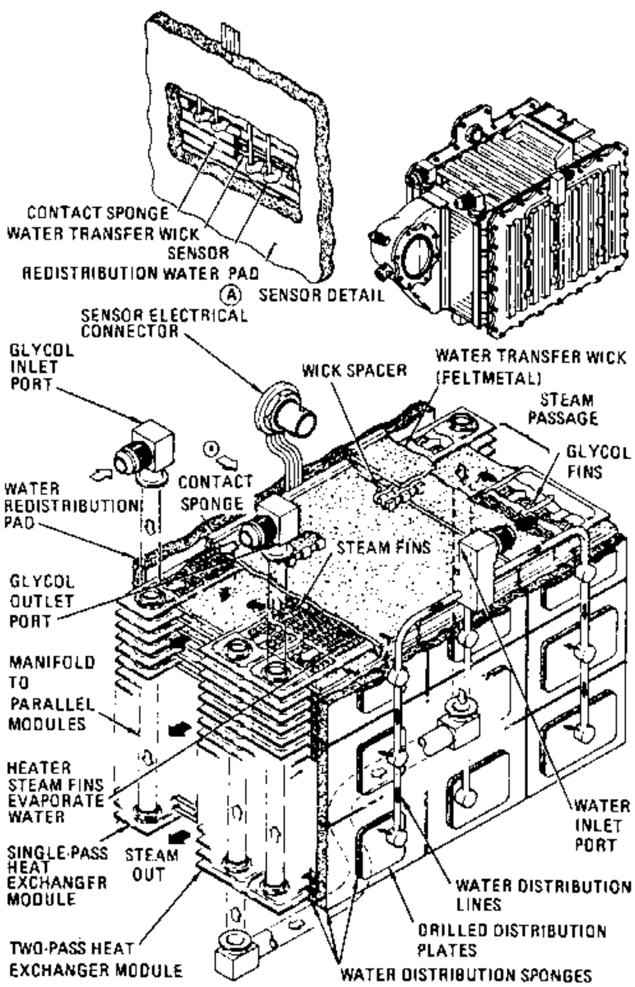
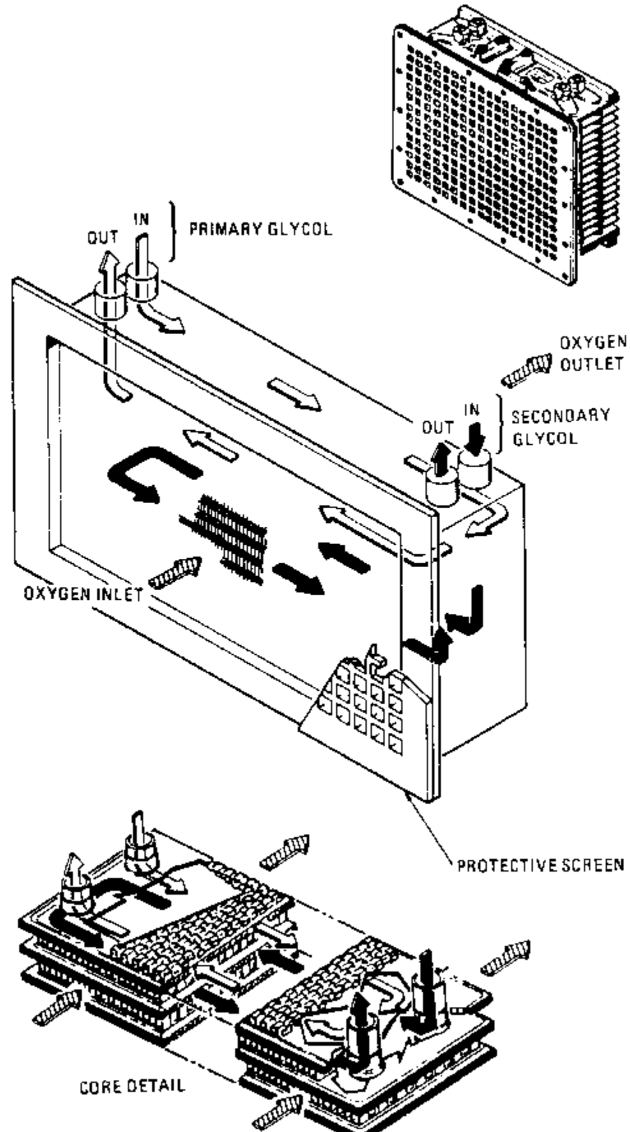
extremes in environments mean large differences in panel efficiencies and outlet temperatures. The panel facing deep space can reject more heat than the panel receiving external radiation; therefore, the overall efficiency of the subsystem can be improved by increasing the flow to the cold panel. The higher flow rate reduces the transit time of the coolant through the radiator, which decreases the quantity of heat radiated.

The flow through the radiators is controlled by a flow-proportioning valve. When the differential temperature between the outlets of the two panels exceeds 10°F, the flow-proportioning valve is positioned to increase the flow to the colder panel.

The flow-proportioning valve assembly contains two individually controlled valves, only one of which can be in operation. When the switches are




P-182 *Glycol evaporator*




P-183 *Cabin heat exchanger*

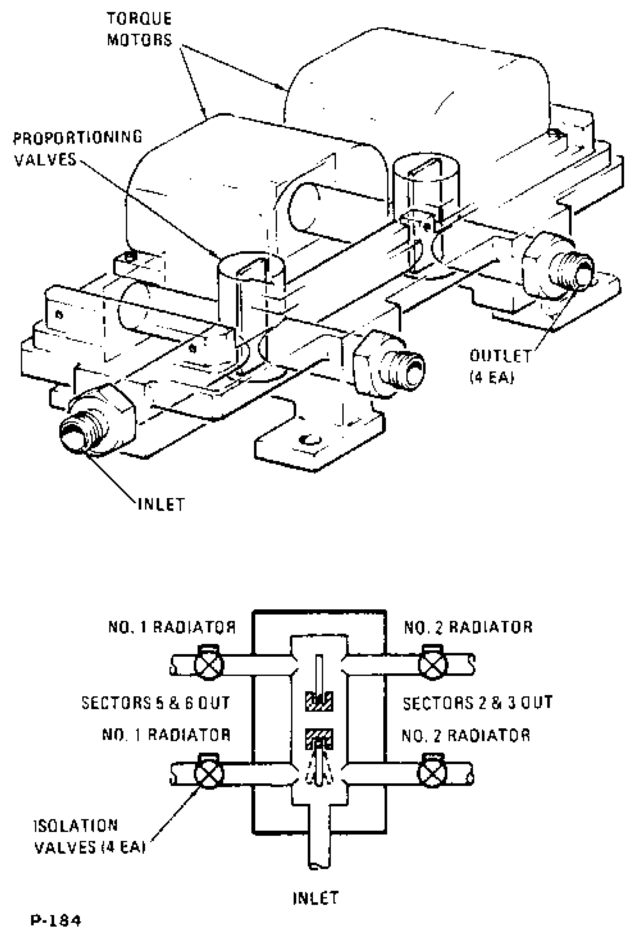
on automatic the flow controller selects the No. 1 valve and positions the appropriate radiator isolation valves. Manual selection and transfer also is possible. Automatic transfer will occur when the temperature differential exceeds 15°F, providing a failure has occurred. In the absence of a failure, the transfer signal will be inhibited. In situations where the radiator inlet temperature is low and the panels have a favorable environment for heat rejection, the radiator outlet temperature starts to decrease and thus the bypass ratio starts to increase. As more flow is bypassed, the radiator outlet temperature decreases until the -20°F minimum desired temperature would be exceeded. To prevent this from occurring, a heater is automatically turned on when radiator mixed outlet temperature drops to -15°F and remains on until -10°F is reached. The controller provides only on-off heater control which results in a nominal 450 watts being added to the coolant each time the heater is energized. The crew can switch to a redundant heater system if the temperature decreases to -20°F.

If the radiator outlet temperature falls below the desired minimum, the effective radiator surface temperature will be controlled passively by the selective stagnation method. The two primary circuits are identical, consisting of five tubes in parallel and one downstream series tube. The two panels, as explained in the flow proportioning control system, are in parallel with respect to each other. The five parallel tubes of each panel have manifolds sized to provide specific flow rate ratios in the tubes, numbered 1 through 5. Tube 5 has a lower flow rate than Tube 4, and so on, through Tube 1 which has the highest flow. For equal fin areas, therefore, the tube with the lower flow rate will have a lower coolant temperature. During minimum CM heat loads, stagnation begins to occur in Tube 5 as its temperature decreases; for as its temperature decreases, the fluid resistance increases, and the flow rate decreases. As the fin area around Tube 5 gets colder, it draws heat from Tube 4 and the same process occurs with Tube 4. In a fully stagnated condition, there is essentially no flow in Tubes 3, 4, and 5, and some flow in Tubes 1 and 2, with most of it in Tube 1.

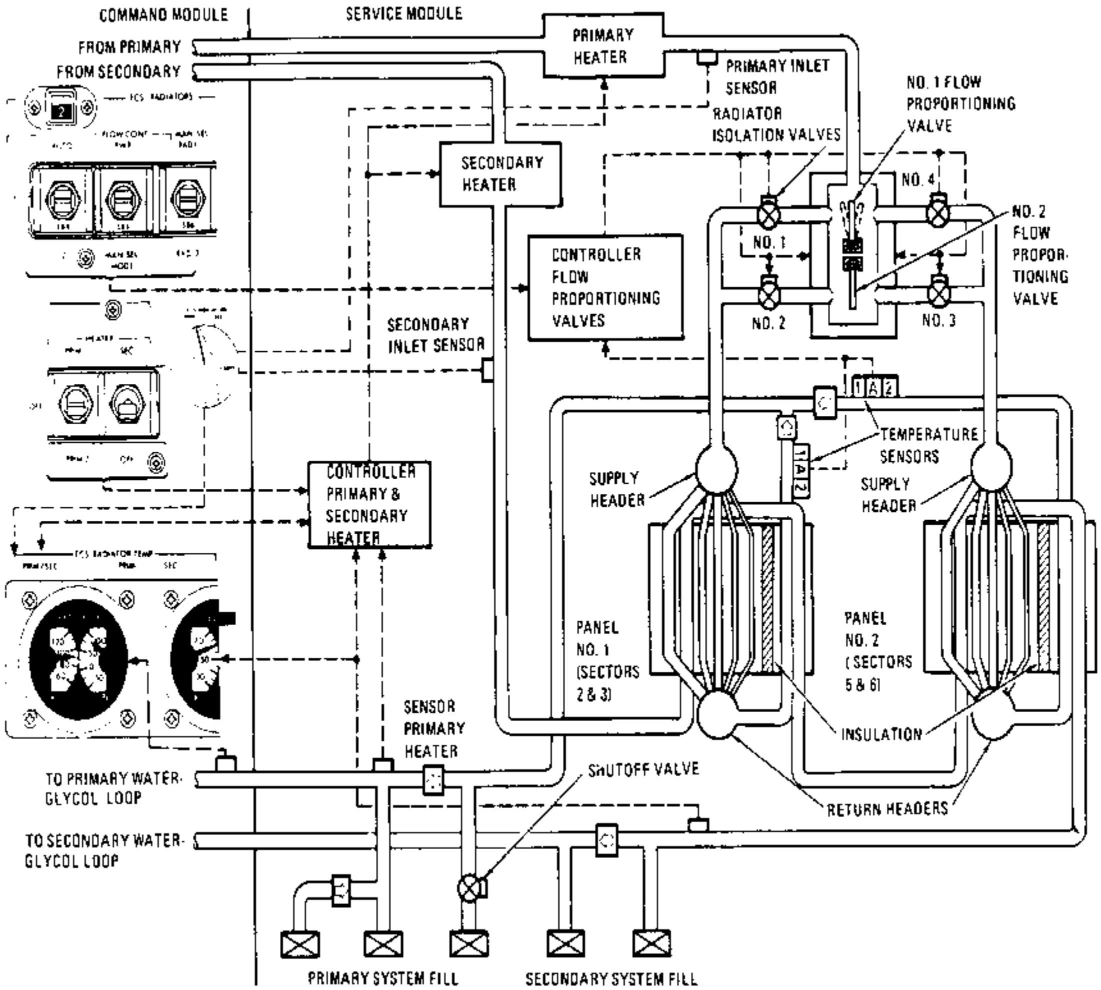
When the CM heat load increases and the radiator inlet starts to increase, the temperature in Tube 1 increases and more heat is transferred through the fin toward Tube 2. At the same time, the glycol evaporator temperature valve starts to close and force more coolant to the radiators, thus helping to thaw the stagnant portion of the panels. As Tube 2 starts to get warmer and receives more flow it in turn starts to thaw Tube 3, and so on. This combination of higher inlet temperatures and higher flow rates quickly thaws out the panel. The panels automatically provide a high effectiveness (completely thawed panels operating at a high average fin temperature) at high heat loads, and a low effectiveness (stagnated panels operating at a low average fin temperature) at low heat loads.

The secondary radiator consists of four tubes which are an integral part of the radiator panel structure. Each tube is purposely placed close to the hottest primary radiator tubes (i.e., Tube 1 and the downstream series tube on each panel) to keep the water-glycol in the secondary tubes from freezing while the secondary circuit is inoperative. The selective stagnation principle is not utilized in the secondary radiator because of the narrower heat load range requirements. This is also the reason the secondary radiator is a series loop. Because of the lack of this passive control mechanism, the secondary circuit depends on the heater control system at low heat loads and the evaporator at high heat loads for control of the water-glycol temperature.

The secondary heaters differ from the primary in that they can be operated simultaneously. When the secondary outlet temperature reaches 43°F the No. 1 heater comes on, and at 42°F the No. 2 heater comes on; at 44°F No. 2 goes off, and at 45°F No. 1 goes off.




*Space radiator flow proportioning valves*




*Schematic of radiator subsystem*

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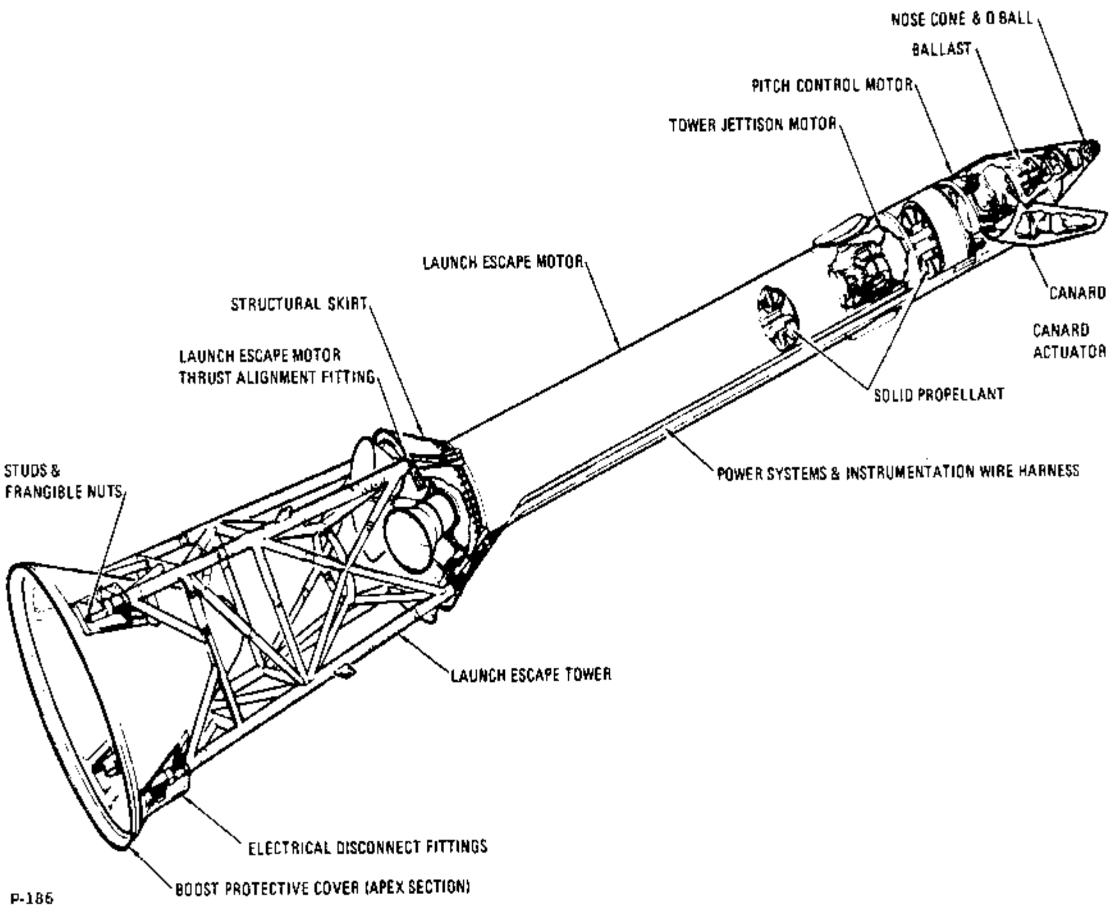
# LAUNCH ESCAPE




*Launch escape subsystem*

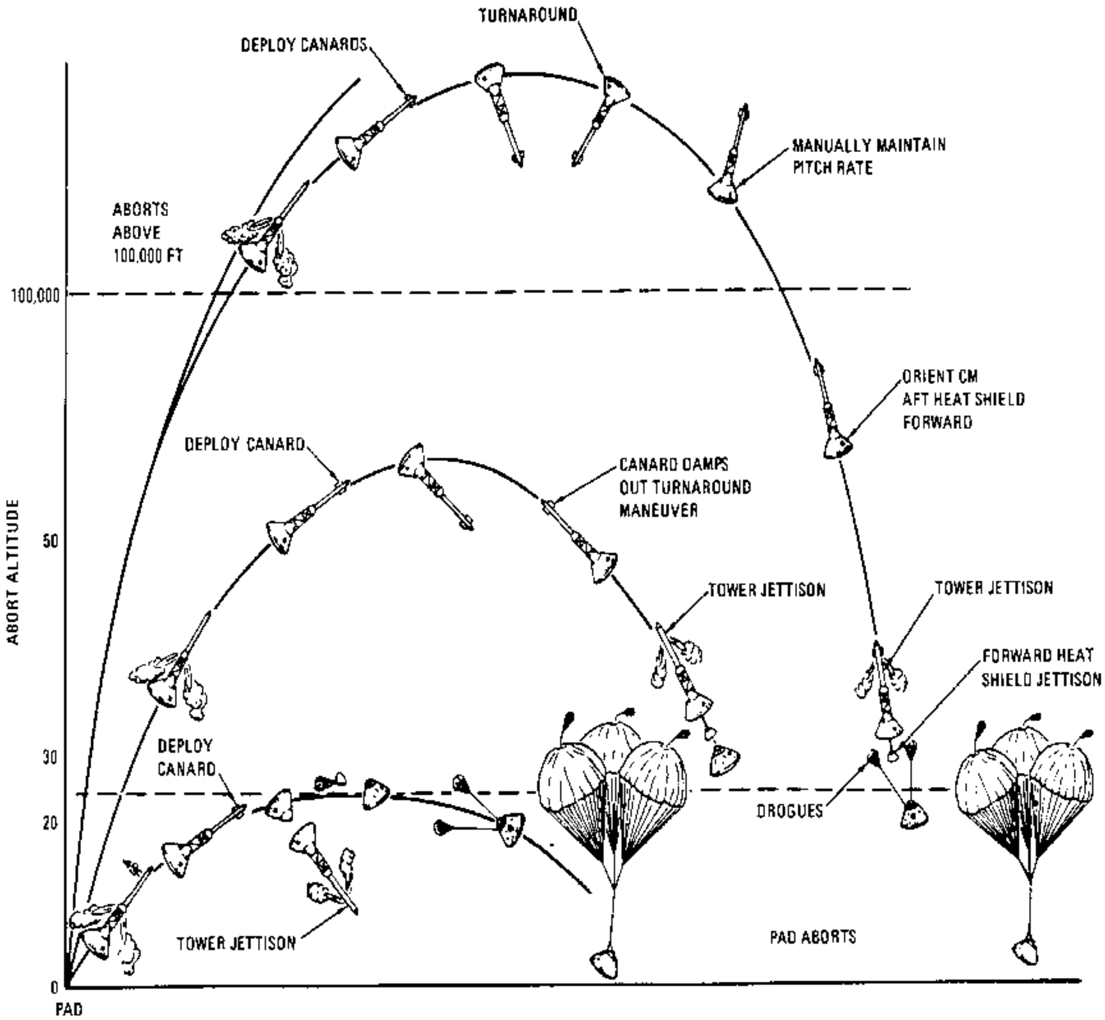
The launch escape subsystem will take the command module containing the astronauts away from the launch vehicle in case of an emergency on the pad or shortly after launch. The subsystem carries the CM to a sufficient height and to the side, away from the launch vehicle, so that the earth landing subsystem can operate.

The subsystem looks like a large rocket connected to the command module by a lattice-work tower. It is 33 feet long and weighs about 8,000 pounds. The maximum diameter of the launch escape assembly is four feet.

The forward or rocket section of the subsystem is cylindrical and houses three solid-propellant rocket motors and a ballast compartment topped by a nose cone containing instruments. The tower is made of titanium tubes attached at the top to a structural skirt that covers the rocket exhaust nozzles and at the bottom to the command module by means of an explosive connection.

A boost protective cover is attached to the tower and completely covers the command module. This cover protects the command module from the rocket exhaust and also from the heating generated by launch vehicle boost through the atmosphere. It remains attached to the tower and is carried away when the launch escape assembly is jettisoned.

The subsystem is activated automatically by the emergency detection system in the first 100 seconds or manually by the astronauts at any time from the pad to jettison altitude. With the Saturn V, the subsystem is jettisoned at about 295,000 feet, or about 30 seconds after ignition of the second stage; with the Saturn IB, the subsystem is jettisoned at about 275,000 feet, about 20 seconds after second stage ignition.

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*How launch escape subsystem operates at different altitudes*

After receiving an abort signal, the booster is cut off (after 40 seconds of flight), the CM-SM separation charges fired, and the launch escape motor ignited. The launch escape motor lifts the CM and the pitch control motor (used only at low altitudes) directs the flight path off to the side.

Two canards (wing-like surfaces at the top of the structure) are deployed 11 seconds after the abort is started. The aerodynamic forces acting on the canard surfaces turn the CM so that its blunt end is forward. Three seconds later on extreme low-altitude aborts, or at approximately 24,000 feet on high-altitude aborts, the tower separation devices are fired and the jettison motor is started. These actions carry the launch escape subsystem assembly away from the CM's landing trajectory. Four-tenths of a second after tower jettisoning the CM's earth landing subsystem is activated and begins its sequence of operations to bring the module down safely.

During a successful launch the launch escape structure is jettisoned by the astronauts at the prescribed altitude. If an abort is necessary after the launch escape assembly has been jettisoned, it is performed with the service propulsion engine in the service module. In that case, the initiation of abort automatically separates the launch vehicle from the spacecraft, the service module reaction control engines fire in an ullage maneuver (which settles fuel and oxidizer so that they will flow properly to the engine), and the service propulsion engine ignites to thrust the spacecraft away from the launch vehicle.

The emergency detection system operates from the time of umbilical separation until 100 seconds after liftoff. It is designed to detect emergency conditions of the launch vehicle, display the information to the astronauts, and, if the system is on automatic, start an abort. Under certain conditions (excessive vehicle rates or two booster engines out), the system initiates an abort signal. This signal resets the event timer, activates the launch escape subsystem, and (after 30 to 40 seconds of flight) cuts off the launch vehicle engines. A "lockout" system prevents the emergency detection system from operating before liftoff.

A manual abort can be initiated before or during launch by the commander's translation control located on the arm of his couch. In an abort from the pad, the launch escape subsystem will carry the command module to a height of about 4,000 feet before it is jettisoned.

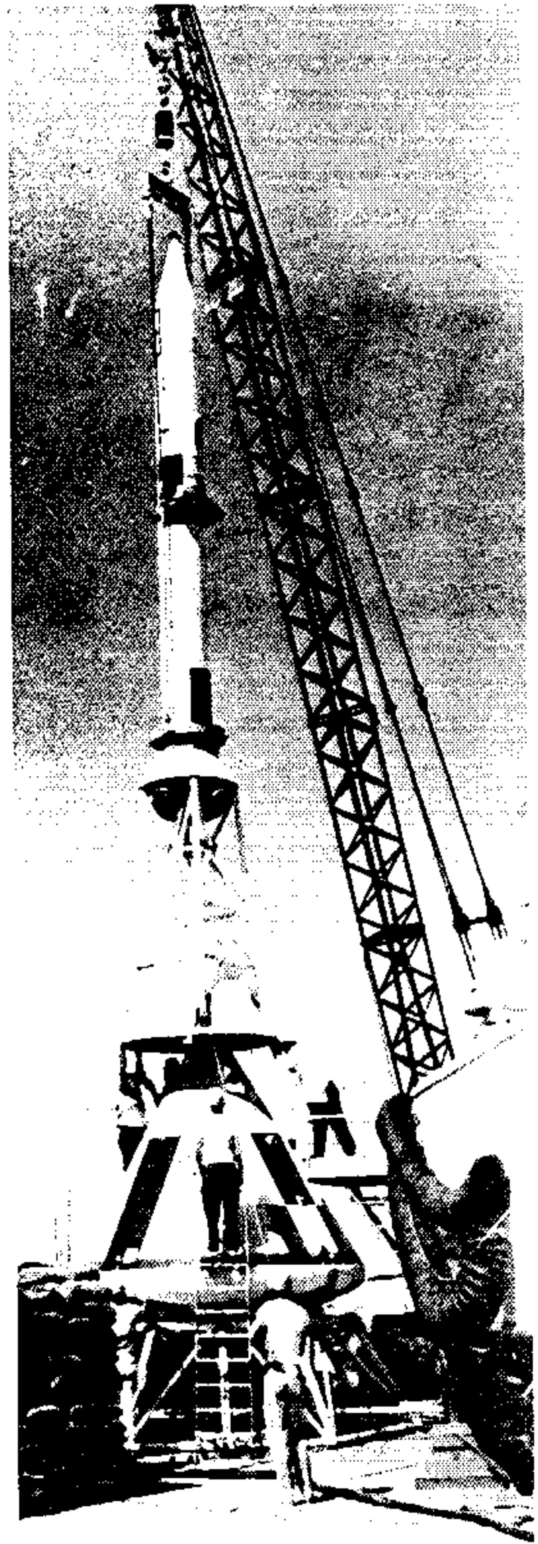
The nose cone of the launch escape assembly contains an instrument package called the Q-ball. The Q-ball has eight static ports (openings) through which pressure changes are measured. The instruments use this information to determine aerodynamic incidence angle and dynamic pressure data. The instruments send information on the angle of attack to an indicator of the CM's main display console and to the launch vehicle guidance.

The canards are two deployable surfaces and operating mechanisms which are faired (attached in a smooth line) into the outer skin of the launch escape assembly just below the nose cone. The operating mechanism is inside the structure. Each canard is mounted on two hinges and is deployed by a gas-operated actuator. Eleven seconds after the abort signal is received by the master events sequence controller, an electric current fires cartridges to open the canards. Gas from the cartridges causes a piston to retract, operating the opening mechanism. The canard surfaces mechanically lock in place when fully opened.

The launch escape and pitch control motors are produced by Lockheed Propulsion Co., Redlands, Calif. The tower jettison motor is produced by Thiokol Chemical Corp., Elkton, Md.

## EQUIPMENT

Launch Escape Motor (Lockheed Propulsion Co.) – Solid rocket motor about 15-1/2 feet long and 26 inches in diameter in steel case;



*Subsystem is lowered onto command module for test at White Sands*

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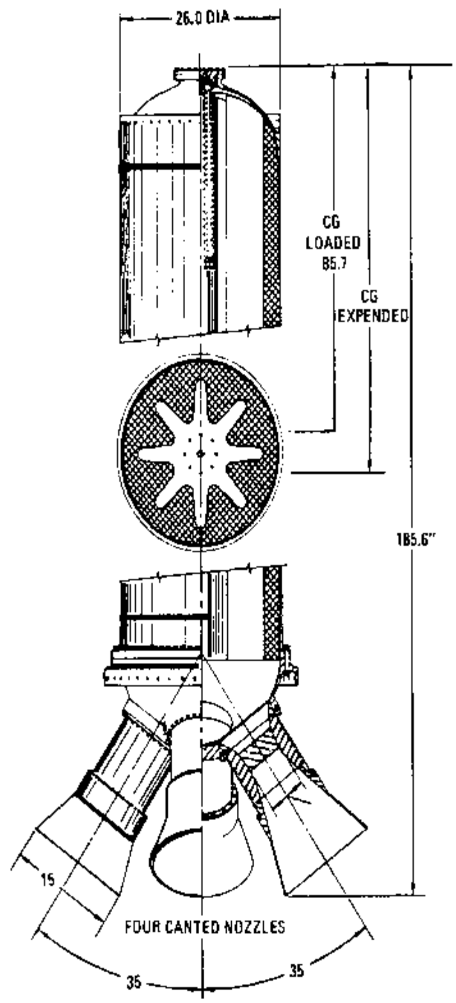
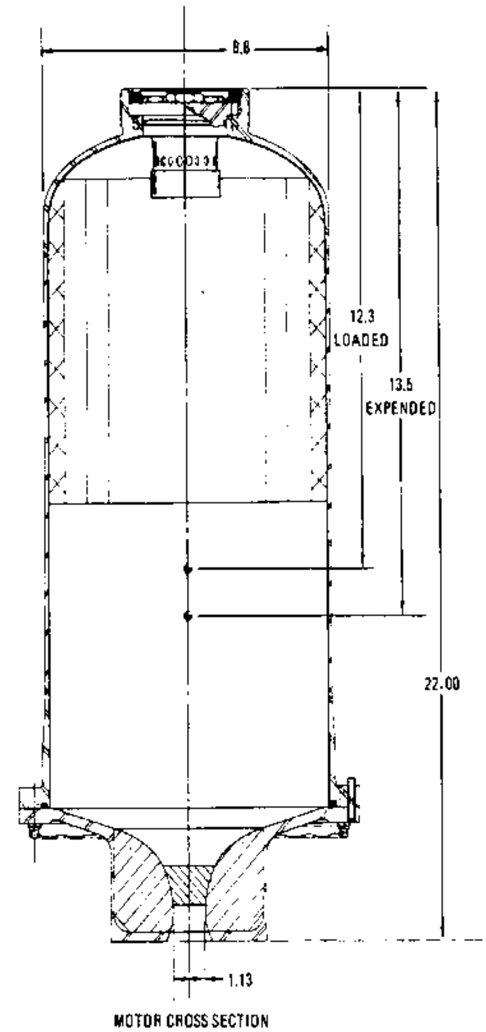
weighs 4700 pounds. Thrust is about 147,000 pounds on pad, increasing with altitude. Propellant is a composite of polysulfides. It provides thrust required to rescue crew from a dangerous situation in the early launch phase.

Pitch Control Motor (Lockheed Propulsion Co.) – Solid rocket motor 2 feet long and 9 inches in diameter in steel case; weighs 50 pounds. Motor generates 2,400 pounds of thrust for half a second. Propellant is a composite of polysulfides. Provides an initial pitch maneuver toward the Atlantic Ocean in case of an abort on the pad or at very low altitude.

Tower Jettison Motor (Thiokol Chemical Corp.) – Solid rocket motor 4-1/2 feet long and 26 inches in diameter in a high carbon chrome-molybdenum steel-forged case. Motor generates 31,500 pounds of thrust for 1 second. Propellant




P-189 *Launch escape motor*

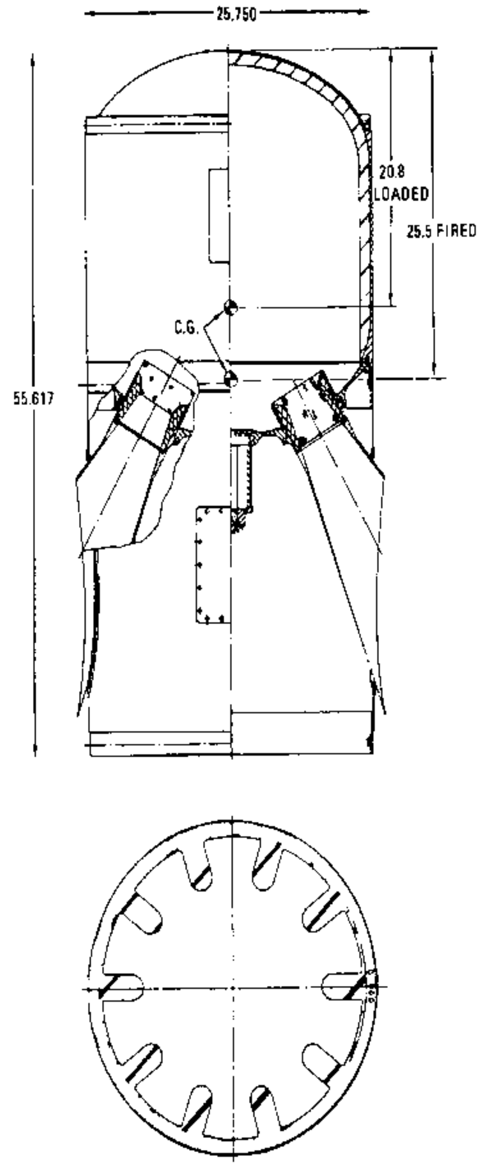



P-190 *Pitch control motor*

is a composite of polysulfides. It jettisons the launch escape tower either after the first stage when the launch escape tower is no longer required or after a launch abort and before parachutes are deployed for recovery.

Launch Escape Tower – Welded titanium tubing truss structure, 10 feet long, about 3 feet square at the top and 4 feet square at the base where it is connected to the command module. It weighs about 500 pounds including all attachments, wiring, and insulation.

Boost Protective Cover – It is made of layers of impregnated fiberglass, honeycomb cored-laminated fiberglass, and cork. It has 12 "blow-out" ports for reaction control motors, vents, and an 8-inch diameter window in front of the



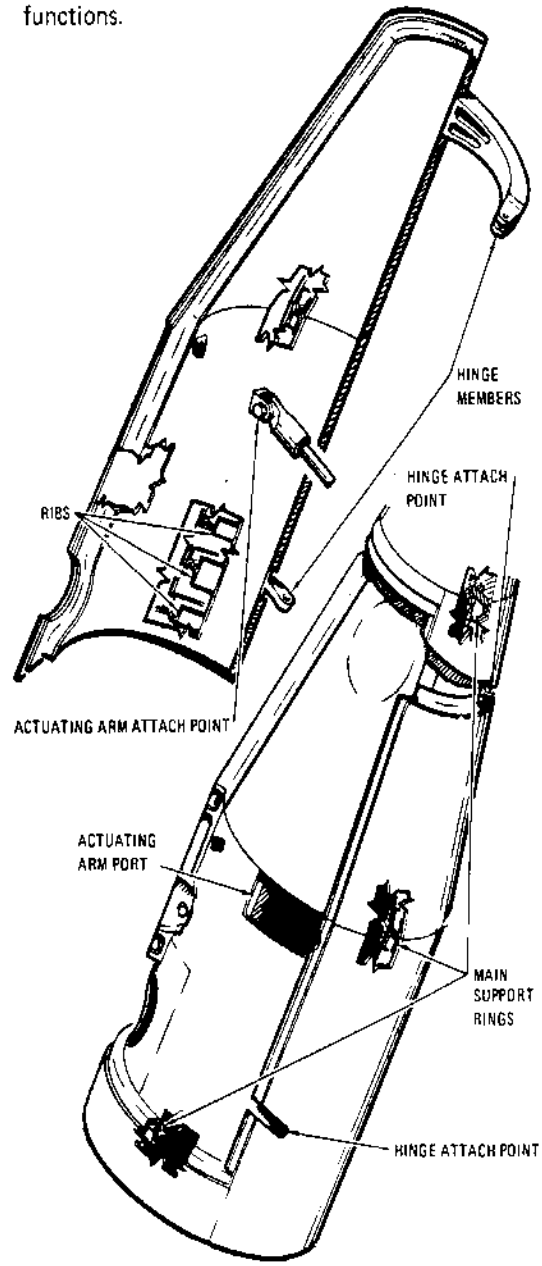

P-191 *Tower jettison motor*

commander's forward viewing window. It completely covers the command module to prevent charring of external surfaces during boost out of the earth's atmosphere. It is jettisoned with the launch escape tower assembly.

Canards – Two metallic clamshell aerodynamic control surfaces about 4 feet long, which are deployed only during launch escape abort modes. They orient the command module so that the heat shield is forward and the parachutes aft. They are deployed to a fixed position 11 seconds after abort initiation.

Q-Ball – Aluminum nose cone of the space vehicle. It is 13.37 inches long with a 13.3-inch diameter at the base. It is made up of differential pressure transducers and electronic modules. It measures the differential of dynamic pressures about the pitch and yaw axes in order to monitor the angle of attack of the space vehicle.

Master Events Sequence Controllers – Two boxes about 14 by 10 by 8 inches, each containing time delays, relays, fuses, and fusistors, located in the forward right-hand equipment bay of the command module. It controls numerous launch abort functions as well as numerous normal mission functions.




P-192 *Canard structure*

## DETAILED DESCRIPTION

### STRUCTURE

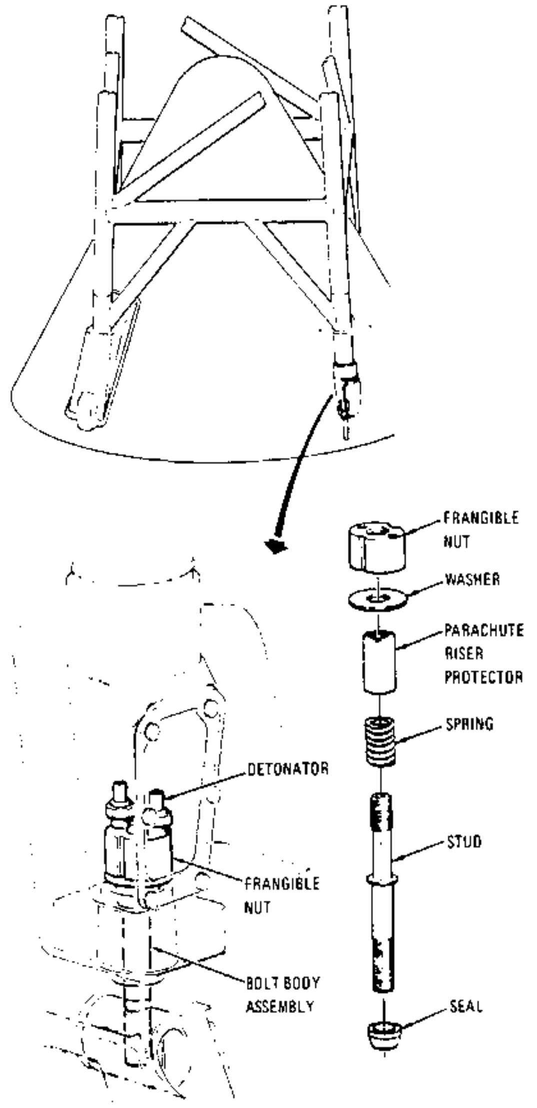
The launch escape subsystem consists of a boost protective cover, tower, launch escape motor, tower jettison motor, pitch control motor, ballast compartment, canards, nose cone, and Q-ball.

The boost protective cover protects the command module from the rocket exhaust of the launch escape motor and from the aerodynamic heating of boost. It is made of layers of resin-impregnated fiberglass covered with cork and fits over the entire command module like a glove. It is 11 feet tall, 13 feet in diameter, and weighs about 700 pounds.

The apex section of the boost cover is attached to the launch escape tower legs. A passive tension tie connects the apex of the boost cover and the docking probe of the command module. During a normal launch, the thrust of the tower jettison motor pulls the cover away and snaps this tension tie, leaving the probe with the command module. During an abort, however, the master events sequence controller and the lunar docking events sequence controller send signals which fire the ordnance devices that separate the docking ring from the CM. When the launch escape assembly is jettisoned the tension tie then pulls the probe and docking ring away with the boost protective cover.

The launch escape tower is made of titanium tubes of 2-½- and 3-½-inch diameter covered with Buna N rubber insulation to protect it against the heat of the rocket motor exhaust. The four legs of the tower fit in wells in the forward structure of the command module. They are fastened with studs and frangible (brittle) nuts. These nuts contain a small charge which breaks them to separate the module from the tower when the launch escape assembly is jettisoned.

The launch escape motor is the largest of the three rockets in the subsystem. It is approximately 15-1/2 feet long (including nozzles), 26 inches in diameter, and weighs 4,700 pounds. Two-thirds of this weight is in its polysulfide solid propellant. The motor produces about 147,000 pounds of thrust in its 3.2 seconds of burning, enough to lift the 13,000-pound command module and carry it a mile away from the launch vehicle. In order to provide a nominal thrust vector angle of approximately 2.75 degrees from the center of gravity excursion line, the throat area of one of the two



*Tower leg attachment*

nozzles in the pitch plane is approximately 5 percent larger than the two nozzles in the yaw plane; and the throat area of the second nozzle in the pitch plane is approximately 5 percent smaller than the two nozzles in the yaw plane. The motor skirt, to which the tower is attached, is 31 inches in diameter and is made of titanium.

Mounted atop the launch escape motor is the tower jettison motor, which is used in all missions to jettison the subsystem. The jettison motor is a little over 4-½ feet long, about 26 inches in diameter, and weighs about 525 pounds. Its solid propellant also is polysulfide. It burns for a little over 1 second and produces about 31,500 pounds of thrust. The motor has two fixed nozzles, located 180 degrees apart, which project from its steel case at a downward and outward angle. These skewed nozzles produced a resultant thrust vector angle of approximately 4 degrees which tips the tower and pulls it free of the CM.

The pitch control motor is used during an abort to push the launch escape assembly carrying the CM to one side, away from the launch vehicle. It is 2 feet long, 9 inches in diameter, and weighs about 50 pounds. Its polysulfide solid propellant burns only for a little more than a half second and produces about 2,400 pounds of thrust.

The tapered ballast compartment and nose cone top the assembly. The ballast compartment contains lead and depleted uranium weights. The nose cone contains the Q-ball instrumentation. Both the ballast compartment and nose cone are made of Inconel (a heat-resistant nickel alloy) and stainless steel.

The Q-ball provides an electrical signal to a display on the main display console and to the ground. The Q-ball has eight static ports (openings) for measuring pressure changes which are a function of angle of attack. The pitch and yaw pressure-change signals are electronically summed in the Q-ball and displayed on the indicator. The Q-ball information provides a basis for crew abort decision in the event of slow launch vehicle divergence.

## EMERGENCY DETECTION SYSTEM

The emergency detection system monitors critical conditions of launch vehicle powered flight. Emergency conditions are displayed to the crew on the main display console to indicate necessity for abort. The system includes provisions for a crew-initiated abort with the use of the launch escape subsystem or with the service propulsion subsystem after tower jettison. The crew can start an abort during countdown until normal spacecraft separation from the launch vehicle. Also included in the system are provisions for an automatic abort in case of the following time-critical conditions:

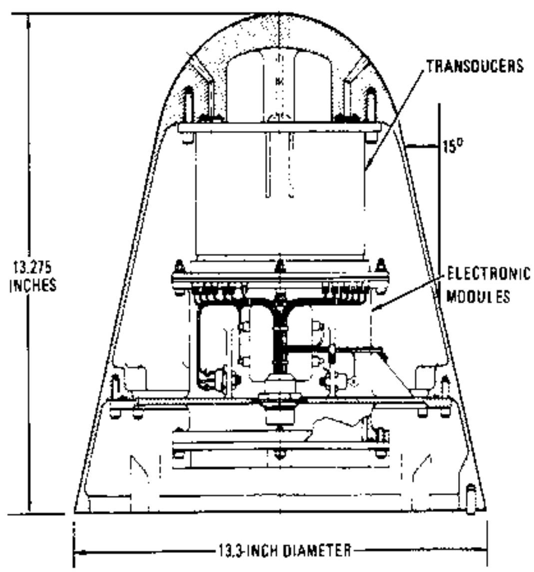
1. Loss of thrust on two or more engines on the first stage of the launch vehicle.

2. Excessive vehicle angular rates in any of the pitch, yaw, or roll planes.

When an abort is initiated (either manual or automatic), the system cuts off booster engines except for the first 40 seconds of flight in the case of the uprated Saturn I, or the first 30 seconds of flight in the case of the Saturn V. Range safety requirements impose the time restrictions.

The emergency detection system automatic abort circuits in the spacecraft are activated automatically at liftoff and deactivated 100 seconds after liftoff. Switches on main display console deactivate the entire automatic abort capability or the "two engines out" and "excessive rates" portions of the system independently. These three switches are placed in the automatic position before liftoff and are switched off before first stage separation. The two automatic abort circuits also are deactivated automatically in the instrument unit just before the first stage inboard engine cutoff as a backup to manual deactivation.

The electrical circuits that control the launch vehicle status lights are in the instrument unit. The "LV Rate" light will illuminate when launch vehicle roll, pitch, or yaw rates are in excess of predetermined limits. The red "LV Guid" light illuminates to indicate loss of attitude reference in the guidance unit. The yellow "LV Engines" lights illuminate when an engine is developing less than the required thrust output. The engine lights provide four cues: ignition, cutoff, engine below thrust, and physical stage separation. A yellow "S-II Sep" light will illuminate at second stage first-plane separation and is extinguished at second-plane separation on vehicles launched by the Saturn V.

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*Nose cone and Q-ball*

The "Abort" light is a red lamp assembly containing four bulbs that provide high-intensity illumination. This light is illuminated if an abort is requested by the launch control center for a pad abort or an abort during liftoff via up-data link. The "Abort" light also can be illuminated after liftoff by the range safety officer, or via the up-data link from the manned spacecraft flight network.

The emergency detection system will automatically initiate an abort signal when two or more first stage engines are out or when launch vehicle excessive rates are sensed by gyros in the instrument unit. The abort signals are sent to the master events sequence controller, which initiates the abort procedure.

## LAUNCH ESCAPE TOWER JETTISON

After second stage ignition, the launch escape tower is jettisoned. Normally both of the tower jettison switches will be used to initiate this function; however, either one will initiate the tower jettison circuits. The frangible nut assemblies which attach the tower legs to the CM each include two detonators which are fired at activation of the jettison switches. The tower jettison circuits also ignite the tower jettison motor. The cues which the flight crew will use when initiating tower jettison are the number one engine status light for the Saturn IB and the "S-II Sep" light for the Saturn V. The crew will use the digital events timer in conjunction with the visual light cues to jettison the tower at the correct time. If the tower jettison motor should fail to ignite, the launch escape motor can be used to jettison the tower.

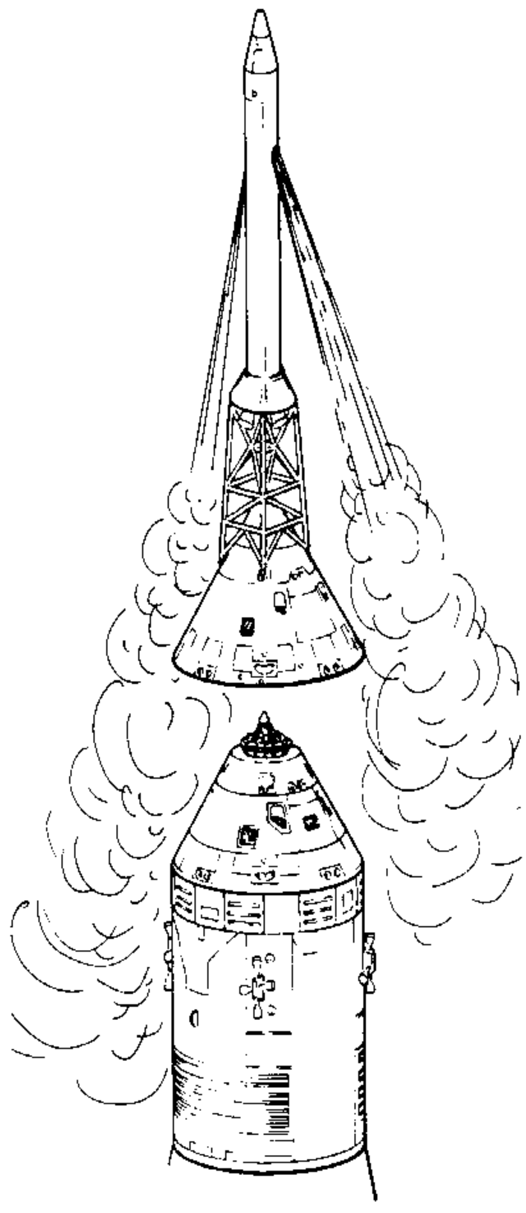
When the launch escape tower is jettisoned, the emergency detection system automatic abort circuits are disabled.

## ABORTS

Abort procedures fall into several categories termed modes. Mode 1 aborts are those using the launch escape subsystem; Modes 2, 3, and 4 aborts are those using the service propulsion subsystem. There are subdivisions within each category, principally due to the altitude of the spacecraft at the time of abort.

Launch escape subsystem abort procedures are controlled automatically by the master events sequence controller. The controller also commands portions of the aborts using the service propulsion subsystem. The sequence commanded by the controller for a Mode 1a abort (pad or low altitude) is:

1. Relay booster engine cutoff signal to the launch vehicle's instrument unit.
2. Reset and start the commander's digital events timer.
3. Deadface (cut off the flow of current) the CM-SM umbilical.
4. Pressurize the CM reaction control subsystem.



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*Launch escape tower jettison*

5. Transfer electrical control from the SM reaction control engines to the CM reaction control engines.

6. Transfer entry and post-landing battery power to the main dc bus tie.

7. Fire ordnance devices to cut CM-SM tension and ties and to activate the CM-SM umbilical guillotine.

8. Ignite the launch escape and pitch control motors.

9. Start rapid CM reaction control subsystem propellant dumping and purging.

10. Deploy launch escape subsystem canards.

11. Activate the earth landing subsystem controller.

12. Jettison the launch escape tower.

13. Fire charges to separate the docking ring.

14. Jettison the forward heat shield.

15. Fire the mortar to deploy the heat shield drag parachute.

16. Deploy the drogue parachutes.

17. Purge CM reaction control subsystem.

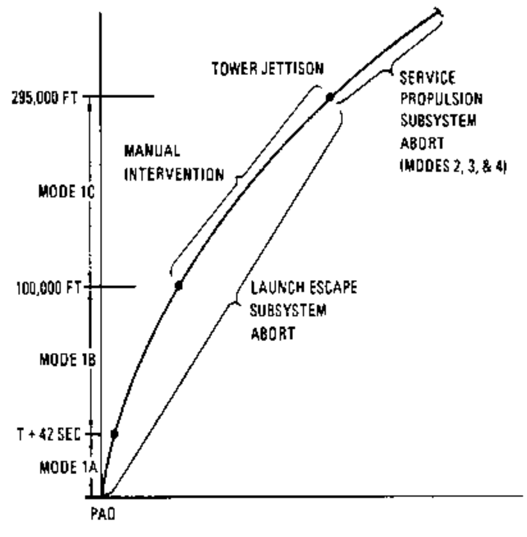
18. Release the drogue parachutes.

19. Deploy the pilot parachutes (which pull out the main parachutes).

20. Deploy the two VHF recovery antennas and the flashing beacon light.

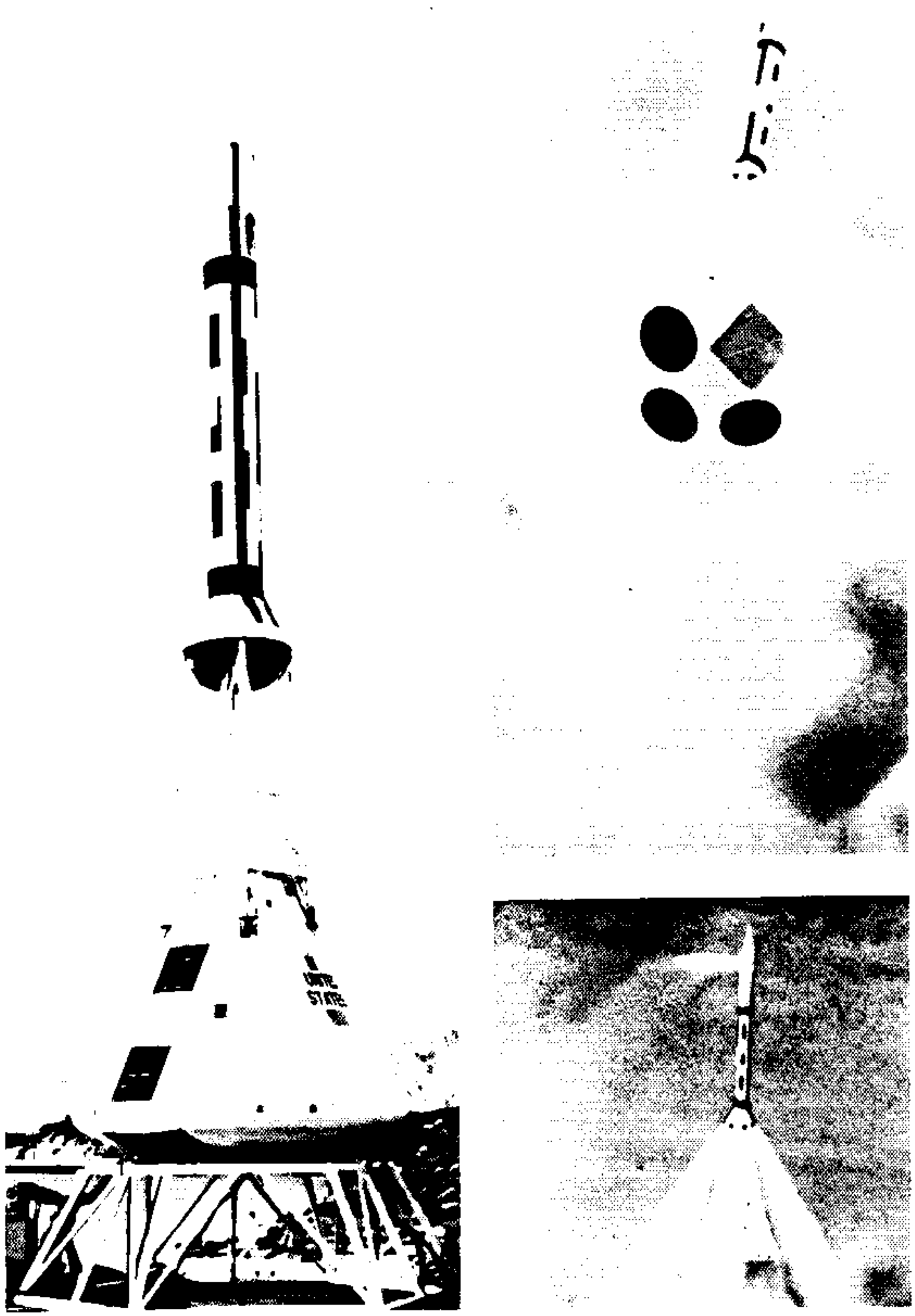
21. After splashdown, release the main parachutes.

The sequence differs slightly for other aborts using the launch escape subsystem. On high-altitude aborts, for example, the pitch control motor is not fired, dumping of the CM reaction control propellant follows the normal entry procedure (during descent on the main parachutes), and the reaction jet engine control is not cut off (enabling the stabilization and control subsystem to control the CM's attitude automatically).



P-196 *Abort modes*

Aborts using the service propulsion subsystem, since they are at a much higher altitude or in space, follow procedures more like a normal entry.



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*Test at White Sands of launch escape subsystem's ability to carry CM to safety during pad abort*

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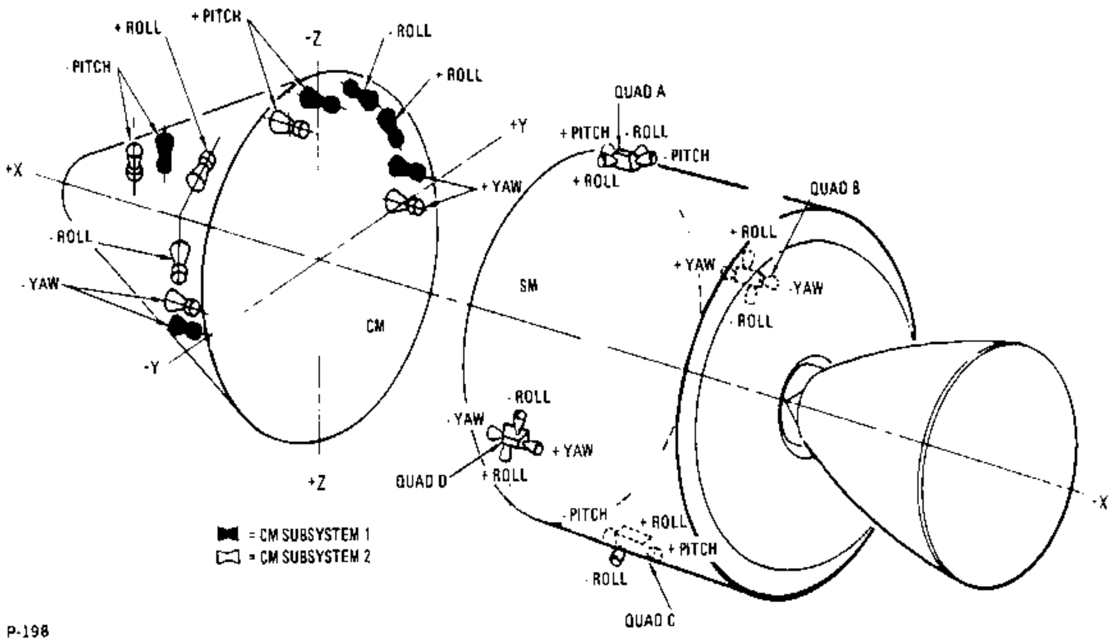
# REACTION CONTROL

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*Location of reaction control subsystem engines*

The reaction control subsystem provides the thrust for normal and emergency attitude maneuvers of the Apollo spacecraft. Operation of the subsystem is in response to automatic control signals from the stabilization and control subsystem in conjunction with the guidance and navigation subsystem. It can be controlled manually by the crew. The reaction control subsystem consists of CM and SM reaction control systems.

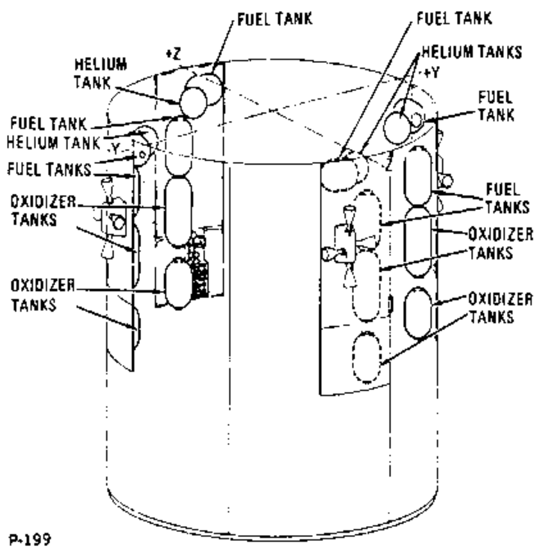
## SM REACTION CONTROL SYSTEM

The SM reaction control system consists of four similar, independent systems (quads) located 90 degrees apart around the service module. It provides thrust required for three-axis stabilization and control of the spacecraft during earth orbit, translunar trajectory abort, transposition and docking, and translunar, lunar orbital, and transearth flight. It also may be used for minor course corrections both on the translunar and transearth flights.

The system provides the small velocity changes required for service propulsion subsystem propellant-settling maneuvers (ullage). Only roll axis control is provided during service propulsion engine thrusting. In addition, it provides velocity changes for spacecraft separation from the third stage during high-altitude or translunar injection abort, for separation from the boost vehicle after injection of the spacecraft into translunar trajectory, LM rendezvous in lunar orbit, and for CM-SM separation.

The four quads can be operated simultaneously or in pairs during spacecraft maneuvers. Each quad is mounted on a honeycomb structural panel about 8 feet long and 3 feet wide. It becomes part of the integrated service module structure when hinged and bolted in place. Center lines of engine mounts are offset about 7 degrees from the Y and Z axes. The cluster of four engines for each quad is rigidly mounted in a housing on the outside of the honeycomb panel. Laterally mounted (roll) engines are used for rotating the vehicle about the X axis. Longitudinally mounted engines are used for rotating the vehicle about the Y and Z axes and translational maneuvers along the X axis. Roll engines are offset to minimize engine housing frontal area to reduce boost heating effects. All engines in each cluster are canted 10 degrees outward to reduce the effects of exhaust plume impingement on the service module structure.

Each engine provides approximately 100 pounds of thrust and uses hypergolic propellant. The fuel is monomethyl hydrazine (MMH) and the oxidizer is nitrogen tetroxide ($N_2O_4$). The engines are produced by The Marquardt Corp., Van Nuys, Calif.




*SM reaction control subsystem quads*

The reaction control engines may be pulse-fired (in bursts) to produce short-thrust impulses or fired continuously to produce a steady thrust. The short-pulse firing is used for attitude-hold and navigation alignment maneuvers. Attitude control can be maintained with two adjacent quads operating.

Each quad contains a pressure-fed, positive-expulsion propellant feed system. The propellant tanks (two fuel and two oxidizer) are located on the inside of the structural panel; feed lines are routed through the panel to the engines. The propellant tanks are produced by Bell Aerosystems Co., Buffalo, N.Y., a division of Textron, Inc.

Helium is used to pressurize the propellant tanks; a single helium tank is located on the inside of the panel. Helium entering the propellant tanks around the positive-expulsion bladders forces the propellant in the tanks into the feed lines. Oxidizer and fuel are thus delivered to the engines. The fuel valve on each engine opens approximately 1/500th of a second before the oxidizer valve to provide proper ignition characteristics. Each valve contains orifices which meter the propellant flow to obtain the proper (2 to 1) mixture ratio. The propellants are hypergolic; that is, they ignite when they come in contact in the engine combustion chamber without an ignition system.

## CM REACTION CONTROL SYSTEM

The CM reaction control system is used after CM-SM separation and for certain abort modes. It provides three-axis rotational and attitude control to orient and maintain the CM in the proper entry attitude before encountering aerodynamic forces. During entry, it provides the torque (turning or twisting force) required to control roll attitude.

The system consists of two independent, redundant systems, each containing six engines, helium and propellant tanks, and a dump and purge system. The two systems can operate in tandem; however, one can provide all the impulse needed for the entry maneuvers and normally only one is used.

The 12 engines of the system (produced by North American Rockwell's Rocketdyne Division, Canoga Park, Calif.) are located outside the crew compartment of the command module, 10 in the aft compartment and 2 in the forward compartment. The nozzle of each engine is ported through the heat shield of the CM and matches the mold line. Each engine produces approximately 93 pounds of thrust.

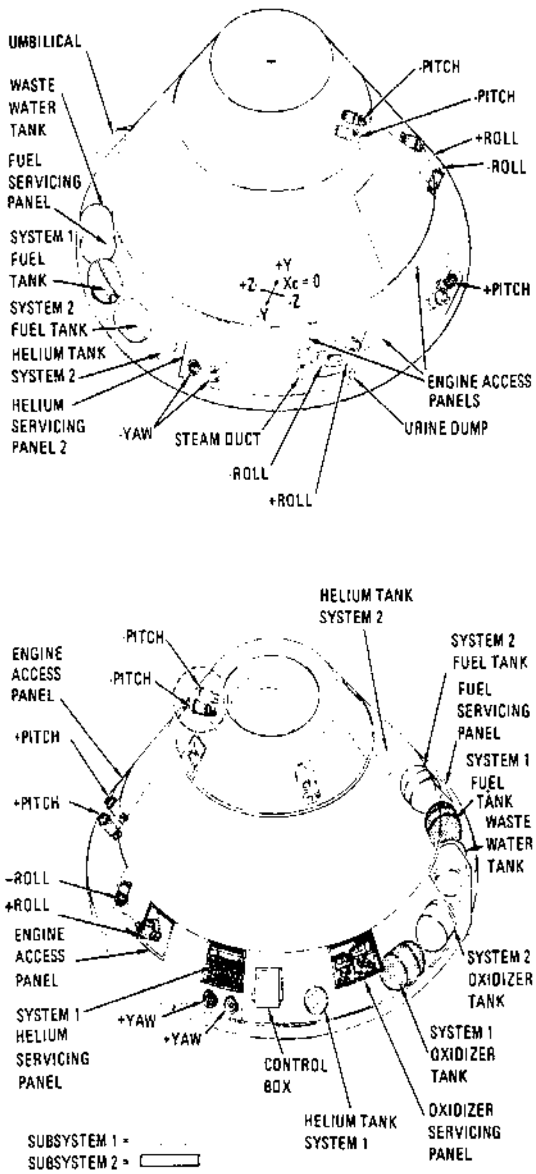
Operation of the CM reaction control engines is similar to the SM. Propellant is the same (monomethyl hydrazine and nitrogen tetroxide) and helium is used for pressurization. Each of the redundant CM systems contains one fuel and one oxidizer tank similar to the fuel and oxidizer tanks of the SM system. Each CM system has one helium tank.

The helium is isolated from the system by squib valves before entry; these are valves which contain small explosive charges (squibs). These valves are activated before CM-SM separation.

High-pressure helium flows through regulators (to reduce the pressure) and check valves to the propellant tanks, where it maintains pressure around the positive-expulsion bladders in each tank. The propellants are forced into the feed lines, through a burst diaphragm, and to the engines. The diaphragm must rupture for propellant to reach the engines; it is additional assurance that the engines cannot be fired inadvertently.

Oxidizer and fuel is fed to the 12 engines by a parallel feed system. The injector valve on each engine contains orifices which meter the fuel and oxidizer so that a flow ratio of 2 oxidizer to 1 fuel is obtained.

The engines may need heating before use so that the oxidizer doesn't freeze when it comes in contact with the injector valve. Astronauts monitor




*Location of CM reaction control subsystem components*

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the temperature of the engines on a cabin display and turn on the engine injector valve direct coils which act as heaters if necessary.

Because the presence of hypergolic propellant can be hazardous at CM splashdown, the propellant remaining in the fuel and oxidizer tanks is disposed of by burning during the final descent on the main parachute. After all propellant is disposed of the feed lines are purged with helium. The burn and purge operations are controlled manually by the crew except during an abort in the early part of boost (up to 42 seconds after liftoff), when dumping and purging is automatic.

# EQUIPMENT

## SERVICE MODULE

Helium Tanks (Airite Div., Sargent Industries, El Segundo, Calif.) – The four spherical tanks are made of titanium and weigh 11.5 pounds each. Each has an internal volume of 910 cubic inches. The helium is pressurized to 4150 psig. The outside diameter is 12.37 inches, a wall thickness of 0.135 inch, and a capacity of 1.35 pounds. The tanks store helium used to pressurize the propellant tanks.

Primary Fuel Tanks (Bell Aerosystems Co., Buffalo, N.Y.) – There are four cylindrical titanium tanks with domed ends, one tank for each quad of engines. The tanks have Teflon bladders. Each tank is 23.717 inches long with an outside diameter of 12.62 inches. Wall thickness is 0.017 to 0.022 inch. Combined propellant ullage volume is 69.1 pounds, resulting in tank pressure no greater than 215 psia at 85 degrees. The tanks store fuel (monomethyl hydrazine) and supply it on demand to the engines.

Primary Oxidizer Tanks (Bell) – There are four cylindrical titanium tanks with domed ends, one tank for each quad of engines. The tanks have Teflon bladders. Each tank is 28.558 inches long with an outside diameter of 12.62 inches. Wall thickness is 0.017 to 0.022 inch. Combined propellant and ullage volume is 137 pounds resulting in tank pressure no greater than 215 psia at 85 degrees. The tanks store oxidizer (nitrogen tetroxide) and supply it on demand to the engines.

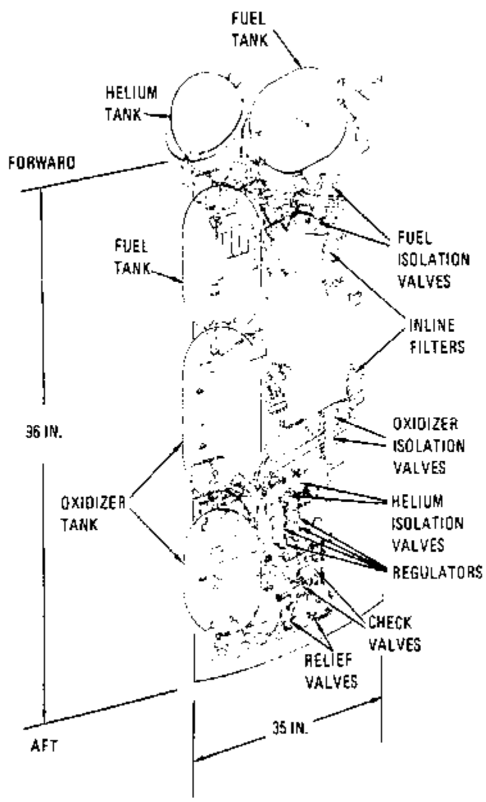
Secondary Fuel Tanks (Bell) – There are four cylindrical titanium tanks with domed ends, one tank for each quad of engines. The tanks have Teflon bladders. Each tank is 17.329 inches long with an outside diameter of 12.65 inches. Wall thickness is 0.022 to 0.027 inch. Combined propellant and ullage volume is 45.2 pounds, resulting in tank pressure no greater than 205 psia at 105 degrees. The tanks store fuel and supply it upon demand to the engines.

Secondary Oxidizer Tanks (Bell) – There are four cylindrical titanium tanks with domed ends, one for each quad of engines. The tanks have Teflon bladders. Each tank is 19.907 inches long and has an outside diameter of 12.65 inches. Wall thickness is 0.022 to 0.027 inch. Combined propellant and ullage volume is 89.2 pounds, resulting in tank pressure no greater than 205 psia at 105 degrees. The tanks store oxidizer and supply it on demand to the engines.

Engines (Marquardt) -- There are 16 radiation-cooled engines grouped in clusters of four 90 degrees apart on the outside of the service module. They are the only nonablative engines on the command and service module. The thrust chambers are pure molybdenum, and nozzle extensions are a cobalt-base alloy. Each engine is 13.400 inches long and weighs 5 pounds. Nozzle exit diameter is 5.6 inches. Each engine has a nominal thrust of 100 pounds. Service life of each engine is 1000 seconds: any combination of pulsed (intermittent) and continuous operation up to a maximum of 500 seconds of steady-state firing. Minimum firing time is 12 milliseconds. Each engine is capable of 10,000 operation cycles. The engines are used for translation and rotational maneuvers and for obtaining star sightings.

COMMAND MODULE

Helium Tanks (Menasco Manufacturing Co., Burbank, Calif.) – The four spherical tanks are made of titanium. Each has a volume of 365 cubic inches. The helium is pressurized to 4150 psig. Outside diameter of each is 9.2 inches, and wall thickness is 0.102 inch. Capacity of each is 0.57 pound. The tanks store helium to pressurize the propellant tanks.




P-201 *Typical SM quad*

Fuel Tanks (Bell) – There are two titanium tanks identical to the secondary fuel tanks on the service module system.

Oxidizer Tanks (Bell) – There are two titanium tanks identical to the secondary oxidizer tanks on the service module system.

Engines (Rocketdyne) – There are 12 engines – 10 in the aft equipment compartment and two in the apex cover area. They are ablative engines and are installed with scarfed (smoothed into the surface) ablative nozzle extensions. Each engine is 12.65 inches long and weighs 8.3 pounds. Nozzle exit diameter is 2.13 inches. Thrust is 93 pounds. Service life for each engine is 200 seconds. Its minimum firing time is approximately 12 milliseconds. Each engine is capable of 3000 operational cycles. The primary use of the engines is for rotation maneuvers, rate damping, and attitude control during entry.

## DETAILED DESCRIPTION

### SM REACTION CONTROL SYSTEM

The SM system is composed of four separate, individual quads, each containing pressurization, propellant, rocket engine, and temperature control systems.

The pressurization system regulates and distributes helium to the propellant tanks. It consists of a helium storage tank, isolation valves, pressure regulators, check valves, relief valves, and lines necessary for filling, draining, and distribution of the helium.

The helium supply is contained in a spherical storage tank, which holds 1.35 pounds of helium at a pressure of about 4150 psia. Isolation valves between the helium tank and pressure regulators contain two solenoids: one is energized momentarily to latch the valve open magnetically; the other is energized momentarily to unlatch the valve, and spring pressure and helium pressure forces the valve closed. The isolation valves in each quad are individually controlled by switches on the main display console. The valves are normally open to pressurize the system. They are held open by a magnetic latch rather than by the application of power which conserves power and prevents overheating of the valve coil. Indicators above each valve switch show gray when the valve is open (the normal position) and diagonal lines when the valve is closed. The valve is closed in the event of a pressure regulator unit problem and during ground servicing.

Helium pressure is regulated by two assemblies connected in parallel, with one assembly downstream of each isolation valve. Each assembly incorporates two (primary and secondary) regulators connected in series. The secondary regulator remains open if the primary regulator functions properly. If the primary regulator fails open, the secondary regulator will maintain slightly higher but acceptable pressures.

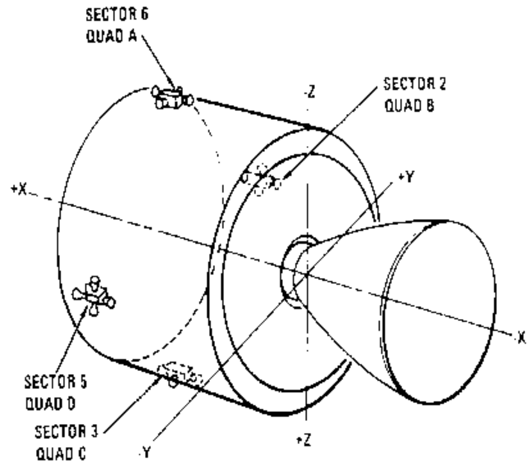
Two check valve assemblies, one for oxidizer and one for fuel, permit helium flow to the tanks and prevent propellant or propellant vapor flow into the pressurization system if seepage or failure occurs in the propellant tank bladders. Filters are incorporated in the inlet to each check valve assembly and each test port.

The helium relief valve contains a diaphragm, filter, a bleed device, and the relief valve. The diaphragm is installed to provide a more positive seal against helium than that of the actual relief valve. The diaphragm ruptures at 228 psia. The filter retains any fragments from the diaphragm and prevents particles from flowing onto the relief valve seat. The relief valve will open at 236 psia and dump excessive pressure overboard. The relief valve will reseat at 220 psia.

A pressure bleed device vents the cavity between the diaphragm and relief valve in the event of any leakage across the diaphragm, or upon completion of checkout of the relief valve. The bleed device is normally open and will be fully closed when the pressure increases to 150 psia; it will be fully opened when the pressure decreases to 20 psia.

The propellant system consists of two oxidizer tanks, two fuel tanks, two oxidizer and two fuel isolation valves, a fuel and oxidizer inline filter, and associated distribution plumbing.

The oxidizer supply is contained in two titanium alloy, hemispherically domed cylindrical tanks. The tanks are mounted to the SM structural panel. The

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*Location of SM quads*

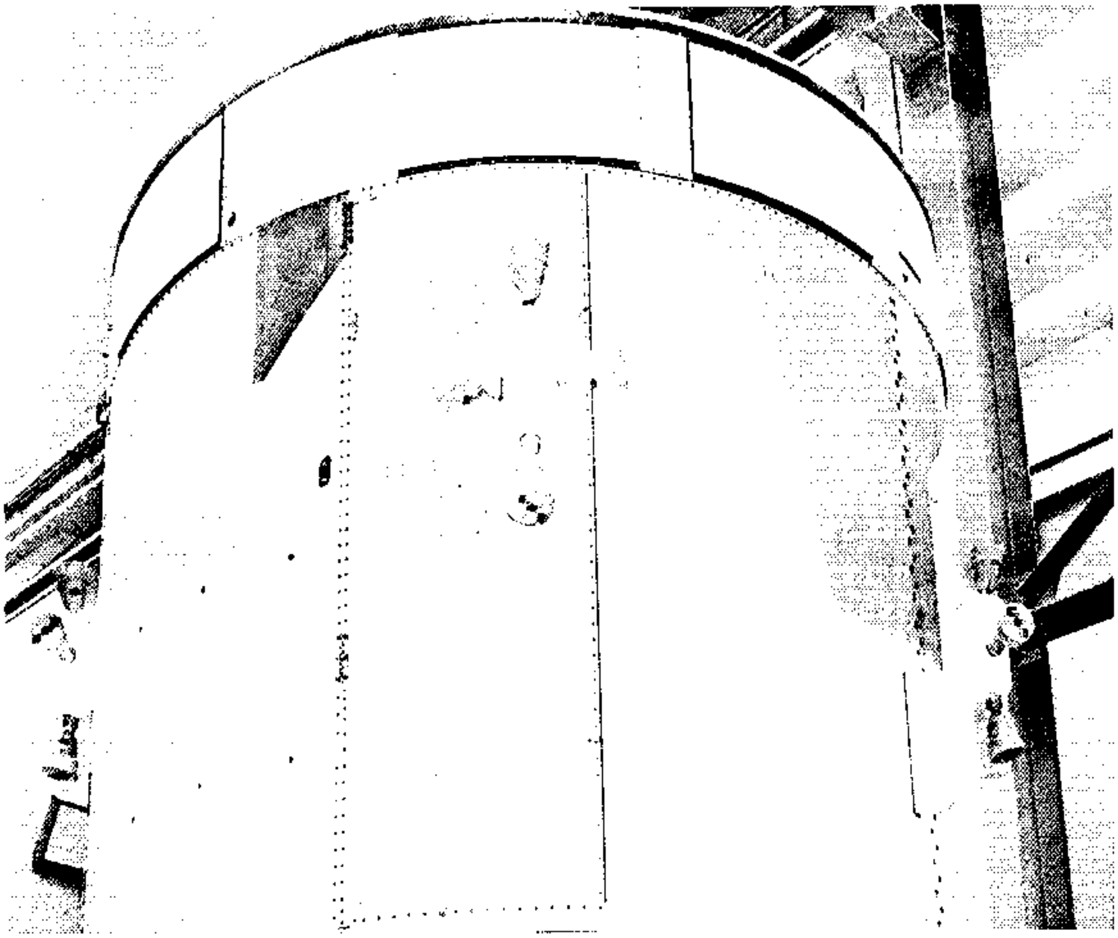
primary tank is about 28-½ inches long, 12-½ inches in diameter, and holds 137 pounds of oxidizer. The secondary tank is about 20 inches long, 12-½ inches in diameter, and holds 89 pounds of oxidizer.

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

When the tanks are pressurized, the helium 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, providing expulsion during zero gravity.

The fuel supply is contained in two tanks that are similar in material, construction, operation, and diameter to oxidizer tanks. The primary tank is about 23-½ inches long and holds 69 pounds of fuel; the secondary tank is about 17 inches long and holds 45 pounds of fuel.

Isolation valves in the fuel and oxidizer tank lines in each quad are controlled by switches on the main display console. Each isolation valve contains solenoids and indicators that operate in the same manner as the helium isolation valves. The primary tank valves are normally open and the secondary valves closed. When a propellant quantity indicator displays 43 percent propellant remaining, the secondary valves are opened and the primary valves are closed. The valves may be closed to prevent fluid flow in the event of a failure such as line rupture or a runaway thruster.



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*Quad panels installed on service module in Downey clean room*

Propellant distribution plumbing is identical in each quad. Each quad contains separate similar oxidizer and fuel plumbing networks. Propellant in each network is directed from the supply tanks through manifolds for distribution to the four engines in the cluster.

Filters are installed in the fuel and oxidizer lines between the propellant isolation valves and the engine manifold to prevent any particles from flowing into the engine injector valves and engine injector.

The SM reaction control engines are radiation cooled, pressure fed, bipropellant thrust generators which can be operated in either the pulse or steady-state mode.

Each engine consists of a fuel and oxidizer injector control valve which controls the flow of propellant by responding to automatic or manual electrical commands and an injector head assembly which directs the flow of the propellant from each control valve to the combustion chamber. A filter is at the inlet of each fuel and oxidizer solenoid injector valve. An orifice in the inlet of each fuel and oxidizer solenoid injector valve meters the propellant flow to obtain a nominal 2:1 oxidizer-fuel ratio.

The propellant solenoid injector valves use two coaxially wound coils, one for automatic and one for direct manual operation. The automatic coil is used when the thrust command originates from the controller reaction jet assembly, which is the electronic circuitry that selects the required automatic coils to be energized for a given maneuver. The direct manual coils are used when the thrust command originates at the rotation control, direct ullage pushbutton, service propulsion subsystem abort, or the SM jettison controller.

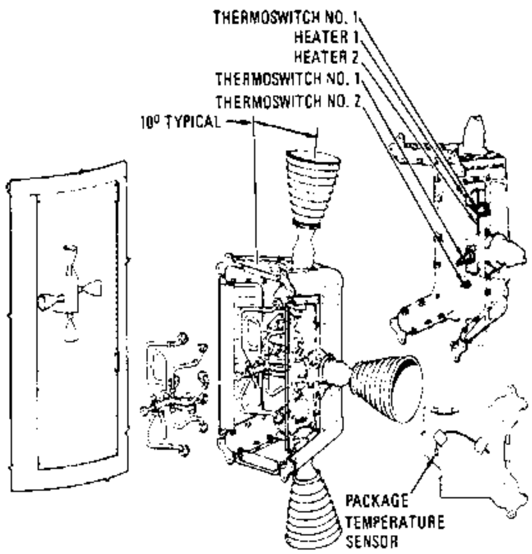
The main chamber portion of the injector will allow 8 fuel streams to impinge upon 8 oxidizer streams for main chamber ignition. There are 8 fuel holes around the outer periphery of the injector which provide film cooling to the combustion chamber walls.

The injector contains a precombustion chamber in which a single fuel and a single oxidizer stream impinge upon each other. The precombustion chamber provides a smoother start transient. There are 8 fuel holes around the outside of the precombustion chamber providing cooling to its walls.

The combustion chamber is constructed of unalloyed molybdenum which is coated with molybdenum disilicide to prevent oxidation of the base metal. Cooling of the chamber is by radiation and fuel film cooling.

The nozzle extension with integral stiffener rings is machined from a cobalt base alloy.

Each of the engine mounts contain two electrical strip heaters. Each heater contains two electrical elements. One element in each heater is controlled by a secondary temperature therm-o-switch that is set to open at 118°F and close at 70°F. When a switch on the main display console for that quad is set for the secondary system, dc power is supplied to the therm-o-switch in each heater of that quad and will automatically open and close according to the temperature.

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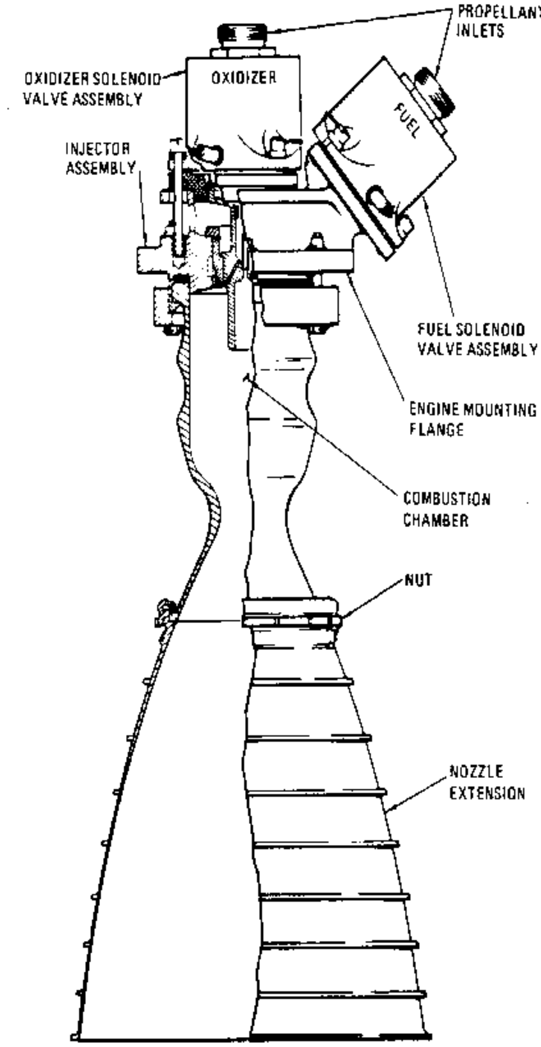
*SM reaction control engine housing*

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*SM reaction control engine*

When the switch is set for the primary heater, power is supplied to the redundant element in each heater for that quad. This therm-o-switch is a higher temperature switch and will automatically open at 134°F and close at 115°F. The heaters provide propellant temperature control by conductance to the engine housing and engine injector valves.

A gauge on the main display console is used to monitor the package temperature of any one of the four SM quads.

The helium tank supply pressure and temperature for each quad is monitored by a pressure/temperature ratio transducer. This provides a signal to a switch on the main display console. When the switch is positioned to a given SM quad, the pressure/temperature ratio signal is transmitted to a