

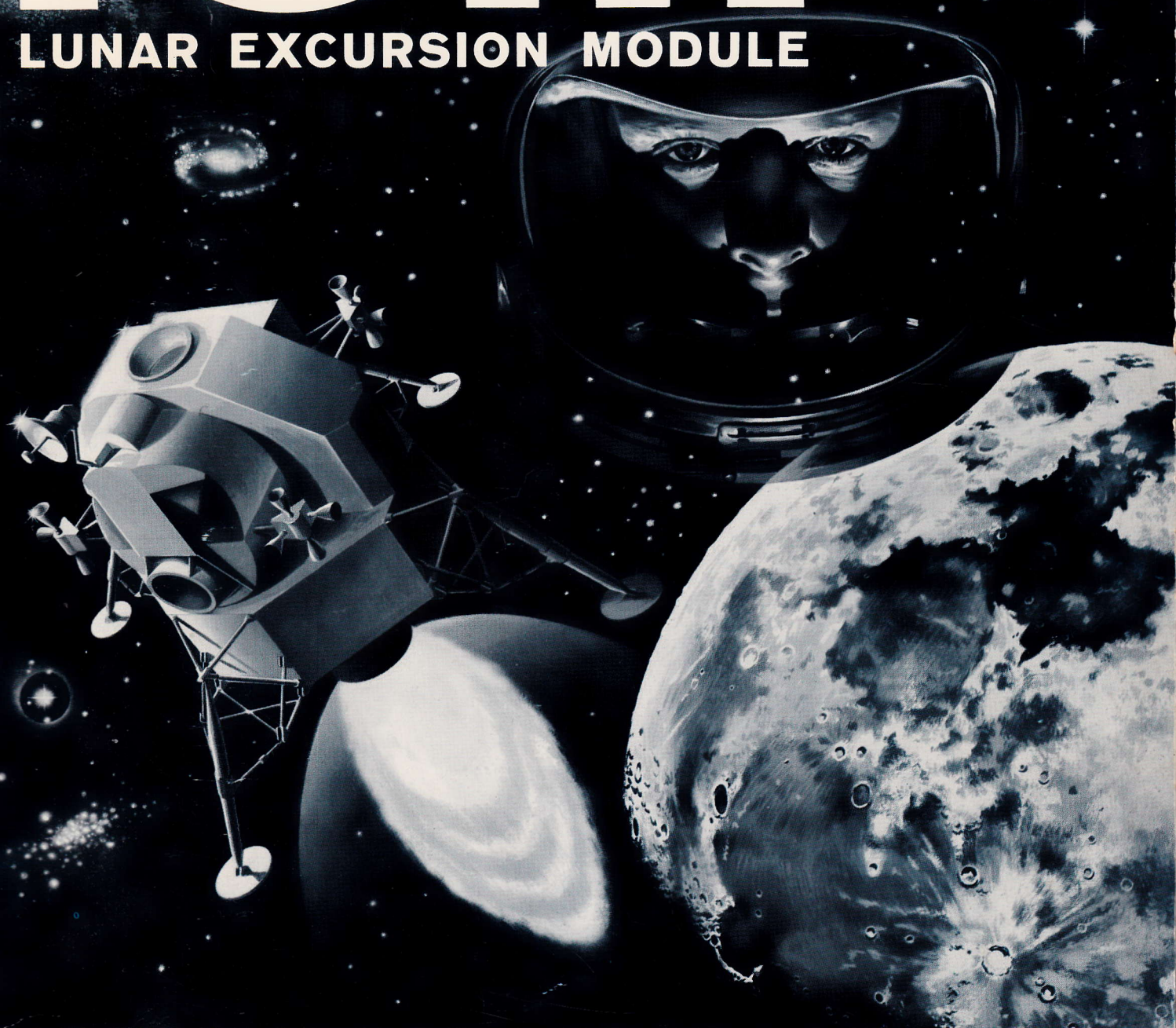
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LUNAR EXCURSION MODULE



FIRST MANNED LUNAR LANDING FAMILIARIZATION MANUAL

GRUMMAN AIRCRAFT ENGINEERING CORPORATION



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FOREWORD

This Familiarization Manual provides an operational description of all subsystems and major components of the lunar landing LEM. The information contained herein is for orientation and indoctrination purposes only. The scope of coverage describes the LEM mission, spacecraft structure, operational subsystems, prelaunch operations, and ground support equipment.

SECTION I

MISSION DESCRIPTION

1-1. GENERAL.

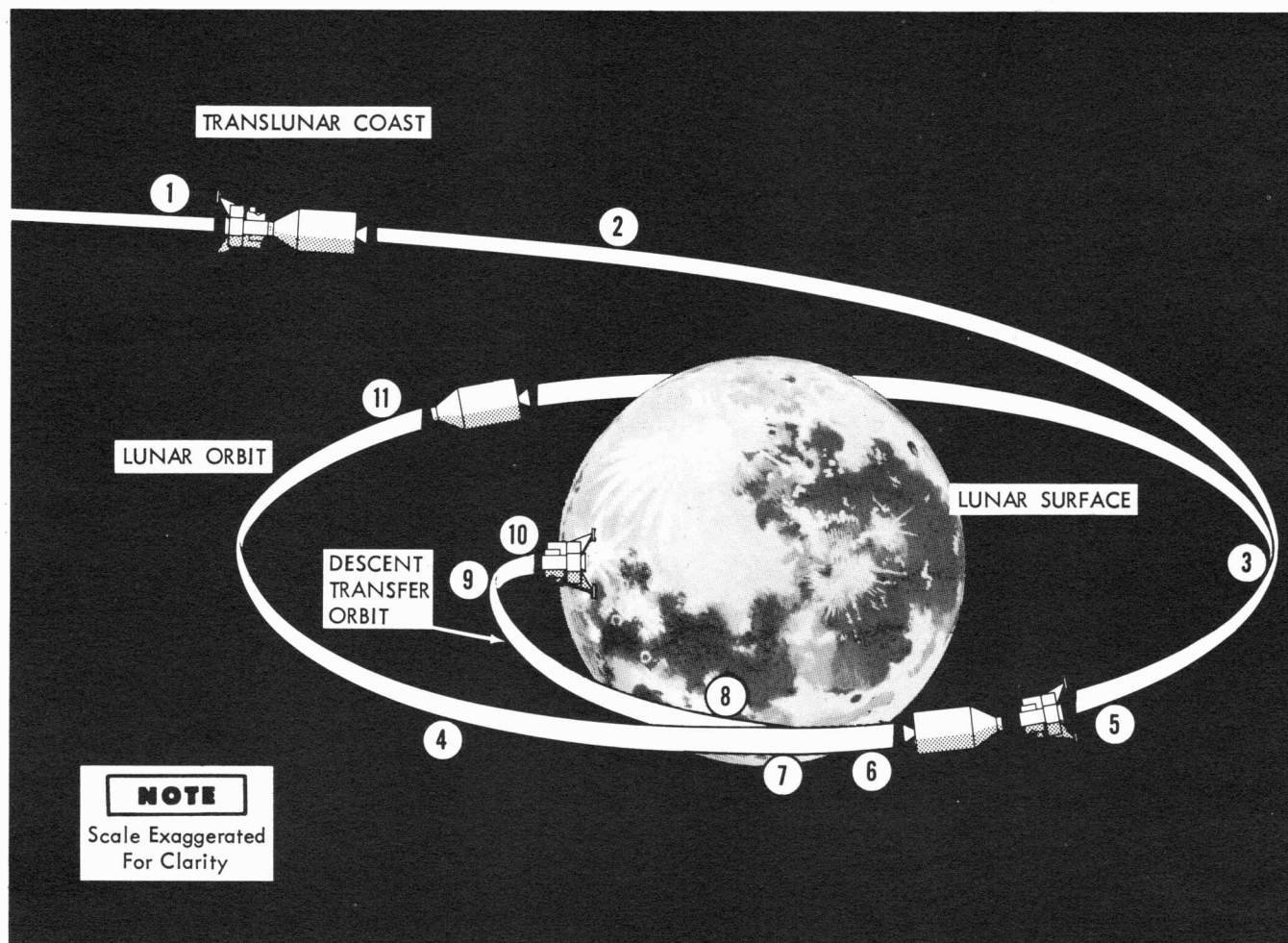
1-2. The Lunar Excursion Module (LEM) System consists of a manned vehicle (module) and various related subsystems. The LEM System enables successful completion of the LEM mission, utilizing the concept known as the Lunar Orbital Rendezvous (LOR) technique. The LEM mission is part of the overall Apollo mission, and begins shortly after separation of the LEM from the Command/Service modules continuing through the injection of the LEM from lunar orbit into a descent trajectory. The LEM lands on the lunar surface, where it serves as a communications and life support center, and finally launches itself for rendezvous with the orbiting Command/Service modules.

1-3. LEM MISSION.

1-4. Prior to earth launch, the LEM System is subjected to rigorous checkout to assure complete mission reliability and maximum crew safety. System acceptance and functional tests, integrated equipment tests, assembly tests, launch pad tests, and the countdown operation permit constant system monitoring. During these tests, each subsystem is checked to that level possible without equipment removal. The tests do not probe deeper than the unit-replacement level. The complete LEM System is exercised through all modes of operation and all redundancies are isolated and checked. An integrated data acquisition, processing, and display system, Preflight Acceptance Checkout Equipment - Spacecraft PACE-S/C, is utilized to monitor all checkout operations and facilitate isolating malfunctions.

1-5. At launch, the LEM System is stowed above the S-IVB stage of the Saturn V launch vehicle, along the longitudinal centerline. The Command/Service modules (the Command module contains the three-man crew) are attached to the LEM and S-IVB stage by an adapter. This arrangement forms the nose of the Saturn. When launched, the Saturn vehicle injects the payload, consisting of the S-IVB stage, LEM, and the Command/Service modules, into an earth orbit.

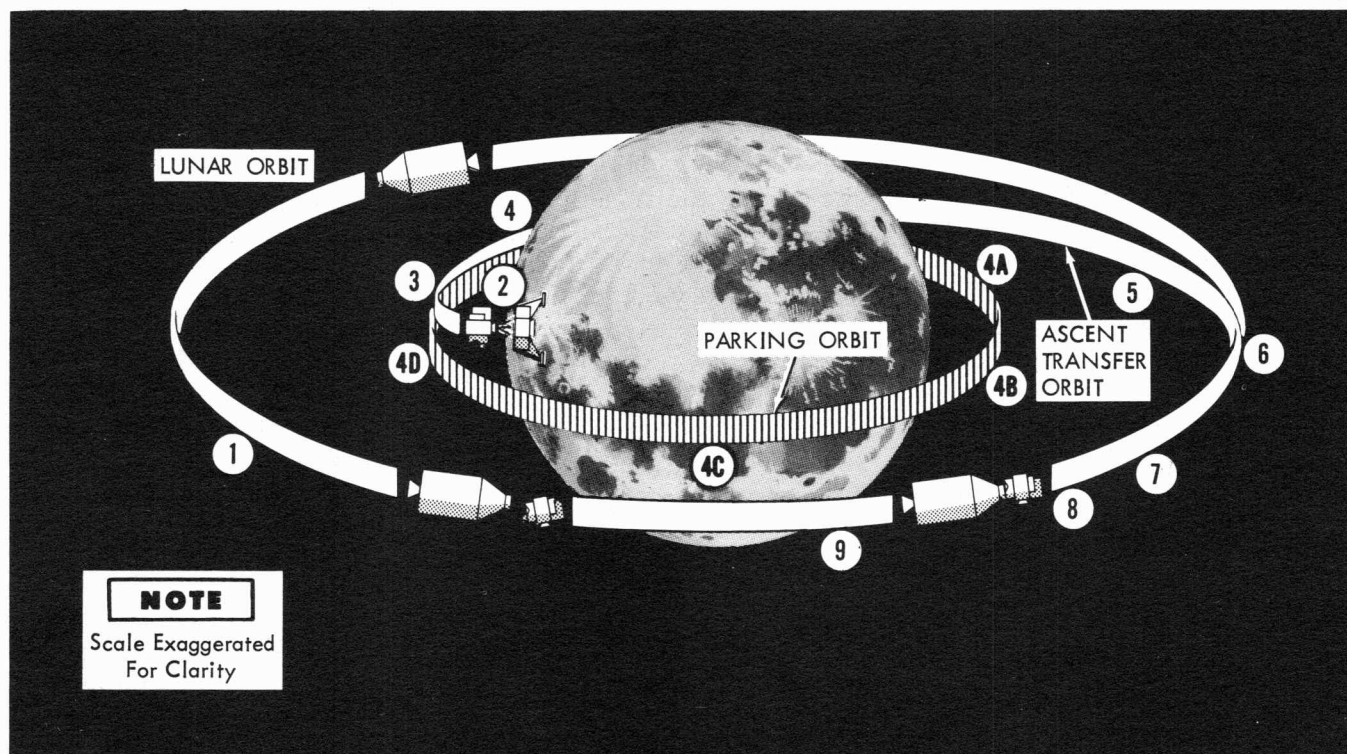
1-6. When this orbit has been achieved, the three astronauts in the Command module perform subsystem checkouts in preparation for escape from the earth orbit. At this time, certain in-flight maintenance operations may be performed, if necessary. Mission abort may be executed now or at any other time during the overall mission. While in orbit, the Command module performs landmark sightings and other navigation and guidance tasks. Upon completion of earth orbit (normally two revolutions), the S-IVB Propulsion System injects the LEM and Command/Service modules into an earth-moon trajectory (translunar injection). After the initial coast of translunar flight, the Command/Service modules detach as a unit from the LEM and S-IVB stage, rotate 180° in free flight, and dock with the nose of the Command module on the top hatch of the LEM (transposition). During transposition, the LEM and S-IVB stage are stabilized by the Stabilization and Control System of the S-IVB stage. Upon completion of transposition,



- ① Transposition near earth.
- ② LEM/CSM continues Translunar Coast. LEM remains passive.
- ③ Service Module Propulsion System injects LEM/CSM into 80 nmi Lunar Orbit.
- ④ Two crew members enter LEM and perform Lunar Orbit Checkout.
- ⑤ LEM crew aligns Navigation & Guidance Subsystem prior to separation from CSM.
- ⑥ Reaction Control Subsystem separates LEM from CSM.
- ⑦ Descent engine injects LEM into Descent Transfer Orbit. CSM remains in Lunar Orbit.
- ⑧ Descent engine cuts off. LEM coasts to Pericynthion.
- ⑨ Descent engine injects LEM into initial powered descent which ends with LEM 20 nmi from landing site.
- ⑩ LEM enters final powered descent to 1000 ft and proceeds to touchdown.
- ⑪ CSM remains in Lunar Orbit for eventual rendezvous with LEM after completion of Lunar stay.

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Figure 1-1. Mission Profile (Sheet 1)



- ① CSM still in Lunar Orbit. Proper LEM launch time occurs when CSM is slightly past LEM launch point. If LEM is launched at this time it enters directly into Ascent Transfer Orbit. If LEM launching is delayed, it must enter into Parking Orbit prior to rendezvous with CSM.
- ② LEM is launched from lunar surface into powered ascent. Descent stage remains on lunar surface.
- ③ LEM reaches Pericyynthion. Ascent engine cuts off.
- ④ If LEM was launched at proper time it enters directly into Ascent Transfer Orbit. If launch was delayed, LEM enters Parking Orbit.
- ④A Rendezvous Radar and landmark sightings used to determine LEM orbit and relative position of CSM. Crew also determines time at which ascent engine must be fired to inject LEM into Ascent Transfer Orbit.
- ④B LEM placed in minimum power consumption state. All unnecessary equipment turned off.
- ④C At 90 minutes before firing ascent engine, LEM is prepared for injection into Ascent Transfer Orbit. IMU is aligned and Rendezvous Radar tracks CSM.
- ④D Ascent engine injects LEM into Ascent Transfer Orbit.
- ⑤ Ascent Transfer Orbit carries LEM from Pericynthion to within rendezvous range of orbiting CSM.
- ⑥ LEM reaches rendezvous range (20 nmi to 500 ft from CSM).
- ⑦ When LEM is approximately 500 ft from CSM, LEM pilot manually maneuvers LEM to a docking attitude and adjusts rate of closure until complete docking is accomplished.
- ⑧ LEM is secured to CSM. Crew transfers from LEM to CSM.
- ⑨ LEM is jettisoned, concluding LEM Mission. Service Module engine is fired, taking CSM out of Lunar Orbit and into earth trajectory.

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Figure 1-1. Mission Profile (Sheet 2)

the spent S-IVB stage and the lower part of the LEM adapter are jettisoned. When the jettisoned S-IVB stage is clear, the Command/Service modules and the LEM are oriented for the translunar coast period (figure 1-1).

1-7. The LEM remains passive during the translunar coasting flight, except for the IMU heaters and portions of the environmental control subsystem EPS, (ECS), and instrumentation subsystem. The Command module performs all navigational guidance functions and, implemented by the Service module reaction controls, initiates mid-course correction maneuvers.

1-8. Approximately 70 hours after launch, the Service module Propulsion System injects the LEM and Command/Service modules into an 80-nmi circular lunar orbit. During the first part of this lunar orbit the Command module performs landmark sightings for orbit determination and Navigation and Guidance Subsystem updating.

1-9. Upon completion of the first portion of the lunar orbit, the LEM is pressurized from the Command module and the LEM internal environment is checked. Two astronauts enter the LEM through the top docking hatch. The third astronaut remains in the Command module. The 2 man LEM crew then performs a checkout of each subsystem using the on board checkout equipment (OBC E).

1-10. Upon completion of the checkout, the two astronauts align the Navigation and Guidance Subsystem. After a final landmark sighting by the Command module, the navigation and guidance parameters of the module are compared with those of the LEM to validate subsystem performance. The inertial altitude reference of the LEM Backup Guidance System is then aligned with respect to the primary system.

1-11. At a predetermined point in lunar orbit, the Reaction Control Subsystem (RCS) separates the LEM from the Command/Service module. The astronauts prepare the LEM for descent by performing a mutual visual inspection, followed by checkout of the transmission capability of the Communication Subsystem and the tracking capability of the rendezvous radar.

1-12. The descent stage of the LEM Propulsion Subsystem injects the LEM into an elliptical descent transfer orbit. This orbit has a pericynthion of 50,000 feet in the vicinity of the proposed landing site. Once in the descent transfer orbit, the descent engine cuts off and the LEM coasts in the orbit and begins passive rendezvous with the orbiting Command module. This passive rendezvous is constantly maintained in the event a decision is made to abort the mission prior to restarting the descent engine. The LEM Stabilization and Control Subsystem operates in the minimum limit cycle mode during all main rocket engine firings.

1-13. During the initial part of the descent transfer orbit coast, the descent transfer orbit ephemeris is determined by using the Command module to track the LEM, or the LEM radar to track the Command module. Approximately halfway through this orbit, the astronauts may have to update the IMU of the Navigation and Guidance Subsystem by star sightings because more than an hour will have elapsed between alignments. Subsystem checkouts are accomplished by the astronauts during the lunar-day part of the orbit.

1-14. At the point where the LEM has reached the pericyynthion, the descent stage of the Propulsion Subsystem is fired to initiate powered descent. During powered descent, landing radar data and IMU information is used. At an altitude of approximately 25,000 feet, the radar data is statistically mixed with the IMU information. Because the inertial data degrades with time while the radar data improves, the radar information is weighted more heavily as the descent progresses. From an altitude of approximately 15,000 feet until touchdown, pure radar data may be used for IMU updating. A meaningful display of noninertial information, independent of the primary Navigation and Guidance Subsystem, is desirable during the descent, to permit monitoring of radar information.

1-15. At about 20 nmi from the landing site, the LEM enters its final powered descent, which includes the flare maneuver initiated at approximately 5,000 feet from the intended landing site and terminated at the hover point (approximately 1,000 feet). Final descent to the lunar surface is then performed from the 1,000-foot altitude with a flight path angle that affords adequate visibility of the landing site. Descent from 1,000 feet to touchdown is performed manually, with one astronaut flying the LEM; the other, acting as observer. An abort may be executed at any point up to the moment of actual lunar touchdown, by means of powered ascent and rendezvous with the orbiting Command/Service modules.

1-16. After LEM touchdown on the lunar surface, the two astronauts perform a check-out of all subsystems to determine whether damage occurred upon landing and to discover any conditions that may hinder the LEM in performing a successful ascent. Required remedial measures or alternate modes of operation may now be implemented. The crew then prepares for one astronaut to leave the LEM. The preparations consist of surveying the surrounding lunar landscape, checking the LEM hatches, and performing a final check of the portable life support systems. All equipment not essential for lunar stay is turned off.

1-17. After the LEM is secured for lunar stay, it is depressurized and one astronaut leaves. The LEM is then pressurized. The exterior of the LEM is inspected by the exploring astronaut and the communication antennas are deployed. A television system is used to send pictures of the lunar scene back to earth via the S-band link. Photographic records are also made and samples of the lunar surface are collected. The astronaut outside the LEM is always in direct visual and voice contact (via VHF) with the astronaut inside the LEM. After approximately 3 hours of exploration, the astronaut must return to the LEM to replenish his life support pack. Life support stores permit six refills of the portable life support pack.

1-18. Upon completion of lunar surface operation, the LEM is depressurized and the exploring astronaut enters. After LEM pressurization, the portable life support system (PLSS) is replenished. For the PLSS to have a 4-hour operating capacity, a 6-hour replenishing period is required. A voice report is made to earth via the S-band link and pertinent scientific data is transmitted and recorded. At this time, the astronauts rest, eat, and perform hygienic tasks.

1-19. When the lunar stay is completed, the astronauts prepare the LEM for launch and ascent. A complete checkout is made of all subsystems. The Navigation and Guidance Subsystem and the backup guidance section of the Stabilization and Control Subsystem are aligned. The LEM location relative to the position of the lunar orbiting

Command/Service modules is determined with the rendezvous radar. The OMU obtains celestial data for alignment of the IMU. Because the LEM descent stage is left behind at launching, all connections between the ascent and descent stages (including electrical cabling and oxygen piping) are severed at this time. The LEM is now ready for launch and ascent from the lunar surface and eventual rendezvous with the lunar orbiting Command/Service modules.

1-20. Nominal launch time occurs when the Command/Service modules in lunar orbit are slightly downrange of their zenith position over the LEM. Assuming the LEM is launched at this time, the ascent engine burns continuously from liftoff to injection into an ascent transfer orbit (approximately 6 minutes). The ascent trajectory begins with an initial vertical rise, followed by two pitchover phases (one at a high pitch rate and a final one at a comparatively low pitch rate), with burnout occurring at 50,000 feet. At this point, the LEM is in the ascent transfer orbit.

1-21. If the launch of the LEM from the lunar surface is delayed, a parking orbit is required after reaching an altitude of 50,000 feet, to attain the proper relative position of the LEM and the Command/Service modules for injection into a rendezvous trajectory. All unnecessary equipment is turned off while in the parking orbit. Approximately 90 minutes before firing the ascent engine, the LEM is prepared for injection into the ascent transfer orbit. Preparation consists of aligning the IMU, and tracking the Command/Service modules with the rendezvous radar. The ascent engine is then fired to place the LEM in the ascent transfer orbit.

1-22. When the LEM is in the free-flight ascent transfer orbit, it is carried from 50,000 feet to within rendezvous range of the Command/Service modules. Rendezvous begins at approximately 20 nmi and extends to 500 feet from the lunar orbiting Command/Service modules.

1-23. When the LEM is approximately 500 feet from the Command/Service modules, a LEM astronaut manually maneuvers the LEM to a docking altitude and adjusts the rate of closure until complete docking is accomplished. The RCS thrusters are used in the manual modes of the Stabilization and Control Subsystem. The Command/Service modules normally remain passive during rendezvous, although they are also capable of maneuvering for rendezvous, if necessary.

1-24. After docking is completed, the LEM is secured to the Command/Service modules and the two astronauts in the LEM prepare for transfer to the Command module. Pressures are equalized, LEM subsystems are turned off, and scientific samples are transferred to the Command module. After the two astronauts transfer from the LEM through the docking hatch, to the Command module, the LEM is jettisoned. This concludes the LEM mission. The Service module engine is then fired to take the Command module out of lunar orbit and into an earth trajectory. The Service module is jettisoned before the Command module is oriented for reentry of the earth's atmosphere.

SECTION II

LEM STRUCTURE

2-1. INTRODUCTION.

2-2. The LEM structure (figure 2-1), consists of two separate stages: the descent stage and the ascent stage. The stages are mated to form a self-sustaining structure. The adjoining faces of the stages provide system continuity during all phases of the mission. Provision is made for separating the stages and interconnecting umbilicals for lunar launch, or for abort at any time during the mission. The approximate dimensions and weights of the LEM and associated units are given in table 2-1.

Table 2-1. Dimensions and Weights

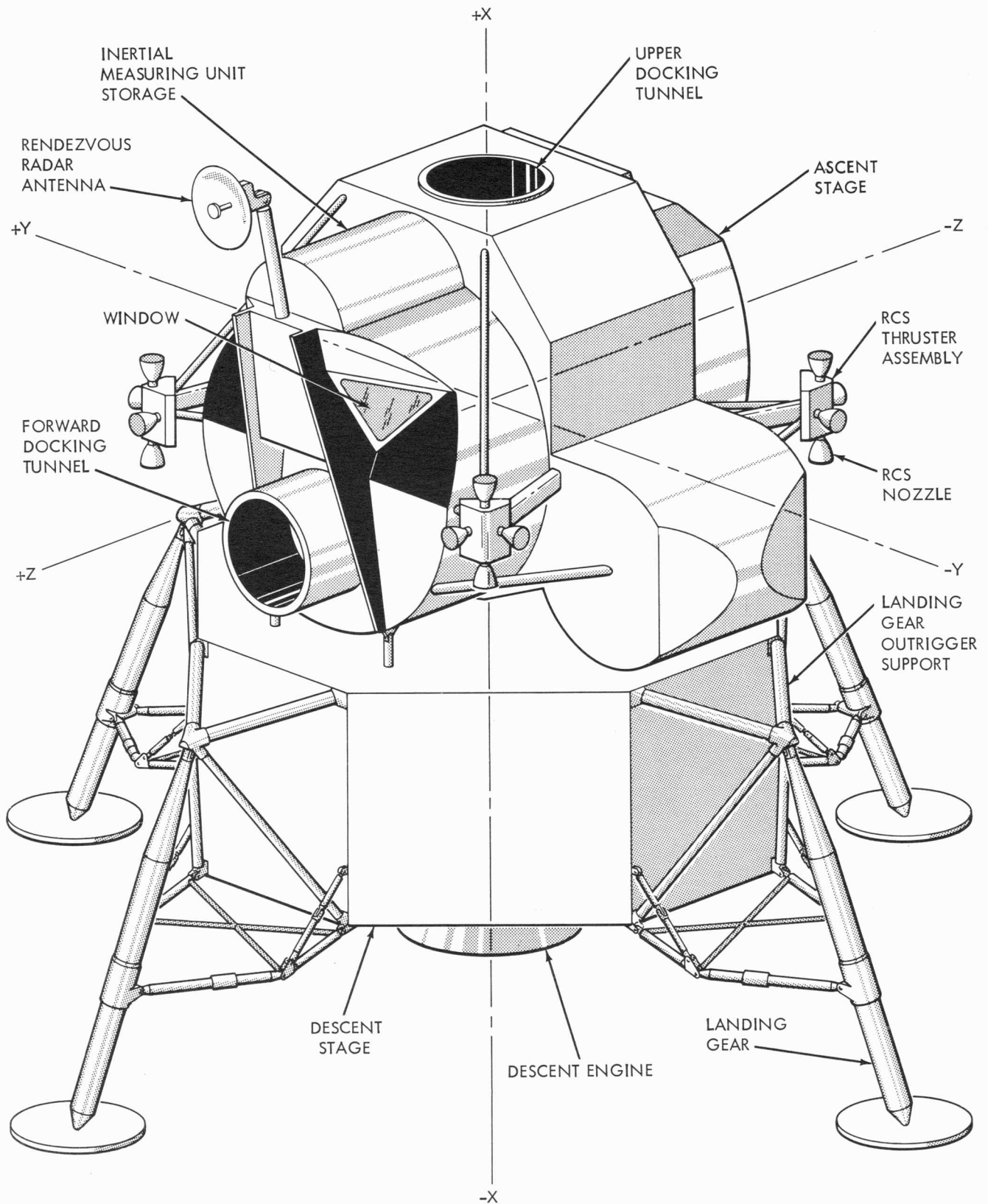
Unit	Dimensions (approx)	Earth Launch Weight (pounds)
LEM (gear folded)	Height: 22 ft 6 in. Width: 19 ft 6 in.	25,000
Descent stage	Height: 10 ft 6 in. Width: 19 ft 6 in.	
Ascent stage	Height: 10 ft Width: 14 ft	4,329
Landing gear	Diameter: 29 ft 9 in.	
Hatches	Diameter: 3 ft Maximum thickness: 4 in.	25

2-3. DESCENT STAGE.

2-4. The descent stage (figure 2-2) is the unmanned portion of the LEM. It is used for safely landing on the lunar surface and serves as sturdy platform for launching the ascent stage after completion of lunar exploration. In addition to the descent engine and related components, the descent stage houses the landing gear, descent control instrumentation, scientific equipment, and secondary tanks for water, oxygen, and hydrogen used by the ECS and Electrical Power Subsystem (EPS).

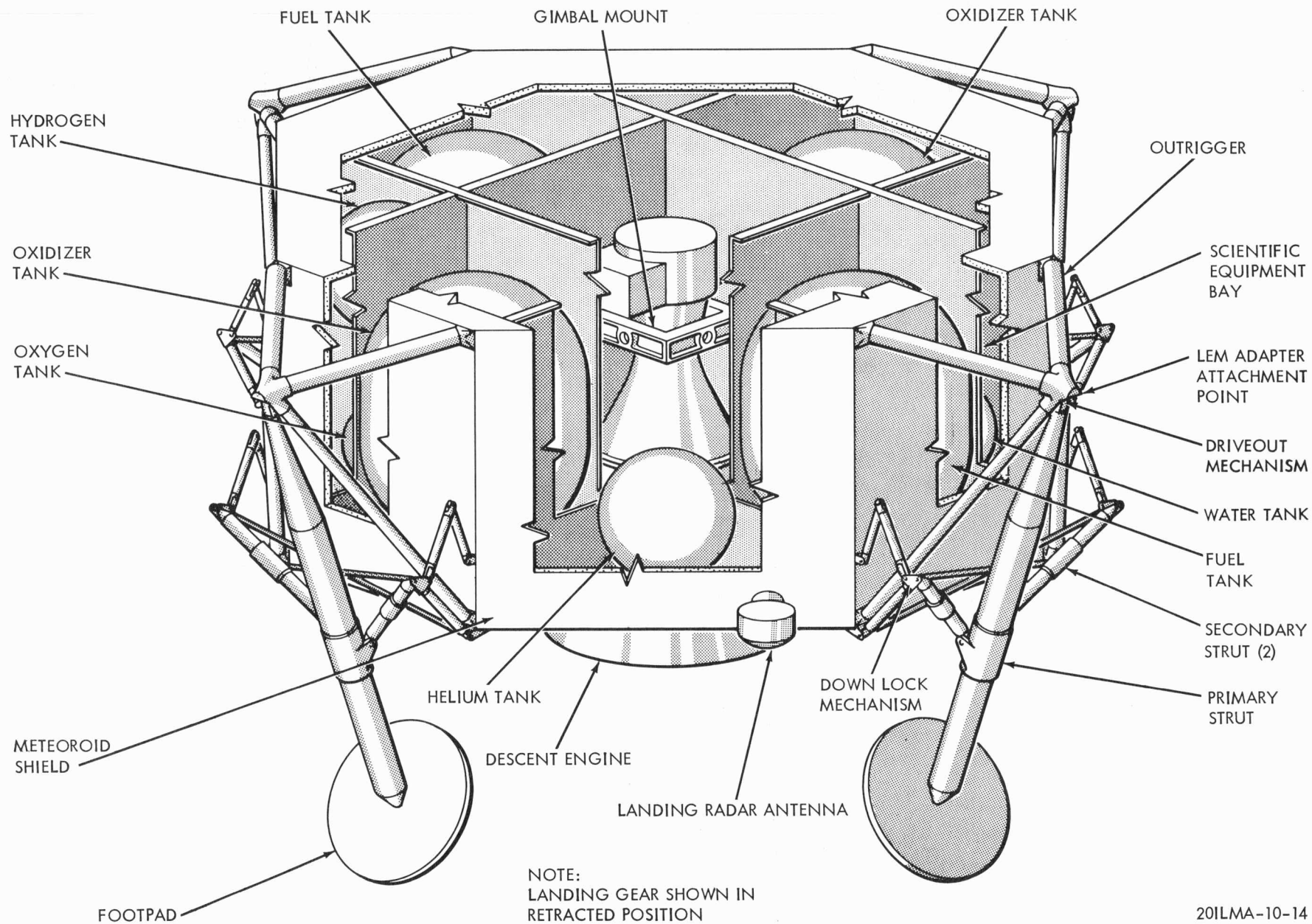
2-5. The descent stage is constructed of aluminum alloy. The structural skin is surrounded with an outer aluminum alloy skin that forms a modified octagonal shape around the descent stage and provides thermal protection for the pressure cylinders, propellant tanks, and rear equipment bay. This outer skin is approximately two inches

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Figure 2-1. LEM Structure



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Figure 2-2. Descent Stage

from the structural skin. Two pairs of transverse beams arranged in a cruciform, together with an upper and lower bulkhead closure, provide the main structural support. The intersection of the beams forms the center compartment. Outriggers that extend from the end of each of the two pairs of beams provide attachment for the landing gear legs and support the LEM while it is housed in the spacecraft adapter. The descent stage engine is in the center compartment. Four main propellant tanks surround the engine. Two oxidizer tanks are between the z-axis beams and the two fuel tanks are between the y-axis beams on the lower bulkhead. Scientific equipment and auxiliary tanks are adjacent to the propellant tanks.

2-6. LANDING GEAR.

2-7. The cantilever-type landing gear (figure 2-2), attached externally to the descent stage, consists of four legs connected to outriggers that extend from the ends of the structural beams. The legs extend from the front, rear, and sides of the LEM at an angle of approximately 45°. Each landing gear leg consists of a primary strut and footpad, a drive-out mechanism, two secondary struts, two downlock mechanism, and a pair of triangular support frames joined together by two crossbeams. All struts are packed with crushable aluminum honeycomb. The primary struts absorb compression loads; the secondary struts, compression and tension loads.

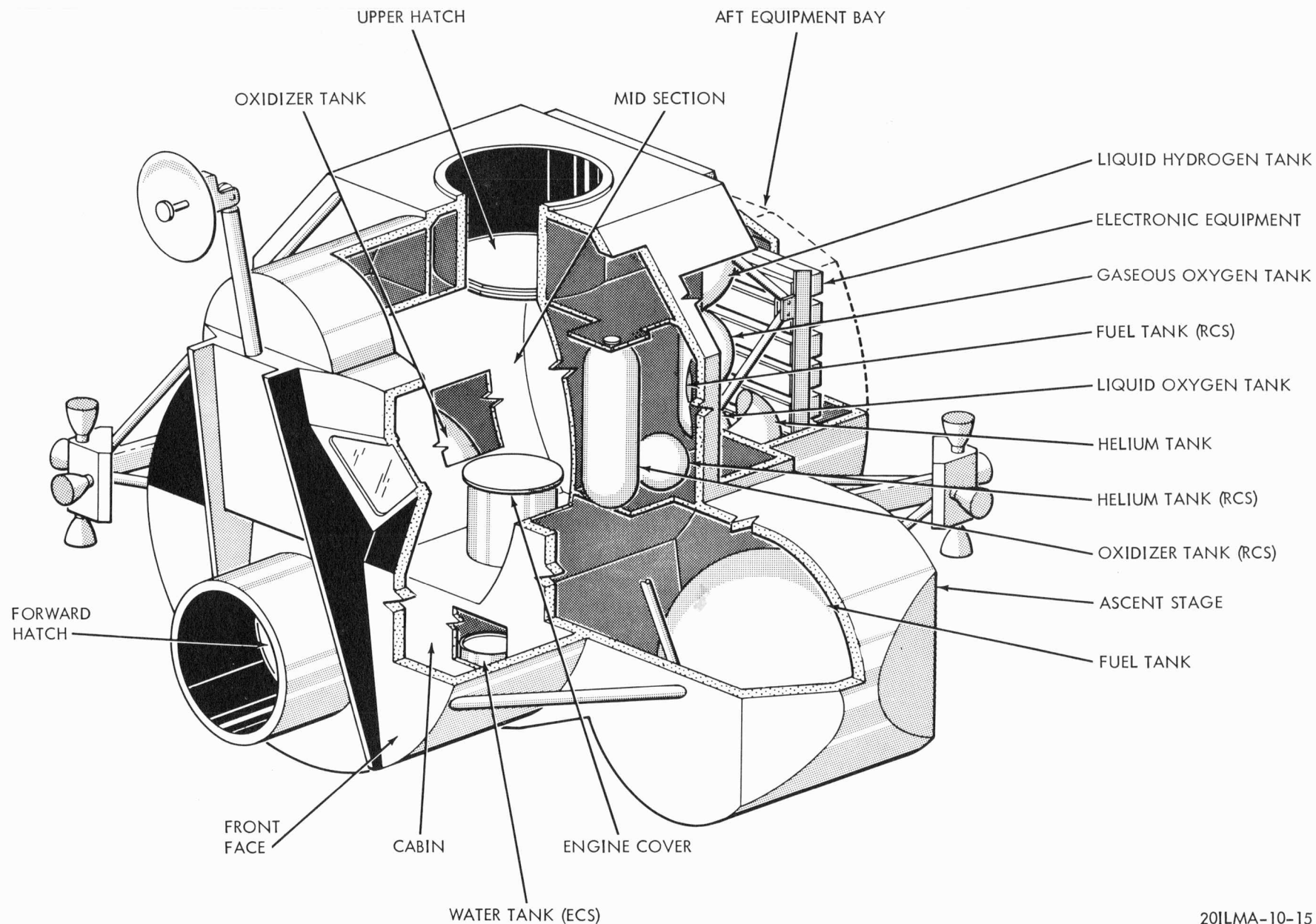
2-8. At launch, the landing gear, is stowed in a retracted position. It remains retracted until shortly after LEM separation from the S-IVB. At this time up-locks are pyrotechnically released and stored energy of the driveout mechanism extends the gear. Once extended, the gear is locked in place by the downlock mechanism.

2-9. ASCENT STAGE.

2-10. The ascent stage (figure 2-3) is the manned portion of the LEM. It is used for launch from the lunar surface and for rendezvous and docking with the Command/Service module. In addition to the ascent engine at the vehicle center of gravity and related components, the ascent stage contains the crew compartment pressure shell, the equipment compartment, the equipment bay section, the tankage sections, windows, and hatches.

2-11. The ascent stage is constructed of aluminum alloy. The structural skin is surrounded with an outer aluminum alloy skin approximately 2 inches from the structural skin. The outer skin provides thermal protection. The crew compartment and the equipment compartment are pressurized. The crew compartment contains two triangular windows, the forward hatch and tunnel, controls and indicators, and items necessary for crew comfort and support. The equipment compartment is a smaller, cylindrical section, directly behind the crew compartment. The equipment compartment contains the ascent engine hatch, top hatch and tunnel, and stowage for equipment requiring crew access.

2-12. The upper docking tunnel, at the top centerline of the ascent stage, is used when transposition is performed and to transfer the crew during translunar flight. The front docking tunnel, at the lower front of the crew compartment, is used for exit to



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Figure 2-3. Ascent Stage

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to the lunar surface and for return of the crew to the Command module after departure from the lunar surface. Pressure-tight, plug-type hatches in each tunnel are mechanically operated and sealed with formed-in-place silicon elastomeric seals.

2-13. The equipment bay and the tankage sections are not pressurized. The equipment bay is aft of the crew compartment and is separated by a pressure-tight bulkhead. This area houses the glycol loop and GOX accumulator for the ECS, two helium tanks for ascent engine pressurization, inverters, batteries, electrical equipment, and cryogenic oxygen and hydrogen tanks for the EPS. The tankage sections are on either side of the equipment compartment and are separated from it by pressure-tight bulkheads. One tankage section contains the ascent engine oxidizer tank while the other contains the ascent engine fuel tank.

2-14. WINDOWS.

2-15. Two triangular windows in the frontal face of the crew compartment provide visibility during the descent transfer orbit, lunar landing, and the rendezvous and docking phases of the LEM mission. Both windows have approximately 2 square feet of viewing area and are canted down and to the side to permit adequate peripheral and downward visibility. Each window consists of two panes separated by an air space. The outer pane is Chemcor glass; the inner pane, Stretchplex 55. A clamp-type seal that consists of a teflon TFE jacket surrounding a metallic spring secures each pane.

2-16. HATCHES.

2-17. Two similar hatches in the ascent stage permit entrance and exit to and from the LEM. The top hatch is on the x-axis, directly above the ascent engine cover; the forward hatch is on the z-axis, beneath the center of the instrument console. Each hatch contains a hatch-latching mechanism that consists of six latches around the outer edge of the hatch, a center drive irreversible gearbox, and six pushrods that connect the latches to the gearbox.

2-18. An elastomeric silicone compound seal for each hatch is mounted in the LEM structure. When the hatch is closed, a lip near the outer circumference of the hatch enters the seal, thereby ensuring a pressure-tight contact. Because both hatches are hinged to open into the LEM, normal cabin pressurization is utilized to force the hatch into the seal.

2-19. After the hatches are closed and the cabin pressurized, the latches are secured with a manually rotated, portable, extension tool stowed inside the LEM. An extension tool is also attached to the outside of each hatch to facilitate opening and closing from the outside. To open either hatch, the portable extension tool is first used to unlock the latches. Cabin pressure is then purged through a dump valve located in the hatch proper.

2-20. INTERSTAGE ATTACHMENTS, UMBILICALS, AND SEPARATIONS.

2-21. The LEM, located at launch between the Command/Service modules and the S-IVB booster, is housed within an adapter attached to the S-IVB booster and Command/Service modules. Landing gear attachment outriggers provide for attachment of the LEM to the adapter. After transposition, the adapter is separated from the LEM by linear-shaped charges.

2-22. While the LEM is docked to the Command/Service modules, umbilicals supply electrical power and pressurization to the LEM. The umbilicals are attached by the crew after transposition; they are manually disconnected prior to separation of the LEM from the Command/Service modules.

2-23. Four explosive nuts and bolts connect the ascent and descent stages. At lunar launch or any other time during the mission, simultaneous explosion of these nuts and bolts in conjunction with engine thrust separates the two stages. Interstage umbilicals (electrical wiring and piping) are disconnected upon stage separation.

SECTION III

OPERATIONAL SUBSYSTEMS

3-1. INTRODUCTION.

3-2. This section provides a general description of the LEM operational subsystems in sufficient detail to convey an understanding of the operation of the LEM as an integrated system. Each of the subsystems is functionally related to one or more of the other subsystems. A block diagram that shows the major relationships between the subsystems is presented in figure 3-1. The LEM operational subsystems are as follows:

Propulsion
Reaction Control
Navigation and Guidance
Stabilization and Control

Electrical Power
Communications
Operational Instrumentation
Environmental Control

A brief description of LEM controls, displays, and crew equipment is also contained in this section.

3-3. PROPULSION SUBSYSTEM.

3-4. The LEM Propulsion Subsystem is divided into separate ascent and descent stages. Each propulsion stage is complete and separate from the other and consists of a liquid propellant rocket engine with its own propellant feed and pressurization sections. The engines are pressure-fed, bipropellant rockets with ablative combustion chambers. The ascent engine also has an ablative nozzle extension; the extension on the descent engine, however, is radiation-cooled. A throttleable, gimbaled engine is used in the descent stage; the ascent stage contains a fixed, constant-thrust engine for lunar launch.

3-5. The propellant for both engines is a 50-50 fuel mixture of hydrazine (N_2H_4) and unsymmetrical dimethylhydrazine (UDMH), with nitrogen tetroxide (N_2O_4) as the oxidizer. The ratio of oxidizer to fuel is 1.6 to 1, by weight. This same hypergolic propellant combination is also used in the LEM Reaction Control Subsystem (RCS).

3-6. In both ascent and descent propulsion stages, the propellant is supplied from baffled tanks that use helium as the tank pressurization gas. The dynamic components in each propellant feed and pressurization section are redundant in order that engine operation is not interrupted by the failure of one component. The feed section in the ascent stage contains provisions for propellant crossfeed to the RCS as a backup supply for the latter.

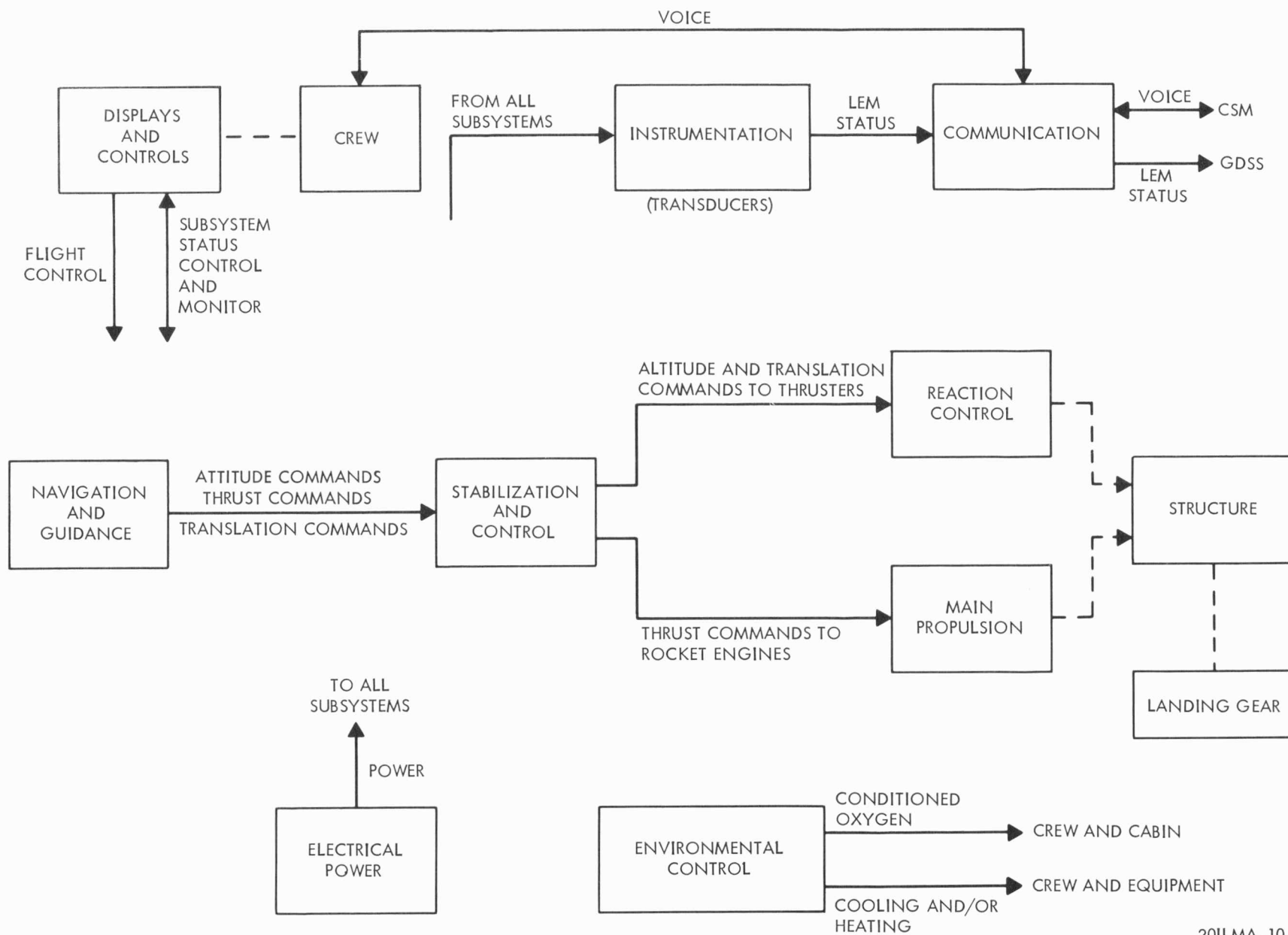


Figure 3-1. LEM Block Diagram

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3-7. Each of the propulsion stages incorporates sensors for measuring fuel and oxidizer inlet pressures and temperatures, injector inlet pressures, thrust chamber pressures (descent only), valve positions, vibration, and exterior engine surface temperatures.

3-8. DESCENT PROPULSION STAGE.

3-9. The descent propulsion stage is fully contained within the descent stage structure and utilizes a single, deep throttling engine built to develop 10,500 pounds thrust in a vacuum at full throttle and 1,050 pounds at minimum thrust. The engine is gimballed $\pm 6^\circ$ in its mount by vehicle-mounted gimbal actuators to provide trim control in the pitch and yaw axes during powered descent.

3-10. The descent engine is currently the subject of a parallel development effort in which a mechanically throttled engine is being evaluated in competition with an engine that employs gas-injection throttling to select the optimum throttling technique. Development on this engine concerns itself with the problem of preventing spray pattern deterioration and chugging at low thrust. Both designs are discussed in subsequent paragraphs.

3-11. Descent Propulsion Propellant Feed and Pressurization Section. The descent propulsion propellant feed and pressurization section comprises the propellant tankage and helium supply assemblies for the delivery of fuel and oxidizer to the rocket engine shutoff and throttling valves. Because two different engine designs are now under consideration, the applicable modifications of the two configurations are discussed here. For a schematic of the section to be used with the helium-injection-throttled engine, see figure 3-2. A schematic of the section to be used with the mechanically throttled engine is shown in figure 3-3.

3-12. The descent propulsion propellant tanks are pressurized by gaseous helium stored at 4,500 psi in two, interconnected spherical vessels. Both vessels discharge into a common manifold; a normally closed explosive valve at the manifold discharge isolates the helium supply prior to start. Downstream of this explosive squib valve, the gas is piped through a filter that retains any debris produced by opening the valve.

3-13. The flow is then divided into two paths, with a normally open solenoid valve and two pressure regulators in series in each line. The solenoid valves are closed during coast periods of descent to prevent propellant tank overpressurization. Each of the series regulators senses downstream of the second regulator and each is capable of handling full system demand. The upstream regulator No. 1 is set to deliver a slightly lower pressure than is No. 2; regulator No. 2 remains full open, sensing a demand, while No. 1 operates normally. Should No. 1 fail open, No. 2 commences operation. If No. 1 fails closed, regulation is achieved by Nos. 3 and 4. Number 3, having been set to a slightly lower pressure than that of No. 1, takes over. Ordinarily, No. 1 operates and No. 3 remains locked up. Failures in regulators No. 3 and 4 are met in a similar manner, in which case the pressure is controlled by Nos. 1 and 2.

3-14. Downstream of the regulator assembly, the helium flow again divides, passing through quadruple check valves to the fuel and oxidizer tanks. Each line has an explosive squib valve to isolate the helium pressurization section from propellant vapors until the section is activated. A burst-disc and pressure relief valve is tapped off the helium line to each pair of propellant tanks to prevent tank overpressurization. An additional flow line is provided for injecting helium into the helium-throttled engine, as shown in figure 3-2. In this installation, the helium lines tee off the tank pressurization lines upstream of the quadruple check valves, and are routed directly to the engine.

3-15. Descent engine fuel and oxidizer are carried in four tanks, two for each. Each pair of tanks is manifolded into a common discharge line and each line incorporates a burst-disc that isolates the propellant from the engine flow control valves until the tanks are pressurized. Filters are located downstream of each burst-disc to prevent contamination of the engine.

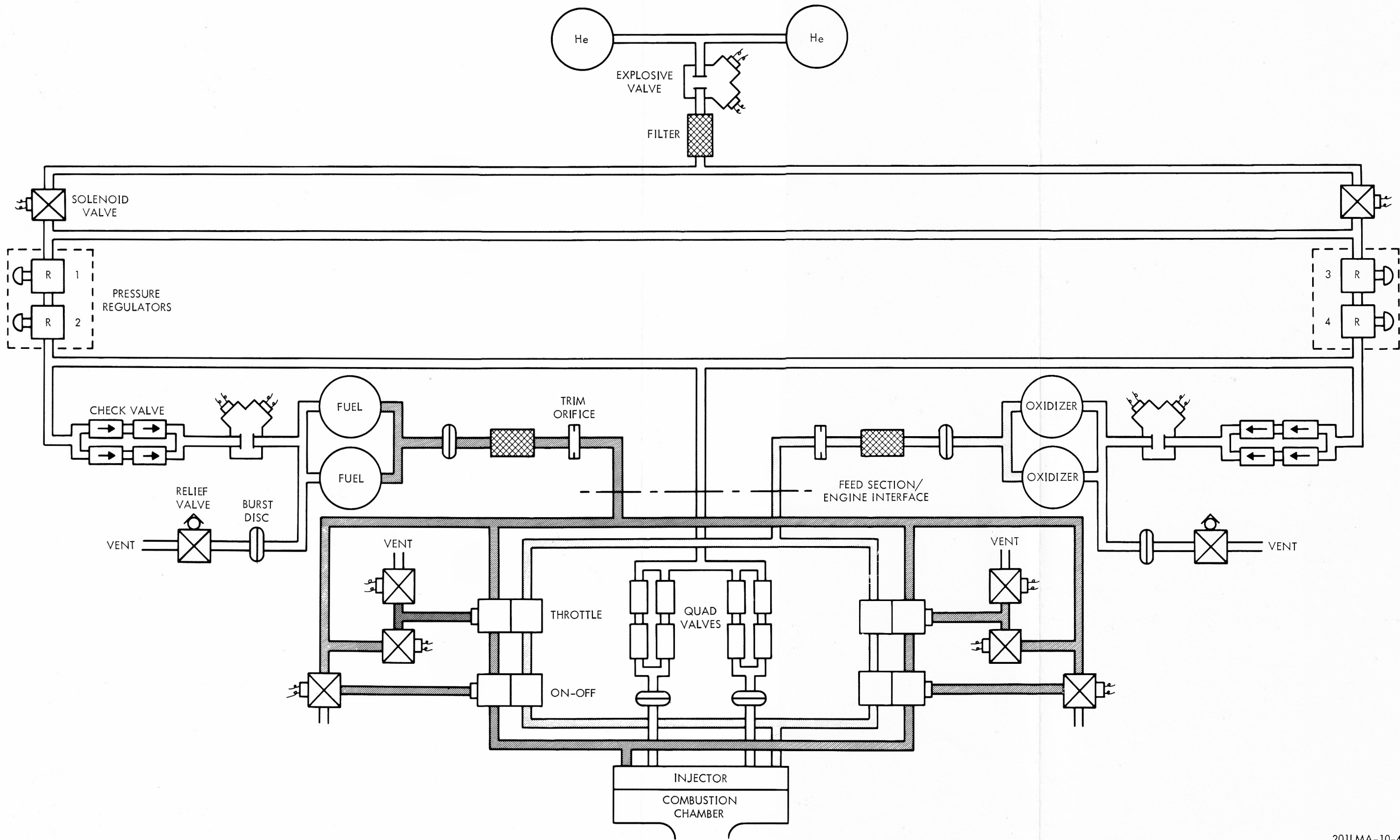
3-16. Descent Engine. Two types of descent engines are currently under study, the chief difference in the types being the throttling techniques. For the purposes of this manual, both types of engines are discussed. A brief description of the helium-injection-throttled engine is included in the paragraphs immediately following. For a description of the mechanically throttled engine, refer to paragraphs 3-24 through 3-31. A comparison of mechanical and helium-injection throttling designs is shown in figure 3-4.

3-17. Helium-Injection-Throttled Engine. The helium injection throttling technique involves the introduction of an inert gas into the injector in order to sustain the propellant flow, velocity, and proper impingement angles obtained with propellant alone at full thrust. Throttling is accomplished by reducing the flow of propellant through upstream bipropellant valves.

3-18. Immediately downstream of the trim orifices at the feed section/engine interface, the fuel and oxidizer supply lines divide to provide dual flow paths to the engine injector. Each flow path contains a set of main propellant valves, consisting of dual throttle and shutoff valves, hydraulically actuated by fuel pressure metered through solenoid-actuated pilot valves. The dual throttle valves are arranged in fuel/oxidizer pairs and operate simultaneously to meter propellant flow rate to the injector at a constant mixture ratio. The shutoff valves are also assembled in fuel/oxidizer pairs.

3-19. The helium supply, from the propellant tank pressurization section, is also introduced at the feed section/engine interface in two separate flow paths. The helium is then piped through quadruple, on-off solenoid valves arranged in series-parallel, from whence it is introduced directly into the propellant inlet manifolds of the engine injector.

3-20. The engine start sequence is initiated with the pressurization of the propellant tanks. During the tank pressure rise, the burst-discs in the fuel and oxidizer lines are ruptured and the propellants flow to the engine valving. At the fire command signal, the pilot valves are opened, feeding fuel, as the actuating fluid, to the actuator pistons of the main propellant shutoff valves. A solenoid valve set is included in the



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Figure 3-2. Descent Propulsion Propellant Feed and Pressurization Schematic
(Helium Injection Throttling)

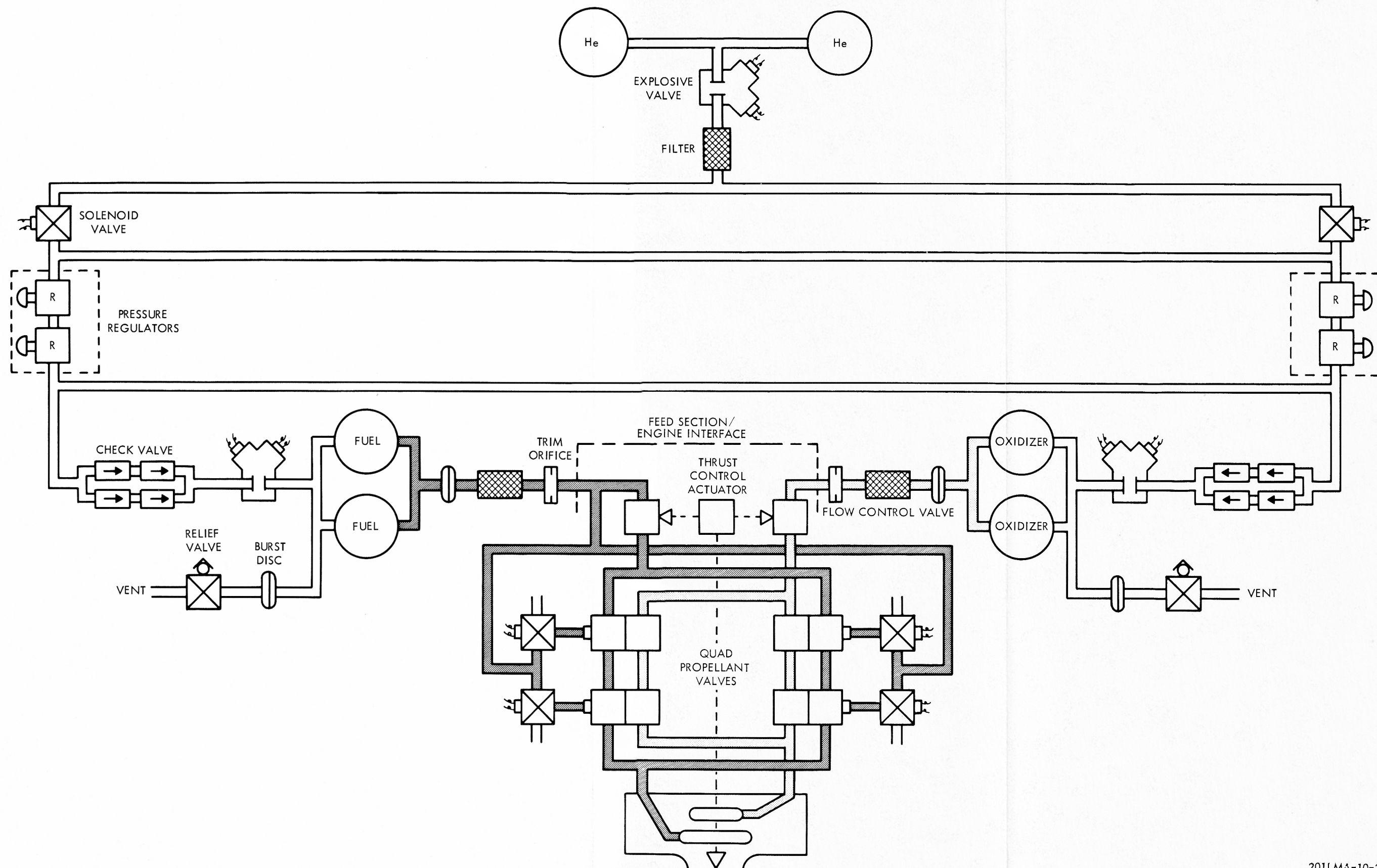


Figure 3-3. Descent Propulsion Propellant Feed and Pressurization Schematic
(Mechanical Throttling)

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thrust control loop and operates in like manner to apply fluid to the throttle valve actuating cylinders. The throttling valves control the flow of fuel and oxidizer to the chamber at a constant mixture ratio through properly shaped valve metering contours and regulate the chamber pressure as a function of propellant flowrate.

3-21. When the engine is throttled to below approximately 50 percent of full thrust, the helium valve set opens and supply helium to the injector at a constant pressure that is sufficient to maintain stable, efficient engine operation down to minimum thrust. Only one of the two redundant valve sets is in operation at any one time. Switchover to alternate helium lines may be accomplished at any time in the mission without significant interruption in engine operation.

3-22. Engine shutoff is accomplished by deenergizing the pilot valve of the main propellant shutoff valve. The helium valves remain open after landing to purge the descent engine safely.

3-23. This engine uses a fixed-area, fixed-orifice injector, the fuel and oxidizer orifices arranged in a series of concentric rings on the injector face. These orifices are fed by propellant manifolds arranged in the form of segments on top of the injector; there are twelve segments, six for oxidizer and six for fuel, arranged in an alternating fashion. Fuel and oxidizer are routed through an annular manifold surrounding the outer circumference of the injector assembly and directed into the segments. At all thrust settings below 50 percent, helium at a constant pressure is supplied to the segments, where it is mixed with the propellant immediately prior to injection. As propellant pressure is reduced by further throttling, the constant flow of helium maintains the velocity of the propellants. The injector orifices are at various angles so that the fuel and oxidizer impinge on each other below the face of the injector.

3-24. Mechanically Throttled Engine. The mechanically throttled engine employs a variable-area, concentric-tube injector and a separate flow control valve arrangement to vary thrust. The injector has a movable sleeve; oxidizer flows through the center of this sleeve and out past a fixed injector tip through ports whose area changes with sleeve motion. The orifice for the fuel is an annular opening between the sleeve and injector face. This annulus is contoured so that the fuel passages enlarge as the sleeve moves upward, away from the injector tip. (See figure 3-4.)

3-25. At reduced thrust, however, propellant flow rate is made insensitive to downstream pressure variations by using a dual-throat, variable-area, cavitating venturi valve. At approximately 70 percent of maximum thrust, cavitation commences in the valve throats. From this level, down to minimum thrust, the valve functions as a cavitating venturi, inducing local cavities in the fluid.

3-26. The cross section area at the valve throat is regulated by a close-tolerance, contoured metering pin. The metering pins are linked directly to a single actuator and this linkage is, in turn, connected to the injector sleeve. Thus, thrust is regulated by actuator movement that simultaneously adjusts the metering pins of the venturi valves and the movable sleeve of the injector. The fuel and oxidizer are thereby injected at velocities and angles compatible with variations in weight flow.

3-27. Propellants are introduced to the engine through inlet lines located near the gimbal ring at the engine throat and are piped directly to the cavitating venturi valves arranged in a pair, one fuel and one oxidizer. After flowing through the cavitating venturis, the propellants pass into a series-parallel shutoff valve assembly. The shutoff valves are mechanically-linked, fuel-actuated ball valves; fuel is introduced as the valve actuating fluid through solenoid operated pilot valves, all of which are energized simultaneously at engine start.

3-28. During startup, the solenoid unseats the caged ball of the pilot valve from the actuator inlet port and seats the ball against the overboard vent port. Fuel then enters the actuator cavities, opening the shutoff valves. During shutdown, the solenoid is deenergized and the spring loaded plunger returns to unseat the pilot valve from the vent port and close the actuator inlet port. Fuel in the actuator is vented overboard and the shutoff valve closes.

3-29. The mechanical linkage at the head of the engine connects the motor-driven thrust control actuator and the flow control valve pintles to the injector sleeve. The linkage is pivoted about a fulcrum attached to the injector housing. For maximum thrust, the actuator piston is withdrawn from the head of the engine to set the flow control valve and the injector apertures in full open position. To reduce thrust, the actuator drives toward the head of the engine, reducing the flow at the venturi and moving the injector sleeve to reduce the injector apertures.

3-30. At maximum thrust, the major portion of the controlling pressure drop, that is, tank pressure minus chamber pressure, occurs in the injector manifold and orifices, so that the engine operates as a calibrated, fixed-thrust, pressure-fed engine. As the engine is throttled, the injector orifice areas are decreased so that the absolute and relative injection velocities of fuel and oxidizer are maintained for combustion efficiency. At the same time, the flow control area of the flow control valve is decreased so that the pressure drop across the valve balances out the difference between engine inlet pressure and injector inlet pressure. That is, the pressure drop across the flow control valve is increased by an amount equal to the decrease in chamber pressure and the decrease in injector manifold losses. At approximately 70 percent of maximum thrust, cavitation commences in the throats of the flow control valves. From this thrust level down to minimum thrust, cavitation is sustained and the propellant flow is controlled only by the throat area of the valve and the propellant inlet conditions to the valve.

3-31. The flow control valve is equipped with a vernier adjustment in the mechanical linkage connecting the fuel and oxidizer pintles. The adjustment changes the relative rate of travel of the fuel and oxidizer pintles for off-nominal conditions of propellant temperature, or of differential tank pressures or of both.

3-32. ASCENT PROPULSION STAGE.

3-33. The ascent propulsion stage consists of a fixed, constant-thrust engine with its own propellant feed and pressurization section. The entire system is contained completely within the ascent stage structure and develops 3,500 pounds of thrust. A schematic diagram of the ascent propulsion is shown in figure 3-5.

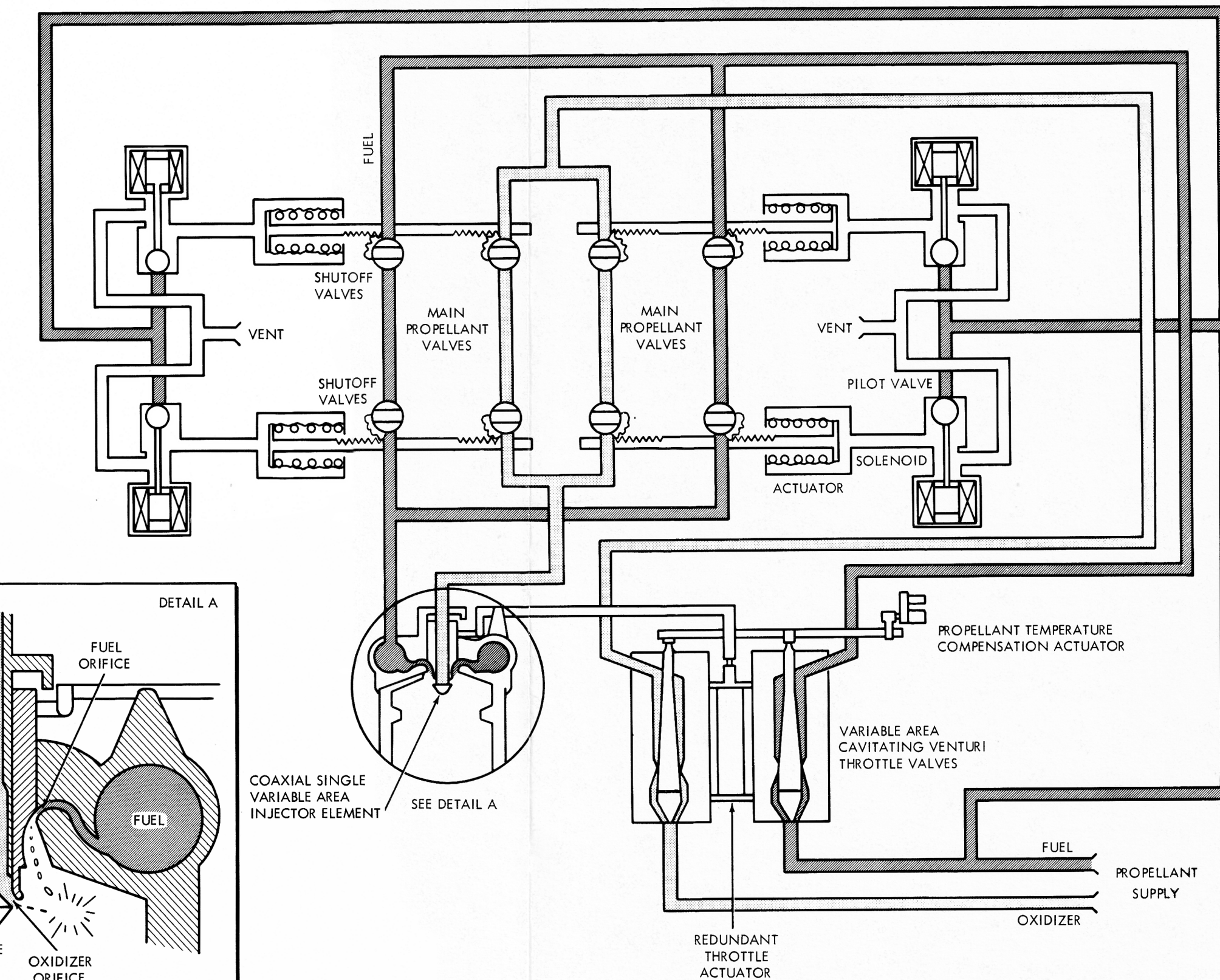
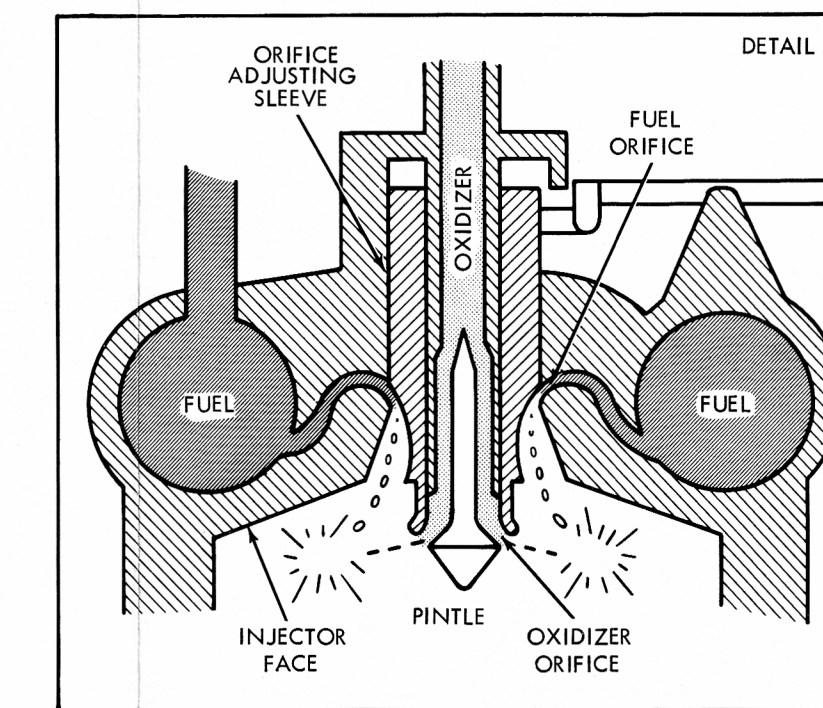
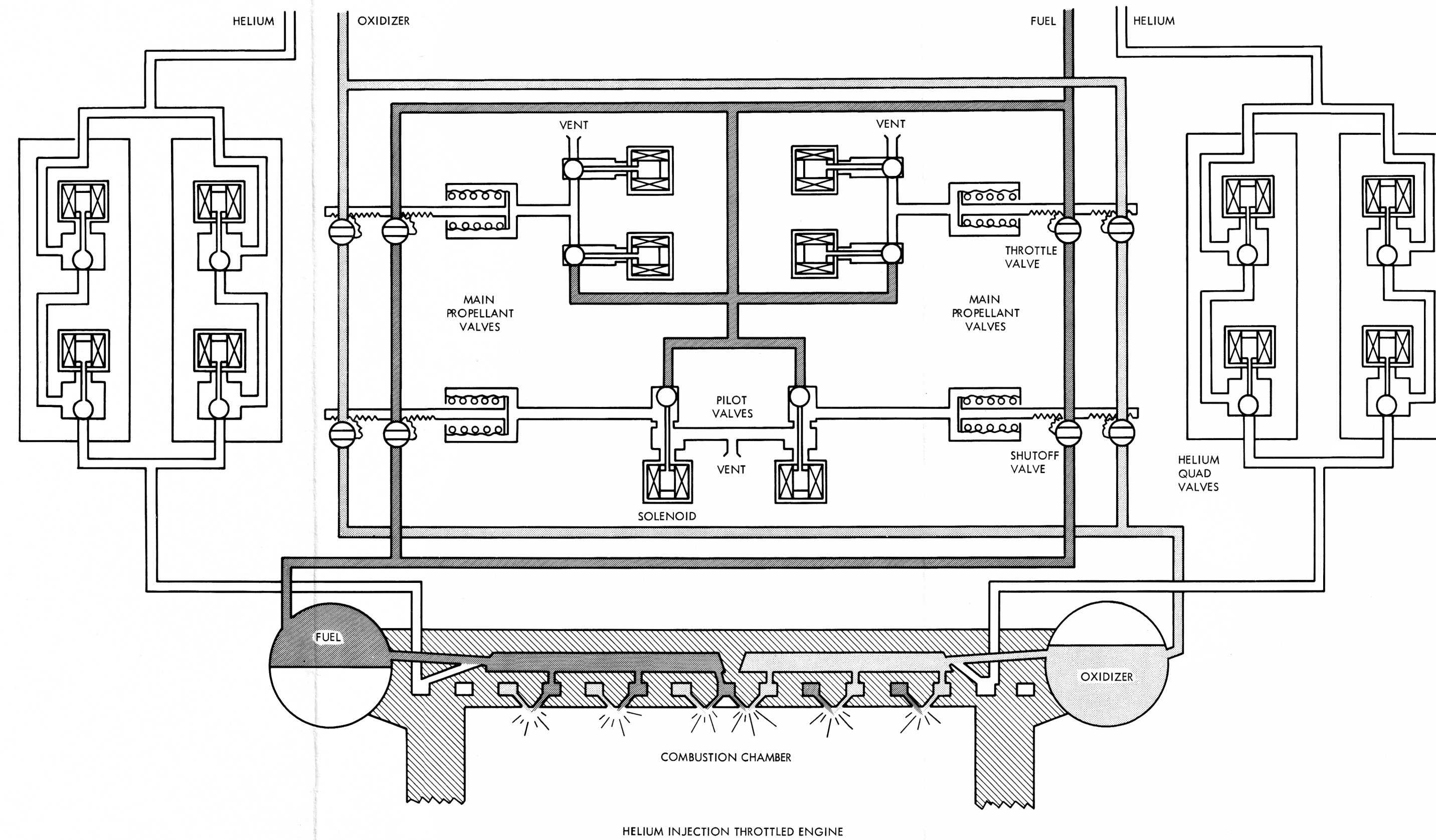


Figure 3-4. Descent Propulsion Throttling Schematic

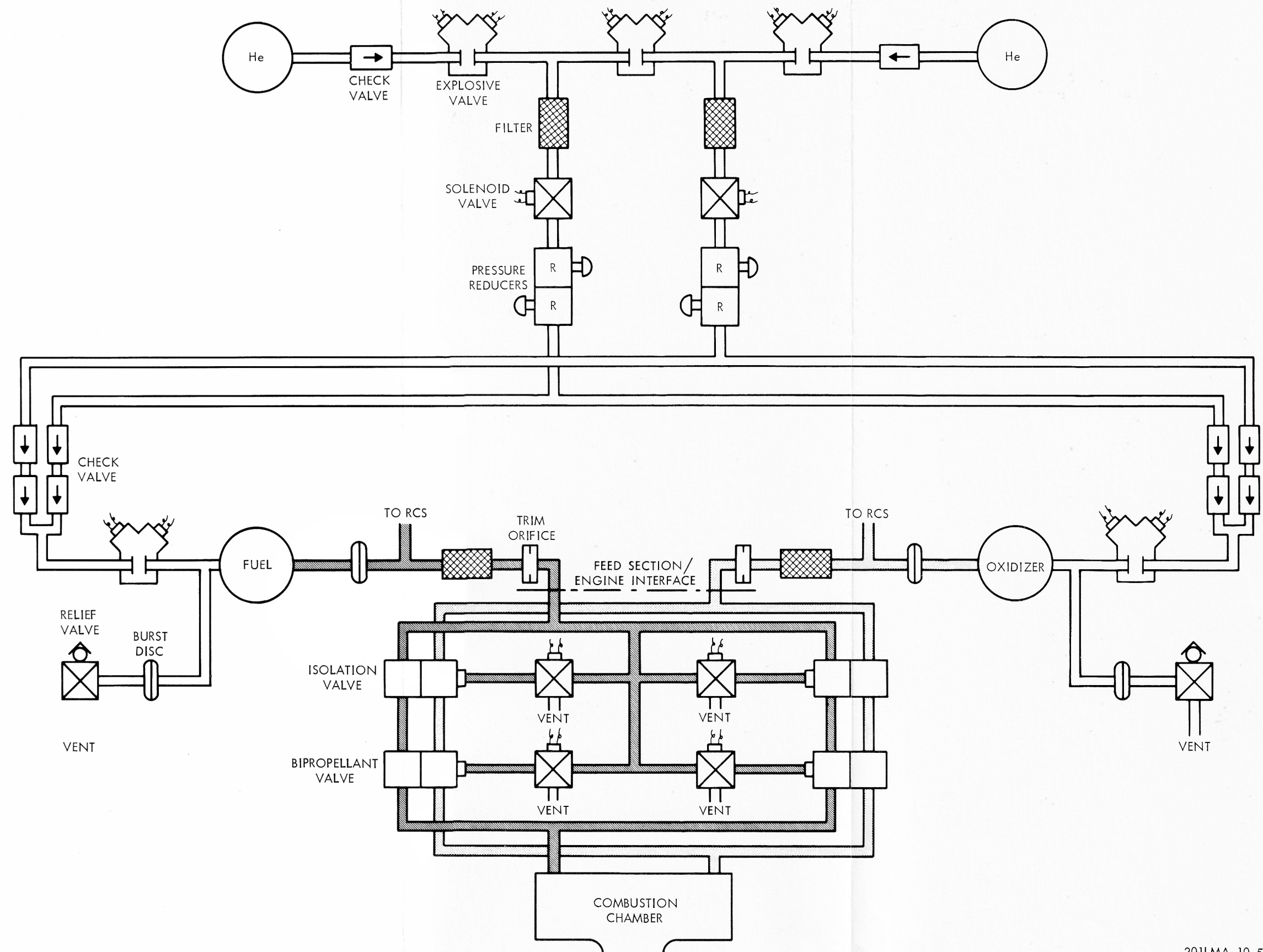


Figure 3-5. Ascent Propulsion Schematic

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3-34. Ascent Propulsion Propellant Feed and Pressurization Section. The ascent propulsion propellant feed and pressurization section has helium and propellant supply assemblies functionally similar to that used in the descent stage. The ascent helium pressurization section, however, is fully redundant. Only two propellant tanks are used in the ascent stage; one for fuel and one for oxidizer.

3-35. Helium is stored at 4,500 psi in two separate tanks. Check valves at the outlet connections on each tank ensure that all helium will not be lost if one tank is lost. To ensure complete redundancy, each half of the section has separate filling connections.

3-36. In the line downstream of each helium tank is a double-squib, double flow, explosive valve. When these valves are fired (at engine start) the helium flows into two separate lines. A third, normally closed, explosive valve is located in a crossover line between both legs to permit pressurization of both sides of the section from one helium supply vessel should a malfunction occur in the other.

3-37. The flow of helium is then controlled by pressure reducers arranged in series in each line, downstream of normally open solenoid valves. The upstream reducers are set to a slightly lower pressure than the downstream reducers and, in addition, the reducers in one leg are set to slightly lower pressures than those in the other leg. Normal operation is for the reducers with the lower pressure setting to close as the propellant tanks are pressurized. The parallel leg then supplies helium from one tank through crossfeed lines downstream of the reducer assembly. As the propellant tank pressure drops to the pressure setting of the reducers in the parallel leg, the other helium supply automatically supplies pressure to the propellant tanks. Only one of the parallel legs will operate at a time.

3-38. Helium flow in both legs is then piped through quadruple check valves to double-flow explosive valves. These valves prevent pressurization of the propellant tanks during pre-launch checkout of the pressure reducers and the solenoid valves.

3-39. Should an upstream pressure reducer fail open, the downstream reducer regulates at a slightly higher pressure setting. Both upstream and downstream reducers are capable of handling the full system load. A downstream reducer failing open is unimportant, since the upstream reducer controls. If an upstream reducer fails closed, the other half of the helium system supplies the pressure. If both reducer series in a particular leg fail to open, the astronaut receives a propellant tank over-pressurization indication. By closing the solenoid valve in the malfunctioning leg, the other half of the helium system supplies propellant pressurization. Sequentially, the astronaut opens the explosive valve connecting both halves of the helium supply and the operating reducer leg continues to control propellant pressurization. The check valves on each tank line prevent pressure loss into the tank that has lower pressure.

3-40. Propellant flows out of the tanks for the first time when helium pressure on the propellants is sufficient to rupture the burst-disc in each propellant line. Particles suspended in the propellants and debris from the burst-disc are trapped by the 70-micron filter. Downstream of the filter, each propellant passes through a calibrated orifice (trimmed at test), which produces the pressure drop required for efficient engine operation.

3-41. Ascent Engine. The ascent engine is a conventional, pressure-fed, restartable rocket engine with an all ablative combustion chamber, throat, and nozzle extension. Fuel and oxidizer enter the engine through inlet lines near the engine mounting pads (at the engine throat). The propellants flow through hard lines to quadruple shutoff valves at the head of the engine and finally into the injector. The injector routes the fuel and oxidizer for efficient combustion in the chamber.

3-42. On the engine proper, each propellant line divides to provide two flow paths to the thrust chamber; each flow path has two main propellant valves, in series. In this engine, all valves are on-off valves, with the upstream valve serving as an isolation valve; the bipropellant valve is downstream. Each valve assembly consists of a pair: one oxidizer and one fuel valve. These valves are controlled by hydraulic actuators that use fuel as the actuating fluid. The application of pressure to the actuators is controlled by normally closed solenoid valves. Each pair of fuel and oxidizer valves is controlled by a single actuator. Valves in the parallel lines are thus opened and closed simultaneously at start and cutoff.

3-43. REACTION CONTROL SUBSYSTEM.

3-44. The Reaction Control Subsystem (RCS) provides the torquing impulses that control LEM attitude and translation about all axes during the hover, rendezvous, and docking maneuvers and that stabilize the LEM attitude during lunar descent and ascent. The RCS consists of two, independent, interconnectable bipropellant sections, a helium pressurization section, and sixteen 100-pound-thrust chambers that are arranged in clusters of four around the periphery of the LEM ascent stage (see figures 3-6 and 3-7). In each cluster, two thrust chambers are on a common axis facing opposite directions and parallel to the LEM's x-axis. The other two thrust chambers are 90 degrees apart in a plane normal to the LEM's x-axis. The thrust vector resulting from the reaction of any couple of engine clusters determines the LEM attitude along the pitch, roll and yaw axes. The RCS thrust is provided, in timed pulses, by the reaction of a 50-50 fuel mixture of hydrazine (N_2H_4) and unsymmetrical dimethylhydrazine (UDMH), with nitrogen tetroxide (N_2O_4) as the oxidizer.

3-45. The RCS may be operated by the astronaut at any time after the LEM is separated from the Command/Service module. Either a fully automatic, semiautomatic, or manual mode of RCS operation may be selected by the attitude mode selector switch of the Stabilization and Control Subsystem Control Panel. In the fully automatic mode, RCS control commands originate in the primary Navigation and Guidance Subsystem and follow a pre-programmed plan. Semiautomatic mode operation combines automatic attitude hold with manual control about each axis by the astronaut's hand controller. During lunar descent and ascent, the semiautomatic mode permits the astronaut to control the attitude of the LEM. In the manual mode, control commands originate at the astronaut's hand controller, and the duration of RCS thrust may be manually controlled. The RCS control commands are processed by a pulse modulator and jet logic network, which establish which of the sixteen thrust chambers are to be fired, when, and for how long to accomplish the control command. Outputs from the pulse modulator and jet logic network are timed voltage pulses that actuate solenoid valves in the appropriate thrust chambers.



Figure 3-6. Reaction Control Subsystem

3-46. HELIUM PRESSURIZATION SECTION.

3-47. Propellant (fuel and oxidizer) tanks are pressurized by regulated helium gas acting upon the propellant tank bladders. Gaseous helium is stored in a spherical titanium tank at a pressure of 3,000 to 3,500 psi (at 70° F). Prior to launch, the helium tank is filled through a port accessible from outside the LEM. Helium quantity is measured by a pressure transducer on the inlet-outlet port of the tank. Two redundant, explosively opened squib valves seal the helium tank until just prior to LEM separation from the Command/Service module, when they are opened. A filter downstream of the squib valves traps possible squib valve debris and helium contaminants.

3-48. From the filter, the helium pressurization section splits into redundant lines. One line begins with a normally open, solenoid-operated, latch-type shutoff valve while the other line begins with a normally closed shutoff valve. Only one helium line is open at a time. If the normally open line should malfunction, it can be shut off and the redundant line opened. A two-stage, line sensing pressure regulator follows each shutoff valve. The first stage reduces helium pressure to 235 ± 2 psi and the second stage further reduces the pressure to 181 ± 2 psi. A pressure transducer, on the line connecting the two redundant lines, measures regulator outlet pressure. The single open helium line then splits into an oxidizer tank line and a fuel tank line. Quad check valves, one on each propellant tank line, prevent backflow and ensure isolation of the pressurizing helium and of one propellant tank from the other.

3-49. A relief valve, close to each helium port on the propellant tanks, is set to relieve at 250 psi if the pressure regulator fails. The relief valve consists of a burst-disc, filter, and relief mechanism; the burst-disc ensures against helium leakage during normal operation. Propellant tank helium fill and vent openings permit the propellant tanks to be purged of gaseous contaminants and a vacuum to be created for propellant filling operations.

3-50. PROPELLANT SECTIONS.

3-51. Each of the two propellant sections contains two cylindrical titanium tanks with hemispherical ends, located in the LEM ascent stage. Each propellant tank contains a 3-ply Teflon bladder supported by a standpipe running lengthwise in the tank. Prior to launch, 203.7 pounds of nitrogen tetroxide is introduced into the bladder of each oxidizer tank through a feed port from the fill point accessible from outside the LEM. Similarly, 103.5 pounds of a 50-50 fuel mixture of hydrazine and unsymmetrical dimethylhydrazine is introduced into the bladder of each fuel tank. Radiation-type quantity gaging devices, using sensors external to the propellant tanks, enable the quantity of propellant to be measured.

3-52. Just before the LEM is separated from the Command/Service module, helium pressurant flows between the bladder and the tank wall to expel the propellants within the bladders. Downstream of each tank feed port, a burst-disc ruptures when propellant pressure reaches approximately 150 psi. A filter downstream of each burst-disc collects possible disc fragments and other contaminants. Nominal propellant tank pressure is 181 psi at 70° F. Normally open, latch-type, solenoid-operated shutoff valves permit isolation of any pair of the four propellant tanks after

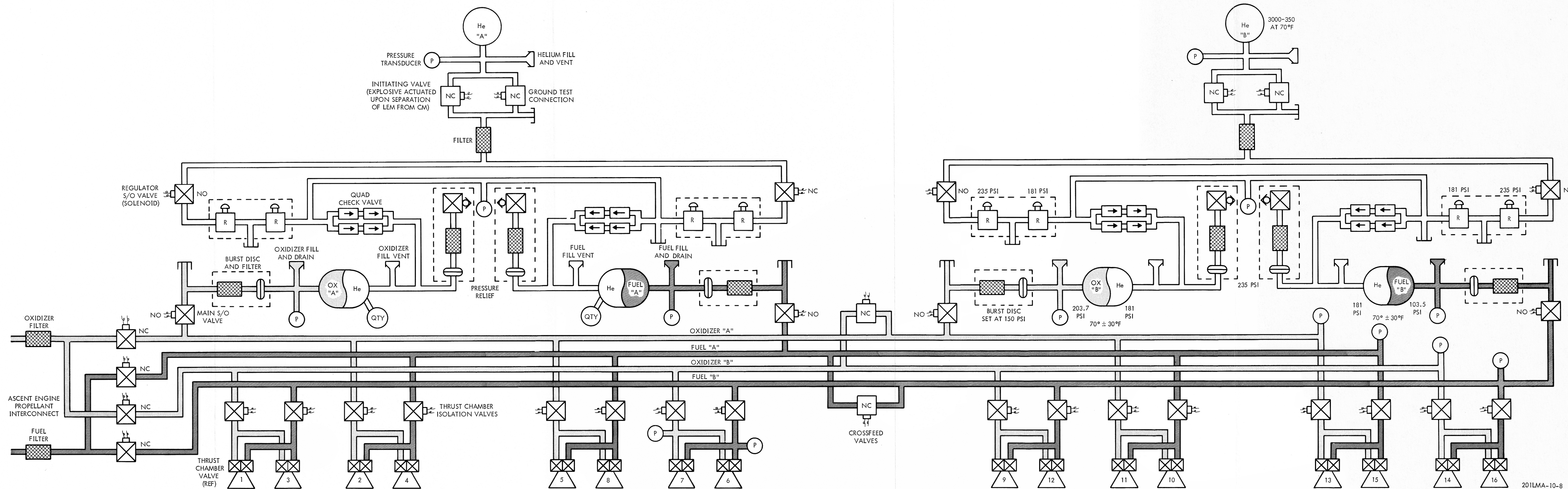


Figure 3-7. Reaction Control Subsystem Schematic

the burst-disc has opened. From this valve, the propellant flows into a manifold feeding the eight thrust chamber assemblies. A pressure transducer on each manifold senses propellant pressure. The manifolds from the two independent propellant sections can be connected through the actuation of normally closed, explosive squib valves. If necessary for completion of orbital rendezvous and docking maneuvers, ascent engine propellant may be transferred into the RCS propellant manifold by opening normally closed, solenoid-operated, latch-type shutoff valves on the ascent engine fuel and oxidizer lines.

3-53. Each of the two independent RCS propellant sections feeds propellant to two thrust chamber assemblies in each of the four engine clusters, ensuring three-axis control even if half the RCS fails. The fuel and oxidizer lines feeding each thrust chamber assembly may be individually closed by normally open, solenoid-operated, thrust chamber isolation valves. This permits the isolation of malfunctioning thrust chamber assemblies or clusters. There is a propellant pressure transducer at the inlet of each thrust chamber assembly.

3-54. THRUST CHAMBER ASSEMBLIES.

3-55. The thrust chamber assemblies section consists of sixteen thrust chambers grouped in clusters of four. In each cluster, two thrust chamber assemblies are on a common axis facing opposite directions and parallel to the roll axis. The other two thrust chamber assemblies are located 90 degrees apart in a plane normal to the roll axis. Each thrust chamber assembly consists of trim orifices, filters, propellant solenoid valves, fuel and oxidizer injectors, and a combustion chamber. The thrust chamber assembly is capable of pulse mode operation at pulse durations of ten milliseconds through one second or steady state operation. At a steady state combustion chamber pressure of 90 psi, each thrust chamber assembly produces a full thrust of 100 pounds (vacuum rating) for a controlled period of time. The propellant lines, valves, thrust and injectors are encased in a radiation shield and insulation blanket that provides protection from solar radiation and radiation from the operating engines while radiating thrust-chamber-generated heat into space. The shield consists of a funnel-shaped glass, paper, and aluminum foil insulating blanket covered with a gold-plated reflective surface. The shield is connected directly to the LEM ascent stage so that all conducted heat is transferred directly to the LEM, bypassing the thrust chamber assemblies.

3-56. NAVIGATION AND GUIDANCE (N & G) SUBSYSTEM.

3-57. The N & G Subsystem provides the measuring and data processing capabilities and control functions necessary to accomplish lunar landing and ascent, and rendezvous and docking with the Command/Service Modules. The N & G Subsystem comprises the landing radar, a rendezvous radar/transponder, the alignment optical telescope, the inertial measurement unit, the LEM guidance computer, the power and servo assembly, and three coupling display units. Figure 3-8 is a simplified block diagram of the N & G Subsystem.

3-58. The N & G Subsystem is primarily an aided inertial system whose principal aids are the landing radar, the rendezvous radar/transponder, and the alignment optical telescope. The inertial measurement unit is aligned to an inertial reference by star tracking with the alignment optical telescope. During descent to the lunar surface, altitude and velocity information from the landing radar are used to update inertially-derived data. During the coasting descent, lunar stay, and rendezvous phases of the mission, the rendezvous radar tracks its transponder on the Command Module to provide range, range rate, and angle rate measurements with respect to inertial space.

3-59. LANDING RADAR (LR).

3-60. The LR is an X-band doppler altimeter and velocity radar that provides the LEM guidance computer with velocity data along each of the three beams, with range data along the altitude beam, and with data on the position of the LR antenna.

3-61. The LR antenna assembly contains a three-beam lens antenna; three circularly-polarized feeds; three power splitters and duplexers; a high-level solid-state varactor-multiplier-transmitter; a low-power solid-state varactor-multiplier local oscillator; three mixers; and three I-F preamplifiers. The LR lens antenna illuminates and receives echos from the lunar surface, both when the LEM is moving tangentially to the lunar surface (coasting descent phase), and when the LEM rotates to a vertical attitude to complete its final descent (powered descent phase). During the final 1,000 feet of descent, reflected energy along the altitude beam is received by the lens antenna, and by an auxiliary horn antenna (a part of the low-altitude auxiliary video receiver), to supply low-altitude range information.

3-62. The three-beam echos received by the lens antenna are applied to the three mixers and i-f preamplifiers, which derive doppler-shifted signals from each beam and transfers them to the receiver signal processor. The receiver signal processor comprises an X, Y, and Z channel; each channel consists of an i-f assembly, a frequency tracker, and a mixer. The doppler-shifted signals are amplified and converted to a second i-f by the i-f assemblies. Carrier leakage (resulting from the overlapping of the transmitted pulse by the leading edge of the receiver gate at altitudes below 1,000 feet) is suppressed by each i-f assembly's carrier eliminator notch filter. The outputs of the i-f assemblies are processed by the three frequency trackers to extract the doppler-shifted frequency along each beam. These doppler-shifted frequency signals are further mixed by the receiver signal processor mixers, whose outputs represent velocity along each beam.

3-63. The output of the altitude beam (Z channel) IF assembly and the output of the low-altitude auxiliary video receiver are applied to the range tracker, which measures range by comparing the phase of the PRF fundamental of both the transmitted and received pulses at altitudes below 1,000 feet, and which controls the transmitted PRF at altitudes above 1,000 feet. The various frequencies required for the second i-f conversion and for the transmitter and local oscillator chains are generated by the synthesizer and modulator.

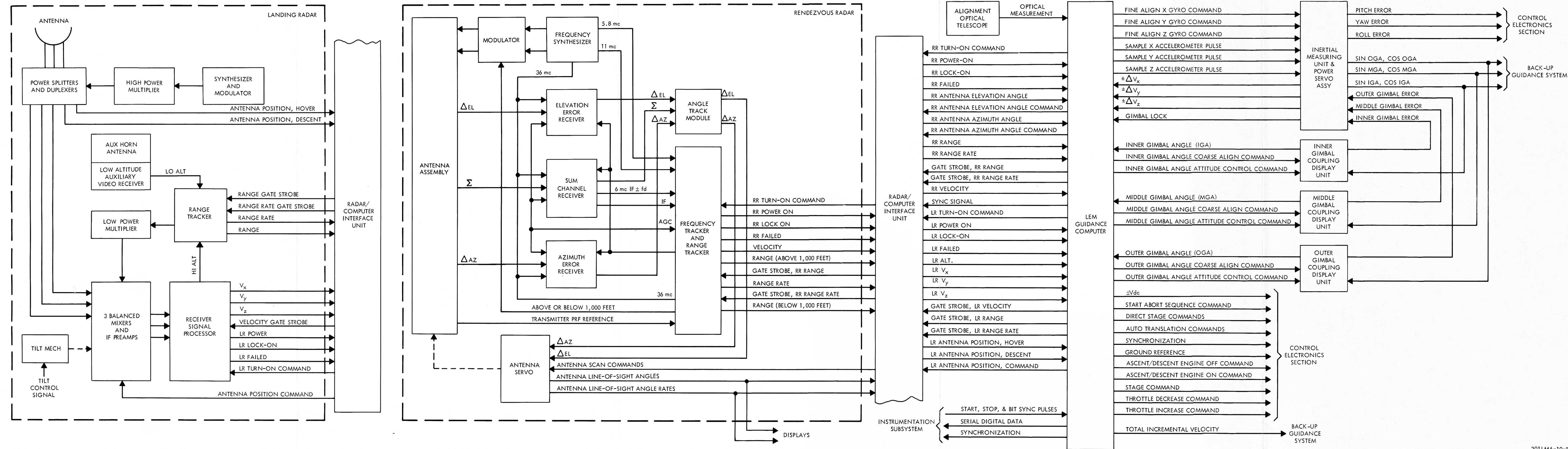


Figure 3-8. Navigation and Guidance Subsystem Block Diagram

3-64. The outputs of the LR are applied to the radar/computer interface unit in the rendezvous radar package. The velocity data are pulses whose PRF is a function of velocity. Altitude beam data are pulses whose PRF is a function of range.

3-65. RENDEZVOUS RADAR/TRANSPONDER (RR/T).

3-66. The rendezvous radar is an X-band, interrupted-constant-wave, amplitude comparison, monopulse radar that can acquire and accurately track its transponder in the Command module at any range between 400 nautical miles and 5 feet. (An identical transponder on the LEM is tracked by the Command module.) Range-rate measurements are provided at any LEM rate of closure or opening (with respect to the Command module) between 4,900 feet per second and 1 foot per second.

3-67. The rendezvous radar antenna assembly includes a gyro-stabilized monopulse antenna; sum-and-difference hybrid networks; a duplexer; a high-level, solid-state varactor-multiplier-transmitter; a low-power, solid-state, varactor-multiplier-local oscillator; three mixers; and three i-f preamplifiers. The elevation error receiver, sum channel receiver, and azimuth error receiver are identical i-f assemblies that convert the one reference and two error signals to an i-f of 1,000 kc. Within each i-f assembly is a 1-kc filter that provides approximately 13 db signal-to-noise ratio improvement for angle tracking. The sum channel receiver output is used as a reference signal for the two phase-sensitive detectors within the angle track module. These detectors convert the outputs of the elevation and azimuth error receivers to two bipolar-video angle error signals and apply them to boxcar detectors, which provide the ΔEL and ΔAZ bipolar d-c error signals for antenna line-of-sight control.

3-68. The Range Tracker has two modes of operation: the variable-PRF, closed-loop mode is used for ranges between 1,000 feet and 400 miles, and the fixed-PRF, open-loop mode is used for ranges less than 1,000 feet. In either mode, transponder returns or surface returns can be used to derive range. In the variable-PRF mode, the range derived by the range tracker is used to control the PRF; in the fixed-PRF mode, the PRF is locked at 250 kc. The frequency tracker measures the doppler-shifted response of transponder or surface returns to derive velocity. The frequency synthesizer generates the various frequencies required by the transmitter and local oscillator chains in the various modes of operation. The LEM guidance computer antenna scan commands, tracking error signals, and gyro signals are combined by the antenna servo to produce antenna drive signals. Signals proportional to antenna line-of-sight angles are applied to the radar/computer interface unit for transfer to the LEM guidance computer.

3-69. The radar/computer interface unit provides the interfaces between the landing and rendezvous radars and the LEM guidance computer. Radar output signals are processed into the format required by the LEM guidance computer and selected sequentially for transfer by coded strobe signals generated by the computer.

3-70. ALIGNMENT OPTICAL TELESCOPE.

3-71. The alignment optical telescope is a non-articulating, unity power, 55-degree field-of-view telescope used for aligning the inertial measurement unit. The telescope optics mechanism has three distinct viewing positions and a stowage position.

3-72. INERTIAL MEASUREMENT UNIT (IMU).

3-73. The IMU is the primary inertial sensing device of the LEM. Three accelerometers and three gyroscopes are mounted on the innermost gimbal of a three-degree-of-freedom gimbal system. The innermost gimbal is held non-rotating with respect to inertial space. Outside forces acting upon the LEM are sensed by the accelerometers, which produce signals representing incremental changes in velocity. Signals proportional to changes in the attitude of the LEM are generated by the inner, middle, and outer gimbal angle resolvers. The outputs of the accelerometers and resolvers are transferred to the LEM guidance computer.

3-74. LEM GUIDANCE COMPUTER (LGC).

3-75. The LGC is the central data-processing device of the N & G Subsystem. It is a parallel, fixed point, one's complement digital computer with a fixed rope core memory and an erasable ferrite core memory. Inputs to the LGC are received from the landing and rendezvous radars through the radar/computer interface unit, from the inertial measurement unit, and from the navigator via the data entry keyboard on the LGC control panel. Using these data, the LGC computes flight control commands and transfers them to the Stabilization and Control Subsystem and to the LGC display panel.

3-76. POWER AND SERVO ASSEMBLY (PSA).

3-77. The PSA consists of the following subassemblies: gimbal servo amplifiers, gyro accelerometer amplifiers, coupling and display unit electronics, power diodes and signal conditioners, and power supplies.

3-78. COUPLING AND DISPLAY UNIT (CDU).

3-79. The CDU's transfer angular information between the major elements of the Navigation and Guidance Subsystem, the Stabilization and Control Subsystem, and the crew displays. The N & G Subsystem uses three CDU's, one for each gimbal of the IMU. The digital-CDU principle is based upon the use of a-c analog computing techniques to derive error voltages from analog resolver angle signals. Digital circuitry continuously alters the analog computational scaling factor to null the error voltages. When this null occurs, the state of the digital memory drive circuit exactly corresponds to the resolver position.

3-80. STABILIZATION AND CONTROL SUBSYSTEM.

3-81. The Stabilization and Control Subsystem consists of a control electronics section (CES) and Backup Guidance Section (BUGS). The CES consists of a guidance coupler assembly (GCA), an attitude and translation control assembly (ATCA), a descent engine control assembly (DECA), a gimbal drive actuator, a rate gyro assembly (RGA), an attitude controller, and a translation controller. The AGS consists of an attitude reference assembly (ARA), a Backup programmer assembly (BPA), a control panel assembly (CPA), and an in-flight monitor assembly (IFMA).

3-82. The CES converts attitude error, rate command, or translation control signals generated in the Primary Navigation and Guidance Subsystem (PNGS), the BUGS, and the manually operated cockpit controls into pulse-ratio-modulated signals for firing the Reaction Control Subsystem (RCS) thrusters. Logic circuits within the CES route the signals to the appropriate thrusters. In addition, the CES generates on-off firing commands for the ascent and descent engines, and routes automatic thrust magnitude control signals to the descent engine. Trim control of the gimballed descent engine is also provided to assure that the thrust vector operates through the center of gravity, within deadband limits.

3-83. The BUGS generates LEM attitude error signals that, after passing through the CES, actuate appropriate RCS thrusters. Three major functions are provided by the section. The functions are: abort capabilities from four points in the lunar descent phase; attitude reference for vehicle stabilization; and capabilities for ascent from the lunar surface.

3-84. CONTROL ELECTRONICS SECTION. (See figure 3-9, sheet 1.)

3-85. The CES has four modes of operation: automatic, attitude hold, rate command, and direct attitude.

3-86. Automatic Mode. The automatic mode provides fully automatic attitude control during all phases of the mission except hover, landing, and docking. When this mode is selected, attitude control signals from the BUGS and the PNGS are applied to a selection circuit of the GCA. Attitude control signals selected with a control panel switch are applied to signal conditioning circuits in the ATCA, where the signals are combined with rate correction signals. The signals are then demodulated and applied through deadband circuits and amplifiers to the RCS thrust select logic circuits. After demodulation, the pitch and roll signals are also coupled to the DECA for automatic trim control of the descent engine. The signals applied to the logic circuits are processed and directed to appropriate pulse modulators and solenoid drivers. The pulse modulators and solenoid drivers generate firing pulses that actuate the RCS thrust chambers. RCS thruster failure information is manually fed back to the CES logic circuits which generate new firing sequences. The selectable deadband feature provides a wide and a narrow deadband. The wide deadband is used during coasting phases of the mission to conserve fuel, while the narrow deadband is used when accurate thrust control is required.

3-87. Attitude Hold Mode. The attitude hold mode is the primary attitude control mode for the hover, landing, and docking phases of the mission. In this mode, the pilot manually commands attitude change rates by displacing the attitude controller from the neutral position. When the controller is in neutral, the LEM holds attitude. The attitude hold mode is implemented to operate with either the PNGS or AGS as the attitude reference.

3-88. Rate Command Mode. The rate command mode functions in the same manner as the attitude hold mode except that attitude hold is not provided when the attitude controller is in the neutral position.

3-89. Direct Attitude Mode. The direct attitude mode permits individual control of the yaw, pitch and roll axes. Two types of direct control are provided: a low frequency pulse control, activated when the attitude controller is moved out of detent; full on-off jet control, activated when the attitude controller is deflected to its limits. The axes to be controlled are selected by setting the corresponding control panel mode switch to the PULSED or DIRECT positions. In the PULSED position, the normal attitude control inputs to the thruster logic are removed and replaced with outputs of a switching circuit in the GCA. The outputs of the switching circuit generate low-frequency minimum pulses in the pulse-ratio modulators consistent with the out-of-detent positions of the attitude controller. Full on-off jet control is provided when the attitude controller is deflected to its limits. The limit switches are wired directly to the direct solenoids of the reaction jets and provide rapid override control in all modes of attitude control. In the DIRECT position, the pulsed operation is inhibited, permitting only direct limit-switch control of the RCS thrusters.

3-90. BACKUP GUIDANCE SECTION. (See figure 3-9, sheet 2).

3-91. The BUGS has three modes of operation: warm-up, alignment, and inertial reference.

3-92. Warm-Up Mode. The warm-up mode provides 28-volt d-c power to the BUGS.

3-93. Alignment Mode. The alignment mode has three sub-modes: IMU (inertial measurement unit of PNGS) alignment, orbital alignment, or lunar alignment of the BUGS. IMU alignment is accomplished by aligning the BUGS to the output of the IMU gimbal resolvers. Orbital alignment is accomplished by manually achieving the proper vehicle attitude with respect to the Command/Service Module orbit, caging the roll and yaw gimbals, and manually pitching the vehicle to a predetermined pitch gimbal angle while holding roll and yaw attitude. Orbital alignment is used if the PNGS malfunctions and the vehicle is in lunar orbit for such extended periods that the sub-systems must be shut down to conserve power. Lunar alignment is accomplished by manually setting a predetermined yaw gimbal angle and aligning the pitch and roll gimbals by means of a two-axis pendulum which determines the local vertical. Lunar alignment is used in preparation for ascent from the lunar surface if the PNGS has malfunctioned.

3-94. Inertial Reference Mode. The inertial reference mode has three sub-modes: follow-up, backup attitude hold, and automatic. The follow-up sub-mode permits the BUGS to follow vehicle motion to prevent transients when control is switched from the PNGS to the BUGS. When the BUGS is selected as the inertial reference, the vehicle enters the backup attitude-hold sub-mode and maintains the last attitude it held prior to the switchover. The automatic mode provides four manually-selectable automatic trajectories for abort from any point in the lunar descent phase, or a preprogrammed ascent from the lunar surface.

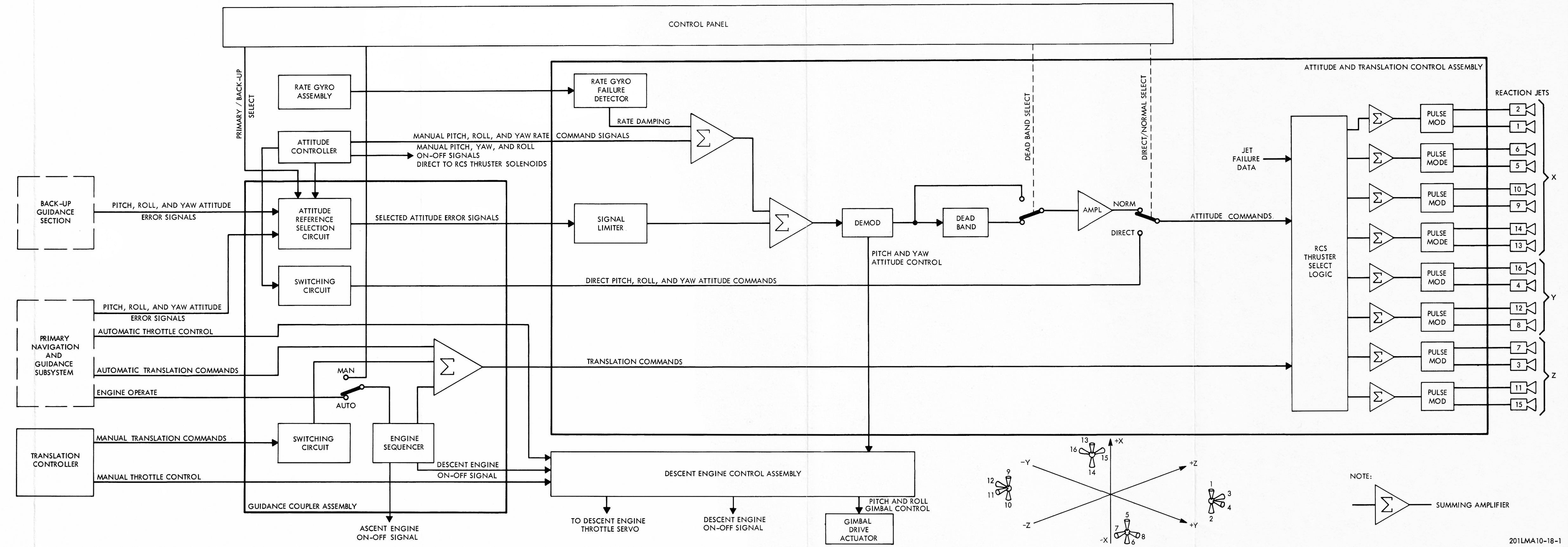
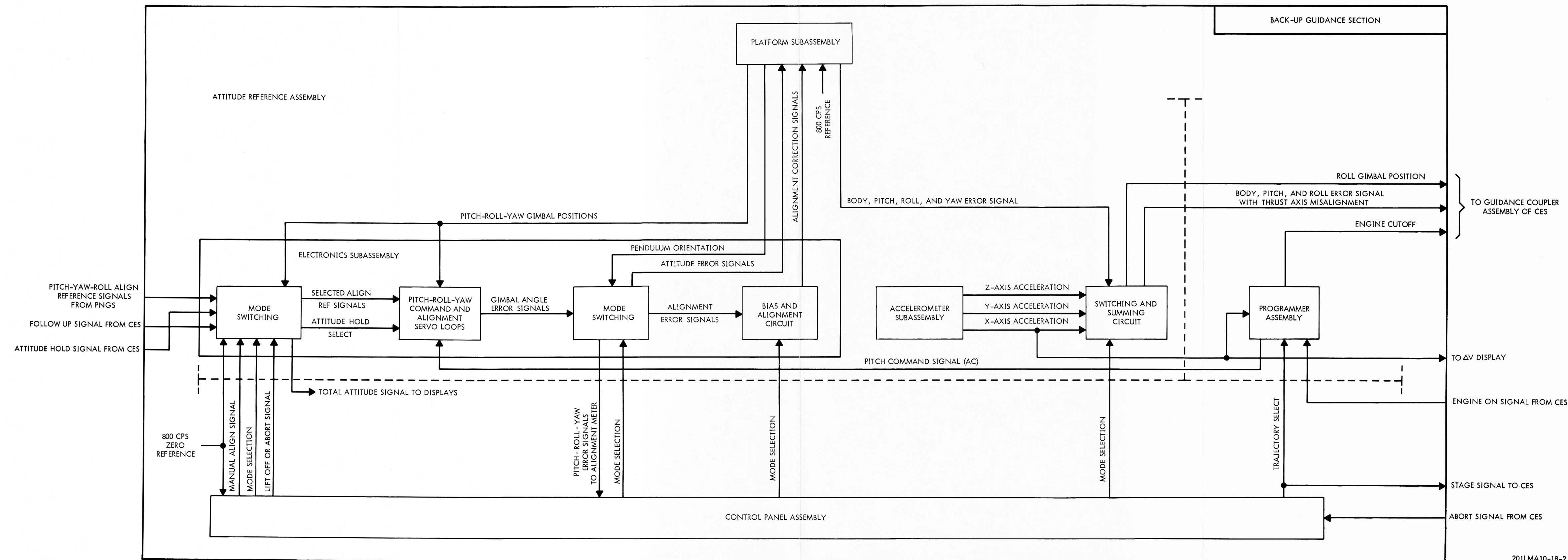


Figure 3-9. Stabilization and Control Subsystem Block Diagram (Sheet 1)



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Figure 3-9. Stabilization and Control Subsystem Block Diagram (Sheet 2)

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3-95. ELECTRICAL POWER SUBSYSTEM.

3-96. The Electrical Power Subsystem (see figure 3-10) provides power to all circuits in the LEM. Power originates in two fuel cell assemblies, or, under emergency conditions, in an auxiliary battery. The two fuel cell assemblies can act independently, or in parallel, to provide 29-volt dc to the non-essential bus and to the essential A and B buses.

3-97. In parallel operation, the two fuel cell assemblies operate with maximum efficiency to provide power to the three buses. Under non-parallel operating conditions, one fuel cell assembly energizes an essential and a non-essential bus and the other energizes a single essential bus. If either fuel cell assembly fails, a logic network in the feeder control assembly automatically deenergizes the non-essential bus so that the operating fuel cell assembly provides power only to the two essential buses. With one fuel cell assembly operating, the non-essential bus may be manually reenergized by a manually operated override switch. The non-essential bus override switch is closed only after all absolutely non-essential loads have been removed from the circuit, to prevent overloading the single operating fuel cell assembly.

3-98. If both fuel cell assemblies fail, the auxiliary battery automatically energizes the essential B bus, which distributes power to all critical survival and pyrotechnique circuits. The kilowatt-hour capacity of the silver-zinc auxiliary battery is adequate for all survival loads during lunar launch, orbital rendezvous, and docking phases of the mission.

3-99. The non-essential bus, in addition to providing power to non-essential d-c loads, transmits dc to the inverter, where it is transformed into 115/200 volt, three-phase, 400-cps ac. The a-c power passes through the a-c bus, where it is distributed to all a-c loads through a four-wire, neutral grounded system.

3-100. FUEL CELL ASSEMBLY.

3-101. Each fuel cell assembly consists of two subassemblies: the reactor subassembly and the fuel cell control subassembly (see figure 3-11). The reactor subassembly contains 30 individual fuel cells, cell and stack heaters, and a manifold system for the delivery of hydrogen, oxygen, and nitrogen, for the purging of oxygen and nitrogen, and for venting hydrogen. The 30 fuel cells are arranged in two stacks of 15. Each individual fuel cell contains two porous nickel-nickel oxide electrodes, aqueous potassium hydroxide electrolyte, a heating unit, reactant and inert gas passages, and all necessary fittings for manifolding to other cells. The liquid hydrogen and oxygen reactants are cryogenically stored in titanium tanks. When the LEM fuel cell assembly is in operation, the reactants ionize, release electrons, and form water. To remove the water and heat produced during this process, an excess of hydrogen is passed through the hydrogen gas space and vented overboard.

3-102. The electrodes are of dual-porosity nickel-nickel oxide and provide a large interface with which reactant and liquid electrolyte is in contact. Each electrode is

made with a thin, fine-pore layer that is in contact with the electrolyte, and a relatively thick, coarse-pore layer that is in contact with a reactant. The configuration of the electrodes is such that mixing of hydrogen and oxygen gas will not occur as long as the electrolyte is in the liquid state.

3-103. To speed-up the reaction process and to keep the potassium hydroxide electrolyte liquified, the fuel cells are operated at a temperature of 500°F. This temperature is maintained by two sets of heaters in the cell stack assembly. In addition, the cell heater separates the hydrogen electrode structure of one cell from the hydrogen electrode structure of the adjacent cell.

3-104. The manifold system in the reactor subassembly provides six manifolds per stack of cells. These are the hydrogen, oxygen, and nitrogen delivery manifolds, oxygen and nitrogen purge manifolds, and a hydrogen vent manifold. Each fuel cell has an inert blanket of nitrogen around its electrodes and its gas reactant passages.

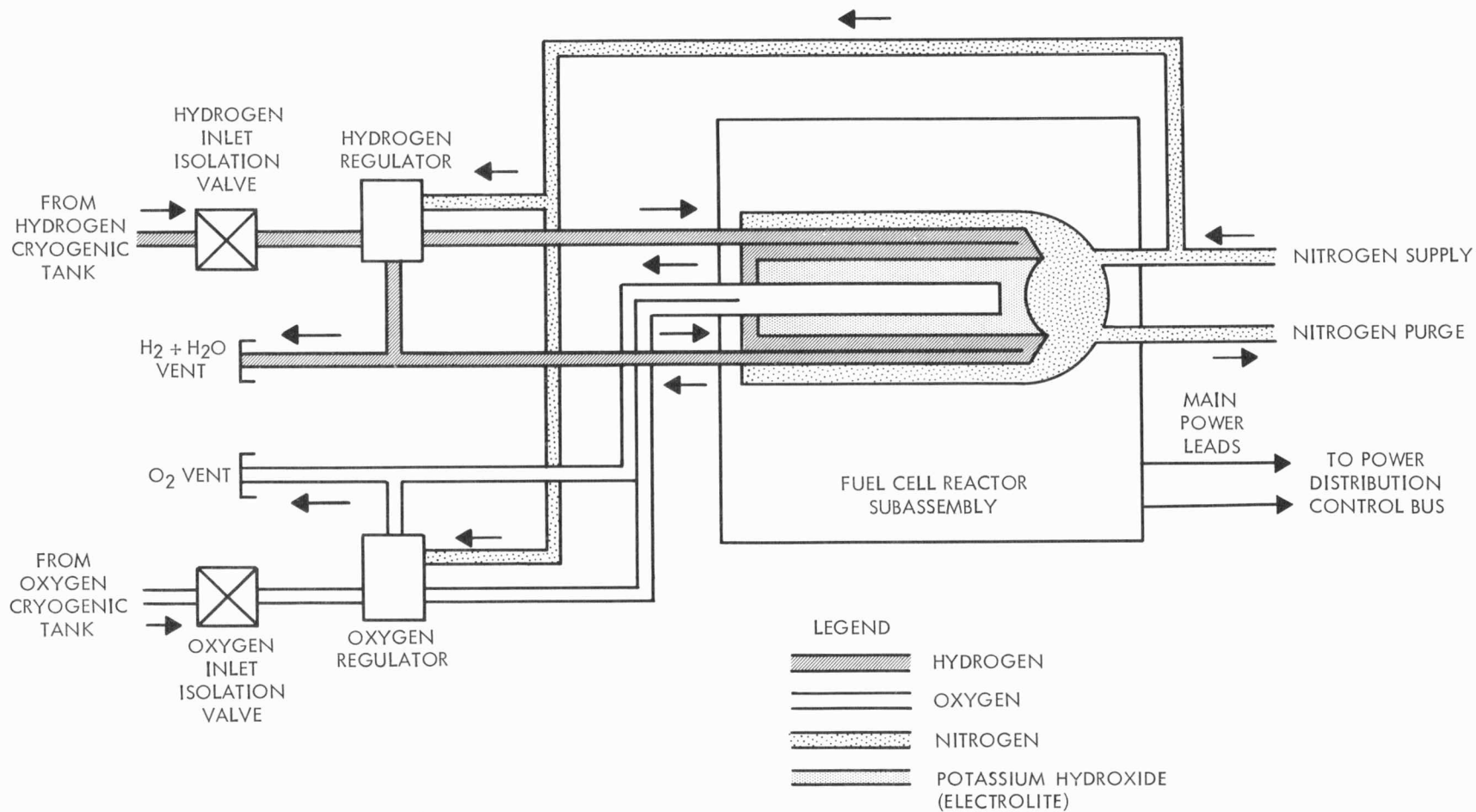
3-105. CRYOGENIC HYDROGEN AND OXYGEN STORAGE AND SUPPLY.

3-106. Cryogenic storage and supply tanks contain the hydrogen and oxygen necessary for operation of the fuel cells of the Electrical Power Subsystem and for the oxygen consumption requirements of the Environmental Control Subsystem. A hydrogen tank assembly and an oxygen tank assembly supply flow to the fuel cell assembly during all phases of the LEM mission, commencing with separation from the Command module and running through the terminal docking maneuver. The hydrogen tank (TH-2) and the oxygen tank (TO-2) in the LEM descent stage contain sufficient reactants to power the fuel cell assemblies through the lunar descent maneuver and during lunar stay time. A second hydrogen tank (TH-1) and a second oxygen tank (TO-1) are located in the ascent stage and are capable of satisfying basic mission electrical power requirements from lunar ascent through orbital docking. If the mission is aborted during the lunar descent maneuver, the descent stage is ejected and the TH-1 and TO-1 tanks provide reactant to the fuel cell assemblies for the rendezvous and docking maneuvers.

3-107. Supercritical hydrogen and supercritical oxygen is pressurized by electrical heating elements in both the descent stage and ascent stage storage tanks. The reactants are heated by passing through the ECS heat exchanger and then passing into the two fuel cell assemblies. A series of latch-type solenoid valves control the flow.

3-108. FUEL CELL CONTROL SUBASSEMBLY.

3-109. The control subassembly contains the various components, controls, and protective devices that control the operation of the fuel cell assembly. It is mounted beneath the reactor subassembly and is shielded from heat transfer by a layer of insulation. There is an isolation inlet valve for each reactant to prevent contamination of the hydrogen and oxygen lines during pre-launch storage and to isolate the LEM hydrogen and oxygen supply from the fuel cell assembly in the event of a malfunction.



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Figure 3-11. Fuel Cell and Cryogenic Storage Section

3-110. The flow of reactants to the fuel cells is controlled by hydrogen and oxygen regulators. In addition, the hydrogen regulator regulates the hydrogen vent flow. Each regulator consists of a bellows assembly linked to supply and vent poppet valves. A reference pressure is established in each regulator assembly using regulated nitrogen from the nitrogen storage tank. The regulator bellows assembly movement actuates the supply valves to maintain the reactant pressure at a pre-determined level above the nitrogen reference pressure.

3-111. An oxygen purge and shutoff valve is incorporated in each control subassembly. The first position of the valve is used during normal fuel cell assembly operation and provides a continuous venting of oxygen through a porous plug to prevent a buildup of contaminants. In the second or manual purge position, the valve is fully open for purging the oxygen system at startup or shutdown. The third position closes the oxygen vent completely for shutdown or storage.

3-112. Each fuel cell control subassembly contains a hydrogen vent shutoff valve, which is two-position, latch-type, solenoid-actuated valve with provisions for a position indicator. The valve is open during fuel cell assembly operation to vent hydrogen, as scheduled by the hydrogen regulator. In the closed position, the regulator permits pressurized shutdown and storage capability of the fuel cell assembly.

3-113. Nitrogen is used in each fuel cell assembly to provide a reference pressure at the various regulators, an inert gas blanket in each fuel cell, and to set the electrolyte pressure in each fuel cell. The nitrogen tank is filled through a valve that is easily accessible to the ground support crew. This valve is a two-position, solenoid-operated valve that is closed once the nitrogen tank is charged during the pre-launch countdown. A regulator automatically controls the nitrogen pressure to a predetermined absolute pressure.

3-114. HEAT AND WATER REMOVAL.

3-115. To initiate and maintain the 500°F temperature at which the fuel cell assemblies operate most efficiently, cell stack heaters are used, and excess heat and water are removed. As a result of this, the concentration of the electrolyte in the fuel cell assemblies is maintained at the desired level. These functions are automatically controlled by the hydrogen flow control valve.

3-116. To remove the heat and water produced when the fuel cell assembly is in operation, an excess of hydrogen is passed through the hydrogen gas space to vent them overboard. Hydrogen temperature is continuously sensed by the bimetallic strip, which positions the poppet-type metering valve to schedule proper hydrogen flow. The temperature sensor also actuates the heater switches and generates an overtemperature signal. The minimum-flow orifice in the hydrogen flow control valve provides a fixed, minimum flow of hydrogen gas when the fuel cell assembly is at minimum power operation. An on-off manual override switch permits astronaut control of heater operation if automatic control by the temperature sensor malfunctions.

3-117. ELECTRICAL CONTROLS.

3-118. The fuel cell assembly electrical controls consist of the following units: control relay, reverse current relay, overcurrent relay, overtemperature switch, pressure and temperature sensors, emergency shutdown switch, and an interlock system.

3-119. The control relay receives a signal when a reverse current, overcurrent, or overtemperature situation exists while the fuel cell assembly is operating in the automatic mode. It also receives a signal from the emergency shutdown switch when the switch is actuated. Any of these four signals causes the control relay to isolate and shut down the fuel cell assembly.

3-120. The reverse current relay is in series with the power lead of the fuel cell assembly and contains a series coil, sensitive to reverse current flow. This coil, when energized, actuates an armature to close two pairs of normally open contacts. One pair sends a signal to the control relay and the other pair sends a signal to the alarm system.

3-121. The overcurrent relay is in series with the power output lead of the fuel cell assembly. When the current exceeds 150 amperes, the relay closes two pairs of normally open contacts. One pair sends a signal to the control relay and the other pair sends a signal to the alarm system.

3-122. The overtemperature switch is operated by the temperature sensor in the hydrogen flow control valve. When an overtemperature condition exists, the switch closes and sends a signal to the control relay and to the alarm system.

3-123. The gas pressure sensors are hermetically sealed potentiometric capsule instruments that monitor the pressure downstream of the oxygen, hydrogen, and nitrogen gas regulators. These instruments provide signals that can be used for telemetry and cockpit readout.

3-124. The cell temperature sensors are platinum-resistance-wire type instruments that sense the temperature of the fuel cell stacks. One sensor is mounted in each stack; the average of the two temperature signals is transmitted to the interface panel for telemetry and cockpit readout.

3-125. The interlock system gives priority to the use of ground support equipment power (in place of fuel cell assembly power) when it is available.

3-126. SPACECRAFT STORAGE AUXILIARY BATTERY.

3-127. The auxiliary battery used in the LEM is a silver oxide-zinc storage battery of sealed, wet construction. Each battery case is sealed and constructed to minimize

leakage or loss of electrolyte for all conditions of battery operation in the earth, space, and lunar environments. The volume between the cover and the cells is filled with dry air and helium (the helium is a tracer gas) at a pressure of approximately 14.7 psi. The connector incorporates redundant pins for the positive and negative terminals. The cell terminals are silver-plated brass.

3-128. COMMUNICATIONS SUBSYSTEM.

3-129. The Communications Subsystem contains two major radio frequency (RF) links, one operating in the VHF range and the other in the S-Band (UHF) range, and a signal processing section. The RF links provide two-way voice communications and telemetry data transfer between earth and the LEM, LEM and the Command Module, and LEM and the roving astronaut. The signal processing section modulates, switches, amplifies, and multiplexes the various signals during the different operating modes. The information to be transmitted includes voice, television, telemetry, tracking and ranging, VHF received Biomedical and Impedance Pneumograph, and emergency keying.

3-130. S-BAND LINK.

3-131. The S-band equipment provides the LEM-earth communication link and is compatible with the Deep Space Instrumentation Facility (DSIF). The S-band equipment comprises a transceiver, a power amplifier, a diplexer, an RF switch, a steerable antenna with appropriate control and servo circuits, an erectable antenna, and an emergency omnidirectional antenna. Television, voice, telemetry, emergency keying, and tracking and ranging signals are accommodated by this equipment.

3-132. VHF LINK.

3-133. The VHF equipment, which includes a VHF/AM transceiver, a VHF diplexer, an RF switch, an in-flight antenna, and a lunar-stay antenna, provides the LEM-Man and LEM-Command module communication links.

3-134. SIGNAL PROCESSING SECTION.

3-135. The signal processing section consists of the premodulation processor (PMP) and the audio center. The section receives signals from the Instrumentation Subsystem and the VHF and S-band sections and processes them for transmission.

3-136. S-BAND COMMUNICATIONS.(See figure 3-12.)

3-137. The S-band communication link receives information from the PMP selected by the astronaut with controls located on the control panel. This information is applied to the inputs of the S-band transceiver, which is an all solid state equipment consisting of a phase modulated (PM) transmitter, a frequency modulated (FM) transmitter

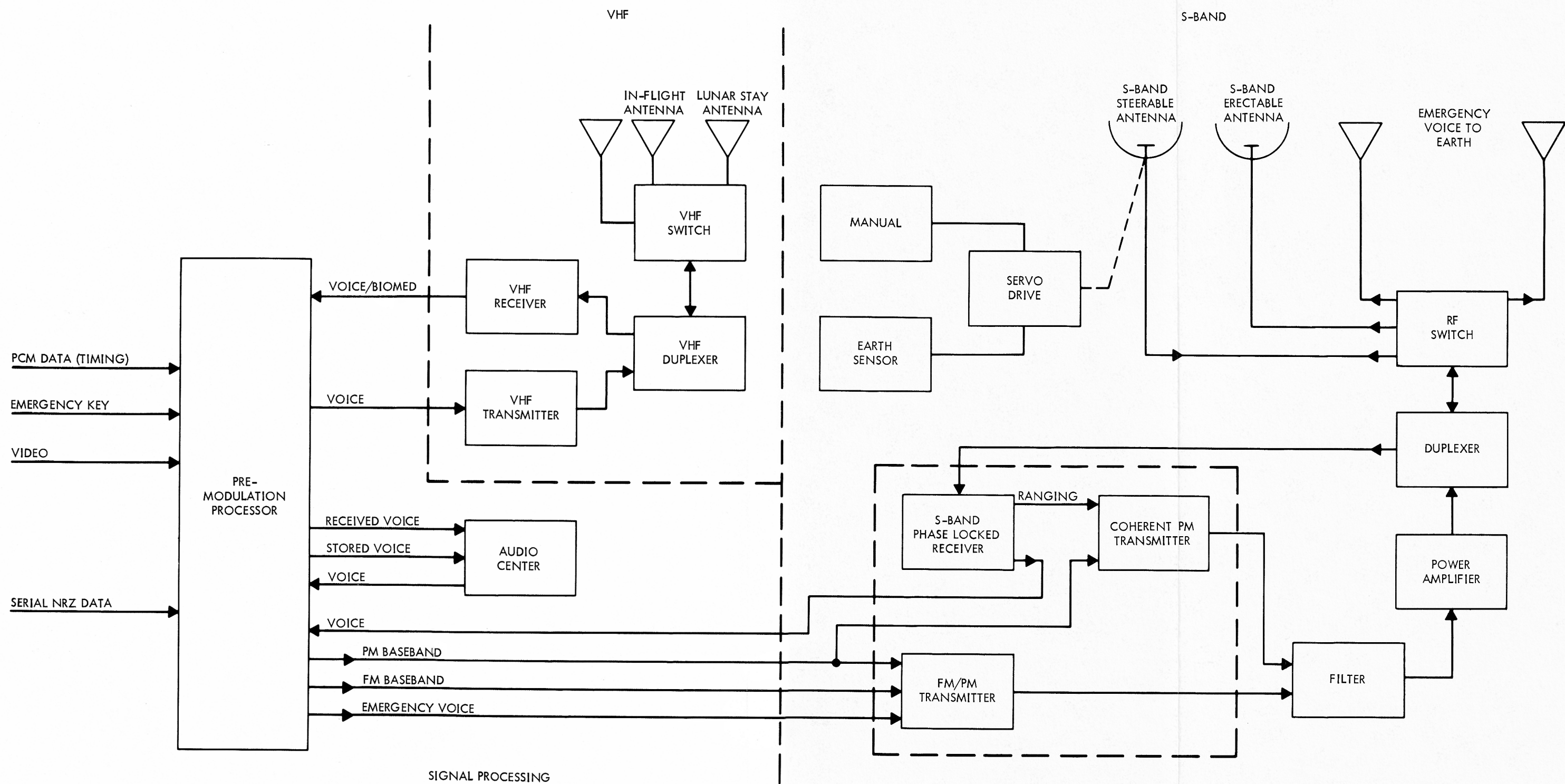


Figure 3-12. Communications Subsystem Block Diagram

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and a phase-locked receiver. The information is transmitted from one of the transmitter assemblies of the transceiver to the power amplifier, which provides an RF power amplification factor of approximately 70. The information is then conducted to the S-Band diplexer, which permits simultaneous reception and transmission from a single antenna, and then through the R-F switch to one of the three S-band antennas. When less gain is required, the power amplifier is bypassed and the signals routed directly to the antennas.

3-138. Signal reception from earth is confined to voice and PRN ranging signals. The signal flow is from the antenna through the RF switch, diplexer, phase locked receiver, premodulation processor, audio center, to the astronaut headset or through the UHF transmitter to the roving astronaut on the lunar surface. All S-band communication is accomplished during line-of-sight phases of the mission.

3-139. Steerable Antenna. The steerable antenna is a medium gain unidirectional antenna which provides hemispherical coverage about its mounting axis. It is mounted to the LEM structure and is used during the LEM lunar orbit, descent, ascent, rendezvous, and docking phases of the mission. The antenna is mounted on a double elevation gimbal that is servo controlled in response to automatic or manual slewing signals. Switches on the control panel provide mode selection and slewing commands to the antenna servos. An infrared earth sensor and an RF signal strength meter provide tracking error signals in the automatic mode.

3-140. Erectable Antenna. The erectable antenna is a high gain unit comprising a helix-fed paraboloidal reflector mounted on a tripod support. This antenna is used during the lunar stay and is easily erected by one man.

3-141. VHF COMMUNICATIONS. (See figure 3-12.)

3-142. The VHF communication link provides two-way voice communication between the LEM and the Command module. Voice transmissions are processed through the audio centers and are coupled to the VHF/AM transceiver. From the transceiver, the signal is coupled to the in-flight antenna or lunar-stay antenna through the VHF diplexer and RF switch. Voice transmissions from the Command module are coupled from the appropriate antenna to the receiver portion of the transceiver through the RF switch and the diplexer. The receiver output is processed in the PMP and the audio center and is fed to the astronauts headsets or routed back to the audio center for VHF transmission to the astronaut on the lunar surface. All VHF communication is accomplished during line-of-sight phases of the mission.

3-143. Communications between the LEM and the astronaut on the lunar surface is accomplished with a VHF link. The VHF transceiver receives biomedical information concerning the physiological functions of the astronaut and the operation of his Portable Life Support System while he is conducting lunar explorations. This information is monitored by the astronaut in the LEM and is also transmitted via the S-band to earth monitors. A television camera connected to the vehicle through an umbilical can be used outside the LEM. An alternate voice channel is provided in the camera umbilical.

3-144. Intercommunications. A closed-circuit intercommunications system permits voice communications when both astronauts are aboard the LEM.

3-145. SIGNAL PROCESSING SECTION. (See figure 3-12.)

3-146. The signal processing equipment, consisting of the premodulation processor and the audio center, provides the interface components for processing signals to be transferred between the various data gathering equipment external to and within the LEM and the various receivers and transmitters. The processing functions include multiplexing, filtering, amplifying, and switching of voice, telemetry, and television signals.

3-147. Premodulation Processor. The PMP contains filters, subcarrier oscillators, matching networks, and switches. It performs signal modulation and mixing and accomplishes signal switching so that the correct intelligence corresponding to a given mode of operation is transmitted.

3-148. Audio Center. The audio center consists of two identical subassemblies. These units operate with complementary panel controls to provide selection, isolation, and amplification of LEM audio to and from the subsystem transceivers.

3-149. OPERATIONAL INSTRUMENTATION SUBSYSTEM.

3-150. The Operational Instrumentation Subsystem (instrumentation subsystem) senses physical data, monitors the LEM subsystems during the unmanned and manned phases of the mission, performs an inflight and lunar surface checkout, prepares LEM status data for transmission to earth, provides timing frequency for the LEM subsystems, and stores data when the LEM is unable to transmit to earth. The instrumentation subsystem consists of sensors, signal conditioner equipment (SCE), emergency detection equipment (EDE), caution and warning equipment (CWE), on-board checkout equipment (OBCE), pulse code modulation and timing equipment (PCMTE), and data storage equipment (DSE). The subsystem equipment operates on 28 volts dc and 115-volt, 400 cps, three-phase power supplied by the Electrical Power Subsystem. The instrumentation subsystem provides the crew and ground facilities with LEM performance data during all phases of the mission. This enhances crew safety and mission success.

3-151. The operation of the instrumentation subsystem is discussed on an equipment basis in the following paragraphs. The equipment that comprises the instrumentation subsystem is shown in solid lined blocks in figure 3-13.

3-152. SENSORS AND SIGNAL CONDITIONER EQUIPMENT.

3-153. The sensors and SCE provide the capability for gathering the various physical data in the LEM subsystems and modifying them into a form compatible with the instrumentation subsystem equipment. The sensors are permanently installed in the

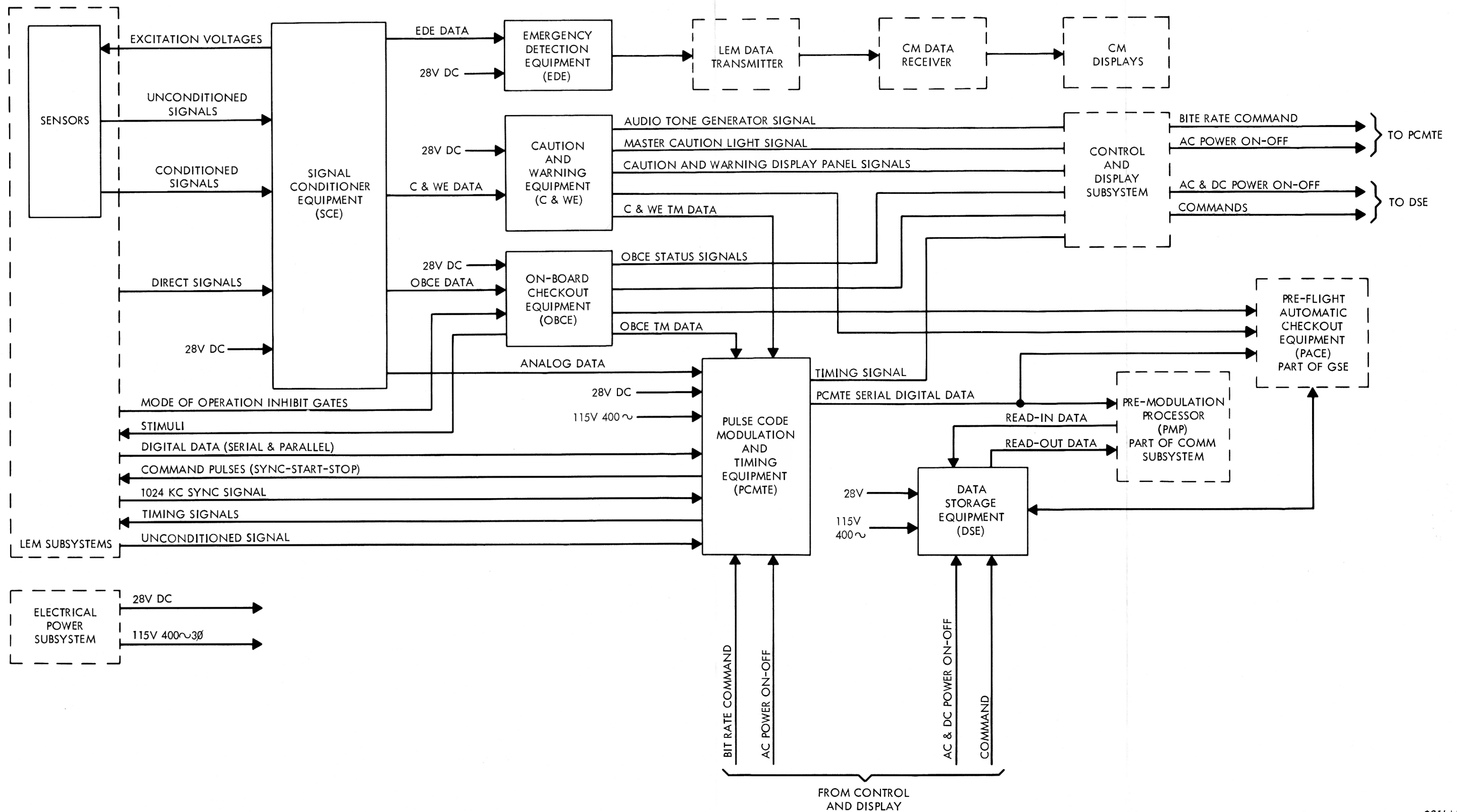


Figure 3-13. Operational Instrumentation Subsystem Block Diagram

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various LEM subsystems. They sense the various physical data (such as temperature, valve action, pressure, switch positions, voltages, currents) and converts the data into signals and presents them to the SCE. The SCE conditions the signals into a form compatible with its output equipment. This equipment contains the various types of signal modifiers, d-c amplifiers, d-c attenuator, a-c to d-c converters, etc., to condition the variety of input signals. In addition to the signals from the sensors, the SCE receives signal directly from other components within the LEM. Not all signals presented to the SCE require conditioning. Signals that do not require conditioning together with those requiring conditioning are fed to one or more of the following: EDE, CWE, OBCE, and PCMTE.

3-154. EMERGENCY DETECTION EQUIPMENT.

3-155. The EDE monitors critical LEM equipment during the unmanned phase of the mission, to detect an imminent catastrophic failure in the unmanned LEM and provide a visible and audible warning to the crew in the Command module. The input to the EDE contains data pertaining to LEM equipment whose failure results in an immediate abort condition. Monitoring is continuously until the LEM is separated from the Command module in lunar orbit. The crew responds to the warning by aborting the LEM.

3-156. CAUTION AND WARNING EQUIPMENT.

3-157. The CWE provides the crew with a rapid check of LEM status during the manned phase of the mission. The input data (CWE DATA) from the SCE is continuously monitored by this equipment, to detect a malfunction. If a malfunction is detected, the CWE provides signals to the Control and Display Subsystem and actuates the audio tone generator, lights the caution or warning indicator, and lights the indicator associated with the malfunctioning equipment. These three indications alert the crew and aids them in isolating the malfunction. There are two types of malfunction indications: one is a warning; the other, a caution. A warning indication means that a malfunction that affects crew safety and requires immediate action has occurred. A caution indication means that a malfunction that does not require immediate action has occurred. Signals that reflect malfunctions are applied to the DCMTE to be telemetered to earth.

3-158. ON-BOARD CHECKOUT EQUIPMENT.

3-159. The OBCE provides the crew with a central checkout facility for in-flight and lunar surface checkout of the LEM subsystems. This equipment contains comparators, stored limits, and logic circuitry for testing and analyzing the LEM subsystem. The OBCE isolating malfunction to either the equipment, assembly or subassembly and provides visual display of subsystem status during checkout. Checkout of the LEM subsystems are performed during post transposition, lunar orbit, post lunar landing, and lunar prelaunch. Post transposition checkout is performed to ensure that all subsystem withstood the launch, translunar injection and transposition. Lunar orbit checkout is performed to ensure that all subsystems are functioning properly before separation and descent to lunar surface. Post lunar landing checkout is performed to ensure that all subsystems withstood the lunar landing. Lunar prelaunch

checkout is performed to ensure all subsystems are functioning properly before ascent. Signals that reflect all checkout malfunctions are applied to the PCMTE to be telemetered to earth.

3-160. PULSE CODE MODULATION AND TIMING EQUIPMENT.

3-161. The PCMTE changes all LEM data into signals for transmission to earth and provides a time reference for any stored data. This equipment contains: analog multiplexers, amplifiers, analog-to-digital converters, coders, digital multiplexers, digital registers, programmer, and a timing generator. It combines analog inputs and parallel and serial digital inputs into a serial digital data train for presentation to the pre-modulation processor (part of Communication Subsystem), for transmission to earth, and to the preflight automatic checkout equipment (PACE). This data can be presented at two selectable rates of 1,600 or 51,200 bits per second. The timing generator is used to provide timing frequencies for guidance, telemetry, calibration, and displays.

3-162. DATA STORAGE EQUIPMENT.

3-163. The DSE provides magnetic tape storage for PCMTE data, selected analog sensor signals, and a voice channel. When the LEM is on the far side of the moon and is unable to transmit to earth, the DSE is switched on to store data from the Pre-modulation Processor. When communications is resumed, the recorded information is read back to the pre-modulation processor at high speeds.

3-164. ENVIRONMENTAL CONTROL SUBSYSTEM.

3-165. The Environmental Control Subsystem (ECS) consists of five integrated sections: atmosphere revitalization, oxygen supply and cabin pressure control, heat transport, water management, and cold plate. The major portion of the ECS is in the pressurized equipment compartment in the ascent stage. A glycol loop and a gaseous oxygen accumulator are in the equipment bay section in the ascent stage. Two water tanks are in the tankage section of the ascent stage; a third larger water tank is in the descent stage.

3-166. The ECS (see figure 3-14) controls the oxygen, pressurization, ventilation, and temperature of the cabin and the space suits worn by the crew; limits the level of carbon dioxide and remove odors, moisture, and particulate matter from the oxygen breathed by the crew; controls the temperature of the electronic equipment; and stores water for drinking, food preparation, and the Portable Life Support System (PLSS).

3-167. ATMOSPHERE REVITALIZATION SECTION.

3-168. The atmosphere revitalization section conditions and provides oxygen to cool and ventilate the space suits worn by the crew. It also controls the recirculation and temperature of the cabin oxygen.

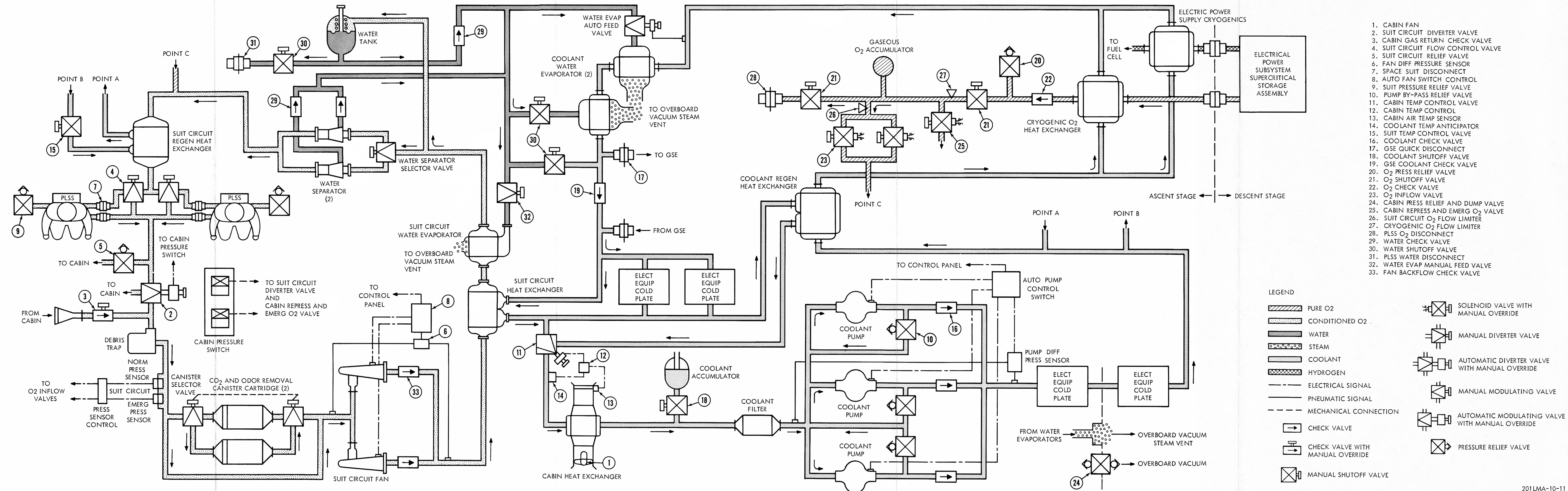


Figure 3-14. Environmental Control Subsystem Schematic

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3-169. Oxygen is circulated through the atmosphere revitalization section by one of two redundant suit circuit fans. Each fan can maintain the required suit-circuit oxygen flow; only one fan is operated at a time. From the fan, the oxygen passes through the suit circuit head exchanger that transfers waste heat from the oxygen to the heat transport section coolant. The oxygen then passes through the suit circuit water evaporator that removes waste heat when heat transfer by the suit-circuit heat exchanger is inadequate. Excess moisture condensed in the suit circuit heat exchanger or suit circuit water evaporator is removed from the oxygen by one of two redundant water separators. Each separator can meet the water removal requirements; only one separator is operated at a time. Before the oxygen enters the space suits, its temperature is manually controlled by the crew as it passes through the suit-circuit regenerative heat exchanger. Warm coolant from the heat transport section flows through the suit-circuit regenerative heat exchanger and transfers heat to the oxygen; the temperature of the oxygen is controlled by varying the coolant flow through the heat exchanger. For individual comfort, the flow of oxygen entering each space suit is controlled by the respective astronaut. A debris trap downstream of the suits removes foreign objects originating in or entering the atmosphere revitalization section. The debris trap contains a ground-replaceable filter element. The oxygen then passes through one of two redundant canister assemblies that removes carbon dioxide and odors. Each assembly consists of a canister and a replaceable cartridge.

3-170. During open-faceplate operation (normal pressurization level), the suit-circuit diverter valve is opened to pass the entire oxygen flow from the atmosphere revitalization section into the cabin. This ensures that a sufficient amount of cabin oxygen is circulated through the atmosphere revitalization section to maintain the desired carbon dioxide and humidity levels in the cabin. In the event of a cabin decompression, the cabin pressure switch provides a signal that automatically closes the diverter valve. The suit circuit relief valve prevents overpressurization of the space suits. When space suit pressure is 4.1 psia or greater, the relief valve is fully open; when space suit pressure is less than 3.8 psia, the relief valve is fully closed.

3-171. Recirculation and temperature control of the cabin oxygen is provided by the cabin recirculation assembly. The assembly contains a fan that recirculates the oxygen, and a cabin heat exchanger that automatically heats or cools the oxygen. Heat is transferred between the cabin oxygen and heat transport section coolant that flows through the cabin heat exchanger. The temperature of the coolant is controlled in the heat transport section (refer to paragraph 3-181).

3-172. OXYGEN SUPPLY AND CABIN PRESSURE CONTROL SECTION.

3-173. The oxygen supply and cabin pressure control section provides oxygen to maintain a normal or an emergency pressurization level in the cabin and space suits and prevents overpressurization of the cabin pressure shells. It also provides oxygen for the PLSS primary oxygen storage tanks.

3-174. At the normal pressurization level, the pressure in the cabin and the space suits is maintained at 5 ± 0.2 psia. This pressure permits the astronauts to open their faceplates and remove their gloves. With the cabin depressurized, the space suits must be sealed and the pressure in the suits is reduced to the emergency

pressurization level of 3.5 (+0.2, -0.0) psia. The pressurizing and ventilating gas is 100 percent oxygen, most of which is stored cryogenically in the Electrical Power Subsystem supercritical storage assembly; a small gaseous oxygen accumulator also stores oxygen for brief high-flow demands and emergencies.

3-175. Oxygen from the supercritical storage assembly enters the cryogenic oxygen heat exchanger, where it is warmed by the heat transport section coolant to make it compatible with the operation of components in the oxygen supply and cabin pressure control section and the atmosphere revitalization section. The oxygen stored in the supercritical storage assembly is sufficient for six cabin repressurizations and two fills and four refills of the PLSS primary oxygen storage tanks, in addition to normal crew consumption and vehicle and space suit leakage. The gaseous oxygen accumulator is used in conjunction with normal oxygen flow for PLSS fills and refills and cabin repressurizations that require high oxygen flow rates. The self-sealing PLSS oxygen disconnect permits filling and refilling the PLSS primary oxygen storage tanks.

3-176. Two redundant oxygen inflow valves control the delivery of oxygen to the atmosphere revitalization section in response to signals from the suit-circuit normal and emergency pressure sensors. The cabin repressurization and emergency oxygen valve controls the delivery of oxygen to the cabin, for cabin repressurization or to slow the loss of cabin pressure in the event of a puncture in the cabin pressure shell, in response to signals from the cabin pressure switch.

3-177. Overpressurization of the oxygen supply and cabin pressure control section is prevented by the oxygen pressure relief valve, which automatically relieves excess pressure by venting oxygen into the cabin. Overpressurization of the cabin is prevented by the cabin pressure relief and dump valve. This valve automatically relieves excess cabin pressure by venting oxygen overboard. The valve can also be manually operated, from inside or outside the cabin, to dump the cabin pressure overboard.

3-178. HEAT TRANSPORT SECTION.

3-179. The heat transport section is a closed-loop system that circulates an ethylene glycol-water coolant. The section provides temperature control of the electronic equipment and oxygen circulated through the cabin and the space suits, warms cryogenically stored fluids, and provides a means for removing waste heat.

3-180. The coolant is circulated through the heat transport section by one of three redundant coolant pumps. Each pump can provide normal flow; only one pump is operated at a time. From the pump, the coolant flows through part of the cold plate section where it absorbs heat from the electronic equipment. Some of this heat is transferred to the oxygen in the suit circuit regenerative heat exchanger (refer to paragraph 3-169). Heat is also transferred, in the coolant regenerative heat exchanger, to the coolant that enters the cabin heat exchanger. Warm coolant then flows in parallel paths through the cryogenic oxygen and hydrogen heat exchangers to warm the oxygen and hydrogen supplied from the supercritical storage assembly. Waste heat is removed from the coolant by two series-connected coolant water evaporators that remove heat from the coolant by a sublimation process. Water vapor from the evaporators is discharged overboard.

3-181. The coolant then flows in parallel paths through the suit circuit heat exchanger where heat is transferred from the oxygen to the coolant (refer to paragraph 3-169), and through another part of the cold plate section where the coolant absorbs heat from the electronic equipment.

3-182. Before the coolant enters the cabinet heat exchanger, the temperature of the coolant is controlled in the coolant regenerative heat exchanger with the cabin temperature control valve. The control valve diverts coolant through the coolant regenerative heat exchanger in response to signals from the cabin temperature controller. The controller receives signals from the cabin temperature sensor attached to the air inlet duct of the cabin heat exchanger and from the coolant temperature anticipator in the coolant supply line to the cabin heat exchanger. The coolant flows through the cabin heat exchanger and controls the temperature of the cabin air flowing through the heat exchanger.

3-183. The coolant accumulator maintains pressure above the coolant vapor pressure at all points in the heat transport section and can accommodate volumetric changes of the coolant. Particles that could cause a malfunction are removed by the coolant filter. Two self-sealing GSE quick disconnects, one for inflow and one for outflow, permit the use of GSE for coolant fill, and coolant recirculation and coolant chilling during ground checkouts and ground operation of the heat transport section.

3-184. WATER MANAGEMENT SECTION.

3-185. The water management section contains three positive-expulsion tanks that store the water required for the metabolic needs of the crew, for the water evaporators, for two fills and four refills of the PLSS water tanks, and for use, in an emergency, as a coolant in the heat transport section.

3-186. Oxygen from the atmosphere revitalization section maintains a constant pressure in the water tanks. The tank located in the descent stage supplies the water required up to the time of lunar launch. After lunar launch, water is obtained from the two smaller tanks in the ascent stage. In addition to water from the tanks, water from the atmosphere revitalization section water separators is used in the water management section. The self-sealing PLSS water disconnect permits filling and refilling the PLSS water tanks and delivery of metabolic water for drinking and food preparation.

3-187. COLD PLATE SECTION.

3-188. A cold plate is physically attached to each piece of electronic equipment requiring thermal control. These cold plates, which make up the cold plate section, are single pass heat exchangers. Coolant from the heat transport section passes through the cold plates and removes heat from the electronic equipment.

3-189. DISPLAYS AND CREW PROVISIONS.

3-190. DISPLAYS AND CONTROLS.

3-191. The LEM displays and controls are in three main areas: the centrally located forward section, the flight commander's left console, and the system engineer's right console. The main panel, in the forward section, is in front of and parallel to the crew station positions. This panel is divided into areas in which critical controls for monitoring LEM status and crew safety are grouped. These controls are accessible to both astronauts.

3-192. CREW PROVISIONS.

3-193. Personal Equipment. Each astronaut in the LEM has a space suit assembly (SSA) that consists of a constant wear garment (CWG), a pressure garment assembly (PGA), a thermal garment, a Portable Life Support System (PLSS), and biomedical and environmental sensors. The CWG is a one-piece tailored coverall worn under the pressure suit during all LEM operations. The PGA includes a helmet, torso and limb suit, pair of gloves, and light-weight boots. These items are enveloped by a 3.5-psi atmosphere during normal operations; during emergency operation, the pressure can be increased to 5.0 psi. The thermal garment, worn over the PGA, consists of a thermal suit, extravehicular gloves, and extravehicular boots that provide insulation and protection against harmful radiation doses. The PLSS, used when the astronaut is on the lunar surface, consists of a waist-attached unit and a backpack.

3-194. Food and Water Facilities. To prevent spoilage and conserve space, dehydrated food is contained in sealed, pliable, plastic packages. To prepare the food for consumption, the cap of the package is torn off and an umbilical hose attached to the package to provide water for mixing with the food. Feeding is accomplished by attaching the package to a food valve adapter which interfaces to the pressurized SSA helmet and, then, squeezing the package to force the food into the mouth.

SECTION IV

PRELAUNCH OPERATIONS

4-1. INTRODUCTION.

4-2. This Section covers the prelaunch operation and the facilities used for LEM at the Atlantic Missile Range. The primary purpose of these procedures is to test and verify the functioning of each subsystem in all operational modes without removal of equipment from the spacecraft.

4-3. PRELAUNCH TESTS AND FACILITIES. (Refer to figure 4-1.)

4-4. Prelaunch tests are divided into four groups, as follows:

a. Functional and Verification tests are performed on all LEM subsystems. Stimuli required for testing the LEM subsystem are provided by Preflight Acceptance Checkout Equipment - Spacecraft (PACE-S/C), applied through the LEM Carry-On PACE-S/C Up Link equipment. Output data signals are obtained through LEM Carry-On PACE-S/C Down Link equipment, utilizing the subsystem circuitry and equipment of the LEM. For radio frequency checkout, NON-PACE interface equipment may be required.

b. Integrated Mated tests are performed to certify the compatibility of the LEM and with the Command/Service module and of the LEM with the S-IVB adapter for all mission configurations.

c. Vertical assembly building tests are performed to certify booster/spacecraft compatibility.

d. Launch Pad tests verify that all systems on the launch pad operate satisfactorily and verify that launch complex/space vehicle compatibility.

4-5. The five major facilities where prelaunch tests are conducted are a.) Operations and Checkout Building. b.) Fluid Test Complex. c.) Static-Firing Complex. d.) Vertical Assembly Building. e.) Launch Complex. The Pace-S/C is located in the Operations and Checkout Building. The test areas in the Vertical Assembly Building, Static-Firing Complex, Fluid Test Complex, and the Launch Complex Operations and Checkout Building, are connected to PACE-S/C by coaxial cables.

4-6. PREFLIGHT ACCEPTANCE CHECKOUT EQUIPMENT - SPACECRAFT (PACE-S/C).

4-7. The PACE-S/C is a general-purpose spacecraft-checkout system used for automatic, semi-automatic, or manually controlled prelaunch testing of the LEM, Command module, and Service module systems and (collectively or individually) their subsystems. Its capabilities include generation of test commands, monitoring of spacecraft

subsystem performance conversion and processing of data, measurement of responses, diagnostic tests, and communication between the spacecraft and PACE-S/C controls.

4-8. The general-purpose PACE-S/C is adapted to the specific LEM subsystems and to the LEM servicing equipment by the LEM Carry On equipment, which consists of two PACE-S/C Up Links and a PACE-S/C Down Link. One PACE-S/C Up Link conditions and routes all PACE-S/C test commands to their proper onboard equipment locations and supplies the necessary stimuli not supplied by PACE-S/C. The second PACE-S/C Up Link performs much the same function for the PACE-S/C-associated servicing equipments. The PACE-S/C Down Link monitors the performance of the spacecraft subsystems and servicing equipments, and conditions and interleaves (time multiplexes) this data for transfer to PACE-S/C.

4-9. Functionally, PACE-S/C comprises the following subsystems:

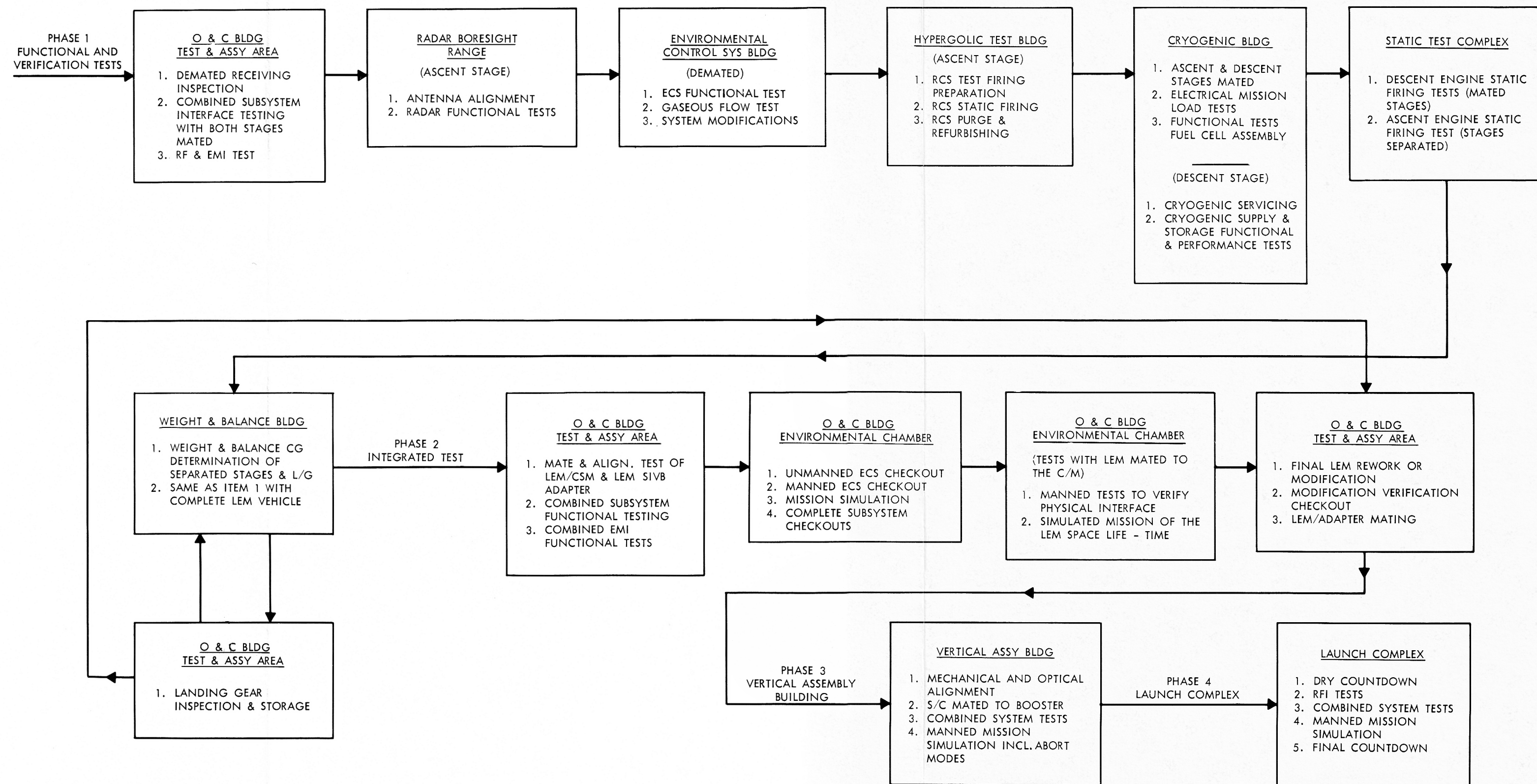
a. Pulse-Code Modulation (PCM) Ground Station Subsystem, which prepares spacecraft checkout data for recording, displaying, and for transfer to the Computing Subsystem.

b. Computing Subsystem, which consists of a data processing computer, a digital command computer, and a common memory. The data processing computer compares spacecraft checkout data from the PCM Ground Station Subsystem with programmed tolerances. If an out-of-tolerance condition is detected, the appropriate indication is made to the test engineer at the malfunctioning subsystem's test console in the LEM control room. Diagnostic action can be initiated manually or automatically. All spacecraft test commands are generated in parallel form by the digital command computer and are converted to a serial format for transmission to the spacecraft.

c. Data Transmission Subsystem, which uses coaxial hardlines and repeater-amplifiers to transmit data to and from the spacecraft, and to remote displays.

d. Display and Control Subsystem, which utilizes CRT's that display real-time test data from the Computing Subsystem in alphanumeric form as the primary display devices. These are supplemented by various analog and digital displays directly driven by decommutators of the PCM Ground Station Subsystem. A summary of the complete spacecraft test is displayed to the system test engineer at his console in the LEM control room, and detailed breakdowns of the subsystem tests are displayed to the subsystem engineers at their control room consoles. The PACE-S/C controls enable three modes of testing. In the manual mode, subsystem engineers manually select individual, programmed, test commands. In the semi-automatic mode, programmed subroutines containing from one to several test commands are also selected manually. In the automatic with manual override mode, test commands are generated under program control, in synchronization with a real-time clock.

4-10. The combined PACE-S/C facilities enable continuous processing of real-time spacecraft checkout data and complete test documentation for post-test analysis, with a minimum of interface cabling.



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Figure 4-1. AMR Prelaunch Checkout Block Diagram

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4-11. VERIFICATION AND FUNCTIONAL TESTS.

4-12. RECEIVING INSPECTION.

4-13. Upon arrival of the LEM at the Test and Assembly Area of the Operations and Checkout Building, the protective covers are removed and the ascent and descent stages are placed in their respective test stations. An overall visual inspection is performed on the LEM to determine its physical condition and to verify that the latest changes have been incorporated. A general cleaning of the LEM commences with the completion of the visual inspection.

4-14. COMBINED SUBSYSTEM FUNCTIONAL TESTS.

4-15. All non-hazardous tests that can be performed under ambient conditions are accomplished at this time in the Operations and Checkout Building. The combined subsystem tests are repeats of the final functional tests performed at Bethpage at the time of equipment release. Subsystem checkout is performed with Carry-On equipment installed and utilizes cockpit displays and inflight PCM instrumentation. Subsystem monitoring and location of malfunctions are to the replaceable unit (black box) level. Diagnosis of the subsystem output data is performed with PACE-S/C.

4-16. Before activating each non-hazardous subsystem, continuity checks are performed within the LEM to check the normal and emergency power supply circuits through the a-c and d-c essential and non-essential buses. Low-pressure leak tests of all pressure fluid sections are performed with inert gas prior to servicing those sections with their operational fluids. Initial tests of high-pressure fluid sections are considered hazardous, as is the use of hypergolics and cryogenics, and are not performed at this time. Final system and subsystem interface testing is performed with ascent and descent stages mated.

4-17. INITIAL RADIO FREQUENCY AND ELECTROMAGNETIC INTERFERENCE TESTS.

4-18. All testing of radiating communications is performed after the ascent and descent stages are mated in the Operations and Checkout Building. Subsequent to radiofrequency interference tests, all LEM equipment capable of generating or being susceptible to electromagnetic radiation is energized for electromagnetic interference tests.

4-19. ANTENNA ALIGNMENT AND FUNCTIONAL RADAR TESTS.

4-20. All antennas are mechanically, optically, and electrically aligned and oriented at the radar boresight range. Functional radar tests are performed to check radar power output, and voltage-standing-wave-ratio measurements are verified at this facility.

4-21. REACTION CONTROL SYSTEM STATIC FIRING.

4-22. The ascent stage is moved from the Environmental Control Building to the Hypergolic Test Building, where it is mounted in a test cell and prepared for Reaction Control Subsystem static-firing tests. A dry run of the test-firing sequence is performed with all ground support equipment attached before servicing the propellant and the pressurization systems. The firing sequence is performed to test each thrust control assembly of the reaction control system under ambient conditions. The firing stimuli are provided through the Stabilization and Control Subsystem in order to determine performance using LEM circuitry. After test-firing, the pressurization and propellant feed systems are purged, dried, and refurbished (if required).

4-23. CRYOGENIC STORAGE AND SUPPLY TESTS.

4-24. Functional cryogenic servicing tests are conducted in the Cryogenics Building on the storage and supply tanks of the descent stage; the functional servicing tests on the propellants for the ascent stage are made in the Hypergolics Building.

4-25. FUEL CELL ASSEMBLY TESTS.

4-26. After the ascent stage arrives at the Cryogenic Building and is mated to the descent stages, fuel cell performance and functional tests are formed under varying electrical loads representative of all phases of the mission.

4-27. DESCENT ENGINE TESTS.

4-28. The LEM is placed in the altitude test cell at the Static Test Complex for descent-engine-firing tests. After completion of pre-firing tests and fluid servicing, the descent engine is static-fired, purged, and dried.

4-29. ASCENT ENGINE TESTS.

4-30. After the LEM is separated into stages, the ascent stage is returned to the altitude test cell for test-firing of the ascent engine. Pre-firing tests and fluid servicing are completed before static firing. After firing tests, the engines are drained and removed from the test cell before purging and drying.

4-31. WEIGHT AND CG DETERMINATION.

4-32. At the Weight and Balance Building, the weight and cg determinations are performed on the ascent and descent stages individually and on the complete LEM.

4-33. INTEGRATED TESTS.

4-34. Combined subsystem integrated tests are conducted in the Test and Assembly area of the Operations and Checkout Building, using PACE-S/C.

4-35. LEM MATING AND ALIGNMENT WITH COMMAND SERVICE MODULE.

4-36. Mechanical mating and optical alignment tests of the LEM with the Command/Service module and of the LEM with the S-IVB adapter are performed in the Test and Assembly Area of the Operations and Checkout Building for all mission configurations.

4-37. COMBINED SYSTEM FUNCTIONAL TESTS.

4-38. Combined systems functional tests are performed with the LEM and Command/Service modules mated. Subsystem operation in the mated configuration, as well as functional interfaces of the LEM and the Command/Service modules are tested. All subsystems that operate while the modules are mated are exercised in flight operational modes.

4-39. COMBINED ELECTROMAGNETIC INTERFERENCE TESTS.

4-40. All subsystem switching and radiating functions are energized with the LEM and Command module mated. Tests are performed to determine if any EMI exists between the LEM and the Command/Service modules.

4-41. UNMANNED ENVIRONMENTAL CONTROL SYSTEM TESTS.

4-42. Unmanned-cabin leakage tests and ECS performance tests are performed in the Environmental Chamber of the Operations and Checkout Building. These performance tests are a complete ECS checkout. Checkout will be sufficient to assure crew safety during subsequent manned chamber tests.

4-43. UNMANNED ENVIRONMENTAL CONTROL SYSTEM TEST AND MISSION SIMULATION.

4-44. Following unmanned-cabin leakage tests, manned ECS tests exercise all systems through mission phases with simulated mission loads. These tests verify the performance of other subsystems that can be tested in the Environmental Chamber.

4-45. MATED TESTS WITH THE COMMAND MODULE (MANNED).

4-46. After the mating of the LEM and the Command module in the Environmental Chamber, manned tests verify the physical interface and the compatibility of the

Environmental Control Subsystem of the LEM with that of the Command module. Missions representative of the greater portion of the LEM lifetime are simulated.

4-47. MODIFICATION AND REWORK.

4-48. At this point in the test sequence, any LEM system modification and rework must be accomplished prior to assembly of the LEM and the adapter. Modification and rework is accomplished in the Test and Assembly Area of the Operations and Checkout Building. After rework and modification and before the LEM is mated to the adapter combined subsystem tests are performed, as required, to verify performance after any modification or rework.

4-49. LEM-TO-ADAPTER MATING.

4-50. Following performance testing after modification and rework, the landing gear is attached to the descent stage and the LEM is mated to the adapter.

4-51. VERTICAL ASSEMBLY BUILDING.

4-52. SPACE VEHICLE MATING TESTS.

4-53. After the LEM is mated to the adapter in the Operations and Checkout Building, they are moved to the Vertical Assembly Building by Grumman personnel. Tests at the VAB consist of mechanical and optical alignment tests, which are performed in conjunction with mating of the spacecraft (LEM and adapter) to the booster.

4-54. COMBINED SYSTEM FUNCTIONAL TESTS.

4-55. The following functional and operational tests will be accomplished during this sequence: 1.) Combined LEM system functional test between the ascent and descent stages 2.) System operation test for interference by other systems in the space vehicle (if operational requirement dictate simultaneous operation) 3.) Functional test of all system interfaces.

4-56. MISSION SIMULATOR.

4-57. The spacecraft undergoes manned mission simulation, including all abort modes, in the Vertical Assembly Building. This mission simulation covers the phase when the spacecraft is in the launch configuration (from launch until transposition).

4-58. LAUNCH COMPLEX.

4-59. DRY COUNTDOWN.

4-60. The assembled space vehicle is transported to the Launch Complex and positioned on the launch pad. A dry countdown is performed to verify equipment readiness and countdown procedures.

4-61. RADIOFREQUENCY INTERFERENCE TESTS.

4-62. Radiofrequency interference tests are performed on the launch pad complex utilizing all equipment normally operational and capable of generating or susceptible to radiofrequencies.

4-63. COMBINED SUBSYSTEM TESTS AND MISSION SIMULATION.

4-64. Combined subsystem functional tests are performed prior to launch simulation on the launch pad. Mission simulation checkout is manned and includes boost phase of the flight using PACE-S/C

4-65. COUNTDOWN.

4-66. Countdown commences after the successful completion of the above tests. It will include pyrotechnic installation, fluid servicing, and verification of the launch configuration. All LEM Carry-On equipment is removed before closeout (approximately T-5 hours). Equipment which must be operating and in which a malfunction could be catastrophic is monitored from PACE-S/C during the countdown.

SECTION V

GROUND SUPPORT EQUIPMENT

5-1. INTRODUCTION

5-2. The LEM ground support equipment (GSE) consists of LEM Carry-On Equipment and the Radio Frequency System Checkout Unit; Servicing Equipment; Transportation, Handling, and Workstand Equipment; and Bench Maintenance Equipment.

5-3. LEM CARRY-ON EQUIPMENT.

5-4. The LEM Carry-On Equipment is a spacecraft-associated extension of the Pre-flight Acceptance Checkout Equipment - Spacecraft (PACE-S/C). PACE-S/C is a general purpose, spacecraft checkout system used to perform computer controlled or manually controlled testing of the LEM system and subsystems. The PACE-S/C control rooms, digital computers, data acquisition and decommutation equipment, and auxiliary support equipment are in the Operations and Checkout Building. The LEM Carry-On Equipment adapts the PACE-S/C to LEM subsystems and servicing equipment and is, for the most part, carried on board the LEM when PACE-S/C controlled pre-launch tests are to be performed.

5-5. The LEM Carry-On Equipment comprises PACE-S/C Up Links and a PACE-S/C Down Link. Digital test commands generated by PACE-S/C and addressed to the LEM subsystems are conditioned and routed to their proper input points by one PACE-S/C Up Link. Another PACE-S/C Up Link performs the same function for test commands addressed to the LEM servicing equipment. The PACE-S/C Down Link monitors, samples, conditions, and interleaves LEM subsystem performance data with LEM telemetry data and with LEM servicing equipment response data; the resultant data train is transmitted to PACE-S/C.

5-6. PACE-S/C UP LINK.

5-7. The PACE-S/C Up Link involves two functional categories: Digital Test Command System (DTCS) and a Stimuli Generator. Together, these can generate up to 2,048 discrete or analog stimuli, or 128 single-point differential output analog signals, or various combinations thereof, and route these stimuli to the PACE-S/C-addressed onboard equipment or servicing equipment input. Upon receipt of a PACE-S/C command, the DTCS transmits a "check reply" to PACE-S/C for validity analysis, automatically providing continuous self-check information to assure the accuracy of checkout data processed by the PACE-S/C Up Link.

5-8. The DTCS used in the LEM comprises the following assemblies:

a. Receiver-decoder. This assembly receives PACE-S/C test commands at rates up to 500 kilobits per second and routes test commands to a baseplate unit group or the guidance and navigation (G & N) computer buffer unit.

b. G & N computer buffer unit. This assembly processes, checks, and routes test commands received from the receiver-decoder and addressed to the LEM G & N Subsystem's guidance computer.

c. Baseplate unit. Up to eight baseplate units can be used to form one baseplate unit group; up to four baseplate unit groups can be used simultaneously. All receiver-decoder outputs not intended for the LEM G & N Subsystem's guidance computer are addressed to one baseplate unit group and to one baseplate unit within that group. The selected baseplate unit selects one of four modules at its output. The four output modules can be any combination of the following three modules (d, e, and f). The combination of modules used depends upon the type of input required by the LEM subsystem undergoing test.

d. Conventional relay (CR) module. Upon PACE-S/C command applied to it by a baseplate unit, the CR module verifies and controls the application of stimuli to the LEM subsystems.

e. Latching relay (LR) module. This assembly performs the same function as the CR module. The LR module relays change state only upon DTCS command, not upon power application or removal. The LR module is used in situations where loss of power to a conventional relay that controls a critical signal or bias would cause the relay to drop out and subsequently damage the subsystem undergoing test.

f. Digital-to-analog converter module. This assembly verifies and converts its binary input from the baseplate unit to analog signals for application to the LEM subsystem.

5-9. The Stimuli Generator comprises a special stimuli unit that provides all necessary stimuli not supplied by PACE-S/C.

5-10. The PACE-S/C Up Link used with the LEM servicing equipment includes all the assemblies previously described, except the G & N computer buffer unit.

5-11. PACE-S/C DOWN LINK.

5-12. The PACE-S/C Down Link involves three functional categories: Pulse Code Modulation (PCM) Response Section, Servicing Equipment - PACE-S/C Adapter, and Data Interleaver. Together, these process all LEM checkout data into a form acceptable to PACE-S/C.

5-13. The PCM Response Section comprises the following assemblies:

a. Digital signal conditioning and multiplexing unit. Using timing signals from the carry-on PCM system (f), this assembly conditions and time multiplexes up to 318 event (on-off) signals from the LEM subsystems into an eight-line parallel format for transfer to the carry-on PCM system.

b. Analog signal conditioning and sampling unit. Using carry-on PCM timing signals, this assembly samples up to 250 analog signals from the LEM subsystems at a rate of one sample per second and up to 50 analog signals at a rate of ten samples per second.

These are transferred to the carry-on PCM system in a pulse-amplitude-modulated (PAM), non-return to zero (NRZ) format.

c. Special signal conditioning unit. This assembly performs much the same function as the analog signal conditioning and sampling unit and is used when nonstandard analog outputs of the LEM subsystems make special analog signal conditioning circuitry necessary.

d. High sampling rate signal conditioning unit. Using carry-on PCM timing signals, this assembly conditions up to 20 analog signals from the LEM subsystems and transfers them to the carry-on PCM system for sampling at rates of either 50 samples per second or 100 samples per second. It also multiplexes conditioned data from the LEM subsystems into a PAM-NRZ data train and transfers this output to the carry-on PCM system.

e. G & N signal conditioning and switching matrix unit. This assembly receives 32 unconditioned analog signals and conditioned analog data from the LEM G & N Subsystem, timing signals from the carry-on PCM system, and commands from the DTCS. The switching matrix of this assembly will, upon DTCS command, select one of the 32 analog signals for sampling at a rate of 400 samples per second. At the same time, the conditioned analog data is interleaved into a PAM-NRZ data train. Both outputs are transferred to the carry-on PCM system.

f. Carry-on PCM system. The inputs to the carry-on PCM system are timing signals from the data interleaving system, and 128 channels of analog data, PAM-NRZ data, and digital data from the signal conditioning units described previously. The carry-on PCM system provides timing signals for these signal conditioning units and converts and interleaves the analog data from the 128 data channels into a PCM-NRZ format for transfer to the data interleaving system.

5-14. The servicing equipment - PACE-S/C adapter assembly receives timing signals from the data interleaving system and up to 1,000 event signals and 200 analog signals from the LEM servicing equipment. The servicing equipment data are multiplexed into a PCM-NRZ data train and transferred to the data interleaving system.

5-15. The Data Interleaver comprises the data interleaving system assembly, which interleaves LEM subsystem performance data from the carry-on PCM system, data supplied by the LEM telemetry, and data from the servicing equipment - PACE-S/C adapter assembly. Operation of the data interleaving system assembly is controlled by command signals from the DTCS and timing signals from the LEM telemetry. The interleaved LEM subsystem, telemetry, and servicing equipment data is transmitted in a return-to-zero, bi-phase, PCM format to PACE-S/C. The data interleaving system assembly also sends non-interleaved LEM telemetry data directly to PACE-S/C.

5-16. RADIO FREQUENCY (RF) SYSTEM CHECKOUT UNIT.

5-17. The RF system checkout unit is used to check and troubleshoot the LEM Communications Subsystem by applying r-f stimuli, measuring transmitted power and frequencies, and analyzing pulse and bandwidth.

5-18. The RF system checkout unit comprises the following assemblies: VHF signal generator, VHF receiver, VHF patch panel, VHF distribution panel, S-band signal

generator, S-band phase-lock receiver, S-band patch panel, S-band distribution panel, pseudo-noise generator, wideband noise generator, dual pulse generator, intercom panel, audio tape recorder, TV monitor, switchable discriminator, 600-kc wideband oscillator with clipper and pulse shaper, VTVM, spectrum analyzer, oscilloscope, transfer oscillator, high frequency counter, traveling wave tube amplifier, r-f power meters, regulated 28-volt d-c power supply, and remote r-f junction box.

5-19. SERVICING EQUIPMENT.

5-20. FUEL TRANSFER UNIT.

5-21. The fuel transfer unit is a four-wheel cart that contains fuel tanks, a weighing system, a control and instrumentation panel, filters, valves, and LEM and launch tower hardline adapters and hoses. When the unit is connected to the fuel hardlines and the reaction control subsystem fill connections, it measures the weight of the fuel supplied, filters the fuel, and monitors the fuel temperature and pressure.

5-22. FUEL FLUSH AND PURGE CART.

5-23. The fuel flush and purge cart is a four-wheel cart that contains nitrogen, hydroxyacetic, and waste tanks; a vacuum system; a nitrogen heater; a fluid pressurization system; adapter lines; readout instrumentation; and flow-indicating lights. When the cart is connected to the hardlines, it pulls vacuum on fuel-tank expulsion pressure lines; flushes the bladder with nitrogen, then hydroxyacetic; and, then, expels the hydroxyacetic with pressurized nitrogen. This unit is an item of common usage GSE.

5-24. OXIDIZER TRANSFER UNIT.

5-25. The oxidizer transfer unit is a four-wheel cart that contains oxidizer tanks, a weighing system, a vacuum pump, a control and instrumentation panel, filters, and valves. When the unit is connected to the oxidizer hardlines and the reaction control subsystem fill connections, it measures the weight of the oxidizer supplied, filters the oxidizer, monitors oxidizer temperature, and bleeds air from the system.

5-26. OXIDIZER FLUSH AND PURGE CART.

5-27. The oxidizer flush and purge cart is a four-wheel cart that contains an oxidizer dump tank and cold trap, a storage tank for flushing fluids, a pressurized nitrogen supply, a vacuum pump, a nitrogen heater, hardline connections, and readout instrumentation and controls. When the cart is connected to the launch tower hardlines, the oxidizer is drained into the dump tank (which contains a cold trap for venting gases) and the cart draws vacuum on the gas side of the LEM tank bladder, flushes the bladder with triethanolamine, and, then, expels the triethanolamine from the bladder with pressurized nitrogen. This unit is an item of common usage GSE.

5-28. REFEREE CRYOGENIC FLUID SUPPLY UNIT.

5-29. The referee cryogenic fluid supply unit is a two-wheel tank trailer that consists of a Dewar vessel for storing 250 gallons of liquid and 50 gallons of vapor, and a fluid transfer system. This unit supplies liquid nitrogen to the hydrogen transfer and monitoring unit and to the oxygen transfer and monitoring unit.

5-30. NITROGEN AND/OR HELIUM SUPPLY UNIT.

5-31. The nitrogen and/or helium supply unit is a four-wheel cart that consists of a flat cart that contains manifolding, 7 nitrogen bottles, and 7 helium bottles; and a panel from which monitoring and control is effected. The unit can supply gaseous nitrogen and/or helium to the hydrogen transfer and monitoring unit and to the oxygen transfer and monitoring unit.

5-32. HYDROGEN TRANSFER AND MONITORING UNIT.

5-33. The hydrogen transfer and monitoring unit is a skid mounted unit that contains cryogenic pumps and piping, subcoolers, conditioning equipment, instrumentation, wiring, and hardware for unit operation. The unit controls and monitors the flow of clean, dry, gaseous nitrogen or gaseous helium, or both, to purge the reactant storage subsystem; clean, dry, gaseous hydrogen to purge inert gases from the reactant storage subsystem; clean, dry, gaseous nitrogen or gaseous helium to purge the fuel cells; and clean, dry gaseous hydrogen to purge inert gases from the fuel cells. It also controls and monitors filling of the reactant storage subsystem with liquid hydrogen and supplies clean gaseous hydrogen to the fuel cells for ground operation.

5-34. OXYGEN TRANSFER AND MONITORING UNIT.

5-35. The oxygen transfer and monitoring unit is a skid-mounted unit that contains cryogenic pumps and piping, subcoolers, conditioning equipment, instrumentation, wiring, and hardware for unit operation. The unit controls and monitors the flow of clean, dry, gaseous nitrogen and/or gaseous helium to purge the liquid oxygen tanks of the reactant storage subsystem; clean, dry, gaseous oxygen to purge inert gases from the liquid oxygen tanks of the reactant storage subsystem; clean, dry, gaseous nitrogen or gaseous helium to purge the fuel cells; and clean, dry, gaseous oxygen to purge inert gases from the fuel cells. It also controls and monitors filling of the liquid oxygen tanks of the reactant storage subsystem with clean, liquid oxygen, and supplied gaseous oxygen to the fuel cells for ground operation.

5-36. WATER SUPPLY UNIT.

5-37. The water supply unit is a skid-mounted unit that contains a pump, starters, tubing, valving and controls, remote and manual controls, explosion proofing, instrumentation, and wiring. It is used in the LEM environmental control subsystem to flush and fill the water management section with triple distilled water, purge the water management section with gaseous oxygen, and evacuate the water management section. This unit is an item of common usage GSE with modifications for LEM use.

5-38. HELIUM TRANSFER AND CONDITIONER UNIT.

5-39. The helium transfer and conditioner unit is a completely enclosed cabinet, four-wheel unit for use in an outdoor, unsheltered location and contains a gas flow control system, a heat exchanger, and an electrical system. It is positioned at the base of the launch tower with its inlet port connected to the helium supply and its outlet port connected to the insulated helium distribution lines. In this configuration, conditioned gaseous helium is transferred from the storage unit to the LEM propulsion and reaction control subsystems helium tanks, and an automatic bleed and top-off functions as the LEM helium tanks come to equilibrium. This unit is an item of common usage GSE.

5-40. HELIUM BOOSTER CART.

5-41. The helium booster cart is a four-wheel cart that contains a boost pump, an electrical driven power subsystem, inter and after coolers, and electrical and pneumatic controls. With the cart connected between the helium storage trailer and the helium supply source, the boost pump establishes equilibrium pressure between the supply source and storage trailer, and boosts the pressure of the helium storage trailer. The boost pump also empties the LEM helium tanks and pumps the helium back to the transfer and conditioner unit, if necessary. This unit is an item of common usage GSE.

5-42. HELIUM STORAGE TRAILER.

5-43. The helium storage trailer is an eight-wheel, pneumatic tire, semi-trailer. Mounted on the trailer are gas cylinders which are filled from the helium supply using the helium booster cart. The LEM helium tanks are pressurized and filled from these cylinders by blowing down through the helium transfer and conditioner unit. The helium stored in the gas cylinders is sufficient to provide two fillings of the propulsion and reaction control subsystems tanks to proper pressure. This unit is an item of common usage GSE.

5-44. TRANSPORTATION, HANDLING, AND WORKSTAND EQUIPMENT.

5-45. ASCENT STAGE TRANSPORTER.

5-46. The ascent stage transporter is a four-wheel trailer that consists of four main assemblies: base platform, chassis frame, suspension system, and environmental cover. The base platform form a rectangular frame and extension frames are attached to each side during ground operation. Flooring covers the structural framework. Tie-down fittings, at four points, are used for mounting and supporting the ascent stage on the base platform. The base platform is mounted to and supported by, the chassis frame. Air brakes, electrical facilities, a tow bar, and steerage linkage are mounted to the chassis. Individual suspension assemblies, tiedown provision, and jacking facilities are attached to the main sills. The suspension system consists of four individually acting suspension assemblies. The environmental cover consists of a canopy-type, aluminum-skin structure secured to the base platform. Hoisting lugs, used in conjunction with a spreader bar, are provided. Continuous rubber seals and tamperproof locking provisions are at the mating surface.

5-47. TRANSPORTER COVER SLING.

5-48. The transporter cover sling consists of a steel spreader bar, four steel cables with a universal fitting swaged on each end, and a pear-shaped universal link attached to the center of the spreader bar. The sling is used in conjunction with a suitable crane or lifting device to lift either the ascent or descent stage transporter cover from the transporter. The sling is proof loaded to four times the weight of the transporter cover.

5-49. ASCENT STAGE CLEAN ROOM DOLLY.

5-50. The ascent stage clean room dolly consists of a welded, rectangular, steel-tube chassis; four heavy-duty, 8-inch, swivel casters; and a tow bar secured with a quick-disconnect pin. Each caster assembly has a mechanically operated parking brake. The dolly is designed to clean room design criteria and is used to transport the ascent stage during all phases of clean room operations. It is also used for interplant transportation that does not require clean room operations.

5-51. DESCENT STAGE TRANSPORTER.

5-52. The descent stage transporter is a four-wheel trailer that consists of four main assemblies: base platform, chassis frame, suspension system, and environmental cover. The base platform forms a rectangular frame and extension frames are attached to each side during ground operations. Flooring covers the structural framework. Tiedown fittings, at four points, are used for mounting and supporting the descent stage on the base platform. The base platform is mounted to, and supported by, the chassis frame. Air brakes, electrical facilities, tow bar, and steerage linkage are mounted to the chassis. Individual suspension assemblies, tiedown provisions, and jacking facilities are attached to the main sills. The suspension system consists of four individually acting suspension assemblies. The environmental cover consists of a canopy-type, aluminum-skin structure secured to the base platform. Hoisting lugs, used in conjunction with a spreader bar, are provided. Continuous rubber seals and tamperproof locking provisions are at the mating surface.

5-53. DESCENT STAGE CLEAN ROOM DOLLY.

5-54. The descent stage clean room dolly consists of a welded, rectangular, steel-tube chassis; four heavy-duty, 8-inch, swivel casters; and a tow bar secured with a quick-disconnect pin. Each caster assembly has a mechanically operated parking brake. The dolly is designed to clean room design criteria and is used to transport the descent stage or the complete LEM (less landing gear) during all phases of clean room operation. It is also used for interplant transportation that does not require clean room operations.

5-55. ASCENT STAGE WORKSTAND.

5-56. The ascent stage workstand is a two-level, knock-down-type stand capable of supporting 18 men with tools and parts. It consists of vertical trusses that support an

aluminum, diamond-plate flooring. The upper partial platform provides access to the top docking hatch. The workstand, comprised of two sections, is assembled to envelop the ascent stage and provide 360° access and separates for removal of the stage. Each section has retractable caster to permit the section to be rolled by hand or two tractor for removal or assembly. Kickplates, at the floor level, prevent tools or equipment from inadvertently falling off. Railings provide for personnel safety. Stairways provide access to both levels of the workstand.

5-57. DESCENT STAGE WORKSTAND.

5-58. The descent stage workstand is a two-level, knock-down-type stand capable of supporting 18 men with tools and parts. It consists of vertical trusses that support an aluminum, diamond-plate flooring. The workstand, comprised of two sections, is assembled to envelop the descent stage and provides 360° access and separates for removal of the stage. Each section has retractable casters to permit the section to be rolled by hand or tow tractor for removal or assembly. Kickplates, at the floor level, prevent tools or equipment from inadvertently falling off. Railings provide for personnel safety. Stairways provide access to both levels of the workstand.

5-59. DESCENT STAGE SUPPORT STAND.

5-60. The descent stage support stand is a structural-steel stand used to support and position the descent stage. It is capable of supporting the entire LEM and permits mating the ascent and descent stages. The descent stage is positioned high enough to permit installation of the landing gear, with the gear above floor level. The stand has a steel frame with support and securing provisions that mate to the descent stage hard points. Four vertical column maintain the LEM at the proper working height. Each column has a bearing plate with provisions for cinching the stand to the floor.

5-61. BENCH MAINTENANCE EQUIPMENT.

5-62. Bench maintenance equipment is presented in Tables 5-1 through 5-10 according to the subsystem to which the equipment applies.

Table 5-1. Propulsion Subsystem

Nomenclature	Used to check:
Propulsion Subsystem checkout unit	Leakage, valve operation, and integrity of Propulsion Subsystem. Unit is PACE-S/C compatible.

Table 5-2. Reaction Control Subsystem

Nomenclature	Used to check:
Reaction Control Subsystem check-out cart	Reaction Control Subsystem.

Table 5-3. Propulsion and Reaction Control Subsystems

Nomenclature	Used to check:
Helium component test stand	Flow and pressure of Propulsion and Reaction Control Subsystems components.
Fuel component test stand	Fuel system components.
Oxidizer component test stand	Oxidizer system components.
Helium leak detector	Leakage in helium pressurization systems.

Table 5-4. Navigation and Guidance Subsystem

Nomenclature	Used to check and troubleshoot:
Radar maintenance test station	Landing and Rendezvous Radar to replaceable component level; simulates analog and digital inputs; characteristics of range and altitude tracking capability; records outputs; measures range signal stability and long-time frequency stability of oscillator sections; and displays radar spectral waveforms for periodic maintenance, overhaul, and calibration.
Rendezvous radar transponder maintenance test station.	Radar Transponder to replaceable component level.

Table 5-5. Stabilization and Control Subsystem

Nomenclature	Used to check and troubleshoot:
Platform electronics and four-gimbal platform maintenance test station	Platform and platform electronics assembly to replaceable component level.

Table 5-5. Stabilization and Control Subsystem (cont)

Nomenclature	Used to check and troubleshoot:
Rate gyro maintenance test station	Rate gyro assembly to replaceable component level; measures pick-off excitation and null signals, torque gradient, power requirements, and cross-coupling.
Accelerometers maintenance test station	Accelerometer assembly to replaceable component level; checks accelerometer bias, scale factor, linearity, cross-acceleration, temperature variations and controls, gradients, excitation voltages and waveforms, and power supply voltages.
Programmer maintenance test station	Programmer assembly to replaceable component level.
Power supply maintenance test station	Power supply assembly to replaceable component level; checks input and output voltage and current, line and load regulation, phase shift, ripple, stability, and input and output frequency.
Descent engine control and gimbal drive actuator assemblies maintenance test station	Descent engine control and gimbal drive actuator assemblies to replaceable component level; checks output voltage, linearity, input frequency, d-c input and output impedances, stability, gimbal drive rpm, limit action, and torque.
Attitude and translation control assembly maintenance test station	Attitude and translation control assembly to replaceable component level; checks power supply, summing and demodulator circuits, modulators, drivers, and combinational logic.
Control panel maintenance test station	Control panel to replaceable component level; checks continuity and switching functions, resolver readout and phase shift functions, and null indicator resolution and accuracy.
Guidance coupler assembly maintenance test station	Guidance coupler assembly to replaceable component level; checks continuity and gate, sequencer, and summing network operation.
In-flight monitor maintenance test station	In-flight monitor assembly to replaceable component level.

Table 5-6. Electrical Power Subsystem

Nomenclature	Used to check and troubleshoot:
Fuel cell test console	Fuel cell assembly to replaceable component level; measures transient response, noise, ripple, overload capacity, voltage regulation, stability, loadsharing, manual purge control, automatic continuous purging operation, reverse current sensing, overcurrent sensing, over-temperature sensing, and temperature control.
Electrical load simulator console	Fuel cell assembly; automatically or manually, provides steady-stage or transient loads to measure fuel cell outputs under varying loads.
Distribution maintenance test station	Power distribution assembly to replaceable component level; measures input and output voltage and current, continuity and logic, response time, and transients.
Electrical Power Subsystem bench maintenance equipment*	Electrical Power Subsystem to replaceable component level.
Cryogenic and gaseous oxygen components checkout bench	Liquid, gaseous, and supercritical oxygen components.
Cryogenic and gaseous hydrogen components checkout bench	Liquid, gaseous, and supercritical hydrogen components.
Helium/hydrogen leak detector mass spectrometer*	Fuel cell assembly; detects leaks; measures leakage rates; used to fill fuel cell assembly with inert gas for storage.
Fuel cell power plant test stand*	Fuel cell assembly; applies loads at various conditions; measures performance of individual cells through their operating range.

*Used on both LEM and Command/Service Modules (common usage)

Table 5-7. Communications Subsystem

Nomenclature	Used to check and troubleshoot:
Antenna maintenance test station	UHF and VHF antennas and gimbal system of steerable antenna; checks vswr, chopper-filter, d-c voltage vs angle off bore-sight, antenna overshoot, linearity, and threshold voltage.

Table 5-7. Communications Subsystem (cont)

Nomenclature	Used to check and troubleshoot:
S-band equipment bench maintenance equipment*	S-band transponder to replaceable component level; checks input power, frequency stability, noise figure, image response, linearity, receiver threshold, phase error, bandwidth, phase modulation, frequency modulation, and power output.
Communications equipment bench maintenance equipment*	Transmitters, transceivers, and antennas of Communications Subsystem to replaceable component level.
TV camera bench maintenance equipment*	TV camera to replaceable component level; checks output of video preamplifier, d-c voltage regulator, and composite video circuitry; measures grid voltage, horizontal and vertical sweep, horizontal and vertical blanking trigger, and power input.

* Used on both LEM and Command/Service Modules (common usage)

Table 5-8. Displays and Controls Subsystem

Nomenclature	Used to check and troubleshoot:
Ball attitude indicator maintenance test station	Ball attitude indicator to replaceable component level.
Flight control maintenance test station	Flight-control, reaction control, and environmental-control panels to replaceable component level.
Power and radar maintenance test station	Radar, power-generation, and power-distribution panels to replaceable component level.
Stabilization - navigation and guidance maintenance test station	Stabilization and control, and main propulsion (ascent/descent) panel to replaceable component level.
Communications panel maintenance test station	Communications, lighting, and audio control panels to replaceable component level.

Table 5-9. Environmental Control Subsystem

Nomenclature	Used to:
Atmosphere revitalization calibration set	Deliver and monitor CO ₂ , latent heat, sensible heat, and water vapor to atmosphere revitalization section and monitor oxygen supply section.
Electrical components test stand	Control and measure temperatures to calibrate temperature sensors and thermocouples and supply operational inputs to electrical components for functional tests.
Gaseous component test stand	Test all components of atmosphere revitalization section and oxygen supply section under operating pressures, measure pressure drop across components, detect internal and external leakage, calibrate in-flight instruments, and check response of remote control components to control signals.
Water components test stand*	Supply and monitor water, measure critical parameters of water delivered, provide evacuated space for component testing, and measure water quantity in supply tank.
Environmental Control Subsystem check-out console	Monitor and display, on schematic representation of Environmental Control Subsystem, all sensors and redundant components, indicate component in operation, and record results.
Water-glycol components test bench*	Supply operational inputs or water-glycol to heat transfer section components under test, measures component pressure drop and pump performance, perform leakage tests, and calibrate flight instrumentation.

* Used on both LEM and Command/Service Modules (common usage)

Table 5-10. Instrumentation Subsystem

Nomenclature	Used to check and troubleshoot:
In-Flight Test System Maintenance test station	In-Flight Test System to replaceable component level; provides complete

Table 5-10. Instrumentation Subsystem (cont)

Nomenclature	Used to check and troubleshoot:
	interface simulation of electrical and mechanical functions.
Spacecraft Instrumentation Test Equipment (SITE) *	Instrumentation Subsystem and Carry-On Equipment. SITE enables checkout of entire Instrumentation Subsystem, PACE-S/C Up Link, and PACE-S/C Down Link; a section (grouping of interrelated assemblies) of any of these equipments; or individual assemblies of any of these equipments.

* Used on both LEM and Command/Service Modules (common usage)

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