propellant quantity gauge, and the propellant quantity remaining for that quad is indicated in percent.

The helium tank temperature for each quad is monitored by a helium tank temperature transducer. A switch allows the crew to monitor either the helium tank temperature/pressure ratio as a percentage of quantity remaining, or helium tank temperature which can be compared against the helium supply pressure readout. Helium tank temperature is not displayed in the first Block II spacecraft, although it is telemetered to the ground.

In the SM reaction control system, the main buses cannot supply electrical power to one leg of the channel enable switches and controller reaction jet assembly until the contacts of the subsystem latching relay are closed. These are closed after separation of the spacecraft from the third stage, or to prepare for a service propulsion subsystem abort.

CM REACTION CONTROL SYSTEM

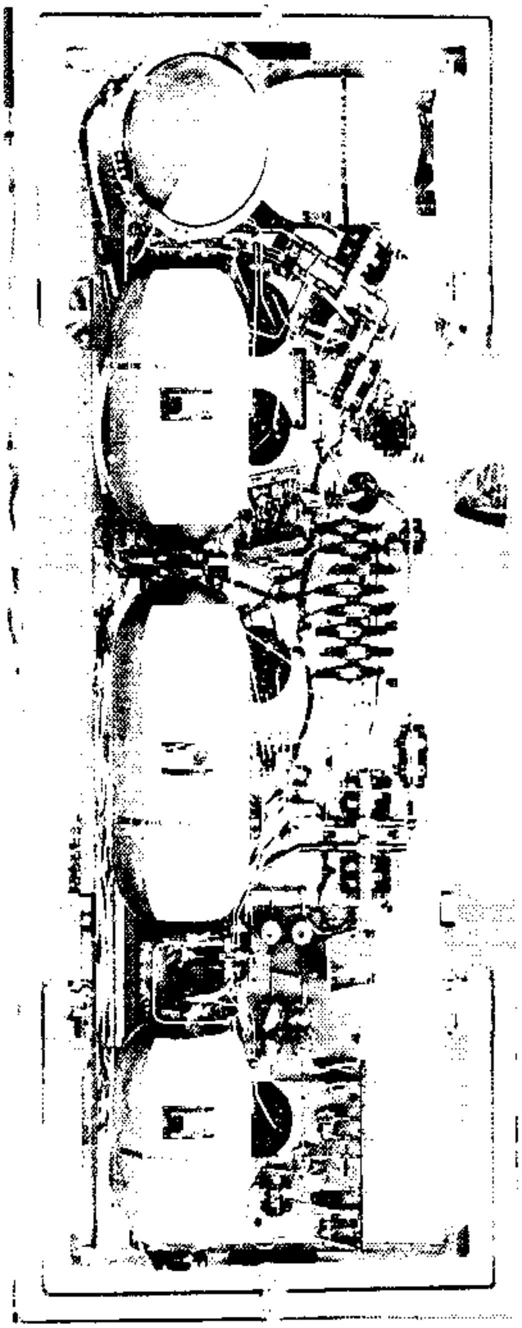
The CM reaction control system is composed of two separate, normally independent systems, called System 1 and System 2. They are identical in operation, each containing pressurization, propellant, rocket engine and temperature control systems.

The pressurization system consists of a helium supply tank, two dual pressure regulator assemblies, two check valve assemblies, two pressure relief valve assemblies, and associated distribution plumbing.

The total high-pressure helium for each system is contained in a spherical storage tank about 9 inches in diameter and containing 0.57 pound of helium at a pressure of 4150 psia.

Two squib-operated helium isolation valves are installed in the plumbing from each helium tank to confine the helium into as small an area as possible to reduce helium leakage until the system is used. Two squib valves are employed in each system to assure pressurization.

The pressure regulators used in the CM systems are similar in type, operation, and function to those used in the SM system. The difference is that the regulators in the CM system are set at a higher pressure than those of the SM system: 291 psia against 181 psia for the primary regulators and 291 against 187 for the secondary regulators.



P-206

SM quad prepared for installation

The check valve assemblies used in CM system are identical in type, operation, and function to those used in the SM system. The helium relief valves also are similar to those in the SM system except that the rupture pressure of the diaphragm in the CM system is higher (340 psia instead of 228) and the relief valve relieves at a higher pressure (346 psia instead of 236 psia).

Each propellant system consists of one oxidizer tank, one fuel tank, oxidizer and fuel isolation valves, oxidizer and fuel diaphragm isolation valves, and associated distribution plumbing.

The oxidizer supply is contained in a single titanium alloy, hemispherical-domed cylindrical tank in each subsystem. These tanks are identical to the secondary oxidizer tanks in the SM system.

Each tank contains a diffuser tube assembly and a Teflon bladder for positive expulsion of the oxidizer similar to that of the SM secondary tank assemblies. The bladder is attached to the diffuser tube at each end of the tank. The diffuser tube acts as the propellant outlet.

When the tank is pressurized, the helium gas surrounds the entire bladder, exerting a force which causes the bladder to collapse about the propellant, forcing the oxidizer into the diffuser tube assembly and out of the tank outlet into the manifold.

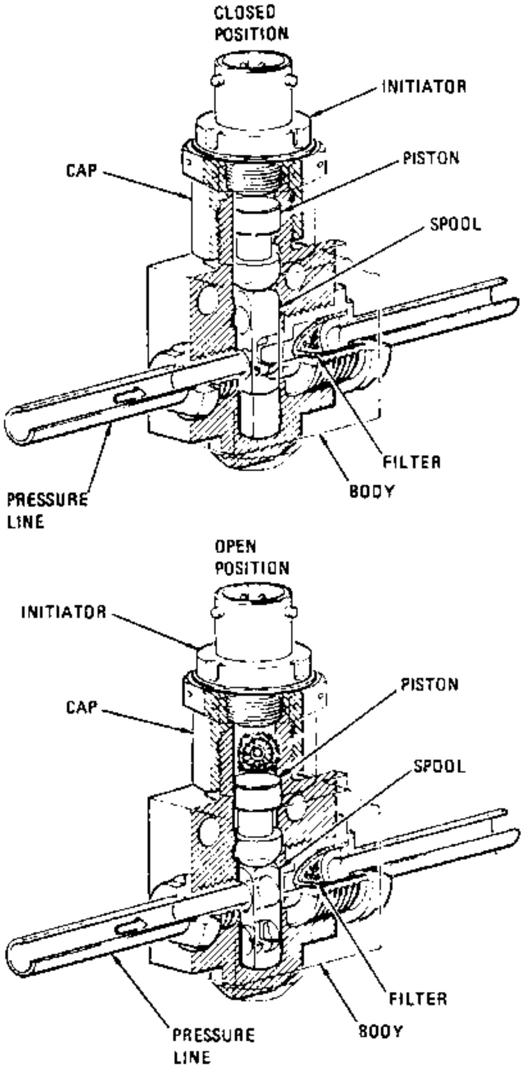
The fuel supply is contained in a single titanium alloy, hemispherical-domed cylindrical tank in each subsystem that is identical to the SM secondary fuel tanks.

The diaphragms are installed in the lines from each tank to confine the propellants to as small an area as possible throughout the mission.

When the helium isolation squib valves are opened, regulated helium pressure pressurizes the propellant tanks creating the positive expulsion of propellants into the respective manifolds to the diaphragms, which rupture and allow the propellants to flow on through the propellant isolation valves to the injector valves on each engine. A filter will prevent any diaphragm fragments from entering the engine injector valves.

When the diaphragms are ruptured, the propellant flows to the propellant isolation valves. These are controlled by a single switch on the main display console. Each propellant isolation valve contains two solenoids, one that is energized momentarily to latch the valve open magnetically, and one that is energized momentarily to unlatch the magnetic latch. Spring force and propellant pressure close the valve. An indicator on the main display console shows gray indicating that the valves are open (the normal position) and diagonal lines when either valve is closed. The valves are closed in the event of a line rupture or runaway thruster.

The distribution lines contain 16 explosive-operated (squib) valves which permit the helium and propellant distribution configuration to be changed for various functions. Each squib valve is actuated by an explosive charge and detonated by an ignitor. After ignition of the explosive device, the valve remains open permanently. Two squib valves are used in each subsystem to isolate the high-pressure helium supply. Two squib valves are used to interconnect System 1 and 2 regulated helium supply which assess pressurization of both systems during dump-burn and helium purge operation. Two squib valves in each subsystem permit helium gas to bypass the propellant tanks and allow helium purging of the propellant subsystem. One squib valve in the oxidizer system permits both oxidizer systems to become common. One squib valve in the fuel system permits both fuel systems



P-207

Typical CM squib valve

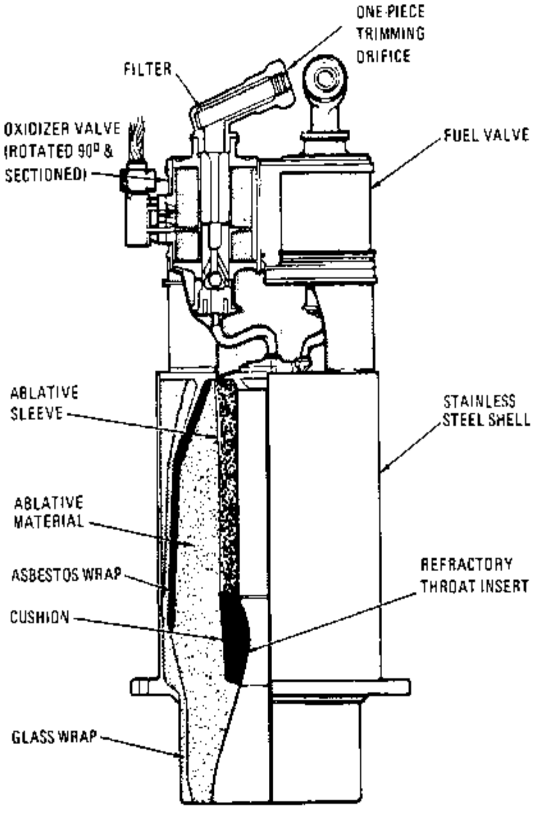
to become common. Two squib valves in the oxidizer system and two in the fuel system are used to dump the respective propellant in the event of an abort from the pad up to 42 seconds after liftoff.

The CM reaction control subsystem engines are ablative-cooled, bipropellant thrust generators that can be operated in either pulse or steady-state mode.

Each engine consists of fuel and oxidizer injector valves which control the flow of propellants, an injector and a combustion chamber in which the propellants are burned to produce thrust.

The injector valves use two coaxially wound coils, one for automatic and one for direct manual control. The automatic coil is used when the thrust command originates in guidance and control electronics. The direct manual coil is used when the thrust command originates at the astronaut hand rotation control. The engine injector valves are spring-loaded closed and energized open.

The automatic coils in the fuel and oxidizer injector valves are connected in parallel from guidance and control electronics. The direct manual coils in the fuel and oxidizer injector valves provide a direct backup to the automatic system. They are connected in parallel.



P-208

CM reaction control engine

The injector contains 16 fuel and 16 oxidizer passages that impinge on a splash plate within the combustion chamber. This pattern is referred to as an unlike impingement splash-plate injector.

The thrust chamber assembly consists of the combustion chamber ablative sleeve, throat insert, ablative body, asbestos, and a fiberglass wrap. The engine is ablative-cooled.

The CM reaction control engines are mounted within the structure of the CM. The nozzle extensions extend through the CM heat shield and are made of ablative material. They match the mold line of the CM.

Temperature of the CM engines before activation is controlled by energizing injector valve direct coils on each engine. Temperature sensors are mounted on 6 of the 12 engine injectors. The temperature transducers have a range from -50° to $+50^{\circ}$F. The temperature transducers from the System 1 and 2 engine injectors provide inputs to two rotary switches located in the lower equipment bay of the CM. The specific engine injector temperature is monitored as dc voltage on the voltmeter in the bay. If any one of the engines registers less than 48°F, the direct manual heating coils of all 12 engines are switched on. If 48°F (approximately 5 volts on the dc voltmeter) is reached from the coldest instrumented engine before 20 minutes, the valves are turned off. If 20 minutes pass before $+48^{\circ}$F is reached, the valves are turned off then. The heaters prevent the oxidizer from freezing at the engine injector valves and the 20-minute time limit assures that the warmest engines will not be overheated.

All automatic thrust commands for CM attitude are generated from the controller reaction jet assembly. These commands may originate at the rotation controls, the stabilization and control subsystem, or the CM computer. If the controller reaction jet assembly is unable to provide commands to the automatic coil of the CM engines, switches on the main display console will provide power to the rotation controls for direct coil control. The CM-SM separation switches automatically energize relays in the reaction control system control box that transfer the controller reaction jet assembly and direct manual inputs from the SM engines to the CM engines. These functions also occur automatically on any launch escape subsystem abort.

The transfer motors in the control box are redundant to assure that the direct manual inputs are transferred from the SM engines to the CM engines, in addition to providing a positive deadface.

The RCS transfer motors may also be activated by a transfer switch placed to "CM" position; this is a manual backup to the automatic transfer.

CM Systems 1 and 2 also may be checked out before CM-SM separation by use of the transfer switch.

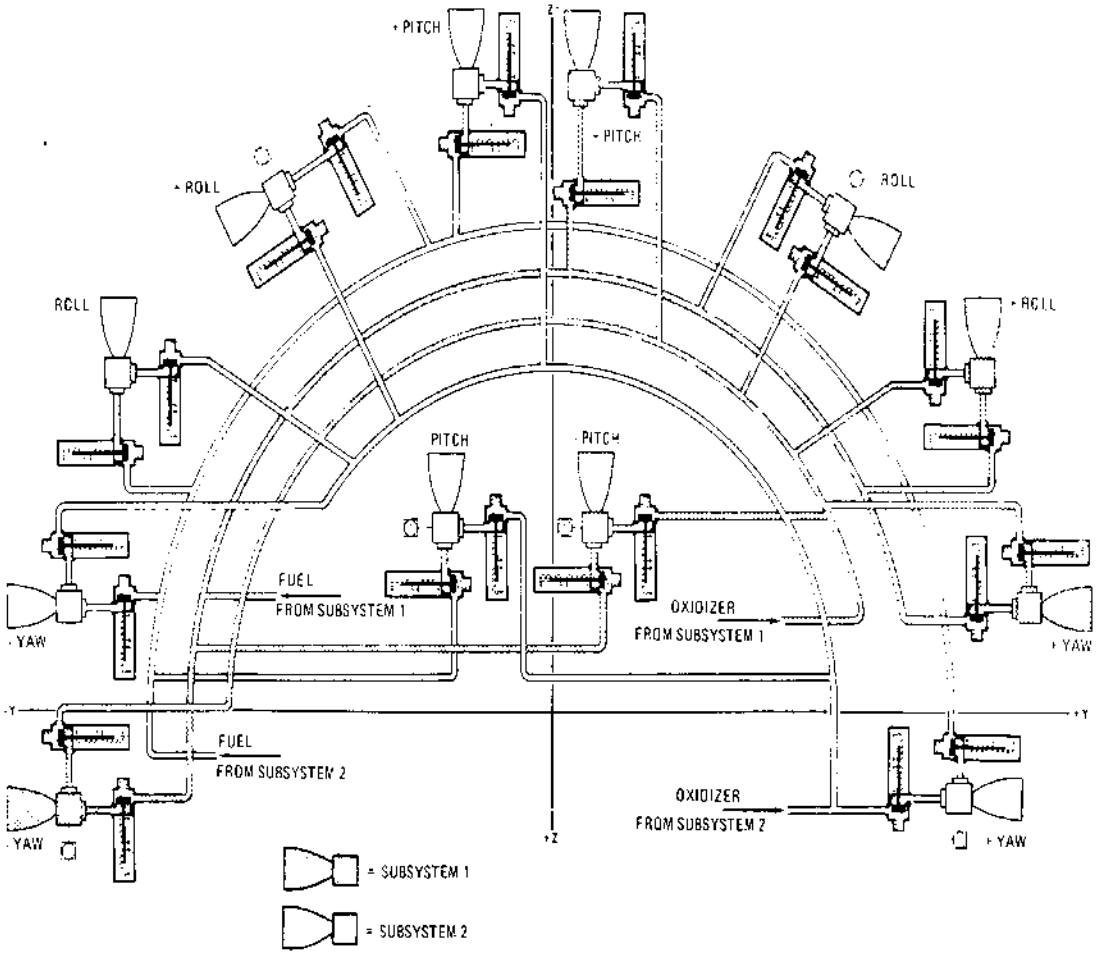
There are two sequences of propellant jettison. One sequence is used in the event of an abort while the vehicle is on the launch pad and through the first 42 seconds of flight. The second is used for all other conditions.

The sequence of events before and during a normal entry is as follows:

1. The CM system is pressurized by manual switching which fires the helium isolation squib valves in both System 1 and 2.

2. The CM reaction control engines provide attitude control during entry; and at approximately 24,000 feet, a barometric switch is activated unlatching the subsystem latching relay, inhibiting any further commands from the controller reaction jet assembly.

3. When the main parachute is fully deployed, a crewman will turn on the CM reaction control propellant dump switch, simultaneously initiating the two helium interconnect squib valves, the fuel interconnect squib valve, and the oxidizer interconnect squib valve, and energizing the fuel and oxidizer injector valve



P-209

Schematic of reaction control engines

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direct manual coils on 10 of the 12 CM engines. (The two forward or pitch engines are not energized because their plume might impinge on the parachutes.) The remaining propellant is burned through the 10 engines. The length of burn time will vary depending on the amount of propellant remaining. If an entire propellant load remained, a nominal burn time would be 88 seconds through 10 engines. In the worst case (only 5 of the 12 engines burning), a nominal burn time would be 155 seconds.

4. Upon completion of propellant burn, the CM propellant purge switch is turned on initiating the four helium bypass squib valves to allow the regulated helium pressure to bypass around each fuel and oxidizer tank bladder and purge the lines and manifolds out through the 10 engines. Purging requires approximately 15 seconds (until helium is depleted).

5. In case of a switch failure, the remaining propellants may be burned by manipulating the two rotation controllers so that 10 of the 12 CM engines will fire.

6. If the purge switch fails, the CM "helium dump" pushbutton would be pressed to initiate the four helium bypass squib valves, purge the lines and manifolds out through 10 of the 12 engines, and deplete the helium source pressure.

7. After purging, the direct coils of the CM engine injector valves are switched off manually.

The sequence of events during an abort from the pad up to 42 seconds after liftoff is controlled automatically by the master event sequence controller by manually rotating the translation control counterclockwise. The following events occur simultaneously:

1. The CM-SM transfer motor-driven switches are automatically driven upon receipt of the abort signal, transferring the logic circuitry from SM reaction control engines to CM engines.

2. When the abort signal is received, the two squib-operated helium isolation valves in each system are initiated, pressurizing Systems 1 and 2.

3. The squib-operated helium interconnect valve for the oxidizer and fuel tanks are opened even if only one of the two squib helium isolation valves opens. Both subsystems are pressurized as a result of the helium interconnect squib valve.

4. The solenoid-operated fuel and oxidizer isolation shutoff valves are closed to prevent fuel and oxidizer from flowing to the thrust chamber assemblies.

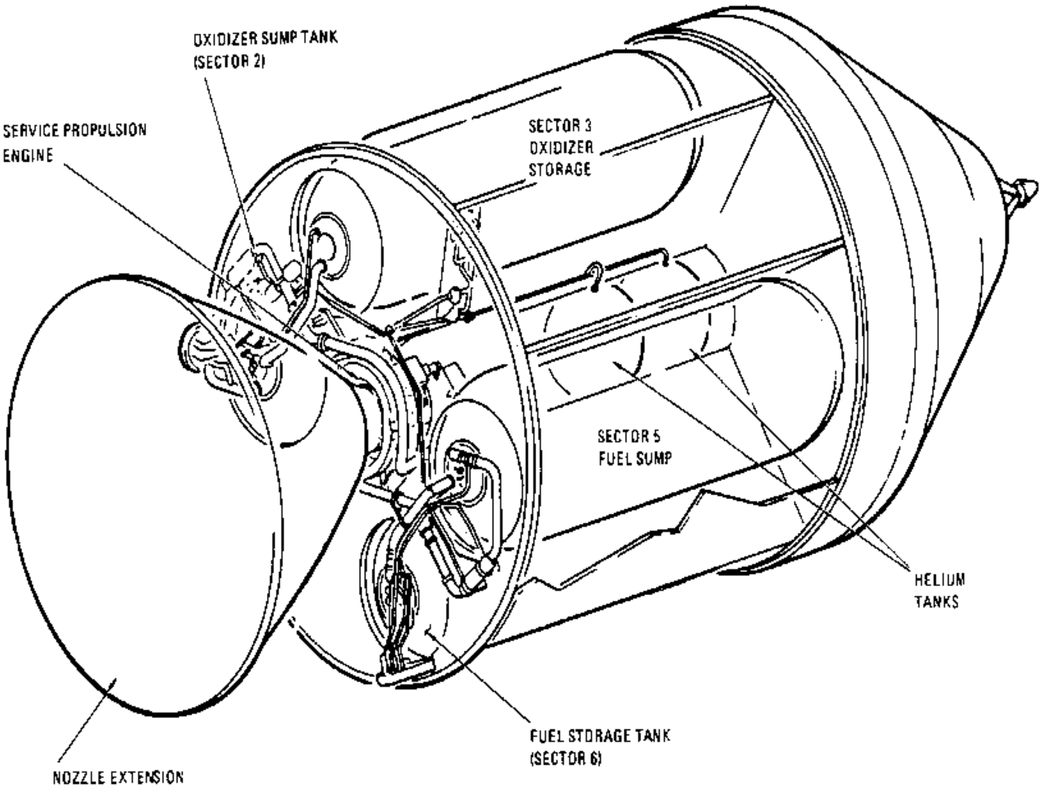
5. The squib-operated fuel and oxidizer interconnect valves are opened. Even if only one of the two oxidizer or fuel overboard dump squib valves opens, the oxidizer and fuel manifolds of each system are common as a result of the oxidizer and fuel interconnect squib valves.

6. The squib-operated oxidizer overboard dump valves are opened and route the oxidizer to blowout plug in the aft heat shield of the CM. The oxidizer shears a pin due to the pressure buildup and blows the plug out, dumping the oxidizer overboard. The entire oxidizer supply is dumped in approximately 13 seconds.

7. Five seconds after abort initiation, the squib-operated fuel overboard dump valves are initiated open and route the fuel to a fuel blow out plug in the aft heat shield of the CM. The fuel shears a pin due to the pressure buildup and blows the plug out, dumping the fuel overboard. The entire fuel supply is dumped in approximately 13 seconds.

8. Thirteen seconds after the fuel dump sequence was started, the fuel and oxidizer bypass squib valves in Systems 1 and 2 are opened to purge the fuel and oxidizer systems through the fuel and oxidizer overboard dumps.

SERVICE PROPULSION



P-210 *Location of main components of service propulsion subsystem*

The service propulsion subsystem provides the thrust for all major velocity changes throughout a mission. These include the retrobraking maneuver for insertion into an orbit around the moon, the thrust for injection into the transearth trajectory, major course corrections, and the power to return the CM to earth's atmosphere during an abort after the launch escape subsystem has been jettisoned.

The subsystem includes a single large rocket engine, its pressurization and propellant subsystems, a bipropellant valve assembly, a thrust mount assembly with a gimbal actuator assembly, and the propellant utilization and gauging subsystem. Displays and sensing devices enable the crew and ground stations to monitor subsystem performance.

All of the components of the service propulsion subsystem except the controls are located in the service module. Control of engine firing normally is automatic, but there are provisions for manual override. Subsystem components occupy about three-quarters of the space in the SM and make up more than 41,500 pounds of its 55,000-pound weight.

The service propulsion engine is 3 feet, 5 inches long with a radiation-cooled extension nozzle of 9 feet 4 inches. The engine is gimbaled (can be turned) and provides 20,500 pounds of thrust in vacuum. Its propellant is composed of fuel of 50-percent hydrazine and 50-percent unsymmetrical dimethylhydrazine (UDMH) and an oxidizer of nitrogen tetroxide. The propellant is hypergolic; that is, the fuel and oxidizer ignite and burn on contact.

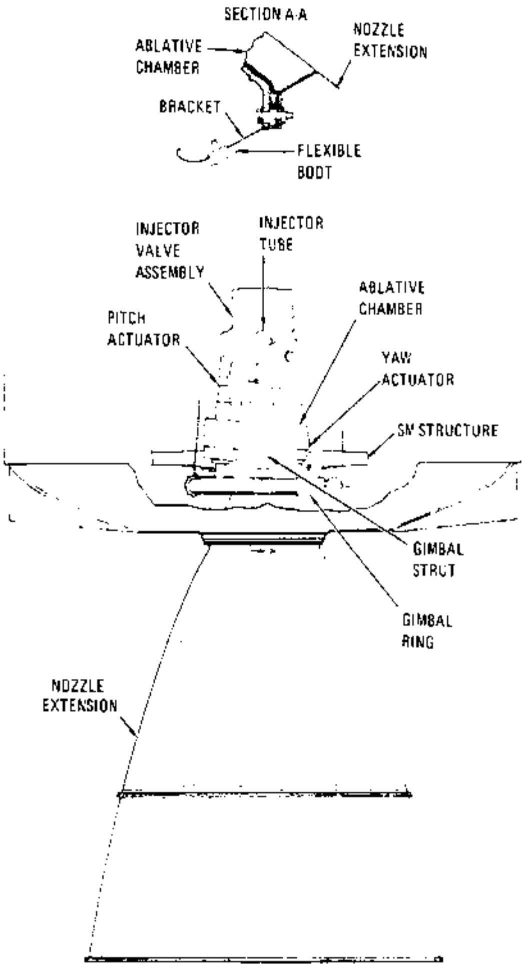
Its major components are a bipropellant valve assembly, injector, propellant lines, electrical wire harness, ablative thrust chamber, nozzle extension, thrust mount, gimbal ring, and gimbal actuator assembly. The engine is produced by Aerojet-General Corp., Sacramento, Calif.

The service propulsion engine responds to automatic firing commands from the guidance and navigation subsystem or to commands from manual controls. The engine assembly is gimbal-mounted to allow engine thrust-vector alignment with the spacecraft's center of mass to preclude tumbling. Thrust-vector alignment control is maintained automatically by the stabilization and control subsystem or manually by the crew. The engine has no throttle, producing a single-value thrust.

The engine's propellant supply is contained in four tanks of similar size and construction, each almost filling one of the sectors of the SM. There are two tanks each for fuel and for oxidizer; one is a storage tank and one a sump tank (which feeds the engine). Total propellant is 15,723 pounds of fuel and 25,140 pounds of oxidizer. (Although the volume in the fuel and oxidizer tanks is identical, the oxidizer weighs a great deal more than the fuel. The tanks, made of titanium, are built by General Motors Corp.'s Allison Division, Indianapolis, Ind.

The storage and sump tanks for fuel and oxidizer are connected in series by a single transfer line. Regulated helium from the pressurization subsystem enters the fuel and oxidizer storage tanks and forces the fluids into a transfer line to a sump tank standpipe. The pressure forces the fluids in the sump tanks into a propellant retention reservoir. This reservoir retains enough propellant to permit starting of the engine in zero gravity when the sump tanks are full without an ullage maneuver. The ullage maneuver is one in which reaction control engines are fired to give the spacecraft positive thrust and settle the propellant in the bottom of the tanks, thus assuring liquid flow through the feed lines.

The helium which pressurizes the propellant tanks is contained in two spherical tanks located in the center section of the SM just above the engine. Valves isolate the helium during non-thrusting periods and allow the gas into the tanks during thrusting periods. Helium pressure in the tanks is reduced by regulators in the pressure lines and then directed to the tanks through check valves. These valves permit the helium to flow into the tanks and prevent a reverse flow of propellant. Heat exchangers transfer heat from the propellant to the helium so that the gas and the propellant will be the same temperature in the tanks. Relief valves open to vent the gas if pressure in the tanks becomes too high.

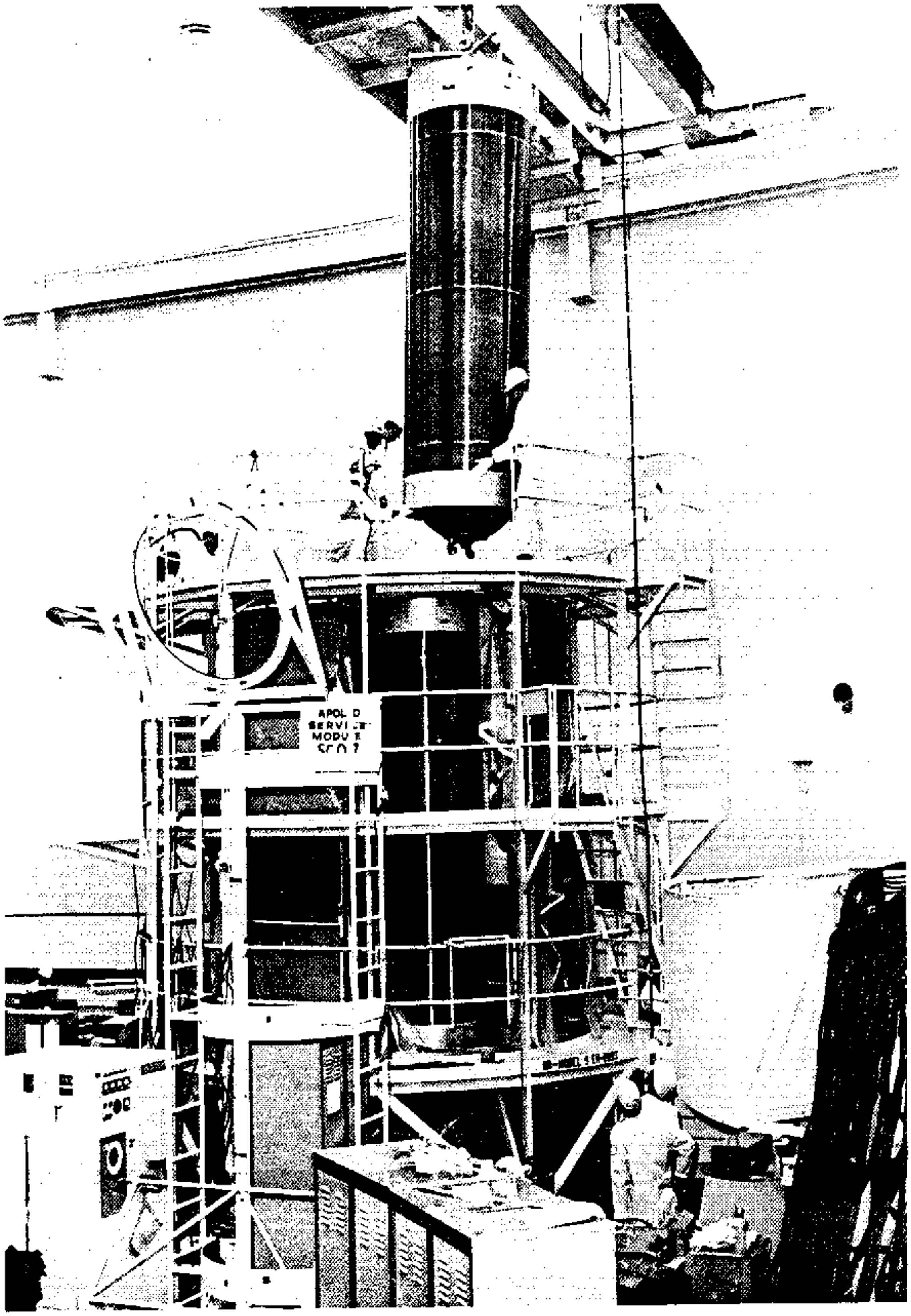


P-211 *Service propulsion engine*

Propellant quantity is measured by primary and secondary sensing systems that are completely independent. Accurate measurement is possible only during periods of thrusting.

EQUIPMENT

Rocket Engine (Aerojet-General Corp.) – The ablative combustion-chamber engine is mounted in the center section of the service module. It is conical shaped and gimballed. The engine and nozzle extension has an overall length of about 12 feet 10 inches and weighs about 650 pounds. The nozzle extension, made of columbium and titanium, is radiant-cooled, is more than 9 feet long, and has an exit diameter of about 7 feet. The engine has a nominal 20,500-pound thrust. Its service life is 750 seconds and can be fired for a minimum of 0.4 second. It can be restarted 50 times. Nitrogen tetroxide is the oxidizer. Fuel is a



P-212

Titanium fuel tank is installed in service module at Space Division's clean room, Downey, Calif.

blended hydrazine. The engine provides for velocity changes along the X axis of the spacecraft.

Helium Tanks – Two spherical pressure vessels are mounted in the center section of the service module. Each has an internal volume of 19.4 cubic feet. Maximum operating pressure is 4400 psia; normal pressure is 3600 psia. Aluminum alloy walls are 0.46 inch thick; tank diameter is 40 inches. The tanks store helium for pressurization of service propulsion system propellant tanks.

Oxidizer Tanks (General Motors Corp.'s Allison Division, Indianapolis, Ind.) – Two hemispherically domed cylindrical tanks located in sectors 2 and 5 of the service module. Tanks (one storage and one sump) are made of titanium. The storage tank is about 13 feet long with an inside diameter of 45 inches. The sump tank is slightly shorter, with an inside diameter of 51 inches. The wall thickness of both tanks is 0.054 inch. Internal volume of each tank is 175 cubic feet, and the nominal working pressure is 175 psia. Storage tank capacity is 11,285 pounds; sump tank is 13,924 pounds. The tanks store propellants during non-thrusting periods and supply propellants during thrusting.

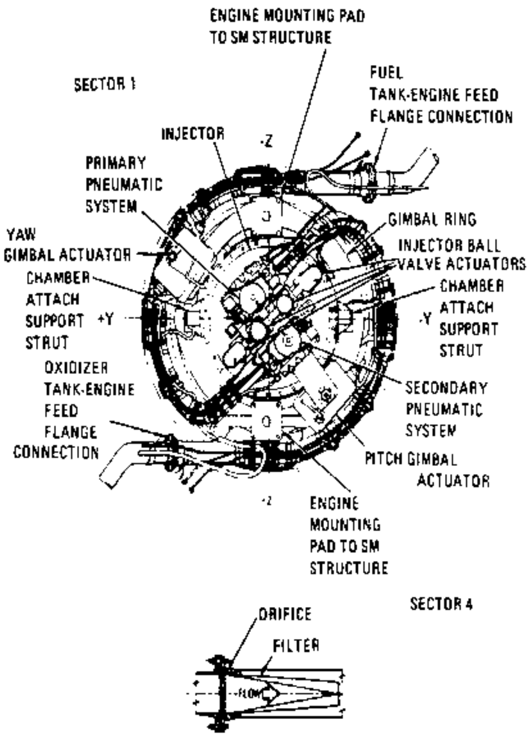
Quantity Sensing System (Simmonds Precision Products, Tarrytown, N.Y.) – Primary system consists of cylindrical capacitance probes 13 feet long located in the tanks. When the liquid level changes, the probe signals register on the command module displays. The auxiliary system consists of point sensors that send signals when a point sensor is uncovered. Oxidizer tank probes are 2-plate capacitance probes. Fuel tank probe is a Pyrex glass rod. The system operates only during thrusting by measuring liquid level by height.

DETAILED DESCRIPTION

Principal components of the service propulsion subsystem include the engine, the pressurization subsystem, the propellant subsystem, the propellant utilization and gauging subsystem, and the flight combustion stability monitor.

ENGINE

The engine is a non-throttleable rocket engine which burns hypergolic propellant to produce a thrust of 20,500 pounds in vacuum. It is 3 feet 5 inches long and is mounted in the center section of the service module. It has a nozzle extension 9 feet 4 inches long which extends out the aft (bottom) of the SM. The bell-shaped nozzle extension, which is made of columbium and titanium, has an exit diameter of 7 feet 10-1/2 inches and is cooled by radiation (dissipating its heat to space). Total weight of the engine is about 650 pounds.



P-213 *Top view of service propulsion engine*

The engine's combustion chamber is lined with an ablative (heat resistant) material which extends from the injector attachment pad to the nozzle extension. The ablative material consists of a liner, a layer of insulation, and metal attachment flanges for mounting the injector.

The engine injector is bolted to the ablative thrust chamber. Propellant is distributed through concentric annuli machined orifices in the injector assembly which are covered by concentric closeout rings. Alternate radial manifolds welded to the back of the injector body distribute propellant to the annuli. The injector is baffled to provide combustion stability.

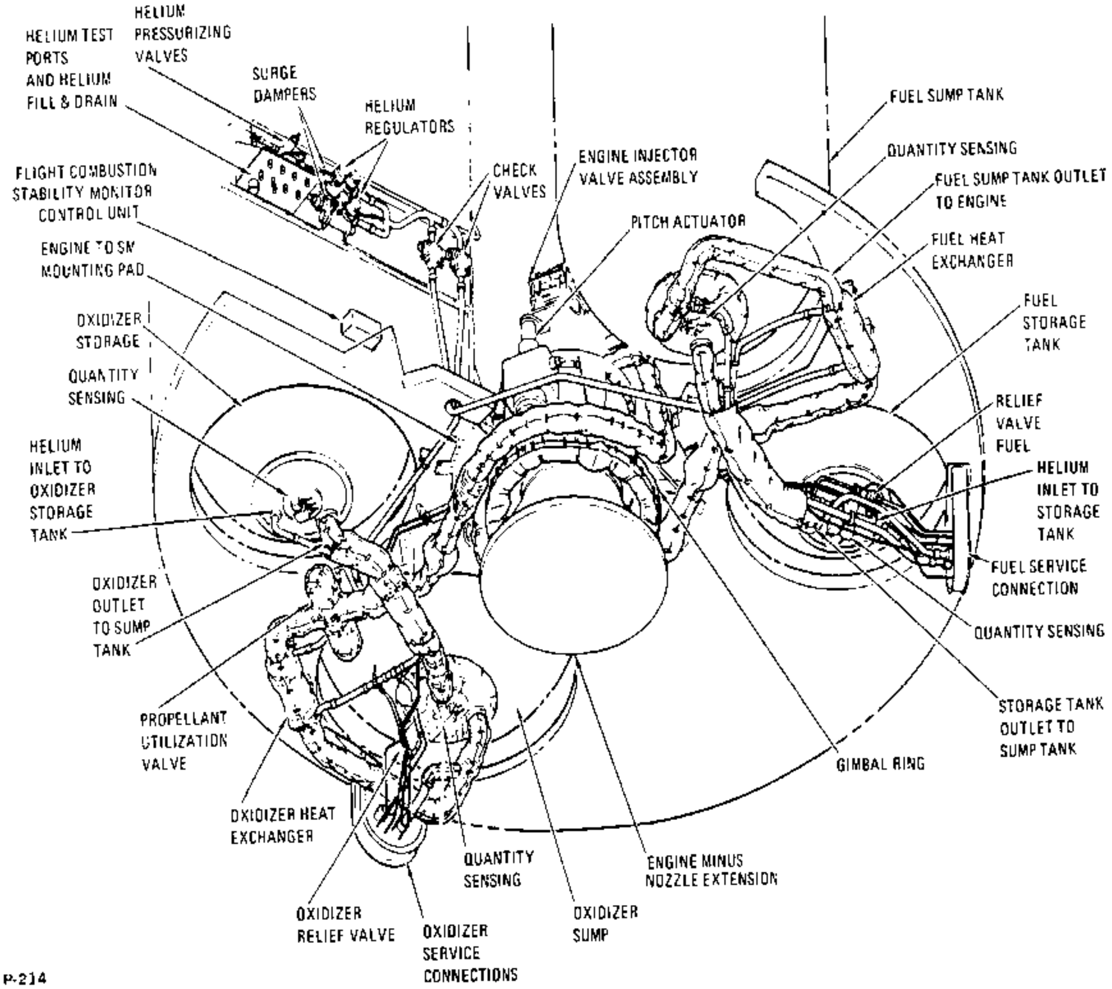
The engine has no ignitor, since the propellant is hypergolic. Fuel and oxidizer are injected into the combustion chamber when they impinge, atomize, and ignite. The engine can fire for nearly 8-1/2 minutes and can be restarted as many as 36 times.

The bipropellant valve assembly consists of two nitrogen pressure vessels, two injector prevalves, two nitrogen regulators, two nitrogen relief valves, four solenoid control valves, four actuators, and eight bipropellant ball valves.

The nitrogen tanks are mounted on the bipropellant valve assembly to supply pressure to the injector prevalves. One tank is in the primary pneumatic control system (A) and the other tank is in the secondary pneumatic control system (B). The tanks each contain 5.8 cubic inches on nitrogen – enough to operate the valves 43 times with an initial nominal pressure of 2500 psi.

The injector prevalves are two-position, solenoid-operated valves, one for each pneumatic control system, and identified as A and B. The valve is energized open and spring-loaded closed. The prevalves, when energized open, allow nitrogen supply tank pressure to be directed through the regulator into a relief valve and to a pair of solenoid control valves.

The single-stage regulator is installed in each pneumatic control system between the injector prevalves and the solenoid control valves. The regulator reduces the nitrogen pressure to 190-230 psi. The pressure relief valve is located downstream from the regulator to limit the pressure applied to the solenoid control valves in case a regulator malfunctions. The orifice between the injector prevalve and regulator restricts the flow of nitrogen and allows the relief valve to relieve the pressure overboard in the event the regulator malfunctions, preventing damage to the solenoid control valves and actuators.

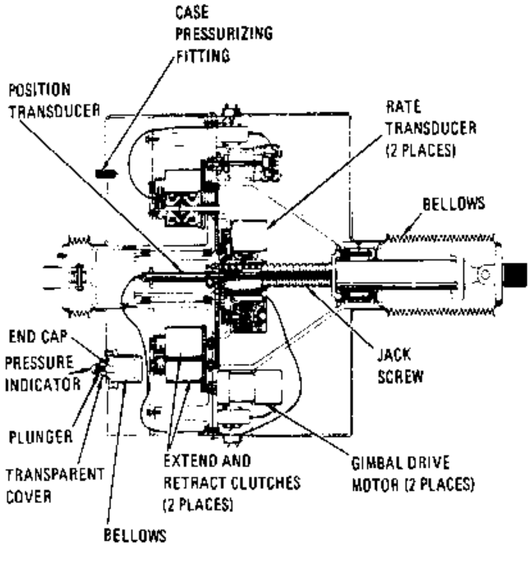


P-214

Aft view of service propulsion engine components and line insulation

Four solenoid-operated, three-way, two-position control valves are used for actuator control. Two solenoid control valves are located in each pneumatic control system. The solenoid control valves in the primary system are identified as 1 and 2 and the two in the secondary system are identified as 3 and 4. The solenoid control valves in the primary system control actuator and ball valves 1 and 2. The two solenoid control valves in the secondary system control actuator and ball valves 3 and 4.

Four piston-type, pneumatically operated actuators control the eight propellant ball valves. Each actuator piston is mechanically connected to a pair of propellant ball valves, one fuel and one oxidizer. When the solenoid control valves are opened, pneumatic pressure is applied to the opening side of the actuators. The spring pressure on the closing side is overcome and the actuator piston moves. Utilizing a rack and pinion gear, linear motion of the actuator connecting arm is converted into rotary motion, which opens the propellant ball valves. When the engine firing signal is removed from the solenoid control valves, the solenoid control valves close, removing the pneumatic pressure source from the opening side of the actuators. The actuator spring pressure then forces the actuator piston to move in the opposite direction, causing the propellant ball valves to close. The piston movement forces the remaining nitrogen on the opening side of the actuator back through the solenoid control valves where it is vented overboard.



P-215 *Engine gimbal actuator*

Each actuator contains a pair of linear position transducers. One supplies information on the position of the ball valve to the main display console and the other information to telemetry.

The eight propellant ball valves are used to distribute fuel and oxidizer to the engine injector assembly. Four linked pairs, each pair consisting of one fuel and one oxidizer ball valve, are controlled by single actuator, and arranged in a series-parallel configuration. The parallel redundancy assures the engine ignition; the series redundancy assures thrust termination. When nitrogen pressure is applied to the actuators, each propellant ball valve is rotated, aligning the ball to a position that allows propellant to flow to the engine injector assembly. The mechanical arrangement is such that the oxidizer ball valves maintain an 8-degree lead over the fuel ball valves upon opening, which results in smoother engine starting.

Check valves are installed in the vent port outlet of each of the four solenoid control valves, spring pressure vent port of the four actuators, and the ambient vent port of the two nitrogen pressure regulator assemblies to protect the seals of these components from the hard vacuum of space.

The thrust mount assembly consists of a gimbal ring, engine-to-vehicle mounting pads, and gimbal ring-to-combustion chamber assembly support struts. The thrust structure is capable of providing ±10 degrees inclination about the Z axis (yaw) and ±6 degrees about the Y axis (pitch).

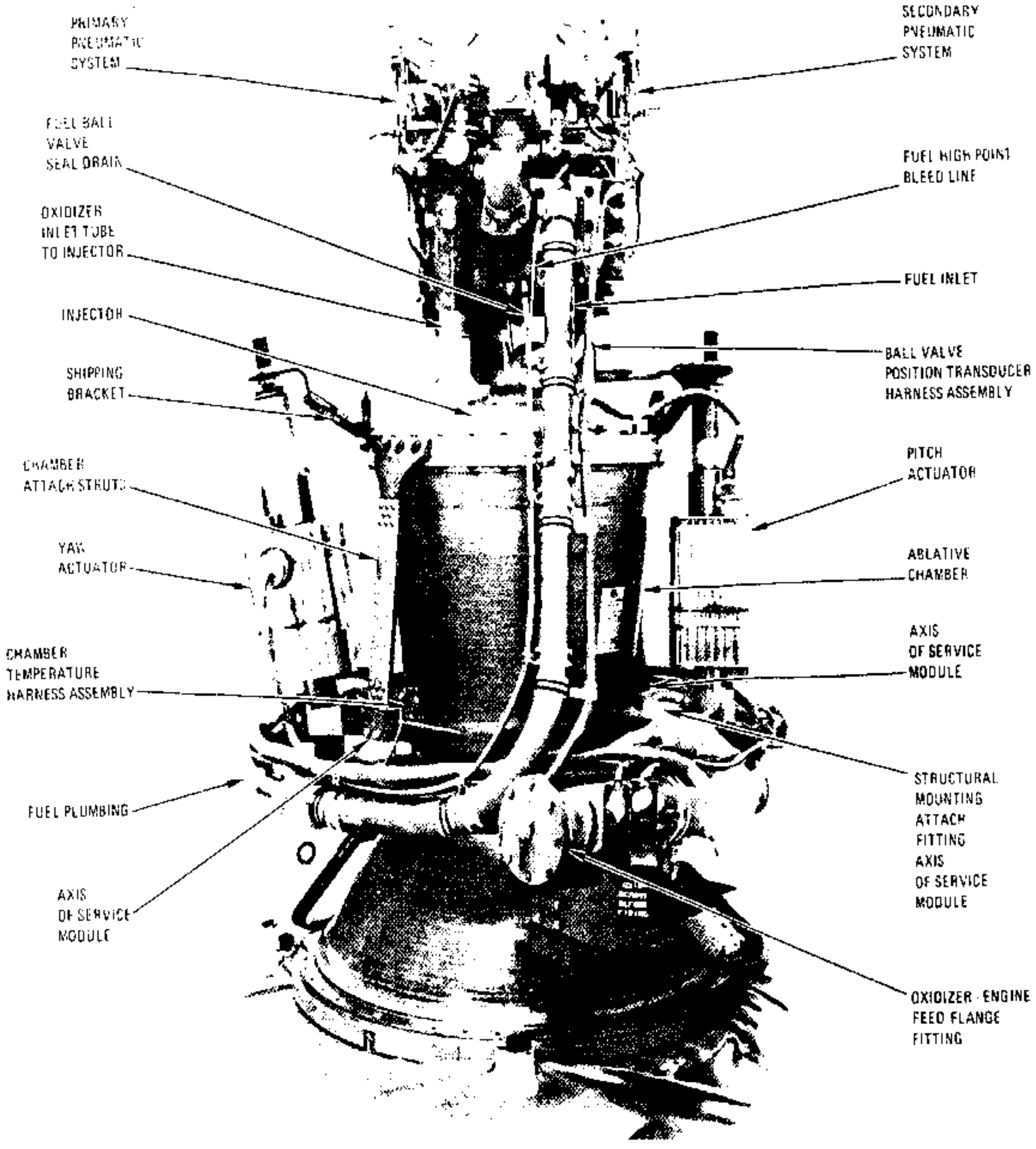
Thrust vector (direction of thrust) control of the service propulsion engine is achieved by dual, servo, electromechanical actuators. The gimbal actuators can provide control around the Z axis (yaw) of ±4.5 degrees in either direction from a +1-degree offset, and around the Y axis (pitch) of ±4.5 degrees in either direction from a -2-degree null offset. The reason for the offset is the offset center of mass of the SM.

Each actuator assembly consists of four electromagnetic particle clutches, two dc motors, a bull gear, jack-screw and ram, ball nut, two linear position transducers, and two velocity generators. The actuator assembly is a sealed unit and encloses those portions protruding from the main housing. One motor and a pair of clutches (extend and retract) in each actuator are identified as System 1 and the other as System 2.

An overcurrent relay in each primary and secondary gimbal motor is controlled by a switch on the main display console. Power from the battery bus is applied to the motor-driven switch within the overcurrent relay of the primary or secondary system. One of the motor switch contacts then supplies power from the main bus to the gimbal motor. When the switch is released, it spring-loads to the "on" position which activates the overcurrent sensing circuitry of the primary or secondary relay that monitors the current to the gimbal motor.

The overcurrent relay of the primary or secondary system is used to monitor current to the gimbal motor for variable current flow during the initial gimbal motor start and normal operation for main dc bus and gimbal motor protection.

Using No. 1 yaw system as an example, the operation of the current monitoring system follows this sequence: If the relay senses an overcurrent to gimbal motor No. 1, the monitor circuitry within

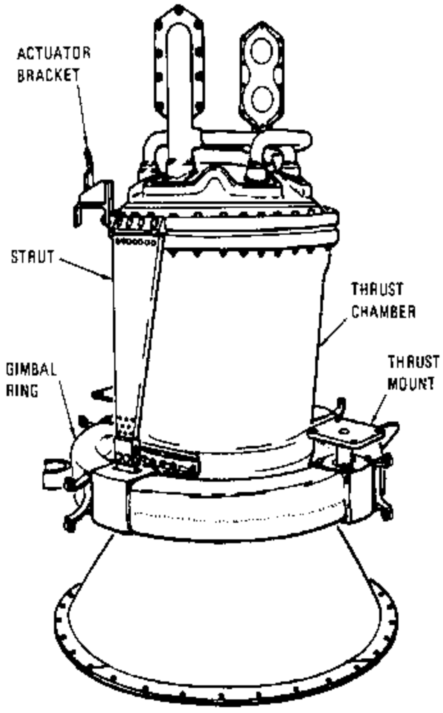


P-216

Service propulsion engine

the relay will drive the motor-driven switch, removing power from gimbal motor No. 1. Simultaneously a fail signal is sent from the relay to the stabilization and control subsystem which opens upper relay contacts to remove inputs from the No. 1 clutches and closes lower relay contacts to apply inputs to the No. 2 clutches within the same actuator. Simultaneously a signal is sent to illuminate a caution and warning light to indicate the primary gimbal motor has failed.

The crew would then switch on the No. 2 yaw system. This would apply power to the motor-driven switch from battery Bus B within the over-current relay of the secondaries. The motor switch then supplies power from Main Bus B through the motor switch contact to the secondary gimbal motor. When the secondary switch is released, it spring-loads to the "on" position which activates the overcurrent sensing circuitry for the secondary. If the relay senses an overcurrent to gimbal motor No. 2, the monitor circuitry within the relay will drive the motor-driven switch, removing power from the motor. There is no fail signal in this case; however, the yaw No. 2 caution and warning light will illuminate to inform of secondary gimbal motor failure. If the No. 2 system has failed due to an overcurrent, that specific actuator is inoperative if the No. 1 system has previously failed.



P-217 *Engine thrust chamber*

This switching procedure is controlled automatically when the gimbal drive switches are turned to automatic operation.

The clutches are of a magnetic-particle type. The gimbal motor drive gear meshes with the gear on the clutch housing. The gears on each clutch housing mesh and as a result, the clutch housings counter-rotate. The current input is applied to the electromagnet mounted to the rotating clutch housing from the stabilization and control subsystem, the CM computer, or the manual control. A quiescent current may be applied to the electromagnet of the extend and retract clutches, preventing any movement of the engine during the boost phase of the mission with the gimbal motors off. The gimbal motors will be turned on before jettisoning the launch escape tower to support the service propulsion subsystem abort after the launch escape tower has been jettisoned. It will be turned off again as soon as possible to reduce the heat increase that occurs due to the gimbal motor driving the clutch housing with quiescent current applied to the clutch.

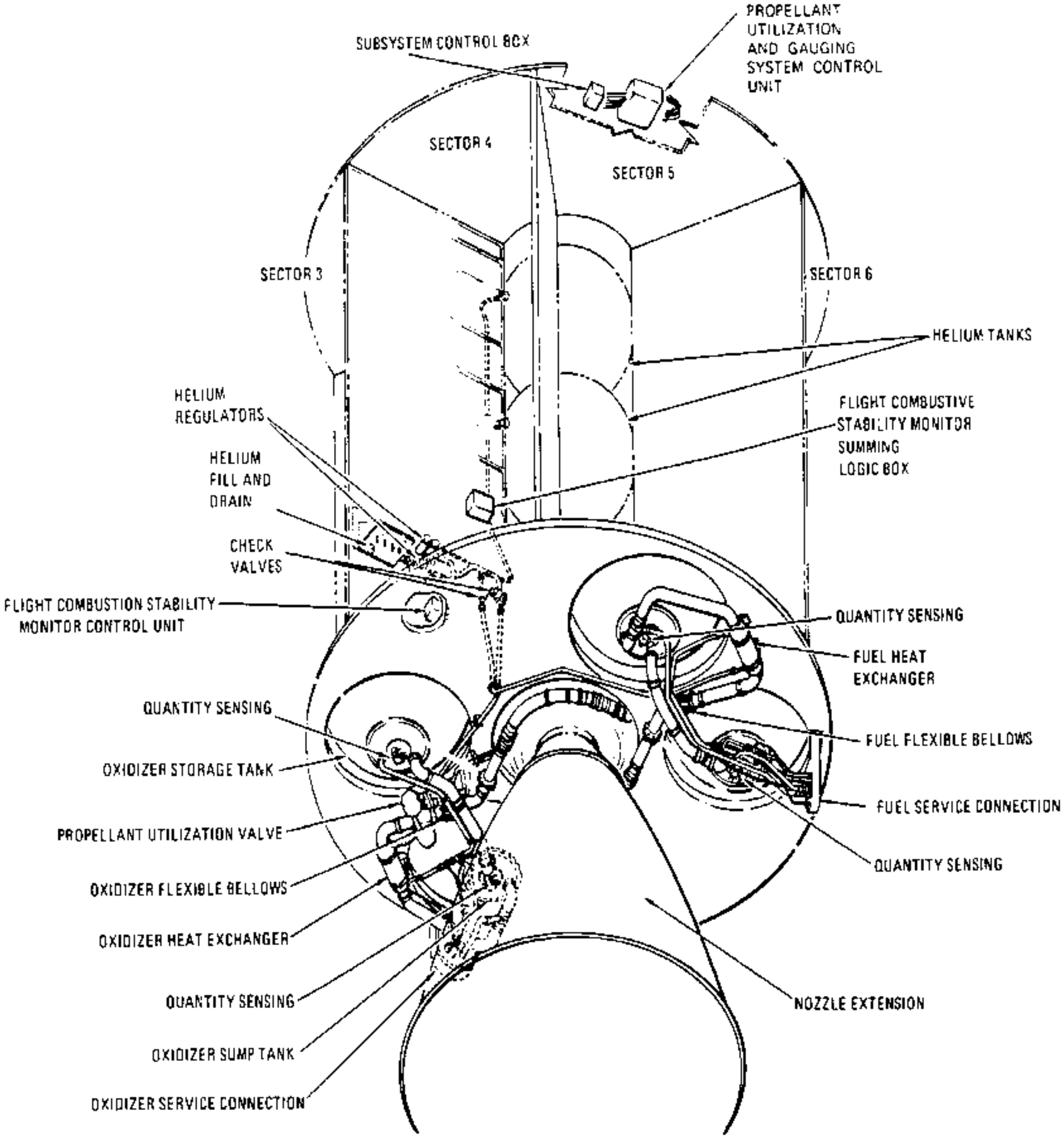
Before any stabilization and control subsystem or manual thrusting period the thumbwheels are set to position the engine. The thumbwheels are for backup; they do not position the engine. In any thrusting mode, the current input required for a gimbal angle change (to maintain the engine thrust vector through the center of mass) to the clutches will increase above the quiescent current. This increases the current into the electromagnets that are rotating with the clutch housings. The dry powder magnetic particles can become magnetized or demagnetized readily. The magnetic particles increase the friction force between the rotating housing and the flywheel, causing the flywheel to rotate. The flywheel arrangement is attached to the clutch output shaft allowing the clutch output shaft to drive the bull gear. The bull gear drives a ball nut which drives the actuator jackshaft to an extend or retract position, depending on which clutch housing electromagnet the current input is supplied to. The larger the excitation current, the higher the clutch shaft rotation rate.

Meshed with the ball nut pinion gear are two tachometer-type rate transducers. When the ball nut is rotated, the rate transducer supplies a feedback to the summing network of the thrust vector control logic to control the driving rates of the jackscrew (acting as a dynamic brake to prevent over- and undercorrecting). There is one rate transducer for each system.

The jackscrew contains two position transducers arranged for linear motion and connected to a single yoke. The position transducers are used to provide a feedback to the summing network and the CM displays. The operating system provides feedback to the summing network that reduces the output current to the clutch, resulting in proportional rate change to the desired gimbal angle position and a return to a quiescent current, in addition to providing a signal to the display. The remaining position transducer provides a feedback to the redundant summing network of the thrust vector logic for the redundant clutches, in addition to the display if the secondary system is the operating system.

A snubbing device provides a hard stop for an additional 1-degree travel beyond the normal gimbal limits.

Twelve electrical heaters are used in the engine propellant feed line brackets and bipropellant valve assemblies. The heaters are controlled by the crew and are used to keep the feedlines from getting too cold and freezing the propellant. Displays in the



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Location of service propulsion engine components crew compartment show the feedline temperature and swiches on the main display console control the heaters.

PRESSURIZATION SUBSYSTEM

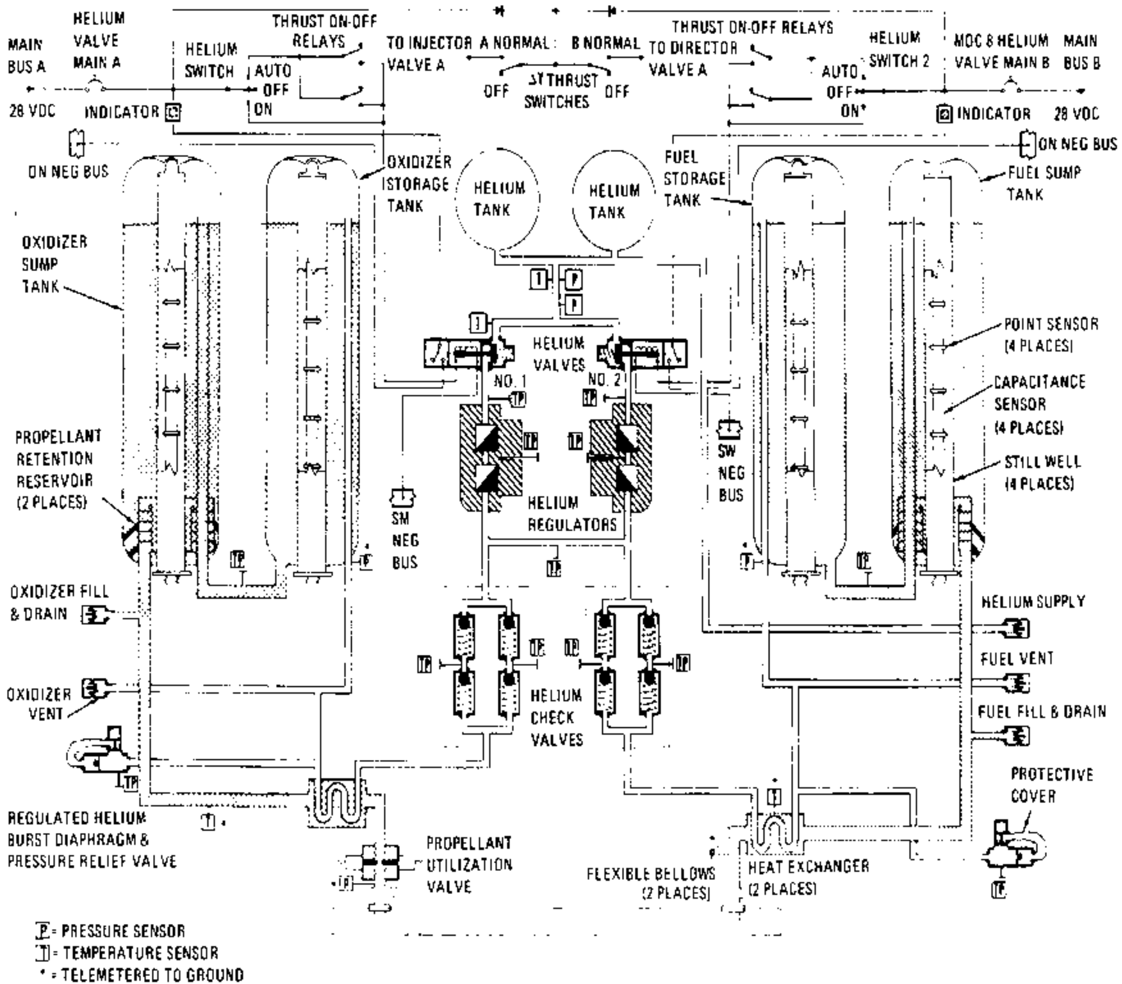
The pressurization subsystem consists of two helium tanks, two helium pressurization valves, two dual pressure regulator assemblies, two dual check valve assemblies, two pressure relief valves, and two heat exchangers. The critical components are redundant to increase reliability.

The two helium supply spherical pressure vessels contain 19.6 cubic feet of gas each, pressurized to 3600 psia. The tanks are located in the center section of the SM above the engine.

The helium valves are continuous-duty, solenoid-operated type. The valves are energized open and spring-loaded closed and can be controlled automatically or manually. An indicator above each valve control switch on the main display console shows the position of the valve. When the valves are closed, the indicator shows diagonal lines (the indication during non-thrusting periods). When the valves are open, the indicator shows gray (the indication during thrusting periods).

Pressure is regulated by an assembly downstream from each helium pressurizing valve. Each assembly contains a primary and secondary regulator in series, and a pressure surge damper and filter installed on the inlet to each regulating unit. These regulators reduce the pressure of the helium gas from 3600 psia to 186 psia nominal.

The primary regulator is normally the controlling regulator. The secondary regulator is normally open during a dynamic flow condition. The secondary



Schematic of service propulsion subsystem's propellant tank system regulator will not become the controlling regulator until the primary regulator allows a higher pressure than normal. All regulator pressures are in reference to a diaphragm assembly that is vented to ambient.

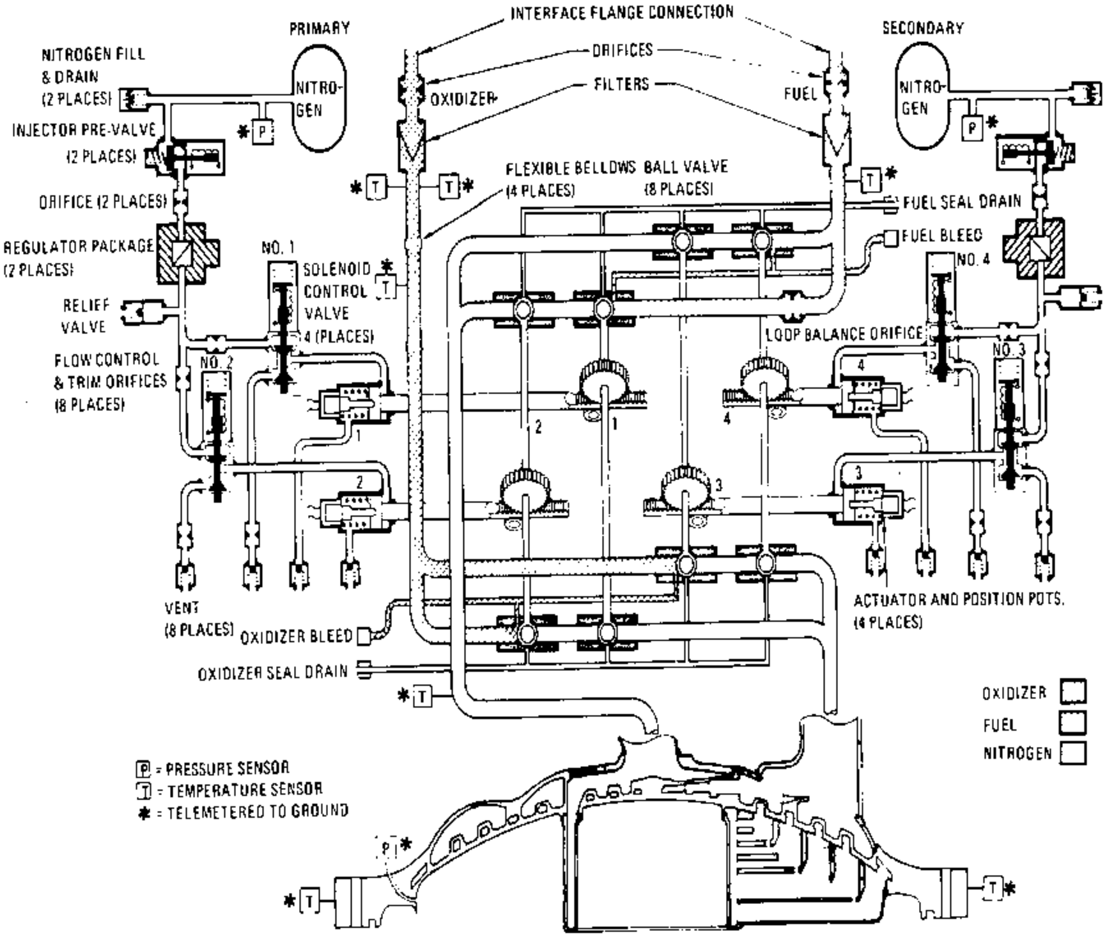
Only one of the parallel regulator assemblies regulates helium pressure under dynamic conditions. The downstream pressure causes the second assembly to lock up (close). When the regulated pressure decreases below the lockup pressure of the non-operating assembly, that assembly becomes operational.

Each assembly contains four independent check valves connected in a series-parallel configuration for added redundancy. The check valves prevent the reverse flow of propellant liquid or vapor and permit helium pressure to be directed to the propellant tanks.

The pressure relief valves consist of a relief valve, a diaphragm, and a filter. In the event that excessive helium or propellant vapor ruptures the diaphragm, the relief valve opens and vents the system. The relief valve will close and reseal after the excessive pressure has returned to the operating level. The diaphragm provides a more positive seal of helium than a relief valve. The filter prevents any fragments from the diaphragm from entering onto the relief valve seat. The relief valve opens at a pressure of 212 psi after the diaphragm ruptures at about 213 psi. The valve will close when pressure drops to 208 psi.

A pressure bleed device is incorporated between the diaphragm and relief valve. The bleed valve vents the cavity between the diaphragm and relief valve in the event of any leakage from the diaphragm. The bleed device is normally open and will close when the pressure increases to 150 psi.

The line-mounted, counterflow heat exchangers consist of the helium pressurization line coiled



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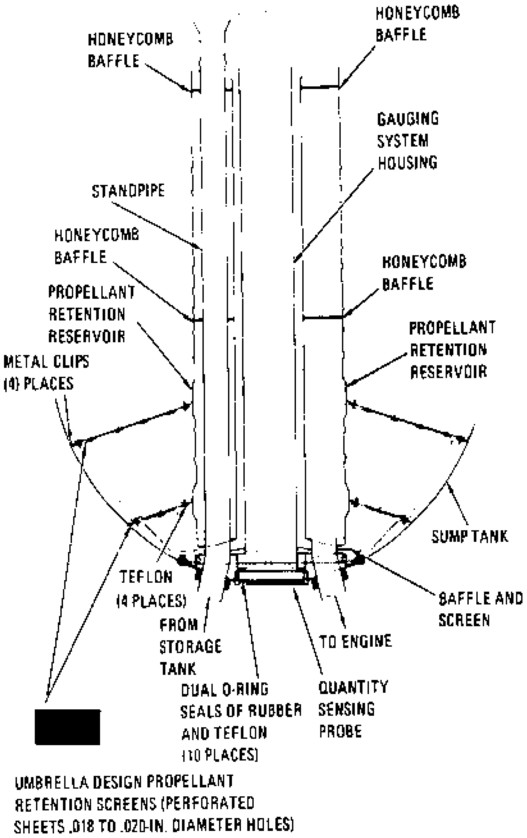
Schematic of service propulsion subsystem engine propellant feed within an enlarged section of the propellant supply line. The helium gas, flowing through the coiled line, absorbs heat from the propellant and approaches the same temperature when it gets to the tanks.

PROPELLANT SUBSYSTEM

This subsystem consists of two fuel tanks (storage and sump), two oxidizer tanks (storage and sump), and propellant feed lines.

The propellant supply is contained in four hemispherical-domed cylindrical tanks constructed of titanium. The tanks each occupy a different sector of the service module. The storage tanks are pressurized by helium. An outlet transfers the propellant and helium from the storage tanks through transfer lines to the sump tanks. Standpipes in the sump tanks allow the propellant and helium from the storage tanks to pressurize the sump tanks. The propellant in the sump tanks flows through an umbrella screen assembly; into a retention reservoir, to the outlet, and to the engine.



P-221 *Propellant retention reservoir*

The umbrella-shaped screen assembly and retention reservoir are installed in the exit end of the sump tanks. The reservoir retains a quantity of propellant at the tank outlet and in the engine plumbing during zero gravity. Normal engine ignition when the sump tanks are full is accomplished without an ullage maneuver. For all other conditions, an ullage maneuver is performed before engine ignition to assure that gas is not trapped below the screens.

The propellant feed lines contain flexible bellows assemblies to align the tank feed plumbing to the engine plumbing.

PROPELLANT UTILIZATION AND GAUGING SUBSYSTEM

The subsystem consists of a primary and auxiliary sensing system, a propellant utilization valve, a control unit, and a display unit.

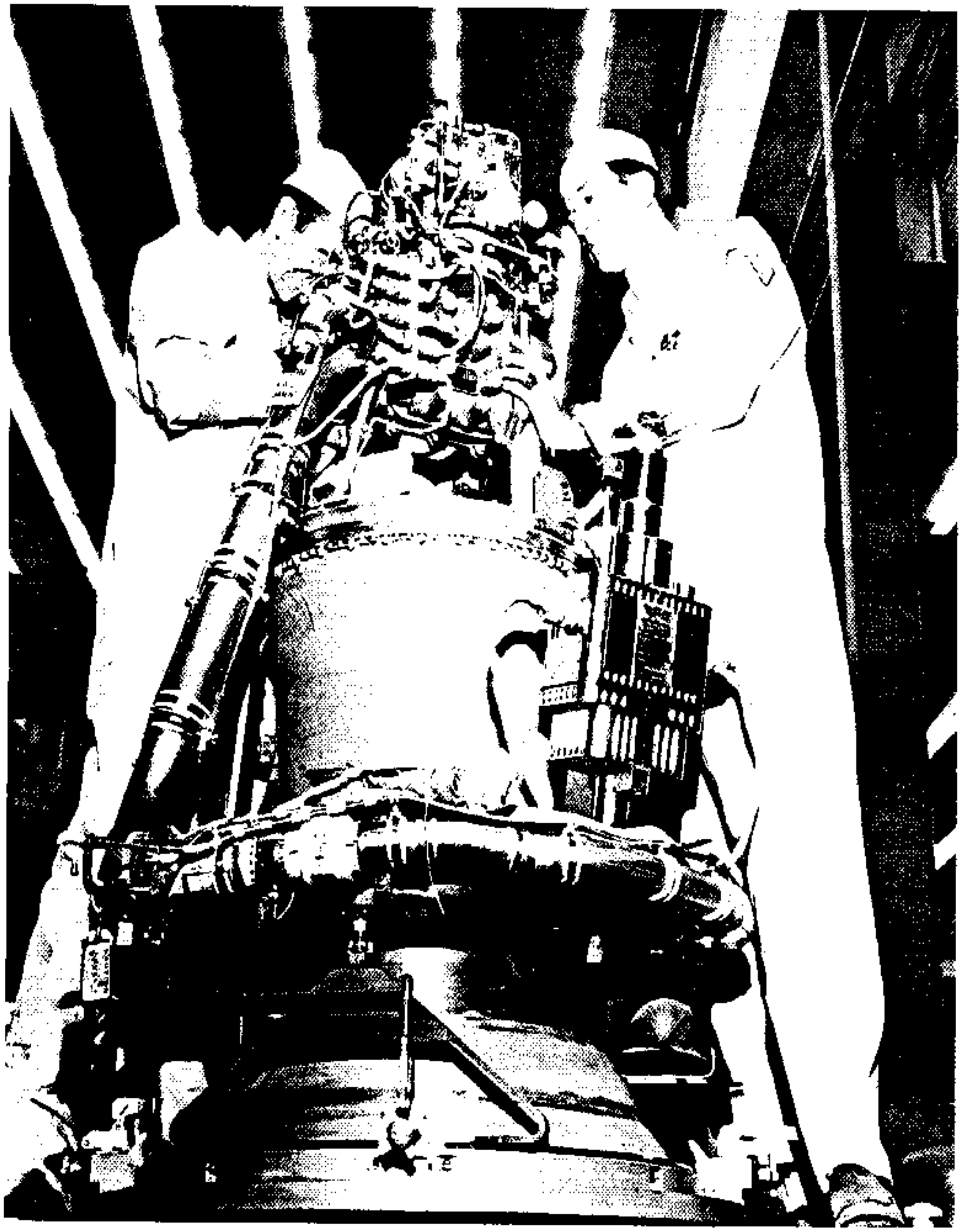
Propellant quantity is measured by two separate sensing systems: primary and auxiliary. The primary quantity sensors are cylindrical capacitance probes mounted the length of each tank. In the oxidizer tanks, the probes consist of a pair of concentric electrodes with oxidizer used as the dielectric. In the fuel tanks, a Pyrex glass probe, coated with silver on the inside, is used as one conductor of the capacitor. Fuel on the outside of the probe is the other conductor. The Pyrex glass forms the dielectric. The auxiliary system utilizes point sensors mounted at intervals along the primary probes to provide a step function impedance change when the liquid level passes their location.

Propellant is measured by the primary system through the probe's capacitance, a function of propellant height.

The auxiliary propellant measurement system uses seven point sensors in the storage tanks and eight in the sump tanks. The point sensors consist of concentric metal rings which present a variable impedance depending on whether they are covered or uncovered by the propellants remaining and are integrated by a rate flow generator which integrates the servos at a rate proportional to the nominal flow rate of the fuel and oxidizer. A mode selector senses when the propellant crosses a sensor and changes the auxiliary servos from the flow rate generator mode to the position mode. The system moves to the location specified by the digital-to-analog converter for 0.9 second to correct for any difference. The system then returns to the flow rate enerator mode until the next point sensor is reached. A non-sequential pattern detector detects false or faulty sensor signals. If a sensor has failed, the information from that sensor is blocked from the system, preventing disruption of system computation.

Propellant flow rate is converted in a quantity measurement and transmitted to displays on the main display console and to telemetry. These displays are updated during thrusting as point sensors are uncovered. Any deviation from the nominal oxidizer to fuel ratio (1.6:1 by mass) is displayed by the "unbalance" indicator in pounds. The indicator is marked to identify the required change in oxidizer flow rate to correct any unbalance condition.

When the sensor switches are set normally, the output of both sensor systems is continually compared in the comparator network. If a differential of 3 ±1 percent occurs between total primary and total auxiliary fuel or oxidizer, a caution and warning indicator is illuminated. The output of the oxidizer sump tank servoamplifier and the primary



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Service propulsion engine is prepared for installation in service module potentiometer of the unbalance indicator are compared in the comparator network and if a nominal 600 pounds or a critical unbalance is reached, a caution and warning light is illuminated

When the primary or auxiliary sensor system is selected on the switch, the output of the oxidizer sump tank servoamplifier and the output the primary or auxiliary potentiometer (whichever system is selected) in the unbalance meter are compared in the comparator network and if a nominal 600 pounds or a critical unbalance is reached, the caution and warning light is illuminated.

Once the warning light is illuminated, the crew can determine whether there is a malfunction within the quantity and indicating systems or if there is a true unbalance condition existing by use of a self-test portion of the system.

If an unbalance condition exists, the crew will use the propellant utilization valve to return the propellants to a balanced condition. The propellant utilization valve housing contains two sliding gate valves within the housing. One of the sliding gate valves is primary, and the other is secondary. Stops are provided in the valve housing for the full increase or decrease portions of the primary and secondary sliding gate valves.

The secondary propellant utilization valve has twice the travel of the primary propellant utilization valve to compensate for primary propellant utilization valve failure in any position. The propellant utilization valve controls are on the main display console.

FLIGHT COMBUSTION STABILITY MONITOR

The flight combustion stability monitor accelerometers are mounted to the SPS engine injector to monitor the engine for vibration buildup characteristic of combustion instability.

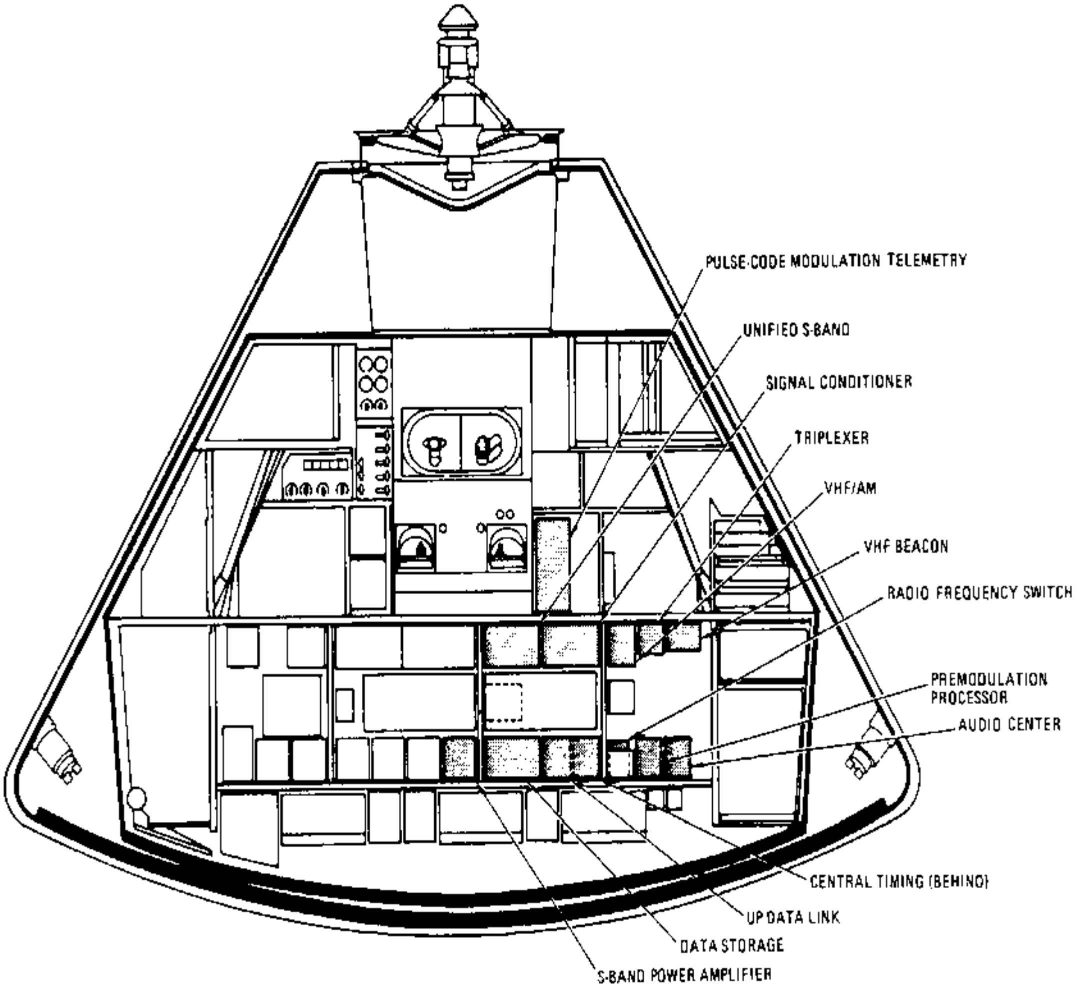
Three accelerometers in the monitor package provide signals to a box assembly which amplifies them. When the vibration level exceeds 180 ±18 g's peak-to-peak for 70 ±20 milliseconds, a level detector triggers a power switch which sends power to the summing logic.

The summing logic will trip if there are two or more rough combustion signals received; the normally closed contacts will open removing power from the inverter in the thrust logic and shutting down the engine. At the same time, a caution and warning light will illuminate. The engine would not shut down in the manual thrust mode.

Trigger circuits in the flight combustion stability monitor provide power to the voting logic relay coils continuously once unstable combustion is sensed. During CM computer or stabilization and control subsystem thrust, power is still applied to the voting logic relays even though the engine is shut down and combustion instability no longer can be sensed.

The flight combustion stability monitor can be reset after triggering engine shutdown, and it also can be bypassed by the crew so that it will not automatically shut down the engine.

TELECOMMUNICATIONS



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Location of main telecommunications equipment

The telecommunications subsystem provides voice, television, telemetry, and tracking and ranging communications between the spacecraft and earth, between the CM and LM, and between the spacecraft and astronauts wearing the portable life support system. It also provides communications among the astronauts in the spacecraft and includes the central timing equipment for synchronization of other equipment and correlation of telemetry equipment.

For convenience, the telecommunications subsystem can be divided into four areas: intercommunications (voice), data, radio frequency equipment, and antennas. Most of the components of the telecommunications subsystem are produced by the Collins Radio Co., Cedar Rapids, Iowa.

INTERCOMMUNICATIONS

The astronauts headsets are used for all voice communications. Each headset has two independently operated earphones and two microphones with self-contained pre-amplifiers. Each astronaut has an audio control panel on the main display console which enables him to control what comes into his headset and where he will send his voice. The headsets are connected to the audio panels by separate umbilical cables. These cables also contain wiring for the biomedical sensors in the constant-wear garment.

The three headsets and audio control panels are connected to three identical audio center modules.