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Chapter 21

The First Manned Lunar Landing Spacecraft*

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Introduction

This paper describes the NASA Apollo 11 space vehicle with emphasis on Lunar Module No. 5 (LM-5) which was the first successful manned spacecraft to land on the Moon and return safely to the mother vehicle in lunar orbit. Design and development tasks, including test articles and facilities are explained. Manufacturing and validation ground testing activities are noted. Finally, the mission itself, highlighting lunar module trajectories, important events and key Astronaut exploration tasks, is reviewed.

Design and Development

On July 20th twenty-five years ago, U.S. Astronauts Neil Armstrong and Buzz Aldrin were the first humans to land on the Moon. This historic feat was achieved during the NASA Apollo 11 mission on board the Grumman Lunar Module Number 5 or LM-5.

A drawing of the launch vehicle and spacecraft is shown in Figure 1 as they were stacked on Pad 39B at the NASA Kennedy Space Center. On the left, the three stages of the Saturn V launch vehicle can be seen. The Apollo 11

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spacecraft, consisting of three modules, is shown on the right. The Command Module housed the three astronauts during liftoff to lunar orbit and return from that orbit to Earth. The unmanned Service Module, which was always coupled to the Command Module until Earth entry, contained the rocket engine, its propellants and other expendibles. The Lunar Module carried two of the astronauts from orbit to the surface of the Moon, provided a base for them during the exploration period, and returned them to the Command and Service Modules in lunar orbit. The launch escape tower, mounted on top of the Command Module, would have pulled this module away from the launch vehicle and the other to escape by parachute in the unlikely event of a failure during launch operations.

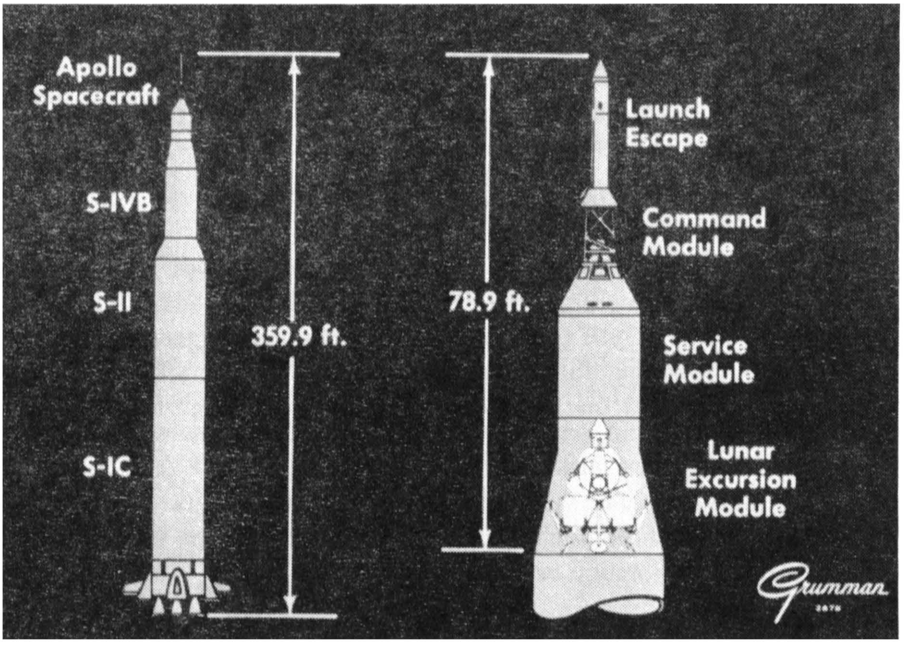

Figure 1 Apollo Launch Vehicle and Spacecraft.

Figure 2 depicts the Lunar Module and the location of its equipment. This spacecraft module is comprised of two separable sections or stages. The descent stage consists of the descent engine, its propellants and tanks, landing radar, extensive landing gear, lunar surface experiments, egress platform, and ladder. The ascent stage includes the crew cabin, with all of the displays and controls, as well as the LM operational subsystems that provide environmental control, and propulsion. During the LM design and development phase at the Grumman Corporation in Bethpage, NY engineers, scientists, mathematicians and other support personnel conducted detailed analyses of the flight performance, structural loads and configuration including materials selection, environmental control and life support, and thermal balance. In addition, requirements were formulated for all of the operational electrical, electronic, mechanical and fluid subsystems. Specifications were developed, procurement competitions were held, and subcontracts were awarded for the purchased hardware.

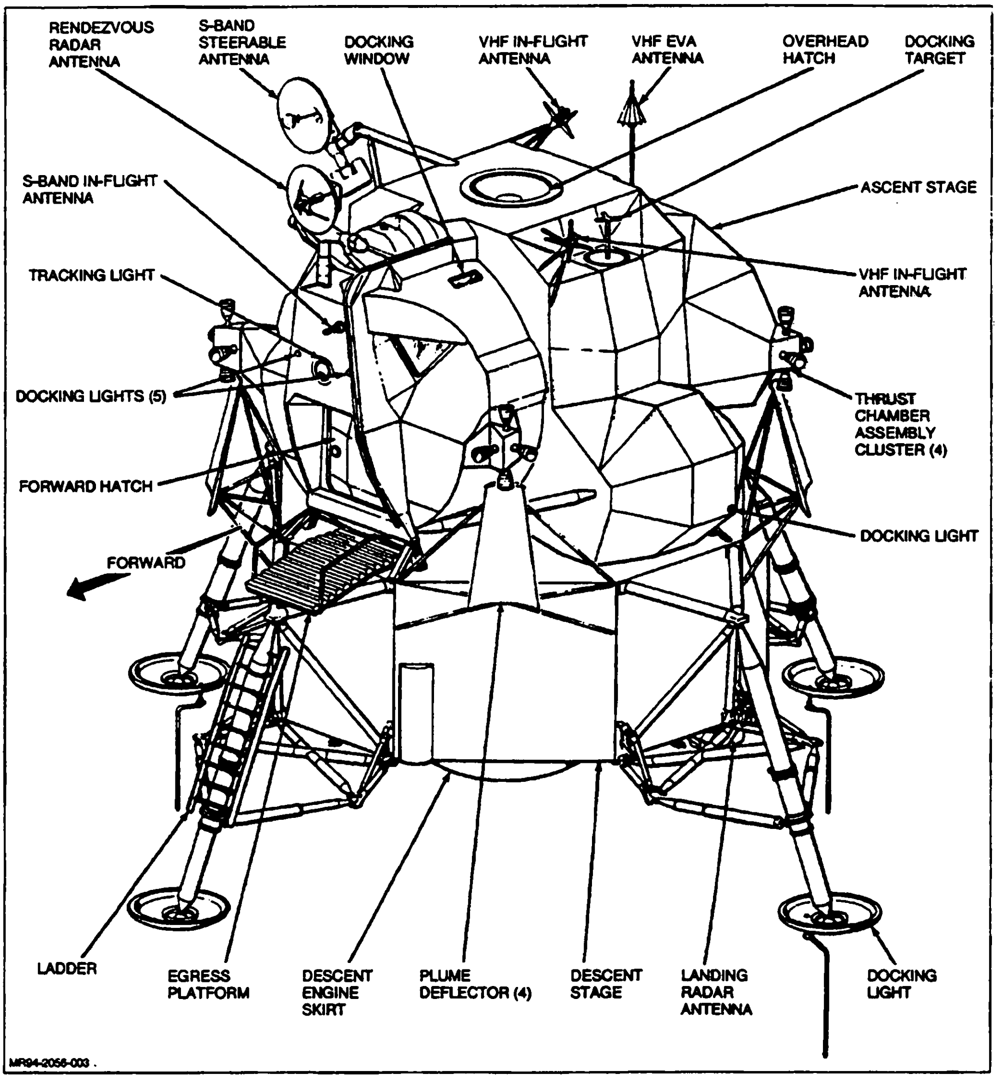

Figure 2 LM Showing Location of its Equipment.

The LM is about 23 feet high and 31 feet across the extended landing gear pads. Its total weight on Earth loaded with propellants and crew is 32,200 pounds. The LM Earth weight less propellants is 9,500 pounds.

Considerable functional performance testing of the hardware was performed when the subsystems were built and delivered. Grumman possessed many kinds of testing facilities for this effort. The Internal Environment Chamber is shown in Figure 3. Photographs of the Space Simulator Chamber and the Centrifuge are presented in Figures 4 and 5.

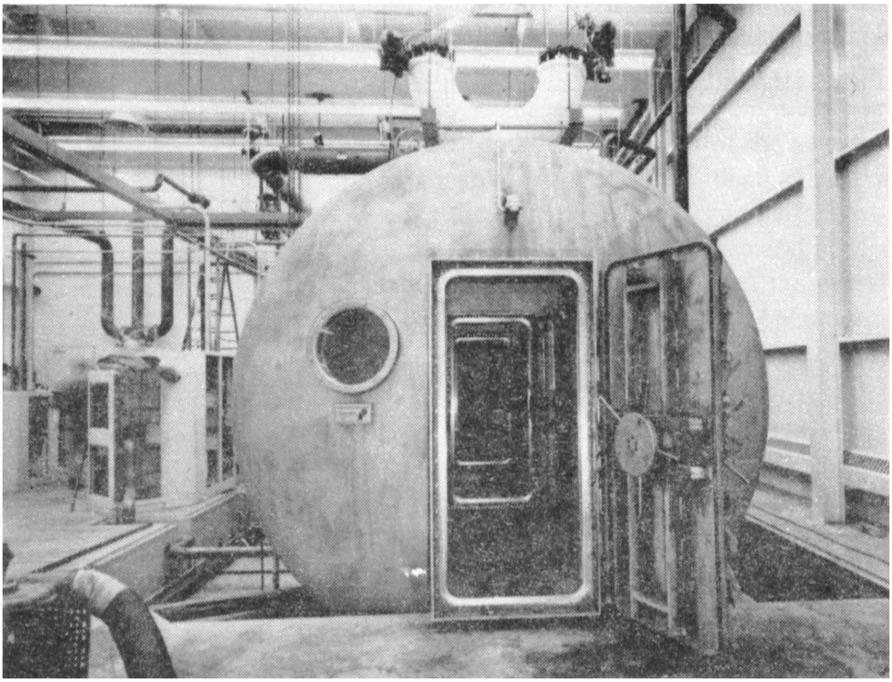

Figure 3 Grumman Internal Environment Simulator.

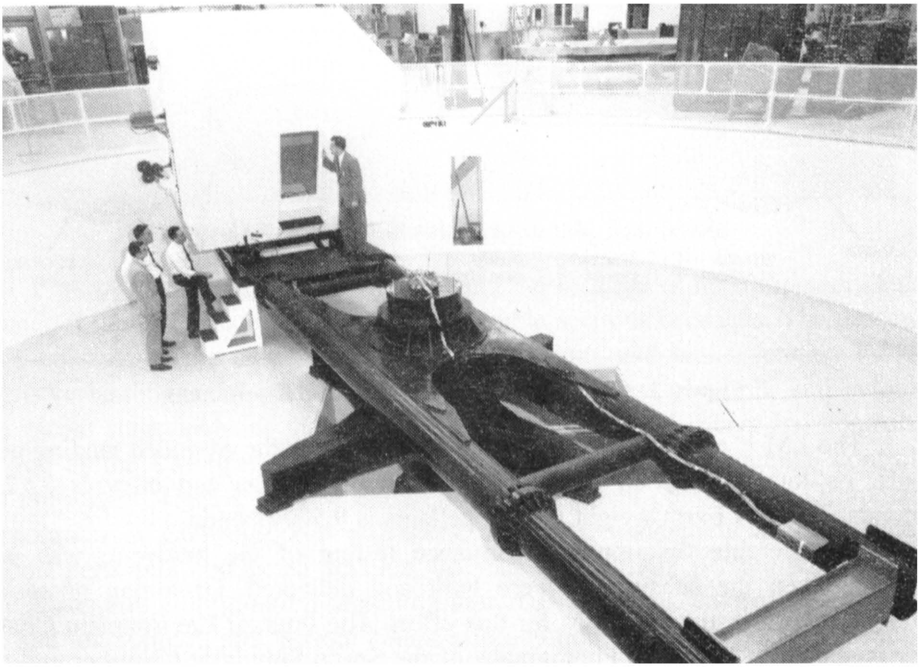

Figure 4 Grumman Centrifuge.

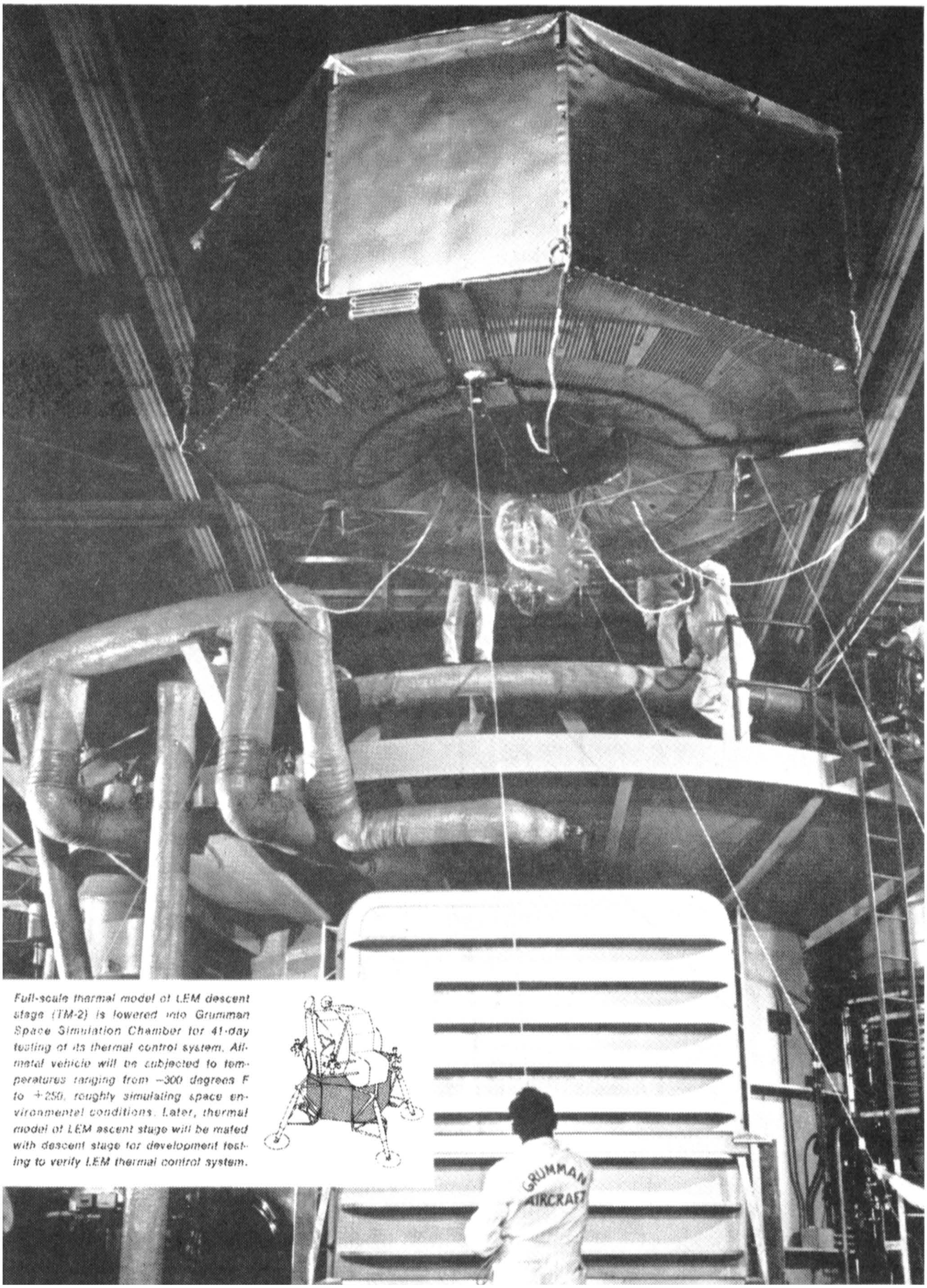

Figure 5 Grumman Space Simulator Chamber.

An ambitious simulation program was undertaken. Part task simulators were constructed to investigate flight performance during LM separation from the Command Module, descent to the lunar surface, landing, ascent to the lunar orbit, and LM rendezvous and docking to the Command Module. As shown in Figure 6, each simulator contained a crew station with operational displays, prototype flight controls and a high resolution closed circuit TV system that focused on realistic space, lunar surface and Command and Service Module views that would be seen from the LM windows.

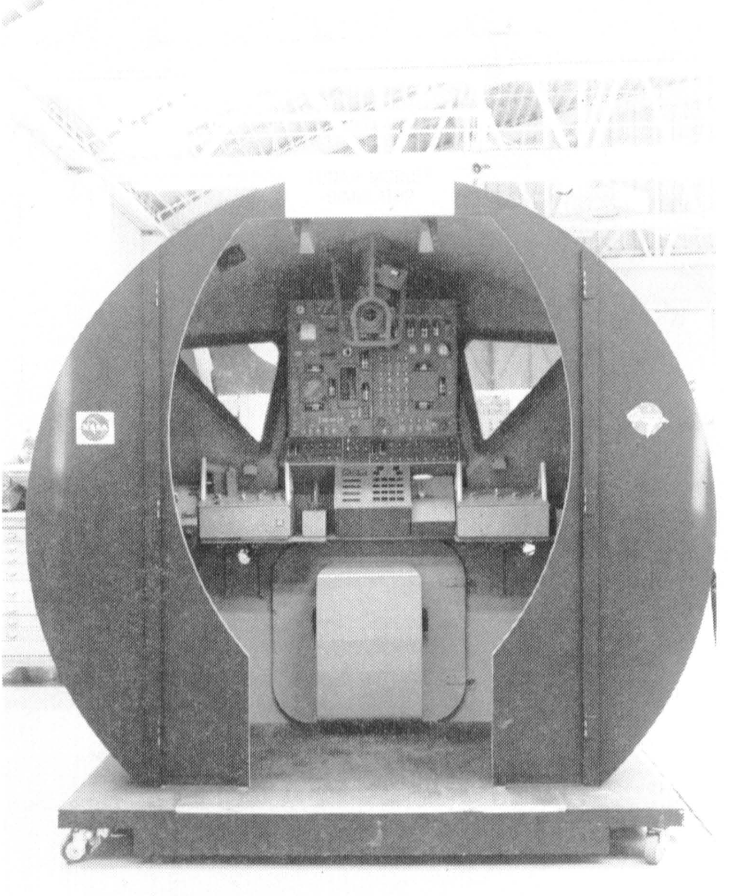

Figure 6 LM Crew Cabin Instrumented for Simulation Program.

The simulation program culminated in the Full Mission Engineering Simulator that was capable of LM man-in-the-loop operation over the entire LM portion of the Apollo 11 mission. This effort investigated LM motion with six degrees of freedom and incorporated actual LM hardware and software. Shown in Figure 7 is the three-axis flight attitude table which housed the inertial instruments that supported this simulation program.

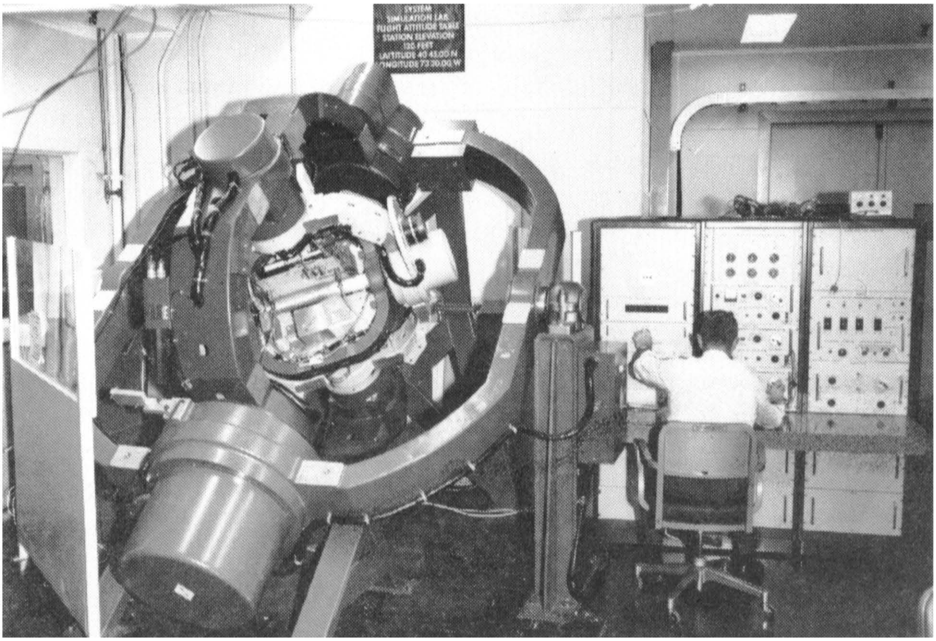

Figure 7 Flight Attitude Table Supporting Full Mission Engineering Simulator.

Additional development testing used extensive breadboard and special test hardware along with early versions of the software. For example, test models were constructed to evaluate crew visibility for several mission phases, crew ingress and egress to the lunar surface from the docking hatch, environmental control subsystem performance under thermal conditions, communication subsystems antenna performance, and radar boresight accuracy. An LM test article was shipped to the NASA Johnson Space Center for evaluation in the large thermal/vacuum chamber. Other test articles assessed the effects of electromagnetic interference on the integrated electronics, static loads and launch vibrations on the LM structure, and the stability of lunar surface touchdown motion. The astronaut's mobility in the cabin once the LM had landed on the Moon was investigated using the "Peter Pan" rig shown in Figure 8. With this device, five-sixths of the crew member's weight was counterbalanced as he moved about the cabin. This simulated the astronauts' one-sixth "g" lunar surface environment.

The full scale LM mockup in Figure 9 was built for examination by Grumman engineers as well as NASA senior management, technical personnel and astronauts. Several other mockups were constructed to check out crew mobility, cabin equipment location, crew ingress and egress, and cabin visibility and lighting.

Actual LM engine test firings could not be performed at the plant in Bethpage for safety reasons. To accomplish live engine testing, a large scale propulsion testing program was established at the NASA White Sands Test Facility shown in Figure 10. Three test stands were built, two of which could accommodate the entire LM ascent or descent stage so that the engines could be fired in near vacuum conditions. A flight weight test article determined the effects of engine-induced vibrations on the LM stages and their subsystems. Additional propulsion testing was conducted on several heavyweight rigs.

Other important activities during the LM design and development phase included: an intensive weight reduction program; a major effort to remove flammable materials and lessen electric arcing possibilities in the cabin to reduce the possibility of fire; and equipment qualification testing under the expected physical conditions of pressure, temperature, shock and vibration.

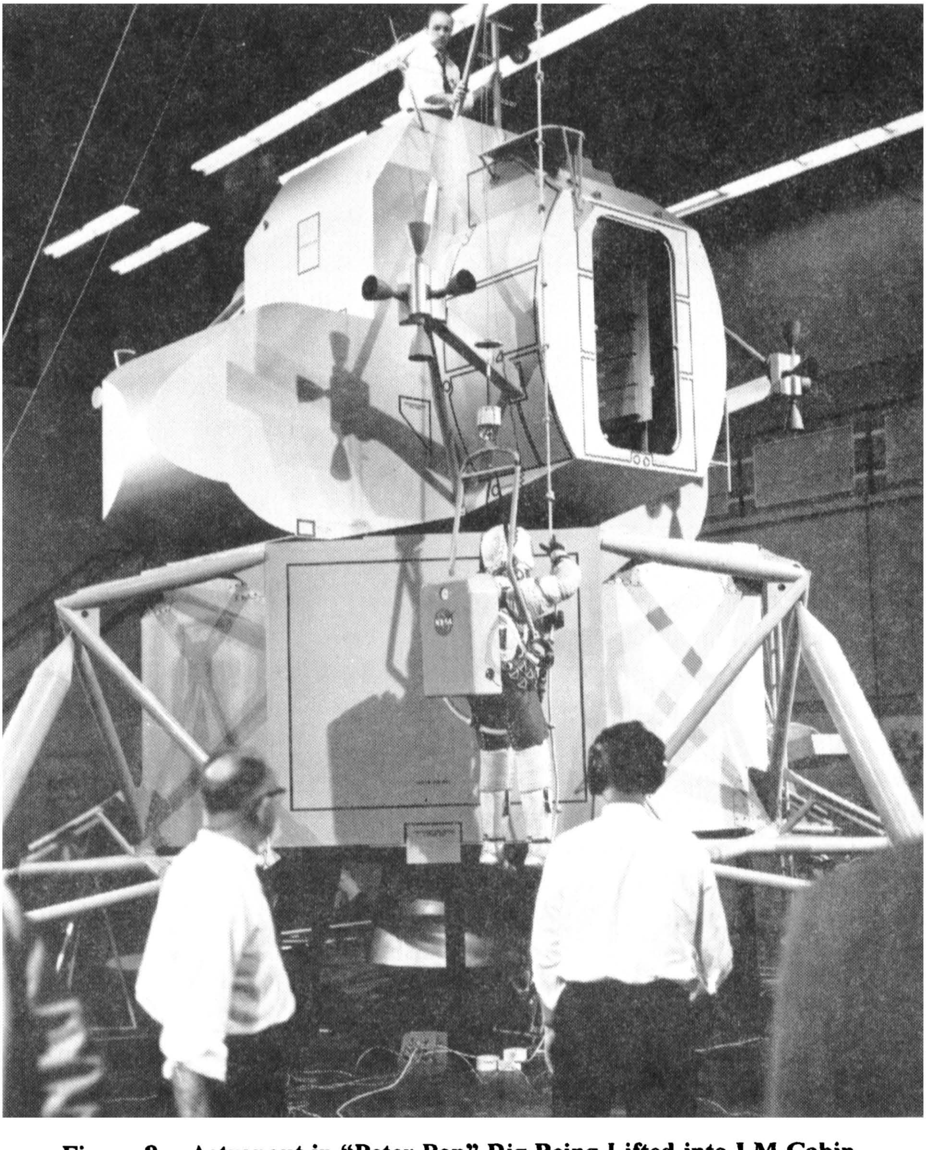

Figure 8 Astronaut in "Peter Pan" Rig Being Lifted into LM Cabin.

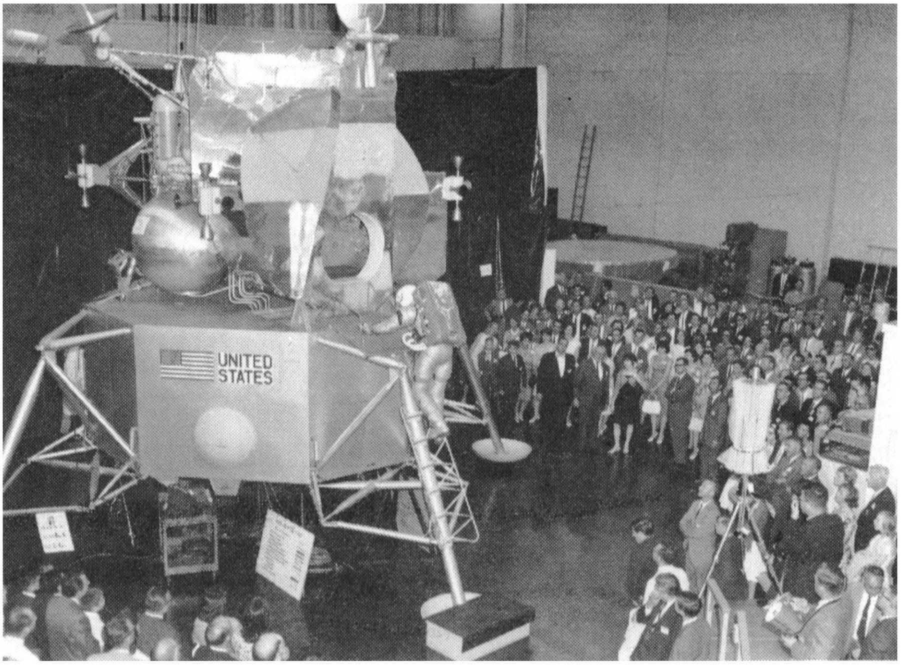

Figure 9 Presentation of the Full Scale Apollo Grumman LM Mockup.

Figure 10 NASA White Sands Test Facility.

Manufacture and Ground Testing

As shown in Figure 11, the LM-5 ascent and descent stages were manufactured at Grumman. First each of the stage structures was fabricated, after which much of the operational equipment was installed and checked out.

Next each stage was placed in the Rotate and Clean Fixture where it was turned over to remove any fabrication debris that may have accumulated in the recesses of the structure or around the installed assemblies. See Figure 12.

Figure 11 LM-5 Ascent Stage Mid-Section Being Assembled in Grumman Plant 3.

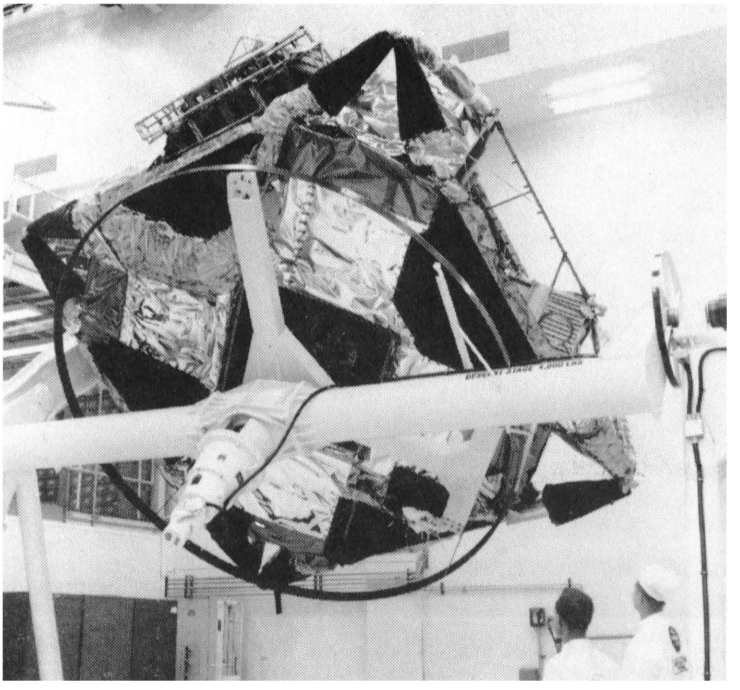

Figure 12 LM Descent Stage in the SCAT Rotate and Clean Fixture.

After these manufacturing operations, both stages entered the Cold Flow Facility, as noted in Figure 13, where referee fluid under pressure was forced through the propellant lines from the engine tanks to the engines to ensure that no leakage would occur. LM fluid line leakage had become a problem at the White Sands Test Facility and at the factory in Bethpage. Grumman technicians had become adept at applying a mass spectrometer helium leak detector to deal with this problem. Once a leaky connection was detected, replacement of the connector and careful rebrazing of the faulty joint eliminated the leak.

From Cold Flow, each stage was moved to its own workstand in the Spacecraft Assembly and Test Facility shown in Figure 14. Grumman had designed and constructed this facility as a "clean room" to complete LM final assembly, integration and test operations. Temperature- and humidity-conditioned air was continually pumped into this facility and exhausted outside the building. Each person who entered this facility wore a nylon smock, hat and booties. This was an effort to reduce contamination in the LM crew compartment and working assemblies.

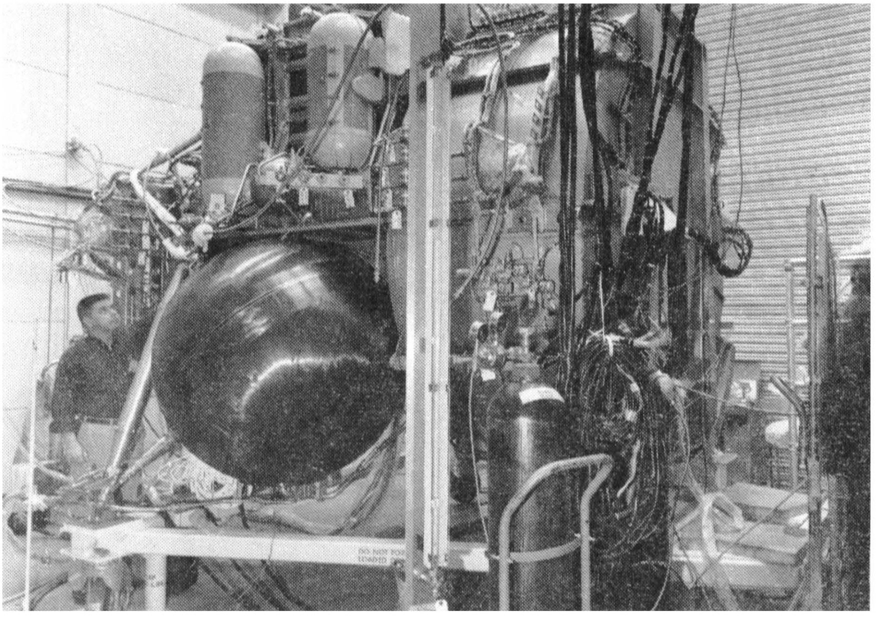

Figure 13 LM Ascent Stage Propulsion Test Article in the Grumman Cold Flow Facility.

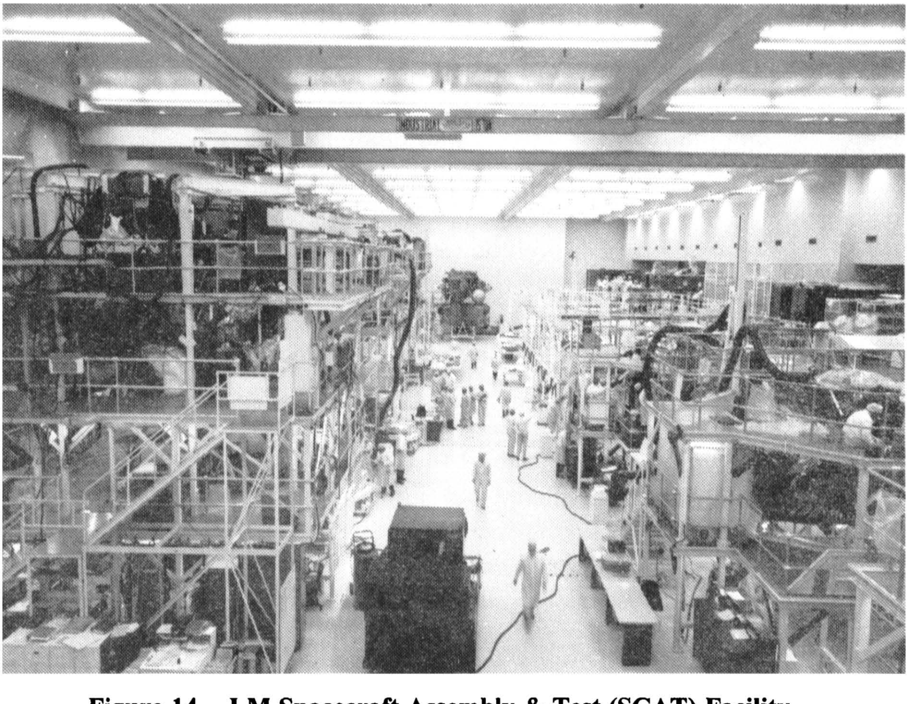

Figure 14 LM Spacecraft Assembly & Test (SCAT) Facility.

The Lunar Module Number 5 team is shown in Figure 15. For each lunar module, the overall operations in the Spacecraft Assembly and Test Facility were directed by a Spacecraft Team Manager. The manager and his team of about 100 engineers, technicians and inspectors were fully dedicated to their assigned lunar module. The Team Manager was responsible for: detailed planning of the daily assembly, integration and test tasks; providing support of the stage structure assembly operations; installation of all of the electrical, electronic, mechanical, and fluid subsystems; and performance validation testing of this equipment. This included integration of the subsystems such as connecting the cables from the batteries to the equipment that required electric power and mating lines from the environmental control and life support subsystem to the units that required cooling fluid.

At a daily morning meeting, the Spacecraft Team Manager briefed the Grumman Lunar Module Program senior managers on the status of assembly, integration and test operations on his lunar module. See Figure 16.

Integrated subsystem tests were conducted from the Test Control Center as shown in Figure 17. Here the test director initiated automated test sequences. Engineers and test technicians monitored the digitized test results in real time on their display consoles from data that were uplinked from the lunar module on the workstand in the Spacecraft Assembly and Test facility. See Figure 18.

The last series of tests were the Final Engineering Acceptance Tests that were witnessed by NASA senior technical personnel including the astronauts. All assembly, integration and test activities were inspected by Grumman quality control personnel and their findings were entered into each lunar module log. If any assembly or integration procedure resulted in noncompliance with engineering drawings or instructions or if a test failed, the anomaly would be reviewed, the failure condition eliminated and the procedure or test done over. This cycle was repeated until acceptable results were obtained. This rigorous approach helped attain the Apollo goal.

After the lunar module tests were completed, the thermal shielding was installed and the LM was removed from the workstand as noted in Figure 19.

The completed stages were then separated and prepared for shipment to the NASA Kennedy Space Center. See Figure 20. Each stage was transported in a hermetically sealed container that was fully instrumented to keep track of the ascent and descent stage travel conditions, such as temperature, acceleration, shock and humidity during the trip to Cape Canaveral. This was to determine if either lunar module stage had experienced any physical condition that would adversely affect its subsequent mission performance. The last task at Grumman in Bethpage, New York, was to pack and ship each stage for its flight in a converted Boeing Stratocruiser aircraft, known as the Super-Guppy as shown in Figure 21.

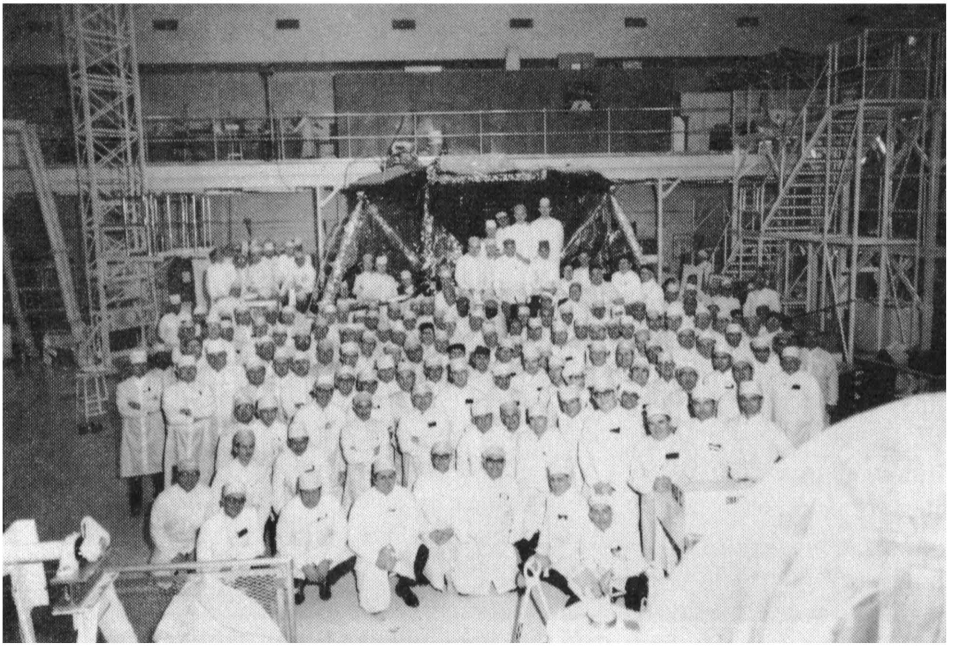

Figure 15 LM-5 Personnel in the SCAT Facility.

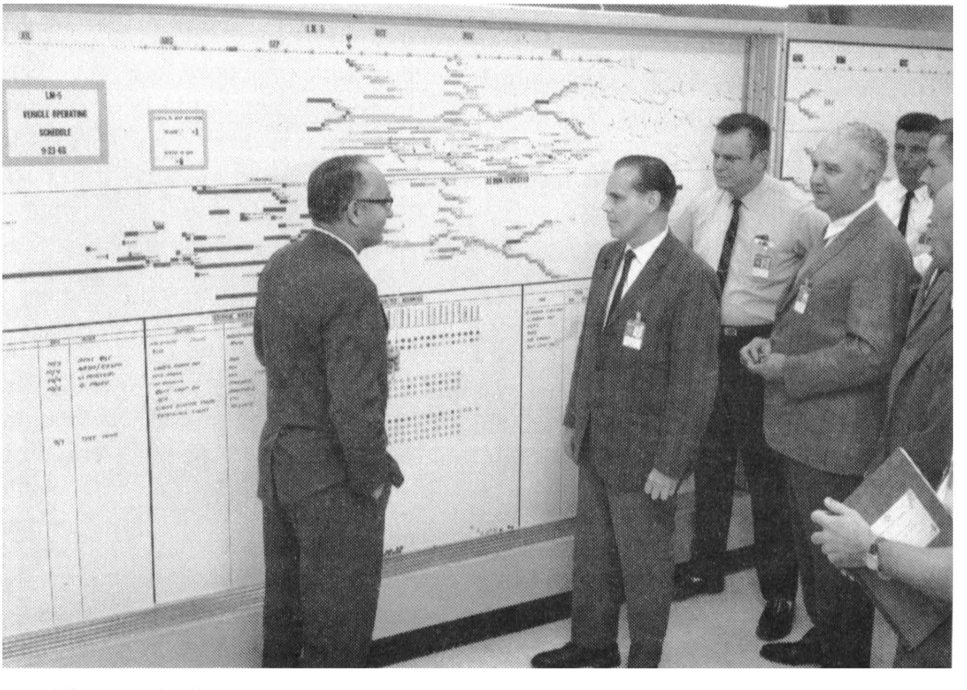

Figure 16 LM-5 Spacecraft Team Manager Briefing LM Management.

Figure 17 LM-5 Undergoing Test with Personnel Manning Display Consoles in the Test Control Center.

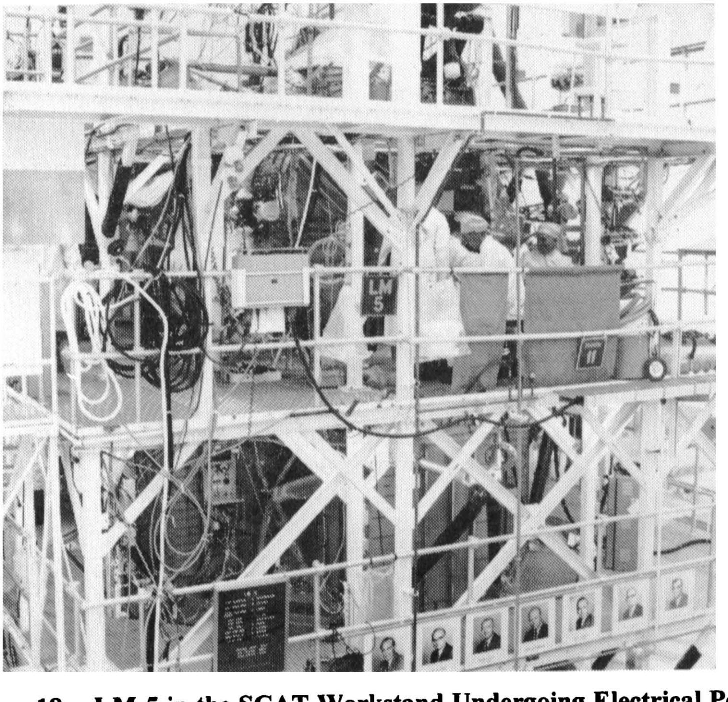

Figure 18 LM-5 in the SCAT Workstand Undergoing Electrical Power Subsystem Testing.

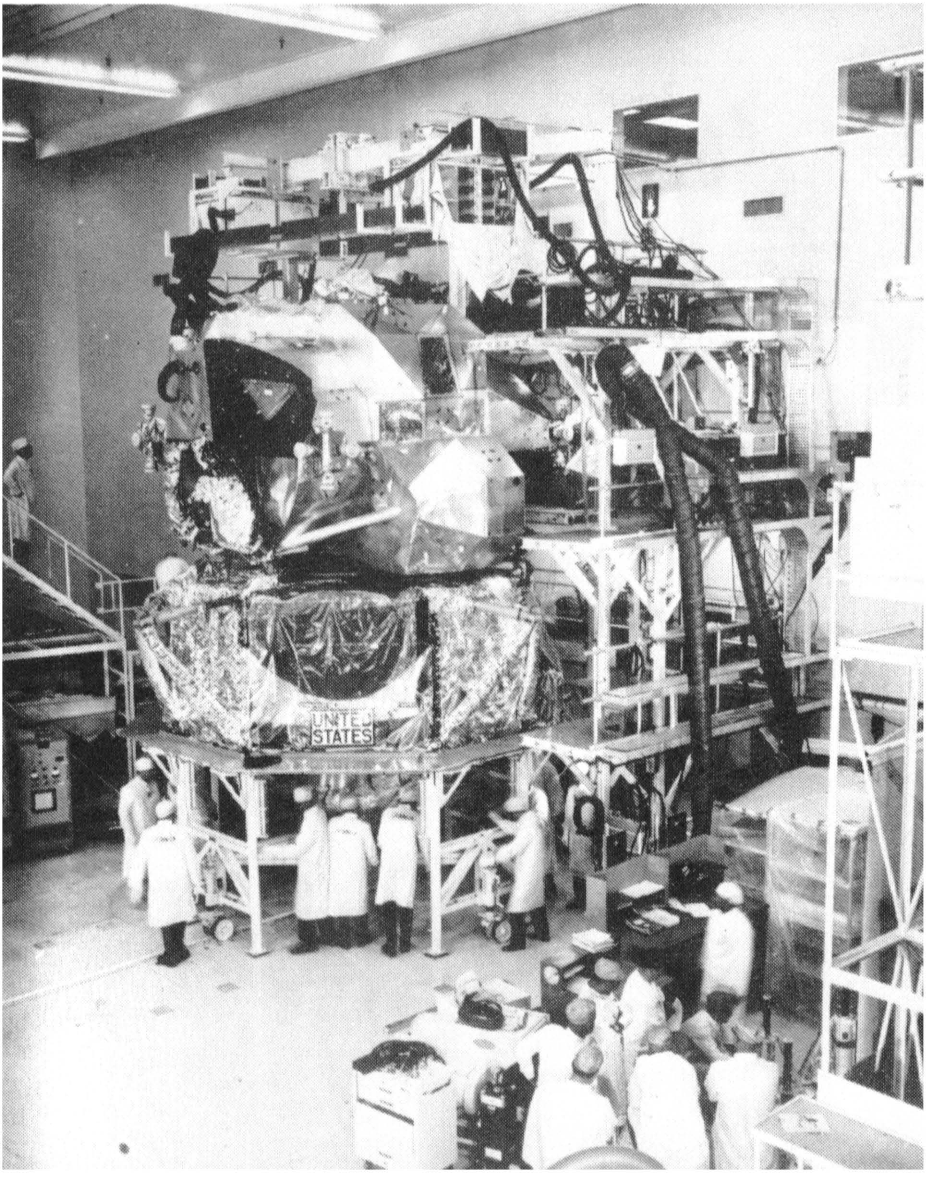

Figure 19 LM Removal from Assembly & Test Facility Workstand.

However, Grumman continued the lunar module effort at the NASA Kennedy Space Center in Florida where a team of more than 1600 engineers, technicians and quality control personnel supported NASA in mating the Lunar Module to the Command and Service Modules. The electrical and mechanical connections between the modules were tested and secured.

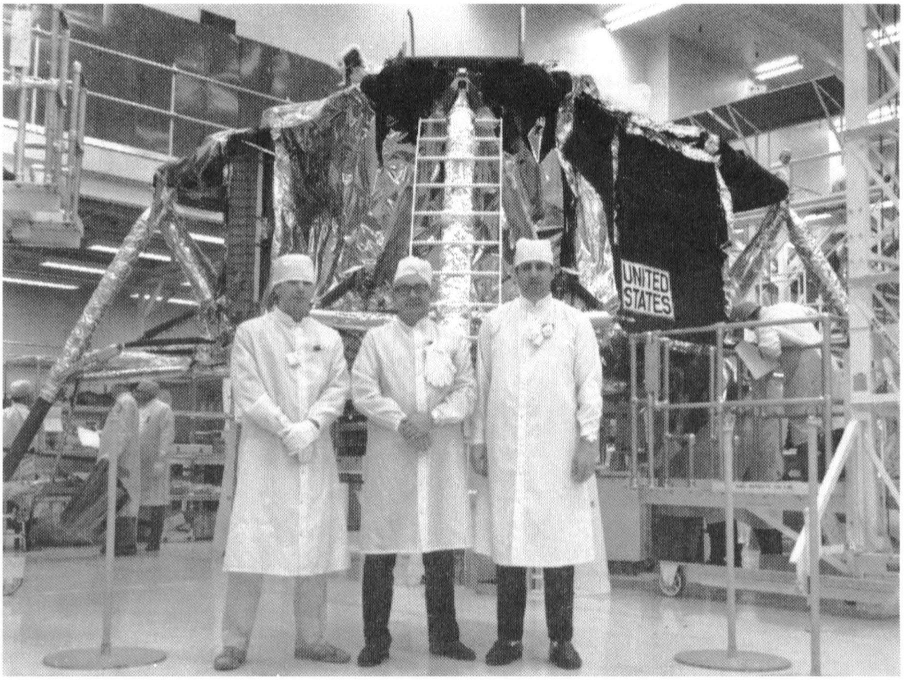

Figure 20 *Left to Right*: LM-5 Technician Supervisor, Spacecraft Team Manager & Quality Control Manager in Front of Completed LM-5 Descent Stage.

Figure 21 LM Ascent Stage in Sealed Shipping Container Being Loaded Aboard Super-Guppy Transport Aircraft.

NASA designed an Apollo identification plate, depicted in Figure 22, and had it mounted on the LM-5 landing gear front strut. The completed spacecraft was then positioned on the Saturn V launch vehicle and their interfaces were tested and secured. The entire Apollo space vehicle was moved several miles on the special transporter and connected to the Launch Umbilical Tower at Pad 39B. This transporter looked like a rectangular playing field held off the ground by an Army tank at each corner.

Figure 22 Mounting Plate for the First Manned Spacecraft (LM-5) to Land on the Moon.

The Mission

The prime crew for Apollo 11, shown in Figure 23, included mission Commander Neil Armstrong on the left, Lunar Module Pilot Edwin "Buzz" Aldrin on the right, and Command and Service Module Pilot Michael Collins. The Apollo 11 Mission lifted off on July 16, 1969. See Figure 24.

To depict the Apollo mission, the flight trajectories are reviewed aided by Figure 25. First, on the outbound leg to the Moon, the three stage Saturn V launch vehicle lifted off form Pad 39B. The final stage, injected its payload, the Command, Service and Lunar Modules, that comprised the Apollo spacecraft, into a translunar trajectory. As noted in Figure 26, the spacecraft was then steered to within 60 miles of the Moon by the Command Module guidance, navigation and control subsystem, and inserted into lunar orbit by the Service Module engine. Then, Astronauts Armstrong and Aldrin transferred into the LM cabin while Astronaut Collins remained with Command and Service Modules in lunar orbit. LM-5 then separated from these modules. To descend to the lunar surface, a retrothrust burn of the LM descent engine reduced the LM's speed that caused the vehicle to coast to the Moon. This variable thrust engine then fired again to steer the LM on a controlled trajectory to Tranquility Base on the lunar surface. Very near the planned landing location, the Commander took control to skillfully maneuver LM-5 away from a large crater to safely touch down.

Astronaut Aldrin is seen in Figure 27 descending on the LM-5 ladder to the lunar surface. During their more than 21 hour stay on the Moon, the two astronauts collected 46.2 pounds of surface materials. Lunar surface physical characteristics and their possible effects on extravehicular activity were evaluated. The solar wind composition experiment was deployed, and, at the end of the stay, was retrieved for the return to Earth. Also, the passive seismic experiment and laser ranging retroreflector were deployed.

Next the return trajectory to Earth is described with the help of Figure 28. Following launch preparations for liftoff form the lunar surface, the LM ascent engine was ignited, and, at the same time, the upper stage was separated from the descent stage as indicated in this artist's rendition. The descent stage was the launch platform for the ascent stage. This liftoff involved considerably fewer resources than for the earlier Apollo 11 launch from Cape Kennedy.

The LM-5 ascent stage rose up from the lunar surface, as depicted in Figure 29, and flew a controlled trajectory to successfully rendezvous with the Command Service Modules.

A spectacular photograph, shown in Figure 30, was taken by the Command and Service Module pilot showing Lunar Module Number 5 in view with the Earth in the background and the Moon below.

Figure 23 The Apollo 11 Astronauts.

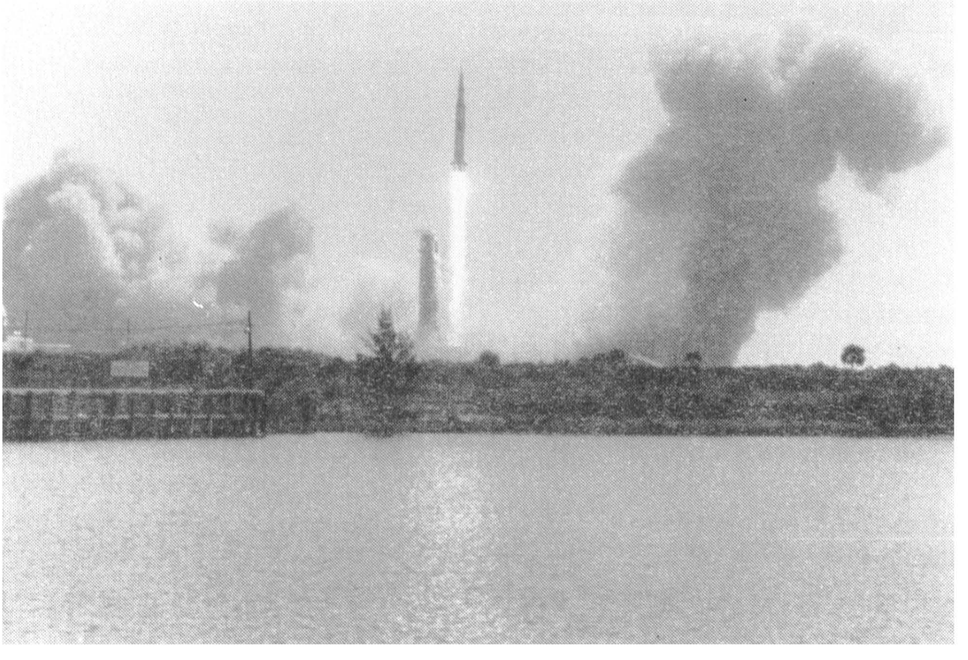

Figure 24 Apollo 11 Liftoff on July 16, 1969.

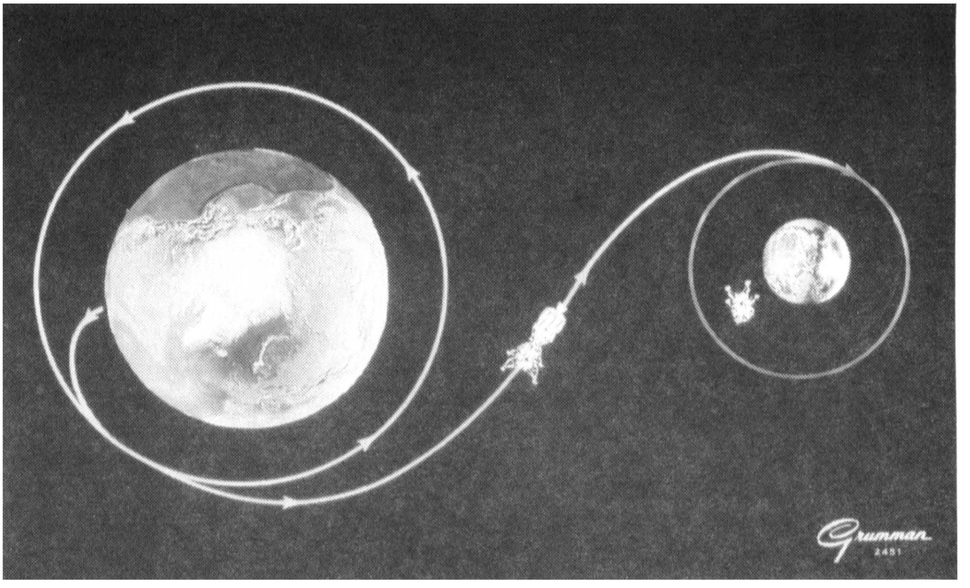

Figure 25 Apollo Mission Trajectory: Outbound from Earth to Moon.

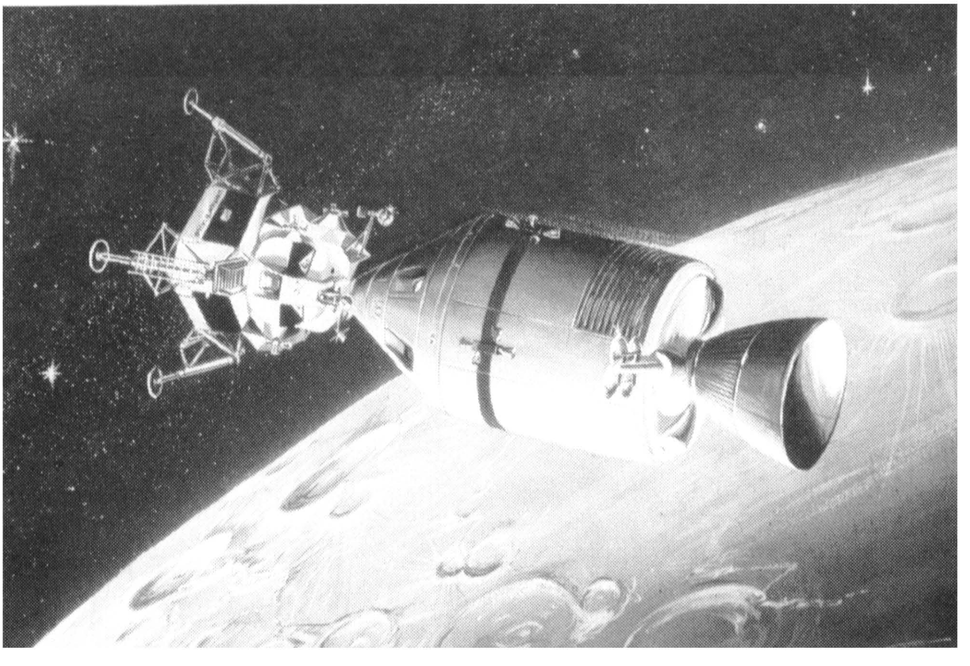

Figure 26 Apollo Spacecraft (LM & CSM) Approaching Lunar Orbit (Artist's Rendition).

Once the Lunar Module closed in on the Command and Service Modules, safe docking operations were performed by the two astronauts. Both crew members, with their lunar samples and experiments, transferred to the Command

Module. The empty ascent stage was maneuvered out of lunar orbit to crash on to the Moon. The Service Module fired its engine to inject the Command and Service Modules into a trans-Earth trajectory. Near the Earth, a Service Module retrothrust burn initiated Command Module entry into the atmosphere after which the Service Module was jettisoned. The ocean landing by parachute was followed by recovery of the crew in the Command Module by the U.S. Navy.

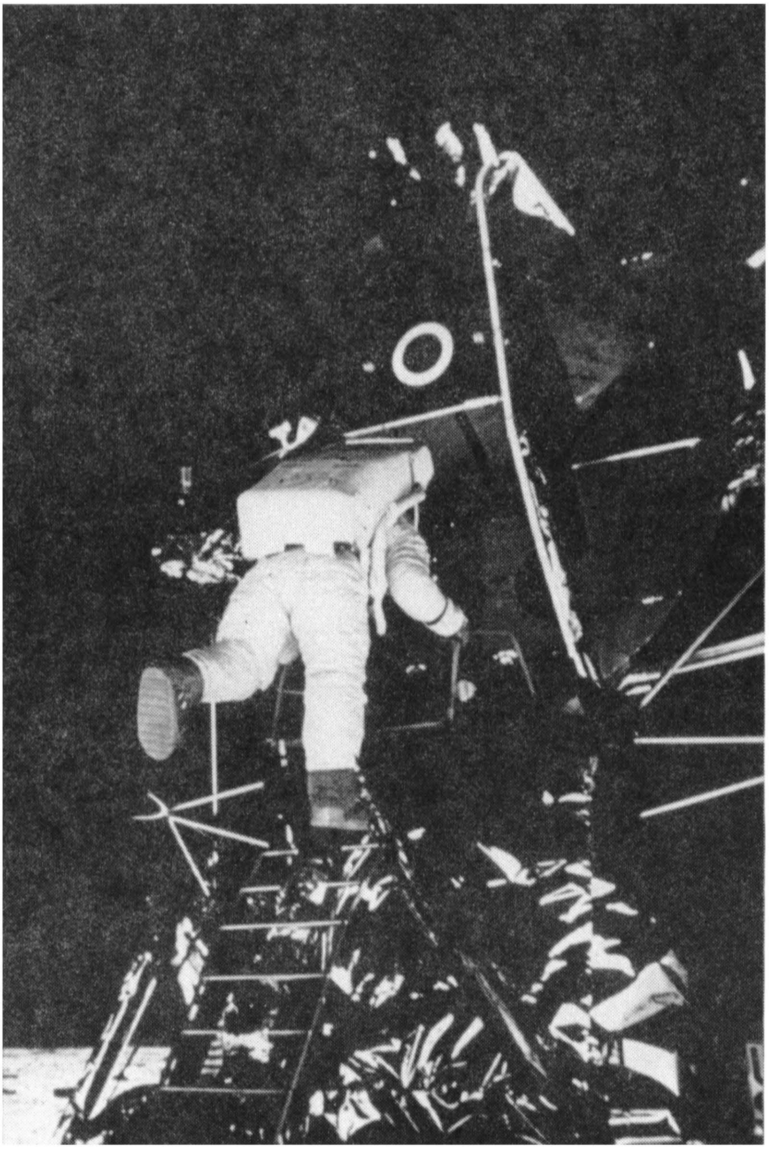

Figure 27 Astronaut Aldrin Stepping Down the LM-5 Ladder to the Lunar Surface.

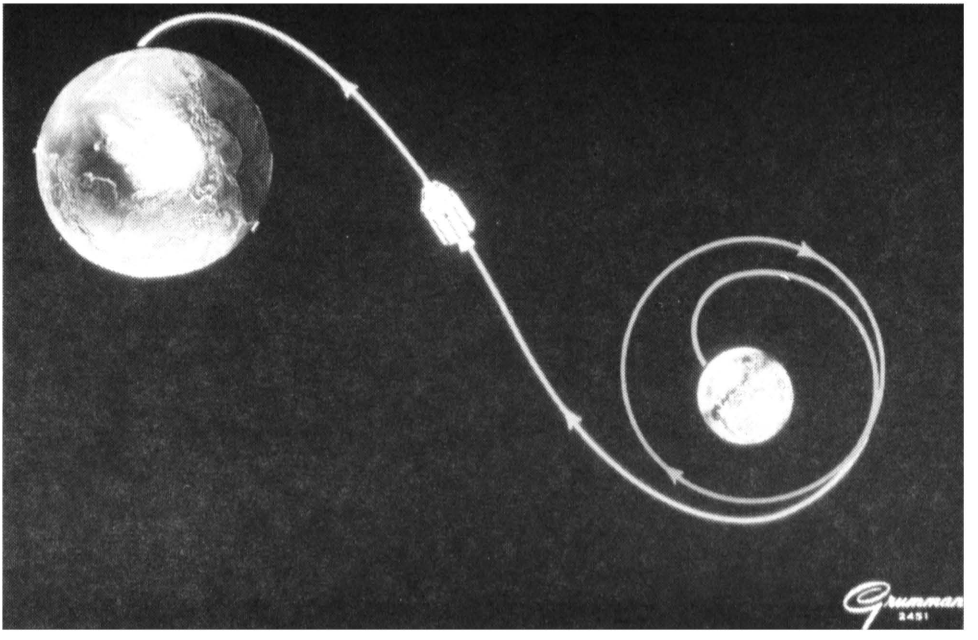

Figure 28 Apollo Mission Trajectory: Return from Moon to Earth.

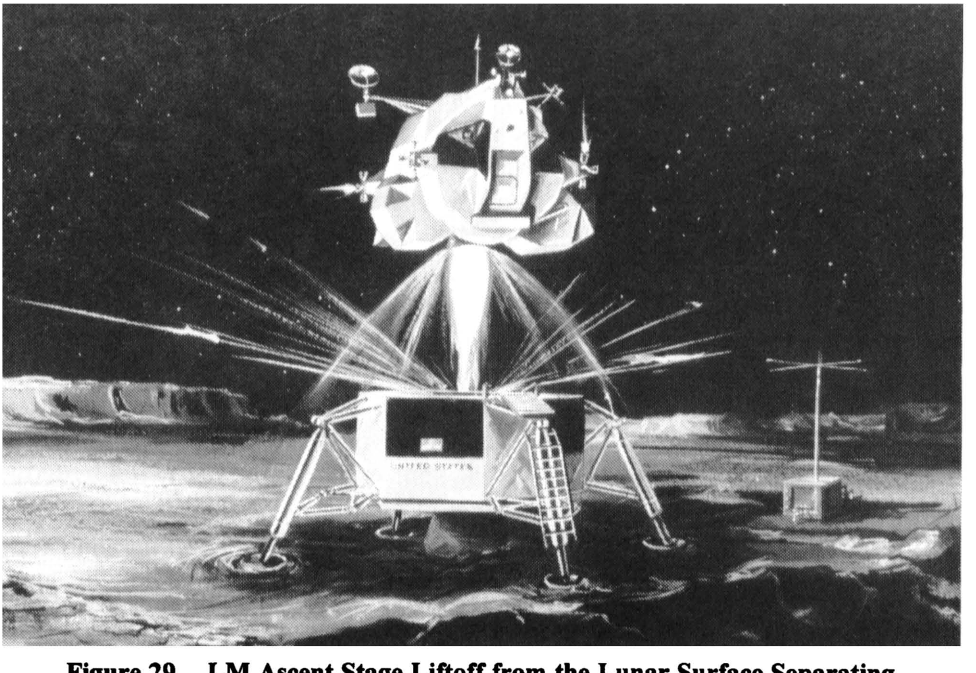

Figure 29 LM Ascent Stage Liftoff from the Lunar Surface Separating from the Descent Stage (Artist's Rendition).

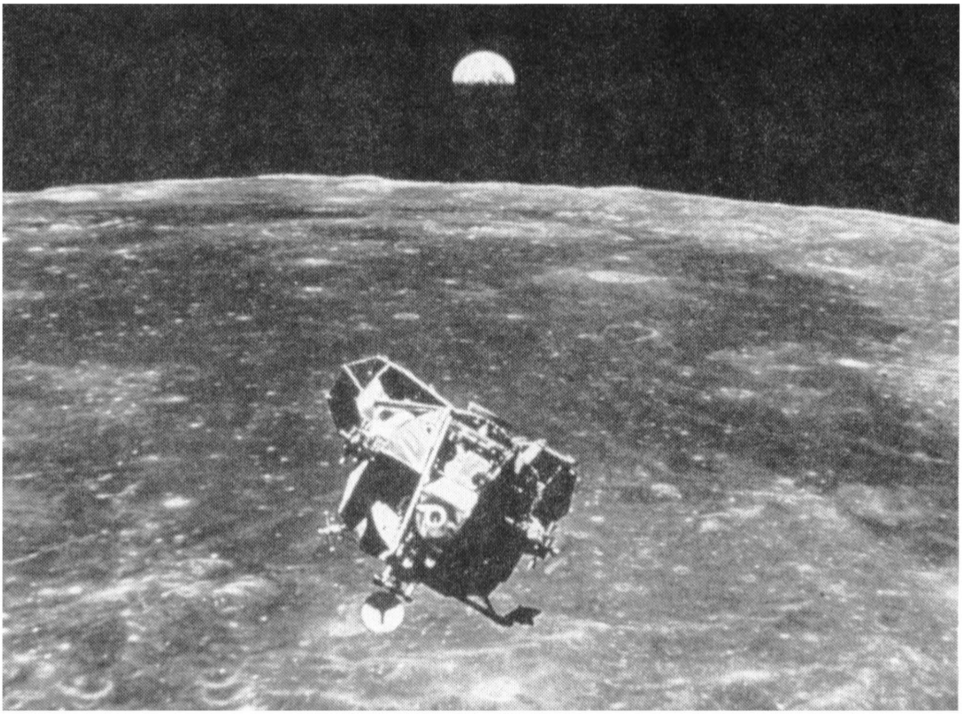

Figure 30 LM-5 Ascent Stage Approaching the CSM with the Earth in the Background and the Lunar Surface Below.

The outstanding performance of Lunar Module Number 5, in response to the astronauts' commands during the Apollo 11 Mission, was a source of great satisfaction to all of the NASA, Grumman and other industrial contractor personnel who worked on it. The successful flight of the Apollo spacecraft and Saturn V launch vehicle had fulfilled the vision and commitment of President Kennedy who announced on May 25, 1961 that "We will send a man to the moon and return him safely before the end of this decade."