition fuel valve which will allow the fuel to flow to the hypergolic igniter. The hypergolic diaphragms will break allowing fuel and hypergol to enter the thrust chamber to come into contact with the oxidizer for ingition. As the hypergol diaphragms will break allowing fuel and hypergol to enter the thrust chamber to come into contact with the oxidizer for ignition. As the hypergol diaphragms break it will also allow fuel pressure to be applied to the opening side of the main fuel valve. Since there is a pressure drop when the diaphragms break, the main fuel valve will open as the pressure is building back up to the desired pressure. After the main fuel valve has opened and fuel flows to the thrust chamber, the fuel will also be applied to the liquid propellant gas generator poppet. When sufficient fuel pressure has built up the fuel poppet will be unseated and will mechanically open the oxidizer poppet allowing fuel and oxidizer in for combustion to occur in the liquid propellant gas generator combustion chamber. Its hot gases will then be applied to the turbopump turbines for continuous operation and the engines will be in mainstage.

QUESTIONS

1. What one component makes the booster No. 2 engine different from the No. 1 engine?

2. How is the booster thrust chamber cooled?

3. How much thrust does each individual booster engine develop?

4. What valve opening is required to allow fuel to burst the hypergol diaphragms?

5. Explain how the main oxidizer valve is opened?

6. For ignition to take place in the booster engine the main fuel valve must be open. True or false.

7. What is the purpose of the solid propellant gas generator?

8. The ignition fuel valve will cam open when the __________ opens.

9. What is the maximum run time of the booster engines?

10. How is booster turbopump gearcase pressurization accomplished?

SECTION III

SUSTAINER ENGINE

INTRODUCTION

The sustainer engine LR105-NA-5 (Figure 20) is a single-start, fixed thrust, liquid bipropellant engine. The engine design allows regenerative cooling, and thrust chamber gimbaling, and a full thrust run of 300 seconds duration.

The engine consists of a thrust chamber and the components that make up the functional groups which concern propellant feed, generation of hot gas, turbine exhaust, hydraulic control, and electrical supply and control. These components along with interconnecting electrical wiring and tubing assemblies are attached to the thrust chamber.

The sustainer engine is designed to produce thrust in an amount sufficient to maintain the acceleration of the missile against all drag forces after booster staging. The controlled gimbaling of the engine also provides directional thrust correction for yaw and pitch control of the missile attitude.

COMPONENTS

Thrust Chamber

The sustainer thrust chamber (Figure 20), is a large, bell like chamber composed of the thrust chamber body, the propellant injector, the oxidizer inlet elbow and flow straightener, the oxidizer dome and flow suppressor, and a thrust chamber gimbal with thrust alignment slides. The thrust chamber body and propellant injector form a combustion chamber where burning propellants create a hot high-pressure gas. The gas moves through a throat in the thrust chamber body where it reaches a critical pressure; then it is rapidly expanded, accelerated and exhausted by the expansion nozzle creating thrust.

The thrust chamber body directs the gases produced by combustion of propellants and conducts fuel to the propellant injector. The body is constructed of tubes running longitudinally, joined by brazing, and supported by external tension bands. A fuel inlet manifold connected to every second tube is positioned at the combustion chamber end of the body. A flow return manifold, common to all the tubes, is located at the nozzle end

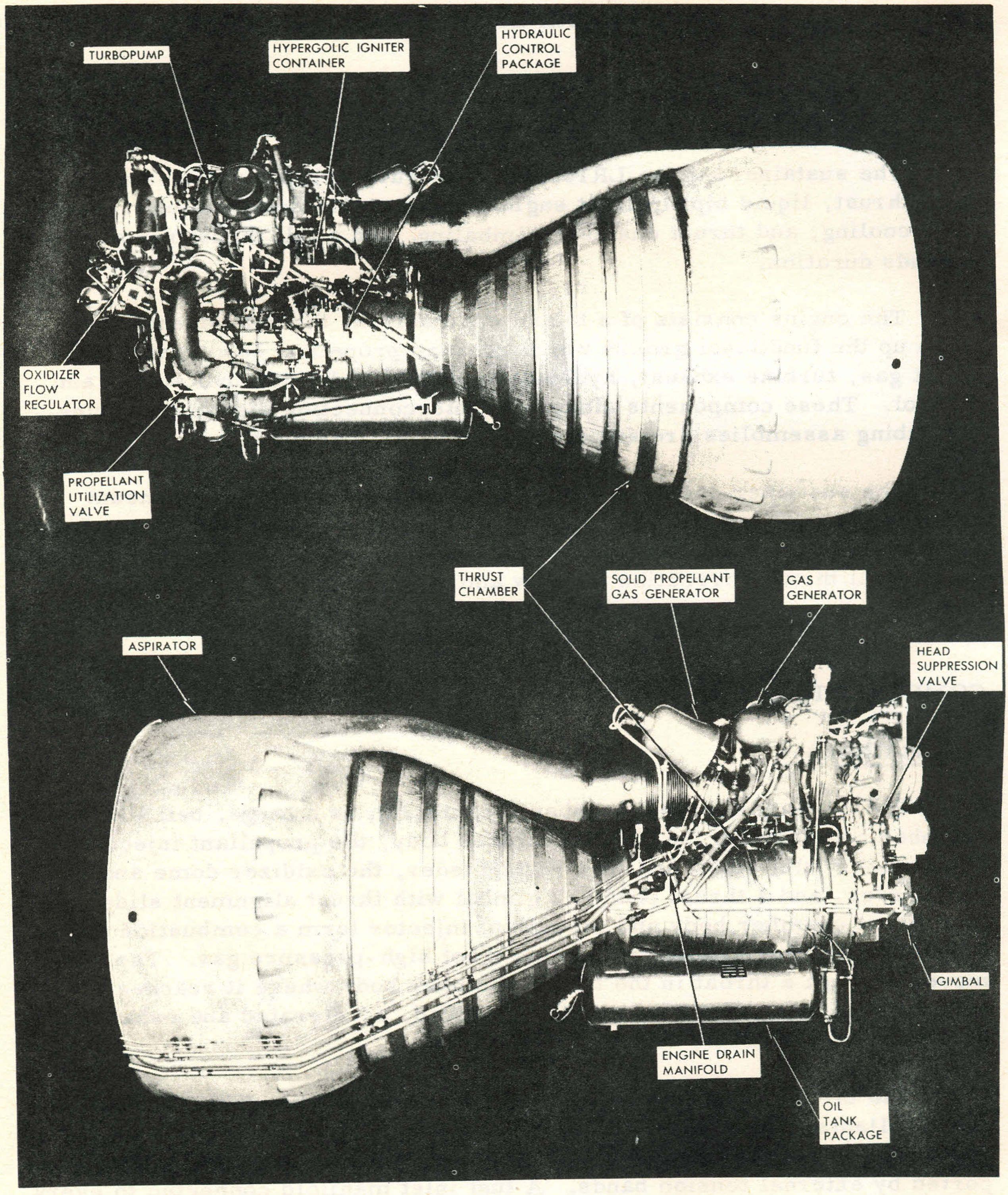


Figure 20 Sustainer Rocket Engine LR105-NA-5

of the body. The tubes are rectangular in cross section and are formed to shape the body profile. Fuel entering the inlet manifold is received by the delivery tubes which conduct flow the length of the body where the return manifold distributes flow to the return tubes. Fuel flow is reversed and returns to the combustion chamber end of the body where it is received by the injector. This flow of fuel is for cooling purposes and holds the temperature of the body at a safe operating level.

The approximate overall dimensions of the sustainer is 103 x 54 1/2 inches with an expansion ratio of 25 to 1. Dry weight is 924 pounds. Thrust developed is 57,000 LBS.

Thrust is developed by the reaction of the mass flow rate from the chamber. Combustion of the fuel, supported by the oxidizer, liberates exhaust gases at a very high rate.

The sustainer thrust chamber is located in the thrust section mounted to the aft end of the missile fuel tank. It is attached as an integral unit, through the gimbal mount to the apex of the missile fuel tank.

After booster cutoff, the sustainer provides thrust for acceleration of missile to maximum powered velocity.

Injector Assembly

The propellant injector is a circular plate which fits across the combustion chamber end of the thrust chamber body. It distributes fuel and oxidizer to the combustion chamber in an amount and pattern most suitable for combustion. The injector consists of a large, metal plate on which a series of concentric grooves, radial passages, and wedges have been machined. A series of flat, ring-like plates, each having a different diameter and each covering a groove are brazed in place. Drilled holes are located in these plates at the proper positions and angles for distribution of propellants. The 11 concentric passages (injector rings) formed by the grooves and plates receive fuel through the radial passages and oxidizer through the wedges. Fuel and oxidizer are separately distributed through the alternate rings, with fuel flowing through the number one outermost ring and every odd numbered ring. The propellants then flow through the drilled holes in an impingement pattern for mixing and dispersion. Fuel for ignition purposes is routed through a specific passage directly to the center of the injector. When the injector is installed, this passage connects to an external port leading to the ignition fuel valve.

Oxidizer Inlet Elbow

The oxidizer inlet elbow is an alloy casting which conducts oxidizer and which provides connection between the thrust chamber and the gimbal. The elbow bolts to the center of the oxidizer dome and is machined to provide a mounting pad for the thrust chamber gimbal and the oxidizer flexible joint. The casting is of high stress construction in order to transfer thrust chamber loads to the gimbal. Oxidizer is received from the oxidizer flexible joint and is directed through the oxidizer flow straightener to the oxidizer dome.

Oxidizer Dome

The thrust chamber oxidizer dome (Figure 21) is a plate that serves as a cover for the propellant injector. It consists of a dome like, circular metal plate which contains a large, central entry hole and 6 plugged ports. A row of bolts and spacers around the entry hole fastens the dome to the injector. A second row of bolts around the circumference fastens the dome to the thrust chamber body. The dome receives oxidizer from the flow straightener and directs it to the wedge shaped oxidizer entrance holes in the injector.

Oxidizer Flow Straightener

The oxidizer flow straightener is a circular series of channels that reduce turbulence in the oxidizer flow. The flow straightener consists of a series of intersecting veins forming channels arranged inside a retaining ring. The flow straightener is located in the entrance to the thrust chamber oxidizer dome and is held in place by the oxidizer inlet elbow. Oxidizer flow turbulence from the inlet elbow is corrected by the straightener, and then is directed into the thrust chamber oxidizer dome.

Gimbal Bearing Assembly

The gimbal bearing is a cross-bearing journal type universal connection constructed of steel. It is located between the oxidizer inlet elbow and the missile structure. The gimbal transfers thrust loads from the thrust chamber to the missile and permits angular variation of the thrust force. A maximum displacement of 4.5 degrees of the thrust chamber is allowed.

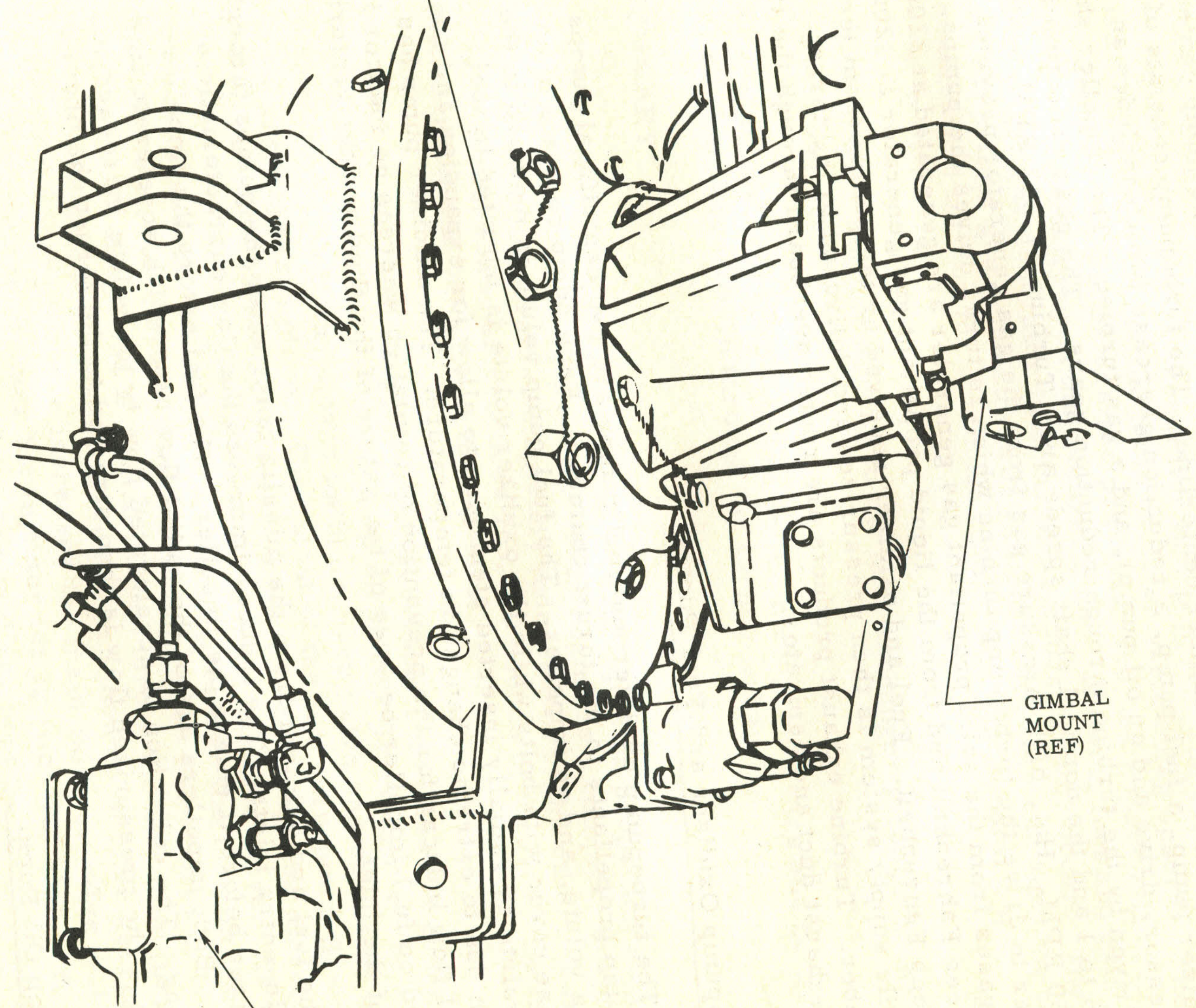


Figure 21 Sustainer Oxidizer Dome

Turbopump

The turbopump is a large, dual pumping unit which delivers fuel and oxidizer to the thrust chamber at the flow rates and pressures necessary for producing rated thrust. This unit is mounted on the thrust chamber by means of coupling links and tubular struts which aline the pump centerline parallel to the thrust chamber centerline. The turbopump consists of an oxidizer pump, a fuel pump, a reduction gearcase (which includes an accessory drive and an oil pump), and a gas turbine. The impeller shaft is driven by the turbine through reduction gears. The gear reduction is 3.75 to 1 and the nominal shaft speeds are: Turbine 37,312 RPM, impeller 9,950 RPM. Hot, high-pressure gas from the gas generator provides the power to drive the turbopump turbine which in turn, drives the pumps. Hot gases from the solid propellant gas generator are generated at 2200 degrees Fahrenheit and from the liquid propellant gas generator at 1200 degrees Fahrenheit. Fuel and oxidizer received by the pumps from the missile supply system is then pressurized and delivered to the thrust chamber. Turbine exhaust products are routed overboard through the turbine exhaust duct and aspirator.

Turbopump Oxidizer and Fuel Pumps

The turbopump oxidizer and fuel pumps are two centrifugal pumps that pump propellants to the thrust chamber. Each pump consists of an inlet, a volute, and an impeller. The fuel pump volute is mounted to the gearcase cover with bolts while the oxidizer volute is mounted to fuel pump volute by radially inserted steel pins to allow for expansion and contraction due to extreme changes in temperature. The oxidizer pump has an axial flow inducer for the prevention of cavitation whereas no inducer is required on fuel impeller because of the nature of the fluid and the venturi action of the inlet.

The fuel and oxidizer from the missile tanks enter the pumps through the single-entry inlets. The inducer improves the flow characteristic of the oxidizer before it enters the impeller. The fuel enters the impeller directly. Both impellers are of the radial flow type which accelerate flow by rotating. The collection of accelerated flow by the volute increases pressure. The pressurized flow is then directed to the thrust chamber.

Turbopump Oil Pump

The turbopump oil pump is a gear-driven, positive-displacement pump that pumps oil to the turbopump bearings and gears. It consists of a shaft which drives two rotors and a relief valve assembled in a body with a gear mounted on one of the shaft extensions. The other shaft extension is internally splined for accessory drive use. The oil pump is bolted to the inside of the gearcase where the oil pump gear meshes with the oil pump drive gear on the impeller drive shaft. The internally splined extension extends into the accessory drive mounting pad. The relief valve lies in a passage connecting the pump inlet and outlet passages. The oil enters the pump through the inlet port. It is then forced by the rotors via the outlet port and external lines to the turbopump oil nozzles where it is later directed to the bearings and to the unmeshed side of the gears.

Turbopump Gearcase

The turbopump gearcase is bolted to the fuel pump inlet casting. The gearcase covers the impeller drive gear and the turbine gear and shaft. It also provides a pad for an internally mounted turbopump oil pump, a turbine mounting pad, an accessory drive mounting pad, and three ports for oil. The gearcase provides the support for alining and meshing the turbine gear and the oil pump gear with the impeller drive gear and the oil pump drive gear. The accessory drive mounting pad is on the exterior of the case opposite the oil pump. The turbine mounting pad is also on the external side of the case. Two ports next to the accessory drive mounting pad provides inlet and outlet passages for the oil pump. A third port located between the mounting pads allows oil to drain from the gearcase.

Turbopump Turbine

The turbopump turbine is a two-stage turbine utilizing hot gas as its motivating power. Power is transferred through the turbine gear to drive the fuel and oxidizer pumps and the oil pump. The turbine consists of an inlet manifold, a turbine wheel housing, a turbine gear, two turbine wheels and a turbine shaft housing. The turbine gear is mounted on the end of the shaft opposite from the first-stage wheel. The second-stage turbine wheel is bolted to the first-stage wheel. The gear end of the shaft is supported by a roller bearing while the wheel end is supported by a ball bearing. The bearings and a portion of the shaft are enclosed by the turbine shaft housing. The inlet manifold incorporates the first-stage nozzles and is bolted to the turbine wheel cover which incorporates the second-stage nozzles. The shaft housing is held to the inlet manifold by screws. Hot gas from the gas generator enters the inlet manifold and is directed at the first-stage turbine wheel by the first-stage nozzles. The gas rotates the wheel and passes to the second-stage nozzles where gas velocity is increased. The speeding gas adds rotational energy to the second-stage wheel and passes overboard through the turbine exhaust.

Turbopump Oil Nozzles

The turbopump oil nozzles consist of four spray nozzles which direct oil at various turbopump bearings and gears. Three are located in the fuel pump. These are directed at the two bearings supporting the impeller shaft and the unmeshing side of the turbine gear and the impeller drive gear. One is located in the gearcase and is directed at the roller bearing supporting the turbine shaft. A coolant fuel inlet is located in the turbine inlet casting. This allows fuel to enter and cool the ball bearing and the end of the turbine shaft housing enclosing it.

Turbopump Seals

The turbopump contains seven seals that are designed to prevent leakage past the impeller shaft, the gearcase, and the turbine shaft. Four seals are located in the fuel and oxidizer pumps, one seal is located in the gearcase, and two seals are located in the hot-gas turbine.

The four pump seals are located on the impeller shaft and function as follows: an oxidizer pump seal prevents oxidizer leakage at the volute, an oil seal prevents oil leakage at the ball bearing retainer, a fuel pump seal prevents oil and fuel leakage at the fuel volute, and another fuel pump seal prevents fuel leakage at the fuel inlet casting. The gearcase seal is located in the accessory drive pad and prevents oil leakage at the accessory drive shaft.

The two turbine seals are located on the turbine shaft and function as follows: the first-stage seal prevents hot gas from bypassing the first-stage nozzle ring at the inlet manifold and reaching the ball bearing; the second-stage seal prevents hot gas from bypassing the second-stage nozzle ring.

Turbopump Drains

The turbopump contains seven drains. Five drains are located on the fuel and oxidizer pumps, one drain is on the gearcase, and one drain is located on the turbine. The five pump drains perform the following functions: two drains conduct lubricating oil from the ball bearing cavity and the roller bearing cavity, two drains conduct any oxidizer seal leakage from the oxidizer seal cavity, and one drain conducts any oil leakage past the oil seal. The gearcase drain is located between the accessory drive mounting pad and the turbine. It conducts lubricating oil from the gearcase. The turbine drain is located in the inlet manifold and drains hot gas, cooling fuel, and oil from the cavity formed by the first-stage seal.

cooling fuel, and oil from the cavity formed by the first-stage seal.

Turbopump Turbine Bearing Coolant Relief Valve

The turbine bearing coolant relief valve is a spring-loaded poppet valve that prevents cooling fuel from reaching the turbine first-stage seal cavity prior to engine start. The valve lies between two external lines tapped into the fuel pump volute and the turbine inlet manifold. When fuel pressure rises in the volute, it unseats the poppet valve and allows fuel to flow.

Turbopump Accessory Drive Adapter

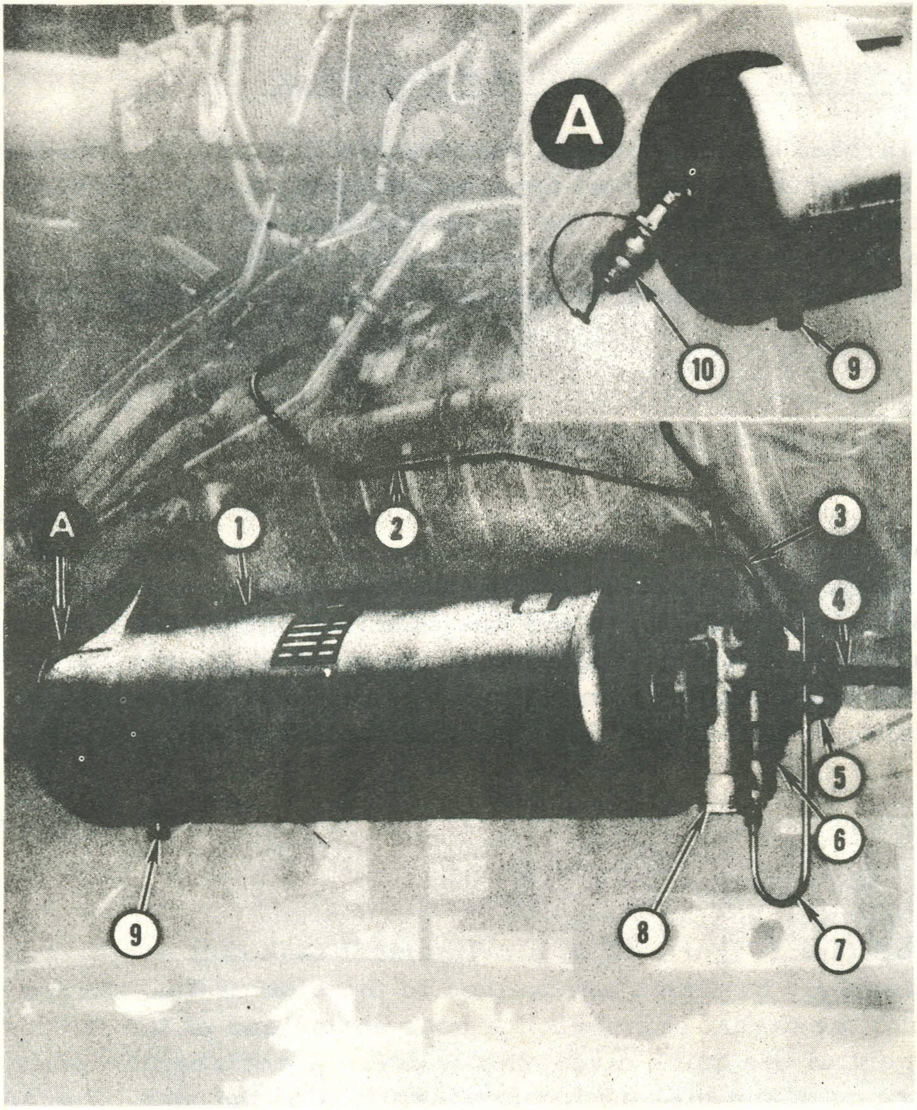
The accessory drive adapter is an integral part of the gearcase housing and consists of an accessory drive pinion, an oil pump drive gear and drive shaft. The accessory drive shaft is geared to transmit 40 horse power at 3500 RPM. It allows for the mounting of the sustainer hydraulic pump to the accessory drive pad that is mounted on the oil pump. Mechanical power is transmitted from oil pump gears to accessory drive adapter. The accessory drive adapter delivers mechanical power to the hydraulic pump.

Oil Tank

The oil tank (Figure 22) is a cylindrical tank that contains the lubricating oil supply. Brackets are welded to the side of the tank for mounting of the tank to the thrust chamber. A boss at one end of the tank is provided for attachment of the quick disconnect valve. A rectangular mounting pad at the other end of the tank allows for insertion of the standpipe and filter and for mounting the pressurizing valve. A boss placed at the side of the mounting pad is provided for entry of pressurized gas. When the tank is pressurized, oil in the tank is forced into the standpipe and through the filter to the pressurizing valve. The oil tank has a capacity of seven gallons.

Oil Tank Pressurization Valve

The oil tank pressurizing valve (Figure 11) is a fuel-pressure-actuated valve located at one end of the oil tank. The pressurization of the oil tank and the exit of lubricating oil from the tank is controlled by this valve. The valve consists of two spring-loaded valves encased in a body which incorporates six ports, a drain, and a mounting pad. Three of the



1 TURBOPUMP OIL TANK
2 OIL TANK VENT LINE
3 OIL TANK PRESSURIZING LINE
4 PNEUMATIC SUPPLY LINE
5 OIL SUPPLY LINE
6 PURGE PORT
7 FUEL PRESSURE LINE
8 TURBOPUMP OIL TANK PRESSURIZING VALVE
9 PLUG
10 OIL FILL QUICK DISCONNECT

Figure 22 Sustainer Turbopump Oil System

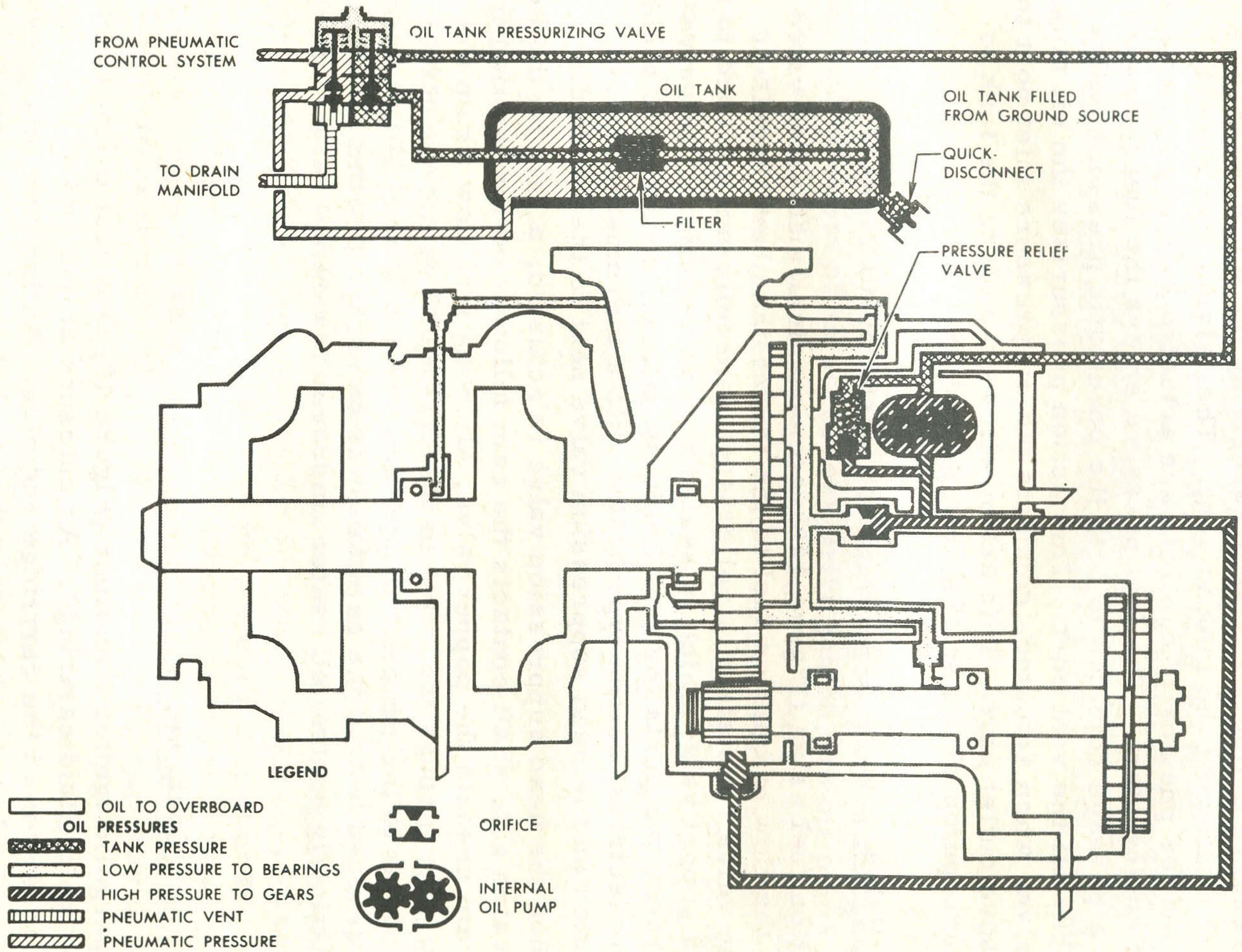


Figure 23 Turbopump Lubrication

ports are pressure inlet ports for oil, pneumatic pressure, and fuel. The other three ports are pressure outlet ports for oil, pneumatic pressure, and tank venting. The drain port is used for maintenance purposes. In the normal position, the valves block flow of pneumatic pressure into the oil tank and block flow of oil from the oil tank. The pneumatic pressure outlet port (for pressurizing the oil tank) is open to the vent port allowing the tank to vent. The valves, one for coil control and one for pneumatic control, are actuated by fuel pressure generated at engine start. The fuel pressure enters the fuel pressure inlet port to a passage common to both the pneumatic pressure outlet port and blocks off the vent port. This action pressurizes the oil tank. The other valve, when actuated, connects the oil pressure inlet port to the oil pressure outlet port. This action allows the oil in the tank to flow to the turbopump oil pump (Figures 22 and 23).

Ignition Fuel Valve

The ignition fuel valve (Figure 14) is a mechanically actuated valve that controls the flow of ignition fuel to the thrust chamber propellant injector. The valve consists of a roller-type cam follower fastened to a spring-loaded poppet valve which is seated in a valve body. The valve body incorporates two ports for fuel (inlet and outlet), a vent port check valve, and an electrical calrod type heater with a thermostat control. The valve is mounted on the head suppression valve next to the hydraulic actuator. When the head suppression valve is actuated, a cam on the head suppression valve gate shaft contacts the cam follower on the ignition fuel valve. The cam unseats the poppet valve, allowing fuel flow (from the turbopump) to pass through the valve to the hypergolic igniter container. The fuel then flows to the propellant injector. The vent port check valve allows fluids trapped behind the cam follower to escape to atmosphere. The thermostatically controlled heater improves low-temperature operating characteristics.

Hypergolic Igniter Container

The hypergolic igniter container (Figure 15) is a cast cylinder which holds the hypergolic fluid cartridge. An entrance at one end of the container allows for insertion of the cartridge and plug. An ignition fuel pressure inlet port is provided at the opposite end of the container. The casting incorporates three lugs for mounting purposes and holes for the cartridge retaining pin. Ignition fuel pressure enters the inlet port of the container (when the ignition fuel valve is opened) and bursts the two diaphragms. This allows fuel and hypergol to flow to the PU pilot valve and to the injector for ignition.

Liquid Propellant Gas Generator Oxidizer Pressure Regulator

The gas generator oxidizer pressure regulator (Figure 24) is a self referencing regulator for controlling the flow of oxidizer to the liquid propellant gas generator. The flow-regulating spool is opened or closed by oxidizer pressure at either the opening or closing side of the spool. The selector valve directs oxidizer pressure to or relieves oxidizer pressure from either end of the flow-regulating spool. The position of the selector valve is determined by two forces acting upon it. One force is preset spring pressure which normally positions the selector valve to route opening pressure to the flow-regulating spool. The other force is oxidizer pressure which is sensed downstream of the flow-regulating spool. This force acts to position the selector valve to direct closing pressure to the flow-regulating spool. Oxidizer enters the regulator inlet port, passes the normally open flow-regulating spool, and passes out of the regulator to the gas generator. When oxidizer sensing pressure downstream of the flow-regulating sppol rises high enough to offset the selector valve against the preset spring pressure, the flow-regulating spool valve will close. Oxidizer pressure downstream of the regulator will then drop and allow the spring to return the selector valve. This directs opening pressure to the flow-regulating spool.

Liquid Propellant Gas Generator

The gas generator (Figure 25) is a sphere-shaped assembly mounted on the turbine inlet manifold. The gas generator produces the hot gas necessary to drive the turbopump turbine. It consists of a propellant valve, a propellant injector, and a combustor. Flow of propellants to the gas generator is controlled by the propellant valve. When the valve opens, it allows propellants to flow through the inj ector to the combustor. The propellants are mixed and burned in the combustor producing hot gas which is then directed into the turbine inlet manifold.

Liquid Propellant Gas Generator Propellant Valve

The gas generator propellant valve (Figure 25) is a hydraulically actuated valve that controls flow of fuel and oxidizer to the gas generator propellant injector. The propellant valve consists of a hydraulic actuator which is fastened to a body incorporating two sliding valve gates mounted on a common shaft. The hydraulic actuator is linked to an actuating lever on the valve shaft. The two sliding valve gates (one for fuel and one for oxidizer) prevent flow of propellants when closing pressure is present in the hydraulic actuator. When closing pressure relieved and opening pressure applied, the actuator moves.

This action raises both sliding gates allowing the fuel and oxidizer (from the turbopump) to flow through the valve to the propellant injector; however, the fuel gate will uncover its passageway first, thus allowing fuel lead into the gas generator combustion chamber.

Liquid Propellant Gas Generator Injector

The gas generator propellant injector (Figure 25) is a circular, metal plate which distributes propellants into the gas generator combustor. The side of the injector toward the propellant valve has a raised central cylinder. Three rings of entry holes are drilled through the portion of the plate surrounding the cylinder. The combustor side of the injector has a spring-loaded, normally closed, flush-mounted poppet valve. The valve is centered in the face of the injector and is surrounded by three rings of holes. When the gas generator propellant valve opens, oxidizer flows through oxidizer outlet into the central portion of the injector. Fuel flows from the fuel outlet to the rings of entry holes surrounding the poppet valve. Oxidizer pressure in the injector unseats the poppet valve which allows entry of oxidizer into the combustor. Fuel enters the combustor through the rings of entry holes and impinges upon the oxidizer flow from the valve thus producing unlike impingement.

Liquid Propellant Gas Generator Combustor

The gas generator combustor (Figure 25) is a sphere shaped shell in which propellants are mixed and burned. The shell has a large open surface on one side which mates with the gas generator injector-propellant valve assembly. The opposite side of the combustor has an exit nozzle which incorporates an inlet boss for mounting the solid propellant gas generator. Propellants entering the combustor are originally ignited by the gas generator igniters. The hot gas produced by combustion passes through the exit nozzle into the turbine inlet manifold where it drives the turbine. The exhaust gas is directed overboard by the turbine exhaust duct and aspirator.

Turbine Exhaust Duct and Aspirator

The turbine exhaust duct and aspirator (Figure 20) is a welded sheetmetal and bellows assembly which conducts turbine exhaust gas overboard. The assembly consists of a flanged bellows, a duct, and an aspirator. The aspirator is a large sheet-metal hood welded to the expansion nozzle of the thrust chamber and extending slightly past it. The duct is welded to the aspirator and extends toward the turbopump turbine. At the turbine end of the duct the flanged bellows connects to the turbine wheel housing. Products of turbine exhaust pass through the bellows and duct into the hood-like aspirator which distributes them into the thrust chamber exhaust flow.

Oil Drain Manifold

The oil drain manifold is a large fitting mounted on the thrust chamber exterior that collects drainage from the turbopump, the oil tank package, and the hydraulic control package. The manifold contains seven inlet ports and one outlet port. One large inlet port collects drainage of the turbopump gearcase and lubricating oil; another inlet port collects a hot-gas and rocket fuel mixture from the turbopump turbine. The oil tank vent line connects to one of the ports. Lubricating oil from the roller bearing cavity and hydraulic oil from the hydraulic control package drains into other separate ports. The two remaining inlet ports are plugged. The manifold collects all these fluids and directs them to the manifold outlet port. A line connected to the outlet conducts the fluids into the turbine exhaust aspirator.

Propellant Utilization Valve

The propellant utilization valve (Figure 26) is a hydraulically actuated valve which is the main fuel valve for the sustainer engine. The valve consists of a double-acting hydraulic actuator linked to a shaft controlling the angular position of a butterfly gate. The gate assembly is three inches in diameter. These items along with an adjustable hydraulically actuated stop, a protractor, and a transducer are mounted on and in a housing which bolts to the inlet of the thrust chamber fuel manifold. The mechanical stop prevents the valve from completely closing as long as opening hydraulic pressure is applied to the valve. The valve has three hydraulic control ports; one for actuating the mechanical stop, one for opening pressure to the actuator shaft to open the valve and one port on the closing side of the actuator shaft. The propellant utilization valve will close when equal hydraulic control pressures are applied to both the opening and closing sides of the actuating piston. The valve will open when closing control pressure is relieved. The transducer produces signals used by the missile propellant utilization system. The protractor is for calibration and checkout purposes. The hydraulic pressure applied to the three control ports is supplied from the sustainer hydraulic control package by shuttling the propellant utilization control valve, the propellant utilization autocontrol valve and the propellant utilization servo valve, which are all located within the hydraulic control package.

The propellant utilization valve is mounted on the fuel high-pressure ducting between the turbopump and thrust chamber fuel inlet manifold, therefore when the valve is open fuel will flow from the turbopump into the thrust chamber body.

Head Suppression Valve

The head suppression valve (Figure 27) is a hydraulically actuated valve which is the main oxidizer flow-control valve for the sustainer engine. The valve consists of a double acting hydraulic actuator linked to a shaft controlling the angular position of the three inch diameter butterfly gate. The valve incorporates two hydraulic control ports. One directs hydraulic fluid from the hydraulic control package to the opening side of the valve and the other to the closing side of the valve. When equal hydraulic control pressures are applied to both the opening and the closing side of the valve it closes. When the closing pressure is relieved the valve opens.

The head suppression valve serves to cam open the ignition fuel valve when the head suppression valve is 28 degrees $\pm$ 6 from the closed position. This action allows ignition fuel pressure to flow to the hypergol igniter for ignition.

The head suppression valve is controlled by hydraulic pressure being applied to the opening and closing ports from the hydraulic control package. The valves within the package that are shuttled for control of the head suppression valve are the head suppression control valve, head suppression auto control valve and the mixture ratio servo valve.

Hydraulic Control Package, Sustainer

The hydraulic control package (Figure 28) controls the operation of the head suppression, propellant utilization, and the liquid propellant gas generator, propellant valves. It is mounted on the exterior of the sustainer combustion chamber. The hydraulic control package consists of pilot valves, control valves, and auto control valves for sequencing of the head suppression and propellant utilization valves. The liquid propellant gas generator control valve will direct opening and closing hydraulic pressures to the liquid propellant gas generator propellant valve. A head suppression mixture radio servo valve, a propellant utilizat ion servo valve and an accumulator are mounted on the exterior of the hydraulic control package.

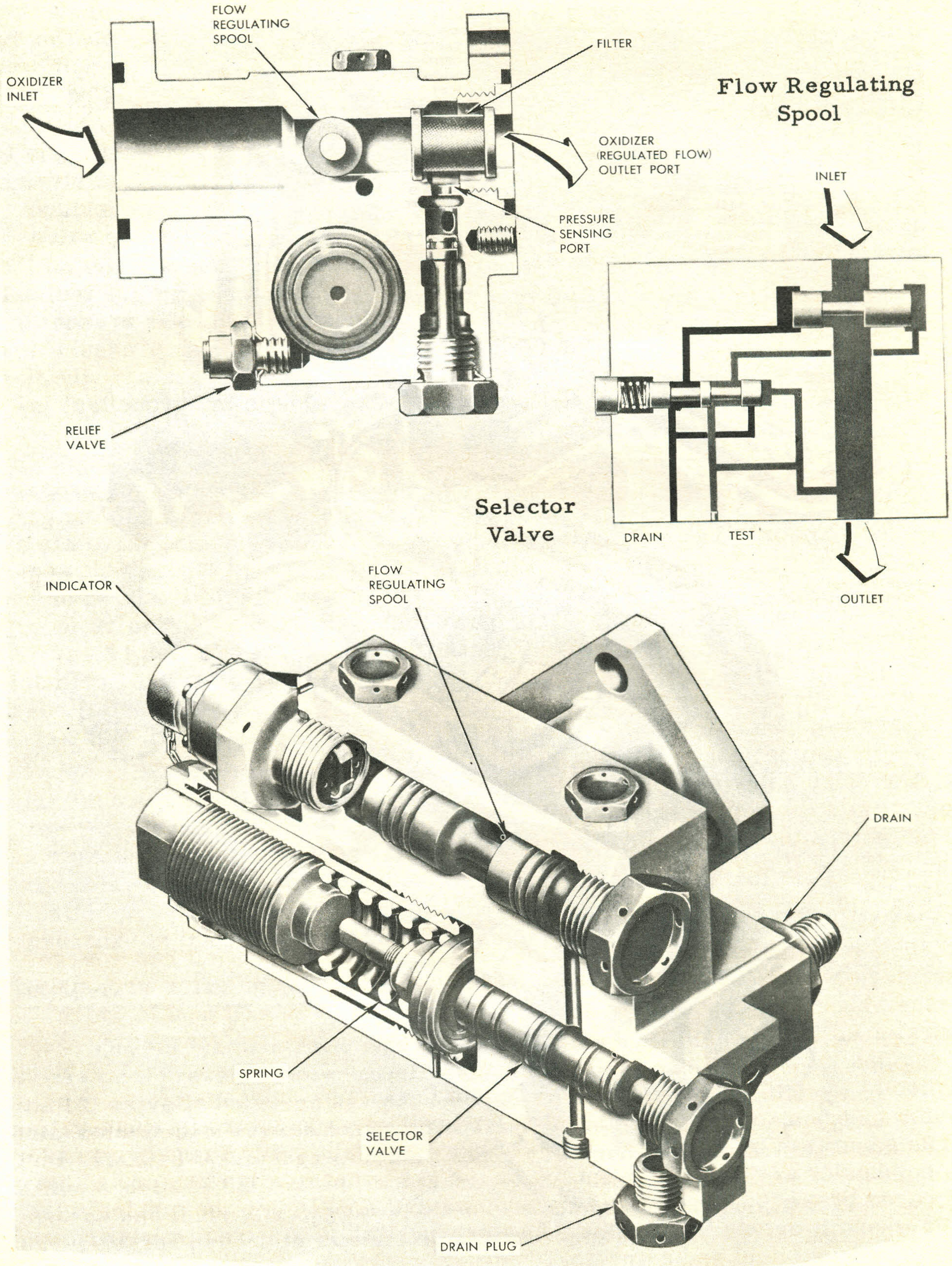


Figure 24 Gas Generator Oxidizer Pressure Regulator

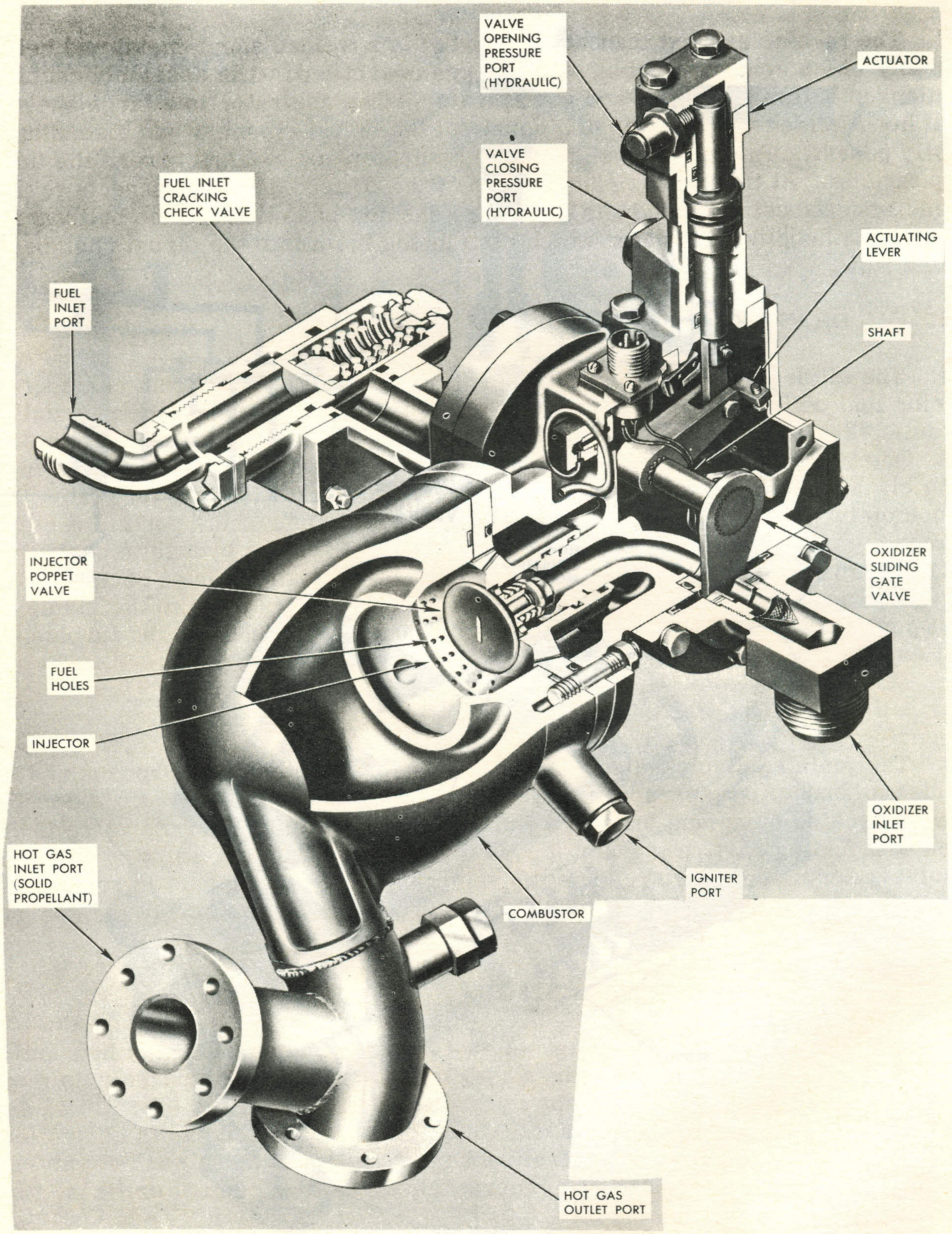


Figure 25 Liquid Propellant Gas Generator

The hydraulic accumulator is charged to 1,000 PSI from a ground source of GN_2 which is then compressed to 3,000 PSI. Hereafter the accumulator acts as a surge absorber, or as a power source in case the hydraulic pump fails. The accumulator charge is sufficient to operate the sustainer propellant valves for a short period of time.

The head suppression pilot valve is a solenoid valve that must be energized before any sustainer valves can open. Once this solenoid is energized, it allows 3000 PSI fluid to move the HS control valve (Figure 29). When the HS control valve is moved, it applies opening pressure to the head suppression valve while returning closing pressure. The HS valve opens, camming open the igniter fuel valve. Hypergol, ignition fuel, and oxidizer are forced into the sustainer thrust chamber. Ignition fuel also is ducted into the hydraulic manifold to move the PU pilot valve when fuel pressure reaches 145 PSI. When the PU pilot valve is actuated, it allows 3000 PSI hydraulic fluid to move the PU control valve. As the PU control valve moves, it decreases closing pressure and applies opening pressure to the PU valve. When the PU valve opens, fuel is ducted to the sustainer thrust chamber. Fuel flows into the combustion chamber and part of it is ducted from the fuel inlet manifold back to the hydraulic control package. This mainstage fuel pressure moves the LPGG control valve when fuel pressure is sufficient. When the LPGG control valve is activated, closing pressure is returned and opening pressure is applied to the LPGG and propellant valve actuator. Fuel and oxidizer enter the LPGG actuator and are gnited by the existing solid propellant and the LPGG igniters, and continue to supply force for accelerating the turbopump. As mainstage fuel pressure builds up, the HS and PU autocontrol valves are depressed, connecting the HS and PU servo valves to the closing side of the PU and HS valve actuators. The PU and HS valves are now able to modulate under the control of their servo valves. The servo valves control the modulation by applying a constant opening pressure and varying the closing pressure to the PU and HS valve actuators.

HS Mixture Ratio Servo Valve

The HS mixture ratio servo valve on the hydraulic control package works on a pressure differential basis. Fuel pressure from upstream of the PU valve is balanced against one end of the spool and oxidizer at sustainer dome pressure is balanced against the other end. The spool is further balanced by springs at either end. The springs and working surfaces of the spool are calibrated to compensate for differences of the propellant masses and their working pressures. Oxidizer is kept from leaking past the seals and getting to the fuel by a diaphragm seal.

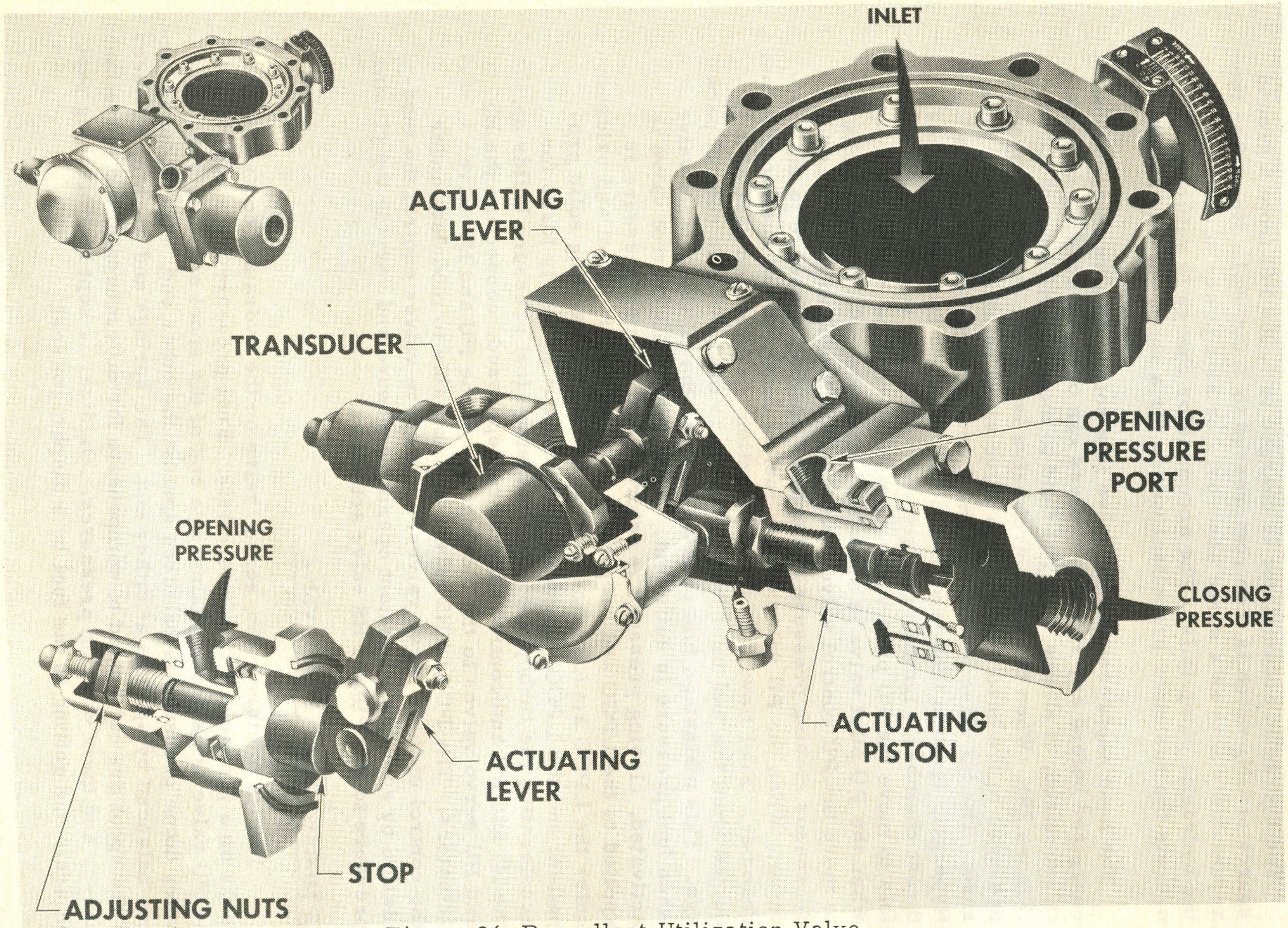


Figure 26 Propellant Utilization Valve

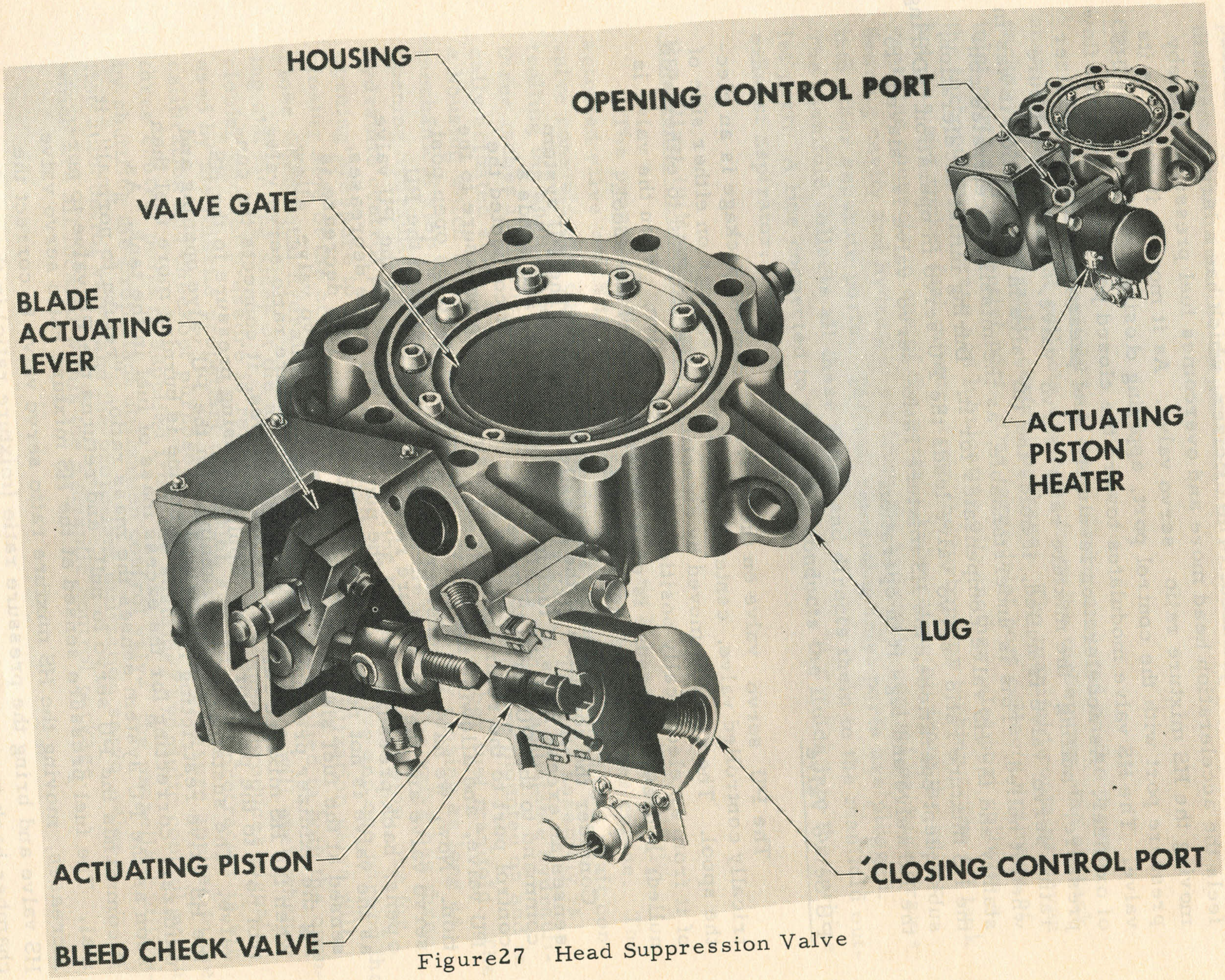


Figure27 Head Suppression Valve

Consider the situation during initial riseoff, after the autocontrol valves have been depressed. The oxidizer, which has a larger mass, feels the acceleration head more and overcomes fuel pressure, thereby moving the HS mixture ratio servo valve. As it moves, it connects its pressure port with the control port, applying closing pressure to the HS valve. The HS valve modulates toward the closed position to restrict flow of oxidizer. As acceleration levels off, fuel pressure balances oxidizer pressure, "nulling" the mixture ratio servo valve. When the mixture ratio servo valve is nulled, it holds the HS valve in the position it was in when it nulled. This is understandable, as the missile accelerates constantly and the HS valve compensates for it. During initial acceleration, the HS mixture ratio servo valve leads the PU servo in operation. During subsequent operations, the HS mixture ratio servo valve is "slaved" to the PU valve and lags it in operation.

PU Servo Valve

The PU servo valve on the hydraulic control package is an electrically controlled valve, centered or nulled by springs on either side of the spool. The spool is moved by directing hydraulic fluid to either side of it from an electrically positioned "flapper" valve. When the valve is nulled, hydraulic pressure is equal on either end of the spool.

Consider the condition of the missile in flight. The PU system senses an excess mass of fuel in the missile tank, and sends a command to the PU servo to move. As it moves it connected the control port to the return port, decreasing closing pressure to the PU valve, and allowing the PU valve to move toward the open position. Now, we have to consider the interaction between the PU servo valve and the HS mixture ratio servo valve. As the PU valve opens, back pressure between the pump and PU valve decreases, as the valve is not restricting flow in the line. This decrease is sensed at the fuel side of the HS mixture ratio servo valve, allowing the oxidizer pressure to move the HS mixture ratio servo valve. When the HS mixture ratio servo valve moves, it connects the control port to the pressure port, appling closing pressure to the HS valve. The sustainer is now running with the PU valve opening and the HS valve restricting flow. The engine is burning more fuel than oxidizer, correcting for the excess mass of fuel in the tank. As soon as the PU system senses the mass ratio, "return to normal", it it commands the PU servo to null, and returns the PU valve to normal. The fuel pressure sensed at the HS mixture ratio servo valve increases, moving the HS mixture ratio servo valve to correct the HS valve and bring the pressure ratio (mixture ratio) in the combustion chamber back to normal. The above explanation is an over simplification, but should illustrate that the HS lags the PU, first to help correct for missile tank mass ratio, then to correct for burning mixture ratio.

Now consider the PU system sensing an excess mass of oxidizer in the missile tanks. The corrective course of action is to restrict the flow of fuel by moving the PU valve toward closed and moving the HS valve toward open. This is accomplished by commanding the PU servo to move, connecting the control port to the pressure port and increasing closing pressure to the PU valve. Partially closing the PU valve restricts fuel flow between the pump and PU valve, which increases fuel pressure. This pressure is sensed on the fuel side of the HS mixture ratio servo valve. Fuel pressure overcomes oxidizer pressure, moving the HS mixture ratio servo valve, connecting the return port with the control port, decreasing closing hydraulic pressure and allowing the HS valve to move toward the open position. Notice again the PU servo leads and the HS mixture ratio servo valve lags. As soon as the PU system senses the correct mass ratio in the tanks, it commands the PU servo to null, and returns the PU valve to the correct position. The fuel back pressure decreases as the PU valve is opened. The fuel pressure becomes less on the HS mixture ratio servo valve and the oxidizer pressure nulls it, correcting for the proper burning mixture by moving the HS valve.

OPERATION (Figure 49)

Preparation Stage

When the missile main fuel tank is brought up to flight pressure the sustainer fuel pre-valve is opened allowing fuel to enter the turbopump. Under gravity flow the fuel will flow through the turbopump to the closed propellant utilization valve, ignition fuel valve, mixture ratio servo valve, turbine coolant check valve and liquid propellant gas generator cracking check valve and the vernier engine. When oxidizer is loaded aboard the missile it will flow through the turbopump to the closed head suppression valve, through the oxidizer pressure regulator to the gas generator blade valve and to the diaphragm in the vernier engine feed line.

Ignition Stage

When the 550 millisecond sustainer start timer has activated, the solid propellant gas generator initiators are fired, causing hot gases to be generated, initially starting the turbopump turbine. When sufficient fuel pressure builds up, the following functions occur: The liquid propellant gas generator cracking check valve unseats allowing fuel to flow to the LPGG propellant valve and lube oil tank pressurizing valve. Simultaneously fuel will flow to the turbine coolant check valve.

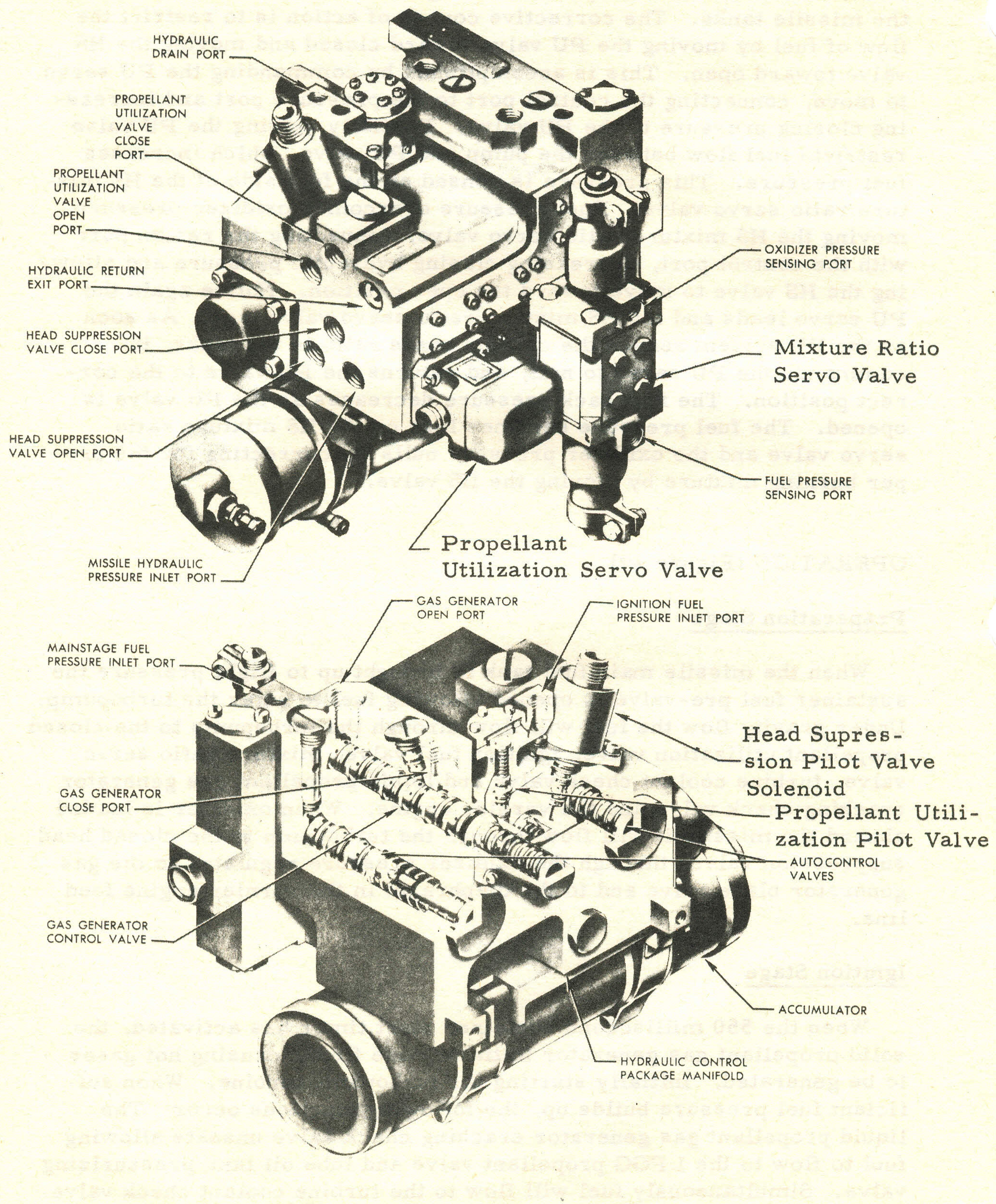
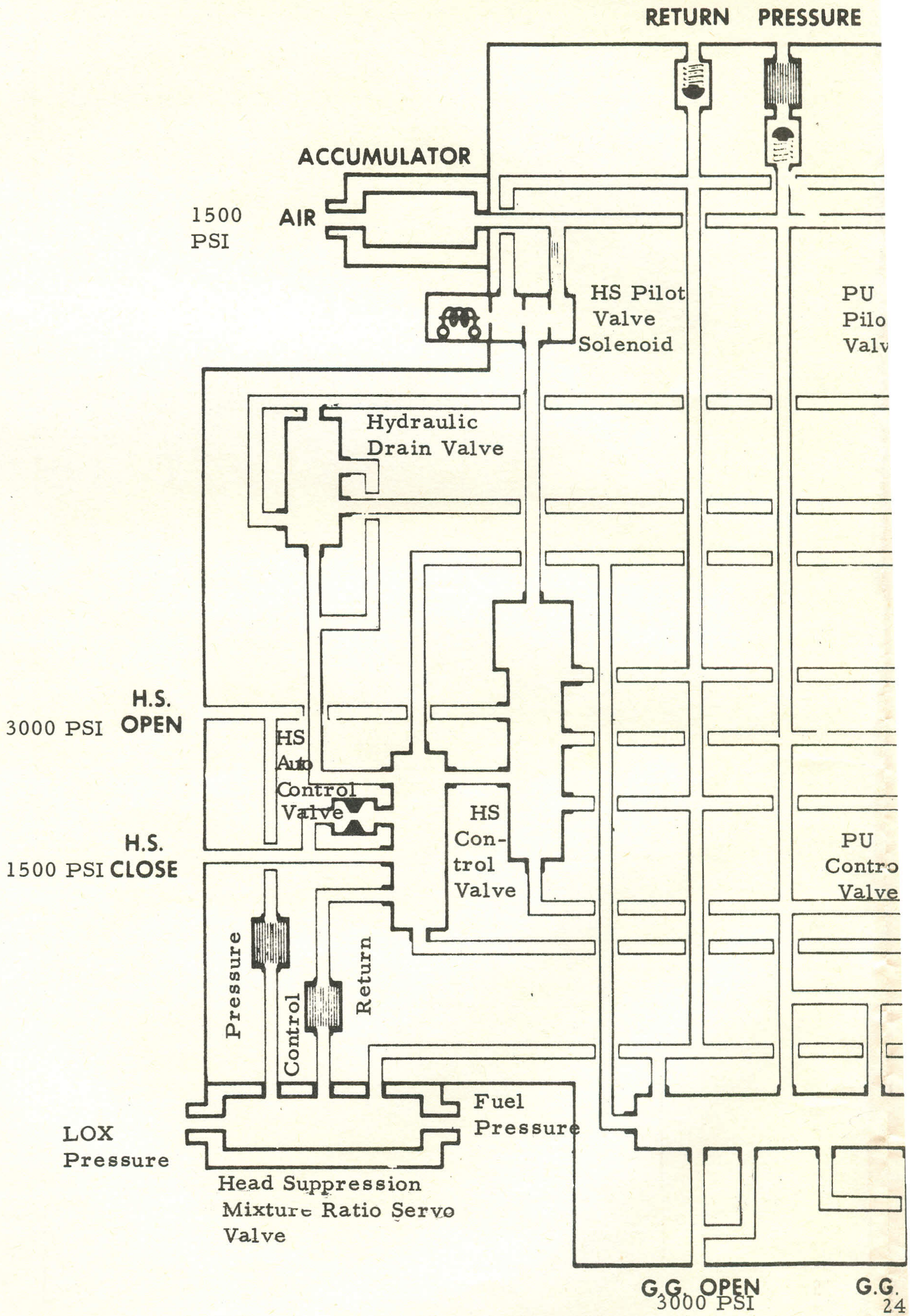
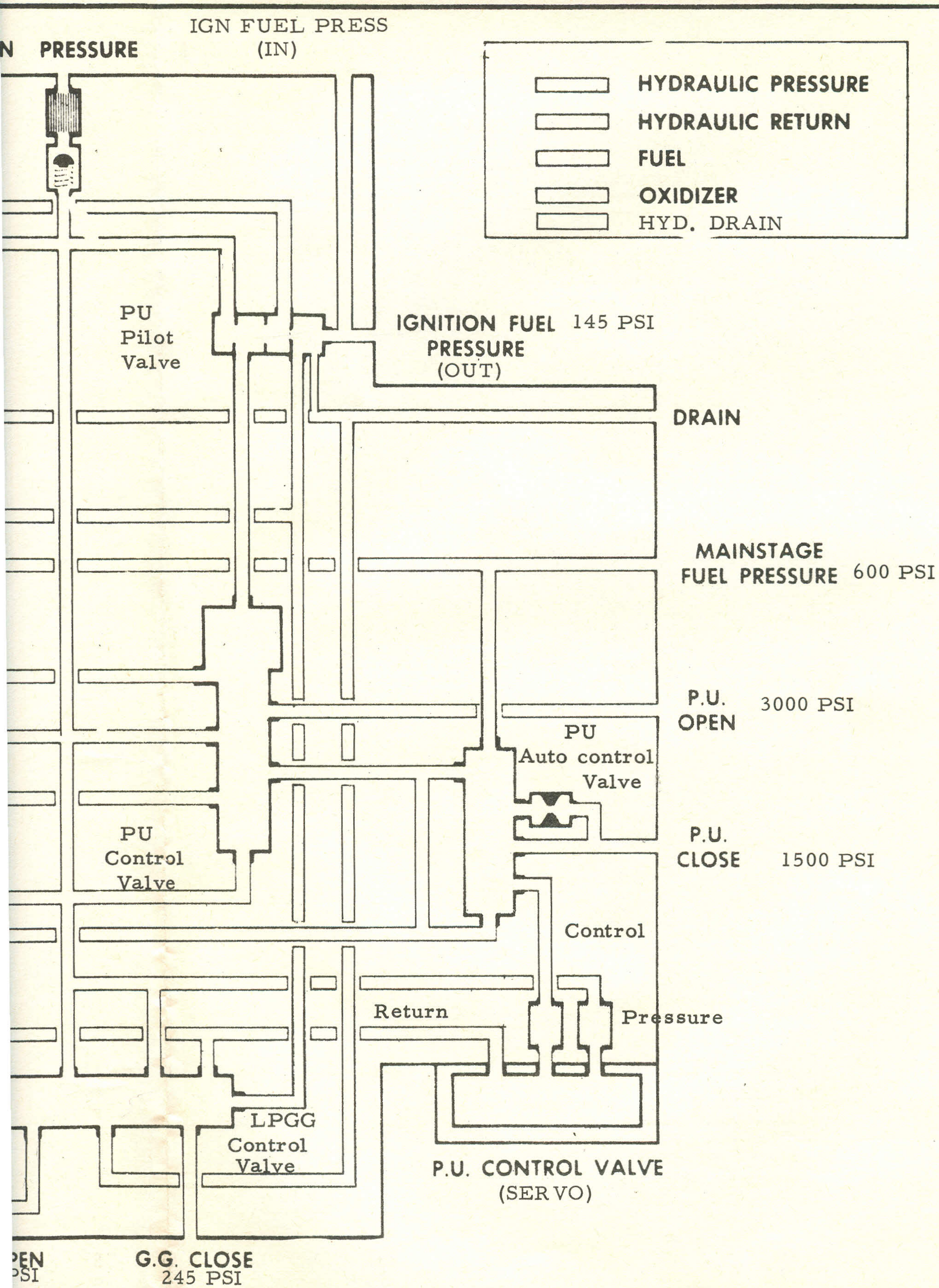


Figure 28 Hydraulic Control Package



SUSTAINER ENGINE HYDRAULIC

Figure 29



HYDRAULIC CONTROL PACKAGE

Figure 29

An electrical signal energizing the head suppression pilot valve in the hydraulic control package allows hydraulic pressire to be applied to the opening side of the head suppression valve. The head suppression valve opening, cams open the ignition fuel valve, allowing fuel to flow to the hypergol cartridge. Also at this time fuel is being applied to one side of the mixture ratio servo valve while oxidizer is being applied to the other side. With sufficient pressure buildup, the diaphragms in the hypergol cartridge will break allowing fuel and hypergol to flow through the propellant utilization pilot valve in the hydraulic control package and back to the injector for ignition. Fuel will also start to flow into the vernier engine fuel solo tank at this time.

When fuel pressure energized the lube oil tank pressurizing valve, it allowed helium to flow into the lube oil tank ullage space forcing the oil to the lube oil pump.

Main Stage

Actuating the propellant utilization pilot valve allowed hydraulic pressure to flow to the opening side of the propellant utilization valve. This action lets fuel flow into the thrust chamber. A portion of the fuel is taken from the fuel manifold and sent to the hydraulic control package. Sufficient fuel pressure will cause the gas generator control valve in the hydraulic control package to be energized allowing the hydraulic pressure to be applied to the opening side of the gas generator propellant valves. Fuel and oxidizer standing by the propellant valves enters the injector and combustor for combustion. The liquid propellant gas generator exhaust generated causes continuous operation of the turbopump turbines and the engine is in mainstage.

SUMMARY

The sustainer is a fixed thrust, liquid bi-propellant engine, regeneratively cooled by its fuel. It develops 57,000 pounds thrust at sea level.

The sustainer engine operates on a fuel pressure ladder or hydraulic pressure for valve control. Fuel flows through the turbopump to the closed propellant utilization valve and to other components where it is in stand by. Oxidizer flows through the turbopump to the closed head suppression valve. When ignition occurs a signal is sent to the head suppression pilot valve in the hydraulic control package starting the sequence of hydraulic pressure to open the head suppression valve, then the propellant utilization valve. As the head suppression valve opens, it cams open the ignition fuel valve allowing fuel under pressure to flow and break the hypergolic igniter diaphragms and permit fuel and hypergol to enter the injector and combustion chamber for combustion. Fuel pressure buildup from ignition stage energizes control valves in the hydraulic control package which allows the gas generator control valve to be shuttled to permit hydraulic pressure to flow to the opening side of the gas generator blade valves. When the blade valves open, fuel and oxidizer enter the liquid propellant gas generator combustor and ignite. The liquid propellant gas generator exhaust causes continuous operation of the turbopump turbine and the engine is in main stage.

QUESTIONS

1. How much thrust is developed by the sustainer engine?

2. What axes can the sustainer engine be gimbaled in?

3. Describe the function of the injector?

4. What is the purpose of the aspirator?

5. Where is the sustainer lube-oil pump located?

6. What medium controls the operation of the liquid propellant gas generator blade valves?

7. The oxidizer pressure regulator controls flow of oxidizer to the ________________ ________________.

8. What medium controls the opening and closing of the propellant utilization and head suppression valves?

9. What unit controls the opening and closing of the propellant utilization and head suppression valves?

10. What is the expansion ratio of the sustainer engine?

SECTION IV

VERNIER ENGINES

INTRODUCTION

The vernier engines LR101-NA-7 (Figure 28) consists of two separate thrust chambers with propellant valves, a vernier fuel and oxidizer solo tank, and a vernier control manifold. The vernier system is dependent upon the sustainer engine for propellants for initial start and up until sustainer engine cutoff, thereafter the solo tanks are utilized for the remainder of the flight.

COMPONENTS

Thrust Chamber

The thrust chamber is a double walled, corrosion resistant steel unit. It is welded to the aft portion of the fuel inlet manifold. Fuel enters the manifold, passes in between the double walls and is directed toward the injector in a spiral path. The spiral motion is induced by a steel helical coil mounted between the walls. The circular path of the fuel insures even regenerative cooling of the vernier thrust chamber. The steel walls are sufficient to contain the combustion pressure (347 PSIA) without additional reinforcing. The expansion nozzle is cone shaped with an expansion ratio of 5 to 1. The hypergolic cartridge and mount are located on the thrust chamber.

The injector is fabricated of aluminum alloy. It is drilled to target fuel on fuel for double impingement at a mixture ratio of 1.8 to 1. The outer fuel ring is targeted on the walls of the combustion chamber for film and boundary layer coolings.

The vernier engine is supported by a tubular steel frame. The aft portion of the frame attaches to the missile thrust ring. In addition to supporting the thrust chamber, the frame supports the vernier propellant valve and boiloff valve, and the rack and sector gear pitch and yaw actuators. Fuel and oxidizer are ducted to the engine through external tubing, swivel joints, and through the tapped and drilled pitch and yaw shafts. Since the tubing is exposed to the missile stream line, the tubing is quite rigid to prevent it from being set in motion by the air. This was accomplished by swivel joints and tapping the shafts, permitting

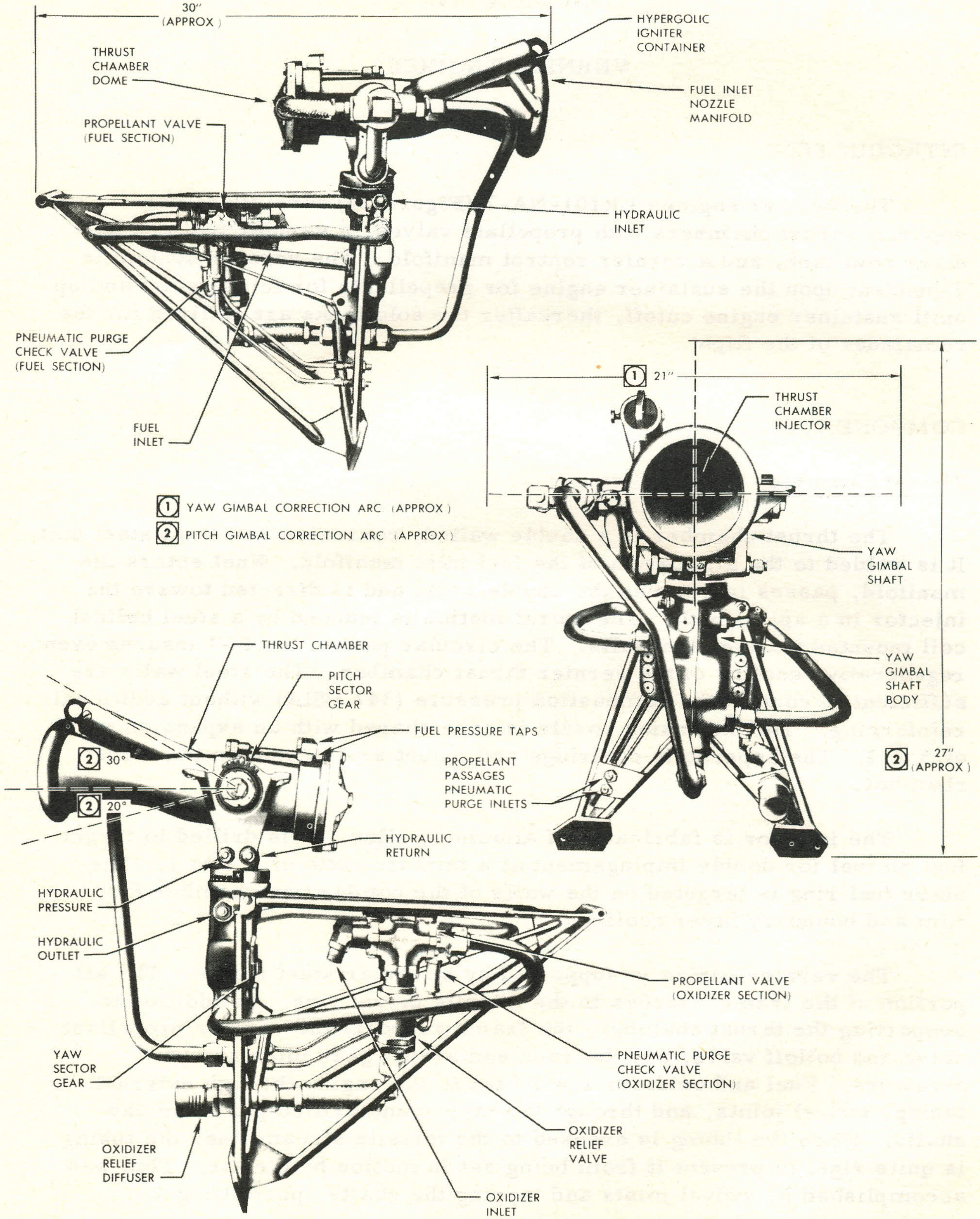


Figure 30 Vernier Engine LR101-NA-7

unrestricted fluid flow without having to go to flexible tubing; and, still allowing the engine to gimbal $\pm 74^\circ$ in yaw and $+34^\circ$, -24° in pitch. An interesting point in vernier gimbal is that it is locked out 30° from the missile centerline in pitch during the first phase of operation, and locked out 50° after booster staging. The additional 20° locked out after staging is to prevent vernier flames from being drawn back into the sustainer section and damaging any components. Prior to staging, the sustainer section is protected from vernier flame propagation by the booster nacelles.

The sea level rated thrust of each vernier engine is 1000 pounds. The maximum run time is 325 seconds. A maximum of 300 seconds run time is from sustainer turbopump feed and a maximum of 25 seconds run time is from solo tank feed. The dry weight of each engine is 51 pounds.

The propellants are injected, mixed, and burned in the vernier thrust chambers to produce thrust for pitch, roll and yaw control, as well as minor velocity adjustments during solo operation.

Oxidizer Dome

The oxidizer dome serves as the oxidizer inlet and as the cover for the oxidizer manifold. Threaded inserts around the edge of the dome permits the installation of a shield over the dome for protection from heat and drag during flight. The dome provides a continuous oxidizer passage from the dome inlet, through the manifold and filter, to the forward side of the injector plate.

Propellant Injector

The injector is designed to force fuel and oxidizer into the thrust chamber combustion zone. Distribution of the propellants is achieved by separate passages through the injector for fuel and oxidizer. The passage openings are arranged on the injector face in a single-hole, double-hole, and triple-hole pattern. Some of the propellant passages are drilled at angles, while others are drilled perpendicular to the injector face. These passages direct the propellants in jets which converge at points in the thrust chamber calculated to produce the most efficient combustion without causing erosion at the injector face or chamber walls. Oxidizer passages in the injector connect with the oxidizer manifold located directly forward of the injector. The fuel passages in the injector connect with radial passages drilled in the side of the injector which open into the fuel manifold. A fuel filter is brazed to the injector, and it encircles the openings of the radial fuel passages.

The function of distributing propellants is a critical one which each injector accomplishes with certain distinct performance characteristics. For this reason, a change of vernier propellant injectors always requires a recalibration of the vernier engine.

Propellant Valve

The propellant valve (Figure 29), controls the flow of fuel and oxidizer to the thrust chamber during start, mainstage, and cutoff sequences. It is composed of three sections: an oxidizer body, a fuel body, and a pneumatic actuator.

The oxidizer body contains inlet, outlet, and bleed passages which form a T shaped configuration. These passages interconnect at the center by aligning with converging passages drilled in the ball end of an integral ball and shaft. The ball and shaft interlock and the pneumatic actuator drive shaft allows rotation of the ball through an arc of 90° in a plane perpendicular to the oxidizer body passages. This arrangement aligns the inlet passage with the bleed passage when the valve is open. A vent check valve is installed in a vent port connected by a passage to the ball and shaft housing. Oxidizer, which collects around the shaft, thus vents overboard.

The inlet and outlet passages of the fuel body interconnect at the center by aligning with a passage drilled in the ball end of an integral ball and shaft. The ball and shaft interlock and the pneumatic actuator drive shaft allows rotation of the ball through an arc of 90° in a plane perpendicular to the fuel body passages. This arrangement aligns the inlet passage with the outlet passage when the valve is open, or closes off both passages when the valve is closed. A vent check valve is installed in a vent port connected by a passage to the ball and shaft housing. Fuel, which collects around the shaft, thus vents overboard.

The pneumatic actuator opens and closes the propellant sections of the propellant valve. The actuator has an open port and a close port, located at opposite ends of the actuator body, to receive pneumatic pressure. This pressure acts against either end of the piston which is spring loaded to the closed position. The piston is slotted longitudinally to accomodate the internal installation and movement of a bellcrank linkage controlling a drive shaft. The drive shaft is slotted at both ends to engage interlocking shaft receptacles in each propellant body. The mechanical linkage thus formed converts the linear motion of the pneumatic piston to rotary motion in the drive shaft.

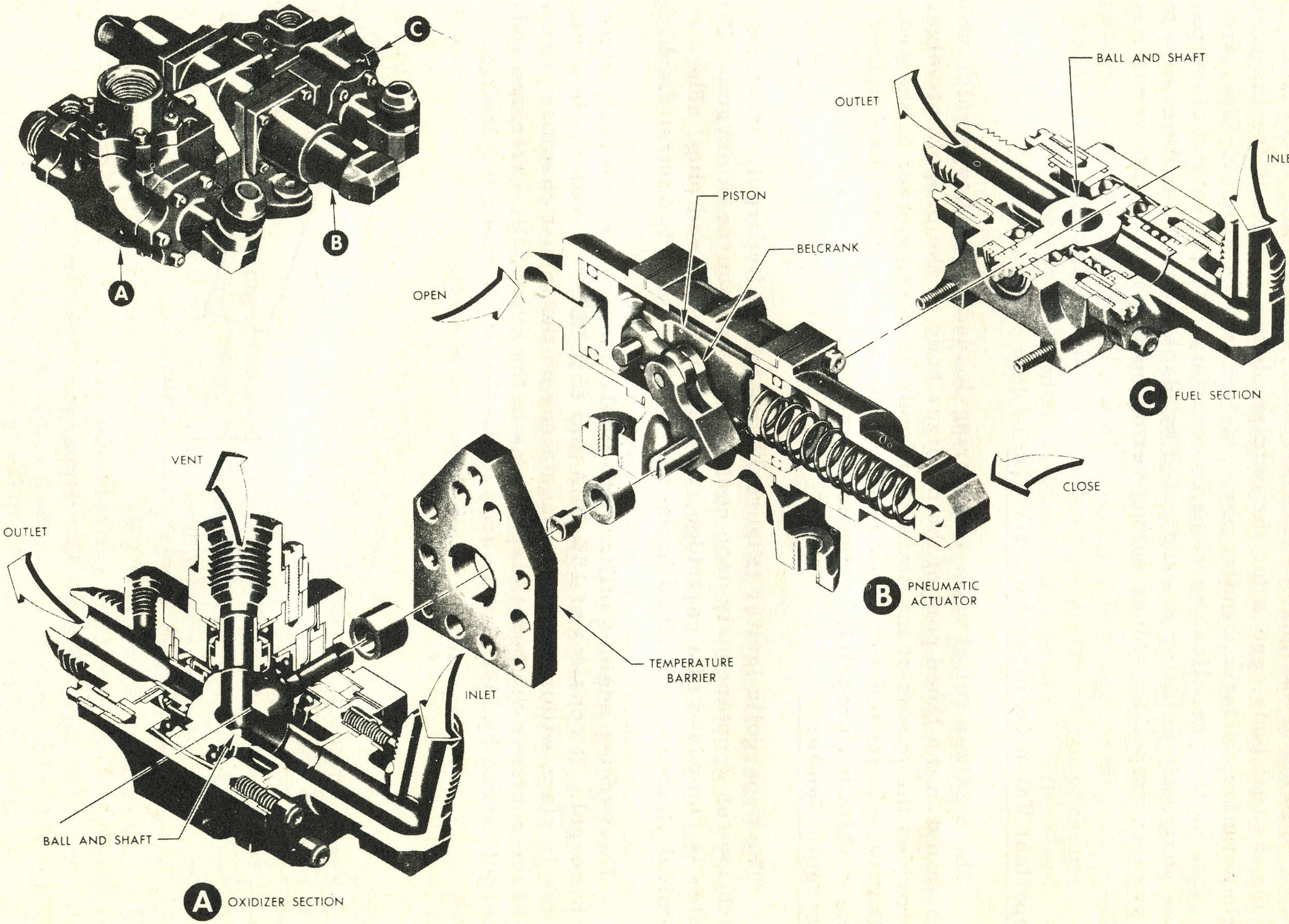


Figure 31 Propellant Valve - - Exploded Cutaway

Each propellant section is attached to the pneumatic actuator. Distinctive coloring is assigned to each section for immediate recognition; red for the fuel body, green for the oxidizer body, and black for the pneumatic actuator. Inlet and outlet ports, as well as direction of flow, are indicated on the propellant sections by imprints. The open and close ports of the pneumatic actuator are indicated by place tabs. Propellant flow to the vernier propellant valves during vernier phase is from the vernier solo tanks.

Propellant Valve Oxidizer Relief Valve

The oxidizer relief valve is a spring-loaded, poppet type valve which is installed in the bleed port of the oxidizer body on the propellant valve. It provides the means of maintaining a liquid head of oxidizer at the propellant valve. Its function is to vent gaseous oxygen from the oxidizer line while the propellant valve is closed.

Hypergolic Igniter

The hypergolic igniter (Figure 30) contains a hypergolic mixture which ignites spontaneously upon contact with any source of oxygen. The igniter is composed of a cartridge, a retainer and an end plug. The chemical charge is contained in the cartridge between two burst diaphragms.

The vernier engines utilize Tri-ethyl-aluminum-boron (TEAB) as the hypergol. It consists of 15% TEA and 85% TEB. A lock pin holds the igniter in place within the igniter container on the thrust chamber. Fuel pressure ruptures the burst diaphragms in the hypergolic cartridge and hypergol forced by fuel is delivered to the thrust chamber for ignition start.

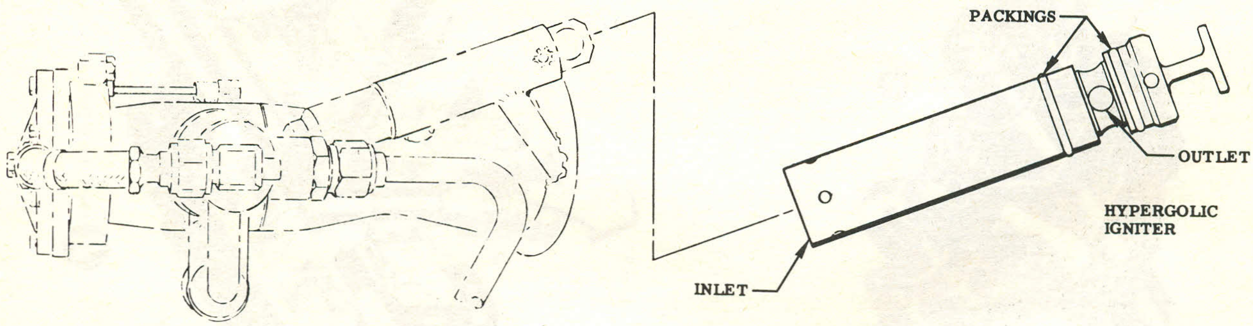


Figure 30 Hypergolic Igniter

Gimbal Components

The gimbal components provide for thrust vector control about the yaw, pitch, and roll axes of the missile. They contain internal passages for channeling the flow of hydraulic fluid and liquid propellants. The gimbal components consist of the pitch gimbal shaft, the pitch gimbal shaft housing, the yaw gimbal shaft, and the yaw gimbal shaft body.

The pitch gimbal shaft provides the axis for pitch gimbaling of the thrust chamber, and also contains passages for propellant flow to the thrust chamber propellant manifolds. Provision is made on the shaft for the installation of bearings, packings, spacers, and rings. A sector gear provides for movement of the thrust chamber through a pitch correction arc of approximately 34 degrees outboard and 24 degrees inboard in the neutral position.

The pitch gimbal shaft housing provides a bearing support for one side of the thrust chamber body. The housing contains passages for fuel and oxidizer which mate with corresponding annular passages in the pitch gimbal shaft. This configuration allows fluid flow while the shaft is rotating within the housing during gimbaling operations.

The yaw gimbal shaft is the pivotal point for yaw gimbal rotation of the thrust chamber. It provides the bearing support for the pitch gimbal shaft and also contains passages for propellant and hydraulic fluid flow. A mounting pad is provided for the installation of a hydraulic actuator which engages the pitch gimbal shaft sector gear. The yaw gimbal shaft provides for movement of the thrust chamber through a yaw-roll correction arc of 74 degrees either side of the neutral position.

The yaw gimbal shaft body houses, and gives bearing support to, the yaw gimbal shaft. In performing this function, the body becomes the primary gimbaling support of the thrust chamber, since it is the only unit of the gimbal components which is secured to the engine mount. The body also contains propellant and hydraulic fluid passages which mate with corresponding annular passages in the yaw gimbal shaft for supplying these fluids during yaw gimbal operation. A cavity in the body accommodates movement of the sector gear installed on the yaw gimbal shaft. A mounting pad is located on the forward side of the body for the installation of a hydraulic actuator which engages the yaw sector gear.

Shields

The vernier engine is provided with heat and drag shields (Figure 31) for protecting the oxidizer dome and the pitch gimbal shaft housing. A cap shield fits over the oxidizer dome and is retained by screws installed in threaded inserts in the edge of the dome. The forward and aft trunnion shields are bolted over the pitch gimbal shaft housing.

Pneumatic Control Package

The pneumatic control package (Figure 32) receives pneumatics from the missile ambient bottle and regulates and distributes the pressure for control and operation of the vernier engines. The package consists of a filter, a pneumatic regulator, a relief valve, two propellant control valves, two pressurizing valves, check valves and vent valves.

The pneumatic regulator section is a balanced piston regulator which provides a constant, regulated pneumatic pressure for component operation. It reduces pneumatic supply pressure of approximately 3,000 PSIG to the required system pressure.

The propellant control valve acts as a selector valve in directing pneumatic pressure to either the open or close ports of the propellant valve actuator. It is a solenoid operated, normally closed, spring-loaded valve. In the closed position, regulated pneumatic pressure is routed to the CLOSE side of the propellant valve actuator, and the OPEN port of the actuator is vented. When the solenoid is energized, the regulated pneumatic pressure is routed to the OPEN side of the propellant valve actuator.

The solo tanks pressurizing control valve section of the pneumatic package is a solenoid-operated, normally closed, spring loaded valve. It acts as a selector valve with a pressurizing port and a vent port. When the solenoid is energized, the control valve vent port closes and the pressure port opens, directing regulated pneumatic pressure to actuate the solo tanks pressurizing control valves. When the solenoid is de-energized, the pressure port closes and the vent port opens to deactuate the solo tanks pressurizing control valves.

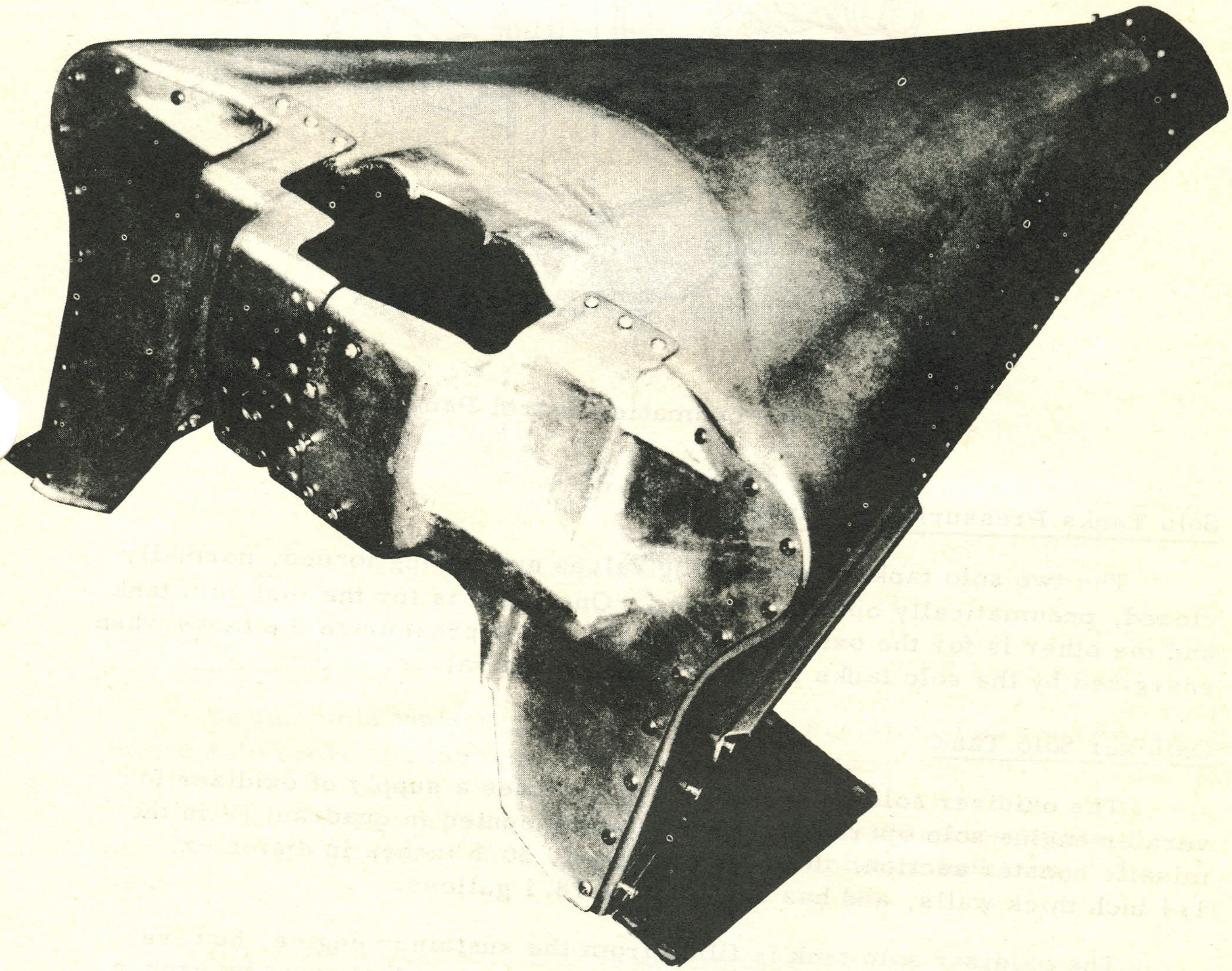


Figure 33 Vernier Engine Fairing

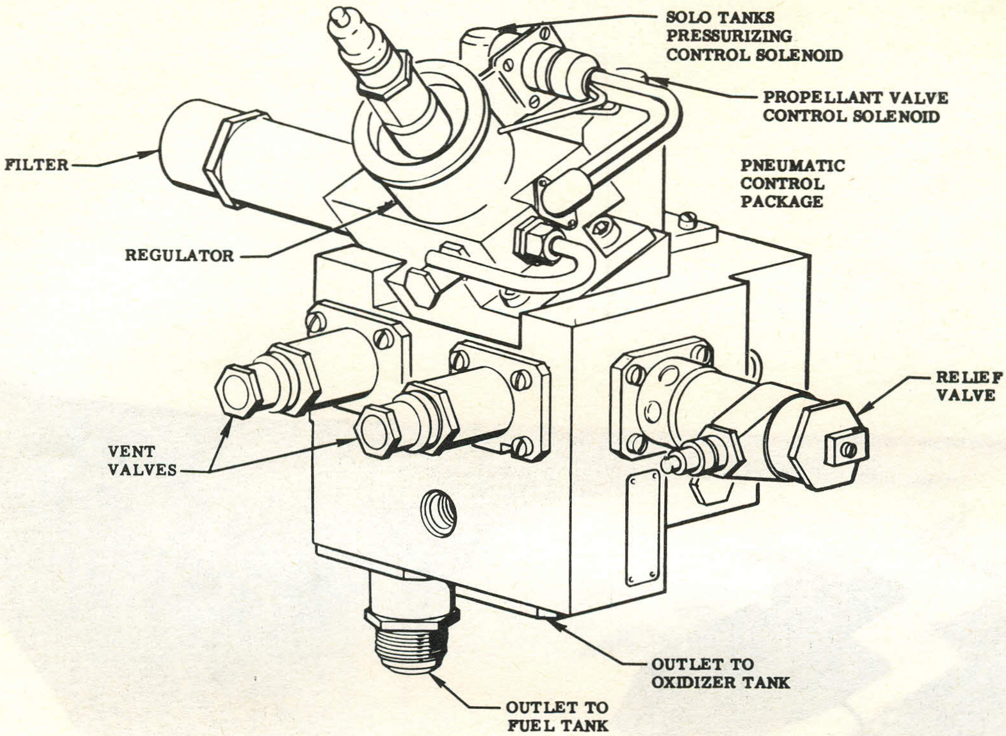


Figure 34 Pneumatic Control Package

Solo Tanks Pressurizing Valves

The two solo tanks pressurizing valves are spring loaded, normally closed, pneumatically operated valves. One valve is for the fuel solo tank and the other is for the oxidizer solo tank. They pressurize the tanks when energized by the solo tanks pressurizing control valves.

Oxidizer Solo Tank

The oxidizer solo tank (Figure 33) provides a supply of oxidizer for vernier engine solo operation. The tank is mounted in quadrant IV in the missile booster section. It is approximately 20.5 inches in diameter, 1/4 inch thick walls, and has a volume of 18.1 gallons.

The oxidizer solo tank is filled from the sustainer engine, however there is a diaphragm in the sustainer-vernier ducting that must be broken by oxidizer pressure from the turbopump before the oxidizer will flow into the solo tank. The tank is pressurized by the pneumatic control package at booster engine cut-off.

The oxidizer solo tank incorporates a vent manifold which furnishes a means of filling, pressurizing, and venting the tank. Separate passages are provided for each of these functions. The vent passage is connected to a relief valve mounted on the exterior of the manifold. Excess pressure in the tank is vented to atmosphere through the relief valve.

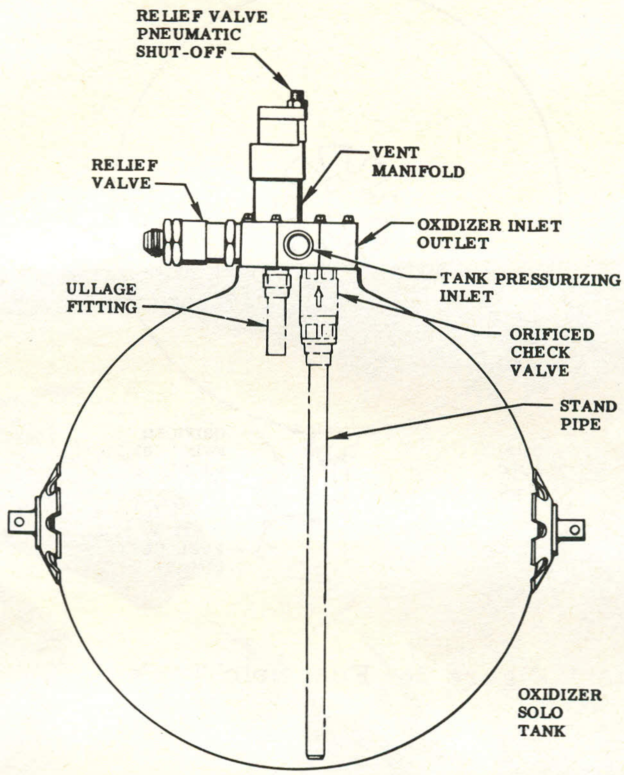


Figure 35 Oxidizer Solo Tank

Fuel Solo Tank

The fuel solo tank (Figure 34) provides a supply of fuel for vernier engine solo operation for a maximum of 25 seconds.

The fuel solo tank is a sphere, 18.7 inches in diameter with a volume of 14.6 gallons. It is located inside the missile fuel tank at the apex.

Filling of the fuel solo tank is accomplished by the sustainer engine. The solo tank begins to fill under gravity flow during the sustainer preparation stage. It will continue filling during flight until trapped ullage pressure reaches a certain point. A one way restrictor is installed in the fill line to control the rate of fill, however it is free flow when fuel is being expelled from the tank during vernier solo.

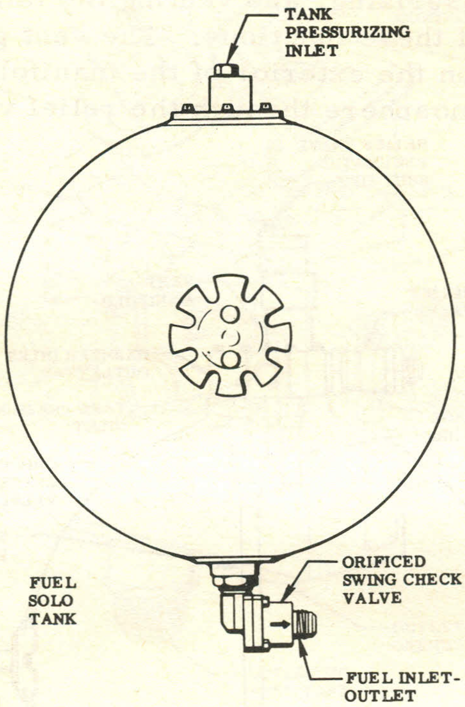


Figure 36 Fuel Solo Tank

ROCKET ENGINE RELAY BOX

The rocket engine relay box (Figure 37) is a pie-shaped container which contains the rocket engine control circuits and relays. The principal structural part of the relay box is a machined metal plate. Three electrical receptacles and a pressurizing valve are mounted on the face of the plate. A ring-shaped fiberglass bracket and a rectifier box are mounted on the reverse side. The bracket is the mounting base for the relays, the terminals, and the ground and power buses. The rectifier box provides a mounting base for the vernier delay timer and the rectifier assembly. These components are enclosed by a cover which is clamped to a plate. The relay box is pressurized with dry gaseous nitrogen. A gasket between the cover and the plate provides a pressure-tight seal.

The relay box is mounted in the B-2 equipment pod aboard the missile, therefore, signals from the ground sequencer and from the missile programmer will be routed through the relay box for controlling the engines start and stop sequence.

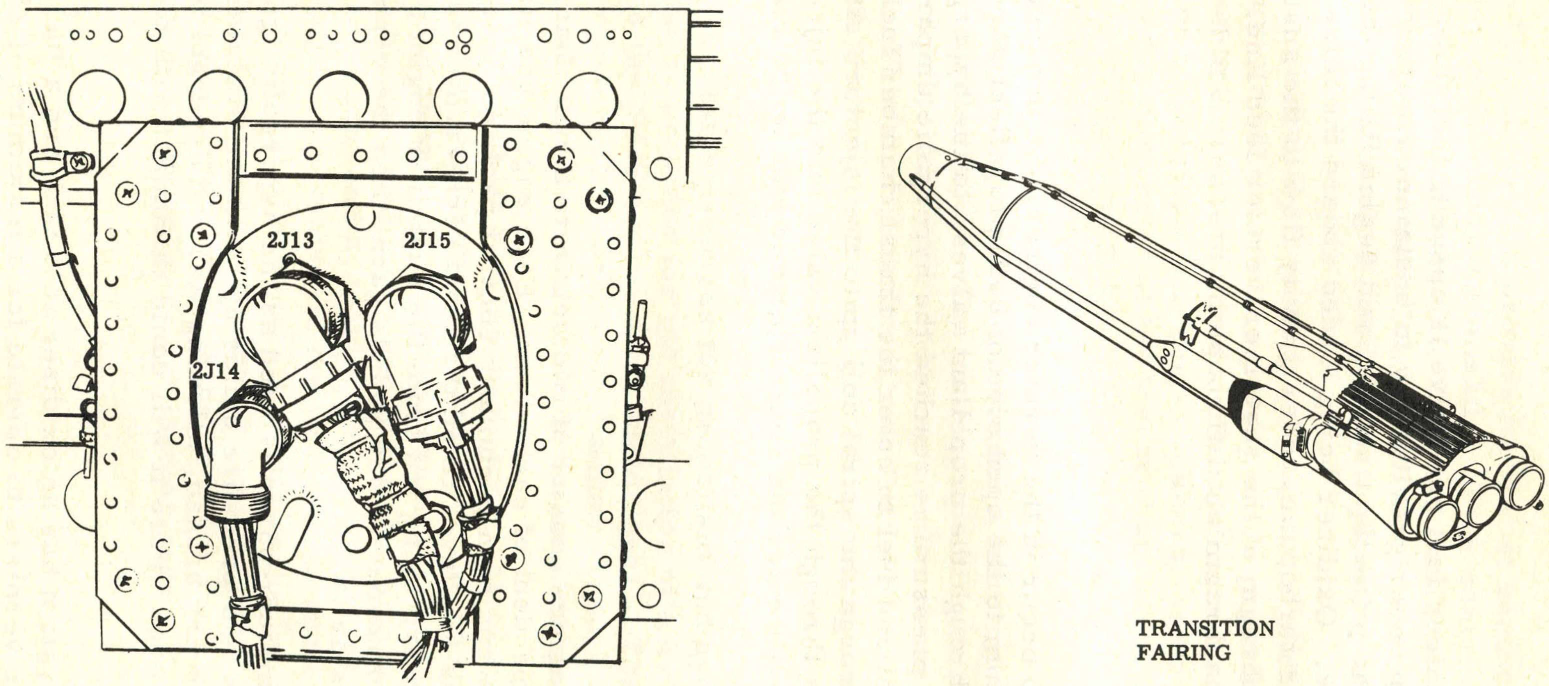


Figure 37 Rocket Engine Relay Box

OPERATION (Figure 49)

Preparation Stage

When the sustainer fuel pre-valve is opened, fuel flows through the sustainer turbopump under gravity flow to sustainer components and to the closed vernier engine propellant valves, and begins filling the vernier engine fuel solo tank. Oxidizer being loaded aboard the missile will flow through the sustainer turbopump under gravity flow to the sustainer components and to the diaphragm in the sustainer-vernier feed line. The oxidizer will not burst this diaphragm until turbopump pressure builds up.

Main Stage

For ignition to occur in the vernier engines, the pneumatic control package directs helium to the open side of both propellant valves. This allows fuel to flow through the propellant valves, to the hypergolic igniters. When sufficient fuel pressure is reached the hypergolic diaphragms burst allowing the hypergol and fuel to enter the thrust chamber fuel manifold and be circulated through the spiral coil up to the injector. At the same time, oxidizer flows through the propellant valve into the injector where the two propellants will enter the combustor and will ignite upon contact with each other.

SUMMARY

The vernier engines consist of two separate thrust chambers which are completely independent of each other. Each engine has its own propellant valves with a common pneumatic control package for the controlling of these valves. The sea level rated thrust of each vernier is 1000 pounds when the propellants are being fed from the sustainer engine, however the thrust decays to approximately 830 pounds each when the verniers are operating off of the solo tanks.

Tri-ethyl-aluminum-boron is used as the hypergolic igniters in the vernier system. As fuel pressure builds up from the sustainer engine the hypergol diaphragms are broken, allowing fuel and hypergol to be forced into the combustion area where it will come in contact with the oxidizer for combustion.

The vernier system has an oxidizer solo tank and a fuel solo tank which will enable the verniers to operate for a maximum of 25 seconds after the sustainer engine has been cut off.

The vernier pneumatic control package incorporates electrical solenoids for controlling the application of pneumatics to various valves at the prescribed time that each valve is scheduled to operate. These valves are not only used during the start sequence of the verniers but are also used during the shutdown sequence.

The vernier engines are started approximately 3.5 seconds after the sustainer engine has started. The sustainer will supply both oxidizer and fuel to the vernier engines plus filling of the fuel and oxidizer solo tanks during flight.

QUESTIONS

1. How much thrust does each individual vernier engine produce at sea level?

2. What two sources do the vernier engines receive propellants from during flight?

3. What is the name of the hypergolic material used to ignite the vernier engines?

4. At what time are the solo tanks used during flight?

5. What is the maximum run time of the verniers on solo tank operation?

6. What axes may the verniers be gimbaled in?

7. What prevents the oxidizer from flowing to the vernier propellant valves before sustainer turbopump pressure buildup?

8. What are two main functions of the pneumatic control package?

9. What pneumatic pressure is utilized downstream of the regulator in the pneumatic control package?

10. What controls the filling rate of the fuel solo tank?

SECTION V

INSPECTION AND CHECKOUT OF MA-3 PROPULSION SYSTEM

INTRODUCTION

The purpose of checkout is to verify the operational capability of the booster, sustainer, and vernier engines. This is accomplished by a pre-installation checkout and a post installation or system checkout. Pre-installation checkout is performed on replacement engine assemblies at the MAMS prior to installation on a missile. The system checkout is performed after installation of the engine assembly, or during the recycle maintenance operation.

The procedures used during checkout are for the purpose of determining that the engine components function correctly and that hydraulic and pneumatic control systems and propellant feed systems do not leak beyond specified limits. Refer to the applicable Technical Order for the step by step procedures for an individual check of each engine.

MAPCHE CHECKOUT

There are two card decks supplied with MAPCHE for performing a continuity check on the MA-3 propulsion system. One deck will be utilized at the MAMS and the other at the launch site. MAPCHE applies a 28V DC discrete signal to one side of the closed circuit and checks for voltage on the opposite side of the circuit. Continuity checks are performed on the following:

1. Solid propellant gas generator. (Booster and Sustainer)
2. Liquid propellant gas gen. igniters. (Booster and Sustainer)
3. Booster NO. 1 gas generator heater.
4. Booster NO. 2 gas generator heater.
5. Sustainer gas generator heater.

The following checks are performed on the rocket engine relay box to determine its operational capability.

1. Booster NO. 1 and NO. 2 cutoff solenoids.
2. Sustainer ignition stage control.
3. Sustainer lock-in relays.
4. Vernier delay timer.
5. Vernier control.

6. Vernier solo tank pressurization control.
7. Complete cutoff.

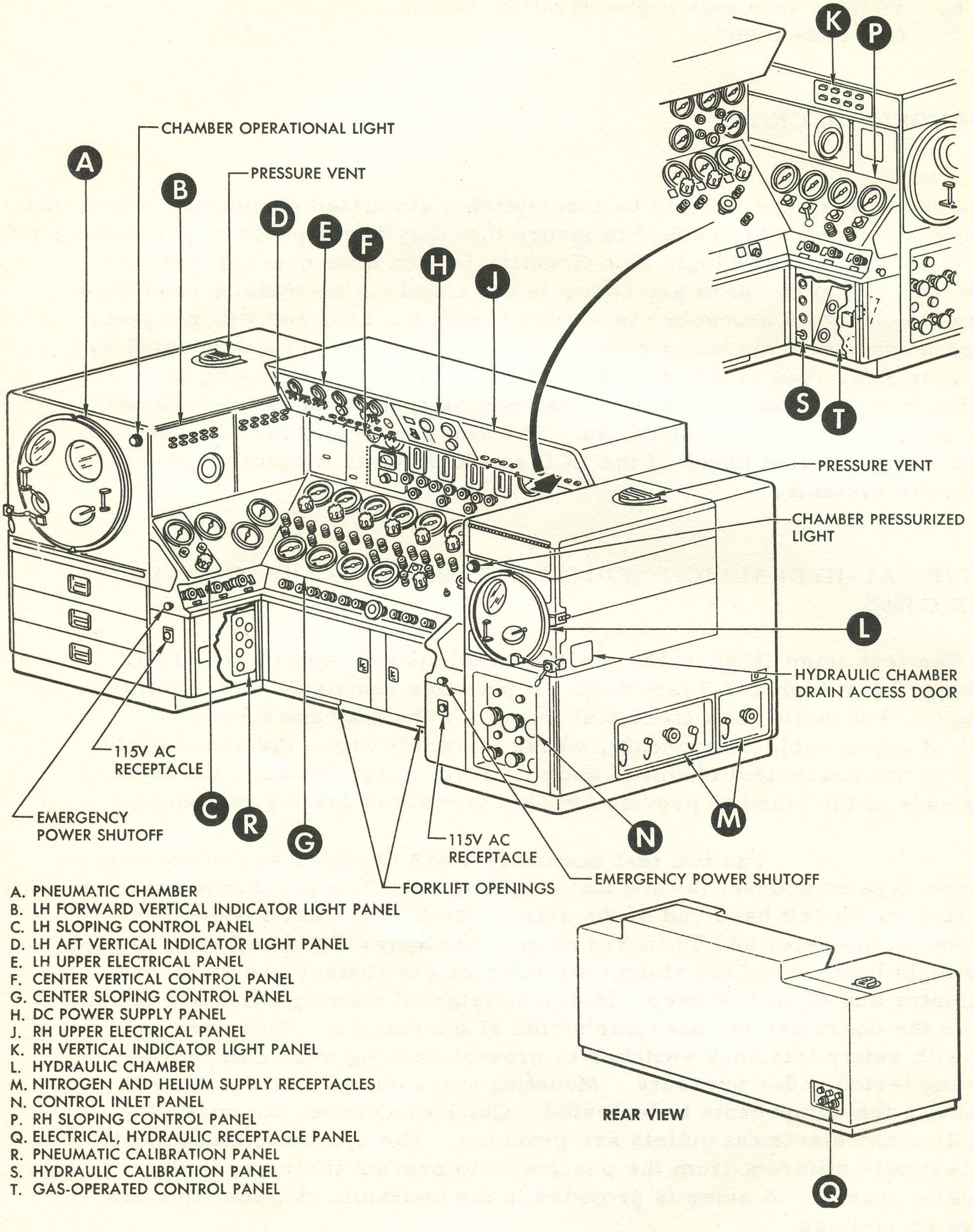
RESPONDER CHECKOUT

The responders are utilized to accomplish a simulated countdown. First, the responders may be self checked to insure that they are capable of simulated a satisfactory countdown. The logic unit circuitry is then disconnected from the missile and the responders are connected to simulate the missile conditions. A normal countdown procedure is initiated from the LCC and will progress through a complete countdown with all missile functions being simulated by the responders. The responders have the capability of simulating malfunctions providing the malfunction has been manually inserted by operating personnel performing the countdown. The simulated countdown has performed an operational check of the LCC and logic units without sequencing the missile systems.

ELECTRICAL-HYDRAULIC-PNEUMATIC COMPONENTS SYSTEM TEST STAND G3065

The test stand (Figure 38) is a U-shaped console approximately 12 feet long, 7 feet high and 5 feet deep. It provides controlled and monitored pneumatic, hydraulic, and electrical inputs for the leak and functional testing of replaceable components, whose tests fall within the scope of this stand. A pneumatic test chamber and a hydraulic test chamber are located on the ends of the stand to provide isolated test areas for the components.

The two test chambers are designed to contain any explosive type component failure that might occur. The pneumatic chamber is located on the left hand end of the stand. Its interior dimensions are 35 inches in diameter and 55 inches deep. The hydraulic chamber is located on the right hand end of the stand. Its interior dimensions are 22 inches in diameter and 42 inches deep. Heavy bulletproof viewing ports are provided in the doors and the operator's side of the cubicle. Doors are provided with safety interlock switches to prevent opening when components are being tested under pressure. Mounting trays on rails are provided for holding the components to be tested. Quick disconnect pneumatic, hydraulic, and electrical outlets are provided. The hydraulic disconnects are physically different from the pneumatic to prevent their use in the pneumatic system. A sump is provided in the hydraulic chamber to catch leakage or spillage.



A. PNEUMATIC CHAMBER
B. LH FORWARD VERTICAL INDICATOR LIGHT PANEL
C. LH SLOPING CONTROL PANEL
D. LH AFT VERTICAL INDICATOR LIGHT PANEL
E. LH UPPER ELECTRICAL PANEL
F. CENTER VERTICAL CONTROL PANEL
G. CENTER SLOPING CONTROL PANEL
H. DC POWER SUPPLY PANEL
J. RH UPPER ELECTRICAL PANEL
K. RH VERTICAL INDICATOR LIGHT PANEL
L. HYDRAULIC CHAMBER
M. NITROGEN AND HELIUM SUPPLY RECEPTACLES
N. CONTROL INLET PANEL
P. RH SLOPING CONTROL PANEL
Q. ELECTRICAL, HYDRAULIC RECEPTACLE PANEL
R. PNEUMATIC CALIBRATION PANEL
S. HYDRAULIC CALIBRATION PANEL
T. GAS-OPERATED CONTROL PANEL

Figure 38 Electrical-Hydraulic-Pneumatic-Components Test Stand, G3065

Pneumatic System: The pneumatic system receives gaseous nitrogen and gaseous helium from a facility supply with three individually selectable sources for each gas.

Hydraulic System: The stand receives hydraulic power from an external source, hydraulic pumping unit G3067. This hydraulic pumping unit supplies 10 GPM at 3000 PSIG, and 5 GPM at 5000 PSIG. This pressure is controlled and monitored to three pressure outlets in the test cubicle. Flows from 0 to 10 GPM may be measured by flowmeters. A remote control panel is provided for starting and stopping the pumping unit, changing compensator control, and legend lights indicate malfunction of certain pumping unit components.

Electrical System: The 115 volt 30 AMP AC, 60 cycle single phase circuit provides power for cubicle lights, the variable 28 volt power supply, certain heater and solenoid valve checks, and provides the time base for the millisecond timer. The facility supplied 28 volt 20 AMP circuit provides power for operation of stand components. The 0 to 28 volt 25 AMP DC variable power supply provides regulated power to various outlets in the test cubicle and on the panel for various component checks.

ELECTRICAL-PNEUMATIC SYSTEM TEST STAND G3077

The stand is a mobile, rocket engine test console. Dimensions: 89 inches long; 48 inches wide; 72 inches high. Weight 1600 pounds. The enclosure of the stand consists of four rack-type units mounted on a cart provided with a hinged towbar and four swivel casters, each provided with swivel locks and two with foot operated parking brakes. The enclosure is completed with side panels mounted on the sides of the end units and a top panel which covers all four units. The design of the units and the cart is such that the number of units can easily be changed from four to seven or rearranged to satisfy future changes. Included in the enclosure of the stand are; two storage compartments for pneumatic hoses, one for oxidizer and pneumatic system test hoses and one for fuel and lubricating system test hoses; four storage compartments for electrical cables; and four storage compartments for handbooks and miscellaneous loose equipment.

The stand contains a pneumatic system and an electrical system. The pneumatic system consists of 12 individually slide-mounted panel assemblies connected by plumbing to the external connectors at the rear of the stand. The stand is connected to the engine from the external pneumatic connectors with test hoses furnished as loose equipment with the stand. The hoses are connected to the engine with the applicable plates, plugs and adapters provided in the G3080 and G3087 Plates and Plugs Kits.

The electrical system consists of 2 individually slide-mounted panel assemblies and a panel assembly mounted on the Differential Pressure Panel connected by cables to the external connectors at the rear of the stand. The stand is connected to the engine from the external electrical connectors with cables furnished as loose equipment with the stand. No electrical adapters are required. The electrical system also contains lights for the Flowmeter Panel and convenience outlets at the rear of the stand. The pneumatic system consists of the oxidizer and pneumatic system test sub-system and a fuel and lubricating system test subsystem. The external pneumatic connectors for the two subsystems are non-interchangeable with each other and the test hoses are of different size.

Leak, functional and electrical continuity tests must be performed on each booster, sustainer, and vernier engine module during maintenance operations on the individual engine modules prior to installation in the missile.

Electrical control circuits operate on 28 volt, DC power, heater circuits operate on 115 volts, single phase, 60 cycle power and pneumatic pressures required for functional tests range up to 1000 PSIG.

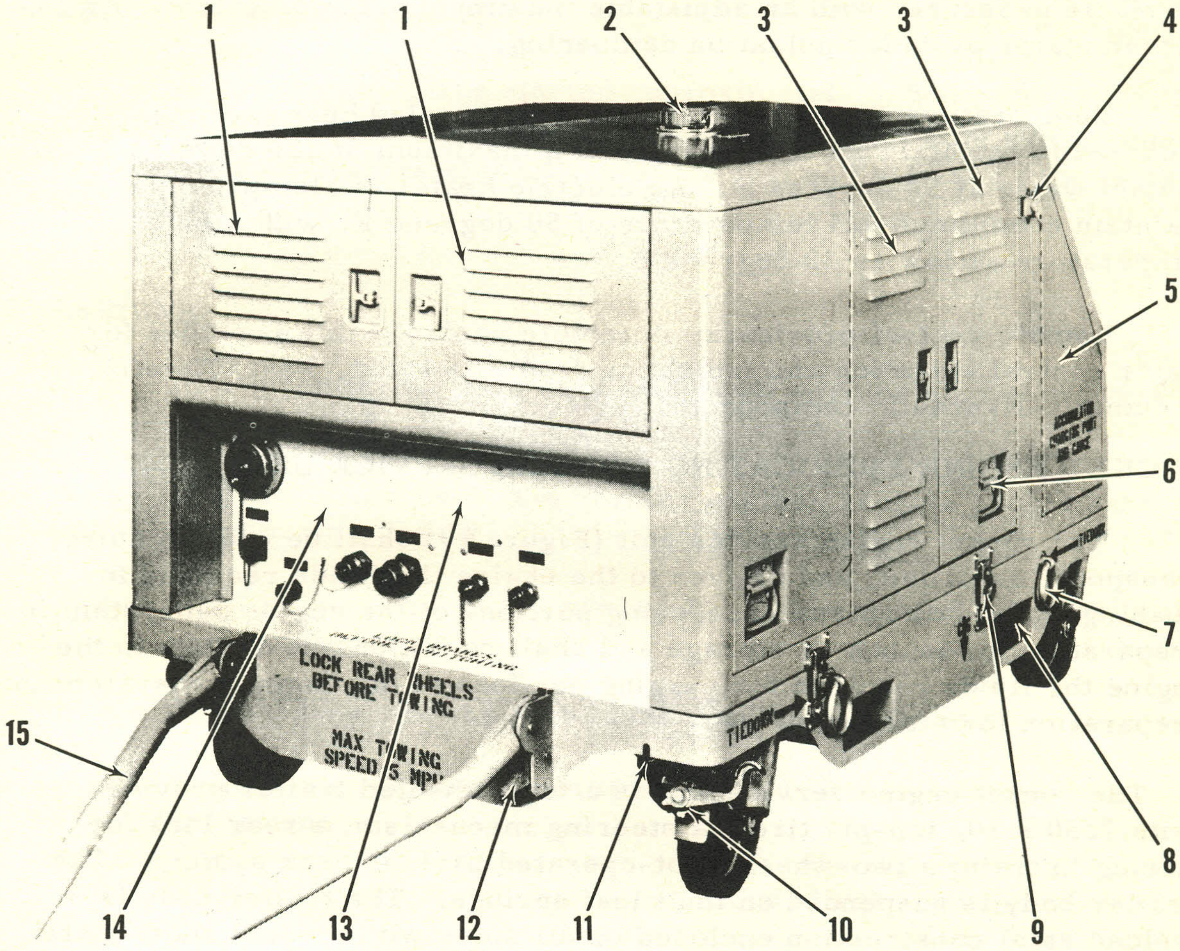
One sustainer engine, vernier engine, or booster engine module will be tested at a time. The engine modules will be mounted on workstands within the engine maintenance area and in the missile within the missile maintenance area during test operations. Minimum hose and cable lengths required are 25 feet. This stand will be located in the engine maintenance area.

HYDRAULIC PUMPING UNIT G3067

This unit (Figure 39) is an air transportable, mobile hydraulic power package which is used in conjunction with the Electrical Pneumatic System Test Stand, in the EMA and the Electrical-Hydraulic-Pneumatic Components Test Stand EMA. This unit shall have the following approximate dimensions: length 60 inches, height 48 inches, width 48 inches; weight 2800 pounds. This unit is mounted on swivel casters and is designed for mobility sheltered equipment.

A sloping control panel provided with a hinged cover is located on one end of the unit. The other end is equipped with a towing bar and facility interconnect hoses and electrical cables.

Hydraulic System - The pumping unit supplies its compatible equipment or the Sustainer and Vernier Engine modules with MIL-H-5606 hydraulic oil at pressures up to 3000 PSIG at flows up to 10 GPM and



1. Front Access Doors
2. Hydraulic Fluid Reservoir Filler Cap
3. Left Side Main Access Doors
4. Latch -- Front Cabinet/Rear Cabinet
5. Left Side Rear Access Door
6. Front Cabinet Lifting Handle
7. Tiedown Ring
8. Hoisting Channel
9. Latch -- Front Cabinet/Chassis
10. Caster Foot Brake
11. Caster Swivel Latch Release Ring
12. Towbar Latch Release Lever
13. Forward Bulkhead
14. External Connection Panel
15. Towbar

Figure 39 Hydraulic Pumping Unit G3067

pressures up to 5000 PSIG at flows up to 5 GPM. A stainless steel cylindrical reservoir with conical bottom provides a capacity of 30 gallons. A high pressure pump is of the axial piston-type with nine pistons and an operational speed of 3600 RPM. It is of variable stroke, variable pressure, with an adjustable maximum volume control. An accumulator provides pulsation dampening.

Temperature Control System: A water cooled heat exchanger is provided to maintain oil temperature at a maximum of 120 degrees F with coolant water at 80 degrees F. An electric heater is also provided to maintain a minimum oil temperature of 80 degrees F, with ambient temperature as low as 32 degrees F.

Remote control provision: A remote control cable provides for major control actuation and indication from the stand, Test, Electrical-Pneumatic-Hydraulic components.

ROCKET ENGINE LUBRICATING-PURGING SERVICE UNIT G2000

The rocket engine service unit (Figure 40) shall be used to store, transport, condition, and deliver to the engine the fluids required for flushing, lubricating, and preserving portions of the engine subsystem in preparation for launch or storage and shall condition and deliver to the engine the fluids required for purging portions of the engine subsystem in preparation for storage.

The rocket engine service unit is a four-wheeled trailer provided with 7.50 x 10, ten-ply tires; a steering mechanism; a rear lock for towing in train; a two-wheel, foot-operated parking brak system. The trailer body is suspended on multileaf springs. The trailer body is of welded steel construction enclosed on all sides with riveted sheet metal; doors are provided all around to allow access to the interior; the top is removable to allow access to the interior. Control panels are located on both sides of the trailer; they mount the various valve controls, meters, and switches to control the delivery of the necessary fluids to the rocket engine.

The service unit utilizes 480-volt 3-phase 60-cycle AC power from an external source to control heat and deliver the lubricating oil, preservative compound, and gaseous nitrogen to the rocket engine.

The service unit contains a pneumatic system capable of receiving gaseous nitrogen from an external source ranging from 1500 to 2500 PSIG at a flow rate of 1200 SCFM and distributing the gas through each of two systems; one system (High pressure purge system) will deliver heated, filtered, gaseous nitrogen to the engines at pressures up to 475 PSIG and at flow rates up to 600 SCFM and the other system (Low Pressure Purge System) will deliver heated, filtered, gaseous nitrogen to the engines at pressures up to 425 PSIG and flow rates up to 600 SCFM. In addition, provision has been made to pressurize the solvent tank for delivery of heated trichloroethylene solvent. The Service Unit contains a hydraulic system including a positive displacement electric pump and the necessary valves and controls for delivery of heated and filtered lubricating oil and preservative oil at proper pressures and volumes to the rocket engine.

The service unit has included five hose reels enveloping four hoses, each forty feet long and one hose fifty feet long. They are identified by numbers 1 through 5. Hoses NO. 1 and 3 deliver gaseous nitrogen; hose NO. 2 delivers either gaseous nitrogen or trichloroethylene; hose NO. 4 delivers either lubricating oil or preservative oil or gaseous nitrogen; hose NO. 5, which is fifty feet long, receives gaseous nitrogen from an external supply source. A fifty-foot length of electrical cable is supplied to transmit electrical power.

The service unit includes three tanks used for storage of lubricating oil, flushing solvent, and preservative oil. The lubrication and preservative oil tanks each have a capacity of 50 gallons and 5 gallons ullage; the flushing solvent tank has capacity of 100 gallons and 10 gallons ullage.

Overall dimensions of the service unit area; length 112 inches, width 73 inches, height 60 inches, and dry weight 5100 pounds maximum.

The booster engine and sustainer engine lube oil tanks must be filled with lubricating oil in preparation for launch; the booster engine and sustainer engine liquid oxygen domes, fuel jackets, and injectors must be flushed with solvent and purged with gaseous nitrogen during maintenance operations, the booster engine and sustainer engine turbopumps must be preserved at all times when in storage and during maintenance operations.

The booster engine lube oil tank has a capacity of 13.0 gallons; the sustainer lube oil tank has a capacity of 6.9 gallons (horizontal attitude). Each lube oil tank is filled separately, using a 100 FT horizontal servicing hose. Allowable pressure for filling tanks is 65 PSIG; draining the oil tanks is accomplished by gravity flow. Filling of the lube oil tanks must be performed in an unsheltered area. Maximum lube oil temperature range and limit at the engine connect point has been established at 35 DEG. F through 130 DEG. F.

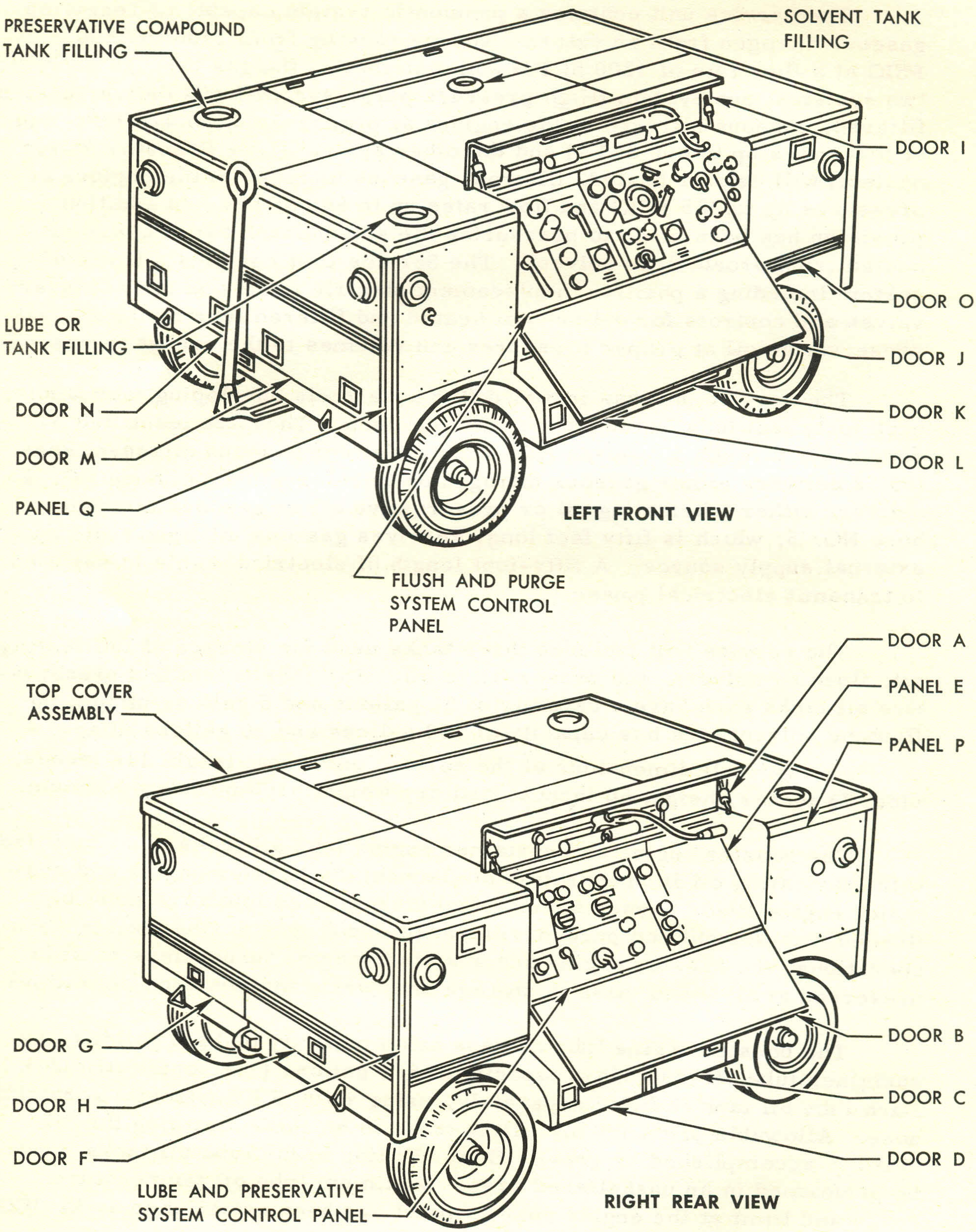


Figure 40 Rocket Engine Lube - Purge Service Unit

Lower temperature limit of 35 DEG. F will minimize expansion and overflow of lube oil due to subsequent heating of lube oil.

Trichloroethylene Solvent - The tank capacity required for flushing the liquid oxygen dome, fuel jacket, and injector is approximately 25 - 35 gallons per engine. The trichloroethylene solvent administered at the engine connect point must have a temperature range and limit of between 35 DEG F and 130 DEG F. Solvent for flushing the oxidizer dome is delivered under a pressure of 80 plus or minus 5 PSIG to the connect point and is drained through the injector. Solvent for flushing the fuel jacket is delivered under a pressure of 30 plus or minus 10 PSIG to the connect point fuel jacket.

Preservative Oil - Preservation of the Booster and Sustainer Engine turbopump gear case requires 11 gallons of preservative oil preheated to a minimum temperature of 75 DEG. F due to flow characteristics of the preservative. A maximum temperature of 100 DEG. F should not be exceeded due to safety of personnel. The preservative is delivered through a service hose 40 FT. long for vertical and 100 FT. for horizontal. Allowable delivery pressure at connect point is 200 plus or minus 20 PSIG. Prior to preserving the turbopump gear case preservative oil must be homogenized by recirculation or other means. Only one turbopump gear case is preserved at a time; allow preservative oil to drain out through the system.

Gaseous Nitrogen - The Booster and Sustainer engine purge gas requirement to dry the liquid oxygen dome and fuel jacket requires approximately 1800 standard cubic feet; the GN-2 gas purge is applied at the same connectors as used for the solvent flush. An allowable pressure of 250 PSIG is required for this purging. When purging through the open main valves it is recommended that unheated GN2 be used to prevent damage or deformation of the lipseal due to the high temperature applied to the lipseal. One engine thrust chamber will be purged at a time; minimum length of service hose required is 40 feet.

ROCKET ENGINE LEAK-TEST PLATE AND PLUG KIT KMU-75/E G3080

The booster engine plate and plug kit (Figure 41) includes all the items required for sealing the engine openings during leak tests and all special tools necessary for component replacement, adjustments, and functional test of the engine. A complete set of adapters is included to provide for attaching the pneumatic or hydraulic test lever used in pressurizing the systems. The systems are contained in a mobile, four-wheeled stand which measures approximately 24 by 48 by 60 inches and weighs approximately 230 pounds.

ROCKET ENGINE LEAK-TEST PLATE AND PLUG KIT KMU-76/E G3087

The sustainer-vernier engine leak-test plate and plug kit (Figure 42) includes all the items required for sealing the engine openings during leak tests and all special hand-tools necessary for component replacement, adjustments, and functional test of the engine. A complete set of adapters is included to provide for attaching the pneumatic or hydraulic test lines used in pressurizing the systems. The items are contained in a mobile, four-wheeled stand which measures approximately 24 by 48 by 60 inches and weighs approximately 230 pounds.

MOBILTAINER 106080

The mobiltainer (Figure 43) is a large, mobile container having two parallel rails installed lengthwise in its interior. The rails are provided for roll-transferring the engine and its support from the trailer into the mobiltainer. A door at the rear of the mobiltainer is provided for access to the interior. A desiccant compartment is provided for the addition of desiccant units for protecting the engine from moisture. A purge valve (used with an external source of gaseous nitrogen) is provided for dehumidifying the mobiltainer interior.

TRANSPORTATION TRAILER 106051

The transportation trailer (Figure 43) is the transportation member of the mobiltainer and work bench group. The trailer has two rails which line up with, and attach to, the mobiltainer and the workstand. The rails are necessary for roll-transferring the engine. Pneumatic tires are provided for mobility of the unit.

WORKSTAND MMU-4/E

The workstand (Figure 44) is a heavy-duty workstand for holding the engine during maintenance operations and for temporary storage. The stand is adjustable to different heights so that the two rails of the platform can be alined with the rails of the transportation trailer. The approximate dimensions are as follows: length, 152 inches; width, 55 inches; and height, 39 inches. The approximate weight is 480 pounds.

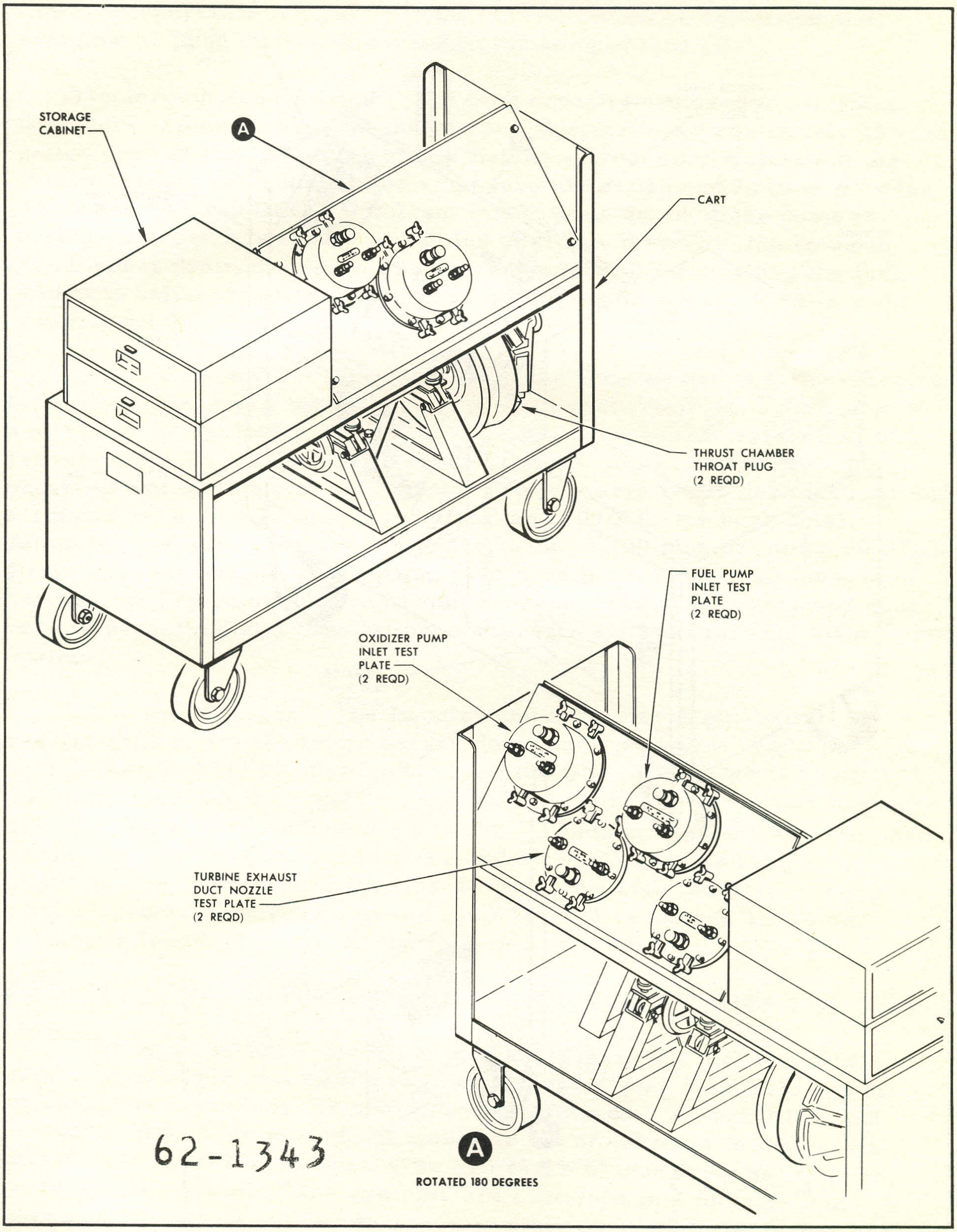


Figure 41 Rocket Engine Maintenance Plates and Plugs Kit G3080

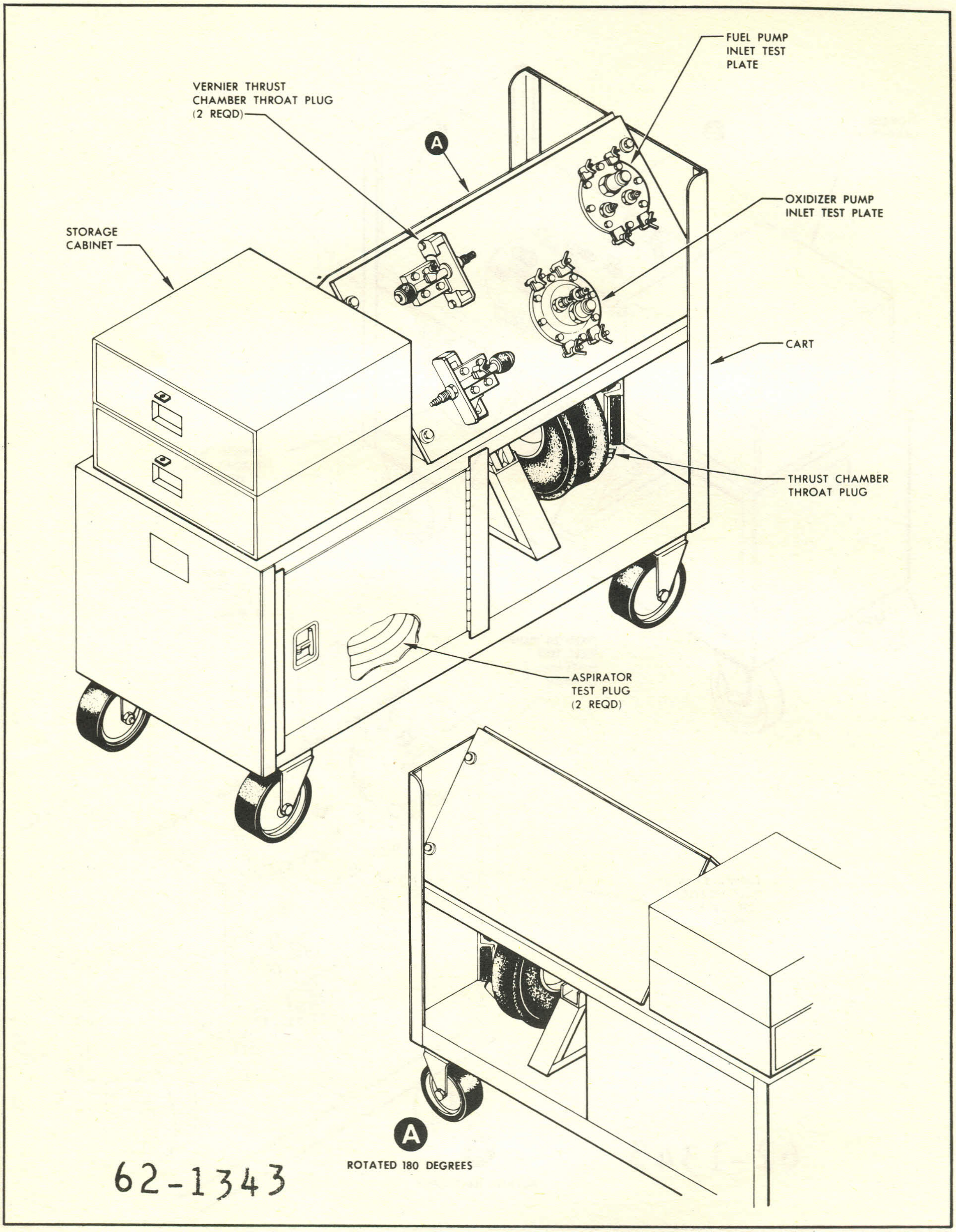


Figure 42 Rocket Engine Maintenance Plates and Plugs Kit G3087

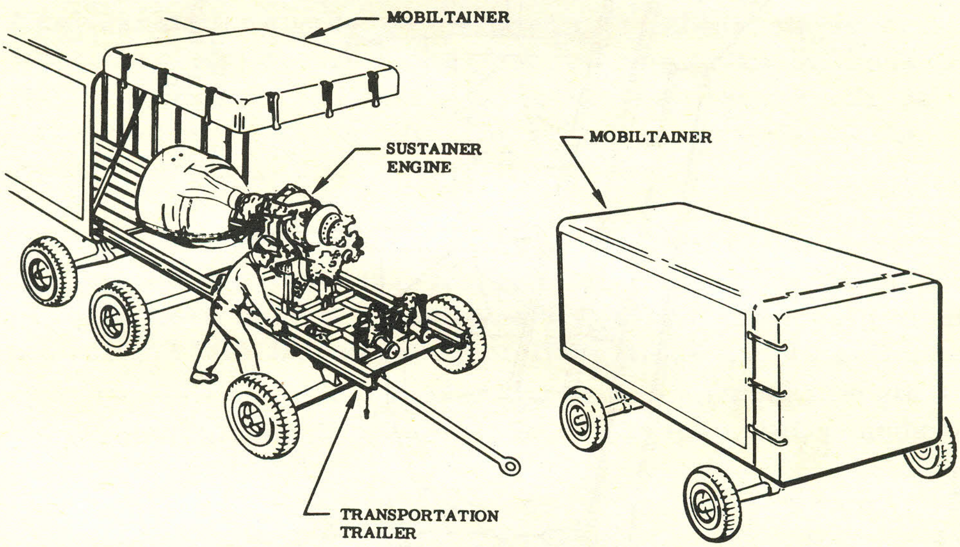


Figure 43 Mobiltainer

NOTE
TELESCOPIC LEGS ON WORKSTAND ARE ADJUSTABLE FOR FIXED RAIL HEIGHTS FROM 30 TO 39 INCHES. ADJUSTABLE SCREWS ARE PROVIDED ON WORKSTAND LEGS FOR HEIGHT ADJUSTMENT OF 1.5 INCHES.

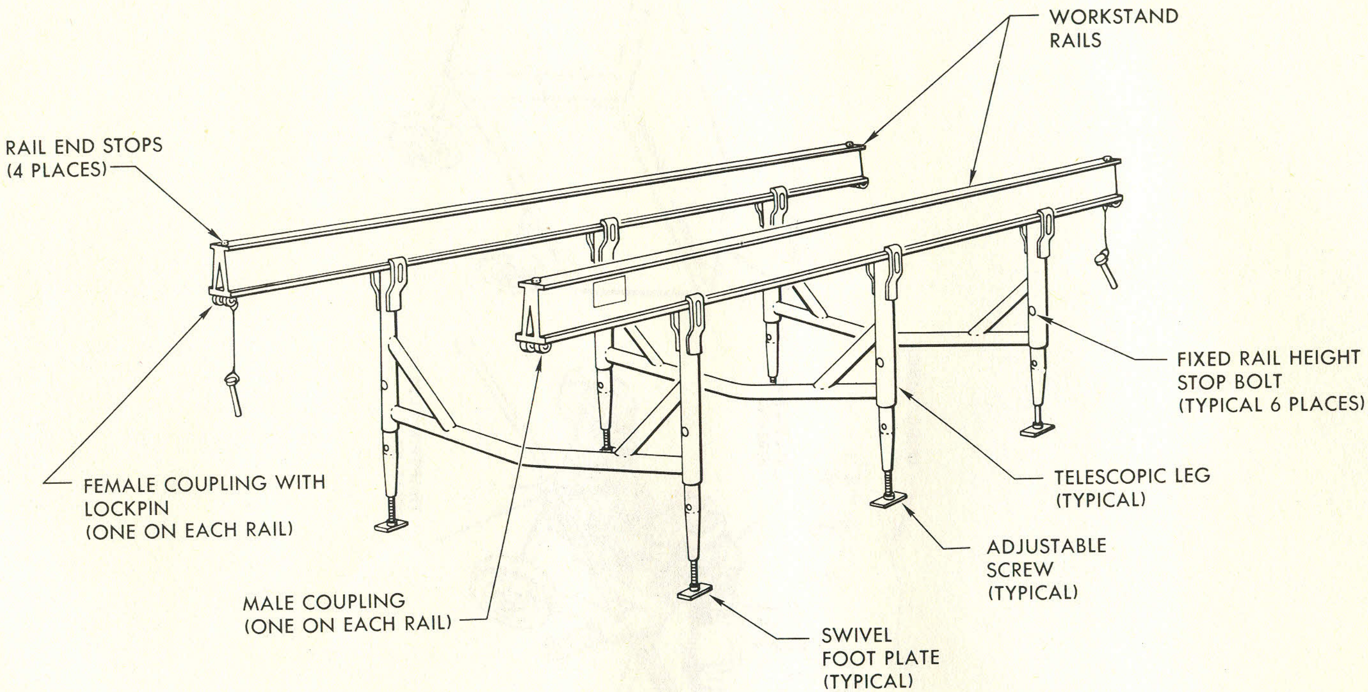


Figure 44 Missile Engine Workstand (105011)

ADAPTER SET, SERVICE UNIT

The adapter set, service unit is a container holding certain disconnect fittings to adapt the delivery hoses of the G2000 service Unit to the MA-3 propulsion system. The approximately weight of the set is 11 pounds.

ROCKET ENGINE MAINTENANCE AND FLUSHING STAND

This stand (Figure 45) is used to support and secure the engine in a vertical position during flushing, purging, and preservation operations. The stand consists of two cradle supported rail assemblies which pivot on pillow blocks. These assemblies are bolted to a castered frame assembly. The rail bed assembly is rotated by actuating the two pump pressurized hydraulic actuators. The approximate dimensions are as follows: length, 120 inches; width, 130 inches; and height, 85 inches.

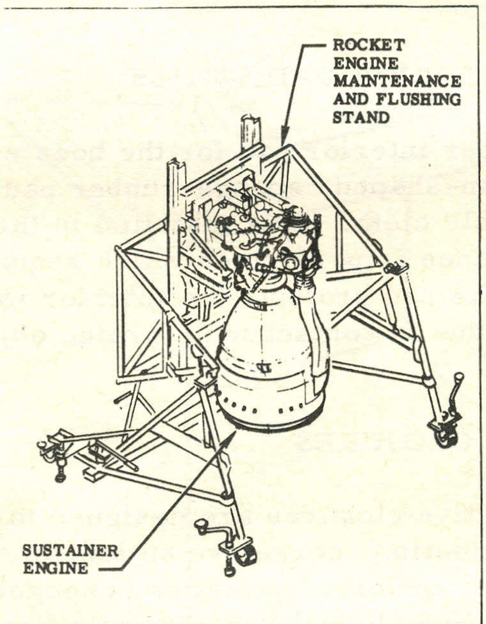


Figure 45 Rocket Engine Maintenance and Flushing Stand

VERNIER ENGINE MAINTENANCE STAND ETU-40/E G4026

The vernier engine maintenance stand (Figure 46 , consists of a commercial cart to which a tubing frame is attached for supporting the vernier engine in a working position. Lockpins and a quick-release fastener hold the engine in place. Two swivel and two rigid casters are provided with the cart, and a lower shelf provides storage area. Overall dimensions are as follows: width, 32 inches; length, 40 inches; height, 35 inches. The cart weighs approximately 85 pounds.

VERNIER ROCKET ENGINE LIFTING SLING HLU-11/E G4004

The vernier rocket engine lifting sling consists of two webbing-strap sling loops and a hoisting ring for mechanically hoisting the vernier engine. (See Figure 47, The sling loops are secured about the vernier thrust chamber at the throat and just forward of the pitch gimbal shaft. The hoisting ring is then placed in the hook of the hoisting mechanism.

THRUST CHAMBER INTERIOR PAD 9011565

The thrust chamber interior pad for the booster and sustainer engines consists of a fan-shaped, sponge-rubber pad, 0.50 by 60 by 66 inches encased in durable cloth. It is installed in the interior of the thrust chamber when maintenance is performed which requires personnel to enter the thrust chamber. The pad protects the interior wall of the thrust chamber from damage due to contact with foreign objects.

ENGINE PROTECTIVE CLOSURES

The engine protective closures are designed to protect the engine from moisture, contamination, corrosive action, and abrasion at all times, except when the engine is undergoing testing, checkout, or maintenance operations. The protective closures incorporate items for sealing all engine openings and a cover for the thrust chamber skirt. Adapters are provided for sealing open tubing ends and plumbing connections. Closures are provided for sealing the turbopump oxidizer and fuel inlet openings, the accessory drive pad opening, and the thrust chamber exit. The adapters, turbopump inlet closures, and thrust chamber exit closure have provisions for the installation of disiccant materials to control moisture within the engine.

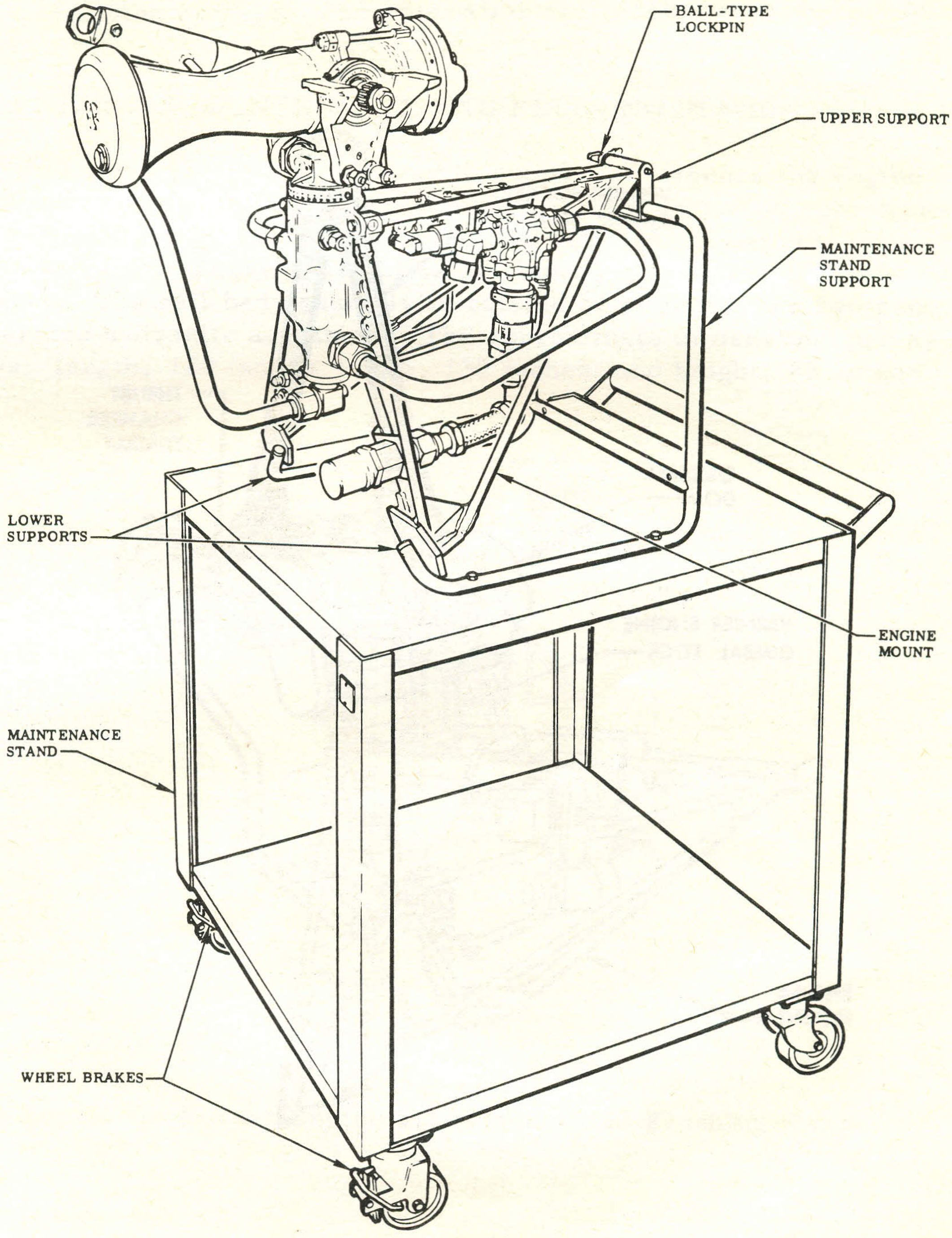


Figure 46 Vernier Engine Maintenance Stand G4026

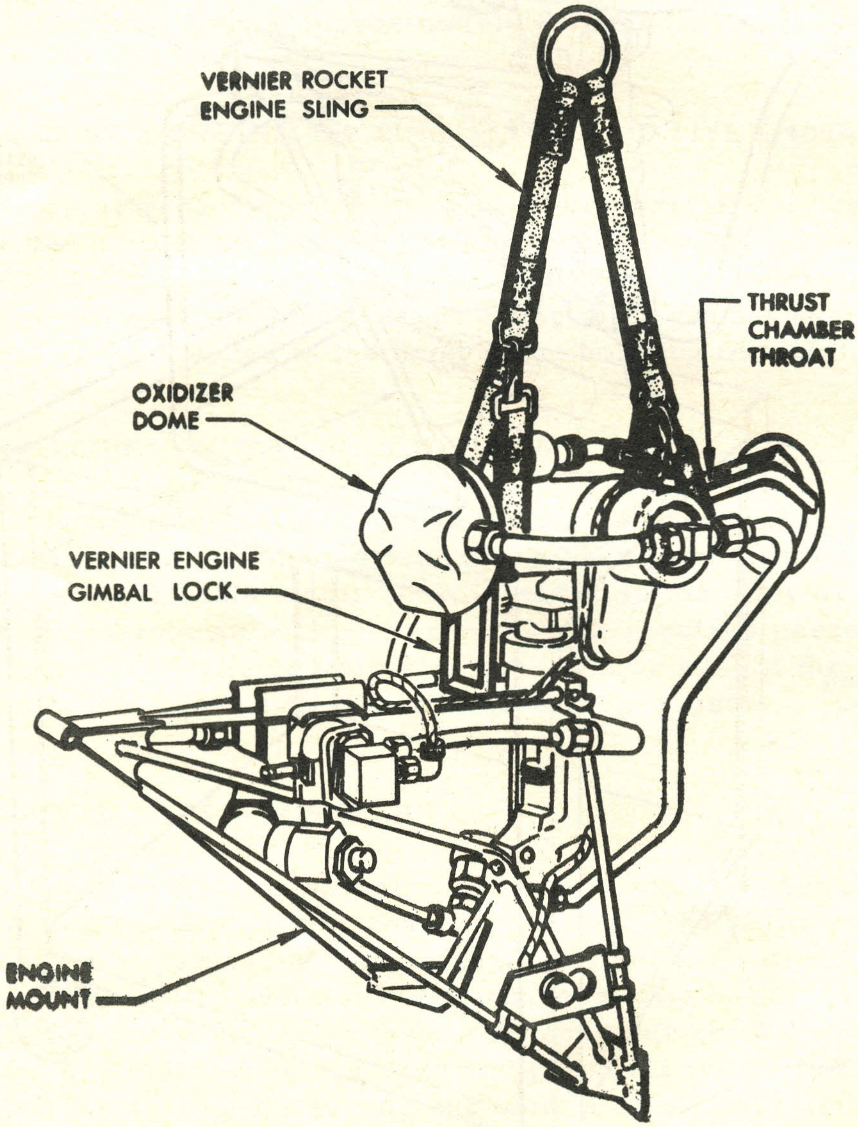


Figure 47 Vernier Engine Sling

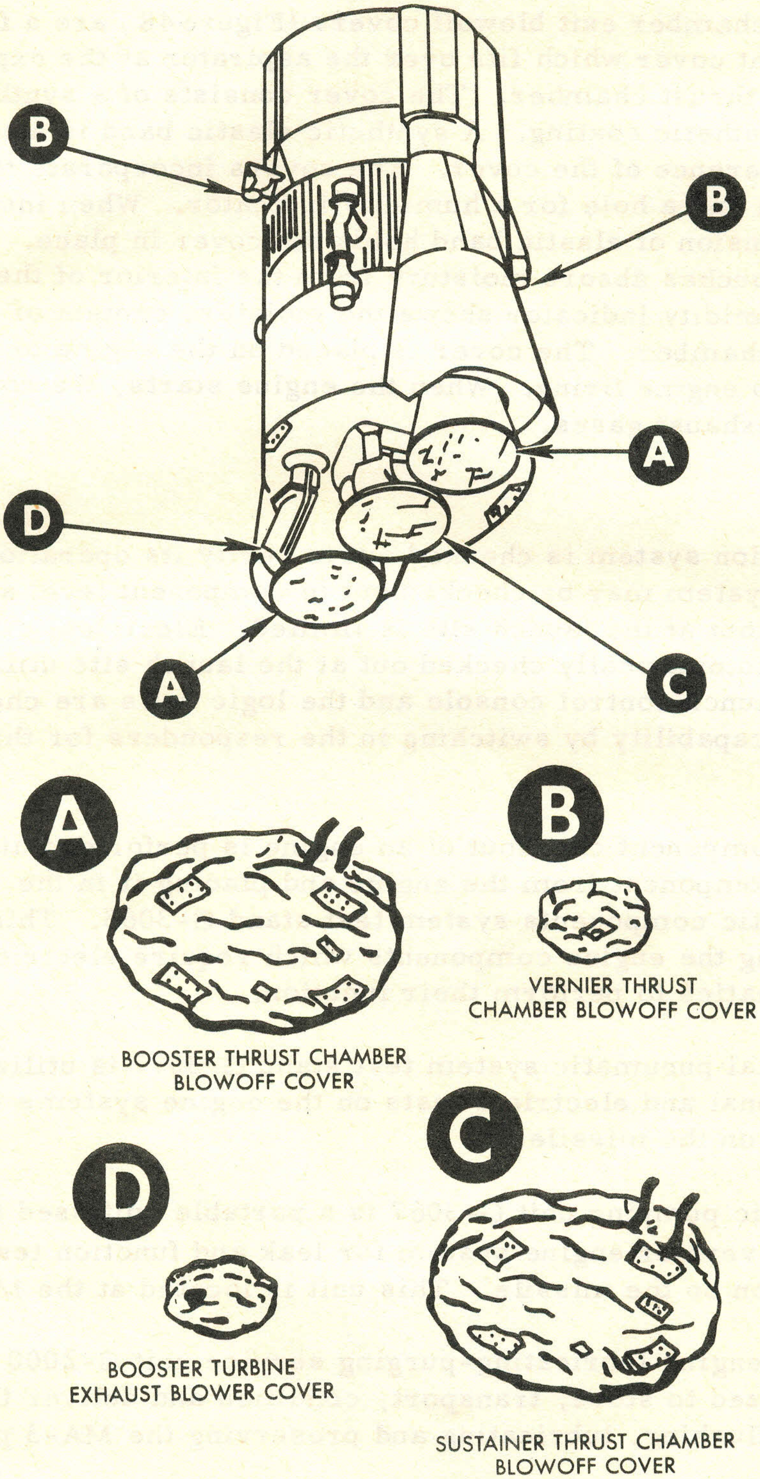


Figure 48 Missile Blowoff Cover Set

THRUST CHAMBER EXIT BLOWOFF COVERS

The thrust chamber exit blowoff covers (Figure 48 / are a flexible moisture-resistant cover which fits over the aspirator at the expansion nozzle exit of the thrust chamber. The cover consists of a synthetic fabric covered with a synthetic coating. A synthetic elastic band is attached about the circumference of the cover. The covers incorporate four desiccant pouches each and a hole for a humidity indicator. When installed on the engine, the tension of elastic band holds the cover in place. The desiccant in the pouches absorb moisture from the interior of the thrust chamber. The humidity indicator shows the moisture content of the air inside the thrust chamber. The cover is placed on the engine to protect the engine prior to engine firing. When the engine starts, the cover is destroyed by the exhaust gases.

SUMMARY

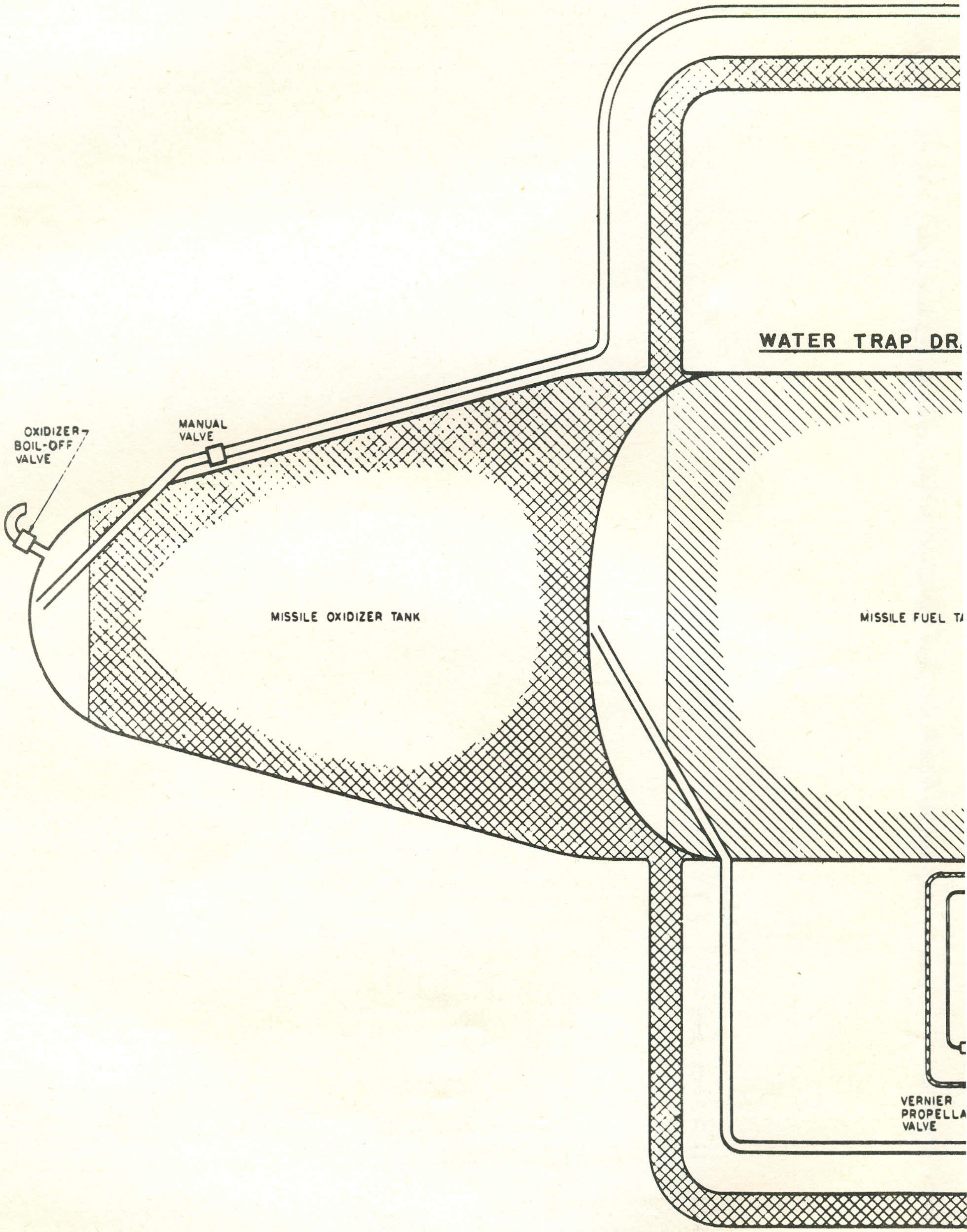
The propulsion system is checked out to verify its operational capability. The system may be checked out to component level at the MAMS whereas the checkout at the launch site is limited. Electrical circuitry to the missile is automatically checked out at the launch site utilizing MAPCHE. The launch control console and the logic units are checked for their operational capability by switching in the responders for this purpose.

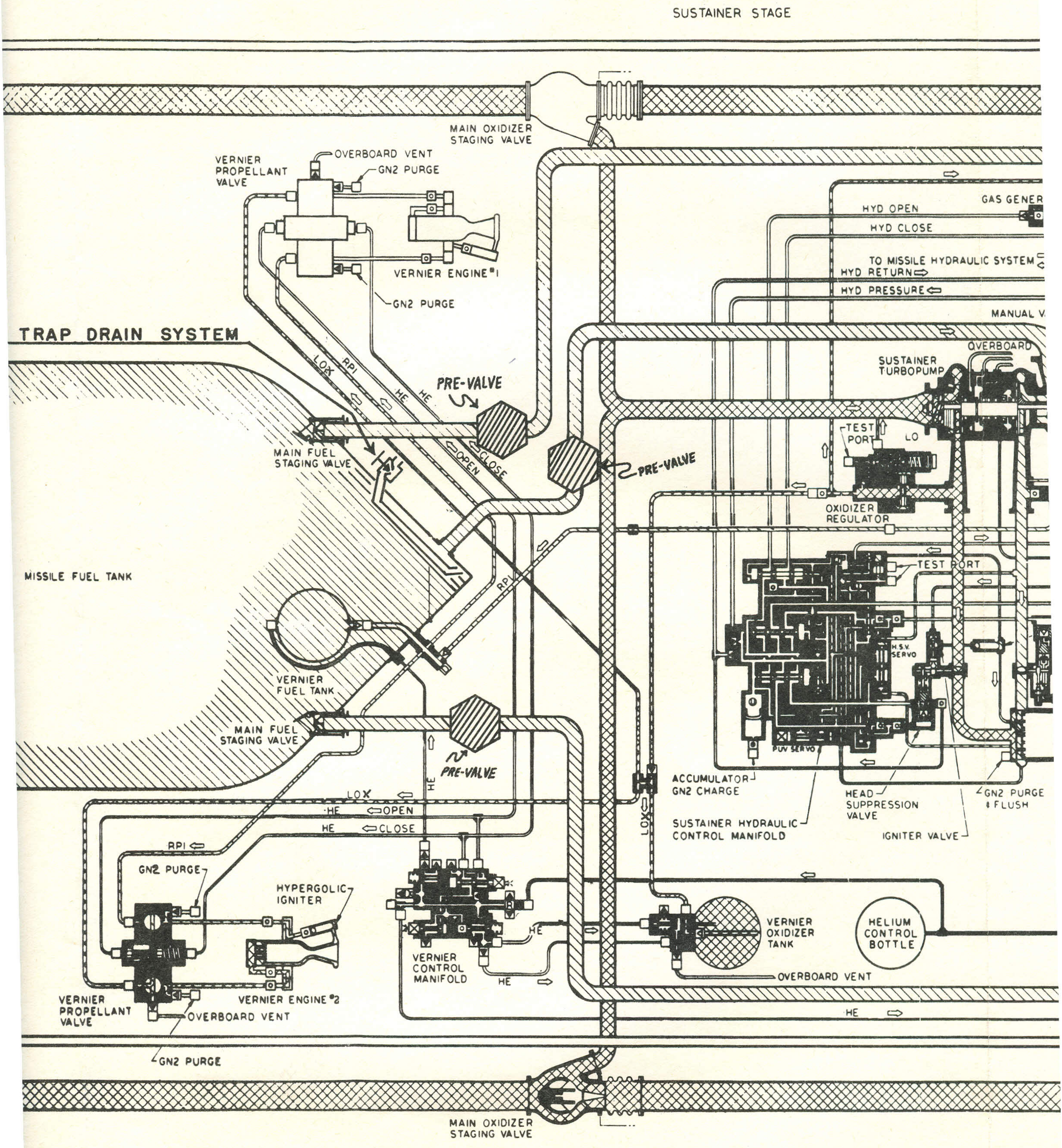
Individual component checkout of an engine is performed at the MAMS by removing the component from the engine and placing it in the electrical-hydraulic-pneumatic components system test stand G-3065. This stand is capable of checking the engine components which require electrical-hydraulics or pneumatics to perform their function.

The electrical pneumatic system test stand G-3077 is utilized to perform leak, functional and electrical tests on the engine systems while they are installed on the missile.

The hydraulic pumping unit G-3067 is a portable unit used to supply the sustainer and vernier engine system for leak and function tests prior to their installation on the missile. This unit is located at the MAMS.

The rocket engine lubricating-purging service unit G-2000 is a portable unit utilized to store, transport, condition and deliver the required fluids for flushing, lubricating and preserving the MA-3 propulsion system.


WATER TRAP DR
OXIDIZER BOIL-OFF VALVE
MANUAL VALVE
MISSILE OXIDIZER TANK
MISSILE FUEL TA
VERNIER PROPELLA VALVE



SUSTAINER STAGE
MAIN OXIDIZER STAGING VALVE
VERNIER PROPELLANT VALVE
OVERBOARD VENT
GN2 PURGE
VERNIER ENGINE #1
GN2 PURGE
TRAP DRAIN SYSTEM
LOX
RPI
HE
HE
PRE-VALVE
MAIN FUEL STAGING VALVE
OPEN
CLOSE
PRE-VALVE
MISSILE FUEL TANK
RPI
VERNIER FUEL TANK
MAIN FUEL STAGING VALVE
PRE-VALVE
HE
HYD OPEN
HYD CLOSE
GAS GENER
TO MISSILE HYDRAULIC SYSTEM
HYD RETURN
HYD PRESSURE
MANUAL V
OVERBOARD
SUSTAINER TURBOPUMP
TEST PORT
LO
OXIDIZER REGULATOR
TEST PORT
H.S.V. SERVO
PUV SERVO
ACCUMULATOR GN2 CHARGE
SUSTAINER HYDRAULIC CONTROL MANIFOLD
HEAD SUPPRESSION VALVE
IGNITER VALVE
GN2 PURGE & FLUSH
LOX
LOX
HE OPEN
HE CLOSE
RPI
GN2 PURGE
HYPERGOLIC IGNITER
VERNIER CONTROL MANIFOLD
HE
HE
VERNIER OXIDIZER TANK
HELIUM CONTROL BOTTLE
OVERBOARD VENT
VERNIER PROPELLANT VALVE
VERNIER ENGINE #2
OVERBOARD VENT
HE
GN2 PURGE
MAIN OXIDIZER STAGING VALVE

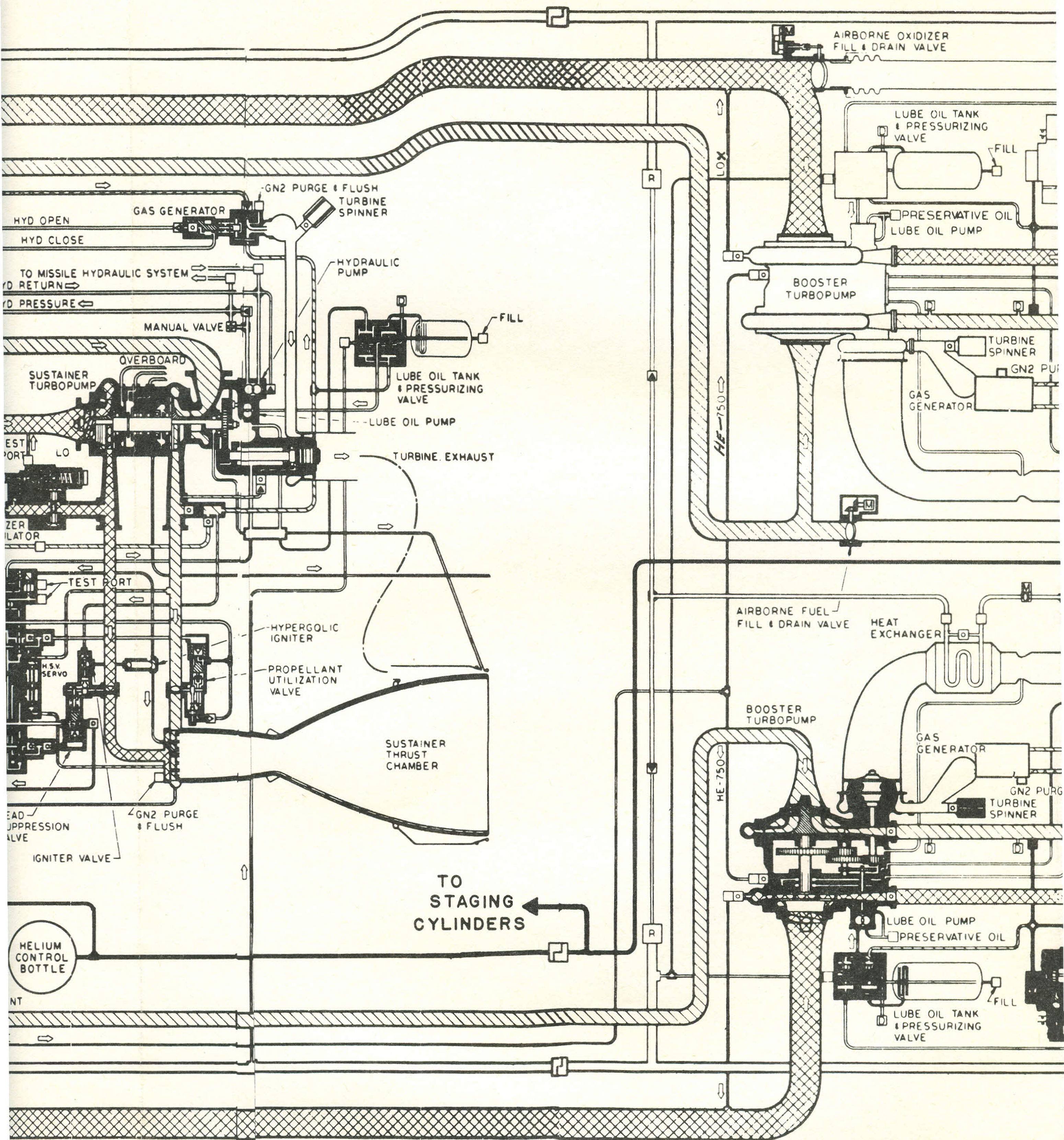
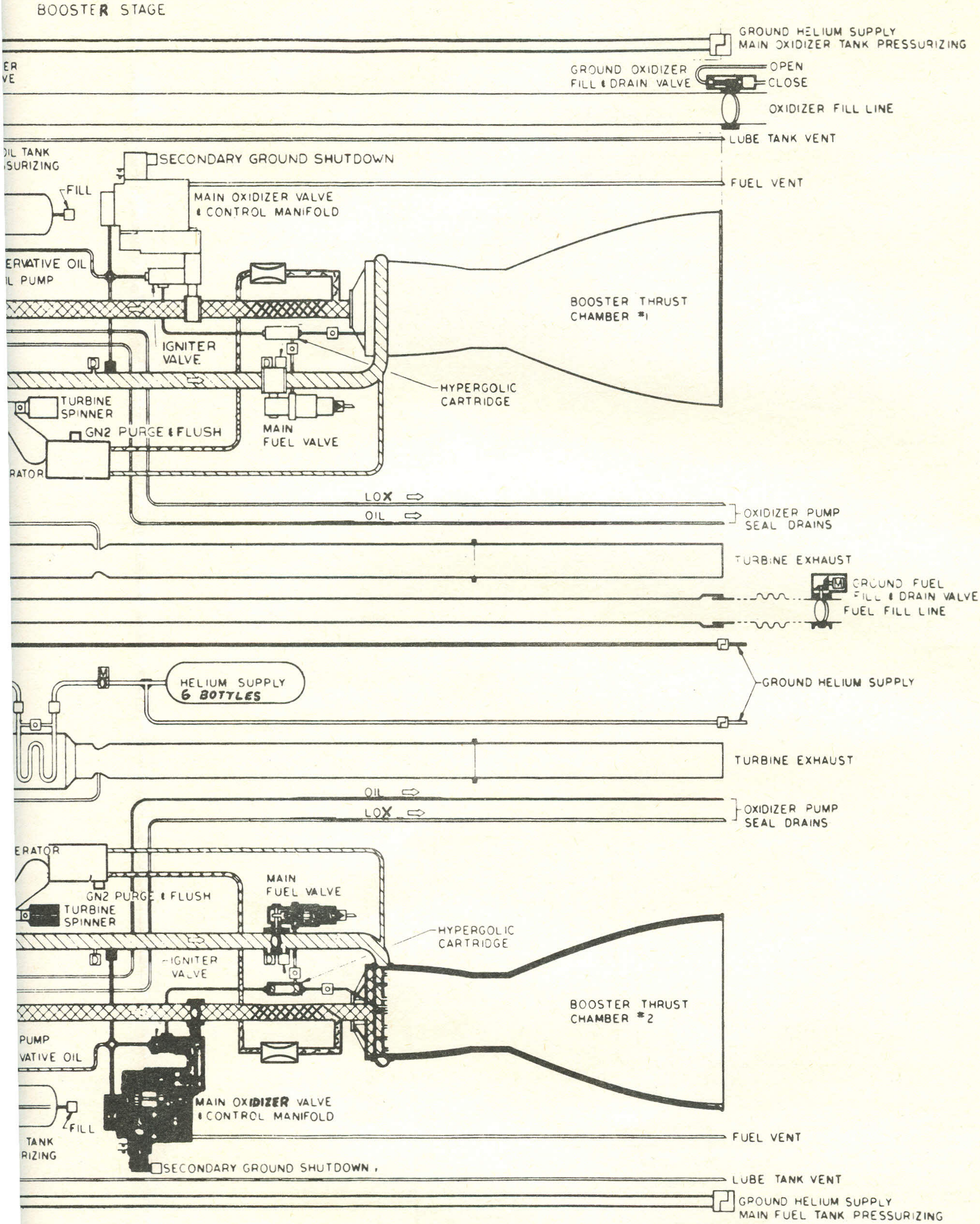


Figure 49 Propulsion System


BOOSTER STAGE
GROUND HELIUM SUPPLY
MAIN OXIDIZER TANK PRESSURIZING
GROUND OXIDIZER
FILL & DRAIN VALVE
OPEN
CLOSE
OXIDIZER FILL LINE
LUBE TANK VENT
SECONDARY GROUND SHUTDOWN
FUEL VENT
FILL
MAIN OXIDIZER VALVE
& CONTROL MANIFOLD
BOOSTER THRUST
CHAMBER #1
IGNITER
VALVE
HYPERGOLIC
CARTRIDGE
TURBINE
SPINNER
GN2 PURGE & FLUSH
MAIN
FUEL VALVE
LOX
OIL
OXIDIZER PUMP
SEAL DRAINS
TURBINE EXHAUST
GROUND FUEL
FILL & DRAIN VALVE
FUEL FILL LINE
HELIUM SUPPLY
6 BOTTLES
GROUND HELIUM SUPPLY
TURBINE EXHAUST
OIL
LOX
OXIDIZER PUMP
SEAL DRAINS
MAIN
FUEL VALVE
GN2 PURGE & FLUSH
TURBINE
SPINNER
HYPERGOLIC
CARTRIDGE
IGNITER
VALVE
BOOSTER THRUST
CHAMBER #2
MAIN OXIDIZER VALVE
& CONTROL MANIFOLD
FILL
FUEL VENT
SECONDARY GROUND SHUTDOWN
LUBE TANK VENT
GROUND HELIUM SUPPLY
MAIN FUEL TANK PRESSURIZING

System

The booster engine leak-test plate and plugs kit G-3080 and the sustainer kit G-3087 are supplied to seal off engine openings so that leak tests on the engine system may be performed.

Transportation trailers and workstands are located at the MAMS handle the engines for maintenance. The workstands are designed for each type of engine configuration for ease of handling and maintenance.

QUESTIONS

1. What is the purpose of the electrical-hydraulic-pneumatic system test stand?

2. Where is the electrical-hydraulic-pneumatic components test stand G-3065 located?

3. What types of checkout is performed at the launch site on the propulsion system utilizing MAPCHE?

4. What unit is used to supply lube oil to the missile?

3500 FPS 62-1343