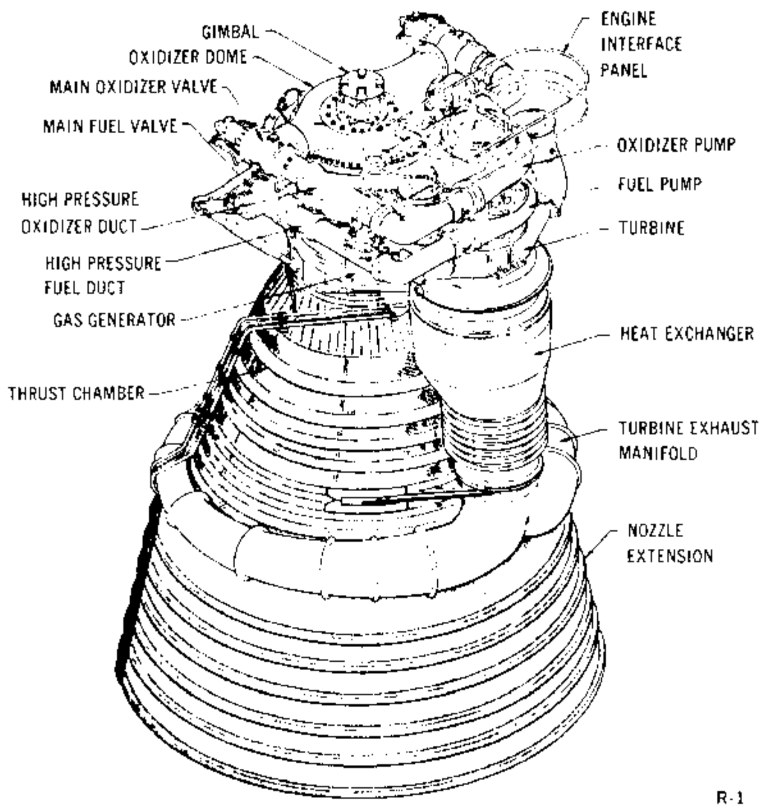
SATURN V NEWS REFERENCE

F-1 ENGINE FACT SHEET



LENGTH	19 ft.
WIDTH	12 ft. 4 in.
THRUST (sea level)	1,500,000 lb.
SPECIFIC IMPULSE (minimum)	260 sec.
RATED RUN DURATION	150 sec.
FLOWRATE: Oxidizer	3,945 lb. sec. (24,811 gpm)
Fuel	1,738 lb. sec. (15,471 gpm)
MIXTURE RATIO	2.27:1 oxidizer to fuel
CHAMBER PRESSURE	965 psia
WEIGHT FLIGHT CONFIGURATION	18,500 lb. maximum
EXPANSION AREA RATIO	16:1 with nozzle extension
	10:1 without nozzle extension
COMBUSTION TEMPERATURE: Thrust Chamber	5,970°F
Gas Generator	1,465°F
MAXIMUM NOZZLE EXIT DIAMETER	11 ft. 7 in.

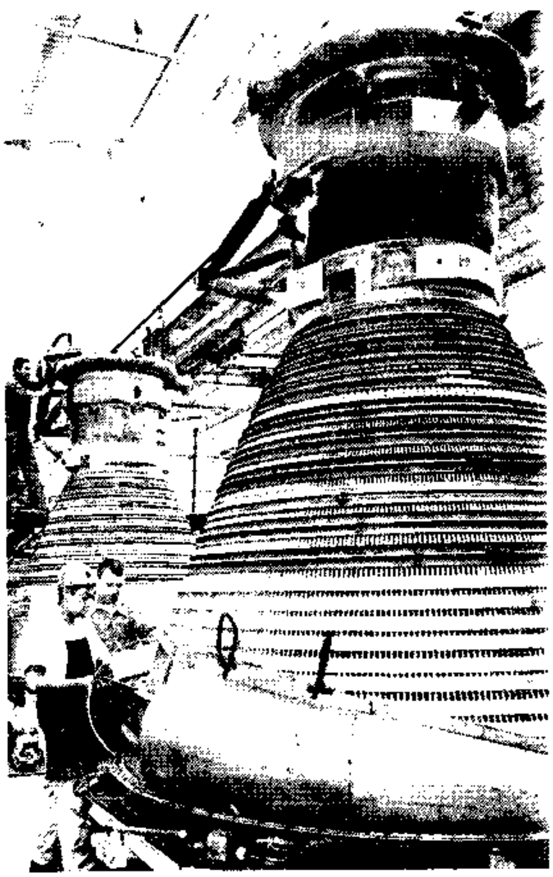
NOTE: F-1 engine will be uprated to 1,522,000 lb. thrust for Vehicle 504 and all subsequent operational vehicles.

F-1 ENGINE

ENGINE DESCRIPTION

The F-1 engine is a single-start, 1,500,000-pound fixed-thrust, bipropellant rocket system. The engine uses liquid oxygen as the oxidizer and RP-1 (kerosene) as fuel. The engine is bell-shaped, with an area expansion ratio—the ratio of the area of the throat to the base—of 16:1. RP-1 and LOX are combined and burned in the engine's thrust chamber assembly. The burning gases are expelled through an expansion nozzle to produce thrust. The five-engine cluster used on the first stage of the Saturn V produces 7,500,000 pounds of thrust. All of the engines are identical with one exception. The four outboard engines gimbal; the center engine does not.

The major engine systems are the thrust chamber assembly, the propellant feed system, the turbopump, the gas generator system, the propellant tank pressurization system, the electrical system, the hydraulic control system, and the flight instrumentation system.



R-2

Assembly. Thrust chambers of the F-1 rocket engine—the most powerful engine under development by the United States—are assembled in this manufacturing line.

THRUST CHAMBER ASSEMBLY

The thrust chamber assembly consists of a gimbal bearing, an oxidizer dome, an injector, a thrust chamber body, a thrust chamber nozzle extension, and thermal insulation. The thrust chamber assembly receives propellants under pressure supplied by the turbopump, mixes and burns them, and imparts a high velocity to the expelled combustion gases to produce thrust. The thrust chamber assembly also serves as a mount or support for all engine hardware.

Gimbal Bearing

The gimbal bearing secures the thrust chamber assembly to the vehicle thrust frame and is mounted on the oxidizer dome. The gimbal is a spherical, universal joint consisting of a socket-type bearing with a bonded Teflon-fiberglass insert which provides a low-friction bearing surface. It permits a maximum pivotal movement of 6 degrees in each direction of both the X and Z axes (roughly analogous to pitch and yaw) to facilitate thrust vector control. The gimbal transmits engine thrust to the vehicle and provides capability for positioning and thrust alignment.

Oxidizer Dome

The oxidizer dome serves as a manifold for distributing oxidizer to the thrust chamber injector, provides a mounting surface for the gimbal bearing, and transmits engine thrust forces to the vehicle structure. Oxidizer at a volume flowrate of 24,811 gpm enters the dome through two inlets positioned 180 degrees apart (to maintain even distribution of the propellant).

Thrust Chamber Injector

The thrust chamber injector directs fuel and oxidizer into the thrust chamber in a pattern which ensures efficient and satisfactory combustion. The injector is multi-orificed with copper fuel rings and copper oxidizer rings forming the face (combustion side) of the injector and containing the injection orifice pattern. Assembled to the face are radial and circumferential copper baffles which extend downward and compartmentalize the injector face. The baffles and rings, together with a segregated igniter fuel system, are installed in a stainless steel body.

Oxidizer enters the injector from the oxidizer dome. Fuel enters the injector from the thrust chamber fuel inlet manifold, and in order to facilitate the engine start phase and to reduce pressure losses, part of the flow is introduced directly into the thrust chamber. The remaining fuel (controlled by orifices) flows through alternate tubes which run the length of the thrust chamber body to the nozzle exit. There, it enters a return manifold and flows back to the injector through the remaining tubes.

Thrust Chamber Body

The thrust chamber body provides a combustion chamber for burning propellants under pressure and an expansion nozzle for expelling gases produced by the burned propellants at the high velocity required to produce the desired thrust. The thrust chamber is tubular-walled and regeneratively fuel-cooled, and the nozzle is bell-shaped. There are four sets of outrigger struts attached to the exterior of the thrust chamber; two sets of the struts are turbopump mounts and the other two are attach points for the vehicle contractor's gimbal actuators. The thrust chamber incorporates a turbine exhaust manifold at the nozzle exit and a fuel inlet manifold at the injector end which directs fuel to the fuel down tubes. Brackets and studs welded to the reinforcing "hatbands" surrounding the thrust chamber provide attach points for thermal insulation blankets.

Fuel enters the fuel inlet manifold through two diametrically opposed inlets. From the manifold, 70 per cent of the fuel is diverted through 89 alternate CRES "down" tubes the length of the chamber. A manifold at the nozzle exit returns the fuel to the injector through the remaining 89 return tubes. The fuel flowing through the chamber tubes provides regenerative cooling of the chamber walls during engine operation. The thrust chamber tubes are bifurcated; that is, they are comprised of a primary tube from the fuel manifold to the 3:1 expansion ratio area. At that point, two secondary tubes are spliced into each primary tube. This is necessary to maintain a desired cross-sectional area in each of the tubes through the large-diameter belled nozzle section.

The turbine exhaust manifold, which is fabricated from preformed sheet metal shells and which forms a torus around the aft end of the thrust chamber body, receives turbine exhaust gases from the heat exchanger. Upon entering the manifold, the gases are distributed uniformly. As the gases are expelled from the manifold, flow vanes in the exit slots provide uniform static pressure distribution in the nozzle extension. Radial expansion joints compensate for thermal growth of the manifold.

Thrust Chamber Nozzle Extension

The thrust chamber nozzle extension increases the expansion ratio of the thrust chamber from 10:1 to 16:1. It is a detachable unit that is bolted to the exit end ring of the thrust chamber. The interior of the nozzle extension is protected from the engine exhaust gas environment (5800 Fahrenheit) by film cooling, using the turbine exhaust gases (1200 Fahrenheit) as the coolant. The gases enter the extension between a continuous outer wall and a shingled inner wall, pass out through injection slots between the shingles, and flow over the surfaces of the shingles forming a boundary layer between the inner wall of the nozzle extension and the hotter exhaust gases exiting from the main engine combustion chamber. The nozzle extension is made of high strength stainless steel.

Hypergol Cartridge

The hypergol cartridge supplies the fluid to produce initial combustion in the thrust chamber. The cartridge, which is cylindrical and has a burst diaphragm welded to either end, contains a hypergolic fluid consisting of 85 per cent triethylborane and 15 per cent triethylaluminum. As long as the fluid is in the hermetically sealed cartridge, it is stable, but it will ignite spontaneously upon contact with oxygen in any form. During the start phase of operation, increasing fuel pressure in the igniter fuel system ruptures the burst diaphragms. The hypergolic fluid and the fuel enter the thrust chamber through a segregated igniter fuel system in the injector and contact the oxidizer. Spontaneous combustion occurs and thrust chamber ignition is established.

Pyrotechnic Igniter

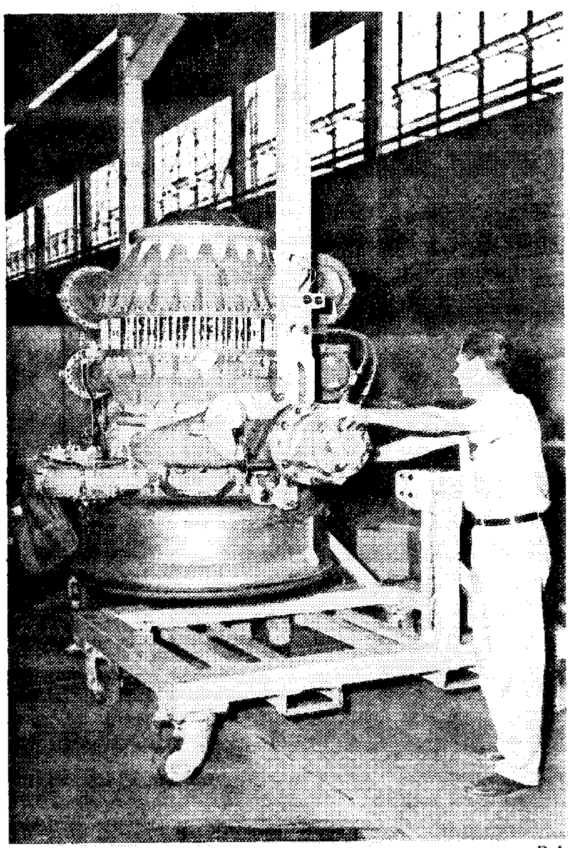
Pyrotechnic igniters, actuated by an electric spark, provide the ignition source for the propellants in the gas generator and re-ignite the fuel-rich turbine exhaust gases as they exit from the nozzle extension.

Thermal Insulation

The thermal insulation protects the F-1 engine from the extreme temperature environment (2550 Fahrenheit maximum) created by radiation from the exhaust plume and backflow during clustered-engine flight operation. Two types of thermal insulators are used on the engine—foil-batt on complex surfaces and asbestos blankets on large, simple surfaces. They are made of lightweight material and are equipped with various mounting provisions, such as grommeted holes, clamps, threaded studs, and safetywire lacing studs.

TURBOPUMP

The turbopump is a direct-drive unit consisting of an oxidizer pump, a fuel pump, and a turbine mounted on a common shaft. The turbopump delivers fuel and oxidizer to the gas generator and the thrust chamber. LOX enters the turbopump axially through a single inlet in line with the shaft and is discharged tangentially through dual outlets. Fuel enters the turbopump radially through dual inlets and is discharged tangentially through dual outlets. The dual inlet and outlet design provides a balance of radial loads in the pump.



F-1 Turbopump

Three bearing sets support the shaft. Matched tandem ball bearings, designated No. 1 and No. 2, provide shaft support between the oxidizer and fuel pumps. A roller bearing, No. 3, provides shaft support between the turbine wheel and the fuel pump. The bearings are cooled with fuel during pump operation. A heater block provides the outer support for No. 1 and No. 2 bearings, and is used during LOX chilldown of the oxidizer pump to prevent freezing of the bearings.

A gear ring installed on the shaft is used in conjunction with the torque gear housing for rotating the pump shaft by hand, and also is used in conjunction with a magnetic transducer for monitoring shaft speed.

There are nine carbon seals in the turbopump: primary oxidizer seal, oxidizer intermediate seal, lube seal No. 1 bearing, lube seal No. 2 bearing, primary fuel seal, fuel inlet seal, fuel inlet oil seal, hot-gas secondary, and hot-gas primary seal.

The main shaft and the parts attaching directly to it are dynamically balanced prior to final assembly on the turbopump.

Oxidizer Pump

The oxidizer pump supplies oxidizer to the thrust chamber and gas generator at a flowrate of 24,811 gpm. The pump consists of an inlet, an inducer, an impeller, a volute, bearings, seals, and spacers. Oxidizer is introduced into the pump through the inlet which is connected by duct to the oxidizer tank. The inducer in the inlet increases the pressure of the oxidizer as it passes into the impeller to prevent cavitation. The impeller accelerates the oxidizer to the desired pressure and discharges it through diametrically opposed outlets into the high-pressure oxidizer lines leading to the thrust chamber and gas generator.

The oxidizer inlet, which attaches to a duct leading to the vehicle oxidizer tank, is bolted to the oxidizer volute. Two piston rings seated between the inlet and the volute expand and contract with temperature changes to maintain an effective seal between the high and low pressure sides of the inlet. Holes in the low-pressure side of the inlet allow leakage past the ring seals to flow into the suction side of the inducer, thus maintaining a low pressure.

The oxidizer volute is secured to the fuel volute with pins and bolts which prevent rotational and axial movement. The primary oxidizer seal and spacer located in the oxidizer volute prevent fuel from leaking into the primary oxidizer seal drain cavity. The oxidizer intermediate seal directs a purge flow into the primary seal and No. 3 drain cavities where the purge acts as a barrier to permit positive separation of the oxidizer and bearing lubricants.

Fuel Pump

The fuel pump supplies fuel to the thrust chamber and gas generator at a flowrate of 15,471 gpm. The pump consists of an inlet, an inducer, an impeller, a volute, bearings, seals, and spacers. Fuel is introduced into the pump from the vehicle fuel tank through the inlet. The inducer in the inlet increases the pressure of the fuel as it passes into the impeller to prevent cavitation. The impeller accelerates the fuel to the desired pressure and discharges it through two diametrically opposed outlets into the high-pressure fuel lines leading to the thrust chamber and gas generator.

The fuel volute is bolted to the inlet and to a ring, which is pinned to the oxidizer volute. A wear-ring installed on the volute mates against the impeller. The cavity formed between the volute and the impeller is called the balance cavity. Pressure in the balance cavity exerts a downward force against the fuel impeller and counterbalances the upward force of the oxidizer impeller to control the amount of shaft axial force applied to the No. 1 and No. 2 bearings. Leakage between the impeller inlet and the discharge is controlled by a wear-ring, which mates with the impeller and acts as an orifice. The fuel volute provides support for the bearing retainer, which supports the No. 1 and No. 2 bearings and houses the bearing heater. The No. 3 seal, which is installed between the oxidizer intermediate seal and the No. 1 bearing, prevents lubricating fuel for the bearings from contacting the oxidizer. If fuel should pass the seal, purge flow from the oxidizer intermediate seal will expel the fuel overboard. On the fuel side of the No. 2 bearing, the No. 4 lube seal contains the lubricant within the bearing cavity. The remaining seal in the fuel volute is the primary seal and contains fuel under pressure in the balance cavity, maintains the desired balance cavity pressure, and keeps high-pressure fuel out of the low-pressure side.

Turbine

The turbine, producing 55,000 brake horsepower, drives the fuel and oxidizer pumps. It is a two-stage, velocity-compounded turbine consisting of two rotating impulse wheels separated by a set of stators. The turbine mounts on the fuel pump end of the turbopump so that the two elements of the turbopump having the greatest operating temperature extremes (1500 Fahrenheit for the turbine and -300 Fahrenheit for the oxidizer pump) are separated.

Hot gas from the gas generator enters the turbine at a flowrate of 170 pounds per second through the inlet manifold and is directed through the first-stage nozzle onto the 119-blade first-stage wheel. The hot gas then passes through the second-stage stators onto the 107-blade second-stage wheel, and then into the heat exchanger. This flow of hot gas rotates the turbine, which in turn rotates the propellant pumps. Turbine speed during mainstage operation is 5,550 rpm.

Bearing Coolant Control Valve

This valve, which incorporates three 40-micron filters, three spring-loaded poppets, and a restrictor, performs two functions. Its primary function is to control the supply of coolant fuel to the turbopump bearings. Its secondary function is to provide a means of preserving the turbopump bearings between static firings or during engine storage. During engine firing, the coolant poppet opens and delivers filtered fuel to the turbopump bearing coolant jets, and the restrictor provides the proper turbopump bearing jet pressure.

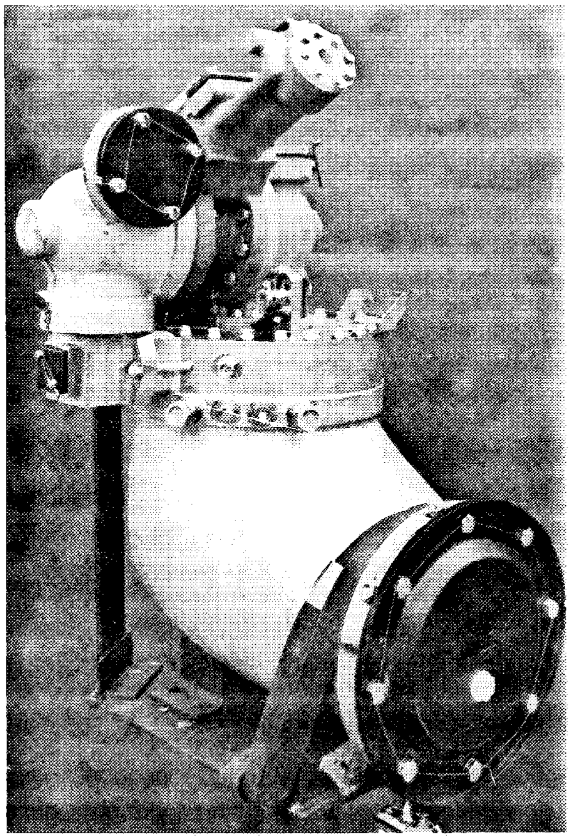
GAS GENERATOR SYSTEM

The gas generator system provides the hot gases for driving the velocity-compounded turbine, which drives the fuel and oxidizer pumps. The system consists of a gas generator valve, an injector, a combustion chamber, and propellant feed lines connecting the No. 2 turbopump fuel and oxidizer outlet lines to the gas generator. The propellants are supplied to the gas generator from the No. 2 turbopump fuel and oxidizer outlet lines. The gas generator mixture ratio, relative to the engine mixture ratio, is fuel-rich. This provides a lower combustion temperature in the uncooled gas generator and in the turbine.

Propellants enter the gas generator through the valve and injector and are ignited in the combustion chamber by dual pyrotechnic igniters. The gas generator valve is hydraulically operated by fuel pressure from the hydraulic control system.

Gas Generator Valve

The gas generator valve is a hydraulically operated valve which controls and sequences entry of propellants into the gas generator. Hydraulic fuel is recirculated through a passage in the valve housing to maintain seal integrity and to prevent the fuel in the fuel ball housing from freezing. Fuel is also recirculated through a passage in the piston between the opening port and the closing port to prevent the piston O-ring from freezing.



R-5

Gas Generator Assembly Including Control Valves

Gas Generator Injector

The gas generator injector directs fuel and oxidizer into the gas generator combustion chamber. It is a flat-faced, multi-orificed injector incorporating a dome, a plate, a ring manifold, five oxidizer rings, five fuel rings, and a fuel disc. The gas generator valve and the gas generator injector fuel inlet housing tee are mounted on the injector.

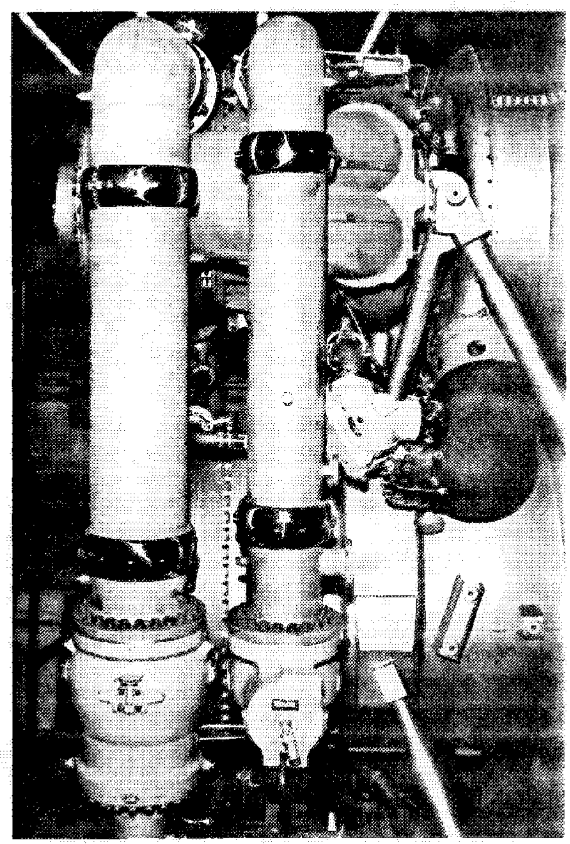
Fuel enters the injector through the gas generator fuel inlet housing tee from the gas generator valve. The fuel is directed through internal passages in the plate and injected into the combustion chamber through orifices in the fuel rings and the disc. Some of the orifices in the outer fuel ring also provide a cooling film of fuel for the combustion chamber wall. Oxidizer enters the injector through the oxidizer inlet manifold from the gas generator valve. The oxidizer is directed from the oxidizer manifold through internal passages in the plate and is injected into the combustion chamber through the orifices in the oxidizer rings.

Gas Generator Combustion Chamber

The gas generator combustion chamber provides a space for burning propellants and exhausts the gases from the burning propellants into the turbopump turbine manifold. It is a single-wall chamber located between the gas generator injector and the turbopump inlet.

PROPELLANT FEED CONTROL SYSTEM

The propellant feed system transfers LOX and fuel from the propellant tanks into the pumps which discharge into the high-pressure ducts leading to the gas generator and the thrust chamber. The system consists of two oxidizer valves, two fuel valves, a bearing coolant control valve, two oxidizer dome purge check valves, a gas generator and pump seal purge check valve, turbopump outlet lines, orifices, and lines connecting the components. High-pressure fuel is supplied from the propellant feed system of the engine to the vehicle-contractor-supplied thrust vector control system.

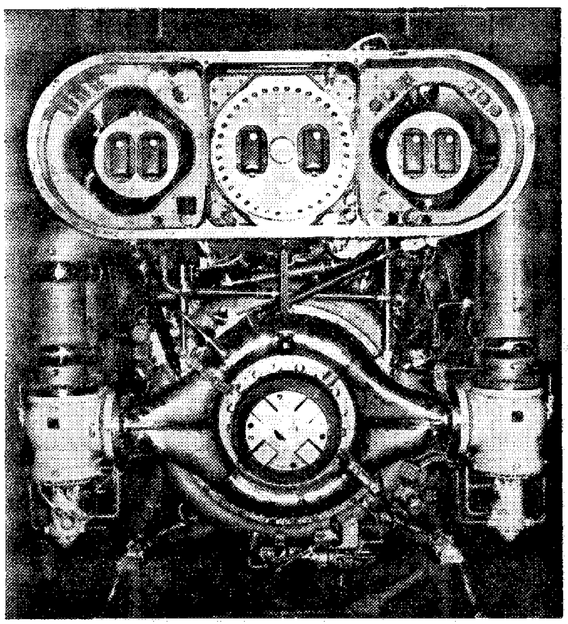


R-3

Propellant Feed—The main LOX valve and high-pressure line are shown at left. At right are the main fuel valve and high-pressure line.

Oxidizer Valves

Two identical oxidizer valves, designated No. 1 and No. 2, control LOX flow from the turbopump to the thrust chamber oxidizer dome and sequence the hydraulic fuel to the opening port of the gas generator valve. When the valves are in the open position at rated engine pressures and flowrates, neither will close if the hydraulic fuel opening pressure is lost. Each of the oxidizer valves is a hydraulically actuated, pressure-balanced, poppet type, and contains a mechanically actuated sequence valve. A spring-loaded gate valve permits reverse flow for recirculation of the hydraulic fluid with the propellant valves in the closed position, but prevents fuel from passing through until the oxidizer valve is open 16.4 per cent. As the oxidizer valve reaches this position, the piston shaft opens the gate, allowing fuel to flow through the sequence valve, which in turn opens the gas generator valve.



R-6

LOX Distribution—Oxidizer is distributed by the LOX dome (lower center). Main LOX valves are shown at left and right with the engine interface panel above.

A position indicator provides relay logic in the engine electrical control circuit and provides instrumentation for recording movement of the oxidizer valve poppet.

The two oxidizer dome purge check valves, mounted on each of the oxidizer valves, allow purge gas to enter the oxidizer valves, but prevent oxidizer from entering the purge system.

Fuel Valves

Two identical fuel valves, designated No. 1 and No. 2, are mounted 180 degrees apart on the thrust chamber fuel inlet manifold and control the flow of fuel from the turbopump to the thrust chamber. When the valves are in the open position at rated engine pressures and flowrates, they will not close if hydraulic fuel pressure is lost.

Position indicators in the fuel valves provide relay logic in the engine electrical control circuit and instrumentation for recording movement of the valve poppets.

Thrust-OK Pressure Switches

Three pressure switches, mounted on a single manifold located on the thrust chamber fuel manifold, sense fuel injection pressure. These thrust-OK pressure switches are used in the vehicle to indicate that all five engines are operating satisfactorily. If pressure in the fuel injection cavity decreases, the switches deactuate, breaking the contact and interrupting the thrust-OK output signal.

PRESSURIZATION SYSTEM

The pressurization system heats GOX and helium for vehicle tank pressurization. The pressurization system consists of a heat exchanger, a heat exchanger check valve, a LOX flowmeter, and various heat exchanger lines. The LOX source for the heat exchanger is tapped from the thrust chamber oxidizer dome, and the helium is supplied from the vehicle. LOX flows from the thrust chamber oxidizer dome through the heat exchanger check valve, LOX flowmeter, and the LOX line to the heat exchanger.

Heat Exchanger

The heat exchanger heats GOX and helium with hot turbine exhaust gases, which pass through the heat exchanger over the coils. The heat exchanger consists of four oxidizer coils and two helium coils installed within the turbine exhaust duct. The heat exchanger is installed between the turbopump manifold outlet and the thrust chamber exhaust manifold inlet. The shell of the heat exchanger contains a bellows assembly to compensate for thermal expansion during engine operation.

Heat Exchanger Check Valve

The heat exchanger check valve prevents GOX or vehicle prepressurizing gases from flowing into the oxidizer dome. It consists of a line assembly and a swing check valve assembly. It is installed between the thrust chamber oxidizer dome and the heat exchanger LOX inlet line.

LOX Flowmeter

The LOX flowmeter is a turbine-type, volumetric, liquid-flow transducer incorporating two pickup coils. Rotation of the LOX flowmeter turbine generates an alternating voltage at the output terminals of the pickup coils.

Heat Exchanger Lines

LOX and helium are routed to and from the heat exchanger through flexible lines. The GOX and helium lines terminate at the vehicle connect interface. The LOX line connects the heat exchanger to the heat exchanger check valve.

ENGINE INTERFACE PANEL

The engine interface panel, mounted above the turbopump LOX and fuel inlets, provides the vehicle connect location for electrical connectors between the engine and the vehicle. It also provides the attachment point for the vehicle flexible heat-resistant curtain. The panel is fabricated from heat-resistant stainless-steel casting made in three sections and assembled by rivets and bolts.

ELECTRICAL SYSTEM

The electrical system consists of flexible armored wiring harnesses for actuation of engine controls and the flight instrumentation harnesses.

HYDRAULIC CONTROL SYSTEM

The hydraulic control system operates the engine propellant valves during the start and cutoff sequences. It consists of a hypergol manifold, a checkout valve, an engine control valve, and the related tubing and fittings.

Hypergol Manifold

The hypergol manifold directs hypergolic fluid to the separate igniter fuel system in the thrust chamber injector. It consists of a hypergol container, an ignition monitor valve, a position switch, and an igniter fuel valve. The hypergol container, position switch, and igniter fuel valve are internal parts of the hypergol manifold.

A spring-loaded, cam-lock mechanism incorporated in the hypergol manifold prevents actuation of the ignition monitor valve until after the upstream hypergol cartridge diaphragm bursts. The same mechanism actuates a position switch that indicates when the hypergol cartridge is installed. The igniter fuel valve is a spring-loaded, cracking check valve that opens and allows fuel to flow into the hypergol container. The hypergol cartridge diaphragms are ruptured by the resultant pressure surge when the igniter fuel valve opens.

Ignition Monitor Valve

The ignition monitor valve is a pressure-actuated, three-way valve mounted on the hypergol manifold. It controls the opening of the fuel valves and permits them to open only after satisfactory combustion has been achieved in the thrust chamber.

When the hypergol cartridge is installed in the hypergol manifold, a cam-lock mechanism prevents the ignition monitor valve poppet from moving from the closed position. The ignition monitor valve has six ports: a control port, an inlet port, two outlet ports, a return port, and an atmospheric reference port. The control port receives pressure from the thrust chamber fuel manifold. The inlet port receives hydraulic fuel pressure for opening the fuel valves. When the ignition monitor valve poppet is in the deactuated position, hydraulic fuel from the inlet port is stopped at the poppet seat. When the hypergol cartridge diaphragm bursts, the spring-loaded cam-lock retracts to permit the ignition monitor valve poppet unrestricted motion. When thrust chamber pressure (directed to the control port from the thrust chamber fuel manifold) increases, the ignition monitor valve poppet moves to the open (actuated) position and hydraulic fuel is directed through the outlet ports to the fuel valves.

Checkout Valve

The checkout valve consists of a ball, a poppet, and an actuator. The checkout valve provides for ground checkout of the ignition monitor valve and fuel valves and prevents the ground hydraulic return fuel, used during checkout, from entering the engine system and consequently the vehicle fuel tank.

When performing the engine checkout or servicing, the checkout valve ball is positioned so fuel entering the engine hydraulic return inlet port will be directed through the ball and out the GSE return port. For engine static firing or flight, the ball is positioned so fuel entering the engine hydraulic return inlet port will be directed through the ball and out the engine return outlet port.

Engine Control Valve (Hydraulic Filter and Four-Way Solenoid Valve Manifold)

The engine control valve incorporates a filter manifold, a four-way solenoid valve, and two swing check valves.

The filter manifold contains three filters. One filter is in the supply system and one each in the opening and closing pressure systems. The filters prevent entry of foreign matter into the four-way solenoid valve or the engine. Two swing check valves are "teed" into the supply system filter. The check valves permit hydraulic system operation from the ground supplied hydraulic fluid for checkout and servicing procedures or engine supplied hydraulic fluid for normal engine operation.

The four-way solenoid valve is comprised of a main spool and sleeves to achieve two-directional control of the fluid flow to the main fuel, main oxidizer, and gas generator valve actuators. The spool is pressure-positioned by two three-way slave pilots. Each slave pilot has a solenoid-controlled, normally open, three-way primary pilot.

The de-energized position of the engine control valve provides hydraulic closing pressure to all engine propellant valves. Momentary application of 28 VDC to the start solenoid will initiate control valve actuations that culminate in the positioning of the main spool so that hydraulic pressure is applied to the opening port, and the pressure previously applied to the closing port is vented to the return port.

An internal passage in the housing maintains common pressure applied between the opening port and start solenoid poppet. This pressure, after start solenoid de-energization, holds the main spool in its actuated position thereby maintaining the pressure directed to the opening port without further application of the start solenoid electrical signal. Momentary application of 28 VDC to the stop solenoid will initiate control valve actuations that culminate in positioning the main spool so that pressure is vented from the opening port and applied to the closing port. The override piston may be actuated at any time by a remote pressure supply, which, in the event of an electrical power loss, would reposition the main spool and apply hydraulic pressure to the closing port. If electrical power and hydraulic power are both removed, the valve will return to the de-energized position by spring force. If hydraulic pressure is then reapplied, pressure will be applied to the closing port. If an electrical signal is simultaneously sent to the start and stop solenoids, the stop solenoid will override the start and return the valve to a deactuated position.

Swing Check Valve

There are two identical swing check valves installed on the engine control valve. They allow the use of ground hydraulic fuel pressure during engine starting transient and engine hydraulic fuel pressure during engine mainstage and shutdown. One check valve is installed in the engine hydraulic fuel supply inlet port, the other in the ground hydraulic fuel supply inlet port.

FLIGHT INSTRUMENTATION SYSTEM

The flight instrumentation system consists of pressure transducers, temperature transducers, position indicators, a flow measuring device, power distribution junction boxes, and associated electrical harnesses, and permits monitoring of engine performance. The basic flight instrumentation system is composed of a primary and an auxiliary system. The primary instrumentation system is critical to all engine static firings and subsequent vehicle launches; the auxiliary system is used during research, development, and acceptance portions of the engine static test program and initial vehicle flights. The flight instrumentation system components, including both the primary and auxiliary systems, are listed below:

Primary Instrumentation

Fuel turbopump inlet No. 1 pressure
Fuel turbopump inlet No. 2 pressure
Common hydraulic return pressure
Oxidizer turbopump bearing jet pressure
Combustion chamber pressure
Gas generator chamber pressure
Oxidizer turbopump discharge No. 2 pressure
Fuel turbopump discharge No. 2 pressure
Oxidizer pump bearing No. 1 temperature
Oxidizer pump bearing No. 2 temperature
Turbopump bearing temperature
Turbopump inlet temperature
Turbopump speed

Auxiliary Instrumentation

Oxidizer turbopump seal cavity pressure
Turbine outlet pressure
Heat exchanger helium inlet pressure
Heat exchanger outlet pressure
Oxidizer turbopump discharge No. 1 pressure
Heat exchanger LOX inlet pressure
Heat exchanger GOX outlet pressure
Fuel turbopump discharge No. 1 pressure
Engine control opening pressure
Engine control closing pressure

Heat exchanger LOX inlet temperature
Heat exchanger GOX outlet temperature
Heat exchanger helium outlet temperature
Fuel pump inlet No. 2 temperature
Heat exchanger LOX inlet flowrate

Primary and Auxiliary Junction Box

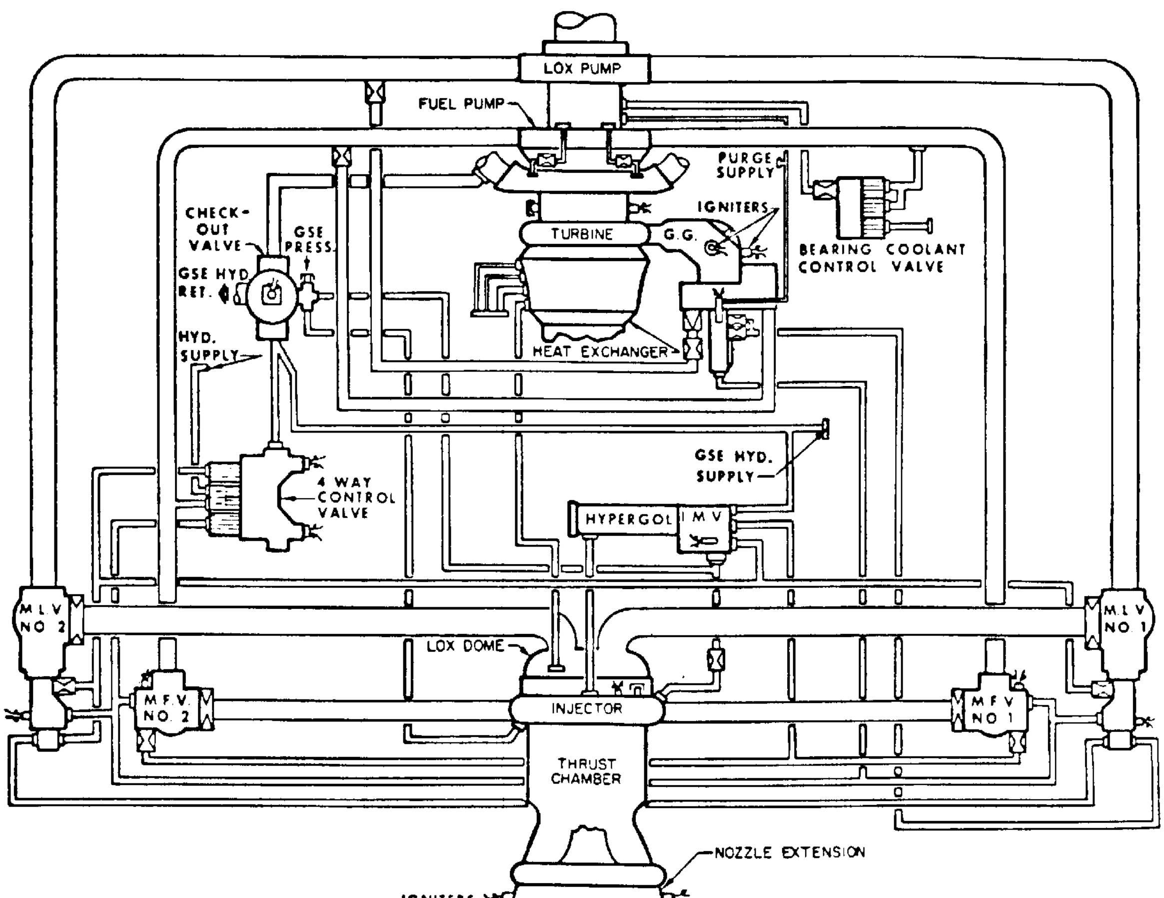
There are two electrical junction boxes in the flight instrumentation system. The primary junction box has provisions for eight electrical connectors, and the auxiliary junction box for five. Both junction boxes are welded closed and pressurized with an inert gas to prevent possible entry of contaminants and moisture.

ENGINE OPERATION

The engine requires a source of pneumatic pressure, electrical power, and propellants for sustained engine operation. A ground hydraulic pressure source, thrust chamber prefill, gas generator and turbine exhaust igniters, and hypergolic fluid are required to start the engine.

When the start button is actuated, the checkout valve moves to transfer the hydraulic fuel return from the ground line to the turbopump low-pressure fuel inlet. The high-level oxidizer purge is initiated to the gas generator and thrust chamber LOX dome.

The gas generator and turbine exhaust gas igniters fire, and the engine control valve start solenoid is energized. Hydraulic pressure is directed to the opening port of the oxidizer valves. The oxidizer valves are part way open, and the hydraulic pressure is directed to the gas generator valve opening port. The gas generator valve opens, propellants under tank pressure enter the gas generator combustion chamber, and the propellant mixture is ignited by the gas generator igniters. The exhaust gas is ducted through the turbopump turbine, the heat exchanger, and the thrust chamber exhaust manifold into the nozzle extension walls where the fuel-rich mixture is ignited by the turbine exhaust gas igniters. As the turbine accelerates the fuel and the oxidizer pumps, the pump discharge pressures increase and propellants at increasing flowrates are supplied to the gas generator. Turbopump acceler-



F-1 Propulsion System

ation continues and, as the fuel pressure increases, the igniter fuel valve opens and allows fuel pressure to build up against the hypergol cartridge burst diaphragm. The hypergol diaphragms burst under the increasing fuel pressure. Hypergolic fluid, followed by the ignition fuel, enters the thrust chamber. When hypergolic fluid enters the thrust chamber and contacts the oxidizer, spontaneous combustion occurs, establishing thrust chamber ignition. Thrust chamber pressure is transmitted through the sense line to the diaphragm of the ignition monitor valve. When the thrust chamber pressure increases, the ignition monitor valve actuates and allows hydraulic fluid flow to the opening port of the fuel valves. The fuel valves open and fuel is admitted to the thrust chamber.

Fuel enters the thrust chamber fuel inlet manifold and passes through the thrust chamber tubes for cooling purposes and then through the injector into the thrust chamber combustion zone. As the thrust chamber pressure increases, the thrust-OK pressure switches are actuated indicating the engine is operating satisfactorily. The thrust chamber pressure continues to increase until the gas generator reaches rated power, controlled by orifices in the propellant lines feeding the gas generator. When engine fuel pressure increases above the ground-supplied hydraulic pressure, the hydraulic pressure supply source is transferred to the engine. Hydraulic fuel is circulated through the engine components and then returned through the engine control valve and checkout valve into the turbopump fuel inlet. The ground hydraulic source facility shutoff valve is actuated to the closed position when the fuel valves open. This allows the engine hydraulic system to supply the hydraulic pressure during the cutoff sequence.

ENGINE CUTOFF

When the cutoff signal is initiated, the LOX dome operational oxidizer purge comes on, and the engine control valve stop solenoid is energized. Hydraulic pressure holding open the gas generator valves, the oxidizer valves, and the fuel valves is routed to return. Simultaneously, hydraulic pressure is directed to the closing ports of the gas generator valve, the oxidizer valves, and the fuel valves. The checkout valve is actuated and, as propellant pressures decay, the high level oxidizer purge begins to flow; then the igniter fuel valve and the ignition monitor valve close. Thrust chamber pressure will reach the zero level at about the same time the oxidizer valves reach full-closed.