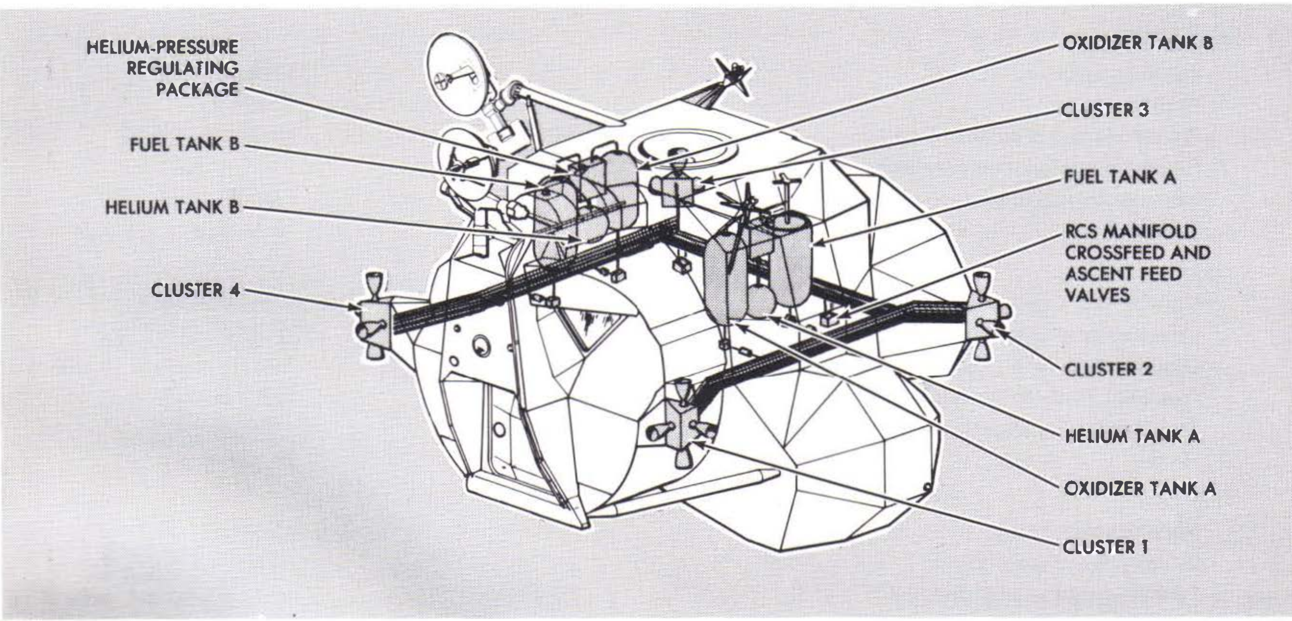
REACTION CONTROL

QUICK REFERENCE DATA

Pressurization section	
Helium tanks	
Unpressurized volume (each tank)	910 cubic inches
Initial fill pressure and temperature	3,050±50 psia at +70° F
Initial filling weight of helium (each tank)	1.03 pounds
Helium temperature range	+40° to +100° F
Proof pressure	4,650 psia
Diameter	12.3 inches
Helium filter absolute filtration	12 microns
Primary pressure regulator	
Output	181±3 psia
Lockup pressure	188 psia (maximum)
Secondary pressure regulator	
Output	185±3 psia
Lockup pressure	192 psia (maximum)
Flow rate through pressure regulator assembly (single thruster operation)	0.036 pound per minute
Relief valve assembly	
Venting pressure	232 psia
Reseat pressure	212 psia (minimum)
Burst-disk rupture pressure	220 psia
Propellant feed section	
Propellant tanks	
Working pressure	176 psia
Proof pressure	333 psia
Propellant pad pressure	50 psia
Propellant storage temperature range	+40° to 100° F
Nominal temperature	+70° F
Diameter	12.5 inches
Oxidizer tanks	
Volume (each tank)	2.38 cubic feet
Ullage volume (each tank)	273.0 cubic inches
Oxidizer flow rate to each thruster	0.240 pound per second
Available oxidizer (each tank)	194.1 pounds
Oxidizer loaded in each system (tank and manifold)	208.2 pounds
Height	38 inches
Fuel tanks	
Volume (each tank)	1.91 cubic feet
Ullage volume (each tank)	158.5 cubic inches
Fuel flow rate to each thruster	0.117 pounds per second
Available fuel (each tank)	99.3 pounds (minimum)
Fuel loaded in each system (tank and manifold)	107.4 pounds
Height	32 inches
Propellant filter absolute filtration	18 microns
Ascent feed filter absolute filtration	25 microns

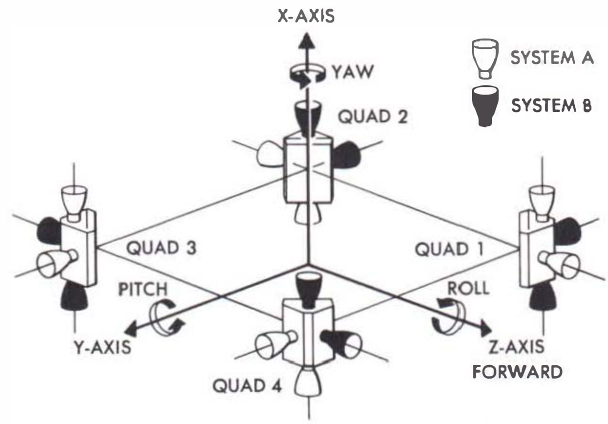
Thrust chamber assembly	
Engine thrust	100 pounds
Engine life	
Total	1000 seconds
Steady-state mode	500 seconds
Pulse mode	500 seconds
Restart capability	10,000 times
Chamber-cooling method	Fuel-film cooling and radiation
Combustion chamber pressure	96 psia
Propellant injection ratio (oxidizer to fuel)	2.05 to 1
Heaters	
Type	Resistance-wire element
Operating power	28 volts dc
Power consumption (each heater)	17.5 watts at 24 volts
Oxidizer inlet pressure (steady state)	170 ± 10 psia
Fuel inlet pressure (steady state)	170 ± 10 psia
Approximate weight	5.25 pounds
Overall length	13.5 inches
Nozzle expansion area ratio	40 to 1
Nozzle exit diameter	5.75 inches



R-88A

Major Reaction Control Equipment Location

The Reaction Control Subsystem (RCS) provides thrust impulses that stabilize the LM during the descent and ascent trajectory and controls attitude and translation – movement of the LM about and along its three axes – during hover, landing, rendezvous, and docking maneuvers. The RCS also provides the thrust required to separate the LM from the CSM and the +X-axis acceleration (ullage maneuver) required to settle Main Propulsion Subsystem (MPS) propellants before a descent or ascent engine start. The RCS accomplishes its task during coasting periods or while the descent or ascent engine is firing; it operates in response to automatic control commands from the Guidance, Navigation, and Control Subsystem (GN&CS) or manual commands from the astronauts.



Thruster Arrangement

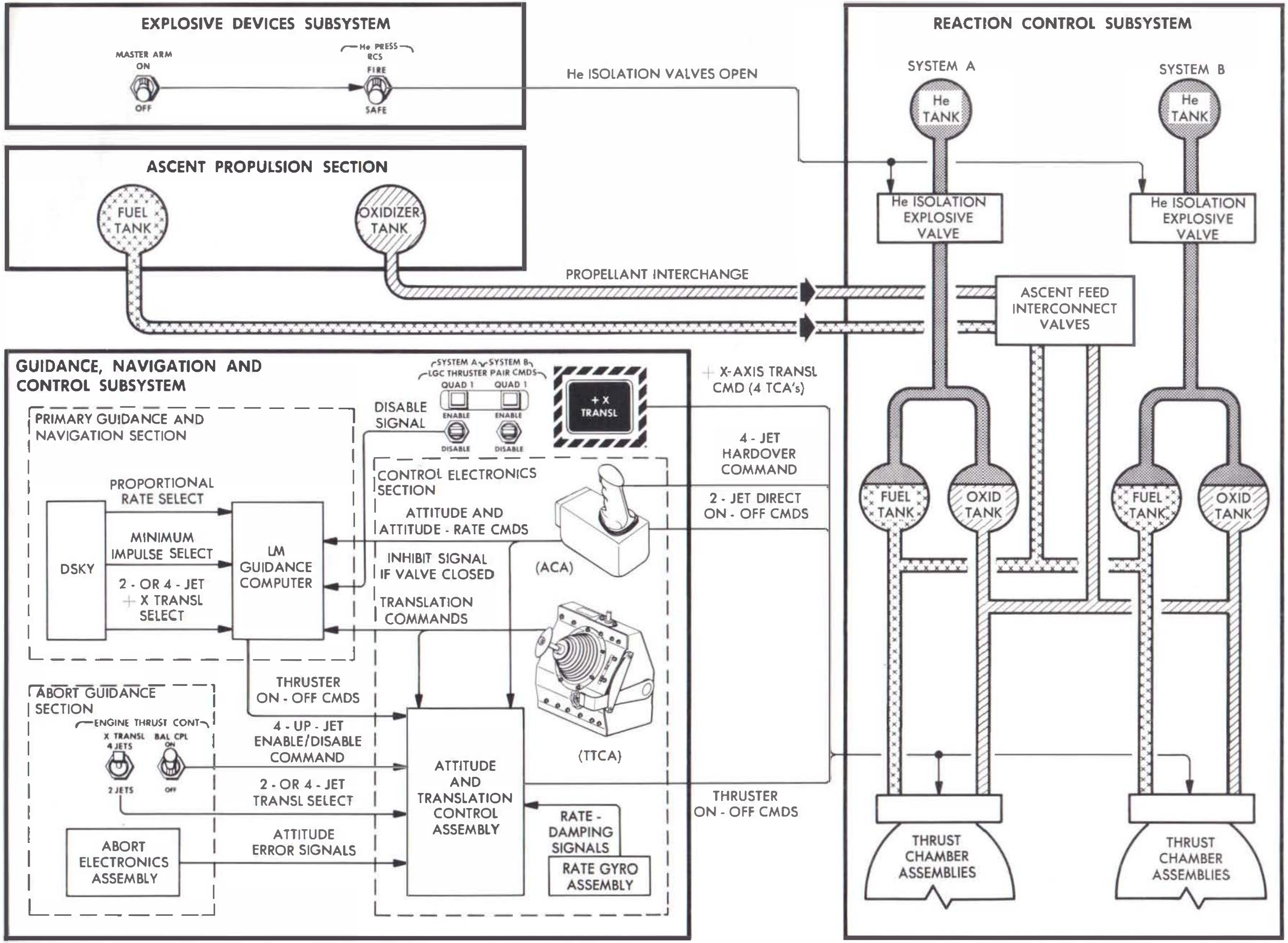
The 16 thrust chamber assemblies (thrusters) and the propellant and helium sections that comprise the RCS are located in or on the ascent stage. The propellants used in the RCS are identical with those used in the MPS. The fuel – Aerozine 50 – is a mixture of approximately 50% each of hydrazine and unsymmetrical dimethylhydrazine. The oxidizer is nitrogen tetroxide. The injection ratio of oxidizer to fuel is approximately 2 to 1. The propellants are hypergolic; that is, they ignite spontaneously when they come in contact with each other.

The thrusters are small rocket engines, each capable of delivering 100 pounds of thrust. They are arranged in clusters of four, mounted on four outriggers equally spaced around the ascent stage. In each cluster, two thrusters are mounted parallel to the LM X-axis, facing in opposite directions; the other two are spaced 90° apart, in a plane normal to the X-axis and parallel to the Y-axis and Z-axis.

The RCS is made up of two parallel, independent systems (A and B), which, under normal conditions, function together to provide complete attitude and translation control. Each system consists of eight thrusters, a helium pressurization section, and a propellant feed section. The two systems are interconnected by a normally closed crossfeed arrangement that enables the astronauts to operate all 16 thrusters from a single propellant supply. Complete attitude and translation control is therefore available even if one system's propellant supply is depleted or fails. Functioning alone, either RCS system can control the LM, although with slightly reduced efficiency. This capability is due to the distribution of the thrusters, because each cluster has two thrusters of each system located in a relatively different position.

In addition to the RCS propellant supply, the thrusters can use propellants from the ascent propulsion section. This method of feeding the thrusters, which requires the astronauts to open interconnect lines between the ascent tanks and RCS manifolds, is normally used only during periods of ascent engine thrusting. Use of ascent propulsion section propellants is intended to conserve RCS propellants, which may be needed during docking maneuvers.

The astronauts monitor performance and status of the RCS with their panel-mounted pressure, temperature, and quantity indicators; talkbacks (flags, that indicate open or closed position of certain valves); and caution and warning annunciators (placarded lights that go on when specific out-of-tolerance conditions occur). These data originate at sensors and position switches in the RCS, are processed in the Instrumentation Subsystem, and are simultaneously displayed to the astronauts in the LM cabin and transmitted to mission controllers through MSFN via the Communications Subsystem.



R-90A

RCS Control Diagram

The 28-volt d-c and 115-volt a-c primary power required by the RCS is furnished by the Electrical Power Subsystem. Interconnect plumbing between the RCS thruster propellant manifolds and the ascent propulsion section tanks permit the RCS to use propellants from the Main Propulsion Subsystem (MPS) during certain phases of the mission.

Control of the RCS is provided by the GN&CS. Modes of operation, thruster selection, and firing duration are determined by the GN&CS.

FUNCTIONAL DESCRIPTION

THRUSTER SELECTION, OPERATION, AND CONTROL

The GN&CS provides commands that select thrusters and fire them for durations ranging from a short pulse to steady-state operation. The thrusters can be operated in an automatic mode, attitude-hold mode, or a manual override mode.

Normally, the RCS operates in the automatic mode; all navigation, guidance, stabilization, and steering functions are initiated and commanded by the LM guidance computer (primary guidance and navigation section) or the abort electronics assembly (abort guidance section).

The attitude-hold mode is a semiautomatic mode in which either astronaut can institute attitude and translation changes. When an astronaut displaces his attitude controller, an impulse proportional to the amount of displacement is routed to the computer, where it is used to perform steering calculations and to generate the appropriate thruster-on command. An input into the DSKY determines whether the computer commands an angular rate change proportional to attitude controller displacement, or a minimum impulse each time the controller is displaced. When the astronaut returns his attitude controller to the neutral (detent) position, the computer issues a command to maintain attitude. For a translation maneuver, either astronaut displaces his thrust/translation controller. This sends a discrete to the computer to issue a thruster-on command to selected thrusters. When this controller is returned to neutral, the thrusters cease to fire.

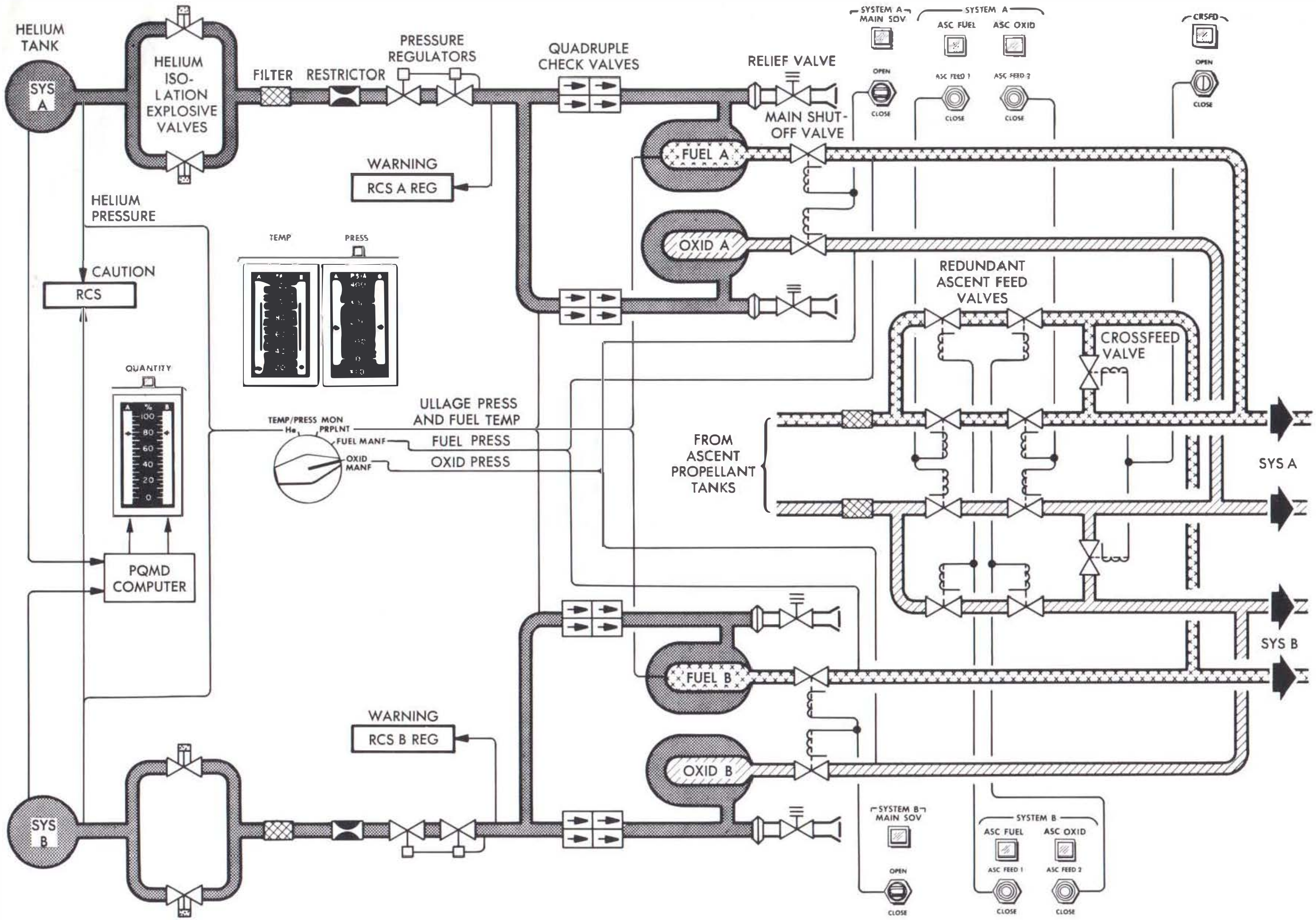
If the abort guidance section is in control, attitude errors are summed with the proportional rate commands from the attitude controller and a rate-damping signal from the rate gyro assembly. The abort guidance equipment uses this data to perform steering calculations, which result in specific thruster-on commands. The astronauts can select two or four X-axis thrusters for translation maneuvers, and they can inhibit the four upward-firing thrusters during the ascent thrust phase, thus conserving propellants. In the manual mode, the four-jet hardover maneuver, instituted when either astronaut displaces his attitude controller fully against the hard stop, fires four thrusters simultaneously, overriding any automatic commands.

For the MPS ullage maneuver, the astronauts select whether two or four downward-firing thrusters should be used. Depending on which guidance section is in control, the astronauts enter a DSKY input (primary) or use a 2-jet/4-jet selector switch (abort) to make their selection. Under manual control, a +X-translation pushbutton fires the four downward-firing thrusters continuously until the pushbutton is released. Firing two thrusters conserves RCS propellants; however, it takes longer to settle the MPS propellants.

RCS OPERATION

Functionally, the RCS can be subdivided into pressurization sections, propellant feed sections, and thruster sections. Because RCS systems A and B are identical, only one system is described.

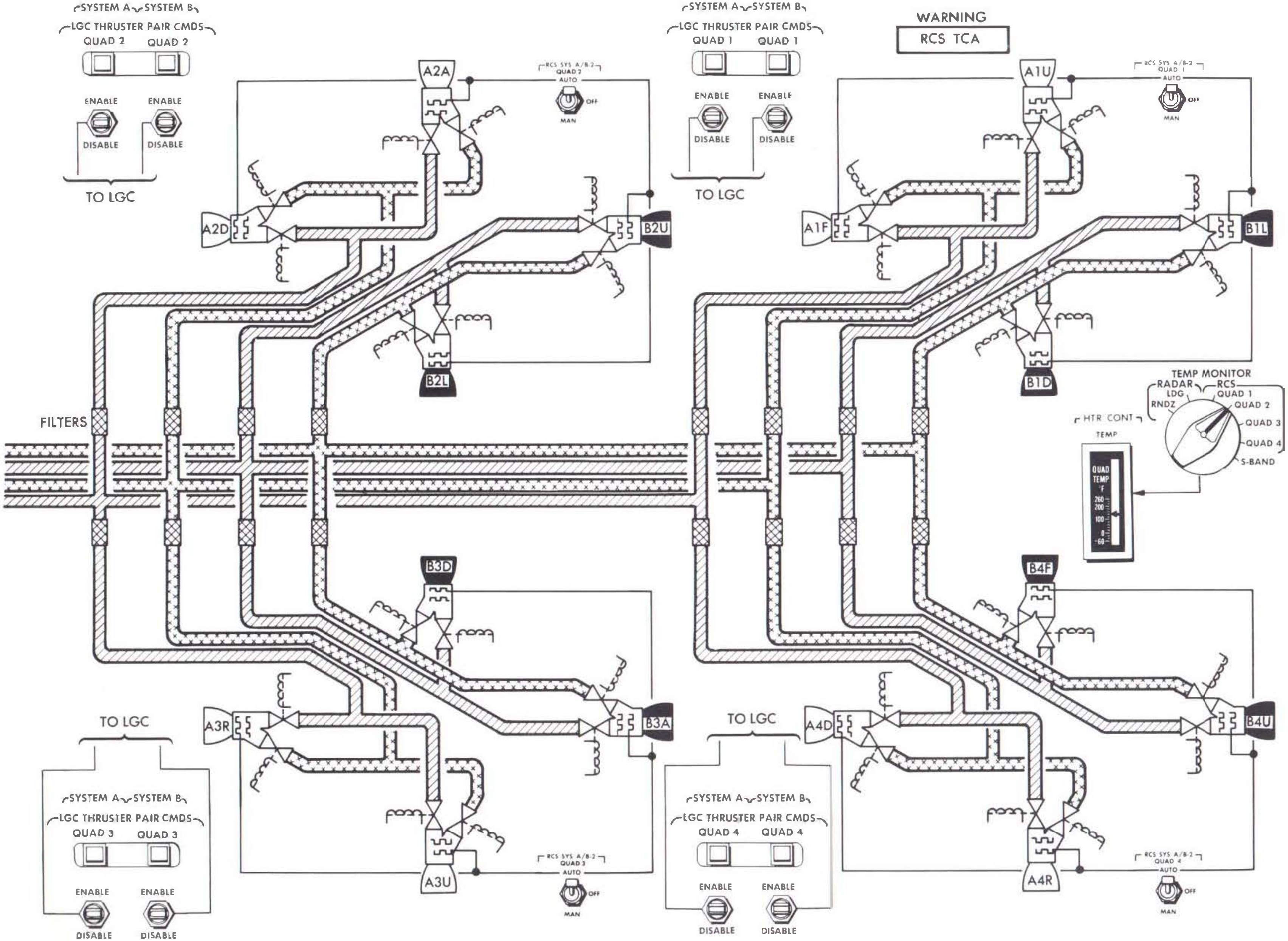
Fuel and oxidizer are loaded into bladders within the propellant tanks and into the manifold plumbing that extends from the tanks through the normally open main shutoff valves up to the solenoid valves at each thruster pair. Before separation of the LM from the CSM, the astronauts set switches on the control panel to preheat the thrusters and fire explosive valves to pressurize the propellant tanks. Gaseous helium, reduced to a working pressure, enters the propellant tanks and forces the fuel and oxidizer to the thrusters. Here, the propellants are blocked by fuel and oxidizer valves that remain closed until a thruster-on command is issued. As the selected thruster receives the



R-91

Helium Pressurization and Propellant Feed Sections Flow Diagram

GRUMMAN



R-92A

Propellant Lines and Thrusters Flow Diagram fire command, its fuel and oxidizer valves open to route the propellants through an injector into the combustion chamber, where they impinge and ignite by hypergolic action. The astronauts can disable malfunctioning thrusters by operating appropriate LGC thruster pair command switches on the control panel. When any of these switches is in the disable position, it issues a signal informing the LM guidance computer that the related thruster pair is disabled and that alternate thrusters must be selected. Talkbacks above each switch informs the astronauts of the status of related thruster pair.

PRESSURIZATION SECTION

The RCS propellants are pressurized with high-pressure gaseous helium, stored at ambient temperature. The helium tank outlet is sealed by parallel-connected, redundant helium isolation explosive valves that maintain the helium in the tank until the astronauts enter the LM and prepare the RCS for operation. When the explosive valves are fired, helium enters the pressurization line and flows through a filter. A restrictor orifice, downstream of the filter, dampens the initial helium surge.

Downstream of the restrictor, the flow path contains a pair of pressure regulators connected in series. The primary (upstream) regulator is set to reduce pressure to approximately 181 psia. The secondary (downstream) regulator is set for a slightly higher output (approximately 185 psia). In normal operation, the primary regulator is in control and provides proper propellant tank pressurization.

Downstream of the pressure regulators, a manifold divides the helium flow into two paths: one leads to the oxidizer tank; the other, to the fuel tank. Each flow has quadruple check valves that permit flow in one direction only, thus preventing backflow of propellant vapors if seepage occurs in the propellant tank bladders. A relief valve assembly protects each propellant tank against overpressurization. If helium pressure builds up to 232 psia, the relief valve opens to relieve pressure by venting helium overboard. At 212 psia, the relief valve closes.

PROPELLANT FEED SECTION

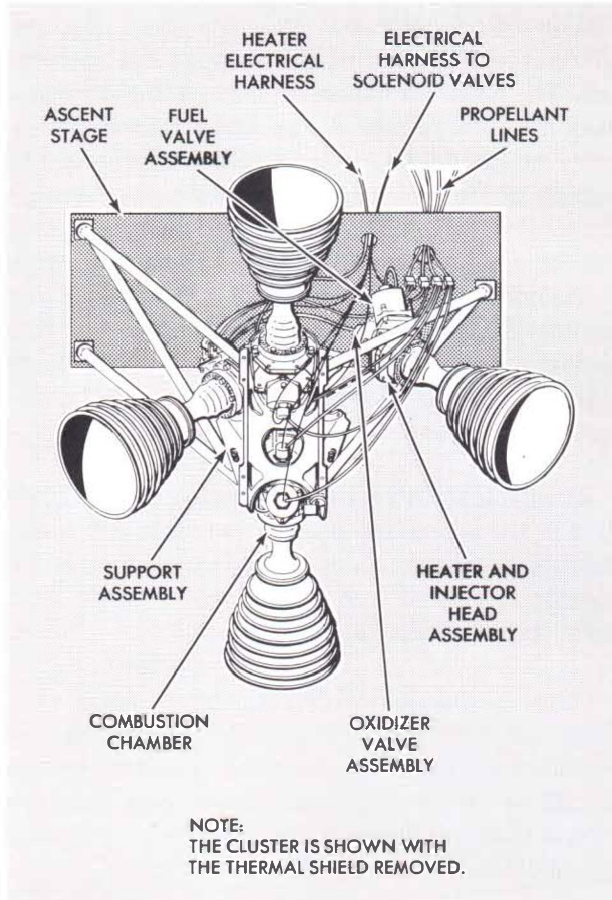
Fuel and oxidizer are contained in flexible bladders in the propellant tanks. Helium routed into the void between the bladder and the tank wall squeezes the bladder to positively expel the propellant under zero-gravity conditions. The propellants flow through normally open main shutoff valves into separate fuel and oxidizer manifolds that lead to the thrusters. A switch on the control panel enables the astronauts to simultaneously close a pair of fuel and oxidizer main shutoff valves, thereby isolating a system's propellant tanks from its thrusters, if the propellants of that system are depleted or if the system malfunctions. After shutting off one system, the astronauts can restore operation of all 16 thrusters by opening the crossfeed valves between the system A and B manifolds.

During ascent engine firing, the astronauts may open the normally closed ascent propulsion section/RCS interconnect lines if the LM is accelerating in the +X-axis (upward) direction; closing the interconnect lines shortly before ascent engine shutdown ensures that no ascent helium enters the RCS propellant lines. Control panel switches open the interconnect valves in fuel-oxidizer pairs, for an individual RCS system, or for both systems simultaneously.

Transducers in the propellant tanks sense helium pressure and fuel temperature. Due to the proximity of the fuel tank to the oxidizer tank, the fuel temperature is representative of propellant temperature. Quantity indicators for system A and B display the summed quantities of fuel and oxidizer remaining in the tanks.

THRUSTER SECTION

Each of the four RCS clusters consists of a frame, four thrusters, eight heating elements, and associated sensors and plumbing. The clusters are diametrically opposed, evenly distributed around the ascent stage. The frame is an aluminum-alloy casting, shaped like a hollow cylinder, to which the four thrusters are attached; the entire cluster assembly is connected to the ascent stage by hollow struts. The vertical-firing thrusters are at the top and bottom of the cluster frame, the horizontal-firing thrusters are at each side. Each cluster is enclosed in a thermal shield; part of the four thruster combustion chambers and the extension nozzles protrude from the shield. The thermal shields aid in maintaining a temperature-controlled environment for the propellant lines from the ascent stage to the thrusters, minimize heat loss, and reflect radiated engine heat and solar heat.



R-93

Thrust Chamber Cluster

The RCS thrusters are radiation-cooled, pressure-fed, bipropellant rocket engines that operate in a pulse mode to generate short thrust impulses for fine attitude corrections (navigation alignment maneuvers) or in a steady-state mode to produce continuous thrust for major attitude or translation changes. In the pulse mode, the thrusters are fired intermittently in bursts of less than 1 second duration – the minimum pulse may be as short as 14 milliseconds – however, the thrust level does not build up to the full 100 pounds that each thruster can produce. In the steady-state mode, the thrusters are fired continuously (longer than 1 second) to produce a stabilized 100 pounds of thrust until the shutoff command is received.

Two electric heaters, which encircle the thruster injector, control propellant temperature by conducting heat to the combustion chamber and the propellant solenoid valves. The heaters maintain the cluster at approximately +140° F, ensuring that the combustion chambers are properly preheated for instantaneous thruster starts. The astronauts can determine, by use of a temperature indicator and a related selector switch, if a cluster temperature is below the minimum operational temperature of 119° F and take corrective action to restore the cluster temperature.

Propellants are prevented from entering the thrusters by dual-coil, solenoid-operated shutoff valves at the fuel and oxidizer inlet ports. These valves are normally closed; they open when an automatic or a manual command energizes the primary or secondary coil, respectively. Seven milliseconds after receiving the thruster-on command, the valves are fully opened and the pressurized propellants flow through the injector into the combustion chamber where ignition occurs. By design, the fuel valve opens 2 milliseconds before the oxidizer valve, to provide proper ignition characteristics. Orifices at the valve inlets meter the propellant flow so that an oxidizer to fuel mixture ratio of 2 to 1 is obtained at the injector.

As the propellants mix and burn, the hot combustion gases increase the chamber pressure, accelerating the gas particles through the chamber exit. The gases are expanded through the divergent section of the nozzle at supersonic velocity, eventually building up to reach a reactive force of 100 pounds of thrust in the vacuum of space. The gas temperature within the combustion chamber stabilizes at approximately 5,200° F. The temperature at the nonablative chamber wall is maintained at a nominal 2,200° F by a combined method of film cooling (a fuel stream sprayed against the wall) and radiation cooling (dissipation of heat from the wall surface into space).

When the thruster-off command is received, the coils in the propellant valves deenergize, and spring pressure closes the valves. Propellant trapped in the injector is ejected and burned for a short time, while thrust decays to zero pounds.

When a thruster-on signal commands a very short duration pulse, engine thrust may be just beginning to rise when the pulse is ended and the propellant valves close. Under these conditions, the thrusters do not develop the full-capacity thrust of 100 pounds.

A failure-detection system informs the astronauts should a thruster fail on (fires without an on command) or off (does not fire despite an on command). Either type of failure produces the same indication: a warning light goes on and the talkback related to the failed thruster pair changes from the normal gray to a red display. The astronauts then disable the malfunctioning thruster pair by operating appropriate LGC thruster pair command switch and pulling associated circuit breaker (if thruster fail on condition exists). To offset the effects of a thruster-on failure, opposing thrusters will automatically receive fire commands and keep firing until the failed-on thruster has been disabled. A thruster-off condition is detected by a pressure switch, which senses combustion chamber pressure. When a fire command is received, the solenoid valves of the thruster open, resulting in ignition and subsequently in pressure buildup in the combustion chamber. When the pressure reaches 10.5 psia, the switch closes, indicating that proper firing is in process. When a very short duration fire command is received (a pulse of less than 80 milliseconds), the combustion chamber pressure may not build up enough for a proper firing. Short pulse skipping does not result in a failure indication, unless six consecutive pulses to the same thruster have not produced a response. In this case, the warning light and the talkback inform the astronauts that they have a nonfiring thruster, which must be isolated.

EQUIPMENT

EXPLOSIVE VALVES

The explosive valves are single-cartridge-actuated, normally closed valves. The cartridge is fired by applying power to the initiator bridgewire. The resultant heat fires the initiator, generating gases in the valve explosion chamber at an extremely high rate. The gases drive the valve piston into the housing, aligning the piston port permanently with the helium pressurization line.

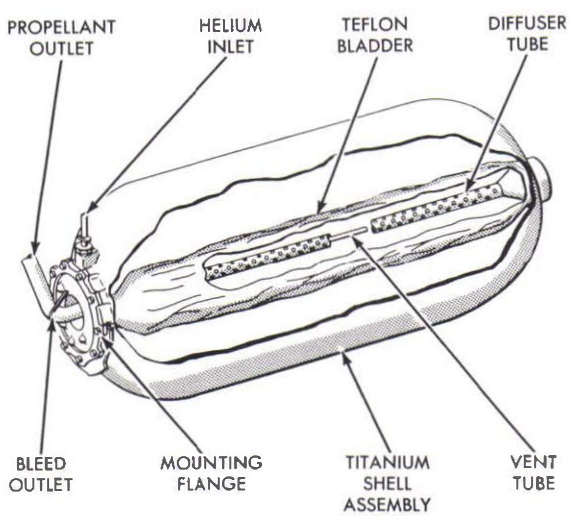
PROPELLANT QUANTITY MEASURING DEVICE

The propellant quantity measuring device, consisting of a helium pressure/temperature probe and an analog computer for each system, measures the total quantity of propellants (sum of fuel and oxidizer) in the fuel and oxidizer tanks. The output voltage of the analog computer is fed to an indicator and is displayed to the astronauts on two scales (one for each RCS system) as percentage of propellant remaining in the tanks.

The propellant quantity measuring device uses a probe to sense the pressure/temperature ratio of the gas in the helium tank. This ratio, directly proportional to the mass of the gas, is fed to an analog computer that subtracts the mass in the helium tank from the total mass in the system, thereby deriving the helium mass in the propellant tanks. Finally, propellant tank ullage volume is subtracted from total tank volume to obtain the quantity of propellant remaining. Before firing the helium isolation explosive valves, the quantity displayed exceeds 100%, so that, after the valves are opened and the gas in the helium tank becomes less dense, the indicated quantity will be 100%.

PROPELLANT STORAGE TANKS

The four propellant tanks, one fuel and one oxidizer tank for each system, are cylindrical with hemispherical ends; they are made of titanium alloy. In each tank, the propellant is stored in a Teflon bladder, which is chemically inert and resistant to the corrosive action of the propellants. The bladder is supported by a standpipe running lengthwise in the tank. The propellant is fed into the tank from a fill point accessible from the exterior of the LM. A bleed line that extends up through the standpipe draws off gases trapped in the bladder. Helium flows between the bladder and the tank wall and acts upon the bladder to provide positive propellant expulsion.



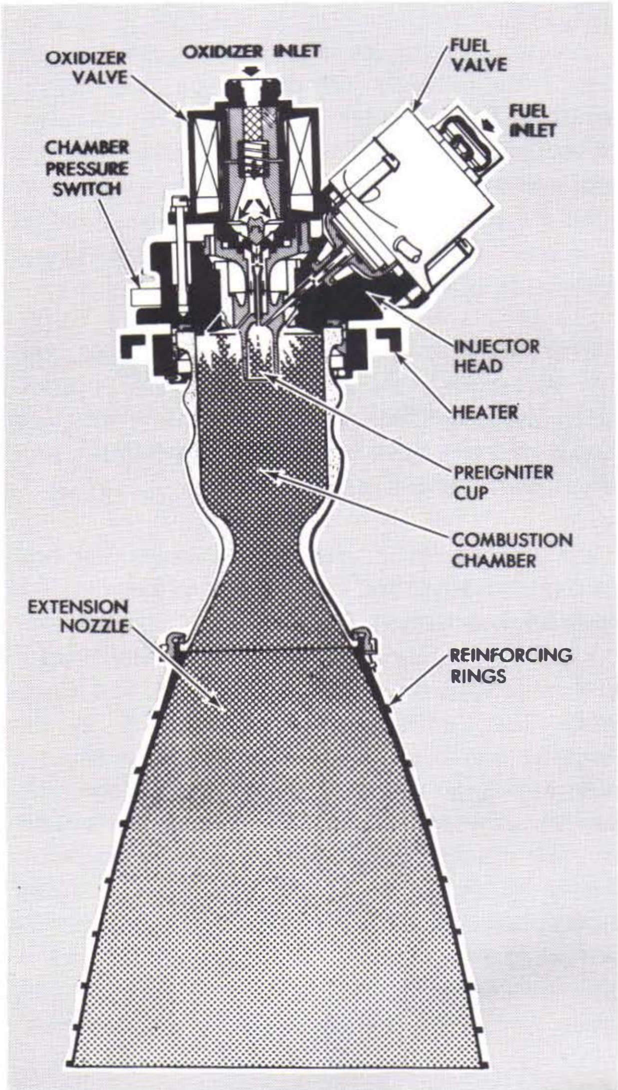
R-94

Propellant Storage Tank

THRUST CHAMBER ASSEMBLIES

The efficiency of a rocket engine is expressed in terms of specific impulse, which is the impulse-producing capacity per unit weight of propellant. The nominal specific impulse of the RCS thrusters at steady-state firing is 281 seconds. The thrusters have a favorable high-thrust to minimum-impulse ratio, meaning that they produce a comparatively high thrust for their size, as well as a very low thrust impulse. In addition, the thrusters have a fast response time. Response time is the elapsed time between a thruster-on command and stable firing at rated thrust, and between a thruster-off command and thrust decay to an insignificant value. Finally, the thrusters have a long cycle life, denoting that the thrusters can be restarted many times.

Each thruster consists of a fuel valve, an oxidizer valve, an injector head assembly, a combustion chamber, an extension nozzle, and thruster instrumentation.



R-95

Reaction Control Thruster

The fuel and oxidizer valves are normally closed, two-coil, solenoid valves that control propellant flow to the injector. Each valve has an inlet filter, an inlet orifice, a spool assembly, a spring, an armature, and a valve seat. The primary and the secondary coils are wound on a magnetic core in the spool assembly. These coils receive the thruster on and off commands. The fuel and oxidizer valves are identical except for the inlet orifice, the valve seat, and the spool assembly. Because the ratio of oxidizer to fuel at the combustion chamber must be approximately 2 to 1, the diameters of the inlet orifices and the valve seat exits differ in the two valves. The spool assembly in the fuel valve produces a faster armature response to open the fuel valve 2 milliseconds before the oxidizer valve. Permitting fuel to enter the combustion chamber first reduces the possibility of ignition delay, which could cause temporary overpressurization (spiking) in the combustion chamber. Spiking is also held to a minimum by preheating and prepressurizing the combustion chamber.

When the thruster-off command is given, the coils deenergize, releasing the armature poppets. Spring and propellant pressure return the armature poppet of each valve to its seat, shutting off propellant flow into the injector.

The injector head assembly supports the fuel and oxidizer valves and the mounting flange for the combustion chamber. The propellant impingement and chamber cooling arrangement in the injector consists of four concentric orifice rings and a preigniter cup. Initial combustion occurs in the preigniter cup (a precombustion chamber) where a single fuel spray and oxidizer stream impinge. This provides a smoother start transient because it raises the main combustion chamber pressure for satisfactory ignition. The main fuel flow is routed through holes in a tube to a chamber that channels the fuel to an annulus. The annulus routes fuel to three concentric fuel rings. The outermost ring sprays fuel onto the combustion chamber wall, where it forms a boundary layer for cooling. The middle ring has eight orifices that spray fuel onto the outer wall of the preigniter cup to cool the cup. Eight primary orifices of the middle ring eject fuel to mix with the oxidizer. The main oxidizer flow is routed through holes in the oxidizer preigniter tube, to a chamber that supplies the eight primary oxidizer orifices of the innermost ring. The primary oxidizer and fuel orifices are arranged in doublets, at angles to each other, so that the emerging propellant streams impinge. Due to the hydraulic delay built into the injector, ignition at these eight doublets occurs approximately 4 milliseconds later than ignition inside the preigniter cup.

The combustion chamber is made of machined molybdenum, coated with silicon to prevent oxidation of the base metal. The chamber is cooled by radiation and by a film of fuel vapor. The extension nozzle is fabricated from L605 cobalt base alloy; eight stiffening rings are machined around its outer surface to maintain nozzle shape at high temperatures. The combustion chamber and extension nozzle are joined together by a large coupling nut and lockring.

HEATERS

Two redundant, independently operating heating systems are used simultaneously to heat the RCS clusters. Two electric heaters, one from each system, encircle the injector area of each thruster. The heaters normally operate in an automatic mode; redundant thermal switches (two connected in parallel for each thruster) sense injector temperature and turn the heaters on and off to maintain the temperature close to +140° F. The heaters of the primary heating system are powered directly from their circuit breakers. Power to the redundant system is routed through switches that permit the astronauts to operate this system for each cluster individually, either under automatic thermal switch control or with heaters continuously on, or off.