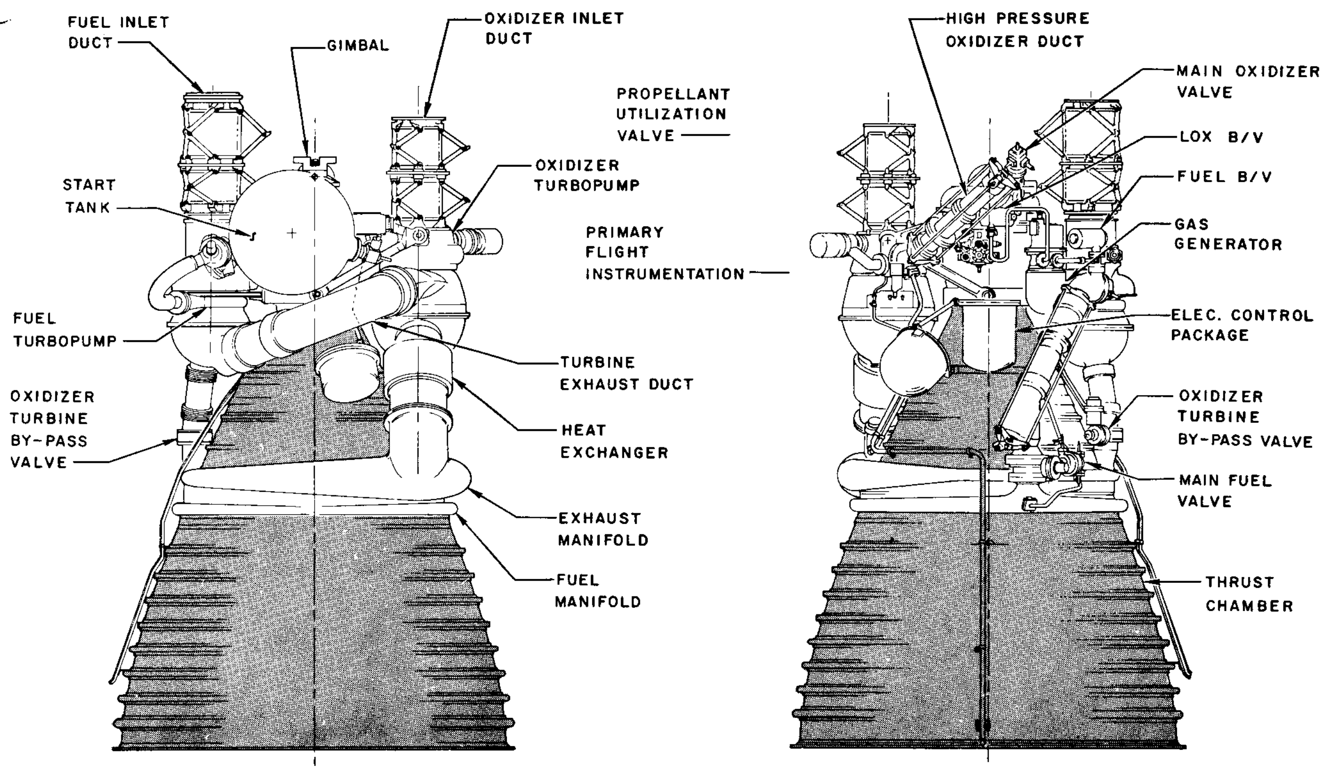
# J-2 ENGINE FACT SHEET

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| | |
|---|---|
| LENGTH | 11 ft. 1 in. |
| WIDTH | 6 ft. 8½ in. |
| NOZZLE EXIT DIAMETER | 6 ft. 5 in. |
| THRUST (altitude) | 230,000 lb. (vehicle 503 2nd stage 225,000 lb.) |
| SPECIFIC IMPULSE | 424 sec. (427 at 5:1 mixture ratio) |
| RATED RUN DURATION | 500 sec. |
| FLOWRATE: Oxidizer | 449 lb/sec (2,847 gpm) |
| Fuel | 81.7 lb/sec (8,365 gpm) |
| MIXTURE RATIO | 5.5:1 oxidizer to fuel |
| CHAMBER PRESSURE (Pc) | 763 psia |
| WEIGHT, DRY, FLIGHT CONFIGURATION | 3,480 lb. |
| EXPANSION AREA RATIO | 27.5:1 |
| COMBUSTION TEMPERATURE | 5,750°F |

# J-2 ENGINE

## J-2 ENGINE DESCRIPTION

The Rocketdyne J-2 engine is a high performance, upper stage, propulsion system utilizing liquid hydrogen and liquid oxygen propellants and develops a maximum vacuum thrust of 225,000 pounds.

All J-2 engines are identical when delivered and may be allocated to either the second or third stage. Each engine is equipped to be restarted in flight. However, the restart capability will be utilized only in the third stage.

The single J-2 engine used in the third stage is gimbal-mounted so that it can be moved in flight and used to steer the stage. Five J-2 engines are arranged in a cluster in the second stage. The four outboard engines of the five-engine cluster are gimbal-mounted to provide the vehicle with pitch, yaw, and roll control. The center engine is mounted in a fixed position.

Major systems of the J-2 engine include a thrust chamber and gimbal assembly system, propellant feed system, gas generator and exhaust system, electrical and pneumatic control system, start tank assembly system, and flight instrumentation system.

## Thrust Chamber and Gimbal System

The J-2 engine thrust chamber serves as a mount for all engine components. It is composed of the following subassemblies: thrust chamber body, injector and dome assembly, gimbal bearing assembly, and augmented spark igniter.

Thrust is transmitted through the gimbal mounted on the thrust chamber assembly dome to the vehicle thrust frame structure. The thrust chamber injector receives the propellants from a dual turbopump system (oxidizer and fuel) under pressure, mixes the propellants, and burns them to impart a high velocity to the expelled combustion gases to produce thrust.

### THRUST CHAMBER

The thrust chamber is constructed of stainless steel tubes of 0.012-inch wall thickness. Tubes with thin walls are required for heat transfer purposes. The thrust chamber tubes are stacked longitudinally and furnace-brazed to form a single unit. The chamber is bell-shaped with a 27.5 to 1 expansion area ratio for efficient operation at altitude, and is regeneratively cooled by the fuel. Fuel enters from a manifold located midway between the thrust chamber throat and the exit at a pressure of more than 1,000 psi. In cooling the chamber the fuel makes a one-half pass downward through 180 tubes and is returned in a full pass up to the thrust chamber injector through 360 tubes. (See schematic drawing.)

### DOME

The injector and oxidizer dome assembly is located at the top of the thrust chamber. The dome provides a manifold for the distribution of the liquid oxygen to the injector and serves as a mount for the gimbal bearing and the augmented spark igniter.

### THRUST CHAMBER INJECTOR

The thrust chamber injector atomizes and mixes the propellants in a manner to produce the most efficient combustion. Six hundred and fourteen hollow oxidizer posts are machined to form an integral part of the injector. Fuel nozzles are threaded and installed over the oxidizer posts forming concentric orifices.

The injector face is porous and is formed from layers of stainless steel wire mesh and is welded at its periphery to the injector body. Each fuel nozzle is swaged to the face of the injector.

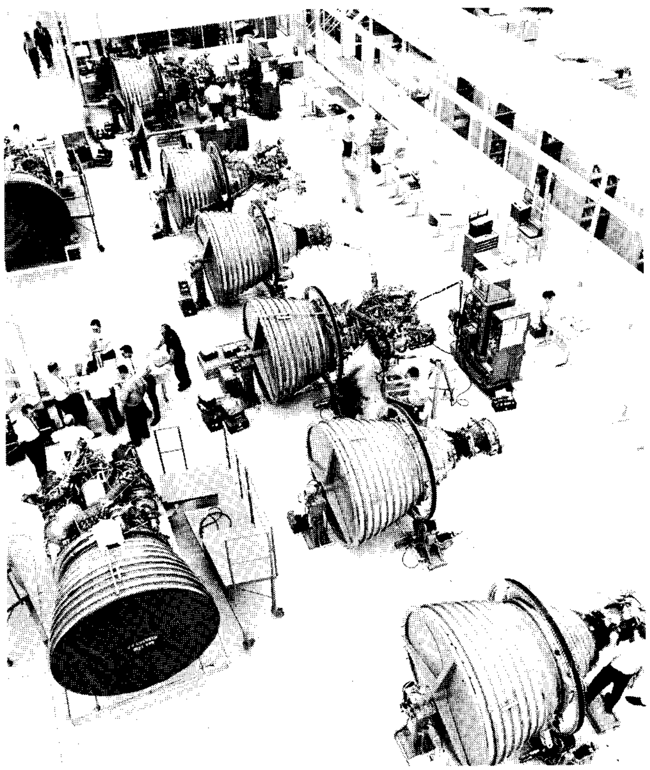
The injector receives liquid oxygen through the dome manifold and injects it through the oxidizer posts into the combustion area of the thrust chamber.

The fuel is received from the upper fuel manifold in the thrust chamber and injected through the fuel orifices which are concentric with the oxidizer orifices. The propellants are injected uniformly to ensure satisfactory combustion.

### GIMBAL

The gimbal is a compact, highly loaded (20,000 psi) universal joint consisting of a spherical, socket-type bearing with a Teflon/fiberglass composition coating that provides a dry, low-friction bearing surface. It also includes a lateral adjustment device for aligning the chamber with the vehicle.

The gimbal transmits the thrust from the injector assembly to the vehicle thrust structure and provides a pivot bearing for deflection of the thrust vector, thus providing flight attitude control of the vehicle. The gimbal is mounted on the top of the injector and oxidizer dome assembly.



R-10

J-2 Assembly—Hydrogen fueled J-2 rocket engines for upper stages of Saturn V vehicles are completed on this assembly line. J-2 develops a maximum thrust of 225,000 pounds.

AUGMENTED SPARK IGNITER

The augmented spark igniter (ASI) is mounted to the injector face. It provides the flame to ignite the propellants in the thrust chamber. When engine start is initiated, the spark exciters energize two spark plugs mounted in the side of the igniter chamber. Simultaneously, the control system starts the initial flow of oxidizer and fuel to the spark igniter. As the oxidizer and fuel enter the combustion chamber of the ASI, they mix and are ignited.

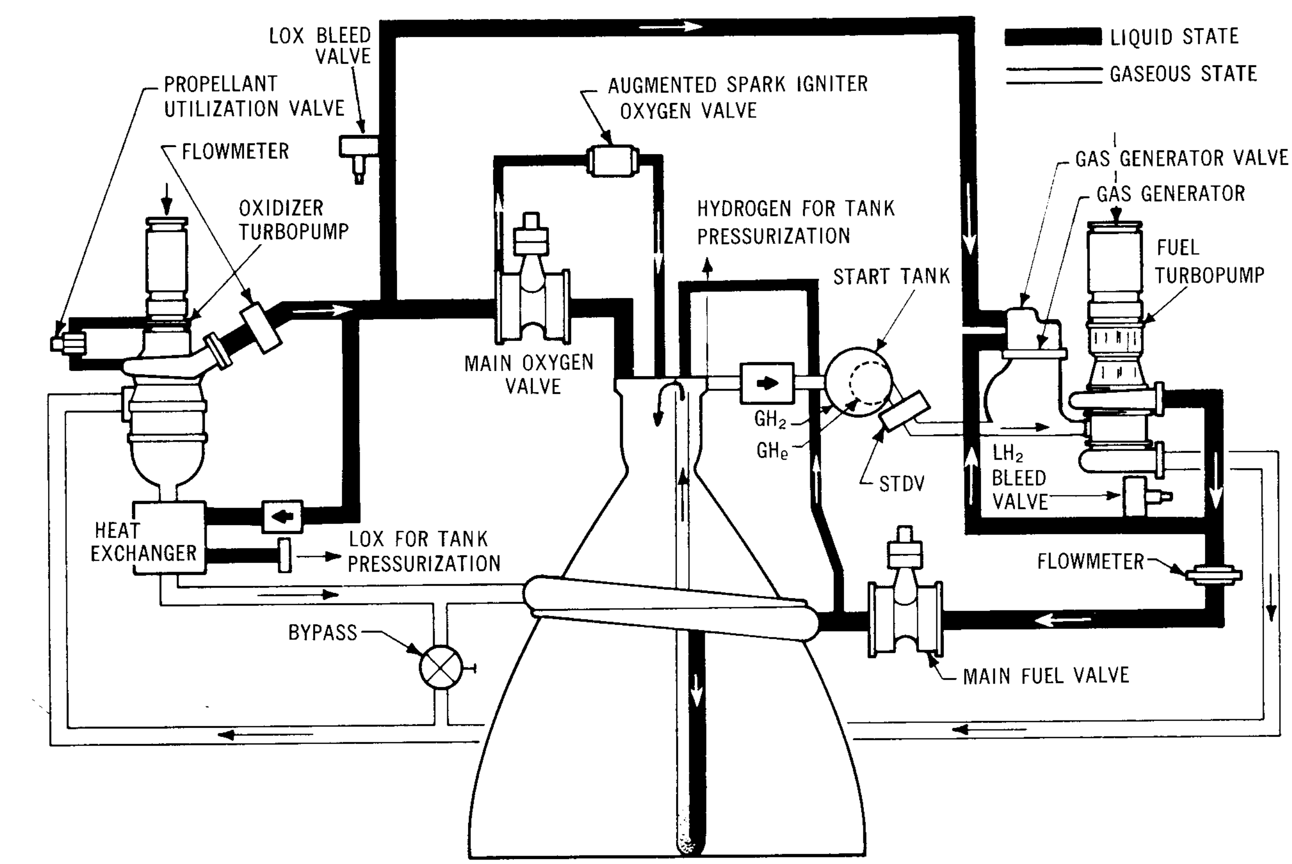
Mounted in the ASI is an ignition monitor which indicates that proper ignition has taken place. The ASI operates continuously during entire engine firing, is uncooled, and is capable of multiple reignitions under all environmental conditions.

## Propellant Feed System

The propellant feed system consists of separate fuel and oxidizer turbopumps, main fuel valve, main oxidizer valve, propellant utilization valve, fuel and oxidizer flowmeters, fuel and oxidizer bleed valves, and interconnecting lines.

FUEL TURBOPUMP

The fuel turbopump, mounted on the thrust cham-




R-8

Basic J-2 Engine Schematic

ber, is a turbine-driven, axial flow pumping unit consisting of an inducer, a seven-stage rotor, and a stator assembly. It is a high-speed pump operating at 27,000 rpm, and is designed to increase hydrogen pressure from 30 psia to 1,225 psia through high-pressure ducting at a flowrate which develops 7,800 brake horsepower.

Power for operating the turbopump is provided by a high-speed, two-stage turbine. Hot gas from the gas generator is routed to the turbine inlet manifold which distributes the gas to the inlet nozzles where it is expanded and directed at a high velocity into the first stage turbine wheel.

After passing through the first stage turbine wheel, the gas is redirected through a ring of stator blades and enters the second stage turbine wheel. The gas leaves the turbine through the exhaust ducting. Three dynamic seals in series prevent the pump fluid and turbine gas from mixing. Power from the turbine is transmitted to the pump by means of a one-piece shaft.

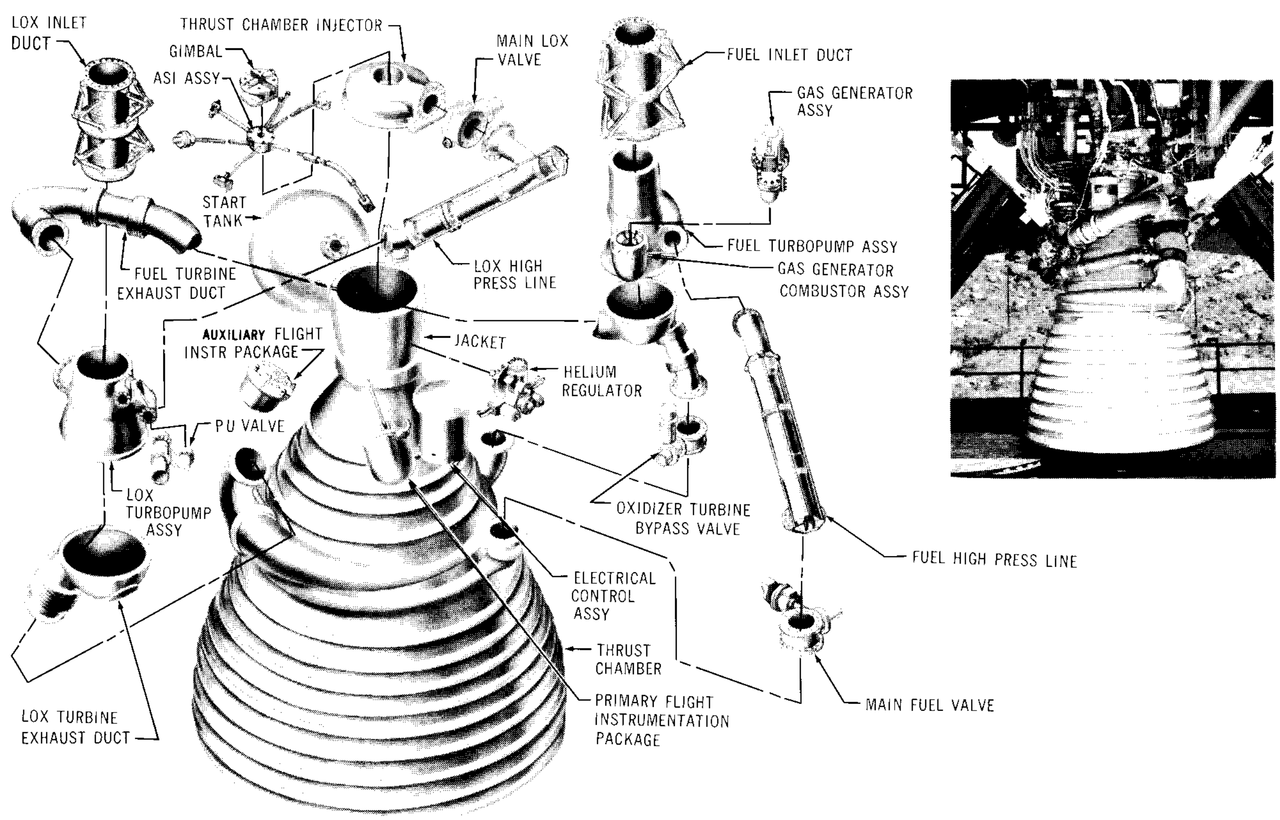
## OXIDIZER TURBOPUMP

The oxidizer turbopump is mounted on the thrust chamber diametrically opposite the fuel turbopump. It is a single-stage centrifugal pump with direct turbine drive. The oxidizer turbopump increases the pressure of the liquid oxygen and pumps it through high-pressure ducts to the thrust chamber.

The pump operates at 8,600 rpm at a discharge pressure of 1,080 psia and develops 2,200 brake horsepower. The pump and its two turbine wheels are mounted on a common shaft.

Power for operating the oxidizer turbopump is provided by a high-speed, two-stage turbine which is driven by the exhaust gases from the gas generator. The turbines of the oxidizer and fuel turbopumps are connected in a series by exhaust ducting that directs the discharged exhaust gas from the fuel turbopump turbine to the inlet of the oxidizer turbopump turbine manifold. One static and two dynamic seals in series prevent the turbopump oxidizer fluid and turbine gas from mixing.

Beginning the turbopump operation, hot gas enters the nozzles and, in turn, the first stage turbine wheel. After passing through the first stage turbine wheel, the gas is redirected by the stator blades and enters the second stage turbine wheel. The gas then leaves the turbine through exhaust ducting, passes through the heat exchanger, and exhausts into the thrust chamber through a manifold directly






J-2 Major Component Breakdown

above the fuel inlet manifold. Power from the turbine is transmitted by means of a one-piece shaft to the pump. The velocity of the liquid oxygen is increased through the inducer and impeller. As the liquid oxygen enters the outlet volute, velocity is converted to pressure and the liquid oxygen is discharged into the outlet duct at high pressure.

Bearings in the liquid hydrogen and liquid oxygen turbopumps are lubricated by the fluid being pumped because the extremely low operating temperature of the engine precludes use of lubricants or other fluids.

## MAIN FUEL VALVE

The main fuel valve is a butterfly-type valve, spring-loaded to the closed position, pneumatically operated to the open position, and pneumatically assisted to the closed position. It is mounted between the fuel high-pressure duct from the fuel turbopump and the fuel inlet manifold of the thrust chamber assembly. The main fuel valve controls the flow of fuel to the thrust chamber. Pressure from the ignition stage control valve on the pneumatic control package opens the valve during engine start. As the gate starts to open, it allows fuel to flow to the fuel inlet manifold.

## MAIN OXIDIZER VALVE

The main oxidizer valve (MOV) is a butterfly-type valve, spring-loaded to the closed position, pneumatically operated to the open position, and pneumatically assisted to the closed position. It is mounted between the oxidizer high-pressure duct from the oxidizer turbopump and the oxidizer inlet on the thrust chamber assembly.

Pneumatic pressure from the normally closed port of the mainstage control solenoid valve is routed to both the first and second stage opening actuators of the main oxidizer valve. Application of opening pressure in this manner, together with controlled venting of the main oxidizer valve closing pressure through a thermal-compensating orifice, provides a controlled ramp opening of the main oxidizer valve through all temperature ranges. A sequence valve, located within the MOV assembly, supplies pneumatic pressure to the opening control part of the gas generator control valve and through an orifice to the closing part of the oxidizer turbine bypass valve.

## PROPELLANT UTILIZATION VALVE

The propellant utilization (PU) valve is an electrically operated, two-phase, motor-driven, oxidizer transfer valve and is located at the oxidizer turbopump outlet volute. The propellant utilization valve ensures the simultaneous exhaustion of the contents of the propellant tanks. During engine operation, propellant level sensing devices in the vehicle propellant tanks control the valve gate position for adjusting the oxidizer flow to ensure simultaneous exhaustion of fuel and oxidizer.

An additional function of the PU valve is to provide thrust variations in order to maximize payload. The second stage, for example, operates with the PU valve in the closed position for more than 70 per cent of the firing duration. This valve position provides 225,000 pounds of thrust at a 5.5:1 propellant (oxidizer to fuel by weight) mixture ratio. During the latter portion of the flight, the PU valve position is varied to provide simultaneous emptying of the propellant tanks.

The third stage also operates at the high-thrust level for the majority of the burning time in order to realize the high thrust benefits.

The exact period of time at which the engine will operate with the PU valve closed will vary with individual mission requirements and propellant tanking levels.

When the PU valve is fully open, the mixture ratio is 4.5:1 and the thrust level is 175,000 pounds.

The propellant utilization valve and its servomotor are supplied with the engine. A position feedback potentiometer is also supplied as a part of the PU valve assembly. The PU valve assembly and a stage or a facility-mounted control system make up the propellant utilization system.

## FUEL AND OXIDIZER FLOWMETERS

The fuel and oxidizer flowmeters are helical-vaned, rotor-type flowmeters. They are located in the fuel and oxidizer high-pressure ducts. The flowmeters measure propellant flowrates in the high-pressure propellant ducts. The four-vane rotor in the hydrogen system produces four electrical impulses per revolution and turns approximately 3,700 revolutions per minute at nominal flow. The six-vane rotor in the liquid oxygen system produces six electrical impulses per revolution and turns at approximately 2,600 revolutions per minute at nominal flow.

## PROPELLANT BLEED VALVES

The propellant bleed valves used in both the fuel and oxidizer systems are poppet-type which are spring-loaded to the normally open position and pressure-actuated to the closed position. Both propellant bleed valves are mounted to the bootstrap lines adjacent to their respective turbopump discharge flanges.

The valves allow propellant to circulate in the propellant feed system lines to achieve proper operating temperature prior to engine start. The bleed valves are engine controlled. At engine start, a helium control solenoid valve in the pneumatic control package is energized allowing pneumatic pressure to close the bleed valves, which remain closed during engine operation.

## Gas Generator and Exhaust System

This system consists of the gas generator, gas generator control valve, turbine exhaust system and exhaust manifold, heat exchanger, and oxidizer turbine bypass valve.

### GAS GENERATOR

The gas generator is welded to the fuel pump turbine manifold, making it an integral part of the fuel turbopump assembly. It produces hot gases to drive the fuel and oxidizer turbines and consists of a combustor containing two spark plugs, a control valve containing fuel and oxidizer ports, and an injector assembly.

When engine start is initiated, the spark exciters in the electrical control package are energized, providing energy to the spark plugs in the gas generator combustor. Propellants flow through the control valve to the injector assembly and into the combustor outlet and are directed to the fuel turbine and then to the oxidizer turbine.

### GAS GENERATOR CONTROL VALVE

The gas generator control valve is a pneumatically operated poppet-type that is spring-loaded to the closed position. The fuel and oxidizer poppets are mechanically linked by an actuator. The gas generator control valve controls the flow of propellants through the gas generator injector.

When the mainstage signal is received, pneumatic pressure is applied against the gas generator control valve actuator assembly which moves the piston and opens the fuel poppet. During the fuel poppet opening, an actuator contacts the piston that opens the oxidizer poppet. As the opening pneumatic pressure decays, spring loads close the poppets.

### TURBINE EXHAUST SYSTEM

The turbine exhaust ducting and turbine exhaust hoods are of welded sheet metal construction. Flanges utilizing dual (Naflex) seals are used at component connections. The exhaust ducting conducts turbine exhaust gases to the thrust chamber exhaust manifold which encircles the thrust chamber approximately halfway between the throat and the nozzle exit. Exhaust gases pass through the heat exchanger and exhaust into the main thrust chamber through 180 triangular openings between the tubes of the thrust chamber.

### HEAT EXCHANGER

The heat exchanger is a shell assembly, consisting of a duct, bellows, flanges, and coils. It is mounted in the turbine exhaust duct between the oxidizer turbine discharge manifold and the thrust chamber. It heats and expands helium gas for use in the third stage or converts liquid oxygen to gaseous oxygen for the second stage for maintaining vehicle oxidizer tank pressurization. During engine operation, either liquid oxygen is tapped off the oxidizer high-pressure duct or helium is provided from the vehicle stage and routed to the heat exchanger coils.

### OXIDIZER TURBINE BYPASS VALVE

The oxidizer turbine bypass valve is a normally open, spring-loaded, gate type. It is mounted in the oxidizer turbine bypass duct. The valve gate is equipped with a nozzle, the size of which is determined during engine calibration. The valve in its open position depresses the speed of the oxygen pump during start, and in its closed position acts as a calibration device for the turbopump performance balance.

## Control System

The control system includes a pneumatic system and a solid-state electrical sequence controller packaged with spark exciters for the gas generator and the thrust chamber spark plugs, plus interconnecting electrical cabling and pneumatic lines.

### PNEUMATIC SYSTEM

The pneumatic system consists of a high-pressure helium gas storage tank, a regulator to reduce the pressure to a usable level, and electrical solenoid control valves to direct the central gas to the various pneumatically controlled valves.

### ELECTRICAL SEQUENCE CONTROLLER

The electrical sequence controller is a completely self-contained, solid-state system, requiring only DC power and start and stop command signals.

Pre-start status of all critical engine control functions is monitored in order to provide an "engine ready" signal. Upon obtaining "engine ready" and "start" signals, solenoid control valves are energized in a precisely timed sequence as described in the "Engine Operation" section to bring the engine through ignition, transition, and into mainstage operation. After shutdown, the system automatically resets for a subsequent restart.

### Start Tank Assembly System

This system is made up of an integral helium and hydrogen start tank, which contains the hydrogen and helium gases for starting and operating the engine. The gaseous hydrogen imparts initial spin to the turbines and pumps prior to gas generator combustion, and the helium is used in the control system to sequence the engine valves.

#### HELIUM AND HYDROGEN TANKS

The spherical helium tank is positioned inside the hydrogen tank to minimize engine complexity. It holds 1,000 cubic inches of helium. The larger spherical hydrogen gas tank has a capacity of 7,257.6 cubic inches. Both tanks are filled from a ground source prior to launch and the gaseous hydrogen tank is refilled during engine operation from the thrust chamber fuel inlet manifold for subsequent restart in third stage application.

### Flight Instrumentation System

The flight instrumentation system is composed of a primary instrumentation package and an auxiliary package.

#### PRIMARY PACKAGE

The primary package instrumentation measures those parameters critical to all engine static firings and subsequent vehicle launches. These include some 70 parameters such as pressures, temperatures, flows, speeds, and valve positions for the engine components, with the capability of transmitting signals to a ground recording system or a telemetry system, or both. The instrumentation system is designed for use throughout the life of the engine, from the first static acceptance firing to its ultimate vehicle flight.

#### AUXILIARY PACKAGE

The auxiliary package is designed for use during early vehicle flights. It may be deleted from the basic engine instrumentation system after the propulsion system has established its reliability during research and development vehicle flights. It contains sufficient flexibility to provide for deletion, substitution, or addition of parameters deemed necessary as a result of additional testing. Eventual deletion of the auxiliary package will not interfere with the measurement capability of the primary package.

### Engine Operation

#### START SEQUENCE

Start sequence is initiated by supplying energy to two spark plugs in the gas generator and two in the augmented spark igniter for ignition of the propellants. Next, two solenoid valves are actuated: one for helium control, and one for ignition phase control. Helium is routed to hold the propellant bleed valves closed and to purge the thrust chamber LOX dome, the LOX pump intermediate seal, and the gas generator oxidizer passage. In addition, the main fuel valve and ASI oxidizer valve are opened, creating an ignition flame in the ASI chamber that passes through the center of the thrust chamber injector.

After a delay of 1, 3, or 8 seconds, during which time fuel is circulated through the thrust chamber to condition the engine for start, the start tank discharge valve is opened to initiate turbine spin. The length of the fuel lead is dependent upon the length of the Saturn V first stage boost phase. When the J-2 engine is used in the second stage of the Saturn V vehicle, a one-second fuel lead is necessary. The third stage of the Saturn V vehicle, on the other hand, utilizes a three-second fuel lead for its initial start and an eight-second fuel lead for its restart.

After an interval of 0.450 second, the start tank discharge valve is closed and a mainstage control solenoid is actuated to: 1) turn off gas generator and thrust chamber helium purges; 2) open the gas generator control valve (hot gases from the gas generator now drive the pump turbines); 3) open the main oxidizer valve to the first position (14 degrees) allowing LOX to flow to the LOX dome to burn with the fuel that has been circulating through the injector; 4) close the oxidizer turbine bypass valve (a portion of the gases for driving the oxidizer turbopump were bypassed during the ignition phase); 5) gradually bleed the pressure from the closing side of the oxidizer valve pneumatic actuator controlling the slow opening of this valve for smooth transition into mainstage. Energy in the spark plugs is cut off and the engine is operating at rated thrust. During the initial phase of engine operation, the gaseous hydrogen start tank will be recharged in those engines having a restart requirement. The hydrogen tank is repressurized by tapping off a controlled mixture of liquid hydrogen from the thrust chamber fuel inlet manifold and warmer hydrogen from the thrust chamber fuel injection manifold just before entering the injector.

## FLIGHT MAINSTAGE OPERATION

During mainstage operation, engine thrust may be varied between 175,000 and 225,000 pounds by actuating the propellant utilization valve to increase or decrease oxidizer flow as described in the section "PU Valve". This is beneficial to flight trajectories and for overall mission performance to make greater payloads possible.

## CUTOFF SEQUENCE

When the engine cutoff signal is received by the electrical control package, it de-energizes the mainstage and ignition phase solenoid valves and energizes the helium control solenoid de-energizer timer. This, in turn, permits closing pressure to the main fuel valve, main oxidizer valve, gas generator control valve, and augmented spark igniter valve. The oxidizer turbine bypass valve and propellant bleed valves open and the gas generator and LOX dome purges are initiated.

## ENGINE RESTART

To provide third stage restart capability for the Saturn V, the J-2 gaseous hydrogen start tank is refilled in 60 seconds during the previous firing after the engine has reached steady-state operation. (Refill of the gaseous helium tank is not required because the original ground-fill supply is sufficient for three starts.) Prior to engine restart, the stage ullage rockets are fired to settle the propellants in the stage propellant tanks, ensuring a liquid head to the turbopump inlets.

Also, the engine propellant bleed valves are opened, the stage recirculation valve is opened, the stage prevalve is closed, and a LOX and $LH_2$ circulation is effected through the engine bleed system for five minutes to condition the engine to the proper temperature to ensure proper engine operation.

Engine restart is initiated after the "engine ready" signal is received from the stage. This is similar to the initial "engine ready". The hold time between cutoff and restart is from a minimum of 1-1/2 hours to a maximum of 6 hours, depending upon the number of earth orbits required to attain the lunar window for translunar trajectory.