

Exploration of the Moon

Ilda Swearingen

First Edition, 2012

ISBN 978-81-323-4644-9

© All rights reserved.

Published by:

The English Press

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

Email: info@wtbooks.com

Table of Contents

Chapter 1 - Introduction to Exploration of the Moon

Chapter 2 - Moon Landing

Chapter 3 - Moon Landing Conspiracy Theories

Chapter 4 - Apollo Program

Chapter 5 - Colonization of the Moon

Chapter- 1

Introduction to Exploration of the Moon



Apollo 12 lunar module *Intrepid* prepares to descend towards the surface of the Moon.
NASA photo.

The physical **exploration of the Moon** began when Luna 2, a space probe launched by the Soviet Union, made an impact on the surface of the Moon on September 14, 1959. Prior to that the only available means of exploration had been observation. The invention of the optical telescope brought about the first leap in the quality of lunar observations.

Galileo Galilei is generally credited as the first person to use a telescope for astronomical purposes; having made his own telescope in 1609, the mountains and craters on the lunar surface were among his first observations using it.

In 1969, NASA's Project Apollo first successfully landed people on the Moon. They placed scientific experiments there and returned rocks and data that suggested the Moon is of a similar composition to the Earth.

Early history

In Mesopotamia, Babylonian astronomers by the early first millennium BC had discovered a repeating 18-year cycle of lunar eclipses. They had also known by this time that 19 solar years is about equal to 235 lunar months. In the 2nd century BC, Seleucus of Seleucia correctly theorized that tides were caused by the Moon, although he believed that the interaction was mediated by the Earth's atmosphere. According to Strabo (1.1.9), Seleucus was the first to state that the tides are due to the attraction of the Moon, and that the height of the tides depends on the Moon's position relative to the Sun.

By the mid-first millennium BC, Indian astronomers described the Moon's monthly elongation in the *Aitareya Brāhmaṇa*. By 499 AD, the Indian astronomer Aryabhata mentioned in his *Aryabhatiya* that reflected sunlight is the cause behind the shining of the moon.

Among the first in the Western world to offer a scientific explanation for the Moon was the Greek philosopher Anaxagoras (d. 428 BC), who reasoned that the Sun and Moon were both giant spherical rocks, and that the latter reflected the light of the former. His atheistic view of the heavens was one cause for his imprisonment and eventual exile. In Aristotle's (384–322 BC) description of the universe, the Moon marked the boundary between the spheres of the mutable elements (earth, water, air and fire), and the imperishable stars of aether. This separation was held to be part of Aristotelian physics for many centuries after. In the philosophy of Aristotle, the heavens, starting at the Moon, were the realm of perfection, the sublunary region was the realm of change and corruption, and any resemblance between these regions was strictly ruled out. Aristotle himself suggested that the Moon partook perhaps of some contamination from the realm of corruption. In his little book *On the Face in the Moon's Orb*, Plutarch expressed rather different views on the relationship between the Moon and Earth. He suggested that the Moon had deep recesses in which the light of the Sun did not reach and that the spots are nothing but the shadows of rivers or deep chasms. He also entertained the possibility that the Moon was inhabited. It had been suggested already in antiquity that the Moon was a perfect mirror and that its markings were reflections of earthly features, but this explanation was easily dismissed because the face of the Moon never changes as it moves about the Earth. The explanation that finally became standard was that there were variations of "density" in the Moon that caused this otherwise perfectly spherical body to appear the way it does. The perfection of the Moon, and therefore the heavens, was thus preserved. Aristarchus went a step further and computed the distance from Earth, together

with its size, obtaining a value of 20 times the Earth radius for the distance (the real value is 60; the Earth radius was roughly known since Eratosthenes).

During the Warring States of China, astronomer Shi Shen (fl. 4th century BC) gave instructions for predicting solar and lunar eclipses based on the relative positions of the Moon and Sun. Although the Chinese of the Han Dynasty (202 BC–202 AD) believed the Moon to be energy equated to *qi*, their 'radiating influence' theory recognized that the light of the Moon was merely a reflection of the Sun (mentioned by Anaxagoras above). This was supported by mainstream thinkers such as Jing Fang (78–37 BC) and Zhang Heng (78–139 AD), but it was also opposed by the influential philosopher Wang Chong (27–97 AD). Jing Fang noted the sphericity of the Moon, while Zhang Heng accurately described a lunar eclipse and solar eclipse. These assertions were supported by Shen Kuo (1031–1095) of the Song Dynasty (960–1279) who created an allegory equating the waxing and waning of the Moon to a round ball of reflective silver that, when doused with white powder and viewed from the side, would appear to be a crescent. He also noted that the reason for the Sun and Moon not eclipsing every time their paths met was because of a small obliquity in their orbital paths.

Habash al-Hasib al-Marwazi, a Persian astronomer, conducted various observations at the Al-Shammisiyyah observatory in Baghdad between 825 and 835 AD. Using these observations, he estimated the Moon's diameter as 3,037 km (equivalent to 1,519 km radius) and its distance from the Earth as 215,209 miles, which come close to the currently accepted values. In 1021, the Islamic physicist, Alhazen, accurately explained the Moon illusion in the *Book of Optics*, which stated that judging the distance of an object depends on there being an uninterrupted sequence of intervening bodies between the object and the observer. With the Moon, there are no intervening objects, therefore since the size of an object depends on its observed distance, which is in this case inaccurate, the Moon appears larger on the horizon. Through Alhazen's work, the Moon illusion gradually came to be accepted as a psychological phenomenon. He also investigated moonlight, which he proved through experimentation that it originates from sunlight and correctly concluded that it "emits light from those portions of its surface which the sun's light strikes."

By the Middle Ages, before the invention of the telescope, an increasing number of people began to recognise the Moon as a sphere, though many believed that it was "perfectly smooth". In 1609, Galileo Galilei drew one of the first telescopic drawings of the Moon in his book *Sidereus Nuncius* and noted that it was not smooth but had mountains and craters. Later in the 17th century, Giovanni Battista Riccioli and Francesco Maria Grimaldi drew a map of the Moon and gave many craters the names they still have today. On maps, the dark parts of the Moon's surface were called *maria* (singular *mare*) or seas, and the light parts were called *terrae* or continents.

The medieval followers of Aristotle, in the Islamic world and then in Christian Europe, tried to make sense of the lunar spots in Aristotelian terms. Thomas Harriot, as well as Galilei, drew the first telescopic representation of the Moon and observed it for several years. His drawings, however, remained unpublished. The first map of the Moon was

made by the Belgian cosmographer and astronomer Michael Florent van Langren in 1645. Two years later a much more influential effort was published by Johannes Hevelius. In 1647 Hevelius published *Selenographia*, the first treatise entirely devoted to the Moon. Hevelius's nomenclature, although used in Protestant countries until the eighteenth century, was replaced by the system published in 1651 by the Jesuit astronomer Giovanni Battista Riccioli, who gave the large naked-eye spots the names of seas and the telescopic spots (now called craters) the name of philosophers and astronomers. In 1753 the Croatian Jesuit and astronomer Roger Joseph Boscovich discovered the absence of atmosphere on the Moon. In 1824 Franz von Gruithuisen explained the formation of craters as a result of meteorite strikes.

The possibility that the Moon contains vegetation and is inhabited by selenites was seriously considered by major astronomers even into the first decades of the 19th century. The contrast between the brighter highlands and darker maria create the patterns seen by different cultures as the Man in the Moon, the rabbit and the buffalo, among others. In 1835, the Great Moon Hoax fooled some people into thinking that there were exotic animals living on the Moon. Almost at the same time however (during 1834–1836), Wilhelm Beer and Johann Heinrich Mädler were publishing their four-volume *Mappa Selenographica* and the book *Der Mond* in 1837, which firmly established the conclusion that the Moon has no bodies of water nor any appreciable atmosphere.

Recent exploration

In 1990 Japan visited the Moon with the Hiten spacecraft, becoming the third country to place an object in orbit around the Moon. The spacecraft released the Hagoromo probe into lunar orbit, but the transmitter failed, thereby preventing further scientific use of the mission. In September 2007, Japan launched the SELENE spacecraft, with the objectives "to obtain scientific data of the lunar origin and evolution and to develop the technology for the future lunar exploration", according to the JAXA official website.

NASA launched the Clementine mission in 1994, and Lunar Prospector in 1998.

The European Space Agency launched a small, low-cost lunar orbital probe called SMART 1 on September 27, 2003. SMART 1's primary goal was to take three-dimensional X-ray and infrared imagery of the lunar surface. SMART 1 entered lunar orbit on November 15, 2004 and continued to make observations until September 3, 2006, when it was intentionally crashed into the lunar surface in order to study the impact plume.

The People's Republic of China has begun the Chang'e program for exploring the Moon and is investigating the prospect of lunar mining, specifically looking for the isotope helium-3 for use as an energy source on Earth. China launched the Chang'e 1 robotic lunar orbiter on October 24, 2007. Originally planned for a one-year mission, the Chang'e 1 mission was very successful and ended up being extended for another four months. On March 1, 2009, Chang'e 1 was intentionally impacted on the lunar surface completing the 16 month mission.

On October 1, 2010, China launched the Chang'e 2 lunar orbiter.

India's national space agency, Indian Space Research Organization (ISRO), launched Chandrayaan-1, an unmanned lunar orbiter, on October 22, 2008. The lunar probe was originally intended to orbit the Moon for two years, with scientific objectives to prepare a three-dimensional atlas of the near and far side of the Moon and to conduct a chemical and mineralogical mapping of the lunar surface. The unmanned Moon Impact Probe landed on the Moon at 15:04 GMT on November 14, 2008 making India the fourth country to touch down on the lunar surface. Among its many achievements was the discovery of the widespread presence of water molecules in lunar soil.

NASA launched a preliminary unmanned mission, the Lunar Reconnaissance Orbiter, on June 18, 2009. LRO will take high resolution imagery of the Moon's surface and carries the Lunar Crater Observation and Sensing Satellite (LCROSS), which will investigate the possible existence of water in Cabeus crater.

Future plans



The planned NASA Lunar Reconnaissance Orbiter

China plans to land the rover Chang'e 3 on the Moon in 2013, and to conduct a sample return mission in 2017.

India expects to launch another indigenous lunar mission by 2013 which would place a motorized rover on the surface of the Moon.

Japanese Aerospace Exploration Agency (JAXA) plans a manned lunar landing around 2020 that would lead to a manned lunar base by 2030; however, there is no budget yet for this project. This is highly unlikely to happen.

Russia also announced to resume its previously frozen project Luna-Glob, an unmanned lander and orbiter, which is slated to launch in 2012.

Germany also announced in March 2007 that it will launch a national lunar orbiter, LEO in 2012. however the mission was cancelled due to budgetary constraints.

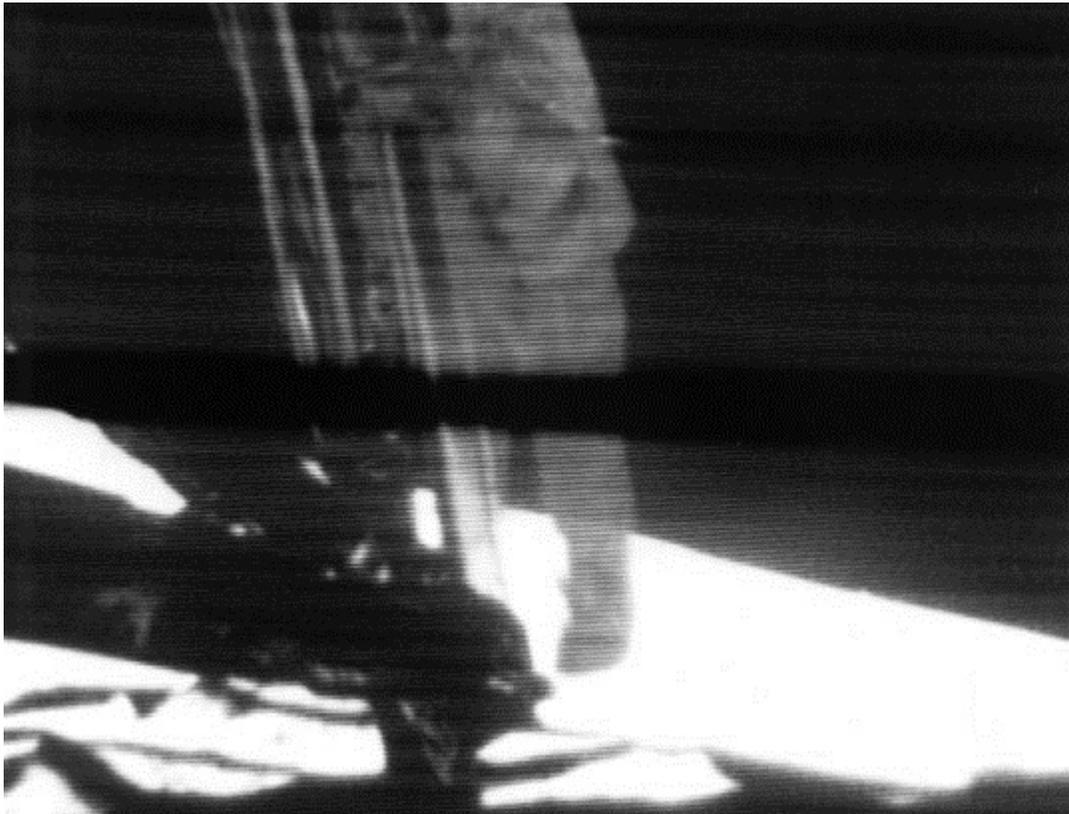
In August 2007, NASA stated that all future missions and explorations of the Moon will be done entirely using the metric system. This was done to improve cooperation with space agencies of other countries which already use the metric system.

The European Space Agency has also announced its intention to send a manned mission to the Moon, as part of the Aurora programme. In September 2010 the agency introduces a "Lunar lander" programme with a target of autonomous mission to the moon in 2018.

On September 13, 2007, the X Prize Foundation, in concert with Google, Inc., announced the Google Lunar X Prize. This contest requires competitors "to land a privately funded robotic rover on the Moon that is capable of completing several mission objectives, including roaming the lunar surface for at least 500 meters and sending video, images and data back to the Earth."

Chapter- 2

Moon Landing



Still frame from the video transmission of Neil Armstrong stepping onto the surface of the Moon at 02:56 UTC on July 21, 1969. An estimated 500 million people worldwide watched this event, the largest television audience for a live broadcast at that time.

A **moon landing** is the arrival of a spacecraft on the surface of the Moon. This includes both manned and unmanned (robotic) missions. The first human-made object to reach the surface of the Moon was the Soviet Union's Luna 2 mission on September 13, 1959. The United States's Apollo 11 was the first manned mission to land on the Moon on July 20, 1969.

Unmanned landings

Since the Soviet Union first succeeded in implementing the concept in 1966, this term referred to 18 spacecraft landings on the Moon up to 1976. The USSR was first to accomplish both a lunar hard landing (crash impact) and a soft landing enabling the gathering of scientific data from the surface. During the time of the Cold War, such contests to be the first on the Moon was one of the most visible facts of the Space Race.

After the American manned Apollo landings, the Soviet Union later achieved sample returns of lunar soil via the unmanned *Luna 16*, *Luna 20* and *Luna 24* Moon landings. *Luna 17* and *Luna 21* were successful rover missions.

Japan executed a controlled impact onto the Moon when its lunar orbiter Hiten impacted the Moon's surface on 10 April 1993, and the European Space Agency performed another controlled impact with the orbiter SMART-1 on 3 September 2006. India performed a controlled impact when its Moon Impact Probe, part of the Chandrayaan-1 mission, hit the lunar surface on 14 November 2008, 20:31 IST (+5:30 UTC.) Also, the Chinese lunar orbiter Chang'e 1 executed a controlled crash onto the surface of the Moon on 1 March 2009.

Manned landings

A total of twelve people have landed on the Moon. This was accomplished with two US pilot-astronauts flying a Lunar Module on each of six NASA missions across a 41-month time span starting on July 21, 1969 UTC, with Neil Armstrong and Buzz Aldrin on Apollo 11 (with Armstrong being first to set foot on the surface), and ending on December 14, 1972 UTC with Gene Cernan and Jack Schmitt on Apollo 17 (with Cernan being the last to step off the lunar surface). All Apollo lunar missions had a third crew member who remained onboard the Command Module. The last three missions had a rover for increased mobility.

Scientific background

The primary concern of any moon landing is the high velocity involved that arises from the effects of gravity. In order to go to any moon, a spacecraft must first leave the gravity well of the Earth. The only practical way of accomplishing this currently is with a rocket. Unlike other airborne vehicles such as balloons or jets, only a rocket can continue to increase its speed at high altitudes in the vacuum outside the Earth's atmosphere.

Upon approach of the target moon, the spacecraft must decelerate enough to land safely. The velocity to be shed from the target moon's gravitational attraction is roughly equal to the escape velocity of the target moon. For Earth's Moon, this figure is 2.4 kilometers per second or around 6,000 miles per hour. This change in velocity (referred to as the delta-v) is usually provided by a landing rocket, which must be carried into space by the original launch vehicle as part of the overall spacecraft. An exception is a moon landing on Titan such as that carried out by the Huygens probe. As the only moon with an atmosphere,

landings on Titan may be accomplished by using atmospheric entry techniques that are generally lighter in weight than a rocket with equivalent capability.

Whatever method is used to slow a spacecraft as it nears a moon, the key requirement for a "true" moon landing is to be traveling at a survivable speed upon reaching the moon's surface that allows continued operation after touchdown. Such landings may be characterized as "soft" if a human could survive them, and "hard" if only a ruggedized machine would do so. Initial American attempts at performing the first hard moon landing in 1962 failed; the Soviets succeeded in making the first successful hard landing on the Moon in 1966. Generally a hard landing is categorized as one occurring at 100 miles per hour or slower.

Above these speeds, the space mission ends not in a landing but a so-called crash impact where the vehicle and its instruments do not survive touchdown, which without braking rockets generally occurs at speeds of 3000–5000 miles per hour. Such impacts can occur because of malfunctions in a spacecraft, or they can be deliberately arranged for vehicles that do not have an on board landing rocket such as the 2008 Indian MIP. There have been many such moon crashes. For example, during the Apollo program the S-IVB third stage of the Saturn V moon rocket as well as the spent ascent stage of the lunar module were deliberately crashed on the moon several times to provide impacts registering as a moonquake on seismometers that had been left on the lunar surface. Such crashes were instrumental in mapping the internal structure of the Moon.

If a return to Earth is desired after a moon landing is accomplished, the escape velocities of the moon and Earth must again be overcome for the spacecraft to come to rest on the surface of the Earth. Rockets must be used to leave the moon and return to space. Upon reaching Earth, atmospheric entry techniques are used to absorb the kinetic energy of a returning spacecraft and reduce its speed for safe landing. These functions greatly complicate a moon landing mission and lead to many additional operational considerations. Any moon departure rocket must first be carried to the moon's surface by a moon landing rocket, increasing the latter's required size. The moon departure rocket, larger moon landing rocket and any Earth atmosphere entry equipment such as heat shields and parachutes must in turn be lifted by the original launch vehicle, greatly increasing its size by a significant and almost prohibitive degree. This necessitates optimizing the sizing of stages in the launch vehicle as well as consideration of using space rendezvous between multiple spacecraft.

Political background

The intense and expensive effort devoted in the 1960s to achieving first an unmanned and then ultimately a manned moon landing can only be understood in the political context of its historical era. World War II with its 60 million dead, half Soviets, was fresh in the memory of all adults. In the 1940s, the war had introduced many new and deadly innovations including blitzkrieg-style surprise attacks used in the invasion of Poland and in the attack on Pearl Harbor; the V-2 rocket, a ballistic missile which killed thousands in attacks on London and Antwerp; and the atom bomb, which killed hundreds of thousands

in the atomic bombings of Hiroshima and Nagasaki. In the 1950s, tensions mounted between the two ideologically opposed superpowers of the United States and the Soviet Union that had emerged as victors in the conflict, particularly after the development by both countries of the hydrogen bomb.

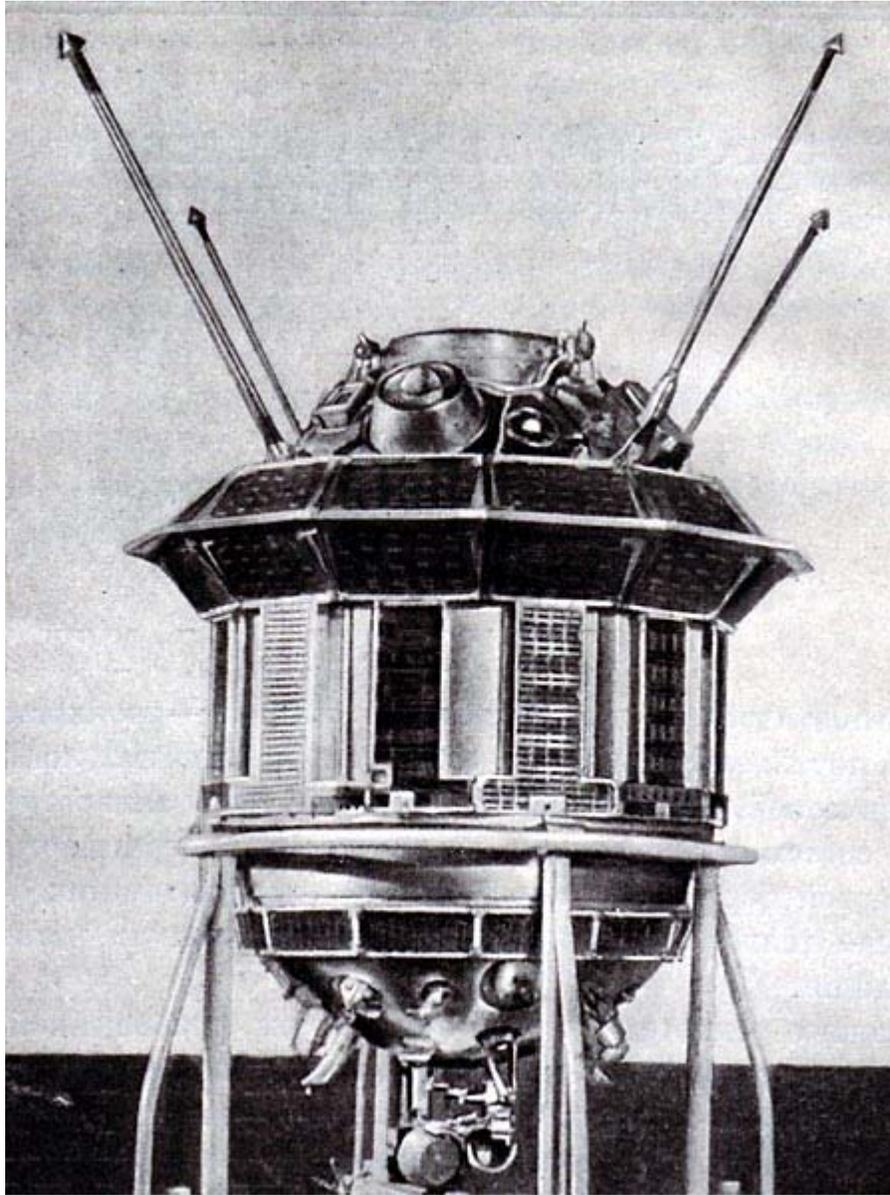
On October 4, 1957, the Soviet Union launched *Sputnik 1* as the first artificial satellite to orbit the Earth and so initiated the Space Age. This unexpected event was a source of pride to the Soviets and shock to the Americans, who could now potentially be surprised and attacked by nuclear-tipped Soviet rockets in under 30 minutes. Also, the steady beeping of the radio beacon aboard *Sputnik 1* as it passed overhead every 96 minutes was widely viewed on both sides as effective propaganda to Third World countries demonstrating the technological superiority of the Soviet political system compared to the American one. This perception was reinforced by a string of subsequent rapid-fire Soviet space achievements. In 1959, the R-7 rocket was used to launch the first escape from Earth's gravity into a solar orbit, the first crash impact onto the surface of the Moon and the first photography of the never-before-seen far side of the Moon. These were the Luna 1, Luna 2 and Luna 3 spacecraft.

The American response to these Soviet achievements was to greatly accelerate previously existing military space and missile projects and to create a civilian space agency, NASA. Military efforts were initiated to develop and produce mass quantities of intercontinental ballistic missiles (ICBMs) that would bridge the so-called missile gap and enable a policy of deterrence to nuclear war with the Soviets known as Mutually Assured Destruction or MAD. These newly developed missiles were made available to civilians of NASA for various projects (which would have the added benefit of demonstrating the payload, guidance accuracy and reliabilities of American ICBMs to the Soviets). While NASA stressed peaceful and scientific uses for these rockets, their use in various lunar exploration efforts also had a secondary goal of realistic, goal-oriented testing of the missiles themselves and development of associated infrastructure, just as the Soviets were doing with their R-7. The tight schedules and lofty goals selected by NASA for lunar exploration also had an undeniable element of generating counter-propaganda to show to other countries that American technological prowess was the equal and even superior to that of the Soviets.

Early Soviet unmanned lunar missions (1958–1966)



Two pennants on board Luna 2 - first man-made object to hit the Moon



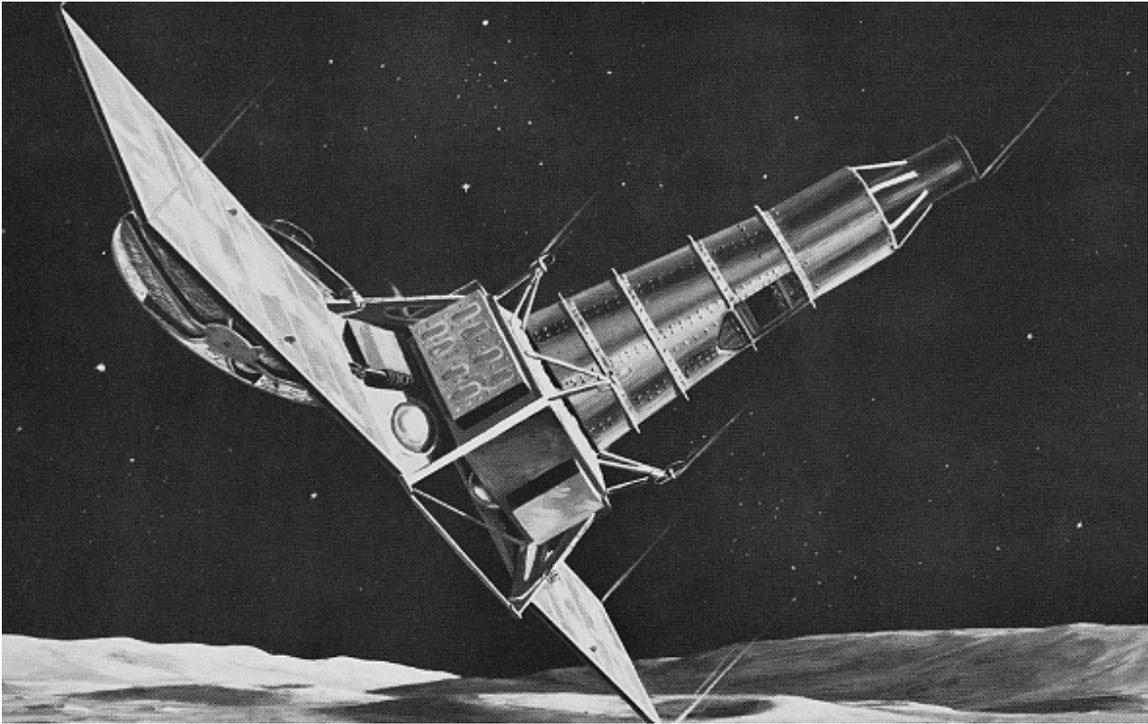
Luna 3 - transmitted first photos of the far side of the Moon

After the fall of the Soviet Union in 1991 historical records were released to allow the true accounting of Soviet lunar efforts. Unlike the American tradition of assigning a particular mission name in advance of launch, the Soviets assigned a public "Luna" mission number only if a launch resulted in a spacecraft going beyond Earth orbit. The policy had the effect of hiding Soviet Moon picture failures from public view. If the attempt failed in Earth orbit before departing for the Moon, it was frequently (but not always) given a "Sputnik" or "Cosmos" earth-orbit mission number to hide its purpose. Launch explosions were not acknowledged at all.

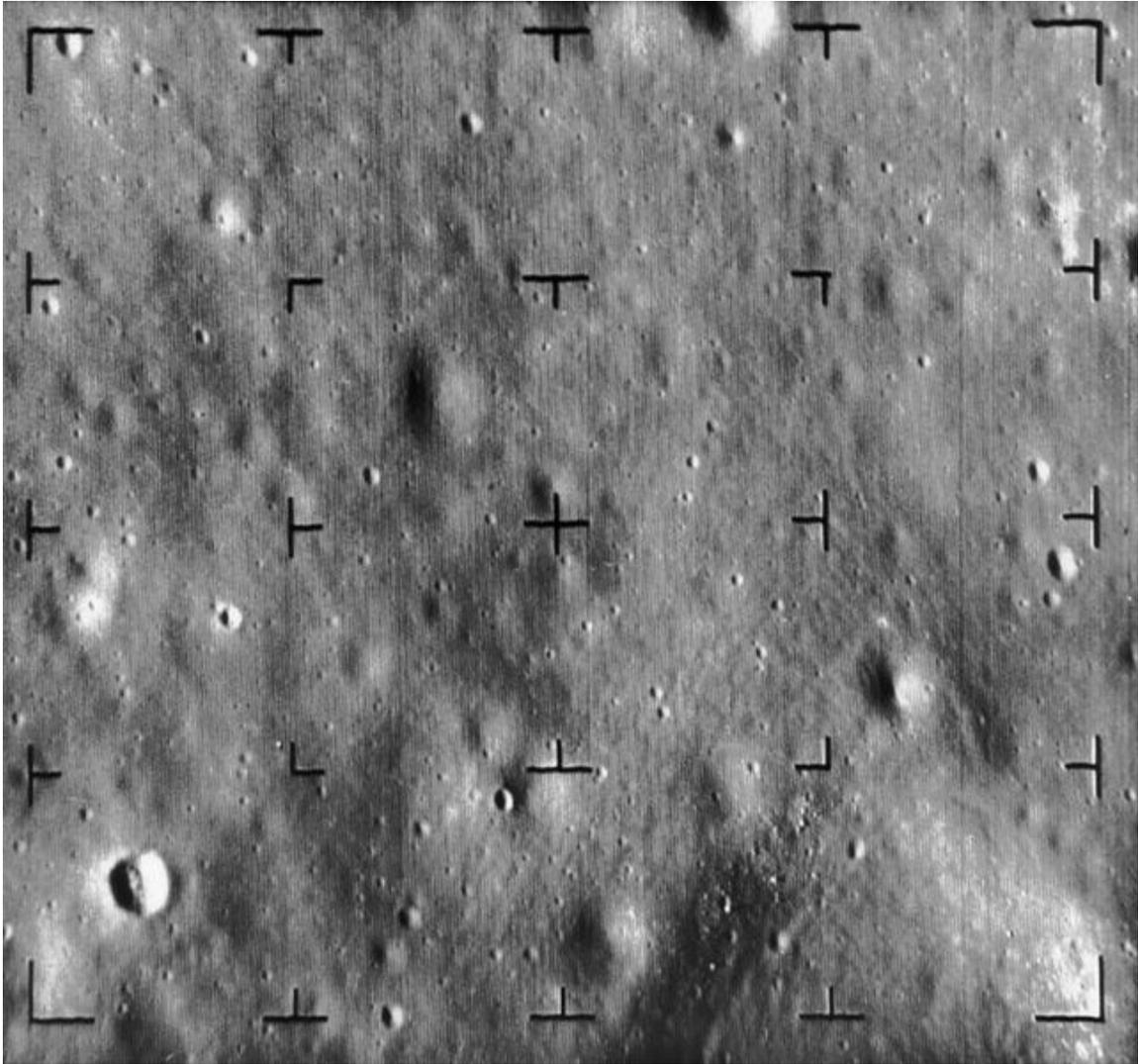
U.S.S.R. Mission	Mass (kg)	Launch Vehicle	Launched	Mission Goal	Mission Result
		Semyorka - 8K72	23 September 1958	Lunar Impact	Failure - booster malfunction at T+ 93 sec
		Semyorka - 8K72	12 October 1958	Lunar Impact	Failure - booster malfunction at T+ 104 sec
		Semyorka - 8K72	4 December 1958	Lunar Impact	Failure - booster malfunction at T+ 254 sec
Luna-1	361	Semyorka - 8K72	2 January 1959	Lunar Impact	Partial Success - first spacecraft to reach escape velocity, lunar flyby, solar orbit; Missed the Moon
		Semyorka - 8K72	18 June 1959	Lunar Impact	Failure - booster malfunction at T+ 153 sec
Luna-2	390	Semyorka - 8K72	12 September 1959	Lunar Impact	Success - first lunar impact
Luna-3	270	Semyorka - 8K72	4 October 1959	Lunar Flyby	Success - first photos of lunar far side
		Semyorka - 8K72	15 April 1960	Lunar Flyby	Failure - booster malfunction, failed to reach Earth orbit
		Semyorka - 8K72	16 April 1960	Lunar Flyby	Failure - booster malfunction at T+ 1 sec

Sputnik-25		Semyorka - 8K78	4 January 1963	Moon landing	Failure - stranded in low Earth orbit
		Semyorka - 8K78	3 February 1963	Moon landing	Failure - booster malfunction at T+ 105 sec
Luna-4	1422	Semyorka - 8K78	2 April 1963	Moon landing	Failure - lunar flyby at 5,000 miles (8,000 km)
		Semyorka - 8K78	21 March 1964	Moon landing	Failure - booster malfunction, failed to reach Earth orbit
		Semyorka - 8K78	20 April 1964	Moon landing	Failure - booster malfunction, failed to reach Earth orbit
Cosmos-60		Semyorka - 8K78	12 March 1965	Moon landing	Failure - stranded in low Earth orbit
		Semyorka - 8K78	10 April 1965	Moon landing	Failure - booster malfunction, failed to reach Earth orbit
Luna-5	1475	Semyorka - 8K78	9 May 1965	Moon landing	Failure - lunar impact
Luna-6	1440	Semyorka - 8K78	8 June 1965	Moon landing	Failure - lunar flyby at 100,000 miles (160,000 km)
Luna-7	1504	Semyorka - 8K78	4 October 1965	Moon landing	Failure - lunar impact
Luna-8	1550	Semyorka - 8K78	3 December 1965	Moon landing	Failure - lunar impact during landing attempt

Early American unmanned lunar missions (1958–1965)



Artist's portrayal of a Ranger spacecraft right before impact



One of the last photos of the Moon transmitted by Ranger-8 right before impact

In contrast to Soviet lunar exploration triumphs in 1959, success eluded initial American efforts to reach the Moon with the Pioneer and Ranger programs. Fifteen consecutive U.S. unmanned lunar missions over a six year period from 1958 to 1964 all failed their primary photographic missions; however, Rangers 4 and 6 successfully repeated the Soviet lunar impacts as part of their secondary missions. Failures included three American attempts in 1962 to hard land small seismometer packages released by the main Ranger spacecraft. These surface packages were to use retrorockets to survive landing, unlike the parent vehicle, which was designed to deliberately crash onto the surface. The final three Ranger probes performed successful high altitude lunar reconnaissance photography missions during intentional crash impacts at around 6,000 miles per hour as planned.

U.S. Mission	Mass (kg)	Launch Vehicle	Launched	Mission Goal	Mission Result
Pioneer 0	38	Thor-Able	17 August 1958	Lunar orbit	Failure - first stage explosion; destroyed
Pioneer 1	34	Thor-Able	11 October 1958	Lunar orbit	Failure - software error; reentry
Pioneer 2	39	Thor-Able	8 November 1958	Lunar orbit	Failure - third stage misfire; reentry
Pioneer 3	6	Juno	6 December 1958	Lunar flyby	Failure - first stage misfire, reentry
Pioneer 4	6	Juno	3 March 1959	Lunar flyby	Partial success - first US craft to reach escape velocity, lunar flyby too far to shoot photos due to targeting error; solar orbit
Pioneer P-1	168	Atlas-Able	24 September 1959	Lunar orbit	Failure - pad explosion; destroyed
Pioneer P-3	168	Atlas-Able	29 November 1959	Lunar orbit	Failure - payload shroud; destroyed
Pioneer P-30	175	Atlas-Able	25 September 1960	Lunar orbit	Failure - second stage anomaly; reentry
Pioneer P-31	175	Atlas-Able	15 December	Lunar orbit	Failure - first stage explosion; destroyed

			1960		
Ranger 1	306	Atlas - Agena	23 August 1961	Prototype test	Failure - upper stage anomaly; reentry
Ranger 2	304	Atlas - Agena	18 November 1961	Prototype test	Failure - upper stage anomaly; reentry
Ranger 3	330	Atlas - Agena	26 January 1962	Moon Landing	Failure - booster guidance; solar orbit
Ranger 4	331	Atlas - Agena	23 April 1962	Moon Landing	Partial success - first U.S. spacecraft to reach another celestial body; crash impact - no photos returned
Ranger 5	342	Atlas - Agena	18 October 1962	Moon Landing	Failure - spacecraft power; solar orbit
Ranger 6	367	Atlas - Agena	30 January 1964	Lunar impact	Failure - spacecraft camera; crash impact
Ranger 7	367	Atlas - Agena	28 July 1964	Lunar impact	Success - returned 4308 photos, crash impact
Ranger 8	367	Atlas - Agena	17 February 1965	Lunar impact	Success - returned 7137 photos, crash impact
Ranger 9	367	Atlas - Agena	21 March 1965	Lunar impact	Success - returned 5814 photos, crash impact

Pioneer missions

Three different designs of Pioneer lunar probes were flown on three different modified ICBMs. Those flown on the Thor booster modified with an Able upper stage carried an

infrared image scanning television system with a resolution of 1 milliradian to study the Moon's surface, an ionization chamber to measure radiation in space, a diaphragm/microphone assembly to detect micrometeorites, a magnetometer, and temperature-variable resistors to monitor spacecraft internal thermal conditions. The first, a mission managed by the United States Air Force, exploded during launch; all subsequent Pioneer lunar flights had NASA as the lead management organization. The next two returned to Earth and burned up upon reentry into the atmosphere after achieved maximum altitudes of around 70,000 and 900 miles (1,400 km), far short of the roughly 250,000 miles (400,000 km) required to reach the vicinity of the Moon.

NASA then collaborated with the United States Army's Ballistic Missile Agency to fly two extremely small cone-shaped probes on the Juno ICBM, carrying only photocells which would be triggered by the light of the Moon and a lunar radiation environment experiment using a Geiger-Müller tube detector. The first of these reached an altitude of only around 64,000 miles (103,000 km), serendipitously gathering data that established the presence of the Van Allen radiation belts before reentering Earth's atmosphere. The second passed by the moon at a distance of over 37,000 miles (60,000 km), twice as far away as planned and too far away to trigger either of the on board scientific instruments, yet still becoming the first American spacecraft to reach a solar orbit.

The final Pioneer lunar probe design consisted of four "paddlewheel" solar panels extending from a one-meter diameter spherical spin-stabilized spacecraft body that was equipped to take images of the lunar surface with a television-like system, estimate the Moon's mass and topography of the poles, record the distribution and velocity of micrometeorites, study radiation, measure magnetic fields, detect low frequency electromagnetic waves in space and use a sophisticated integrated propulsion system for maneuvering and orbit insertion as well. None of the four spacecraft built in this series of probes survived launch on its Atlas ICBM outfitted with an Able upper stage.

Following the unsuccessful Atlas-Able Pioneer probes, NASA's Jet Propulsion Laboratory embarked upon an unmanned spacecraft development program whose modular design could be used to support both lunar and interplanetary exploration missions. The interplanetary versions were known as Mariners; lunar versions were Rangers. JPL envisioned three versions of the Ranger lunar probes: Block I prototypes, which would carry various radiation detectors in test flights to a very high Earth orbit that came nowhere near the Moon; Block II, which would try to accomplish the first Moon landing by hard landing a seismometer package; and Block III, which would crash onto the lunar surface without any braking rockets while taking very high resolution wide-area photographs of the Moon during their descent.

Ranger missions

The Ranger 1 and 2 Block I missions were virtually identical. Spacecraft experiments included a Lyman-alpha telescope, a Rubidium-vapor magnetometer, electrostatic analyzers, medium-energy-range particle detectors, two triple coincidence telescopes, a cosmic-ray integrating ionization chamber, cosmic dust detectors, and scintillation

counters. The goal was to place these Block I spacecraft in a very high Earth orbit with an apogee of 670,000 miles (1,080,000 km). From that vantage point, scientists could make direct measurements of the magnetosphere over a period of many months while engineers perfected new methods to routinely track and communicate with spacecraft over such large distances. Such practice was deemed vital to be assured of capturing high-bandwidth television transmissions from the Moon during a one-shot fifteen minute time window in subsequent Block II and Block III lunar descents. Both Block I missions suffered failures of the new Agena upper stage and never left low earth parking orbit after launch; both burned up upon reentry after only a few days.

The first attempts to perform a Moon landing took place in 1962 during the Rangers 3, 4 and 5 missions flown by the United States. All three Block II missions carried a 94 pound, 2-foot-diameter (0.61 m) landing sphere (made of balsa wood) designed to withstand a 150-mile-per-hour impact. This lander (code-named *Tonto*) was designed to provide impact cushioning using an exterior blanket of crushable balsa wood and an interior filled with incompressible liquid freon. A 56-pound, 1-foot-diameter (0.30 m) metal payload sphere floated and was free to rotate in a liquid freon reservoir contained in the landing sphere. This payload sphere contained six silver-cadmium batteries to power a fifty-milliwatt radio transmitter, a temperature sensitive voltage controlled oscillator to measure lunar surface temperatures, and a seismometer that was designed with sensitivity high enough to detect the impact of a five pound meteorite on the opposite side of the Moon. Weight was distributed in the payload sphere so it would rotate in its liquid blanket to place the seismometer into an upright and operational position no matter what the final resting orientation of the external landing sphere. After landing plugs were to be opened allowing the freon to evaporate and the payload sphere to settle into upright contact with the landing sphere. Four pounds of water were also included to provide thermal control for the lander, absorbing heat and boiling off as low-pressure steam during the hot lunar daytime and retaining sufficient heat to allow the lander electronics to avoid freezing temperatures during the cold lunar nighttime. The batteries and water supply were sized to allow up to three months of operation for the payload sphere. Various mission constraints limited the landing site to Oceanus Procellarum on the lunar equator, which the lander ideally would reach 66 hours after launch.

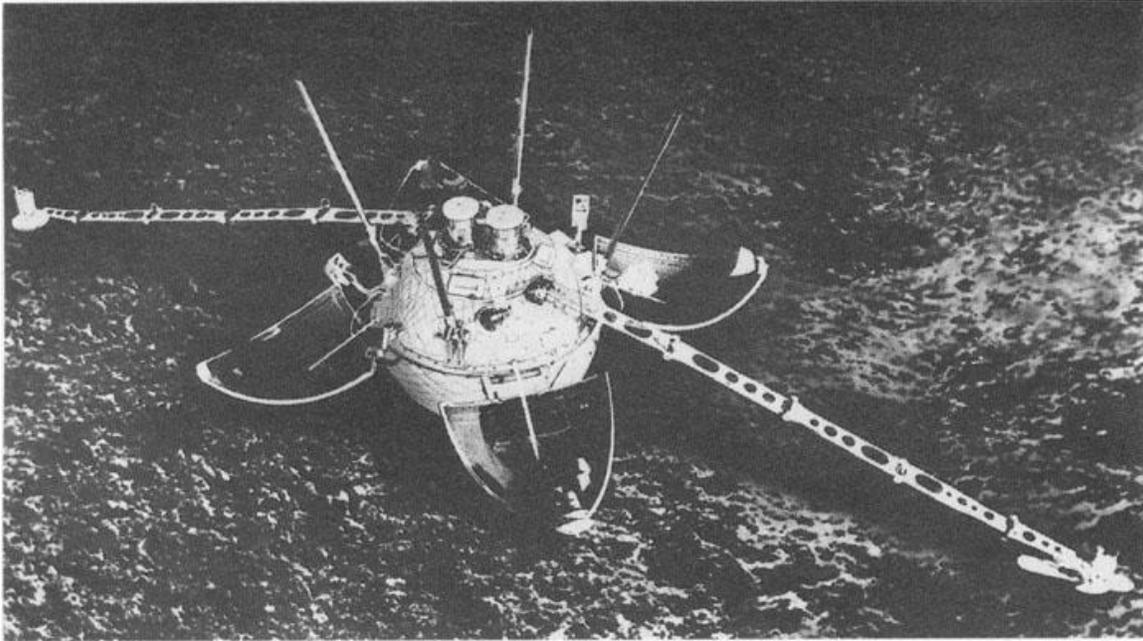
No cameras were carried by the Ranger landers, and no pictures were to be captured from the lunar surface during the mission. Instead, the ten-foot-high, 730 pound Ranger Block II mother ship carried a 200-scan-line television camera which was to capture images from 2,400 miles (3,900 km) down to 37 miles (60 km) during the free-fall descent to the lunar surface. The 13-pound camera was designed to transmit a picture every 10 seconds. Other instruments gathering data before the mother ship crashed onto the Moon at 6,500 miles per hour were a gamma ray spectrometer to measure overall lunar chemical composition and a radar altimeter. At eight seconds before impact and 13 miles (21 km) above the lunar surface, the radar altimeter was to give a signal ejecting the landing capsule and its 236 pound solid-fueled braking rocket overboard from the Block II mother ship. The braking rocket was to slow the landing sphere to a dead stop at

1,100 feet (340 m) above the surface and separate, allowing the landing sphere to free fall once more and hit the surface at a survivable speed of 100 miles per hour.

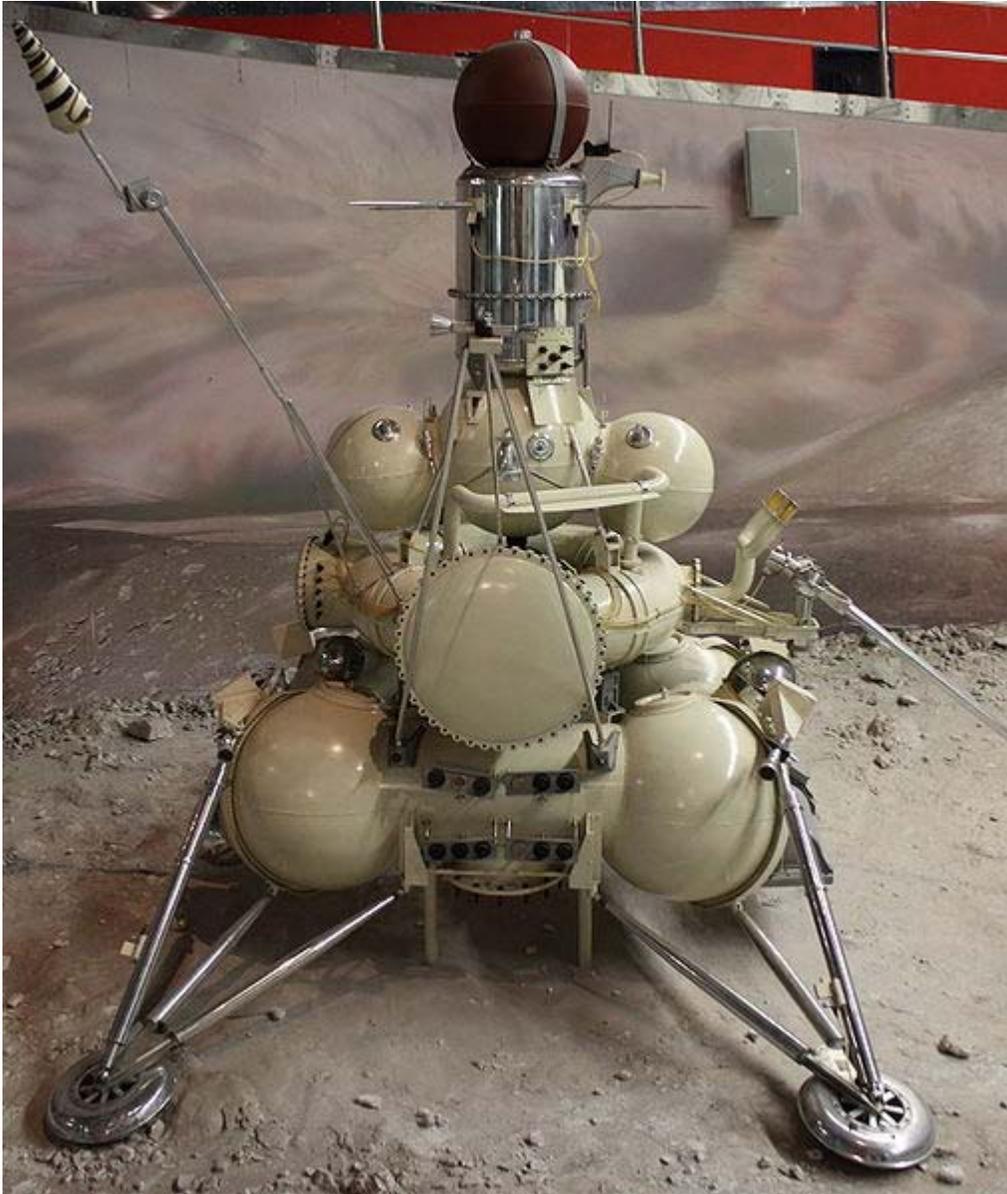
On Ranger 3, failure of the Atlas guidance system and a software error aboard the Agena upper stage combined to put the spacecraft on a course that would miss the Moon. Attempts to salvage lunar photography during a flyby of the Moon were thwarted by in-flight failure of the onboard flight computer. This was probably because of prior heat sterilization of the spacecraft by keeping it above the boiling point of water for 24 hours on the ground, to protect the Moon from being contaminated by Earth organisms. Heat sterilization was also blamed for subsequent in-flight failures of the spacecraft computer on Ranger 4 and the power subsystem on Ranger 5. Only Ranger 4 reached the Moon in an uncontrolled crash impact on the far side of the Moon.

Heat sterilization was discontinued for the final four Block III Ranger probes. These replaced the Block II landing capsule and its retrorocket with a heavier, more capable television system to support landing site selection for upcoming Apollo manned Moon landing missions. Six cameras weighing a total of 350 pounds were designed to take thousands of high-altitude photographs in the final twenty minute period before crashing on the lunar surface. Camera resolution was 1,132 scan lines, far higher than the 525 lines found in a typical American 1964 home television. The final pictures taken were expected to have a resolution of around two feet. While Ranger 6 suffered a failure of this camera system and returned no photographs despite an otherwise successful flight, the subsequent Ranger 7 mission to Mare Cognitum was a complete success. Breaking the six-year string of failures in American attempts to photograph the Moon at close range, the Ranger 7 mission was viewed as a national turning point and instrumental in allowing the key 1965 NASA budget appropriation to pass through the United States Congress intact without a reduction in funds for the Apollo manned Moon landing program. Subsequent successes with Ranger 8 and Ranger 9 further buoyed American hopes.

Soviet unmanned soft landings (1966–1976)



Luna 13 lander



Model of Luna 16 Moon soil sample return lander



Model of Soviet Lunokhod automatic moon rover

U.S.S.R. Mission	Mass (kg)	Booster	Launched	Mission Goal	Mission Result	Landing Zone	Lat/Lon
Luna-9	1580	Semyorka - 8K78	31 January 1966	Moon landing	Success - first lunar soft landing, numerous photos	Oceanus Procellarum	7.13°N 64.37°W
Luna-13	1580	Semyorka - 8K78	21 December 1966	Moon landing	Success - second lunar soft landing, numerous photos	Oceanus Procellarum	18°52'N 62°3'W

		Proton	19 February 1969	Lunar rover	Failure - booster malfunction, failed to reach Earth orbit		
		Proton	14 June 1969	Sample return	Failure - booster malfunction, failed to reach Earth orbit		
Luna-15	5,700	Proton	13 July 1969	Sample return	Failure - lunar crash impact	Mare Crisium	unknown
Cosmos- 300		Proton	23 September 1969	Sample return	Failure - stranded in low Earth orbit		
Cosmos- 305		Proton	22 October 1969	Sample return	Failure - stranded in low Earth orbit		
		Proton	6 February 1970	Sample return	Failure - booster malfunction, failed to reach Earth orbit		
Luna-16	5,600	Proton	12 September 1970	Sample return	Success - returned 0.10 kg of Moon soil back to Earth	Mare Fecunditatis	000.68S 056.30E
Luna-17	5,700	Proton	10 November	Lunar rover	Success - Lunokhod-1 rover traveled	Mare Imbrium	038.28N 325.00E

			1970		10.5 km across lunar surface		
Luna-18	5,750	Proton	2 September 1971	Sample return	Failure - lunar crash impact	Mare Fecunditatis	003.57N 056.50E
Luna-20	5,727	Proton	14 February 1972	Sample return	Success - returned 0.05 kg of Moon soil back to Earth	Mare Fecunditatis	003.57N 056.50E
Luna-21	5,950	Proton	8 January 1973	Lunar rover	Success - Lunokhod-2 rover traveled 37.0 km across lunar surface	LeMonnier Crater	025.85N 030.45E
Luna-23	5,800	Proton	28 October 1974	Sample return	Failure - Moon landing achieved, but malfunction prevented sample return	Mare Crisium	012.00N 062.00E
		Proton	16 October 1975	Sample return	Failure - booster malfunction, failed to reach Earth orbit		
Luna-24	5,800	Proton	9 August 1976	Sample return	Success - returned 0.17 kg of Moon soil back to Earth	Mare Crisium	012.25N 062.20E

The Luna 9 spacecraft, launched by the Soviet Union, performed the first successful soft Moon landing on February 3. Airbags protected its 200 pound ejectable capsule which survived an impact speed of over 30 miles per hour. Luna 13 duplicated this feat with a similar Moon landing on December 24, 1966. Both returned panoramic photographs that were the first views from the lunar surface.

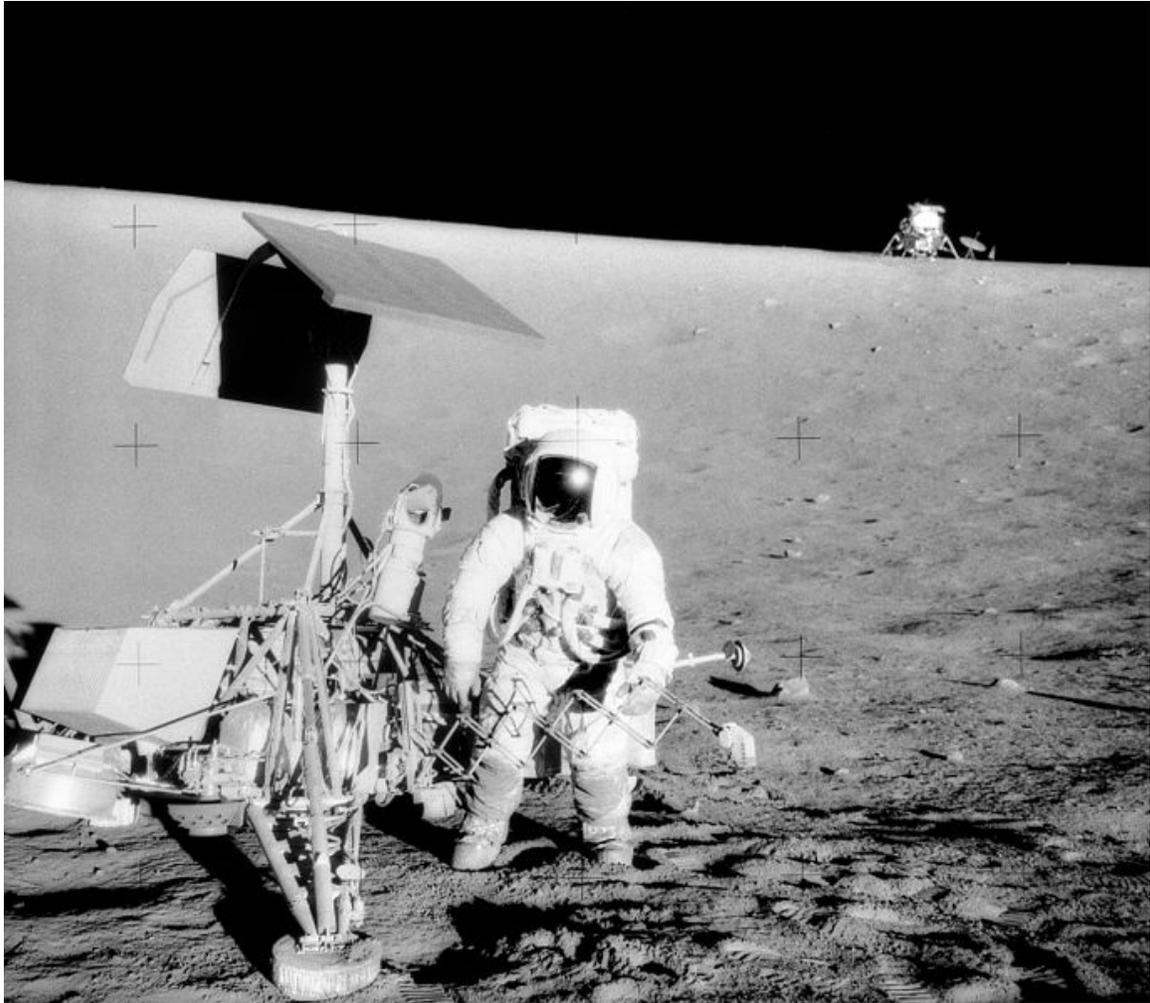
Luna 16 was the first robotic probe to land on the Moon and safely return a sample of lunar back to Earth. It represented the first lunar sample return mission by the Soviet Union, and was the third lunar sample return mission overall, following the Apollo 11 and Apollo 12 missions. This mission was later successfully repeated by Luna 20 (1972) and Luna 24 (1976).

In 1970 and 1973 two Lunokhod ("Moonwalker") robotic lunar rovers were delivered to the moon where they successfully operated for 10 and 4 months respectively, covering 10.5 km (Lunokhod 1) and 37 km (Lunokhod 2). These rover missions were in operation concurrently with the Zond and Luna series of Moon flyby, orbiter and landing missions.

American unmanned soft landings (1966–1968)



Launch of Surveyor 1



Alan L. Bean, Lunar Module pilot of Apollo 12, stands next to Surveyor 3 lander. In the background is the Apollo 12 lander, *Intrepid*.

The American robotic Surveyor program was part of an effort to locate a safe site on the Moon for a human landing and test under actual lunar conditions the radar and landing systems required to make a true controlled touchdown. Five of Surveyor's seven missions made successful unmanned Moon landings. Surveyor 3 was visited two years after its Moon landing by the crew of Apollo 12. They removed parts of it for examination back on Earth to determine the effects of long-term exposure to the lunar environment.

U.S. Mission	Mass (kg)	Booster	Launched	Mission Goal	Mission Result	Landing Zone	Lat/Lon
Surveyor 1	292	Atlas - Centaur	30 May 1966	Moon landing	Success - 11,000 pictures returned, first American	Oceanus Procellarum	002.45S 043.22W

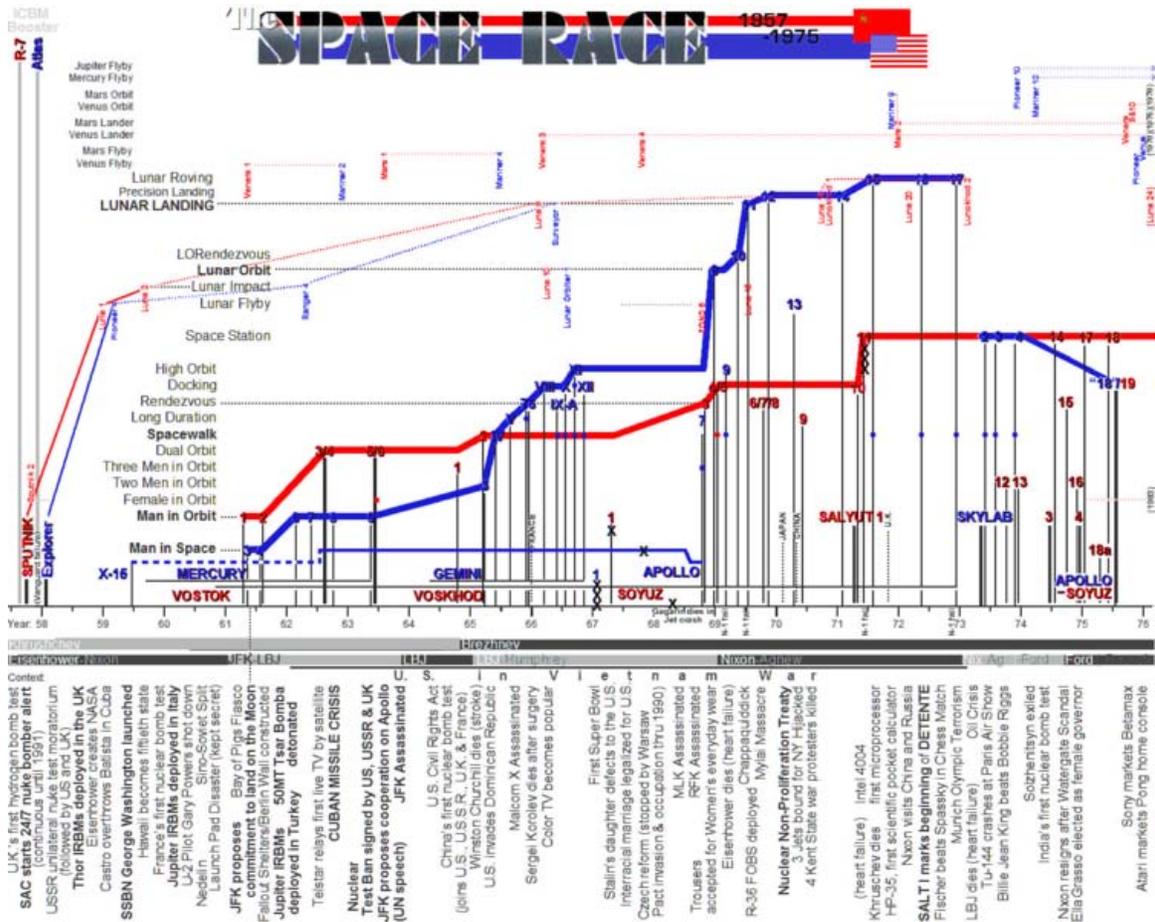
					Moon landing		
Surveyor 2	292	Atlas - Centaur	20 September 1966	Moon landing	Failure - midcourse engine malfunction, placing vehicle in unrecoverable tumble; crashed southeast of Copernicus Crater	Sinus Medii	004.00S 011.00W
Surveyor 3	302	Atlas - Centaur	20 April 1967	Moon landing	Success - 6,000 pictures returned; trench dug to 17.5 cm depth after 18 hr of robot arm use	Oceanus Procellarum	002.94S 336.66E
Surveyor 4	282	Atlas - Centaur	14 July 1967	Moon landing	Failure - radio contact lost 2.5 minutes before touchdown; perfect automated Moon landing possible but actual outcome unknown	Sinus Medii	unknown
Surveyor 5	303	Atlas - Centaur	8 September 1967	Moon landing	Success - 19,000 photos returned, first use of alpha scatter soil composition monitor	Mare Tranquillitatis	001.41N 023.18E
Surveyor 6	300	Atlas - Centaur	7 November 1967	Moon landing	Success - 30,000 photos returned, robot arm & alpha scatter	Sinus Medii	000.46N 358.63E

					science, engine restart, second landing 2.5 m away from first		
Surveyor 7	306	Atlas - Centaur	7 January 1968	Moon landing	Success - 21,000 photos returned; robot arm & alpha scatter science; laser beams from Earth detected	Tycho Crater	041.01S 348.59E

Transition from direct ascent landings to lunar orbit operations

Within four months of each other in early 1966 the Soviet Union and the United States had accomplished successful Moon landings with unmanned spacecraft. To the general public both countries had demonstrated roughly equal technical capabilities by returning photographic images from the surface of the Moon. These pictures provided a key affirmative answer to the crucial question of whether or not lunar soil would support upcoming manned landers with their much greater weight.

However, the Luna 9 hard landing of a ruggedized sphere using airbags at a 30-mile (48 km)-per-hour ballistic impact speed had much more in common with the failed 1962 Ranger landing attempts and their planned 100-mile (160 km)-per-hour impacts than with the Surveyor 1 soft landing on three footpads using its radar-controlled, adjustable-thrust retrorocket. While Luna 9 and Surveyor 1 were both major national accomplishments, only Surveyor 1 had reached its landing site employing key technologies that would be needed for a crewed flight. Thus as of mid-1966, the United States had begun to pull ahead of the Soviet Union in the so-called Space Race to land a man on the Moon.



A chart showing relative accomplishments with probes and human flights

Advances in other areas were necessary before manned spacecraft could follow unmanned ones to the surface of the Moon. Of particular importance was developing the expertise to perform flight operations in lunar orbit. Ranger, Surveyor and initial Luna Moon landing attempts all utilized flight paths from Earth that traveled directly to the lunar surface without first placing the spacecraft in a lunar orbit. Such direct ascents use a minimum amount of fuel for unmanned spacecraft on a one-way trip.

In contrast, manned vehicles need additional fuel after a lunar landing to enable a return trip back to Earth for the crew. Leaving this massive amount of required Earth-return fuel in lunar orbit until it is actually used later in the mission is far more efficient than taking such fuel down to the lunar surface in a Moon landing and then hauling it all back into space yet again, working against lunar gravity both ways. Such considerations lead logically to a lunar orbit rendezvous mission profile for a manned Moon landing.

Accordingly, beginning in mid-1966 both the U.S. and U.S.S.R. naturally progressed into missions which featured lunar orbit operations as a necessary prerequisite to a manned Moon landing. The primary goals of these initial unmanned orbiters were extensive photographic mapping of the entire lunar surface for the selection of manned landing

sites and, for the Soviets, the checkout of radio communications gear that would be used in future soft landings.

An unexpected major discovery from initial lunar orbiters were vast volumes of dense materials beneath the surface of the Moon's maria. Such mass concentrations ("mascons") can send a manned mission dangerously off course in the final minutes of a Moon landing when aiming for a relatively small landing zone that is smooth and safe. Mascons were also found over a longer period of time to greatly disturb the orbits of low-altitude satellites around the Moon, making their orbits unstable and forcing an inevitable crash on the lunar surface in the relatively short period of months to a few years. Thus all lunar orbiter satellites eventually become unintentional "lunar landers" at the end of their missions.

Controlling the location of impact for spent lunar orbiters can have scientific value. For example, in 1999 the NASA Lunar Prospector orbiter was deliberately targeted to impact a permanently shadowed area of Shoemaker Crater near the lunar south pole. It was hoped that energy from the impact would vaporize suspected shadowed ice deposits in the crater and liberate a water vapor plume that would be detectable from Earth. No such plume was observed. However, a small vial of ashes from the body of pioneer lunar scientist Eugene Shoemaker was delivered by the Lunar Prospector to the crater named in his honor - currently the only human remains on the Moon today.

Soviet lunar orbit satellites (1966–1974)

U.S.S.R Mission	Mass (kg)	Booster	Launched	Mission Goal	Mission Result
Cosmos - 111		Molniya-M	1 March 1966	Lunar orbiter	Failure - stranded in low Earth orbit
Luna-10	1,582	Molniya-M	31 March 1966	Lunar orbiter	Success - 2,738 km x 2,088 km x 72 deg orbit, 178 m period, 60 day science mission
Luna-11	1,640	Molniya-M	24 August 1966	Lunar orbiter	Success - 2,931 km x 1,898 km x 27 deg orbit, 178 m period, 38 day science mission
Luna-12	1,620	Molniya-M	22 October 1966	Lunar orbiter	Success - 2,938 km x 1,871 km x 10 deg orbit, 205 m period, 89 day

					science mission
Cosmos-159	1,700	Molniya-M	17 May 1967	Prototype test	Success - high Earth orbit manned landing communications gear radio calibration test
		Molniya-M	7 February 1968	Lunar orbiter	Failure - booster malfunction, failed to reach Earth orbit - attempted radio calibration test?
Luna-14	1,700	Molniya-M	7 April 1968	Lunar orbiter	Success - 870 km x 160 km x 42 deg orbit, 160 m period, unstable orbit, radio calibration test?
Luna-19	5,700	Proton	28 September 1971	Lunar orbiter	Success - 140 km x 140 km x 41 deg orbit, 121 m period, 388 day science mission
Luna-22	5,700	Proton	29 May 1974	Lunar orbiter	Success - 222 km x 219 km x 19 deg orbit, 130 m period, 521 day science mission

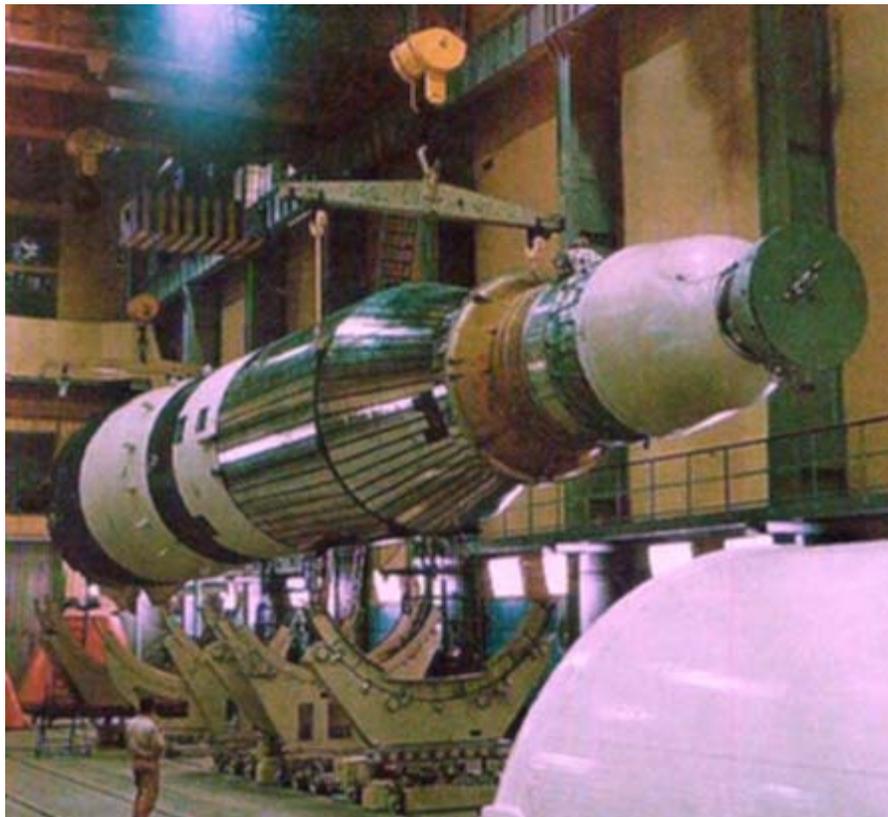
Luna 10 became the first spacecraft to orbit the Moon on 3 April 1966.

American lunar orbit satellites (1966–1967)

U.S. Mission	Mass (kg)	Booster	Launched	Mission Goal	Mission Result
Lunar Orbiter 1	386	Atlas - Agena	10 August 1966	Lunar orbiter	Success - 1,160 km X 189 km x 12 deg orbit, 208 m period, 80 day photography mission
Lunar Orbiter 2	386	Atlas - Agena	6 November 1966	Lunar orbiter	Success - 1,860 km X 52 km x 12 deg orbit, 208 m period, 339 day photography mission

Lunar Orbiter 3	386	Atlas - Agena	5 February 1967	Lunar orbiter	Success - 1,860 km X 52 km x 21 deg orbit, 208 m period, 246 day photography mission
Lunar Orbiter 4	386	Atlas - Agena	4 May 1967	Lunar orbiter	Success - 6,111 km X 2,706 km x 86 deg orbit, 721 m period, 180 day photography mission
Lunar Orbiter 5	386	Atlas - Agena	1 August 1967	Lunar orbiter	Success - 6,023 km X 195 km x 85 deg orbit, 510 m period, 183 day photography mission

Soviet circumlunar loop flights (1967–1970)



Zond mounted on top stage of Proton booster in assembly hangar



Earthrise image by Zond 7, 1969 (RKA)

It was possible to aim a spacecraft from Earth so that it will loop around the Moon and return to Earth without actually entering lunar orbit, following the so-called free return trajectory. Such circumlunar loop missions are simpler than actual lunar orbit missions because rockets for lunar orbit braking and Earth return are not required. However, a manned circumlunar loop trip poses significant challenges above and beyond those found in a manned low-Earth-orbit mission, offering valuable lessons in preparation for a manned Moon landing. Foremost among these are mastering the demands of re-entering the Earth's atmosphere upon returning from the Moon. Manned Earth-orbiting vehicles such as the Space Shuttle return to Earth from speeds of around 17,000 miles per hour (27,400 km/h, 7,600 m/s). Due to the effects of gravity, a vehicle returning from the Moon hits Earth's atmosphere at a much higher speed of around 25,000 miles per hour (40,200 km/h, 11,200 m/s). The g-loading on astronauts during the resulting deceleration can be at the limits of human endurance even during a nominal reentry. Slight variations

in the vehicle flight path and reentry angle during a return from the Moon can easily result in fatal levels of deceleration force.

Achieving a manned circumlunar loop flight prior to a manned lunar landing became a primary goal of the Soviets with their Zond spacecraft program. The first three Zonds were unmanned planetary probes; after that, the Zond name was transferred to a completely separate manned program. The initial focus of these later Zonds was extensive testing of required high-speed reentry techniques. This focus was not shared by the Americans, who chose instead to bypass the stepping stone of a manned circumlunar loop mission and never developed a separate spacecraft for this purpose.

Initial manned spaceflights in the early 1960s placed a single person in low Earth orbit during the Soviet Vostok and American Mercury programs. A two-flight extension of the Vostok program known as Voskhod effectively used Vostok capsules with their ejection seats removed to achieve Soviet space firsts of multiple person crews in 1964 and spacewalks in early 1965. These capabilities were later demonstrated by the Americans in ten Gemini low Earth orbit missions throughout 1965 and 1966, using a totally new second-generation spacecraft design that had little in common with the earlier Mercury. These Gemini missions went on to prove critical techniques for orbital rendezvous and docking that were crucial to a manned lunar landing mission profile.

After the end of the Gemini program, the Soviets Union began flying their second-generation Zond manned spacecraft in 1967 with the ultimate goal of looping a cosmonaut around the Moon and returning him immediately to Earth. The Zond spacecraft was launched with the simpler and already operational Proton launch rocket, unlike the parallel Soviet manned Moon landing effort also underway at the time based on third-generation Soyuz spacecraft requiring development of the advanced N-1 booster. The Soviets thus believed they could achieve a manned Zond circumlunar flight years before an American manned lunar landing and so score a propaganda victory. However, significant development problems delayed the Zond program and the success of the American Apollo lunar landing program led to the eventual termination of the Zond effort.

Like Zond, Apollo Moon flights were generally launched on a free return trajectory that would return them to Earth via a circumlunar loop in the event that a Service Module malfunction failed to place them in lunar orbit as planned. This option was implemented after an explosion aboard the Apollo 13 mission in 1970, which is the only manned circumlunar loop mission flown to date.

U.S.S.R Mission	Mass (kg)	Booster	Launched	Mission Goal	Payload	Mission Result
Cosmos-	5,400	Proton	10 March	High Earth	unmanned	Partial Success - Successfully reached high

146			1967	Orbit		Earth orbit, but became stranded and was unable to initiate controlled high speed atmospheric reentry test
Cosmos-154	5,400	Proton	8 April 1967	High Earth Orbit	unmanned	Partial Success - Successfully reached high Earth orbit, but became stranded and was unable to initiate controlled high speed atmospheric reentry test
		Proton	28 September 1967	High Earth Orbit	unmanned	Failure - booster malfunction, failed to reach Earth orbit
		Proton	22 November 1967	High Earth Orbit	unmanned	Failure - booster malfunction, failed to reach Earth orbit
Zond-4	5,140	Proton	2 March 1968	High Earth Orbit	unmanned	Partial success - launched successfully to 300,000 km high Earth orbit, high speed reentry test guidance malfunction, intentional self-destruct to prevent landfall outside Soviet Union
		Proton	23 April 1968	Circumlunar Loop	non-human biological payload	Failure - booster malfunction, failed to reach Earth orbit; launch preparation tank explosion kills three in pad crew
Zond-5	5,375	Proton	15 September	Circumlunar	non-human biological	Success - looped around Moon, returned live

			1968	Loop	payload	biological payload safely to Earth despite landing off-target outside the Soviet Union in the Indian Ocean
Zond-6	5,375	Proton	10 November 1968	Circumlunar Loop	non-human biological payload	Partial Success - looped around Moon, successful reentry, but loss of cabin air pressure caused biological payload death, parachute system malfunction and severe vehicle damage upon landing
		Proton	20 January 1969	Circumlunar Loop	non-human biological payload	Failure - booster malfunction, failed to reach Earth orbit
Zond-7	5,979	Proton	8 August 1969	Circumlunar Loop	non-human biological payload	Success - looped around Moon, returned biological payload safely to Earth and landed on-target inside Soviet Union. Only Zond mission whose reentry G-forces would have been survivable by human crew had they been aboard.
Zond-8	5,375	Proton	20 October 1970	Circumlunar Loop	non-human biological payload	Success - looped around Moon, returned biological payload safely to Earth despite landing off-target outside Soviet Union in the Indian Ocean

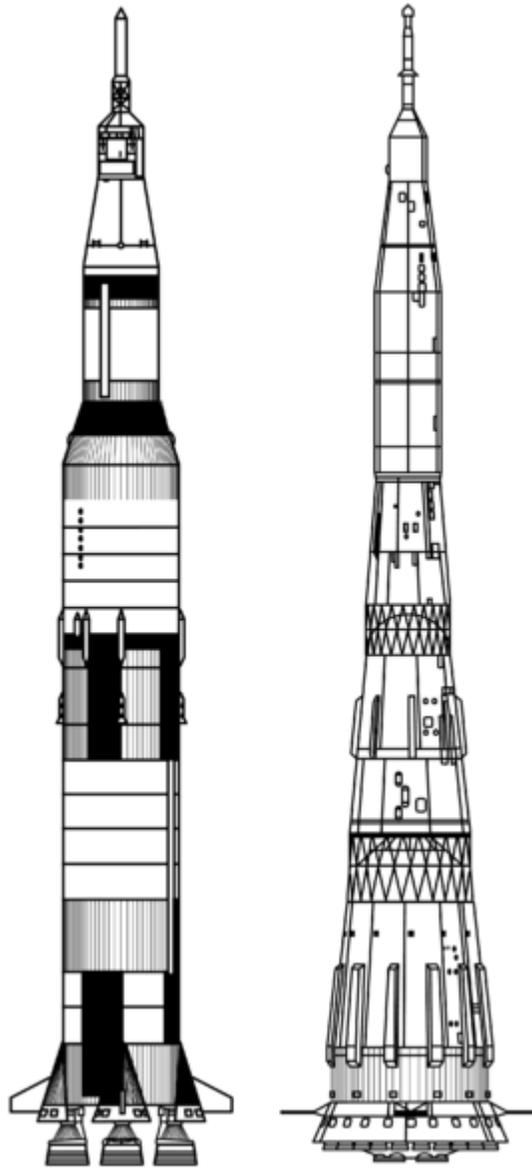
Zond 5 was the first spacecraft to carry life from Earth to the vicinity of the Moon and return, initiating the final lap of the Space Race with its payload of turtles, insects, plants and bacteria. Despite the failure suffered in its final moments, the Zond 6 mission was

reported by Soviet media as being a success as well. Although hailed worldwide as remarkable achievements, both of these Zond missions actually flew off-nominal reentry trajectories resulting in deceleration forces that would have been fatal to human crewmembers had they been aboard. As a result, the Soviets secretly planned to continue unmanned Zond tests until their reliability to support manned flight had been demonstrated. However, due to NASA's continuing problems with the lunar module, and because of CIA reports of a potential Soviet manned circumlunar flight in late 1968, NASA fatefully changed the flight plan of Apollo 8 from an Earth-orbit lunar module test to a lunar orbit mission scheduled for late December 1968.

In early December 1968 the launch window to the Moon opened for the Soviet launch site in Baikonur, giving the USSR their final chance to beat the US to the Moon. Cosmonauts went on alert and asked to fly the Zond spacecraft then in final countdown at Baikonour on the first manned trip to the Moon. Ultimately, however, the Soviet Politburo decided the risk of crew death was unacceptable given the combined poor performance to that point of Zond/Proton and so scrubbed the launch of a manned Soviet lunar mission. Their decision proved to be a wise one, since this unnumbered Zond mission was destroyed in another unmanned test when it was finally launched several weeks later.

By this time flights of the third generation American Apollo spacecraft had begun. Far more capable than the Zond, the Apollo spacecraft had the necessary rocket power to slip into and out of lunar orbit and to make course adjustments required for a safe reentry during the return to Earth. The Apollo 8 mission carried out the first manned trip to the Moon on 24 December 1968, certifying the Saturn V booster for manned use and flying not a circumlunar loop but instead a full ten orbits around the Moon before returning safely to Earth. Apollo 10 then performed a full dress rehearsal of a manned Moon landing in May 1969. This mission stopped short at ten miles (16 km) altitude above the lunar surface, performing necessary low-altitude mapping of trajectory-altering mascons using a factory prototype lunar module that was too overweight to allow a successful landing. With the failure of the unmanned Soviet sample return Moon landing attempt Luna 15 in July 1969, the stage was set for Apollo 11.

Manned Moon landings (1969–1972)

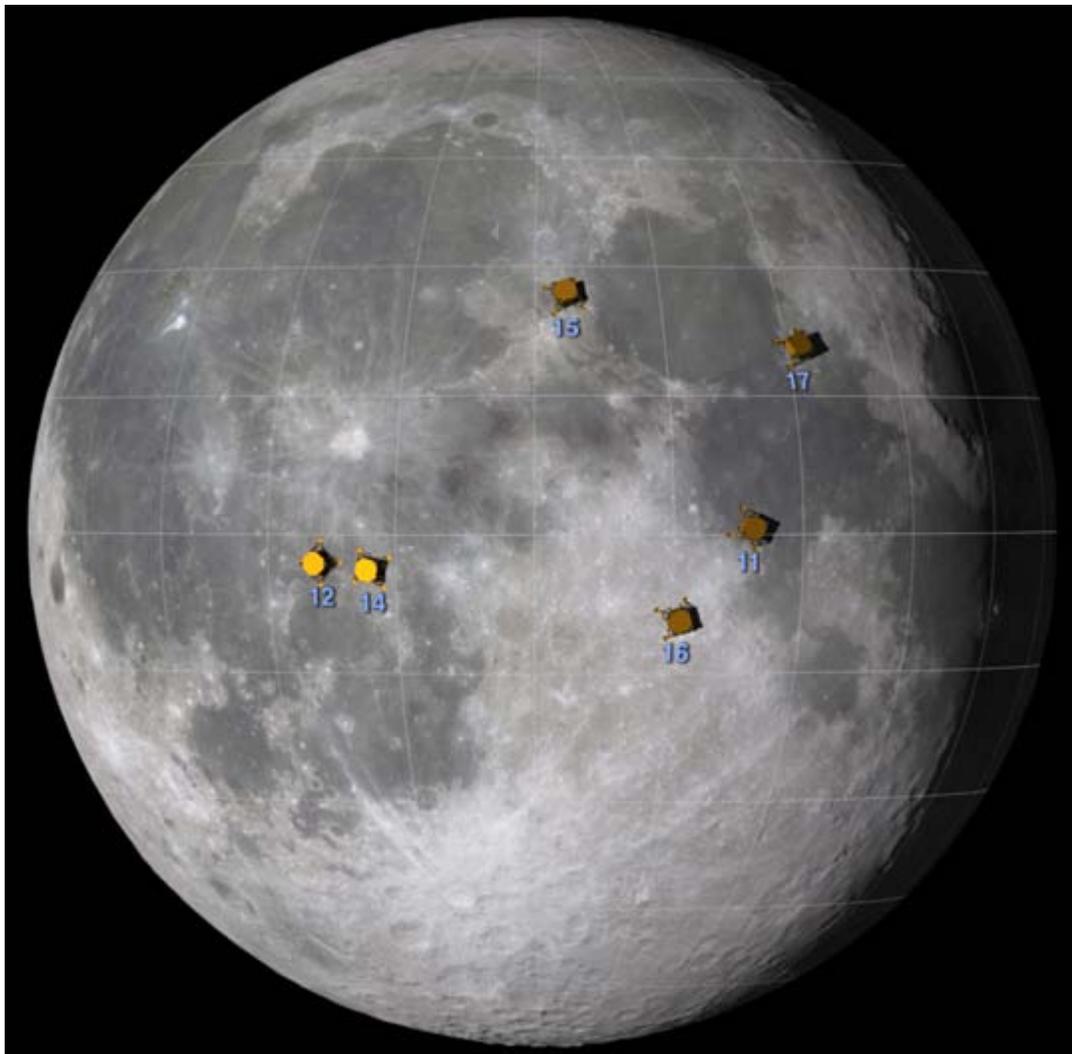


The U.S. Saturn V versus the Soviet N1

American strategy

The U.S. Moon exploration program originated during the Eisenhower administration. In a series of mid-1950s articles in *Collier's* magazine, Wernher von Braun had popularized the idea of a manned expedition to the Moon to establish a lunar base. A manned Moon landing posed several daunting technical challenges to the U.S. and USSR. Besides guidance and weight management, atmospheric re-entry without ablative overheating was a major hurdle. After the Soviet Union's launch of Sputnik, von Braun promoted a plan for the United States Army to establish a military lunar outpost by 1965.

After the early Soviet successes, especially Yuri Gagarin's flight, U.S. President John F. Kennedy looked for an American project that would capture the public imagination. He asked Vice President Lyndon Johnson to make recommendations on a scientific endeavor that would prove U.S. world leadership. The proposals included non-space options such as massive irrigation projects to benefit the Third World. The Soviets, at the time, had more powerful rockets than the United States, which gave them an advantage in some kinds of space missions. Advances in U.S. nuclear weapons technology had led to smaller, lighter warheads, and consequently, rockets with smaller payload capacities. By comparison, Soviet nuclear weapons were much heavier, and the powerful R-7 rocket was developed to carry them. More modest potential missions such as flying around the Moon without landing or establishing a space lab in orbit (both were proposed by Kennedy to von Braun) were determined to offer too much advantage to the Soviets, since the U.S. would have to develop a heavy rocket to match the Soviets. A Moon landing, however, would capture world imagination while functioning as propaganda.



Apollo landing sites

Mindful that the Apollo Program would economically benefit most of the key states in the next election—particularly his home state of Texas because NASA's base was in Houston—Johnson championed the Apollo program. This superficially indicated action to alleviate the fictional "missile gap" between the U.S. and USSR, a campaign promise of Kennedy's in the 1960 election. The Apollo project allowed continued development of dual-use technology. Johnson also advised that for anything less than a lunar landing the USSR had a good chance of beating the U.S. For these reasons, Kennedy seized on Apollo as the ideal focus for American efforts in space. He ensured continuing funding, shielding space spending from the 1963 tax cut and diverting money from other NASA projects. This dismayed NASA's leader, James E. Webb, who urged support for other scientific work.

The Saturn V booster was the key to U.S. Moon landings. The Saturn had a perfect record of zero failures in thirteen launches.

Whatever he said in private, Kennedy needed a different message to gain public support to uphold what he was saying and his views. Later in 1963, Kennedy asked Vice President Johnson to investigate the possible technological and scientific benefits of a Moon mission. Johnson concluded that the benefits were limited, but, with the help of scientists at NASA, he put together a powerful case, citing possible medical breakthroughs and interesting pictures of Earth from space. For the program to succeed, its proponents would have to defeat criticism from politicians on the left, who wanted more money spent on social programs, and on those on the right, who favored a more military project. By emphasizing the scientific payoff and playing on fears of Soviet space dominance, Kennedy and Johnson managed to swing public opinion: by 1965, 58 percent of Americans favored Apollo, up from 33 percent two years earlier. After Johnson became President in 1963, his continuing defense of the program allowed it to succeed in 1969, as Kennedy had originally hoped.

Soviet strategy

Soviet leader Nikita Khrushchev did not relish "defeat" by any other power, but equally did not relish funding such an expensive project. In October 1963 he said that the USSR was "not at present planning flight by cosmonauts to the Moon," while insisting that the Soviets had not dropped out of the race. Only after another year would the USSR fully commit itself to a Moon-landing attempt, which ultimately failed.

At the same time, Kennedy had suggested various joint programs, including a possible Moon landing by Soviet and American astronauts and the development of better weather-monitoring satellites. Khrushchev, sensing an attempt by Kennedy to steal Russian space technology, rejected the idea: if the USSR went to the Moon, it would go alone. Korolyov, the RSA's chief designer, had started promoting his Soyuz craft and the N-1 launcher rocket that would have the capability of carrying out a manned Moon landing. Khrushchev directed Korolyov's design bureau to arrange further space firsts by modifying the existing Vostok technology, while a second team started building a completely new launcher and craft, the Proton booster and the Zond, for a manned

cislunar flight in 1966. In 1964 the new Soviet leadership gave Korolyov the backing for a Moon landing effort and brought all manned projects under his direction. With Korolyov's death and the failure of the first Soyuz flight in 1967, the co-ordination of the Soviet Moon landing program quickly unraveled. The Soviets built a landing craft and selected cosmonauts for the mission that would have placed Aleksei Leonov on the Moon's surface, but with the successive launch failures of the N1 booster in 1969, plans for a manned landing suffered first delay and then cancellation.

Apollo missions

U.S. Mission	Booster	Crew	Launched	Mission Goal	Mission Result
AS-201 (Apollo 1A)	Saturn 1B	Unmanned	26 February 1966	Suborbital	Partial Success - Unmanned suborbital flight was the first test flight of Saturn 1B and of the Apollo Command and Service Modules; problems included the failure of service module engine to fire for longer than 60 seconds and an electrical systems failure in the command module
AS-203 (Apollo 2)	Saturn 1B	Unmanned	5 July 1966	Earth orbit	Success - fuel tank behaviour test and booster certification - informally known as Apollo 2
AS-202 (Apollo 3)	Saturn 1B	Unmanned	25 August 1966	Suborbital	Success - command module reentry test successful, even though reentry was very uncontrolled - informally known as Apollo 3
AS-204 (Apollo 1)	Saturn 1B	Virgil I. "Gus" Grissom, Edward White, Roger B. Chaffee	(Launch cancelled)	Earth orbit	Failure - never launched: command module destroyed and three astronauts killed on 27 January 1967 by fire in the module during a test exercise - Retroactively, the

					mission's name was officially changed to "Apollo 1" after the fire. Despite the fact that it was scheduled to be the fourth Apollo mission (and despite the fact that NASA planned to call the mission AS-204), the flight patch worn by the three astronauts, which was approved by NASA in June 1966, already referred to the mission as "Apollo 1"
Apollo 4	Saturn V	Unmanned	9 November 1967	Earth orbit	Success - first test of new booster and all elements together (except lunar module), successful reentry of command module
Apollo 5	Saturn 1B	Unmanned	22 January 1968	Earth orbit	Success - first flight of lunar module, multiple space tests of lunar module, no controlled reentry - used the Saturn 1B rocket original slated for the cancelled "Apollo 1" mission
Apollo 6	Saturn V	Unmanned	4 April 1968	Earth orbit	Partial Success - severe oscillations during orbital insertion, several engines failing during flight, successful reentry of command module (though mission parameters for a 'worst case' reentry scenario could not be achieved)
Apollo 7	Saturn 1B	Walter M. "Wally" Schirra, Donn Eisele, Walter	11 October 1968	Earth orbit	Success - eleven-day manned Earth orbit, command module testing (no lunar module), some minor crew

		Cunningham			issues
Apollo 8	Saturn V	Frank Borman, Jim Lovell, William A. Anders	21 December 1968	Lunar orbit	Success - ambitious mission profile (changed relatively shortly before launch), first human lunar orbit (no lunar module), first earthrise seen by men and major publicity success, some minor sleeping and illness issues
Apollo 9	Saturn V	James McDivitt, David Scott, Russell L. "Rusty" Schweickart	3 March 1969	Earth orbit	Success - ten-day manned Earth orbit, with EVA and successful manned flight / docking of lunar module
Apollo 10	Saturn V	Thomas P. Stafford, John W. Young, Eugene Cernan	18 May 1969	Lunar orbit	Success - second manned lunar orbit, test of lunar module in lunar orbit, coming as close as 8.4 nautical miles (15.6 km) to the Moon's surface
Apollo 11	Saturn V	Neil Armstrong, Michael Collins, Edwin A. "Buzz" Aldrin	20 July 1969	Lunar landing	Success - First manned landing, exploration on foot.
Apollo 12	Saturn V	Charles "Pete" Conrad, Richard Gordon, Alan Bean	14 November 1969	Lunar landing	Success - mission almost aborted in-flight after lightning strike on takeoff caused telemetry loss, successful landing within 200 meters of the Surveyor 3 probe

Apollo 13	Saturn V	Jim Lovell, Jack Swigert, Fred Haise	11 April 1970	Lunar landing	Failure - problematic oscillations on start, unrelated explosion in service module during Earth-Moon transition caused mission to be aborted - crew took temporary refuge in lunar module and eventually returned to Earth with command module after single pass around Moon and made it through reentry.
Apollo 14	Saturn V	Alan B. Shepard, Stuart Roosa, Edgar Mitchell	31 January 1971	Lunar landing	Success - software and hardware problems with lunar module almost caused landing abort during lunar orbit, first color video images from the Moon, first materials science experiments in space
Apollo 15	Saturn V	David Scott, Alfred Worden, James Irwin	26 July 1971	Lunar landing	Success - first longer (3 days) stay on Moon, first use of lunar rover to travel total of 17.25 miles (27.76 km), more extensive geology investigations
Apollo 16	Saturn V	John W. Young, Ken Mattingly, Charles Duke	16 April 1972	Lunar landing	Success - malfunction in a backup yaw gimbal servo loop almost aborted landing (and reduced stay duration on Moon by one day to three for safety reasons), only mission to target lunar highlands
Apollo 17	Saturn V	Eugene Cernan, Ronald Evans, Harrison H.	7 December 1972	Lunar landing	Success - last (and still most recent) manned landing on the Moon, only mission with geologist

		"Jack" Schmitt			
Skylab 1	Saturn V	Unmanned	May 14, 1973	Earth orbit	Success - Launch of Skylab space station
Skylab 2	Saturn 1B	Charles "Pete" Conrad, Paul Weitz, Joseph Kerwin	May 25, 1973	Space station mission	Success - Apollo spacecraft takes first US crew to Skylab, the first American space station, for a 28 day stay
Skylab 3	Saturn 1B	Alan Bean, Jack Lousma, Owen Garriott	July 28, 1973	Space Station mission	Success - Apollo spacecraft takes second US crew to the Skylab space station for a 59 day stay
Skylab 4	Saturn 1B	Gerald Carr, William Pogue, Edward Gibson	November 16, 1973	Space station mission	Success - Apollo spacecraft takes third US crew to the Skylab space station for an 84 day stay
ASTP (Apollo 18)	Saturn 1B	Thomas P. Stafford, Vance D. Brand, Donald K. "Deke" Slayton	July 15, 1975	Earth orbit	Success - Apollo-Soyuz Test Project, in which an Apollo space craft conducted rendezvous and docking exercises with Soviet Soyuz 19 in space - sometimes referred to as "Apollo 18"
Planned Apollo 18, Apollo 19, and Apollo 20 Moon Missions	Saturn V	Missions cancelled	Never launched	Lunar landings	Cancelled - Several more missions (with detailed planning for up to Apollo 20) were cancelled

In total, twenty-four American astronauts have traveled to the Moon, with twelve walking on its surface and three making the trip twice. Apollo 8 was a lunar-orbit-only mission, Apollo 10 included undocking and Descent Orbit Insertion (DOI), followed by LM staging to CSM redocking, while Apollo 13, originally scheduled as a landing, ended up

as a lunar fly-by, by means of free return trajectory; thus, none of these missions made landings. Apollo 7 and Apollo 9 never left Earth orbit. Apart from the inherent dangers of manned Moon expeditions as seen with Apollo 13, one reason for their cessation according to astronaut Alan Bean is the cost it imposes in government subsidies.

Manned Moon landings

Mission Name	Lunar Lander	Lunar Landing Date	Lunar Blastoff Date	Lunar Landing Site	Duration on Lunar Surface	Crew	Number of EVAs	Total EVA Time
Apollo 11	<i>Eagle</i>	20 July 1969	21 July 1969	Sea of Tranquility	21:31	Neil Armstrong, Edwin "Buzz" Aldrin	1	2:31
Apollo 12	<i>Intrepid</i>	19 November 1969	21 November 1969	Ocean of Storms	1 day, 7:31	Charles "Pete" Conrad, Alan Bean	2	7:45
Apollo 14	<i>Antares</i>	5 February 1971	6 February 1971	Fra Mauro	1 day, 9:30	Alan B. Shepard, Edgar Mitchell	2	9:21
Apollo 15	<i>Falcon</i>	30 July 1971	3 August 1971	Hadley Rille	2 days, 18:55	David Scott, James Irwin	3	18:33
Apollo 16	<i>Orion</i>	21 April 1972	24 April 1972	Descartes Highlands	2 days, 23:02	John Young, Charles Duke	3	20:14
Apollo 17	<i>Challenger</i>	11 December	14 December	Taurus-Littrow	3 days, 2:59	Eugene Cernan, Harrison H.	3	22:04

		1972	1972			"Jack" Schmitt		
--	--	------	------	--	--	-------------------	--	--

Other aspects of the Apollo Moon landings

Unlike other international rivalries, the Space Race has remained unaffected in a direct way regarding the desire for territorial expansion. After the successful landings on the Moon, the U.S. explicitly disclaimed the right to ownership of any part of the Moon.

President Richard Nixon had speechwriter William Safire prepare a condolence speech for delivery in the event that Armstrong and Aldrin became marooned on the Moon's surface and could not be rescued.

In the 1940s writer Arthur C. Clarke forecast that man would reach the Moon by 2000.

On August 16, 2006, the Associated Press reported that NASA is missing the original Slow-scan television tapes (which were made before the scan conversion for conventional TV) of the Apollo 11 Moon walk. Some news outlets have mistakenly reported that the SSTV tapes were found in Western Australia, but those tapes were only recordings of data from the Apollo 11 Early Apollo Surface Experiments Package.

20th-21st century unmanned crash landings

Hiten (Japan)

At the end of its mission, the Japanese lunar orbiter Hiten was commanded to crash into the lunar surface and did so on 10 April 1993 at 18:03:25.7 UT (11 April 03:03:25.7 JST).

SMART-1 (ESA)

At the end of its mission, the ESA lunar orbiter SMART-1 performed a controlled crash into the Moon, at about 2 km/sec. The time of the crash was 3 September 2006, at 5:42 UT.

Chandrayaan-1 (India)

Chandrayaan-1 was India's first unmanned lunar probe. It was launched by the Indian Space Research Organisation (ISRO) in October 2008, and operated until August 2009. The mission, including a lunar orbiter and an impactor, was launched by a modified version of the PSLV, PSLV C11 on 22 October 2008 from Satish Dhawan Space Centre, Sriharikota, Nellore District, Andhra Pradesh, about 80 km north of Chennai, at 06:22 IST (00:52 UTC). The mission was a major boost to India's space program, as India researched and developed its own technology in order to explore the Moon. The vehicle was successfully inserted into lunar orbit on 8 November 2008, and the impactor, the

Moon Impact Probe, impacted near Shackleton Crater at the south pole of the lunar surface at 14 November 2008, 20:31 IST. The estimated cost for the project was 3.86 billion Indian rupees (US\$80 million).

Weighing 34 kilograms, the box shaped impactor carried three instruments—a video imaging system, a mass spectrometer and a radar altimeter. The video imaging system took pictures of the Moon’s surface from high altitudes, relaying those pictures back to Earth during the descent. The mass spectrometer made measurements of the extremely thin lunar atmosphere. The radar altimeter measured the rate of descent of the probe to the lunar surface, testing that technology for future soft landing missions. The probe did not include braking rockets and was destroyed upon impacting the lunar surface at its planned speed of 3,100 miles per hour.

The orbiter completed 3,000 orbits acquiring 70,000 images of the lunar surface. They were first transmitted to Indian Deep Space Network at Byalalu near Bangalore, and then to the Indian Space Research Organisation Telemetry, Tracking and Command Network at Bangalore. ISRO claims that the landing sites of the Apollo Moon missions have been mapped by the orbiter using multiple payloads. Six of the sites have been mapped including that of Apollo 11, the first mission that brought humans on the Moon.

The Moon Mineralogy Mapper instrument, provided by NASA, confirmed the presence of water on the Moon. This was also confirmed by the mass spectrometer on the MIP.

Mission Name	Payload	Mass (kg)	Booster	Launched	Mission Goal	Mission Result	Landing Zone	Lat/Lon
Chandrayaan-1	MIP	32	PSLV C11	14 November 2008	Lunar Impact	Success - Crashed at 3,100 miles per hour as planned, measured atmosphere and descent rate, returned high-altitude photos taken before impact.	Shackleton (crater)	000.00S 016.30E

Chang'e 1 (China)

The Chinese lunar orbiter Chang'e 1 executed a controlled crash onto the surface of the Moon on 1 March 2009, 2044 GMT, after a 16-month mission.

US orbital missions (2009)-

The most recent lunar mission has been the NASA's Lunar Reconnaissance Orbiter mission. The Lunar Precursor Robotic Program (LPRP) is a program of robotic spacecraft missions which NASA will use to prepare for future human spaceflight missions to the Moon. Two missions, the Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation and Sensing Satellite (or LCROSS), originally planned to be launched in October 2008, but was launched on June 18, 2009.

Moon Landings Commemorated

In 1969 and 1971 the US Post Office issued commemorative stamps honoring the Astronauts and Moon landing missions of those years.



First Man on the moon commemorative of 1969



Space Achievement Decade, Issue of 1971

In late 1960s early 1970s the USSR and other Soviet bloc countries issued stamps commemorating Soviet unmanned lunar efforts



Luna 9 First soft moonlanding



Soviet Luna-16 postal stamp



Lunokhod lunar lab DDR stamp

Other moon landings

Progress in space exploration has recently broadened the phrase *moon landing* to include other moons in the solar system as well. The Huygens probe of the Cassini mission to Saturn performed a successful unmanned moon landing on Titan in 2005. Similarly, the Soviet probe Phobos 2 came within 120 miles (190 km) of performing an unmanned moon landing on Mars' moon Phobos in 1989 before radio contact with that lander was suddenly lost. A similar Russian sample return mission called Phobos-Grunt ("grunt" means "soil" in Russian) is scheduled for launch in early 2012. There is widespread interest in performing a future moon landing on Jupiter's moon Europa to drill down and explore the possible liquid water ocean beneath its icy surface.

Proposed future missions

The most recently launched lunar orbiter is China's Chang'e 2, which was launched in early October 2010. China is also planning to land motorized rovers and collect samples in the Chang'e 3 and Chang'e 4 missions and return lunar soil samples by 2018.

Russia's Luna-Glob 1 expected to be launched in 2012. In 2007 the head of the Russian Space Agency announced plans to send cosmonauts to the Moon by 2025 and establish a permanent manned base there in 2027-2032.

ISRO, the Indian National Space agency, is planning a second version of Chandrayaan named Chandrayaan 2. According to former ISRO Chairman G. Madhavan Nair, "The Indian Space Research Organisation (ISRO) hopes to land two motorised rovers - one Indian and another Russian - on the Moon in 2013, as a part of its second Chandrayaan mission. The rover will be designed to move on wheels on the lunar surface, pick up samples of soil or rocks, do on-site chemical analysis and send the data to the mother-spacecraft Chandrayaan II, which will be orbiting above. Chandrayaan II will transmit the data to Earth." The payloads have already been finalized. ISRO has mentioned that due to weight restrictions it will not be carrying any overseas payloads on this mission. The lander weight is projected to be 1,250 kg, and the spacecraft will be launched by the Geosynchronous Satellite Launch Vehicle.

The Google Lunar X Prize competition offers a \$20 million award for the first privately funded team to land a robotic probe on the Moon. Like the Ansari X Prize before it, the competition aims to advance the state of the art in private space exploration.

Hoax accusations

Some people have insisted that the Apollo Moon landings were a hoax. These accusations flourish in part because predictions by enthusiasts that Moon landings would become commonplace have not yet come to pass. Some claims can be empirically discredited by three retroreflector arrays left on the Moon by Apollo 11, 14 and 15. With new technology, it is possible for anyone on Earth with an appropriate laser and telescope system to bounce laser beams off these devices, verifying deployment of the Lunar Laser

Ranging Experiment at historically documented Apollo Moon landing sites. This evidence indicates the deployment of equipment which was constructed on Earth and successfully transported to the surface of the Moon. In addition, NASA's Lunar Reconnaissance Orbiter, in August 2009, began to send back high resolution photos showing the Apollo landing sites.

Chapter- 3

Moon Landing Conspiracy Theories



Astronauts Buzz Aldrin and Neil Armstrong in the NASA's training mockup of the Moon and lander module. Hoax proponents say that the film of the missions was made using similar sets to this training mockup.

Different **Moon landing conspiracy theories** claim that some or all elements of the Apollo Project and the associated Moon landings were falsifications staged by NASA and members of other organizations. Since the conclusion of the Apollo program, a number of related accounts espousing a belief that the landings were faked in some fashion have been advanced by various groups and individuals. Some of the more notable of these various claims include allegations that the Apollo astronauts did not set foot on the Moon; instead NASA and others intentionally deceived the public into believing the landings did occur by manufacturing, destroying, or tampering with evidence, including photos, telemetry tapes, transmissions, rock samples, and even some key witnesses themselves. Such claims are common to most of the conspiracy theories.

There is abundant third-party evidence for Apollo Moon landings, and commentators have published detailed rebuttals to the hoax claims. Various polls have shown that 6% to 28% of the people surveyed in various locations do not think the Moon landing happened.

Origins and history

The first book dedicated to the subject, Bill Kaysing's self-published *We Never Went to the Moon: America's Thirty Billion Dollar Swindle*, was released in 1974, two years after the Apollo Moon flights had ceased. Folklorist Linda Degh suggests that writer-director Peter Hyams's 1978 film *Capricorn One*, which depicts a hoaxed journey to Mars in a spacecraft that looks identical to the Apollo craft, may have given a boost to the hoax theory's popularity in the post-Vietnam War era. She notes that this occurred during the post-Watergate era, when segments of the American public were inclined to distrust official accounts. Degh writes: "The mass media catapult these half-truths into a kind of twilight zone where people can make their guesses sound as truths. Mass media have a terrible impact on people who lack guidance." In *A Man on the Moon*, published in 1994, Andrew Chaikin mentions that at the time of Apollo 8's lunar-orbit mission in December 1968 similar conspiracy ideas were already in circulation.

Public opinion

There are subcultures worldwide which advocate the belief that the Moon landings were faked. James Oberg of *ABC News* stated that claims made that the Moon landings were faked are actively taught in Cuban schools and wherever Cuban teachers are sent. A 1999 Gallup poll found that 6% of the American public doubted that the Moon landings had occurred and that 5% had no opinion on the subject, which roughly matches the findings of a similar 1995 *Time/CNN* poll. Officials of Fox television stated that such skepticism increased to about 20% after the February 15, 2001 airing of that network's TV show entitled *Conspiracy Theory: Did We Land on the Moon?* Seen by approximately 15 million viewers, the 2001 Fox special is viewed as having promoted the hoax claims.

A 2000 poll conducted by the Russian *Public Opinion Fund* found that 28% do not believe that American astronauts have been on the Moon, and this percentage is roughly equal in all social-demographic groups. In 2009, a poll conducted by the British

Engineering & Technology magazine found that 25% of Britons do not believe that humans have walked on the Moon. Similarly, 25% of Americans between the age of 18 and 25 are not sure the landings happened.

Predominant hoax claims

Numerous conspiracy theories have been advanced that outline concerted action by NASA employees (and sometimes others) to perpetuate false information about landings that never occurred, or to cover up accurate information about the landings that occurred in a different manner than have been publicized. Believers have focused on perceived gaps or inconsistencies in the historical record of the missions. The Flat Earth Society was one of the first organizations to accuse NASA of faking the landings, arguing that they were staged by Hollywood with Walt Disney sponsorship and based on a script by Arthur C. Clarke and directed by Stanley Kubrick.

The most predominant idea is that the entire human landing program was a complete hoax from start to finish. Some claim that the technology to send men to the Moon was insufficient or that the Van Allen radiation belts, solar flares, solar wind, coronal mass ejections and cosmic rays made such a trip impossible.

Bart Sibrel has claimed that the crew of Apollo 11 and subsequent astronauts had faked their orbit around the Moon and their walk on its surface by trick photography and that they never got more than halfway to the Moon. A subset of this proposal is advocated by those who concede the existence of retroreflectors and other observable human-made objects on the Moon. British publisher Marcus Allen represented this argument when he said "I would be the first to accept what [telescope images of the landing site] find as powerful evidence that something was placed on the Moon by man". He goes on to say that photographs of the lander would not prove that the United States put men on the Moon. "Getting to the Moon really isn't much of a problem – the Russians did that in 1959, the big problem is getting people there". He suggests that NASA sent robot missions because radiation levels in space would be lethal to humans. Another variant on this is the idea that NASA and its contractors did not recover quickly enough from the Apollo 1 fire, and so all the early Apollo missions were faked, with Apollo 14 or 15 being the first authentic mission.

Philippe Lheureux, French author of *Moon Landings: Did NASA Lie?* and *Lights on the Moon: Did NASA Lie? (Lumières sur la Lune: La NASA a-t-elle menti?)*, said that astronauts did land on the Moon but in order to prevent other nations from benefiting from scientific information in the real photos, NASA published fake images.

Motives

Proponents of the view that the Moon landings were faked give several differing theories about the motivation for the United States government to fake the Moon landings. Cold War prestige, monetary gain and providing a distraction are some of the more notable motives given.

The United States government considered it vital that the United States win the Space Race against the Soviet Union. Going to the Moon would be risky and expensive, as exemplified by John F. Kennedy famously stating that the United States chose to go *because* it was hard. Proponents also claim that the United States government benefited from a popular distraction from the Vietnam War; and so lunar activities suddenly stopped, with planned missions canceled, around the same time that the United States ceased its involvement in the Vietnam War.

Bill Kaysing maintains that, despite close monitoring by the Soviet Union, it would have been easier for the United States to fake the Moon landing, thereby guaranteeing success, than for the United States to actually go there. Kaysing claimed that the chance of a successful landing on the Moon was calculated to be 0.017%. NASA raised approximately US\$30 billion in order to go to the Moon as well, and Kaysing claims that this amount could have been used to pay off a large number of people, providing significant motivation for complicity. The issue of delivering on the promise is often brought up as well. Since most proponents believe that the technical issues involved in getting people to the Moon either were insurmountable at the time or remain insurmountable, the Moon landings had to be faked in order to fulfill President Kennedy's 1961 promise "to achieving the goal, *before this decade is out*, of landing a man on the Moon and returning him safely to the Earth."

Others have made the claim that, with all the known and unknown hazards of traveling into deep space, NASA would not have risked the public humiliation of astronauts crashing to their deaths on the lunar surface, broadcast on live TV. So, with time running out, instead of risking a national fiasco and embarrassment and a cut-off of funding of billions of dollars should some catastrophe happen, it is argued that NASA had to stage and fake the Moon landing to avoid such a major risk.

Involvement of the Soviet Union

A primary reason for the race to the Moon was the Cold War. Philip Plait states in *Bad Astronomy* that the Soviets, with their own competing Moon program and a formidable scientific community able to analyze NASA data, could be expected to have cried foul if the United States tried to fake a Moon landing, especially since their own program had failed. Successfully pointing out a hoax would have been a major propaganda coup. Bart Sibrel has responded, "the Soviets did not have the capability to track deep spacecraft until late in 1972, immediately after which, the last three Apollo missions were abruptly canceled."

However, the Soviet Union had been sending unmanned spacecraft to the Moon since 1959, and "during 1962, deep space tracking facilities were introduced at IP-15 in Ussuriisk and IP-16 in Evpatoria (Crimean Peninsula), while Saturn communication stations were added to IP-3, 4 and 14", the latter having a 100 million km range. The Soviet Union monitored the missions at the Space Transmissions Corps, which was "fully equipped with the latest intelligence-gathering and surveillance equipment". Vasily Mishin, in an interview for the article "The Moon Programme That Faltered"

(*Spaceflight*, March 1991, vol. 33, 2-3), describes how the Soviet Moon programme lost energy after the Apollo landing.

Hoax proponents and their proposals

- Bill Kaysing (1922–2005) an ex-employee of Rocketdyne, the company which built the F-1 engines used on the Saturn V rocket. Kaysing was not technically qualified, and worked at Rocketdyne as a librarian. Kaysing's self published book, *We Never Went to the Moon: America's Thirty Billion Dollar Swindle*, made many allegations, effectively beginning the discussion of the Moon landings possibly being hoaxed. NASA and others have debunked the claims made in the book.
- Bart Sibrel, a filmmaker, produced and directed four films for his company AFTH, including a film in 2001 called *A Funny Thing Happened on the Way to the Moon*, examining the evidence of a hoax. The arguments that Sibrel puts forward in this film have been debunked by numerous sources, including Svector's video series *Lunar Legacy*, which disproves the documentary's primary argument that the Apollo crew faked their distance from the Earth command module, while in low orbit. Sibrel has stated that the effect on the shot covered in his film was produced through the use of a transparency of the Earth. Some parts of the original footage, according to Sibrel, were not able to be included on the official releases for the media. On such allegedly censored parts, the correlation between Earth and Moon Phases can be clearly confirmed, refuting Sibrel's claim that these shots were faked. Sibrel was also punched in the face by Buzz Aldrin after Sibrel confronted Aldrin with his theories about the moon hoax while accusing the former astronaut of being "a coward, and a liar, and a thief". Sibrel attempted to press charges against Aldrin but the case was thrown out of court when the judge ruled that Aldrin was within his rights given Sibrel's invasive and aggressive behavior.
- William L. Brian, a nuclear engineer who self-published a book in 1982 called *Moongate: Suppressed Findings of the U.S. Space Program*, in which he disputes the Moon's surface gravity.
- David Percy, TV producer and expert in audiovisual technologies and member of the Royal Photographic Society, is co-author, along with Mary Bennett of *Dark Moon: Apollo and the Whistle-Blowers* (ISBN 1-898541-10-8) and co-producer of *What Happened On the Moon?*. He is the main proponent of the "whistle-blower" accusation, arguing that the errors in the NASA photos in particular are so obvious that they are evidence that insiders are trying to 'blow the whistle' on the hoax by deliberately inserting errors that they know will be seen.
- Ralph Rene - An inventor and 'self taught' engineering buff. Author of *NASA Mooned America* (second edition OCLC 36317224).
- James M. Collier (d. 1998) - American journalist and author, producer of the video *Was It Only a Paper Moon ?* in 1997.
- Jack White - American photo historian known for his attempt to prove forgery in photos related to the assassination of U.S. President John F. Kennedy.

- Marcus Allen - British publisher of Nexus who said that photographs of the lander would not prove that the U.S. put men on the Moon. "Getting to the Moon really isn't much of a problem - the Russians did that in 1959 - the big problem is getting people there".
- Aron Ranen states in his documentary film *Did We Go?* (2005) "at this point right now I'm about 75% believing we went". On July 20, 2009, Ranen appeared on *Geraldo at Large* (Fox News Channel) to argue that no one has landed on the moon.
- Clyde Lewis - Radio talk show host.
- David Groves - Works for Quantech Image Processing and worked on some of the NASA photos. Notably he has examined the photo of Aldrin emerging from the LM. He said he can pinpoint the exact point at which an artificial light was used. Using the focal length of the camera's lens and an actual boot, he has calculated, using ray-tracing, that the artificial light source is between 24 to 36 centimetres (9.4 to 14 in) to the right of the camera. This corresponds with the sunlit part of Armstrong's spacesuit.
- Yuri Mukhin - Russian opposition politician, publicist and writer and author of the book *The Moon affair of the USA* (2006) in which he denies all Moon landing evidence and accuses the U.S. establishment of plundering the money paid by the American taxpayers for the Moon program and the Central Committee of the Communist Party of the Soviet Union and some Soviet scientists for helping NASA commit the hoax without being denounced.
- Alexander Popov - Russian doctor of physical-mathematical sciences and author of the book *Americans on the Moon - a great breakthrough or a space affair?* (Moscow, 2009, ISBN 978-5-9533-3315-3) in which he aims to prove that Saturn V was in fact a camouflaged Saturn 1B and denies all Moon landing evidence.
- Stanislav Pokrovsky - Russian candidate of technical sciences and General Director of a scientific-manufacturing enterprise *Project-D-MSK* who calculated that the real speed of the Saturn V rocket at S-IC staging time was only half of what was declared. His analysis appears to assume that the solid rocket plumes from the fuselage and retro rockets on the two stages came to an instant halt in the surrounding air so they can be used to estimate the velocity of the rocket. He ignored high altitude winds and the altitude at staging, 67 km, where air is about 1/10,000 as dense as at sea level, and claimed that only a loop around the Moon was possible, not a manned landing on the Moon with return to the Earth. He also determined the reason for this - problems with the Inconel superalloy used in the F-1 engine.

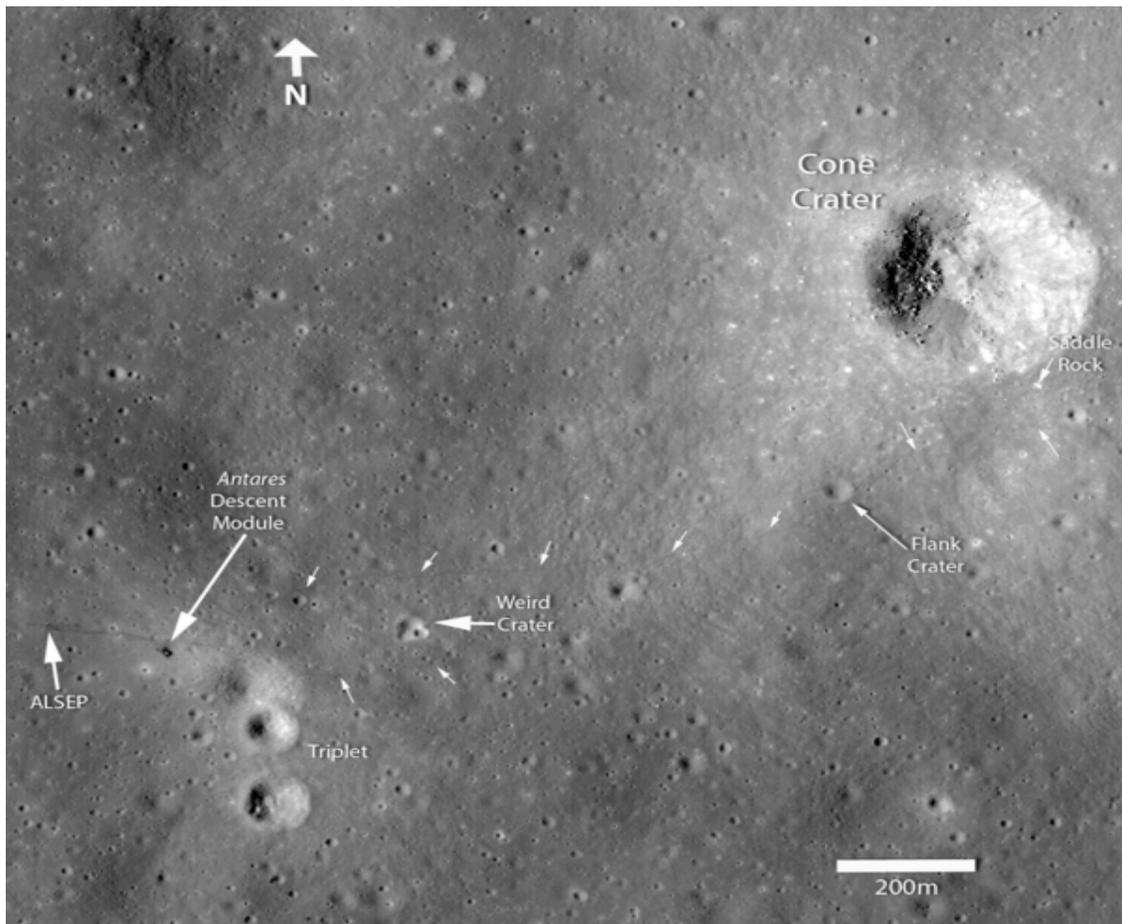
Critical examination of hoax accusations

According to James Longuski, Professor of Aeronautics and Astronautics Engineering at Purdue University, the size and complexity of the alleged conspiracy theory scenarios make their veracity an impossibility. More than 400,000 people worked on the Apollo project for nearly ten years, and a dozen men who walked on the Moon returned to Earth to recount their experiences. Hundreds of thousands of people, including astronauts, scientists, engineers, technicians, and skilled laborers, would have had to keep the secret.

Longuski also contends that it would have been significantly easier to actually land on the Moon than to generate such a massive conspiracy to fake such a landing.

Vince Calder and Andrew Johnson provided a detailed rebuttal to the conspiracy theorists' claims, in a question and answer format, on the Argonne National Laboratory web site. They show that NASA's portrayal of the Moon landing is fundamentally accurate, allowing for such common errors as mislabeled photos and imperfect personal recollections. Through application of the scientific process, any hypothesis that is contradicted by the observable facts may be rejected. The lack of narrative consistency in the hoax hypothesis occurs because hoax accounts vary from proponent to proponent. The 'real landing' hypothesis is a single story, since it comes from a single source, but there are many hoax hypotheses, each of which addresses a specific aspect of the Moon landing, and this variation is considered a key indicator that the hoax hypothesis actually constitutes a conspiracy theory.

Imaging the landing sites

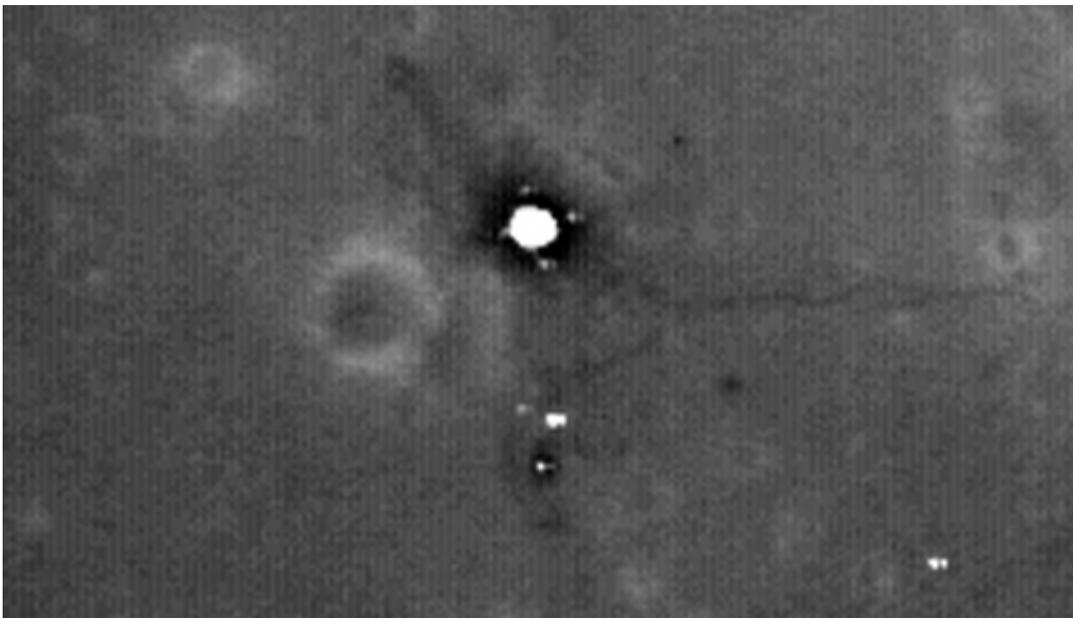


A later LRO photo of the Apollo 14 landing site

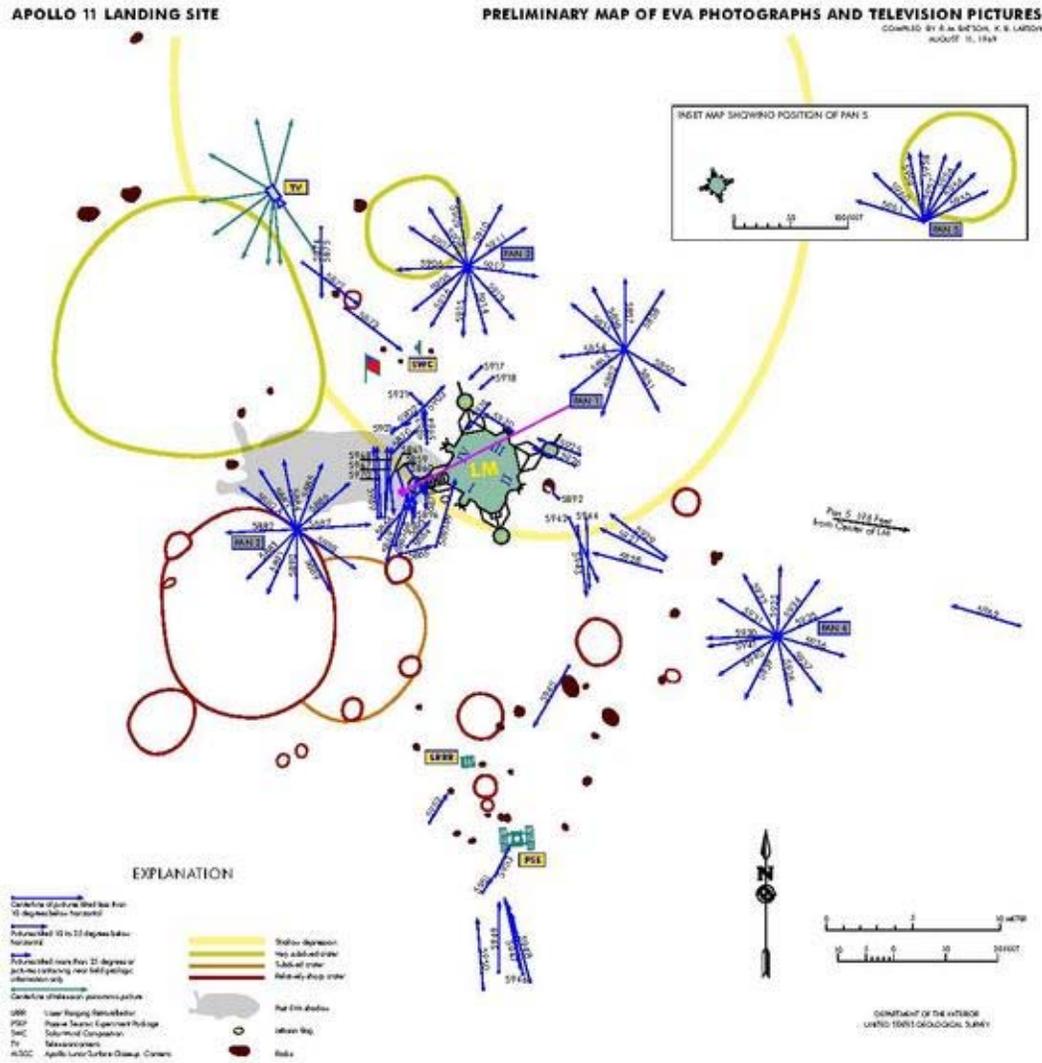
Another component of the Moon hoax theory is based on the argument that professional observatories and the Hubble Space Telescope should be able to take pictures of the lunar landing sites. The argument runs that if telescopes can "see to the edge of the universe" then they ought to be able to take pictures of the lunar landing sites, implying that the world's major observatories (as well as the Hubble Program) are complicit in the Moon landing hoax by refusing to take pictures of the landing sites. Images of the moon have been taken by Hubble, including at least two Apollo landing sites; but the Hubble resolution limits viewing of lunar objects to sizes no smaller than 60-75 yards (55-69 meters), which is insufficient to see any landing site features.

The Daily Telegraph (London) published a story in 2002 saying that European astronomers at the Very Large Telescope would use it to view the remains of the Apollo lunar landers. According to the article, Dr Richard West said that his team would take "a high-resolution image of one of the Apollo landing sites". Marcus Allen, a Moon hoax proponent, pointed out in the story that no images of hardware on the Moon would convince him that manned landings had taken place. As the VLT is capable of resolving equivalent to the distance between the headlights of a car as seen from the Moon, it may be able to directly image some features of the Apollo landing site. Such photos, if and when they become available, would be the first non-NASA produced images of the site at that definition.

The Japan Aerospace Exploration Agency (JAXA) launched their SELENE lunar orbiter on September 14, 2007 (JST) from Tanegashima Space Center. SELENE orbited the Moon at about 100 kilometres (62 mi) altitude. In May 2008 JAXA reported detecting the "halo" generated by the Apollo 15 lunar module engine exhaust from a Terrain Camera image. A 3-D reconstructed photo also matched the terrain of an Apollo 15 photograph taken from the surface.



Apollo 11 landing site - "There the lunar module sits, parked just where it landed 40 years ago, as if it still really were 40 years ago and all the time since merely imaginary."
 –The New York Times



Map of the Apollo 11 landing site. Arrows indicate location and direction of photos shot during EVA

On July 17, 2009 NASA released low-resolution engineering test photographs of the Apollo 11, Apollo 14, Apollo 15, Apollo 16 and Apollo 17 landing sites that have been imaged by the Lunar Reconnaissance Orbiter as part of the process of starting its primary mission. The photographs show the descent stage of the lunar module from each mission on the surface of the Moon. The picture of the Apollo 14 landing site also shows tracks created by an astronaut between a science experiment (ALSEP) and the lunar lander. Photographs of the Apollo 12 landing site were released by NASA on September 3, 2009.

The *Intrepid* lunar module descent stage, experiment package (ALSEP), Surveyor 3 spacecraft, and astronaut footpaths are all visible.

While the LRO images have been enjoyed by the scientific community as a whole, they have not done anything to convince conspiracy theorists that the landings took place.

Academic work

In 2004, Martin Hendry and Ken Skeldon of the University of Glasgow were awarded a grant by the UK based Particle Physics and Astronomy Research Council in order to investigate 'Moon Hoax' proposals. In November 2004, they gave a lecture at the Glasgow Science Centre where the top ten lines of evidence advanced by hoax proponents were individually addressed and refuted.

Alex R. Blackwell, of the University of Hawaii has pointed out that photos taken by Apollo astronauts are currently the best available images of the landing sites; they show shadows of the lander, but not the lander itself.

MythBusters special

An episode of *MythBusters* in August 2008 was dedicated to NASA, and each myth addressed during the show was related to the Moon landings, such as the pictures and video footage. A few members of the *MythBusters* crew were allowed into a NASA training facility to test some of the myths. All of the hoax-related myths examined on the show were labeled as having been "Busted", meaning that the myths were not true.

Missing data

Blueprints and design and development drawings of the machines involved are missing. Apollo 11 data tapes containing telemetry and the high quality video (before scan conversion) of the first moonwalk are missing.

Tapes

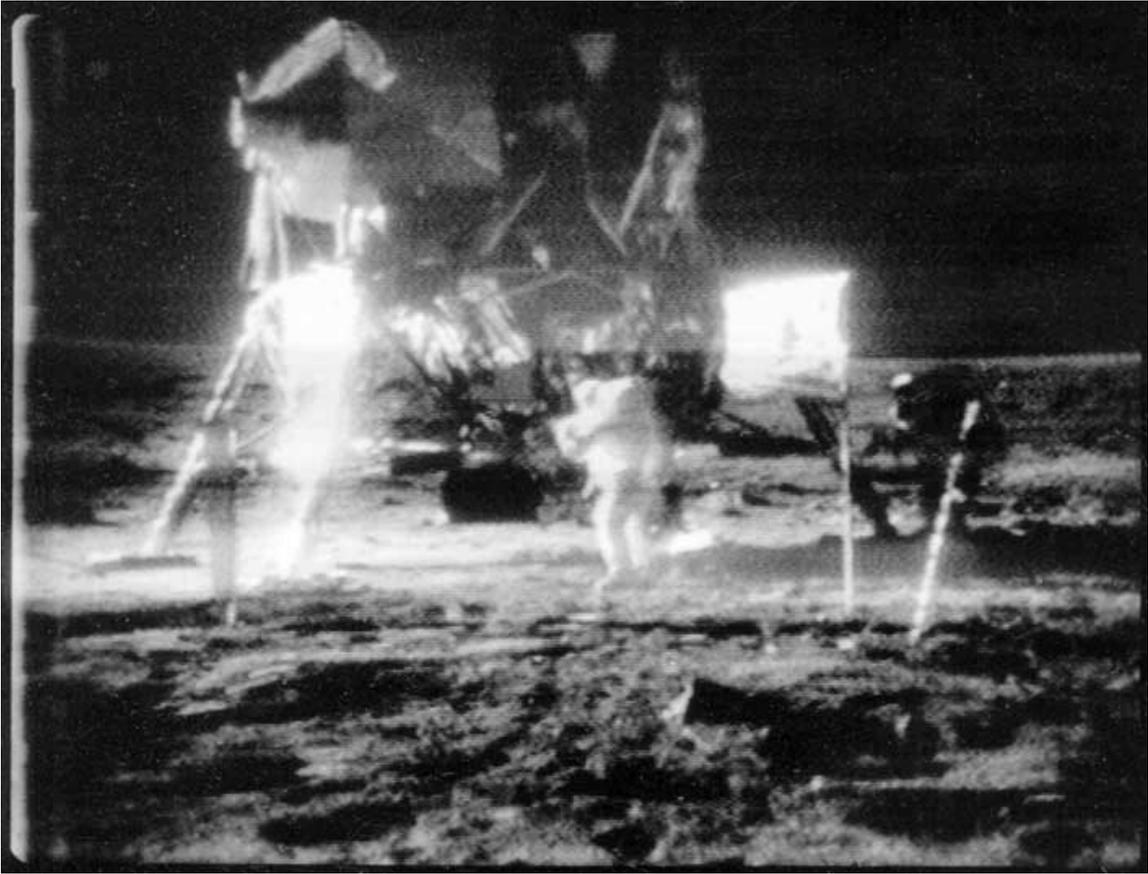


Photo of the high-quality SSTV image before the scan conversion

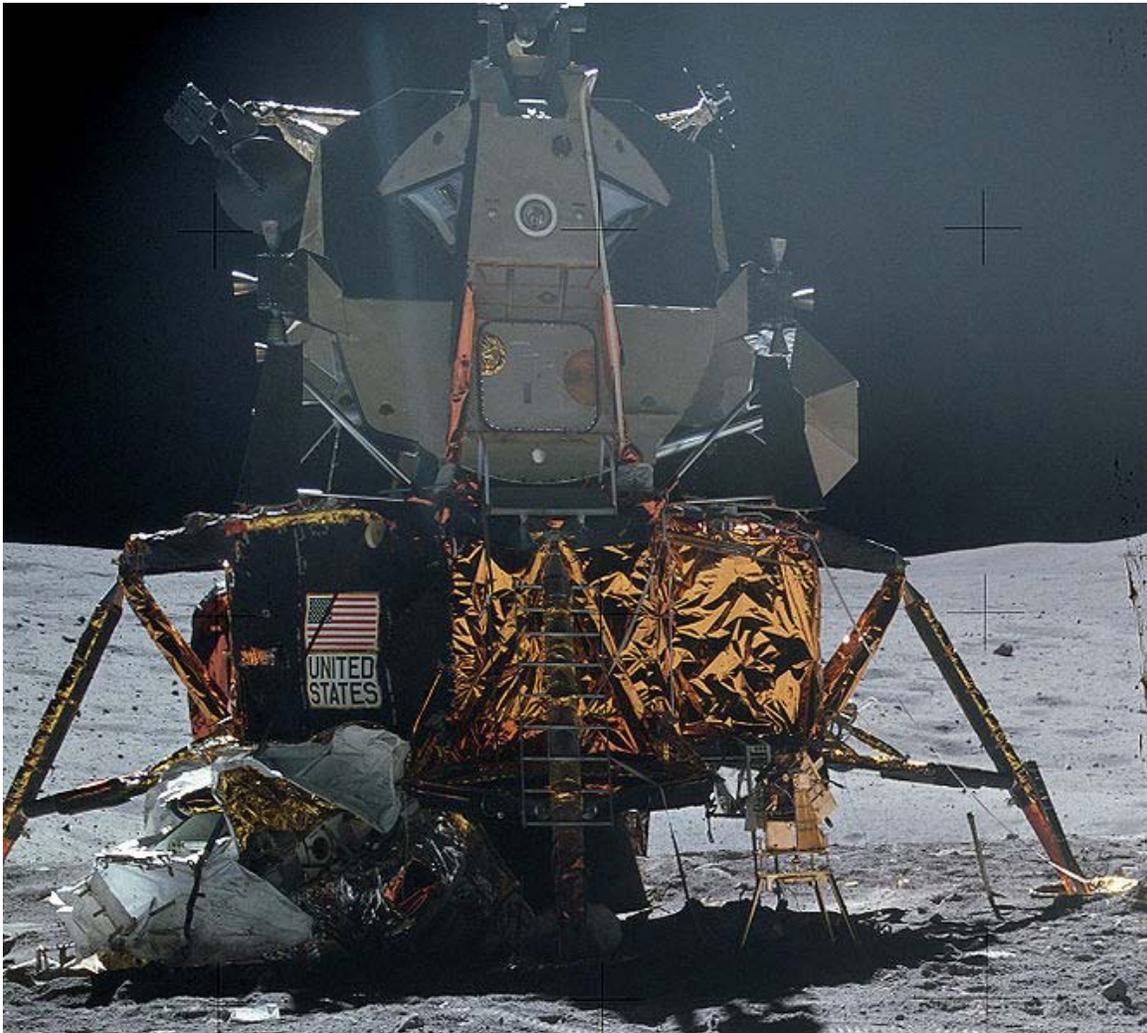


Photo of the degraded image after the SSTV scan conversion

Dr. David Williams (NASA archivist at Goddard Space Flight Center) and Apollo 11 flight director Eugene F. Kranz both acknowledged that the Apollo 11 telemetry data tapes are missing. Hoax proponents interpret this as support for the case that they never existed. The Apollo 11 telemetry tapes were different from the telemetry tapes of the other Moon landings because they contained the raw television broadcast. For technical reasons, the Apollo 11 Lunar Module (LM) carried a slow-scan television (SSTV) camera. In order to be broadcast to regular television, a scan conversion has to be done. The radio telescope at Parkes Observatory in Australia was in position to receive the telemetry from the Moon at the time of the Apollo 11 Moonwalk. Parkes had a larger antenna than NASA's antenna in Australia at the Honeysuckle Creek Tracking Station, so it received a better picture. It also received a better picture than NASA's antenna at Goldstone Deep Space Communications Complex. This direct TV signal, along with telemetry data, was recorded onto one-inch fourteen-track analog tape there. A crude, real-time scan conversion of the SSTV signal was done in Australia before it was broadcast around the world. The original SSTV transmission had better detail and contrast than the scan-converted pictures. It is this tape, that was recorded in Australia, before the scan conversion, which is missing. Tapes or films of the scan-converted pictures exist and are available. Still photographs of the original SSTV image are available. About fifteen minutes of the SSTV images of the Apollo 11 moonwalk were filmed by an amateur 8 mm film camera, and these are also available. Later Apollo

missions did not use SSTV. At least some of the telemetry tapes from the ALSEP scientific experiments left on the Moon (which ran until 1977) still exist, according to Dr. Williams. Copies of those tapes have been found.

Others are looking for the missing telemetry tapes, but for different reasons. The tapes contain the original and highest quality video feed from the Apollo 11 lunar landing which a number of former Apollo personnel want to recover for posterity, while NASA engineers looking towards future moon missions believe the Apollo telemetry data may be useful for their design studies. Their investigations have determined that the Apollo 11 tapes were sent for storage at the U.S. National Archives in 1970, but by 1984 all the Apollo 11 tapes had been returned to the Goddard Space Flight Center at their request. The tapes are believed to have been stored rather than re-used, and efforts to determine where they were stored are ongoing. Goddard was storing 35,000 new tapes per year in 1967, even before the lunar landings.

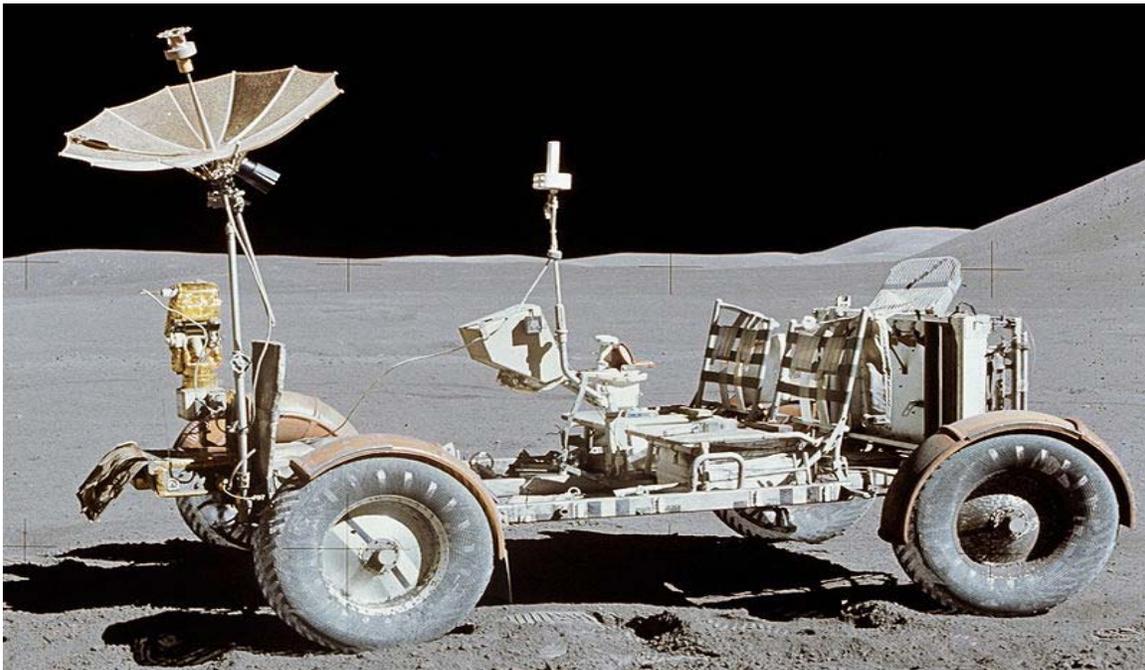


Apollo 16 Lunar Module

On November 1, 2006 Cosmos Magazine reported that some one-hundred data tapes recorded in Australia during the Apollo 11 mission had been discovered in a small marine science laboratory in the main physics building at the Curtin University of Technology in Perth, Australia. One of the old tapes has been sent to NASA for analysis. The slow-scan television images were not on the tape. Britain's Sunday Express reported in late June 2009 that the missing tapes were found in storage facility in the basement of a building on a university campus in Perth, Australia.

On July 16, 2009, NASA indicated that it must have erased the original Apollo 11 Moon footage years ago so that it could reuse the tape. On December 22, 2009 NASA issued a final report on the Apollo 11 telemetry tapes Senior engineer Dick Nafzger, who was in charge of the live TV recordings back during the Apollo missions, is now in charge of the restoration project. After an extensive three-year search, an "inescapable conclusion" was that approximately 45 tapes (estimated 15 tapes recorded at each of the three tracking stations) of Apollo 11 video were erased and reused, said Nafzger. In time for the 40th anniversary of the Apollo moon landing, Lowry Digital of Burbank, California has been tasked with restoring the surviving footage. President of Lowry Digital Mike Inchalik stated that, "this is by far and away the lowest quality" video the company has previously dealt with. Nafzger praised Lowry for restoring "crispness" to the Apollo video, which will remain in black and white and contain conservative digital enhancements. The \$230,000 restoration project that will take months to complete will not include sound quality improvements. Some selections of restored footage in high definition have been made available on the NASA website.

Blueprints



Apollo 15 Lunar Rover

An unused LM is on exhibit at the Cradle of Aviation Museum. The Lunar Module designated LM-13 would have landed on the Moon during the Apollo 18 mission, but was instead put into storage when the mission was canceled: it has since been restored and put on display. Other unused Lunar Modules are on display: LM-2 at the National Air and Space Museum and LM-9 at Kennedy Space Center.

Four mission-worthy Lunar Rovers were built. Three of them were carried to the Moon on Apollo 15, 16, and 17, and left there. After Apollo 18 was canceled, the other lunar rover was used for spare parts for the Apollo 15 to 17 missions. The only lunar rovers on display are test vehicles, trainers, and models. The "Moon buggies" were built by Boeing. The 221-page operation manual for the Lunar Rover contains some detailed drawings, although not the design blueprints.

An original Saturn V rocket is currently on display at the USA Space and Rocket Center in Huntsville, Alabama. The rocket's components are on public display as well, as is much of the original equipment used in the Apollo missions.

Technology

At the time that the Apollo Program occurred, Bart Sibrel claims that the Soviet Union had five times more manned hours in space than the United States, and that they had put the first man-made satellite in orbit (October 1957, Sputnik 1); the first living creature to enter orbit, a dog named Laika, (November 1957, Sputnik 2), the first to safely return living creature from orbit, two dogs Belka and Strelka, 40 mice, 2 rats (August 1960, Sputnik 5); the first man in space, Yuri Gagarin, also the first man to orbit the Earth (April 1961, Vostok 1); the first to have two spacecraft in orbit at the same time [*though it was **not** a space rendezvous, as frequently described*] (August 1962, Vostok 3 and Vostok 4); the first woman in space, Valentina Tereshkova (June 1963, Vostok 6, as part of a second dual-spacecraft flight including Vostok 5); the first crew of three cosmonauts on board one spacecraft (October 1964, Voskhod 1); and the first spacewalk (EVA) (Alexei Leonov in March 1965, Voskhod 2).

On January 27, 1967, the three astronauts aboard Apollo 1 died in a fire on the launch pad during training. The fire was triggered by a spark in the oxygen-rich atmosphere used in the spacecraft test, and fueled by a significant quantity of combustible material within the spacecraft. Extreme conspiracy theorists have even put forward the suggestion that the crew of Apollo 1 were murdered, as the mission commander, America's top astronaut Virgil "Gus" Grissom (who despite having the reputation of being something of a maverick had already been pencilled in to be the first man on the moon), knew the truth about the true state of the Apollo programme and had to be silenced. Two years later all of the problems were declared fixed. The first manned Apollo flight, Apollo 7, occurred in October 1968, 21 months after the fire.

Before the first manned Earth-orbiting Apollo flight (Apollo 7), the USSR had made nine spaceflights (seven with one cosmonaut, one with two, one with three). The U.S. had made sixteen flights (six with one astronaut, ten with two). The USSR and U.S. each had

six spaceflights in 1961-63, each with one astronaut or cosmonaut. The USSR had only three spaceflights in 1964-67 (each only a little longer than one day) whereas the U.S. had ten in this period (averaging over four days each). In terms of spacecraft hours, the USSR had 460 hours of space flight; the U.S. had 1,024 hours. In terms of astronaut/cosmonaut time, the USSR had accumulated 534 hours of manned spaceflight whereas the U.S. had accumulated 1,992 hours. By the time of Apollo 11, the United States's lead was much wider than that.

NASA and others say that these achievements by the Soviets are not as impressive as the simple list implies; that a number of these firsts were mere stunts that did not advance the technology significantly, or at all (e.g. the first woman in space).

A close examination of the many flight missions reveal *many* problems, risks, and *near-catastrophes* for both the Soviet and American programs. A negative first for the Soviets was the first in-flight fatality, in April 1967, three months after the Apollo I fire, as Soyuz 1 crash-landed. Despite that disaster, the Soyuz program continued, after a lengthy interval to solve design problems, as with the Apollo program.

Most of the Soviet accomplishments listed above were matched by the U.S. within a year, and occasionally within weeks. In 1965 the U.S. started to achieve many firsts which were important steps in a mission to the Moon. The USSR never developed a successful rocket capable of a Moon landing mission — their N1 rocket failed on all four launch attempts. They never tested a lunar lander on a manned mission.

Photographs and films

Moon hoax proponents devote a substantial portion of their efforts to examining NASA photos. They point to various oddities of photographs and films purportedly taken on the Moon. Experts in photography (even those unrelated to NASA) respond that the anomalies, while sometimes counter-intuitive, are in fact precisely what one would expect from a real Moon landing, and contrary to what would occur with manipulated or studio imagery. Hoax proponents also state that whistleblowers may have deliberately manipulated the NASA photos in hope of exposing NASA.

1. Crosshairs appear to be behind objects.

- *Overexposure causes white objects to bleed into the black areas on the film.*

2. Crosshairs are sometimes misplaced or rotated.

- *Popular versions of photos are sometimes cropped or rotated for aesthetic impact.*

3. The quality of the photographs is implausibly high.

- *There are many poor quality photographs taken by the Apollo astronauts. NASA chose to publish only the best examples.*
- *The Apollo astronauts used high resolution Hasselblad 500 EL/M Data cameras with Carl Zeiss optics and a 70-mm film magazine.*

4. There are no stars in any of the photos; the Apollo 11 astronauts also claimed in a post-mission press conference to not remember seeing any stars.

- *The astronauts were talking specifically about naked-eye observations of stars during the daytime. They regularly sighted stars through the spacecraft navigation optics while aligning their inertial reference platforms.*
- *The sun was shining. Cameras were set for daylight exposure, and could not detect the faint points of light. Even the brightest stars are dim and difficult to see in the daytime on the Moon. Neil Armstrong said that he could not see stars on the daylight side of the Moon with his naked eyes. Edwin Aldrin saw no stars from the Moon Harrison Schmitt saw no stars from the Moon. The astronauts' eyes were adapted to the brightly sunlit landscape around them so that they could not see the relatively faint stars. Camera settings can turn a well-lit background into ink-black when the foreground object is brightly lit, forcing the camera to increase shutter speed in order not to have the foreground light completely wash out the image. A demonstration of this effect is here. The effect is similar to not being able to see stars outside when in a brightly lit room—the stars only become visible when the light is turned off. The astronauts could see stars with the naked eye only when they were in the shadow of the Moon. All of the landings were in daylight.*
- *An ultraviolet telescope was taken to the lunar surface on Apollo 16 and operated in the shadow of the lunar module. (It is seen in the background of the pictures showing John Young's jump salutes of the US flag.) It captured pictures of the earth and of many stars, some of which are dim in visible light but bright in the ultraviolet. These observations were later matched up with observations taken by orbiting ultraviolet telescopes. Furthermore, the positions of those stars with respect to the earth are correct for the time and location of the Apollo 16 photographs.*
- *Pictures of the solar corona that included the planet Mercury and some background stars were taken from lunar orbit by Apollo 15 Command Module Pilot Al Worden shortly before lunar sunrise and after lunar sunset.*

5. The color and angle of shadows and light are inconsistent.

- *Shadows on the Moon are complicated by uneven ground, wide angle lens distortion, light reflected from the Earth, and lunar dust. Shadows also display the properties of vanishing point perspective leading them to converge to a point on the horizon.*
- *This theory was demonstrated to be unsubstantiated on the MythBusters episode "NASA Moon Landing".*

6. Identical backgrounds in photos which, according to their captions, were taken miles apart.

- *Shots were not identical, just similar. Background objects were mountains many miles away. Without an atmosphere to obscure distant objects, it can be difficult to tell the relative distance and scale of lunar features. One specific case is debunked in Who Mourns For Apollo? by Mike Bara.*

7. The number of photographs taken is implausibly high. Up to one photo per 50 seconds.

- *Simplified gear with fixed settings permitted two photographs a second. Many were taken immediately after each other as stereo pairs or panorama sequences. This calculation was based on a single astronaut on the surface, and does not take into account that there were two persons sharing the workload during the EVA.*

8. The photos contain artifacts like the two seemingly matching 'C's on a rock and on the ground.

- *The "C"-shaped image was from printing imperfections, not in the original film from the camera.*

9. A resident of Perth, Australia, with the pseudonym "Una Ronald", said she saw a soft drink bottle in the frame.

- *No such newspaper reports or recordings have been verified. "Una Ronald"'s existence is authenticated by only one source. There are also flaws in the story, i.e. the emphatic statement that she had to "stay up late" is easily discounted by numerous witnesses in Australia who observed the event to occur in the middle of their daytime, since this event was an unusual compulsory viewing for school children in Australia.*

10. The book *Moon Shot* contains an obvious composite photograph of Alan Shepard hitting a golf ball on the Moon with another astronaut.

- *It was used in lieu of the only existing real images, from the TV monitor, which the editors of the book apparently felt were too grainy to present in a book's picture section. The book publishers did not work for NASA.*

11. There appear to be "hot spots" in some photographs that look like a huge spotlight was used at a close distance.

- *Pits in Moon dust focus and reflect light in a manner similar to minuscule glass spheres used in the coating of street signs, or dew-drops on wet grass. This creates a glow around the photographer's own shadow when it appears in a photograph.*
- *If the photographer is standing in sunlight while photographing into shade, light reflected off his white spacesuit produces a similar effect to a spotlight.*
- *Some widely published Apollo photos were high contrast copies. Scans of the original transparencies are in general much more uniformly illuminated.*

12. Footprints in the extraordinarily fine lunar dust, with no moisture or atmosphere or strong gravity, are unexpectedly well preserved, in the minds of some observers – as if made in wet sand.

- *The moon dust has not been weathered like Earth sand and has sharp edges. These properties allow the moon dust particles to stick together and retain their shape in the vacuum environment of the moon. The astronauts described it as being like "talcum powder or wet sand".*
- *This theory was demonstrated to be unsubstantiated on the MythBusters episode "NASA Moon Landing".*



TV image of the actual scene



The original Buzz Aldrin photograph



Photo of Earth taken from behind the Apollo 11 Lunar Module

Ionizing radiation and heat

1. The astronauts could not have survived the trip because of exposure to radiation from the Van Allen radiation belt and galactic ambient radiation. Some hoax theorists have suggested that Starfish Prime (high altitude nuclear testing in 1962) was a failed attempt to disrupt the Van Allen belts.

- *The spacecraft moved through the belts in about four hours, and the astronauts were protected from the ionizing radiation by the aluminium hulls of the spacecraft. In addition, the orbital transfer trajectory from the Earth to the Moon through the belts was selected to minimize radiation exposure. Even Dr. James Van Allen, the discoverer of the Van Allen radiation belts, rebutted the claims that radiation levels were too dangerous for the Apollo missions. Plait cited an average dose of less than 1 rem (10 mSv), which is equivalent to the ambient radiation received by living at sea level for three years. The spacecraft passed through the intense inner belt and the low-energy outer belt. The astronauts were*

mostly shielded from the radiation by the spacecraft. The total radiation received on the trip was about the same as allowed for workers in the nuclear energy field for a year.

- *The radiation is actually evidence that the astronauts went to the Moon. Irene Schneider reports that thirty-three of the thirty-six Apollo astronauts involved in the nine Apollo missions to leave Earth orbit have developed early stage cataracts that have been shown to be caused by radiation exposure to cosmic rays during their trip. However, only twenty-seven astronauts left Earth orbit. At least thirty-nine former astronauts have developed cataracts. Thirty-six of those were involved in high-radiation missions such as the Apollo lunar missions.*

2. Film in the cameras would have been fogged by this radiation.

- *The film was kept in metal containers that prevented radiation from fogging the film's emulsion. In addition, film carried by unmanned lunar probes such as the Lunar Orbiter and Luna 3 (which used on-board film development processes) was not fogged.*

3. The Moon's surface during the daytime is so hot that camera film would have melted.

- *There is no atmosphere to efficiently couple lunar surface heat to devices such as cameras not in direct contact with it. In a vacuum, only radiation remains as a heat transfer mechanism. The physics of radiative heat transfer are thoroughly understood, and the proper use of passive optical coatings and paints was adequate to control the temperature of the film within the cameras; lunar module temperatures were controlled with similar coatings that gave it its gold color. Also, while the Moon's surface does get very hot at lunar noon, every Apollo landing was made shortly after lunar sunrise at the landing site. During the longer stays, the astronauts did notice increased cooling loads on their spacesuits as the sun continued to rise and the surface temperature increased, but the effect was easily countered by the passive and active cooling systems. The film was not in direct sunlight, so it wasn't overheated.*
- *Note: all of the lunar landings occurred during the lunar daytime. The Moon's day is approximately 29½ days long, and as a consequence a single lunar day (dawn to dusk) lasts nearly fifteen days. As such there was no sunrise or sunset while the astronauts were on the surface. Most lunar missions occurred during the first few Earth days of the lunar day.*

4. The Apollo 16 crew should not have survived a big solar flare firing out when they were on their way to the Moon. They should have been fried.

- *No large solar flare occurred during the flight of Apollo 16. There were large solar flares in August 1972, after Apollo 16 returned to Earth and before the flight of Apollo 17.*

Transmissions

1. The lack of a more than two-second delay in two-way communications at a distance of a 400,000 km (250,000 miles).

- *The round trip light travel time of more than two seconds is apparent in all the real-time recordings of the lunar audio, but this does not always appear as expected. There may also be some documentary films where the delay has been edited out. Principal motivations for editing the audio would likely come in response to time constraints or in the interest of clarity.*



The relative sizes of, and distance between, Earth and Moon, to scale, with a beam of light traveling between them at the speed of light.

2. Typical delays in communication were on the order of half a second.

- *Claims that the delays were only on the order of half a second are unsubstantiated by an examination of the actual recordings. It should also be borne in mind that there should not be a straightforward, consistent time delay between every response, as the conversation is being recorded at one end - Mission Control. Responses from Mission Control could be heard without any delay, as the recording is being made at the same time that Houston receives the transmission from the Moon.*

3. The Parkes Observatory in Australia was billed to the world for weeks as the site that would be relaying communications from the Moon, then five hours before transmission they were told to stand down.

- *The timing of the first Moonwalk was moved up after landing. In fact, delays in getting the Moonwalk started meant that Parkes did cover almost the entire Apollo 11 Moonwalk.*

4. Parkes supposedly provided the clearest video feed from the Moon, but Australian media and all other known sources ran a live feed from the United States.

- *While that was the original plan, and, according to some sources, the official policy, the Australian Broadcasting Commission (ABC) did take*

the transmission direct from the Parkes and Honeysuckle Creek radio telescopes. These were converted to NTSC television at Paddington, in Sydney. This meant that Australian viewers saw the Moonwalk several seconds before the rest of the world.

5. Better signal was supposedly received at Parkes Observatory when the Moon was on the opposite side of the planet.

- *This is not supported by the detailed evidence and logs from the missions.*

Mechanical issues



Under the Apollo 11 LM

1. No blast crater or any sign of dust scatter as was seen in the 16 mm movies of each landing.

- *No crater should be expected. The Descent Propulsion System was throttled very far down during the final landing. The Lunar Module was no longer rapidly decelerating, so the descent engine only had to support the module's own weight, diminished by the 1/6 g lunar gravity and by the near exhaustion of the descent propellants. At landing, the engine thrust divided by the nozzle exit area is only about 10 kilopascals (1.5 PSI). Beyond the engine nozzle, the plume spreads and the pressure drops very rapidly. (In comparison the Saturn V F-1 first stage engines produced 3.2 MPa (459 PSI) at the mouth of the nozzle.) Rocket exhaust gases expand much more rapidly after leaving the engine nozzle in a vacuum than in an atmosphere. The effect of an atmosphere on rocket plumes can be easily seen in launches from Earth; as the rocket rises through the thinning atmosphere, the exhaust plumes broaden very noticeably. To reduce this, rocket engines designed for vacuum operation have longer bells than those designed for use at the Earth's surface, but they still cannot prevent this spreading. The Lunar Module's exhaust gases therefore expanded rapidly well beyond the landing site. However, the descent engines did scatter a lot of very fine surface dust as seen in 16mm movies of each landing, and many mission commanders commented on its effect on visibility. The landers were generally moving horizontally as well as vertically, and photographs do show scouring of the surface along the final descent path. Finally, the lunar regolith is very compact below its surface dust layer, further making it impossible for the descent engine to blast out a "crater". In fact, a blast crater was measured under the Apollo 11 Lunar Module using shadow lengths of the descent engine bell and estimates of the amount that the landing gear had compressed and how deep the lander footpads had pressed into the lunar surface and it was found that the engine had eroded between 4 and 6 inches of regolith out from underneath the engine bell during the final descent and landing.*^{pp. 97-98}

2. The second stage of the launch rocket and / or the Lunar Module ascent stage produced no visible flame.

- *The Lunar Module used Aerozine 50 (fuel) and dinitrogen tetroxide (oxidizer) propellants, chosen for simplicity and reliability; they ignite hypergolically –upon contact– without the need for a spark. These propellants produce a nearly transparent exhaust. The same fuel was used by the core of the American Titan rocket. The transparency of their plumes is apparent in many launch photos. The plumes of rocket engines fired in a vacuum spread out very rapidly as they leave the engine nozzle (see above), further reducing their visibility. Finally, rocket engines often run*

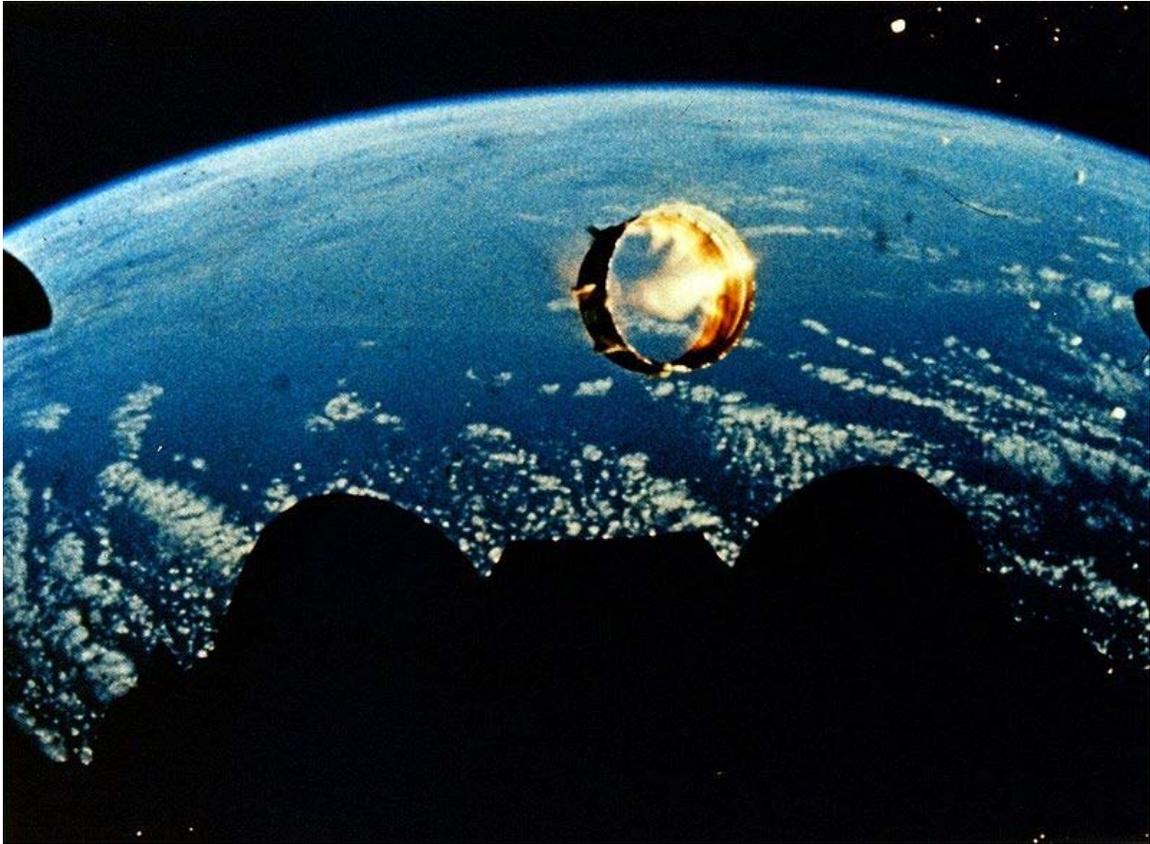
"rich" to slow internal corrosion. On Earth, the excess fuel burns in contact with atmospheric oxygen. This cannot happen in a vacuum.



Apollo 17 LM leaving the Moon; rocket exhaust visible only briefly



Apollo 8 launch through the first stage separation



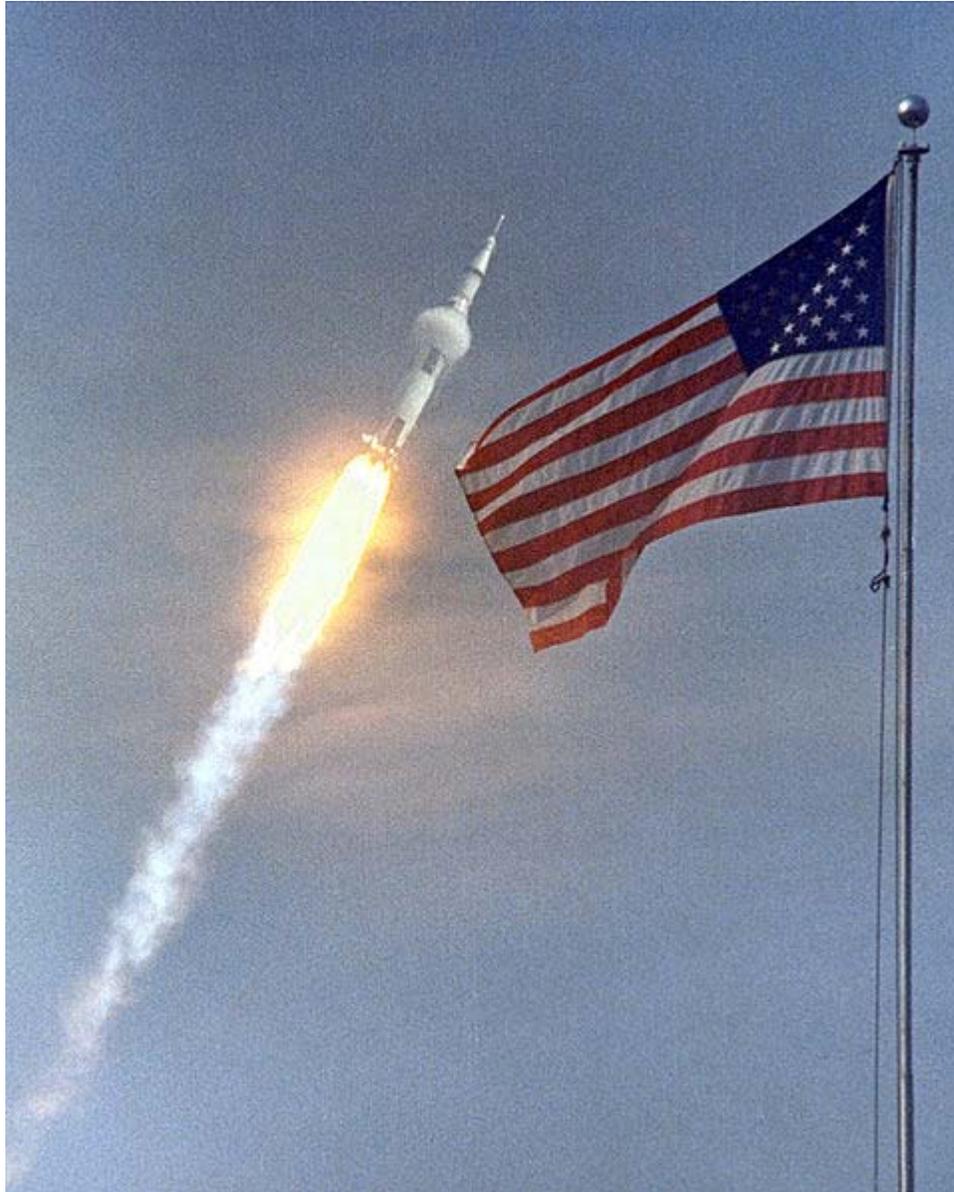
Exhaust flame may not be visible outside the atmosphere, as in this photo. Rocket engines are the dark structures at the bottom center.



The launch of a Titan II, burning hypergolic Aerozine-50/ N_2O_4 , 430,000 pounds-force (1.9 MN) of thrust. Note the near-transparency of the exhaust, even in air (water is being sprayed up from below).



Atlas uses non-hypergolic kerosene (RP-1) fuel which gives a bright and very visible exhaust, 340,000 lb_f (1.5 MN) of thrust



Bright flame from first stage of the Saturn V, burning RP-1

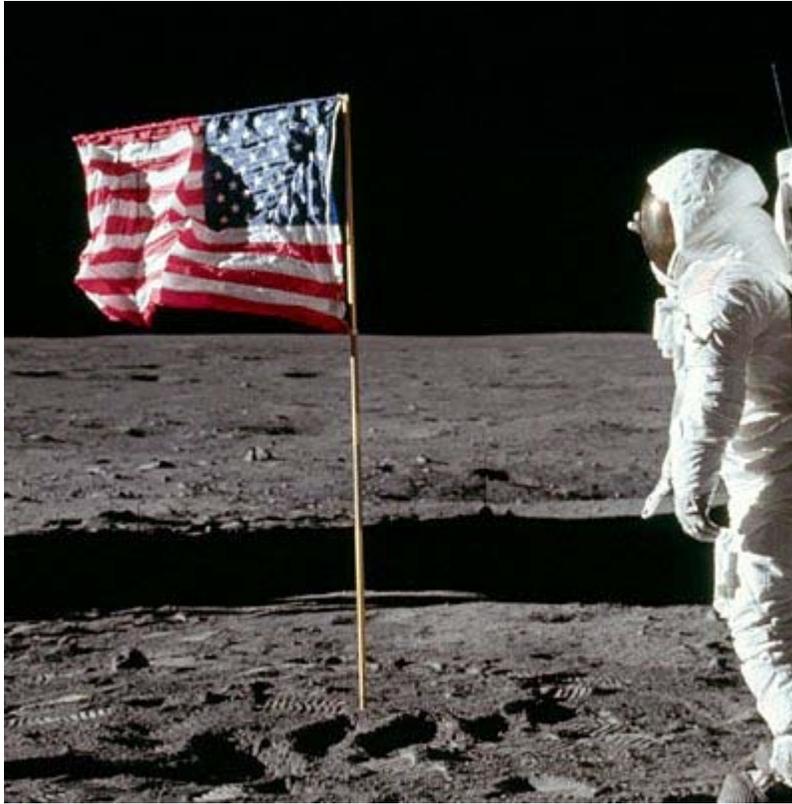
3. The rocks brought back from the Moon are identical to rocks collected by scientific expeditions to Antarctica.
4. The presence of deep dust around the module; given the blast from the landing engine, this should not be present.
 - *The dust is created by a continuous rain of micro-meteoroid impacts and is typically several inches thick. It forms the top of the lunar regolith, a layer of impact rubble several meters thick and highly compacted with depth. On the Earth, an exhaust plume might stir up the atmosphere over a*

wide area. On the Moon, only the exhaust gas itself can disturb the dust. Some areas around descent engines were scoured clean.

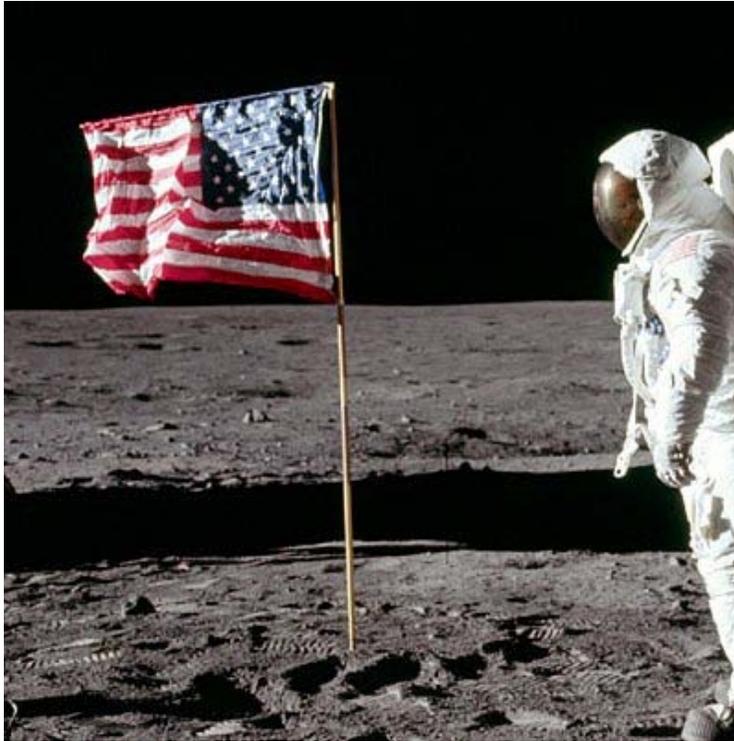
Note: In addition, moving footage of astronauts and the lunar rover kicking up lunar dust clearly show the dust particles kicking up quite high due to the low gravity, but settling immediately without air to stop them. Had these landings been faked on the Earth, dust clouds would have formed. (They can be seen as a 'goof' in the movie Apollo 13 when Jim Lovell (played by Tom Hanks) imagines walking on the Moon). This clearly shows the astronauts to be (a) in low gravity and (b) in a vacuum.

5. The flag placed on the surface by the astronauts flapped despite there being no wind on the Moon. Sibrel said "The wind was probably caused by intense air-conditioning used to cool the astronauts in their lightened, uncirculated space suits. The cooling systems in the backpacks would have been removed to lighten the load not designed for Earth's six times heavier gravity, otherwise they might have fallen over".

- *The astronauts were moving the flag into position. Without air drag, these movements caused the free corner of the flag to swing like a pendulum for some time. A horizontal rod, visible in many photographs, extended from the top of the flagpole to hold the flag out for proper display. The flag's rippled appearance was from folding during storage, and it could be mistaken for motion in a still photograph. The top support rod telescoped and the crew of Apollo 11 could not fully extend it. Later crews preferred to only partially extend the rod. Videotapes show that when the flag stops after the astronauts let it go, it remains motionless. At one point the flag remains completely motionless for well over thirty minutes. See the photographs below.*



Cropped photo of Buzz Aldrin saluting the flag (note the fingers of Aldrin's right hand can be seen behind his helmet).



Cropped photo taken a few seconds later, Buzz Aldrin's hand is down, head turned toward the camera, the flag is unchanged.

The flag is not waving, but is swinging as a pendulum after being touched by the astronauts.

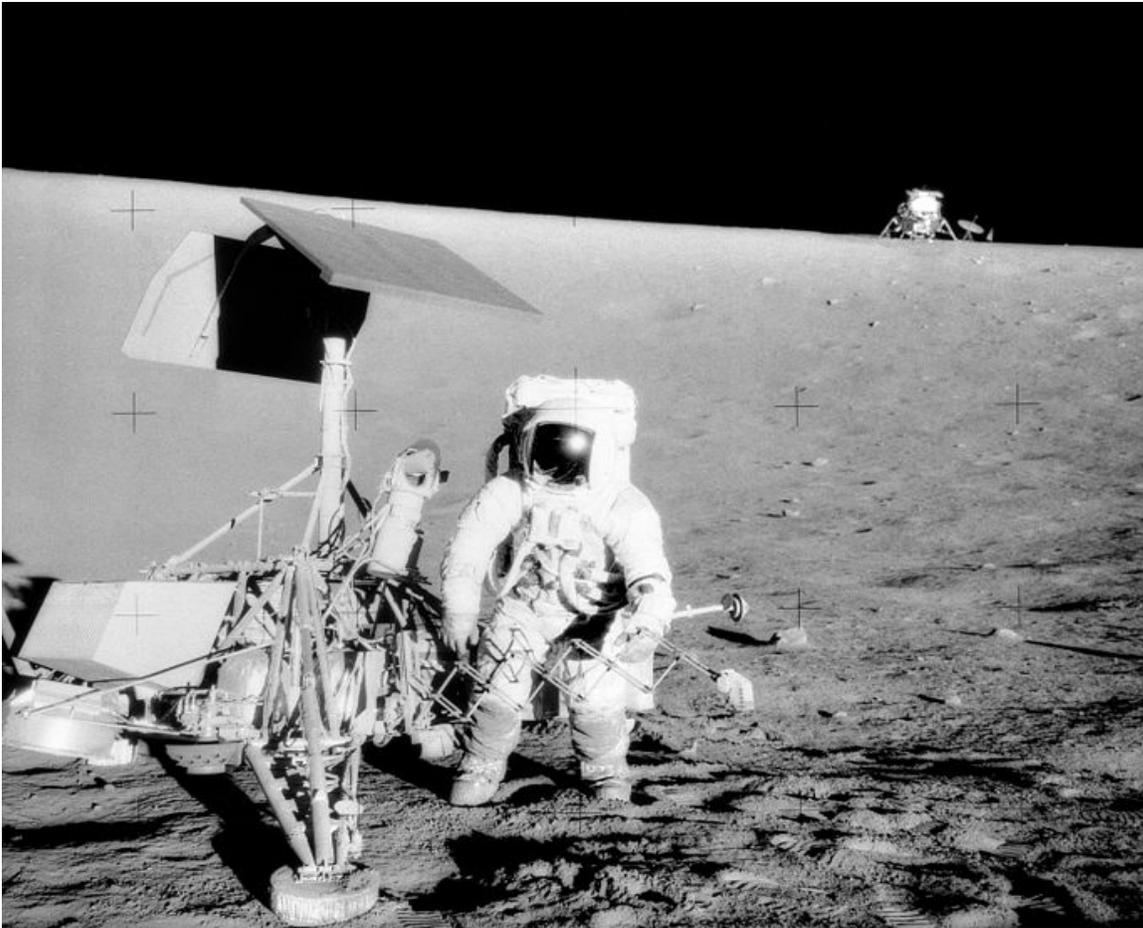
- *This theory was demonstrated to be unsubstantiated on the MythBusters episode "NASA Moon Landing".*

6. The Lander weighed 17 tons and sat on top of the sand making no impression but directly next to it footprints can be seen in the sand.

- *The lander weighed less than three tons on the Moon. The astronauts were much lighter than the lander, but their boots were much smaller than the 1-meter landing pads. Pressure, or force per unit area, rather than force, determines the extent of regolith compression. In some photos the landing pads did press into the regolith, especially when they moved sideways at touchdown. (The bearing pressure under the lander feet, with the lander being more than 100 times the weight of the astronauts would in fact have been of similar magnitude to the bearing pressure exerted by the astronauts' boots.)*

7. The air conditioning units that were part of the astronauts' spacesuits could not have worked in an environment of no atmosphere.

- *The cooling units could only work in a vacuum. Water from a tank in the backpack flowed out through tiny pores in a metal sublimator plate where it quickly vaporized into space. The loss of the heat of vaporization froze the remaining water, forming a layer of ice on the outside of the plate that also sublimated into space (turning from a solid directly into a gas). A separate water loop flowed through the LCG (Liquid Cooling Garment) worn by the astronaut, carrying his metabolic waste heat through the sublimator plate where it was cooled and returned to the LCG. Twelve pounds [5.4 kg] of feedwater provided some eight hours of cooling; because of its bulk, it was often the limiting consumable on the length of an EVA. Because this system could not work in an atmosphere, the astronauts required large external chillers to keep them comfortable during Earth training.*
- *Radiative cooling would have avoided the need to consume water, but it could not operate below body temperature in such a small volume. The radioisotope thermoelectric generators could use radiative cooling fins to permit indefinite operation because they operated at much higher temperatures.*



Surveyor 3 with Apollo 12 LM in background

8. Although Apollo 11 had made an almost embarrassingly imprecise landing well outside the designated target area, Apollo 12 succeeded, on November 19, 1969, in making a pin-point landing, within walking distance (less than 200 meters) of the *Surveyor 3* probe, which had landed on the Moon in April 1967.

- *The Apollo 11 landing was several kilometers to the southeast of the center of their intended landing ellipse, but still within it. Armstrong took semi-automatic control of the lander and directed it further down range when it was noted that the intended landing site was strewn with boulders near a moderate sized crater. By the time Apollo 12 flew, the cause of the large error in the landing location was determined and improved procedures were developed and were demonstrated by the pin-point landing next to Surveyor III made by Apollo 12. Apollo 11 fulfilled its purpose by simply landing safely on the lunar surface and a pin-point landing was not a requirement on that mission.*
- *The Apollo astronauts were highly skilled pilots, and the LM was a maneuverable craft that could be accurately flown to a specific landing point. During the powered descent phase the astronauts used the PNGS (Primary Navigation Guidance System) and LPD (Landing Point Designator) to predict where the LM was going to land, and then they would manually pilot the LM to a selected point with great accuracy.*



Jim Lovell training for Apollo 13

9. The alleged Moon landings used either a sound stage, or were put outside in a remote desert location with the astronauts either using harnesses or slow-motion photography to make it look like they were on the Moon and acting in lunar gravity.

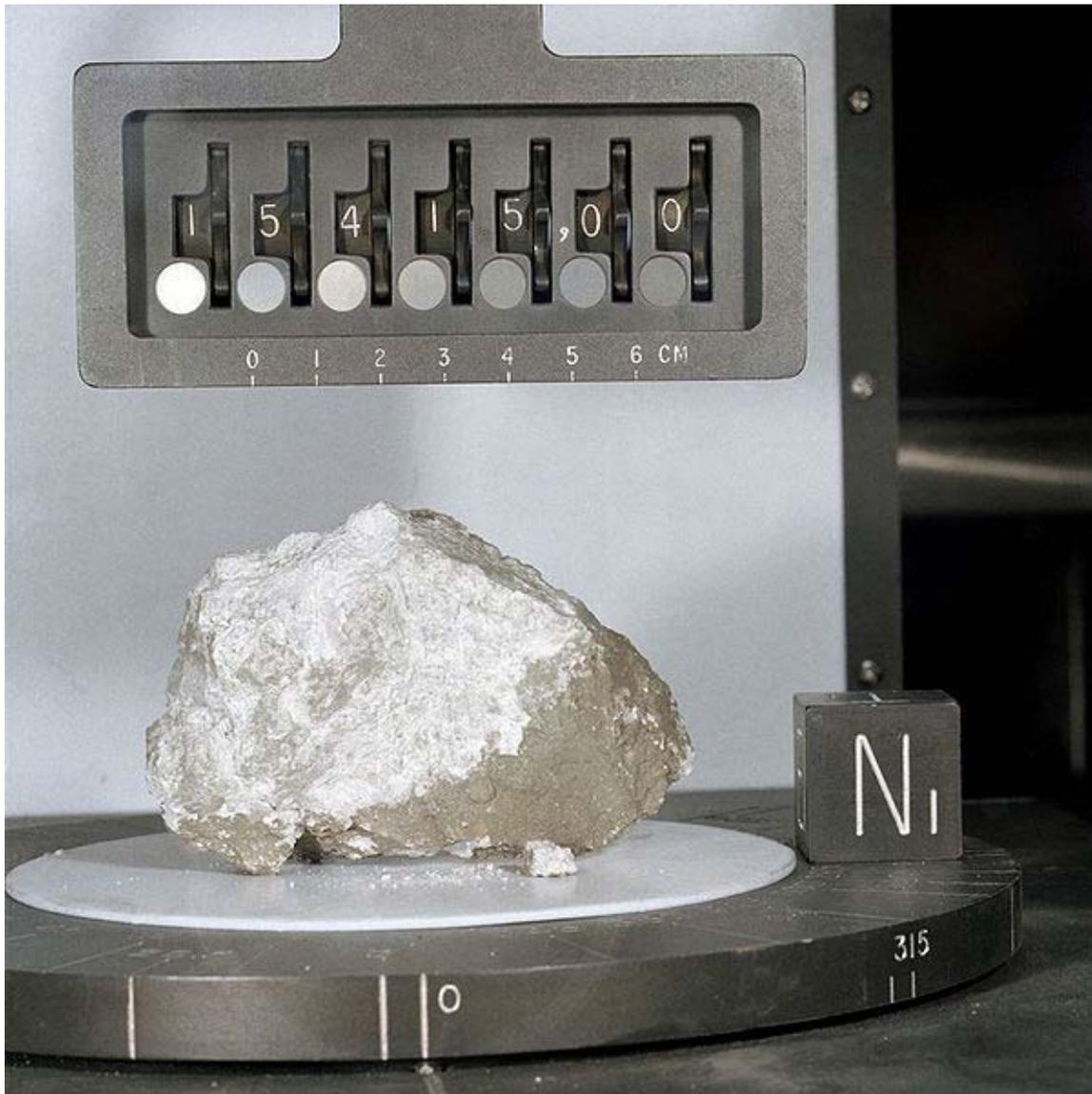
- *While the HBO Mini-series "From the Earth to the Moon", and a scene from "Apollo 13" used the sound-stage and harness setup, it is clearly seen from those films that dust kicked up did not quickly settle (some dust briefly formed clouds). In the film footage from the Apollo missions, dust kicked up by the astronauts' boots and the wheels of the lunar rovers shot up quite high (due to the lunar gravity), and settled immediately to the surface in an uninterrupted parabolic arc (due to there being no air to*

support the dust). Even if there had been a sound stage for hoax Moon landings that had had the air pumped out, the dust would have reached nowhere near the height and trajectory as the dust shown in the Apollo film footage because of terrestrial gravity.

10. All six lunar landings occurred during the first presidential administration of Richard Nixon and no other national leader of any country has even claimed to have landed astronauts on the Moon, even though the mechanical means of doing so should have become progressively much easier after almost 40 years of steady or even rapid technological development.

- *Other nations and later presidential administrations were evidently less interested in spending large sums to be merely the second nation to land on the Moon or to explore the barren Moon further. Had Nixon faked the Moon landings, the Soviets would have been happy to argue for a hoax as a propaganda victory, but the Soviets never did. Further exploration by the U.S. or U.S.S.R., such as establishing a Moon base, would have been much more expensive and perhaps too provocative to be in any nation's self-interest during the Cold War arms race.*
- *Furthermore, the development of the Saturn V rocket, the Apollo CSM and LM and the flights up to Apollo 8 (which orbited the moon) were completed before Richard Nixon became president on January 20, 1969. Additionally, Nixon did not personally care much for the program started by the man who defeated him in the 1960 Presidential Election, and his administration pushed for NASA to cancel Apollo 18, 19, and 20 in favor of development of the space shuttle.*

Moon rocks



Genesis Rock brought back by Apollo 15 - older than any rocks on Earth

The Apollo Program collected a total of 382 kilograms (840 lb) of Moon rocks during the Apollo 11, 12, 14, 15, 16, and 17 missions. Analyses by scientists worldwide all agree that these rocks came from the Moon — no published accounts in peer-reviewed scientific journals exist that dispute this claim. The Apollo samples are easily distinguishable from both meteorites and terrestrial rocks in that they show a complete lack of hydrous alteration products, they show evidence for having been subjected to impact events on an airless body, and they have unique geochemical characteristics. Furthermore, most are significantly older than the oldest rocks found on Earth. The Moon rocks are more than 600,000,000 years older than the oldest Earth rocks known at the time. In 2008 some rocks were found on Earth that are older than any previously found

Earth rocks but the Moon rocks are still more than 200,000,000 years older than them. The Moon rocks also share the same characteristics as the Soviet lunar samples that were obtained at a later date.

Hoax proponents argue that Wernher von Braun's trip to Antarctica in 1967 (approximately two years before the July 16, 1969 Apollo 11 launch) was in order to study and/or collect lunar meteorites to be used as fake Moon rocks. Because von Braun was a former SS officer (though one who had been detained by the Gestapo), the documentary film *Did We Go?* suggests that he could have been susceptible to pressure to agree to the conspiracy in order to protect himself from recriminations over the past. While NASA does not provide much information about why von Braun, the Marshall Space Flight Center Director, and three others were in Antarctica at that time; NASA has said that the purpose was "to look into environmental and logistic factors that might relate to the planning of future space missions, and hardware". NASA continues to send teams to work in McMurdo Dry Valleys, and to mimic the conditions on other planets such as Mars and the Moon.

It is now accepted by the scientific community that rocks have been ejected from both the Martian and lunar surface during impact events, and that some of these have landed on the Earth in the form of Martian and lunar meteorites. However, the first Antarctic lunar meteorite was collected in 1979, and its lunar origin was not recognized until 1982. Furthermore, lunar meteorites are so rare that it is very improbable that they could account for the 382 kilograms of Moon rocks that NASA obtained between 1969 and 1972. Currently, there are only about 30 kilograms of lunar meteorites discovered thus far, despite private collectors and governmental agencies worldwide searching for these for more than 20 years.

The large combined mass of the Apollo samples makes this scenario implausible. While the Apollo missions obtained 382 kilograms of Moon rocks, the Soviet Luna 16, Luna 20, and Luna 24 robotic sample return missions only obtained 326 grams combined (that is, less than one-thousandth as much). Indeed, current plans for a Martian sample return would only obtain about 500 grams of soil, and a recently proposed South Pole-Aitken basin sample return mission would only obtain about 1 kilogram of Moon rock. If a similar technology to collect the Apollo Moon rocks was used as with the Soviet missions or modern sample return proposals, then between 300 and 2000 robotic sample return missions would be required to obtain the current mass of Moon rocks that is curated by NASA.

Concerning the composition of the Moon rocks, Kaysing asked: *"Why was there no mention of gold, silver, diamonds, or other precious metals on the Moon? It was never discussed by the press or astronauts."* Geologists realize that gold and silver deposits on Earth are the result of the action of hydrothermal fluids concentrating the precious metals into veins of ore. Since in 1969 water was believed to be absent on the Moon, no geologist would bother discussing the possibility of finding these on the Moon in any significant quantity.

President Nixon gave 135 nations of the world, all 50 states and the U.S. territories each an Apollo 11 Moon rock and Apollo 17 Goodwill Moon Rock. Many of these Moon rocks have been stolen, destroyed, or are missing and in one celebrated case a moon rock housed in a museum in the Netherlands was found to be petrified wood. The loss of so many moon rocks has been used by conspiracy theorists to bolster their claim that man never went to the moon. NASA counters that accusation by stating that the vast majority of moon rocks and soil collected on the moon are securely maintained at Johnson Space Center in Houston, Texas and Brooks Air Force Base in San Antonio, Texas. In addition NASA is quick to point out that independent scientists have studied the moon rocks collected on the Moon for 40 years.

Deaths of astronauts and NASA personnel

In a television program about the hoax allegations, Fox Entertainment Group listed the deaths of ten astronauts and of two civilians related to the manned spaceflight program as having possibly been killed as part of a cover-up.

- Theodore Freeman (killed ejecting from T-38 which had suffered a bird strike, October 1964)
- Elliot See and Charlie Bassett (T-38 crash in bad weather, February 1966)
- Virgil Ivan "Gus" Grissom, Edward Higgins "Ed" White, and Roger B. Chaffee (*Apollo 1* fire, January 1967)
- Edward "Ed" Givens (car accident, June 1967)
- Clifton "C. C." Williams (killed ejecting from T-38, October 1967)
- Michael J. "Mike" Adams (X-15 crash, November 1967. The only pilot killed during the X-15 flight test program. He was a test-pilot, not a NASA astronaut, but had flown the X-15 above 50 miles)
- Robert Henry Lawrence, Jr. (F-104 crash, December 1967, shortly after being selected as a pilot with the Air Force's (later canceled) Manned Orbiting Laboratory program.
- NASA worker Thomas Ronald Baron (automobile collision with train, April 1967, shortly after making accusations before Congress about the cause of the Apollo 1 fire, after which he was fired). Ruled as suicide. Baron was a quality control inspector who wrote a report critical of the Apollo program and was an outspoken critic after the Apollo 1 fire. Baron and his family were killed as their car was struck by a train at a train crossing.
- Brian D. Welch, a leading official in NASA's Public Affairs Office and Director of Media Services, died a few months after appearing in the media to debunk the Fox pro-Moon hoax television show cited above. His obituary claims he died of a heart attack at the relatively young age of 42. Conspiracy theorists find his age at death suspiciously young and would note that heart attacks can be induced, for example, through the stress of torture or through ingestion of certain chemicals.

All of the astronaut deaths were directly related to their respective jobs with NASA or with the Air Force. Two of them, X-15 pilot Mike Adams and MOL pilot Robert Lawrence, had no connection with the civilian manned space program of which Apollo

was a part. All of the deaths listed occurred at least 20 months *before* Apollo 11 and the subsequent flights.

As of January 2011, nine of the twelve Apollo astronauts who landed on the Moon between 1969 and 1972 still survive, including Neil Armstrong and Buzz Aldrin. Also, nine of the twelve Apollo astronauts who flew to the Moon without landing between 1968 and 1972 still survive, including Michael Collins.

The number of deaths within the American astronaut corps during the run-up to Apollo and while the lunar landing missions were taking place is comparable with the number of fatalities suffered by the Russians. During the period 1961 to 1972, *at least* eight of its corps of serving and ex-cosmonauts are known to have died:

- Valentin Bondarenko (ground training accident, March 1961)
- Grigori Nelyubov (suicide, February 1966)
- Vladimir Komarov (*Soyuz 1* accident, April 1967)
- Yuri Gagarin (MiG-15 crash, March 1968)
- Pavel Belyayev (complications following surgery, January 1970)
- Georgi Dobrovolski, Vladislav Volkov, and Viktor Patsayev (*Soyuz 11* accident, June 1971).

Also, the overall chief of their manned-spaceflight program, Sergei Korolev, died while undergoing surgery in January 1966.

Brian Welch's death is a blow *against* the alleged Hoax Conspirators since he was a debunker of hoax claims. Conspiracy theorists would argue his death was to prevent any public reversal of his position after he had served his purpose of debunking hoax claims and to prevent his leaking of any inside info about a hoax.

There is no evidence to support Gelvani's claim that Apollo 15 astronaut James Irwin was about to come forward before his death, by a heart attack, in 1989. Irwin had suffered several heart attacks in the years prior to his death.

Alleged non-NASA involvement

Stanley Kubrick is accused of having produced much of the footage for Apollo 11 and 12, presumably because he had just directed *2001: A Space Odyssey* which is partly set on the moon and featured advanced special effects. It has been claimed that when *2001* was in post-production in early 1968, NASA secretly approached Kubrick to direct the first three Moon landings. The launch and splashdown would be real but the spacecraft would remain in Earth orbit and fake footage broadcast as "live" from the lunar journey. No evidence was presented for this theory, which ignores many facts. For example, *2001* was released before the first Apollo landing and Kubrick's depiction of the lunar surface is vastly different from its actual appearance in Apollo video, film and photography. Kubrick did hire Frederick Ordway and Harry Lange, both of whom had worked for NASA and major aerospace contractors, to work with him on *2001*. Kubrick also used

some 50 mm f/0.7 lenses that were left over from a batch made by Zeiss for NASA. However, Kubrick only acquired this lens for *Barry Lyndon* (1975). The lens was originally a still-photo lens and required modifications to be used for motion filming. (There *is* a mockumentary based on this idea, *Dark Side of the Moon*, which is clearly tongue-in-cheek by claiming to interview people with names as Dave Bowman or Jack Torrance, but could have contributed to the conspiracy theory in the eyes of casual viewers.)

To date, nobody from the United States government or NASA who would have had a connection to the space program has come forward claiming the moon landings were staged. Penn Jillette made note of this in the "Conspiracy Theories" episode of his contrarian television show *Penn & Teller: Bullshit!* in 2005. He stated that, with the number of people that would have been required to be "in the know" of the staging, *somebody* would have outed the hoax by now. With the government's track record of keeping secrets (especially the Nixon administration, noting Watergate as an example), Jillette said there's no way the U.S. government could have silenced everybody if the landings were faked.

NASA book incident

In 2002, NASA granted US\$15,000 to James Oberg for a commission to write a point-by-point rebuttal of the hoax claims. NASA subsequently canceled the commission later in the year, in the face of complaints that the book would dignify the accusations. Oberg stated that he intended to finish the project. In November 2002 Peter Jennings said "NASA is going to spend a few thousand dollars trying to prove to some people that the United States did indeed land men on the Moon." and " NASA had been so rattled, [they] hired [somebody] to write a book refuting the conspiracy theorists." Oberg says that belief in the hoax theories is not the fault of the hoax proponents or believers, and that he puts the blame on educators and people (including NASA) who should provide information to the public.

Chapter- 4

Apollo Program



Apollo program insignia

The **Apollo program** was the United States spaceflight effort which landed the first humans on Earth's Moon. Conceived during the Eisenhower administration and conducted by the National Aeronautics and Space Administration (NASA), Apollo began in earnest after President John F. Kennedy's 1961 address to Congress declaring a national goal of "landing a man on the Moon" by the end of the decade in a competition with the Soviet Union for supremacy in space.



Buzz Aldrin during Apollo 11's first moon landing mission in 1969

This goal was first accomplished during the Apollo 11 mission on July 20, 1969 when astronauts Neil Armstrong and Buzz Aldrin landed, while Michael Collins remained in lunar orbit. Five subsequent Apollo missions also landed astronauts on the Moon, the last in December 1972. In these six Apollo spaceflights, 12 men walked on the Moon. These are the only times humans have landed on another celestial body.

The Apollo program ran from 1961 until 1975, and was America's third human spaceflight program (following Mercury and Gemini). It used Apollo spacecraft and Saturn launch vehicles, which were also used for the Skylab program in 1973–74, and a joint U.S.–Soviet mission in 1975. These subsequent programs are thus often considered part of the Apollo program.

The program was successfully carried out despite two major setbacks: the 1967 Apollo 1 launch pad fire that killed three astronauts; and an oxygen tank rupture during the 1970 Apollo 13 flight which disabled the Command Module. Using the Lunar Excursion Module as a "lifeboat", the three crewmen narrowly escaped with their lives, thanks to their skills and the efforts of flight controllers, project engineers, and backup crew members.

Apollo set major milestones in human spaceflight. It stands alone in sending manned missions beyond low Earth orbit; Apollo 8 was the first manned spacecraft to orbit another celestial body, while Apollo 17 marked the last moonwalk and the last manned mission beyond low Earth orbit. The program spurred advances in many areas of technology incidental to rocketry and manned spaceflight, including avionics, telecommunications, and computers. Apollo also sparked interest in many fields of engineering and left many physical facilities and machines developed for the program as landmarks. Its command modules and other objects and artifacts are displayed throughout the world, notably in the Smithsonian's Air and Space Museums in Washington, DC and at NASA's centers in Florida, Texas and Alabama.

Background

The Apollo program was conceived early in 1960, during the Eisenhower administration, as a follow-up to America's Mercury program. While the Mercury capsule could only support one astronaut on a limited earth orbital mission, the Apollo spacecraft was to be able to carry three astronauts on a circumlunar flight and eventually to a lunar landing. The program was named after the Greek god of light and music by NASA manager Abe Silverstein, who later said that "I was naming the spacecraft like I'd name my baby." While NASA went ahead with planning for Apollo, funding for the program was far from certain given Eisenhower's ambivalent attitude to manned spaceflight.



May 25, 1961: President John Kennedy addresses Congress on his plan to put a man on the Moon within nine years.

In November 1960, John F. Kennedy was elected president after a campaign that promised American superiority over the Soviet Union in the fields of space exploration and missile defense. Using space exploration as a symbol of national prestige, he warned of a "missile gap" between the two nations, pledging to make the U.S. not "first but, first and, first if, but first period." Despite Kennedy's rhetoric, he did not immediately come to a decision on the status of the Apollo program once he became president. He knew little about the technical details of the space program, and was put off by the massive financial commitment required by a manned Moon landing. When NASA Administrator James Webb requested a 30 percent budget increase for his agency, Kennedy supported an acceleration of NASA's large booster program but deferred a decision on the broader issue.



President Kennedy delivers a speech at Rice University on the American space program, September 12, 1962.

On April 12, 1961, Soviet cosmonaut Yuri Gagarin became the first person to fly in space, reinforcing American fears about being left behind in a technological competition with the Soviet Union. At a meeting of the U.S. House Committee on Science and Astronautics one day after Gagarin's flight, many congressmen pledged their support for a crash program aimed at ensuring that America would catch up. Kennedy, however, was circumspect in his response to the news, refusing to make a commitment on America's response to the Soviets. On April 20, Kennedy sent a memo to Vice President Lyndon B. Johnson, asking Johnson to look into the status of America's space program, and into programs that could offer NASA the opportunity to catch up. Johnson responded approximately one week later, concluding that "we are neither making maximum effort

nor achieving results necessary if this country is to reach a position of leadership." His memo concluded that a manned Moon landing was far enough in the future that it was likely the United States would achieve it first.

On May 25, 1961, Kennedy announced his support for the Apollo program during a special address to a joint session of Congress:

I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important in the long-range exploration of space; and none will be so difficult or expensive to accomplish.

—John F. Kennedy

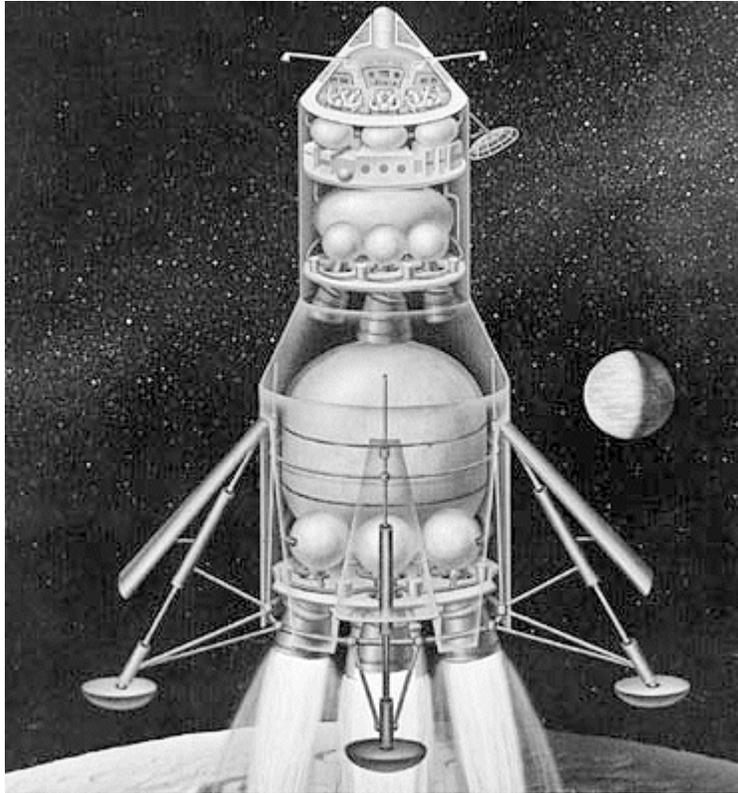
At the time of Kennedy's speech, only one American had flown in space—less than a month earlier—and NASA had not yet sent an astronaut into orbit. Even some NASA employees doubted whether Kennedy's ambitious goal could be met.

Landing men on the Moon by the end of 1969 required the most sudden burst of technological creativity, and the largest commitment of resources (\$24 billion), ever made by any nation in peacetime. At its peak, the Apollo program employed 400,000 people and required the support of over 20,000 industrial firms and universities.

“ We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too... Many years ago the great British explorer George Mallory, who was to die on Mount Everest, was asked why did he want to climb it. He said, "Because it is there." Well, space is there, and we're going to climb it, and the Moon and the planets are there, and new hopes for knowledge and peace are there. And, therefore, as we set sail we ask God's blessing on the most hazardous and dangerous and greatest adventure on which man has ever embarked. ”

Choosing a mission mode

Once Kennedy had defined a goal, the Apollo mission planners were faced with the challenge of designing a set of flights that could meet it while minimizing risk to human life, cost, and demands on technology and astronaut skill. Four possible mission modes were considered:



Early Apollo configuration for Direct Ascent and Earth Orbit Rendezvous (1961)

- **Direct Ascent:** A spacecraft would travel directly to the Moon, landing and returning as a unit. This plan would have required a more powerful booster, the planned Nova rocket.
- **Earth Orbit Rendezvous (EOR):** Multiple rockets (up to fifteen in some claims) would be launched, each carrying various parts of a Direct Ascent spacecraft and propulsion units that would have enabled the spacecraft to escape earth orbit. After a docking in earth orbit, the spacecraft would have landed on the Moon as a unit.
- **Lunar Surface Rendezvous:** Two spacecraft would be launched in succession. The first, an automated vehicle carrying propellants, would land on the Moon and would be followed some time later by the manned vehicle. Propellant would be transferred from the automated vehicle to the manned vehicle before the manned vehicle could return to Earth.
- **Lunar Orbit Rendezvous (LOR):** One Saturn V would launch a spacecraft that was composed of modular parts. A command module would remain in orbit around the Moon, while a lunar excursion module would descend to the Moon and then return to dock with the command ship while still in lunar orbit. In contrast with the other plans, LOR required only a small part of the spacecraft to land on the Moon, thereby minimizing the mass to be launched from the Moon's surface for the return trip.

In early 1961, direct ascent was generally the mission mode in favor at NASA. Many engineers feared that a rendezvous —let alone a docking— neither of which had been attempted even in Earth orbit, would be extremely difficult in lunar orbit. However, dissenters including John Houbolt at Langley Research Center emphasized the important weight reductions that were offered by the LOR approach. Throughout 1960 and 1961, Houbolt campaigned for the recognition of LOR as a viable and practical option. Bypassing the NASA hierarchy, he sent a series of memos and reports on the issue to Associate Administrator Robert Seamans; while acknowledging that he spoke "somewhat as a voice in the wilderness," Houbolt pleaded that LOR should not be discounted in studies of the question.

Seamans' establishment of the Golovin committee in July 1961 represented a turning point in NASA's mission mode decision. While the ad-hoc committee was intended to provide a recommendation on the boosters to be used in the Apollo program, it recognized that the mode decision was an important part of this question. The committee recommended in favor of a hybrid EOR-LOR mode, but its consideration of LOR —as well as Houbolt's ceaseless work— played an important role in publicizing the workability of the approach. In late 1961 and early 1962, members of NASA's Space Task Group at the Manned Spacecraft Center in Houston began to come around to support for LOR. The engineers at Marshall Space Flight Center took longer to become convinced of its merits, but their conversion was announced by Wernher von Braun at a briefing in June 1962. NASA's formal decision in favor of LOR was announced on July 11, 1962. Space historian James Hansen concludes that:

Without NASA's adoption of this stubbornly held minority opinion in 1962, the United States may still have reached the Moon, but almost certainly it would not have been accomplished by the end of the 1960s, President Kennedy's target date.

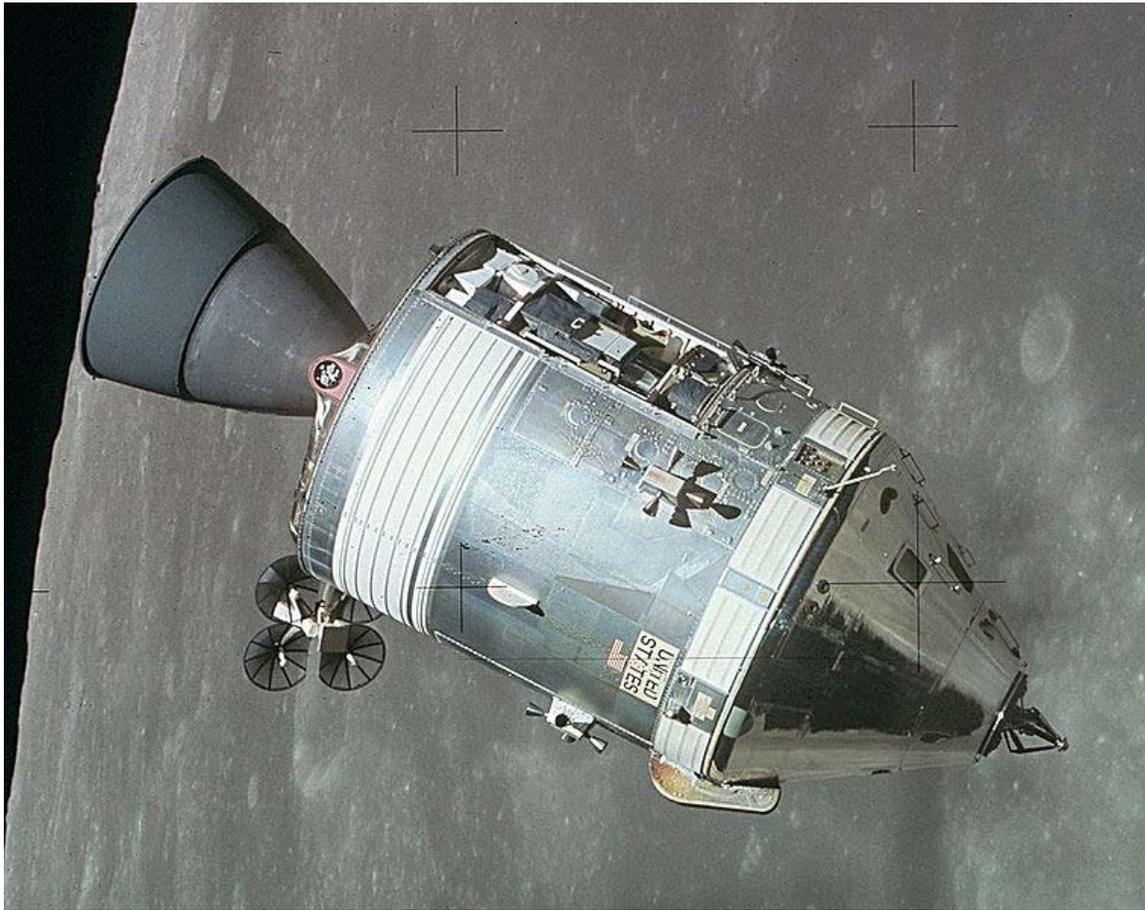
—James Hansen, *Enchanted Rendezvous*

The LOR method had the advantage of allowing the lander spacecraft to be used as a "life boat" in the event of a failure of the command ship. This happened on Apollo 13 when an oxygen tank failure left the command ship without electrical power. The Lunar Module provided propulsion, electrical power and life support to get the crew home safely.

Spacecraft

The decision in favor of lunar orbit rendezvous dictated the basic design of the Apollo spacecraft. It would consist of two main sections: the **Command/Service Module** (CSM), in which the crew would spend most of the mission, and the **Lunar Module** (LM), which would descend to and return from the lunar surface.

Command/Service Module



Apollo 15 CSM in lunar orbit

The Command Module (CM) was the crew cabin, surrounded by a conical re-entry heat shield, designed to carry three astronauts from launch to lunar orbit and back to an Earth ocean splashdown. As such, it was the only component of the Apollo spacecraft to survive without major configuration changes as the program evolved from the early Apollo study designs. Equipment carried by the Command Module included reaction control engines, a docking tunnel, guidance and navigation systems and the Apollo Guidance Computer.

Attached to the Command Module was the cylindrical Service Module (SM), which housed the service propulsion system and its propellants, the fuel cell power system, four maneuvering thruster quads, a high-gain S-band antenna for communications between the Moon and Earth, and storage tanks for water and oxygen. On the last three lunar missions, it also carried a scientific instrument package.

As the program concept evolved, use of the term "module" changed from its true meaning of an interchangeable component of systems with multiple variants, to simply a component of the complete lunar landing system. The original pre-1961 studies

contemplated a single Command Module with different sized Service Modules for various missions such as an earth-orbit shuttle to a space station, a ferry to lunar orbit, or return to Earth from a lunar landing (which would require an even larger descent stage attached to the SM.)

As used in the actual lunar program, the two modules remained attached throughout most of the flight to make a single ferry craft, somewhat awkwardly known as the Command/Service Module (CSM) which carried a separate lunar lander (only half as heavy as the CSM) to the Moon, and the astronauts home to Earth. Just before re-entry, the Service Module was discarded and only the Command Module re-entered the atmosphere, using its heat shield to survive the intense heat caused by air friction. After re-entry it deployed parachutes that slowed its descent, allowing a smooth splashdown in the ocean.

Under the leadership of Harrison Storms, North American Aviation won the contract to build the CSM, and also the second stage of the Saturn V launch vehicle for NASA. Relations between North American and NASA were strained during the winter of 1965-66 by delivery delays, quality shortfalls, and cost overruns in both components. They were strained even more a year later when a cabin fire killed the crew of Apollo 1 during a ground test. The cause was determined to be an electrical short in the wiring of the Command Module; while the determination of responsibility for the accident was complex, the review board concluded that "deficiencies existed in Command Module design, workmanship and quality control." This eventually led to the removal of Storms as Command Module program manager.

Lunar Module



Apollo 16 LM on the lunar surface

The Lunar Module (LM) (originally known as the Lunar Excursion Module, or LEM), was designed to fly between lunar orbit and the surface, landing two astronauts on the Moon and taking them back to the Command Module. It had no aerodynamic heat shield and was of a construction so lightweight that it would not have been able to fly through the Earth's atmosphere. It consisted of two stages, a descent and an ascent stage. The descent stage contained compartments which carried cargo such as the Apollo Lunar Surface Experiment Package and Lunar Rover.

The contract for design and construction of the Lunar Module was awarded to Grumman Aircraft Engineering Corporation, and the project was overseen by Tom Kelly. There were also problems with the Lunar Module; due to delays in the test program, the LM became a "pacing item," meaning that it was in danger of delaying the schedule of the whole Apollo program. Because of these issues, the Apollo missions were rescheduled so that the first manned mission with the Lunar Module would be Apollo 9, rather than Apollo 8 as was originally planned.

Launch vehicles

When the team of engineers led by Wernher von Braun began planning for the Apollo program, it was not yet clear what mission their rockets would have to support. Direct ascent would require a more powerful launch vehicle, the planned Nova, which could carry a very large payload to the Moon. NASA's decision in favor of Lunar Orbit Rendezvous re-oriented the work of the Marshall Space Flight Center towards the development of the Saturn I, Saturn IB and Saturn V. While the Saturn V was less powerful than the Nova would have been, it was still much more powerful than any rocket developed before, or since. (The USSR N1 was approximately as powerful, but it was never successful.)

Saturn IB



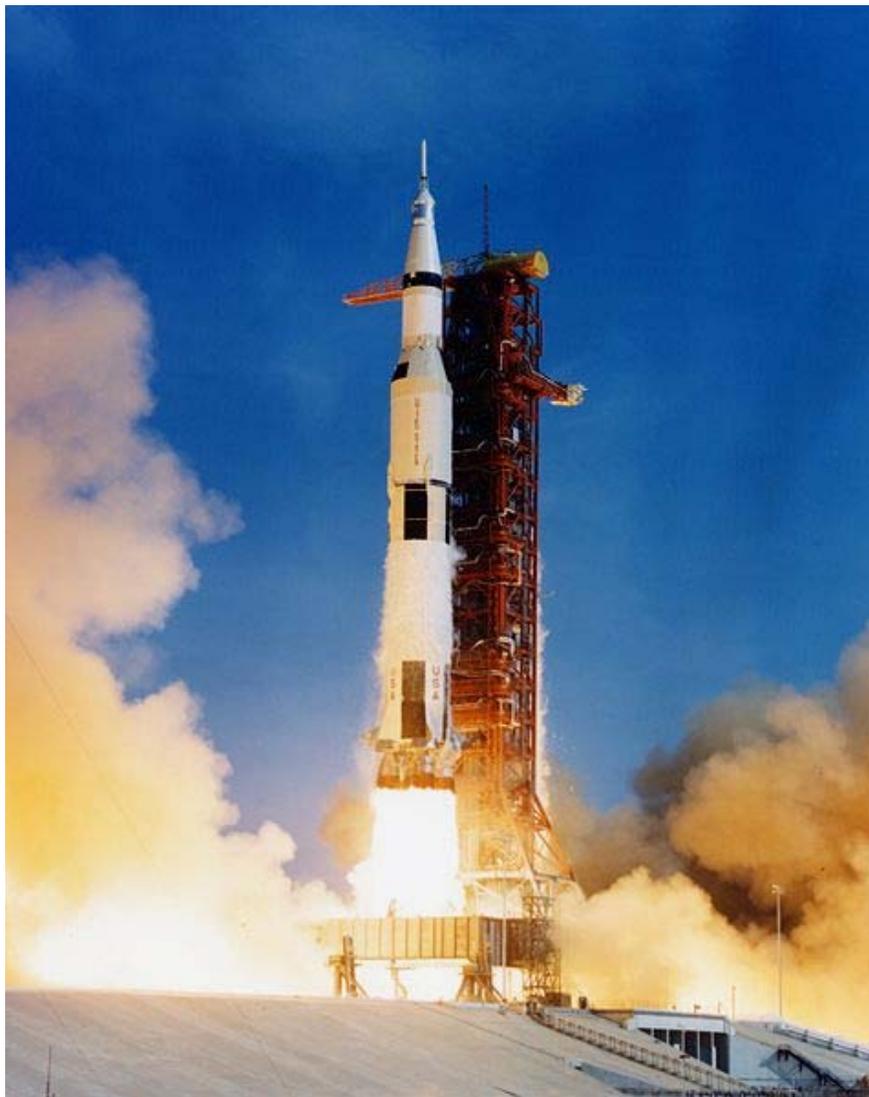
A Saturn IB rocket launches Apollo 7 into Earth orbit, October 11, 1968

The Saturn IB was an upgraded version of the earlier Saturn I rocket, which was used in early Apollo boilerplate launches. It consisted of:

- An S-IB first stage powered by eight H-1 engines burning RP-1 with LOX oxidizer, to produce 1,600,000 pounds-force (7,100 kN) of thrust;
- An S-IVB-200 second stage, powered by one J-2 engine burning liquid hydrogen with LOX oxidizer, to produce 225,000 lbf (1,000 kN) of thrust; and
- An Instrument Unit which contained the rocket's guidance system.

The Saturn IB was capable of putting a partially-fueled Command/Service Module, or a Lunar Module, into earth orbit. It was used in five of the Apollo test missions including the first manned mission. It was also used in the manned missions for the Skylab program and the Apollo-Soyuz Test Project.

Saturn V



A Saturn V rocket launches Apollo 11 in 1969

The Saturn V was a three-stage rocket consisting of:

- An S-IC first stage, powered by five F-1 engines arranged in a cross pattern, burning RP-1 with LOX oxidizer to produce 7,500,000 lbf (33,000 kN) of thrust. They burned for 2.5 minutes, accelerating the spacecraft to a speed of approximately 6,000 miles per hour (2.68 km/s).
- An S-II second stage, powered by five of the J-2 engines used in the S-IVB. They burned for approximately six minutes, taking the spacecraft to a speed of 15,300 miles per hour (6.84 km/s) and an altitude of about 115 miles (185 km).
- An S-IVB-500 third stage similar to the Saturn IB's second stage, with capability to restart the J-2 engine. The engine would burn for approximately two and a half minutes and shut down when a low-Earth parking orbit was achieved. After approximately two orbits to confirm the spacecraft was ready to commit to the lunar trip, the engine was restarted to make the translunar injection maneuver taking the spacecraft into an extremely high orbit where it would be captured by the Moon's gravity.
- An instrument unit with a guidance system similar to that used on the Saturn IB.

Three Saturn V vehicles launched on Earth orbital flights. Two of the three (Apollo 4 and 6) were unmanned tests of the command and service modules, and the third was a manned flight, Apollo 9, testing the lunar module. Nine Saturn Vs launched manned Apollo missions to the Moon, including Apollo 11. It was also used for the unmanned launch of Skylab.

Astronauts

The following astronauts flew on the 11 manned Apollo missions, plus the Apollo 1 crew who were killed in a ground test one month before they were to have flown the first manned mission. Not included are the astronauts who subsequently flew on the Skylab (Apollo Applications Program) or Apollo-Soyuz Test Project missions which used the Apollo CSM.

From Astronaut Group 1			
Astronaut	Service	Mission	Mercury/Gemini Flights
Virgil "Gus" Grissom	USAF	Apollo 1 Command Pilot	Mercury-Redstone 4, Gemini 3
Walter M. Schirra	USN	Apollo 7 CDR	Mercury-Atlas 8, Gemini 6A
Alan Shepard	USN	Apollo 14 CDR	Mercury-Redstone 3
From Astronaut Group 2			
Astronaut	Service	Mission	Gemini Flights
Neil A. Armstrong	ex-USN	Apollo 11 CDR	Gemini 8
Frank Borman	USAF	Apollo 8 CDR	Gemini 7
Charles "Pete" Conrad	USN	Apollo 12 CDR	Gemini 5, Gemini 11

James A. Lovell	USN	Apollo 8 CMP, Apollo 13 CDR	Gemini 7, Gemini 12
James A. McDivitt	USAF	Apollo 9 CDR	Gemini 4
Thomas P. Stafford	USAF	Apollo 10 CDR	Gemini 6A, Gemini 9A
Edward H. White II	USAF	Apollo 1 Senior Pilot	Gemini 4
John W. Young	USN	Apollo 10 CMP, Apollo 16 CDR	Gemini 3, Gemini 10

From Astronaut Group 3

Astronaut	Service	Mission	Gemini Flights
Edwin "Buzz" Aldrin	USAF	Apollo 11 LMP	Gemini 12
William A. Anders	USAF	Apollo 8 LMP	
Alan L. Bean	USN	Apollo 12 LMP	
Eugene A. Cernan	USN	Apollo 10 LMP, Apollo 17 CDR	Gemini 9A
Roger B. Chaffee	USN	Apollo 1 Pilot	
Michael Collins	USAF	Apollo 11 CMP	Gemini 10
R. Walter Cunningham	ex-USMC	Apollo 7 LMP	
Donn F. Eisele	USAF	Apollo 7 CMP	
Richard F. Gordon, Jr.	USN	Apollo 12 CMP	Gemini 11
Russell L. "Rusty" Schweickart	ex-USAF	Apollo 9 LMP	
David R. Scott	USAF	Apollo 9 CMP, Apollo 15 CDR	Gemini 8

From Astronaut Group 4

Astronaut	Service	Mission
Harrison H. Schmitt	Geologist	Apollo 17 LMP

From Astronaut Group 5

Astronaut	Service	Mission
Charles M. Duke	USAF	Apollo 16 LMP
Ronald E. Evans	USAF	Apollo 17 CMP
Fred W. Haise	ex-USMC	Apollo 13 LMP
James B. Irwin	USAF	Apollo 15 LMP
T. Kenneth Mattingly	USN	Apollo 16 CMP
Edgar D. Mitchell	USN	Apollo 14 LMP
Stuart A. Roosa	USAF	Apollo 14 CMP
John L. Swigert	ex-USAF	Apollo 13 CMP
Alfred M. Worden	USAF	Apollo 15 CMP

Mission	CDR	Group	Mission #	CMP	Group	Mission #	LMP	Group	Mission #
Apollo 1	Grissom	1	(3)	White	2	(2)	Chaffee	3	(1)
Apollo 7	Schirra	1	3	Eisele	3	1	Cunningham	3	1
Apollo 8	Borman	2	2	Lovell	2	3	Anders	3	1
Apollo 9	McDivitt	2	2	Scott	3	2	Schweickart	3	1
Apollo 10	Stafford	2	3	Young	2	3	Cernan	3	2
Apollo 11	Armstrong	2	2	Collins	3	2	Aldrin	3	2
Apollo 12	Conrad	2	3	Gordon	3	2	Bean	3	1
Apollo 13	Lovell	2	4	Swigert	5	1	Haise	5	1
Apollo 14	Shepard	1	2	Roosa	5	1	Mitchell	5	1
Apollo 15	Scott	3	3	Worden	5	1	Irwin	5	1
Apollo 16	Young	2	4	Mattingly	5	1	Duke	5	1
Apollo 17	Cernan	3	3	Evans	5	1	Schmitt	4	1

Capsule Communicator (CAPCOM)

Mission rules specified that, in most circumstances, only one person in the Mission Control Center would communicate directly with the in-flight crew, and that this was to be another astronaut, who would be best able to understand the situation in the spacecraft and communicate with the crew in the clearest way. These individuals were designated *Capsule Communicators* or CAPCOMs, a term carried over from the Mercury and Gemini programs. They were usually chosen from the backup and support crews, and worked in shifts during long missions.

The periodic *beeps* heard during communications with the astronauts are known as Quindar tones.

Chapter- 5

Colonization of the Moon

The **colonization of the Moon** is the proposed establishment of permanent human communities on the Moon. Advocates of space exploration have seen settlement of the Moon as a logical step in the expansion of humanity beyond the Earth. Recent indication that water might be present in quantities at the Lunar poles have increased interest in the Moon. Polar colonies could also avoid the problem of long Lunar nights (about 354 hours, a little more than two weeks) and take advantage of the sun continuously.

Permanent human habitation on a planetary body other than the Earth is one of science fiction's most prevalent themes. As technology has advanced, and concerns about the future of humanity on Earth have increased, the argument that space colonization is an achievable and worthwhile goal has gained momentum. Because of its proximity to Earth, the Moon has been seen as a prime candidate for the location of humanity's first permanently occupied extraterrestrial base.

Proposals



Concept art from NASA showing astronauts entering a Lunar outpost

The notion of siting a colony on the Moon originated before the space age. In 1638 Bishop John Wilkins wrote *A Discourse Concerning a New World and Another Planet*, in which he predicted a human colony on the Moon. Konstantin Tsiolkovsky (1857–1935), among others, also suggested such a step. From the 1950s onwards, a number of concepts and designs have been suggested by scientists, engineers and others.

In 1954 the noted science-fiction author Arthur C. Clarke proposed a Lunar base of inflatable modules covered in Lunar dust for insulation. A spaceship, assembled in low Earth orbit, would launch to the Moon, and astronauts would set up the igloo-like modules and an inflatable radio mast. Subsequent steps would include the establishment of a larger, permanent dome; an algae-based air purifier; a nuclear reactor for the provision of power; and electromagnetic cannons to launch cargo and fuel to interplanetary vessels in space.

In 1959, John S. Rinehart suggested that the safest design would be a structure that could "[float] in a stationary ocean of dust", since there were, at the time this concept was outlined, theories that there could be mile-deep dust oceans on the Moon. The proposed design consisted of a half-cylinder with half-domes at both ends, with a micrometeoroid shield placed above the base.

Project Horizon

Project Horizon was a 1959 study regarding the U.S. Army's plan to establish a fort on the Moon by 1967. H. H. Koelle, a German rocket engineer of the Army Ballistic Missile Agency (ABMA) led the Project Horizon study. The first landing would be carried out by two "soldier-astronauts" in 1965 and more construction workers would soon follow. Through numerous launches (61 Saturn I and 88 Saturn II), 245 tons of cargo would be transported to the outpost by 1966.

Lunar ark

In 2007 Jim Burke of the International Space University in France said people should plan to preserve humanity's culture in the event of a civilization stopping asteroid impact with Earth. A Lunar ark was proposed. Subsequent planning may be taken up by the International Lunar Exploration Working Group (ILEWG).

Moon exploration

Exploration of the Lunar surface by spacecraft began in 1959 when the Soviet Luna 2 mission crash-landed into the surface. The same year, the Luna 3 mission radioed photographs to Earth of the Moon's hitherto unseen far side, marking the beginning of a decade-long series of unmanned Lunar explorations.

Responding to the Soviet program of space exploration, US President John F. Kennedy in 1961 told the U.S. Congress on May 25: "I believe that this nation should commit itself to achieving the goal before this decade is out of landing a man on the moon and returning

him safely to the Earth." The same year the Soviet leadership made some of its first public pronouncements about landing a man on the Moon and establishing a Lunar base.

In 1962, John DeNike and Stanley Zahn published their idea of a sub-surface base located at the Sea of Tranquility. This base would house a crew of 21, in modules placed 4 meters below the surface, which was believed to provide radiation shielding as well as the Earth's atmosphere does. They favored nuclear reactors for energy production, because they are more efficient than solar panels, and would also overcome the problems with the long Lunar nights. For life support system, an algae-based gas exchanger was proposed.

Manned exploration of the Lunar surface began in 1968 when the Apollo 8 spacecraft orbited the Moon with three astronauts on board. This was mankind's first direct view of the far side. The following year, the Apollo 11 Lunar module landed two astronauts on the Moon, proving the ability of humans to travel to the Moon, perform scientific research work and bring back sample materials.

Additional missions to the Moon continued this exploration phase. In 1969 the Apollo 12 mission landed next to the Surveyor 3 spacecraft, demonstrating precision landing capability. Following the near-disaster of Apollo 13, Apollo 14 was the last mission on which astronauts were quarantined on their return from the Moon. The use of a manned vehicle was demonstrated in 1971 with the Lunar Rover during Apollo 15. Apollo 16 made the first landing within the rugged Lunar highlands. However, interest in further exploration of the Moon was beginning to wane among the American public. In 1972 Apollo 17 was the final Apollo Lunar mission, and further planned missions were scrapped at the directive of President Nixon. Instead, focus was turned to the Space Shuttle and manned missions in near Earth orbit.

The Soviet Luna program failed to send a manned mission to the Moon. However, in 1966 Luna 9 was the first probe to achieve a soft landing and return close-up shots of the Lunar surface. Luna 16 in 1970 returned the first Soviet Lunar soil samples, while in 1970 and 1973 during the Lunokhod program two robotic rovers landed on the Moon. Lunokhod 1 explored the Lunar surface for 322 days, but the contact with Lunokhod 2 was lost after about 4 months of its operation. 1974 saw the end of the Soviet Moonshot, two years after the last American manned landing.

In the decades following, interest in exploring the Moon faded considerably, and only a few dedicated enthusiasts supported a return. However, evidence of Lunar ice at the poles gathered by NASA's Clementine (1994) and Lunar Prospector (1998) missions rekindled some discussion, as did the potential growth of a Chinese space program that contemplated its own mission to the Moon. Subsequent research suggested that there was far less ice present (if any) than had originally been thought, but that there may still be some usable deposits of hydrogen in other forms. However, in September 2009, the Chandrayaan probe, carrying a NASA instrument, discovered that the Lunar regolith contains 0.1% water by weight, overturning theories that had stood for 40 years.

In 2004, U.S. President George W. Bush called for a plan to return manned missions to the Moon by 2020. Propelled by this new initiative, NASA issued a new long-range plan that includes building a base on the Moon as a staging point to Mars. This plan envisions a Lunar outpost at one of the moon's poles by 2024 which, if well-sited, might be able to continually harness solar power; at the poles, temperature changes over the course of a Lunar day are also less extreme, and reserves of water and useful minerals may be found nearby. In addition, the European Space Agency has a plan for a permanently manned Lunar base by 2025. Russia has also announced similar plans to send a man to the moon by 2025 and establish a permanent base there several years later.

A Chinese space scientist has said that the People's Republic of China could be capable of landing a human on the moon by 2022, and Japan and India also have plans for a Lunar base by 2030. Neither of these plans involves permanent residents on the Moon. Instead they call for sortie missions, in some cases followed by extended expeditions to the Lunar base using rotating crew members, as is currently done for the International Space Station.

NASA's LCROSS/LRO mission had been scheduled to launch in October 2008. The launch was delayed until the 18th of June 2009, resulting in LCROSS's impact with the Moon at 11:30 UT on the 9th of October, 2009. The purpose is preparing for future Lunar exploration.

Water discovered on moon

In September 2009 it was announced that NASA's Moon Mineralogy Mapper on India's Chandrayaan-1 had detected water on the moon.

On November 13, 2009 NASA announced that the LCROSS mission had discovered large quantities of water ice on the moon around the LCROSS impact site at Cabeus. "Large" is a relative term. The amount of water discovered is put in perspective by this comment from Robert Zubrin: "The 30 m crater ejected by the probe contained 10 million kilograms of regolith. Within this ejecta, an estimated 100 kg of water was detected. That represents a proportion of 10 parts per million, which is a lower water concentration than that found in the soil of the driest deserts of the Earth. In contrast, we have found continent sized regions on Mars, which are 600,000 parts per million, or 60% water by weight."

In March 2010, NASA reported that the NASA mini-SAR radar aboard Chandrayaan-1 detected ice deposits at the moon's north pole. It is estimated there is at least 600 million tons of ice at the north pole in sheets of relatively pure ice at least a couple of meters thick.

Advantages and disadvantages

Putting aside the general questions of whether a human colony beyond the Earth is feasible or scientifically desirable in light of cost-efficiency, proponents of space colonization point out that the Moon offers both advantages and disadvantages as a site for such a colony.

Advantages

Placing a colony on a natural body would provide an ample source of material for construction and other uses, including shielding from radiation. The energy required to send objects from the Moon to space is much less than from Earth to space. This could allow the Moon to serve as a construction site or fueling station for spacecraft. Some proposals include using electric acceleration devices (mass drivers) to propel objects off the Moon without building rockets. Others have proposed momentum exchange tethers (see below). Furthermore, the Moon does have some gravity, which experience to date indicates may be vital for fetal development and long-term human health. Whether the Moon's gravity (roughly one sixth of Earth's) is adequate for this purpose, however, is uncertain.

In addition, the Moon is the closest large body in the solar system to Earth. While some Earth-crosser asteroids occasionally pass closer, the Moon's distance is consistently within a small range close to 384,400 km. This proximity has several benefits:

- Monetary (including space tourism), security, and technological gains.
- The energy required to send objects from Earth to the Moon is lower than for most other bodies.
- Transit time is short. The Apollo astronauts made the trip in three days and future technologies could improve on this time.
- If the Moon were colonized then it could be tested if humans can survive in low gravity. Those results could be utilized for a viable Mars colony as well.
- The short transit time would also allow emergency supplies to quickly reach a Moon colony from Earth, or allow a human crew to evacuate relatively quickly from the Moon to Earth in case of emergency. This could be an important consideration when establishing the first human colony.

- The round trip communication delay to Earth is less than three seconds, allowing near-normal voice and video conversation, and allowing some kinds of remote control of machines from Earth that are not possible for any other celestial body. The delay for other solar system bodies is minutes or hours; for example, round trip communication time between Earth and Mars ranges from about eight minutes to about forty minutes. This again would be of particular value in an early colony, where life-threatening problems requiring Earth's assistance could occur. (See, for example, Apollo 13.)
- On the Lunar near side, the Earth appears large and is always visible as an object 60 times brighter than the Moon appears from Earth, unlike more distant locations where the Earth would be seen merely as a star-like object, much as the planets appear from Earth. As a result, a Lunar colony might feel less remote to humans living there.
- A Lunar base would provide an excellent site for any kind of observatory. Particular advantages arise from building observatory facilities on the Moon from Lunar materials. As the Moon's rotation is so slow, visible light observatories could perform observations for days at a time. It is possible to maintain near-

constant observations on a specific target with a string of such observatories spanning the circumference of the Moon. The fact that the Moon is geologically inactive along with the lack of widespread human activity results in a remarkable lack of mechanical disturbance, making it far easier to set up interferometric telescopes on the Lunar surface, even at relatively high frequencies such as visible light.

- A Lunar base could also hold a future site for launching rockets, to distant planets such as Mars. Launching rockets from the Moon would be an easier prospect than on Earth due to the Moon's lower gravity requiring a lower escape velocity. A lower escape velocity would require less propellant, but there is no guarantee that less propellant would cost less money is required to launch from Earth.
- A farm at the Lunar North Pole could provide eight hours of sunlight per day for rotating crops, a beneficial temperature, radiation protection, insects for pollination, and all other plant needs artificially during the local summer for a cost. One estimate suggested a 0.5 hectare space farm could feed 100 people.
- A moon colony provides us with most of the experiments, skills, and knowledge we need to colonize another planet.
- A moon colony can easily be seen from the Earth, and might inspire many more humans to seriously consider the advantages and future of colonization. A clear sign or signal can be made to remind humans on Earth, inspiring future leaders, astronauts, and scientists.

Disadvantages

There are several disadvantages to the Moon as a colony site:

- The long Lunar night would impede reliance on solar power and require a colony to be designed that could withstand large temperature extremes. An exception to this restriction are the so-called "peaks of eternal light" located at the Lunar north pole that are constantly bathed in sunlight. The rim of Shackleton Crater, towards the Lunar south pole, also has a near-constant solar illumination. Other areas near the poles that get light most of the time could be linked in a power grid.
- The Moon is highly depleted in light elements (volatiles), such as carbon, nitrogen and hydrogen. A number of robot probes including Lunar Prospector gathered evidence of hydrogen generally in the Moon's crust consistent with what would be expected from implantation from the solar wind, and higher concentrations near the poles. There had been some disagreement whether the hydrogen must necessarily be in the form of water. The LCROSS mission has definitely found evidence of water. This water would be in ice form perhaps mixed in small crystals in the regolith in a colder landscape than people have ever mined. Other volatiles containing carbon and nitrogen could conceivably also be in the same cold traps as the ice. If no sufficient means is found for recovering these volatiles on the Moon, they would need to be imported from some other source to support life and industrial processes. Volatiles would need to be stringently recycled. This would limit the colony's rate of growth and keep it dependent on Earth. The transportation cost of importing volatiles from Earth could be reduced by

- constructing the upper stage of supply ships using materials high in volatiles, such as carbon fiber and other plastics. The 2006 announcement by the Keck Observatory that the binary Trojan asteroid 617 Patroclus, and possibly large numbers of other Trojan objects in Jupiter's orbit, are likely composed of water ice, with a layer of dust, and the hypothesized large amounts of water ice on the closer, main-belt asteroid 1 Ceres, suggest that importing volatiles from this region via the Interplanetary Transport Network may be practical in the not-so-distant future. However, these possibilities are dependent on complicated and expensive resource utilization from the mid to outer solar system, which are not likely to become available to a Moon colony for a significant period of time.
- It is uncertain whether the low (one-sixth g) gravity on the Moon is strong enough to prevent detrimental effects to human health in the long term. Exposure to weightlessness over month-long periods has been demonstrated to cause deterioration of physiological systems, such as loss of bone and muscle mass and a depressed immune system. Similar effects could occur in a low-gravity environment, although virtually all research into the health effects of low gravity has been limited to zero gravity. Countermeasures such as an aggressive routine of daily exercise have proven at least partially effective in preventing the health deterioration that is caused by low gravity.
 - The lack of a substantial atmosphere for insulation results in temperature extremes and makes the Moon's surface conditions somewhat like a deep space vacuum. It also leaves the Lunar surface exposed to half as much radiation as in interplanetary space (with the other half blocked by the moon itself underneath the colony) raising the issues of the health threat from cosmic rays and the risk of proton exposure from the solar wind, especially since two-thirds of the Moon's orbit is outside the protection of the Earth's magnetosphere. Although Lunar materials would potentially be useful as a simple radiation shield for living quarters, shielding against solar flares during expeditions outside is more problematic.
 - Also, the lack of an atmosphere increases the chances of the colonial site being hit by meteors, which would impact upon the surface directly, as they have done throughout the Moon's history. Even small pebbles and dust (micrometeoroids) have the potential to damage or destroy insufficiently protected structures.
 - Moon dust is an extremely abrasive glassy substance formed by micrometeorites and unrounded due to the lack of weathering. It sticks to everything, can damage equipment, and it may be toxic.
 - Growing crops on the moon faces many difficult challenges due to the long Lunar night (354 hour), extreme variation in surface temperature, exposure to solar flares, and lack of insects for pollination. (Due to the lack of any atmosphere on the Moon, plants would need to be grown in sealed chambers, though experiments have shown that plants can thrive at pressures much lower than those on Earth.) The use of electric lighting to compensate for the 354 hour night might be difficult: a single acre of plants on Earth enjoys a peak 4 megawatts of sunlight power at noon. Experiments conducted by the Soviet space program in the 1970s suggest it is possible to grow conventional crops with the 354 hour light, 354 hour dark cycle. A variety of concepts for Lunar agriculture have been proposed,

including the use of minimal artificial light to maintain plants during the night and the use of fast growing crops that might be started as seedlings with artificial light and be harvestable at the end of one Lunar day.

Locations

Three criteria that a Lunar outpost should meet are:

- good conditions for transport operations;
- a great number of different types of natural objects and features on the Moon of scientific interest; and
- natural resources, such as oxygen. The abundance of certain minerals, such as iron oxide, varies dramatically over the Lunar surface.

While a colony might be located anywhere, potential locations for a Lunar colony fall into three broad categories.

Polar regions

There are two reasons why the Lunar poles might be attractive as locations for a human colony. First, there is evidence that water may be present in some continuously shaded areas near the poles. Second, because the Moon's axis of rotation is almost perfectly perpendicular to the ecliptic plane, it may be possible to power polar colonies exclusively with solar energy. Power collection stations can be located so that at least one is in sunlight at all times. Some sites have nearly continuous sunlight. For example, Malapert mountain, located near the Shackleton crater at the Lunar south pole, offers several advantages as a site:

- It is exposed to the sun most of the time; two closely spaced arrays of solar panels would receive nearly continuous power.
- Its proximity to Shackleton Crater (116 km, or 69.8 mi) means that it could provide power and communications to the crater. This crater is potentially valuable for astronomical observation. An infrared instrument would benefit from the very cold temperatures. A radio telescope would benefit from being shielded from Earth's broad spectrum radio interference.
- The nearby Shoemaker and other craters are in constant deep shadow, and might contain valuable concentrations of hydrogen and other volatiles.
- At around 5,000 meters (16,500 ft) elevation, it offers line of sight communications over a large area, as well as to Earth.
- The South Pole-Aitken basin is located at the south Lunar pole. This is the second largest known impact basin in the solar system, as well as the oldest and biggest impact feature on the Moon, and should provide geologists access to deeper layers of the Moon's crust.

NASA chose to use a south-polar site for the Lunar outpost reference design in the Exploration Systems Architecture Study chapter on Lunar Architecture.

At the north pole, the rim of Peary crater has been proposed as a favorable location for a base. Examination of images from the Clementine mission appear to show that parts of the crater rim are permanently illuminated by sunlight (except during Lunar eclipses). As a result, the temperature conditions are expected to remain very stable at this location, averaging $-50\text{ }^{\circ}\text{C}$ ($-58\text{ }^{\circ}\text{F}$). This is comparable to winter conditions in Earth's Poles of Cold in Siberia and Antarctica. The Peary crater interior may also harbor hydrogen deposits.

Although hydrogen appears to be concentrated at the poles, the presence of Lunar ice has not yet been confirmed. A bistatic radar experiment performed during the Clementine mission suggested the presence of water ice around the south pole. The Lunar Prospector spacecraft reported enhanced hydrogen abundances not only at the south pole, but also at the north pole — actually more so. On the other hand, results reported using the Arecibo radio telescope have been interpreted by some to indicate that the anomalous Clementine radar signatures are not indicative of ice, but surface roughness. This interpretation, however, is not universally agreed upon.

A potential limitation of the polar regions is that the inflow of solar wind can create an electrical charge on the leeward side of crater rims. The resulting voltage difference can affect electrical equipment, change surface chemistry, erode surfaces and levitate Lunar dust.

Equatorial regions

The Lunar equatorial regions are likely to have higher concentrations of helium-3 (rare on Earth but much sought after for use in nuclear fusion research) because the solar wind has a higher angle of incidence. They also enjoy an advantage in extra-Lunar traffic: The rotation advantage for launching material is slight due to the Moon's slow rotation, but the corresponding orbit coincides with the ecliptic, nearly coincides with the Lunar orbit around Earth and nearly coincides with the equatorial plane of Earth.

Several probes have landed in the Oceanus Procellarum area. There are many areas and features that could be subject to long-term study, such as the Reiner Gamma anomaly and the dark-floored Grimaldi crater.

Far side

The Lunar far side lacks direct communication with Earth, though a communication satellite at the L_2 Lagrangian point, or a network of orbiting satellites, could enable communication between the far side of the Moon and Earth. The far side is also a good location for a large radio telescope because it is well shielded from the Earth. Due to the lack of atmosphere, the location is also suitable for an array of optical telescopes, similar to the Very Large Telescope in Chile. To date, there has been no ground exploration of the far side.

Scientists have estimated that the highest concentrations of helium-3 will be found in the maria on the far side, as well as near side areas containing concentrations of the titanium-based mineral ilmenite. On the near side the Earth and its magnetic field partially shields the surface from the solar wind during each orbit. But the far side is fully exposed, and thus should receive a somewhat greater proportion of the ion stream.

Lunar lava tubes

Lunar lava tubes form a potentially important location for constructing a future Lunar base, which may be used for local exploration and development, or as a human outpost to serve exploration beyond the Moon. Any intact lava tube on the moon could serve as a shelter from the severe environment of the Lunar surface, with its frequent meteorite impacts, high-energy ultra-violet radiation and energetic particles, and extreme diurnal temperature variations.; March 5, 2010; Discover Magazine; Phil Plait Astronomy. The second lunar lava tube was discovered by LRO.

Structure

Habitat



A NASA model of a proposed inflatable module

There have been numerous proposals regarding habitat modules. The designs have evolved throughout the years as mankind's knowledge about the Moon has grown, and as the technological possibilities have changed. The proposed habitats range from the actual spacecraft landers or their used fuel tanks, to inflatable modules of various shapes. Early on, some hazards of the Lunar environment such as sharp temperature shifts, lack of atmosphere or magnetic field (which means higher levels of radiation and micrometeoroids) and long nights, were recognized and taken into consideration.

Some suggest building the Lunar colony underground, which would give protection from radiation and micrometeoroids. This also greatly reduce the risk of air leakage, as the colony will be fully sealed from the outside except for a few exits to the surface. This is not the only advantage to this option. The average temperature on the moon is about -5°C . The day period (about 354 hours) has an average temperature of about 107°C (225°F), although it can rise as high as 123°C (253°F). The night period (also 354 hours) has

an average temperature of about $-153\text{ }^{\circ}\text{C}$ ($-243\text{ }^{\circ}\text{F}$). Underground, both periods would be around $-23\text{ }^{\circ}\text{C}$ ($-9\text{ }^{\circ}\text{F}$), and humans could install ordinary air conditioners.

The construction of such a base would probably be more complex; one of the first machines from Earth might be a remote controlled excavating machine to excavate living quarters. Once created, some sort of hardening would be necessary to avoid collapse, possibly a spray-on concrete-like substance made from available materials. A more porous insulating material also made *in-situ* could then be applied. Mining methods such as the room and pillar might also be used. Inflatable self-sealing fabric habitats might then be put in place to retain air. Eventually an underground city similar to The Forum Shops at Caesars and Underground City, Montreal can be constructed. Farms setup underground would need artificial sunlight. As an alternative to excavating, a lava tube could be covered and insulated, thus solving the problem of radiation exposure. One such lava tube has been discovered in early 2009.

A possibly easier solution would be to build the Lunar base on the surface, and cover the modules with Lunar soil. The Lunar regolith is composed of a unique blend of silica and iron-containing compounds that may be fused into a glass-like solid using microwave energy. This may allow for the use of "Lunar bricks" in structural designs, or the "glassing" of loose dirt to form a hard, ceramic crust. Others have put forward the idea that the Lunar base could be built on the surface and protected by other means, such as improved radiation and micrometeoroid shielding. Building the Lunar base inside a deep crater would provide at least partial shielding against radiation and micrometeoroids. Artificial magnetic fields have been proposed as a means to provide radiation shielding for long range deep space manned missions, and it might be possible to use similar technology on a Lunar colony. Some regions on the Moon possess strong local magnetic fields that might partially mitigate exposure to charged solar and galactic particles.

Moon Capital

The Moon Capital Competition will be offering a prize for an architectural design of a Lunar habitat intended to be an underground international commercial center capable of supporting a residential staff of 60 people and their families. The Moon Capital is intended to be self-sufficient with respect to food and other material required for life support. Prize money will be provided primarily by the Boston Society of Architects and The New England Council of the American Institute of Aeronautics and Astronautics.

Energy

A Lunar base would need power for its operations — from fuel production and communications to life support systems and scientific research.

Nuclear power

A nuclear fission reactor might fulfill most of the base's power requirements. Fission reactors can also overcome the difficulty of the 354 hour Lunar night. Radioisotope

thermoelectric generators could be used as backup and emergency power sources for solar powered colonies.

Solar energy

Solar energy is a possible source of power for a Lunar base. Many of the raw materials needed for solar panel production can be extracted on site. However, the long Lunar night (354 hours) is a drawback for solar power on the Moon's surface. This might be solved by building several power plants, so that at least one of them is always in daylight. Another possibility would be to build such a power plant where there is constant or near-constant sunlight, such as at the Malapert mountain near the Lunar south pole, or on the rim of Peary crater near the north pole. A third possibility would be to leave the panels in orbit, and beam the power down as microwaves.

The solar energy converters need not be silicon solar panels. It may be more advantageous to use the larger temperature difference between sun and shade to run heat engine generators. Concentrated sunlight could also be relayed via mirrors and used in Stirling engines or solar trough generators, or it could be used directly for lighting, agriculture and process heat. The focused heat might also be employed in materials processing to extract various elements from Lunar surface materials.

Energy storage

In the early days, a combination of solar panels for 'day-time' operation and fuel cells for 'night-time' operation could be used.

Fuel cells on the Space Shuttle have operated reliably for up to 17 Earth days at a time. On the Moon, they would only be needed for 354 hours — the length of the Lunar night. Fuel cells produce water directly as a waste product. Current fuel cell technology is more advanced than the Shuttle's cells — PEM (Proton Exchange Membrane) cells produce considerably less heat (though their waste heat would likely be useful during the Lunar night) and are physically lighter, not to mention the reduced mass of the smaller heat-dissipating radiators. This makes PEMs more economical to launch from Earth than the shuttle's cells, but PEMs have not yet been proven in space.

Combining fuel cells with electrolysis would provide a 'perpetual' source of electricity - solar energy could be used to provide power during the Lunar day, and fuel cells at night. During the Lunar day, solar energy would also be used to electrolyze the water created in the fuel cells - although there would be small losses of gases that would have to be replaced.

Transport

Earth to Moon

Conventional rockets have been used for most Lunar exploration to date. The ESA's SMART-1 mission from 2003 to 2006 used Hall effect thrusters. NASA will use chemical rockets on its Ares V booster and Lunar Surface Access Module, being developed for a planned return to the Moon around 2019. The construction workers, location finders, and other astronauts vital to building, will be taken in NASA's Orion spacecraft.

On the surface



A Lunar rover being unloaded from a cargo spacecraft. Conceptual drawing.

Within the colony it will be difficult to set up a public transport system. However a system of Escalators, moving walkways and elevator can be used to quickly transport people and cargo around.

Lunar colonists will also want the ability to move over long distances, to transport cargo and people to and from modules and spacecraft, and to carry out scientific study of a larger area of the Lunar surface for long periods of time. Proposed concepts include a variety of vehicle designs, from small open rovers to large pressurised modules with lab equipment, and also a few flying or hopping vehicles.

Rovers could be useful if the terrain is not too steep or hilly. The only rovers to have operated on the surface of the Moon (as of 2008) are the three Apollo Lunar Roving Vehicles (LRV), developed by Boeing, and the two robotic Soviet Lunokhods. The LRV was an open rover for a crew of two, and a range of 92 km during one Lunar day. One NASA study resulted in the Mobile Lunar Laboratory concept, a manned pressurised rover for a crew of two, with a range of 396 km. The Soviet Union developed different rover concepts in the Lunokhod series and the L5 for possible use on future manned missions to the Moon or Mars. These rover designs were all pressurised for longer sorties.

If multiple bases were established on the Lunar surface, they could be linked together by permanent railway systems. Both conventional and magnetic levitation (Mag-Lev) systems have been proposed for the transport lines. Mag-Lev systems are particularly attractive as there is no atmosphere on the surface to slow down the train, so the vehicles could achieve velocities comparable to aircraft on the Earth. In addition achieving the extremely cold temperatures necessary for the superconducting magnets that levitate and drive the Mag-Lev trains would be much easier to achieve than on Earth due to the lack of an atmosphere. One significant difference with Lunar trains, however, is that the cars would need to be individually sealed and possess their own life support systems. The trains would also need to be highly resistant to derailment, as a punctured car could lead to rapid loss of life.

For difficult areas, a flying vehicle may be more suitable. Bell Aerosystems proposed their design for the Lunar Flying Vehicle as part of a study for NASA. Bell also developed the Manned Flying System, a similar concept.

Surface to space

Launch technology



A Lunar base with a mass driver (the long structure that goes toward the horizon.) NASA conceptual illustration.

A Lunar base will need efficient ways to transport people and goods of various kinds between the Earth and the Moon and, later, to and from various locations in interplanetary space. One advantage of the Moon is its relatively weak gravity field, making it easier to launch goods from the Moon than from the Earth. The lack of a Lunar atmosphere is both an advantage and a disadvantage; while it is easier to launch from the Moon because there is no drag, aerobraking is not possible, which makes it necessary to bring extra fuel in order to land. An alternative, which may work for supplies, is to surround the payload with impact-absorbing materials, something that was tried in the Ranger program. This can be efficient if the impact protection is made of needed lighter elements that are absent from the Moon (Ranger used balsa wood)

One way to get materials and products from the Moon to an interplanetary waystation might be with a mass driver, a magnetically accelerated projectile launcher. Cargo would be picked up from orbit or an Earth-Moon Lagrangian point by a shuttle craft using ion propulsion, solar sails or other means and delivered to Earth orbit or other destinations such as near-Earth asteroids, Mars or other planets, perhaps using the Interplanetary Transport Network. If a Lunar space elevator is ever built, it could transport people, raw materials and products to and from an orbital station at Lagrangian points L_1 or L_2 .

Launch costs

- Estimates of the cost per pound of launching cargo or people from the Moon vary and the cost impacts of future technological improvements are difficult to predict. An upper bound on the cost of launching material from the Moon might be about \$40,000,000 per kilogram, based on dividing the Apollo program costs by the amount of material returned. At the other extreme, the incremental cost of launching material from the moon using an electromagnetic accelerator could be quite low. The efficiency of launching material from the Moon with a proposed electric accelerator is suggested to be about 50%. If the carriage of a mass driver weighs the same as the cargo, two kilograms must be accelerated to orbital velocity for each kilogram put into orbit. The overall system efficiency would then drop to 25%. So 1.4 kilowatt-hours would be needed to launch an incremental kilogram of cargo to low orbit from the Moon. At \$0.1/kilowatt-hour, a typical cost for electrical power on Earth, that amounts to \$0.16 for the energy to launch a kilogram of cargo into orbit. For the actual cost of an operating system, energy loss for power conditioning, the cost of radiating waste heat, the cost of maintaining all systems, and the interest cost of the capital investment are considerations. David R. Criswell believes that there is a potential for the cost of electrical power on the Moon to become enough less than the cost on Earth for electrical power to be exported from the Moon to Earth by microwave.
- Passengers cannot be divided into the parcel size suggested for the cargo of a mass driver, nor subjected to hundreds of gravities acceleration. However, technical developments could also affect the cost of launching passengers to orbit from the Moon. Instead of bringing all fuel and oxidizer from Earth, liquid oxygen could be produced from Lunar materials and hydrogen should be available from the Lunar poles. The cost of producing these on the Moon is yet unknown, but they will be more expensive than on Earth. The situation of the local hydrogen is most open to speculation. As a rocket fuel, hydrogen could be extended by combining it chemically with silicon to form silane, which has yet to be demonstrated in an actual rocket engine. In the absence of more technical developments, the cost of transporting people from the Moon will be an impediment to colonization.

Surface to and from cis-Lunar space

A cis-Lunar transport system has been proposed using tethers to achieve momentum exchange. This system requires zero net energy input, and could not only retrieve payloads from the Lunar surface and transport them to Earth, but could also soft land payloads on to the Lunar surface.

Economic development

For long term sustainability, a space colony should be close to self sufficient. On site mining and refining of the Moon's materials could provide an advantage over deliveries from Earth – for use both on the Moon and elsewhere in the solar system – as they can be

launched into space at a much lower energy cost than from Earth. It is possible that vast sums of money will be spent in interplanetary exploration in the 21st century, and the cost of providing goods from the Moon might be attractive.

Space-based materials processing

In the long term, the Moon will likely play an important role in supplying space-based construction facilities with raw materials. Zero gravity allows for the processing of materials in ways impossible or difficult on Earth, such as "foaming" metals, where a gas is injected into a molten metal, and then the metal is annealed slowly. On Earth, the gas bubbles rise and burst, but in a zero gravity environment, that does not happen.

Annealing is a process that requires large amounts of energy, as a material is kept very hot for an extended period of time. (This allows the molecular structure to realign.) Materials which cannot be alloyed or mixed on Earth because of gravity-field effects on density differences could be combined in space, resulting in composites which could have exceptional qualities. No one knows, because no one has been able to experiment along these lines on any scale. However, it is possible that materials or processes will be identified which will be highly valuable on Earth, but impossible to make here. (This is the foundation of the free MoonBaseOne game made by a non-profit that teaches children about space.)

Exporting material to Earth

Exporting material to Earth in trade from the Moon is more problematic due to the cost of transportation which will vary greatly if the Moon is industrially developed (see above). One suggested candidate is Helium-3 from the solar wind, which is thought to have accumulated on the Moon's surface over billions of years, and which is rare on Earth. Helium might be present in the Lunar regolith in quantities of 0.01 ppm to 0.05 ppm (depending on soil). 2006 market price for He-3 was about \$46,500 per troy ounce (\$1500/gram, \$1.5M/kg), more than 120 times the value per unit weight of Gold and over eight times the value of Rhodium.

In the long term future He-3 may prove to be a desirable fuel in thermonuclear fusion reactors.

Solar power satellites

Gerard K. O'Neill, noting the problem of high launch costs in the early 1970s, came up with the idea of building Solar Power Satellites in orbit with materials from the Moon. Launch costs from the Moon will vary greatly if the Moon is industrially developed (see above). This 1970s proposal was predicated on the then advertised future launch costs of NASA's space shuttle.

On 30 April 1979 the Final Report "Lunar Resources Utilization for Space Construction" by General Dynamics Convair Division under NASA contract NAS9-15560 concluded

that use of Lunar resources would be cheaper than terrestrial materials for a system comprising as few as thirty Solar Power Satellites of 10 GW capacity each.

In 1980, when it became obvious NASA's launch cost estimates for the space shuttle were grossly optimistic, O'Neill et al. published another route to manufacturing using Lunar materials with much lower startup costs. This 1980s SPS concept relied less on human presence in space and more on partially self-replicating systems on the Lunar surface under telepresence control of workers stationed on Earth.