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Chapter 19

The Lunar Roving Vehicle—A Legacy of Lunar Surface Exploration*

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Abstract

The year 2012 marks the 40th anniversary of a significant event in the history of manned spaceflight: Apollo 17, which was the last of the Apollo missions and the most recent mission to carry man beyond the orbit of Earth. The use of the Lunar Roving Vehicle, or LRV, was one of the primary characteristics of the mission, as it had been on the two previous Apollo missions. The main purpose of the LRV was to transport the astronauts, which saved time, oxygen, and the astronauts' energy. The LRV also had benefits as far as the geological prospects of the mission, as the astronauts of Apollo 17 were able to return more than 100 kilograms of rock to the Lunar Module using the LRV. The need for a lunar surface vehicle for the Apollo missions was recognized as early as 1952, when Wernher von Braun, the mastermind of the Saturn rockets, addressed the issue in *Collier's Weekly* magazine. At this point, the concept was to have three 10-ton tractor trailers hauling equipment and rock samples around the lunar surface. Twelve years later, von Braun gave an interview in the February 1964 issue of *Popular Science*, stating, more realistically, that a "moon jeep" with an open platform would be used for short-distance travel. By this time investigations of

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lunar mobility were already taking place at Marshall Space Flight Center (MSFC) in Huntsville, Alabama. It was initially thought that a lunar mission would utilize two boosters, one for the astronauts and one for equipment. This caused many years of lunar vehicle development to become invalid, since budget cuts ultimately made it impossible to have dual boosters for a single mission and thus cut the mass budget in half also. The contract for the final LRV was given to Boeing in 1969. Boeing would produce the chassis and electronics, as well as perform the assembly and testing. General Motors was given a subcontract to produce the wheels, suspension, and motors. Three LRVs were manufactured, one each for Apollo 15, 16, and 17. To this day, the Lunar Roving Vehicle remains the only manned surface vehicle to have ever operated on the lunar surface. The anniversary of Apollo 17 calls for an historical overview of the Lunar Roving Vehicle, and an exploration of its technical characteristics.

History

Beginnings, Pre-1950

The Apollo Lunar Roving Vehicle (LRV) is one of humanity's greatest accomplishments of locomotion, but it is not without humble beginnings. The concept of a lunar surface vehicle predates the Apollo missions by almost three-quarters of a century. Although numerous late-19th and early-20th century authors wrote about manned trips to the Moon, few make mention of a lunar surface vehicle. In his 1903 novel *On the Silver Globe*, Polish writer Jerzy Żuławski tells the story of a team of scientists that traverse to the far side of the Moon using a wheeled vehicle (Figure 19–1).[1] Russian astronautics pioneer Konstantin Tsiolkovsky wrote about a lunar lander that also acted as a roving vehicle and return vehicle in his 1920 novel *Outside the Earth*.[2] He proposed that the four-wheeled vehicle have a pressurized cabin and temperature control system.

The Arrival of the Space Age, 1950–1959

With the coming of the Space Age, the idea was to be revisited from a different point of view. Dr. Wernher von Braun wrote on the topic of lunar surface exploration in the well-known "Man Will Conquer Space Soon!" series of *Collier's Weekly* magazines ranging from 1952 to 1954. Von Braun, along with Fred Whipple, Willy Ley, Joseph Kaplan, and Heinz Haber discussed the feasibility of topics such as manned space travel, lunar colonization, space stations, and trips to Mars. In the 25 October 1952 issue,[3] von Braun and Whipple write about a trip to the lunar surface involving roving "tractors" which pull trailers with supplies.

They envisioned a ten-day stay on the Moon, which included a 250-mile traverse to different craters in the region. Ten years later, *Popular Science* magazine published an article proposing a wide variety of lunar surface vehicles in the March 1962 issue.[4] Among the many concepts for locomotion were rovers with wheels, legs, skis, augers, and giant spheres which rolled over obstacles. Many of these concept designs included solar panels, cameras, drills for soil sampling, and antennas. This article was dedicated to unmanned roving vehicles, and was followed by two more in 1963[5] and 1964.[6] They each focus on remotely controlled prototypes of lunar rovers made by Grumman and General Motors. *Popular Science* ran another article on the same subject in the February 1964 issue,[7] this time concerning manned lunar exploration. The article was written by von Braun. By 1964 von Braun's stance on lunar surface exploration had changed drastically. He envisioned two different roving vehicles, one for traveling short distances (Figure 19–2) and one for longer traverses. Concerning a short distance vehicle, von Braun writes "[f]or short-distance travel a nonpressurized moon jeep may suffice. The astronauts would hop onto its open platform and depend for protection upon their pressurized space suits, while life support and communication would be provided by their back packs."

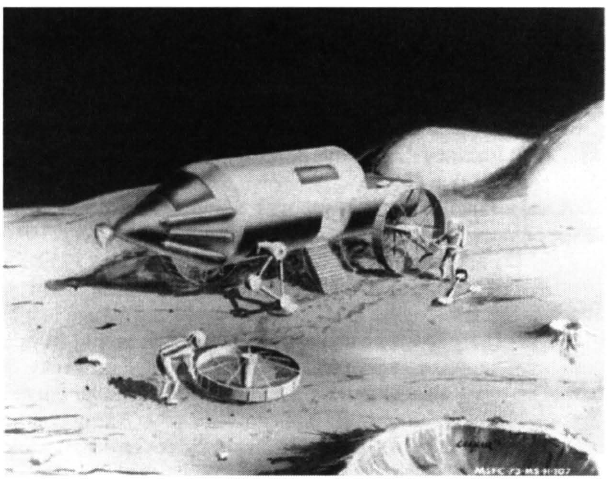

Figure 19–1: Jerzy Zulawski's concept of a lunar rover from the 1903 novel *On the Silver Globe*. Credit: NASA MSFC.

Furthermore, the proposed long distance vehicle was also to have research equipment and an airlock. In the article, von Braun also discusses several possibilities for the wheels. He argues that wheels would be preferred to tracks because of energy concerns. He believed that the additional mass and power used to move the tracks during a traverse did not outweigh the benefits they ensued.

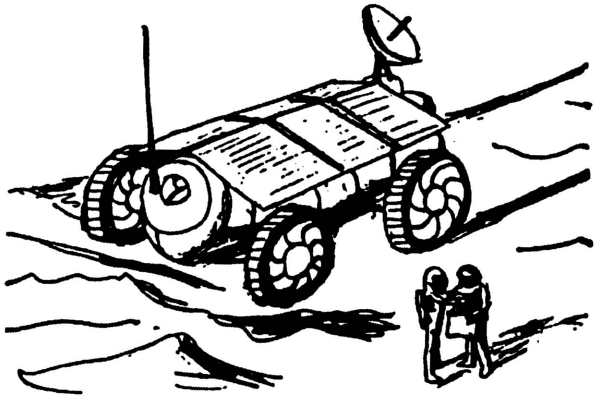

Figure 19–2: Wernher von Braun's concept of a long distance roving vehicle.

Before This Decade Is Out, 1959–1969

Initial studies for a lunar rover began with Project Horizon in 1959, funded by the U.S. Army Ordnance Missile Command in Huntsville, Alabama. The project turned out an LRV concept which was very assumptive of the capabilities of its launch vehicle. The rover was to have a mass of almost 1,000 kg, and house a life support system capable of sustaining a team of astronauts for months during a traverse of several hundred kilometers.

With the creation of NASA in 1958, the task of investigating lunar mobility was passed to the industry. Among the companies were Grumman, Boeing, Bendix, Lockheed, General Motors, Brown Engineering, and Bell Aerospace.

Figure 19–3: MOLAB (Mobile Laboratory) concept by Bendix and General Motors.

Unfortunately, most of the studies performed during the years leading up to the Apollo program were based on the assumption that there would be two launch vehicles dedicated to each mission; one for carrying the astronauts and one for carrying equipment, vehicles, supplies, and a spacecraft for returning to Earth. Without a doubt, having a second launch vehicle would have opened opportunity for an extended stay on the Moon. Sadly, budget cuts ultimately made it impossible to devote two rockets to a single mission.

Among the concepts proposed following the industry's initial involvement in conceptualizing the LRV were large wheeled vehicles with pressurized cabins and trailers for hauling supplies, smaller vehicles with tracks, and vehicles with large inflatable wheels. In the latter part of the 1960s, General Motors proposed an LRV concept that would be sent to the Moon in the same launch vehicle as the astronauts. It is interesting to note that the proposed LRV would be controllable from Earth, as well as manually driven by the astronauts. This would allow additional exploration to be performed after the astronauts left the Moon.

A concept investigated by Bell Aerosystems up through 1969 was a "Jet Belt," a backpack that included two small jet engines. The fuel they used was kerosene. The jet belt had a range of several miles. The concept was eventually shot down by NASA because of safety concerns.

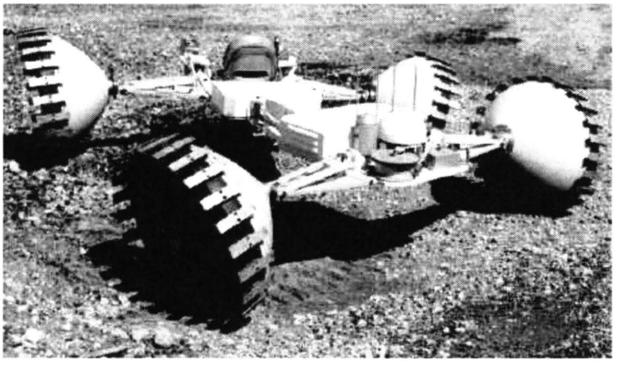

Figure 19–4: Lunar Roving Vehicle concept produced by Grumman.

In June 1969, NASA established the Lunar Roving Vehicle Project Office. Saverio Morea, a rocket engine specialist who had managed the F-1 engine, was named project manager. In July 1969, the newly formed office called for proposals from the industry for the final LRV. Detailed requirements were set down, all assuming the use of only one launch vehicle per mission, and delivery dates were decided. The first flight LRV was to be delivered by April 1971. By October 1969, four companies had responded to the call for proposal: Bendix, Chrysler, Boeing, and Grumman.

One Small Step for Man, 1969–1972

Boeing was awarded the primary contract for the Lunar Roving Vehicle on 28 October 1969, just months after the first Moon landing, and less than 17 months before the first flight unit was to be delivered. Development and production happened at Marshall Space Flight Center and at Boeing's facilities in Kent, Washington. The primary subcontractor was General Motors, who worked out of California. The estimated cost of the project was $18,000,000.

Technical Characteristics

The technical characteristics of the LRV can be separated into eight subsystems: mobility, power, navigation, communications, thermal protection, crew station, control and display, and stowage and deployment.

Mobility

The LRV's alloy 2024 aluminum chassis consisted of three sections. The front section was for housing the batteries, navigational electronics, and the TV camera, which could be controlled from Earth. The middle section supported the weight of the astronauts and the control and display console, as well as the seating. The rear section was for storing instrumentation, tools, and samples collected by the astronauts during their traverses.

The LRV wheels (Figure 19–5) were made of an aluminum hub wrapped with woven zinc-coated steel "piano wire." Chevron patterned rivets made of titanium were attached to the steel wire for traction. The traction drive for each wheel was attached directly to the hub. However, there was a procedure for decoupling the wheel from the traction drive if the need for it arose. A brake assembly was mounted onto each wheel.

The LRV had powered steering. Both the back and front wheels were able to turn, doubling the turn radius. However, two of the flight lunar rovers experienced problems with the rear steering. The LRV had a turn radius small enough that it could, as Morea said, "turn within its own length."

The Lunar Roving Vehicle had a suspension system that consisted of shock absorbers and torsion bars connecting the hubs the chassis.

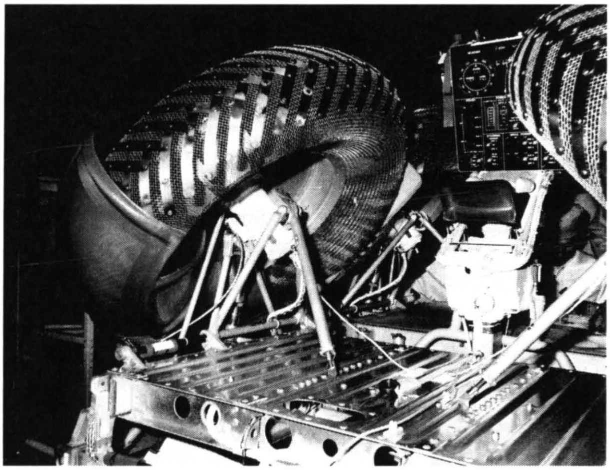

Figure 19–5: The collapsed LRV wheels.

Power

The LRV was powered by two silver-zinc potassium hydroxide batteries. Each 36-volt battery was rated for 121 amp-hours, and had 23 individual cells in it. The cell wall casings were made out of magnesium. The power system operated by drawing equal current from the batteries at all times, which prevented overheating. The battery capacity and temperature were displayed on the control console, and were carefully monitored by the astronauts. Most of the subsystems of the LRV were dependent upon electricity, including the traction drive, navigation system, communications system, control console, power steering, and the TV camera. The batteries were situated on the front section of the LRV chassis, near the astronauts' feet. Circuit breakers were incorporated into the system to prevent overloading.

Navigation

The LRV navigation subsystem provided information to the astronauts that would assist them in finding their way back to the Lunar Module. The navigational data displayed on the control console included range, speed, heading,* and distance traveled. The navigation subsystem gained this information using three different components: a directional gyro, a "sun-shadow" device, and odometers. Thus, every component of the navigation system was relative to the starting position; only the sun-shadow device was absolute. Each instrument passed data to an

* Heading was displayed as both an analog and digital value, as well as heading with reference to the Sun.

imbedded signal processing unit (computer). The directional gyro worked by establishing an inertial platform with a rotating disk, which could detect changes in the vehicle's north-south orientation. The sun-shadow device was used to re-establish a reference direction for the directional gyro.* The vehicle had an odometer on each traction drive. The processing unit averaged the measurements from each odometer to prevent error pileup from wheel slippage. North-south position with respect to the Lunar Module could be calculated from the measurements from each set of instruments. Since the odometers provided the distance traveled, and the gyro provided the directional heading, the computer could log the vehicle's path as it traveled. The navigation system was not without flaws, however. The odometers used on each traction drive were not able to determine the difference between forward and backward motion. Thus, whenever the astronauts drove the LRV in reverse the computer logged it as forward motion. During the design phase it was determined that the cost, mass, and complexity of introducing a solution to the problem did not outweigh correcting the small amount of error that came about as the result of driving the LRV in reverse.

Communications

The communications subsystem consisted of the television camera, radio equipment, and high and low gain antennas. Each comms system was not stowed with the rest of the LRV. The astronauts manually installed the antennas and camera after deployment. An auxiliary power outlet on the back of the control and display console was used to provide power to the communications equipment.

Thermal Control

The surface of the Moon can reach 100°C during the lunar day. For this reason a rigorous heat rejection system was required for the LRV. The batteries were the most important component that could not exceed a certain temperature. Heat sinks were used to reject heat to space from the battery casings. Most parts of the LRV were given a special thermal surface finish.

Crew Station

The Crew Station subsystem of the LRV consisted of the seating and the hand controller. The seats were made from aluminum tubing with strips of nylon

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* This same procedure is used in modern day aviation. When an aircraft's compass becomes unreliable due to banking, the Earth's magnetic field, etc., the pilot will resort to a directional gyro.

with Velcro* as the backrest. They were unfolded after deploying the LRV from the Lunar Module. There were foot rests at the astronauts' feet, which were also unfoldable.

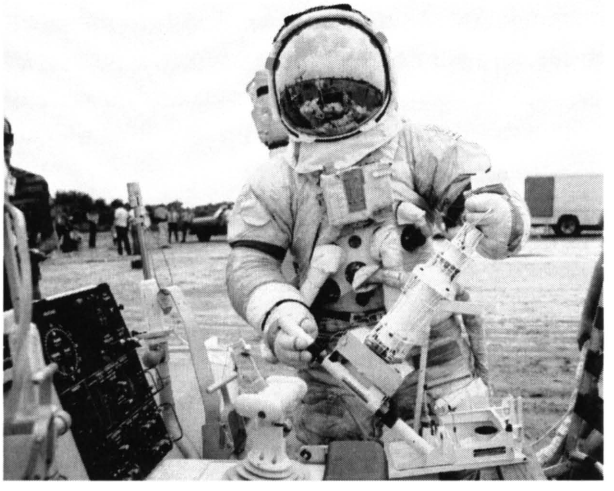

Figure 19–6: Apollo 17 astronaut Gene Cernan working around an evaluation LRV. The 'T' shaped hand control and display console can be seen on the lower left.

Two toe holds were installed after deployment to assist the astronauts when getting into the LRV. The toeholds were added during the testing phase after the LRV was flown on a parabolic arc in a KC-135 to simulate 1/6 gravity.

The hand controller (Figure 19–6) for driving the LRV was situated between the two seats. It was shaped like a 'T' so that the driver could easily grip it with large astronaut gloved on. The hand controller allowed several functions within a single design. The driver could accelerate, steer, brake, drive in reverse, and apply the parking brake to the LRV with just the hand controller. An arm rest was situated behind the hand controller.

Control and Display

The control and display panel (Figure 19–7) of the LRV was located between the astronauts' seats in front of the hand controller. It was divided into two sections: an upper portion for navigational instrumentation, and a lower portion for monitoring and control of the batteries. The display console was painted with Promethium 147 to illuminate the switches and panels, since the astronauts

* The first large scale application of Velcro was during the Apollo program. Other industries caught on soon afterward.

would sometimes drive through overshadowed areas, and also overshadow it themselves. The instrumentation panel consisted of indicators for attitude, bearing, heading, range, distance, speed, and sun-shadow. The attitude indicator consisted of a sphere suspended in a fluid (as in an aircraft) that would tell the astronauts whether the LRV was on an incline. The information obtained from the attitude indicator was used to correct the sun-shadow device, which was, respectively, used to prevent the gyro from giving false measurements due to error pileup. It seems like the gyro was not the only place that there was potential error pileup.

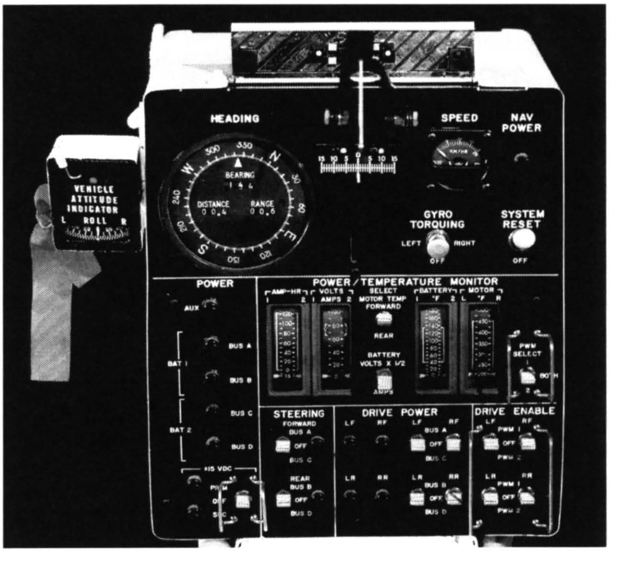

Figure 19–7: The control console of the LRV.

The heading indicator displayed the direction the LRV was pointed with respect to north. The bearing indicator showed the direction of the Lunar Module. This information was provided from the signal processing unit, which calculated the bearing, distance, range, etc. from the odometers and the directional gyro. The speed indicator displayed the speed of the LRV on a scale of 0–20 km/h. The data for speed was obtained from only the right rear odometer. A system reset switch on the upper right side of the control panel allowed the astronauts to reset the accumulative (e.g. distance, range) indicators to zero. The lower part of the console displayed the LRV battery power, temperature and had controls for steering, drive power, and drive enable. The battery power section housed the circuit breakers to prevent the system from overloading, and a power outlet for the communications relay unit. The power and temperature section displayed the temperature of the battery and the traction drives. The astronauts had to switch the display to be able to read the temperature of each traction drive. The voltage of each battery and the current being drawn was also displayed. A battery capacity indicator showed the remaining energy available in amp-hours. The steering and drive power section housed circuit breakers for the steering and traction drive motors. The drive enable section housed a switch for selecting which pulse width modulator (motor speed control signal) to use. Lastly, a warning flag was included on the left side of the display panel. If a circuit breaker blew or the batteries or drive motors were overheating the flag would pop out to alert the astronauts.

Stowage and Deployment

The Lunar Roving Vehicle was stowed in the descent stage of the Lunar Module. It was released and unfolded when the astronauts arrived on the lunar surface. Astronaut David Scott remarked, "the volume into which it could be folded was one of its most significant features."

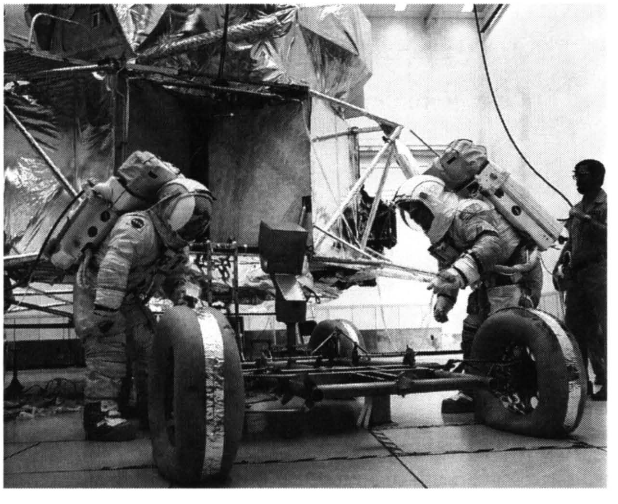

Figure 19–8: Astronauts Cernan and Duke participate in LRV deployment training at Cape Canaveral.

Without a doubt, the large LRV could be folded into an extremely small area inside the Lunar Module. The LRV was deployed by the team of astronauts by pulling a sequence of cords (Figure 19–8). Most of the unfoldable parts of the LRV were spring loaded, so that they automatically snapped into place when the astronauts unloaded it. The seats and foot rests had to be manually unfolded.

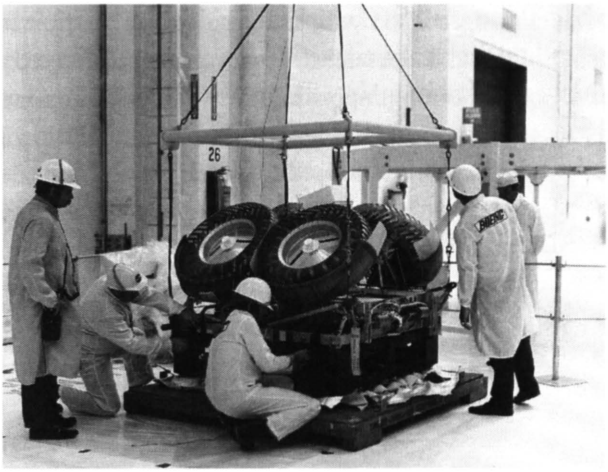

Figure 19–9: A flight LRV being folded at Kennedy Space Center.

Lunar Operations

Apollo 15

The Lunar Roving Vehicle made its operational debut during Apollo 15, which was originally designated as a type H mission, meaning that it would only consist of two days on the Moon. With the Apollo program being cut short, however, it was decided that the three-day long type J mission would replace the previous planning, and the first LRV would be launched with Apollo 15. The launch took place on 26 July 1971.

When the Apollo Lunar Module *Falcon* touched down on the Moon, astronauts David Scott and James Irwin rested before their first day of extra vehicular activity (EVA). Afterward, they stepped out of the LM and became the seventh and eighth humans, respectively, to walk on the Moon. One of their first tasks was to unload the LRV. There was some trouble releasing it because the LM had landed on an incline. On 31 July 1971, 13:52 GMT, its wheels touched the lunar soil for the first time. The astronauts had three stations to travel to on their first EVA, but the third was canceled due to time constraints.

At the first station, which was located at a curved point on Hadely Rille, their tasks included soil sampling, panoramic photography, and aligning the LRV's high-gain antenna with Earth so that mission control could move the camera. They spent 12 minutes at station one. They next departed for station two, which was located 500 meters south of the first station. The main feature they were concerned with was a 1.5-meter wide boulder. They sampled the soil around and underneath the boulder. They spent almost an hour at station two.

After a 30-minute traverse back to the LM, they unloaded the LRV and did not use it again until the next EVA.

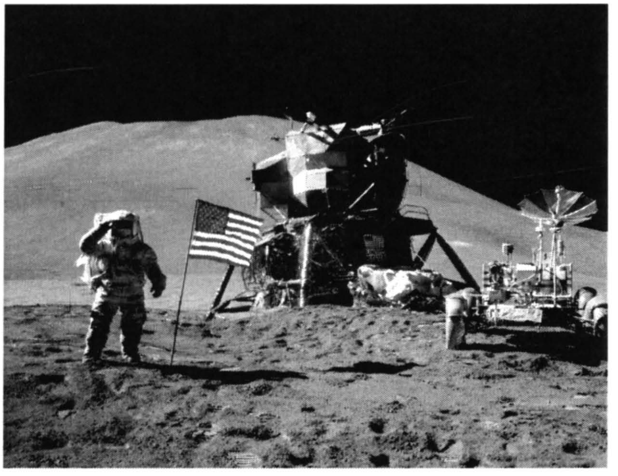

Figure 19–10: A well-known photo of Apollo 15 LM pilot Jim Irwin saluting next to old glory. It is easy to tell that the LM (*Falcon*) is on an incline, which made it difficult to unload the Lunar Roving Vehicle.

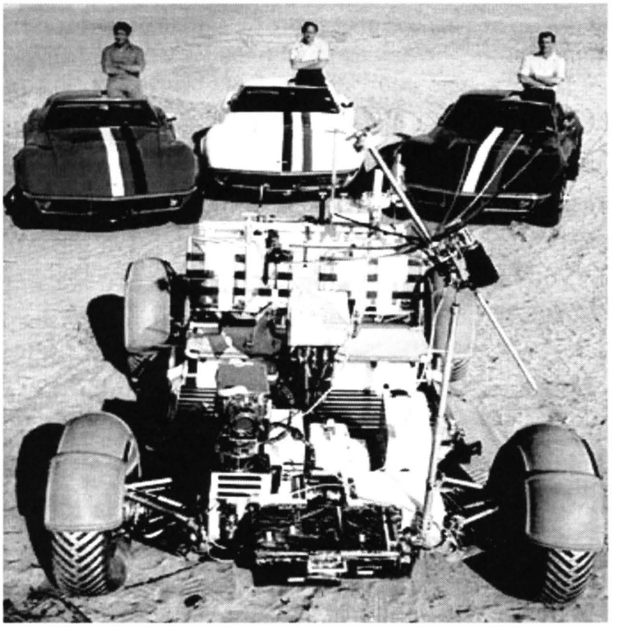

Figure 19–11: The Apollo 15 astronauts pose in cleverly colored Corvettes behind the LRV.

The astronauts visited five stations using the LRV on the second EVA. The first two stations were canceled due to time constraints. The first stop (station six) was at a 3-meter wide crater. They gathered core samples and took photography. Scott and Irwin moved to a larger crater nearby (station six-a), and took a second core sample from inside of it. The next station was about 200 meters away at a large boulder.

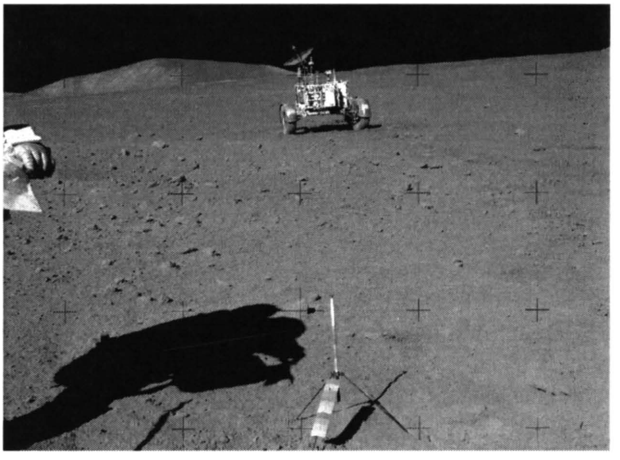

Figure 19–12: The shadow of Apollo 15 Commander David Scott taking samples during the first EVA with the LRV in the background.

Since the LRV was parked on an incline, Irwin stayed with the vehicle to ensure that it didn't roll away. The next stop was at "Spur" crater (Figure 19–13), which was 100 meters across and 20 meters deep. After working for about 15 minutes, Scott noticed a rock on the rim of the crater that glinted in the Sun. Both of the astronauts had been trained to recognize rocks that had significant geological value, and Scott immediately recognized that this rock was special. Upon seeing the rock, Scott exclaimed, "guess what we just found! I think we found what we came for!" Without doubt, the rock would eventually become one of the most famous discoveries of the Apollo program. Composed of anorthosite, the rock proved to be one of the oldest found during Apollo. It is believed that the rock was part of the Moon's primordial crust. They returned to the Lunar Module, and planted the United States flag in the lunar soil (Figure 19–10).

The third EVA suffered activity cuts due to time constraints, just as the previous one had. The first station they visited included taking a core sample. Scott discovered that the vice on the LRV had been installed backwards. This aggravated him even more than having stations canceled. Concerning the core sample mission control had decided was more important than the station at

Hadely Rille, Scott remarked, "How many hours do you want to spend on this drill, Joe?" By this time the TV camera on the LRV began to have problems. Mission control was unable to point it up or down, so the astronauts had to manually point it.

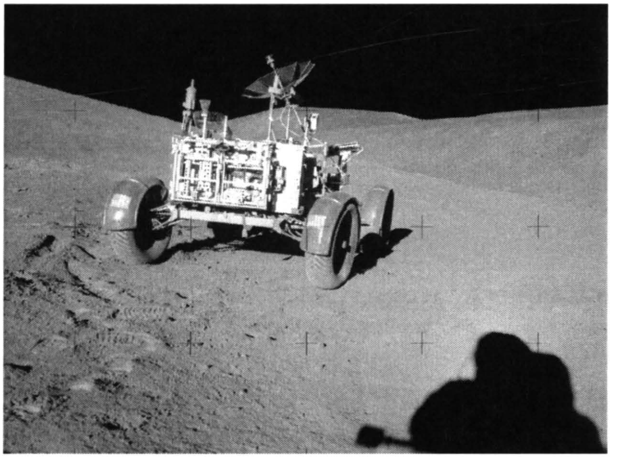

Figure 19–13: A rear view of the LRV during EVA-2. The photo was taken at the crater where the Genesis Rock was found. Hadely Rille can be seen in the background.

After returning to the Lunar Module, Scott performed his famous feather and hammer experiment before the end of the EVA. The experiment was meant to jokingly test Galileo's theory of falling objects. Scott said, "I guess one of the reasons we got here today was because of a gentleman named Galileo, a long time ago, who made a rather significant discovery about falling objects in gravity fields." Scott dropped a feather and hammer from waist level at the same time, and, since the Moon has no atmosphere to cause air resistance, they hit the ground at the same time. Scott drove the rover to a point about 100 meters from the Lunar Module (Figure 19–14), so that mission control could observe the lift-off with the camera.* Scott and Irwin had driven the LRV 27.75 kilometers for a total travel time of 3 hours and 2 minutes. The max range they traveled from the LRV was 5 kilometers.

* However, since mission control was unable to move the camera, they were not able to track the ascent.

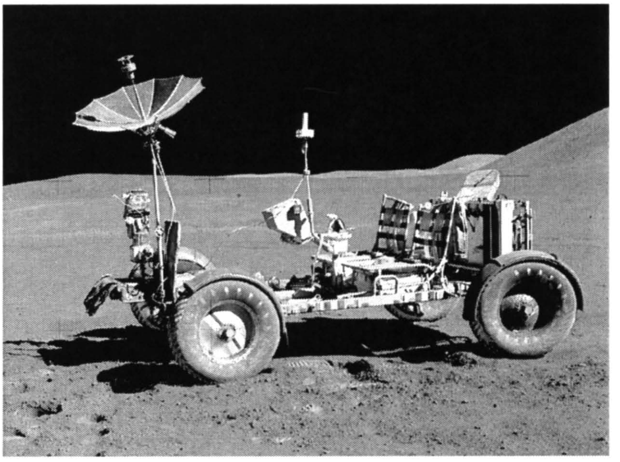

Figure 19–14: The final resting place of the Apollo 15 LRV.

Apollo 16

Astronauts John Young, Charles Duke, and Thomas Mattingly launched from Cape Canaveral on Apollo 16 on 16 April 1972. They landed in a region known as the Descartes Highlands.

The first activity of EVA-1 was to unload the LRV. Unlike most of the other Apollo missions, the U.S. flag was planted during the first EVA on Apollo 16. Before the astronauts departed for the first station, they unloaded the lunar surface experiments package and configured each instrument. After the LRV was configured for the first traverse, Young discovered that the rear steering was not working. It's odd that this happened since the LRV front steering was not functional during the first EVA of Apollo 15. The LRV was first used to mark a straight line for a geophone cable. The tire tracks made it easier for the astronauts to lay down the wire. Doing this was Young's idea, and had not been previously planned. The astronauts visited three stations using the LRV during the first EVA. Back at the Lunar Module (*Orion*), they worked with the previously deployed instrumentation, gathered samples, took photography, and prepared to close out the EVA. Young drove the LRV around the Lunar Module as a demonstration while Duke filmed. They then reentered the cabin. The second EVA consisted of traveling to six different stations in the Descartes area (one station was canceled to give the astronauts more time). The first stop was at a point called Stone Mountain, which had an interesting array of five craters on top of it. After getting off of the LRV, Young decided that it was not parked in a place that made it easy for them to load samples and use the tools.

Figure 19–15: Apollo 16 Astronauts Young and Duke train on a rover mock-up in Taos, New Mexico.

Instead of taking time to sit down and drive it to a new location, the two astronauts picked it up and walked it to a better spot. The mass of the LRV was 210 kg (463 lb), but with the reduced gravity on the Moon, its apparent weight to the astronauts was 35 kg (77.2 lb).

Figure 19–16: The Apollo 16 LM (*Orion*) and LRV at the beginning of EVA-2. Astronaut Young is in the background.

Young and Duke gathered samples and took panoramic photography of the area. The LRV took quite a bit of damage during the second EVA. Two instruments on the control and display panel broke off during the day: the attitude indicator and the sun-shadow device. Neither of the instruments were critical to the mission. They were able to improvise the sun-shadow device by replacing the dial with their long-handled scoop.

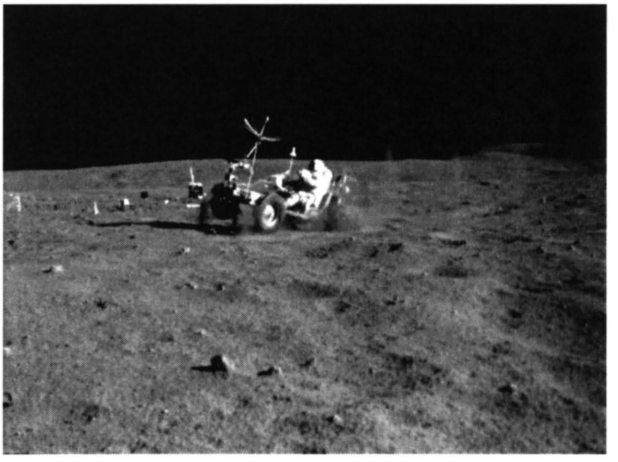

Figure 19–17: Astronaut Young driving the LRV for a demonstration film. The drive became known as the "Grand Prix," not least to the fact that front end of the LRV went airborne.

Young accidentally bumped against the right rear fender of the LRV, and part of the dust guard was damaged. This caused dust to be thrown in air as they drove, and caused the battery temperature to increase. To make matters worse, the LRV suddenly lost power on the way back to the Lunar Module. Young and Duke were able to get it running again by changing some of the switch settings, but the navigation system was now ineffective. However, they were able to find their way to the LM without any trouble. The EVA lasted nearly seven and a half hours, which broke the record Apollo 15 had set.

The last EVA consisted of three stations. Probably the most well known stop of Apollo 16 was made during EVA-3, at a site called House Rock, which was reportedly the size of a small house. The rover TV camera came in handy at this site, as it always did, in filming both astronauts as they worked. The camera was controlled by mission control on Earth. The film taken at house rock is particularly marvelous. The EVA was cut short to adjust the two astronauts sleep schedules, since the lunar landing had occurred a few hours behind schedule. They collected 94 kilograms of samples during their three day stay on the Moon, thanks to the LRV. In total, they drove 26.55 kilometers, and had a max range of 4.5 kilometers from the LM.

Apollo 17

The last of the eleven manned Apollo missions lifted off during the middle of the night on 7 December 1972, with astronauts Gene Cernan, Harrison Schmitt, and Ronald Evans. Their target landing area was at Taurus-Littrow, a lunar valley. The sequence of events following the astronauts' exit from the Lunar Module (*Challenger*) on the first EVA was very similar to the previous two Apollo missions. The crew's first task was to unload the LRV and plant the U.S. flag in the soil near the LM. While maneuvering around the rover, Cernan caught his hammer on a fender and broke it off. The astronauts attempted to fix it by taping it on, but tape was not able to adhere very well with the lunar dust being thrown against it, and it fell off after a while.

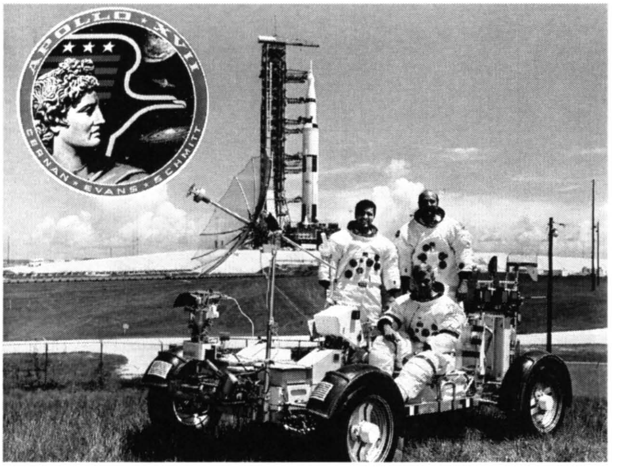

Figure 19–18: The Apollo 17 astronauts pose on an evaluation LRV prior to launch.

The astronauts would try to fix it again during the next EVA. Cernan used the rover to do the same maneuver that John Young had done on Apollo 16. He drove in a straight line to form an "X" with the rover tracks to make it easier for them to lay out the Apollo Lunar Surface Experiments Package.

During the second EVA the astronauts attempted to fix the rover's fender again. During the night, mission control had designed an alternate fender using four cronopaque maps and duct tape (Figure 19–19). The design held, and it prevented dust from being thrown all over the astronauts and the LRV, which had caused the battery temperature to rise during Apollo 16.

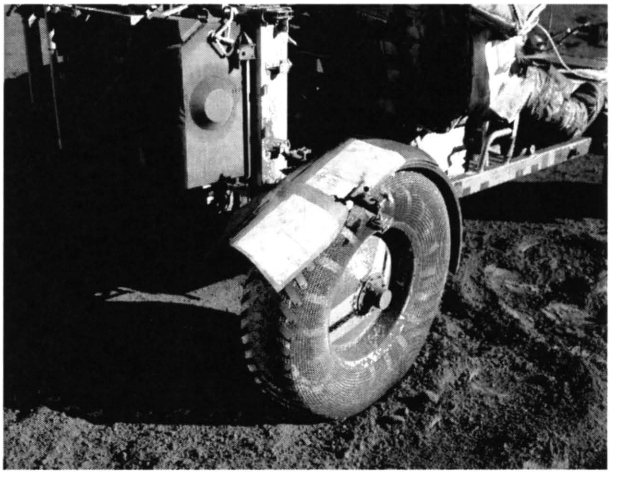

Figure 19–19: The makeshift fender the Apollo 17 astronauts fashioned out of maps and duct tape after the original fender broke off.

Figure 19–20: Gene Cernan posing with the LRV during Apollo 17.

After the third EVA, before they climbed back into the cabin they drove the rover to a safe distance from the Lunar Module to allow mission control to film the ascent. Because of the delay in radio transmissions from Earth to the Moon, attempts to film the Lunar Module from the LRV as it ascended had been unsuccessful on Apollo 15 and Apollo 16 (the Apollo 16 rover TV camera was unable to be moved from Earth by the third EVA). On mission control's last attempt, they were able to track the Lunar Module as it ascended. The Apollo 17 astronauts drove the LRV a total of 35.9 kilometers, with the max range from the LM 7.6 kilometers.

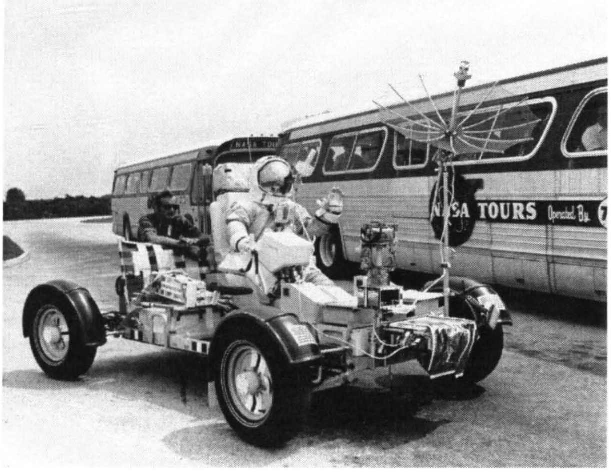

Figure 19–21: Gene Cernan waves to tourists at Kennedy Space Center prior to the launch of Apollo 17.

Legacy

LRV Exhibits

Since the three flight Lunar Roving Vehicles remain on the lunar surface, only replicas, training units, and qualification units are on display today. Testing units are on display at The National Air and Space Museum in Washington, DC; The Davidson Center for Space Exploration in Huntsville, Alabama; Johnson Space Center in Houston, Texas; and Kennedy Space Center in Cape Canaveral, Florida. Replicas of the LRV are on display at The National Museum of Naval Aviation in Pensacola, Florida; The Evergreen Aviation and Space Museum in McMinnville, Oregon; The Kansas Cosmosphere and Space Center in Hutchinson, Kansas; and Walt Disney World in Orlando, Florida.

Planned Lunar Rovers

Six national space agencies and two private organizations have declared that they intended to put a human on the Moon within the near future. Most of these programs have anticipated launch dates of 2025 or later. Unmanned missions in the near future include China's Chang'e 3, India's Chandrayaan-2, Russia's Luna-Glob 1, and the United States' LADEE.

Google Lunar X Prize

Announced by the X Prize foundation in 2007, the Google Lunar X Prize seeks out private organizations willing to design, build, launch, and operate a robotic rover on the Moon. Monetary prizes are offered for completing various missions, including a visit to any of the Apollo landing sites. There are currently 25 teams competing.

NASA's Great Moonbuggy Race

As part of Marshall Space Flight Center's heritage, the Lunar Roving Vehicle is acknowledged by holding a student engineering design competition each year. The competition is held in April of every year at the U.S. Space and Rocket Center in Huntsville, Alabama. Student teams are required to design and build a "moonbuggy" vehicle that is capable of traversing over an obstacle course with two drivers. Prizes are awarded to high school and college level participants based on who can complete the course in the fastest time.

Biography

Saverio F. Morea

Saverio "Sonny" Morea was born in Queens, New York, in 1932, the son of Italian immigrants. Morea was encouraged to pursue a career in engineering early on, after a teacher recognized his mathematical aptitude. He attended a Brooklyn Technical High School, where he had a focus in aeronautical engineering and was active in the ROTC program. He earned his pilot's license when he was 17 years old.

Morea attended the City College of the City of New York (CCNY), and graduated with a bachelor's degree in mechanical engineering in 1954. He moved to California the same year with his wife, Anne, and began to work for North American Aviation, which would later become part of Boeing. In 1957, Morea went to Huntsville, Alabama, under military orders and reported to Major General Holger Toftoy, who assigned him to the Guided Missile Development Division at Redstone Arsenal. He met Wernher von Braun the first day he was there. Morea worked as project manager for the H-1, F-1, and J-2 rocket engines. When the Lunar Roving Vehicle contract was announced in 1969, Morea was selected to be Project Manager. Morea was awarded the NASA Exceptional Service Medal twice; first for his management of the F-1 Engine Development Program in 1969, and the second for his management of the LRV. Morea served some twelve years as the Assistant Director of the Structures and Propulsion Laboratory and more than two years as the Director of the Research and Technology Office at the Marshall Space Flight Center. He currently resides in Huntsville, Alabama.

Figure 19–22: Saverio "Sonny" Morea, project manager of the Lunar Roving Vehicle and the F-1 engine.

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About the Author

John Alcorn is an undergraduate student at the University of Alabama in Huntsville. He is pursuing a Bachelor's Degree in Aerospace Engineering. He plans to begin his graduate studies in 2014. Alcorn spent summer 2012 interning at NASA Marshall Space Flight Center, where he worked in the Metal Joining and Processes branch on SLS (Space Launch System) flight hardware. Alcorn is very active in a student engineering group at his university, where he has been involved in several projects. He acted as Project Manager during both 2011 and 2012 for UAHuntsville's International Cansat Competition team, and has been involved in multiple science payloads that have been launched on high-altitude weather balloons.

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