America's Greatest Projects and Their Engineers - VIII

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America's Greatest Projects & Their Engineers-Vol. VIII
The Apollo Project-Part 2

American Space Travel to the Moon

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I. Plans to Land on the Moon Are Committed

A. Process Decisions Are Reconciled

Following President John F. Kennedy's challenge to a joint session of Congress on 25 May 1961 to land an American on the Moon and return him safely to Earth by the end of the decade, there were several critical decisions that had to be made by NASA (National Aeronautics and Space Administration). Key among these was to develop and insure that the actual procedure for doing this would be both successful and less expensive to the American taxpayers. As was noted in Part 1 of the Apollo Project, these were the options that confronted NASA:

Options and Evaluations

a. Direct flight from the Earth to the Moon
b. Earth Orbit Rendezvous (EOR)
c. Lunar Orbit Rendezvous (LOR)

a. The Space Task Group, which was responsible for Project Mercury and the Headquarters Office of Launch Vehicle Programs, favored using the huge Nova rocket for a direct flight from Earth to the Moon. Landing the entire spacecraft on the lunar surface, as would be necessary with a direct flight approach, would have required an increase in rocket thrust because of the much heavier load of fuel tanks and fuel.
b. Marshall Space Flight Center (MSFC) in Huntsville, Alabama advocated an Earth Orbit Rendezvous. This method would require the use of several smaller Saturn launch vehicles to rendezvous in a Low Earth Orbit LEO). One of the vehicles would then be refueled in orbit for the long flight to the Moon.
c. Key members of the Langley Research Center advocated the LOR. Its premise was to have one spacecraft launched from Earth, travel and orbit the Moon's surface, and detach a separate spacecraft, known as an LEM (Lunar Excursion Module), down to the Moon's surface. The LEM would then rendezvous and re-attach to the Moon-orbiting spacecraft.

To compound the early dilemma with the project, some in NASA did not think that the mission was possible, and many more had serious doubts the project would accomplish its goal by the end of the 60's. We do know that NASA authorized several serious studies on a direct landing method for the Apollo program, but dropped the ideas because they would require too big a rocket.

Decisions Made

After much review by NASA administrators and engineers, the LOR method was selected. The payload for the LOR was estimated to be just slightly over 45 tons, as opposed to more than 100 tons for a direct flight. In addition, the LOR method would require only one large booster instead of the two required for either of the other two options. At the time the decision to not need so big a rocket was very logical; the Atlas rocket for the Mercury Project was still in development, which had necessitated that the smaller Redstone rocket be used to launch the first American astronaut (Alan Shepard) into space for a suborbital flight in April 1961. Furthermore, the Titan I and Titan II rockets, which would eventually be used for the manned spaceflights of Project Gemini, were still on the drawing board at Aerojet General since the "bridge project" between Mercury (Gemini) and Apollo had yet to be announced. Even though this decision was not reached until July of 1962, this did allow NASA to proceed full speed ahead for a potential lunar landing.

B. Design Considerations and Equipment Are Established

1. Rockets – Launch Vehicles

The U.S. Army Ordnance Missile Command (AOMC), was established at Redstone Arsenal in Huntsville, Alabama in the early 1950's, and they were permitted by the ABMA (U. S. Army Ballistic Missile Agency) to develop a large space booster of approximately 1.5 million-pounds thrust using a cluster of available rocket engines. However, this booster was considered to be a Department of Defense (DOD) missile, and was not to be used in the U. S. Space Program. In early 1959, this vehicle was first designated as Saturn. However, the U.S. manned satellite space program was struggling, and had to use the Redstone rocket to launch the first American satellites as well as the first two suborbital flights of Project Mercury. There followed a typical political squabble over the next eighteen months, when the Air Force proposed a Super Nova rocket that would be better and cheaper than the Saturn. However, its development was barely in the design stage, whereas the Saturn had construction drawings and parts on the ground. NASA solved the infighting by absorbing the ABMA.

The ABMA, under the direction of Dr. Wernher von Braun, had begun to develop the Saturn I rocket in 1957. The unique first stage was composed of a cluster of eight Redstone booster rockets around a Jupiter tank. This clustering of smaller boosters, rather than manufacturing larger rockets, allowed the use of tooling from the Redstone and Jupiter missile programs. The first Saturn rocket to fly was the **Saturn I,** which had a thrust capacity of about 200,000 lbf, and was the first launch vehicle that was capable of carrying more than 20,000 pounds into outer space and propelling the load into a Low Earth Orbit (LEO). Designed specifically to launch larger payloads, most of the rocket's power came from a clustered lower stage consisting of boosters taken from older rocket designs strapped together to make a single large booster. Its design proved sound and very flexible. Although it served only for a brief period for NASA, ten Saturn I rockets were flown before it was replaced by the Saturn 1B, its successor, which featured a more powerful upper stage and improved instrumentation.

Chrysler Corporation had opened a Huntsville operation in the 1950's, which was designated as their Space Division. It became Marshall Space Flight Center's prime contractor for the first stage of both the Saturn 1 and Saturn 1B rocket versions. The design, based on this cluster of boosters from the Redstone as well as the Jupiter missiles, was actually the first nuclear-tipped, medium-range ballistic missile (MRBM). Chrysler built them for the early Apollo program at their huge Michoud Assembly Plant, one of the largest manufacturing plants in the world, in East New Orleans. Between October 1961 and July 1965, all of Chrysler's missiles and boosters were successful and NASA never suffered a launch failure.

Saturn V Chosen

On 10 January 1962 NASA announced plans to build the **C-5**, a three-stage rocket consisting of the S-IC first stage, the S-II second stage, and the S-IVB third stage. The C-5 would be designed for a 90,000-pound (45 ton) payload capacity, capable of carrying American astronauts to the Moon. This was to be the largest production model of the Saturn family of rockets, and was already in the process of being designed at the Marshall Space Flight Center in Huntsville under the direction of Dr. von Braun. He and his team had been working on greatly improving rocket thrust in Huntsville since the early 1950's and had created a less complex operating system, designing better mechanical systems. During these revisions the decision to reject the single engine of the V-2's design had come about, and the team moved to a multiple-engine design. **Arthur Rudolph**, an integral part of the V-2 rocket team coordinated by von Braun, was the assistant director under von Braun at the Marshall Space Flight Center.

Saturn V Design

The Saturn V's size and payload capacity dwarfed all other previous rockets which had successfully flown at that time. With the Apollo spacecraft on top, Saturn V had an overall height of 363 feet and was slightly more than 33 feet in diameter, including guidance fins. Fully fueled, the Saturn V weighed nearly 6.5 million pounds, and had a thrust capability of 7.5 million lbf. Its Low Earth Orbit capacity was originally estimated at 261,000 pounds, and it was designed to send at least 90,000 pounds to the Moon, including the third stage (S-IVB), necessary fuel, the Command Service Module (CSM) and the Lunar Excursion Module (LEM). The stages were designed by the Marshall Space Flight Center (MSFC) in Huntsville, and numerous outside contractors were chosen for the construction. By late 1962, NASA had finalized its plans to proceed with von Braun's Saturn designs, and the Apollo space program gained speed. The C-5 was confirmed as NASA's choice for the Apollo Program in early 1963, and was renamed the **Saturn V** and used by NASA between 1967 and 1973. It would be a three-stage, heavy-lift launch vehicle, human-rated and liquid-fueled but expendable. The Saturn V was designed and manufactured to be a vehicle capable of launching a manned spacecraft on a trajectory to the Moon. In addition to Saturn V being used for human exploration of the Moon, it was later used to launch Skylab, the first American space station.

A total of fifteen flight-capable Saturn V vehicles were built, and it was the launch vehicle from the Kennedy Space Center in Florida for thirteen missions, never losing a manned crew or a payload. As of this day the Saturn V remains the tallest, heaviest, and most powerful rocket ever brought to operational status, and holds records for the heaviest payload launched and largest payload capacity ever placed into Low Earth Orbit (LEO). The weight of the lunar expedition system, which included the third stage and propellant necessary for translunar navigation as well as the Command Service Module and the Lunar Module, exceeded 160,000 tons. With the configuration of Saturn V finalized, NASA turned its attention to procedural missions for the translunar flights. Despite much controversy, the lunar orbit rendezvous combined with a lunar module had been chosen over an Earth orbital rendezvous or direct landing. Issues such as type of fuel injections, the needed amount of fuel for such a trip, and rocket manufacturing processes were ironed out, and the designs for the Saturn V were accelerated.

2. Spacecraft

Once the decision was made to adopt the lunar orbit rendezvous, this meant that two astronauts would remain in lunar orbit and control the CSM, while a lunar module (LM) with the other astronaut would descend to the Moon's surface. Many other aspects of the mission were significantly based on this fundamental design decision. Realizing that space rendezvous would be an integral part of any Moon landing, NASA inaugurated Project Gemini, a bridge project between the Mercury and Apollo programs, which would focus on spacecraft rendezvous and docking techniques. They also chose the second group of American astronauts in 1962, known as the New Nine, primarily to command and fly in the Gemini program.

The **Apollo spacecraft** was composed of several parts designed to accomplish the Apollo program's goal of landing American astronauts on the Moon by the end of the 1960s and returning them safely to Earth. The partially expendable (single-use) spacecraft consisted of a combined Command and Service Module (CSM) and a Lunar Module (LM). Two additional components complemented the spacecraft stack for space vehicle assembly. The first was the Spacecraft Lunar Module Adapter (SLA) designed to shield the LM from the aerodynamic stress of launch and to connect the CSM to the third stage (S-IVB) of the Saturn. It also included the Launch Escape System (LES), originally developed at the Langley Research Center for the Mercury Project, to carry the crew in the Command Module safely away from the launch vehicle in the event of a launch emergency. The LES was jettisoned during launch upon reaching the point where it was no longer needed, and the SLA remained attached to the launch vehicle's upper stage.

The change to lunar orbit rendezvous, plus several technical obstacles encountered in some subsystems (such as environmental controls internal to the CSM), soon made North American Aviation aware that substantial redesign would be required. Per an agreement with Faget, North American's project team determined that the most time-saving and efficient way to keep the program on track was to proceed with the development of the CSM in two versions. Thus, Block I and Block II came into being.

- **Block I** would continue the preliminary design, to be used for early low Earth orbit test flights only.

- **Block II** would be the lunar-capable version, including a docking hatch and incorporating weight reduction and lessons learned in Block I.

Detailed design of the docking capability depended on design of the LM, which wasn't contracted to Grumman Aircraft until November 1962, nearly one full year after North American had been awarded the contract for the CSM. The original plan was to have North American build capsules ready for flight by 1965. However, with the major concept being changed to a Lunar Module, the logical plan was to discontinue design changes on the Block I capsule, and to continue the design changes on the Block II capsule, which would not be needed until sometime in 1967.

Command Module

The CSM consisted of two segments: the cone-shaped **Command Module**, which was a cabin that housed the crew and carried equipment needed for reentry and splashdown; and the cylindrical **Service Module,** which provided electrical power and storage for various consumables required during a mission, and also included the S-IVB which would propel the CSM to and from the Moon. An umbilical connection transferred the electrical power and consumables such as oxygen and water between the two modules, and provided the astronauts with the necessary communication capabilities. Just before re-entry of the Command Module on the return to Earth, the Service Module would be separated from the Command Module, the umbilical connection would be severed, and the Service Module would be cast off and allowed to burn up in the atmosphere. The Block I (original CSM) had no provisions for docking with another spacecraft, specifically the Lunar Module. This plus other required design changes led to the decision to design two versions of the CSM. Block I was to be used for unmanned missions and a single manned Earth orbit flight, which was then referenced as AS204, but later was known as Apollo 1.

Service Module

Block I command modules lacked forward docking tunnels, and had no hatches which would allow EVA's. All this fell to the service module, the cylindrical spacecraft mated to the command module that fed the electrical, propulsion, and environmental systems for the bulk of the mission to the Moon. It was 12 feet 10 inches in diameter and 24 feet 11 inches long, and was divided into six sections around a central area. The central part of the cylinder held the main Service Propulsion System engine and its associated plumbing while the six other sections held hydrogen-oxygen fuel cells, and cryogenic liquid hydrogen and liquid oxygen for the S-IVB rocket.

The Service Module was an unpressurized cylindrical structure, and its interior was a simple structure. It consisted of a central tunnel section 44 inches in diameter, surrounded by six pie-shaped sectors. The sectors were topped by a forward bulkhead and fairing, separated by six radial beams, covered on the outside by four honeycomb panels, and supported by an aft bulkhead and engine heat shield. The sectors were not all equal 60° angles, but varied according to required size.

The Service Module was connected to the Command Module using three tension ties and six compression pads. The tension ties were stainless steel straps bolted to the Command Module's aft heat shield. It remained attached to the Command Module throughout the mission, until being jettisoned just prior to the Command Module’s re-entry into the Earth's atmosphere. At jettison, the umbillical connections were cut using a pyrotechnic-activated guillotine assembly. Following jettison, the Service Module aft translation thrusters automatically fired continuously to distance it from the Command Module, until either its Re-entry Control System fuel or the fuel cell power was depleted. The roll thrusters were also fired for five seconds to make sure it followed a different trajectory from the Command Module and would incur faster break-up on re-entry.

3. Lunar Module (LM)

The design and construction of the Lunar Module was arguably the most serious, if not the most complicated, technical challenge of the Apollo program. Begun more than a year later than most of the other parts of the Apollo Project, the LM was consistently behind schedule and over budget. The design which NASA used was based on the Lunar Orbit Rendezvous, in which two docked modules were sent to the Moon and went into lunar orbit. While the LM separated and landed, the CSM remained in lunar orbit, usually at an apogee of between sixty-eight and seventy miles above the lunar surface. After the lunar landing and debarking, the LM would ascend, the two craft would rendezvous and dock in lunar orbit, and the CSM would return the crew to Earth. The Command Module would be the only part of the space vehicle that returned with the crew to the Earth's surface.

Most of the problems with the LM consisted of designing and developing a propulsion system for the descent stage of the LM in tandem with a propulsion system for the ascent, all of this in a no-atmosphere, near-weightless environment. Guidance and maneuverability in those conditions, with one or two astronauts standing at the LM controls, was also critical or the astronauts could have been stranded on the lunar surface. To add to the problems with Grumman’s design, the LM had to be fairly lightweight, but sturdy and mostly shock-proof. **Dr. Thomas Kelly**, a mechanical engineering graduate from Cornell University, is generally credited with the great success of the LM.

The Apollo Lunar Module (LM) was a two-stage vehicle designed by Grumman to ferry two astronauts from lunar orbit to the lunar surface and back. It was 23 feet high (with landing gear extended), 31 feet wide, and 31 feet deep. The upper ascent stage consisted of a pressurized crew compartment, equipment areas, and an ascent rocket engine. The lower descent stage had the landing gear and contained the descent rocket engine. It was capable of operation only in outer space; structurally and aerodynamically it was incapable of flight through the Earth's atmosphere. Due primarily to much politicking by the American astronauts and their supporters, it was eventually designed for lunar orbit rendezvous by Grumman to carry a crew of two from lunar orbit to the surface of the Moon and back. Its ascent stage and descent stage would be ferried to lunar orbit by the Command Service Module.

At launch, the LM weighed about 33,500 pounds and would sit directly beneath the CSM with its legs folded, inside the CSM-LM Adaptor, which was designed and built by North American Aviation as part of their CSM contract. The Adaptor was in turn attached to the S-IVB, which was the third stage of the Saturn V rocket. It would remain there through Earth parking orbit and through the Trans Lunar Injection (TLI) rocket burn, which would propel the entire spacecraft toward the Moon.

Soon after TLI, the Adaptor would open and the CSM initially would separate from the LM and turn around. It would then come back to dock with the Lunar Module, and then would extract the LM from the S-IVB. During the flight to the Moon, the docking hatches would be opened and the LM Pilot could enter the LM to temporarily power up – it was battery-powered - and test its systems (except for propulsion). Throughout the flight to the Moon, an astronaut could perform the role of an engineering officer, responsible for monitoring the systems of both spacecraft modules.

Once the spacecraft was placed into a Moon parking orbit, the two modules would undock, and the CSM would raise and optimize its circularized orbit for the remainder of the mission at the Moon. The LM would engage the descent stage and gradually land on the lunar surface. When ready to leave the Moon, the LM would separate the descent stage and fire the ascent engine to climb back into orbit, using the descent stage as a launch platform. After a few course correction burns, the LM would rendezvous with the CSM and dock for transfer of the two-man crew and any souvenirs and/or rock samples. Having completed its transfer, the LM would be separated from the CSM and sent into solar orbit or to crash into the Moon.

II. NASA’s Plans and Objectives

Following the great success of Apollo 8, during which American astronauts Frank Borman, Ed Lovell, and William Anders navigated their spacecraft to the Moon, NASA had developed extreme confidence in the Apollo program. Considering the speeds of the Earth rotating around the sun and the Moon moving around the Earth, everything worked flawlessly. The computerized translunar injection (TLI) and the trans Earth injection (TEI), including the guidance system and the rocket burns, proved to be perfect. Apollo 8 and its astronauts experienced many firsts, including the first to leave the Earth’s gravitational field and the first to travel around the dark side of the Moon. Not only were the Apollo 8 and its crew the first to orbit the Moon, performing ten orbits, but the Apollo 8 crew became the first humans to see Earth as a whole planet. Now that all the important parts were in place, the NASA administration was anxious to meet its ultimate goal by the end of the decade.

A. Pre-Lunar Test Missions

1. Apollo 9

The next flight on NASA's aggressive agenda was **Apollo 9**, which had undergone several crew changes due to illnesses and changes in program objectives. The LM was now seemingly ready and its controls and maneuvers could be astronaut-tested. **Apollo 9** was the third crewed mission of the Apollo program and would be the first crewed flight of the Command Service Module in conjunction with the Lunar Module. The three-man crew consisted of Commander James McDivitt, Command Module Pilot David Scott, and Lunar Module Pilot Rusty Schweickart. McDivitt, a Brigadier General in the USAF, was in the 2nd group of astronauts chosen by NASA in 1962. He was the Commander of Gemini 4, during which astronaut Ed White became the first American to walk in space. McDivitt, Scott, and Schweickart were originally the backup crew for Apollo 1, and were scheduled to fly on Apollo 2. However, that all changed after the fatal fire in Apollo 1 on 27 January 1967.

Their next scheduled flight was to be on Apollo 8 when all of the lunar landing equipment would be available. However, the LM for which they had been intensely training, was still not ready. Once again, they were pushed back, this time to Apollo 9, and NASA made the decision to send Borman, Lovell, and Anders on the momentous journey to the Moon on Apollo 8. Finally, McDivitt and his crew got their opportunity, launching in Apollo 9 on **03 March 1969**. This was the second crewed launch of a Saturn V rocket, but only the first flight when all phases of the complete lunar landing system could be tested.

Mission Objectives

Apollo 9 was a low Earth orbit (LEO) flight, and its primary objective was an engineering evaluation of the first crewed Lunar Module (LM), testing several aspects of the LM critical to landing on the Moon. The major functions to be tested included:

1. the descent and ascent engines.
2. the astronauts' backpack life support systems.
3. the LM navigation system.
4. the docking maneuvers between the LM and the CSM.

The list of tests also included an overall checkout of the launch vehicle and numerous spacecraft systems, further development of flight procedures and an analysis of the crew's performance. This was done by performing an integrated series of flight tasks with the command module (CM), the service module (SM), the LM and S-IVB stage while they were linked in LEO or in various docked configurations. This was also the first time that the LM was being tested as a self-sufficient spacecraft, and Apollo 9 was also able to perform active rendezvous and docking maneuvers paralleling those which were scheduled for the following Apollo 10 lunar-orbit mission.

A top priority was to have the CSM and LM undock, and to then have them rendezvous and dock again. This was performed twice - once while the LM was still attached to the S-IVB, to prepare for a TLI (trans lunar injection), and again when the LM was active in preparation for a TEI (trans Earth injection). Further goals included internal crew transfer from the docked CSM to the LM; special tests of the LM's support systems, and extravehicular activity, or EVA. The crew also configured the LM to support a two-hour EVA (Moon walk), and even simulated an LM crew rescue.

The LM descent and ascent engines fired on orbital change patterns to simulate a lunar-orbit rendezvous and backup abort procedures. The CSM service propulsion system, or SPS, fired five times, including a simulation of an active rendezvous to rescue an LM that had become inactive. After separation of the CSM from the SLA in Earth orbit and jettison of the SLA's LM protective panels, the CSM transposed position and docked with the exposed LM. The docked modules separated and the spacecraft adjusted its orbit 2,000 feet away from the S-IVB stage. The S-IVB engine was then restarted twice, placing the stage in an Earth-escape trajectory and into solar orbit, simulating a translunar injection (TLI) for Apollo 10 and subsequent lunar missions.

All prime mission objectives were met and the mission proved the LM worthy of crewed spaceflight. Various firings of the SPS changed Apollo 9's orbit, but were somewhat erratic. The firing did improve orbital lifetime, checked the capability of the guidance and navigation system to control the burn, and performed a hard check of the LM's ability to withstand thrust acceleration and vibration.

On Flight Day 3, McDivitt and Schweickart put on spacesuits and transferred to the LM through the tunnel connection to perform a systems checkout. This included a 367-second firing of the LM descent engine to simulate the throttle pattern to be used during a lunar landing mission. McDivitt controlled the final 59 seconds, varying the thrust from 10 to 40 percent and shutting it off manually. This was the first crewed throttling of an engine in space and increased the spacecraft's orbit to 130 by 300 miles. On Flight Day 5, with McDivitt and Schweickart again aboard the LM, it separated from Scott's CSM. McDivitt and Schweickart flew the LM up to 111 miles from the CSM, using the engine on the descent stage to propel them away, before jettisoning it and using the ascent stage to return. This test represented the first flight of a crewed spacecraft that was not equipped to reenter the Earth's atmosphere. The CSM and LM redocked ten hours later, and the LM ascent stage was jettisoned and was commanded to fire its engine to fuel depletion.

Apollo 9 was the first space test of the complete Apollo spacecraft, including the Lunar Module. It was also the first space undocking and docking of any two vehicles (LM and CSM) with an internal crew transfer between them. For ten days, the astronauts put both Apollo spacecraft through their paces in Earth orbit, just as the landing mission crew would perform in lunar orbit. Apollo 9 gave proof that both Apollo spacecrafts were up to this critical task, on which the lives of lunar landing crews would depend. In addition, Schweickart checked out the new Apollo spacesuit, the first to have its own life support system rather than being dependent on an umbilical connection to the spacecraft, On the tenth day, 13 March 1969, re-entry of Apollo 9, nicknamed Gumdrop, occurred and it splashed down in the North Atlantic Ocean, about 341 miles north of Puerto Rico. The crew was within three miles and in full view of their recovery ship USS Guadalcanal. The flight totaled nearly 241 hours, as had been planned. For this and all subsequent Apollo flights, the crews were allowed to name their own spacecraft. The gangly LM was named Spider, and the CSM was labeled Gumdrop because of the Command Module's shape. These names were actually required as radio call signs when the vehicles flew independently.

2. Apollo 10

The next flight on NASA's aggressive agenda was **Apollo 10**, which launched from Cape Kennedy on **18 May 1969**. The LM was now seemingly working well and its controls and maneuvers could be tested under more stringent conditions. **Apollo 10** was the fourth crewed mission of the Apollo program and would be the first crewed flight whereby all three astronauts would be veterans of spaceflight. The three-man crew consisted of Commander Thomas Stafford, Command Module Pilot John Young, and Lunar Module Pilot Eugene Cernan.

1. Stafford, a Lt. General in the USAF, was selected to become an astronaut in the 2nd group of astronauts chosen by NASA in 1962 and flew aboard both Gemini 6A and Gemini 9. He was the Commander of Gemini 4, during which astronaut Ed White became the first American to walk in space.
2. Young, a captain in the U. S. Navy, was the first astronaut of the 2nd group that was selected by NASA in 1962 to go into outer space. He flew on the first manned Gemini mission (Gemini 3) and commanded another Gemini mission (Gemini 10) the following year. Young eventually became the longest-serving astronaut in the American space program.
3. Although Cernan, also a captain in the U. S. Navy, was not selected by NASA until the third group of astronauts in 1963, he did fly on the partially successful Gemini 9A mission. He was also a backup on Gemini 12, and would eventually become the last man to walk on the Moon.

Mission Objective

The Apollo 10 mission planned to encompass all aspects of an actual crewed lunar landing, except for the actual landing. This would be the first flight of a complete, crewed Apollo spacecraft to operate around the moon. Objectives included a scheduled eight-hour lunar orbit of the separated lunar module (LM), and descent to about nine miles above the moon's surface. The LM would then ascend for rendezvous and docking with the command and service module (CSM), which was to be in an approximately 70-mile circular lunar orbit. Pertinent data to be gathered in this "lunar landing rehearsal" included the effect of the lunar gravitational field, to refine the Earth-based crewed spaceflight network tracking techniques, and to check out LM programmed trajectories and lunar flight control systems. Twelve television transmissions to Earth were planned. Apollo 10 was the first mission to carry a color television camera inside the spacecraft, and made the first live color TV transmissions from space.

Mission Highlights

The launch of Saturn V placed Apollo 10 into a nominal 115-mile circular Earth-parking orbit. The orbital vehicle was comprised of the full complement of equipment needed to land on the Moon. This included the S-IVB third stage and its payload of the CSM, the LM and spacecraft-lunar module adapter (SLA) shroud. Only one-and-a-half orbits later, translunar injection (TLI) occurred when the S-IVB fired to increase velocity from 17,450 to 24,990 miles per hour on a **free-return trajectory**, meaning that the spacecraft was still subject to the Earth's gravitational field. About twenty-five minutes after TLI, Young performed the transposition maneuver, separating the Command/Service Module (CSM) from the S-IVB/LM, and transposing the CSM to 180 degrees toward the LM atop the S-IVB. Turning it around, the CSM docked its nose to the top of the Lunar Module (LM) during the second orbit. The linked modules ejected from the S-IVB, and the thrust placed the CSM-LM a safe distance away from the S-IVB. A 60-second restart of the S-IVB raised its apogee to nearly 1,900 miles, similar to the maneuver performed on Apollo 9.

The launch trajectory had been so satisfactory that only one of the four planned mid-course corrections was needed, and the burn was accomplished 26.5 hours into the flight. About 76 hours into the mission, lunar-orbit insertion occurred with the firing of the service propulsion system, or SPS. A second firing of the engine 4 hours and thirty minutes later circularized the lunar orbit of Apollo 10 at approximately 69 miles, which was followed by the first color TV pictures to Earth of the moon's surface. A little more than 98 hours into the flight, Stafford and Cernan entered Snoopy, the LM, and prepared for the undocking maneuver that occurred on the 12th lunar orbit, while Young stayed on Charley Brown, the CSM, and became the first person to fly solo around the Moon. About 2 hours later, on 22 May, the vehicles separated and briefly flew a station-keeping lunar orbit of 66.7 by 71.5 miles. To achieve a simulation of the future Apollo 11 landing, the LM descent engine fired for 27.4 seconds, with 10 percent thrust for the first 15 seconds and 40 percent thrust for the rest. This brought the LM to an elliptical orbit of 9.7 by 70.5 miles.

The LM flew over the Sea of Tranquility, and the LM landing radar was tested for altitude functioning. Following a 7.5-second firing of the LM reaction control system (RCS) thrusters, the descent engine was fired twice, placing the LM into an orbit of 13.7 by 219 miles. On the 14th revolution, it reached a low elevation above the lunar surface of 12.7 miles. Upon descent stage separation and jettison on the second attempt, and ascent engine ignition, the LM began to roll violently because the crew accidentally duplicated commands into the flight computer which took the LM out of abort mode, the correct configuration for this maneuver. After spinning eight times, Cernan and Stafford regained control of the LM under ascent engine power. While the incident was downplayed by NASA, the roll was just several revolutions from being unrecoverable, which would have resulted in the LM crashing into the lunar surface.

The ascent engine fired for 15 seconds, and the RCS thrusters were fired twice, closing the distance from 230 miles behind and 17 miles below the CSM, yielding an orbit of 54.5 by 48.1 miles. Stafford sighted the CSM's running lights at about 48 miles. The 15-second terminal phase initiation firing reduced velocity as the LM entered an intercept trajectory and the two vehicles achieved station-keeping of the 16th lunar revolution. With Young in the CSM taking on an active rendezvous role, the vehicles were re-docked on May 23. After 106 hours into the mission, the LM ascent stage was jettisoned and its engine was fired to fuel depletion, sending it on a trajectory past the Moon into a heliocentric, or circumsolar, orbit. All subsequent jettisoned ascent stages were intentionally steered into the Moon to obtain readings from seismometers placed on the surface.

On the 31st orbit, when Apollo 10 was on the back side of the Moon, the SPS was fired and it was injected (TEI) into a trans-Earth trajectory. After a midcourse correction, and command and service module separation, Apollo 10 re-entered Earth's atmosphere and splashed down in the Pacific Ocean on 26 May 1969, approximately 465 miles east of American Samoa. Its landing was within television range of its primary recovery ship, the USS Princeton. Apollo 10 had completed a flight of slightly more than 192 hours, and all mission objectives were achieved.

III. Lunar Landing Mission

A. Apollo 11

The next flight on NASA's aggressive agenda was the one that they and all of America were hoping and waiting for. **Apollo 11**, which launched from Cape Kennedy on **16 July 1969**. The LM had apparently worked so well that its controls and maneuvers could now be operated under lunar conditions. **Apollo 11** was the fifth crewed mission of the Apollo program and would be the first crewed flight to actually land two American astronauts on the Moon and return them safely to Earth. The three-man crew consisted of Mission Commander Neil Armstrong and Lunar Module Pilot Buzz Aldrin, who would descend to the lunar surface, while Command Module Pilot Michael Collins orbited the Moon.

1. Armstrong, commissioned a Lt. JG in the US Navy, was actually one of three civilians in the American Astronaut Corp. He was selected in the 2nd group of astronauts (known as the "New Nine") chosen by NASA in 1962 and flew aboard Gemini 8. This was the first mission when both a rendezvous and a docking would occur. However, the mission had to be aborted when the spacecraft started to roll severely following undocking and Armstrong had to utilize the Re-entry Control System (RCS) to stabilize the spacecraft, triggering re-entry at the next possible opportunity.

   In order to give the astronauts experience with how the LM would fly on its final landing descent, NASA commissioned Bell Aircraft to build two Lunar Landing Research Vehicles (LLRV), to simulate the Moon's one-sixth of Earth's gravity by using a turbofan engine to support five-sixths of the craft's weight. On 06 May 1968, while only 100 feet above the ground, the LLRV failed. Armstrong ejected safely and parachuted to the ground, and suffered only minor injuries. Although he was nearly killed, Armstrong maintained that without the LLRV, the lunar landings would not have been successful, as they gave commanders valuable experience in the behavior of lunar landing craft.

2. Aldrin, a colonel in the USAF, was selected by NASA with the third group of astronauts in 1963, and was the first astronaut to hold a Ph. D. He flew on the last manned Gemini mission (Gemini 12) and was generally credited for docking twice (both times without radar) with the Agena Target Vehicle. During Gemini 12, the last flight of the Gemini program, Aldrin proved that long-term extra vehicular activity was both possible and practical, performing three EVA's for a total of five hours.

3. Although Collins, a Major General in the USAF, was also not selected by NASA until the third group of astronauts in 1963, he did fly on the very successful Gemini 10 mission. He and Commander John Young performed a rendezvous with two different spacecrafts (both Agena Target Vehicles), and he performed two successful Eva's before splashdown.

Mission Objective – Apollo 11

Having abandoned names used in cartoons, the basic mission objective was very simple, but also probably the most daring enterprise ever undertaken by the United States of America, or any other nation: fly the "Columbia" to the Moon, land the "Eagle" with an American astronaut(s) on the Moon and return him safely to Earth. While on the lunar surface, a secondary objective, of course, was to collect rock and soil samples of the lunar surface.

Launch & Flight to Lunar Orbit – Apollo 11

Apollo 11 was launched by a Saturn V rocket from Kennedy Space Center in Florida on **16 July 1969** at about 8:30 a.m. EDT, and was the fifth crewed mission of NASA's Apollo program. The Saturn V consisted of three main parts: the S-IC first stage, the S-II second stage, and the S-IVB third stage, all of which were expendable. The Apollo spacecraft was also comprised of three principal parts: a command module (CM) with a cabin for the three astronauts, and the only part that would return to Earth intact; a service module (SM), which supported the command module with propulsion, electrical

Saturn V Carrying Apollo 11

power, oxygen, and water; and a lunar module (LM) that had two stages – a descent stage for landing on the Moon, and an ascent stage to place the astronauts back into lunar orbit. An estimated one million spectators watched the launch of Apollo 11 from the highways and beaches vicinity of the launch site.

Many political dignitaries were present for the launch, including U. S. Cabinet Members, more than 200 Congress men and women, Governors, mayors, and ambassadors. The list also included more than 3,500 media representatives from the U. S. and 55 other nations. The launch was televised live in 33 countries, with an estimated 25 million viewers in the United States alone, including President Richard Nixon and former President Lyndon Johnson. Millions more around the world listened to radio broadcasts.

Apollo 11 entered a near-circular Earth orbit at an altitude of 118 miles by 114.5 miles twelve minutes later. After one and a half orbits, the S-IVB third-stage engine pushed the spacecraft onto its trajectory toward the Moon with the trans-lunar injection (TLI) burn slightly less than 5 hours into the flight. The trajectory of Apollo 11 approximated an elliptical orbit around the Earth with its apogee near to the radius of the Moon's orbit. The TLI burn was sized and timed to precisely target the Moon as it revolved around the Earth. The burn was timed so that the spacecraft would be near the same apogee as it approached the Moon. About 30 minutes later, the three-part transposition, docking, and extraction maneuvers were performed: this involved separating "Columbia" from the spent S-IVB stage, turning around, and docking with "Eagle", which was still attached to the stage three rocket. After the Lunar Module was extracted, the combined spacecraft headed for the Moon, while the rocket stage flew on a trajectory past the Moon. This was done to avoid colliding with the spacecraft, the Earth or the Moon. Supposedly, a slingshot effect from passing around the Moon would be sufficient to throw the rocket into a circumsolar orbit.

After the TLI and separation from the Saturn V's third stage, the astronauts traveled for three days until they entered into lunar orbit. Armstrong and Aldrin then moved into *Eagle* on **19 July 1969,** and Apollo 11 passed behind the Moon and fired its service propulsion engine to enter a lunar orbit. In the thirty orbits that followed, the crew saw passing views of their landing site in the Southern Sea of Tranquillity about 12 miles southwest of a crater known as Sabine D. The site was selected in part because it had been characterized as relatively flat and smooth by the automated Ranger 8, which had previously crashed, and Surveyor 5, which had landed about 42 miles southwest of the Ranger 8 crash site and was unlikely to present major landing or EVA challenges.

Descent – Apollo 11

After achieving a lunar parking orbit, Armstrong and Aldrin entered and powered up the LM, replaced the hatches and docking equipment, unfolded and locked its landing legs, and separated from the CSM, flying independently. The LM was withdrawn to a safe distance, then the descent engine was pointed forward into the direction of travel to perform the 30 second Descent Orbit Insertion burn, which reduced speed and dropped the LM's perilune to within approximately 50,000 feet of the lunar surface and nearly 300 miles uprange of the landing site. Armstrong operated the flight controls and engine throttle, while Aldrin operated other spacecraft systems and kept Armstrong informed on systems status and navigational information. Collins, who was now alone aboard Columbia, made a visual inspection of the LM and landing gear as it pirouetted before him to ensure the craft was not damaged, and that the landing gear was correctly deployed.

During the descent, Armstrong and Aldrin found that they were passing landmarks on the surface two or three seconds early, Eagle was traveling too fast, and that they would land several miles west of their target point. Because this was happening, the LM crew shut down the descent engine, and various computer alarms were sounded. Inside Mission Control Center, a computer engineer told the guidance officer that the alarms were computer overload, and that the descent should continue. During the mission, the cause was diagnosed as the rendezvous radar switch being in the wrong position, causing the computer to process data from both the rendezvous and landing radars at the same time. However, this anomaly was later attributed to an electrical phasing mismatch between two parts of the rendezvous radar system, which caused the stationary antenna to appear to the computer as oscillating back and forth between two positions.

This was relayed to the crew, and the descent engine was restarted at about 6,000 feet above the lunar surface for a Powered Descent. During this time the crew flew on their backs, depending on the computer to slow the craft's forward and vertical velocity to near zero. Control was exercised with a combination of engine throttling and attitude thrusters, guided by the computer with the aid of landing radar. Following this “braking” phase, the final approach phase went to approximately 700 feet in altitude and began approximately 2,000 feet uprange of the targeted landing site. During the final approach, the vehicle pitched over to a near-vertical position, allowing the crew to look forward and down to see the lunar surface for the first time.

Landing on the Moon – Apollo 11

At this point manual control was enabled for Armstrong, and enough propellant reserve had been allocated to allow approximately two minutes of hover time to survey where the computer was taking the craft and to make any necessary corrections. If necessary, landing could have been aborted at almost any time by jettisoning the descent stage and firing the ascent engine to climb back into orbit for an emergency return to the CSM. Finally, one or more of four 67-inch long probes extending from footpads on the legs of the lander touched the surface, activating the contact indicator light. This signaled Armstrong to manually shut off the descent engine, allowing the LM to settle onto the surface. Armstrong announced "Houston, Tranquillity Base here. The Eagle has landed." On touchdown, the probes could be bent as much as 180 degrees, or even break off. The original design used the probes on all four legs, but after Apollo 11, the one at the ladder was removed out of concern that the bent probe could possibly puncture an astronaut's suit while he descended or stepped off the ladder.

The Eagle landed at 3:17 PM EDT on Sunday **20 July 1969** with only about 25 seconds of fuel left. Apollo 11 landed with less fuel than subsequent missions, and the astronauts encountered a premature low fuel warning. This was later found to be the result of greater propellant 'slosh' than expected. When Armstrong again looked outside, he saw that the computer's landing target was in a boulder-strewn area just north and east of a 980 ft. diameter crater (later determined to be West Crater), named for its location in the western part of the originally planned landing area.

The landing was broadcast on live TV to a worldwide audience. The schedule for the mission called for the astronauts to follow the landing with a five-hour sleep period. However, they elected to forgo the sleep period and begin the preparations for the EVA early, thinking that they would be unable to sleep. The LM crew actually spent nearly two and a half hours after landing before they began preparations for their excursion (EVA) onto lunar soil. Armstrong then became the first person to step onto the lunar surface six hours after the LM had landed, and described the event as "one small step for [a] man, one giant leap for mankind." Apollo 11 effectively ended the “Space Race” and fulfilled the national goal that had been proposed in 1961 by President John Kennedy: "…before this decade is out, of landing a man on the Moon and returning him safely to the Earth.” Aldrin joined Armstrong about 20 minutes later. They spent a total of two hours and fifteen minutes together outside the spacecraft, and collected 47½ pounds of lunar material to bring back to Earth.

Aldrin, carefully crafting his statement so as to not cause any more anti-religious lawsuits than the one already filed by an atheist named O’Hair, simply asked everyone listening in to his radio broadcast to give thanks in their own way; then he took private communion. Aldrin was an elder at the Webster Presbyterian Church, and his communion kit was prepared by the pastor of the church, which possesses the chalice used on the Moon and commemorates the event each year on the Sunday closest to July 20. With some difficulty the astronauts lifted film and two sample boxes containing the lunar surface material to the LM hatch, using a flat cable pulley device called the Lunar Equipment Conveyor. This proved to be an inefficient device, and later missions preferred to carry equipment and samples up to the LM by hand.

After transferring to LM life support, the lunar explorers lightened the ascent stage for the return to lunar orbit by tossing out their PLSS backpacks, lunar overshoes, an empty Hasselblad camera, and other equipment. in addition to the scientific instruments, the astronauts left behind an Apollo 1 mission patch and a memorial bag containing a gold replica of an olive branch as a traditional symbol of peace as well as a silicon message disk. The disk carries the goodwill statements by Presidents Eisenhower, Kennedy, Johnson, and Nixon and messages from leaders of 73 countries around the world. The disc also carries a listing of the leadership of the US Congress, a listing of members of the four committees of the House and Senate responsible for the NASA legislation, and the names of NASA's past and present top management. The hatch was closed again, and the crew then pressurized the LM and settled down to sleep. Altogether, Armstrong and Aldrin would spend nearly 21½ hours on the lunar surface before rejoining Columbia in lunar orbit.

Lunar Ascent and Return – Apollo 11

After about seven hours of rest, the crew was awakened by Houston to prepare for the return flight. While moving inside the cabin, Aldrin accidentally damaged the circuit breaker that would arm the main ascent engine for lift off from the Moon. There was a concern this might prevent firing the engine and stranding them on the Moon. However, a felt-tip pen was sufficient to activate the switch. Had this not worked, the Lunar Module circuitry could have been reconfigured to allow firing the ascent engine. Two and a half hours later the astronauts first separated the descent stage, using it as a launch platform, then fired the Eagle's ascent engine to lift off from the lunar surface and enter a lunar orbit in order to rejoin Collins in the command module.

After a few course correction burns, the LM performed its rendezvous and docking with Columbia. The two-man crew with the rock samples transferred out of the LM, then jettisoned Eagle's ascent stage, which crashed on the Moon's surface. Before they performed the maneuvers that blasted them out of lunar orbit the LM was separated and sent into lunar orbit and on a collision course with the lunar surface. When Apollo 11 was on the back side of the Moon, the SPS was fired and it was injected into a trans-Earth injection (TEI) trajectory back to Earth. Film taken from the LM Ascent Stage upon liftoff from the Moon revealed the American flag, which had been planted only about 25 feet from the descent stage, was whipping violently in the exhaust of the ascent stage engine. Aldrin looked up in time to witness the flag topple. Astronauts on subsequent Apollo missions usually planted the American flags further from the LM to prevent them being blown over by the ascent engine exhaust. Just before the Apollo 12 flight, NASA noted that *Eagle* was still possibly orbiting the Moon. Since the ascent stage was not tracked after it was jettisoned *Eagle*'s orbit had decayed, resulting in it impacting in an "uncertain location" on the lunar surface and the lunar gravity field is sufficiently non-uniform to make the orbit of the spacecraft unpredictable after a short time.

Splashdown and Quarantine – Apollo 11

The aircraft carrier USS Hornet had been dispatched from her home port of Long Beach, CA and reached Pearl Harbor on 05 July 1969. One week later on 12 July, with Apollo 11 still on the launch pad, Hornet departed Pearl Harbor for the recovery area in the central Pacific. A 35-man detachment of NASA's recovery team, along with several dozen media representatives, were on the carrier, and had partially displaced many of the regular ship's crew**.** However, the USAF had discovered with one of their spy satellites that a storm front was threatening the Apollo recovery area. Poor visibility could jeopardize the entire mission; if the carrier's helicopters could not locate Columbia, the spacecraft, its crew, and its priceless cargo of Moon rocks might be lost.

Navy Divers Retrieve the Apollo 11 Crew

NASA was strongly advised to change the recovery area. This modification to the landing area, which was about 250 miles further northeast of the original landing spot, altered the flight plan. A different sequence of computer programs was used, one never before attempted. Four helicopters were dispatched to the predicted spot, 1650 miles northeast of Wake Island, and were able to observe Columbia's hard landing just before dawn on 24 July 1969.

Because NASA was concerned that the astronauts might by subject to lunar pathogens, they had developed a protocol that included the crew being wiped down with sodium hypochlorite and then placed in biological isolation garments. They were winched onto the helicopter, which proceeded to land them on the carrier. After touchdown, the helicopter was lowered into a separate quarantine bay, where the astronauts were to remain for the next twenty-one days. This practice was continued for two more Apollo Moon landing missions, before NASA was given proof that the Moon was barren of life, and the quarantine process was discontinued.

A presidential party consisting of President Richard Nixon, National Security Advisor Henry Kissinger, and several other dignitaries had flown to Johnson Atoll on Air Force One. They spent one night on board the USS Arlington. They flew in Marine One to the USS Hornet for a few hours of ceremonies. He told them: "As a result of what you've done, the world has never been closer together before." After Nixon departed, the Columbia *was* lifted aboard the USS Hornet, placed on a dolly, and also placed into the ship's quarantine bay. A few days later the Columbia and its crew were flown to the Manned Spacecraft Center in Houston. The astronauts arrived at the Lunar Receiving Laboratory on 28 July 1969, where they spent the rest of their twenty-one days in quarantine. The lunar samples, film, data tapes and other items had been removed in the USS hornet quarantine bay through a special tunnel, and the Columbia was taken to Ford Island at Pearl Harbor, where it was deactivated, and its pyrotechnics were made safe. Two days later, it also arrived at the Lunar Receiving Laboratory.

President Nixon and the Apollo Crew

B. Apollo 12

Apollo 12 was the sixth manned flight in the United States Apollo program and the second to land astronauts on the Moon. Apollo 12 was launched on **14 November 1969** from the Kennedy Space Center in Florida nearly four months after Apollo 11's historic flight. Mission Commander was Charles "Pete" Conrad, and Lunar Module Pilot was Alan Bean, who would both land on the Moon, while Command Module Pilot Richard Gordon remained in lunar orbit. The landing site for the mission had been established as being located in the southeastern portion of the Ocean of Storms.

Charles "Pete" Conrad Jr., a Captain in the US Navy, was certainly no stranger to the U. S. space program, having been chosen by NASA in their second group (New Nine) of American astronauts in 1962. Regarded as one of the top pilots in his group, he was quickly assigned to the Gemini program. Along with his Command Pilot Gordon Cooper, Conrad set an eight-day space endurance record on his first spaceflight, the Gemini 5 mission. Eight days was the projected time by NASA for a successful lunar landing and safe return. Conrad also commanded the Gemini 11 mission, during which he and Pilot Richard Gordon were able to dock with an Agena Target Vehicle immediately after achieving orbit, thus replicating a lunar rendezvous and docking. During Gemini 11, the spacecraft reached the highest ever Earth-based orbit apogee of 850 miles.

Alan Bean, also a Captain in the US Navy, was selected by NASA in the third group of American astronauts in 1963. He was selected to be the backup command pilot for Gemini 10, which, according to NASA protocol, would have been his assigned command for Gemini 13; the Gemini program concluded with Gemini 12. He was placed in the Apollo Application Program, and was the first astronaut to dive in the simulator process for astronauts training to walk on the Moon. When fellow astronaut Clifton Williams was killed in another T-38 air crash on his way to visit his parents in Mobile, AL, a space was opened for Bean on the backup crew for Apollo 9. Apollo 12 Commander Conrad, who had instructed Bean at the Naval Flight Test School several years before, personally requested Bean to replace Williams. Apollo 12 was his first flight into space.

Richard "Dick" Gordon was the third of the Apollo 12 crew who was a US Navy Captain. A Seattle native, he graduated from the University of Washington with a BS in Chemical Engineering. A distinguished pilot, Gordon was also flight safety officer and assistant operations officer. He logged more than 4,500 hours flying time, with 3,500 hours of those hours in jet aircraft. In May 1961 he won the Bendix Trophy, flying from Burbank to New York City, in which he established a new speed record of 870 miles per hour and a transcontinental time record of 2 hours and 47 minutes. Gordon was chosen by NASA in the third group of astronauts in 1963. In September 1966, he made his first space flight, as Pilot of Gemini 11 alongside Commander Pete Conrad, his good friend from their US Navy days. Gordon had been assigned as backup Command Module Pilot for Apollo 9, which put him directly in line for the Apollo 12 mission.

Mission Objectives – Apollo 12

The primary mission objective of Apollo 12, the second crewed lunar landing, included an extensive series of lunar exploration tasks by the crew of the Lunar Module. In addition, the crew was assigned with the deployment of the Apollo Lunar Surface Experiments Package, which was to be left on the moon's surface to gather seismic, scientific and engineering data throughout a long period of time. Other Apollo 12 objectives included a selenological inspection, or astronomic study of the Moon and its physical characteristics and origin. The tasks given to Conrad and Gordon included surveys and samplings in landing areas; development of techniques for precision-landing capabilities; further evaluations of the human capability to work in the lunar environment for a prolonged period of time; deployment and retrieval of other scientific experiments; and photography of candidate exploration sites for future missions. The astronauts also were to retrieve portions of the Surveyor III spacecraft, which had soft-landed on the Moon 20 April 1967, a short distance from the selected landing site of Apollo 12.

Launch and Flight to Lunar Orbit – Apollo 12

Apollo 12 launched on **14 November 1969** into a cloudy, rain-swept sky. Launch controllers lost telemetry contact initially at 36 seconds, and then again at 52 seconds, when the Saturn V launch vehicle was apparently struck by lightning. Protective circuits on the fuel cells in the Service Module (SM) detected instrumentation. Despite the strike, the booster stages continued firing, placing Apollo 12 into a near circular Earth-parking orbit of 115 by 118 miles. Once in orbit the astronauts and ground control proceeded to check out all instrumentation and controls for lightning damage.

The lightning strikes had taken all three fuel cells off line, and had placed the CSM entirely on batteries, which were unable to maintain normal 75-ampere launch loads on the 28-volt DC bus. These power supply failures lit nearly every warning light on the control panel and caused much of the instrumentation to malfunction. However, NASA engineer John Aaron remembered the telemetry failure pattern from an earlier test when a power supply malfunctioned in the CSM Signal Conditioning Electronics (SCE), which converted raw signals from instrumentation to standard voltages for the spacecraft instrument displays and telemetry encoders. Aaron had Lunar Module Pilot Alan Bean, flying in the right seat as the spacecraft systems engineer, switch the SCE to Aux, a fairly obscure process which Bean remembered. Aaron's quick thinking and Bean's memory saved what could have been an aborted mission.

Bean put the fuel cells back on line and the crew carefully checked out their spacecraft, determining that the lightning strikes had caused no serious permanent damage. After one-and-a-half orbits, the electrical circuits were all functioning properly and no significant problems were noted. Then, the S-IVB stage was re-ignited for a second burn of five minutes, 45 seconds, placing Apollo 12 into an initial free-return translunar trajectory (TLI). About 40 minutes later, the Apollo 12 CSM known as the Yankee Clipper separated from the S-IVB, performed its transposition, and then docked with the Lunar Module Intrepid, a procedure that was televised on Earth. The S-IVB stage was then jettisoned. However, based on incorrect data of trajectory commands, it failed to go into the planned heliocentric orbit. Instead, it was placed into an elliptical Earth-orbit of

101,350 by 535,522 miles, for a period of 42 days. Charles Conrad and Alan Bean then entered the Intrepid to check for possible damages from the lightning strike. After a thorough inspection in which no problems were found, they re-entered the Yankee Clipper

The flight plan for Apollo 12 was similar to that of Apollo 11, except Apollo 12 was to fly a higher inclination to the **lunar equator** and leave the free-return trajectory after the second translunar midcourse correction. This first non-free-return trajectory on an Apollo mission was designed for three primary reasons:

1. To allow a daylight launch and a corresponding translunar injection above the Pacific Ocean.
2. To allow a stretch of the translunar coast to gain the desired landing site lighting at the time of LM descent.
3. To conserve fuel and permit the Goldstone, CA tracking antenna to monitor the LM descent and landing.

Descent and Lunar Landing – Apollo 12

On 19 November 1969, with the LM behind the Moon in the 14th orbit of the CSM, and 109½ hours into the mission, the descent orbit insertion maneuver began. The LM descent engine fired for 29 seconds, lowering the orbit of the Intrepid to about 9 miles by 69 miles. After the LM emerged from behind the Moon, telemetry contact was re-established with Mission Control in Houston. Using a newly developed "Lear" powered-flight data processor in Houston, the actual trajectory data, as well as correction maneuver information, were transmitted to the LM crew. This enabled them to update the automatic downrange navigation computer program, permitting the precision touchdown at the intended site.

With Conrad controlling the descent semi-manually for the last 500 feet, a precision landing occurred about one hour after the maneuver began. Closer to the target than anyone expected, Intrepid landed in the Ocean of Storms about 120 feet northeast of Head Crater, and about 600 feet northwest from where Surveyor III, an inactive lunar probe, had landed on the Moon in April 1967. Conrad and Bean had achieved a precise landing at their expected location. Conrad and Bean did not formally name their landing site, although Conrad nicknamed the intended touchdown area "Pete's Parking Lot". The second lunar landing was an exercise in precision targeting, which would be needed for future Apollo missions. Most of the descent was automatic, with manual control assumed by Conrad during the final few hundred feet of descent. Apollo 12 had "caught up" to a probe sent to land on another world.

Conrad opened the Intrepid hatch at just over 115 hours into the mission to begin the first lunar “Moon walk” for the Apollo 12 crew. In their first lunar exploration, Conrad spent three and a half hours outside Intrepid, and Bean logged about three hours. During this EVA, Conrad collected lunar surface samples and deployed both the S-band communication antenna and the solar wind experiment. Bean was assigned to mount the color TV camera on a tripod. In the process of doing so, it was inadvertently pointed into the sun and ceased to function. Throughout this first EVA, Conrad and Bean also took photographs of the experiment equipment, the spacecraft, the lunar terrain (lurain), and of themselves. The crew then re-entered the LM, ate, recharged their backpacks to prepare for the second EVA the following day, and slept for about five hours.

On 20 November, 1½ hours earlier than planned, the Apollo 12 crew began their second EVA. Their second EVA included the collection of 70 pounds of rock and dirt samples, the retrieval of 10 to 15 pounds of randomly selected selenological samples, and further probing of two areas to retrieve lunar material from depths up to 32 inches below the surface. The crew retrieved the inactive TV camera and stored it in the LM for return to Earth. The most important part of this second EVA was a one-mile traverse of the lunar terrain, ranging up to 1,300 feet away from Intrepid. Walking northwest to the site of the ALSEP (**Apollo Lunar Surface Experiments Package**, which comprised a set of scientific instruments placed by the astronauts at the landing site of each of the five Apollo missions to land on the Moon following Apollo 11) deployment, Conrad and Bean then turned south to perform a selenological rock survey. They skirted past several craters. Eventually, they entered the 650-foot-wide Surveyor Crater to retrieve parts of Surveyor III, which was perched some 150 feet from the edge at the southern quadrant.

Lunar Ascent and Return – Apollo 12

Approximately six hours later on 20 November, after a total of thirty-one and a half hours on the Moon, the LM ascent stage was fired for about seven minutes, putting Intrepid into an initial lunar orbit of 10 by 54 miles for rendezvous and docking with the Yankee Clipper. About three and a half hours later, the rendezvous and docking maneuvers were televised to Earth by Gordon.

Following crew return to the CSM, a controlled burn of the remaining propellants in the empty ascent stage, it was jettisoned and allowed to deorbit, causing the stage to crash into the Moon, providing a measurable seismic shock impulse. This provided predictable impact data for the ALSEP seismometer, even though the impact occurred about forty miles from the ALSEP. The combined length and severity of the seismic disturbance set up by the impact was estimated to equal that of one ton of TNT. To the surprise of seismologists, strong signals lasted for more than a half hour, and weaker signals ceased about an hour later.

While the Yankee Clipper was in its 27th and 28th revolutions, Gordon had conducted a multi-spectral photographic survey of the lunar surface. With the three-man crew on board the CSM, the crew then made a change of plane maneuver 3.8 degrees to the north on the 39th lunar orbit. During the 45th revolution and in the 89th hour of the mission, the crew performed a nineteen second burn to put Apollo 12 into a trans-Earth trajectory, which occurred on 21 November. Both maneuvers were performed by a burn of the service propulsion system (SPS). The crew stayed an extra day in lunar orbit taking photographs of future landing sites on the lunar surface for a total time in lunar orbit of eighty-nine hours.

The return flight was uneventful; however, the crew of Apollo 12 did witness (and photograph) a solar eclipse, although this one was of the Earth eclipsing the Sun. A midcourse correction maneuver occurred 22 November, when Apollo 12 was about 208,000 miles from Earth. On 23

November, when the spacecraft was still 108,000 miles from Earth, the crew held a televised news conference, followed by some much-needed sleep. A second scheduled midcourse correction maneuver was not necessary.

Splashdown – Apollo 12

The Apollo 12 mission ended on 24 November with a successful splashdown in the Pacific Ocean. Following the same nominal re-entry procedure scheduled for Apollo 11, Apollo 12 ended its 10-day, 4½ hour flight by splashing down between 400 and 500 miles southeast of American Samoa. Splashdown occurred about three miles from the target area, and just three miles south of the recovery ship USS Hornet, which was within sight of the splashdown. During splashdown, a 18 mm film camera dislodged from overhead storage and struck astronaut Alan Bean in the forehead, rendering him briefly unconscious. He suffered a mild concussion and received a serious cut that required six stitches. After recovery by the Hornet, the crew was flown to Pago Pago International Airport in Tafuna for a reception, before being flown on a C-141 cargo plane to Honolulu. Following the usual reception and their flight to Honolulu, the crew of Apollo 12 became the second to be quarantined.

IV. Apollo 13 – Miraculous Recovery

The first two lunar landings had gone reasonably well, with some minor glitches and a few bumps and bruises. Apollo was the third and final phase of the Moon Landing project begun in 1961, and it had been culminated when the Americans put the first man on the Moon in July, 1969. That was an achievement of gigantic proportions, and involved many engineers, scientists, contractors and project leaders, and was the epitome of successful project management. Nine missions were planned to land men on the Moon, and Apollo 11 and Apollo 12 had been successful beyond even the most optimistic of NASA's visions.

Apollo 13 would be the third lunar landing in the Apollo program, and was launched from Cape Kennedy Space Center on **11 April 1970**. On board were James Lovell, the Commander, Jack Swigart, the Command Module Pilot, and Fred Haise, the Lunar Module Pilot. Lovell, considered by many at NASA to be one of the most competent of all the American astronauts, had already been in space three times (Gemini 7 and Gemini 12, as well as Apollo 8 – the first spacecraft to perform a lunar orbit.) Swigart who was selected in the fifth group of astronauts by NASA in 1966, was initially part of the Apollo 13 backup crew; however, a German measles scare forced NASA to replace Ken Mattingly, who was susceptible to the virus, with Swigart just three days before the launch. Haise, also selected by NASA in the fifth group of astronauts, had been the backup Lunar Module Pilot for both Apollo 8 and Apollo 11, but this was his first space flight.

At launch the two main Saturn V rockets did not perform perfectly, but with some slight maneuvering, they lifted Apollo 13 into a near-circular orbit 100 miles above and around the Earth. Apollo 13 made nearly two orbits around the Earth, then fired its third Saturn V booster rocket (S-IVB) and headed for the Moon. In the 56th hour of the flight, when Apollo 13 was approximately 205,000 miles beyond the Earth's surface, the crew had just completed a live TV broadcast from their spacecraft.

"Houston, We Had a Problem"

Haise was in the process of powering down the Lunar Module, and flight control in Houston requested that Swigart turn on the hydrogen and oxygen tank stirring fans in the Service Module. About two minutes later the crew heard a loud bang, followed almost immediately by variations in the electrical power and the firing of the attitude control thrusters. The crew's first inclination was that a meteoroid had struck somewhere on the Lunar Module. However, within a few minutes they quickly realized that an explosion had taken place in the Service Module, the large separately docked module that provided power, oxygen, and water to the command module, and was also responsible for removing carbon dioxide and other human waste.

Investigation later revealed that one of the two oxygen tanks had exploded because of an electrical fire that had occurred due to a breakdown in the thermal insulation, and all the oxygen for the fuel cells was depleted in about two hours. The crew did not panic, and immediately shut down the emergency battery backup power system in the Command Module in order to preserve it for re-entry back to earth. This meant that the crew would have to move into the Lunar Landing module for the nearly three-day return flight back to earth, a premise that had been discussed several years earlier, but had been discarded as being impractical. The Lunar Module was designed to carry two men and support them for 1 1/2 days. It was now being asked to carry three men and to sustain them for three days.

Project Teams Evaluate the Options

Ground Control in Houston, Texas immediately recognized that a safe return from a lunar landing would be impossible under the circumstances, so Flight Director Gene Kranz gave the order to abort the mission, and thus began a series of events that saved the three astronauts' lives. The quickest abort plan was to use a direct trajectory by implementing the Service Module propulsion system, and its operation was now questionable. In addition, this plan required the jettison of the Lunar Module, which was out of the question since the crew's survival depended on their using the Lunar Module for a safe return. Another option was to burn the Service Module propulsion to depletion, then to disconnect the Service Module from the CM and LM. However, the Service Module provided thermal protection to the Command Module's heat shield and needed to stay connected to the Command Module as long as possible.

By this time Apollo 13 was less than one hour from the Moon's gravitational field, and there was also concern regarding the structural integrity of the Service Module. For these reasons Director Kranz and his project team chose a circumlunar abort plan, which would use the Moon's gravity to essentially boomerang the spacecraft and return it toward Earth with a catapult effect. A series of short propulsion system burns would place the spacecraft on an expedient trajectory that would have it land in the Pacific Ocean, approximately ten hours sooner than if its landing were to occur in the Indian Ocean.

Each Problem Required a Decision

The Lunar Module was powered by silver-zinc batteries and, although it carried enough oxygen to support the three-man crew, other consumables such as electrical power and water were at a premium. Considerable planning and experience were required by the crew, the flight controllers, and all ground support personnel to assure the crew's safe return. In order to maintain communications with ground personnel, the Lunar Module was powered down to the lowest level possible, and an abort guidance system was used instead of the primary guidance system in order to conserve even more power.

Another problem involved the use of lithium hydroxide canisters for the removal of carbon dioxide from the Lunar Module. The Command Module had an adequate supply of canisters, but they were not compatible with those in the Lunar Module. Another project team improvised a way to join the Command Module canisters, which were cone-shaped, with those in the Lunar Module that had a rectangular shape, by drawing air through a tightly fitted return hose.

Help from an Astronaut

Still another problem that had to be solved to ensure a safe return was providing a complete power-up of the Command Module, which had been completely shut down. Estimates of the power supply without any modifications would have left the Apollo 13 stranded in a circumsolar orbit when their power deteriorated while they were still nearly 100,000 miles from Earth. Although this had never been done in-flight, Flight Controller John Aaron and his project team acted on the initiative of grounded astronaut Ken Mattingly, who had discovered a unique method for extending the spacecraft’s limited power supply. Engineers and designers reconfigured the upgraded power supply for the spacecraft in just a few hours, which would allow for a safe re-entry and full parachute splashdown. As a side note, Mattingly never did contract German measles.

One Final Critical Solution

Finally, the last problem to be solved was figuring out how to separate the Lunar Module a safe distance from the Command Module just prior to reentry into the earth's atmosphere. The normal procedure was to use the Service Module's reaction control system to pull the Command Module away from the Lunar Module, but the reaction control system had been rendered useless due to the limited power available in the Service Module; furthermore, the inoperative Service Module would have to be released before the Lunar Module was undocked. To solve this problem Grumman Aerospace Corporation called on a project team of engineers and scientists from the University of Toronto.

Led by senior scientist Bernard Etkin, the six engineers on the UT team were asked to solve the problem in twenty-four hours. Using their slide rules (this was pre-calculator and pre-computer), the team concluded that pressurizing the tunnel that connected the Lunar Module with the Command Module just prior to re-entry would provide the crew with enough force to push the

Lunar Module a safe distance away from the Command Module. The pressure calculation was critical because too low of a pressure would fail to provide sufficient separation, whereas too high of a pressure would cause damage to the hatch and jeopardize the lives of the astronauts.

Re-entry, Splashdown, and Rescue

As Apollo 13 neared the earth's atmosphere, the crew first disconnected and separated the Service Module, using the Lunar Module's reaction control system to pull themselves safely away from it. In doing so, they took several photographs of the Service Module, which allowed NASA to later make an assessment of the damages and future improvements of Apollo's other Service Modules. Then the crew jettisoned the Lunar Module, using the procedure developed by the project team from the University of Toronto. There was heightened tension by ground support personnel, as the usual blackout period upon entering the earth's atmosphere of four minutes without communications extended to almost six minutes. If you ever saw the movie "Apollo 13" with Tom Hanks playing the role of Commander Jim Lovell, you will understand the intensity of this scenario.

However, the re-entry went smoothly and the Command Module splashed down in the South Pacific Ocean, less than four miles from the recovery ship Iwo Jima. The total flight time was almost exactly 6 days. The crew was safely on board the ship about 45 minutes later and in good condition, thanks to their training and expertise, and thanks to the ingenuity and capabilities of the many project leaders and design team members that were involved. The time frame for devising a workable plan to safely return a crippled Apollo 13 spacecraft to Earth had been less than three days. The many valuable members of the diverse groups that made up the Apollo 13 recovery team were all to be commended. The success of this accomplishment, particularly since it took place in the days before computers were well-established, was truly remarkable

V. Successful Lunar Landing Missions

A. Apollo 14

Beginning with **Apollo 14**, increased LM propellant reserve was made available for the powered descent and landing, by using the CSM engine to achieve the 50,000-foot (9½ mile) perilune. After the LM undocked from the CSM, the CSM would raise and begin a circularized orbit for the remainder of the mission.

Mission Objectives – Apollo 14

The primary objectives of this mission were to explore the Fra Mauro region centered around deployment of the Apollo Lunar Surface Scientific Experiments Package (ALSEP); lunar field geological investigations and materials, and deployment of other scientific instruments not part of ALSEP. In addition, the crew was to perform various communications tests using S-band and

VHF signals to determine reflective properties of the lunar surface, and to provide further photographic details of the lunar surface from the lunar-orbiting CSM.

Mission Crew – Apollo 14

The crew for **Apollo 14** included Commander Alan Shepard, Lunar Module Pilot Edgar Mitchell, and Command Module Pilot Stuart Roosa. Shepard was a US Naval Academy graduate, and had the rank of Rear Admiral. He was selected as one of the original NASA Mercury Seven astronauts in 1959. In May 1961 he became the first American to travel into space, making the first manned Project Mercury flight in a spacecraft he named Freedom 7.

Mitchell was a graduate of Carnegie Tech and a US Navy Captain, who later received his Ph. D. in aeronautical engineering from MIT. Selected in the 5th group of astronauts by NASA in 1966, his crew was originally scheduled to fly in Apollo 13, but NASA rescheduled the entire crew to allow for additional training for Commander Shepard. When Apollo 13 had its near-fatal explosion, Mitchell joined astronaut Mattingly in a spacecraft simulator, and both men were instrumental in Apollo 13 returning safely to Earth.

Command Module Pilot Roosa, a USAF Colonel, had received his B.S.in Aeronautical Engineering from Oklahoma State University. Selected by NASA in the fifth group of astronauts in 1966, Roosa was serving as the CAPCOM (Capsule Communicator), responsible for communicating with the crew at Launch Complex 34, when Apollo 1 had its fatal fire on 27 January 1967 that took the lives of three American astronauts.

Lunar Descent/Mission Highlights– Apollo 14

Apollo 14 was the eighth manned mission in the United States Apollo program, and was launched on **Sunday, 31 January 1971**, at 4:03 p.m. EST. Liftoff was delayed forty minutes, due to launch site weather restrictions, the first such delay in the Apollo program. After achieving a near-circular orbit and transposing the spacecraft, the crew experienced difficulties in docking with the LM. Six attempts were required before a "hard dock" was achieved. An in-flight televised inspection of the docking mechanism revealed no apparent reason for the malfunction, and the system appeared to be functioning normally.

The Kitty Hawk reached lunar orbit about 100 hours after launch, and began separation from the Lunar Module Antares, which had two serious problems. First, the LM computer began getting an ABORT signal from a faulty switch. NASA believed that the computer was getting erroneous readings because of a bad solder connection. If the problem recurred after the descent engine fired, the computer would think the signal was real and would initiate an auto-abort, causing the ascent stage to separate from the descent stage and climb back into orbit. NASA and the software teams at MIT solved that problem by having Mitchell manually enter software modifications on the LM computer pad just in time to avoid aborting the lunar landing.

A second problem occurred during the powered descent, when the LM landing radar failed to automatically lock onto the Moon's surface, depriving the navigation computer of vital information on the vehicle's altitude and vertical descent speed (due to an unrelated bug in the radar's operation). After the astronauts cycled the radar breaker, the unit successfully acquired a signal at 18,000 feet (3½ miles), again just in time to avoid an abort. Shepard then manually landed the LM closer to its intended target than any of the other five Moon landing missions. A post-flight review of the descent data showed astronauts probably would have been forced to abort the landing as they approached the lunar surface.

Commander Alan Shepard began the first lunar EVA about one hour later than scheduled, but it included ALSEP deployment and it lasted nearly five hours. The second EVA began on 06 February 1971, and during this EVA, Shepard and Edgar Mitchell moved more than half a mile from their LM. They conducted selenological investigations, collected lunar samples and attempted to reach the rim of Cone crater, approximately 300 feet above their landing site. The total time for the two EVA's was about 9½ hours, and Shepard set a new distance-traveled record on the lunar surface of approximately 9,000 feet. During the second traverse, the astronauts collected 94 pounds of rocks and soil for return to Earth. The samples were scheduled to go to 187 scientific teams in the United States, as well as 14 other countries for study and analysis. Also during the second EVA, Shepard hit two golf balls with a modified six-iron that he had managed to smuggle aboard the Antares. Restricted by his spacesuit, he was only able to swing with one hand, nevertheless, he claimed that the second ball went "miles and miles" due to the low gravity of the Moon. Later he amended his claim, saying that the ball only traveled 200 to 400 yards; that was still quite an achievement. In the meantime, Command Module Pilot Roosa had been performing orbital science activities and was attempting to photograph the Descartes area of the Moon, the landing site planned for Apollo 16.

Lunar Ascent/Return to Earth – Apollo 14

The liftoff of Antares from the lunar surface took place precisely on schedule. Rendezvous and docking occurred only two minutes later than scheduled. The command module Kitty Hawk splashed down safely in the Pacific Ocean at 4:05 p.m. EST on 09 February 1971, exactly nine days and two minutes after launch. The actual landing point was only about 2,050 yards off its targeted point, which was approximately 880 miles south of American Samoa, and just four miles from the prime recovery ship, the USS New Orleans. They were eventually flown to Honolulu, where the Apollo 14 astronauts were quarantined, becoming the last lunar explorers to be quarantined on their return from the Moon.

C. Apollo 15

Apollo 15 was the ninth manned mission in America's Apollo program, and was the fourth actual mission to land astronauts on the Moon (Apollo 11, Apollo 12, and Apollo 14). This was the first of what were considered long-term missions, during which the astronauts would have long stays on the Moon, with a greater focus on the lunar and astral science activities than had been performed on previous missions.

Mission Objectives – Apollo 15

Apollo 15 was the first of the Apollo missions capable of extending the astronauts to a longer stay time on the Moon while giving them greater surface mobility. There were several objectives falling in the general categories of lunar surface science and lunar orbital science. The major mission objectives were to explore the Hadley-Apennine region, set up and activate lunar surface scientific experiments, make engineering evaluations of new Apollo equipment, and conduct lunar orbital experiments and photographic tasks. Another major mission objective involved the launching of a subsatellite into lunar orbit by the command service module shortly before beginning its return to Earth portion of the mission. The subsatellite was designed to investigate the Moon's mass and gravitational variations, particle composition of space near the Moon, and the interaction of the Moon's magnetic field with that of Earth. Other objectives for the Apollo 15 mission included the third in a trio of operating ALSEPs (the first two were by Apollo 12 and Apollo 14). Engineering and operational objectives included evaluation of modifications to the lunar module, which had been redesigned for carrying a heavier payload and for a lunar stay time of almost three days. Changes to the Apollo spacesuit and to the portable life support system were also evaluated.

Mission Crew - Apollo 15

The crew for **Apollo 15** included Commander David R. Scott, Lunar Module Pilot James B. Irwin, and Command Module Pilot Alfred M. Worden. Dave Scott was an engineering graduate from the US Military Academy at West point, but chose the USAF, where he eventually achieved the rank of Colonel. Scott was selected by NASA in the third group of astronauts in 1963, and flew more missions than any of the other Group Three astronauts. Scott made his first flight into outer space as Pilot of the Gemini 8 mission, along with Neil Armstrong, in March 1966. Scott then spent ten days in orbit as Command Module Pilot aboard Apollo 9, his second spaceflight. Scott was the backup Commander for Apollo 12, which put him into the position as Commander for Apollo 15.

Jim Irwin received a BS degree in Science from the US Naval Academy and an MS degree in Aeronautical Engineering from the University of Michigan. Irwin joined the USAF, becoming a test pilot and flight instructor, before achieving the rank of Colonel. He was one of the 19 astronauts selected by NASA in April, 1966. He served as a member of the astronaut support crew for Apollo 10, and as backup Lunar Module Pilot for the second Moon landing mission, Apollo 12, before being assigned to Apollo 15.

Al Worden received a BS degree in Military Science from the US Military Academy, and MS degrees in Astronautical/Aeronautical Engineering and Instrumentation Engineering from the University of Michigan. Worden chose the USAF as his career, and also achieved the rank of Colonel upon his retirement. He was one of the19 Astronauts selected by NASA in April 1966. He served as a member of the astronaut support crew for the Apollo 9 flight and as backup Command Module Pilot for the Apollo 12 flight, which led to his assignment on Apollo 15.

Mission Highlights – Apollo 15

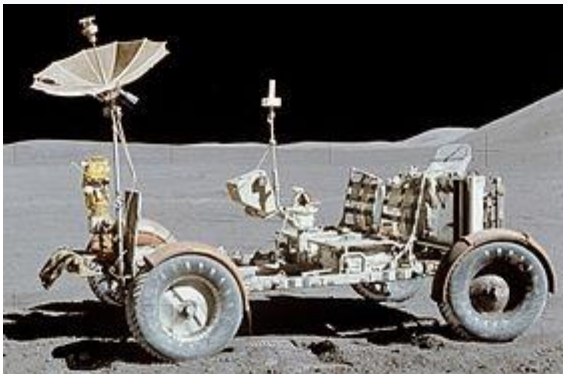
Apollo 15 was launched on **26 July 1971**, at 9:34 AM EDT from Pad 39A at the Kennedy Space Center, Florida, from which all Apollo lunar landing missions were launched. The timing of the launch was such that Apollo 15 would be able to arrive at the Moon with the proper lighting conditions at Hadley-Apennine region; had the mission been scrubbed, it would have necessarily been rescheduled for one month later. The astronauts had been suited up and taken to the launch site and entered the spacecraft three hours before launch. There were no unplanned delays in the countdown.

Once in its low-Earth-orbit, Apollo 15 remained in its parking orbit for two hours and forty minutes, allowing the crew (and Houston, via telemetry) to check the spacecraft's systems. As the spacecraft completed it first 1½ Earth orbits, S-IVB was restarted for trans-lunar-injection (TLI), placing the craft on a path to the Moon. The Command/Service Module (CSM) and the Lunar Module remained attached to the nearly-exhausted S-IVB booster. Once trans-lunar injection had been achieved, placing the spacecraft on a trajectory towards the Moon, explosive cords separated the CSM from the booster. Worden operated the CSM's thrusters to push it away from the S-IVB, then maneuvered the CSM to dock with the LM (docking went relatively smoothly on this flight). After Apollo 15 separated from the booster, the S-IVB maneuvered away, and would impact the Moon about an hour after the crewed spacecraft entered lunar orbit, though due to an error in calculations, the impact was more than 90 miles away from the intended target. The booster's impact was detected by the ALSEP seismometers left on the Moon by Apollo 12 and Apollo 14, providing useful scientific data.

Lunar Descent – Apollo 15

David Scott and James Irwin flew their LM to a perfect landing at 6:16 p.m. EDT 30 July 1971, at their primary site of Hadley Rille, a valley on the Moon, about 1,500 feet north and east of the targeted landing point. This site was typical of the class of features known as sinuous rilles, which are believed to be ancient lava flow channels, and was near a crater named Salyut. The landing approach over the Apennine Range - one of the highest on the moon - was at an angle of 26 degrees, and was the steepest approach yet used in Apollo lunar landings. Exploration and geological investigations at the Hadley-Apennine landing site were enhanced by the addition of the Lunar Roving Vehicle (LRV). This was also the first mission on which the Lunar Roving Vehicle became transportation for the astronauts. The LRV, or Lunar Rover, was a battery-powered,

Lunar Roving Vehicle



The Apollo Lunar Roving Vehicle from Apollo 15 on the Moon in 1971

four-wheeled vehicle used on the Moon the last three missions of the American Apollo program (15, 16, and 17) to move astronauts and materials on the lunar surface during 1971 and 1972. It was popularly known as "**Moon buggy**", a play on the words “dune buggy”. NASA had contracted the LRV to Boeing through the Marshall Space Flight Center in Huntsville on 28 October 1969, after recognizing that the “Moonwalk” from Apollo 11 was slow and plodding. The LRV was 10 feet long and two astronauts wide. It had a height of 45 inches, and weighed 463 pounds on the Earth (only 1/6th of that on the Moon.) The LRV was transported to the Moon on the Lunar Module (LM) and, once unpacked on the Moon’s surface, could carry two astronauts, their equipment, and lunar samples. The three LRVs used on Apollos 15, 16, and 17 remain on the Moon.

Performance of the Lunar Roving Vehicle, along with some of the other new mission equipment that went with it, such as the lunar communications relay unit and the ground-controlled television assembly, was extremely valuable and informative. During three periods of extravehicular activity, doing both “Moon walks” and buggy rides, on 31 July, 01 August, and 02 August, Scott and Irwin completed a record 18 hours, 37 minutes of exploration. They traveled 17½ miles, riding in the first car that humans had ever driven on the Moon. Together they collected more than 170 pounds of lunar samples, were able to set up the ALSEP array, and even obtained a core sample from about 10 feet beneath the lunar surface. Their extensive travels provided detailed oral descriptions and photographic documentation of geologic features in the vicinity of the landing site during the almost three days that they were on the lunar surface.

Lunar Ascent and Return to Earth – Apollo 15

On 02 August 1971, the LM Falcon fired its ascent stage engine and lifted off the Moon for its rendezvous with the command module Endeavor. The lunar liftoff was seen on Earth by using a television camera that was mounted on the LRV and trained on the LM. Although the two spacecrafts docked as Endeavor began its 50th lunar orbit, the crew had some difficulty launching the sub-satellite. On the 74th revolution, the subsatellite was spring-launched from the service module. On the next revolution, which was now on 04 August, the crew performed a 2-minute, 21-second SPS burn that put Apollo 15 on its path back to Earth. The next day (05 August), Worden became the first human to carry out a deep space EVA. He exited the CSM, climbed toward the rear of the SM, retrieved film cassettes from the cameras, and returned to the CSM. The entire operation was completed in 18 minutes, even though one whole hour had been scheduled in the original flight plan.

At approximately 4:46 p.m. EDT on **07 August 1971**, Apollo 15 splashed down in the Pacific Ocean, about 335 miles north of Honolulu, ending a flight of 12 days, seven hours. The crew was picked up by helicopters from the prime recovery ship, the USS Okinawa, about six miles from the targeted touchdown point. During the final stages of descent on its three main parachutes, the CM crew and shipboard observers noted one of the parachutes became only partially inflated following jettison of RSC fuel remaining on board. As a result of the loss of one parachute, the CM impacted at 21.8 mph, instead of the planned 19 mph, but none of the crew were injured. Apollo 15 had set several new records for crewed spaceflight:

1. heaviest payload in a lunar orbit of approximately 107,000 pounds,
2. maximum radial distance traveled on the lunar surface away from the spacecraft of about 17.5 miles,
3. most lunar surface EVAs (three) and longest total of duration for lunar surface EVAs (18 hours, 37 minutes,
4. longest time (about 145 hours) in lunar orbit,
5. longest Apollo mission (295 hours),
6. the first satellite placed in lunar orbit by a crewed spacecraft,
7. first deep space and operational EVA.

D. Apollo 16

Apollo 16 was the tenth manned mission in the American Apollo space program, the fifth and penultimate (next to last) mission to land astronauts on the lunar surface, and the first to land in the lunar highlands. Apollo 16 was the second of the Apollo missions that featured the use of the Lunar Roving Vehicle (LRV), increased scientific capability, and planned lunar surface stays by the astronauts of three days. As Apollo 16 was the penultimate mission in the Apollo program and there was no new hardware or procedures to test on the lunar surface, the last two missions presented opportunities for astronauts to clear up some uncertainties in understanding the Moon's properties. Although previous Apollo expeditions, including Apollo 14 and Apollo 15 had obtained samples of pre-mare (lunar volcanic eruption) material before lava began to upwell from the Moon's interior and flood the low areas and basins, none had actually visited the lunar highlands.

Mission Objectives – Apollo 16

Three primary objectives were to:

1. inspect, survey, and sample materials and surface features at a selected landing site in the Descartes region;
2. emplace and activate surface experiments;
3. conduct in-flight experiments and photographic tasks from lunar orbit.

Additional objectives included performance of experiments requiring zero gravity and engineering evaluation of spacecraft and equipment. The Descartes landing site is in a highlands region of the Moon's southeast quadrant, characterized by hilly, grooved, furrowed terrain. It was selected as an outstanding location for sampling two volcanic constructional units of the highlands. The location also became the fourth lunar station for the ALSEP (Apollo Lunar Surface Experiments Package). Some of the improvements from Apollo 15 included better handheld cameras, longer seat belts on the LRV for better astronaut retention, and continuous fluting of drill bits to eliminate drill jamming due to bit binding.

Mission Crew - Apollo 16

The crew for Apollo 16 included Commander John Young, Command Module Pilot Ken Mattingly, and Lunar Module Pilot Charles Duke. Young received his BS in Aeronautical Engineering from Georgia Tech, joined the US Navy after graduation, and rose to the rank of Captain. He was selected by NASA in the second group of astronauts in 1962, and became the first astronaut from that group to fly into space. Highly regarded as an aviator and test pilot by his peers, Young flew on Gemini 3, the first manned Gemini mission in 1965, and commanded Gemini 10 the next year. During his next flight assignment in 1969 on Apollo 10, he became the first person to fly solo around the Moon while his fellow astronauts, Gene Cernan and Tom Stafford, descended to within about nine miles of the lunar surface on the LM. Including Apollo 16, Young enjoyed the longest career of any astronaut, becoming the first person to fly six space missions (counting two later on the Space Shuttle).

Thomas Kenneth “Ken” Mattingly held a BS in Aeronautical Engineering from Auburn University. A naval aviator, test pilot and naval officer, Mattingly rose to the rank of Rear Admiral in the US Navy. Despite his achievements, he was not selected by NASA (probably because of his youth, he was only thirty years old) until the fifth group of astronauts in 1966. He had been scheduled to fly as the Command Module Pilot on Apollo 13, but was held back due to concerns about his exposure to German measles, which he did not contract. He was replaced by the backup CM Pilot Jack Swigart, and. missed the dramatic abort of the Apollo 13 spacecraft. However, as was recounted earlier, Mattingly spent considerable time in the CM simulator, and helped NASA solve the problem of power conservation for a safe Apollo 13 re-entry.

Duke, just a year older than Mattingly, was also selected by NASA in the group of astronauts in 1966. After receiving his BS from the US Naval Academy, he joined the United States Air Force, received his MS in Aeronautics and Astronautics from MIT, and rose to the rank of Brigadier General in the USAF. Duke gained a measure of fame as the CAPCOM for Apollo 11, broadcasting to a worldwide television audience as Neil Armstrong’s LM slowly descended to the Moon’s surface. He than followed that incident with a degree of notoriety when, as part of the backup crew for Apollo 13, he contracted German measles. He exposed Ken Mattingly, who was vulnerable to the disease, and had to be replaced by Tom Swigart just three days before the flight.

Mission Highlights – Apollo 16

Apollo 16 lifted off at 12:54 p.m. EST on **16 April 1972** from Launch Complex 39 at Kennedy Space Center in Florida. The launch of Apollo 16 had been delayed one month from 17 March to 16 April 16, the first launch delay in the Apollo program due to a technical problem. Problems included damage to a CM fuel tank earlier in January, and concerns that the explosive mechanism designed to separate the docking ring from the Command Module would not create enough pressure to completely sever the ring. The launch was nominal, although the crew did experience vibration similar to that of previous crews. The first and second stages of the Saturn V rocket performed as expected; the spacecraft entered low Earth orbit just under 12 minutes after lift-off. After reaching orbit, the crew spent time adapting to the zero-gravity environment and prepared the spacecraft for TLI (Trans-Lunar Injection).

After two orbits, the rocket's third stage reignited for just over five minutes, propelling the craft towards the Moon at about 22,000 mph. Six minutes after the burn of the S-IVB, the Command/Service Module, containing the crew, separated from the rocket about fifty feet before performing the transposition and smoothly extracting the Lunar Module from inside the expended rocket stage. Once on course towards the Moon, the crew put the spacecraft into a rotating axis mode in which the craft rotated along its long axis three times per hour to ensure even heat distribution about the spacecraft from the Sun. After further preparing the craft for the voyage, the crew began the first sleep period of the mission just under 15 hours after launch.

Just before the end of flight day three after nearly sixty hours from liftoff, while 207,000 miles from the Earth and still 39,000 miles from the Moon, the spacecraft's velocity began increasing as it accelerated towards the Moon after entering the lunar sphere of influence. The original plan for Apollo 16 was a nine-day mission, but two significant CSM problems contributed to a delay in landing and a subsequent early termination of the mission by one day. 1) en-route to the Moon an erroneous signal indicating guidance system gimbal lock during translunar coast was neutralized by a real time programming change by Mattingly, instructing the spacecraft computer to ignore input; and 2) in lunar orbit after undocking of <u>Casper</u> (LM) and <u>Orion</u> (CSM), circularization burn of the CSM was delayed when a backup circuit caused yaw oscillations of the SPS (Service Propulsion System). <u>Orion</u>'s descent was delayed until NASA engineers could determine that oscillations would not seriously affect the CSM's steering.

Lunar Descent – Apollo 16

On day four, the crew began preparations for the maneuver that would take the spacecraft into orbit around the Moon for final lunar orbit insertion. While over the far side of the Moon, the CSM's Service Propulsion System engine burned for 6 minutes and 15 seconds, braking the spacecraft and placing it into an orbit around the Moon with a low point of 67.5 miles and a high point of 197 miles. After entering lunar orbit, the crew prepared for the Descent Orbit Insertion (DOI) maneuver to further modify the spacecraft's orbital trajectory. The maneuver was successful, decreasing the craft's low point to 12.5 miles. The remainder of flight day four was spent preparing for activation of the Lunar Module, undocking, and lunar landing the next day.

With the preparations finished, Young and Duke undocked Orion from Mattingly in Casper a little over 96 hours into the mission. Mattingly prepared to shift Casper to a circular orbit while Young and Duke prepared Orion for the descent to the lunar surface. At this point, there was a malfunction during tests of the CSM's steerable rocket engine in preparation for the burn to modify the spacecraft's orbit. After several hours of analysis, mission controllers determined that the malfunction could be worked around and Young and Duke could proceed with the landing. As a result of this, powered descent to the lunar surface began about six hours behind schedule. Although Young and Duke began their descent to the surface at an altitude higher than planned, they were able to throttle-down the LM's landing engine on time, and the spacecraft landed within several hundred feet north and west of the planned landing site.

Even though their mission was shortened by one whole day, Young and Duke did manage to spend 71 hours on the Moon’s surface, and the astronauts explored the Descartes region on three separate EVA’s totaling more than twenty hours. Their first EVA included the Lunar Roving Vehicle setup and ALSEP deployment. The Rover travel took the astronauts west to Flag Crater, where they collected samples and photographed the area. The return drive was south of the outbound track to Spook Crater, where the astronauts took their first measurement with the lunar portable magnetometer. Just before returning to the lunar module, they deployed the solar wind composition experiment at the ALSEP site. Overall, their first EVA duration was just over seven hours, with about 2½ miles driven in the LRV.

The second EVA began with a drive south to Stone Mountain, where surface and core samples, along with a trench sample, were collected at two stations in the area of Cinco Craters. They traveled west, then north with stops at five additional stations for similar work. Young and Duke returned to the LM and ended their second EVA after seven and a half hours, traveling almost seven miles on the LRV. The third EVA was slightly shortened due to time constraints necessary to meet the ascent schedule. The astronauts did stop at "Shadow Rock" for additional sampling and photography. On their final stop near the LM, they added samples and core tubes to the collection. Closeout, including retrieval of solar wind composition, or SWC, and film from a long-distance ultraviolet camera/spectroscope, completed the third EVA after five hours, 40 minutes, and an LRV distance of seven miles.

Lunar Ascent and Return to Earth – Apollo 16

NASA engineers had determined that the Apollo 16 mission would end one day early, due to the previous problems that had been encountered. CAPCOM James Irwin notified Young and Duke from Mission Control that they were go for liftoff, and lunar liftoff came at 8:26 p.m. EST 23 April. When the ascent stage ignited, small explosive charges severed the ascent stage from the descent stage and cables connecting the two were severed. Six minutes after liftoff, at a speed of about 3,100 mph, Young and Duke reached lunar orbit. They successfully rendezvoused and re-docked with Mattingly in the CSM. After opening the hatch and reuniting with Mattingly, the crew transferred the samples Young and Duke had collected on the lunar surface into the CSM for transfer to Earth. After transfers were completed, the crew slept for a few hours before jettisoning the empty Lunar Module ascent stage the next day, which would have allowed it to be crashed intentionally into the lunar surface. However, it initially tumbled after separation and did not execute the rocket burn necessary for the craft's intentional de-orbit. The ascent stage eventually crashed into the lunar surface nearly a year after the mission.

After jettisoning the Lunar Module ascent stage, the crew released a subsatellite into lunar orbit from the CSM's Scientific Instrument Bay. Just under five hours later, on the CSM's 65th orbit around the Moon, its Service Propulsion System main engine was reignited to propel the craft on a trajectory (TLI) that would return it to Earth. The SPS engine performed the burn flawlessly despite the malfunction that had delayed the lunar landing several days before. During the return flight, Mattingly performed a "deep-space" extra-vehicular activity, or spacewalk, during which he retrieved several film cassettes from the CSM's SIM bay. The astronauts prepared the spacecraft for its re-entry the next day. At the end of the crew's final full day in space, the spacecraft was still approximately 90,000 miles from Earth and closing at a rate of about 4,772 miles per hour.

About three hours before re-entry, the crew performed a final course correction burn, altering their velocity by less than one mph. Approximately ten minutes before reentry into Earth's atmosphere, the cone-shaped Command Module containing the three crewmembers separated from the Service Module, which burned up during re-entry. After successful parachute deployment and less than 14 minutes after reentry began, the Command Module splashed down in the Pacific Ocean 220 miles southeast of Christmas Island, where the spacecraft and its crew were retrieved and safely aboard the aircraft carrier USS Ticonderoga within 37 minutes. Total mission from liftoff to splashdown was just over 290½ hours.

VI. Final Apollo Mission – Apollo 17

With the success of Apollo 16, the United States now could claim twenty-four Americans who had traveled to the Moon, and ten American astronauts had actually set foot on the lunar surface. Due to budget constraints as well as a growing lack of interest, Apollo 17 would become NASA’s last scheduled mission to the Moon. NASA had made the decision nearly two years prior that Apollo 17 would be the last mission in the Apollo program.

Mission Objectives – Apollo 17

Several landing sites had been suggested for the lunar landing site of Apollo 17. Some of the sites were too mountainous to risk a failed landing, and some of the sites were similar to those that had already been traveled. Even one site that was suggested on the dark side of the Moon was rejected, because the cost to provide realistic communication would have been prohibitive. This site that was selected for Apollo 17 was the Taurus-Littrow highlands and valley area, a location where the astronauts might find rocks both older and younger than those previously returned from other Apollo missions. The Apollo 17 mission would also be the final in a series of three missions that NASA named as J-type missions planned for the Apollo Program. These J-type missions were distinguished from previous G- and H-series missions by extended hardware capability, larger scientific payload capacity, and by the use of the battery-powered Lunar Roving Vehicle (LRV).

Scientific objectives of the Apollo 17 mission included: 1) geological surveying and sampling of materials and surface features in a preselected area of the Taurus-Littrow region, 2) deploying and activating surface experiments, and 3) conducting in-flight experiments and photographic tasks during lunar orbit and trans-Earth injection. These objectives included the Apollo Lunar Surface Experiments Package (ALSEP), lunar seismic profiling; lunar surface gravimeter, and impact of meteorites and meteoroids

Mission Crew – Apollo 17

Eugene Cernan, Ronald Evans, and former X-15 pilot Joe Engle were assigned as the backup crew of Apollo 14. Following the rotation pattern established by Deke Slayton, Director of Flight Crew Operations, and usually supported by NASA, the backup crew would fly as the prime crew three missions later, meaning that Cernan, Evans, and Engle would have flown Apollo 17. Harrison Schmitt served on the backup crew of Apollo 15 and, following the crew rotation cycle, was slated to fly as Lunar Module Pilot on Apollo 18. However, Apollo 18 was canceled in September of 1970. Following this decision, the scientific community pressured NASA to assign a geologist to an Apollo landing, as opposed to a pilot trained in geology. In light of this pressure, Harrison Schmitt, a professional geologist, was assigned the Lunar Module Pilot position on Apollo 17. Engle, who had flown sixteen X-15 flights, three of which exceeded the fifty miles border of space, was replaced.

Harrison Schmitt was raised in New Mexico and received his BS in geology from Caltech. He received a Ph. D. in geology from Harvard University in 1964, and was selected by NASA as a member of the first group of scientist-astronauts in September 1965. Although Schmitt spent his first year in training to become a jet pilot, his return to the astronaut corps in Houston allowed him to play a key role in training Apollo crews to be geologic observers when they were in lunar orbit and competent geologic field workers when they were on the lunar surface

Subsequent to the decision to assign Schmitt to Apollo 17, there remained the question of which crew (the full backup crew of Apollo 15 or the backup crew of Apollo 14) would become the prime crew of the mission. Slayton ultimately assigned the backup crew of Apollo 14 (Cernan and Evans), along with Schmitt, to the prime crew of Apollo 17. Gene Cernan received his B. S. in Electrical Engineering from Purdue University while in the US Navy ROTC program. He was selected by NASA in the third group of astronauts in 1963. He piloted Gemini 9A, which simulated a lunar orbit rendezvous. Then in May 1969, during the Apollo 10 mission, Cernan and Commander Tom Stafford piloted the Lunar Module Snoopy in lunar orbit to within ten miles of the lunar surface, successfully executing every phase of a lunar landing up to final powered descent, which provided NASA planners with critical knowledge of technical systems and lunar gravitational conditions. That mission enabled Apollo 11 to land on the Moon two months later.

Evans was born and raised in Kansas and, similar to Cernan, received his B. S. in Electrical Engineering from the University of Kansas through the Navy ROTC program. A naval aviator and combat pilot, Evans logged over 4,600 hours in jet aircraft, and went on to receive an M. S. in Aeronautical Engineering from the U. S. Naval Postgraduate School. He achieved the rank of

Captain in the US Navy, and was a member of the group of nineteen astronauts selected by NASA in April 1965. While Evans was part of the backup crew for Apollo 14, Apollo 17 was his first space flight.

Launch and Outbound Flight – Apollo 17

Apollo 17, the final mission of NASA's Apollo program, launched at **12:33 a.m. EST on 07 December 1972** from the Kennedy Space Center. Apollo 17 was the last manned Saturn V launch as well as the only night launch. The launch had been delayed by two hours and forty minutes due to an automatic cutoff in the launch sequencer during the countdown. The issue was quickly determined to be a minor technical error. The clock was reset and held at the "T minus 22-minute" mark while technicians resolved the malfunction in order to continue with the launch. This pause was the only launch delay in the Apollo program caused by this type of hardware failure. Because of the night launch, observers were able to see a red streak crossing the northern sky from as far away (500 miles) as Miami, FL.

Following the circular low-Earth-orbits, the S-IVB third stage was re-ignited three hours and thirteen minutes after launch, propelling the spacecraft towards the Moon. One half hour later, the command and service module, was separated from the S-IVB. Approximately 15 min later, following transposition by the CSM, it docked with the lunar module. After CSM/LM extraction from the S-IVB, the S-IVB was targeted for lunar impact, which occurred 10 December 1972. The impact location was approximately 97 miles northwest of the planned target landing point of Apollo 17. The event was recorded by the passive seismic experiments deployed on one of the four previous lunar landing missions. At approximately 2:47 pm EST on 10 December 1972, the SPS (Service Propulsion System) engine on the CSM ignited to slow down the CSM/LM stack in order to place the spacecraft into lunar orbit. Following orbit insertion and orbital stabilization, the crew began preparations for landing in the Taurus-Littrow valley.

Lunar Descent/Mission Highlights – Apollo 17

The initial lunar orbit insertion, which occurred two days and nineteen hours after launch, placed the spacecraft into a lunar orbit of 195 by 60 miles. The crew spent the next four and a half hours reducing the spacecraft orbit to 68 by 22 miles, and it remained in this low orbit for more than 18 hours, during which time the CSM/LM undocking and separation were performed. Once undocked, the CSM performed a circularization maneuver, which placed it into an orbit of 81 by 62 miles. A short time later, Cernan and Schmitt entered the LM Challenger to prepare for descent to the lunar surface. They placed the LM into an orbit with a perilune altitude of approximately seven miles, and began the powered descent to the lunar surface after one lunar orbit. The last American lunar landing (so far) occurred as planned on the fourth day at 8:00 p.m. on 11 **December** in the Taurus-Littrow valley**.**

Cernan and Schmitt made a total of three EVA's (extravehicular activities), which lasted a total of 22 hours. EVA No. 1 was seven hours, 12 minutes long, the second EVA lasted seven hours, 37 minutes, and the final EVA was concluded in about seven hours, 11 minutes. Apollo 17, which was the last lunar mission, conducted several scientific experiments because a geologist was on board. There were two experiments that were particularly significant: the gravimeter and the SIM.

Apollo 17 was the only Apollo lunar landing mission to carry the traverse gravimeter experiment (TGE). As gravimeters had proven to be useful in the geologic investigation of the Earth, the objective of this experiment was to determine the feasibility of using the same techniques on the Moon to learn about its internal structure. The gravimeter was used to obtain readings at the landing site in the immediate vicinity of the lunar module, as well as various locations on the mission's traverse routes. The TGE was carried on the Lunar Roving Vehicle; measurements were taken by the astronauts while the LRV was not in motion or after the gravimeter was placed on the surface. A total of twenty-six measurements were taken with the TGE during the mission's three moonwalks, with very productive results. As part of the ALSEP, the astronauts also deployed a Lunar Surface Gravimeter in a similar experiment, but the equipment failed to function properly.

Sector one of the Apollo 17 Service Module contained the scientific instrument module, known as the SIM bay. The SIM bay housed three experiments for use in lunar orbit:

a. a **lunar sounder**, beamed electromagnetic impulses toward the lunar surface
b. an **infrared scanning radiometer**, with the objective of generating a temperature map of the lunar surface and locating volcanic activity.
c. a **far-ultraviolet spectrometer**, to be used to obtain data pertaining to the composition, density, and constituency of the lunar atmosphere.

The LRV's were designed with a top speed of about 8 mph, although Cernan is on record as having reached a maximum speed of 11.2 mph, giving him the (unofficial) lunar land-speed record.

Lunar Ascent and Return to Earth – Apollo 17

Cernan and Harrison Schmitt, the first and only scientist-astronaut to land on the Moon, successfully lifted off from the lunar surface in the ascent stage of the LM on 14 December, at 5:55 pm EST. Their time on the lunar surface was 75 hours, and their time in lunar orbit was another 17 hours. The lunar rover vehicle had traversed the lunar surface a total of 19 miles, and the two astronauts had gathered more than 220 pounds of lunar matter.

After a successful rendezvous with Ron Evans in the CSM in orbit, the CSM and LM docked a little after 1:10 a.m. The crew transferred equipment and lunar samples between the LM and the CSM for return to Earth. Following this, the LM ascent stage was sealed off and inserted into a 56 by 11 miles orbit, and jettisoned at 1:31 am on 15 December. The ascent stage was then deliberately crashed into the Moon in a collision recorded by seismometers that had been deployed by Apollo 17 and by each ALSEP installed on previous Apollo expeditions.

Two days later Evans successfully conducted a one hour and seven minutes trans-Earth EVA, during which he retrieved the lunar sounder film, as well as the panoramic and mapping camera film cassettes from the instrument bay on the exterior of the CSM. On 19 December, the crew jettisoned the Service Module, and re-entered the Earth's atmosphere in the Command Module America. The Apollo 17 spacecraft splashed down safely in the Pacific Ocean at 2:25 pm, 4 miles from the recovery ship, USS Ticonderoga. Cernan, Evans, and Schmitt were then retrieved by a recovery helicopter and were safely aboard the recovery ship less than one hour after landing.

Summary

At its zenith in the mid-1960's, more than 400,000 Americans were involved in the Apollo program and its satellite programs. A total of twenty-seven space pioneers traveled to the Moon, but only twelve astronauts actually set foot on the lunar surface. Those twelve were:

1.	**Neil Armstrong**	**Apollo 11**	**(1930-2012)**
2.	**Buzz Aldrin**	**Apollo 11**	**(1930-)**
3.	**Pete Conrad**	**Apollo 12**	**(1930-1999)**
4.	**Alan Bean**	**Apollo 12**	**(1932-2018)**
5.	**Alan Shepard**	**Apollo 14**	**(1923-1998)**
6.	**Edgar Mitchell**	**Apollo 14**	**(1930-2016)**
7.	**David Scott**	**Apollo 15**	**(1932-)**
8.	**James Irwin**	**Apollo 15**	**(1930-1991)**
9.	**John Young**	**Apollo 16**	**(1930-2018)**
10.	**Charles Duke**	**Apollo 16**	**(1935-)**
11.	**Gene Cernan**	**Apollo 17**	**(1934-2017)**
12.	**Harrison Schmitt**	**Apollo 17**	**(1935-)**

As you can see from the above exhibit, only four of the "Moonwalkers" are still alive, which is regrettable but understandable, since 2019 is the 50th anniversary of the first Moon landing. Placing a man on the Moon was arguably the greatest physical achievement ever performed by mankind. The United States of America, less than 200 years old, had accomplished what most people felt was unachievable if not impossible. The effort, which had taken place over a fifteen-year period, was the result of the concerted efforts of American politicians, project leaders, engineers, suppliers, contractors, and astronauts. Let us hope that even greater achievements than this will be realized in the future.