A Brief History of the Lunar Roving Vehicle

As Part of the History of the NASA Marshall Space Flight Center, Huntsville, Alabama

April 3, 2002

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Mike Wright and Bob Jaques, Editors
Saverio Morea, Technical Editor

For more information about the history
of the Marshall Space Flight Center
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Introduction

It has now been more than 30 years since NASA astronauts drove the first lunar roving vehicle on the surface of the moon. This booklet generally recounts the steps that the Marshall Space Flight Center in Huntsville, Alabama and its contractor partners across the country took to make the lunar roving vehicle possible on Apollo 15, 16 and 17. Marshall Space Flight Center historians Mike Wright and Bob Jaques prepared this booklet in April 2002. Saverio Morea, who managed the Lunar Roving Vehicle Project for Marshall, reviewed the booklet for technical accuracy.

Official U.S. Post Office first day cancellation of the twin space stamps "A Decade of Achievement" featuring the lunar roving vehicle, a Huntsville, Alabama postmark and the signature of Lunar Roving Vehicle Project Manager Sonny Morea.

The Challenge

Imagine the excitement. You have won an all-expense paid trip to New York City. But imagine first, that you will only have enough time to walk around an area about half the size of Central Park. Now imagine, you have a vehicle that will allow you to explore almost all of Manhattan Island in the same amount of time.

Now think about exploring the moon. Would you want to spend the limited time you have there exploring on foot or riding in a vehicle?

That's the kind of capability that the lunar roving vehicle, developed by the NASA Marshall Space Flight Center in Huntsville, Alabama, provided to the NASA astronauts on their last three Apollo expeditions to the moon in the early 1970s. The lunar roving vehicle enabled the last three Apollo crews to explore much more of the lunar surface than the first three Apollo crews that explored the moon on foot.

During the Apollo era, the Marshall Center designed the mammoth Saturn V launch vehicle that boosted the first humans to the surface of the moon in 1969. That same year, Marshall assumed responsibility for the design, development and testing of a lunar roving vehicle to transport astronauts and materials on the moon.

The lunar roving vehicle became a two-person, four-wheeled vehicle. It was 10 feet 2 inches long, 44 inches high with a 7-foot 6-inch wheel base. It stood in stark contrast to the towering Saturn V Launch Vehicle. The lunar surface vehicle had large mesh wheels, antenna appendages, tool caddies and cameras. The finished lunar rover weighed only about 450 pounds or just 75 pounds in the moon's one-sixth gravity. At the same time, the rover could carry up to about 1,000 Earth-pounds — more than twice its own weight.

Dr. Wernher von Braun, seated, drives an early lunar surface vehicle concept at Marshall Space Flight Center.

Historical Concepts

Saverio F. Morea managed the Lunar Roving Vehicle Project for the Marshall Center. Morea and others have cited references to a lunar surface vehicle by Jerzy Zulawski. As a Polish science fiction writer, Zulawski published a work called "A Silvery Globe" in 1901. In the story, Zulawski's space travelers land on the moon and then use a roving vehicle to perform a traverse beginning at the lunar north pole through Mare Frigoris, Mare Imbrium, and ending near Mare Vaporum and the lunar equator. "A very ambitious traverse," wrote Morea.

Space historians Bettye B. Burkhalter and Mitchell Sharpe note that in 1915 American science fiction writer Hugo Gernsback also referred to a vehicle that could travel on the moon.

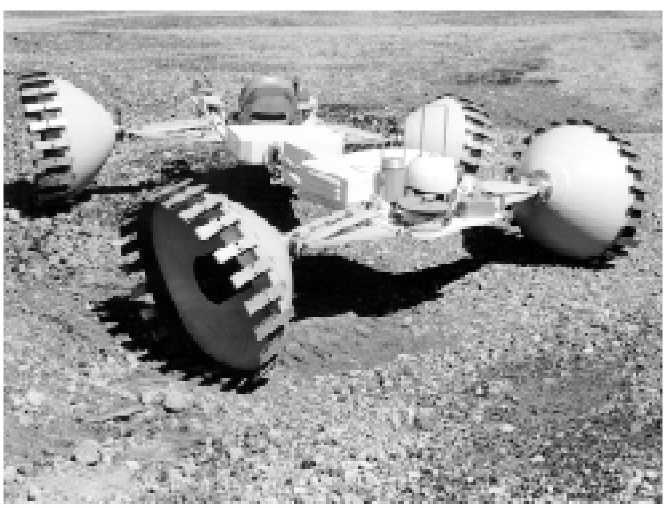
Eric M. Jones, another space historian, points out that in the early 1950s Wernher von Braun, astronomer Fred Whipple, and science fiction writer Willy Ley published a story in Collier's Magazine. They envisioned a grandiose plan that included a six-week stay on the moon and the capability to move materials and supplies on the moon using three 10-ton tractor trailers.

By the mid part of the 20th century, however, engineers and scientists at Boeing, Bendix, Lockheed, General Motors, Northrup, Grumman and other companies were working on initial studies for a lunar vehicle.

During the 1960s, von Braun, then serving as the first director of the Marshall Center, wrote a series of space-related question and answer articles for Popular Science. In the February 1964 issue, von Braun discussed the need for a lunar surface vehicle. "The visible part of the moon extends over an area twice the size of the United States — and the far side of the moon is just as large," von Braun wrote. "As there are no superhighways on the moon (yet), all vehicles must have cross-country capability. Just as on Earth, the terrain on the moon is partially smooth and flat, while other parts are rugged and mountainous."

The Marshall Center started lunar surface vehicle research in 1964 with a concept known as MOLAB, for Mobile Laboratory, a two-man, three-ton, closed-cabin vehicle with a range of 100 kilometers, wrote Eric M. Jones. MOLAB was later cancelled but that work and subsequent studies contributed to NASA's design for the Lunar Roving Vehicle. In fact, engineers envisioned an entire spectrum of vehicles including those that walked, crawled, jumped and even flew over the moon. From these efforts, came


A full-scale mock up of the Grumman Mobile Laboratory (MOLAB).


A proposed concept for a lunar surface vehicle by Grumman.

the knowledge that directly contributed to the development of the lunar roving vehicle. Of course, safety and reliability ruled out some of these designs.

Adding extra weight to the Apollo/Saturn missions was a very serious concern that engineers had regarding the lunar roving vehicle. Additional weight meant increased costs. Additional weight also related to safety and reliability concerns.

On April 7, 1969, von Braun announced that he was establishing a Lunar Roving Task Team at Marshall. "On May 23, 1969, a portion of the responsibility of this task team, the Manned Lunar Rover Vehicle Program, was approved by NASA Headquarters as an MSFC hardware development program," von Braun wrote.

Von Braun and others believed the vehicle would ease situations related to exploring the moon on foot with bulky spacesuits and limited life supplies. In addition, the vehicle would increase human mobility on the lunar surface for astronauts on Apollo 15, 16 and 17.

Contractor and Government Roles

Boeing was selected for the lunar roving vehicle contract award, and work began in 1970 with flight expected the following year. Boeing used facilities in Huntsville and in Kent, Washington. General Motor's Delco Electronics Division in California served as major subcontractor.

Engineers at Marshall, Boeing and other contractor sites tackled the project with relish — inventing a car for drivers on the moon was as appealing to a grown-up's imagination as to a child's. Engineers at Marshall were deeply involved in the drive motors, the battery system and all of the electronics.

The Center's laboratories also contributed substantially to designing and testing the navigation and deployment systems. In fact, the backup manual deployment system developed by Marshall proved more reliable than the automated system and became the primary method of deployment.

To help develop the navigation system, the Marshall Center created a lunar surface simulator, complete with rocks and craters, where operators could test drive the vehicle. Engineers also used the simulator during the Apollo mission as an aid. Space scientists at Marshall and General Motors also focused on lunar soil mechanics.

More than any other project, the lunar roving vehicle gave Marshall engineering insight regarding space hardware for human-tended missions.

Although the vehicle was not as complex as a habitable laboratory, it represented a small work place with similar crew requirements. Thus, the rover provided engineers with valuable experience regarding crew systems and mission support for later projects like Skylab, space shuttle, and the International Space Station.

Design Features

Developing the lunar roving vehicle meant solving many challenging technical problems that lacked precedents in terrestrial vehicle design and operation. Designers had to consider the lack of an atmosphere on the moon; extreme surface temperature, plus or minus 250 degrees Fahrenheit; very weak gravity, one-sixth of Earth's; and many unknowns associated with the lunar soil and topography. All these factors imposed severe and unique requirements on the lunar roving vehicle. To meet these requirements, lunar roving vehicle development focused on several major systems. These included mobility, power, navigation, communications, thermal protection, crew station, control and display and vehicle deployment.

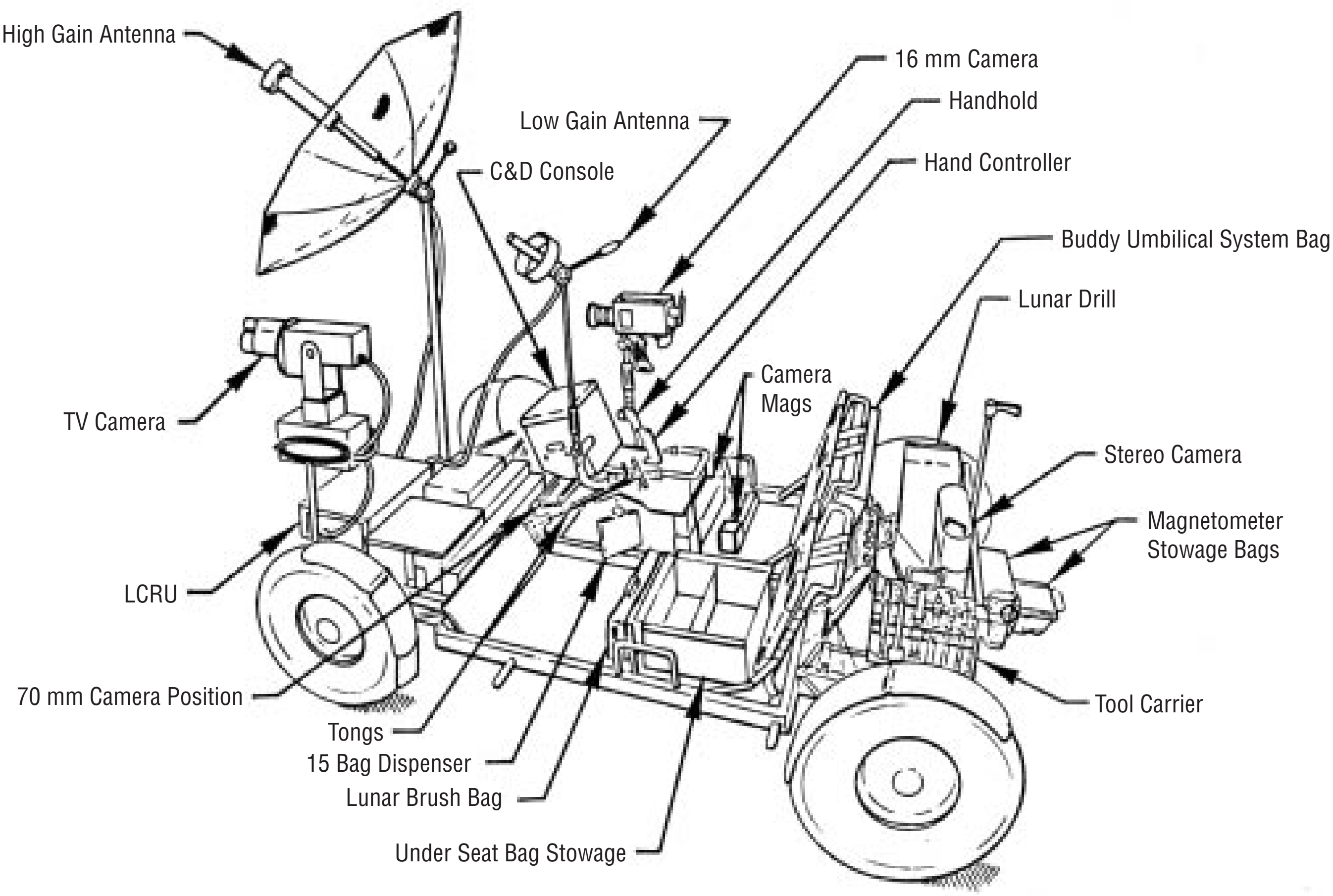


Diagram of the main components of the lunar roving vehicle.

Lunar Roving Vehicle Systems

Astronauts Jack Lousma (seated) and Gerald Carr test the lunar roving vehicle mobility test unit on the sands near Pismo Beach, California.

The **mobility system** had to permit crossing 12-inch high obstacles and 28-inch diameter craters. The system included the wheels, traction drive, suspension, steering and drive control electronics. The system was designed, developed, and tested by General Motors. The first assemblies were put through development tests to measure strength, deflection, endurance and other factors. A fixture that simulated a rolling road was used to test the wheel assembly under Earth conditions. The assembly was also placed in test chambers that reproduced environmental conditions of the moon. The lunar roving vehicle tires were made of a woven mesh of zinc-coated piano wire to which titanium threads were riveted in a chevron pattern. This pattern kept the wheels from sinking into the soft lunar soil. The test assembly was supported by springs to relieve most of its weight thus simulating the one-sixth gravity of the moon. A mobility test unit was used in early phases of development to validate the lunar roving vehicle mobility system. The astronauts participated in this as they did in all aspects of lunar roving vehicle development.

The **power system** featured two 36-volt silver zinc batteries. Four one-fourth horsepower electric motors individually powered each wheel. A harmonic drive unit connected each motor to its wheel. This eliminated the need for a transmission and gears.

A remote control navigation system to be used for the lunar roving vehicle is tested in Arizona using a jeep and a station wagon. The jeep, simulating the lunar roving vehicle, uses the television camera to view the terrain to the station wagon, simulating control on Earth.

On the forsaken moonscape, the astronauts had more than fond regard for the lunar module — it was their home. It was a haven that they returned to periodically. While the lunar roving vehicle carried the astronauts across the lonely surface of the moon, the hills would occasionally hide the lunar module from their view. The **navigation system** allowed the astronauts to drive beyond sight of the lunar module and still be able to return to it by the most direct route. The system recorded direction and distance traveled from the starting point. It provided the astronauts with an accurate determination of their position relative to their home base — the lunar module. This meant the astronauts could make extended excursions with the assurance that they knew the distance and how to head back to the lunar module. The system also helped them pinpoint moon features and dimensions and it allowed them to travel to areas of prime scientific interest.

A directional gyro unit served as the heart of the navigation system. It provided a stable reference for calculating heading, range and bearing. An attitude indicator and a sun-shadow device assisted the gyro in establishing reference. The attitude indicator determined if the vehicle was going uphill or down and if it was tilted to one side or the other — a tough job for an astronaut wearing a space suit and working in the deceiving lunar sunlight. The sun-shadow device determined the vehicle's heading with respect to the sun. The odometer — actually one on each wheel — recorded the rate of rotation of the wheels to compute speed and distance. All four wheels were measured to be sure a correct reading was obtained even if one or two wheels were spinning in the lunar dust. The computer in the signal-processing unit selected the median signal from the four odometers.

The **communications system** consisted of a television camera, radio-communications equipment and telemetry. RCA supplied the system to the NASA Manned Spacecraft Center in Houston, now the Johnson Space Center. The communications equipment transmitted data to Earth regarding vehicle and astronaut performance, allowed mission control to assist in vehicle navigation and gave scientists on Earth better information than they had ever had on the areas being investigated.

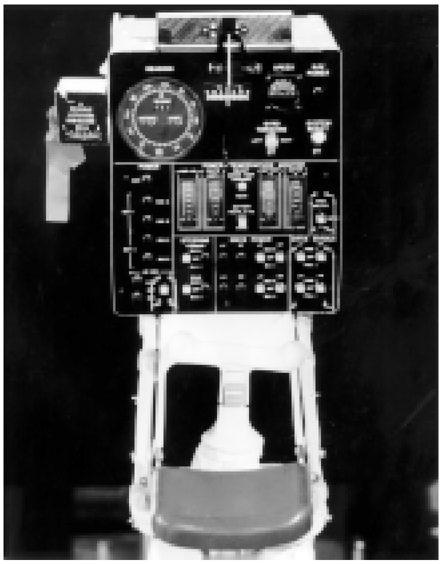
A **thermal protection system** protected the lunar roving vehicle and its equipment from temperature extremes on the moon, and it dissipated the heat generated by the operating equipment. The presence of lunar dust greatly influenced the system design. While the vehicle was moving, it stirred up dust. To protect the equipment from the dust, some parts were sealed and others were covered. This meant that some heat had to be collected and stored during a lunar sortie. Then, after they completed each traverse, the astronauts had to uncover the equipment so the accumulated heat could escape.

The Lunar Roving Vehicle was the first human-tended spacecraft designed to be operated on its first mission. There was no dress rehearsal. Therefore, designers focused hard on the **crew station system**. It had to be as simple as possible.

Engineers studied how the astronauts would relate to the machine. For example, the crew took flights in a KC–135 jet that featured a lunar roving vehicle. To simulate one-sixth gravity, the airplane flew in a parabolic arc while the astronauts tried getting in and out of the moon vehicle. As a result, they identified ways to reduce the time from as much as 10 minutes to between 1 and 3 minutes. This increased their effective time on the lunar surface.

The lunar roving vehicle seats resembled webbed patio furniture. The material was nylon, with a Velcro® facing strip. Designers also applied a similar material to the portable life support system that the astronauts wore on their backs. These two materials tended to engage each other. Reduced gravity on the moon meant this alone was almost enough to keep the astronauts in place in the vehicle. Designers also added lightweight fiberglass fenders to the vehicle to hold down the lunar dust.

The **crew station** included the control and display console, seats and seat belts, armrests, footrests, hand and toeholds, floor panels and fenders. Marshall and its contractors conducted crew station reviews to learn how the astronauts in their pressurized space suits related to the vehicle. They conducted these reviews using Earth gravity and simulated one-sixth gravity. They also studied how the astronauts could manipulate the control switches while wearing gloves. A hand controller provided steering, speed and braking commands to the vehicle's drive control, electronics and mechanical brake system. Engineers wanted to be sure the hand controller was properly designed. Only one hand was needed, and because the device was located between



The main console of the lunar roving vehicle showing the instrumentation.

the astronauts, either of the two-person crew could operate the vehicle. A T-shaped design for the controller evolved after engineers found it was easier for the astronauts to use instead of a straight handle. Engineers designed the hand controller so the astronauts could steer the lunar roving vehicle rapidly in a 10-foot radius — the same length as the lunar roving vehicle. These extremely sharp turns were possible because both front and rear wheels pivoted.

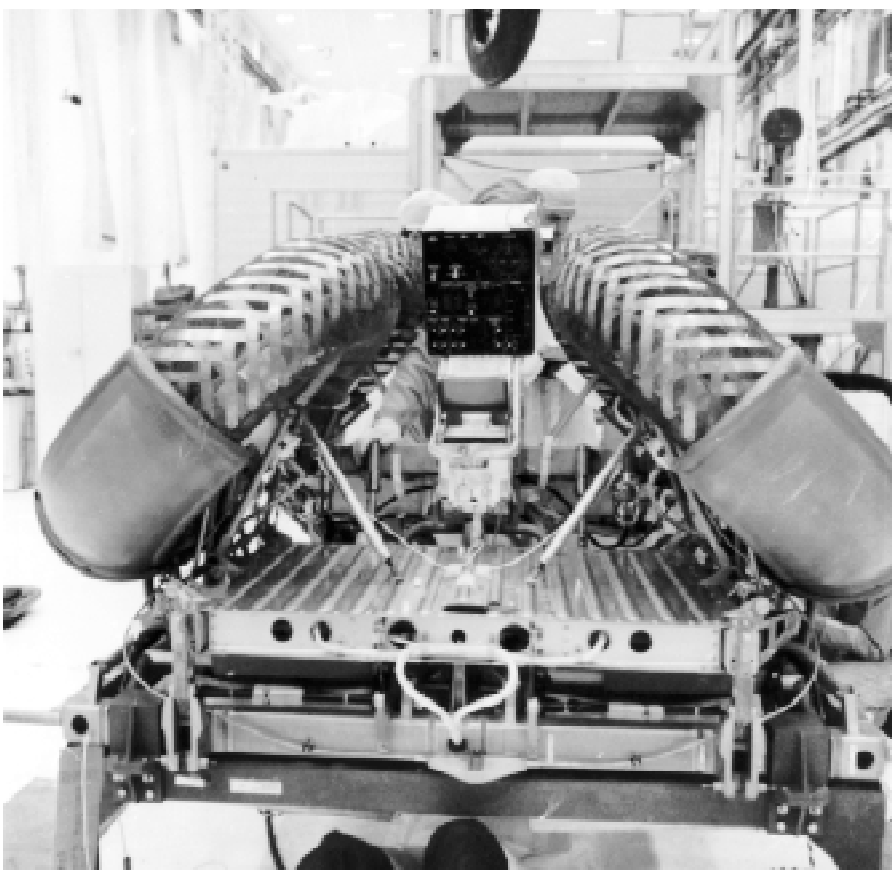
The astronauts executed commands by maneuvering the controller. To move forward, they pushed the controller forward. They varied their speed by the degree to which they advanced the controller. They traveled in reverse by depressing a switch on the controller and pulling the controller to the rear. They pulled back on the controller to set the brakes and turned by tilting the controller in the desired direction.

The upper part of the **control and display system** console was designed for navigating the lunar roving vehicle as described earlier. The lower part involved spacecraft monitoring and control. The various switches on the lower part consisted of power, steering, drive power and drive enabled. The switches allowed the astronauts to choose their source of power for these various functions. A power/temperature monitor provided the astronauts with data on the batteries and motors. It also told them how much electricity they had left measured in remaining ampere hours.

At the top of the console, a caution and warning indicator warned the astronauts if the batteries or drive motors were overheating. The crew could then isolate the fault and take corrective action.

This feature came directly from similar devices on other human-tended spacecraft.

Designers also gave careful consideration to the lunar roving vehicle's **deployment system**. The vehicle traveled to the moon in the descent stage of the lunar module, with wheels neatly folded against the chassis to save space. It weighed 460 pounds and could be folded up and stored like an intricate toy. As Apollo 15 astronaut Dave Scott remarked, "The volume into which it could be folded was one of its most significant features." Space limitations within the Apollo/Saturn meant the vehicle had to be folded into a 4-foot cubic space. However, it also had to be designed so that the astronauts could easily unfold it on the moon. When the lunar roving vehicle was fully deployed, it was the size of a large automobile." To accomplish this, engineers developed procedures that the astronauts relied on with the help of springs to manually unfold the vehicle so that its wheels would then lock into the deploy position.



Testing the wheel deployment of the lunar roving vehicle at Marshall Space Flight Center.

Lunar Roving Vehicle Test Units

To assure the performance of the three flight vehicles for Apollo 15, 16 and 17, eight nonflight units were built — just for testing. The eight test units included —

A **full-scale mockup** to make sure that the spacecraft was properly tailored to the needs of the astronauts.

A **mobility test unit** to help develop and verify the design for the motors, wheels, suspension, hand controller and drive control electronics.

A **lunar module unit** to determine the effects of the lunar roving vehicle's weight on stresses in the lunar module.

Two one-sixth weight units to test the deployment mechanism that would unfold and deploy the vehicle from the lunar module.

A normal **Earth-gravity unit** for astronaut training.

Seven astronauts inspect the lunar roving vehicle at Marshall Space Flight Center. Pictured from left to right are John Young, Eugene Cernan, Fred Haise, Charles Duke, Anthony England, Charles Fullerton and Donald Peterson.

A **vibration test unit** to ensure that the spacecraft structure could withstand the stresses that came with launch, space flight and lunar travel.

A **qualification test unit** to be subjected to environments simulating those on the moon. Most components of this unit were designed to be qualified almost four times the period of a lunar mission and at higher forces than were expected to be encountered during the mission.

Lunar Roving Vehicle Project Manager Saverio "Sonny" Morea briefing the media on the operation of the lunar roving vehicle.

Ground Testing

These vehicle-level tests were in addition to a comprehensive program of subsystem-level testing. This lower-tier testing was conducted as stringently as any item of Apollo hardware. The number of components manufactured for subsystems testing was equivalent to another whole vehicle.

The wheeled spacecraft had to undergo the same assurance program as any human-tended spacecraft. The development test program proved the design concepts, established manufacturing procedures and determined the best alternative design. Twenty-nine development tests were accomplished in a five-month period. They included chassis structural tests, traction-drive tests under thermal-vacuum conditions, gyro vibration tests and vehicle deployment tests.

The qualification test program required demonstrating that the components of the spacecraft would perform in an environment more severe than the vehicle experienced on the moon. This program included 32 major tests.

Acceptance testing was performed on each major component to demonstrate that it was acceptable for space use. Both qualification and acceptance testing activities involved tests on the component level as well as testing the total vehicle. Some 30 acceptance tests were scheduled for each flight vehicle.


The rear wheels and chassis are ready for operation during deployment tests at Boeing's Kent, Washington facility.

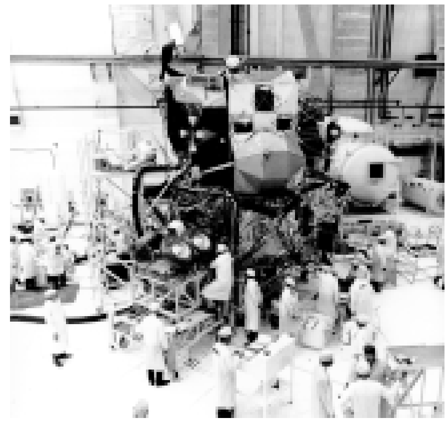
Schedule

Development of the lunar roving vehicle was accomplished on a difficult and demanding schedule. Just 17 months were allowed from contract go-ahead in late October 1969 to the scheduled delivery of the first human-rated flight vehicle at Kennedy Space Center on April 1, 1971. In that time, the vehicle had to be defined, designed, tested, manufactured, and qualified for its moon journey and operation. By comparison, the shortest development, manufacture and delivery schedule of previous manned space flight hardware took from three to four years.

To meet the deadline, a plan was established for systematically moving through each task and delivering the results into the next program phase already underway. Because various tasks had to be done in parallel, this approach did not allow for many wrong assumptions, nor much time for exploration of alternative design choices — and certainly little time to correct errors. Where difficulties were anticipated or encountered, alternate equipment or procedures were developed in concert with the primary effort. For example, both automatic and manual methods of vehicle deployment were developed, and a backup motor for the mobility subsystem was developed. Some minor changes were incorporated as the design evolved. The hand controller changed from a pistol grip to a T-design.

First Flight Lunar Roving Vehicle

Early in 1971, production and testing of the first flight lunar roving vehicle neared completion. Vibration tests were conducted with the vehicle in both the folded and unfolded modes to determine critical frequencies. Other acceptance tests checked and rechecked every facet of the vehicle.



Technicians at Kennedy Space Center, Florida check the fit of the lunar roving vehicle into the bay of the lunar module for the Apollo 15 mission.

Boeing delivered the first flight model to NASA on March 10, 1971, two weeks ahead of schedule. It had been less than 18 months since the inception of the lunar roving vehicle program, and only 13 months since the prime contract was awarded. After NASA accepted the vehicle, it was folded, covered and crated for shipment to the launch site. After it was delivered to the Kennedy Space Center, engineers unfolded the vehicle, checked it out again and conducted another crew station review.

The lunar roving vehicle was then folded for the final time and installed in its flight-position inside the lunar module of the Apollo 15 spacecraft several months before launch. The lunar roving vehicle received its final go while the rest of the Apollo hardware and the Saturn V launch vehicle underwent further checkouts.

Then the entire Saturn/Apollo vehicle was moved from the vehicle assembly building three and one half miles to the launch pad where it would undergo constant check and recheck right up until launch date.

Driving on the Moon

On July 26, 1971 NASA launched **Apollo 15** carrying the first lunar roving vehicle. After a three-day translunar coast the astronauts spotted the landing site, a potentially hazardous but scientifically interesting area of the moon.

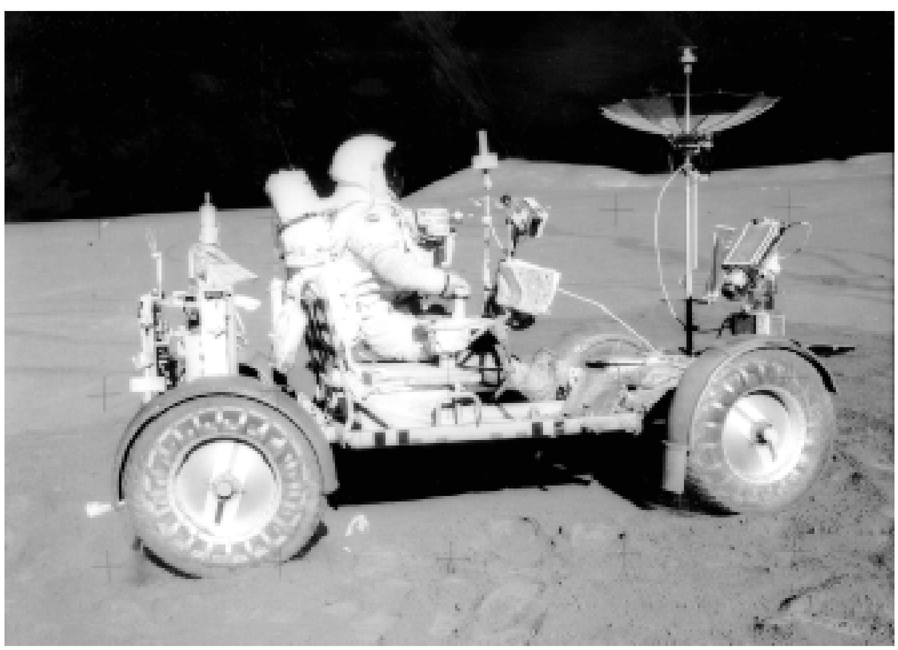
After landing, the astronauts set about deploying the lunar roving vehicle for their first drive over the lunar surface. “Looks like she’s coming down OK. We can pull it out a little bit Jim. That looks good,” Scott said. With minor difficulty, deployment and set up were successfully accomplished in 26 minutes.

During their 67-hour stay on the moon, astronauts Dave Scott and Jim Irwin used the lunar roving vehicle to make three separate motor trips to explore the rim of Hadley Rille, the edges of deep craters and the slopes of the Apennine Mountains. Meanwhile, Astronaut Al Worden conducted scientific experiments and observations from the orbiting command module.

During initial checkout, Scott discovered that the front steering mechanism was inoperable. However, the first lunar traverse, of a scheduled three proceeded satisfactorily using only rear-wheel steering.

On the first traverse, Scott said, “The rover handles quite well ... We’re moving at an average of about eight kilometers (five miles) per hour … The steering is quite responsive … It does quite well … There’s no accumulation of dust in the wire wheels.”

At each stop, the astronauts collected samples, took photographs and conducted scientific experiments and observations. On the return trip to the lunar module, Scott remarked, “This is a super way to travel … This is great … and it’s easy to drive … No problem at all.”



Astronaut Jim Irwin, Commander of Apollo 15 driving the lunar roving vehicle on the moon.

Before the second traverse, the astronauts succeeded in freeing the front steering mechanism. "You know what I bet you did last night Joe? You had some of those Marshall (Space Flight Center) guys come up here and fix it didn't you," Scott told Joe Allen in mission control.

"Does it work Dave?" mission control replied.

"Yes Sir. It's working my friend. Beautiful," Scott said.

On their second motor trip, Scott said they were climbing a slope of approximately eight degrees at 10 kilometers (6.2 miles) an hour. After another rest period in the lunar module, Scott and Irwin made a third trip that included three science stops before traveling back to the lunar module for liftoff and return home.

In overall performance, the lunar roving vehicle more than met its standards giving a total of three hours and three minutes of stop and go driving on the moon. The vehicle traveled a total of 25 kilometers, about 15 statute miles.

Scott and Irwin covered almost four times as much lunar terrain as the total covered by the crews of the Apollo 11, 12 and 14 missions before them.

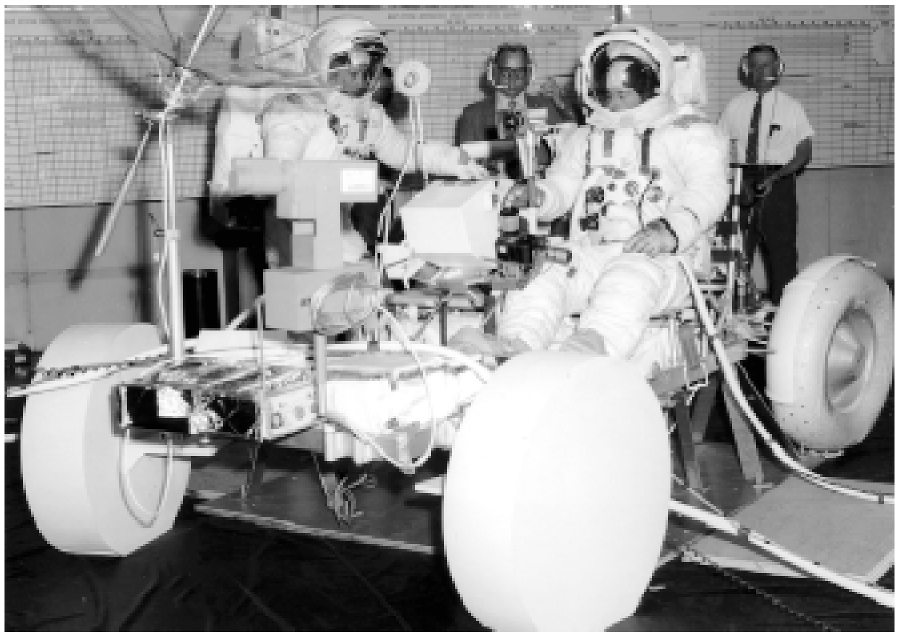
The lunar soil proved much less troublesome than expected with the lunar roving vehicle wheel treads leaving tracks only about half an inch deep. The suspension system worked extremely well keeping the vehicle very stable even on several rather sharp turns to avoid lunar obstacles.

Average speed was nine kilometers, about six miles per hour, more than one mile an hour faster than planned. The energy usage rate was much less than expected, only about 52 amp hours compared to an anticipated usage of 102. The vehicle still had about 80 kilometers of driving capability remaining when it was parked after the final traverse.

The navigation system performed well averaging missed distance of only one tenth of one kilometer upon return to the lunar module after each traverse. All in all, the lunar roving vehicle proved to be in the words of Astronaut Scott "about as optimum as you can build."

After almost 67 hours on the moon, Scott and Irwin re-entered the lunar module with their collection of scientific samples. As they lifted off in the ascent stage, the remote controlled television camera left behind on the lunar roving vehicle photographed their departure.

On April 21, 22 and 23, **Apollo 16** astronauts John Young and Charles Duke explored the lunar surface using a second lunar roving vehicle. As on Apollo 15, using the lunar roving vehicle multiplied the amount of information the moon explorers gathered by a factor of at least three.



Apollo 16 astronauts Charles Duke (left) and John Young practice using the controls of the lunar roving vehicle at Marshall Space Flight Center.

Young reported that the area was far more rugged than expected. He estimated that without the lunar roving vehicle for transportation he and Duke would not have accomplished more than five percent of their assignment.

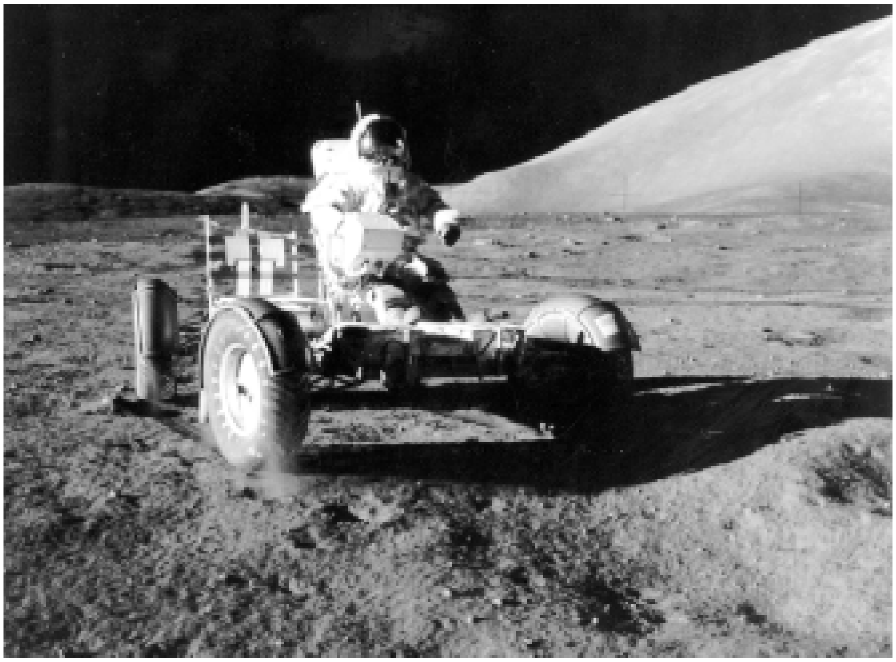
They gathered 213 pounds of geologic samples for return to Earth. The samples included moon rocks of a different type than ever seen before and better data than any earlier mission.

On the first traverse, the lunar roving vehicle traveled 4.2 kilometers or 2.6 miles. On the second, it traveled 11.5 kilometers or 7.1 miles. On the third, the astronauts logged 11.4 kilometers or 7.06 miles. The astronauts traveled a total of three hours and seventeen minutes.

During the third excursion, Young and Duke reported a "new lunar speed record" when the rover hit 17 kilometers per hour, or 10.5 mph while driving down hill on their return trip to the lunar module. They called the vehicle's handling characteristics excellent.

Apollo 17 astronauts Eugene Cernan and Harrison Schmitt drove the lunar roving vehicle 35 kilometers or 21.7 miles during their three excursions — more than it had been driven on either of the two previous missions.

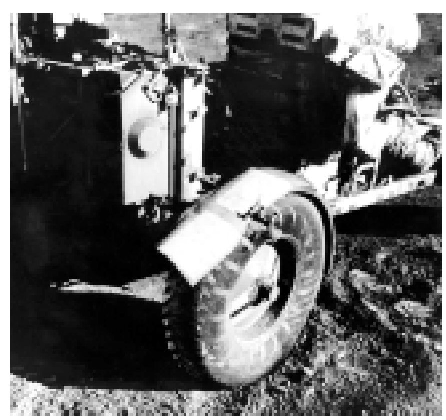
Cernan was also credited with a speed record of about 18 kilometers per hour. The lunar roving vehicle on Apollo 17 also made it possible for the crew to gather 112.2 kilograms or 249.3 pounds



Apollo 17 Commander Gene Cernan driving the lunar roving vehicle on the moon.

of lunar samples, more than collected on any previous exploration. In addition, the astronauts took more than 2,100 photographs on the lunar surface during their excursions, which totaled 22 hours and four minutes, also a record.

A close-up view of the repaired right rear fender of Apollo 17 Commander Gene Cernan's lunar roving vehicle on the moon.



Before their first excursion, Cernan accidentally hit the lunar roving vehicle's right rear fender with a hammer and knocked off the fender extension. This allowed lunar dust to be thrown on the astronauts and cargo during their first outing. However, Cernan and Schmitt later improvised a fender extension using leftover plastic-covered maps and lamp clamps. The repair required only nine minutes. The crew called the repair a good fix.

"This is quite a machine, I tell you," Cernan reported to Mission Control.

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