LUNAR MODULE
Subsystem Assembly and Installations

Grumman Aircraft Engineering Corporation
Manufacturing Engineering

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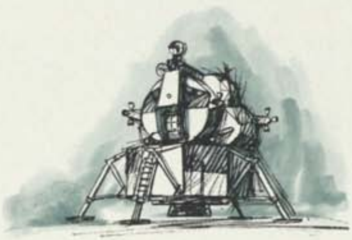

Grumman Aircraft Engineering Corporation
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December 1967

FOREWORD

This document provides a general introduction to the tasks and requirements associated with the manufacture of a Lunar Module. Major components of each subsystem are described and illustrated. Flow charts and allied exhibits are also included to show the various phases of subsystem fabrication, installation, and checkout.

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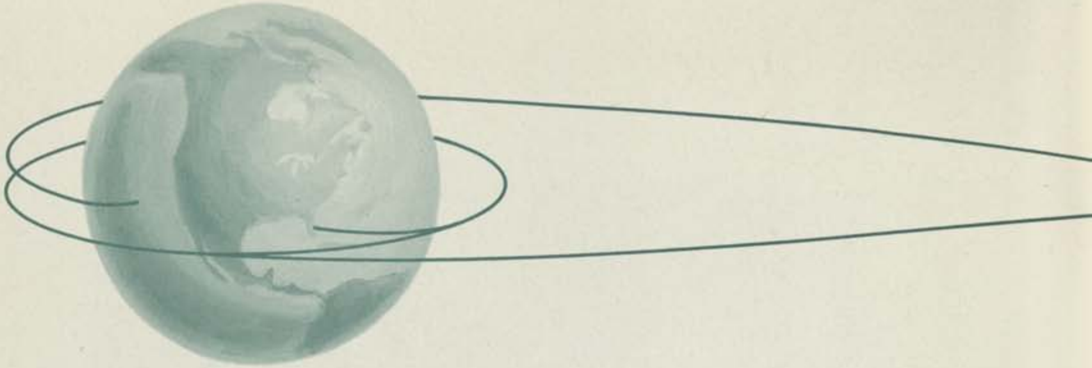
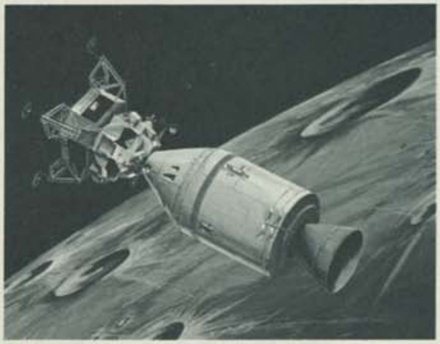
General Information

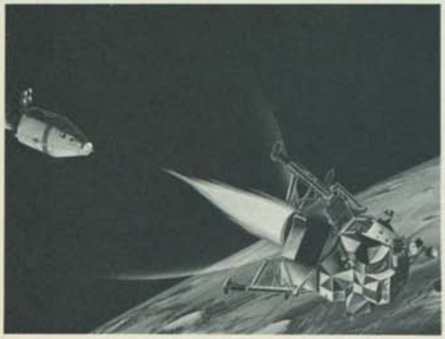


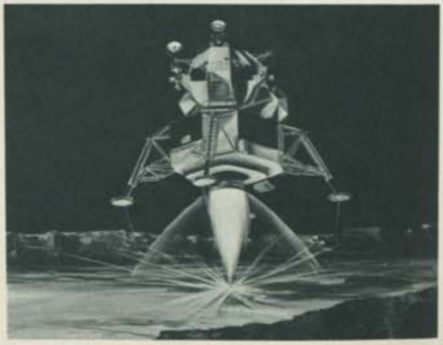
1. THE LM MISSION



Grumman is currently building the Lunar Module (LM) which will function as a space ferry to transport two astronauts from a lunar-orbiting Apollo Command Module (CSM) to the moon's surface and back. The LM will be coupled to the CSM via a turn-around docking maneuver, to be performed during the earth-to-moon passage. Shortly after the combined CSM-LM arrives in the vicinity of the moon and achieves a lunar orbit, two of three astronauts riding in the CSM will enter LM through a connecting tunnel. LM will then be separated from the CSM mother ship and, under the control of its crew, will descend and land on the moon at a pre-selected landing site.

During their planned stay on the lunar surface,





the astronauts will carry out such scientific tasks as gathering soil samples, measuring temperature, gravity, and magnetic field strength, and conducting communications experiments. Local explorations in the vicinity of the LM are also planned. Re-embarking, the astronauts will lift off in LM's Ascent Stage. The Descent Stage will act as a launch cradle for the Ascent Stage and will remain on the moon.

The launch profile will bring LM to a rendezvous point with the orbiting CSM. After docking with the CSM, the LM crewmembers will transfer and rejoin the third astronaut in the CSM. The LM Ascent Stage will then be left in a lunar orbit as the CSM starts the trip back to earth.

2. GENERAL DESCRIPTION AND CHARACTERISTICS

The Ascent Stage of the Lunar Module (LM) is the manned portion of the space vehicle (Figure 1). It contains a crew compartment, hypergolic ascent engine, an aft equipment bay and tank section, and 16 reaction control engines. The crew compartment is used as an operations center by the astronauts during their lunar stay. Lunar descent, lunar landing, lunar launch, and rendezvous and docking with the Command and Service Module (CSM) are also controlled from this compartment.

All or part of the following subsystems are contained in the Ascent Stage:

- Guidance, Navigation & Control
- Crew Provisions/Displays
- Environmental Control
- Electro-Explosive Devices
- Instrumentation
- Electrical Power
- Propulsion
- Reaction Control
- Communications

The unmanned Descent Stage contains equipment essential for landing on the lunar surface and serves as a platform for launching the Ascent Stage after completion of the lunar mission. In addition to the descent engine and its pressurization and propellant components, the Descent Stage houses the landing radar, electrical power and pyrotechnics components, and the Apollo Lunar Surface Experiments Package (ALSEP). It also contains outriggers that extend from the ends of the structural beams. These outriggers have provisions for:

- Attaching the cantilever-type landing gear.
- Locating the Lunar Module within the shroud of the Saturn V aerodynamic shell.

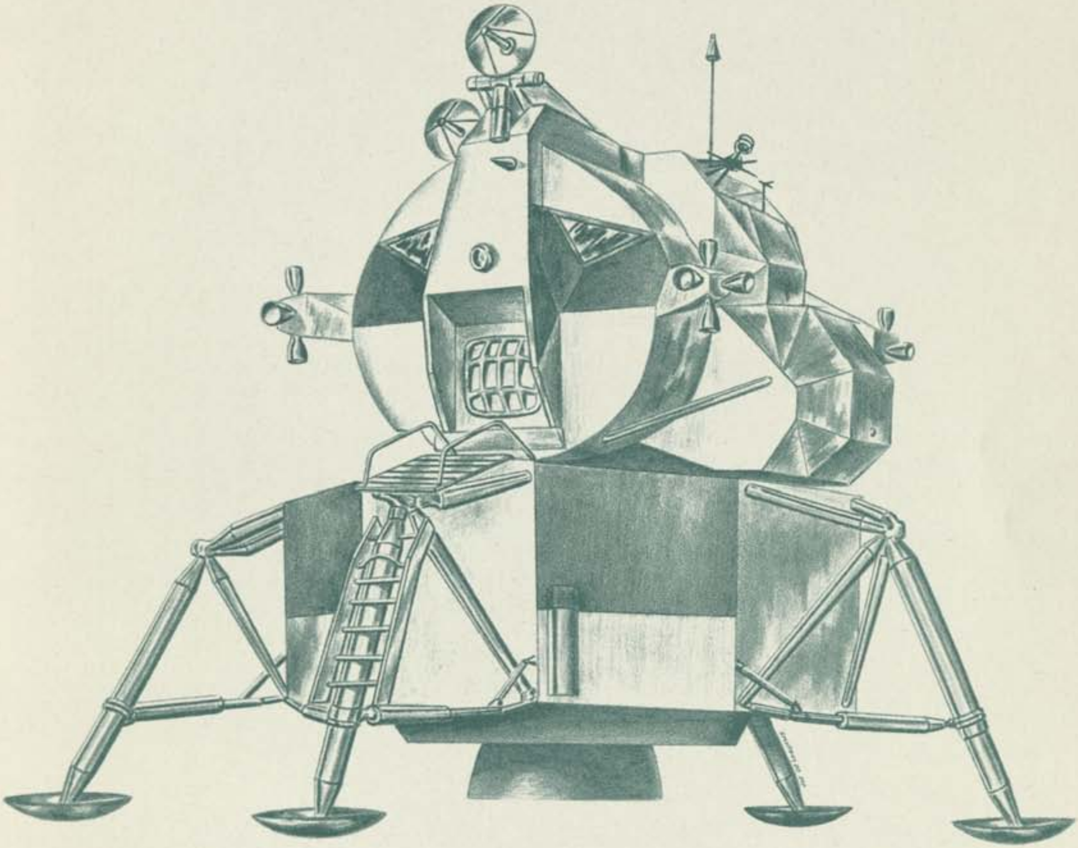


Figure 1 Lunar Module

LUNAR MODULE GENERAL CHARACTERISTICS

DIMENSIONS (Legs Extended)

Overall height:	22 feet, 11 inches
Overall width:	14 feet, 1 inch
Diameter (diagonally across landing gear):	31 feet
Ascent stage height:	12 feet, 4 inches
Descent stage height:	10 feet, 7 inches

GENERAL DATA

Earth launch weight:	32,000 pounds
Pressurized cabin volume:	235 cubic feet
Cabin environment:	75°F 100% oxygen at 4.8 ±0.2 psia

Subsystems

1. ASCENT STAGE STRUCTURE

The Ascent Stage structure (Figure 2) consists of the following subassemblies: front face, cabin skin, mid section and aft equipment bay. The front face is mechanically assembled from 10 welded and machined sections. After a sealing and curing operation, the outer flange contour is machined for accurate mating to the cabin skin subassembly. The installation of secondary structure (stringers, shelves, brackets, etc.) completes the front face assembly.

The cabin skin subassembly is fabricated from formed chem-milled skin panels that are welded and mechanically fastened. Sealing of the mechanical joints, trimming of the forward edge to match the front face contour, and the addition of formed longerons and stringers complete the operation for this assembly.

The mid section, the largest of the subassemblies in the Ascent Stage, consists basically of two machined bulkheads, an upper deck tunnel weldment, a lower (engine) deck weldment and chem-milled skins. The mid section is mechanically joined with the front face and cabin skin subassembly and sealed to form the cabin pressure shell of the Ascent Stage.

Cold rails, chem-milled beams, struts, and machined fittings comprise the major structural components in the aft equipment bay. The attachment of this subassembly to the cabin pressure shell completes the Ascent Stage structure.

2. DESCENT STAGE STRUCTURE

The Descent Stage structure (Figure 2) consists primarily of machined parts and chem-milled panel/stiffener assemblies that are mechanically fastened. Fabrication of the Descent Stage begins with the joining of the machined picture frames and the chem-milled panel/stiffener assemblies to form the engine compartment. After the outrigger bulkhead assemblies are attached to the engine compartment with machined cap strips, the eight remaining panel/stiffener assemblies, the upper and lower machined decks, and the machined interstage fittings are added to complete the Descent Stage structure.

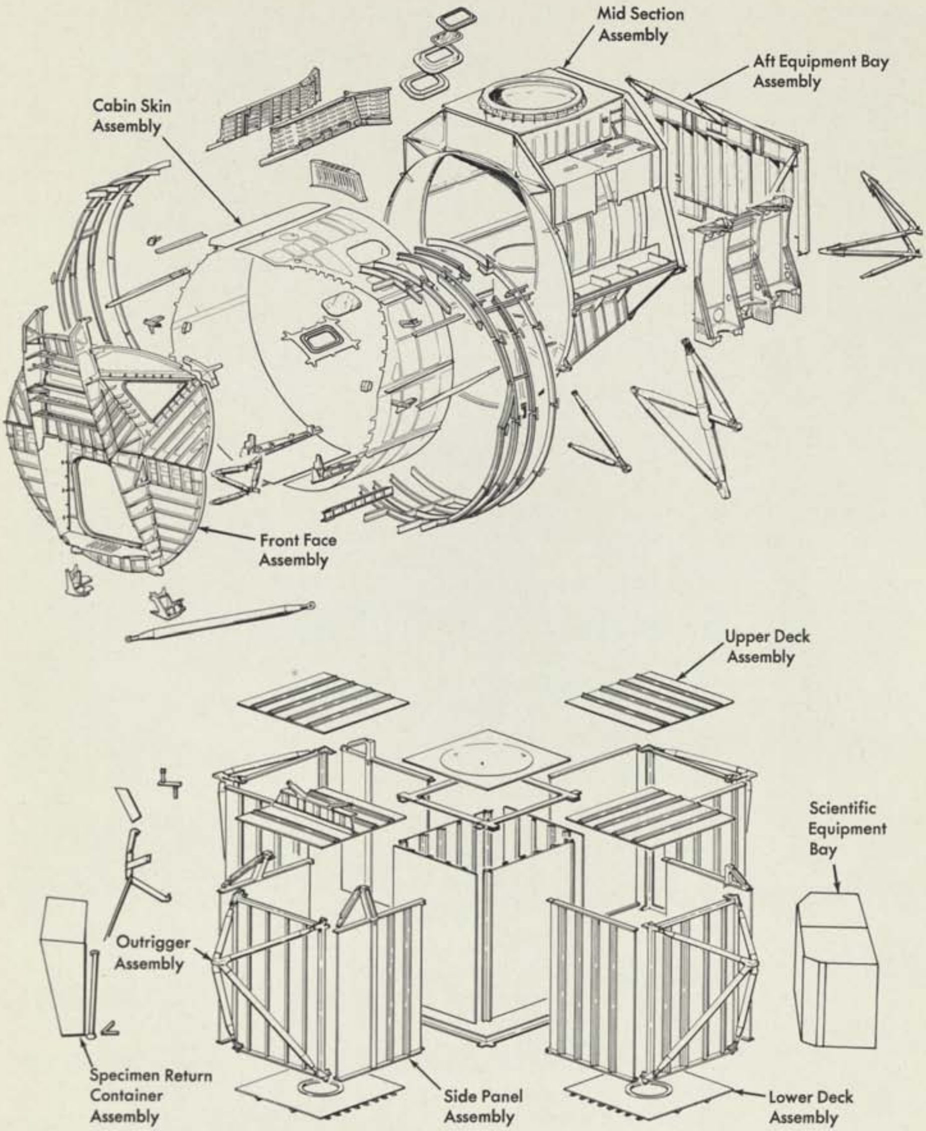


Figure 2 Ascent and Descent Stage Structure

3. LANDING GEAR

The cantilever-type landing gear (Figure 3) is attached externally to the Descent Stage and folds inward to fit within the shroud of the Saturn V aerodynamic shell. It consists of four sets of legs connected to outriggers that extend from the ends of the Descent Stage structural beams. Each landing gear consists of a primary strut and foot pad, a drive-out mechanism, two secondary struts, two down-lock mechanisms, and a truss. The struts are machined aluminum with machined fittings mechanically attached at the ends. The foot pads consist of inner and outer layers of spun aluminum that are bonded to honeycomb core. The formed aluminum tube probes on the foot pads are each equipped with a sensing device. The side braces are made of swaged tubing.

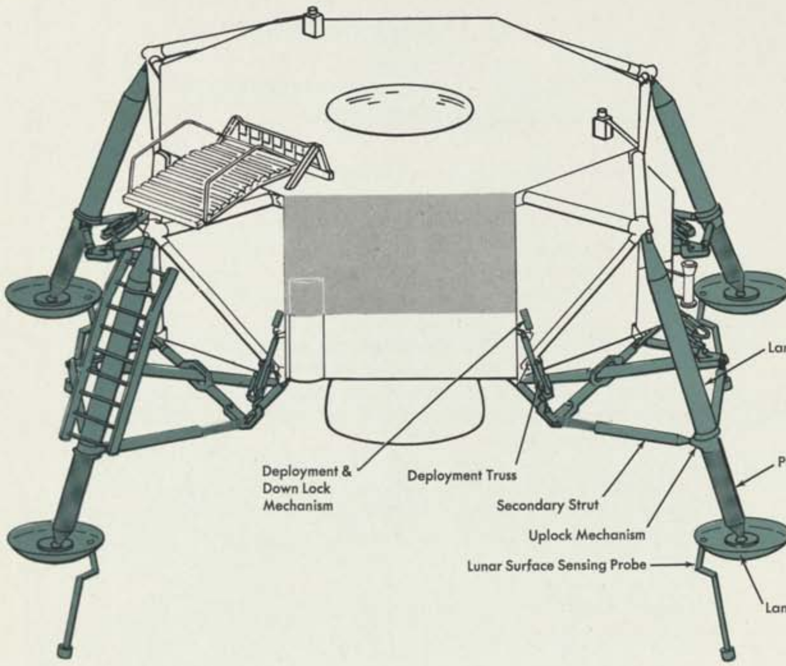


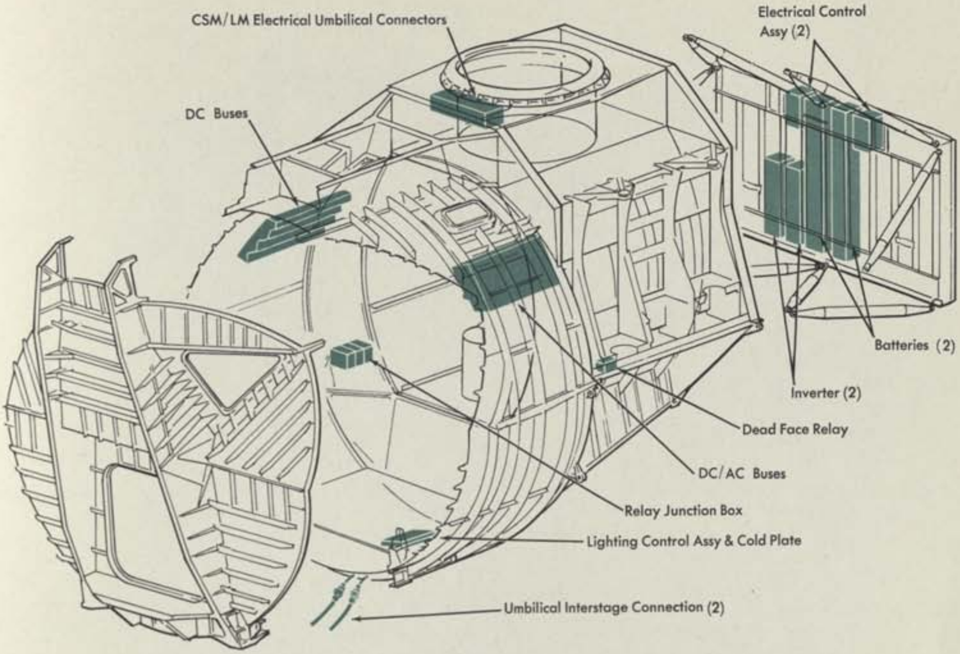
Figure 3 Landing Gear

4. ELECTRICAL POWER (EPS)

The Electrical Power Subsystem (Figure 4) consists of the following major components: four silver-zinc Descent batteries, two Descent electrical control assemblies, two silver-zinc Ascent batteries, two Ascent electrical control assemblies, a relay junction box, a deadface relay, two circuit breaker panels, two inverters, and one lighting control assembly.

The four Descent batteries will supply power to the LM during all but the translunar phase on a normal mission from T-minus 30 minutes up to powered ascent. In the event of a battery failure, an abbreviated mission can be flown with the three remaining Descent batteries.

The Ascent batteries are used during a normal mission from powered ascent to docking, and during an abort requiring separation of the Ascent Stage from the Descent Stage. Prior to separation and during lunar stay, the Ascent batteries will be checked periodically. During powered descent they will be paralleled with the Descent batteries. Failure of an Ascent battery would require an abort.



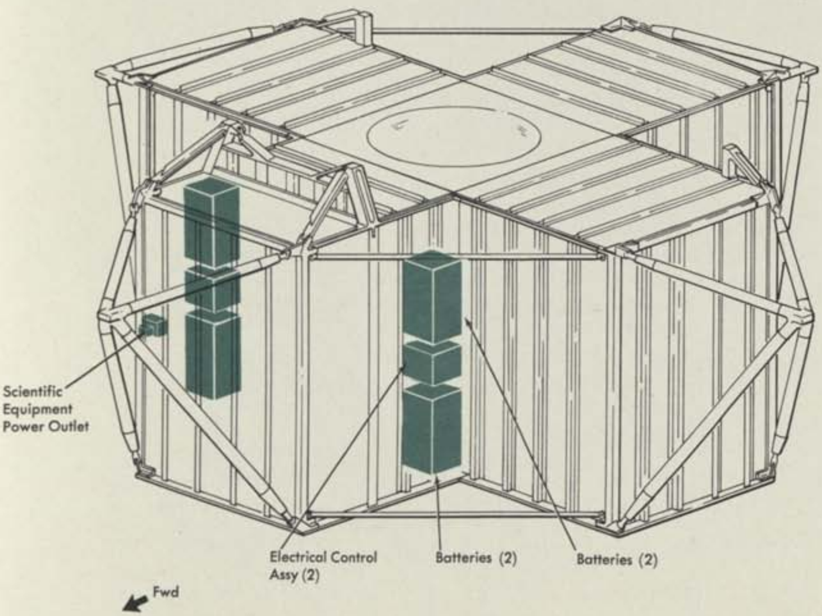
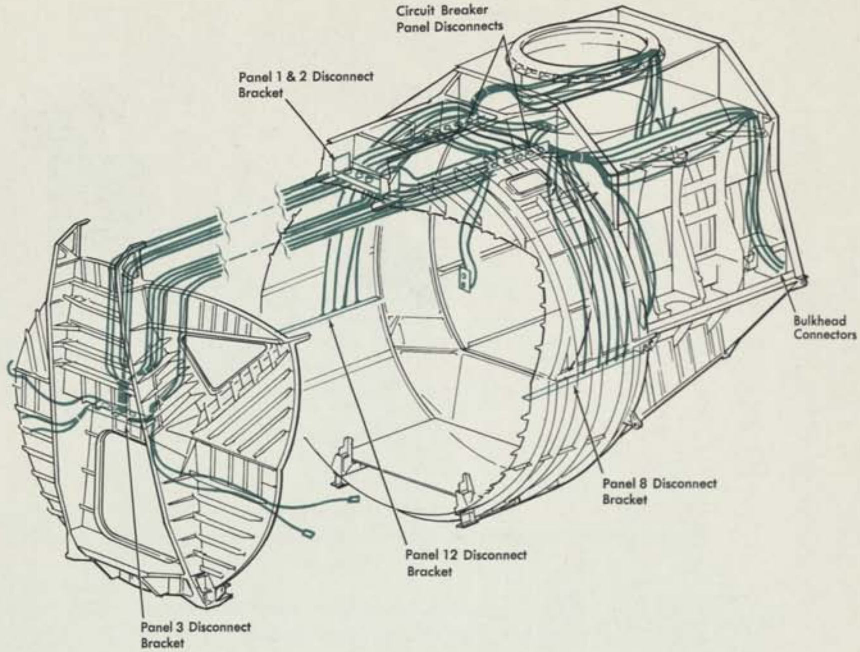
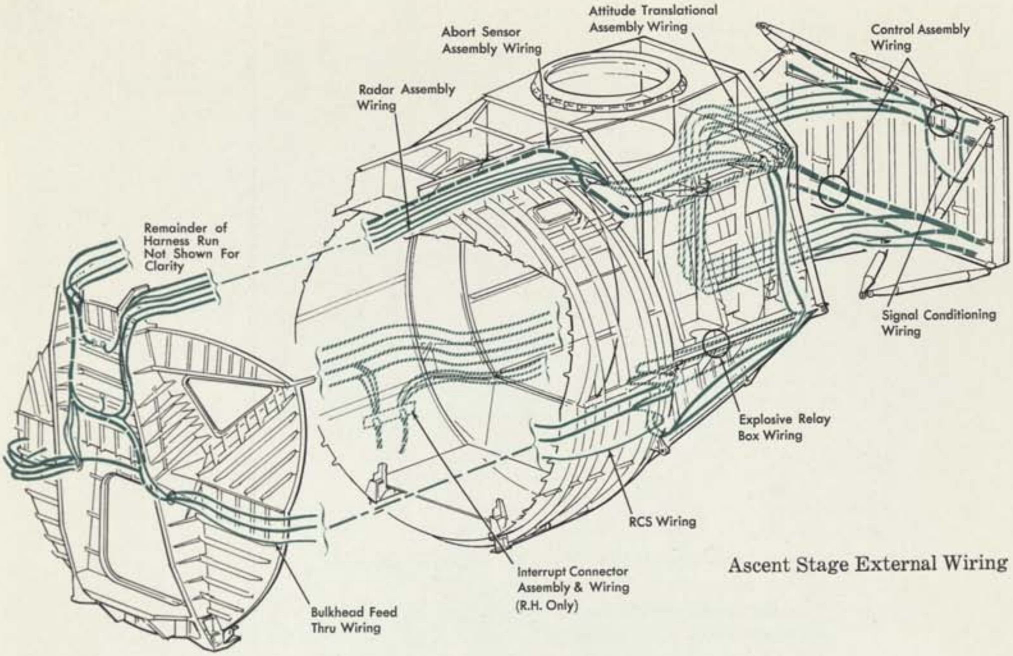


Figure 4 Electrical Power Subsystem

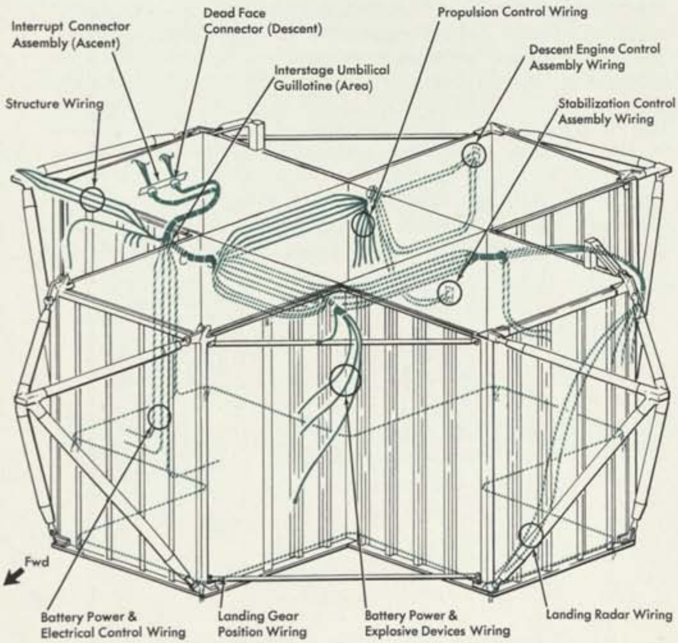


Ascent Stage Internal Wiring

Included in the Electrical Power Subsystem are all the electrical harness and cable assemblies on the Lunar Module. The Ascent Stage has approximately 20 major electrical harnesses and 60 electrical cable assemblies. The Descent Stage has approximately 5 major electrical harnesses and 45 electrical cable assemblies. Major harness and cable assemblies contained in the two stages are shown in Figure 5.



Ascent Stage External Wiring

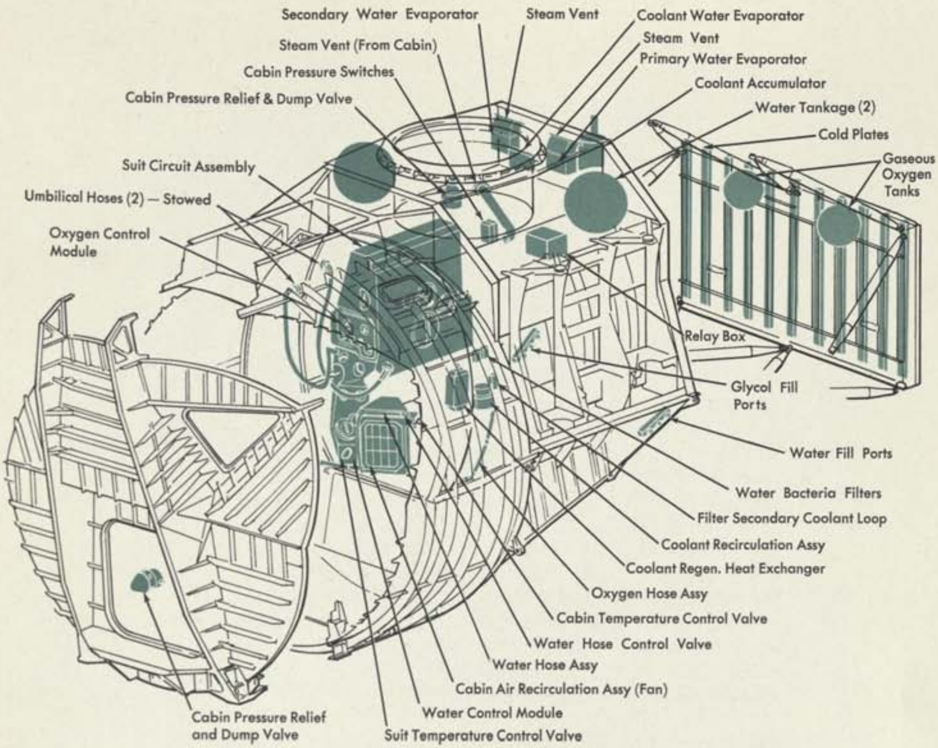


Descent Stage Internal and External Wiring

Figure 5 Electrical Harness and Cable Assemblies

5. ENVIRONMENTAL CONTROL (ECS)

The Environmental Control Subsystem (Figure 6) provides a temperature- and pressure-controlled oxygen atmosphere in the LM Cabin and Crew Suits, as well as a resupply of water and oxygen for the portable life support system. It also provides temperature control for on-board electronic equipment, as well as potable water. The subsystem 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 portion of the glycol loop and two gaseous oxygen tanks are in the Ascent Stage aft equipment bay. A portion of the glycol loop (battery cold plates) is also in the Descent Stage. Two ECS water tanks are in the tankage section of the Ascent Stage; a larger water tank and an oxygen tank and pressure regulator are in the Descent Stage.



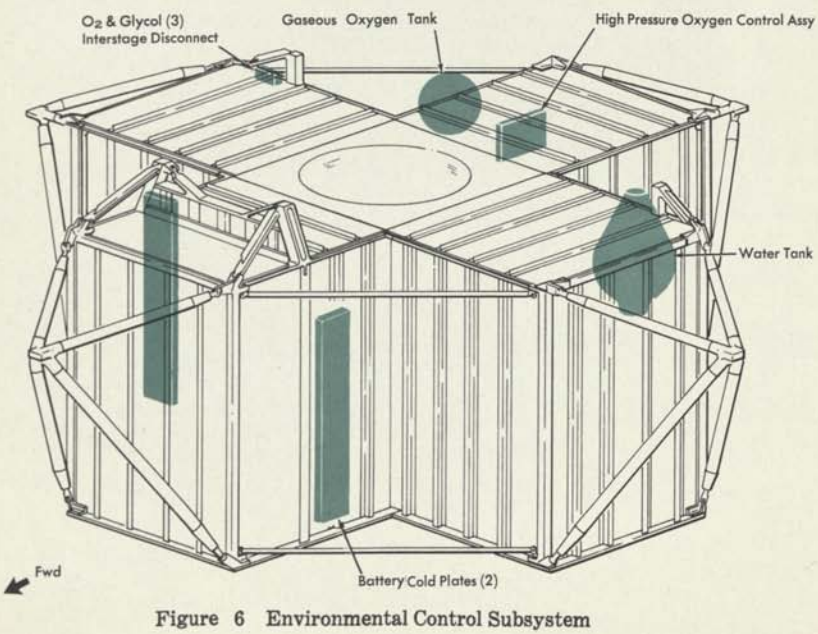


Figure 6 Environmental Control Subsystem

6. PROPULSION (P/S)

The Ascent Propulsion Subsystem (Figure 7) uses a fixed, constant-thrust rocket engine. The system includes the associated ambient helium pressurization and propellant supply components. The engine develops 3,500 pounds of thrust in vacuum, sufficient to launch the Ascent Stage from the lunar surface and place it in orbit. Two main propellant tanks are used: one for fuel, the other for oxidizer. The tanks are installed on either side of the Ascent Stage structure. The propellant supply sections in this subsystem also provide for fuel and oxidizer interconnect to the Reaction Control Subsystem as a propellant supply for the latter during select mission phases. The fuel is a 50/50 mixture of hydrazine and unsymmetrical dimethyl hydrazine. The oxidizer is nitrogen tetroxide. These propellants constitute a hypergolic system, that is, engine ignition results when the propellants come in contact with each other.

The Descent Propulsion Subsystem consists of two fuel and two oxidizer tanks with interconnecting gas and liquid balance lines for the like tanks. The pressurization system consists of cryogenically stored helium and an auxiliary ambient start system. The system is centered about a deep-throttling ablative rocket engine which has restart capabilities. The maximum thrust level is approximately 10,000 lbs. and the engine can be throttled to 1050 lbs. The engine is mounted in the center compartment of the Descent Stage cruciform, suspended at the throat of the combustion chamber on a gimbal ring that is an integral portion of the engine assembly. The engine is gimballed to maintain thrust vector c.g. alignment. The propellants are identical to those used in the Ascent engine and Reaction Control thrusters.

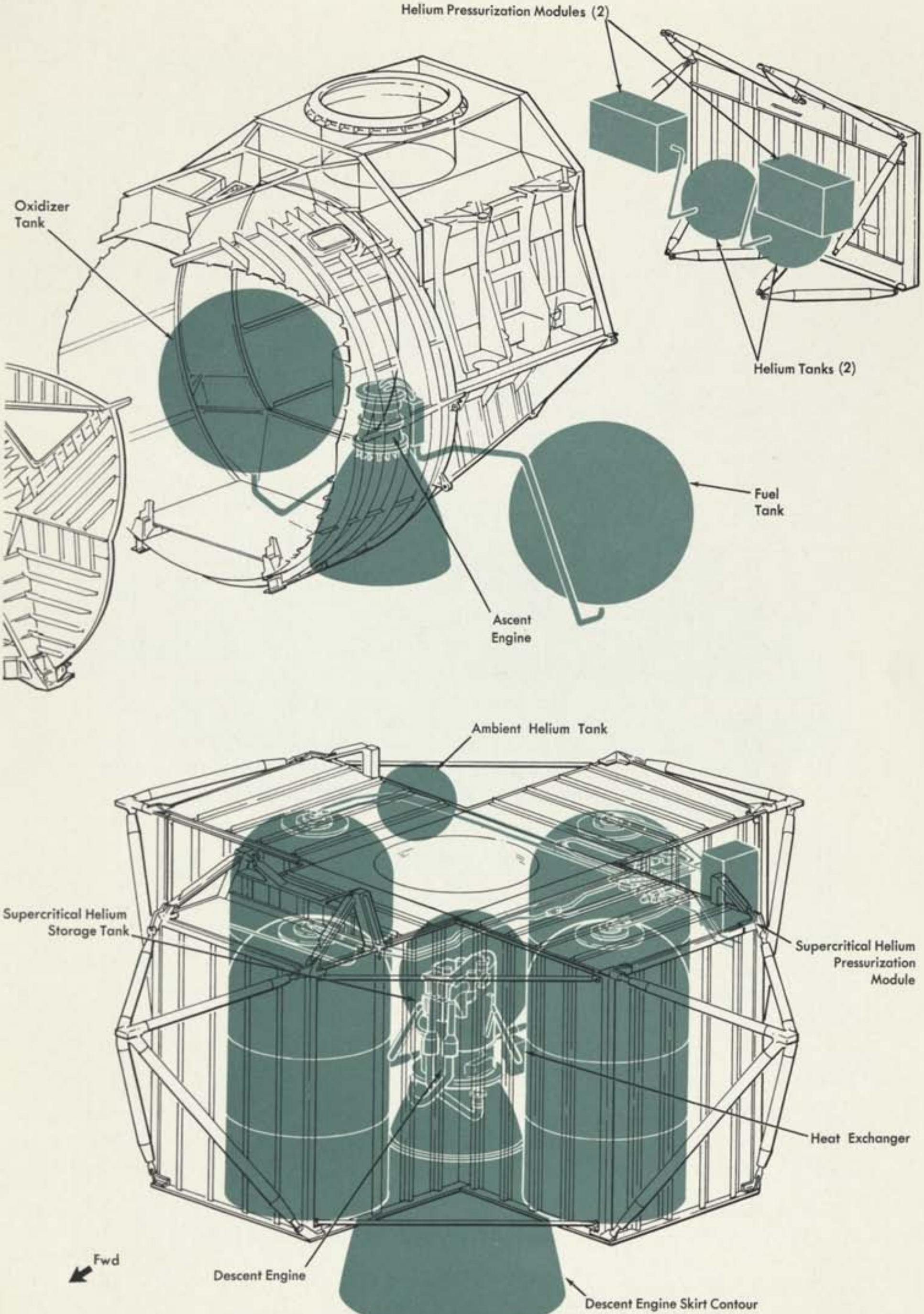


Figure 7 Propulsion Subsystem

7. REACTION CONTROL (RCS)

The Reaction Control Subsystem (Figure 8) serves to stabilize the LM vehicle during descent and ascent, and to control the vehicle attitude about, and translation along, all axes during landing, rendezvous and docking maneuvers. The RCS consists basically of 16 thrust chambers supplied by two separate helium pressurized propellant supply sections. The 100-lb. thrusters can be fired in a pulsed or continuous mode, and are radiation-cooled. The thrusters and the dual propellant supply sections make up two parallel, independent systems. The propellants are identical to those used in the Descent and Ascent engines. The ascent system propellants can be used to supply the RCS thrusters in certain operational modes.

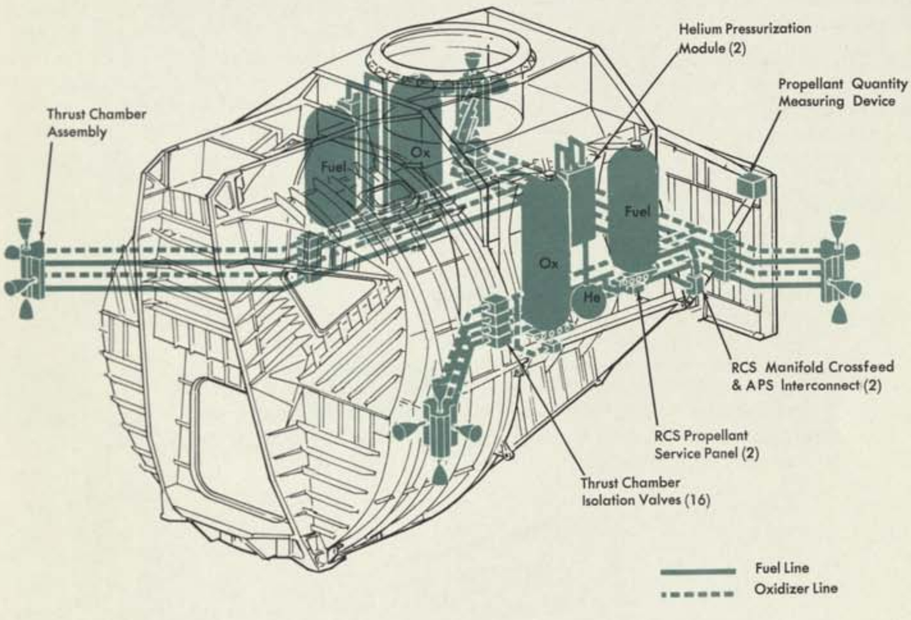


Figure 8 Reaction Control Subsystem

8. CREW PROVISIONS/DISPLAYS (CP/DS)

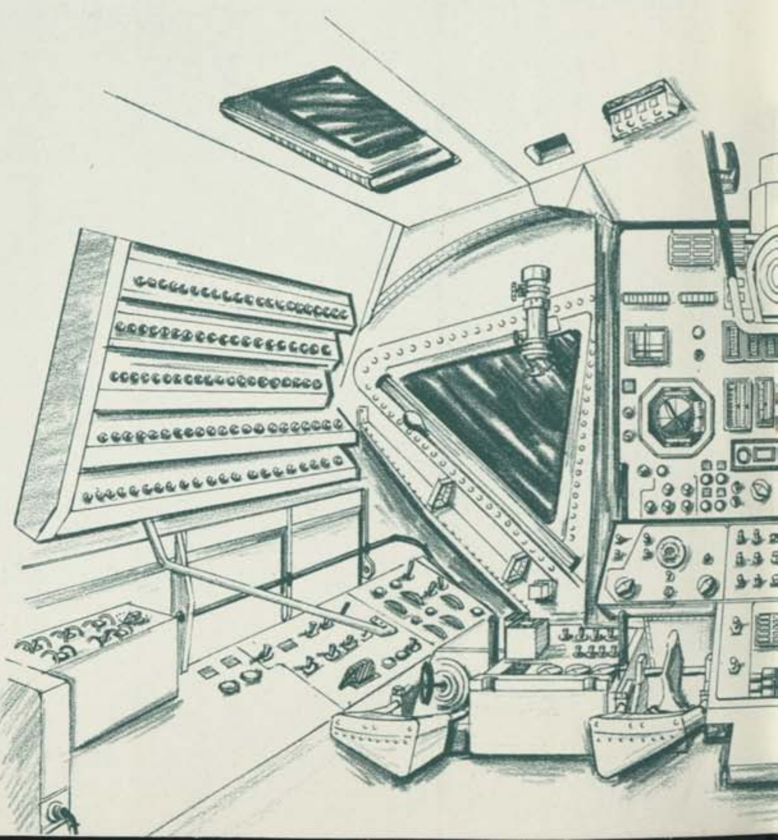
The Crew Provisions/Displays Subsystem on the LM is shown in Figure 9. Support and restraint equipment is provided in the forward part of the main cabin. During flight, the support and restraint equipment provides the astronaut with stability to help him accomplish his tasks, and augments his ability to withstand the lunar landing impact.

Other items included under Crew Provisions are control panels, interior and exterior lighting, food and water containers, pressure and thermal garments, and boots.

The Portable Life Support System (PLSS) is a self-contained rechargeable system that provides limited-time life support for an astronaut exposed to extra-vehicular free space, a decompressed LM, or the lunar surface environment.

Waste management is controlled by means of devices which provide for removal and decontamination of urine and feces. These operations are possible under pressurized and unpressurized conditions. Waste water from the PLSS is also collected through waste management devices.

Displays and Controls provide the astronauts with sufficient information and control of the LM subsystems to successfully complete the mission or to return the LM safely to the CSM in an emergency. Located to optimize astronaut safety and mission success, the primary navigation and guidance readouts and data entry panel, propulsion, reaction control, environmental control, flight control and stabilization and control systems panels are either shared or duplicated at both stations. Each astronaut is assigned specific mission responsibilities, and only those parameters are displayed for which there is a potential human response (i.e., control action).



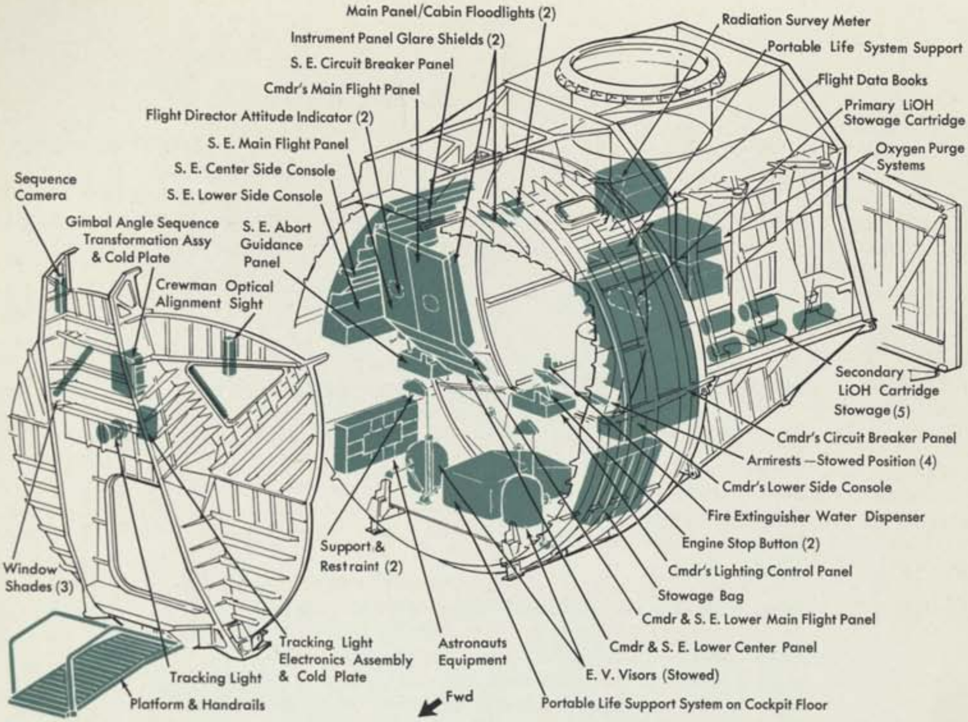
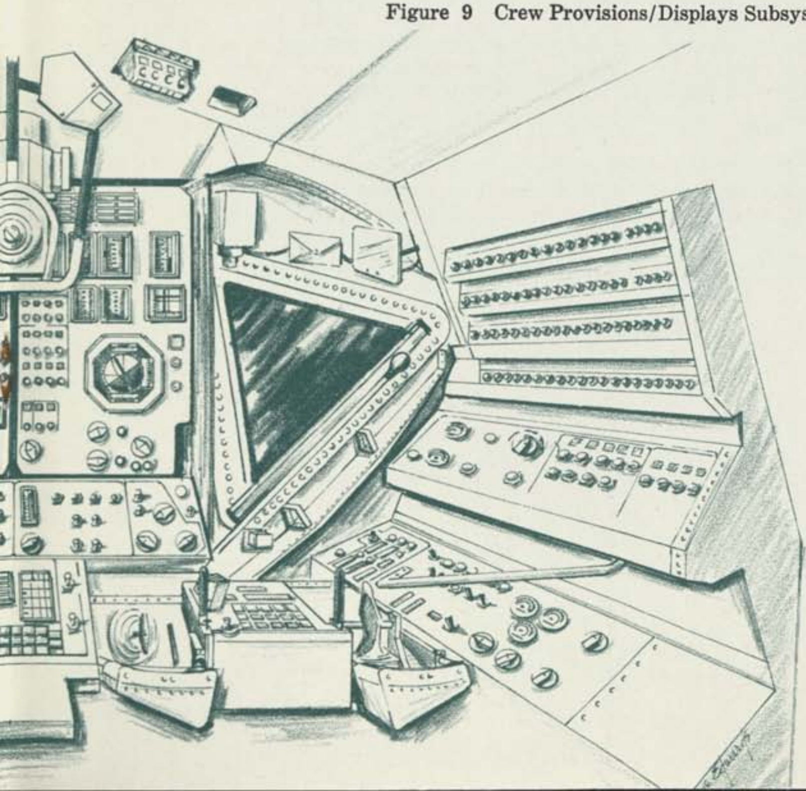


Figure 9 Crew Provisions/Displays Subsystem



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9. GUIDANCE, NAVIGATION AND CONTROL (GN & C)

The Guidance, Navigation and Control Subsystem (Figure 10) provides for flight path control of the LM throughout the mission. It consists of four major sections: Primary Guidance and Navigation Section, Radar Section, Control Electronics Section and the Abort Guidance Section.

The Primary Guidance and Navigation Section is essentially an aided inertial system whose principal aids are the alignment optical telescope and Radar Section consisting of the landing radar and rendezvous radar. The inertial measurement unit is aligned to an inertial reference by star sightings with the alignment optical telescope. Altitude and velocity information from the landing radar is used to update the inertially derived data. During the coasting descent, lunar stay, and rendezvous phases of the mission, the rendezvous radar coherently tracks its transponder in the CSM to provide range, range rate, and angle measurements (with respect to antenna axes) to the LM guidance computer.

The Control Electronics Section processes the flight data that controls the LM vehicle during all phases of the mission. The Abort Guidance Section provides semi-automatic pre-programmed flight control data to the Control Electronics section when a mission abort maneuver is being executed due to malfunction of the Primary Guidance and Navigation Section.

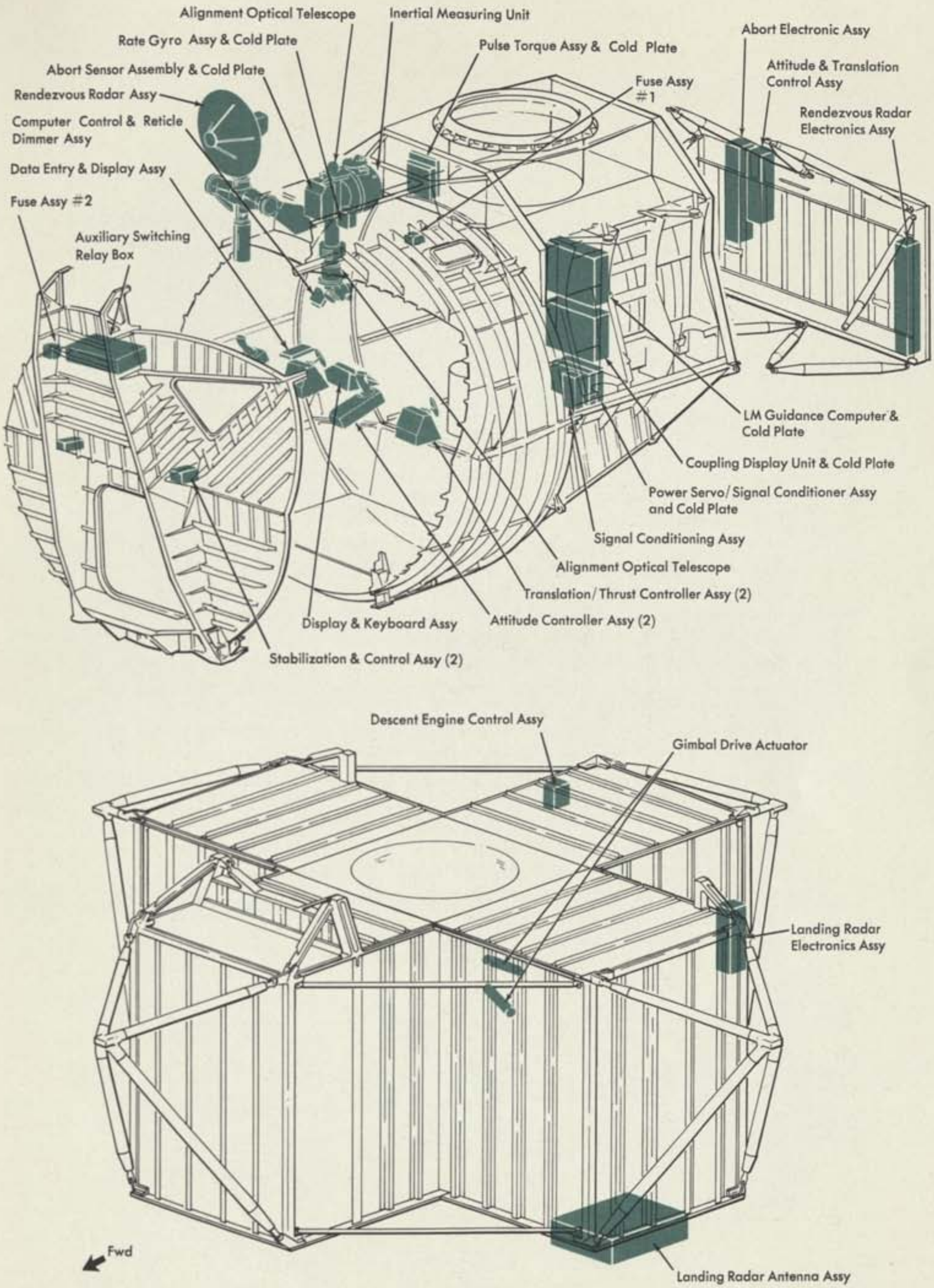


Figure 10 Guidance, Navigation and Control Subsystem

10. INSTRUMENTATION (INSTS)

The Instrumentation Subsystem (Figure 11) consists of sensors and the signal conditioning, caution and warning, pulse code modulation and timing, and data storage electronic assemblies. The subsystem monitors the LM subsystems during manned phases of the mission, provides signal inputs to the vehicle displays and caution and warning array, prepares status data for transmission to earth, provides timing frequencies for the subsystems, and stores voice data.

Pulse code modulation telemetry changes data generated by subsystem sensors to digital form for S-band and VHF transmissions to keep ground stations informed of vehicle status.

Included within the subsystem are scientific instruments which will be used by the astronauts during their lunar stay for surface experiments.

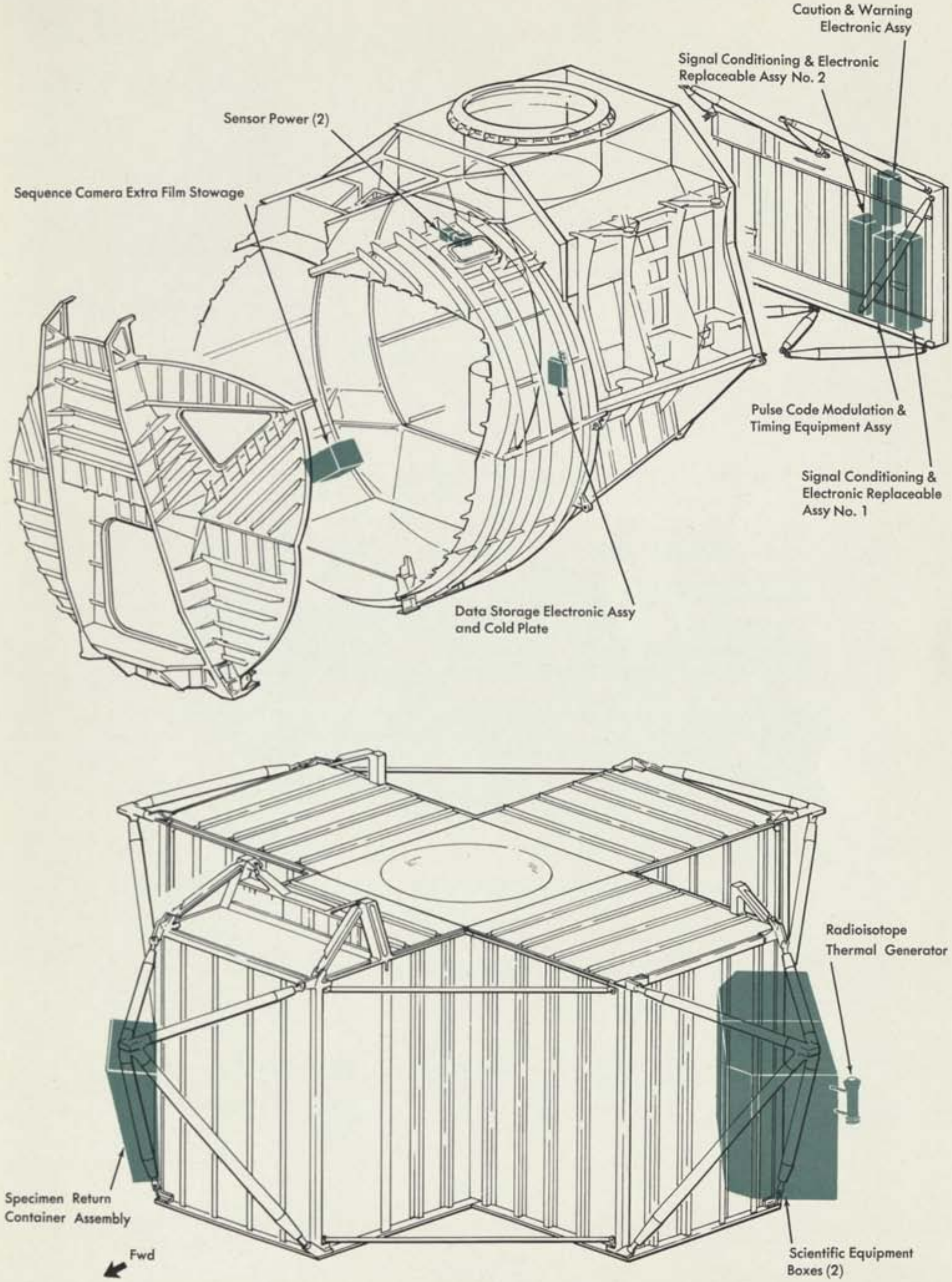


Figure 11 Instrumentation Subsystem

11. COMMUNICATIONS (CS)

The Communications Subsystem (Figure 12) is made up of redundant S-band transceivers and power amplifiers, redundant VHF transceivers, and signal processing equipment with associated antenna systems. These equipments provide the following capabilities: 1) S-band for transmission of PCM telemetry, TV, voice, emergency key and range data between LM and earth; 2) VHF for linking LM and Command Module, and the LM and astronaut on the lunar surface; 3) VHF telemetry capability from LM to Command Module on the far side of the moon; 4) EVA (Extravehicular Astronaut) link to earth via VHF/S-band relay.

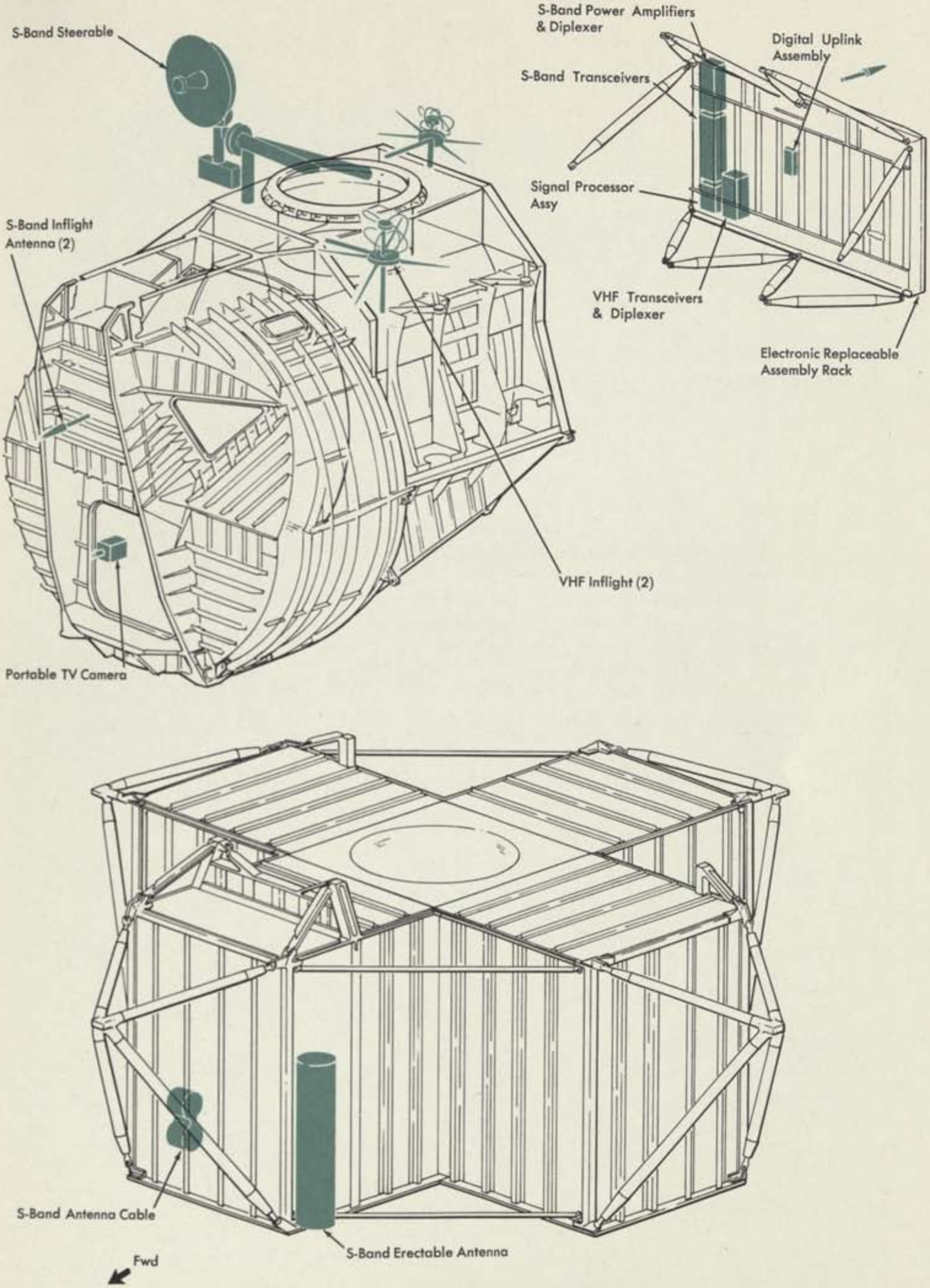


Figure 12 Communications Subsystem

12. ELECTRO-EXPLOSIVE DEVICES (EED)

The Electro-Explosive Devices Subsystem (Figure 13) consists of its own redundant power supplies, relay boxes and wiring to accomplish the following:

- Release of the landing gear for deployment
- Enable helium pressurization of the Ascent Propulsion, Descent Propulsion, and Reaction Control Subsystems
- Stage separation
- Venting of Descent Propulsion Subsystem on the lunar surface

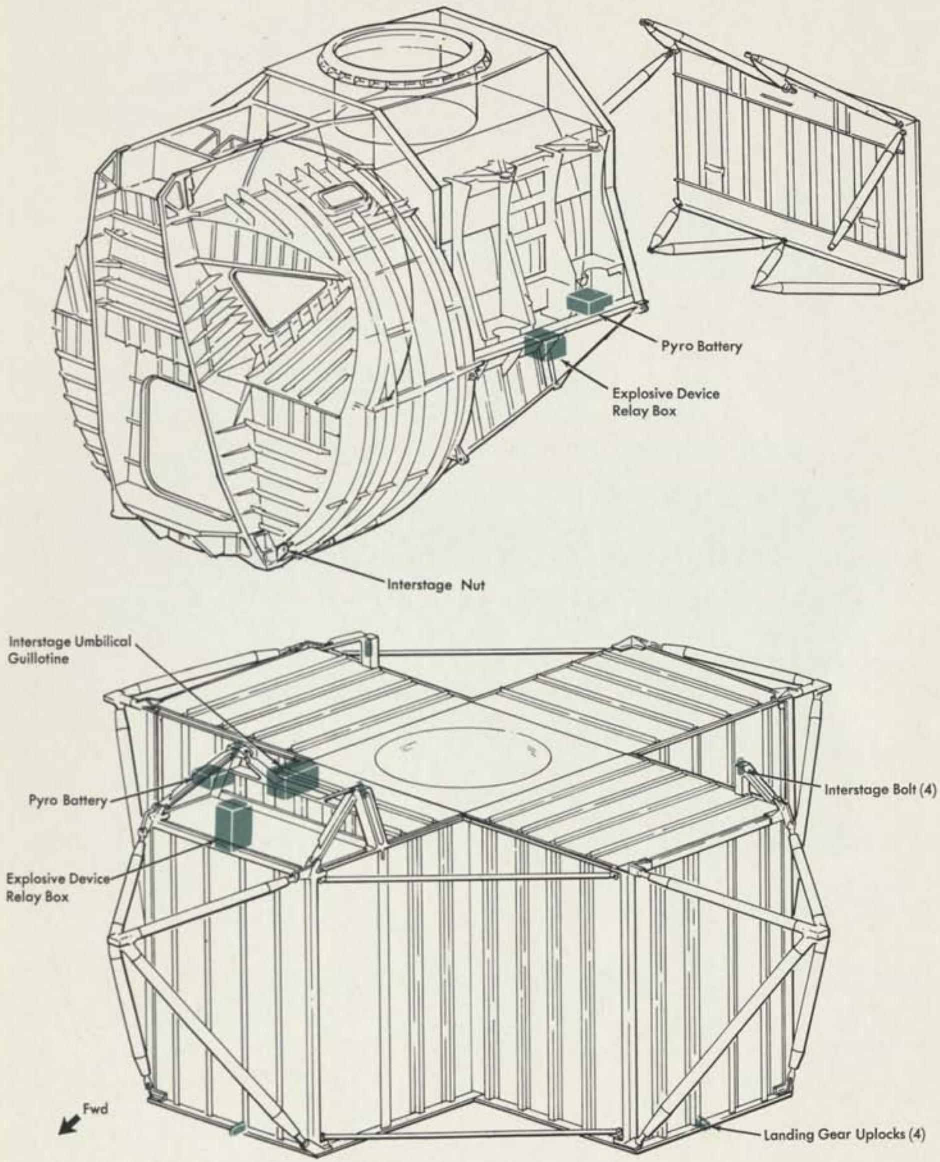


Figure 13 Electro-Explosive Devices Subsystem

Subsystem Assembly, Installation and Test Flows

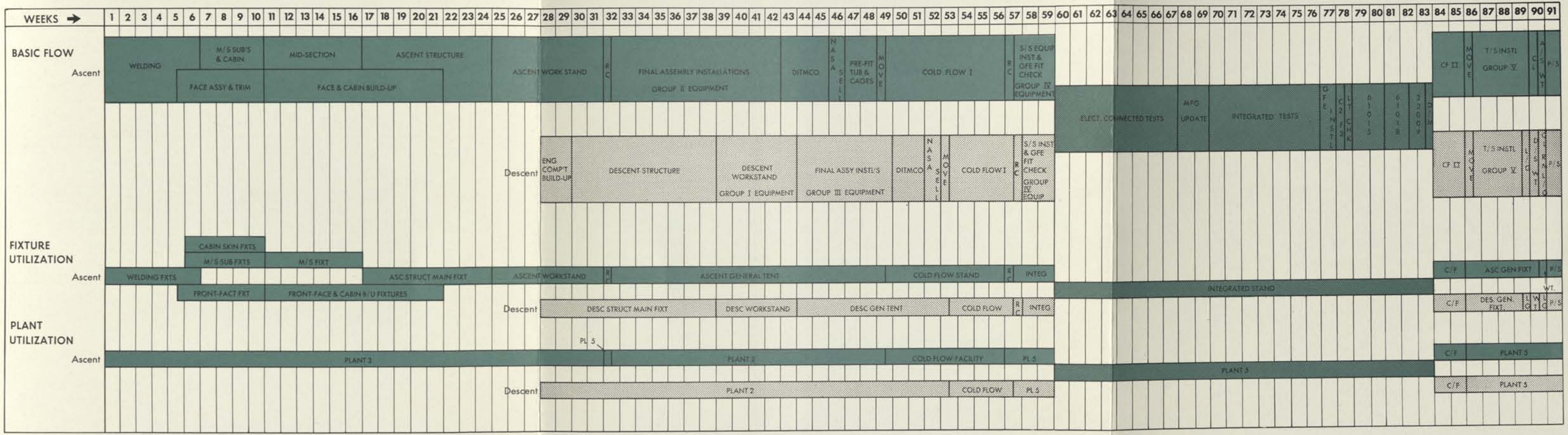
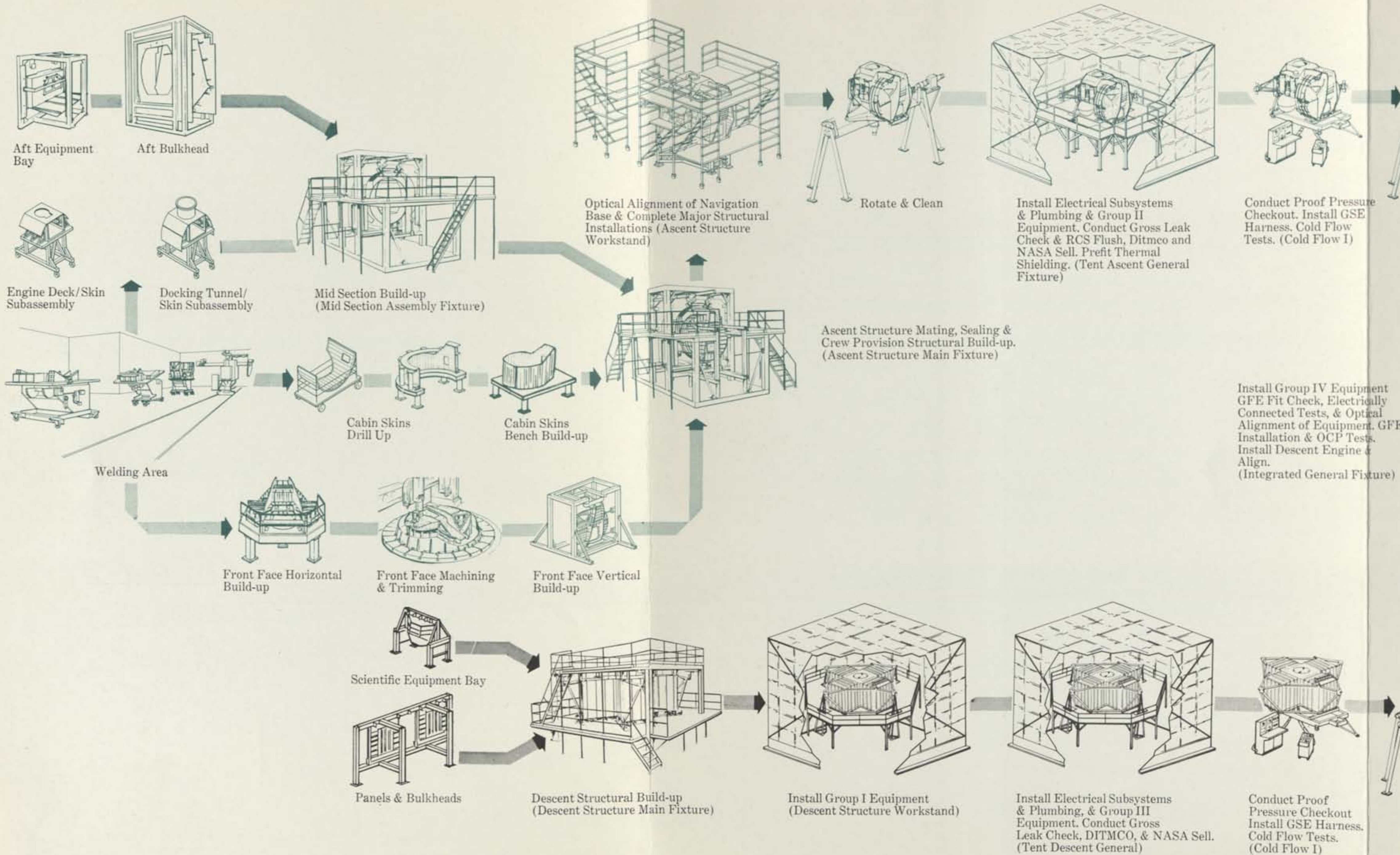


Figure 14 Lunar Module Integrated Flow



Aft Equipment Bay
Aft Bulkhead
Engine Deck/Skin Subassembly
Docking Tunnel/ Skin Subassembly
Mid Section Build-up (Mid Section Assembly Fixture)
Welding Area
Cabin Skins Drill Up
Cabin Skins Bench Build-up
Front Face Horizontal Build-up
Front Face Machining & Trimming
Front Face Vertical Build-up
Optical Alignment of Navigation Base & Complete Major Structural Installations (Ascent Structure Workstand)
Ascent Structure Mating, Sealing & Crew Provision Structural Build-up. (Ascent Structure Main Fixture)
Rotate & Clean
Install Electrical Subsystems & Plumbing & Group II Equipment. Conduct Gross Leak Check & RCS Flush, Ditmco and NASA Sell. Prefit Thermal Shielding. (Tent Ascent General Fixture)
Conduct Proof Pressure Checkout. Install GSE Harness. Cold Flow Tests. (Cold Flow I)
Install Group IV Equipment GFE Fit Check, Electrically Connected Tests, & Optical Alignment of Equipment. GFE Installation & OCP Tests. Install Descent Engine & Align. (Integrated General Fixture)
Scientific Equipment Bay
Panels & Bulkheads
Descent Structural Build-up (Descent Structure Main Fixture)
Install Group I Equipment (Descent Structure Workstand)
Install Electrical Subsystems & Plumbing, & Group III Equipment. Conduct Gross Leak Check, DITMCO, & NASA Sell. (Tent Descent General)
Conduct Proof Pressure Checkout Install GSE Harness. Cold Flow Tests. (Cold Flow I)

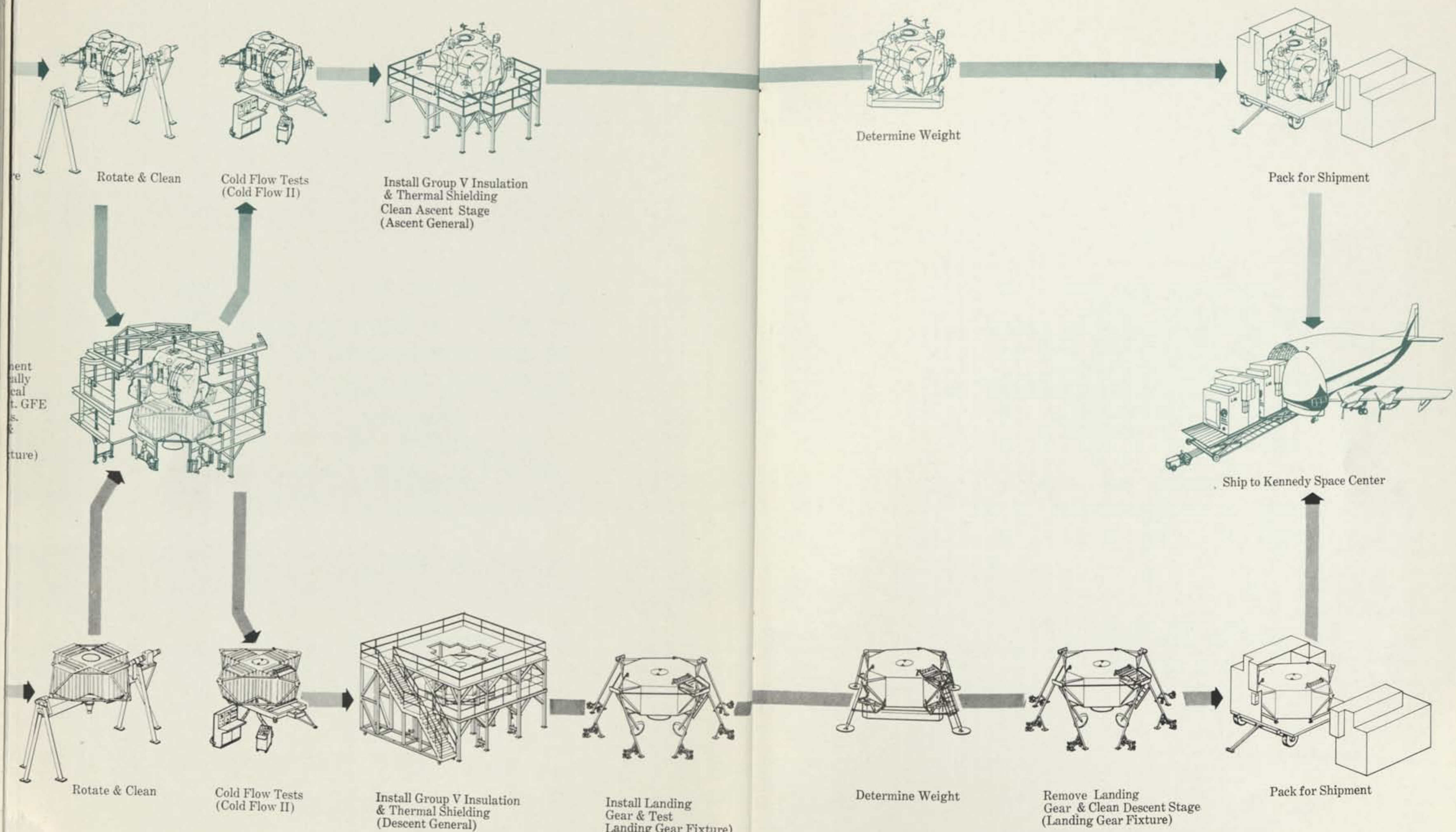


Figure 15 Lunar Module Assembly, Installation and Test Flow

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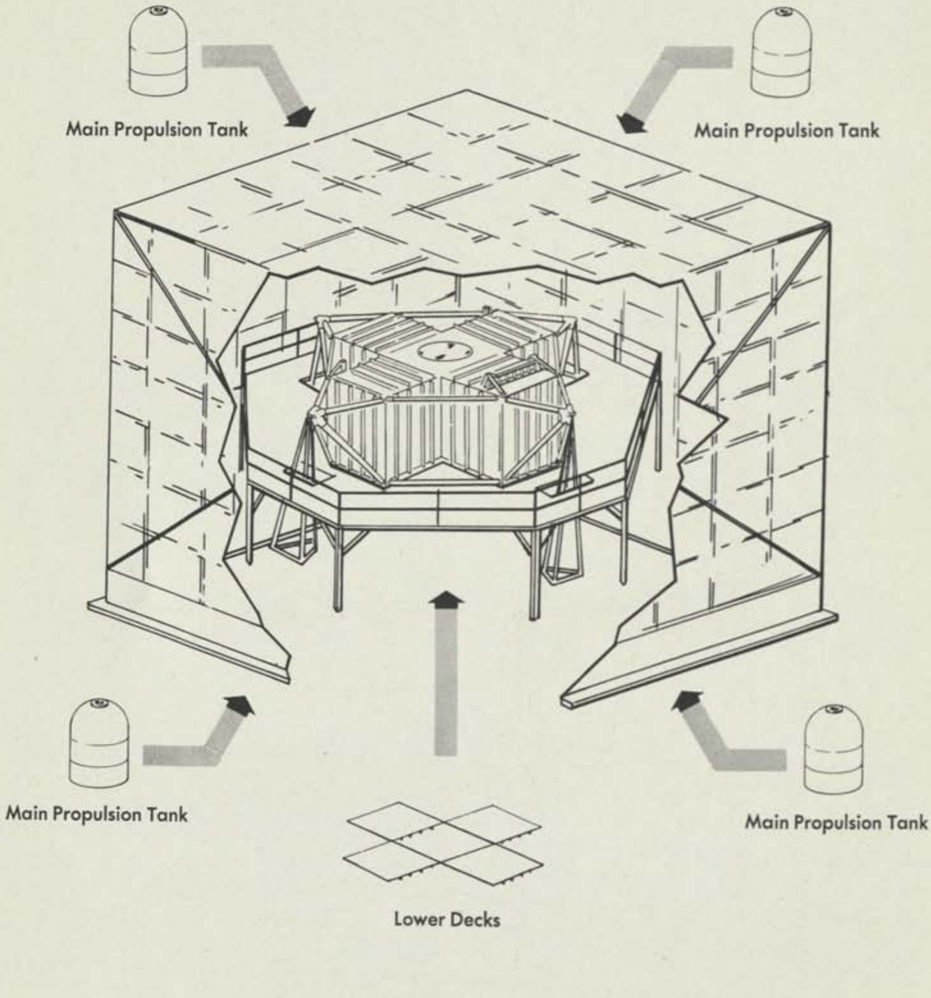


Figure 16 Descent Stage, Group I Equipment

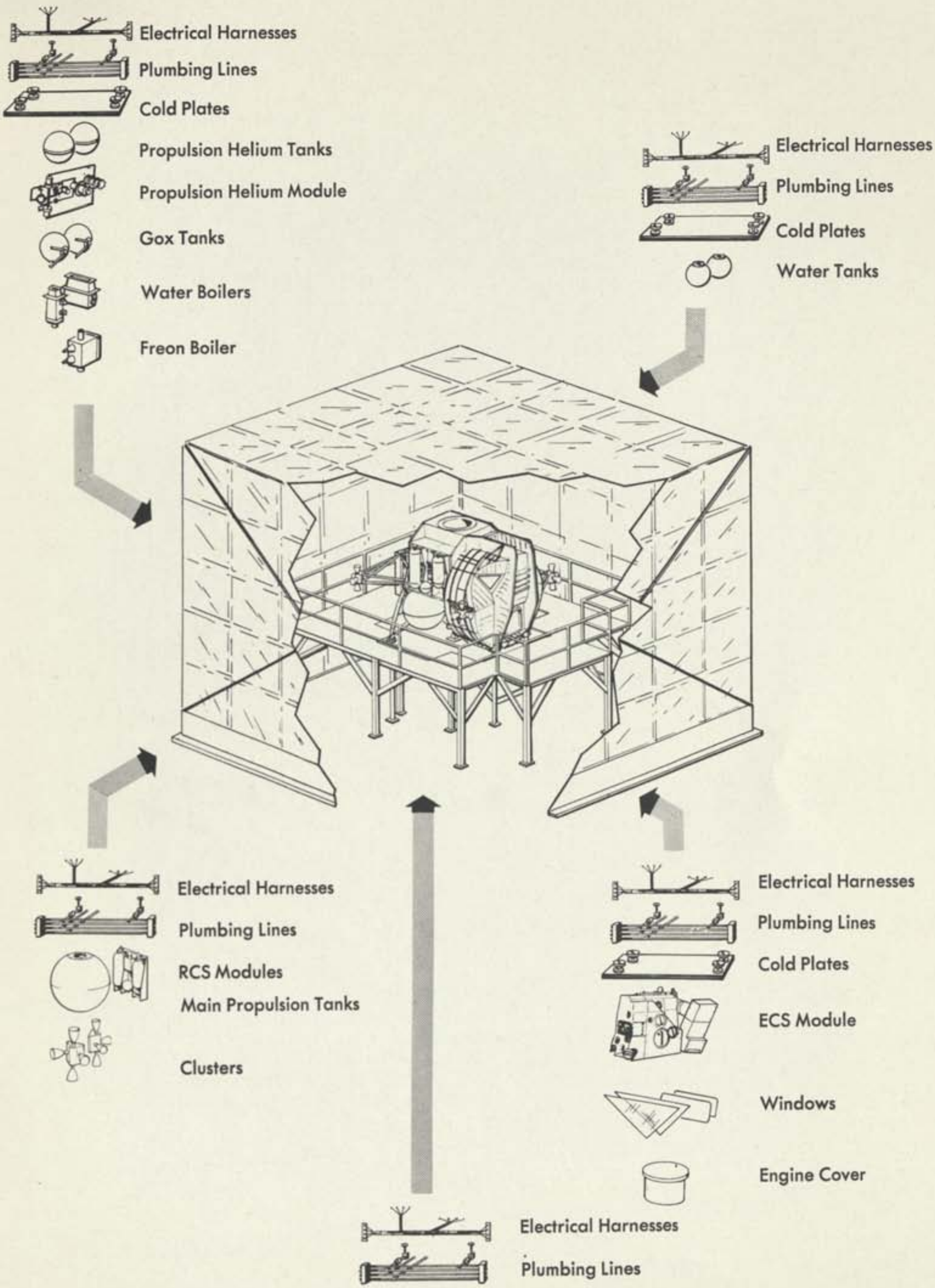


Figure 17 Ascent Stage, Group II Equipment

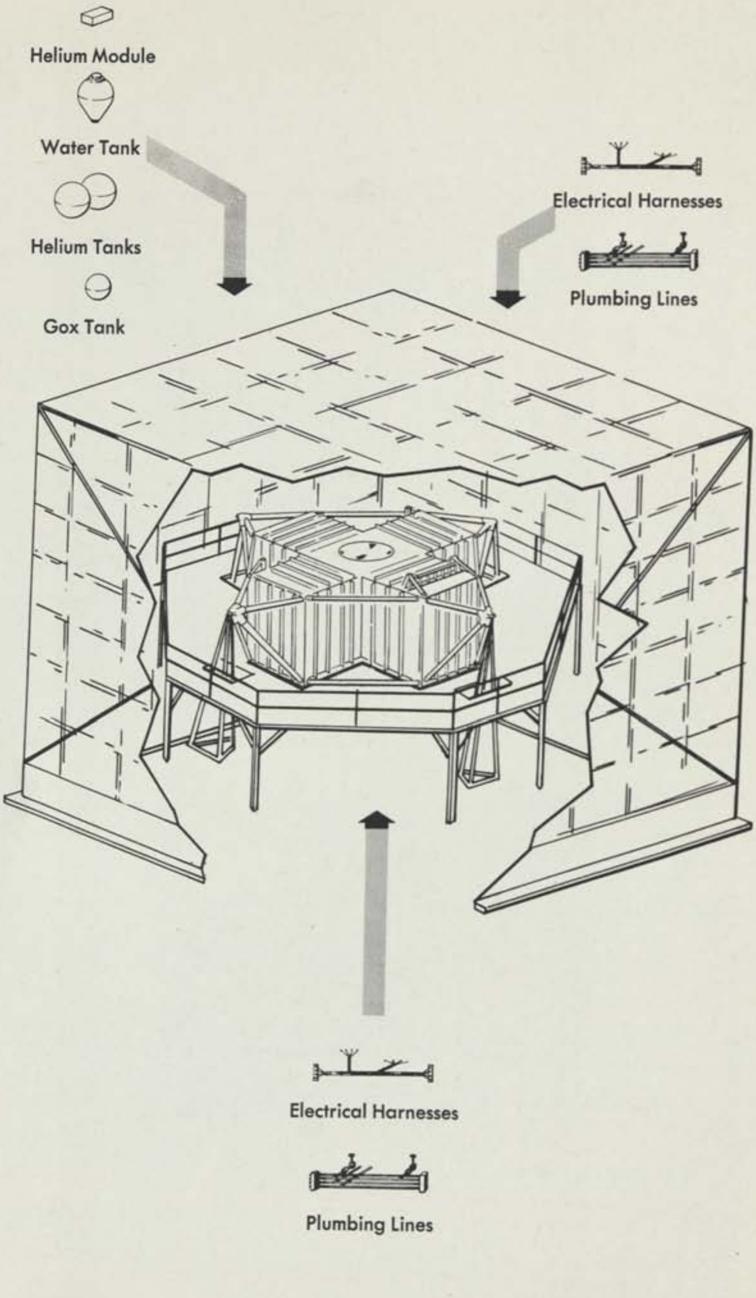


Figure 18 Descent Stage, Group III Equipment

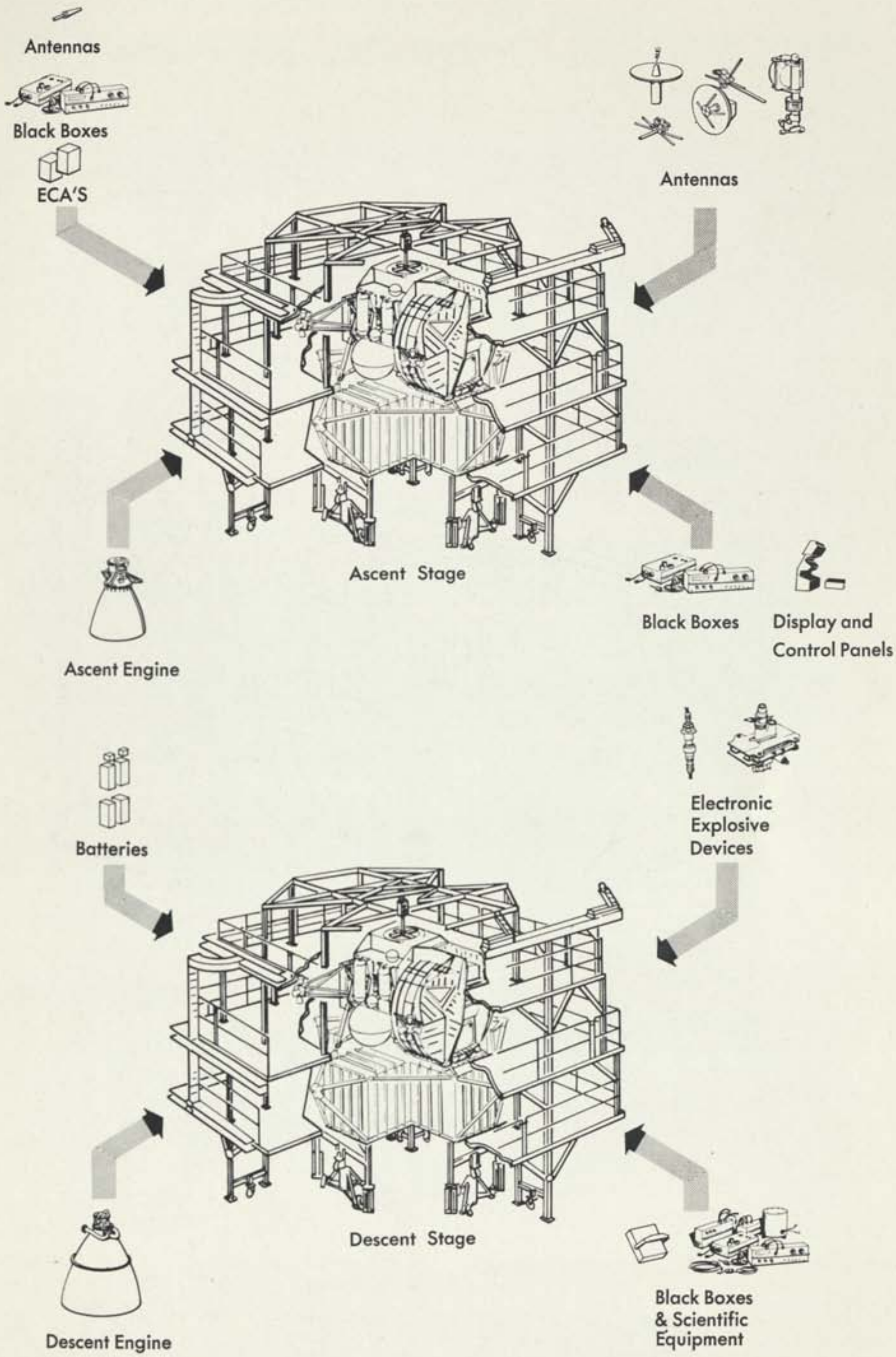


Figure 19 Ascent and Descent Stages, Group IV Equipment

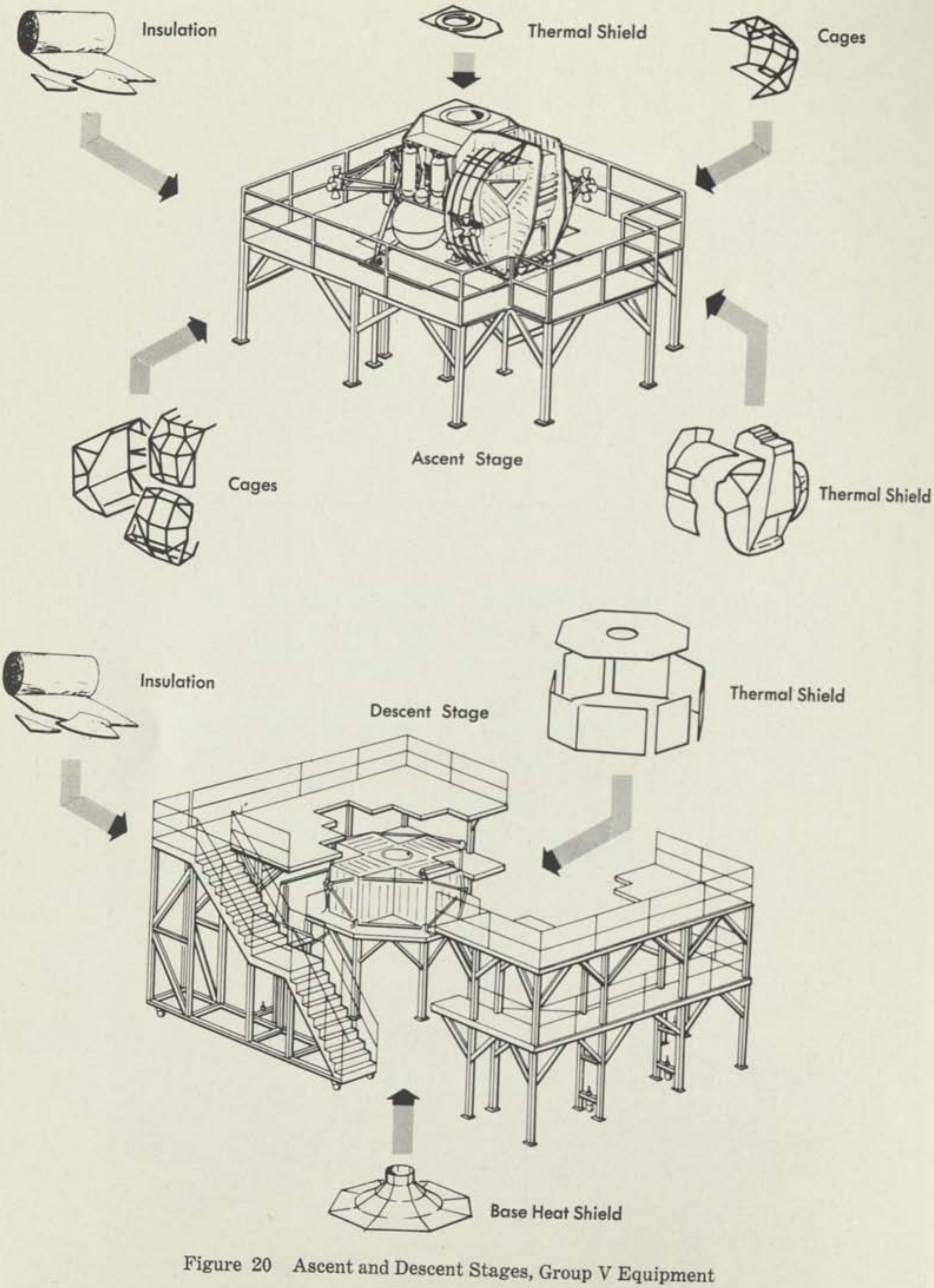
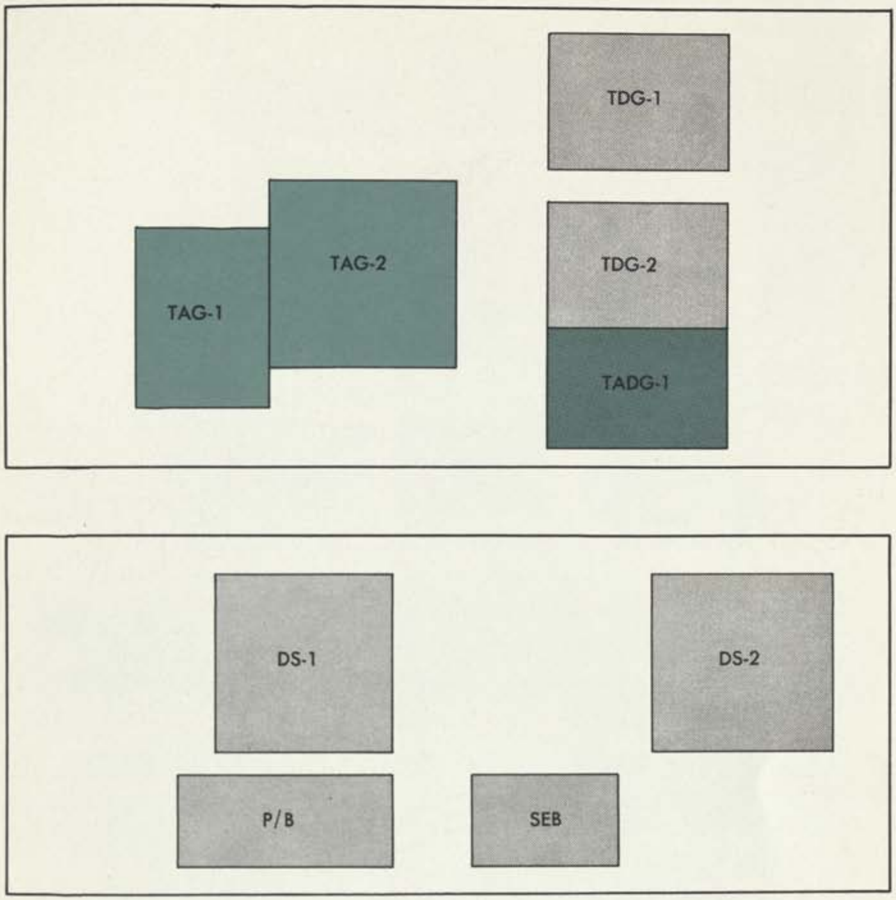


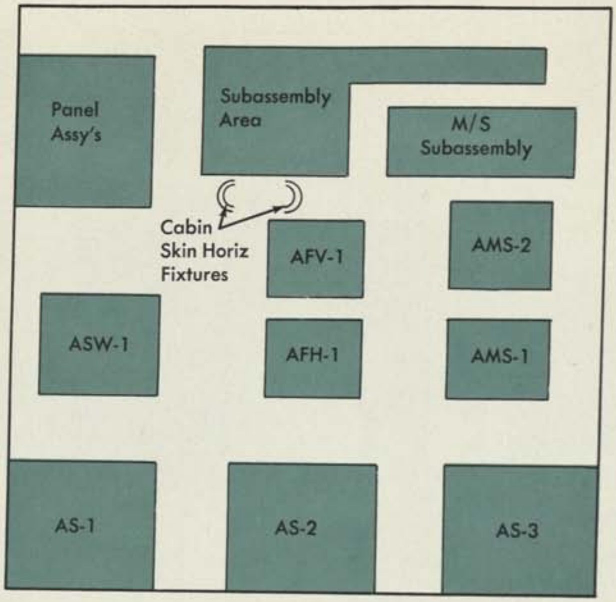
Figure 20 Ascent and Descent Stages, Group V Equipment

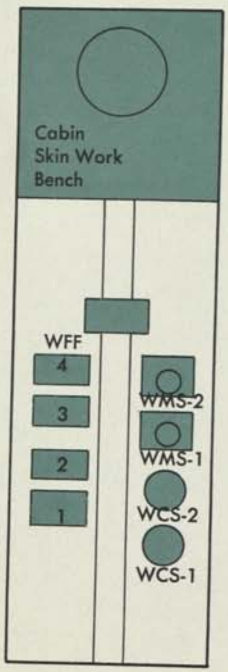


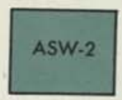
LEGEND

CODE LETTERS	FIXTURE AND OPERATIONS PERFORMED
DS-1, DS-2	Descent Structure Main Fixtures. Descent Structural Assembly Operations
TDG-1, TDG-2	Tent Descent General Fixtures. Fluid and Electrical Installations. Ditmco
TAG-1, TAG-2	Tent Ascent General Fixtures. Fluid and Electrical Installations. Ditmco
TADG-1	Tent Ascent or Descent General Fixture - Fluid and Electrical Installations. Ditmco.
PB	Panel and Bulkhead Subassembly Area-Buildup of Panel and Bulkhead Subassemblies
SEB	Scientific Equipment Bay Fixture. Buildup of Scientific Bay

Figure 21 Plant 2, Descent Stage Structural Assembly and Ascent/Descent Final Assembly and Test



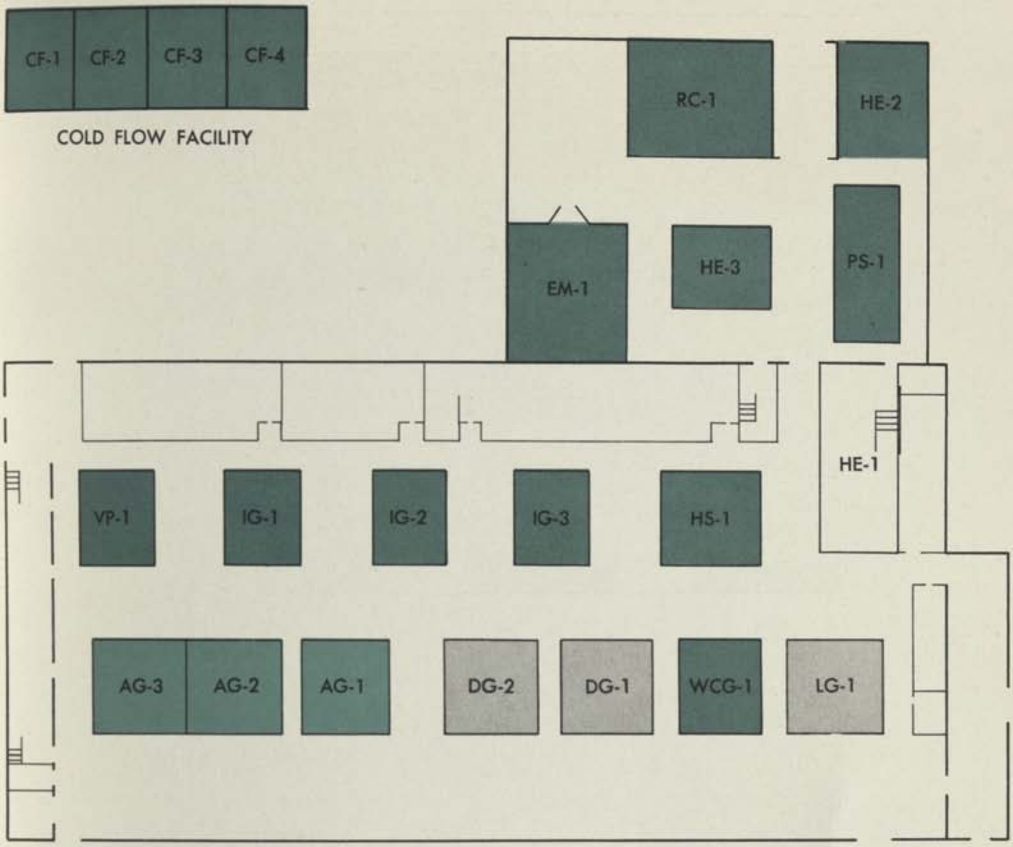




LEGEND

CODE LETTERS	FIXTURE AND OPERATIONS PERFORMED
WCS-1, WCS-2	Welding Cabin Skin Fixtures - Weld Cabin Skins
WMS-1, WMS-2	Welding Mid Section Fixtures - Weld Mid Section Machined Subassemblies
WFF-1, WFF-2, WFF-3, WFF-4	Welding Front Face Fixtures - Weld Front Face Machined Assemblies
AS-1, AS-2, AS-3	Ascent Structure Main Fixtures - Ascent Structural Mating & Assembly Operations
AMS-1, AMS-2	Ascent Mid Section Fixtures - Ascent Mid Section Buildup
AFH-1	Ascent Front Face Horizontal Fixture - Front Face Horizontal Buildup
AFV-1	Ascent Front Face Vertical Fixture Front Face Vertical Buildup
ASW-1, ASW-2	Ascent Structure Workstands - Complete Buildup, Pot, and Alignment of Navigational Base

Figure 22 Plant 3, Ascent Stage Structural Assembly



LEGEND

CODE LETTERS	FIXTURE AND OPERATIONS PERFORMED
CF-1, CF-2, CF-3, CF-4	Cold Flow Facility-Cold Flow Operations-Proof Pressure Check
AG-1, AG-2, AG-3	Ascent General-Completion of Final Assembly operations-Installation of Thermal Shield-and Manufacturing update.
DG-1, DG-2	Descent General-Completion of Final Assembly Operations-Installation of Thermal Shield-and Manufacturing Update.
IG-1, IG-2, IG-3	Integrated General-Ascent and Descent Installations-Electronic Subsystems Checkout-Electrically Connected Tests-Alignment-Operational Checkout Procedures.

LEGEND

CODE LETTERS	FIXTURE AND OPERATIONS PERFORMED
LG-1	Landing Gear-Installation, Test and Removal of Landing Gear
WCG-1	Weight and CG of Vehicle
EM-1	Electromagnetic Test Station-Electro Magnetic Capabilities Checks
PS-1	Pack for Ship-Packing of Ascent and Descent Stages for Shipment
HS-1	House Spacecraft-House Space-Craft Operations.
HE-1	Handling Equipment-Temporary Storage of Handling Equipment.
VP-1	Vehicle Position-Temporary Holding of Vehicle.

Figure 23 Plant 5, Ascent/Descent Stages Assembly and Test

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