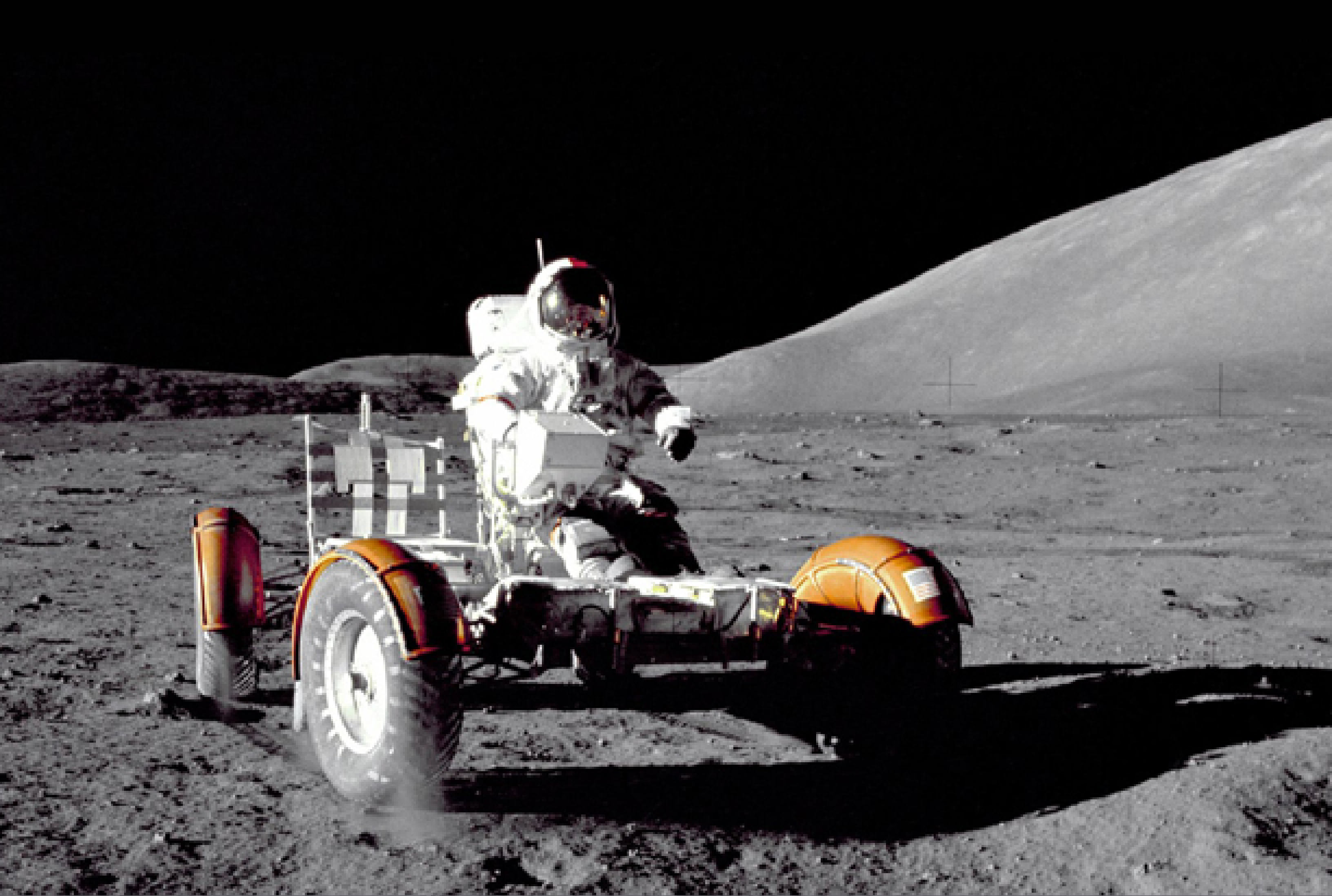
Exploration of Moon and Mars



Brent Malcolm

Ilda Swearingen

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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 Brāhmana*. 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.

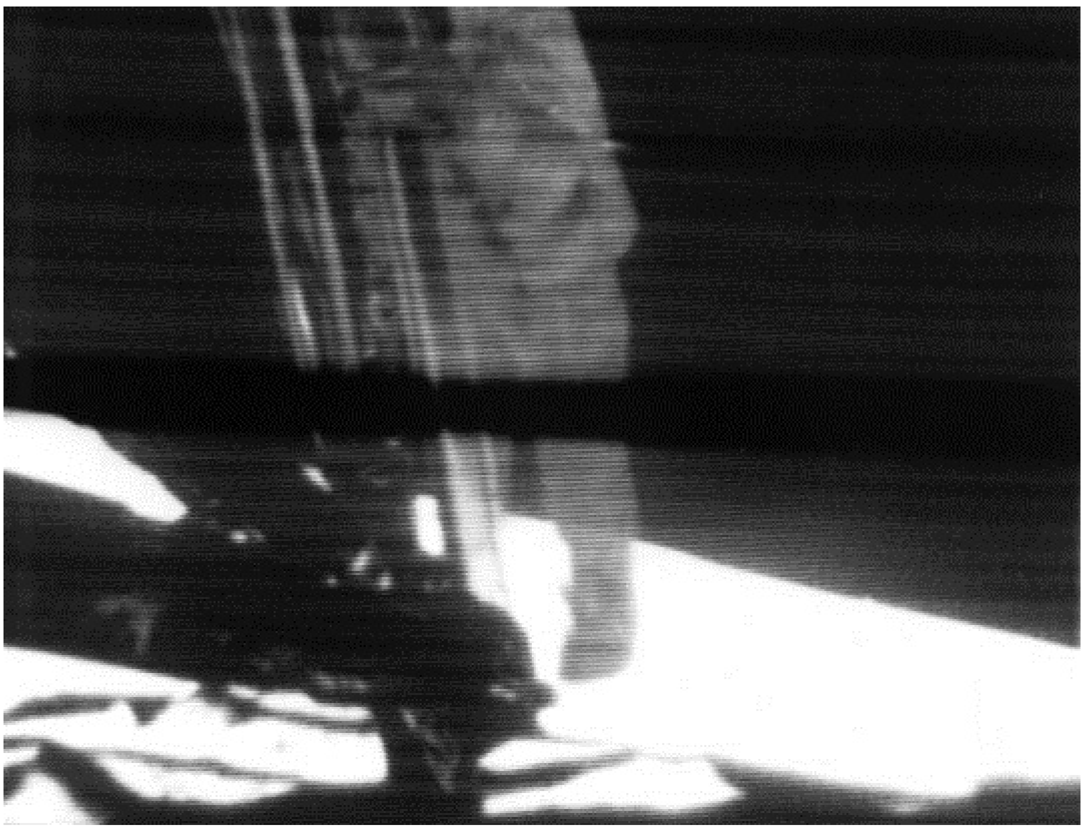
In August 2007, NASA stated that all future missions and explorations of the Moon will be done entirely using the metric system. This was done to improve cooperation with space agencies of other countries which already use the metric system.

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

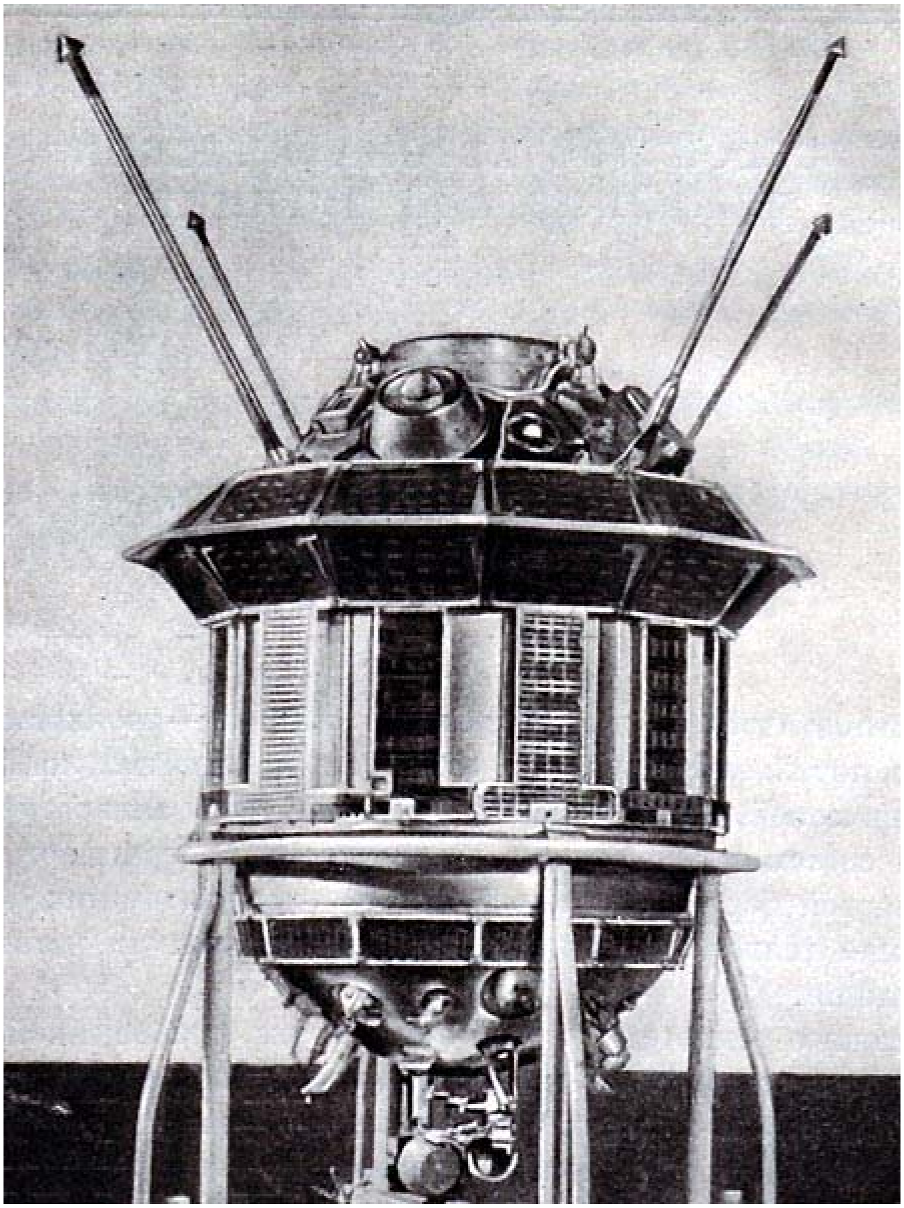
The intense and expensive effort devoted in the 1960s to achieving first an unmanned and then ultimately a manned moon landing can only be understood in the political context of its historical era. World War II with its 60 million dead, half Soviets, was fresh in the memory of all adults. In the 1940s, 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 surprise 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 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



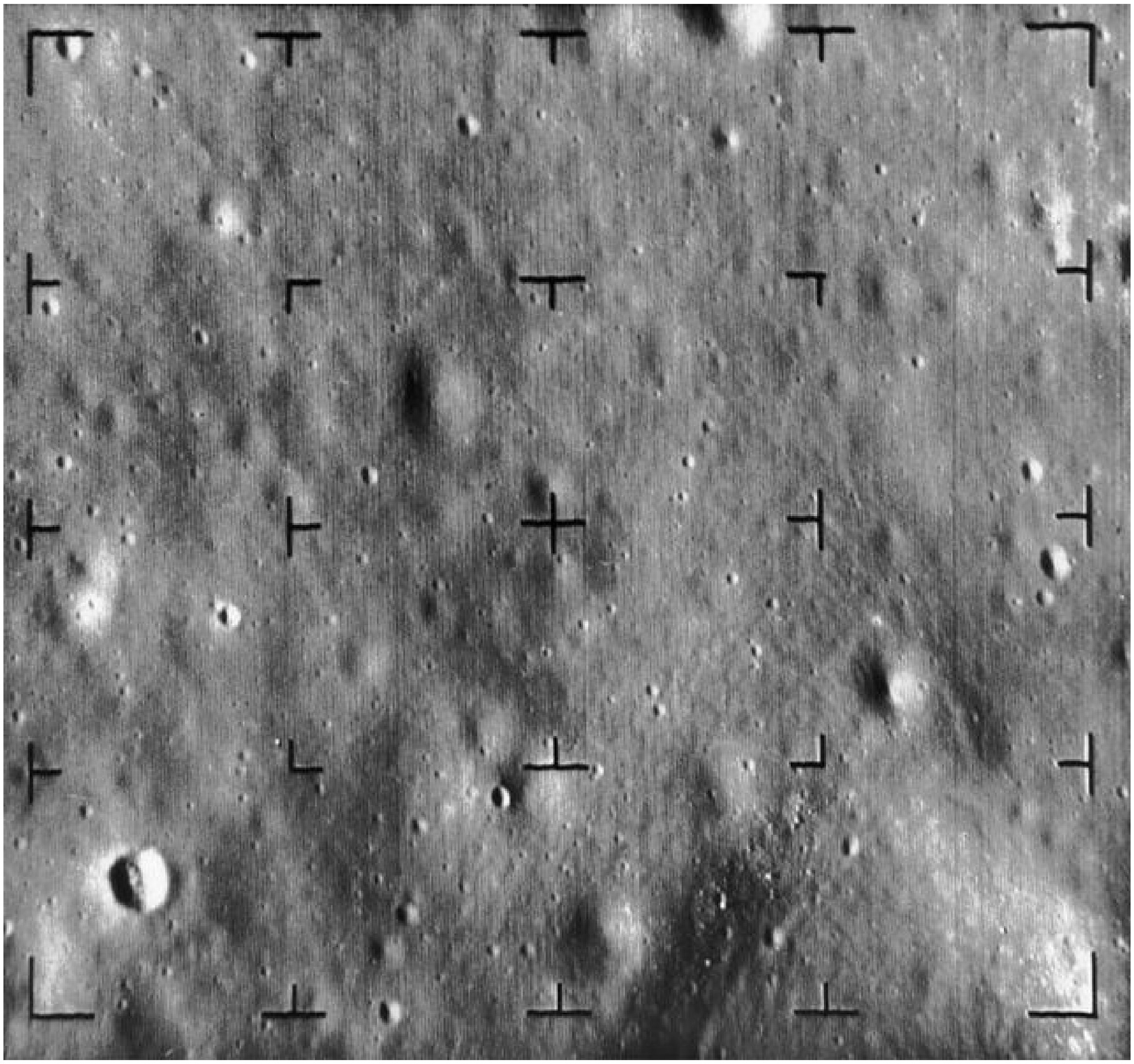
Luna 3 - transmitted first photos of the far side of the Moon

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.

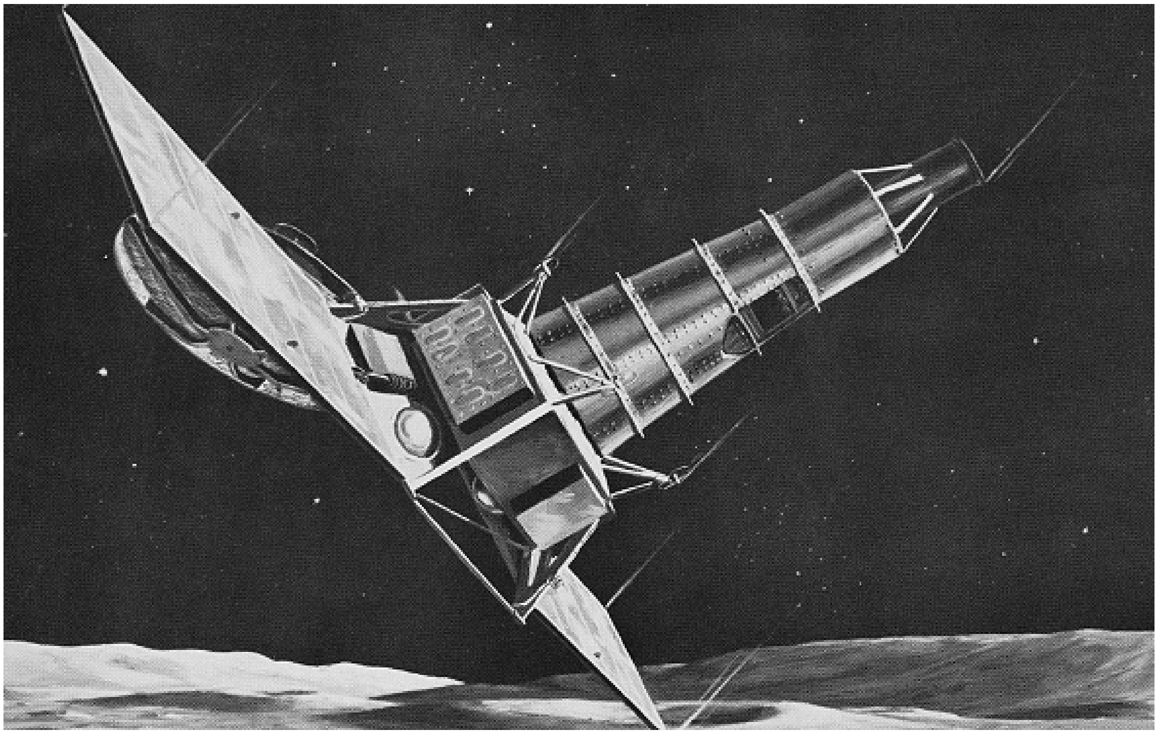
U.S.S.R. Mission	Mass (kg)	Launch Vehicle	Launched	Mission Goal	Mission Result
		Semyorka - 8K72	23 September 1958	Lunar Impact	Failure - booster malfunction at T+ 93 sec
		Semyorka - 8K72	12 October 1958	Lunar Impact	Failure - booster malfunction at T+ 104 sec
		Semyorka - 8K72	4 December 1958	Lunar 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)



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



Artist's portrayal of a Ranger spacecraft 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-	11 October	Lunar	Failure - software error; reentry

		Able	1958	orbit	
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 1960	Lunar orbit	Failure - first stage explosion; destroyed
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.

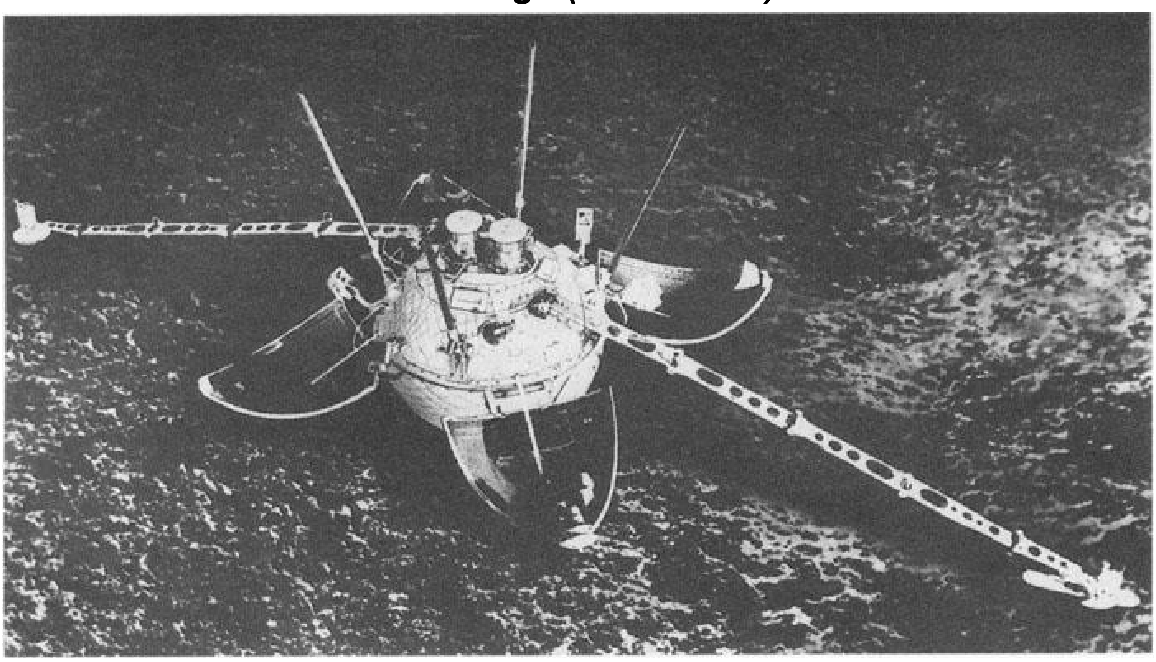
The first attempts to perform a Moon landing took place in 1962 during the Rangers 3, 4 and 5 missions flown by the United States. All three Block II missions carried a 94 pound, 2-foot-diameter (0.61 m) landing sphere (made of balsa wood) designed to withstand a 150-mile-per-hour impact. This lander (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.

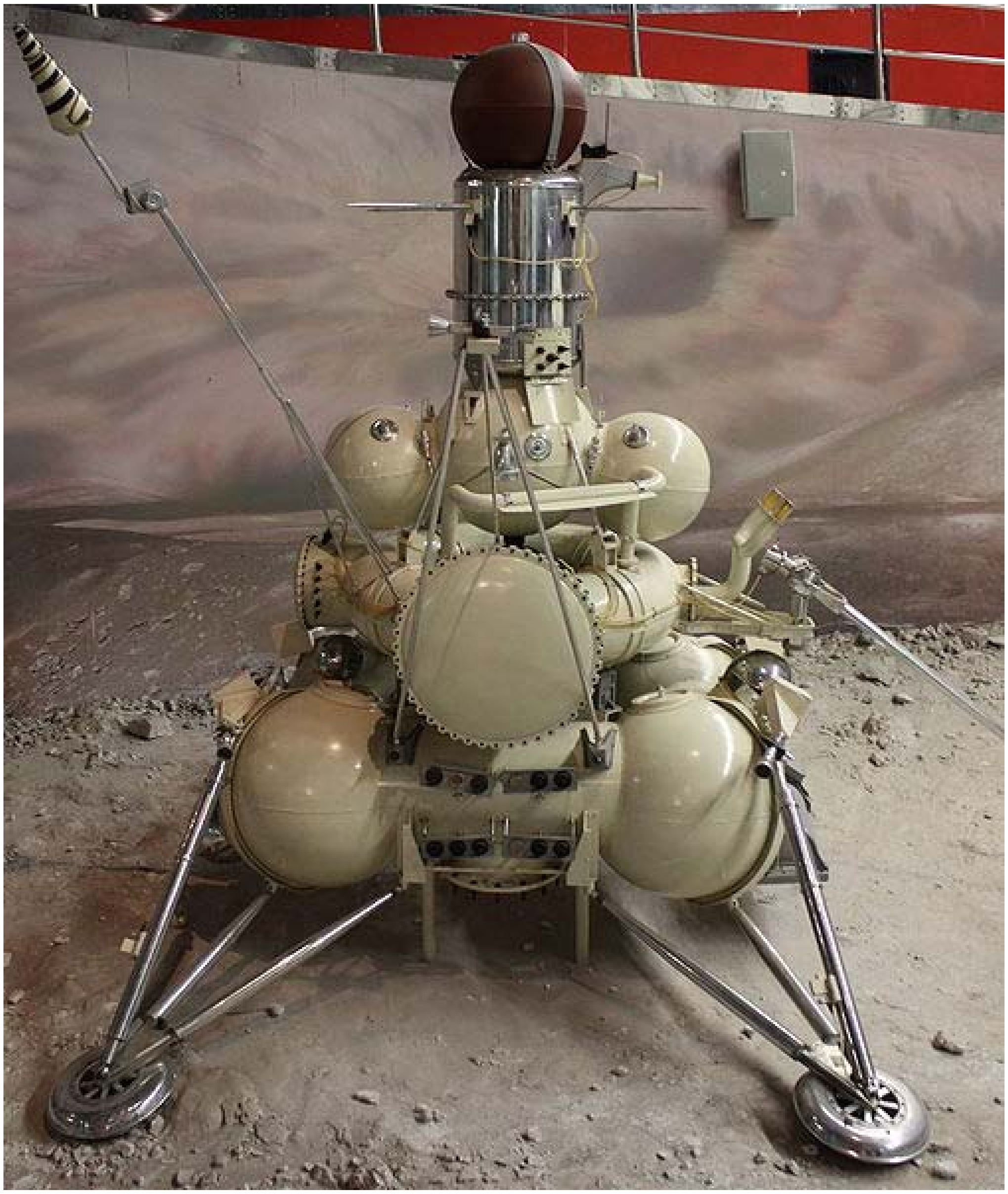
On Ranger 3, failure of the Atlas guidance system and a software error aboard the Agena upper stage combined to put the spacecraft on a course that would miss the Moon. Attempts to salvage lunar photography during a flyby of the Moon were thwarted by in-flight failure of the onboard flight computer. 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.

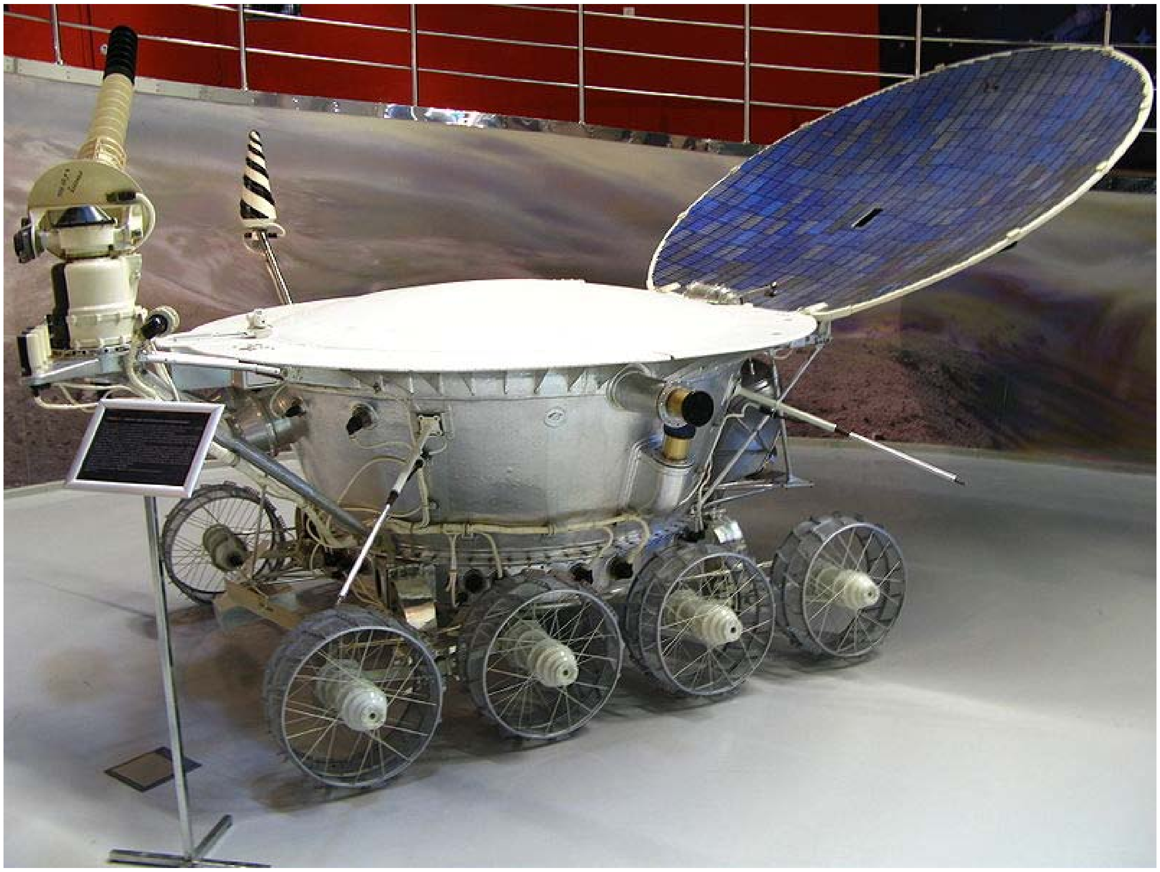
Soviet unmanned soft landings (1966–1976)



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

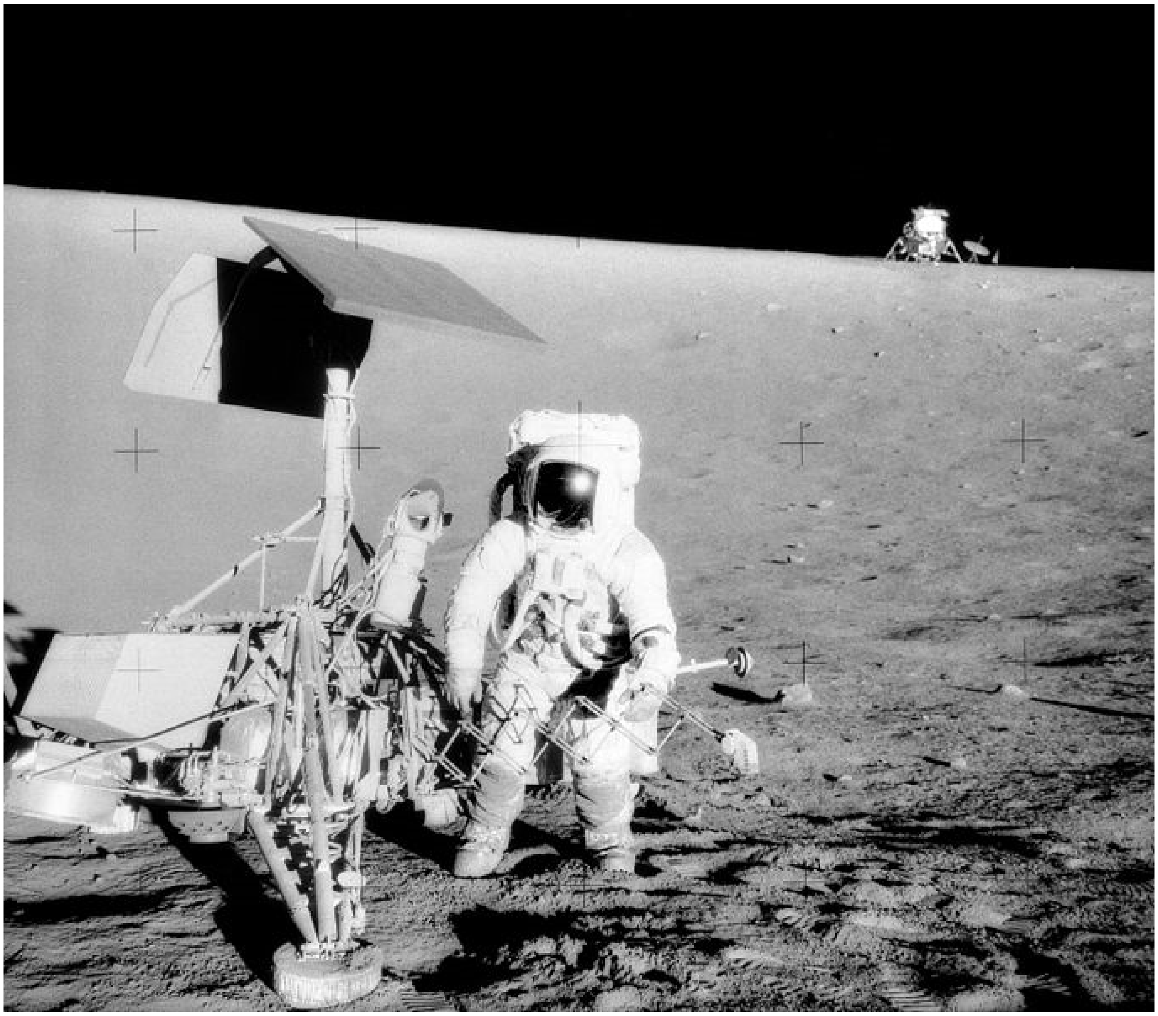
The Luna 9 spacecraft, launched by the Soviet Union, performed the first successful soft Moon landing on February 3. Airbags protected its 200 pound ejectable capsule which survived an impact speed of over 30 miles per hour. Luna 13 duplicated this feat with a similar Moon landing on December 24, 1966.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

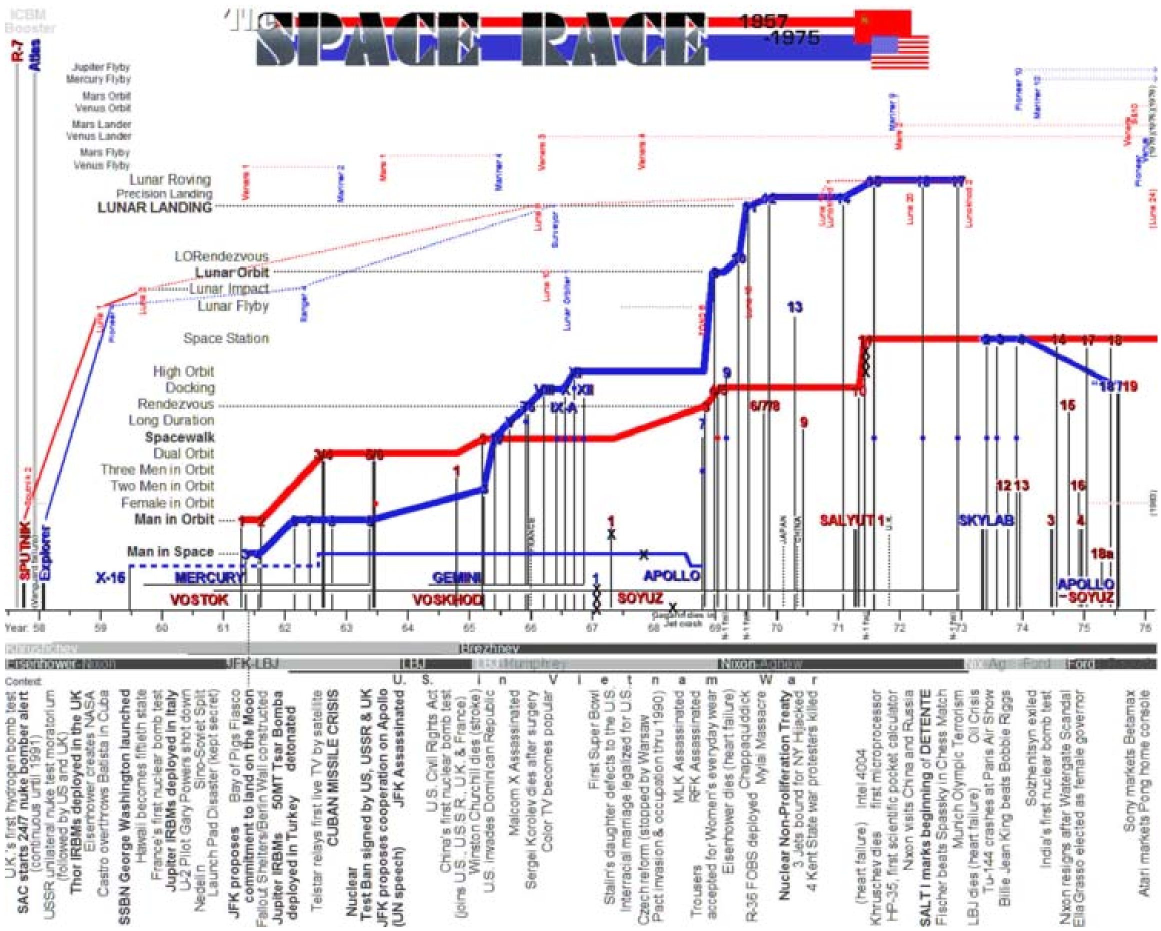
					Moon landing		
Surveyor 2	292	Atlas - Centaur	20 September 1966	Moon landing	Failure - midcourse engine malfunction, placing vehicle in unrecoverable tumble; crashed southeast of Copernicus Crater	Sinus Medii	004.00S 011.00W
Surveyor 3	302	Atlas - Centaur	20 April 1967	Moon landing	Success - 6,000 pictures 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

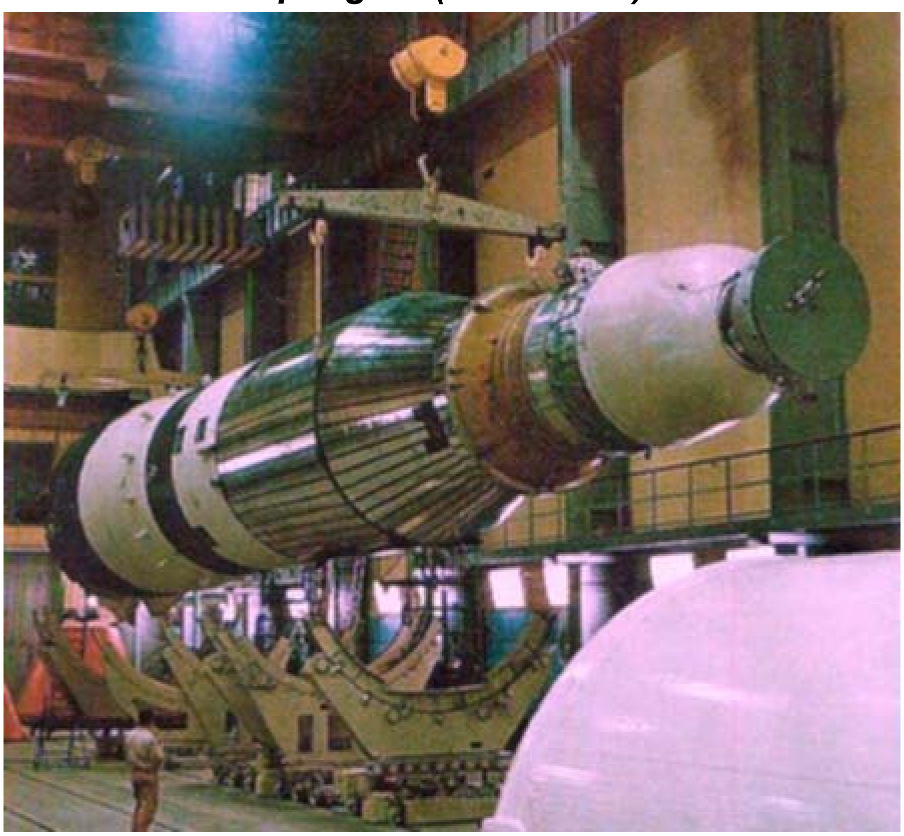
Luna 10 became the first spacecraft to orbit the Moon on 3 April 1966.

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

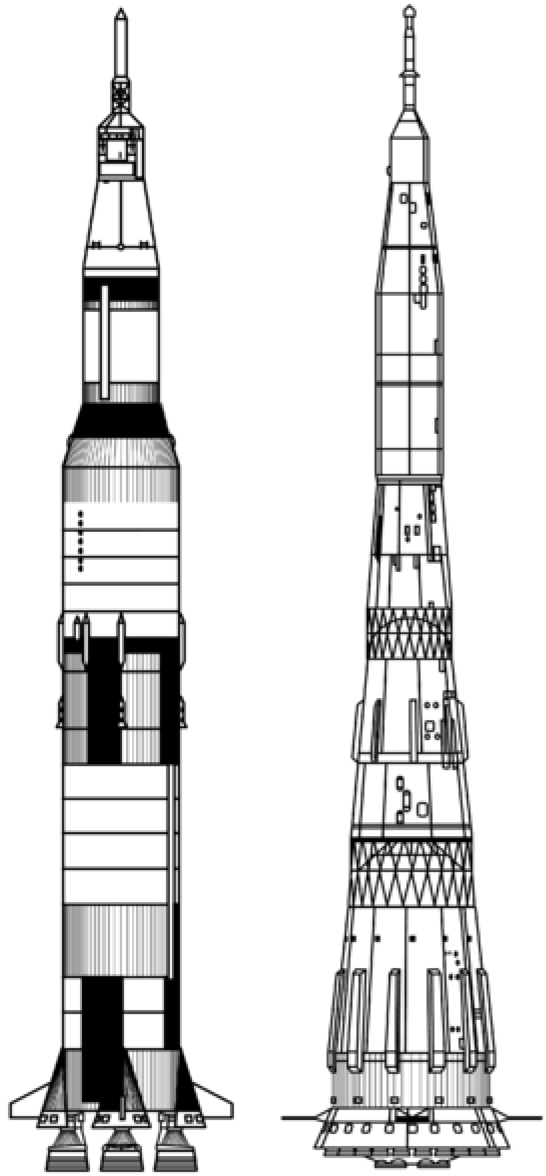
			1968	Loop	payload	biological payload safely to Earth despite landing off-target outside the Soviet Union in the Indian Ocean
Zond-6	5,375	Proton	10 November 1968	Circumlunar Loop	non-human biological payload	Partial Success - looped around Moon, successful reentry, but loss of cabin air pressure caused 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)

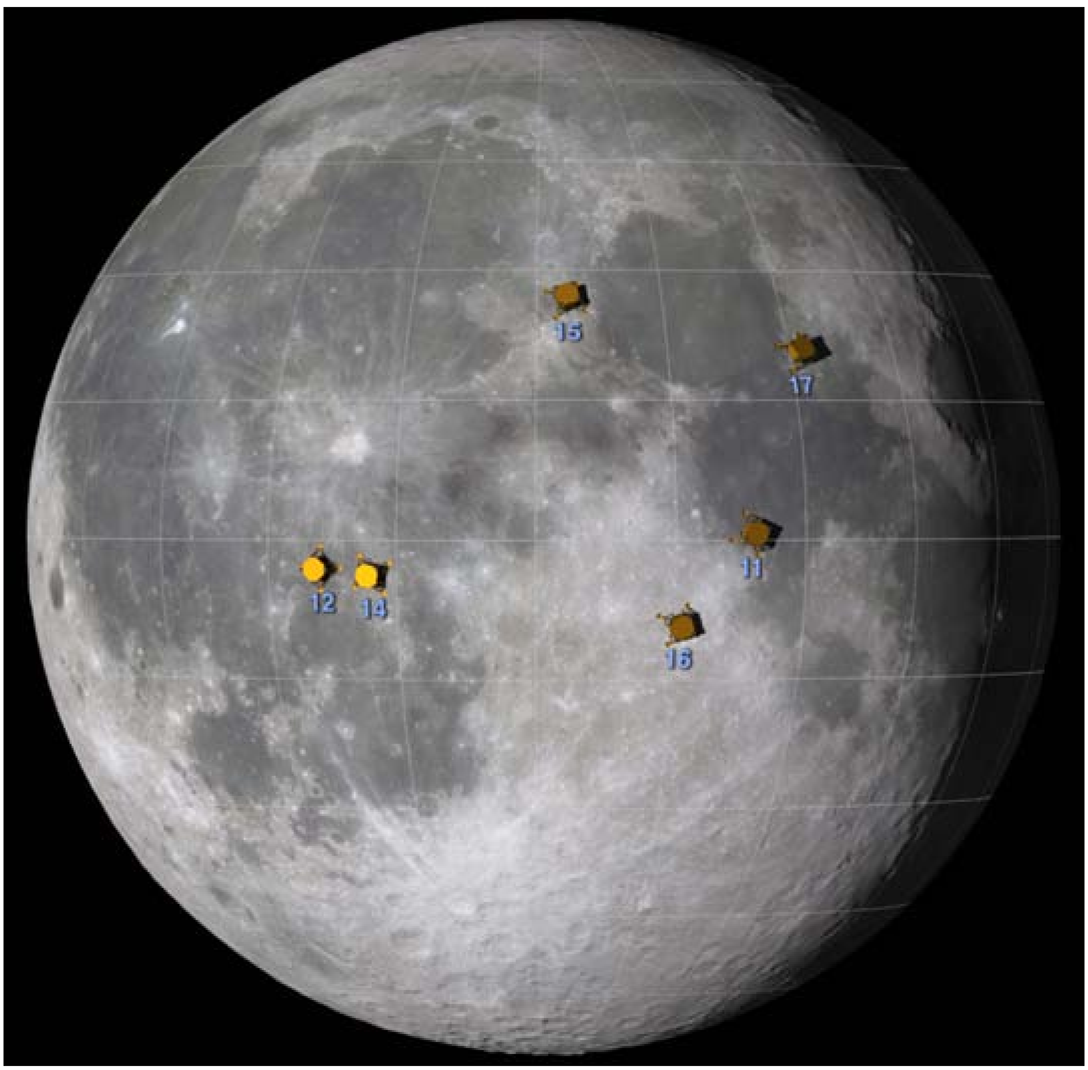


The U.S. Saturn V versus the Soviet N1

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	*Eagle*	20 July 1969	21 July 1969	Sea of Tranquility	21:31	Neil Armstrong, Edwin "Buzz" Aldrin	1	2:31
Apollo 12	*Intrepid*	19 November 1969	21 November 1969	Ocean of Storms	1 day, 7:31	Charles "Pete" Conrad, Alan Bean	2	7:45
Apollo 14	*Antares*	5 February 1971	6 February 1971	Fra Mauro	1 day, 9:30	Alan B. Shepard, Edgar Mitchell	2	9:21
Apollo 15	*Falcon*	30 July 1971	3 August 1971	Hadley Rille	2 days, 18:55	David Scott, James Irwin	3	18:33
Apollo 16	*Orion*	21 April 1972	24 April 1972	Descartes Highlands	2 days, 23:02	John Young, Charles Duke	3	20:14
Apollo 17	*Challenger*	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.

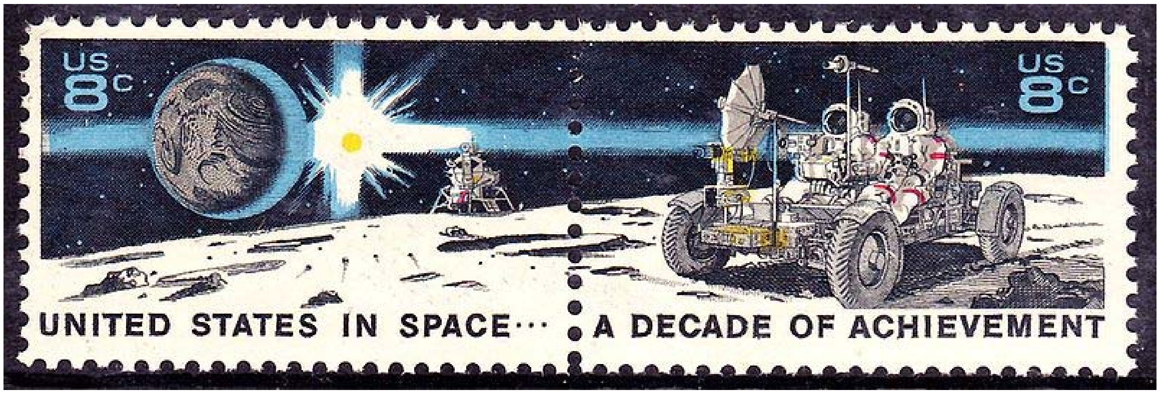
US orbital missions (2009)-

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 AchievementDecade, 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 poatal 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 fusellage 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.

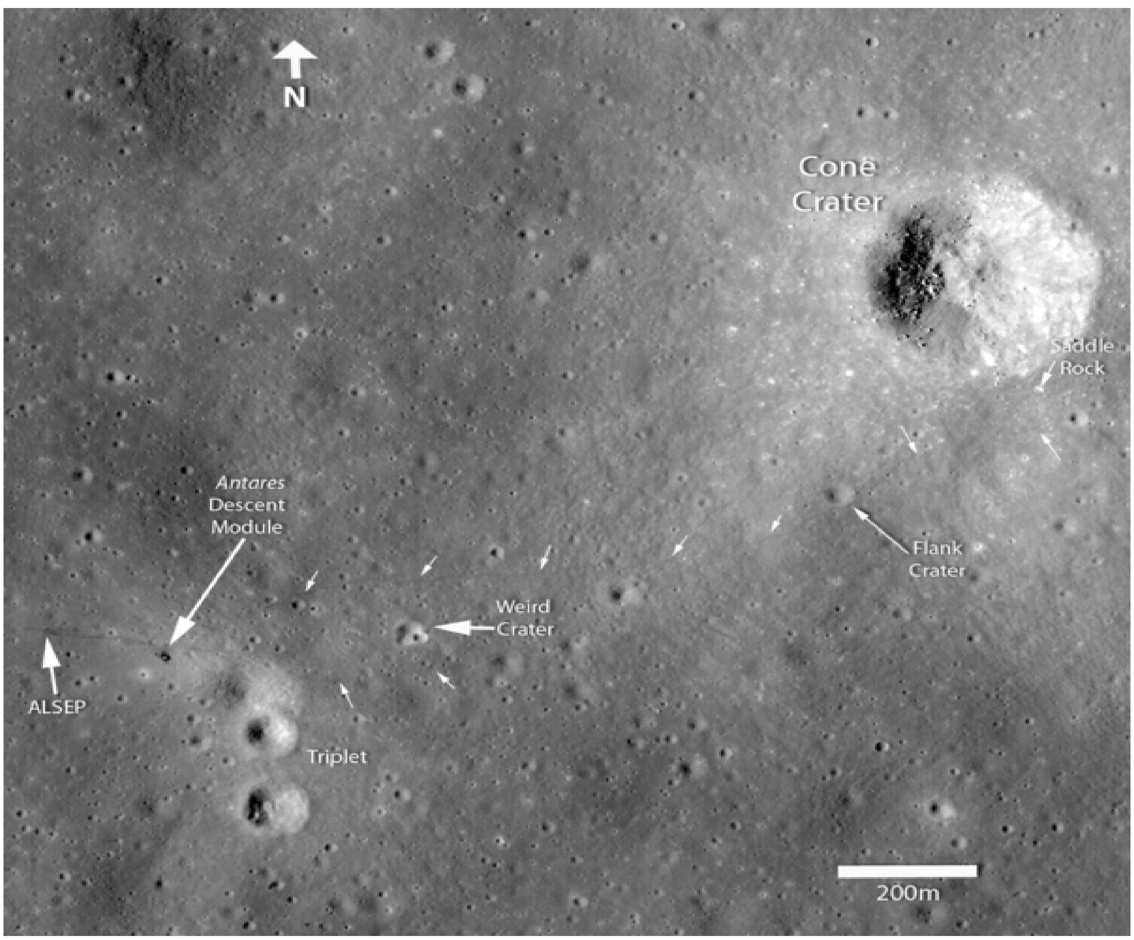
Critical examination of hoax accusations

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

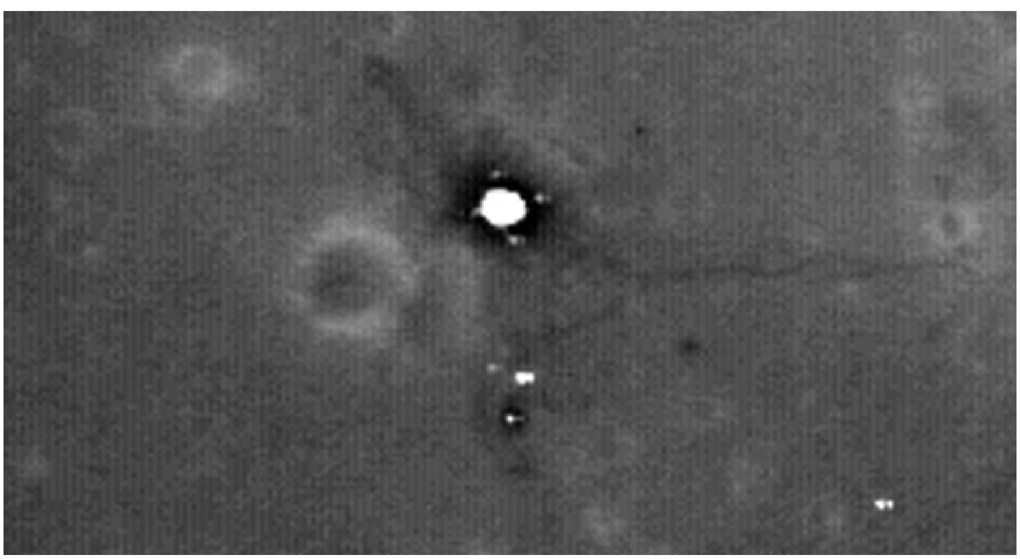


A later LRO photo of the Apollo 14 landing site

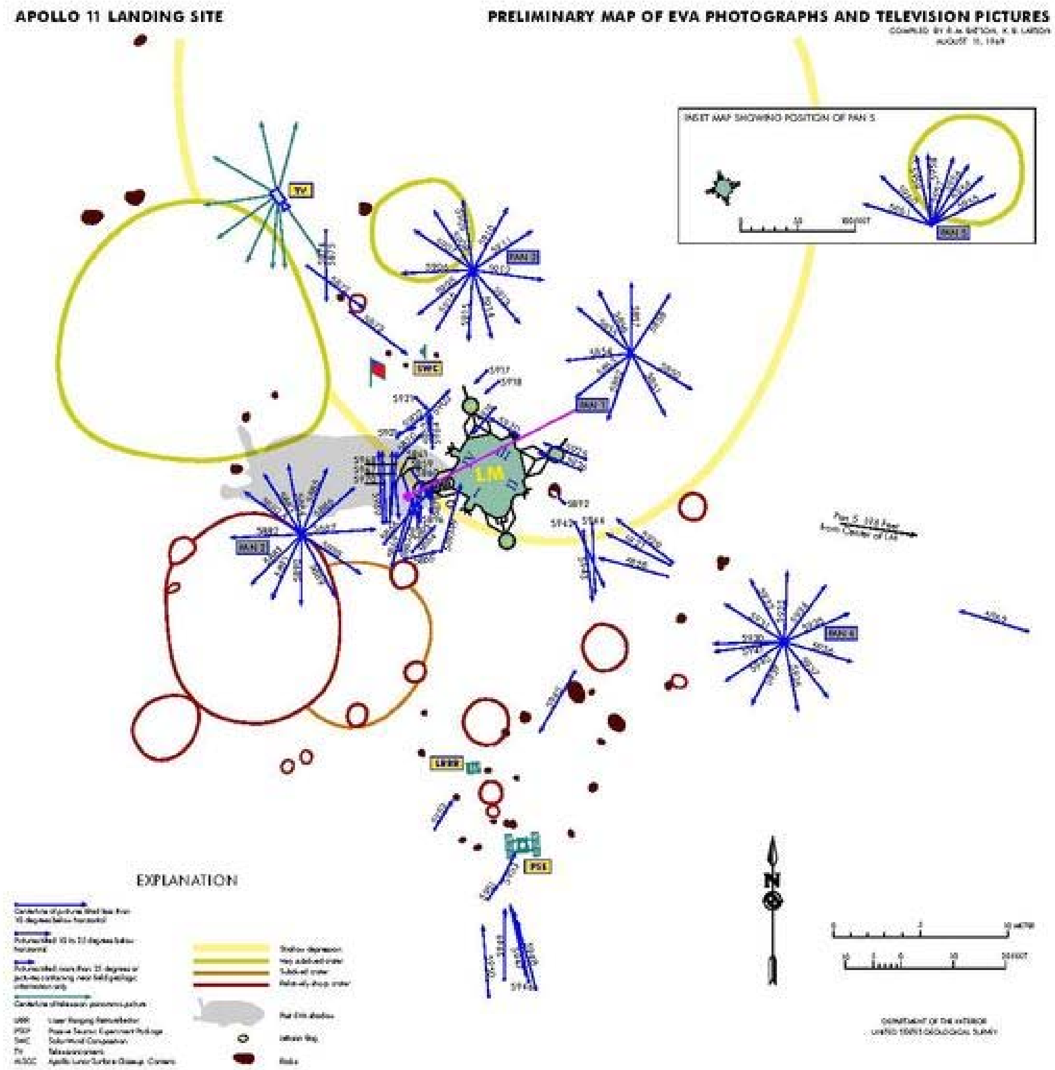
Another component of the Moon hoax theory is based on the argument that professional observatories and the Hubble Space Telescope should be able to take pictures of the lunar landing sites. The argument runs that if telescopes can "see to the edge of the universe" then they ought to be able to take pictures 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

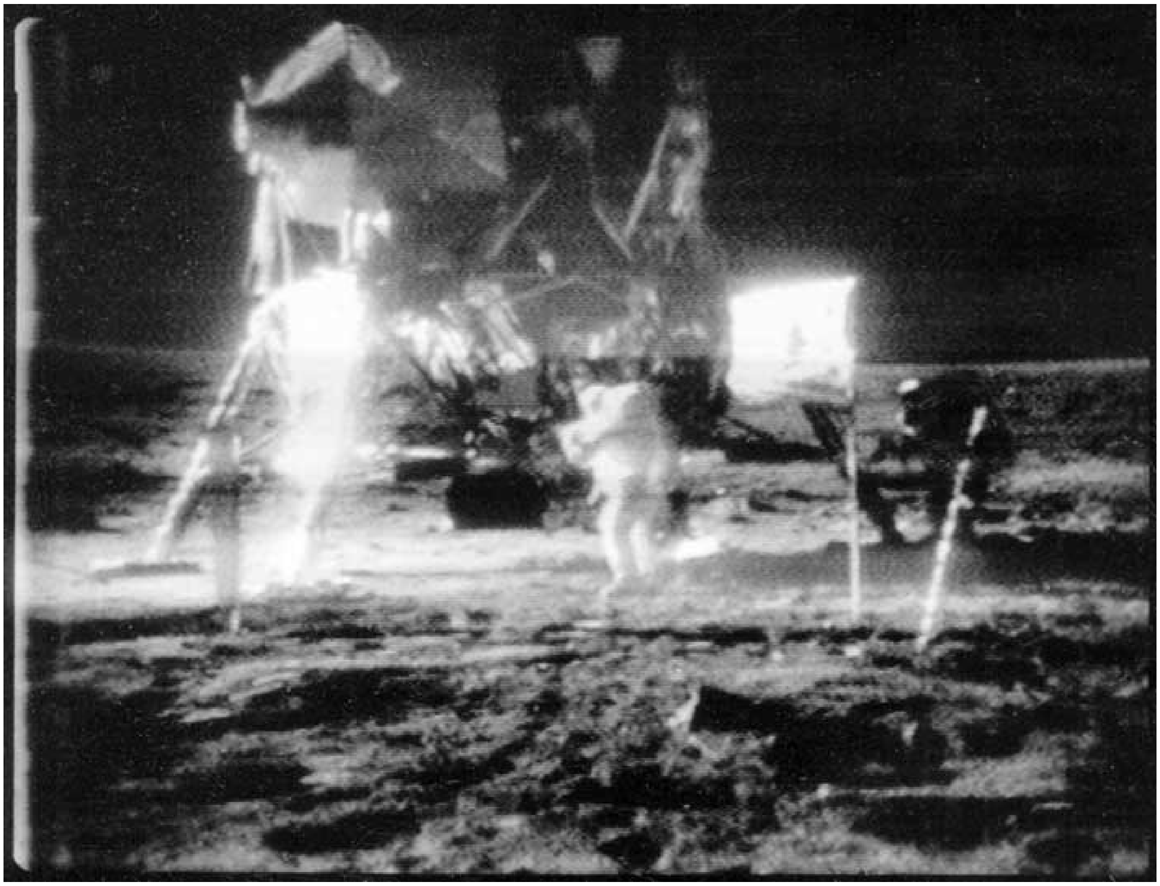
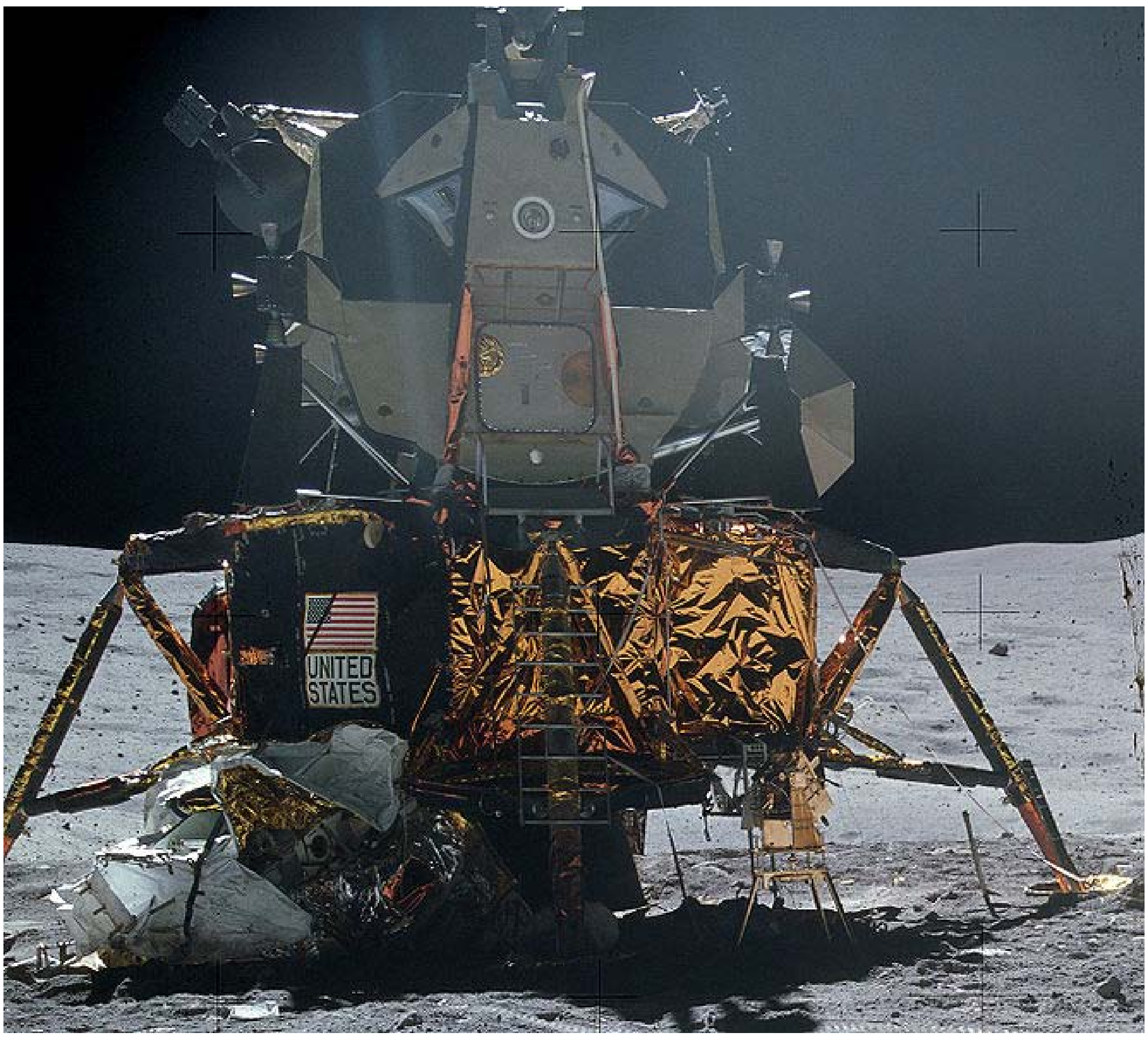


Photo of the high-quality SSTV image before the scan conversion

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.

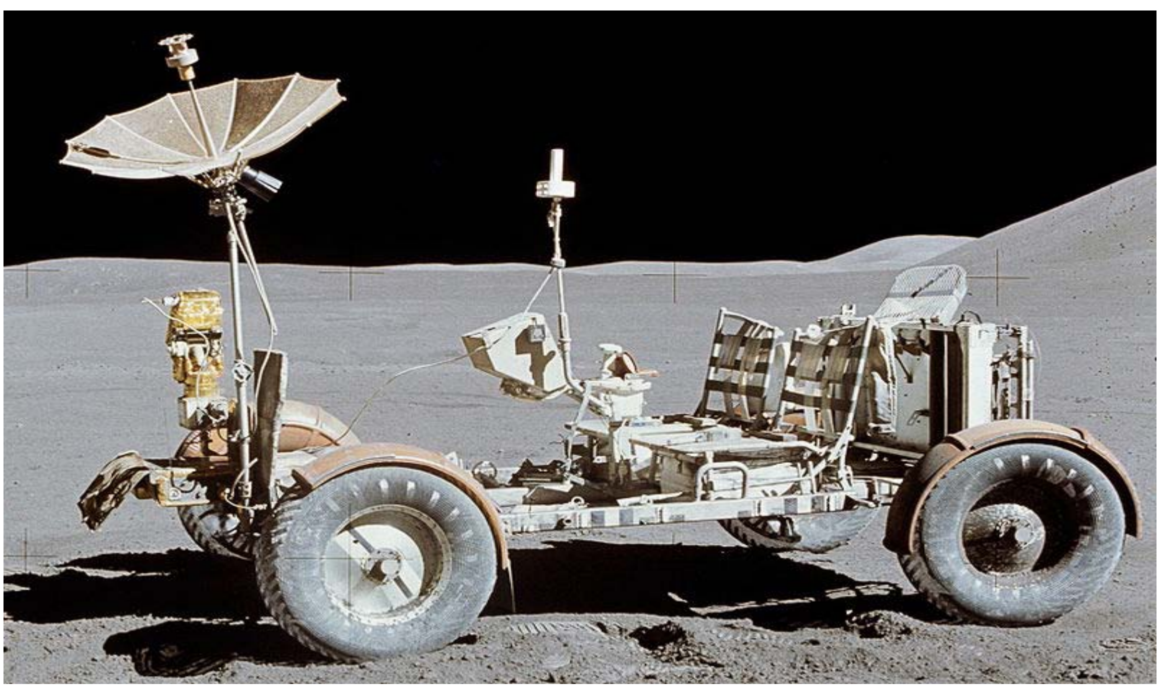


Apollo 16 Lunar Module

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 rockets 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 JohnYoung'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.

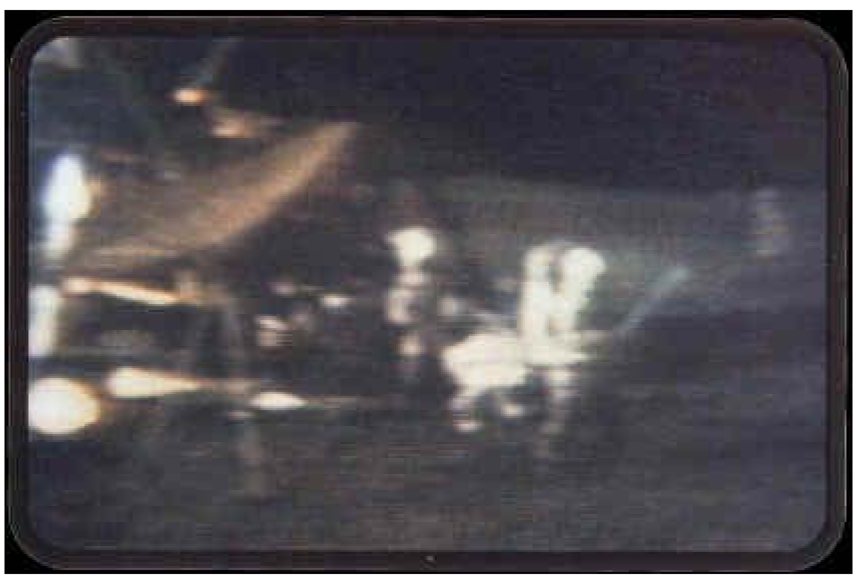
- *It was used in lieu of the only existing real images, from the TV monitor, which the editors of the book apparently felt were too grainy to present in a book's picture section. The book publishers did not work for NASA.*

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.

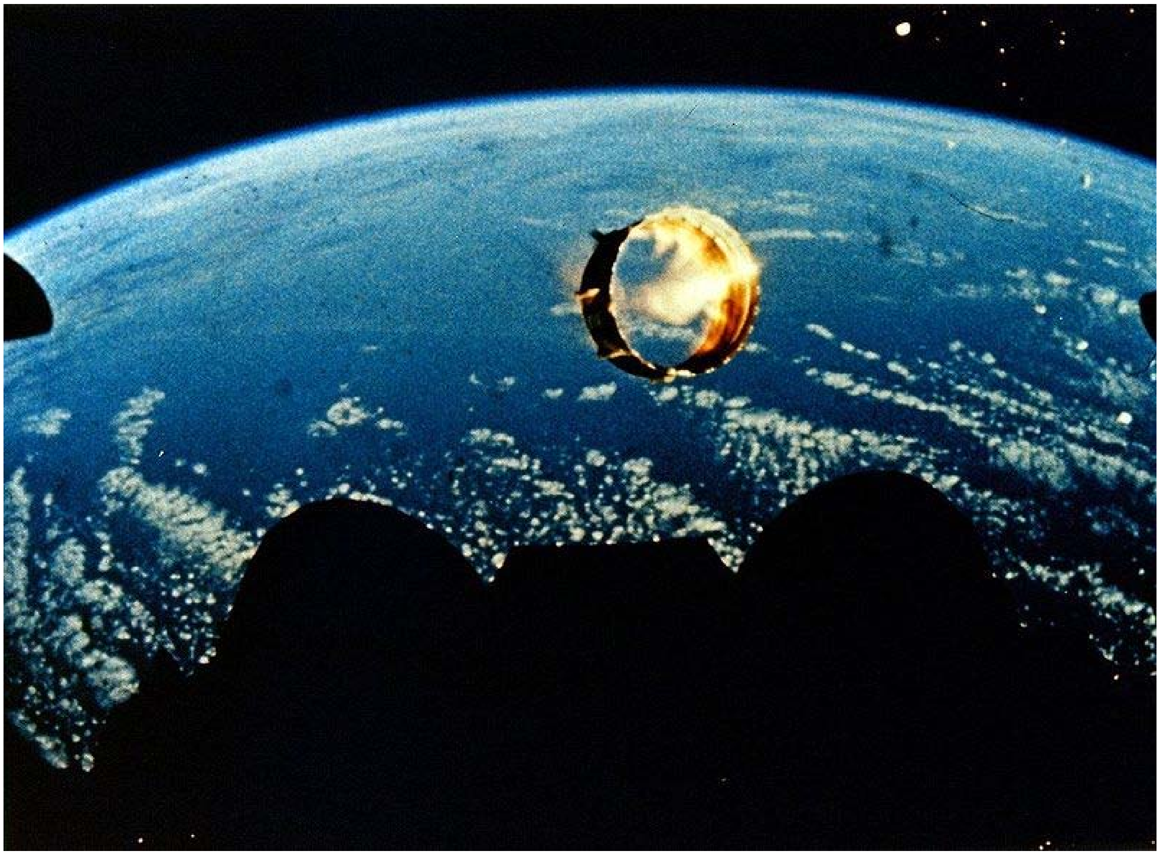
- *No crater should be expected. The Descent Propulsion System was throttled very far down during the final landing. The Lunar Module was no longer rapidly decelerating, so the descent engine only had to support the module's own weight, diminished by the 1/6 g lunar gravity and by the near exhaustion 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.

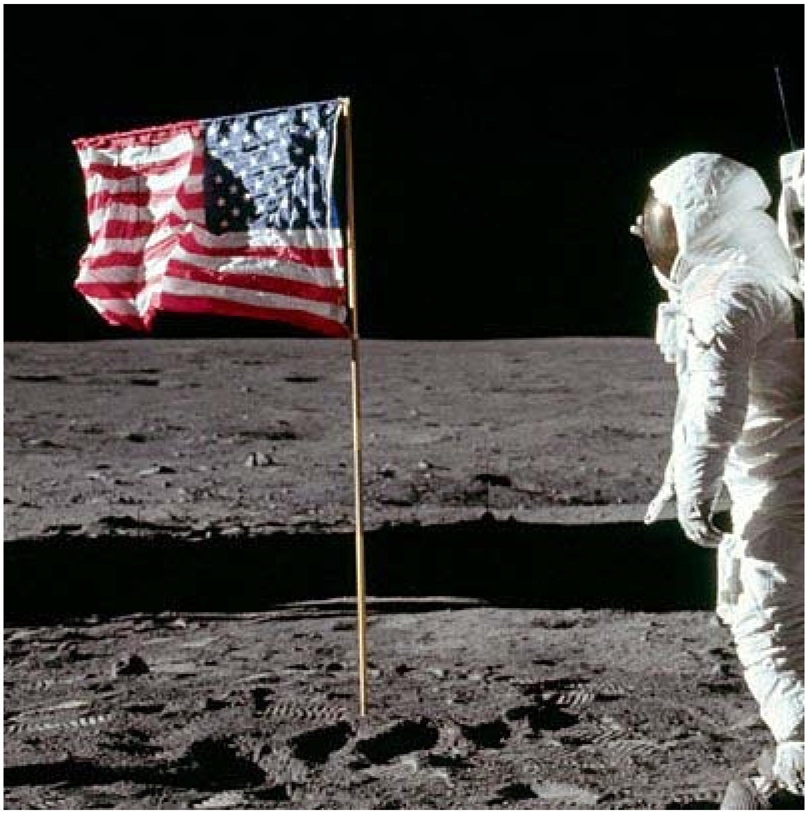
4. The presence of deep dust around the module; given the blast from the landing engine, this should not be present.

- *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.*

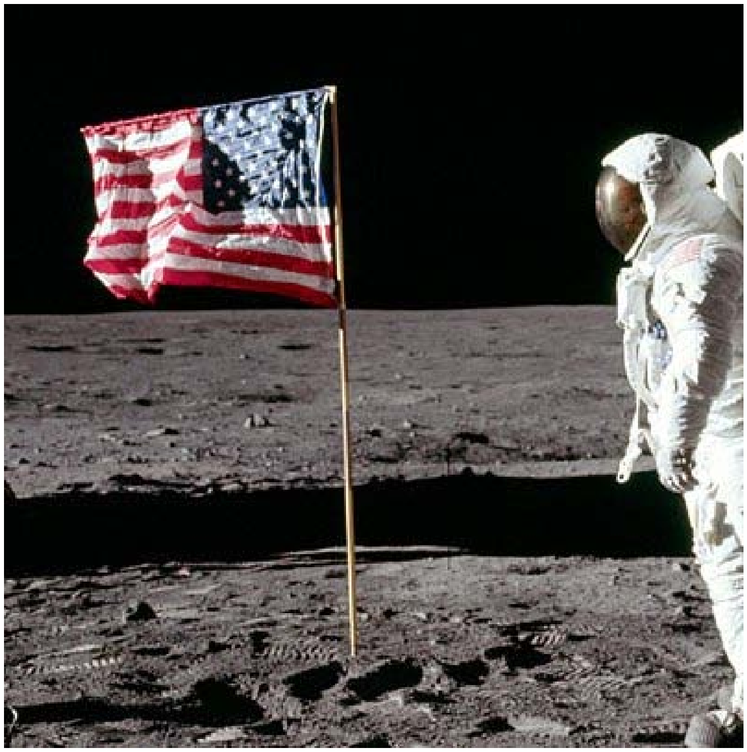
Note: In addition, moving footage of astronauts and the lunar rover kicking up lunar dust clearly show the dust particles kicking up quite high due to the low gravity, but settling immediately without air to stop them. Had these landings been faked on the Earth, dust clouds would have formed. (They can 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.*

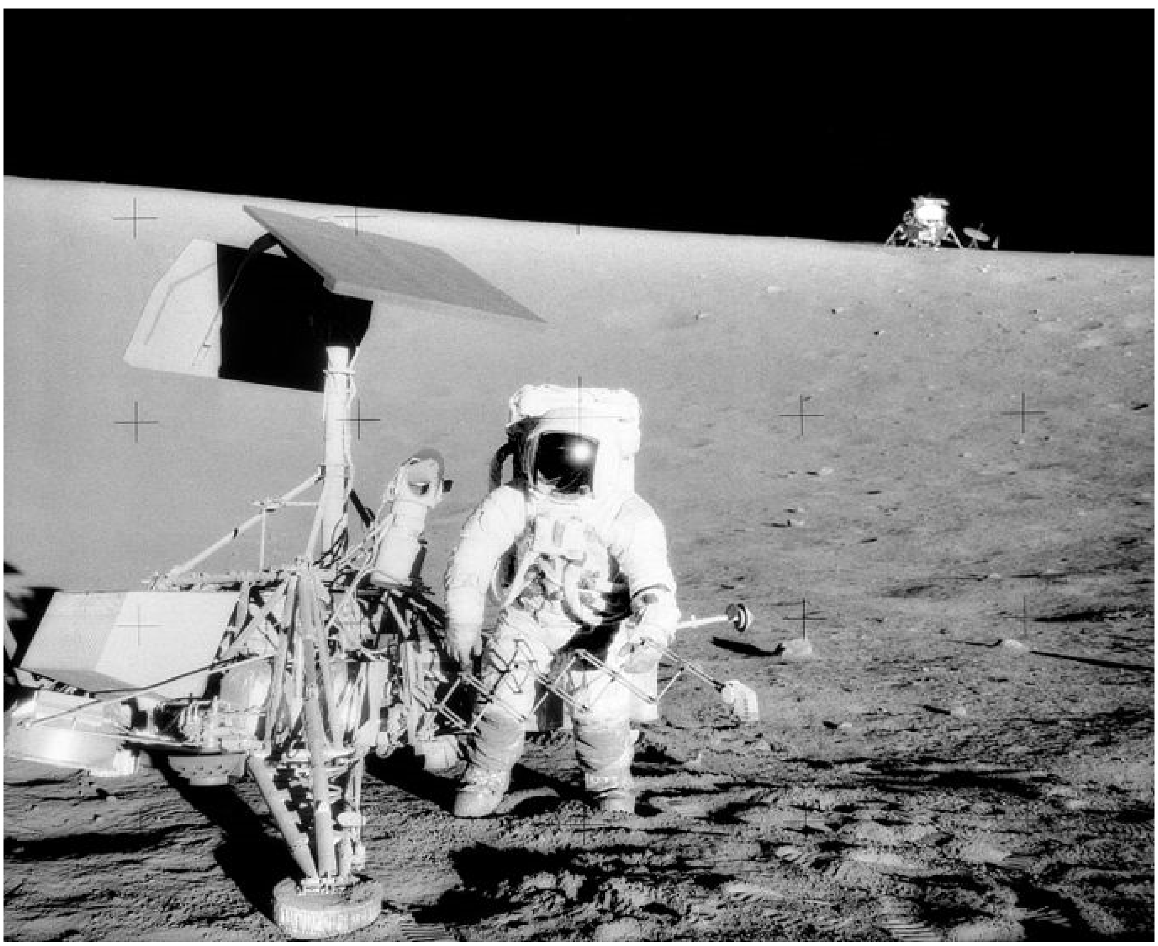
- *This theory was demonstrated to be unsubstantiated on the* MythBusters *episode "NASA Moon Landing".*

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.

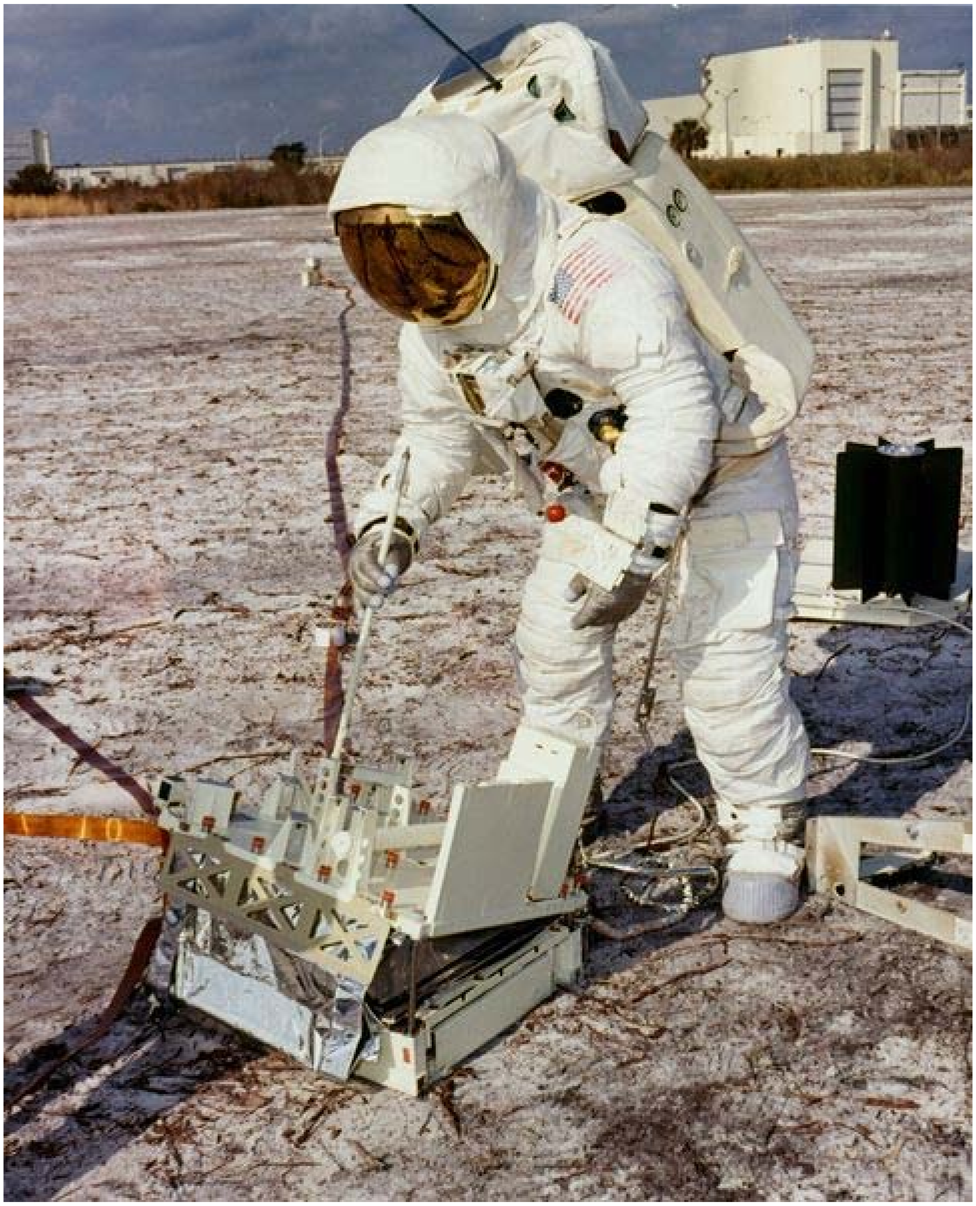
- *The cooling units could* only *work in a vacuum. Water from a tank in the backpack flowed out through tiny pores in a metal sublimator plate where it quickly vaporized into space. The loss of the heat of vaporization froze the remaining water, forming a layer of ice on the outside of the plate that 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.

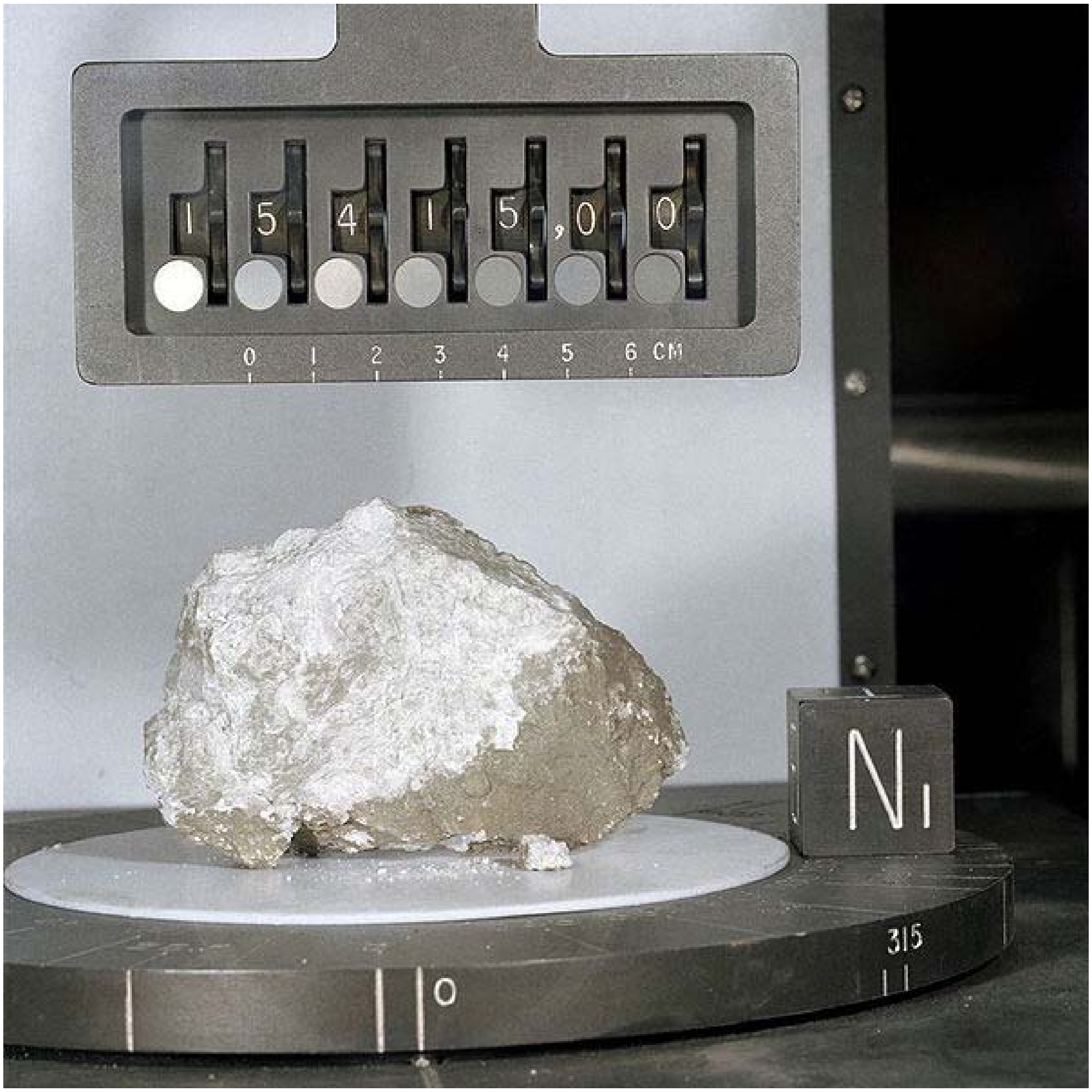
- *While the HBO Mini-series "From the Earth to the Moon", and a scene from "Apollo 13" used the sound-stage and harness setup, it is clearly seen from those films that dust kicked up did not quickly settle (some dust briefly formed clouds). In the film footage from the Apollo missions, dust kicked up 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 comparible 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.)

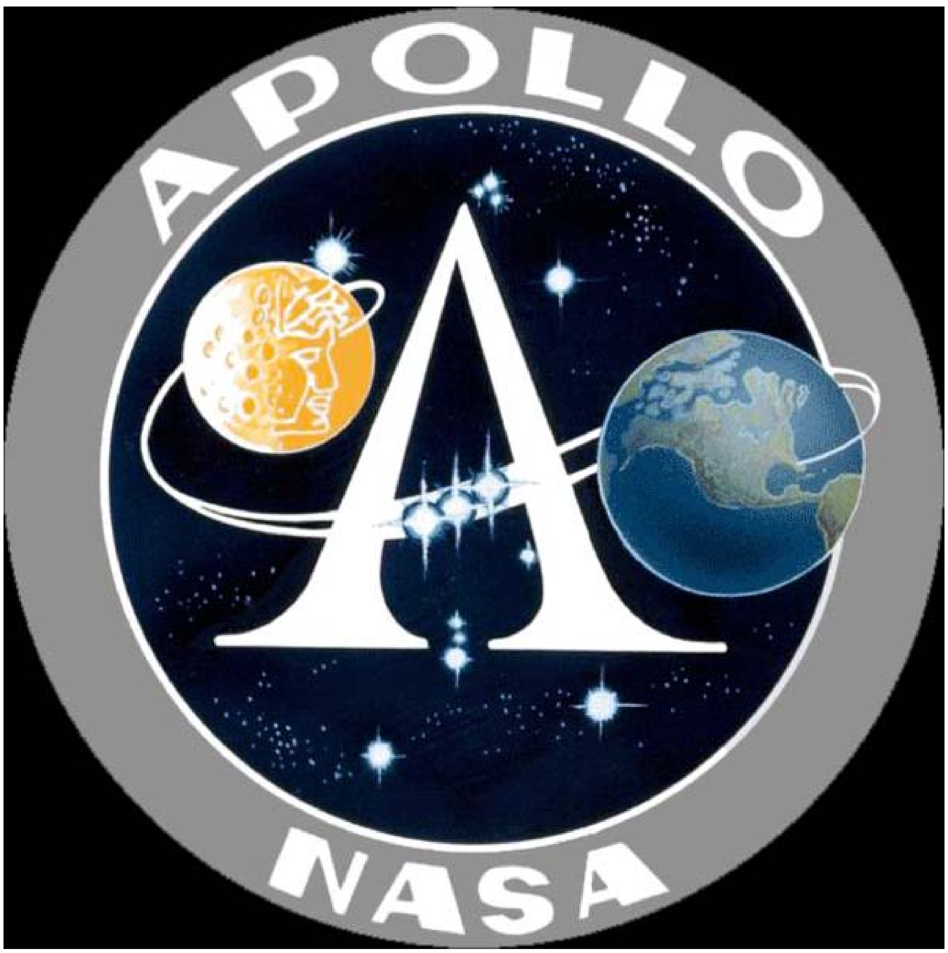
To date, nobody from the United States government or NASA who would have had a connection to the space program has come forward claiming the moon landings were staged. Penn Jillette made note of this in the "Conspiracy Theories" episode of his contrarian television show *Penn & Teller: Bullshit!* in 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.

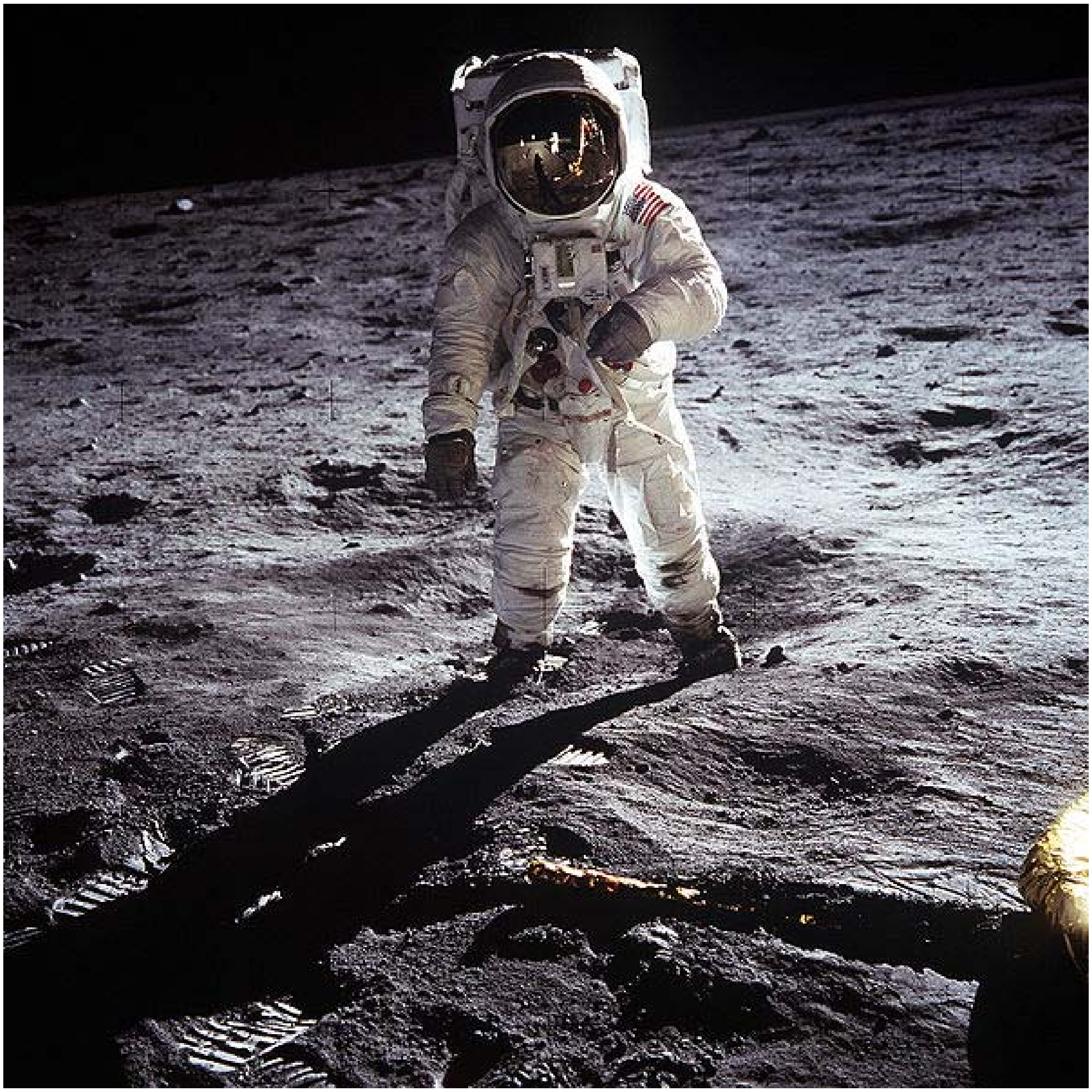
Chapter 4

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

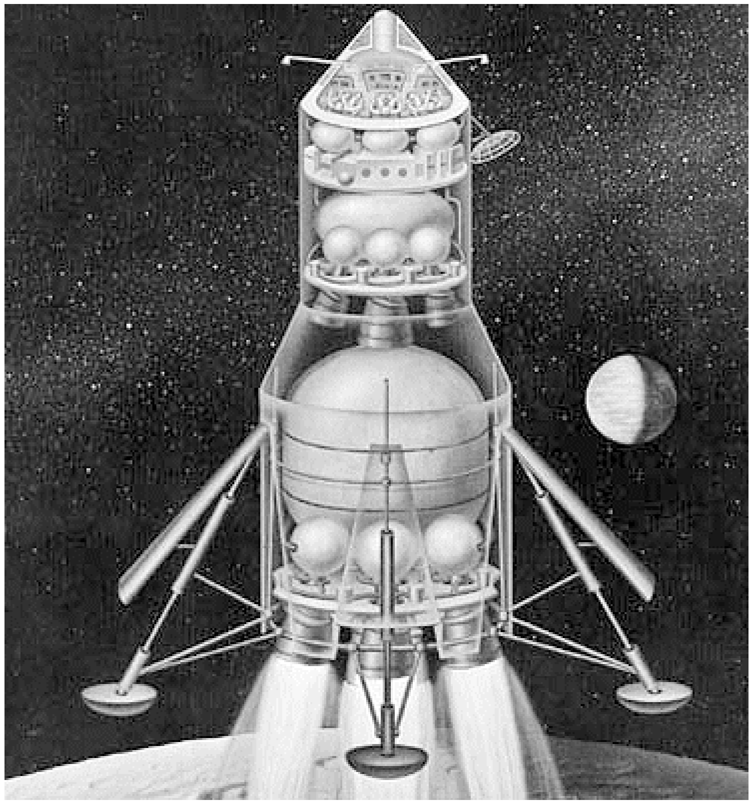
At the time of Kennedy's speech, only one American had flown in space—less than a month earlier—and NASA had not yet sent an astronaut into orbit. Even some NASA employees doubted whether Kennedy's ambitious goal could be met.

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.

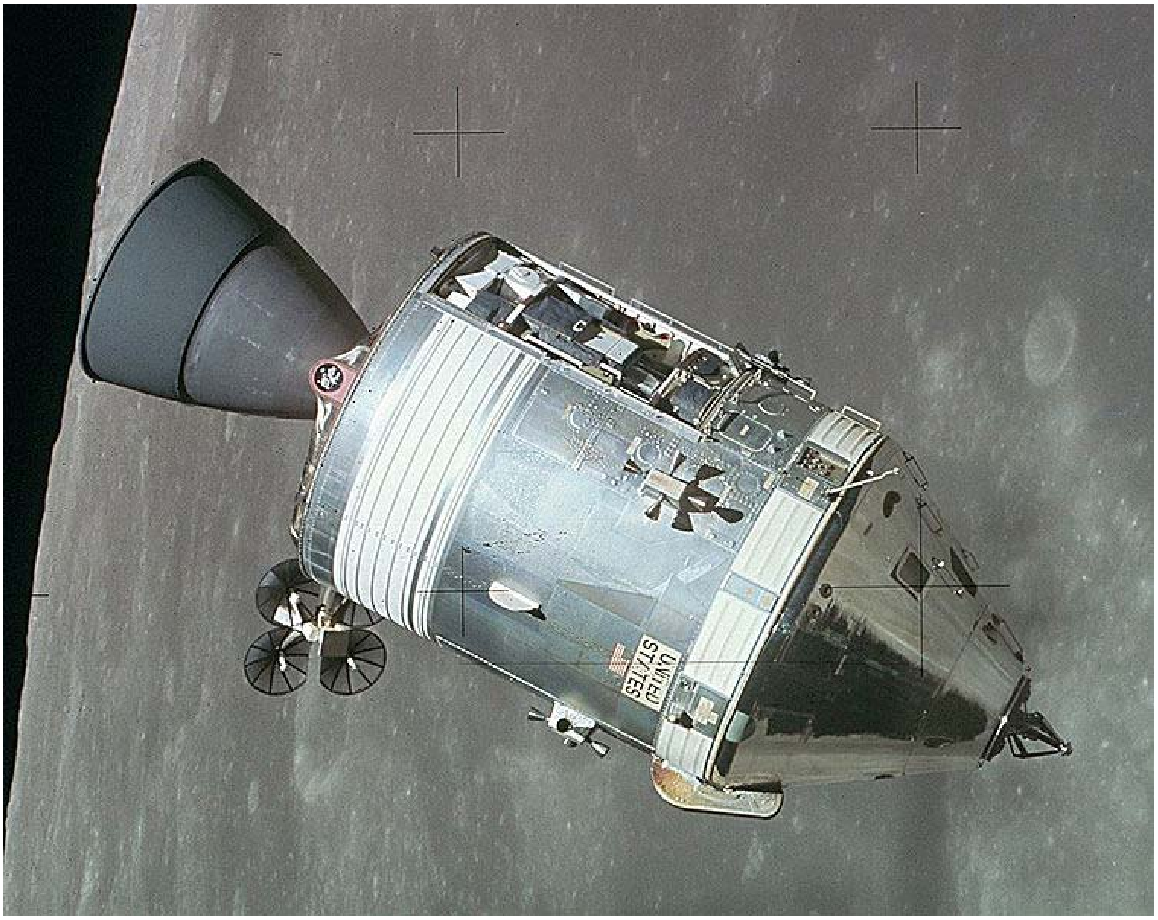
—James Hansen, *Enchanted Rendezvous*

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.

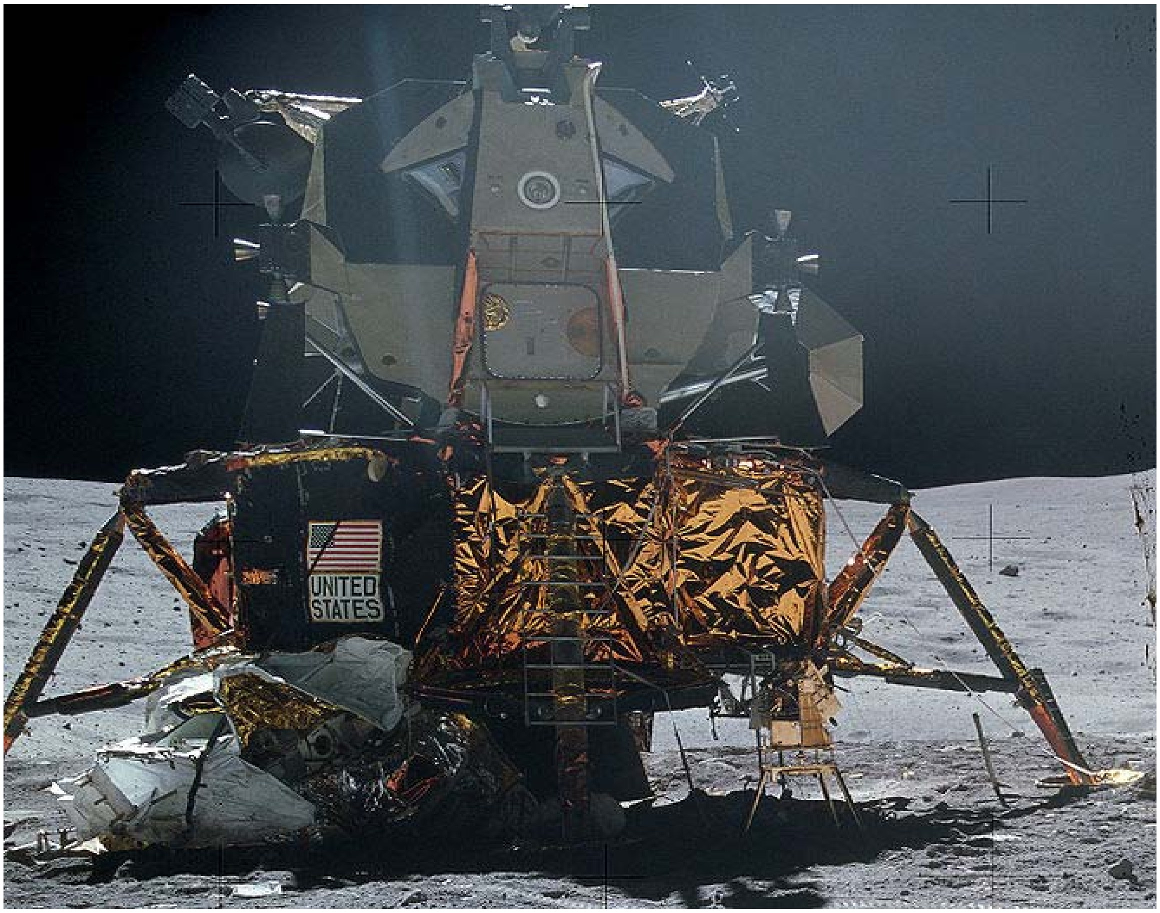
Attached to the Command Module was the cylindrical Service Module (SM), which housed the service propulsion system and its propellants, the fuel cell power system, four maneuvering thruster quads, a high-gain S-band antenna for communications between the Moon and Earth, and storage tanks for water and 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)

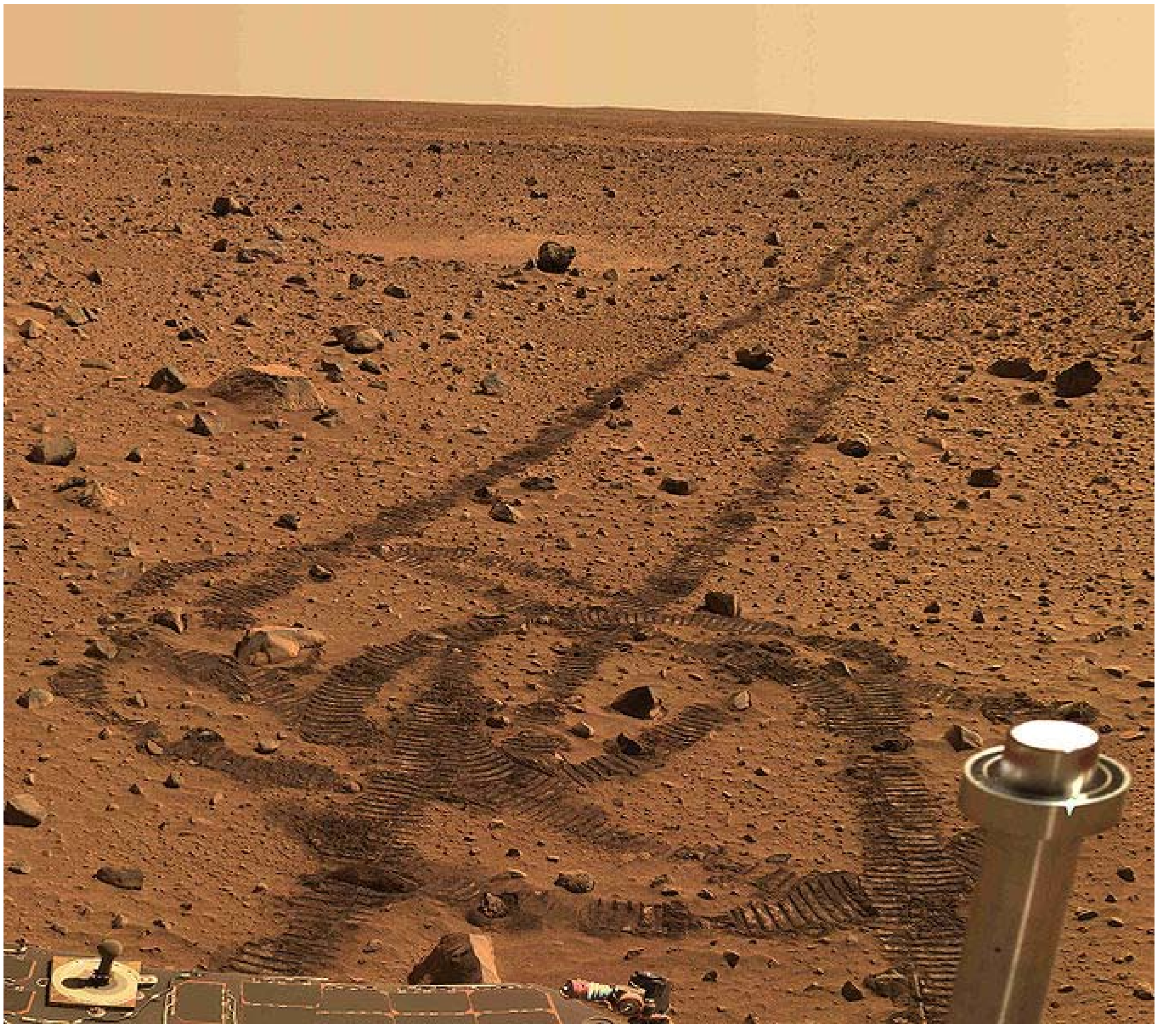
Mission rules specified that, in most circumstances, only one person in the Mission Control Center would communicate directly with the in-flight crew, and that this was to be another astronaut, who would be best able to understand the situation in the spacecraft and communicate with the crew in the clearest 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.

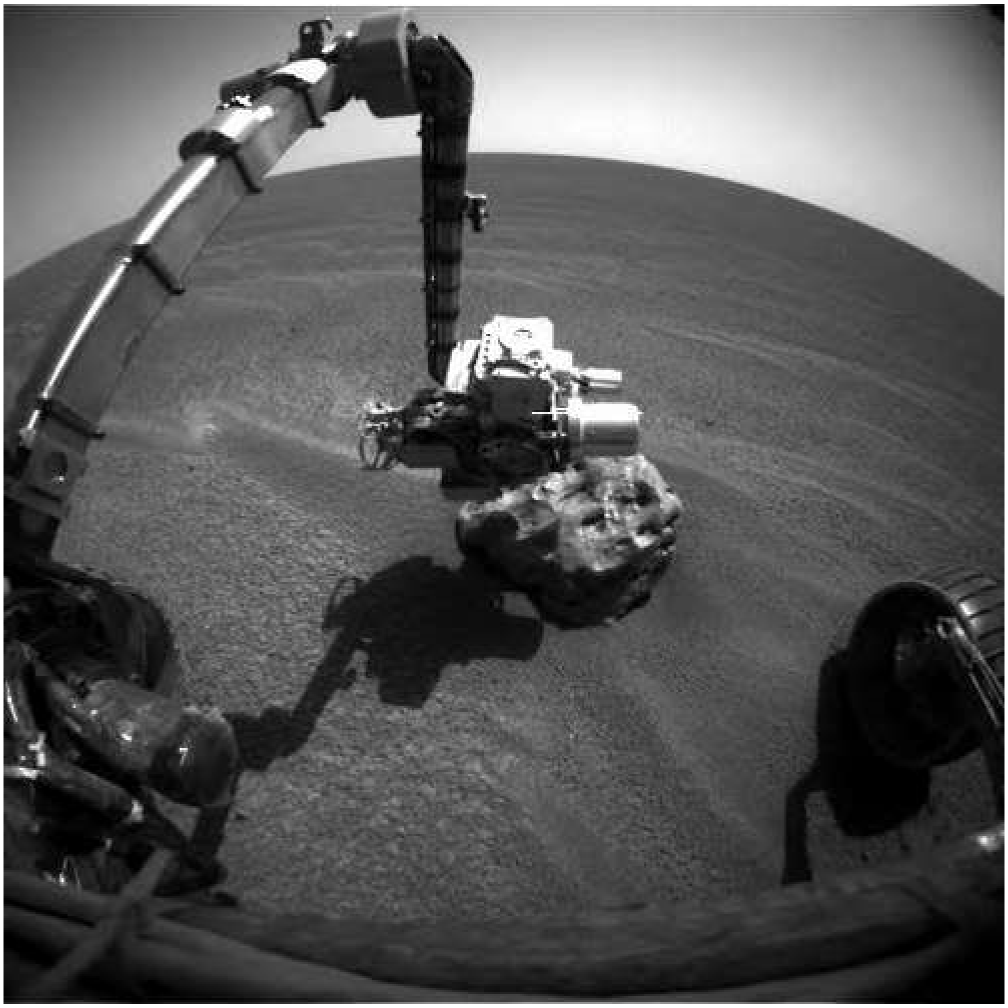
Chapter 5

Exploration of Mars

Computer-generated image of Spirit Mars Exploration Rover which touched down in Gusev Crater in 2004



Real image from Mars, part of a panorama taken by the Spirit rover in 2004



Heat Shield Rock (Meridiani Planum) is examined by Opportunity rover (MER-B) in 2005

The **exploration of Mars** has been an important part of the space exploration programs of the Soviet Union, the United States, Europe, and Japan. Dozens of robotic spacecraft, including orbiters, landers, and rovers, have been launched toward Mars since the 1960s. These missions were aimed at gathering data about current conditions and answering questions about the history of Mars as well as a preparation for a possible human mission to Mars. The questions raised by the scientific community are expected to not only give a better appreciation of the red planet but also yield further insight into the past, and possible future, of Earth.

The exploration of Mars has come at a considerable financial cost with roughly two-thirds of all spacecraft destined for Mars failing before completing their missions, with some failing before they even begin. Such a high failure rate can be attributed to the complexity and large number of variables involved in an interplanetary journey, and has led researchers to jokingly speak of *The Great Galactic Ghoul* which subsists on a diet of Mars probes. This phenomenon is also informally known as the *Mars Curse*. As of

January 2011, there is one functioning piece of equipment on the surface of Mars beaming signals back to Earth: the Opportunity rover.

In October 2009, an agreement was signed between United States' space agency, NASA, and Europe's space agency, ESA in order to increase cooperation and expand collective capabilities, resources and expertise to continue the exploration of Mars; this agreement is named the Mars Exploration Joint Initiative (MEJI).

The planet Mars

Mars has long been the subject of human fascination. Early telescopic observations revealed color changes on the surface which were originally attributed to seasonal vegetation as well as apparent linear features which were ascribed to intelligent design. These early and erroneous interpretations led to widespread public interest in Mars. Further telescopic observations found Mars' two moons - Phobos and Deimos, the polar ice caps and the feature now known as Olympus Mons, the solar system's tallest mountain. These discoveries piqued further interest in the study and exploration of the red planet. Mars is a rocky planet, like Earth, that formed around the same time, yet with only half the diameter of Earth, and a far thinner atmosphere, it has a cold and desert-like surface. It is notable, however, that although the planet has only one quarter of the *surface area* of the Earth, it has about the same *land area*, since only one quarter of the surface area of the Earth is land.

Launch windows

In order to understand the history of the robotic exploration of Mars it is important to note that minimum-energy launch windows occur at intervals of approximately 2.135 years, i.e. 780 days (the planet's synodic period with respect to Earth). This is a consequence of the Hohmann transfer orbit for minimum-energy interplanetary transfer. The slight inclination and eccentricity of Mars' orbit relative to Earth's orbit means that the minimum energy launch date differs from that implied by the synodic period slightly. Launch window width is subject to vehicle constraints but are typically on the order of one month wide. The windows for recent/future years were/will be centred on the following dates:

- 18 November 1996 (MJD 50405)
- 22 January 1999 (MJD 51200)
- 19 April 2001 (MJD 52018)
- 5 June 2003 (MJD 52795)
- 10 August 2005 (MJD 53592)
- 21 September 2007 (MJD 54364)
- 15 October 2009 (MJD 55119)
- 7 November 2011 (MJD 55872)
- 2 January 2014 (MJD 56659)

Minimum energy inbound (Mars to Earth) launch windows also occur at similar intervals.

In addition to these minimum-energy trajectories, which occur when the planets are aligned so that the Earth to Mars transfer trajectory goes halfway around the Sun, an alternate trajectory which has been proposed goes first inward toward Venus orbit, and then outward, resulting in a longer trajectory which goes about 360 degrees around the Sun ("opposition-class trajectory").

Early flyby probes and orbiters

Mars Curse

The high failure rate of missions launched from Earth attempting to explore Mars has become informally known as the "Mars Curse". The "Galactic Ghoul" is a fictional space monster that consumes Mars probes, a term coined in 1997 by Time Magazine journalist Donald Neff.

Of 38 launches from Earth in an attempt to reach the planet, only 19 succeeded, a success rate of 50%. Twelve of the missions included attempts to land on the surface, but only seven transmitted data after landing.

The majority of the failed missions occurred in the early years of space exploration and were part of the Soviet and later Russian Mars probe program that suffered several technical difficulties, other than the largely successful Venera program for the exploration of Venus.

Modern missions have an improved success rate; however, the challenge, complexity and length of the missions make it inevitable that failures will occur.

The U.S. NASA Mars exploration program has had a somewhat better record of success in Mars exploration, achieving success in 13 out of 20 missions launched (a 65% success rate), and succeeding in six out of seven (an 86% success rate) of the launches of Mars landers.

Timeline of Mars exploration

Mission (1960–1969)	Launch	Arrival at Mars	Termination	Objective	Result
Mars 1960A	10 October 1960		10 October 1960	Flyby	Launch failure
Mars 1960B	14 October 1960		14 October 1960	Flyby	Launch failure
Sputnik 22 (Mars 1962A)	24 October 1962		24 October 1962	Flyby	Broke up shortly after launch

Mars 1	1 November 1962		21 March 1963	Flyby	Some data collected, but lost contact before reaching Mars, flyby at approx. 193,000 km
Sputnik 24 (Mars 1962B)	4 November 1962		19 January 1963	Lander	Failed to leave Earth's orbit
Mariner 3	5 November 1964		5 November 1964	Flyby	Failure during launch ruined trajectory.
Mariner 4	28 November 1964	14 July 1965	21 December 1967	Flyby	Success (first successful flyby)
Zond 2	30 November 1964		May 1965	Flyby	Communication lost three months before reaching Mars
Mariner 6	25 February 1969	31 July 1969	August 1969	Flyby	Success
Mariner 7	27 March 1969	5 August 1969	August 1969	Flyby	Success
Mars 1969A	27 March 1969		27 March 1969	Orbiter	Launch failure
Mars 1969B	2 April 1969		2 April 1969	Orbiter	Launch failure
Mission (1970–1989)	**Launch**	**Arrival at Mars**	**Termination**	**Objective**	**Result**
Mariner 8	8 May 1971		8 May 1971	Orbiter	Launch failure
Cosmos 419 (Mars 1971C)	10 May 1971		12 May 1971	Orbiter	Launch failure
Mariner 9	30 May 1971	13 November 1971	27 October 1972	Orbiter	Success (first successful orbit)
Mars 2	19 May 1971	27 November 1971	22 August 1972	Orbiter	Success
			27 November 1971	Lander / rover	Crashed on surface of Mars

			22 August 1972	Orbiter	Success
Mars 3	28 May 1971	2 December 1971	2 December 1971	Lander / rover	Partial Success. First successful landing; landed softly, but ceased transmission within 15 seconds.
Mars 4	21 July 1973	10 February 1974	10 February 1974	Orbiter	Did not enter orbit, but made a close flyby
Mars 5	25 July 1973	2 February 1974	21 February 1974	Orbiter	Partial success. Entered orbit, and returned data, but failed within 9 days
Mars 6	5 August 1973	12 March 1974	12 March 1974	Lander	Partial success. Data returned during descent, but not after landing on Mars
Mars 7	9 August 1973	9 March 1974	9 March 1974	Lander	Landing probe separated prematurely; entered heliocentric orbit.
Viking 1	20 August 1975	20 July 1976	17 August 1980	Orbiter	Success
			13 November 1982	Lander	Success
Viking 2	9 September 1975	3 September 1976	25 July 1978	Orbiter	Success
			11 April 1980	Lander	Success
Phobos 1	7 July 1988		2 September 1988	Orbiter	Contact lost while on route to Mars
				lander	Not deployed

Phobos 2	12 July 1988	29 January 1989	27 March 1989	Orbiter	Partial success: entered orbit and returned some data. Contact lost just before deployment of landers
				Landers	Not deployed

Mission (1990–1999)	Launch	Arrival at Mars	Termination	Objective	Result
Mars Observer	25 September 1992	24 August 1993	21 August 1993	Orbiter	Lost contact just before arrival
Mars Global Surveyor	7 November 1996	11 September 1997	5 November 2006	Orbiter	Success
Mars 96	16 November 1996		17 November 1996	Orbiter / landers	Launch failure
Mars Pathfinder	4 December 1996	4 July 1997	27 September 1997	Lander / rover	Success
Nozomi (Planet-B)	3 July 1998		9 December 2003	Orbiter	Complications while on route; Never entered orbit
Mars Climate Orbiter	11 December 1998	23 September 1999	23 September 1999	Orbiter	Crashed on surface due to metric-imperial mix-up
Mars Polar Lander	3 January 1999	3 December 1999	3 December 1999	Lander	Crash landed on surface due to improper hardware testing
Deep Space 2 (DS2)				Hard landers	

Mission (2000–present)	Launch	Arrival at Mars	Termination	Objective	Result
2001 Mars Odyssey	7 April 2001	24 October 2001	Currently operational	Orbiter	Success
Mars Express	2 June 2003	25 December	Currently operational	Orbiter	Success

		2003			
Beagle 2			6 February 2004	Lander	Lost contact in December 2003 after separation from Mars Express. Fate unknown.
MER-A Spirit	10 June 2003	4 January 2004	last contact March 2010, stuck	Rover	Success
MER-B Opportunity	7 July 2003	25 January 2004	Currently operational	Rover	Success
Rosetta	2 March 2004	February 25, 2007	Currently operational	Gravity assist enroute to comet 67P/Churyumov-Gerasimenko	Success
Mars Reconnaissance Orbiter	12 August 2005	10 March 2006	Currently operational	Orbiter	Success
Phoenix	4 August 2007	25 May 2008	10 November 2008	Lander	Success
Dawn	27 September 2007	17 February 2009	Currently operational	Gravity assist to Vesta	Success
Future missions	**Launch schedule**	**Estimated arrival at Mars**	—	**Objective**	**Notes**
Fobos-Grunt	2012			Orbiter, lander, sample return	Will attempt to bring samples of Phobos' soil back to Earth in 2014 (*or* 2012).
Yinghuo-1				Orbiter	Will travel with the Russian Phobos-Grunt mission
MSL Curiosity	Between November 25 and December 18, 2011	2012		Rover	Powered by radioisotopes, it will perform chemical and physical analysis on martian soil and

			atmosphere.
MetNet	2011–2019	Multi-lander network	Simultaneous meteorological measurements at multiple locations.
Northern Light	2012	Lander / rover	Solar powered, it will perform chemical and physical analysis on Martian soil and atmosphere.
MAVEN	2013	Orbiter	Part of the Mars Scout Program
Mars mission	Between 2013-2015	Orbiter	The ISRO has begun the conceptual phase for an orbiter mission to Mars.
ARES (martian rocketplane)	Possibly by 2016	aircraft	Search for life on Mars, water, atmospherics, magnetics
esa and ExoMars	2016	Orbiter, static lander	TGM orbiter will deliver the ExoMars static lander.
	2018	Two rovers	ExoMars rover and MAX-C rover.
esa and Mars sample return mission	Possibly by 2020	Orbiter, lander, rover, sample return	Being considered but not yet funded or scheduled.

Cancelled missions

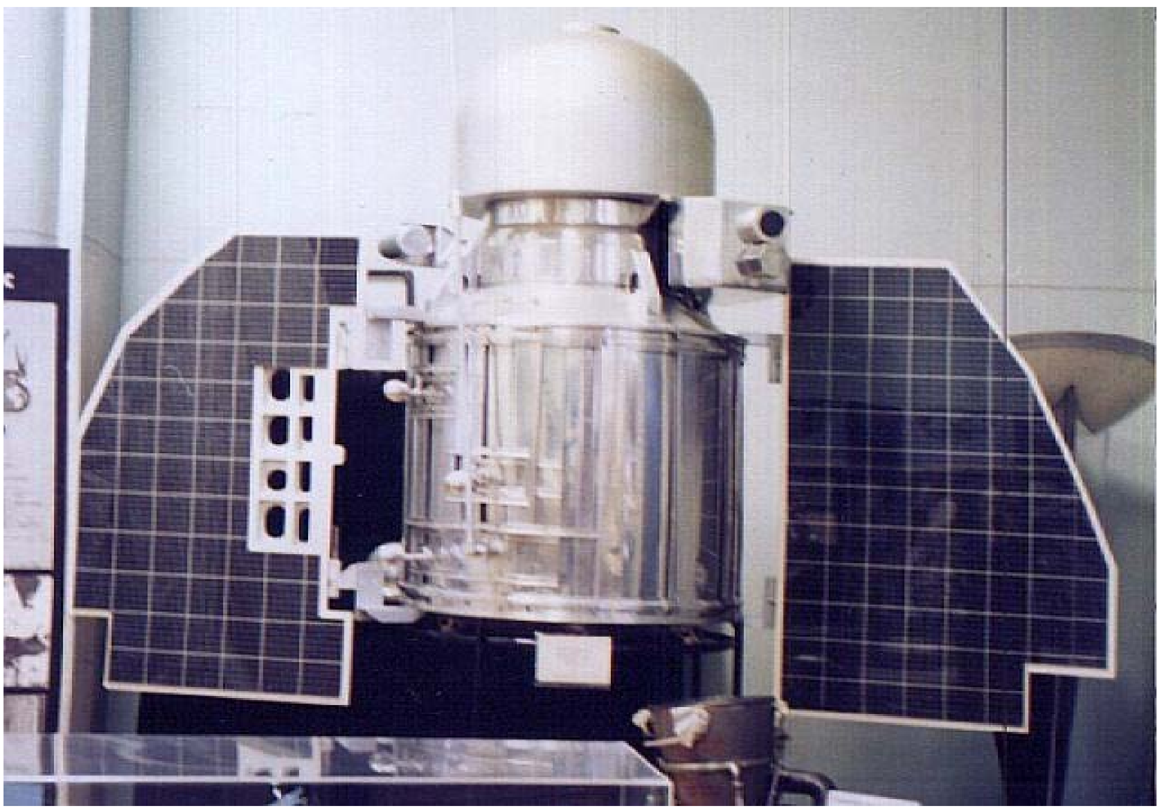
- *Mars 4NM* and *Mars 5NM* - projects intended by the Soviet Union for heavy Marsokhod (in 1973 according to initial plan of 1970) and Mars sample return (planned for 1975) missions by launching on N1 rocket that has never flown successfully.

- *Voyager* - USA, 1970s - Two orbiters and two landers, launched by a single Saturn V rocket.
- *Mars Aerostat* - Russian/French balloon mission, originally planned for the 1992 launch window, postponed to 1994 and then to 1996 before being cancelled.
- *Mars Environmental Survey* - set of 16 landers planned for 1999–2009
- *Mars-98* - Russian mission including an orbiter, lander, and rover, planned for 1998 launch opportunity
- *Mars Surveyor 2001 Lander* - October 2001 - Mars lander
- *Beagle 3* - 2009 British lander mission meant to search for life, past or present.
- *NetLander* - 2007 or 2009 - Mars netlanders
- *Mars Telecommunications Orbiter* - September 2009 - Mars orbiter for telecommunications
- *Kitty Hawk* - Mars airplane micromission, proposed for December 17, 2003, the centennial of the Wright brother's first flight.

Chapter 6

Mars 1M and Mars 1

Mars 1M



Mars 1M spacecraft

Mars 1M was a series of two unmanned spacecraft which were used in the first Soviet missions to explore Mars. They were the earliest missions of the Mars program. The Western media dubbed the spacecraft "***Marsnik***", a portmanteau of *Mars* and *Sputnik*.

Mars 1M No.1, known in the west as Marsnik 1, Mars 1960A and Korabl 4, was destroyed in a launch failure on October 10, 1960. In 1962 NASA Administrator James E. Webb informed the United States Congress that NASA believed the mission was an attempt at a Mars flyby probe. Some Soviet scientists involved with the program at that time claim no knowledge of this mission, stating that only the second launch was an intended Mars mission. However V.G. Perminov, the leading designer of planetary spacecraft at the Lavochkin design bureau, states that this mission was indeed intended for Mars, and was identical to the later mission.

Mars 1M No.2, known in the west as Marsnik 2, Korabl 5 and Mars 1960B, was launched on October 14, 1960.

Both Mars 1M spacecraft were launched by Molniya rockets. The third stage pumps on both rockets were unable to develop enough thrust to commence ignition, and as a result neither spacecraft achieved its initial geocentric parking orbit. The spacecraft reached an altitude of 120 km before reentry.

Mission profile

The objectives of the mission were to investigate interplanetary space between Earth and Mars, to study Mars and return surface images from a flyby trajectory, and to study the effects of extended spaceflight on onboard instruments and provide radio communications from long distances.

Spacecraft and subsystems

NASA describes the spacecraft as:

nearly identical to the Venera 1 design, a cylindrical body about 2 meters high with two solar panel wings, a 2.33 meter high-gain net antenna, and a long antenna arm, and had a mass of about 650 kg. It carried a 10 kg science payload consisting of a magnetometer on a boom, cosmic ray counter, plasma-ion trap, a radiometer, a micrometeorite detector, and a spectroreflectometer to study the CH band, a possible indicator of life on Mars. These instruments were mounted on the outside of the spacecraft. A photo-television camera was held in a sealed module in the spacecraft and could take pictures through a viewport when a sensor indicated the Sun-illuminated martian surface was in view. Attitude was controlled by a Sun-star sensor with attitude correction performed by a dimethylhydrazine/nitric acid bipropellant rocket engine. The spacecraft orientation was to be maintained so that the solar panels faced the Sun throughout the flight. Power was provided by the two-square meter solar panels which charged silver-zinc batteries. Radio communications were made using a decimeter band transmitter via the high gain antenna for spacecraft commands and telemetry. Radio bearing was used to maintain the antennas' orientation to Earth. Images were to be transferred using an 8-cm wavelength transmitter through the high-gain antenna. A fourth stage was added to the booster, the Molniya or 8K78, the new launcher was designated SL-6/A-2-e.

Mars 1

Mars 1, also known as *1962 Beta Nu 1*, *Mars 2MV-4* and *Sputnik 23*, was an automatic interplanetary station launched in the direction of Mars on November 1, 1962, the first of the Soviet Mars probe program, with the intent of flying by the planet at a distance of about 11,000 km. It was designed to image the surface and send back data on cosmic radiation, micrometeoroid impacts and Mars' magnetic field, radiation environment, atmospheric structure, and possible organic compounds. After leaving Earth orbit, the spacecraft and the booster fourth stage separated and the solar panels were deployed. Early telemetry indicated that there was a leak in one of the gas valves in the orientation system so the spacecraft was transferred to gyroscopic stabilization. Sixty-one radio transmissions were held, initially at two day intervals and later at five days in which a large amount of interplanetary data were collected. On 21 March 1963, when the spacecraft was at a distance of 106,760,000 km from Earth on its way to Mars, communications ceased, probably due to failure of the spacecraft's antenna orientation system. Mars 1 closest approach to Mars occurred on June 19, 1963 at a distance of approximately 193,000 km, after which the spacecraft entered a heliocentric orbit.

Spacecraft design

Mars 1 was a modified Venera-type spacecraft in the shape of a cylinder 3.3 m long and 1.0 m in diameter. The spacecraft measured 4 meters across with the solar panels and radiators deployed. The cylinder was divided into two compartments. The upper 2.7 m, the orbital module, contained guidance and on-board propulsion systems. The experiment module, containing the scientific instrumentation, comprised the bottom 0.6 m of the cylinder. A 1.7 m parabolic high gain antenna was used for communication, along with an omnidirectional antenna and a semi-directional antenna. Power was supplied by two solar panel wings with a total area of 2.6 square meters affixed to opposite sides of the spacecraft. Power was stored in a 42 ampere-hour cadmium-nickel battery.

Communications were via a decimeter wavelength radio transmitter mounted in the orbital module which used the high-gain antenna. This was supplemented by a meter wavelength range transmitter through the omnidirectional antenna. An 8 centimeter wavelength transmitter mounted in the experiment module was designed to transmit the TV images. Also mounted in the experiment module was a 5-centimeter range impulse transmitter. Temperature control was achieved using a binary gas-liquid system and hemispherical radiators mounted on the ends of the solar panels. The craft carried various scientific instruments including a magnetometer probe, television photographic equipment, a spectroreflexometer, radiation sensors (gas-discharge and scintillation counters), a spectrograph to study ozone absorption bands, and a micrometeoroid instrument.

Scientific results

The probe recorded one micrometeorite strike every two minutes at altitudes ranging from 6000 to 40,000 km due to the Taurids meteor shower and also recorded similar densities at distances from 20 to 40 million km. Magnetic field intensities of 3–4 nanoteslas (nT, also known as gammas) with peaks as high as 6–9 nT were measured in interplanetary space and the solar wind was detected. Measurements of cosmic rays showed that their intensity had almost doubled since 1959. The radiation zones around the Earth were detected and their magnitude confirmed.

This spacecraft is also referenced as *Sputnik 23* and *Mars 2MV-4*. It was originally designated *Sputnik 30* in the U.S. Naval Space Command Satellite Situation Summary.

Chapter 7

Mariner Program

Launch of Mariner 1 in 1962

The **Mariner program** was a program conducted by the American space agency NASA that launched a series of robotic interplanetary probes designed to investigate Mars, Venus and Mercury. The program included a number of firsts, including the first planetary flyby, the first pictures from another planet, the first planetary orbiter, and the first gravity assist maneuver.

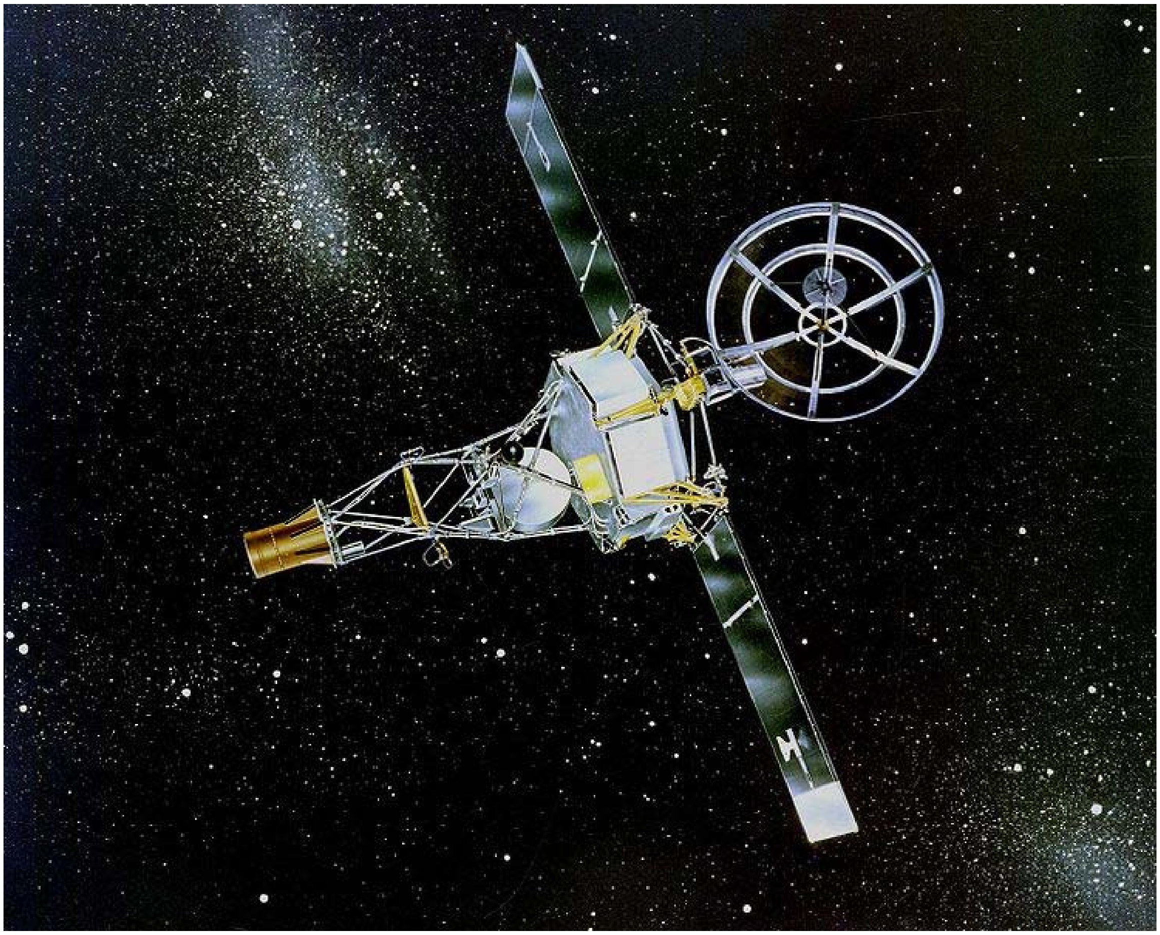
Of the ten vehicles in the Mariner series, seven were successful and three were lost. The planned Mariner 11 and Mariner 12 vehicles evolved into Voyager 1 and Voyager 2 of the Voyager program, while the Viking 1 and Viking 2 Mars orbiters were enlarged versions of the Mariner 9 spacecraft. Other Mariner-based spacecraft, launched since Voyager, included the Magellan probe to Venus, and the Galileo probe to Jupiter. A second-generation Mariner spacecraft, called the Mariner Mark II series, eventually evolved into the Cassini-Huygens probe, now in orbit around Saturn.

Basic layout

All Mariner spacecraft were based on a hexagonal or octagonal "bus", which housed all of the electronics, and to which all components were attached, such as antennae, cameras, propulsion, and power sources. All of the Mariners launched after Mariner 2 had four solar panels for power, except for Mariner 10, which had two, and Mariner 2, which was based on the Ranger Lunar probe. Additionally, all except Mariner 1, Mariner 2 and Mariner 5 had TV cameras.

The first five Mariners were launched on Atlas-Agena rockets, while the last five used the Atlas-Centaur. All Mariner-based probes after Mariner 10 used the Titan IIIE, Titan IV unmanned rockets or the Space Shuttle with a solid-fueled Inertial Upper Stage and multiple planetary flybys.

Mariners 1 and 2



Mariner 1 was intended to fly by Venus. The spacecraft was launched on July 22, 1962, but was destroyed approximately 5 minutes after liftoff by the Air Force Range Safety Officer when its malfunctioning Atlas-Agena rocket went off course. Mariner 2 was built as a backup to Mariner 1 and was launched on August 27, 1962, sending it on a 3½-month flight to Venus. The mission was a success, and Mariner 2 became the first spacecraft to have flown by another planet.

- Mission: Venus flyby
- Mass: 203 kg (446 lb)
- Sensors: microwave and infrared radiometers, cosmic dust, solar plasma and high-energy radiation, magnetic fields

Status:

- Mariner 1 – Destroyed shortly after liftoff.
- Mariner 2 – Defunct after successful mission, occupies a heliocentric orbit.

Mariners 3 and 4

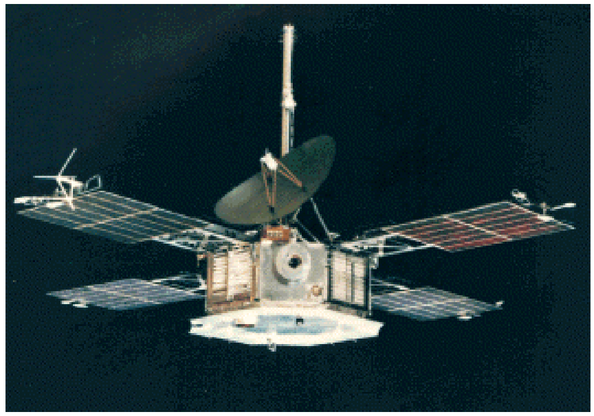
Mariner 3 and Mariner 4 were Mars flyby missions. Mariner 3 was lost when the launch vehicle's nose fairing failed to jettison. Its sister ship, Mariner 4, launched on November 28, 1964, was the first successful flyby of the planet Mars and gave the first glimpse of Mars at close range.

- Mission: Mars flyby
- Mass: 261 kg (575 lb)
- Sensors: camera with digital tape recorder (about 20 pictures), cosmic dust, solar plasma, trapped radiation, cosmic rays, magnetic fields, radio occultation and celestial mechanics

Status:

- Mariner 3 – Malfunctioned. Trapped in a Heliocentric orbit.
- Mariner 4 – Unknown. Communications lost after bombardment by micrometeoroids.

Mariner 5

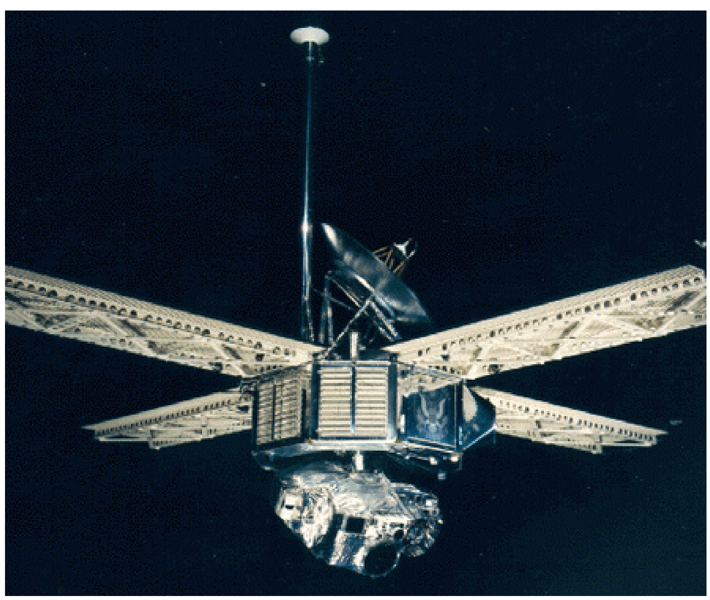


The Mariner 5 spacecraft was launched to Venus on June 14, 1967 and arrived in the vicinity of the planet in October 1967. It carried a complement of experiments to probe Venus' atmosphere with radio waves, scan its brightness in ultraviolet light, and sample the solar particles and magnetic field fluctuations above the planet.

- Mission: Venus flyby
- Mass: 245 kg (540 lb)
- Sensors: ultraviolet photometer, cosmic dust, solar plasma, trapped radiation, cosmic rays, magnetic fields, radio occultation and celestial mechanics

Status: Mariner 5 – Defunct. Trapped in a Heliocentric orbit.

Mariners 6 and 7



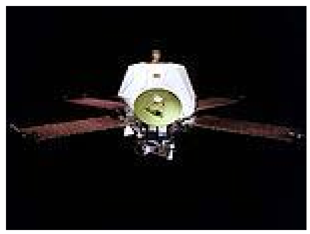
Mariners 6 and 7 were identical teammates in a two-spacecraft mission to Mars. Mariner 6 was launched on February 24, 1969, followed by Mariner 7 on March 21, 1969. They flew over the equator and southern hemisphere of the planet Mars.

- Mission: Mars flybys
- Mass 413 kg (908 lb)
- Sensors: wide- and narrow-angle cameras with digital tape recorder, infrared spectrometer and radiometer, ultraviolet spectrometer, radio occultation and celestial mechanics.

Status:

- Mariner 6 – Defunct. Trapped in a Heliocentric orbit.
- Mariner 7 – Defunct. Trapped in a Heliocentric orbit.

Mariners 8 and 9



Mariner 8 and Mariner 9 were identical sister craft designed to map the Martian surface simultaneously, but Mariner 8 was lost in a launch vehicle failure. Its identical sister craft, Mariner 9, was launched in May 1971 and became the first artificial satellite of Mars. It entered Martian orbit in November 1971 and began photographing the surface and analyzing the atmosphere with its infrared and ultraviolet instruments.

- Mission: orbit Mars
- Mass 998 kg (2,200 lb)
- Sensors: wide- and narrow-angle cameras with digital tape recorder, infrared spectrometer and radiometer, ultraviolet spectrometer, radio occultation and celestial mechanics

Status:

- Mariner 8 – Destroyed in a launch vehicle failure.
- Mariner 9 – Shut off. In Areocentric (Mars) orbit until at least 2022 when it will fall out of orbit and into the Martian atmosphere.

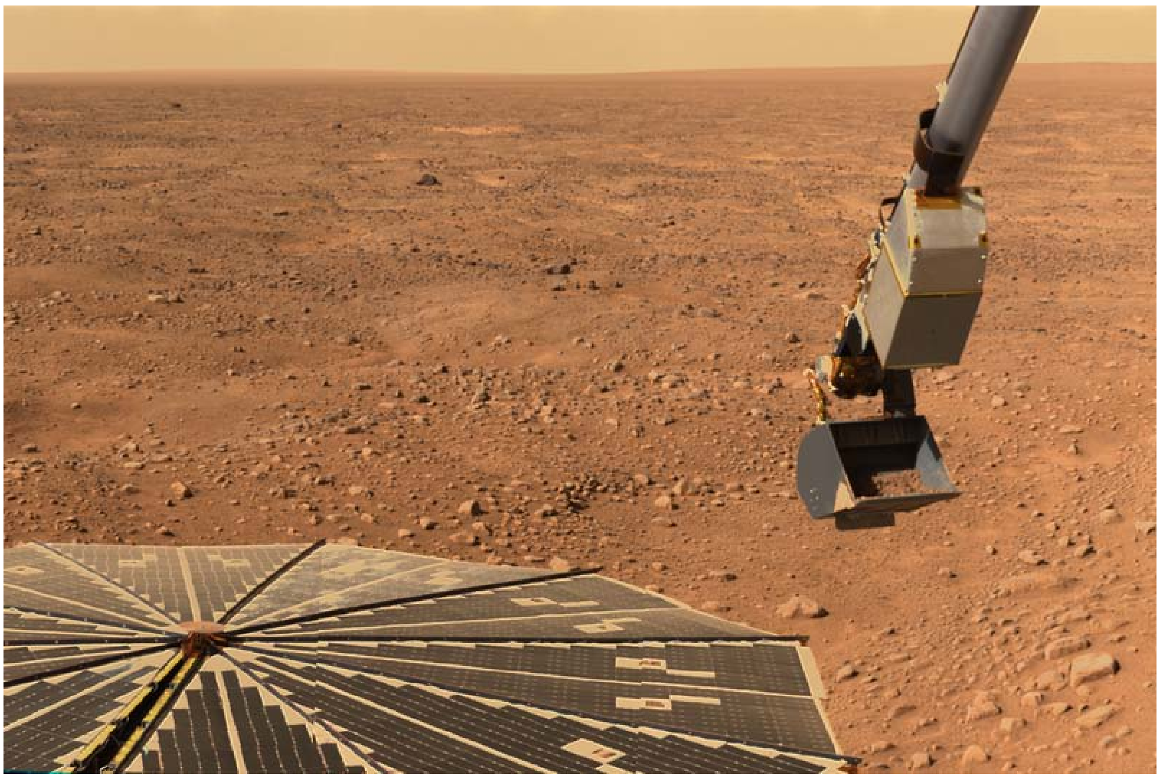
Mariner 10

The Mariner 10 spacecraft launched on November 3, 1973 and was the first to use a gravity assist trajectory, accelerating as it entered the gravitational influence of Venus, then being flung by the planet's gravity onto a slightly different course to reach Mercury. It was also the first spacecraft to encounter two planets at close range, and for 33 years the only spacecraft to photograph Mercury in closeup.

- Mission: Venus and Mercury flybys
- Mass: 433 kg (952 lb)
- Sensors: twin narrow-angle cameras with digital tape recorder, ultraviolet spectrometer, infrared radiometer, solar plasma, charged particles, magnetic fields, radio occultation and celestial mechanics

Chapter 8

Mars Landing



View from the NASA Phoenix lander in 2008

A **Mars landing** is a landing of a spacecraft on the surface of Mars. Of multiple attempted Mars landings by robotic, unmanned spacecraft, six were successful. There have also been studies for a possible manned mission to Mars, including a landing, but none have been attempted.

Unmanned landings

Mars probe program

In 1969, the Soviet Union prepared a 5-ton orbiter called M-69. Two copies of the probe, Mars 1969A and Mars 1969B, were lost in launch related complications caused by problems with the newly developed Proton rockets.

In 1971, shortly after the Cosmos 419 (Mars 1971C), that intended to be a first Martian orbiter, was lost in the fourth stage of the launch due to issues concerning the failure in the separation of Cosmos' payload from the launch vehicle, the Soviet Union successfully sent probes Mars 2 and Mars 3, as part of the Mars probe program M-71. The Mars 2 and 3 probes each carried a lander, both of which failed upon landing. They were the first human artifacts to touch down on Mars. Mars 2 lander impacted on Mars only while Mars 3 was the first Martian lander and was able to transmit from Martian surface during 20 second the first data and a portion of the first picture. These spaceprobes also contained the first Mars mini-rovers, although they were broken on landing.

The Mars 2 and 3 orbiters sent back a large volume of data covering the period from December 1971 to March 1972, although transmissions continued through to August. By 22 August 1972, after sending back data and a total of 60 pictures, Mars 2 and 3 concluded their missions. The images and data enabled creation of surface relief maps, and gave information on the Martian gravity and Magnetosphere.

In 1973, the Soviet Union sent four more probes to Mars: the Mars 4 and Mars 5 orbiters and the Mars 6 and Mars 7 fly-by/lander combinations. All missions except Mars 7 sent back data, with Mars 5 being most successful. Mars 5 transmitted 60 images before a loss of pressurization in the transmitter housing, ended the mission. Mars 6 lander transmitted data during descent, but failed upon impact. Mars 4 flew by the planet at a range of 2200 km returning one swath of pictures and radio occultation data, which constituted the first detection of the nightside ionosphere on Mars. Mars 7 probe separated prematurely from the carrying vehicle due to a problem in the operation of one of the onboard systems (altitude control or retro-rockets) and missed the planet by 1300 km.

Years earlier, in 1970 Soviet Union began the design of Mars 4NM and Mars 5NM missions with superheavy unmanned Martian spacecrafts. First was Marsokhod with planned date of start in 1973 and second was Mars sample return mission planned to 1975. Both spacecrafts intended to launch on N1 superrocket. But this rocket never flew successfully and Mars 4NM and Mars 5NM projects were cancelled.

Viking program

Viking Lander 1 landing site

In 1976 the two American Viking probes entered orbit about Mars and each released a lander module that made a successful soft landing on the planet's surface. The two missions returned the first color pictures and extensive scientific information. Measured temperatures at the landing sites ranged from 150 to 250 K, with a variation over a given day of 35 to 50 K. Seasonal dust storms, pressure changes, and movement of atmospheric gases between the polar caps were observed. A biology experiment produced possible evidence of life, but it was not corroborated by other on-board experiments.

While searching for a suitable landing spot for Viking 2's lander, the Viking 1 orbiter photographed the landform that constitutes the so-called "Face on Mars" on July 25, 1976.

The Viking program was a descendant of the cancelled Voyager program, whose name was later reused for a pair of outer solar system probes.

Phobos program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Artist impression of Phobos spacecraft

Two Soviet probes were sent to Mars in 1988 as part of the Phobos program. Phobos 1 operated nominally until an expected communications session on 2 September 1988 failed to occur. The problem was traced to a software error, which deactivated altitude thrusters causing the spacecrafts' solar arrays to no longer point at the Sun, depleting Phobos 1 batteries. Phobos 2 operated nominally throughout its cruise and Mars orbital insertion phases on January 29, 1989, gathering data on the Sun, interplanetary medium, Mars, and Phobos. Shortly before the final phase of the mission, during which the spacecraft was to approach within 50 m of Phobos' surface and release two landers, one a mobile 'hopper', the other a stationary platform, contact with Phobos 2 was lost. The mission ended when the spacecraft signal failed to be successfully reacquired on March 27, 1989. The cause of the failure was determined to be a malfunction of the on-board computer.

Mars Global Surveyor

This image from Mars Global Surveyor spans a region about 1500 meters across. Gullies, similar to those formed on Earth, are visible from Newton Basin in Sirenum Terra (NASA).

After the 1992 failure of NASA's Mars Observer orbiter, NASA retooled and launched Mars Global Surveyor (MGS). This mission was the first successful United States mission, and the first fully successful mission overall, to the red planet in two decades when it launched November 7, 1996, and entered orbit on September 12, 1997. After a year and a half trimming its orbit from a looping ellipse to a circular track around the planet, the spacecraft began its primary mapping mission in March 1999. It has observed the planet from a low-altitude, nearly polar orbit over the course of one complete Martian year, the equivalent of nearly two Earth years. Mars Global Surveyor completed its primary mission on January 31, 2001, and completed several extended mission phases.

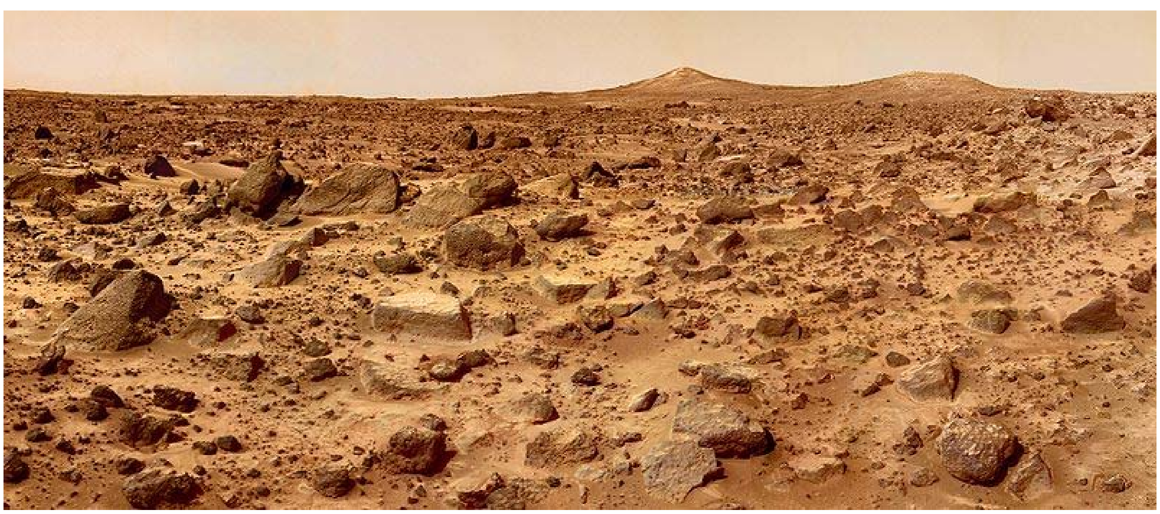
The mission has studied the entire Martian surface, atmosphere, and interior, and has returned more data about the red planet than all other Mars missions combined. These valuable data are archived and available publicly.

Among key scientific findings so far, Global Surveyor has taken pictures of gullies and debris flow features that suggest there may be current sources of liquid water, similar to an aquifer, at or near the surface of the planet. Similar channels on Earth are formed by flowing water, but on Mars the temperature is normally too cold and the atmosphere too thin to sustain liquid water. Nevertheless, many scientists hypothesize that liquid groundwater can sometimes surface on Mars, erode gullies and channels, and pool at the bottom before freezing and evaporating.

Magnetometer readings show that the planet's magnetic field is not globally generated in the planet's core, but is localized in particular areas of the crust. New temperature data and closeup images of the Martian moon Phobos show its surface is composed of powdery material at least 1 metre (3 feet) thick, caused by millions of years of meteoroid impacts. Data from the spacecraft's laser altimeter have given scientists their first 3-D views of Mars' north polar ice cap.

On November 5, 2006 MGS lost contact with Earth and hasn't been heard from since.

Mars Pathfinder

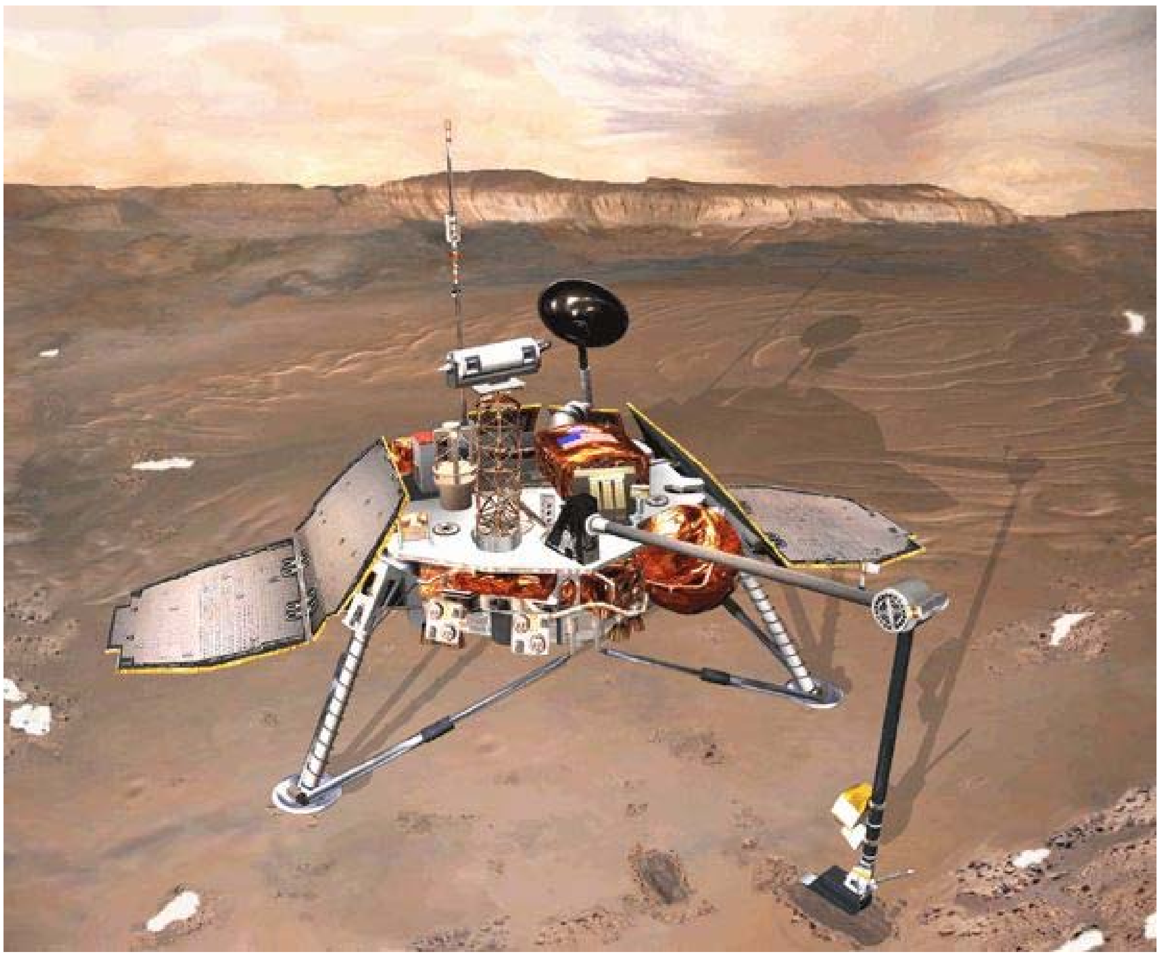


"Ares Vallis" as photographed by Mars Pathfinder

The Mars Pathfinder spacecraft, launched one month after Global Surveyor, landed on July 4, 1997. Its landing site was an ancient flood plain in Mars' northern hemisphere called Ares Vallis, which is among the rockiest parts of Mars. It carried a tiny remote-controlled rover called Sojourner, which traveled a few meters around the landing site, exploring the conditions and sampling rocks around it. Newspapers around the world carried images of the lander dispatching the rover to explore the surface of Mars in a way never achieved before.

Until the final data transmission on September 27, 1997, Mars Pathfinder returned 16,500 images from the lander and 550 images from the rover, as well as more than 15 chemical analyses of rocks and soil and extensive data on winds and other weather factors. Findings from the investigations carried out by scientific instruments on both the lander and the rover suggest that Mars was at one time in its past warm and wet, with water existing in its liquid state and a thicker atmosphere. The mission website was the most heavily-trafficked up to that time.

Spate of failures



Conceptual drawing of the *Mars Polar Lander* on the surface of Mars

Mars 96, an orbiter launched on November 16, 1996 by Russia failed, when the planned second burn of the Block D-2 fourth stage did not occur.

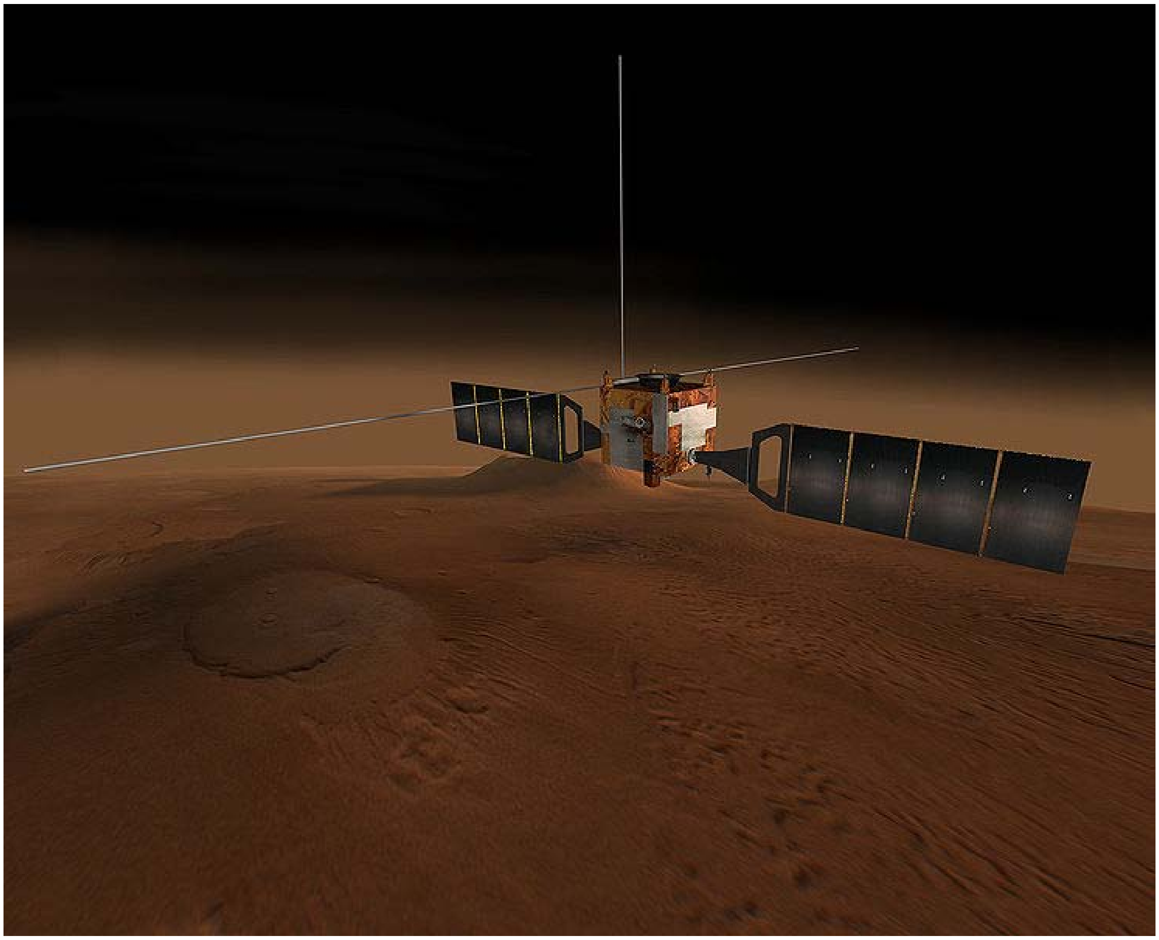
Following the success of Global Surveyor and Pathfinder, another spate of failures occurred in 1998 and 1999, with the Japanese Nozomi orbiter and NASA's Mars Climate Orbiter, Mars Polar Lander, and Deep Space 2 penetrators all suffering various fatal errors. Mars Climate Orbiter is infamous for Lockheed Martin engineers mixing up the usage of English units with metric units, causing the orbiter to burn up while entering Mars' atmosphere.

Mars Odyssey

Mars Odyssey drawing

In 2001 the run of bad luck ended when NASA's Mars Odyssey orbiter arrived. Its mission is to use spectrometers and imagers to hunt for evidence of past or present water and volcanic activity on Mars. In 2002, it was announced that the probe's gamma ray spectrometer and neutron spectrometer had detected large amounts of hydrogen, indicating that there are vast deposits of water ice in the upper three meters of Mars' soil within 60° latitude of the south pole.

Mars Express and Beagle 2



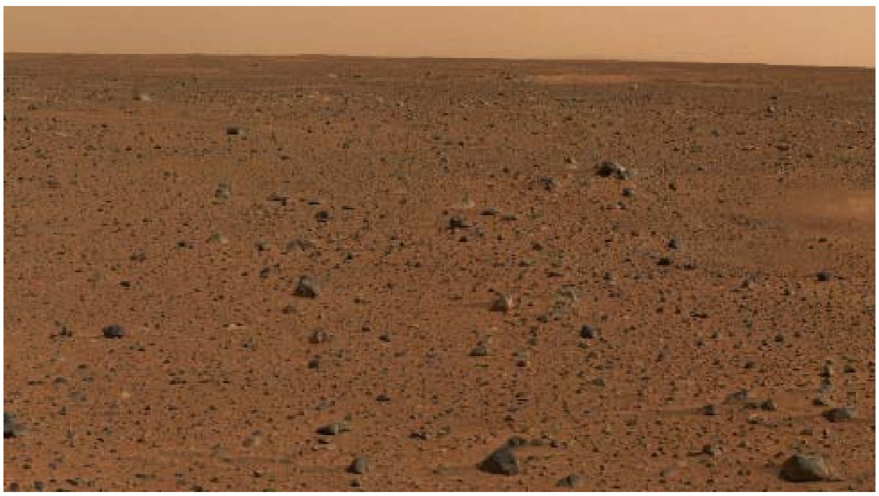
Artists rendering of the Mars Express orbiter

On June 2, 2003, the European Space Agency's Mars Express set off from Baikonur Cosmodrome to Mars. The Mars Express craft consists of the Mars Express Orbiter and the lander Beagle 2. Although the landing probe was not designed to move, it carried a digging device and the smallest mass spectrometer created to date, as well as a range of other devices, on a robotic arm in order to accurately analyse soil beneath the dusty surface.

The orbiter entered Mars orbit on December 25, 2003, and Beagle 2 entered Mars' atmosphere the same day. However, attempts to contact the lander failed. Communications attempts continued throughout January, but Beagle 2 was declared lost in mid-February, and a joint inquiry was launched by the UK and ESA. Nevertheless, Mars Express Orbiter confirmed the presence of water ice and carbon dioxide ice at the planet's south pole. NASA had previously confirmed their presence at the north pole of Mars.

Mars Exploration Rovers

Shortly after the launch of Mars Express, NASA sent a pair of twin rovers toward the planet as part of the Mars Exploration Rover Mission. On 10 June 2003, NASA's MER-A *(Spirit)* Mars Exploration Rover was launched. It successfully landed in Gusev Crater (believed once to have been a crater lake) on 3 January 2004. It examined rock and soil for evidence of the area's history of water. On July 7, 2003, a second rover, MER-B *(Opportunity)* was launched. It landed on 24 January 2004 in Meridiani Planum (where there are large deposits of hematite, indicating the presence of past water) to carry out similar geological work.



Part of a 360 degree panorama photo of the Gusev crater landing site, taken by NASA's Spirit Rover in 2004

Despite a temporary loss of communication with the Spirit Rover (caused by too many files being stored in its flash memory) delaying exploration for several days, both rovers eventually began exploring their landing sites. The rover *Opportunity* landed in a particularly interesting spot, a crater with bedrock outcroppings. In fast succession mission team members announced on 2 March that data returned from the rover showed that these rocks were once "drenched in water", and on 23 March that it was concluded that they were laid down underwater in a salty sea. This represented the first strong direct evidence for liquid water being on Mars at some time in the past.

Towards the end of July 2005, it was reported by the Sunday Times that the rovers may have carried the bacteria *Bacillus safensis* to Mars. According to one NASA microbiologist, this bacteria could survive both the trip and conditions on Mars. A book containing this claim, *Out of Eden* by Alan Burdick, is due to be published in the United Kingdom. Despite efforts to sterilise both landers, neither could be assured to be completely sterile.

Having only been designed for three month missions, both rovers are still operating as of April 2008, but Spirit and Opportunity are starting to show their age. These rovers have discovered new things, including Heat Shield Rock, the first meteorite to be discovered on another planet.

Mars Reconnaissance Orbiter

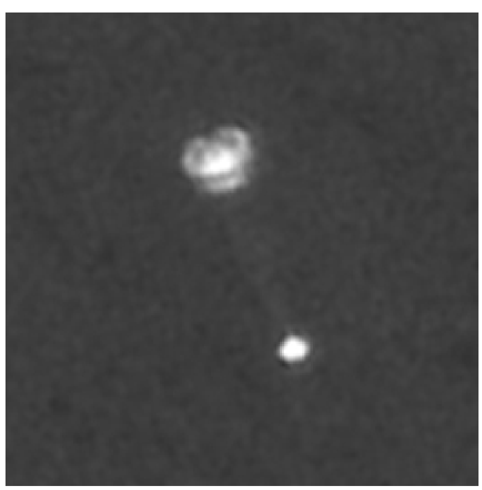
Mars Reconnaissance Orbiter is a multipurpose spacecraft designed to conduct reconnaissance and exploration of Mars from orbit. The $720 million USD spacecraft was built by Lockheed Martin under the supervision of the Jet Propulsion Laboratory, launched August 12, 2005, and attained Martian orbit on March 10, 2006.

The MRO contains a host of scientific instruments such as the HiRISE camera, CRISM, and SHARAD. The HiRISE camera is used to analyze Martian landforms, whereas CRISM and SHARAD can detect water, ice, and minerals on and below the surface. Additionally, MRO is paving the way for upcoming generations of spacecraft through daily monitoring of Martian weather and surface conditions, searching for future landing sites, and testing a new telecommunications system that will enable the orbiter to send and receive information at an unprecedented bitrate. Data transfer to and from the spacecraft will occur faster than all previous interplanetary missions combined and allowing it to serve as an important relay satellite for future missions.

Rosetta and Dawn

The ESA Rosetta space probe mission to the comet 67P/Churyumov-Gerasimenko flew within 250 km of Mars on February 25, 2007 in a gravitational slingshot designed to slow and redirect the spacecraft. The NASA Dawn spacecraft also used the gravity of Mars to change direction and velocity, and did a little science in conjunction with the many probes already there. Dawn passed the red planet in February 2009.

Phoenix Lander



Camera on Mars orbiter snaps *Phoenix* suspended from its parachute during descent through Mars' atmosphere.

Being the latest mission to Mars, Phoenix launched on August 4, 2007, and touched down on the northern polar region of Mars on May 25, 2008. It is famous for having been successfully photographed while landing, since this was the first time one spacecraft captured the landing of another spacecraft onto a planetary body (the Moon not being a planet, but a satellite).

Future Missions

Phoenix is to be followed by the Mars Science Laboratory, a rover more capable than *Spirit* and *Opportunity*. Originally the Mars Science Laboratory was intended for a launch during the 2009 opportunity, however the launch has been delayed to 2011. A second Scout mission, MAVEN has been selected for 2013. In the far future there's the proposed Mars Sample Return Mission, but this has been delayed until at least 2016, and more probably to 2024. This mission, a collaboration between ESA and NASA, is part of the Aurora Programme.

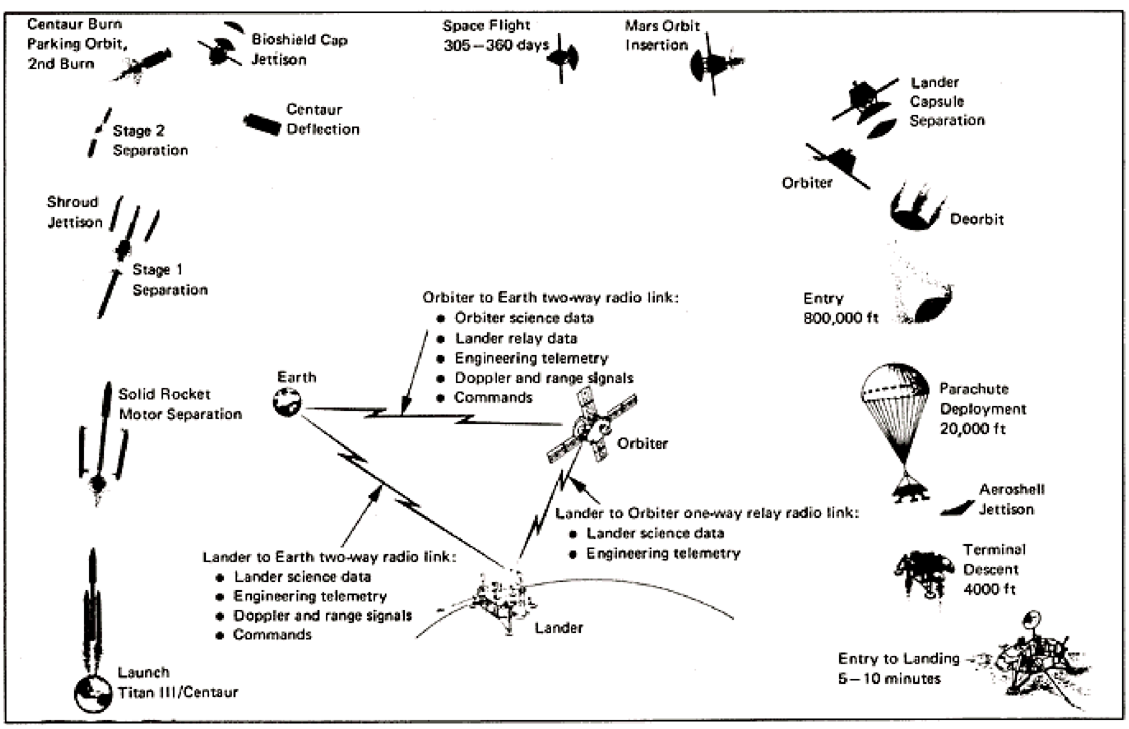
Russia plans to launch Phobos-Grunt, a sample return mission to Phobos, along with the joint Chinese Yinghuo-1 Mars orbiter in late 2011 or early 2012.

The ESA ExoMars mission is tentatively planned for 2018. ExoMars should obtain soil samples from up to 2 meters depth and make an extensive search for organic and biochemical substances.

Chapter 9

Viking Program

Viking mission patch



Viking mission profile

NASA's **Viking program** consisted of a pair of space probes sent to Mars, Viking 1 and Viking 2. Each spacecraft was composed of two main parts, an orbiter designed to photograph the surface of Mars from orbit, and a lander designed to study the planet from the surface. The orbiters also served as communication relays for the landers once they touched down.

It was the most expensive and ambitious mission ever sent to Mars, with a total cost of roughly US$1 billion. It was highly successful and formed most of the database of information about Mars until the late 1990s and early 2000s. The Viking program grew from NASA's earlier, and more ambitious Voyager Mars program, which was not related to the successful Voyager deep space probes of the late 1970s. Viking 1 was launched on August 20, 1975, and the second craft, Viking 2, was launched on September 9, 1975, both riding atop Titan III-E rockets with Centaur upper stages. After orbiting Mars and returning images used for landing site selection, the orbiter and lander detached and the lander entered the Martian atmosphere and soft-landed at the selected site. The orbiters continued imaging and performing other scientific operations from orbit while the landers deployed instruments on the surface. The fully fueled orbiter-lander pair had a mass of 3527 kg. After separation and landing, the lander had a mass of about 600 kg and the orbiter 900 kg.

Viking orbiters

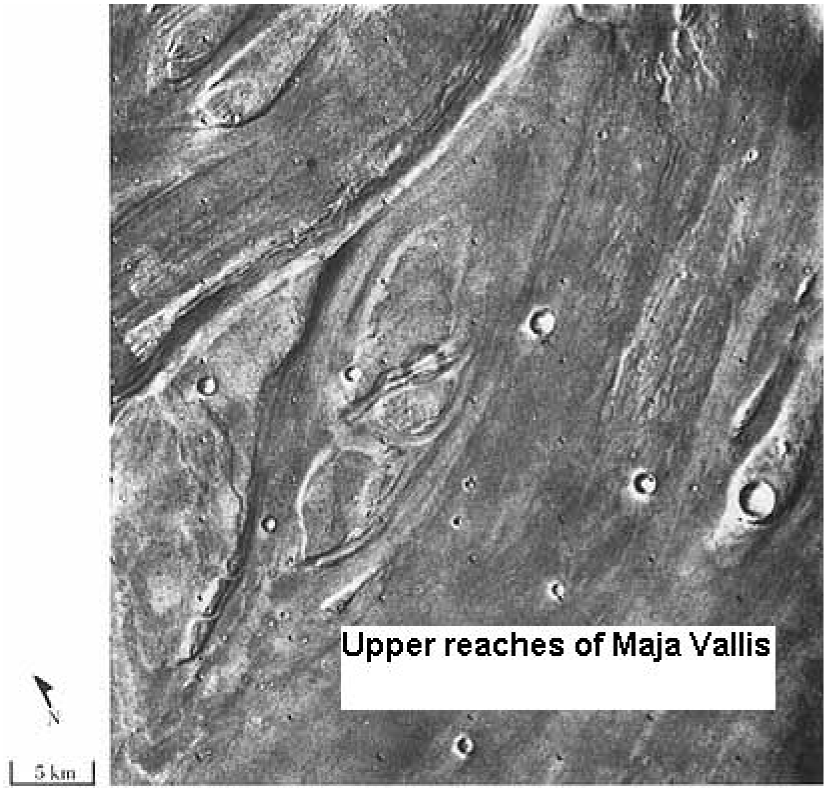
Viking orbiter (NASA)

The primary objectives of the Viking orbiters were to transport the landers to Mars, perform reconnaissance to locate and certify landing sites, act as a communications relays for the landers, and to perform their own scientific investigations. Each orbiter, based on the earlier Mariner 9 spacecraft, was an octagon approximately 2.5 m across. The total launch mass was 2328 kg, of which 1445 kg were propellant and attitude control gas. The eight faces of the ring-like structure were 0.4572 m high and were alternately 1.397 and 0.508 m wide. The overall height was 3.29 m from the lander attachment points on the bottom to the launch vehicle attachment points on top. There were 16 modular compartments, 3 on each of the 4 long faces and one on each short face. Four solar panel wings extended from the axis of the orbiter, the distance from tip to tip of two oppositely extended solar panels was 9.75 m. The power was provided by eight 1.57 × 1.23 m solar panels, two on each wing. The solar panels were made up of a total of 34,800 solar cells and produced 620 W of power at Mars. Power was also stored in 2 nickel-cadmium 30-A·h batteries.

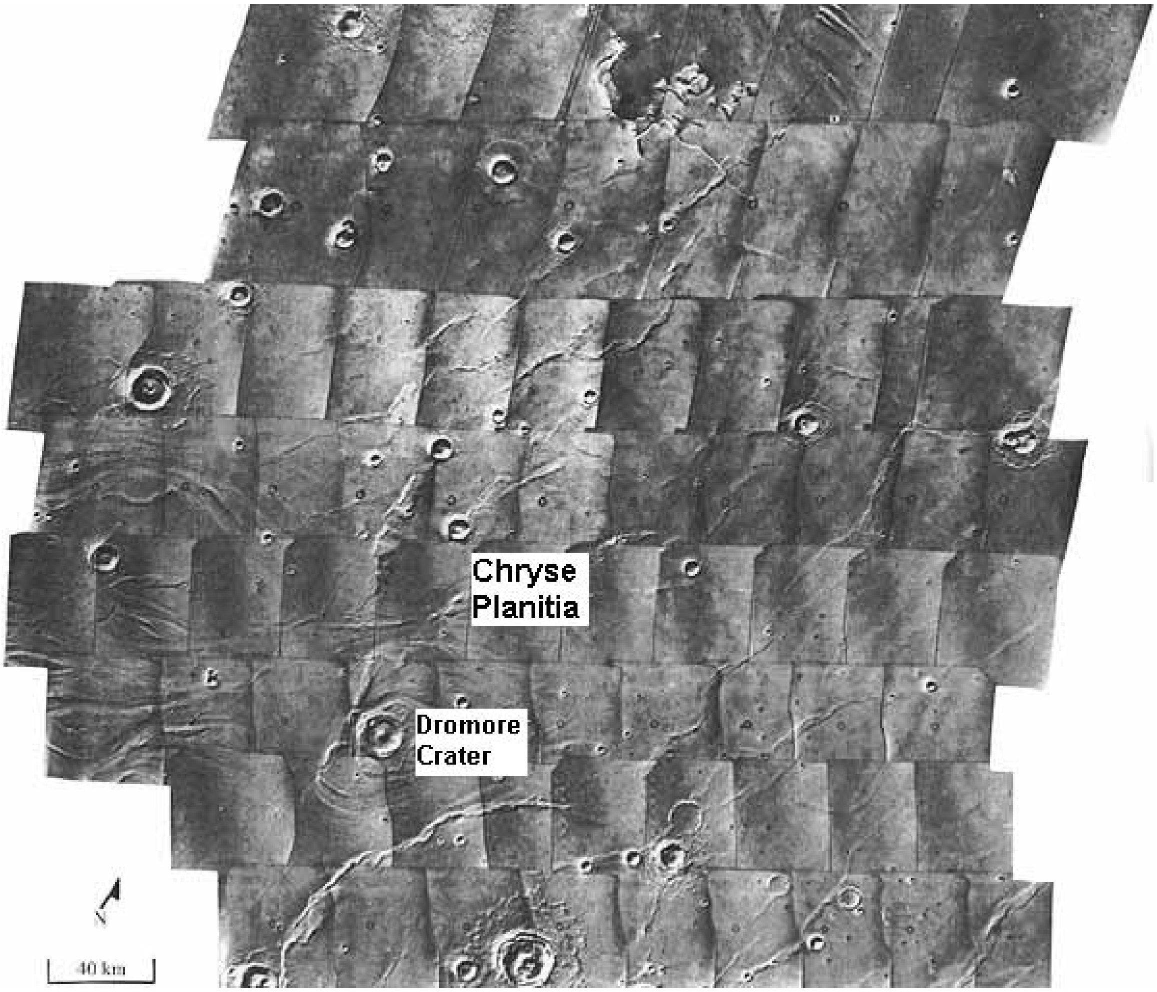
By discovering many geological forms that are typically formed from large amounts of water, they caused a revolution in our ideas about water on Mars. Huge river valleys were found in many areas. They showed that floods of water broke through dams, carved deep valleys, eroded grooves into bedrock, and traveled thousands of kilometers. Large areas in the southern hemisphere contained branched stream networks, suggesting that rain once fell. The flanks of some volcanoes are believed to have been exposed to rainfall because they resemble those caused on Hawaiian volcanoes. Many craters look as if the impactor fell into mud. When they were formed, ice in the soil may have melted, turned the ground into mud, then flowed across the surface. Normally, material from an impact goes up, then down. It does not flow across the surface, going around obstacles, as it does on some Martian craters. Regions, called "Chaotic Terrain," seemed to have quickly lost great volumes of water, causing large channels to be formed. The amount of water involved was estimated to ten thousand times the flow of the Mississippi River. Underground volcanism may have melted frozen ice; the water then flowed away and the ground collapsed to leave chaotic terrain.

The main propulsion unit was mounted above the orbiter bus. Propulsion was furnished by a bipropellant (monomethylhydrazine and nitrogen tetroxide) liquid-fueled rocket engine which could be gimballed up to 9 degrees. The engine was capable of 1323 N (297 lbf) thrust, translating to a delta-V of 1480 m/s. Attitude control was achieved by 12 small compressed-nitrogen jets. An acquisition Sun sensor, a cruise Sun sensor, a Canopus star tracker and an inertial reference unit consisting of six gyroscopes allowed three-axis stabilization. Two accelerometers were also on board. Communications were accomplished through a 20 W S-band (2.3 GHz) transmitter and two 20 W TWTAs. An X band (8.4 GHz) downlink was also added specifically for radio science and to conduct communications experiments. Uplink was via S band (2.1 GHz). A two-axis steerable high-gain parabolic dish antenna with a diameter of approximately 1.5 m was attached at one edge of the orbiter base, and a fixed low-gain antenna extended from the top of the bus. Two tape recorders were each capable of storing 1280 megabits. A 381-MHz relay radio was also available.

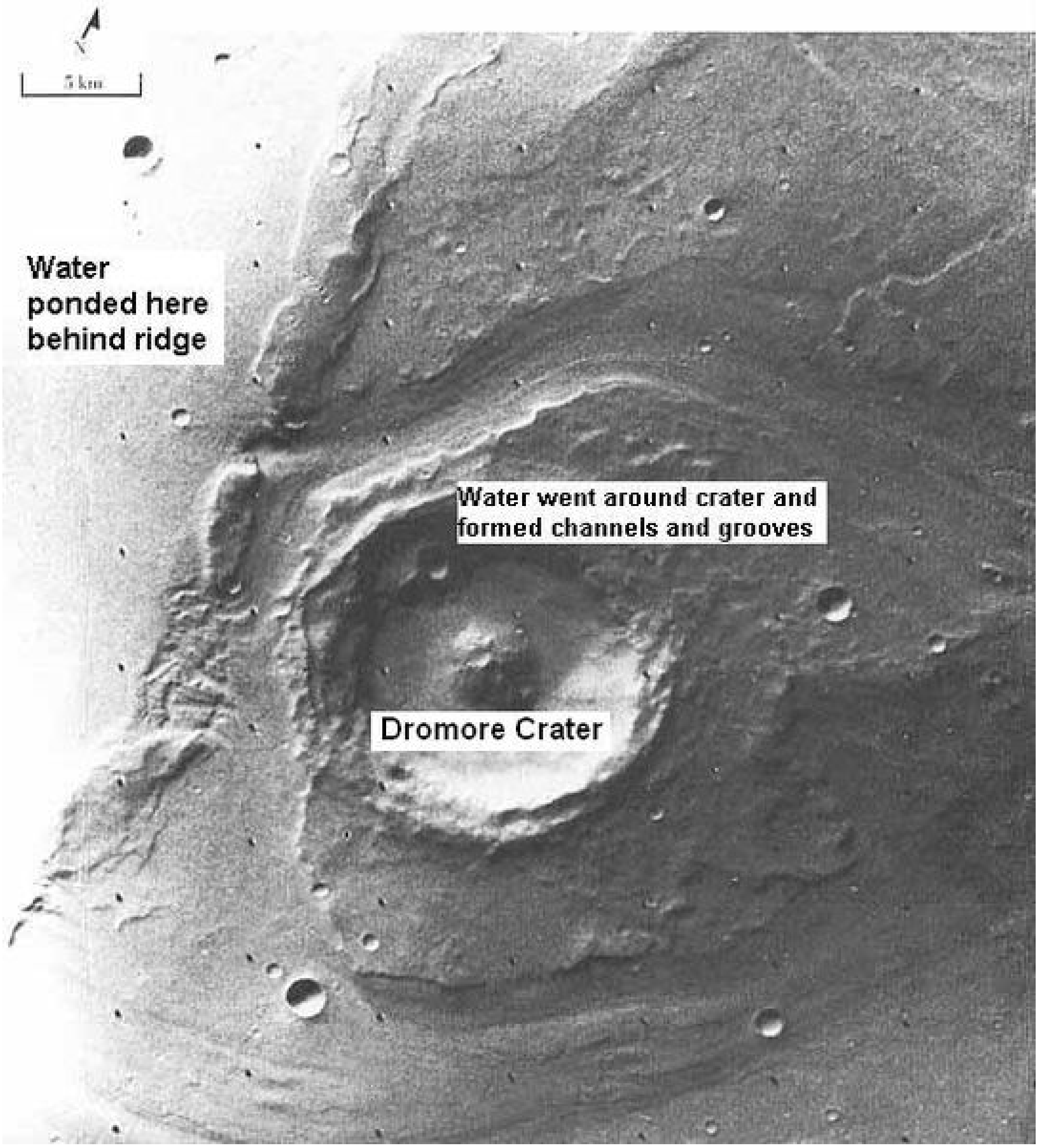
Viking Mosaics



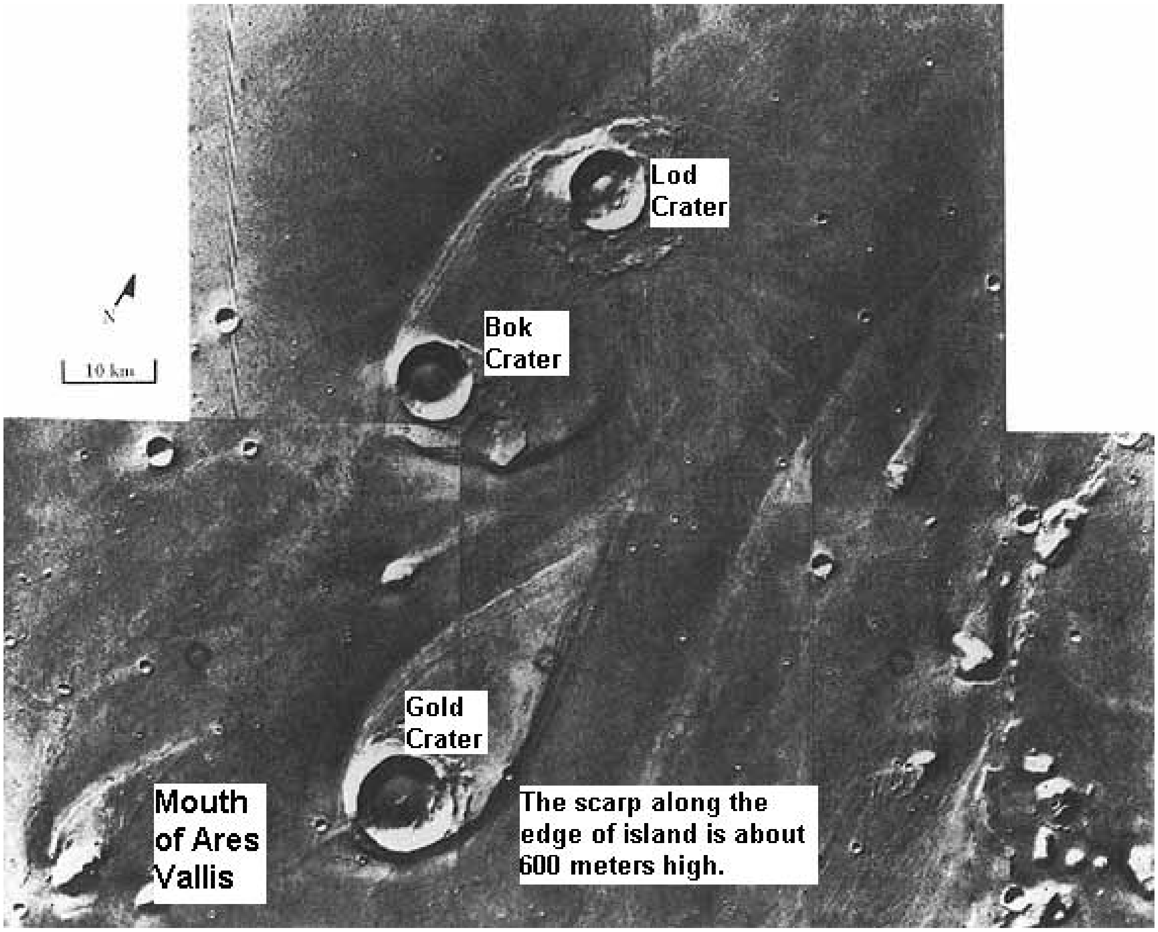
Streamlined Islands showed that large floods occurred on Mars. Image is located in Lunae Palus quadrangle.



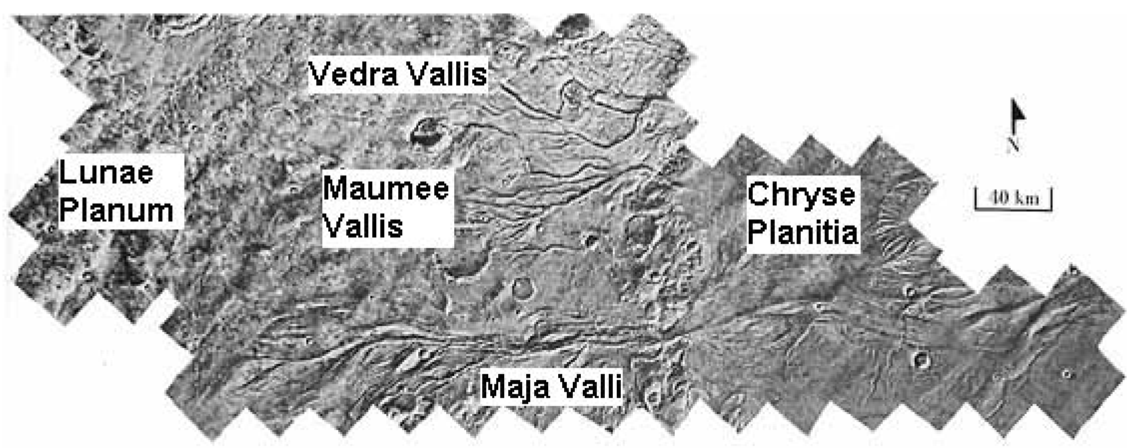
Scour Patterns were produced by flowing water from Maja Vallis, which lies just to the left of this mosaic. Detail of flow around Dromore Crater is shown on another image. Image is located in Lunae Palus quadrangle.



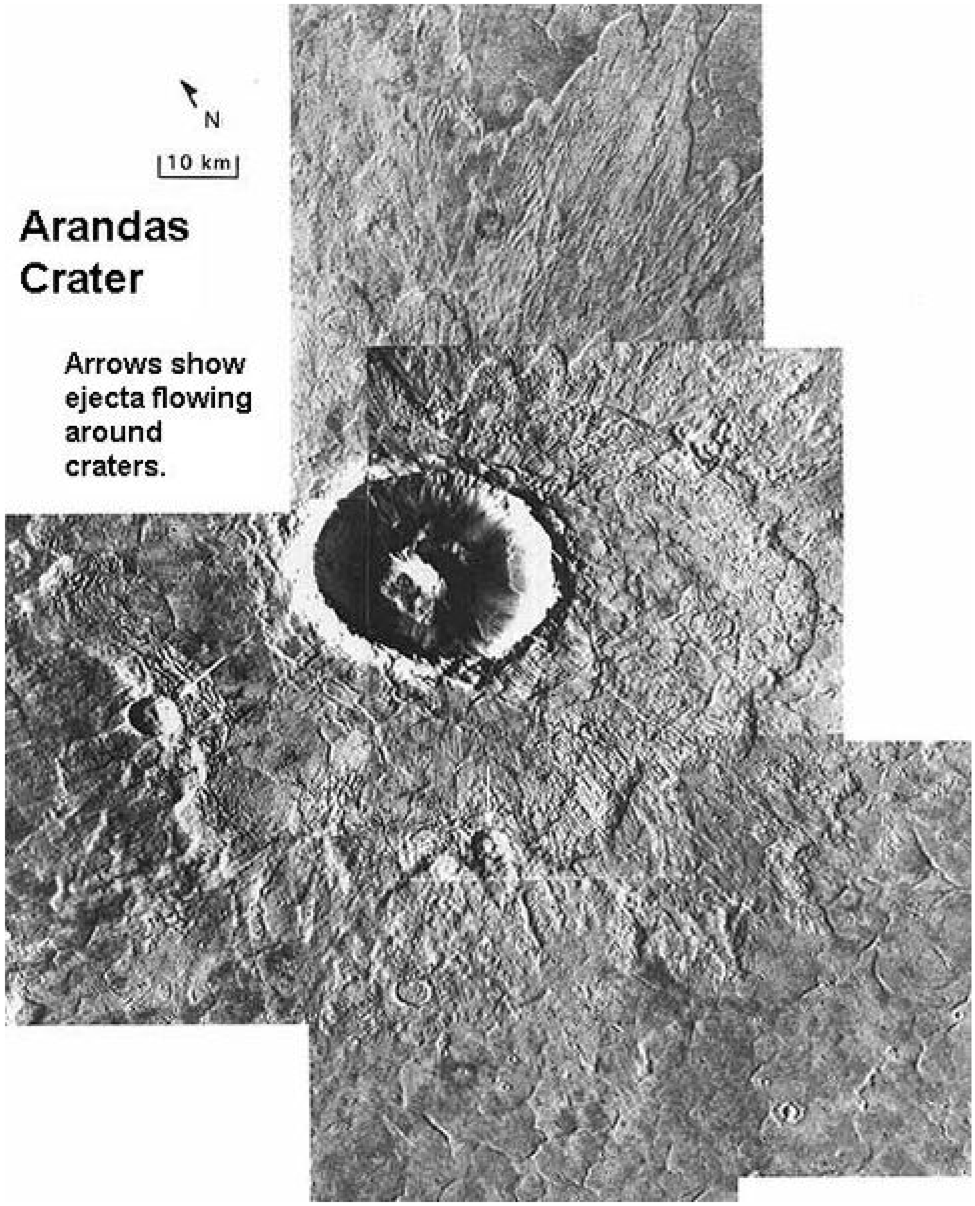
Great amounts of water were required to carry out the erosion shown in this Viking image. Image is located in Lunae Palus quadrangle.



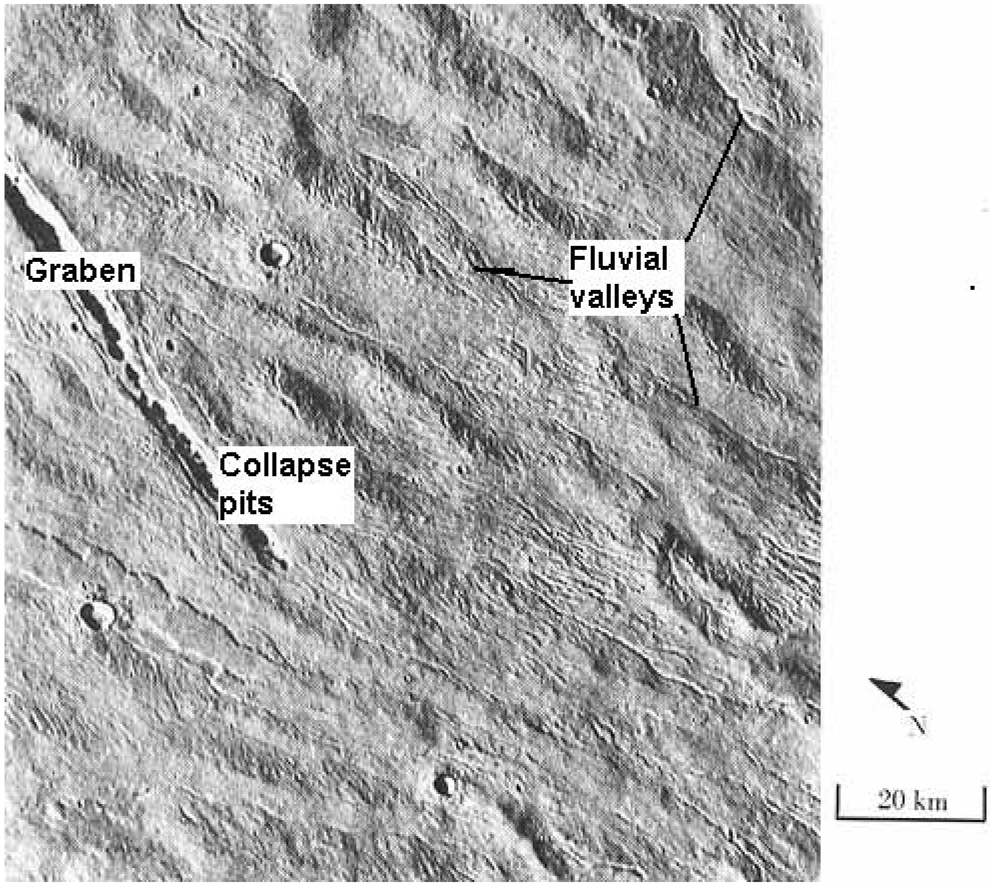
Tear-drop shaped islands caused by flood waters from Maja Valles. Image is located in Oxia Palus quadrangle.



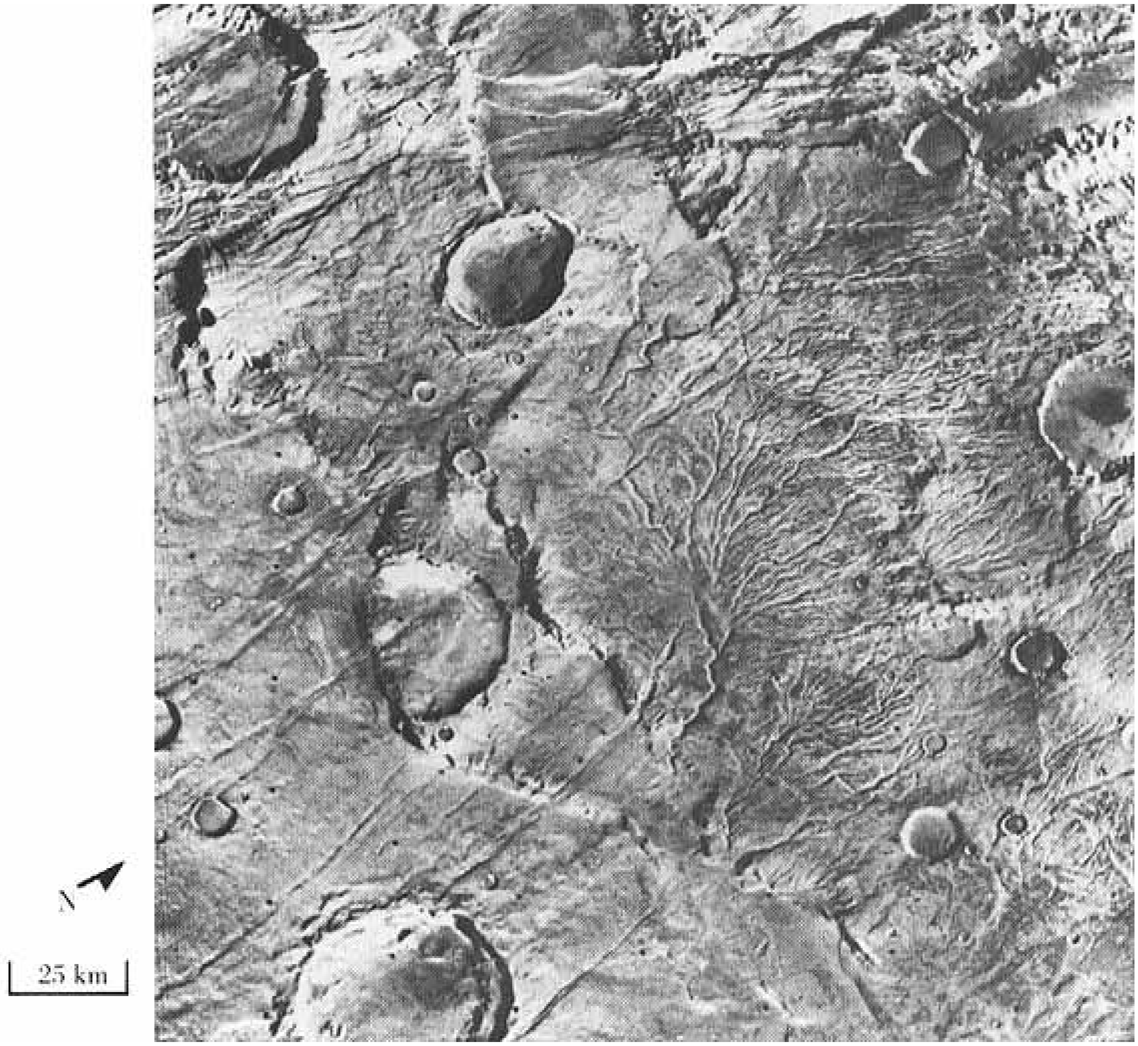
Vedra Vallis, Maumee Vallis, and Maja Valles move from Lunae Planum on the left to Chryse Planitia on the right. Image is located in Lunae Palus quadrangle.



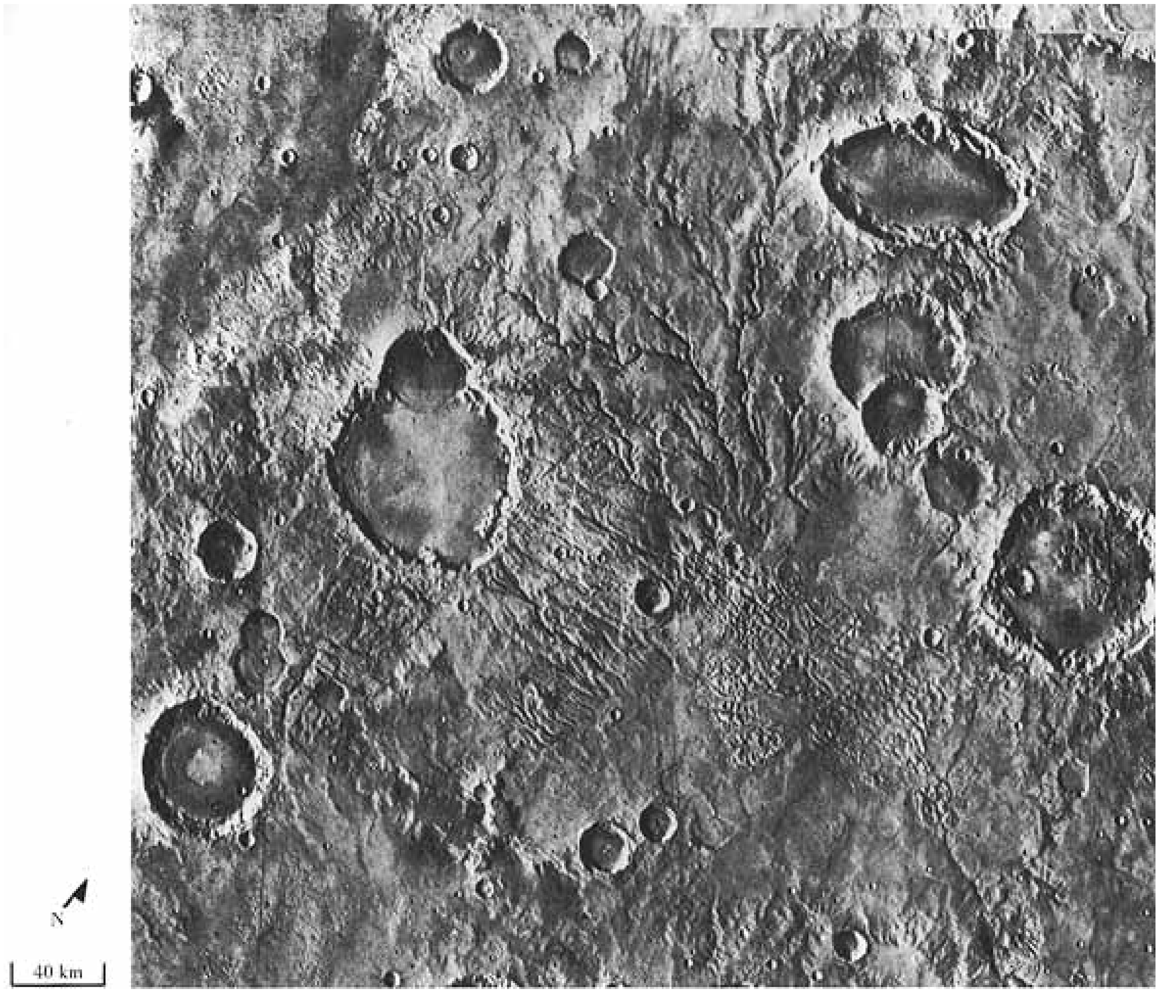
The ejecta from Arandas Crater acts like mud. It moves around small craters (indicated by arrows), instead of falling down on them. Craters like this suggest that large amounts of frozen water were melted when the impact crater was produced. Image is located in Mare Acidalium quadrangle.



This view of the flank of Alba Patera shows several features. Some channels are associated with lava flows; others are probably caused by running water. A large trough or graben turns into a line of collapse pits. Image is located in Arcadia quadrangle.



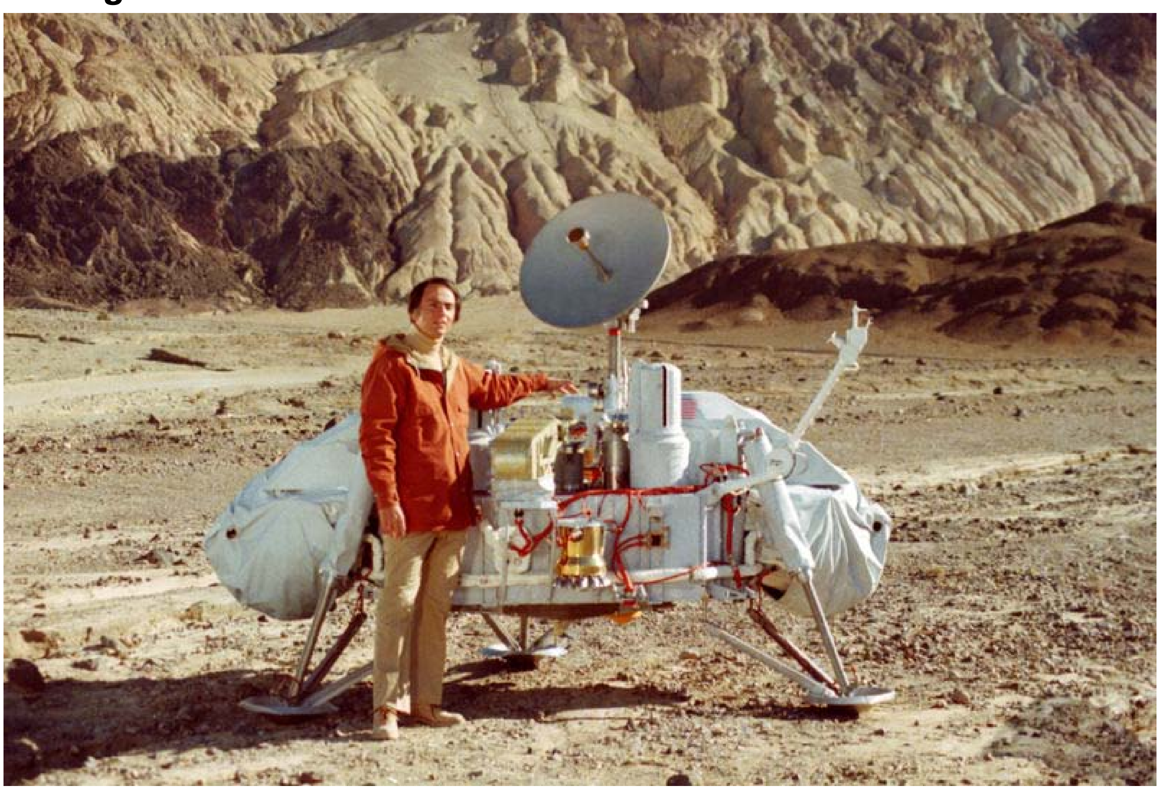
Branched channels in Thaumasia quadrangle. Networks of channels like this are strong evidence for rain on Mars in the past.



The branched channels strongly suggests that it rained on Mars in the past. Image is located in Margaritifer Sinus quadrangle.

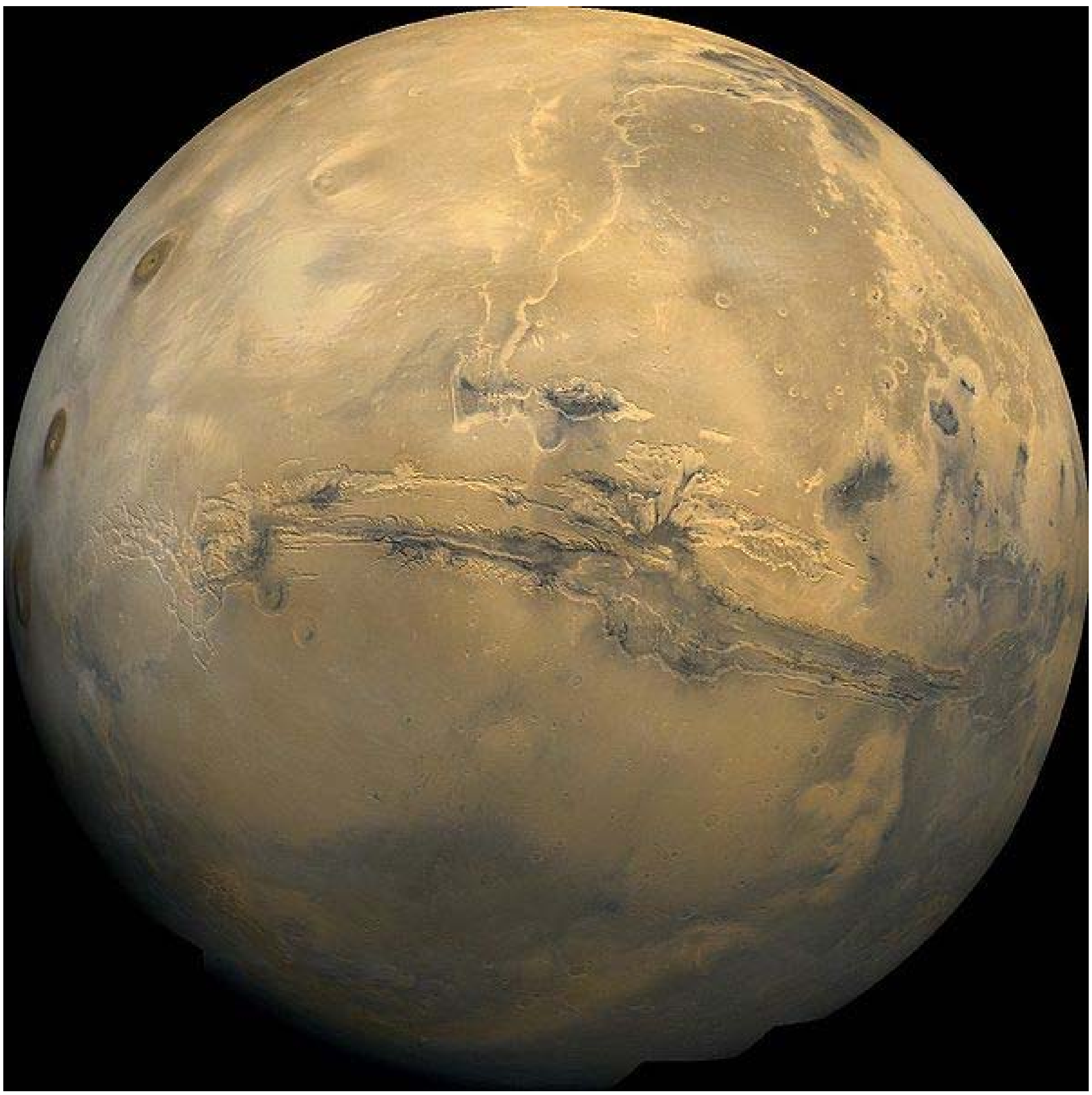
Ravi Vallis. Ravi Vallis was probably formed when catastrophic floods came out of the ground to the right (chaotic terrain). Image located in Margaritifer Sinus quadrangle.

Viking landers



Carl Sagan with a model of the Viking Lander, to scale (NASA)

Each lander consisted of a six-sided aluminum base with alternate 1.09 m (3 ft 7 in) and 0.56 m (1 ft 10 in) long sides, supported on three extended legs attached to the shorter sides. The leg footpads formed the vertices of an equilateral triangle with 2.21 m (7 ft 3 in) sides when viewed from above, with the long sides of the base forming a straight line with the two adjoining footpads. Instrumentation was attached to the top of the base, elevated above the surface by the extended legs. Power was provided by two radioisotope thermal generator (RTG) units containing plutonium-238 affixed to opposite sides of the lander base and covered by wind screens. Each generator was 28 cm (11 in) tall, 58 cm (23 in) in diameter, had a mass of 13.6 kg (30 lb) and provided 30 watts continuous power at 4.4 volts. Four wet cell sealed nickel-cadmium 8 ampere-hours (28,800 Coulombs), 28 volts rechargeable batteries were also onboard to handle peak power loads.



Mars from the Viking Orbiter

Propulsion for deorbit was provided by a monopropellant called hydrazine (N_2H_4), through a rocket with 12 nozzles arranged in four clusters of three that provided 32 newtons (7.2 lb_f) thrust, providing a delta-V of 180 m/s (590 ft/s). These nozzles also acted as the control thrusters for translation and rotation of the lander. Terminal descent and landing utilized three (one affixed on each long side of the base, separated by 120 degrees) monopropellant hydrazine engines. The engines had 18 nozzles to disperse the exhaust and minimize effects on the ground, and were throttleable from 276 to 2,667 newtons (62 to 600 lb_f). The hydrazine was purified in order to prevent contamination of the Martian surface with Earth microbes. The lander carried 85 kg (190 lb) of propellant at launch, contained in two spherical titanium tanks mounted on opposite sides of the lander beneath the RTG windscreens, giving a total launch mass of 657 kg (1,450 lb). Control was achieved through the use of an inertial reference unit, four gyros, a parachute, a radar altimeter, a terminal descent and landing radar, and the control thrusters.

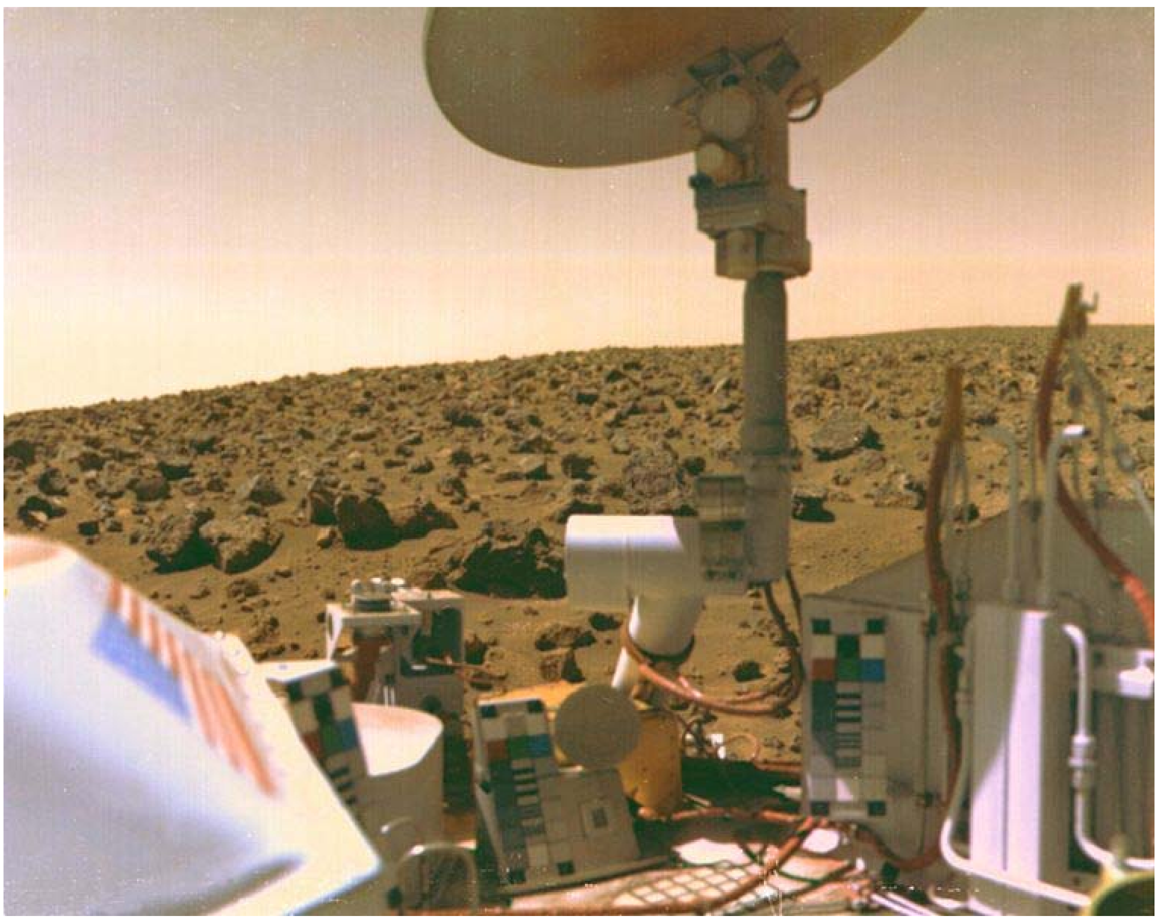


Image from Mars taken by Viking 2

Each lander was covered over from launch until Martian atmospheric entry with an aeroshell heat shield designed to slow the lander down during the entry phase, and also to prevent contamination of the Martian surface with Earthly microbial life that can survive the harsh conditions of deep space (as evident on the Surveyor 3 moon probe). As a further precaution, each lander, upon assembly and enclosure within the aeroshell, were "baked" at a temperature of 250 °F (121 °C) for a total of seven days, after which a "bioshield" was then placed over the aeroshell that was jettisoned after the Centaur upper stage fired the Viking orbiter/lander combination out of Earth orbit. The methods and standards developed for planetary protection for the Viking mission are still used for other missions.

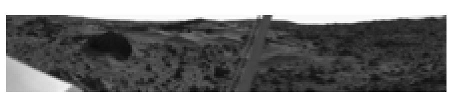
Communications were accomplished through a 20 watt S-band transmitter using two traveling-wave tubes. A two-axis steerable high-gain parabolic antenna was mounted on a boom near one edge of the lander base. An omnidirectional low-gain S-band antenna also extended from the base. Both these antennae allowed for communication directly with the Earth, permitting Viking 1 to continue to work long after both orbiters had failed. A UHF (381 MHz) antenna provided a one-way relay to the orbiter using a 30 watt relay radio. Data storage was on a 40-Mbit tape recorder, and the lander computer had a 6000-word memory for command instructions.

The lander carried instruments to achieve the primary scientific objectives of the lander mission: to study the biology, chemical composition (organic and inorganic), meteorology, seismology, magnetic properties, appearance, and physical properties of the Martian surface and atmosphere. Two 360-degree cylindrical scan cameras were mounted near one long side of the base. From the center of this side extended the sampler arm, with a collector head, temperature sensor, and magnet on the end. A meteorology boom, holding temperature, wind direction, and wind velocity sensors extended out and up from the top of one of the lander legs. A seismometer, magnet and camera test targets, and magnifying mirror are mounted opposite the cameras, near the high-gain antenna. An interior environmentally controlled compartment held the biology experiment and the gas chromatograph mass spectrometer. The X-ray fluorescence spectrometer was also mounted within the structure. A pressure sensor was attached under the lander body. The scientific payload had a total mass of approximately 91 kg (200 lb).

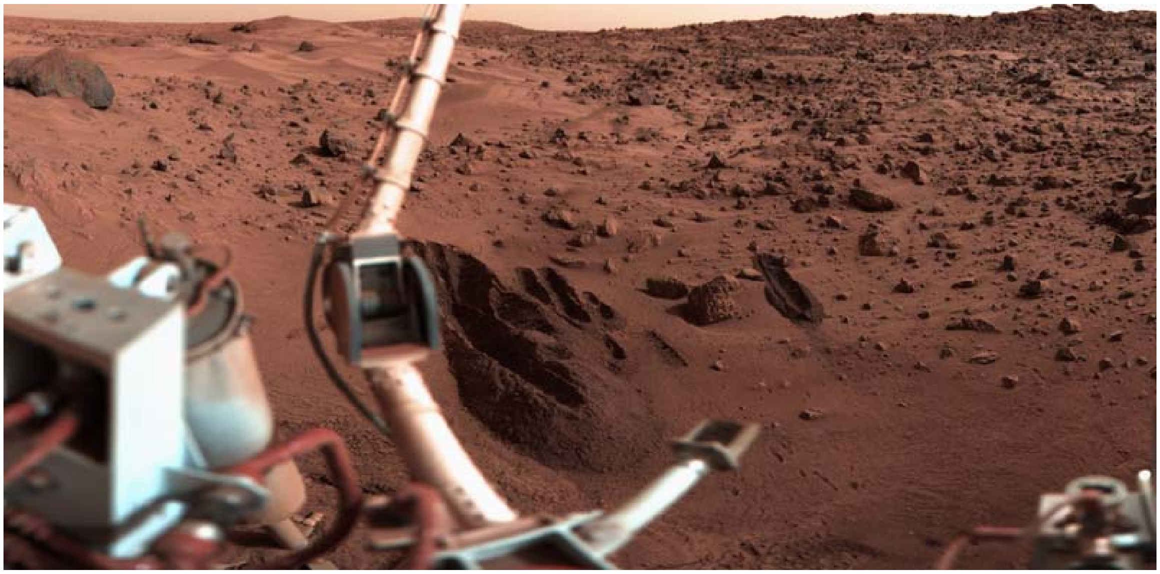
Control systems

The Viking landers used a Guidance, Control and Sequencing Computer (GCSC) consisting of two Honeywell HDC 402 24-bit computers with 18K of plated-wire memory, while the Viking orbiters used a Command Computer Subsystem (CCS) using two custom-designed 18-bit bit-serial processors.

Biological experiments



Dust dunes and a large boulder taken by the Viking 1 lander



Trenches dug by the soil sampler of the Viking 1 lander

The Viking landers conducted biological experiments designed to detect life in the Martian soil (if it existed) with experiments designed by three separate teams, under the direction of chief scientist Gerald Soffen of NASA. One experiment turned positive for the detection of metabolism (current life), but based on the results of another test that failed to reveal any organic molecules in the soil, most scientists became convinced that the positive results were likely caused by non-biological chemical reactions from highly oxidizing soil conditions.

Although there is general consensus that the Viking Lander results demonstrated a lack of robust microorganism biotas in soils at the two landing sites, the test results and their limitations are still under assessment. The validity of the positive 'Labeled Release' (LR) results hinged entirely on the absence of an oxidative agent in the Martian soil, but one was recently discovered by the Phoenix lander in the form of perchlorate salts. The question of microbial life on Mars remains unresolved.

Research, published in the Journal of Geophysical Research in December 2010, proposed that organic compounds could have been present in the soil analyzed by both Viking 1 and 2. NASA's Phoenix lander in 2008 detected perchlorate which can break down organic compounds. The study's authors found that perchlorate will destroy organics when heated and will produce chloromethane and dichloromethane, the identical chlorine compounds discovered by both Viking landers when they performed the same tests on Mars. Because perchlorate would have broken down any Martian organics, the question of life on Mars becomes more probable.

Mission end

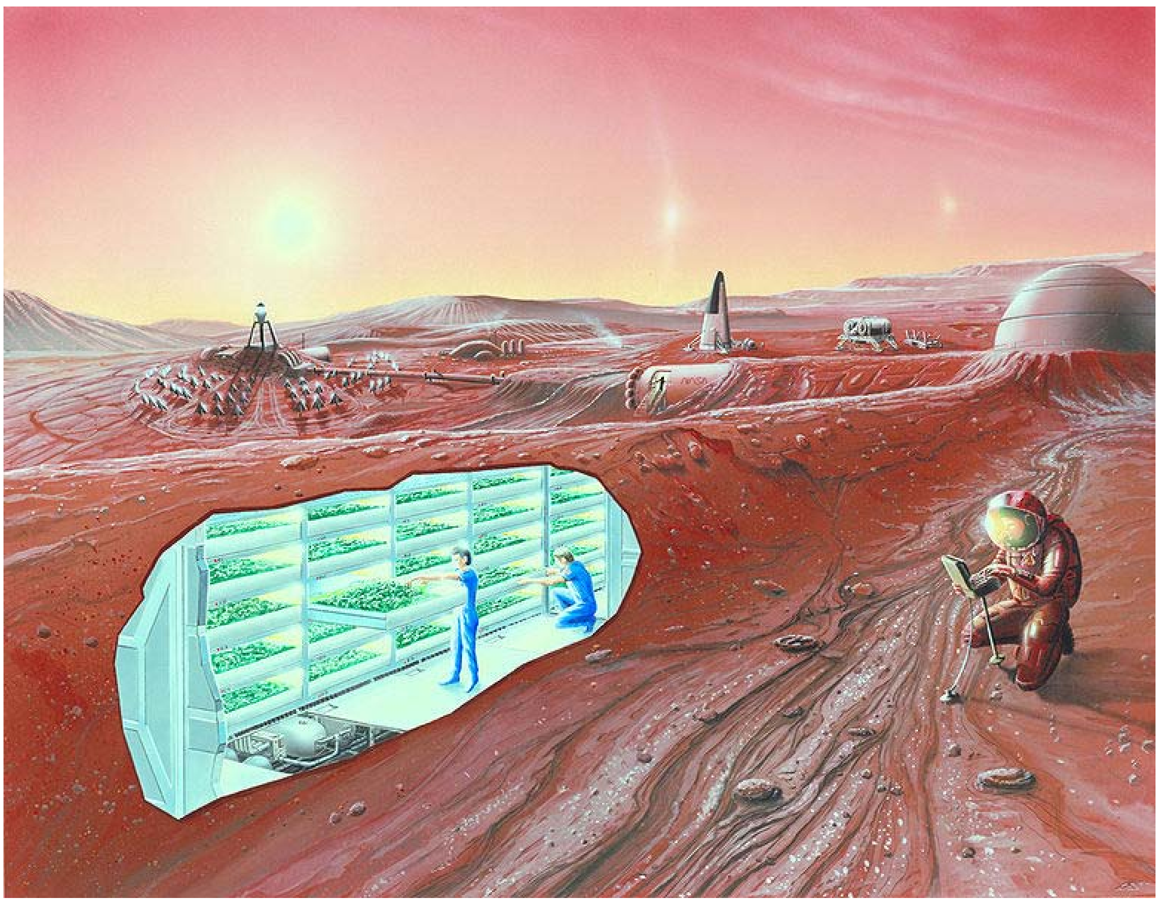
The crafts eventually failed, one by one, as follows:

Craft	Arrival date	Shut-off date	Operational lifetime	Cause of failure
Viking 2 orbiter	August 7, 1976	July 25, 1978	1 year, 11 months, 18 days	Shut down after fuel leak in propulsion system.
Viking 2 lander	September 3, 1976	April 11, 1980	3 years, 7 months, 8 days	Battery failure.
Viking 1 orbiter	June 19, 1976	August 17, 1980	4 years, 1 month, 19 days	Shut down after depletion of attitude control fuel
Viking 1 lander	July 20, 1976	November 13, 1982	6 years, 3 months, 22 days	Human error during software update that caused the antenna to go down causing the termination of communication with the lander.

The whole of the Viking program was finally shut down on May 21, 1983.

Chapter 10

Colonization of Mars



An artist's conception of the colonization of Mars, with a cutaway showing part of the interior (NASA Ames, 2005)

The **colonization of Mars** by humans is the focus of speculation and serious study because the surface conditions and availability of water on Mars make it arguably the most hospitable planet in the solar system other than Earth. The Moon has been proposed as the first location for human colonization but Mars has an atmosphere, giving it the potential capacity to host human and other organic life.

Relative similarity to Earth

The Earth is very like its "sister planet" Venus in bulk composition, size and surface gravity but Mars' similarities to Earth are arguably more compelling when considering colonization. These include:

- The Martian day (or **sol**) is very close to Earth's. A Mars solar day is 24 hours 39 minutes 35.244 seconds.

- Mars has a surface area that is 28.4% of Earth's, only slightly less than the amount of dry land on Earth (which is 29.2% of Earth's surface). Mars has half the radius of Earth and only one-tenth the mass. This means that it has a smaller volume (~15%) and lower average density than Earth.

- Mars has an axial tilt of 25.19°, compared with Earth's 23.44°. As a result, Mars has seasons much like Earth, though they last nearly twice as long because the Martian year is about 1.88 Earth years. The Martian north pole currently points at Cygnus, not Ursa Minor.

- Mars has an atmosphere. Although it is very thin (about 0.7% of Earth's atmosphere) it provides some protection from solar and cosmic radiation and has been used successfully for aerobraking of spacecraft.

- Recent observations by NASA's Mars Exploration Rovers, ESA's Mars Express and NASA's Phoenix Lander confirm the presence of water ice on Mars. Mars appears to have significant quantities of all the elements necessary to support Earth-based life.

Differences from Earth

- The surface gravity on Mars is 0.38 of that on Earth. It is not known if this is enough to prevent the health problems associated with weightlessness.

- Mars is much colder than Earth, with a mean surface temperature of -63°C and a low of -140°C. The lowest temperature ever recorded on Earth was −89.2°C, in Antarctica.

- There are no standing bodies of liquid water on the surface of Mars.

- Because Mars is further from the Sun, the amount of solar energy reaching the upper atmosphere (the solar constant) is less than half of what reaches the Earth's upper atmosphere or the Moon's surface. However, the solar energy that reaches the surface of Mars is not impeded by a thick atmosphere like on Earth.

- Mars' orbit is more eccentric than Earth's, exacerbating temperature and solar constant variations.

- The atmospheric pressure on Mars is ~6 mbar, far below the Armstrong Limit (61.8 mbar) at which people can survive without pressure suits. Since terraforming cannot be expected as a near-term solution, habitable structures on Mars would need to be constructed with pressure vessels similar to spacecraft, capable of containing a pressure between a third and a whole bar.

- The Martian atmosphere consists mainly of carbon dioxide. Because of this, even with the reduced atmospheric pressure, the partial pressure of CO_2 at the surface of Mars is some 52 times higher than on Earth. It also has significant levels of carbon monoxide.

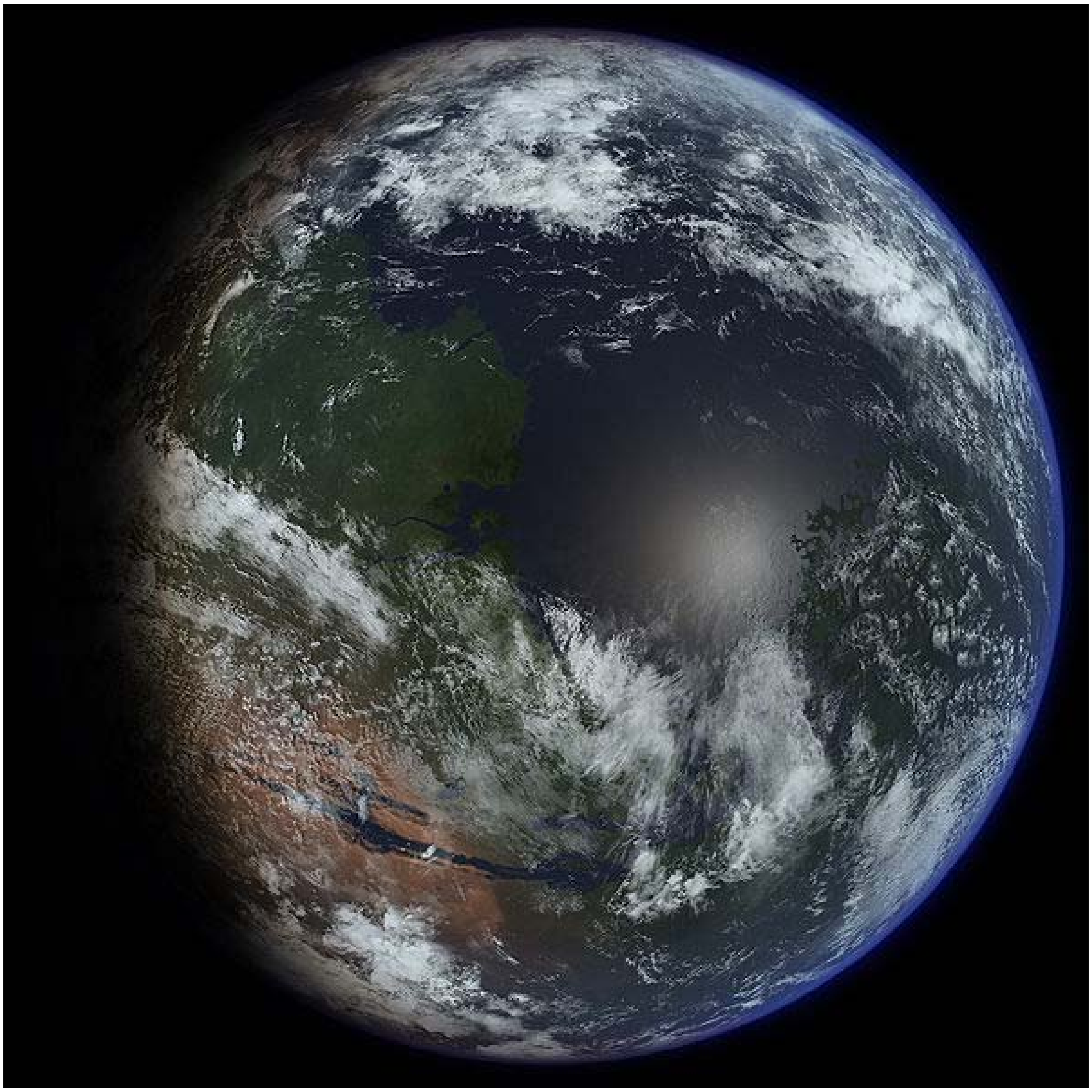
- Mars has a very weak magnetosphere, so it deflects solar winds poorly.

Habitability

Conditions on the surface of Mars are much closer to habitability than the surface of any other known planet or moon, as seen by the extremely hot and cold temperatures on Mercury, the furnace-hot surface of Venus, or the cryogenic cold of the outer planets and their moons. Only the cloud tops of Venus are closer in terms of habitability to Earth than Mars is. There are natural settings on Earth where humans have explored that match most conditions on Mars. The highest altitude reached by a manned balloon ascent, a record set in May 1961, was 34,668 meters (113,740 feet). The pressure at that altitude is about the same as on the surface of Mars. Extreme cold in the Arctic and Antarctic match all but the most extreme temperatures on Mars.

NASA Deputy Administrator Shana Dale said, "We also hope to discover if Mars can provide a second home for humans—an extension of our civilization—40 million miles from Earth."

Terraforming



An artist's conception of a terraformed Mars (2009)

It may be possible to terraform Mars to allow a wide variety of living things, including humans, to survive unaided on Mars' surface.

Radiation

Mars has no global magnetic field comparable to Earth's geomagnetic field. Combined with a thin atmosphere, this permits a significant amount of ionizing radiation to reach the Martian surface. The Mars Odyssey spacecraft carried an instrument, the Mars Radiation Environment Experiment (MARIE), to measure the dangers to humans. MARIE found that radiation levels in orbit above Mars are 2.5 times higher than at the

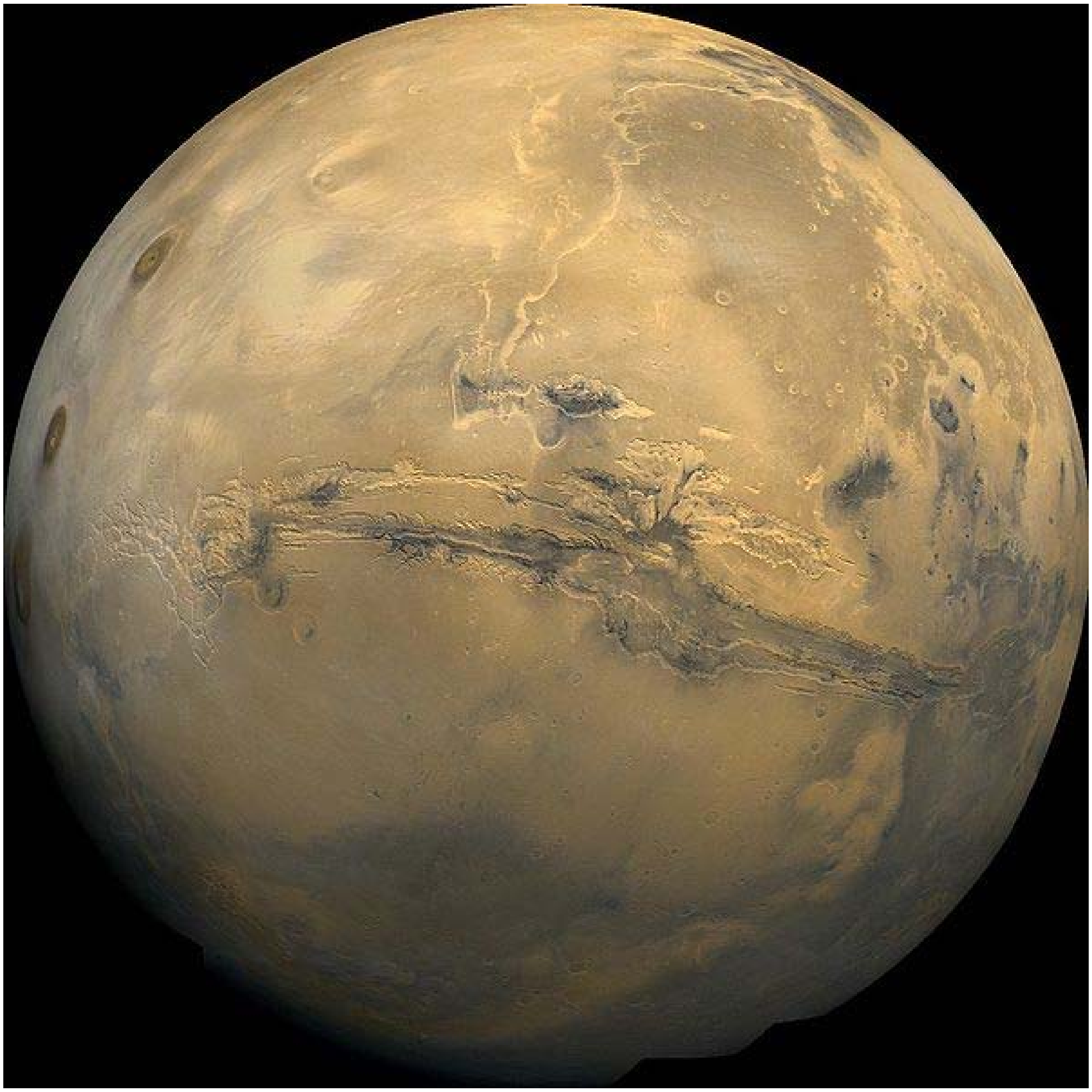
International Space Station. Average doses were about 22 millirads per day (220 micrograys per day or 0.08 gray per year.) A three year exposure to such levels would be close to the safety limits currently adopted by NASA. Levels at the Martian surface would be somewhat lower and might vary significantly at different locations depending on altitude and local magnetic fields.

Occasional solar proton events (SPEs) produce much higher doses. Some SPEs were observed by MARIE that were not seen by sensors near Earth due to the fact that SPEs are directional, making it difficult to warn astronauts on Mars early enough.

Much remains to be learned about space radiation. In 2003, NASA's Lyndon B. Johnson Space Center opened a facility, the NASA Space Radiation Laboratory, at Brookhaven National Laboratory that employs particle accelerators to simulate space radiation. The facility will study its effects on living organisms along with shielding techniques. There is some evidence that this kind of low level, chronic radiation is not quite as dangerous as once thought; and that radiation hormesis occurs. The consensus among those that have studied the issues is that radiation levels, with the exception of the SPEs, that would be experienced on the surface of Mars, and while journeying there, are certainly a concern, but are not thought to prevent a trip from being made with current technology.

Transportation

Interplanetary spaceflight



Mars (Viking 1, 1980)

Mars requires less energy per unit mass (delta V) to reach from Earth than any planet except Venus. Using a Hohmann transfer orbit, a trip to Mars requires approximately nine months in space . Modified transfer trajectories that cut the travel time down to seven or six months in space are possible with incrementally higher amounts of energy and fuel compared to a Hohmann transfer orbit, and are in standard use for robotic Mars missions. Shortening the travel time below about six months requires higher delta-v and an exponentially increasing amount of fuel, and is not feasible with chemical rockets, but would be perfectly feasible with advanced spacecraft propulsion technologies, some of which have already been tested, such as VASIMR, and nuclear rockets, in the formers case, a trip time of forty days could be attainable, and in the latter, a trip time down to about two weeks. Another possibility is constant-acceleration technologies such as space proven solar sails and ion drives which permits passage times at close approaches on the order of several weeks. Both of these propulsion systems have been deployed and could readily obtain a constant acceleration of 0.1g.

During the journey the astronauts are subject to radiation, which requires a means to protect them. Cosmic radiation and solar wind cause DNA damage, which increases the risk of cancer significantly. The effect of long term space travel in the interplanetary space is unknown, but scientists estimate up to 19% probability for male persons to die of cancer because of the radiation during the journey to Mars and back to Earth. Together with the base probability of 20% for a male person on Earth to die from cancer this gives a probability of 39%. For women the probability is even higher due to their larger glandular tissues.

Landing on Mars

Mars has a gravity 0.38 times that of the Earth and the density of its atmosphere is 1% of that on Earth. The relatively strong gravity and the presence of aerodynamic effects makes it difficult to land heavy, crewed spacecraft with thrusters only as was done with the Apollo moon landings, yet the atmosphere is too thin for aerodynamic effects to be of much help in braking and landing a large vehicle. Landing piloted missions on Mars will require braking and landing systems different from anything used to land crewed spacecraft on the Moon or robotic missions on Mars.

If one assumes carbon nanotube construction material will be available with a strength of 130 GPa then a space elevator could be built to land men and material on Mars. A space elevator on Phobos has also been proposed.

Communication

Communications with Earth are relatively straightforward during the half-sol when the Earth is above the Martian horizon. NASA and ESA included communications relay equipment in several of the Mars orbiters, so Mars already has communications satellites. While these will eventually wear out, additional orbiters with communication relay capability are likely to be launched before any colonization expeditions are mounted.

The one-way communication delay due to the speed of light ranges from about 3 minutes at closest approach (approximated by perihelion of Mars minus aphelion of Earth) to 22 minutes at the largest possible superior conjunction (approximated by aphelion of Mars plus aphelion of Earth). Telephone conversations or Internet Relay Chat between Earth and Mars would be highly impractical due to the long time lags involved. NASA has found that direct communication can be blocked for about two weeks every synodic period, around the time of superior conjunction when the Sun is directly between Mars and Earth, although the actual duration of the communications blackout varies from mission to mission depending on various factors - such as the amount of link margin designed into the communications system, and the minimum data rate that is acceptable from a mission standpoint. In reality most missions at Mars have had communications blackout periods of the order of a month.

A satellite at either of the Earth-Sun L_4/L_5 Lagrange points could serve as a relay during this period to solve the problem; even a constellation of communications satellites would be a minor expense in the context of a full colonization program. However the size and power of the equipment needed for these distances make the L4 and L5 locations unrealistic for relay stations, and the inherent stability of these regions, while beneficial in terms of station-keeping, also attracts asteroids, which could pose a severe risk to any satellite.

Recent work by the University of Strathclyde's Advanced Space Concepts Laboratory, in collaboration with the European Space Agency, has suggested an alternative relay architecture based on highly non-Keplerian orbits. These are a special kind of orbit produced when continuous low-thrust propulsion, such as that produced from an ion engine or solar sail, modifies the natural trajectory of a spacecraft. Such an orbit would enable continuous communications during solar conjunction by allowing a relay spacecraft to "hover" above Mars, out of the orbital plane of the two planets. Such a relay avoids the problems of satellites stationed at either L4 or L5 by being significantly closer to the surface of Mars while still maintaining continuous communication between the two planets.

Robotic precursors

The path to a human colony could be prepared by robotic systems such as the Mars Exploration Rovers *Spirit* and *Opportunity*. These systems could help locate resources, such as ground water or ice, that would help a colony grow and thrive. The lifetimes of these systems would be measured in years and even decades, and as recent developments in commercial spaceflight have shown, it may be that these systems will involve private as well as government ownership. These robotic systems also have a reduced cost compared with early crewed operations, and have less political risk.

Wired systems might lay the groundwork for early crewed landings and bases, by producing various consumables including fuel, oxidizers, water, and construction materials. Establishing power, communications, shelter, heating, and manufacturing basics can begin with robotic systems, if only as a prelude to crewed operations.

Early human missions

Early human missions to Mars, such as those being tentatively planned by NASA, FKA and ESA would not be direct precursors to colonization. They are intended solely as exploration missions, as the *Apollo* missions to the Moon were not planned to be sites of a permanent base.

Colonization requires the establishment of permanent bases that have potential for self-expansion. A famous proposal for building such bases is the Mars Direct plan, advocated by Robert Zubrin. The Mars Society has established the Mars Analogue Research Station Programme at sites Devon Island in Canada and in Utah, United States, to experiment with different plans for human operations on Mars, based on Mars Direct. Modern Martian architecture concepts often include facilities to produce oxygen and propellant on the surface of the planet.

Economics

As with early colonies in the New World, economics would be a crucial aspect to a colony's success. The reduced gravity well of Mars and its position in the solar system may facilitate Mars-Earth trade and provide the rationalization for continued settlement of the planet.

Mars' reduced gravity together with its rotation rate makes it possible for the construction of a space elevator with today's materials, although the low orbit of Phobos could present engineering challenges. If constructed, the elevator could transport minerals and other natural resources extracted from the planet.

A major economic problem is the enormous up-front investment required to establish the colony and perhaps also terraform the planet.

Some early Mars colonies might specialize in developing local resources for Martian consumption, such as water and/or ice.

Another main inter-Martian trade good during early colonization could be manure. Assuming that life doesn't exist on Mars, the soil is going to be very poor for growing plants, so manure and other fertilizers will be valued highly in any Martian civilization until the planet changes enough chemically to support growing vegetation on its own.

Solar power is a candidate for power for a Martian colony. Solar insolation (the amount of solar radiation that reaches Mars) is about 42% of that on Earth, since Mars is about 52% farther from the Sun and insolation falls off as the square of distance. But the thin atmosphere would allow almost all of that energy to reach the surface as compared to Earth, where the atmosphere absorbs roughly a quarter of the solar radiation.

Nuclear power is also a good candidate, since the fuel is very dense for cheap transportation from Earth. Nuclear power also produces heat, which would be extremely valuable to a Mars colony.

Heating requirements could be lowered if the colonists use domes to trap solar heat, especially for greenhouses.

Possible locations for colonies

Mars can be considered in broad regions for discussion of possible colony sites.

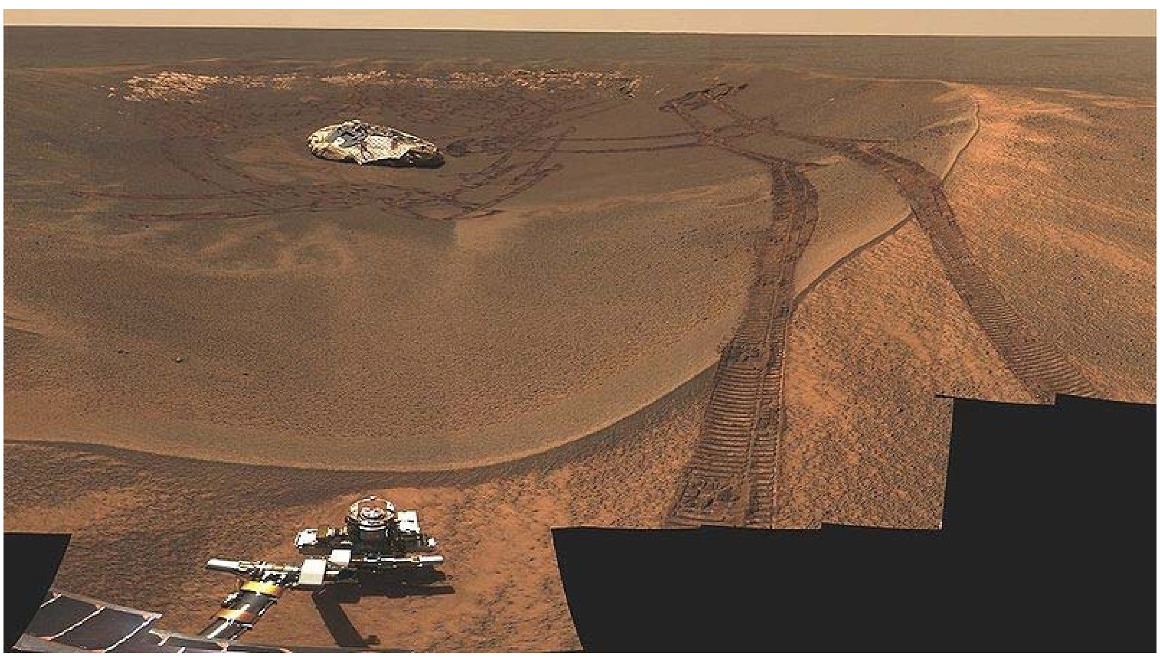
Polar regions

Mars' north and south poles once attracted great interest as colony sites because seasonally-varying polar ice caps have long been observed by telescope from Earth. Mars Odyssey found the largest concentration of water near the north pole, but also showed that water likely exists in lower latitudes as well, making the poles less compelling as a colony locale. Like Earth, Mars sees a midnight sun at the poles during local summer and polar night during local winter.

Equatorial regions

Mars Odyssey found what appear to be natural caves near the volcano Arsia Mons. It has been speculated that colonists could benefit from the shelter that these or similar structures could provide from radiation and micrometeoroids. Geothermal energy is also suspected in the equatorial regions.

Midlands



Eagle Crater, as seen from *Opportunity* (2004)

The exploration of Mars' surface is still underway. The two Mars Exploration Rovers, *Spirit* and *Opportunity*, have encountered very different soil and rock characteristics. This suggests that the Martian landscape is quite varied and the ideal location for a colony would be better determined when more data becomes available. As on Earth, seasonal variations in climate become greater with distance from the equator.

Valles Marineris

Valles Marineris, the "Grand Canyon" of Mars, is over 3,000 km long and averages 8 km deep. Atmospheric pressure at the bottom would be some 25% higher than the surface average, 0.9 kPa vs 0.7 kPa. The canyon runs roughly east-west, so shadows from its walls should not interfere too badly with solar power collection. River channels lead to the canyon, indicating it was once flooded.

Lava Tubes

Several lava tube skylights on Mars have been located. Earth based examples indicate that some should have lengthy passages offering complete protection from radiation and be relatively easy to seal using on site materials, especially in small subsections.

Advocacy

Making Mars colonization a reality is advocated by several groups with different reasons and proposals. One of the oldest is the Mars Society. They promote a NASA program to accomplish human exploration of Mars and have set up Mars analog research stations in Canada and the United States. Another group is Marsdrive, which is dedicated to private initiatives for the exploration and settlement of Mars.

Concerns

Besides the general criticism of human colonization of space, there are specific concerns about a colony on Mars:

- Mars has a gravity 0.38 times that of the Earth and a density of the atmosphere of 1% that on Earth. The stronger gravity than the Moon and the presence of aerodynamic effects makes it more difficult to land heavy, crewed spacecraft with thrusters only, yet the atmosphere is also too thin to get very much use out of aerodynamic effects for braking and landing. Landing piloted missions on Mars will require a braking and landing system different from anything used to land crewed spacecraft on the Moon or robotic missions on Mars.

- The question of whether life once existed or exists now on Mars has not been settled, raising concerns about possible contamination of the planet with Earth life.

- Advocates of a return to the Moon say the Moon is a more logical first location for a first planetary colony, perhaps using it as practice for future manned missions to Mars. However, in several ways experience gained on the moon would not be applicable to the task of colonizing Mars. The moon has no atmosphere, no analogous geology and a much greater temperature range and rotational period. These differences make Mars more in common with Earth than the Moon. Antarctica or desert areas of Earth provide much better training grounds at vastly lesser cost. Also, the Moon is extremely poor in several of the key elements required for life, most notably hydrogen, nitrogen and carbon (50 – 100 ppm) , and has only 47.2% of the delta-v requirement for launching to orbit that Mars has.

- It is unknown whether Martian gravity can support human life in the long term (all experience is at either ~1g or zero gravity). Space medicine researchers have theorized on whether the health benefits of gravity rise slowly or quickly between weightlessness and full Earth gravity. One theory is that sleeping chambers built inside centrifuges would minimize the health problems. The Mars Gravity Biosatellite experiment was due to become the first experiment testing the effects of partial gravity, artificially generated at 0.38 *g* to match Mars gravity, on mammal life, specifically on mice, throughout the life cycle from conception to death. However, in 2009 the Biosatellite project was cancelled due to lack of funds.

- Mars' escape velocity is 5 km/s, which, though less than half that for Earth, is reasonably high compared to the Moon's 2.38 km/s or the negligible escape velocity of most asteroids. This could make physical export trade from Mars to other planets and habitats less viable economically.

- There is likely to be little economic return from the colonization of Mars while Lunar and Near Earth Asteroid industry is likely to be exporting to Earth.

- Mars has dust storms which can reduce solar power. The largest of these storms can cover much of the planet.

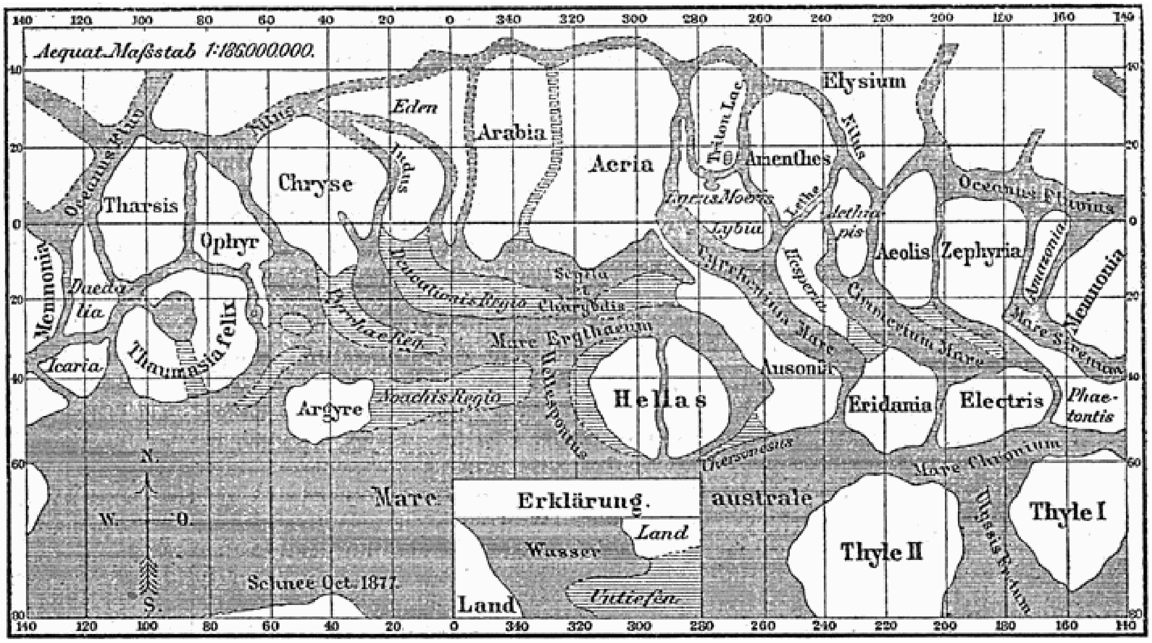
Chapter 11

Life on Mars

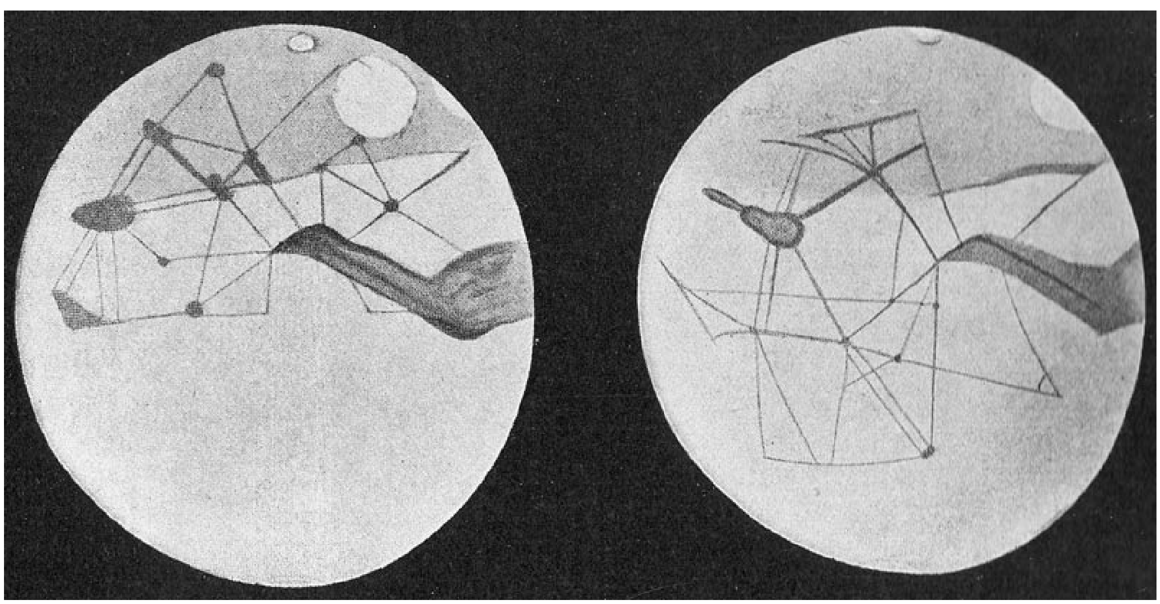
An artist's impression of what Mars' surface and atmosphere may look like if Mars were terraformed.

Scientists have long speculated about the possibility of **life on Mars** owing to the planet's proximity and similarity to Earth. Although fictional Martians have been a recurring feature of popular entertainment, it remains an open question whether life currently exists on Mars, or has existed there in the past.

Early speculation



Historical map of Mars from Giovanni Schiaparelli



Mars canals, as seen by astronomer P. Lowell, 1898

Mars' polar ice caps were observed as early as the mid-17th century, and they were first proven to grow and shrink alternately, in the summer and winter of each hemisphere, by William Herschel in the latter part of the 18th century. By the mid-19th century, astronomers knew that Mars had certain other similarities to Earth, for example that the length of a day on Mars was almost the same as a day on Earth. They also knew that its axial tilt was similar to Earth's, which meant it experienced seasons just as Earth does -

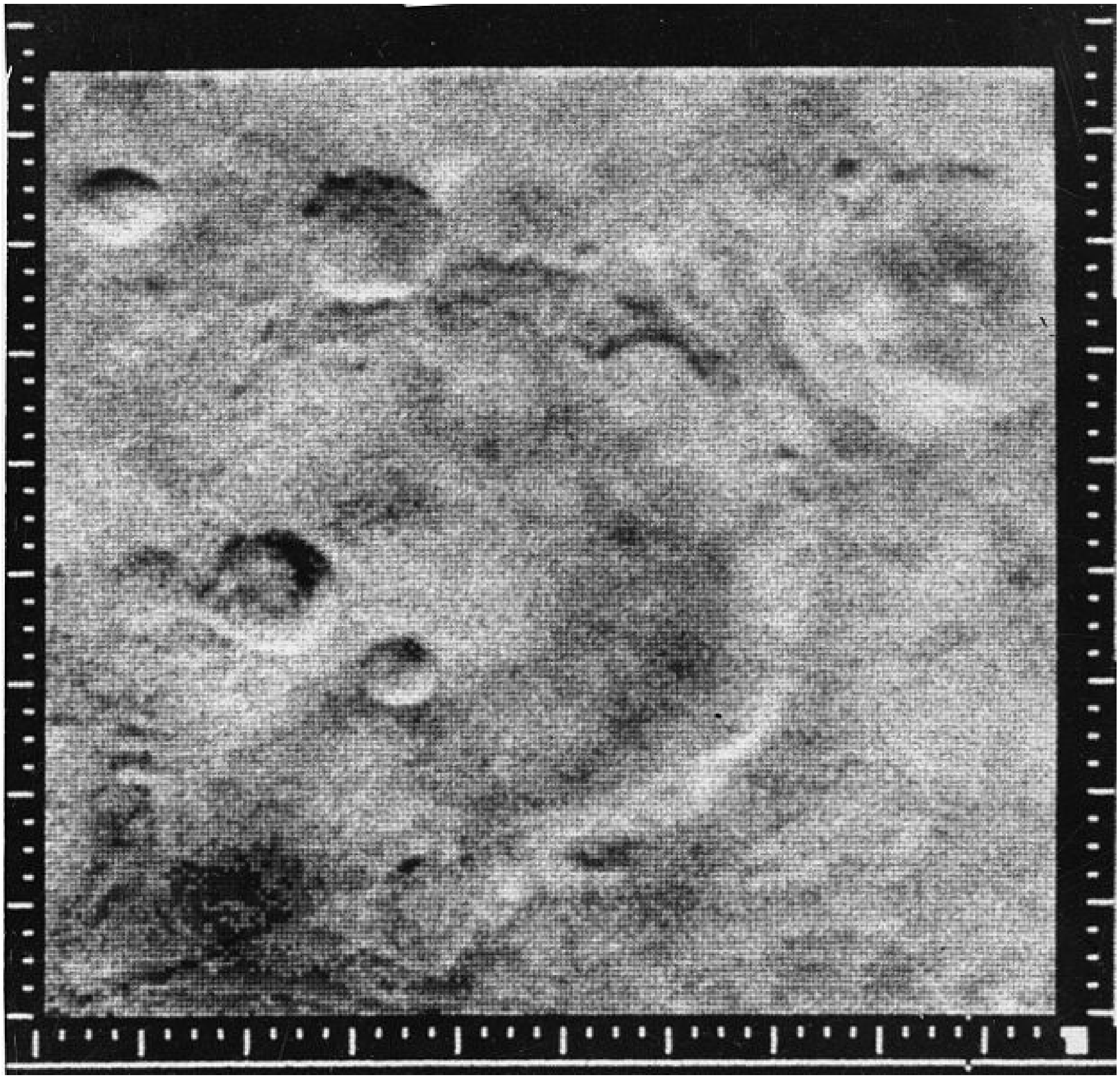
but of nearly double the length owing to its much longer year. These observations led to the increase in speculation that the darker albedo features were water, and brighter ones were land. It was therefore natural to suppose that Mars may be inhabited by some form of life.

In 1854, William Whewell, a fellow of Trinity College, Cambridge, who popularized the word *scientist,* theorized that Mars had seas, land and possibly life forms. Speculation about life on Mars exploded in the late 19th century, following telescopic observation by some observers of apparent Martian canals — which were however soon found to be optical illusions. Despite this, in 1895, American astronomer Percival Lowell published his book *Mars,* followed by *Mars and its Canals* in 1906, proposing that the canals were the work of a long-gone civilization. This idea led British writer H. G. Wells to write *The War of the Worlds* in 1897, telling of an invasion by aliens from Mars who were fleeing the planet's desiccation.

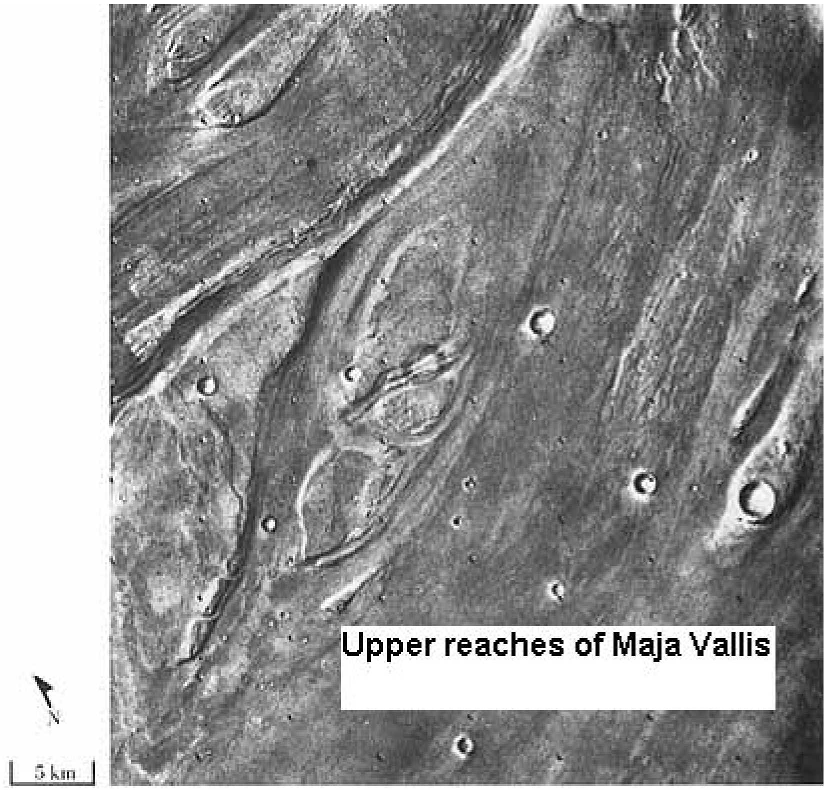
Spectroscopic analysis of Mars' atmosphere began in earnest in 1894, when U.S. astronomer William Wallace Campbell showed that neither water nor oxygen were present in the Martian atmosphere. By 1909 better telescopes and the best perihelic opposition of Mars since 1877 conclusively put an end to the canal theory.

Missions

Mariner 4



Mariner Crater, as seen by Mariner 4 in 1965. Pictures like this suggested that Mars is too dry for any kind of life.



Streamlined Islands seen by Viking orbiter showed that large floods occurred on Mars. Image is located in Lunae Palus quadrangle.

Mariner 4 probe performed the first successful flyby of the planet Mars, returning the first pictures of the Martian surface in 1965. The photographs showed an arid Mars without rivers, oceans or any signs of life. Further, it revealed that the surface (at least the parts that it photographed) was covered in craters, indicating a lack of plate tectonics and weathering of any kind for the last 4 billion years. The probe also found that Mars has no global magnetic field that would protect the planet from potentially life-threatening cosmic rays. The probe was able to calculate the atmospheric pressure on the planet to be about 0.6 kPa (compared to Earth's 101.3 kPa), meaning that liquid water could not exist on the planet's surface. After Mariner 4, the search for life on Mars changed to a search for bacteria-like living organisms rather than for multicellular organisms, as the environment was clearly too harsh for these.

Viking orbiters

Liquid water is necessary for life and metabolism, so if water was present on Mars, the chances of it having supported life may have been determinant. The Viking orbiters found evidence of possible river valleys in many areas, erosion and, in the southern hemisphere, branched streams.

Carl Sagan poses next to a replica of the Viking landers

Viking experiments

The primary mission of the Viking probes of the mid-1970s was to carry out experiments designed to detect microorganisms in Martian soil. The tests were formulated to look for life similar to that found on Earth. Of the four experiments, only the Labeled Release (LR) experiment returned a positive result, showing increased $^{14}CO_2$ production on first exposure of soil to water and nutrients. All scientists agree on two points from the Viking missions: that radiolabeled $^{14}CO_2$ was evolved in the Labeled Release experiment, and that the GC-MS detected no organic molecules. However, there are vastly different interpretations of what those results imply.

One of the designers of the Labeled Release experiment, Gilbert Levin, believes his results are a definitive diagnostic for life on Mars. However, this result is disputed by many scientists, who argue that superoxidant chemicals in the soil could have produced this effect without life being present. An almost general consensus discarded the Labeled Release data as evidence of life, because the gas chromatograph & mass spectrometer, designed to identify natural organic matter, did not detect organic molecules. The results of the Viking mission concerning life are considered by the general expert community, at best, as inconclusive.

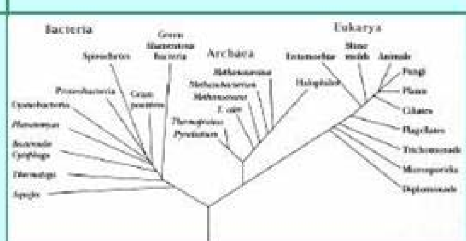
In 2007, during a Seminar of the Geophysical Laboratory of the Carnegie Institution (Washington, D.C., USA), Gilbert Levin's investigation was assessed once more. Levin maintains that his original data were correct, as the positive and negative control experiments were in order.

Ronald Paepe, an edaphologist (soil scientist), communicated to the European Geosciences Union Congress that the discovery of the recent detection of phyllosilicate clays on Mars may indicate pedogenesis, or soil development processes, extended over the entire surface of Mars. Paepe's interpretation views most of Mars surface as active soil, colored red by eons of widespread wearing by water, vegetation and microbial activity.

A research team from the Salk Institute for Biological Studies headed by Rafael Navarro-González, concluded that the equipment used (TV-GC-MS) by the Viking program to search for organic molecules, may not be sensitive enough to detect low levels of organics. Because of the simplicity of sample handling, TV–GC–MS is still considered the standard method for organic detection on future Mars missions, Navarro-González suggests that the design of future organic instruments for Mars should include other methods of detection.

Gillevinia straata

Table 2: Life's major domains (*) and formal systematic position of the active agent characterized by its reported behavior as responsible of the results of the 1976 Viking Mission's Labeled Release experiment.

Organic Life System	Biosphere	Domains	Middle taxa	Known Genera & Species
Solaria	Terrestria		...	Many
	Marciana	Jakobia	...	Levinia straata

* Observational knowledge about Solaria's biospheres is unbalanced; about extra-Solaria biospheres, unexisting.

Newly proposed taxonomic system

The claim for life on Mars, in the form of *Gillevinia straata*, is based on old data reinterpreted as sufficient evidence of life, mainly by professors Gilbert Levin, Rafael Navarro-González and Ronalds Paepe. The evidence supporting the existence of *Gillevinia straata* microorganisms relies on the data collected by the two Mars *Viking* landers that searched for biosignatures of life, but the analytical results were, officially, inconclusive.

In 2006, Mario Crocco, a neurobiologist at the Neuropsychiatric Hospital Borda in Buenos Aires, Argentina, proposed the creation of a new nomenclatural rank that classified the Viking landers' results as 'metabolic' and therefore belonging to a form of life. Crocco proposed to create new biological ranking categories (taxa), in the new kingdom system of life, in order to be able to accommodate the genus of Martian microorganisms. Crocco proposed the following taxonomical entry:

- Organic life system: Solaria
- Biosphere: Marciana
- Kingdom: Jakobia (named after neurobiologist Christfried Jakob)
- Genus et species: *Gillevinia straata*

As a result, the hypothetical *Gillevinia straata* would not be a bacterium (which rather is a terrestrial taxon) but a member of the kingdom 'Jakobia' in the biosphere 'Marciana' of the 'Solaria' system. The intended effect of the new nomenclature was to reverse the burden of proof concerning the life issue, but the taxonomy proposed by Crocco has not been accepted by the scientific community and is considered a single *nomen nudum*. Further, no Mars mission has found traces of biomolecules.

An artist's concept of the Phoenix spacecraft

Phoenix lander, 2008

The Phoenix mission landed a robotic spacecraft in the polar region of Mars on May 25, 2008 and it operated until November 10, 2008. One of the mission's two primary objectives was to search for a 'habitable zone' in the Martian regolith where microbial life could exist, the other main goal being to study the geological history of water on Mars. The lander has a 2.5 meter robotic arm that was capable of digging shalow trenches in the regolith. There is an electrochemistry experiment which analysed the ions in the regolith and the amount and type of antioxidants on Mars. The Viking program data indicate that oxidants on Mars may vary with latitude, noting that Viking 2 saw fewer oxidants than Viking 1 in its more northerly position. Phoenix landed further north still. Phoenix's preliminary data revealed that Mars soil contains perchlorate, and thus may not be as life-friendly as thought earlier. The pH and salinity level were viewed as benign from the standpoint of biology. The analysers also indicated the presence of bound water and CO_2.

Future missions

- Mars Science Laboratory, a NASA project planned for launch in late 2011, will contain instruments and experiments designed to look for past or present conditions relevant to biological activity.

- ExoMars is a European-led multi-spacecraft programme currently under development by the European Space Agency (ESA) and NASA for launch in 2016 and 2018. Its primary scientific mission will be to search for possible biosignatures on Mars, past or present. Two rovers with a 2 m core drill each will be used to sample various depths beneath the surface where liquid water may be found and where microorganisms might survive cosmic radiation.

- Mars Sample Return Mission — The best life detection experiment proposed is the examination on Earth of a soil sample from Mars. However, the difficulty of providing and maintaining life support over the months of transit from Mars to Earth remains to be solved. Providing for still unknown environmental and nutritional requirements is daunting. Should dead organisms be found in a sample, it would be difficult to conclude that those organisms were alive when obtained.

Meteorites

NASA maintains a catalog of 34 Mars meteorites. These assets are highly valuable since they are the only physical samples available of Mars. Studies conducted by NASA's Johnson Space Center show that at least three of the meteorites contain potential evidence of past life on Mars, in the form of microscopic structures resembling fossilized bacteria (so-called biomorphs). Although the scientific evidence collected is reliable, its interpretation varies. To date, none of the original lines of scientific evidence for the hypothesis that the biomorphs are of exobiological origin (the so-called biogenic hypothesis) have been either discredited or positively ascribed to non-biological explanations.

Over the past few decades, seven criteria have been established for the recognition of past life within terrestrial geologic samples. Those criteria are:

1. Is the geologic context of the sample compatible with past life?

2. Is the age of the sample and its stratigraphic location compatible with possible life?
3. Does the sample contain evidence of cellular morphology and colonies?
4. Is there any evidence of biominerals showing chemical or mineral disequilibria?
5. Is there any evidence of stable isotope patterns unique to biology?
6. Are there any organic biomarkers present?
7. Are the features indigenous to the sample?

For general acceptance of past life in a geologic sample, essentially most or all of these criteria must be met. All seven criteria have not yet been met for any of the Martian samples, but continued investigations are in progress.

As of 2010, reexaminations of the biomorphs found in the three Martian meteorites are underway with more advanced analytical instruments than previously available. The scientists conducting the study at Johnson Space Center believed that before the end of the year they would find in the meteorites definitive evidence for past life on Mars.

ALH84001 meteorite

An electron microscope reveals bacteria-like structures in meteorite fragment ALH84001

The ALH84001 meteorite was found on December 1984 on Antarctica, by members of the ANSMET project; the meteorite weighs 1.93 kilograms (4.3 lb). The sample was ejected from Mars about 17 million years ago and spent 11,000 years in or on the Antarctic ice sheets. Composition analysis by NASA revealed a kind of magnetite that on Earth, is only found in association with certain microorganisms; Then, in August 2002, another NASA team led by Thomas-Keptra published a study indicating that 25% of the magnetite in ALH 84001 occurs as small, uniform-sized crystals that, on Earth, is associated only with biologic activity, and that the remainder of the material appears to be normal inorganic magnetite. The extraction technique did not permit determination as to whether the possibly biological magnetite was organized into chains as would be expected. The meteorite displays indication of relatively low temperature secondary mineralization by water and show evidence of preterrestrial aqueous alteration. Evidence of polycyclic aromatic hydrocarbons (PAHs) have been identified with the levels increasing away from the surface.

Some structures resembling the mineralized casts of terrestrial bacteria and their appendages (fibrils) or by-products (extracellular polymeric substances) occur in the rims of carbonate globules and preterrestrial aqueous alteration regions. The size and shape of the objects is consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial.

In November 2009, NASA scientists said that a recent, more detailed analysis showed that the meteorite "contains strong evidence that life may have existed on ancient Mars".

Nakhla meteorite

Nakhla Meteorite

The Nakhla meteorite fell on Earth on June 28, 1911 on the locality of Nakhla, Alexandria, Egypt.

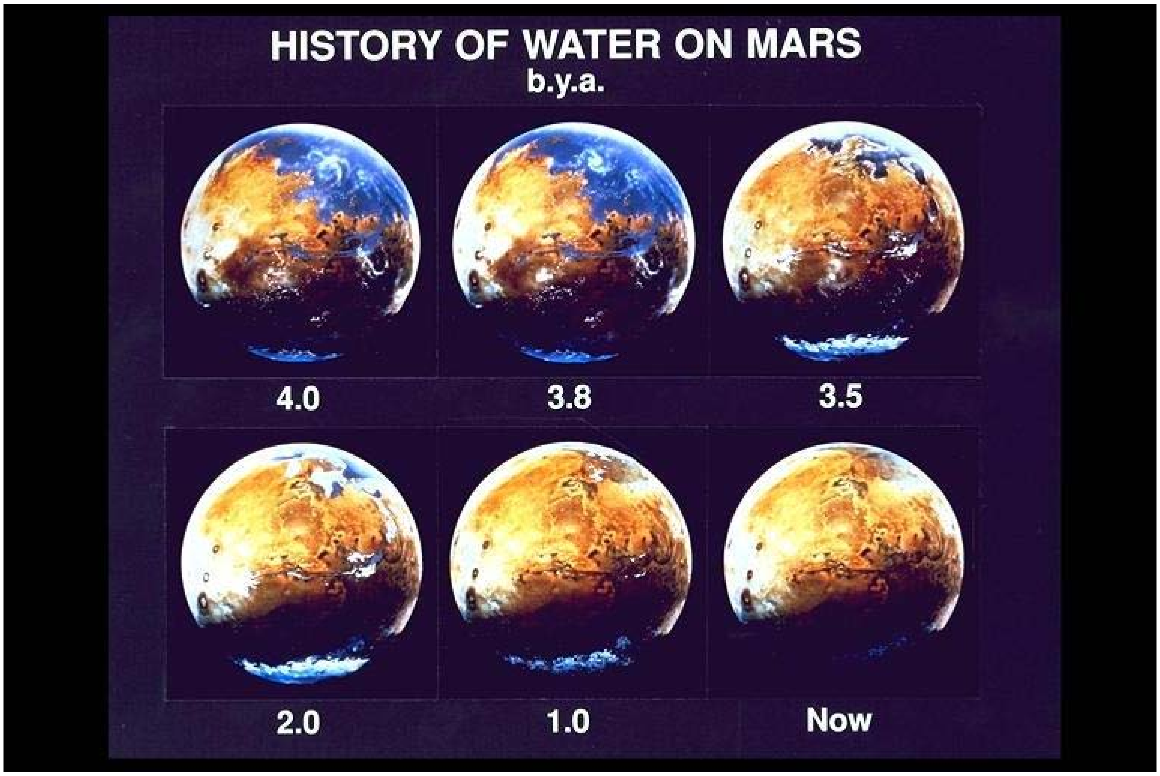
In 1998, a team from NASA's Johnson Space Center obtained a small sample for analysis. Researchers found preterrestrial aqueous alteration phases and objects of the size and shape consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial. Analysis with gas chromatography and mass spectrometry (GC-MS) studied its high molecular weight polycyclic aromatic hydrocarbons in 2000, and NASA scientists concluded that as much as 75% of the organic matter in Nakhla "may not be recent terrestrial contamination".

This caused additional interest in this meteorite, so on 2006, NASA managed to obtain an additional and larger sample from the London Natural History Museum. On this second sample, a large dendritic carbon content was observed. When the results and evidence were published on 2006, some independent researchers claimed that the carbon deposits are of biologic origin. However, it was remarked that since carbon is the fourth most abundant element in the Universe, finding it in curious patterns is not indicative or suggestive of biological origin.

Shergotty meteorite

The Shergotty meteorite, a 4 kg martian meteorite, fell on Earth on Shergotty, India on August 25, 1865 and was retrieved by witnesses almost immediately. This meteorite is relatively young, calculated to have been formed in Mars only 165 million years ago from volcanic origin. It is composed mostly of pyroxene and thought to have undergone preterrestrial aqueous alteration for several centuries. Certain features in its interior suggest to be remnants of biofilm and their associated microbial communities. Work is in progress on searching for magnetites within alteration phases.

Liquid water



A series of artist's conceptions of hypothetical past water coverage on Mars

No Mars probe since Viking has tested the Martian regolith specifically for metabolism which is the ultimate sign of current life. NASA's recent missions have focused on another question: whether Mars held lakes or oceans of liquid water on its surface in the ancient past. Scientists have found hematite, a mineral that forms in the presence of water. Thus, the mission of the Mars Exploration Rovers of 2004 was not to look for present or past life, but for evidence of liquid water on the surface of Mars in the planet's ancient past.

Since Mars lost most of its magnetic field about 4 billion years ago, the Martian ionosphere is unable to stop the solar wind or radiation, and it interacts directly with exposed soil, making life, as we know it, impossible to exist. Also, liquid water, necessary for life and for metabolism, cannot exist on the surface of Mars under its present low atmospheric pressure and temperature, except at the lowest shaded elevations for short periods and liquid water does not appear at the surface itself.

In June 2000, evidence for water currently under the surface of Mars was discovered in the form of flood-like gullies. Deep subsurface water deposits near the planet's liquid core might form a present-day habitat for life. However, in March 2006, astronomers announced the discovery of similar gullies on the Moon, which is believed never to have had liquid water on its surface. The astronomers suggest that the gullies could be the result of micrometeorite impacts.

In March 2004, NASA announced that its rover *Opportunity* had discovered evidence that Mars was, in the ancient past, a wet planet. This had raised hopes that evidence of past life might be found on the planet today. ESA confirmed that the Mars Express orbiter had directly detected huge reserves of water ice at Mars' south pole in January 2004.

On July 28, 2005, ESA announced that they had recorded photographic evidence of surface water ice near Mars' North pole.

In December 2006, NASA showed images taken by the Mars Global Surveyor that suggested that water occasionally flows on the surface of Mars. The images did not actually show flowing water. Rather, they showed changes in craters and sediment deposits, providing the strongest evidence yet that water coursed through them as recently as several years ago, and is perhaps doing so even now. Some researchers were skeptical that liquid water was responsible for the surface feature changes seen by the spacecraft. They said other materials such as sand or dust can flow like a liquid and produce similar results.

Recent analysis of Martian sandstones, using data obtained from orbital spectrometry, suggests that the waters that previously existed on the surface of Mars would have had too high a salinity to support most Earth-like life. Tosca *et al.* found that the Martian water in the locations they studied all had water activity, $a_w \leq 0.78$ to 0.86—a level fatal to most Terrestrial life. Haloarchaea, however, are able to live in hypersaline solutions, up to the saturation point.

The Phoenix Mars lander from NASA, which landed in the Mars Arctic plain in May 2008, confirmed the presence of frozen water near the surface. This was confirmed when bright material, exposed by the digging arm of the lander, was found to have vaporized and disappeared in 3 to 4 days. This has been attributed to sub-surface ice, exposed by the digging and sublimated on exposure to the atmosphere.

Methane

Trace amounts of methane in the atmosphere of Mars were discovered in 2003 and verified in 2004. The presence of methane indicates, as it is an unstable gas, that there must be an active source on the planet in order to keep such levels in the atmosphere. It is estimated that Mars must produce 270 ton/year of methane, but asteroid impacts account for only 0.8% of the total methane production. Although geologic sources of methane such as serpentinization are possible, the lack of current volcanism, hydrothermal activity or hotspots are not favorable for geologic methane. It has been suggested that the methane was produced by chemical reactions in meteorites, driven by the intense heat during entry through the atmosphere. However, research published in December 2009, ruled out this possibility.

The existence of life in the form of microorganisms such as methanogens are among possible but as yet unproven sources. If microscopic Martian life is producing the methane, it likely resides far below the surface, where it is still warm enough for liquid water to exist.

Since the 2003 discovery of methane in the atmosphere, some scientists have been designing models and *in vitro* experiments testing growth of methanogenic bacteria on simulated Martian soil, where all four methanogen strains tested produced substantial levels of methane, even in the presence of 1.0wt% perchlorate salt. The results reported indicate that the perchlorates discovered by the Phoenix Lander would not rule out the possible presence of methanogens on Mars.

A team led by Levin suggested that both phenomena—methane production and degradation—could be accounted for by an ecology of methane-producing and methane-consuming microorganisms.

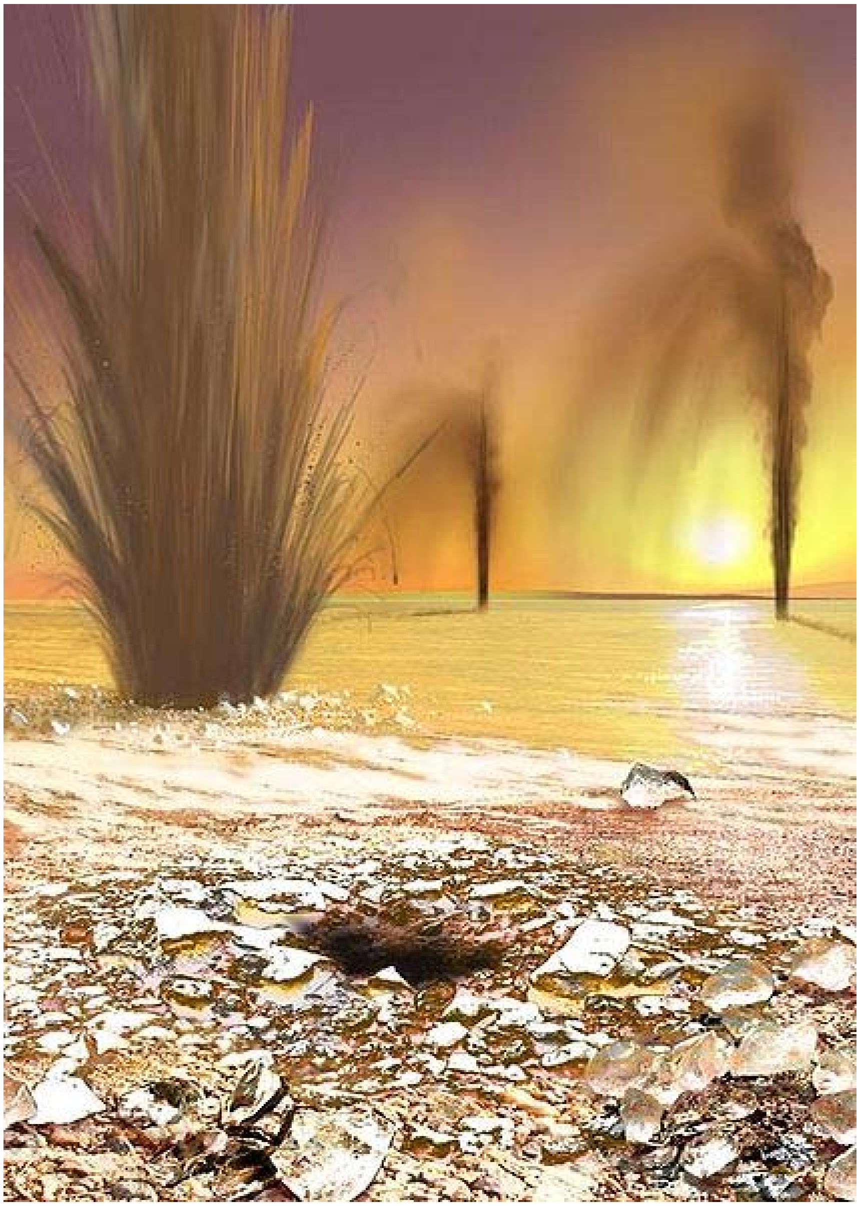
Formaldehyde

In February 2005, it was announced that the Planetary Fourier Spectrometer (PFS) on the European Space Agency's Mars Express Orbiter, detected traces of formaldehyde in the atmosphere of Mars. Vittorio Formisano, the director of the PFS, has speculated that the formaldehyde could be the byproduct of the oxidation of methane, and according to him, would provide evidence that Mars is either extremely geologically active, or harbouring colonies of microbial life. NASA scientists consider the preliminary findings are well worth a follow-up, but have also rejected the claims of life.

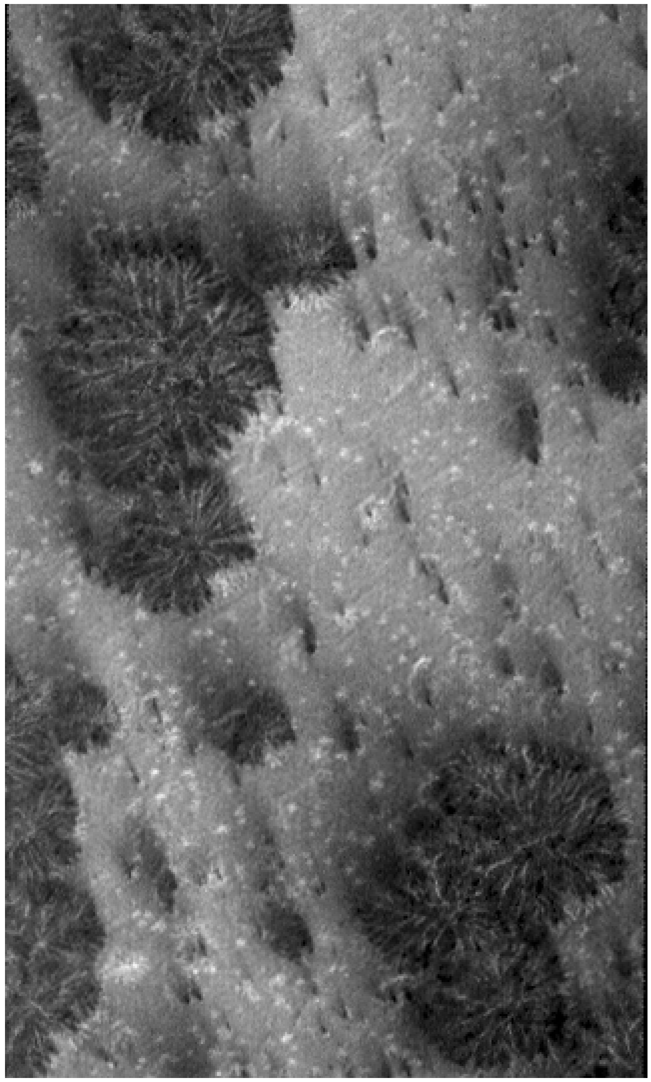
Silica

In May 2007, the Spirit rover disturbed a patch of ground with its inoperative wheel, uncovering an area extremely rich in silica (90%). The feature is reminiscent of the effect of hot spring water or steam coming into contact with volcanic rocks. Scientists consider this as evidence of a past environment that may have been favorable for microbial life, and theorize that one possible origin for the silica may have been produced by the interaction of soil with acid vapors produced by volcanic activity in the presence of water. Another possible origin could have been from water in a hot spring environment.

Geysers on Mars



Artist concept showing sand-laden jets erupt from geysers on Mars



Close up of dark dune spots, likely created by cold geyser-like eruptions

The seasonal frosting and defrosting of the southern ice cap results in the formation of spider-like radial channels carved on 1 meter thick ice by sunlight. Then, sublimed CO_2 - and probably water- increase pressure in their interior producing geyser-like eruptions of cold fluids often mixed with dark basaltic sand or mud. This process is rapid, observed happening in the space of a few days, weeks or months, a growth rate rather unusual in geology - especially for Mars.

A team of Hungarian scientists propose that the geysers' most visible features, dark dune spots and spider channels, may be colonies of photosynthetic Martian microorganisms, which over-winter beneath the ice cap, and as the sunlight returns to the pole during early spring, light penetrates the ice, the microorganisms photosynthesise and heat their immediate surroundings. A pocket of liquid water, which would normally evaporate instantly in the thin Martian atmosphere, is trapped around them by the overlying ice. As this ice layer thins, the microorganisms show through grey. When it has completely melted, they rapidly desiccate and turn black surrounded by a grey aureole. The Hungarian scientists believe that even a complex sublimation process is insufficient to explain the formation and evolution of the dark dune spots in space and time. Since their discovery, fiction writer Arthur C. Clarke promoted these formations as deserving of study from an astrobiological perspective.

A multinational European team suggests that if liquid water is present in the spiders' channels during their annual defrost cycle, they might provide a niche where certain microscopic life forms could have retreated and adapted while sheltered from solar radiation. A British team also considers the possibility that organic matter, microbes, or even simple plants might co-exist with these inorganic formations, especially if the mechanism includes liquid water and a geothermal energy source. However, they also remark that the majority of geological structures may be accounted for without invoking any organic "life on Mars" hypothesis.

Cosmic radiation

In 1965, the Mariner 4 probe discovered that Mars had no global magnetic field that would protect the planet from potentially life-threatening cosmic radiation and solar radiation; observations made in the late 1990s by the Mars Global Surveyor confirmed this discovery. Scientists speculate that the lack of magnetic shielding helped the solar wind blow away much of Mars's atmosphere over the course of several billion years.

In 2007, it was calculated that DNA and RNA damage by cosmic radiation would limit life on Mars to depths greater than 7.5 metres below the planet's surface. Therefore, the best potential locations for discovering life on Mars may be at subsurface environments that have not been studied yet.