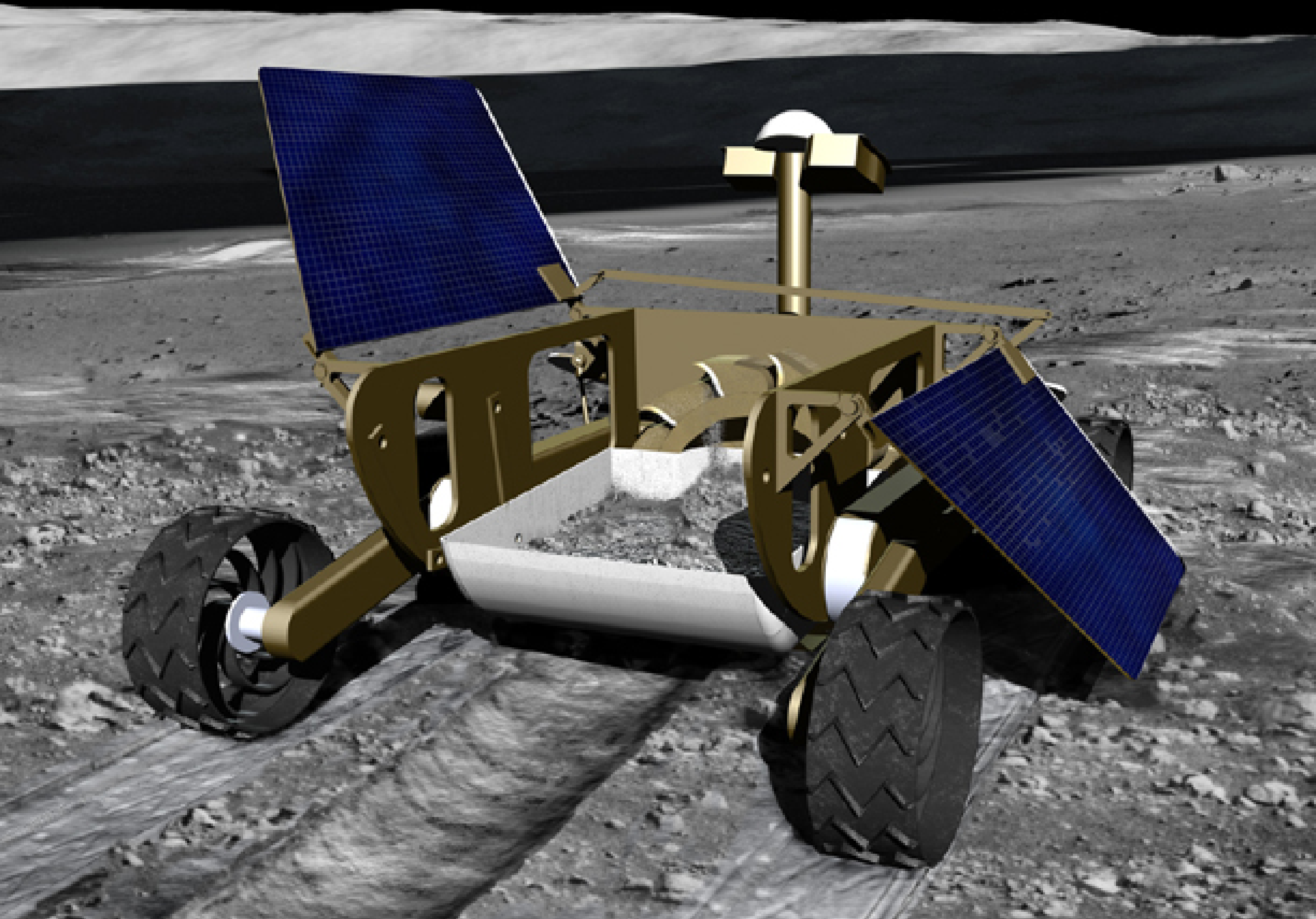
# Robotic Exploration of the Moon



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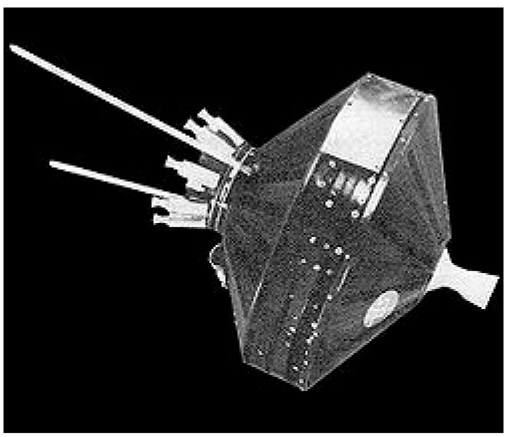
# Pioneer Program

## Pioneer 0

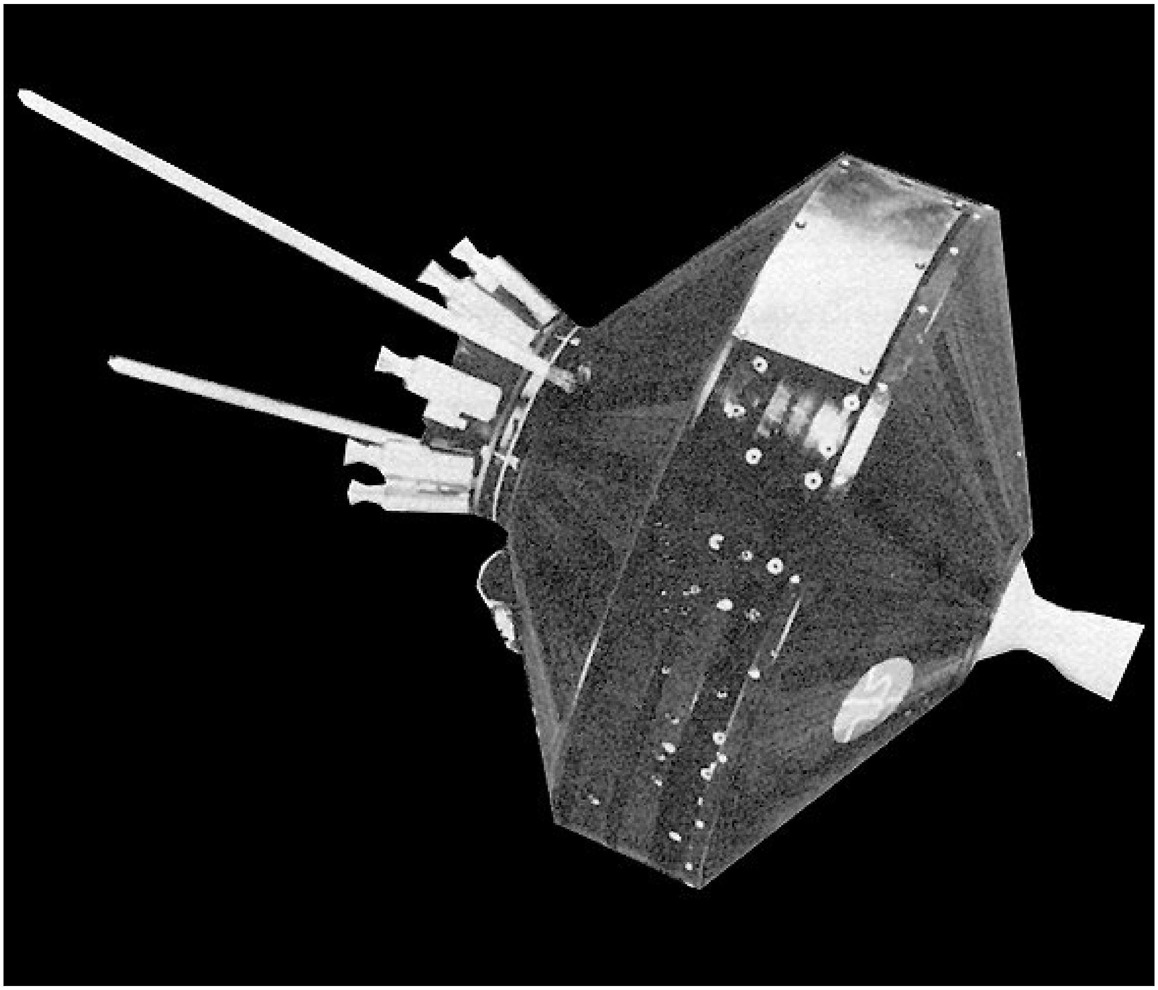
**Pioneer 0**



| | |
|---|---|
| **Operator** | United States Air Force |
| **Major contractors** | Space Technology Laboratories (TRW) |
| **Mission type** | Lunar orbiter |
| **Launch date** | August 17, 1958 |
| **Launch vehicle** | Thor-Able |
| **Launch site** | Cape Canaveral LC17A |
| **Mission duration** | 73.6 seconds |
| **Landing site** | |
| **COSPAR ID** | ABLE1 |

| | |
|---|---|
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 83.8 pounds (38.0 kg) |
| | **Orbital elements** |
| **Apoapsis** | 16 km |
| | **Instruments** |
| **Main instruments** | Television camera, magnetometer, micrometeoroid impact detector |

**Pioneer 0** (also known as **Thor-Able 1**) was a failed United States space probe that was designed to go into orbit around the Moon, carrying a television camera, a micrometeorite detector and a magnetometer, as part of the first International Geophysical Year (IGY) science payload. It was designed by the United States Air Force (USAF) as the first satellite in the Pioneer program and was one of the first attempted launches beyond Earth orbit by any country, but the rocket failed shortly after launch. The probe was intended to be called Pioneer (or Pioneer 1), but the launch failure precluded that name.



## Spacecraft design

The spacecraft consisted of a thin cylindrical midsection with a squat truncated cone frustum of 6.5 inches (17 cm) high on each side. The cylinder was 29 inches (74 cm) in diameter and the height from the top of one cone to the top of the opposite cone was 76 cm. Along the axis of the spacecraft and protruding from the end of the lower cone was an 11 kg solid propellant injection rocket and rocket case, which formed the main structural member of the spacecraft. Eight small low-thrust solid propellant velocity adjustment rockets were mounted on the end of the upper cone in a ring assembly which could be jettisoned after use. A magnetic dipole antenna also protruded from the top of the upper cone. The shell was composed of laminated plastic and was painted with a pattern of dark and light stripes to help regulate temperature.

The scientific instrument package had a mass of 11.3 kg and consisted of:

- An image scanning infrared television system of the Naval Ordance Test Station (NOTS) design to study the Moon's surface, particularly the part normally unseen from Earth.

- A diaphragm/microphone assembly to detect micrometeorites. A micrometeorite hitting the diaphragm would generate an acoustic pulse that would travel through the diaphragm to the microphone. The microphone contained a piezoelectrical crystal that rang at 100 kc under influence of the acoustic pulse. A bandpass amplifier would amplify the signal, so it could be detected.
- A search-coil magnetometer with nonlinear amplifier to measure the Earth's, Moon's and interplanetary magnetic field. At the time it was not known whether the Moon had a magnetic field or not.

The spacecraft was powered by nickel-cadmium batteries for ignition of the rockets, silver cell batteries for the television system, and mercury batteries for the remaining circuits. Radio transmission was on 108.06 MHz, a standard frequency used by satellites in the International Geophysical Year, through an electric dipole antenna for telemetry and doppler information and a magnetic dipole antenna for the television system. Ground commands were received through the electric dipole antenna at 115 MHz. The spacecraft was to be spin-stabilized at 1.8 rps, the spin direction approximately perpendicular to the geomagnetic meridian planes of the trajectory.

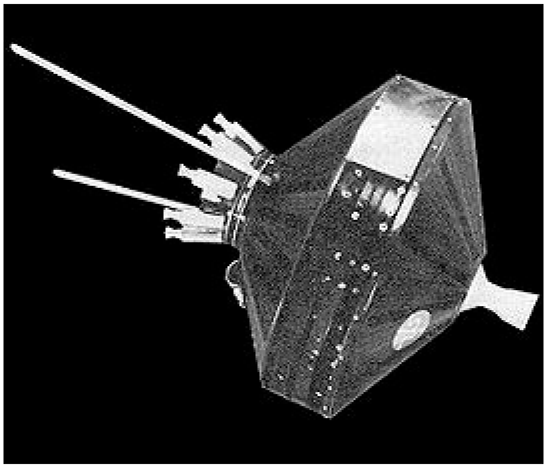
## Launch and failure

Pioneer 0 was launched on Thor Missile number 127 at 12:18:00 UTC on August 17, 1958 by the United States Air Force, only 4 minutes after the scheduled launch time. It was destroyed by an explosion of the first stage of the Thor booster, 73.6 seconds after lift-off at 16 km altitude, 16 km downrange over the Atlantic Ocean. The failure was suspected to be due to a failing turbopump bearing, causing the liquid oxygen pump to stop. Erratic telemetry signals were received from the payload and upper stages for 123 seconds after the explosion, and the upper stages were tracked to impact in the ocean. The original plan was for the spacecraft to travel for 2.6 days to the Moon at which time a TX-8-6 solid propellant motor would fire to put it into a 29,000 km lunar orbit which was to nominally last for about two weeks.

It was the only mission in the Pioneer program carried out by the United States Air Force, as subsequent missions were conducted by NASA.

## Pioneer 1

**Pioneer 1**



| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | TRW |
| **Mission type** | Flyby |
| **Flyby of** | Moon |
| **Launch date** | October 11, 1958 at 06:53:14 UTC |
| **Launch vehicle** | Thor-Able |
| **Landing site** | |
| **COSPAR ID** | 1958-007A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 84.39 pounds (38.28 kg) |

On October 11, 1958, **Pioneer 1** became the first spacecraft launched by NASA, the newly formed space agency of the United States. The flight was the second and most successful of the three Thor-Able space probes.

## Spacecraft design

Pioneer 1 atop its launcher

**Pioneer 1** was fabricated by Ramo-Wooldridge Corp.(TRW), and consisted of a thin cylindrical midsection with a squat truncated cone on each side. The cylinder was 74 cm (29 in) in diameter and the height from the top of one cone to the top of the opposite cone was 76 cm (30 in). Along the axis of the spacecraft and protruding from the end of the lower cone was an 11 kg solid propellant injection rocket and rocket case, which formed the main structural member of the spacecraft. Eight small low-thrust solid propellant velocity adjustment rockets were mounted on the end of the upper cone in a ring assembly which could be jettisoned after use. A magnetic dipole antenna also protruded from the top of the upper cone. The shell was composed of laminated plastic. The total mass of the spacecraft after vernier separation was 34.2 kg, after injection rocket firing it would have been 23.2 kg.

The scientific instrument package had a mass of 17.8 kg and consisted of an image scanning infrared television system to study the Moon's surface to a resolution of 0.5 degrees, an ionization chamber to measure radiation in space, a diaphragm/microphone assembly to detect micrometeorites, a spin-coil magnetometer to measure magnetic fields to 5 microgauss, and temperature-variable resistors to record the spacecraft's internal conditions. The spacecraft was powered by nickel-cadmium batteries for ignition of the rockets, silver cell batteries for the television system, and mercury batteries for the remaining circuits. Radio transmission was at on 108.06 MHz through an electric dipole antenna for telemetry and doppler information at 300 mW and a magnetic dipole antenna for the television system at 50 W. Ground commands were received through the electric dipole antenna at 115 MHz. The spacecraft was spin-stabilized at 1.8 rps, the spin direction was approximately perpendicular to the geomagnetic meridian planes of the trajectory.

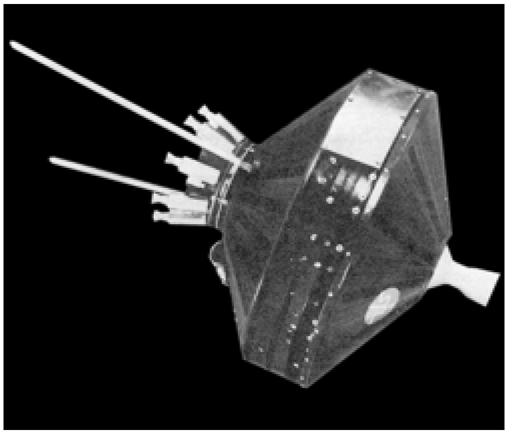
# Mission

Due to a launch vehicle malfunction, the spacecraft attained only a ballistic trajectory and never reached the Moon. However, it did return data on the near-Earth space environment.

The spacecraft was launched from LC-17A at 08:42:00 UTC on October 11, 1958 but it did not reach the Moon as planned due to a programming error in the upper stage causing a slight error in burnout velocity and angle (3.5 deg.). This resulted in a ballistic trajectory with a peak altitude of 113,800 km (70,712 mi) around 13:00 local time. The real-time transmission was obtained for about 75% of the flight, but the percentage of data recorded for each experiment was variable. Except for the first hour of flight, the signal-to-noise ratio was good. The spacecraft ended transmission when it reentered the Earth's atmosphere after 43 hours of flight on October 13, 1958 at 03:46 UT over the South Pacific Ocean. A small quantity of useful scientific information was returned, showing the radiation surrounding Earth was in the form of bands and measuring the extent of the bands, mapping the total ionizing flux, making the first observations of hydromagnetic oscillations of the magnetic field, and taking the first measurements of the density of micrometeorites and the Interplanetary Magnetic Field.

# Pioneer 2

**Pioneer 2**



| | |
|---|---|
| **Mission type** | Orbiter |
| **Satellite of** | Moon |
| **Launch date** | November 8, 1958 at 07:30:00 UTC |
| **Landing site** | |
| **Mass** | 87.3 pounds (39.6 kg) |

**Pioneer 2** was the last of the three project Able space probes designed to probe lunar and cislunar space. Shortly after launch at 07:30:00 UTC on November 8, 1958, the third stage of the launch vehicle separated but failed to ignite, and Pioneer 2 did not achieve its intended lunar orbit. The spacecraft attained a maximum altitude of 1550 km (963 miles) before reentering Earth's atmosphere at 28.7 N, 1.9 E over NW Africa. A small amount of data was obtained during the short flight, including evidence that the equatorial region around Earth has higher flux and higher energy radiation than previously considered and that the micrometeorite density is higher around Earth than in space.

## Spacecraft design

Pioneer 2 was nearly identical to Pioneer 1. It consisted of a thin cylindrical midsection with a squat truncated cone frustum on each side. The cylinder was 74 cm in diameter and the height from the top of one cone to the top of the opposite cone was 76 cm. Along the axis of the spacecraft and protruding from the end of the lower cone was an 11 kg solid propellant injection rocket and rocket case, which formed the main structural member of the spacecraft. Eight small low-thrust solid propellant velocity adjustment rockets were mounted on the end of the upper cone in a ring assembly which could be jettisoned after use. A magnetic dipole antenna also protruded from the top of the upper cone. The shell was composed of laminated plastic. The total mass of the spacecraft after vernier separation but before injection rocket firing was 39.5 kg.

The scientific instrument package had a mass of 15.6 kg (34.4 lb) and consisted of an STL image-scanning television system (which replaced the NOTS image scanning infrared television system on Pioneer 1), a proportional counter for radiation measurements, an ionization chamber to measure radiation in space, a diaphragm/microphone assembly to detect micrometeorites, a spin-coil magnetometer to measure magnetic fields to 5 microgauss, and temperature-variable resistors to record spacecraft internal conditions. The spacecraft was powered by nickel-cadmium batteries for ignition of the rockets, silver cell batteries for the television system, and mercury batteries for the remaining circuits. Radio transmission was at 108.06 MHz through a magnetic dipole antenna for the television system, telemetry, and doppler. Ground commands were received at 115 MHz. The spacecraft was to be spin-stabilized at 1.8 rps, the spin direction approximately perpendicular to the geomagnetic meridian planes of the trajectory.

## Pioneer 3

**Pioneer 3**

| | |
|---|---|
| **Operator** | U.S. Army Ballistic Missile Agency, NASA |
| **Mission type** | Fly-by |
| **Flyby of** | Moon |
| **Launch date** | December 12, 1958 |
| **Landing site** | |

**Pioneer 3** was a spin stabilized spacecraft launched at 05:45:12 UTC on 6 December 1958 by the U.S. Army Ballistic Missile Agency in conjunction with the National Aeronautics and Space Administration. This spacecraft was intended as a lunar probe, but failed to go past the Moon and into a heliocentric orbit as planned, but did reach an altitude of 102,360 km before falling back to the Earth. The revised spacecraft objectives were to measure radiation in the outer Van Allen radiation belt using two Geiger-Müller tubes and to test the trigger mechanism for a lunar photographic experiment.

## Spacecraft design

**Pioneer 3** was a cone-shaped probe 58 cm high and 25 cm diameter at its base. The cone was composed of a thin fiberglass shell coated with a gold wash to make it electrically conducting and painted with white stripes to maintain the temperature between 10 and 50 degrees Celsius. At the tip of the cone was a small probe which combined with the cone itself to act as an antenna. At the base of the cone a ring of mercury batteries provided power. A photoelectric sensor protruded from the center of the ring. The sensor was designed with two photocells which would be triggered by the light of the Moon when the probe was within about 30,000 km of the Moon. At the center of the cone was a voltage supply tube and two Geiger-Müller tubes. A transmitter with a mass of 0.5 kg delivered a phase-modulated signal of 0.1 W at a frequency of 960.05 MHz. The modulated carrier power was 0.08 W and the total effective radiated power 0.18 W. A despin mechanism consisted of two 7 gram weights which could be spooled out to the end of two 150 cm wires when triggered by a hydraulic timer 10 hours after launch. The weights would slow the spacecraft spin from 400 rpm to 6 rpm and then weights and wires would be released.

## Mission

Pioneer 3

The flight plan called for the **Pioneer 3** probe to pass close to the Moon after 33.75 hours and then go into solar orbit. However, depletion of propellant caused the first stage engine to shut down 3.7 seconds early preventing the spacecraft from reaching escape velocity. The injection angle was also about 71 degrees instead of the planned 68 degrees. The spacecraft reached an altitude of 102,360 km (109,740 km from the center of the Earth) before falling back to Earth. It re-entered Earth's atmosphere and burned up over Africa on December 7 at approximately 19:51 UT (2:51 p.m. EST) at an estimated location of 16.4 N, 18.6 E. The probe returned telemetry for about 25 hours of its 38 hour 6 minute journey. The other 13 hours were blackout periods due to the location of the two tracking stations. The returned information showed that the internal temperature remained at about 43 °C over most of the period.

While **Pioneer 3** did not meet is primary mission objective of a lunar flyby, the data obtained was of particular value to James Van Allen. The **Pioneer 3** probe data in addition to the data from the previous Explorer 1 and Explorer 3 satellites led to the discovery of a distinct second radiation belt around the Earth (e.g. characteristics). The trapped radiation starts at an altitude of several hundred miles from Earth (where the outer belt was first observed by Sputnik 2 and Sputnik 3) and extends for several thousand miles into space. These Van Allen radiation belt surrounding the Earth are named for Dr. James Van Allen, in honor of his discovery.

## Pioneer 4

**Pioneer 4**

| | |
|---|---|
| **Operator** | NASA |
| **Mission type** | Lunar flyby |
| **Satellite of** | Sun |
| **Launch date** | March 3, 1959 17:11:00 UTC |
| **Launch vehicle** | Juno II |
| **Landing site** | |
| **COSPAR ID** | 1959-013A |
| **Mass** | 6.1 kg |
| | **Orbital elements** |
| **Eccentricity** | 0.07109 |
| **Inclination** | 29.9° |
| **Apoapsis** | 1.13 AU |
| **Periapsis** | 0.98 AU |

| | |
|---|---|
| **Orbital period** | 398.0 days |

**Pioneer 4** was a spin-stabilized spacecraft launched as part of the Pioneer program on a lunar flyby trajectory and into a heliocentric orbit making it the first U.S. probe to escape from the Earth's gravity. It carried a payload similar to Pioneer 3: a lunar radiation environment experiment using a Geiger-Müller tube detector and a lunar photography experiment. It passed within 60,000 km of the Moon's surface. However, Pioneer 4 did not come close enough to trigger its photoelectric sensor. The spacecraft was still in solar orbit as of 1969.

## Spacecraft design

Pioneer 4 was a cone-shaped probe 51 cm high and 23 cm in diameter at its base. The cone was composed of a thin fiberglass shell coated with a gold wash to make it electrically conducting and painted with white stripes to maintain the temperature between 10 and 50 degrees Celsius. At the tip of the cone was a small probe which combined with the cone itself to act as an antenna. At the base of the cone a ring of mercury batteries provided power. A photoelectric sensor protruded from the center of the ring. The sensor was designed with two photocells which would be triggered by the light of the Moon when the probe was within about 30,000 km of the Moon. At the center of the cone was a voltage supply tube and two Geiger-Müller tubes. A transmitter with a mass of 0.5 kg delivered a phase modulated signal of 0.1 W at a frequency of 960.05 MHz. The modulated carrier power was 0.08 W and the total effective radiated power 0.18 W. A despin mechanism consisted of two 7 gram weights which spooled out to the end of two 150 cm wires when triggered by a hydraulic timer 10 hours after launch. The weights were designed to slow the spacecraft spin from 400 rpm to 6 rpm and then weights and wires were released.

Pioneer 3

Pioneer IV was named Artificial Planet Two. Science News Letter March 14, 1959.

## Launching vehicle

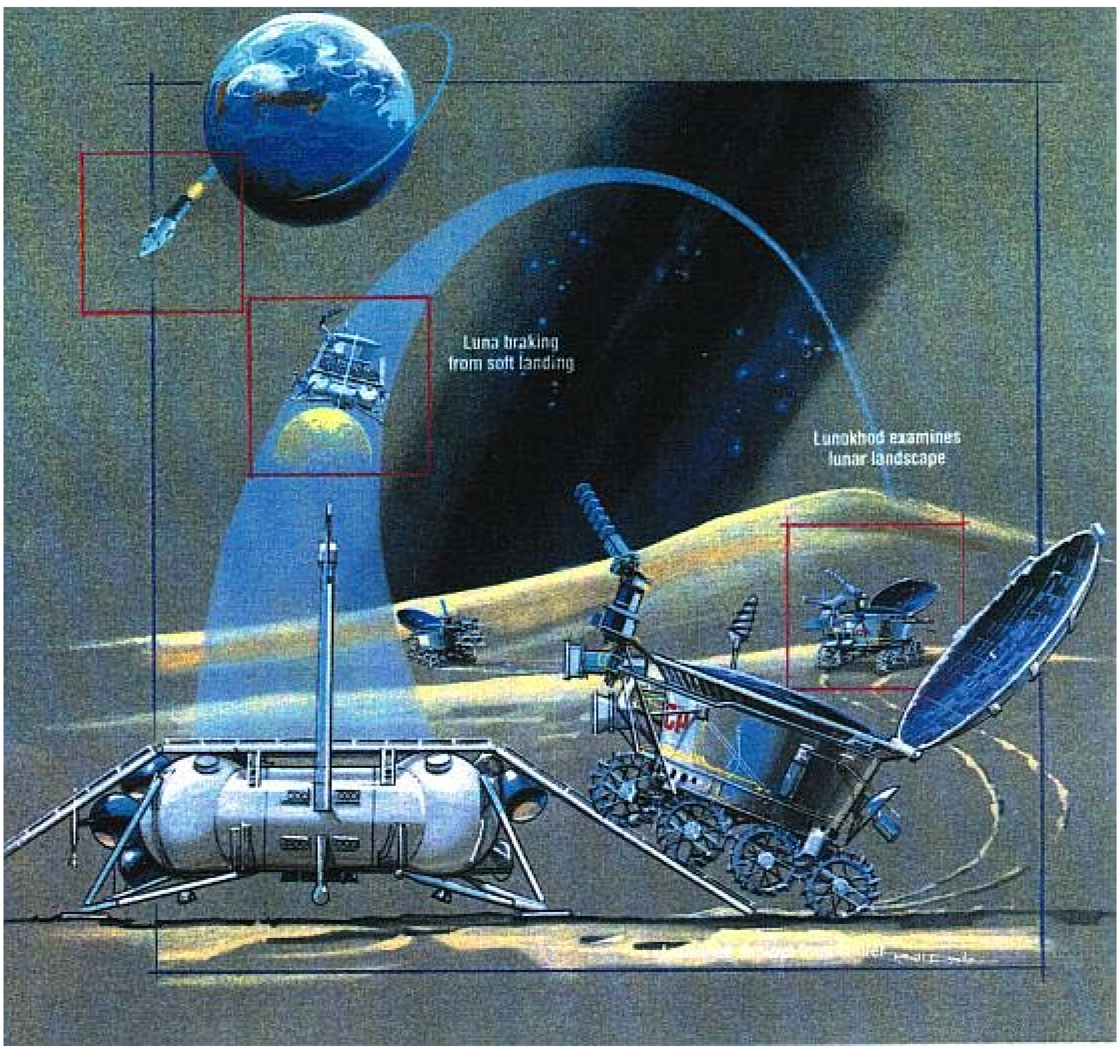
Pioneer 4 was launched with a Juno II launching vehicle, which also launched Pioneer 3. Juno II closely resembled the Juno I (Jupiter-C based) vehicle that launched Explorer 1. Its first stage was a 64 feet elongated Jupiter IRBM missile that was used by the US Army. On top of the Jupiter propulsion section was a guidance and control compartment that supported a rotating tub containing the rocket stages 2, 3 and 4. Pioneer 4 was mounted on top of stage 4.

## Mission

After a successful launch Pioneer 4 achieved its primary objective (an Earth-Moon trajectory), returned radiation data and provided a valuable tracking exercise. The probe passed within 60,000 km of the Moon's surface (7.2° E, 5.7° S) on 4 March 1959 at 22:25 UT (5:25 p.m. EST) at a speed of 7,230 km/h. The distance was not close enough to trigger the photoelectric sensor. The probe continued transmitting radiation data for 82.5 hours, to a distance of 658,000 km, and reached perihelion on 18 March 1959 at 01:00 UT. The cylindrical fourth stage casing (173 cm long, 15 cm diameter, 4.65 kg) went into orbit with the probe.

Chapter- 2

# Lunokhod Program




The Lunokhod mission diagram.

**Lunokhod** (Russian: *Луноход*, "Moonwalker") was a series of Soviet robotic lunar rovers designed to land on the Moon between 1969 and 1977. The 1969 Lunokhod 1A was destroyed during launch, the 1970 Lunokhod 1 and the 1973 Lunokhod 2 landed on the moon and the 1977 Lunokhod was never launched. The successful missions were in operation concurrently with the Zond and Luna series of Moon flyby, orbiter and landing missions. The Lunokhods were primarily designed to support the Soviet manned moon missions and to be used as automatic remote-controlled robots to explore the surface and return pictures. The Lunokhods were transported to the lunar surface by Luna spacecraft, which were launched by Proton rockets. The moon lander part of the Luna spacecraft for Lunokhods were similar to the ones for sample return missions. The Lunokhods were designed by Alexander Kemurdjian at NPO Lavochkin. Not until the 1997 Mars Pathfinder was another remote-controlled vehicle put on an extraterrestrial body.

# Development

Parabolic dish TNA-400 and abandoned NIP-10

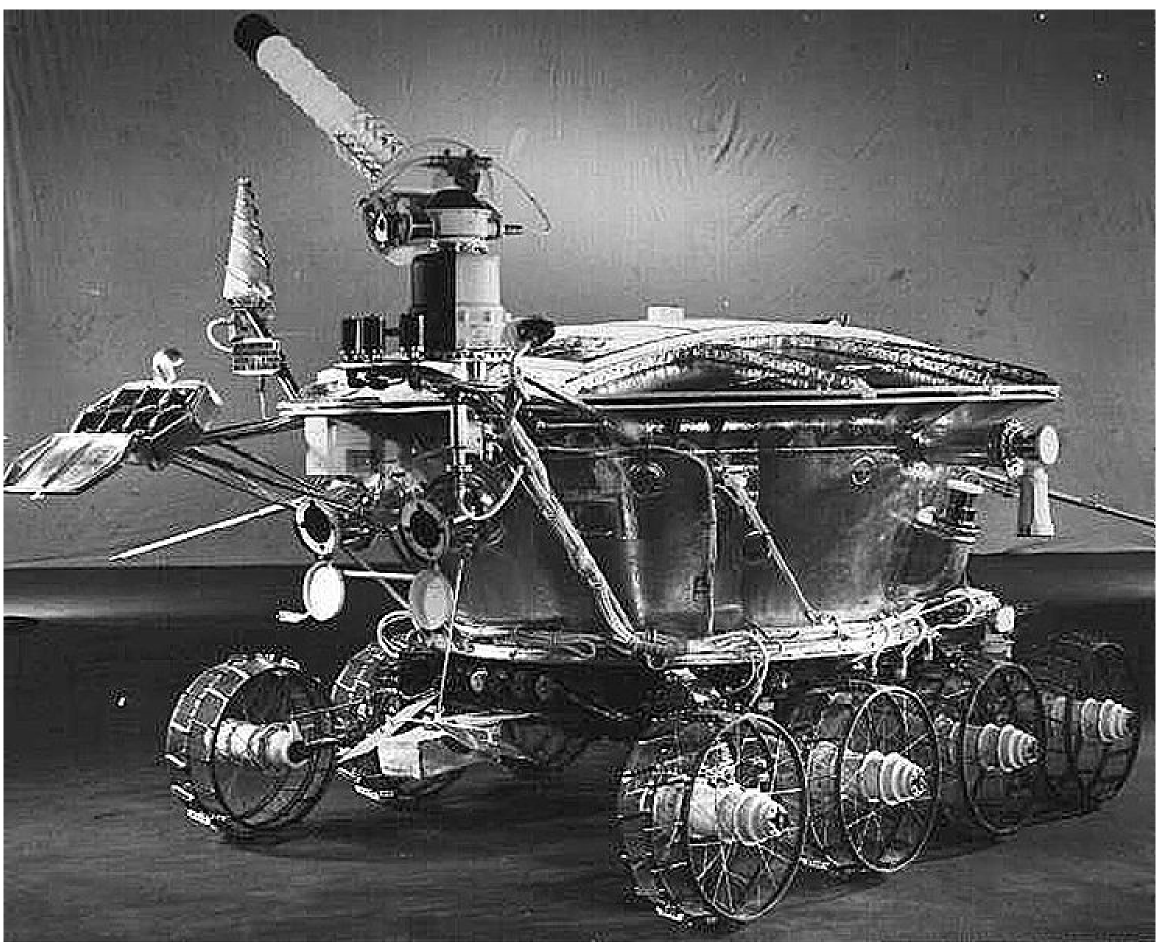
Lunokhod's original primary mission was the survey of sites for later manned landings and lunar bases. It was intended that the spacecraft would provide a radio beacon for precision landings of manned spacecraft. Also, the vehicle was designed to be used by a single cosmonaut to move from the primary LK lander to the back-up LK Landers in case of failure. Instead, it was used for remote exploration of the lunar surface after the successful Apollo manned lunar landings.

In mid-1968, at the KIP-10 or NIP-10 (КИП-10 or НИП-10) in the secret village Shkolnoye (ru:Школьное (Крым)), near Simferopol, a lunodrom (moondrome) was built. It covered an area of one hectare (120 meters by 70 meters) and was very similar to some parts of the lunar surface. It was constructed using more than 3,000 cubic meters of soil, and included 54 craters up to 16 m in diameter and around about 160 rocks of various sizes. The whole area was surrounded with bricks, painted in gray and black. It was used to analyze problems with the Lunokhod chassis.

## Lunokhod 1A

After years of secret engineering development and training, the first Lunokhod was launched on February 19, 1969. Within a few seconds the rocket disintegrated and the first Lunokhod was lost. The rest of the world did not learn of the rocket's valuable payload until years later.

## Lunokhod 1



Lunokhod 1 robot vehicle

After the destruction of the original Lunokhod, Soviet engineers began work immediately on another lunar vehicle. Lunokhod 1 was the first of two unmanned lunar rovers successfully landed on the Moon by the Soviet Union as part of its Lunokhod program. The spacecraft which carried Lunokhod 1 was named Luna 17. Lunokhod was the first roving remote-controlled robot to land on another world.

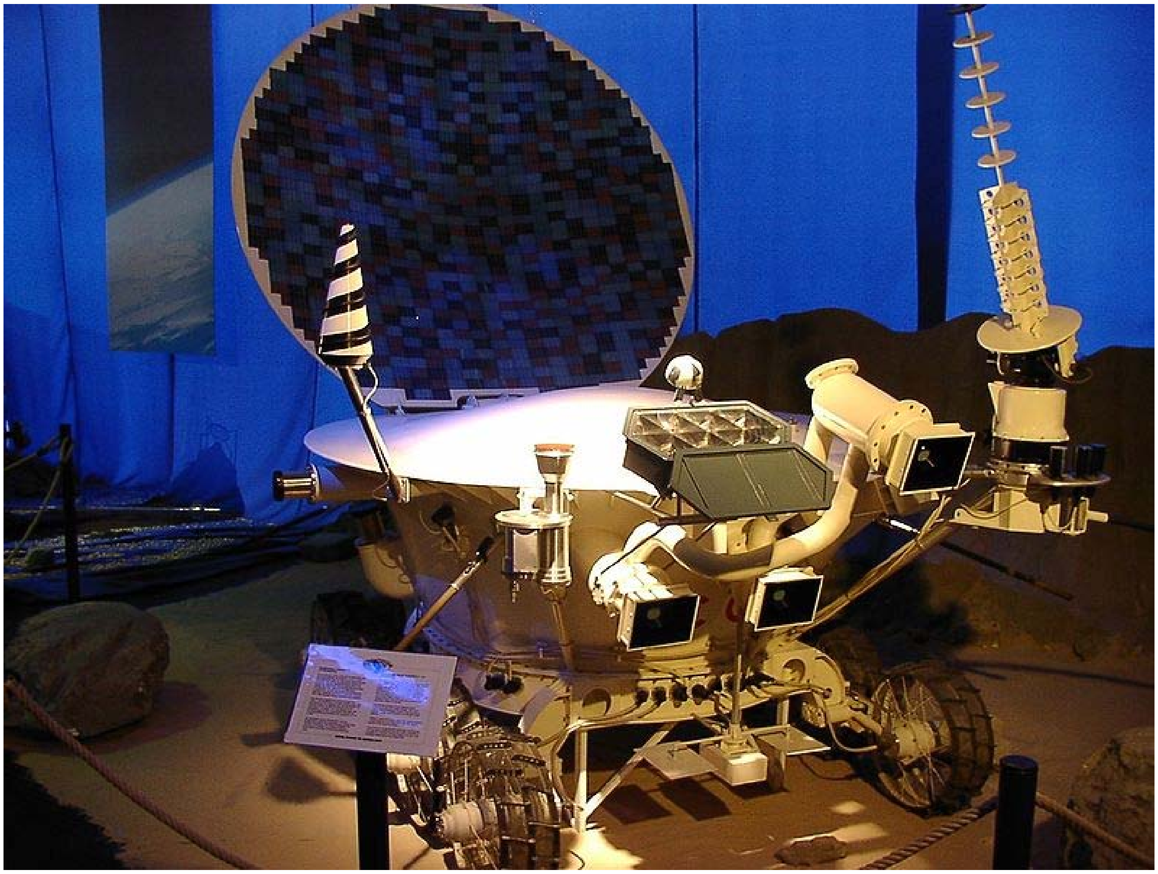
Luna 17 was launched on November 10, 1970 at 14:44:01 UTC. After reaching Earth parking orbit, the final stage of Luna 17's launching rocket fired to place it into a trajectory towards the Moon (November 10, 1970 at 14:54 UTC). After two course correction manoeuvres (on November 12 and 14) it entered lunar orbit on November 15, 1970 at 22:00 UTC.

The spacecraft soft-landed on the Moon in the Sea of Rains on November 17, 1970 at 03:47 UTC. The lander had dual ramps from which the payload, Lunokhod 1, could descend to the lunar surface. At 06:28 UT the rover moved onto the Moon's surface.

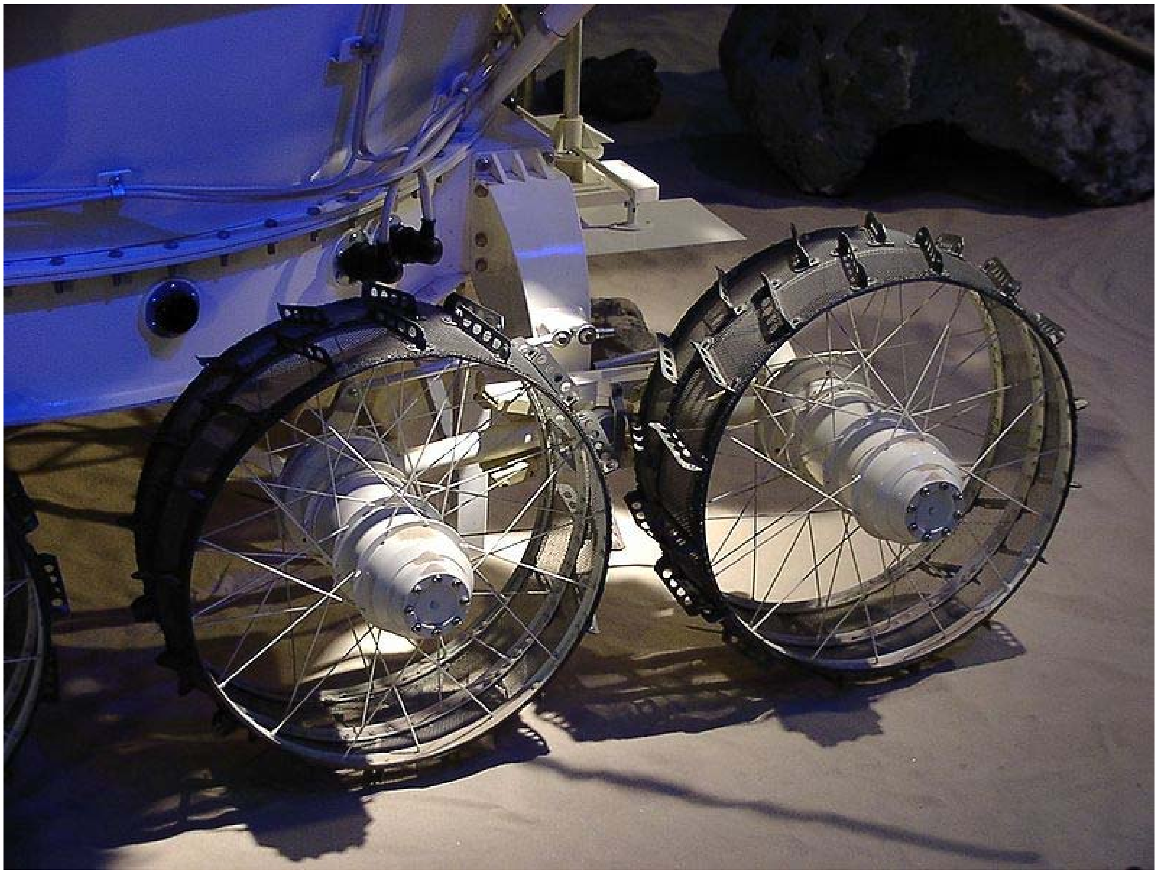
To be able to work in vacuum a special fluoride based lubricant was used for the mechanical parts and the electric motors (one in each wheel hub) were enclosed in pressurised containers.

The rover ran during the lunar day, stopping occasionally to recharge its batteries via the solar panels. At night the rover hibernated until the next sunrise, heated by the radioisotope heater unit.

## Rover description



Model of Lunokhod series Soviet Moon exploration robot vehicle



Detail of Lunokhod's wheels

Lunokhod 1 was a lunar vehicle formed of a tub-like compartment with a large convex lid on eight independently powered wheels. Its length was 2.3 metres. Lunokhod 1 was equipped with a cone-shaped antenna, a highly directional helical antenna, four television cameras, and special extendable devices to impact the lunar soil for density measurements and mechanical property tests.

An X-ray spectrometer, an X-ray telescope, cosmic ray detectors, and a laser device were also included. The vehicle was powered by batteries which were recharged during the lunar day by a solar cell array mounted on the underside of the lid. During the lunar nights, the lid was closed and a polonium-210 heat source kept the internal components at operating temperature.

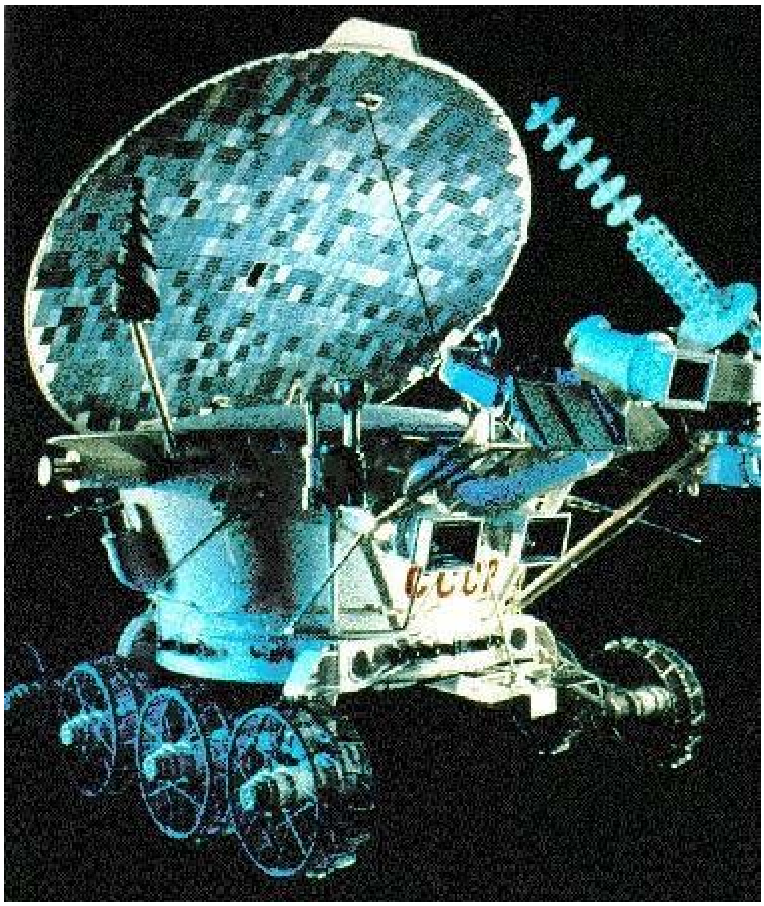
The rover stood 135 cm (4 ft 5 in) high and had a mass of 840 kg (1,850 lb). It was about 170 cm (5 ft 7 in) long and 160 cm (4 ft 11 in) wide and had eight wheels each with an independent suspension, motor and brake. The rover had two speeds, ~1 km/h and ~2 km/h (0.6 mph and 1.2 mph).

## Payload

- Cameras (two TV & four panoramic telephotometers)

- RIFMA X-ray fluorescence spectrometer
- RT-1 X-ray telescope
- PrOP odometer/penetrometer
- RV-2N radiation detector
- TL laser retroreflector

# Lunokhod 2



Lunokhod 2 robot vehicle

Lunokhod 2 was the second and more advanced of two unmanned lunar rovers landed on the Moon by the Soviet Union as part of the Lunokhod program.

The launcher put the spacecraft into Earth parking orbit on January 8, 1973, followed by translunar injection. On January 12, 1973, Luna 21 was braked into a 90 by 100 km (approx. 56 by 62 mile) lunar orbit.

The Luna 21 spacecraft landed on the Moon and deployed the second Soviet lunar rover, Lunokhod 2. The primary objectives of the mission were to collect images of the lunar surface, examine ambient light levels to determine the feasibility of astronomical observations from the Moon, perform laser ranging experiments from Earth, observe solar X-rays, measure local magnetic fields, and study mechanical properties of the lunar surface material.

The landing occurred on January 15, 1973 at 23:35 UT in Le Monnier crater at 25.85 degrees N, 30.45 degrees E.

After landing, the Lunokhod 2 took TV images of the surrounding area, then rolled down a ramp to the surface at 01:14 UT on 1973-01-16 and took pictures of the Luna 21 lander and landing site.

### Rover description

Lunokhod 2 was equipped with three slow-scan television cameras, one mounted high on the rover for navigation, which could return high resolution images at different rates—3.2, 5.7, 10.9 or 21.1 seconds per frame (not frames per second). These images were used by a five-man team of controllers on Earth who sent driving commands to the rover in real time. There were 4 panoramic cameras mounted on the rover.

Power was supplied by a solar panel on the inside of a round hinged lid which covered the instrument bay, which would charge the batteries when opened. A polonium-210 radioactive heat source was used to keep the rover warm during the long lunar nights.

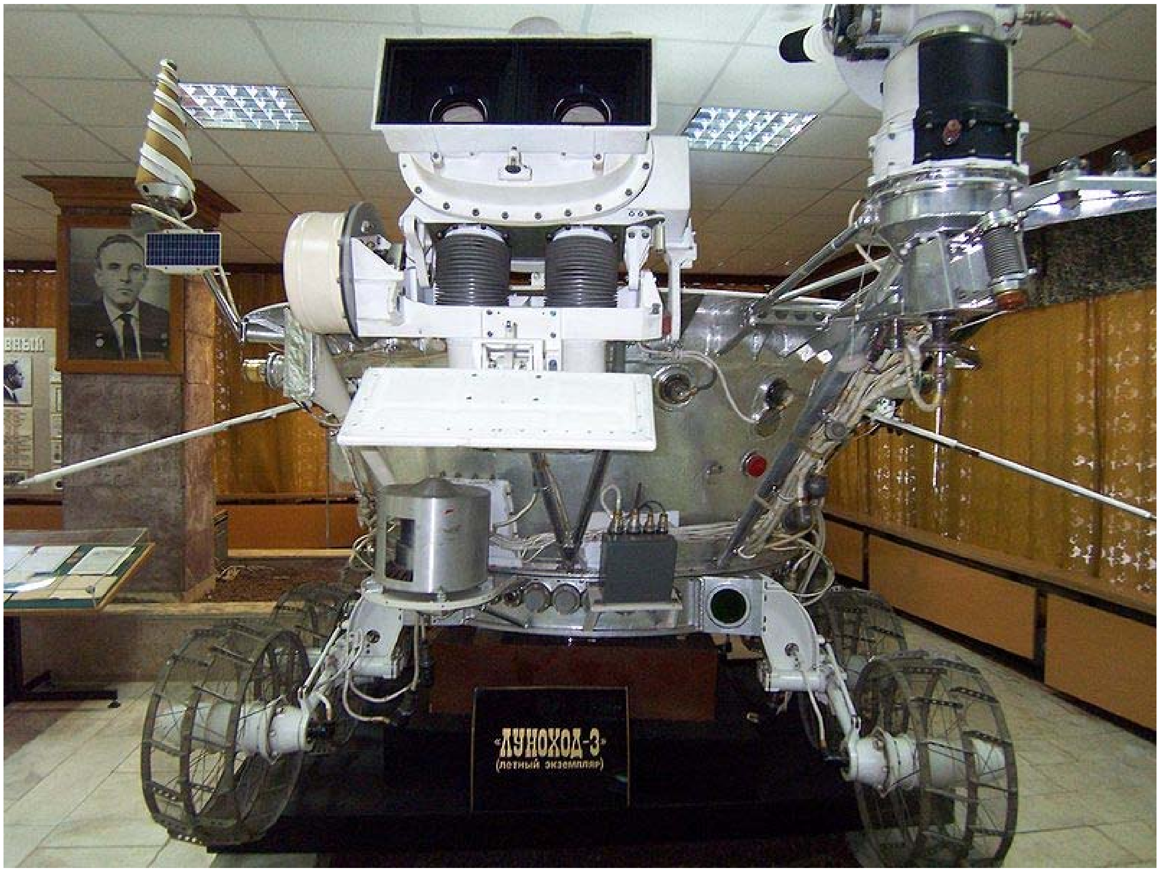
Scientific instruments included a soil mechanics tester, solar X-ray experiment, an astrophotometer to measure visible and ultraviolet light levels, a magnetometer deployed in front of the rover on the end of a 2.5 m (8 ft 2 in) boom, a radiometer, a photodetector (Rubin-1) for laser detection experiments, and a French-supplied laser corner reflector.

### Payload

- Cameras (three TV & four panoramic telephotometers)
- RIFMA-M X-ray fluorescence spectrometer
- X-ray telescope
- PROP odometer/penetrometer
- RV-2N-LS radiation detector
- TL laser retroreflector
- AF-3L UV/visible astrophotometer
- SG-70A magnetometer
- Rubin 1 photodetector

## Lunokhod 3

Lunokhod 3 (side view)




Lunokhod 3 (front view)

Lunokhod 3 was built for a moon landing in 1977, but never flew to the Moon due to lack of launchers and funding. It remains at the NPO Lavochkin museum.

## Results

During its 322 Earth days of operations, Lunokhod 1 traveled 10.5 km and returned more than 20,000 TV images and 206 high-resolution panoramas. In addition, it performed twenty-five soil analyses with its RIFMA x-ray fluorescence spectrometer and used its penetrometer at 500 different locations.

Lunokhod 2 operated for about 4 months, covered 37 km (23 miles) of terrain, including hilly upland areas and rilles, and currently holds the record for the longest distance of surface travel of any extraterrestrial vehicle. It sent back 86 panoramic images and over 80,000 TV pictures. Many mechanical tests of the surface, laser ranging measurements, and other experiments were completed during this time.

For comparison, the similarly sized NASA Mars Exploration Rovers, Spirit and Opportunity had, by their fifth anniversary in January 2009, traveled a total of 21 km (13 miles) and transmitted over 125,000 images.

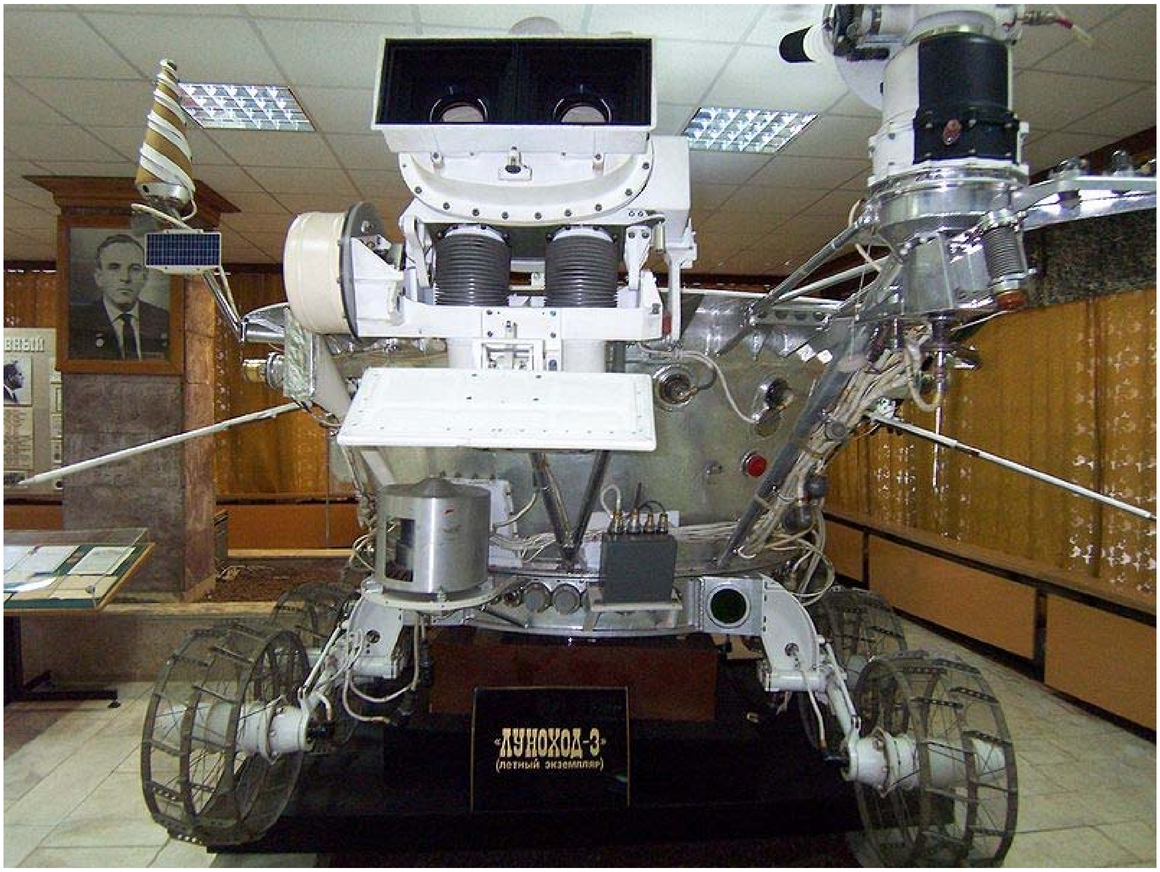
## Chernobyl legacy

According to a French documentary TV film "Tank on the Moon" by Jean Afanassieff, the Lunokhod design returned to limelight 15 years later due to the Chernobyl nuclear powerplant disaster. The East German-made remote controlled bulldozers available to Soviet Civil Defence troops weighed dozens of tons - too heavy to operate on the remaining parts of the partially collapsed reactor building roof. Human labourers could not be employed effectively to shovel debris, since workshifts were limited to 90-second intervals due to intense ionising radiation.

Lunokhod designers were called back from retirement, and in two weeks they produced a six wheel remote control vehicle prototype that was light enough to operate on the weakened roof. Since the original Lunokhod moon rovers used nuclear decay heatsources for internal rack climate control, their electronic systems were already hardened to resist radiation. This benefit allowed the 1986 designers to quickly devise a derived vehicle type for nuclear disaster recovery work. Eventually two such rovers were delivered to the Chernobyl accident zone and proved useful for clearing debris, earning awards for the designers. Due to extremely high radiation levels, all rovers eventually failed, and human workers (later named liquidators) were called in.

## Locations and ownership

Until 2010, the final location of Lunokhod 1 was uncertain by a few kilometers. Lunar laser ranging experiments had failed to detect a return signal from it since the 1970s. On March 17, 2010, Albert Abdrakhimov found both the lander and the rover in Lunar Reconnaissance Orbiter image M114185541RC.

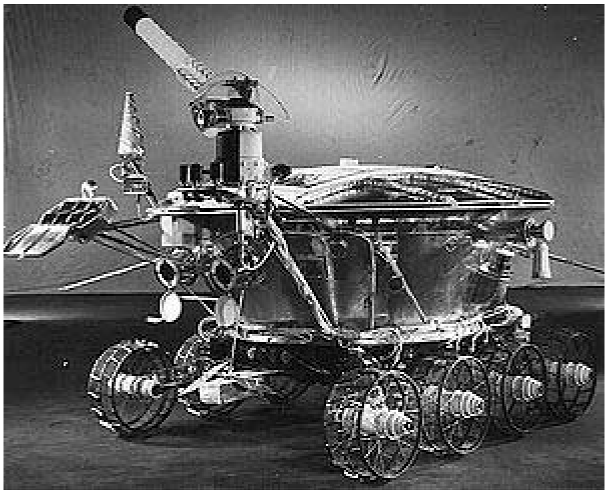



Soviet moonrover.

Lunokhod 2 continues to be detected by lunar laser ranging experiments and its position is known to sub-meter accuracy. Ownership of Lunokhod 2 and the Luna 21 lander was sold by the Lavochkin Association for US$68,500 in December 1993 at a Sotheby's auction in New York (although the catalog incorrectly lists lot 68A as Luna 17/Lunokhod 1). The buyer was computer gaming entrepreneur and astronaut's son Richard Garriott (also known by his gaming character Lord British), who stated in a 2001 interview: "I purchased Lunakod 21 [sic] from the Russians. I am now the world's only private owner of an object on a foreign celestial body. Though there are international treaties that say no government shall lay claim to geography off planet earth, I am not a government. Summarily, I claim the moon in the name of Lord British!" In 2007, Garriott said he is the owner of Lunokhod 2.

## Lunokhod 1

**Lunokhod 1**



Lunokhod series Soviet Moon exploration robot vehicle

| | |
|---|---|
| **Operator** | Soviet Union |
| **Mission type** | Rover |
| **Orbital insertion date** | Landed on November 17, 1970 at 03:47:00 UTC |
| **Launch date** | November 10, 1970 |
| **Launch vehicle** | Proton |
| **Mission duration** | ended on October 4, 1971 |
| **Landing site** | |
| **COSPAR ID** | 1970-095A |
| **Homepage** | Lunar and Planetary Department Moscow University Lunokhod 1 page |
| **Mass** | 5600 kg (rover itself 756 kg) |
| **Power** | 180 W solar panel |
| | **Planetary landing** |
| **Coordinates** | 38°19′30″N 36°59′42″W / 38.32507°N 36.9949°W |

**Lunokhod 1** (**Луноход**, *moon walker* in Russian; *Аппарат 8ЕЛ № 203*, *vehicle 8ЕЛ№203*) was the first in the world rover, successfully working on a surface other astronomical body — Moon. It was the first of two unmanned lunar rovers landed on the

Moon by the Soviet Union as part of its Lunokhod program. The spacecraft which carried Lunokhod 1 was named Luna 17. Lunokhod was the first roving remote-controlled robot to land on another celestial body.

## Rover description

Lunokhod 1 was a lunar vehicle formed of a tub-like compartment with a large convex lid on eight independently powered wheels. Its length was 2.3 metres. Lunokhod was equipped with a cone-shaped antenna, a highly directional helical antenna, four television cameras, and special extendable devices to impact the lunar soil for soil density and mechanical property tests. An X-ray spectrometer, an X-ray telescope, cosmic ray detectors, and a laser device were also included. The vehicle was powered by batteries which were recharged during the lunar day by a solar cell array mounted on the underside of the lid. To be able to work in vacuum a special fluoride based lubricant was used for the mechanical parts and the electric motors (one in each wheel hub) were enclosed in pressurised containers. During the lunar nights, the lid was closed and a polonium-210 radioisotope heater unit kept the internal components at operating temperature. Lunokhod was intended to operate through three lunar days (approximately 3 Earth months) but actually operated for eleven lunar days.

## Launch and lunar orbit

Luna 17 was launched on November 10, 1970 at 14:44:01 UTC. After reaching earth parking orbit, the final stage of Luna 17's launching rocket fired to place it into a trajectory towards the Moon (1970-11-10 at 14:54 UTC). After two course correction maneuvers (on November 12 and 14), it entered lunar orbit on November 15, 1970 at 22:00 UTC.

## Landing and surface operations

The spacecraft soft-landed on the Moon in the Sea of Rains on November 17 at 03:47 UTC. The lander had dual ramps from which the payload, Lunokhod 1, could descend to the lunar surface. At 06:28 UT the rover moved onto the moon's surface.

The rover would run during the lunar day, stopping occasionally to recharge its batteries via the solar panels. At night the rover hibernated until the next sunrise, heated by the radioactive source.

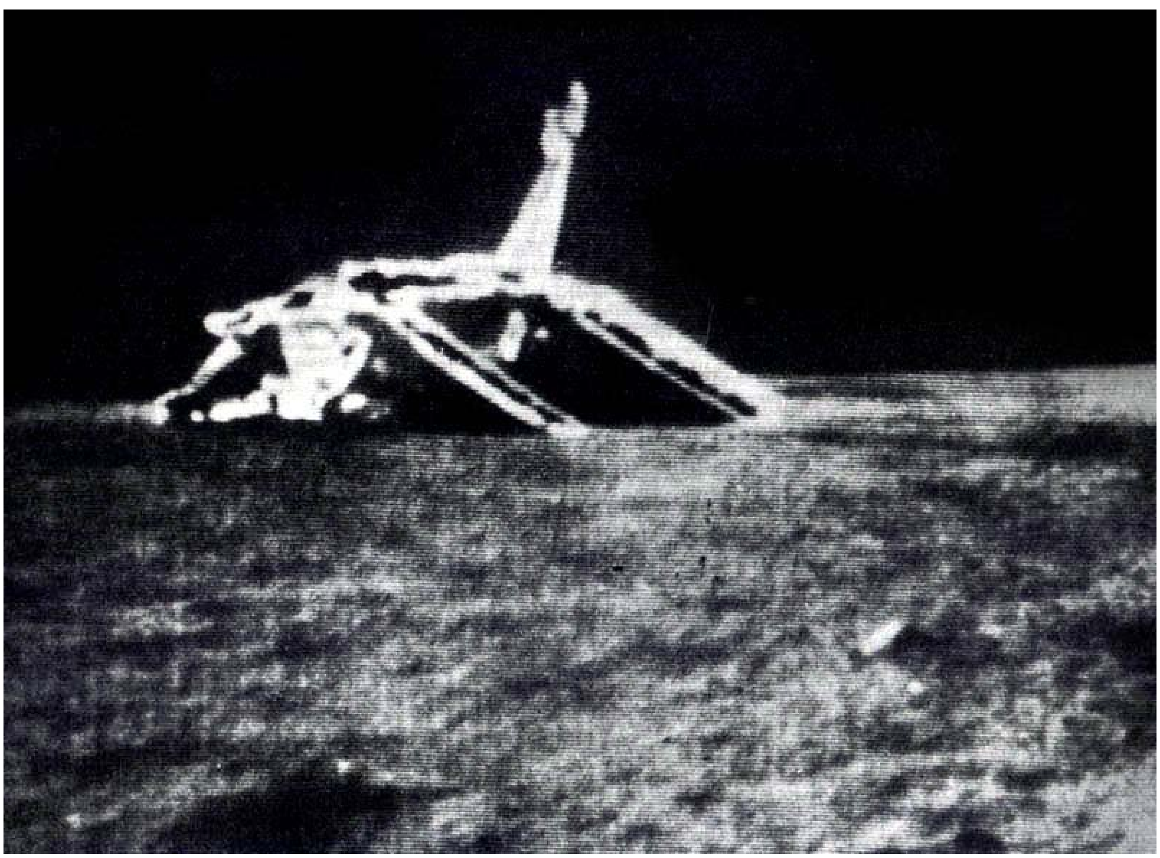
1970:

- November 17 - November 22: The rover drives 197 m, returns 14 close up pictures of the Moon and 12 panoramic views, during 10 communication sessions. It also conducts analyses of the lunar soil.
- December 9 - December 22: 1,522 m

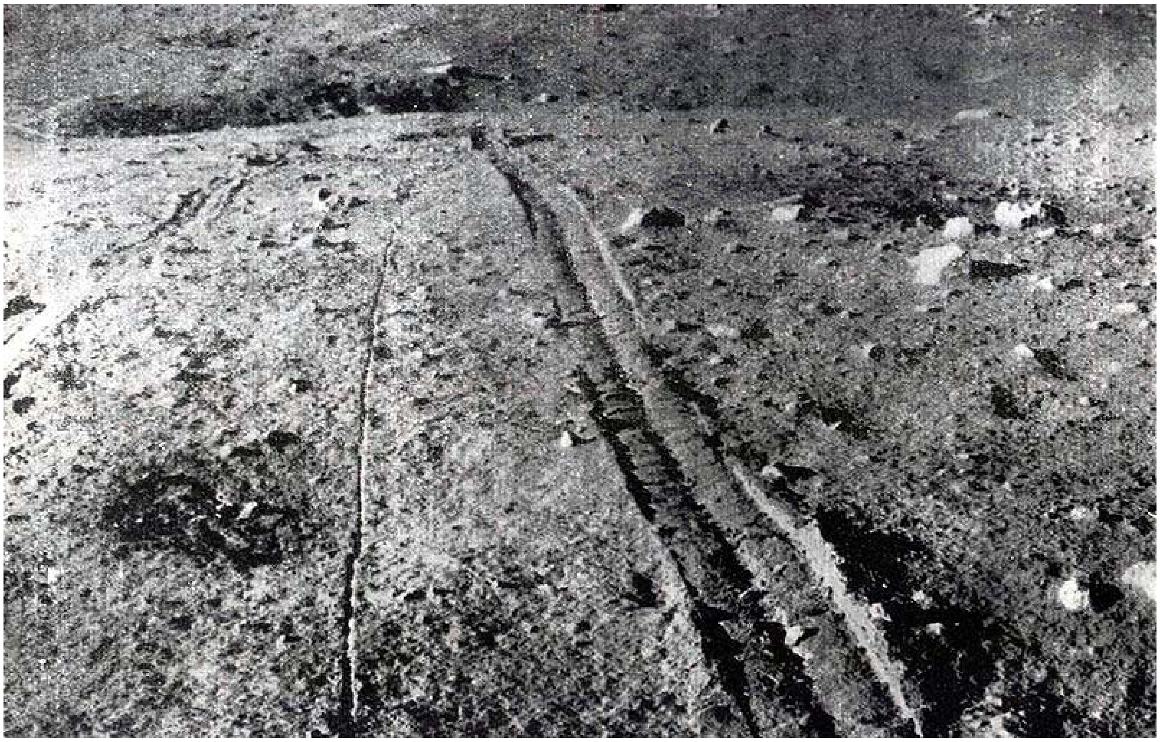
1971:

- January 8 - January 20: 1,936 m
- February 8 - February 19: 1,573 m
- March 9 - March 20: 2,004 m
- April 8 - April 20: 1,029 m
- May 7 - May 20: 197 m
- June 5 - June 18: 1,559 m
- July 4 - July 17: 220 m
- August 3 - August 16: 215 m
- August 31 - September 14: 88 m

A panorama shot from Lunokhod 1



A photo from Lunokhod 1 showing the Luna 17 lander

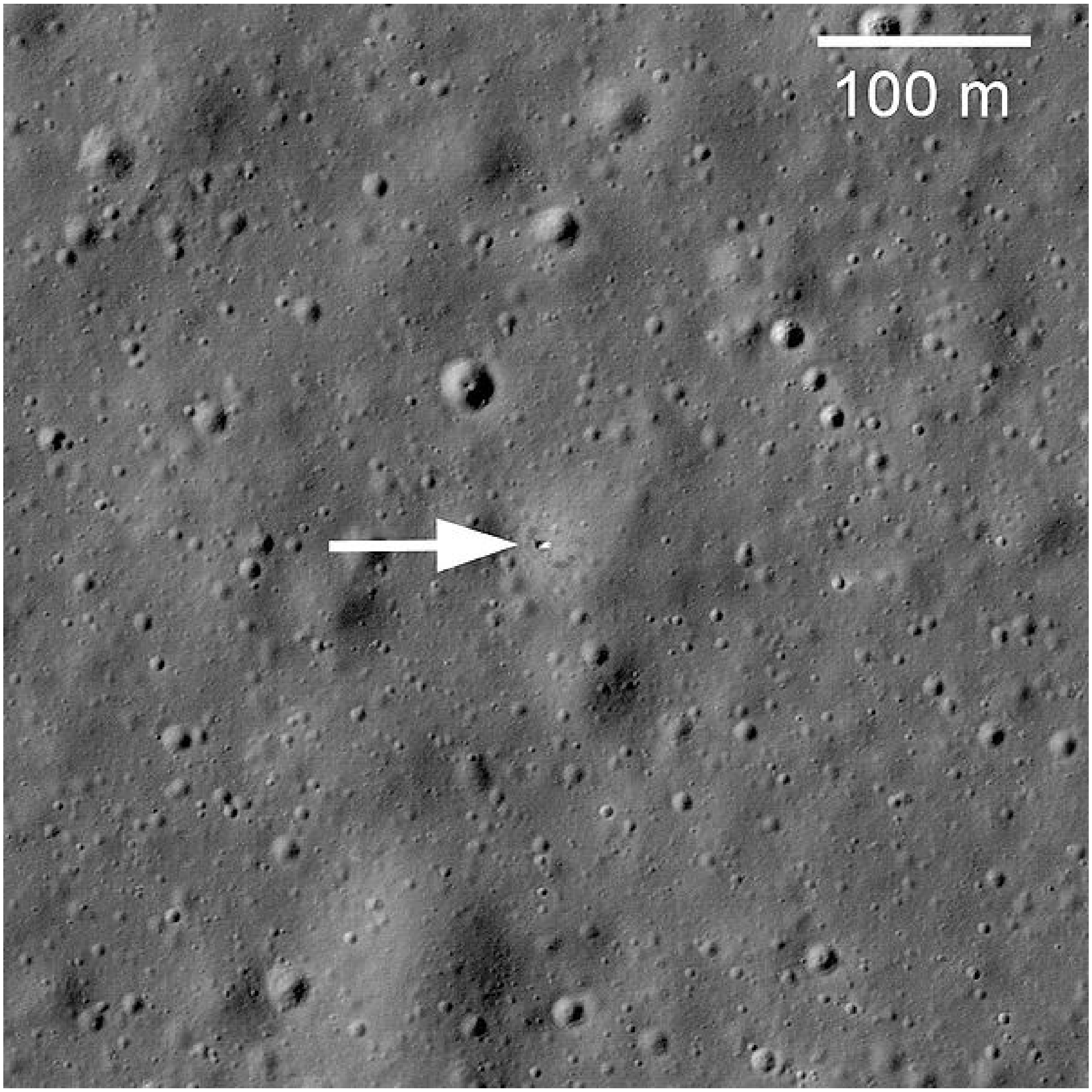


The tracks of Lunokhod showing the "little wheel" in the center that was used for odometry.

## End of mission and results

Controllers finished the last communications session with Lunokhod 1 at 13:05 UT on September 14, 1971. Attempts to reestablish contact were finally discontinued and the operations of Lunokhod 1 officially ceased on October 4, 1971, the anniversary of Sputnik 1. During its 322 Earth days of operations, Lunokhod traveled 10,540 metres and returned more than 20,000 TV images and 206 high-resolution panoramas. In addition, it performed 25 lunar soil analyses with its RIFMA x-ray fluorescence spectrometer and used its penetrometer at 500 different locations.

## Current location



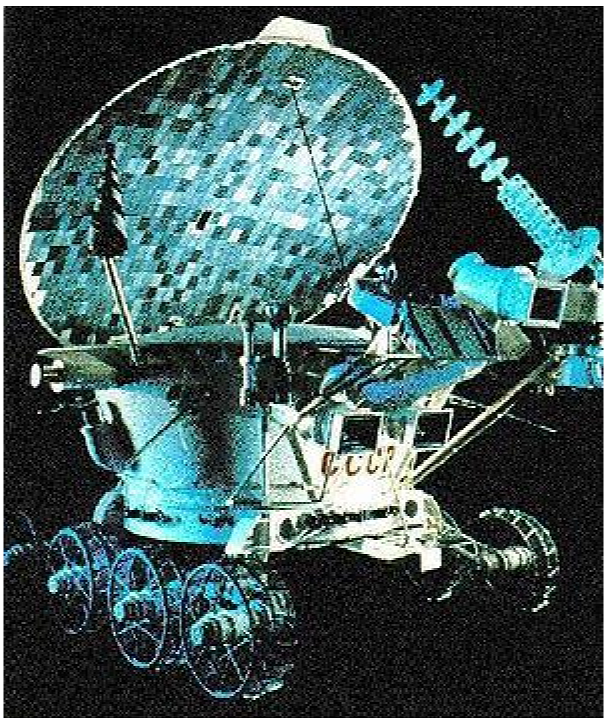

LRO image from 2010

The final location of Lunokhod 1 was uncertain until 2010, as lunar laser ranging experiments had failed to detect a return signal from it since 1971. In April 2010, the Apache Point Observatory Lunar Laser-ranging Operation (APOLLO) team from the University of California at San Diego used images from NASA's Lunar Reconnaissance Orbiter to locate the orbiter closely enough for laser range (distance) measurements. On April 22, 2010 and days following, the team successfully measured the distance several times. The intersection of the spheres described by the measured distances then pinpoint the current location of Lunokhod 1 to within 1 meter. APOLLO is now using Lunokhod 1's reflector for experiments, as they discovered, to their surprise, that it was returning much more light than other reflectors on the moon. According to a NASA press release, APOLLO researcher Tom Murphy said, "We got about 2,000 photons from Lunokhod 1 on our first try. After almost 40 years of silence, this rover still has a lot to say."

By fall of 2010, the location of the rover had been determined to about a centimeter. The location near the limb of the moon, combined with the ability to range the rover even when it is in sunlight, promises to be particularly useful for determining aspects of the Earth-Moon system.

## Lunokhod 2

**Lunokhod 2**



Lunokhod series Soviet Moon exploration robot vehicle

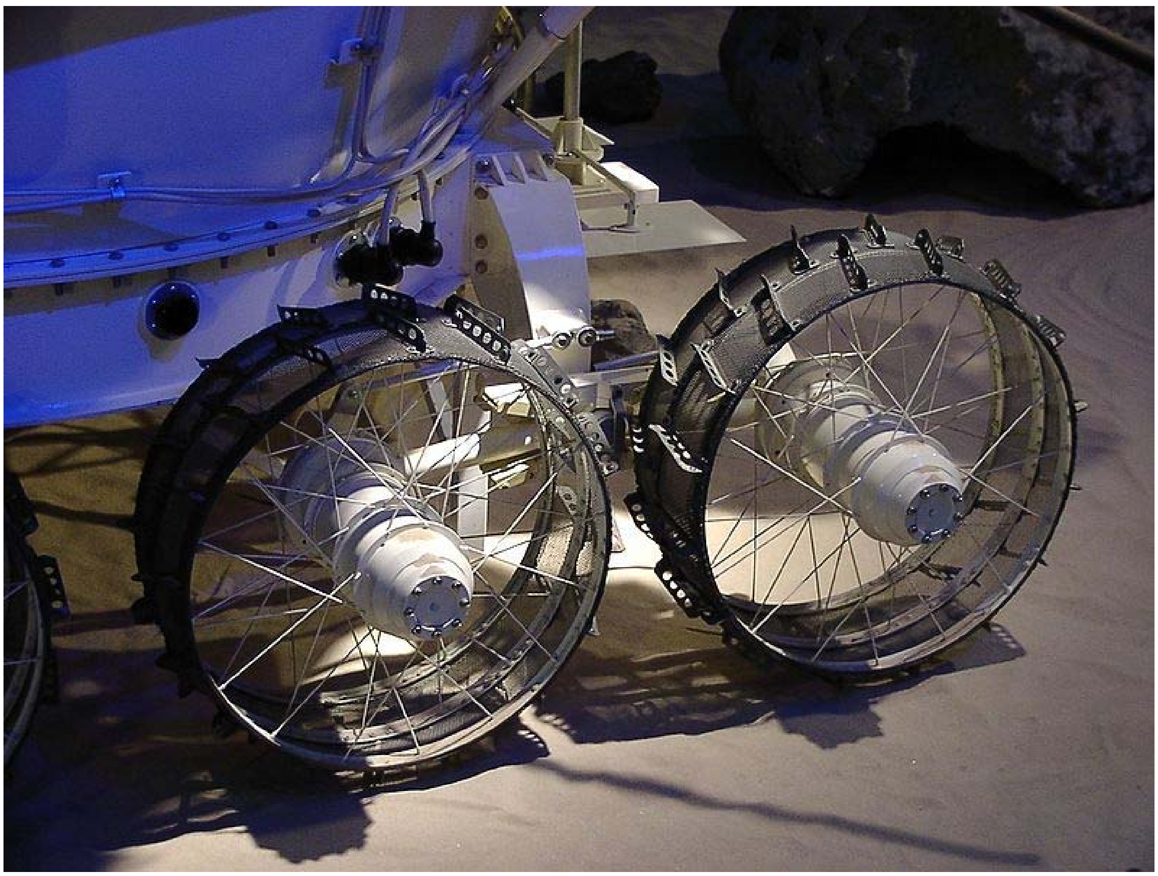
| | |
|---|---|
| **Operator** | Soviet Union |
| **Mission type** | Rover |
| **Orbital insertion date** | Landed on January 15, 1973 |
| **Launch date** | January 11, 1973 at 06:55:38 UTC |
| **Launch vehicle** | Proton |
| **Mission duration** | ended on June 4, 1973 |
| **Landing site** | |
| **COSPAR ID** | 1973-001A |
| **Mass** | 840 kg (rover) |

| | |
|---|---|
| **Power** | solar panel |

**Lunokhod 2** (**Луноход**, *moon walker* in Russian) was the second of two unmanned lunar rovers landed on the Moon by the Soviet Union as part of the Lunokhod program.

The Luna 21 spacecraft landed on the Moon and deployed the second Soviet lunar rover (Lunokhod 2). The primary objectives of the mission were to collect images of the lunar surface, examine ambient light levels to determine the feasibility of astronomical observations from the Moon, perform laser ranging experiments from Earth, observe solar X-rays, measure local magnetic fields, and study the soil mechanics of the lunar surface material.

# Lunokhod 2 rover and subsystems



Detail of Lunokhod's wheels

The rover stood 135 cm (4 ft 5 in) high and had a mass of 840 kg (1,850 lb). It was about 170 cm (5 ft 7 in) long and 160 cm (5 ft 3 in) wide and had 8 wheels each with an independent suspension, electric motor and brake. The rover had two speeds, ~1 km/h and ~2 km/h (0.6 mph and 1.2 mph). Lunokhod 2 was equipped with three television cameras, one mounted high on the rover for navigation, which could return high resolution images at different frame rates—3.2, 5.7, 10.9 or 21.1 seconds per frame. These images were used by a five-man team of controllers on Earth who sent driving commands to the rover in real time. Power was supplied by a solar panel on the inside of a round hinged lid which covered the instrument bay, which would charge the batteries when opened. A polonium-210 radioisotope heater unit was used to keep the rover warm during the long lunar nights. There were four panoramic cameras mounted on the rover. Scientific instruments included a soil mechanics tester, solar X-ray experiment, an astrophotometer to measure visible and ultraviolet light levels, a magnetometer deployed in front of the rover on the end of a 2.5 m (8 ft 2 in) boom, a radiometer, a photodetector (Rubin-1) for laser detection experiments, and a French-supplied laser corner reflector. The lander carried a bas relief of Lenin and the Soviet coat of arms. The lander and rover together massed 1814 kg.

## Mission profile

The SL-12/D-1-e launcher put the spacecraft into Earth parking orbit followed by translunar injection. On January 12, 1973 Luna 21 was braked into a 90 by 100 km (56 by 62 mile) lunar orbit. On January 13 and January 14, the perilune was lowered to 16 km (10 mi) altitude.

## Landing and surface operations

On January 15 after 40 orbits, the braking rocket was fired at 16 km (10 mi) altitude, and the craft went into free fall. At an altitude of 750 m (2,460 ft) the main thrusters began firing, slowing the fall until a height of 22 m (72 ft) was reached. At this point the main thrusters shut down and the secondary thrusters ignited, slowing the fall until the lander was 1.5 m (5 ft) above the surface, where the engine was switched off. Landing occurred at 23:35 UT in Le Monnier crater at 25.85 degrees N, 30.45 degrees E.

After landing, the Lunokhod 2 took TV images of the surrounding area, then rolled down a ramp to the surface at 01:14 UT on January 16 and took pictures of the Luna 21 lander and landing site, driving for 30 metres. After a period of charging up its batteries, it took more pictures of the site and the lander, and then set off to explore the moon.

The rover would run during the lunar day, stopping occasionally to recharge its batteries with the solar panels. At night the rover hibernated until the next sunrise, heated by the radioactive source.

- January 18, 1973 to January 24, 1973: The rover drives 1,260 metres
- February 8, 1973 to February 23, 1973: The rover drives 9,086 metres further
- March 11, 1973 to March 23, 1973: The rover drives 16,533 metres further
- April 9, 1973 to April 22, 1973: The rover drives 8,600 metres further

- May 8, 1973 to June 3, 1973: The rover drives 880 metres further

## End of mission

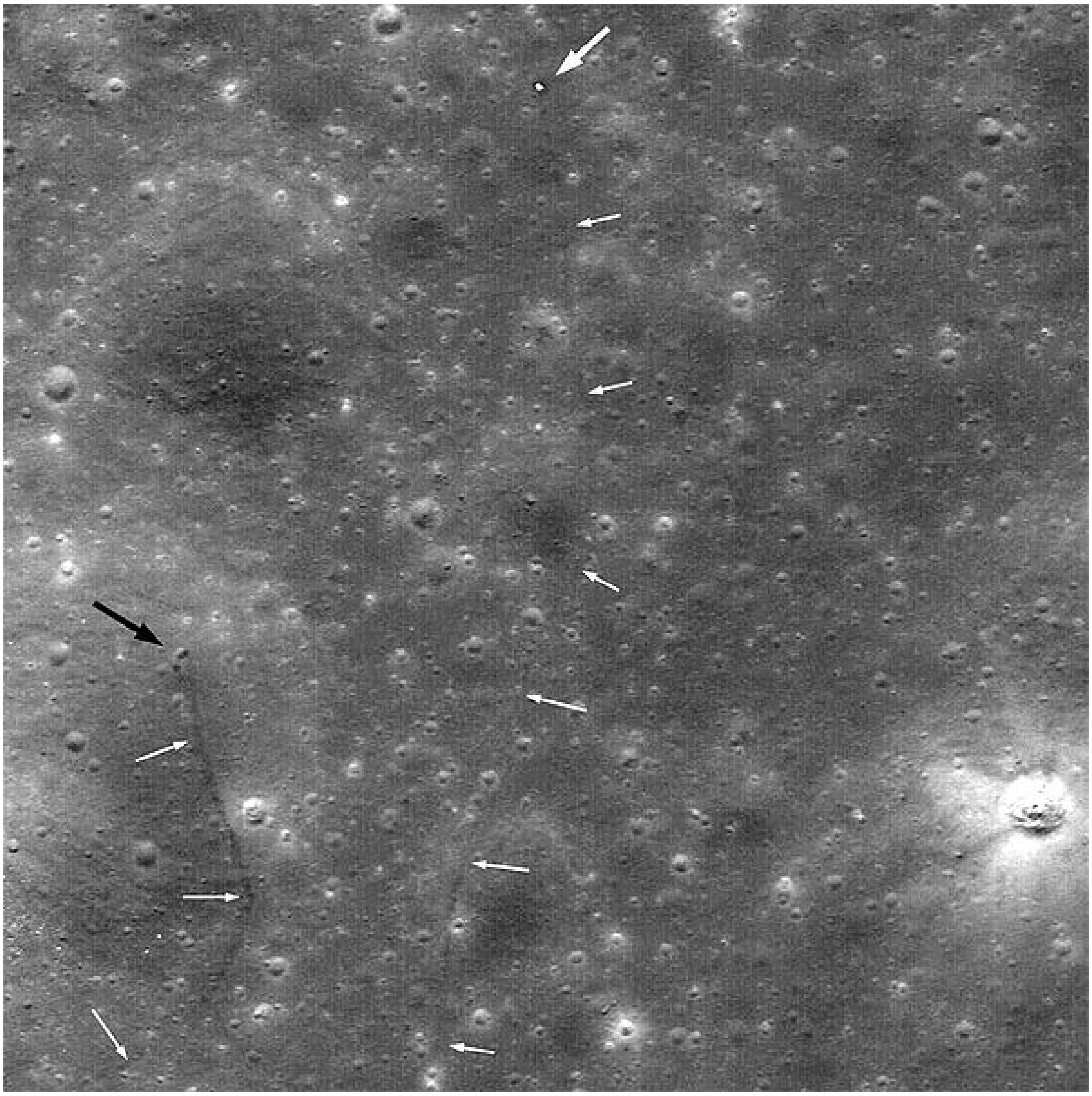
On June 4, 1973 it was announced that the program was completed, leading to speculation that the vehicle probably failed in mid-May or could not be revived after the lunar night of May-June.

More recently, Alexander Basilevsky related an account where on May 9, 1973, the rover's open lid touched a crater wall and became covered with dust. When the lid was closed for the lunar night, this dust (a very good insulator) was dumped on to the radiators. The following lunar day, controllers saw the internal temperature of the Lunokhod climb as it was unable to cool itself, eventually rendering the rover inoperable.

## Results

Lunokhod 2 operated for about 4 months, covered 37 km (23 miles) of terrain, including hilly upland areas and rilles, and sent back 86 panoramic images and over 80,000 TV pictures. At the time, the journey was the longest any robotic rover had ever been driven on another celestial body. Many mechanical tests of the surface, laser ranging measurements, and other experiments were completed during this time.

## Current status



Lunar Reconnaissance Orbiter image of Lunokhod 2 and its tracks. The large white arrow indicates the rover, the smaller white arrows indicate its tracks, and the black arrow indicates the crater where it picked up its fatal load of lunar dust.

Lunokhod 2 continues to be detected by lunar laser ranging experiments and its position is known to sub-meter accuracy. On March 17, 2010 Phil Stooke, a professor at the University of Western Ontario announced that he had located Lunokhod 2's final resting place in photographs made by the Lunar Reconnaissance Orbiter.

## Present ownership

Ownership of Lunokhod 2 and the Luna 21 lander was sold by the Lavochkin Association for $68,500 in December 1993 at a Sotheby's auction in New York. (The catalog incorrectly lists lot 68A as Luna 17/Lunokhod 1).

The buyer was computer gaming entrepreneur and astronaut's son Richard Garriott (also known as Lord British), who stated in a 2001 interview with Computer Games Magazine's Cindy Yans that:

> *I purchased Lunakod 21 [sic] from the Russians. I am now the world's only private owner of an object on a foreign celestial body. Though there are international treaties that say, no government shall lay claim to geography off planet earth, I am not a government. Summarily, I claim the moon in the name of Lord British!*

Richard Garriott has more recently confirmed that he is the owner of Lunokhod 2.

## Chapter- 3

# Luna Program

## Luna 1

**Luna 1 (Mechta)**

| | |
|---|---|
| **Operator** | Soviet Union |
| **Major contractors** | OKB-1 |
| **Mission type** | Planetary Science |
| **Satellite of** | Sun |
| **Orbits** | 37 (as of 2005) |
| **Launch date** | 2 January 1959 at 16:41:21 UTC |

| | |
|---|---|
| **Launch vehicle** | SS-6/R-7 (8K72) |
| **Mission highlight** | Fly-by of Moon on 4 January 1959 at distance of 5,995 km |
| **Landing site** | |
| **COSPAR ID** | 1959-012A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 361 kg |
| **Orbital elements** | |
| **Semimajor axis** | 1.146 AU |
| **Eccentricity** | 0.14767 |
| **Inclination** | 0.01° |
| **Apoapsis** | 1.315 AU |
| **Periapsis** | 0.9766 AU |
| **Orbital period** | 450 d |
| **Lunar landing** | |
| **Date** | None |
| **Instruments** | |
| Magnetometer (magnetic fields) | |
| Geiger counter (radiation environment) | |
| Micrometeoroid detector | |
| Scintillation counter (magnetospheric studies) | |

**Luna 1** (E-1 series), first known as *First Cosmic Ship*, then known as **Mechta** (Russian: Мечта, *lit.*: *Dream*) was the first spacecraft to reach the vicinity of the Moon and the first of the Luna program of Soviet automatic interplanetary stations successfully launched in the direction of the Moon.

While traveling through the outer Van Allen radiation belt, the spacecraft's scintillator made observations indicating that a small number of high energy particles exist in the outer belt. The measurements obtained during this mission provided new data on the Earth's radiation belt and outer space. The Moon was found to have no detectable magnetic field. The first ever direct observations and measurements of the solar wind, a strong flow of ionized plasma emanating from the Sun and streaming through interplanetary space, were performed. That ionized plasma concentration was measured to be some 700 particles per $cm^3$ at altitudes 20-25 thousand km and 300 to 400 particles per $cm^3$ at altitudes 100-150 thousand km. The spacecraft also marked the first instance of radio communication at the half-million-kilometer distance.

A malfunction in the ground-based control system caused an error in the rocket's burntime, and the spacecraft missed the target and flew by the Moon at a distance of 5,900 km at the closest point. Luna 1 then became the first man-made object to reach heliocentric orbit and was then dubbed a "new planet" and renamed *Mechta*. Its orbit lies between those of Earth and Mars. The name "Luna-1" was applied retroactively years later. Luna-1 was originally referred to as the "First Cosmic Rocket", in reference to its achievement of escape velocity.

## The spacecraft

The scientific equipment and the satellite's power center were located in the spherical container, combining for a mass of 361.3 kg. Five antennae extended from one hemisphere. Instrument ports also protruded from the surface of the sphere. The spacecraft contained radio equipment, a tracking transmitter, a telemetry system, five different sets of scientific devices for studying interplanetary space (including a magnetometer, Geiger counter, scintillation counter, and micrometeorite detector), and other equipment. The total final (with fuel spent) mass of the third (upper) stage rocket with the spacecraft was 1472 kg.

It was intended that after a completion of its scientific mission of in-flight measurements, Luna-1 would crash into the Moon, delivering two metallic pennants with the Soviet coat of arms that were included into its package.

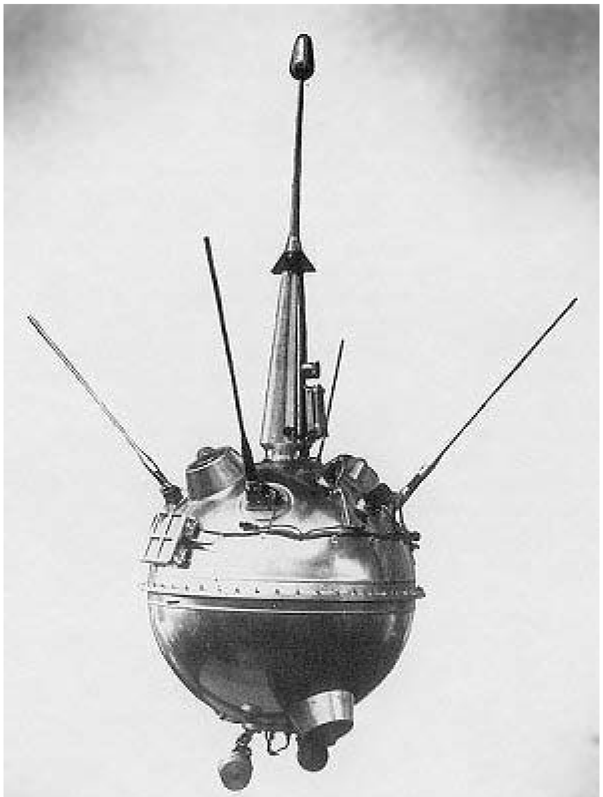
# The flight

Luna 1 was launched 2 January 1959 at 16:41 GMT (19:41 Moscow Time) from the Baikonur Cosmodrome by a Luna 8K72 rocket.

Luna 1 became the first ever man-made object to reach the escape velocity of the Earth (what is also known as the *second cosmic velocity*), when it separated from its 1472 kg third stage. The third stage, 5.2m long and 2.4m in diameter, traveled along with Luna 1. On 3 January, 3:56:20 Moscow Time, at a distance of 119,500 km from Earth, a large (1 kg) cloud of sodium gas was released by the spacecraft, thus making this probe also the first artificial comet. This glowing orange trail of gas, visible over the Indian Ocean with the brightness of a sixth-magnitude star for a few minutes, was photographed by Mstislav Gnevyshev at the Mountain Station of the Main Astronomical Observatory of the Academy of Sciences of the USSR near Kislovodsk. It served as an experiment on the behavior of gas in outer space. Luna 1 passed within 5995 km of the Moon's surface on 4 January after 34 hours of flight. It went into orbit around the Sun, between the orbits of Earth and Mars.

## Luna 2

**Luna 2**



| | |
|---|---|
| **Operator** | Soviet Union |
| **Major contractors** | OKB-1 |
| **Mission type** | Lunar Science<br>Lunar impact |
| **Satellite of** | Moon |
| **Orbits** | none |
| **Launch date** | September 12, 1959 at 06:39:42 UTC |
| **Launch vehicle** | R-7 - (Luna 8K72) |
| **Mission duration** | 33.5 hours |
| **Mission highlight** | Lunar impact (see below) |
| **Landing site** | |
| **COSPAR ID** | 1959-014A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 390.2 kg (860.2 lb) |

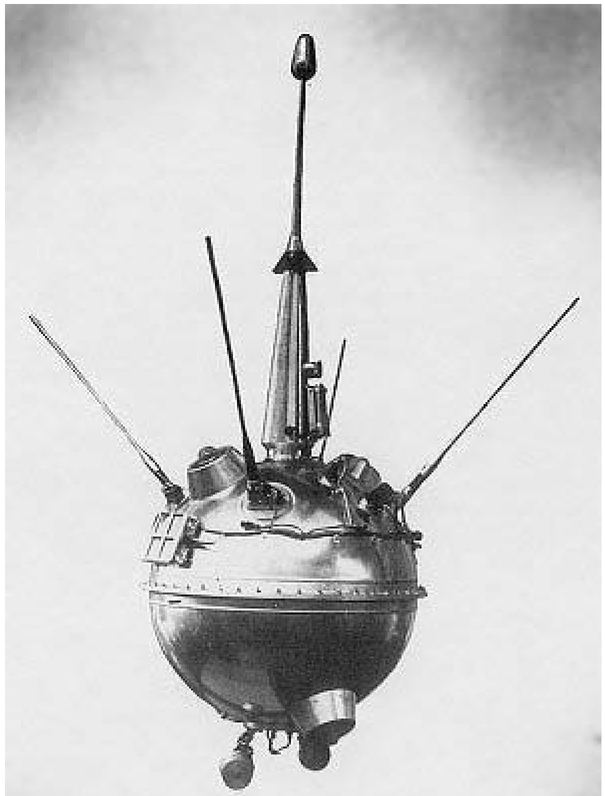
| | |
|---|---|
| **Lunar landing** | |
| **Date** | Lunar collision<br>September 13, 1959, 21:02:24 UTC |
| **Coordinates** | 29°06′N 0°00′W / 29.1°N 0°W |
| **Instruments** | |
| Magnetometer (magnetic fields) | |
| Geiger counter (radiation environment) | |
| Micrometeoroid detector | |
| Scintillation counter (magnetospheric studies) | |

**Luna 2** (E-1A series) was the second of the Soviet Union's Luna programme spacecraft launched to the Moon. It was the first spacecraft to reach the surface of the Moon. It successfully impacted with the lunar surface east of Mare Serenitatis near the craters Aristides, Archimedes, and Autolycus.

Luna 2 was similar in design to Luna 1, a spherical spacecraft with protruding antennae and instrument parts. The instrumentation was also similar, including scintillation counters, geiger counters, a magnetometer, Cherenkov detectors, and micrometeorite detectors. There were no propulsion systems on Luna 2 itself.

# Van Allen Radiation Belt

Luna 2 showed time variations in the electron flux and energy spectrum within the outer belt.



Luna 2 was instrumented with a three component fluxgate magnetometer, similar to that used on Luna 1, but with the dynamic range reduced by a factor of 4 to -750 to +750 nanoteslas (gammas) so that the quantization uncertainty was -12 to +12 nT. The spacecraft spin period was 840 seconds about the major axis, and there was a precession with a period of 86 seconds. The sampling rate of the instrument was approximately once per minute. According to the Principal Investigator, the errors associated with the experiment zero levels and spacecraft fields were such that the accuracy was approximately 50 to 100 nT. The spacecraft gave results similar to those of Luna 1 in the Earth's radiation belts and, upon impact, placed an upper limit of 100 nT on the lunar magnetic field at the surface.

## USSR pennants


Elements of the USSR pennants, delivered by Luna 2 to the moon

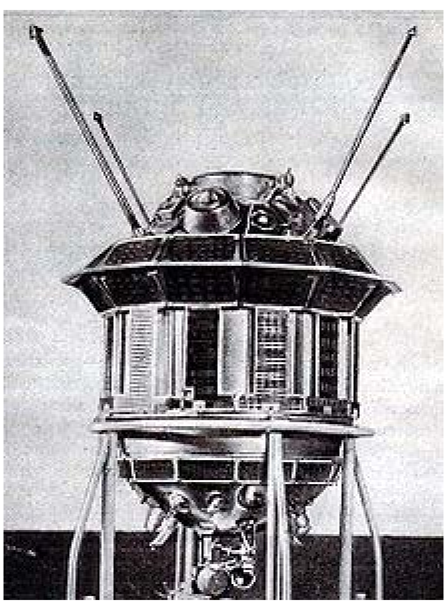
The spacecraft also carried Soviet pennants. Two of them, located in the spacecraft, were sphere-shaped, with the surface covered by identical pentagonal elements. In the center of this sphere was an explosive for the purpose of slowing the huge impact velocity. This was designed as a very simple way to provide the last necessary delta-v for those elements on the retro side of the sphere to not get vaporized. Each pentagonal element was made of stainless steel and had the USSR Coat of Arms and the Cyrillic letters *СССР* (Russian; it translates into English as *USSR*) relief engraved on one side, and the words *СССР СЕНТЯБРЬ 1959* (English: *USSR SEPTEMBER 1959*) relief engraved on the other side. The third pennant was located in the last stage of the Luna 2 rocket, which collided with the moon's surface 30 minutes after the spacecraft did. It was a capsule filled with liquid, with aluminium strips placed into it. On each of these strips the USSR Coat of Arms, the words *1959 СЕНТЯБРЬ* (English: *1959 SEPTEMBER*) and the words *СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК* (English: *UNION OF SOVIET SOCIALIST REPUBLICS*) were engraved.

On September 15, 1959, the premier of the USSR, Nikita Khrushchev, presented to the American president Dwight D. Eisenhower a copy of the spherical pennant as a gift. That sphere is located at the Eisenhower Presidential Library and Museum in Abilene Kansas.

The only other known copy of the spherical pennant is located at the Kansas Cosmosphere in Hutchinson, Kansas.

## Luna 3

**Luna 3**

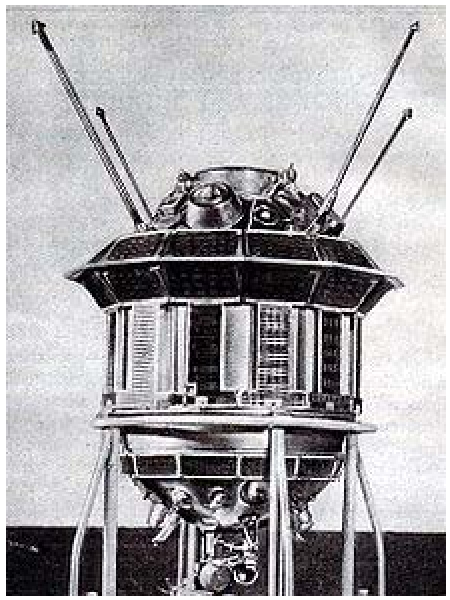


Luna 3

| | |
|---|---|
| **Operator** | Soviet Union |

| | |
|---|---|
| **Major contractors** | OKB-1 |
| **Mission type** | Planetary Science<br>Lunar Flyby |
| **Satellite of** | Earth |
| **Orbits** | ~14 |
| **Launch date** | October 4, 1959 at 00:43:39.7 UTC |
| **Launch vehicle** | SS-6/R-7 (8K72) |
| **Mission duration** | ~207 days |
| **Mission highlight** | Lunar flyby on 6 October 1959, 14:16 UTC at distance of 6,200 km over the lunar south pole |
| **Landing site** | |
| **COSPAR ID** | 1959-008A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 278.5 kg |
| **Orbital elements** | |
| **Semimajor axis** | 250,682 km |
| **Eccentricity** | 0.8379 |
| **Inclination** | 76.8° |
| **Apoapsis** | 460,725 km |
| **Periapsis** | 40,638 km |
| **Orbital period** | 15 days |
| **Instruments** | |
| Yenisey-2 Camera/Film processor (Lunar photography) | |

The Soviet space probe **Luna 3** of 1959 (of the E-3 series) was the third space probe to be sent to the neighborhood of the Moon, and this mission was an early feat in the spaceborne exploration of outer space. Though it returned rather poor pictures by later standards, the historic, never-before-seen views of the far side of the Moon caused excitement and interest when they were published around the world, and a tentative *Atlas of the Far Side of the Moon* was created after image processing improved the pictures. This space probe has been commonly called "Lunik 3", predominantly in the Western world.



These views showed mountainous terrain, very different from the near side, and only two dark, low-lying regions which were named Mare Moscovrae (Sea of Moscow) and Mare Desiderii (Sea of Desire). Mare Luna Desiderii was later found to be composed of a smaller mare, Mare Ingenii (Sea of Ingenuity), and several other dark craters.

## The Space Probe's Design

The space probe was a cylindric canister with hemispheric ends and a wide flange near the top. The probe was 130 cm long and 120 cm at its maximum diameter at the flange. Most of the cylindric section was roughly 95 cm in diameter. The canister was hermetically-sealed and pressurized to about 0.22 atmosphere (23 kilopascals). Several solar cells were mounted on the outside of the cylinder, and these provided electric power to the storage batteries inside the space probe.

Shutters for thermal control were positioned along the cylinder and opened to expose a radiating surface when the internal temperature exceeded 25 celsius. The upper hemisphere of the probe held the covered opening for the cameras. Four antennas protruded from the top of the probe and two from its bottom. Other scientific equipment was mounted on the outside, including micrometeoroid and cosmic ray detectors, and the Yenisey-2 imaging system. The gas jets for its attitude control system were mounted on the lower end of the spacecraft. Several photoelectric cells helped maintain orientation with respect to the Sun and the Moon.

This space probe had no rocket motors for course corrections.

Its interior held the cameras and the photographic film processing system, radio transmitter, storage batteries, gyroscopic units, and circulating fans for temperature control. This space probe was spin-stabilized for most of its flight, but its three-axis attitude control system was activated while taking photos. Luna 3 was radio-controlled from ground stations in the Soviet Union.

## Mission

After launching on an 8K72 (number I1-8) rocket over the North Pole, the Blok-E escape stage was shut down by radio control to put Luna 3 on its course to the Moon. Initial radio contact showed that the signal from the space probe was only about one-half as strong as expected, and the internal temperature was rising. The spacecraft spin axis was reoriented and some equipment was shut down, resulting in a temperature drop from 40 celsius to about 30 celsius. At a distance of 60,000 to 70,000 km from the moon, the orientation system was turned on and the spacecraft rotation was stopped. The lower end of the craft was pointed at the sun, which was shining on the far side of the moon.

The space probe passed within 6,200 km of the moon near its south pole at the closest lunar approach at 14:16 UT on 6 October 1959, and it continued on over the far side. On 7 October, the photocell on the upper end of the space probe detected the sunlit far side of the moon, and the photography sequence was started. The first picture was taken at 03:30 UT at a distance of 63,500 km from the moon, and the last picture was taken 40 minutes later from a distance of 66,700 km.

A total of 29 pictures were taken, covering 70% of the far side. After the photography was complete the spacecraft resumed spinning, passed over the north pole of the moon and returned towards the Earth. Attempts to transmit the pictures to the Soviet Union began on October 8th but the early attempts were unsuccessful due to the low signal strength. As Luna 3 drew closer to the Earth, a total of about 17 viewable but poor quality photographs were transmitted by 18 October. All contact with the probe was lost on 22 October 1959. The space probe was believed to have burned up in the Earth's atmosphere in March or April 1960, but it might have survived in orbit until 1962 or later.

## Lunar photography

Luna-3 phototelegraph system at Tsiolkovsky State Museum of the History of Cosmonautics


1959 USSR stamp commemorating first photographs of the Far side of the Moon

The purpose of this experiment was to obtain photographs of the lunar surface as the spacecraft flew by the moon. The imaging system was designated Yenisey-2 and consisted of a dual-lens camera AFA-E1, an automatic film processing unit, and a scanner. The lenses on the camera were a 200 mm focal length, *f*/5.6 aperture objective and a 500 mm, *f*/9.5 objective. The camera carried 40 frames of temperature- and radiation-resistant 35 mm isochrome film. The 200 mm objective could image the full disk of the moon and the 500 mm could take an image of a region on the surface. The camera was fixed in the spacecraft and pointing was achieved by rotating the craft itself.

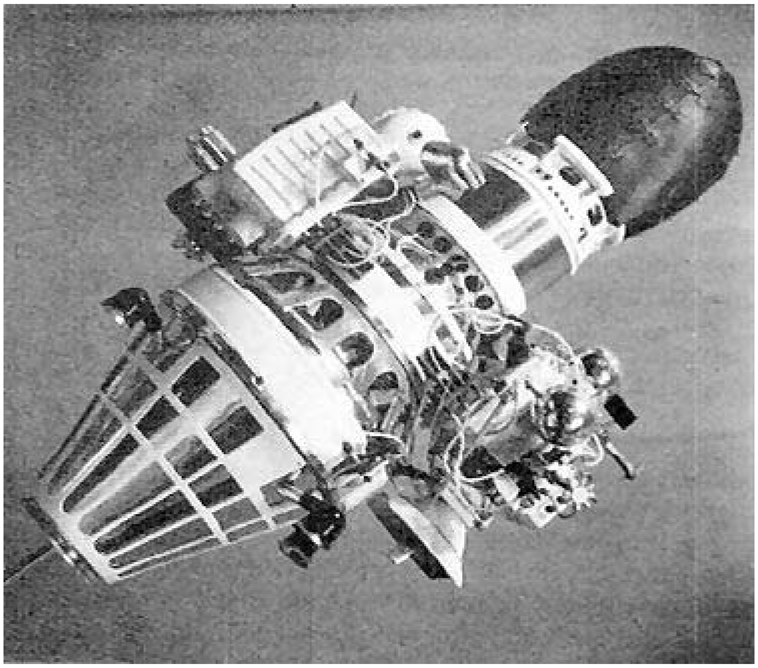
Luna-3 was the first successful three-axis stabilized spacecraft. During most of the mission, the spacecraft was spin stabilized, but for photography of the moon, the spacecraft oriented one axis toward the Sun and then a photocell was used to detect the moon and orient the cameras towards it. Detection of the moon signalled the camera cover to open and the photography sequence to start automatically. The images alternated between both cameras during the sequence. After photography was complete, the film was moved to an on-board processor where it was developed, fixed, and dried. Commands from the Earth were then given to move the film into a scanner where a spot produced by a cathode ray tube was projected through the film onto a photoelectric multiplier. The spot was scanned across the film and the photomultiplier converted the intensity of the light passing through the film into an electric signal which was transmitted to the Earth (via frequency-modulated analog video, similar to a facsimile). A frame could be scanned with a resolution of 1000 (horizontal) lines and the transmission could be done at a slow-scan television rate at large distances from the Earth and a faster rate at closer ranges.

The camera took 29 pictures over 40 minutes on 7 October 1959, from 03:30 UT to 04:10 UT at distances ranging from 63,500 km to 66,700 km above the surface, covering 70% of the lunar far side. Seventeen (some say twelve) of these frames were successfully transmitted back to the Earth, and six were published (frames numbered 26, 28, 29, 31, 32, and 35). They were mankind's first views of the far hemisphere of the moon.

The imaging system was developed by P.F. Bratslavets and I.A. Rosselevich at the Leningrad Scientific Research Institute for Television and the returned images were processed and analyzed by Iu.N. Lipskii and his team at the Sternberg Astronomical Institute. The camera AFA-E1 was developed and manufactured by the KMZ factory (Krasnogorskiy Mekhanicheskiy Zavod).

## Luna 4

**Luna 4**



| | |
|---|---|
| **Operator** | Soviet Union |
| **Major contractors** | OKB-1 |
| **Mission type** | Planetary Science<br>Lunar landing |
| **Satellite of** | Earth |
| **Launch date** | April 2, 1963 at 08:04:00 UTC |
| **Launch vehicle** | Molniya 8K78 (4-Stage R-7 / SS-6) |
| **Mission duration** | > April 6, 1963 |
| **Mission highlight** | Lunar flyby<br>April 5, 1963, 13:25 UTC<br>at distance of 8336.2 km |
| **Landing site** | |
| **COSPAR ID** | 1963-008B |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 1,422 kg |

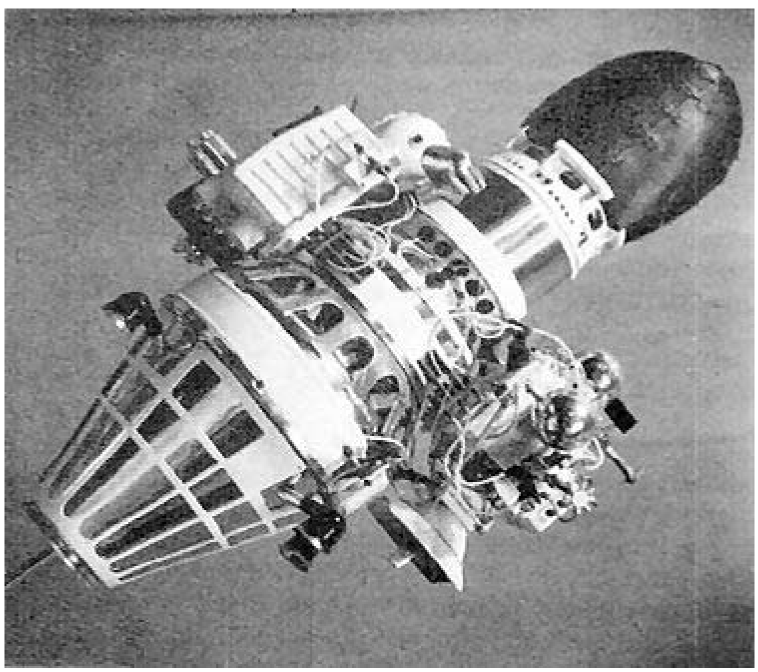
**Orbital elements**

| | |
|---|---|
| **Semimajor axis** | 394,128 km |
| **Eccentricity** | 0.772 |
| **Apoapsis** | 698,455 km |
| **Periapsis** | 89,801 km |
| **Orbital period** | ~28.365 d |

**Instruments**

Close-Up Lunar Surface Photography

**Luna 4** (E-6 series) was the USSR's first successful spacecraft of their "second generation" Luna program. The spacecraft, rather than being sent on a straight trajectory toward the Moon, was placed first in a low Earth orbit (167 to 182 km altitude) and then the rocket stage reignited to send it on a curving path towards the Moon.



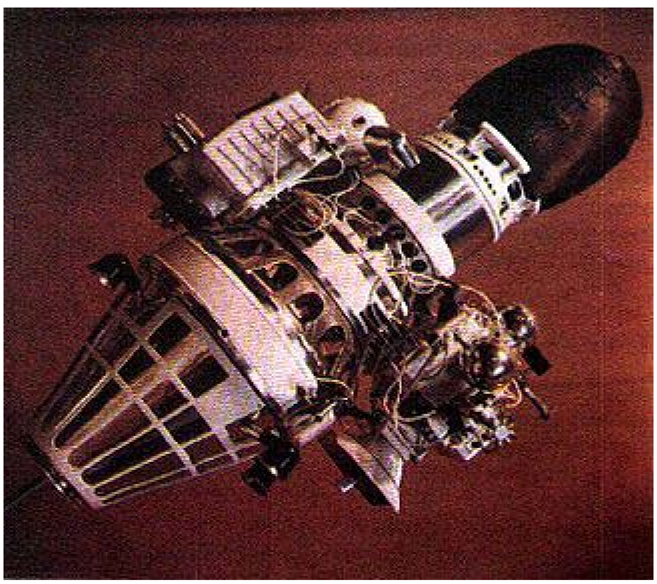
Luna 4, the second attempt of this program, achieved the desired trajectory but a failure to make a required midcourse correction resulted in it missing the Moon by 8336.2 km at 13:25 UT on April 5, 1963. It then entered a barycentric 90,000 × 700,000 km Earth orbit. The intended mission of the probe is not known, it was speculated the probe was designed to land on the Moon with an instrument package based on the trajectory and on the later attempted landings of the Luna 5 and Luna 6 spacecraft and successful landing of Luna 9. (A lecture program entitled "Hitting the Moon" was scheduled to be broadcast on Radio Moscow at 7:45 p.m. the evening of April 5 but was cancelled.) The spacecraft transmitted at 183.6 MHz at least until April 6.

# Lunar surface close-up photography

The purpose of this experiment was to obtain information on the characteristics of the lunar surface. These characteristics include the amount of cratering, structure and size of craters, the amount, distribution, and sizes of ejecta, mechanical properties of the surface such as bearing strength, cohesiveness, compaction, etc. Determination and recognition of processes operating to produce the lunar surface features also were among the objectives of this photographic experiment.

## Luna 9

**Luna 9**



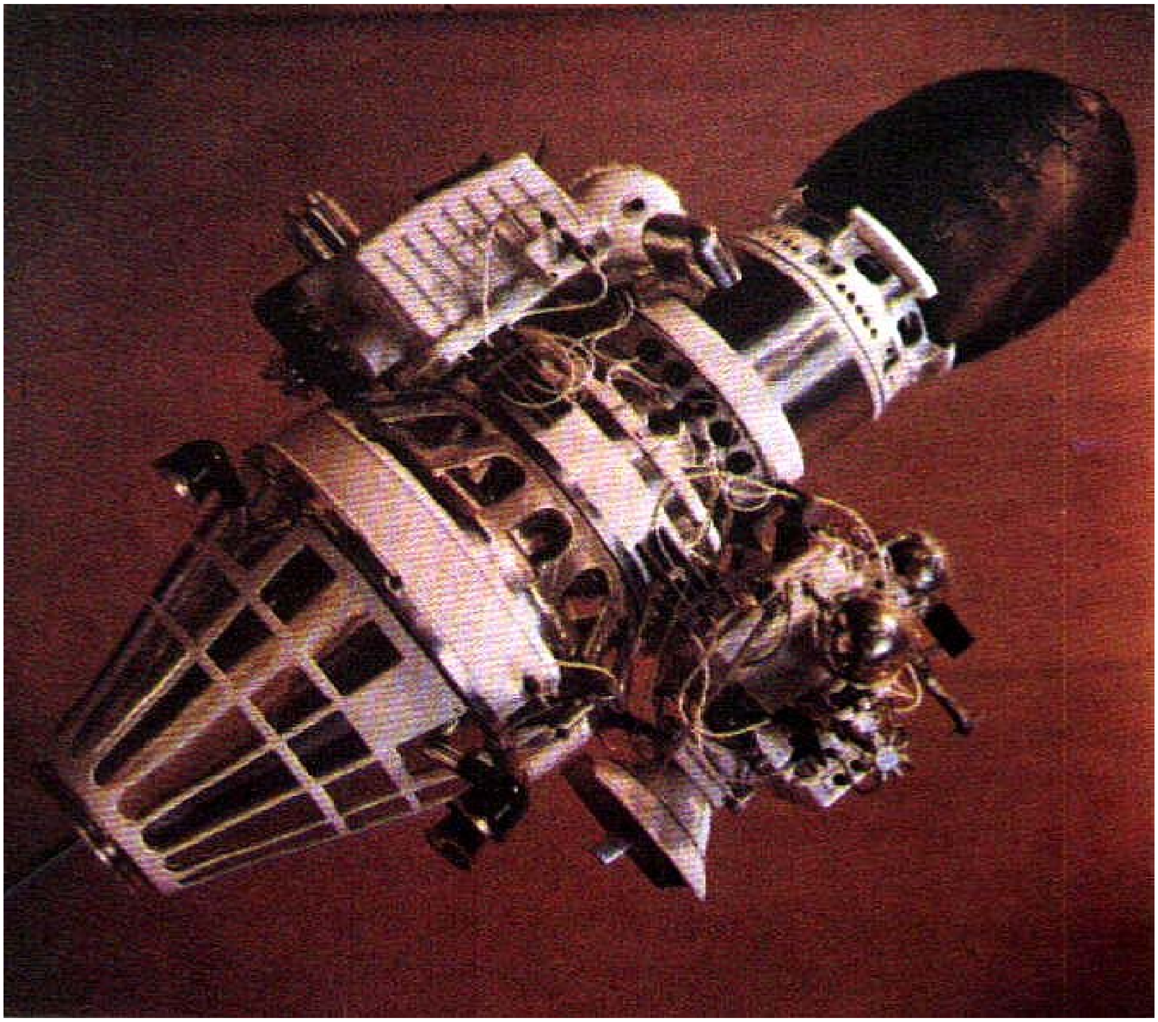
Luna 9

| | |
|---|---|
| **Operator** | Soviet Union |
| **Major contractors** | GSMZ Lavochkin |
| **Mission type** | Lander |
| **Satellite of** | Moon |
| **Launch date** | January 31, 1966 at 11:45:00 UTC |
| **Launch vehicle** | Molniya 8K78M (4-Stage R-7 / SS-6) |

| | |
|---|---|
| **Mission duration** | 6 days. Last transmission February 6, 1966, 22:55 UTC. |
| **Orbital decay** | Landed on Moon February 3, 1966, 18:44:52 UTC at 7°08′N 64°22′W / 7.13°N 64.37°W |
| **Landing site** | |
| **COSPAR ID** | 1966-006A |
| **Mass** | 1580 kg |

**Luna 9** (E-6 series) (internal name E-6 N. 13) was an unmanned space mission of the Soviet Union's Luna program. On February 3, 1966 the Luna 9 spacecraft was the first spacecraft to achieve a soft landing on any planetary body other than Earth and to transmit photographic data to Earth.

The automatic lunar station that achieved the survivable landing weighed 99 kg. It used a landing bag and survived the impact at 15 meters/second (54 km/h or 34 mph). It was a hermetically sealed container with radio equipment, a program timing device, heat control systems, scientific apparatus, power sources, and a television system. The Luna 9 payload was carried to Earth orbit by an A-2-E vehicle and then conveyed toward the Moon by a fourth stage rocket that separated itself from the payload. The flight apparatus separated from the payload shortly before Luna 9 landed.



After landing in the Oceanus Procellarum on February 3, the four petals, which covered the top half of the spacecraft, opened outward and stabilized the spacecraft on the lunar surface. Spring-controlled antennas assumed operating positions, and the television camera rotating mirror system, which operated by revolving and tilting, began a photographic survey of the lunar environment. Seven radio sessions, totaling 8 hours and 5 minutes, were transmitted as were three series of TV pictures.

When assembled, the photographs provided a panoramic view of the nearby lunar surface. The pictures included views of nearby rocks and of the horizon 1.4 km away from the spacecraft.

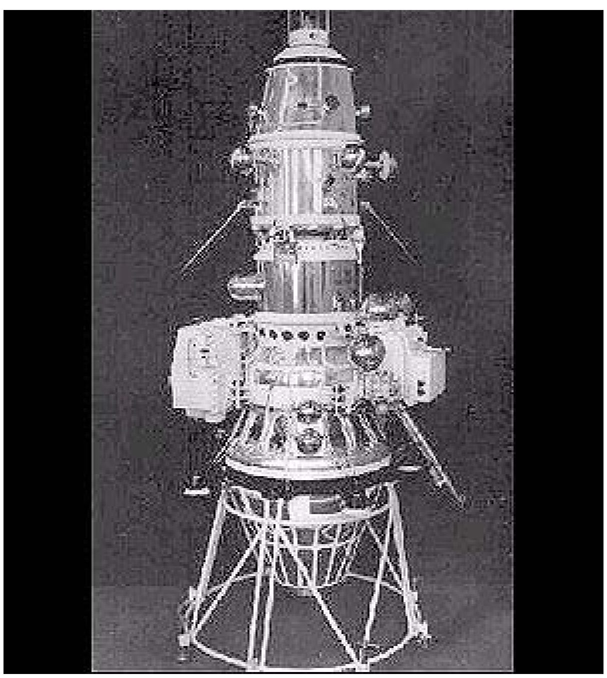
For unknown reasons, the pictures from Luna 9 were not released immediately by the Soviet authorities. Instead, the Jodrell Bank Observatory, which was monitoring the craft, noticed that the signal format used was identical to the internationally-agreed system used by newspapers for transmitting pictures. The Daily Express rushed a suitable receiver to the Observatory and the pictures from Luna 9 were decoded and published worldwide. The BBC reports speculated that the spacecraft's designers deliberately fitted the probe with equipment that conformed to the standard, specifically to enable reception of the pictures by Jodrell Bank.

With this mission, the Soviets accomplished another spectacular first in the space race, the first survivable landing of a manmade object on another celestial body. Luna 9 was the twelfth attempt at a soft-landing by the Soviets; it was also the first deep space probe built by the Lavochkin design bureau, which ultimately would design and build almost all Soviet (and Russian) lunar and interplanetary spacecraft. All operations prior to landing occurred without fault, and the 58 centimeter spheroid ALS capsule landed on the Moon at 18:45:30 UT on February 3, 1966 west of the craters Reiner and Marius in the Ocean of Storms (at 7°8' north latitude and 64°22' west longitude). Approximately five minutes after touchdown, Luna 9 began transmitting data to Earth, but it was seven hours (after the Sun climbed to 7° elevation) before the probe began sending the first of nine images (including five panoramas) of the surface of the Moon.

These were the first images sent from the surface of another planetary body. The radiation detector, the only scientific instrument on board, measured a dosage of 30 millirads (0.3 milligrays) per day. Perhaps the most important discovery of the mission was determining that a foreign object would not simply sink into the lunar dust, that is, that the ground could support a heavy lander. Last contact with the spacecraft was at 22:55 UT on February 6, 1966.

## Luna 10

**Luna 10**

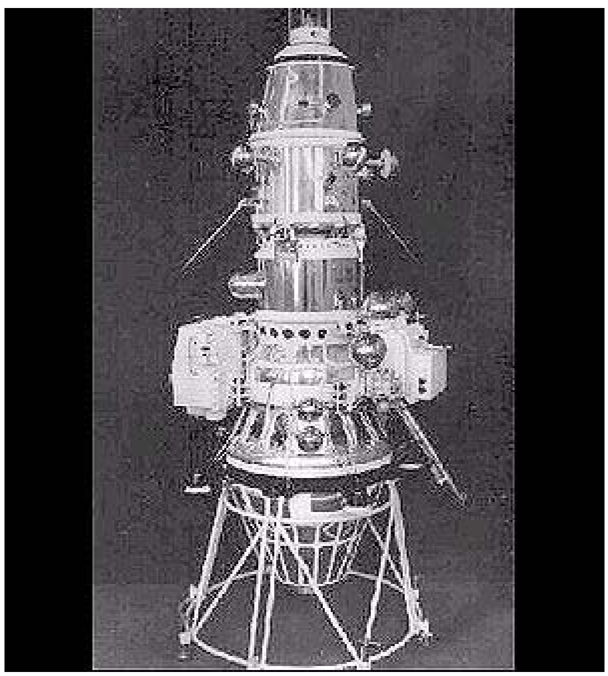


**Operator** Soviet Union

| | |
|---|---|
| **Major contractors** | GSMZ Lavochkin |
| **Mission type** | Planetary Science Lunar Orbit |
| **Satellite of** | Moon |
| **Launch date** | March 31, 1966 at 10:48:00 UTC |
| **Launch vehicle** | Molniya 8K78M (4-Stage R-7 / SS-6) |
| **Mission duration** | 60 days. Last contact May 30, 1966 |
| **Mission highlight** | Entered lunar orbit on April 3, 1966, 18:44 UTC. |
| **Landing site** | |
| **COSPAR ID** | 1966-027A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 1,582 kg |
| **Orbital elements** | |
| **Semimajor axis** | 2,413.0 km |
| **Eccentricity** | .14 |
| **Inclination** | 71.9° |
| **Apoapsis** | 2,738 km |
| **Periapsis** | 2,088 km |
| **Orbital period** | 178.05 minutes |
| **Instruments** | |
| **Main instruments** | • Magnetometer<br>• Gamma-ray spectrometer<br>• Five gas-discharge counters<br>• Two ion traps/charged particle trap<br>• Piezoelectric micrometeorite detector<br>• Infrared detector |

- Low-energy x-ray photon counters

**Luna 10** (E-6S series) was a Luna program, robotic spacecraft mission, also called Lunik 10. The Luna 10 spacecraft was launched towards the Moon from an Earth orbiting platform on March 31, 1966. It was the first artificial satellite of the Moon (or another heavenly body, for that matter). The spacecraft entered lunar orbit on April 3, 1966 and completed its first orbit 3 hours later (on April 4, Moscow time). Scientific instruments included a gamma-ray spectrometer for energies between 0.3—3 MeV (50–500 pJ), a triaxial magnetometer, a meteorite detector, instruments for solar-plasma studies, and devices for measuring infrared emissions from the Moon and radiation conditions of the lunar environment. Gravitational studies were also conducted. The spacecraft played back to Earth *The Internationale* during the Twenty-third Congress of the Communist Party of the Soviet Union. Luna 10 was battery powered and operated for 460 lunar orbits and 219 active data transmissions before radio signals were discontinued on May 30, 1966.



After a midcourse correction on 1 April, Luna 10, the second of two hastily prepared Soviet Ye-6S probes (that is, the backup), successfully entered lunar orbit two days later at 18:44 UT, thus becoming the first man-made object to go into orbit around another planetary body. A 245-kilogram instrument compartment separated from the main bus, which was in a 350 x 1,000-kilometer orbit inclined at 71.9° to the lunar equator. The spacecraft carried a set of solid-state oscillators that had been programmed to reproduce the notes of *The Internationale*, so that it could be broadcast live to the 23rd Communist Party Congress. During a rehearsal on the night of 3 April, the playback went well, but the following morning, controllers discovered a missing note and played the previous night's tape to the assembled gathering at the Congress—claiming it was a live broadcast from the Moon. Luna 10 conducted extensive research in lunar orbit, gathering important data on the strength of the Moon's magnetic field, its radiation belts, and the nature of lunar rocks (which were found to be comparable to terrestrial basalt rocks), cosmic radiation, and micrometeoroid density. Perhaps its most important finding was the first evidence of mass concentrations (called "mascons")—areas of high density below the mare basins that distort lunar orbital trajectories. Their discovery has usually been credited to the American Lunar Orbiter series. Last contact was on 30 May 1966.

- Launch Date/Time: 1966-03-31 at 10:48:00 UTC
- On-orbit dry mass: 540 kg

## Luna 11

**Luna 11** (E-6LF series) was an unmanned space mission of the Soviet Union's Luna program. It is also called Lunik 11. Luna 11 was launched towards the Moon from an earth-orbiting platform and entered lunar orbit on 27 August 1966. The objectives of the mission included the study of:

1. lunar gamma- and X-ray emissions in order to determine the Moon's chemical composition;
2. lunar gravitational anomalies;
3. the concentration of meteorite streams near the Moon; and,
4. the intensity of hard corpuscular radiation near the Moon.

A total of 137 radio transmissions and 277 orbits of the Moon were completed before the batteries failed on 1 October 1966.

This subset of the "second-generation" Luna spacecraft, the Ye-6LF, was designed to take the first photographs of the surface of the Moon from lunar orbit. A secondary objective was to obtain data on mass concentrations ("mascons") on the Moon first detected by Luna 10. Using the basic Ye-6 bus, a suite of scientific instruments (plus an imaging system similar to the one used on Zond 3) replaced the small lander capsule used on the soft-landing flights. The resolution of the photos was reportedly 15 to 20 meters. A technological experiment included testing the efficiency of gear transmission in vacuum as a test for a future lunar rover. Luna 11, launched only two weeks after the U.S. Lunar Orbiter, successfully entered lunar orbit at 21:49 UT on 27 August. Parameters were 160 x 1,193 kilometers. During the mission, the TV camera failed to return usable images because the spacecraft lost proper orientation to face the lunar surface when a foreign object was lodged in the nozzle of one of the attitude-control thrusters. The other instruments functioned without fault before the mission formally ended on 1 October 1966 after the power supply had been depleted.

- Launch Date/Time: 1966-08-24 at 08:09:00 UTC
- On-orbit dry mass: 3616 kg

Chapter- 4

# Ranger Program

## Ranger 3

**Ranger 3**

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Jet Propulsion Laboratory |
| **Mission type** | Lunar Science |
| **Satellite of** | Sun |

| | |
|---|---|
| **Orbits** | Heliocentric orbit |
| **Launch date** | January 26, 1962 at 20:30:00 UTC |
| **Launch vehicle** | Atlas-Agena B |
| **Mission duration** | 2 days |
| **Orbital decay** | Flew past Moon at 36,800 km distance on January 28, 1962, now in heliocentric orbit. |
| **Landing site** | |
| **COSPAR ID** | 1962-001A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 329.8 kg (727.1 lb) |

**Ranger 3** is a spacecraft of the Ranger program that was launched to study the Moon on January 26, 1962. The space probe was designed to transmit pictures of the lunar surface to Earth stations during a period of 10 minutes of flight prior to impacting on the Moon, to rough-land a seismometer capsule on the Moon, to collect gamma-ray data in flight, to study radar reflectivity of the lunar surface, and to continue testing of the Ranger program for development of lunar and interplanetary spacecraft. Due to a series of malfunctions the spacecraft missed the Moon by 22,000 miles (35,000 km).

## Spacecraft design

Ranger 3 was the first of the Block II Ranger designs. The basic vehicle was 3.1 m high and consisted of a lunar capsule covered with a balsa wood impact-limiter, 650 mm in diameter, a mono-propellant mid-course motor, a retrorocket with a thrust of 5080 pounds force (22.6 kN), and a gold- and chrome-plated hexagonal base 1.5 m in diameter. A large high-gain dish antenna was attached to the base. Two wing-like solar panels (5.2 m across) were attached to the base and deployed early in the flight. Power was generated by 8680 solar cells contained in the solar panels which charged an 11.5 kg 1 kW·h capacity AgZn launching and backup battery. Spacecraft control was provided by a solid-state computer and sequencer and an earth-controlled command system. Attitude control was provided by Sun and Earth sensors, gyroscopes, and pitch and roll jets. The telemetry system aboard the spacecraft consisted of two 960 MHz transmitters, one at 3 W power output and the other at 50 mW power output, the high-gain antenna, and an omni-directional antenna. White paint, gold and chrome plating, and a silvered plastic sheet encasing the retrorocket furnished thermal control.

The experimental apparatus included: (1) a vidicon television camera, which employed a scan mechanism that yielded one complete frame in 10 s; (2) a gamma-ray spectrometer mounted on a 1.8 m boom; (3) a radar altimeter; and (4) a seismometer to be rough-landed on the lunar surface. The seismometer (code-named "Tonto") was encased in the lunar capsule along with an amplifier, a 50 mW transmitter, voltage control, a turnstile antenna, and 6 silver-cadmium batteries capable of operating the lunar capsule transmitter for 30 days, all designed to land on the Moon at 130 to 160 km/h (80 to 100 mph). The radar altimeter would be used for reflectivity studies, but was also designed to initiate capsule separation and ignite the retro-rocket.

## Mission

The mission was designed to boost towards the Moon by an Atlas/Agena, undergo one mid-course correction, and impact the lunar surface. At the appropriate altitude the capsule was to separate and the retrorockets ignite to cushion the landing. A malfunction in the booster guidance system resulted in excessive spacecraft speed. Reversed command signals caused the spacecraft to pitch in the wrong direction and the TM antenna to lose earth acquisition, and mid-course correction was not possible. Finally a spurious signal during the terminal maneuver prevented transmission of useful TV pictures. Ranger 3 missed the Moon by approximately 36,800 km on 28 January and is now in a heliocentric orbit. Some useful engineering data were obtained from the flight.

This was the first U.S. attempt to achieve impact on the lunar surface. The Block II Ranger spacecraft carried a TV camera that used an optical telescope that would allow imaging down to about 24 kilometers above the lunar surface during the descent. The main bus also carried a 42.6-kilogram instrument capsule that would separate from the bus at 21.4 kilometers altitude and then independently impact on the Moon. Protected by a balsa-wood outer casing, the capsule was designed to bounce several times on the lunar surface before coming to rest. The primary onboard instrument was a seismometer. Because of a malfunction in the Atlas guidance system (due to faulty transistors), the probe was inserted into a lunar transfer trajectory with an excessive velocity. A subsequent incorrect course change ensured that the spacecraft reached the Moon 14 hours early and missed it by 36,793 kilometers on 28 January. The central computer and sequencer failed and the spacecraft returned no TV images. The probe did, however, provide scientists with the first measurements of interplanetary gamma-ray flux. Ranger 3 eventually entered and currently maintains a heliocentric orbit.

## Ranger 4

**Ranger 4** was a spacecraft of the Ranger program designed to transmit pictures of the lunar surface to Earth stations during a period of 10 minutes of flight prior to crashing upon the Moon, to rough-land a seismometer capsule on the Moon, to collect gamma-ray data in flight, to study radar reflectivity of the lunar surface, and to continue testing of the Ranger program for development of lunar and interplanetary spacecraft. An onboard computer failure caused failure of the deployment of the solar panels and navigation systems; as a result the spacecraft crashed on the far side of the Moon without returning any scientific data.

## Spacecraft design

Ranger 4 was a Block II Ranger spacecraft virtually identical to Ranger 3. The basic vehicle was 331 kg, 3.1 m high and consisted of a lunar capsule covered with a balsawood impact-limiter, 650 mm in diameter, a mono-propellant mid-course motor, a 5080 lbf (22.6 kN) thrust retrorocket, and a gold- and chrome-plated hexagonal base 1.5 m in diameter. A large high-gain dish antenna was attached to the base. Two wing-like solar panels (5.2 m across) were attached to the base and deployed early in the flight. Power was generated by 8680 solar cells contained in the solar panels which charged an 11.5 kg 1 kWh capacity AgZn launching and backup battery. Spacecraft control was provided by a solid-state computer and sequencer and an earth-controlled command system. Attitude control was provided by Sun and Earth sensors, gyroscopes, and pitch and roll jets. The telemetry system aboard the spacecraft consisted of two 960 MHz transmitters, one at 3 W power output and the other at 50 mW power output, the high-gain antenna, and an omni-directional antenna. White paint, gold and chrome plating, and a silvered plastic sheet encasing the retrorocket furnished thermal control.

The experimental apparatus included: (1) a vidicon television camera, which employed a scan mechanism that yielded one complete frame in 10 s; (2) a gamma-ray spectrometer mounted on a 1.8 m boom; (3) a radar altimeter; and (4) a seismometer to be rough-landed on the lunar surface. The seismometer was encased in the lunar capsule along with an amplifier, a 50-milliwatt transmitter, voltage control, a turnstile antenna, and 6 silver-cadmium batteries capable of operating the lunar capsule transmitter for 30 days, all designed to land on the Moon at 130 to 160 km/h (80 to 100 mph). The radar altimeter would be used for reflectivity studies, but was also designed to initiate capsule separation and ignite the retro-rocket.

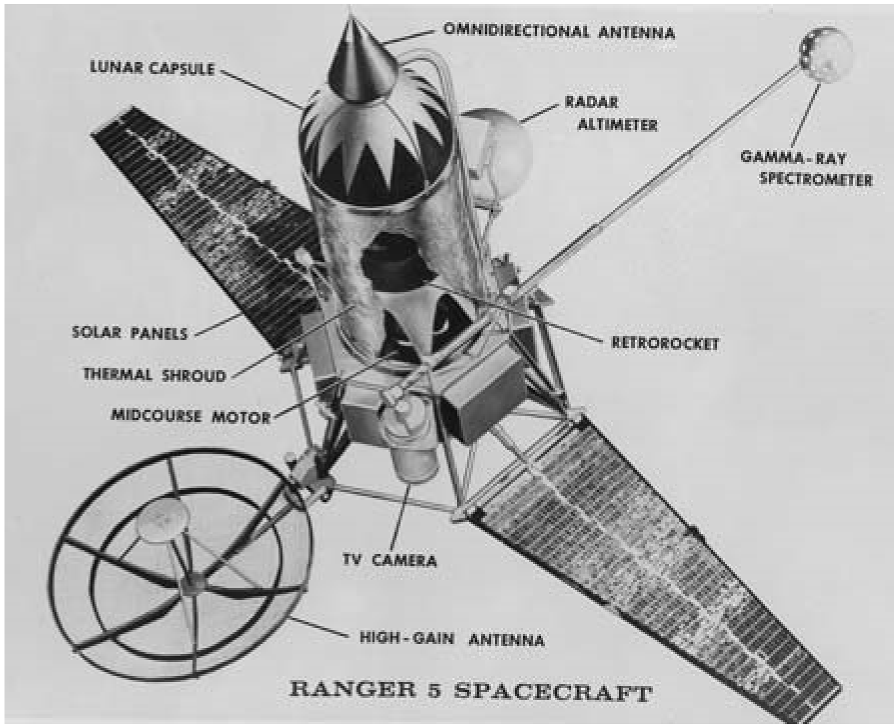
## Mission

The mission was designed to be boosted towards the Moon by an Atlas/Agena, undergo one mid-course correction, and impact the lunar surface. At the appropriate altitude, a smaller capsule was to separate and the retrorockets ignite to cushion the landing. Due to an apparent failure of a timer in the spacecraft's central computer and sequencer following launch the command signals for the extension of the solar panels and the operation of the sun and earth acquisition system were never given. The instrumentation ceased operation after about 10 hours of flight. The spacecraft was tracked by the battery-powered 50 milliwatt transmitter in the lunar landing capsule. Ranger 4 crashed upon the far side of the Moon (15°30′S 229°18′E / 15.5°S 229.3°E) at 9600 km/h at 12:49:53 UT on April 26, 1962 after 64 hours of flight.

This spacecraft, similar in design to Ranger 3, was the first U.S. spacecraft to reach another celestial body. A power failure in the central computer and sequencer stopped the spacecraft's master clock and prevented the vehicle from performing any of its preplanned operations, such as opening its solar panels. Drifting aimlessly and without any midcourse corrections, Ranger 4 crashed upon the far side of the Moon at 12:49:53 UT on 26 April 1962. Impact coordinates were 15°30' south latitude and 130°42' west longitude. Although the spacecraft did not achieve its primary objective, the Atlas-Agena-Ranger combination performed without fault for the first time.

# Ranger 5

**Ranger 5** was a spacecraft of the Ranger program designed to transmit pictures of the lunar surface to Earth stations during a period of 10 minutes of flight prior to impacting on the Moon, to rough-land a seismometer capsule on the Moon, to collect gamma-ray data in flight, to study radar reflectivity of the lunar surface, and to continue testing of the Ranger program for development of lunar and interplanetary spacecraft. Due to an unknown malfunction, the spacecraft ran out of power and ceased operation. It passed within 725 km of the Moon.




## Spacecraft design

Ranger 5 was a Block II Ranger spacecraft similar to Ranger 3 and Ranger 4. The basic vehicle was 3.1 m high and consisted of a lunar capsule covered with a balsawood impact-limiter, 65 cm in diameter, a mono-propellant mid-course motor, a retrorocket with a thrust of 5080 lbf (23 kN), and a gold and chrome plated hexagonal base 1.5 m in diameter. A large high-gain dish antenna was attached to the base. Two wing-like solar panels (5.2 m across) were attached to the base and deployed early in the flight. Power was generated by 8680 solar cells contained in the solar panels which charged an 11.5 kg 1 kWh capacity AgZn launching and backup battery. Spacecraft control was provided by a solid-state digital computer and sequencer and an earth-controlled command system. Attitude control was provided by six Sun and one Earth sensor, gyroscopes, and pitch and roll cold nitrogen gas jets. The telemetry system aboard the spacecraft consisted of two 960 MHz transmitters, one at 3 W power output and the other at 50 mW power output, the high-gain antenna, and an omnidirectional antenna. White paint, gold and chrome plating, and a silvered plastic sheet encasing the retrorocket furnished thermal control.

The experimental apparatus included: (1) a vidicon television camera, which employed a scan mechanism that yielded one complete frame in 10 s; (2) a gamma-ray spectrometer in a 300 mm sphere mounted on a 1.8 m boom; (3) a radar altimeter; and (4) a seismometer to be rough-landed on the lunar surface. The seismometer was encased in the lunar capsule along with an amplifier, a 50 mW transmitter, voltage control, a turnstile antenna, and 6 silver-cadmium batteries capable of operating the lunar capsule transmitter for 30 days, all designed to land on the Moon at 130 to 160 km/h (80 to 100 mph). The instrument package floated in a layer of freon within the balsawood sphere. The radar altimeter would be used for reflectivity studies, but was also designed to initiate capsule separation and ignite the retro-rocket.

## Mission

The mission was designed to boost towards the Moon by an Atlas/Agena, undergo one mid-course correction, and impact the lunar surface. At the appropriate altitude the capsule was to separate and the retrorockets ignite to cushion the landing. Due to an unknown malfunction after injection into lunar trajectory from Earth parking orbit, the spacecraft failed to receive power. The batteries ran down after 8 hours, 44 minutes, rendering the spacecraft inoperable. Ranger 5 missed the Moon by 725 km. It is now in a heliocentric orbit. Gamma-ray data were collected for four hours prior to the loss of power. Mission controllers tracked it to a distance of 1.3 million km (808,000) miles.

This was the third attempt to impact the lunar surface with a Block II Ranger spacecraft. On this mission, just 15 minutes after normal operation, a malfunction led to the transfer of power from solar to battery power. Normal operation never resumed; battery power was depleted after 8 hours, and all spacecraft systems died. The first midcourse correction was never implemented, and Ranger 5 passed the Moon at a range of 724 kilometers on 21 October and entered heliocentric orbit. It was tracked to a distance of 1,271,381 kilometers. Before loss of signal, the spacecraft sent back about 4 hours of data from the gamma-ray experiment.

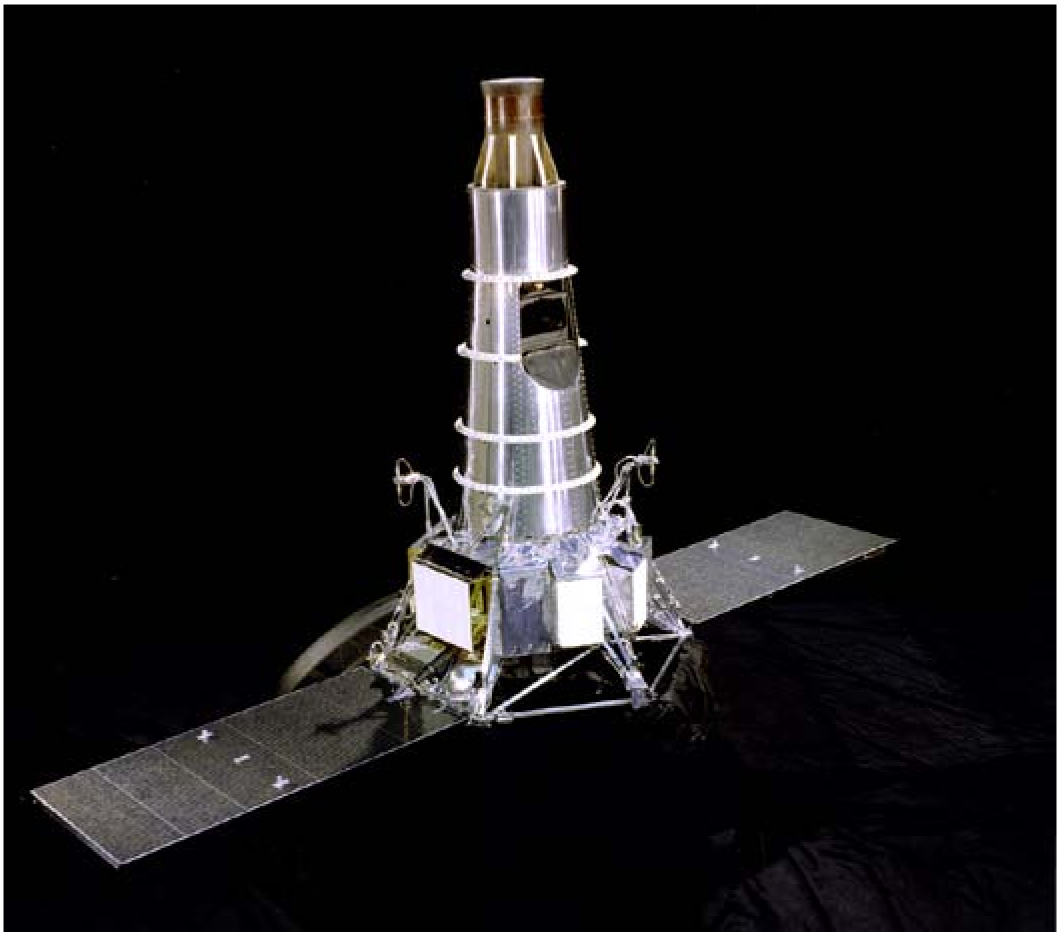
Following the failure of this launch (missing the moon), the electronic assembly for the next versions were completely rebuilt by RCA Astro Electronics Division in East Windsor, New Jersey. The satellites rebuilt by RCA Astro worked beautifully. All photos were returned and helped NASA determine good landing sites for the Lunar Landers. The main harness for the subsequent Rangers is considered by some to be a work of art. It truly is beautiful and from the Harness Shop of RCA Astro.

# Ranger 6

**Ranger 6** was designed to achieve a lunar impact trajectory and to transmit high-resolution photographs of the lunar surface during the final minutes of flight up to impact. The spacecraft carried six television vidicon cameras, 2 wide angle (channel F, cameras A and B) and 4 narrow angle (channel P) to accomplish these objectives. The cameras were arranged in two separate chains, or channels, each self-contained with separate power supplies, timers, and transmitters so as to afford the greatest reliability and probability of obtaining high-quality Television pictures. No other experiments were carried on the spacecraft. Due to a failure of the camera system no images were returned.

## Spacecraft design

Rangers 6, 7, 8, and 9 were so-called Block III versions of the Ranger spacecraft. The spacecraft consisted of a hexagonal aluminum frame base 1.5 m across on which was mounted the propulsion and power units, topped by a truncated conical tower which held the TV cameras. Two solar panel wings, each 739 mm wide by 1537 mm long, extended from opposite edges of the base with a full span of 4.6 m, and a pointable high gain dish antenna was hinge mounted at one of the corners of the base away from the solar panels. A cylindrical quasiomnidirectional antenna was seated on top of the conical tower. The overall height of the spacecraft was 3.6 m.



Propulsion for the mid-course trajectory correction was provided by a 224 N thrust monopropellant hydrazine engine with 4 jet-vane vector control. Orientation and attitude control about 3 axes was enabled by 12 nitrogen gas jets coupled to a system of 3 gyros, 4 primary Sun sensors, 2 secondary Sun sensors, and an Earth sensor. Power was supplied by 9792 Si solar cells contained in the two solar panels, giving a total array area of 2.3 square meters and producing 200 W. Two 1200 watt.hour AgZnO batteries rated at 26.5 V with a capacity for 9 hours of operation provided power to each of the separate communication/TV camera chains. Two 1000 watt-hour AgZnO batteries stored power for spacecraft operations.

Communications were through the quasiomnidirectional low-gain antenna and the parabolic high-gain antenna. Transmitters aboard the spacecraft included a 60 W TV channel F at 959.52 MHz, a 60 W TV channel P at 960.05 MHz, and a 3 W transponder channel 8 at 960.58 MHz. The telecommunications equipment converted the composite video signal from the camera transmitters into an RF signal for subsequent transmission through the spacecraft high-gain antenna. Sufficient video bandwidth was provided to allow for rapid framing sequences of both narrow- and wide-angle television pictures.

## Mission profile

**Ranger 6** was launched into an Earth parking orbit and injected on a lunar trajectory by a second Agena burn. The midcourse trajectory correction was accomplished early in the flight by ground control. On February 2, 1964, 65.5 hours after launch, Ranger 6 impacted the Moon on the eastern edge of Mare Tranquillitatis (Sea of Tranquility). The orientation of the spacecraft to the surface during descent was correct, but no video signal was received and no camera data obtained. A review board determined the most likely cause of failure was due to an arc-over in the TV power system when it inadvertently turned on for 67 seconds approximately 2 minutes after launch during the period of booster-engine separation.

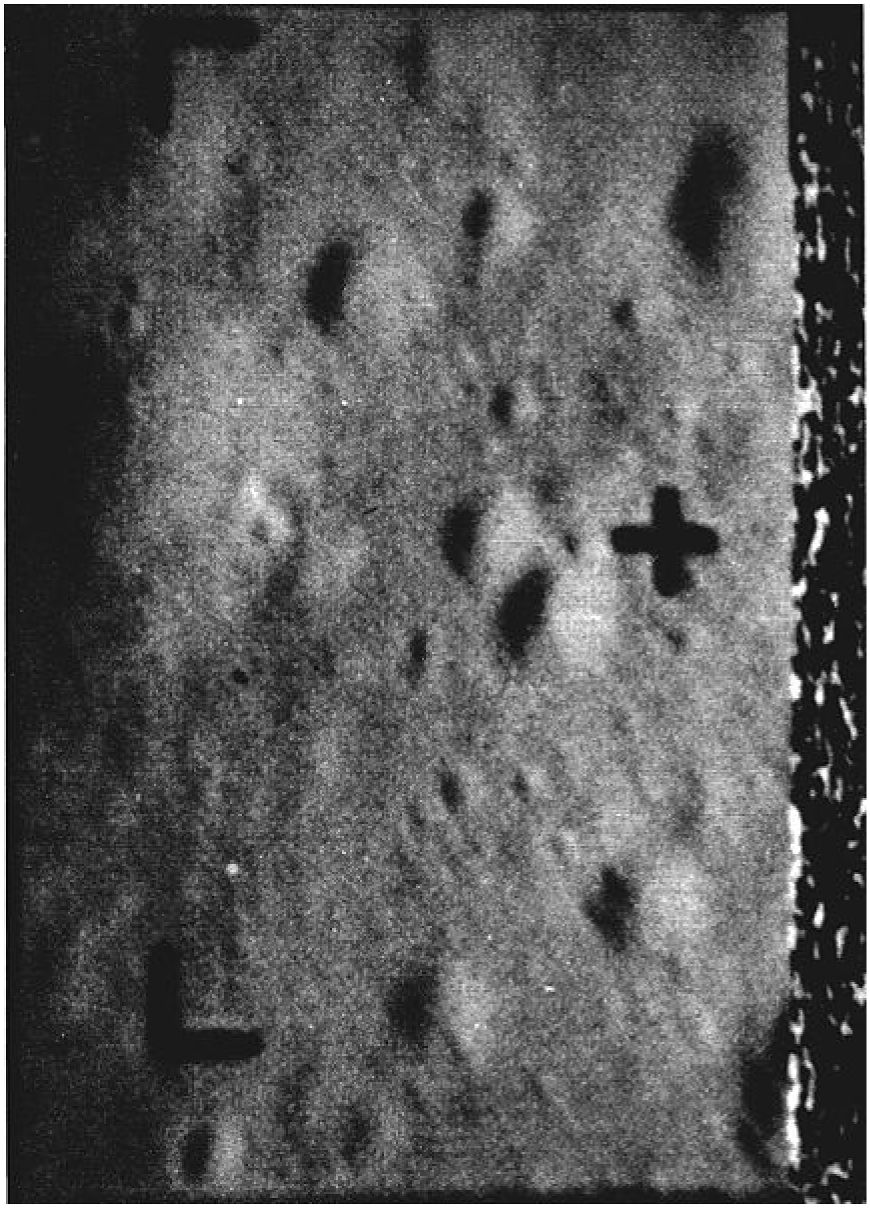
This fourth American attempt at lunar impact was the closest success. The spacecraft, the first Block III type vehicle with a suite of six TV cameras, was sterilized to avoid contaminating the lunar surface. The series would also serve as a test bed for future interplanetary spacecraft by deploying systems (such as solar panels) that could be used for more ambitious missions. The Block III spacecraft carried a 173-kilogram TV unit (replacing the impact capsule carried on the Block II Ranger spacecraft). The six cameras included two full-scan and four partial-scan cameras. Ranger 6 flew to the Moon successfully and impacted precisely on schedule at 09:24:32 UT on 2 February. Unfortunately, the power supply for the TV camera package had short-circuited three days previously during Atlas booster separation and left the system inoperable. The cameras were to have transmitted high-resolution photos of the lunar approach from 1,448 kilometers to 6.4 kilometers range in support of Project Apollo. Impact coordinates were 9°24' north latitude and 21°30' east longitude.

# Ranger 7

**Ranger 7**

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Jet Propulsion Laboratory |
| **Mission type** | Lunar Science |
| **Satellite of** | Moon |
| **Orbits** | Lunar impact |
| **Launch date** | July 28, 1964 at 16:50:00 UTC |
| **Launch vehicle** | Atlas-Agena B |
| **Mission duration** | 65.5 hours |
| **Orbital decay** | Impacted on Moon on<br>July 31, 1964,13:25:48.82 UT<br>at 10°21′S 339°25′E / 10.35°S 339.42°E. |
| **Landing site** | |
| **COSPAR ID** | 1964-041A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 365.7 kg |

First image of the Moon taken by a US spacecraft. The large crater at center right is Alphonsus



Last picture by Ranger 7, taken about 488 m above the Moon, reveals features as small as 38 cm across. The noise pattern at right results from spacecraft impact while transmitting.

**Ranger 7** was the first US space probe to successfully transmit close images of the lunar surface back to Earth. It was also the first completely successful flight of the Ranger program. Launched on 28 July 1964, Ranger 7 was designed to achieve a lunar impact trajectory and to transmit high-resolution photographs of the lunar surface during the final minutes of flight up to impact. The spacecraft carried six television vidicon cameras, 2 wide angle (channel F, cameras A and B) and 4 narrow angle (channel P) to accomplish these objectives. The cameras were arranged in two separate chains, or channels, each self-contained with separate power supplies, timers, and transmitters so as to afford the greatest reliability and probability of obtaining high-quality video pictures. No other experiments were carried on the spacecraft.

## Spacecraft design

Rangers 6, 7, 8, and 9 were the so-called Block 3 versions of the Ranger spacecraft. The spacecraft consisted of a hexagonal aluminum frame base 1.5 m across on which was mounted the propulsion and power units, topped by a truncated conical tower which held the TV cameras. Two solar panel wings, each 739 mm wide by 1537 mm long, extended from opposite edges of the base with a full span of 4.6 m, and a pointable high gain dish antenna was hinge mounted at one of the corners of the base away from the solar panels. A cylindrical quasiomnidirectional antenna was seated on top of the conical tower. The overall height of the spacecraft was 3.6 m.

Propulsion for the mid-course trajectory correction was provided by a 224 N thrust monopropellant hydrazine engine with 4 jet-vane vector control. Orientation and attitude control about 3 axes was enabled by 12 nitrogen gas jets coupled to a system of 3 gyros, 4 primary Sun sensors, 2 secondary Sun sensors, and an Earth sensor. Power was supplied by 9792 Si solar cells contained in the two solar panels, giving a total array area of 2.3 square meters and producing 200 W. Two 1200 watt.hour AgZnO batteries rated at 26.5 V with a capacity for 9 hours of operation provided power to each of the separate communication/TV camera chains. Two 1000 watt.hour AgZnO batteries stored power for spacecraft operations.

Communications were through the quasiomnidirectional low-gain antenna and the parabolic high-gain antenna. Transmitters aboard the spacecraft included a 60 W TV channel F at 959.52 MHz, a 60 W TV channel P at 960.05 MHz, and a 3 W transponder channel 8 at 960.58 MHz. The telecommunications equipment converted the composite video signal from the camera transmitters into an RF signal for subsequent transmission through the spacecraft high-gain antenna. Sufficient video bandwidth was provided to allow for rapid framing sequences of both narrow- and wide-angle television pictures.

## Mission profile

The Atlas 250D and Agena B 6009 boosters performed nominally at launch inserting the Agena and Ranger into a 192 km altitude Earth parking orbit. Half an hour after launch the second burn of the Agena engine injected the spacecraft into a lunar intercept trajectory. After separation from the Agena, the solar panels were deployed, attitude control activated, and spacecraft transmissions switched from the omniantenna to the high-gain antenna. The next day, 29 July, the planned mid-course maneuver was initiated at 10:27 UT, involving a short rocket burn. The only anomaly during flight was a brief loss of two-way lock on the spacecraft by the DSIF tracking station at Cape Kennedy following launch.

Ranger 7 reached the Moon on 31 July. The F-channel began its one minute warm up 18 minutes before impact. The first image was taken at 13:08:45 UT at an altitude of 2110 km. Transmission of 4,308 photographs of excellent quality occurred over the final 17 minutes of flight. The final image taken before impact has a resolution of 0.5 meters.

The spacecraft encountered the lunar surface in direct motion along a hyperbolic trajectory, with an incoming asymptotic direction at an angle of -5.57 degrees from the lunar equator. The orbit plane was inclined 26.84 degrees to the lunar equator. After 68.6 hours of flight, Ranger 7 impacted in an area between Mare Nubium and Oceanus Procellarum (subsequently named Mare Cognitum) at approximately 10°21′S 339°25′E / 10.35°S 339.42°E. (The impact site is listed as 10.63 S, 339.34 E in the initial report "Ranger 7 Photographs of the Moon".) Impact occurred at 13:25:48.82 UT at a velocity of 2.62 km/s. The spacecraft performance was excellent.

## Ranger 8

**Ranger 8**

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Jet Propulsion Laboratory |
| **Mission type** | Lunar Science |
| **Satellite of** | Moon |
| **Orbits** | Lunar impact |
| **Launch date** | February 17, 1965 at 17:05:00 UTC |
| **Launch vehicle** | Atlas-Agena B |
| **Mission duration** | 65 hours |
| **Orbital decay** | Impacted on Moon on February 20, 1965, 09:57:36.756 UTC at 2°43′N 24°37′E / 2.72°N 24.61°E |
| **Landing site** | |
| **COSPAR ID** | 1965-010A |

**Homepage** NASA NSSDC Master Catalog

**Mass** 367 kg

**Ranger 8** was a spacecraft designed to achieve a lunar impact trajectory and to transmit high-resolution photographs of the lunar surface during the final minutes of flight up to impact. The spacecraft carried six television vidicon cameras, two wide angle (channel F, cameras A and B) and four narrow angle (channel P) to accomplish these objectives. The cameras were arranged in two separate chains, or channels, each self-contained with separate power supplies, timers, and transmitters so as to afford the greatest reliability and probability of obtaining high-quality Television pictures. No other experiments were carried on the spacecraft.

## Spacecraft design

Rangers 6, 7, 8, and 9 were called the Block 3 versions of the Ranger spacecraft. The spacecraft consisted of a hexagonal aluminum frame base 1.5 m across on which was mounted the propulsion and power units, topped by a truncated conical tower which held the TV cameras. Two solar panel wings, each 739 mm wide by 1537 mm long, extended from opposite edges of the base with a full span of 4.6 m, and a pointable high gain dish antenna was hinge mounted at one of the corners of the base away from the solar panels. A cylindrical quasiomnidirectional antenna was seated on top of the conical tower. The overall height of the spacecraft was 3.6 m.

Propulsion for the mid-course trajectory correction was provided by a 224 N thrust monopropellant hydrazine engine with four jet-vane vector control. Orientation and attitude control about three axes was enabled by twelve nitrogen gas jets coupled to a system of three gyroscopes, four primary Sun sensors, two secondary Sun sensors, and an Earth sensor. Power was supplied by 9792 silicon solar cells contained in the two solar panels, giving a total array area of 2.3 square meters and producing 200 W. Two 1200 watt.hour AgZnO batteries rated at 26.5 V with a capacity for nine hours of operation provided power to each of the separate communication/TV camera chains. Two 1000 watt.hour AgZnO batteries stored power for spacecraft operations.

Communications were through the quasiomnidirectional low-gain antenna and the parabolic high-gain antenna. Transmitters aboard the spacecraft included a 60 watt TV channel F at 959.52 MHz, a 60 watt TV channel P at 960.05 MHz, and a three watt transponder channel 8 at 960.58 MHz. The telecommunications equipment converted the composite video signal from the camera transmitters into an RF signal for subsequent transmission through the spacecraft's high-gain antenna. Sufficient video bandwidth was provided to allow for rapid framing sequences of both narrow- and wide-angle television pictures.

## Mission profile

The Atlas 196D and Agena B 6006 boosters performed nominally, injecting the Agena and Ranger 8 into an Earth parking orbit at 185 km altitude after launch. Fourteen minutes later a 90 second burn of the Agena put the spacecraft into lunar transfer trajectory, and several minutes later the Ranger and Agena separated. The Ranger solar panels were deployed, attitude control activated, and spacecraft transmissions switched from the omniantenna to the high-gain antenna by 21:30 UT. On 18 February at a distance of 160,000 km from Earth the planned mid-course maneuver took place, involving reorientation and a 59 second rocket burn. During the 27 minute maneuver, spacecraft transmitter power dropped severely, so that lock was lost on all telemetry channels. This continued intermittently until the rocket burn, at which time power returned to normal. The telemetry dropout had no serious effects on the mission. A planned terminal sequence to point the cameras more in the direction of flight just before reaching the Moon was cancelled to allow the cameras to cover a greater area of the Moon's surface.

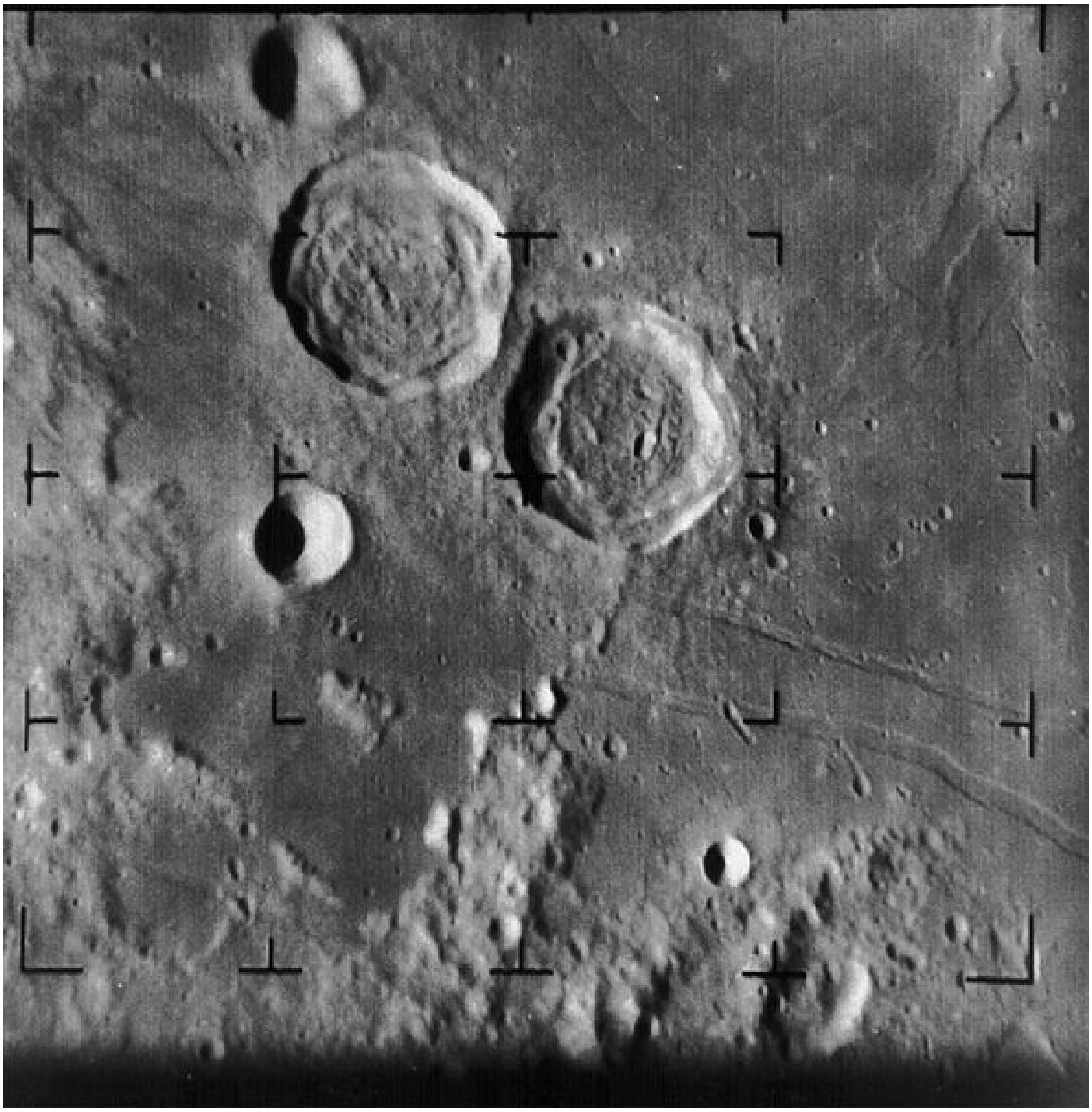
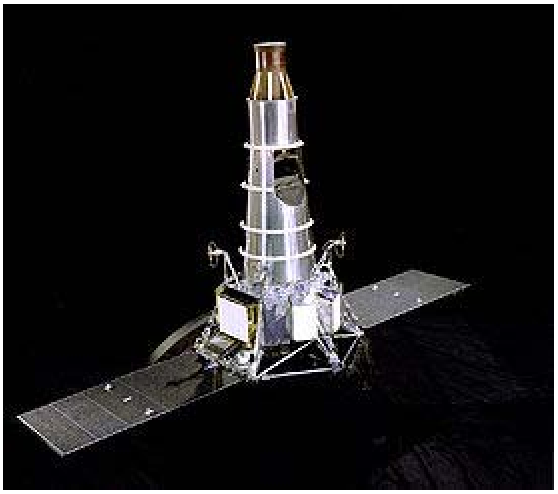


Image of the moon taken by the Ranger 8 space probe, showing the craters Ritter and Sabine.

Ranger 8 reached the Moon on February 20, 1965. The first image was taken at 9:34:32 UT at an altitude of 2510 km. Transmission of 7,137 photographs of good quality occurred over the final 23 minutes of flight. The final image taken before impact has a resolution of 1.5 meters. The spacecraft encountered the lunar surface in a direct hyperbolic trajectory, with incoming asymptotic direction at an angle of -13.6 degrees from the lunar equator. The orbit plane was inclined 16.5 degrees to the lunar equator. After 64.9 hours of flight, impact occurred at 09:57:36.756 UT on 20 February 1965 in Mare Tranquillitatis at approximately 2.67 degrees N, 24.65 degrees E. (The impact site is listed as about 2.72° N, 24.61° E in the initial report "Ranger 8 Photographs of the Moon".) Impact velocity was slightly less than 2.68 km/s. The spacecraft performance was excellent.

# Ranger 9

**Ranger 9**



| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Jet Propulsion Laboratory |
| **Mission type** | Lunar Science |
| **Satellite of** | Moon |
| **Orbits** | Lunar impact |
| **Launch date** | March 21, 1965 at 21:37:00 UTC |
| **Launch vehicle** | Atlas-Agena B |
| **Mission duration** | 64.5 hours |
| **Orbital decay** | Impacted on Moon on March 24, 1965, 14:08:19.994 UTC at 12°50′S 357°38′E / 12.83°S 357.63°E |
| **Landing site** | |
| **COSPAR ID** | 1965-023A |
| **Homepage** | NASA NSSDC Master Catalog |

**Mass** 367 kg

**Ranger 9** was designed to achieve a lunar impact trajectory and to transmit high-resolution photographs of the lunar surface during the final minutes of flight up to impact. The spacecraft carried six television vidicon cameras, 2 wide angle (channel F, cameras A and B) and 4 narrow angle (channel P) to accomplish these objectives. The cameras were arranged in two separate chains, or channels, each self-contained with separate power supplies, timers, and transmitters so as to afford the greatest reliability and probability of obtaining high-quality Television pictures. No other experiments were carried on the spacecraft.

# Spacecraft design

Rangers 6, 7, 8 , and 9 were the so-called Block 3 versions of the Ranger spacecraft. The spacecraft consisted of a hexagonal aluminum frame base 1.5 m across on which was mounted the propulsion and power units, topped by a truncated conical tower which held the TV cameras. Two solar panel wings, each 739 mm wide by 1537 mm long, extended from opposite edges of the base with a full span of 4.6 m, and a pointable high gain dish antenna was hinge mounted at one of the corners of the base away from the solar panels. A cylindrical quasiomnidirectional antenna was seated on top of the conical tower. The overall height of the spacecraft was 3.6 m.

Propulsion for the mid-course trajectory correction was provided by a 224-N thrust monopropellant hydrazine engine with 4 jet-vane vector control. Orientation and attitude control about 3 axes was enabled by 12 nitrogen gas jets coupled to a system of 3 gyros, 4 primary Sun sensors, 2 secondary Sun sensors, and an Earth sensor. Power was supplied by 9792 Si solar cells contained in the two solar panels, giving a total array area of 2.3 square meters and producing 200 W. Two 1200 watt.hour AgZnO batteries rated at 26.5 V with a capacity for 9 hours of operation provided power to each of the separate communication/TV camera chains. Two 1000 watt.hour AgZnO batteries stored power for spacecraft operations.

Communications were through the quasiomnidirectional low-gain antenna and the parabolic high-gain antenna. Transmitters aboard the spacecraft included a 60 W TV channel F at 959.52 MHz, a 60 W TV channel P at 960.05 MHz, and a 3 W transponder channel 8 at 960.58 MHz. The telecommunications equipment converted the composite video signal from the camera transmitters into an RF signal for subsequent transmission through the spacecraft high-gain antenna. Sufficient video bandwidth was provided to allow for rapid framing sequences of both narrow and wide-angle television pictures.

# Mission profile

The Atlas 204D and Agena B 6007 boosters performed nominally, injecting the Agena and Ranger 9 into an Earth parking orbit at 185 km altitude. A 90 second Agena 2nd burn put the spacecraft into lunar transfer trajectory. This was followed by the separation of the Agena and Ranger. Seventy minutes after launch the command was given to deploy solar panels, activate attitude control, and switch from the omniantenna to the high-gain antenna. The accuracy of the initial trajectory enabled delay of the planned mid-course correction from 22 March to 23 March when the maneuver was initiated at 12:03 UT. After orientation, a 31 second rocket burn at 12:30 UT, and reorientation, the maneuver was completed at 13:30 UT.

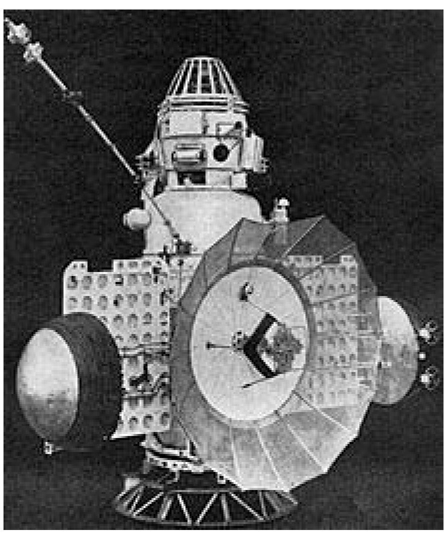
Ranger 9 reached the Moon on 24 March 1965. At 13:31 UT a terminal maneuver was executed to orient the spacecraft so the cameras were more in line with the flight direction to improve the resolution of the pictures. Twenty minutes before impact the one-minute camera system warm-up began. The first image was taken at 13:49:41 at an altitude of 2363 km. Transmission of 5,814 good contrast photographs was made during the final 19 minutes of flight. The final image taken before impact has a resolution of 0.3 meters. The spacecraft encountered the lunar surface with an incoming asymptotic direction at an angle of -5.6 degrees from the lunar equator. The orbit plane was inclined 15.6 degrees to the lunar equator. After 64.5 hours of flight, impact occurred at 14:08:19.994 UT at approximately 12.83 S latitude, 357.63 E longitude in the Alphonsus. Impact velocity was 2.67 km/s. The spacecraft performance was excellent. Real time television coverage with live network broadcasts of many of the F-channel images (primarily camera B but also some camera A pictures) were provided for this flight.

## Chapter- 5

# Zond Program

## Zond 3

| Zond 3 | |
|---|---|



Zond 3

| | |
|---|---|
| **Operator** | Soviet Union |
| **Major contractors** | OKB-1 |
| **Mission type** | Planetary Science |
| **Satellite of** | Sun |
| **Launch date** | July 18, 1965 at 14:38:00 UTC |

| | |
|---|---|
| **Launch vehicle** | SL-6/A-2-e |
| **Mission highlight** | Fly-by of Moon on July 20, 1965 at distance of 9,200 km |
| **Landing site** | |
| **COSPAR ID** | 1965-056A |
| **Homepage** | NASA NSSDC Master Catalog |
| **Mass** | 960 kg |
| **Orbital elements** | |
| **Semimajor axis** | 1 AU |
| **Eccentricity** | 0.2683 |
| **Inclination** | 0.5° |
| **Apoapsis** | 1.56 AU |
| **Periapsis** | 0.9 AU |
| **Orbital period** | 500 d |

**Instruments**

*f*/106 mm Camera and TV system with automatic inflight film processing

Magnetometer

Ultraviolet (0.25–0.35 µm and 0.19–0.27 µm) spectrograph

Infrared (3–4 µm) spectrograph

Radiation sensors (gas-discharge and scintillation counters)

Radiotelescope

Micrometeoroid instrument

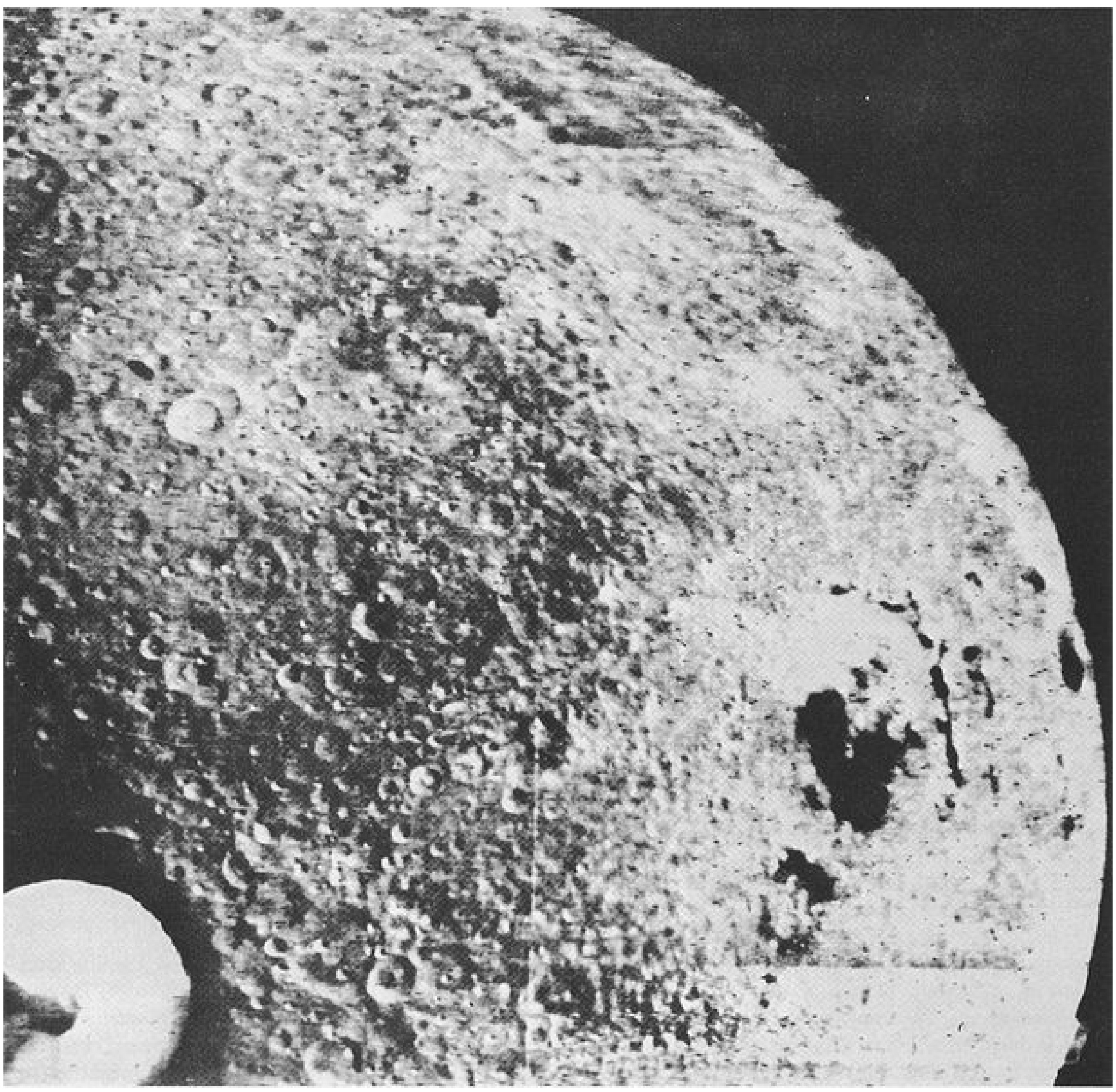
Experimental ion engine

**Zond 3** was a member of the Soviet Zond program sharing designation Zond, while being part of Mars 3MV project. It was unrelated to Zond spacecraft designed for manned circumlunar mission (Soyuz 7K-L1). Zond 3 completed a successful Lunar flyby, taking a number of good quality photographs for its time. It is believed that Zond 3 was initially designed as a companion spacecraft to Zond 2 to be launched to Mars during the 1964 launch window. The opportunity to launch was missed, and the spacecraft was launched on a Mars trajectory as a spacecraft test, even though Mars was no longer attainable.

## Spacecraft design

The spacecraft design was similar to Zond 2, in addition to the imaging equipment it carried a magnetometer, ultraviolet (0.25 to 0.35 micrometre and 0.19 to 0.27 micrometre) and infrared (3 to 4 micrometre) spectrographs, radiation sensors (gas-discharge and scintillation counters), a radiotelescope and a micrometeoroid instrument. It also had an experimental ion engine.

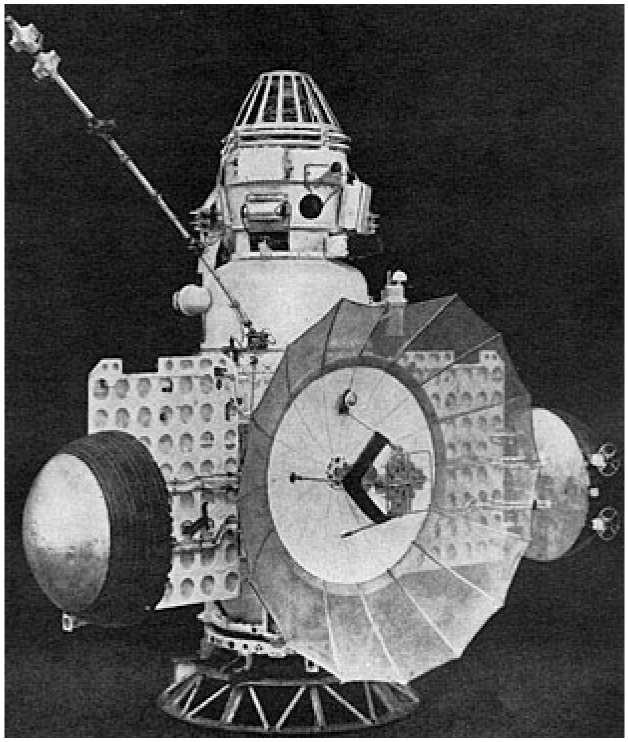
## Mission



One of the last Zond 3 (frame 28) images of the Lunar limb.


Mosaic of all the Zond 3 images created with modern image processing tools.

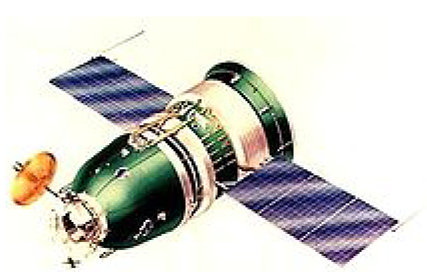
The spacecraft, a *Mars 3MV-4A*, was launched from a Tyazheliy Sputnik (65-056B) earth orbiting platform towards the Moon and interplanetary space. The spacecraft was equipped with an *f*/106 mm camera and TV system that provided automatic inflight film processing. On July 20 lunar flyby occurred approximately 33 hours after launch at a closest approach of 9200 km. 23 photographs and 3 ultraviolet spectra of very good



quality were taken of the lunar farside from distances of 11,570 to 9960 km over a period of 68 minutes. The photos covered 19,000,000 km² of the lunar surface. Zond 3 proceeded on a Mars trajectory, but not at a time when planetary encounter would occur. To test telemetry, the images were rewound and transmitted at 2.2 million km, 31.5 million km and possibly again at greater distances, thus proving the ability of the communications system. The mission was ended and radio contact ceased when it was at a distance of 150 million km.

## Zond 5

**Zond 5**



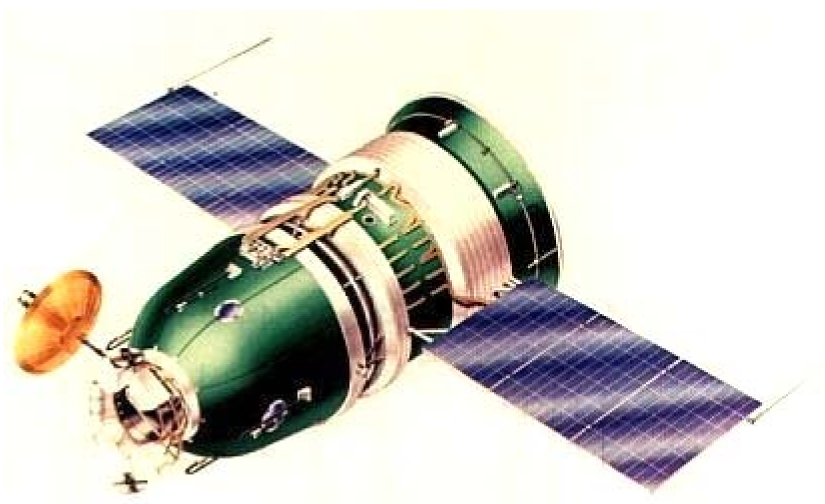
Zond 5

| | |
|---|---|
| **Major contractors** | OKB-1 |
| **Bus** | Soyuz 7K-L1 |

| | |
|---|---|
| **Mission type** | Lunar flyby<br>Spacecraft test |
| **Launch date** | 15 September 1968<br>21:42:11 UTC |
| **Carrier rocket** | Proton-K/D |
| **Launch site** | Baikonur |
| **Landing site** | |
| **Mass** | 5,375 kilograms (11,850 lb) |

**Zond 5**, a formal member of the Soviet Zond program and unmanned version of Soyuz 7K-L1 manned moon-flyby spacecraft, was launched from a Tyazheliy Sputnik (68-076B) in Earth parking orbit to make scientific studies during a lunar flyby and to return to Earth.

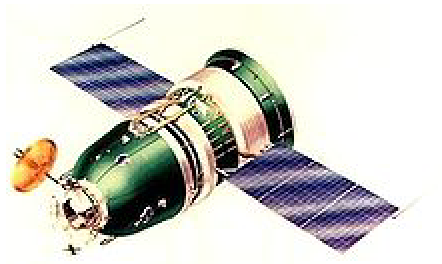
Zond-5 became the first spacecraft to circle the Moon and return to land on Earth. On September 18, 1968, the spacecraft flew around the Moon. The closest distance was 1,950 km. High quality photographs of the Earth were taken at a distance of 90,000 km. A biological payload of two russian tortoises, wine flies, meal worms, plants, seeds, bacteria, and other living matter was included in the flight.



September 21, 1968, the reentry capsule entered the Earth's atmosphere, braked aerodynamically by means of skip reentry, and deployed its parachutes at 7 km. The capsule splashed down in the Indian Ocean and was successfully recovered, with its biological payload intact, also making it the first group of animals from Earth to perform lunar flyby. It was announced that the turtles had lost about 10% of their body weight but remained active and showed no loss of appetite. The spacecraft was planned as a precursor to manned lunar spacecraft.

- Launch Date/Time: 1968-09-14 at 21:42:11 UTC
- On-orbit dry mass: 5375 kg

## Zond 6

| **Zond 6** | |
|---|---|
|  | |
| **Operator** | Soviet Union |
| **Major contractors** | NPO Energia Company |
| **Mission type** | Planetary Science |
| **Satellite of** | Moon |
| **Launch date** | November 10, 1968 at 19:11:31 [GMT] |
| **Launch vehicle** | Proton-K/11S824 |
| **Mission duration** | 5.79 days |
| **Mission highlight** | Fly-by of Moon on November 14, 1968 at distance of 2,420km |
| **Landing site** | |
| **Homepage** | |
| **Mass** | 5375 kg |
| **Orbital elements** | |
| **Inclination** | 51.5° |
| **Apoapsis** | 400,000 km |
| **Periapsis** | 120 km |
| **Orbital period** | 500 d |

**Instruments**

cosmic ray and micrometeoroid detectors, photography equipment, and a biological payload

**Zond 6**, a formal member of the Soviet Zond program and unmanned version of Soyuz 7K-L1 manned moon-flyby spacecraft, was launched on a lunar flyby mission from a parent satellite (68-101B) in Earth parking orbit. The spacecraft, which carried scientific probes including cosmic ray and micrometeoroid detectors, photography equipment, and a biological payload, was a precursor to a manned circumlunar flight which the Soviets hoped could occur in December 1968, beating the American Apollo 8 in first Moon-flyby phase of Moon Race.

Zond 6 flew around the moon on November 14, 1968, at a minimum distance of 2420 km. Photographs of the lunar near side and far side were obtained with panchromatic film. Each photo was 5 by 7 in (130 by 180 mm). Some of the views allowed for stereo pictures. The photos were taken from distances of approximately 11,000 km and 3300 km. Skipped reentry of the spacecraft did not occur, Zond 6 landed in an undetermined region of the Soviet Union.

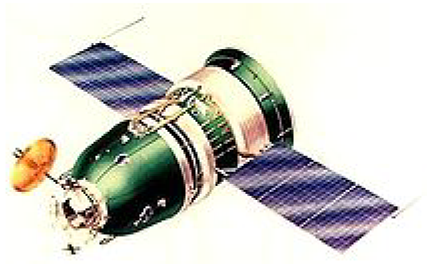
Zond 6 used a relatively uncommon technique called "skip reentry" to shed velocity upon returning to Earth. A few hours before reentry, a faulty O-ring rubber gasket caused the cabin to depressurise, killing all biologicals aboard. Zond 6's parachutes also deployed too early and it crashed on Soviet soil. Only one negative was recovered from the camera container and a small victory obtained over the Americans. For propaganda reasons, the Soviets claimed the flight was a success, but they were not able to launch a manned flight to the Moon before Apollo 8. A State Commission investigating the crash later determined that the coronal discharge effect which caused the parachute to jettison would only occur at the 25 mm capsule pressure. If the capsule had been completely depressurised to a high vacuum, the accident would not have occurred.

Zond 6 was the official designation for Soyuz 7K-L1 s/n 12. It was supposed to photograph the moon in colour and black and white from 8000 km and 2600 km ranges, then return to earth, landing at Tyuratam only 16 km from the launch pad. It had been a long and difficult road to develop the L1 guidance system, but it worked perfectly that time.

- Launch Date/Time: 1968-11-10 at 19:11:31 UTC
- On-orbit dry mass: 5375 kg

# Zond 7

**Zond 7**



Zond 7

| | |
|---|---|
| **Major contractors** | OKB-1 |
| **Bus** | Soyuz 7K-L1 |
| **Mission type** | Lunar flyby<br>Spacecraft test |
| **Launch date** | 7 August 1969<br>23:48:06 UTC |
| **Carrier rocket** | Proton-K/D |
| **Launch site** | Baikonur |
| **Landing site** | |
| **Mass** | 5,979 kilograms (13,180 lb) |

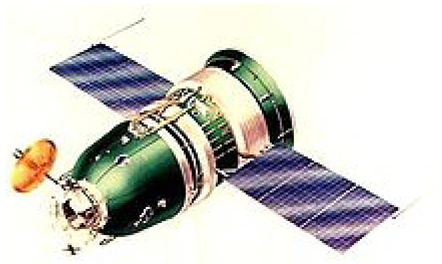
**Zond 7**, a formal member of the Soviet Zond program and unmanned version of Soyuz 7K-L1 manned moon-flyby spacecraft, the only truly successful test of L1, was launched towards the Moon from a mother spacecraft (69-067B) on a mission of further studies of the Moon and circumlunar space, to obtain color photography of Earth and the Moon from varying distances, and to flight test the spacecraft systems. Earth photos were obtained on August 9, 1969. On August 11, 1969, the spacecraft flew past the Moon at a distance of 1984.6 km and conducted two picture taking sessions. Zond 7 reentered Earth's atmosphere on August 14, 1969, and achieved a soft landing in a preset region south of Kustanai, Kazakhstan.

Like other Zond circumlunar craft, Zond 7 used a relatively uncommon technique called skip reentry to shed velocity upon returning to Earth. Out of all circumlunar Zond craft launches Zond 7 would have been the first completely safe flight for a crew, had it been manned.

- Launch Date/Time: 1969-08-07 at 23:48:06 UTC
- On-orbit dry mass: 5979 kg

# Zond 8

**Zond 8**



Zond 8

| | |
|---|---|
| **Major contractors** | OKB-1 |
| **Bus** | Soyuz 7K-L1 |
| **Mission type** | Lunar flyby<br>Spacecraft test |
| **Launch date** | 20 October 1970<br>19:55:39 UTC |
| **Carrier rocket** | Proton-K/D |
| **Launch site** | Baikonur |
| **Landing site** | 730 km SE of the Chagos Islands, Indian Ocean |
| **Mass** | 5,375 kilograms (11,850 lb) |

**Zond 8**, a formal member of the Soviet Zond program and unmanned version of Soyuz 7K-L1 manned moon-flyby spacecraft, was launched from an Earth orbiting platform, Tyazheliy Sputnik (70-088B), towards the Moon. The announced objectives were investigations of the moon and circumlunar space and testing of onboard systems and units. The spacecraft obtained photographs of Earth on October 21 from a distance of 64,480 km. The spacecraft transmitted flight images of Earth for three days. Zond 8 flew past the Moon on October 24, 1970, at a distance of 1110.4 km and obtained both black and white and color photographs of the lunar surface. Scientific measurements were also obtained during the flight. Zond 8 reentered Earth's atmosphere and splashed down 730

km SE of the Chagos Islands, in the Indian Ocean on October 27, 1970, 24 km from the USSR recovery ship Taman.

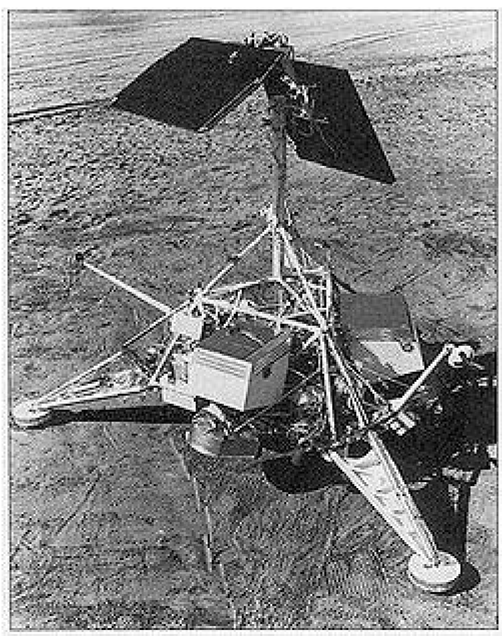
- Launch Date/Time: 1970-10-20 at 19:55:39 UTC
- Launch Site: Tyuratam (Baikonur Cosmodrome), U.S.S.R
- On-orbit dry mass: 5375 kg

## Chapter- 6

# Surveyor Program

## Surveyor 1

**Surveyor 1**

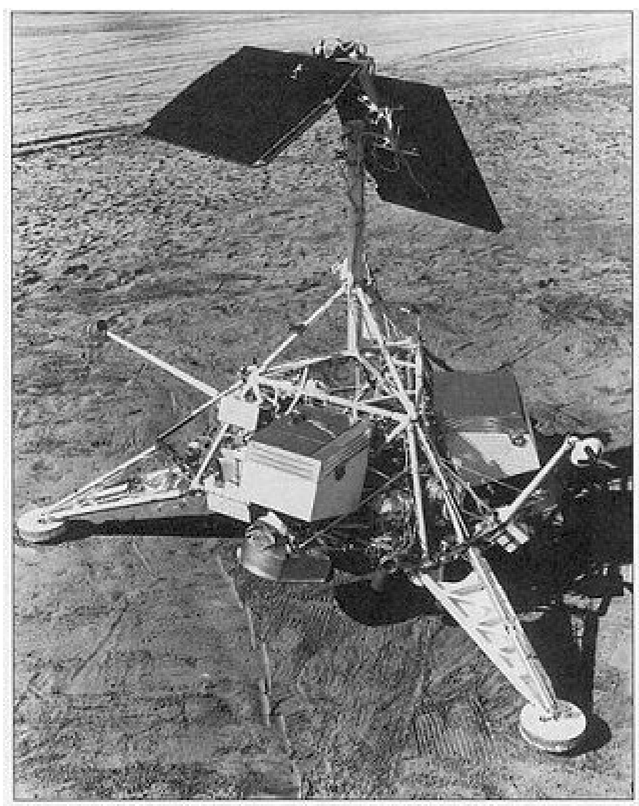


Surveyor model on Earth

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Hughes Aircraft |
| **Mission type** | Lander |
| **Satellite of** | Moon |

| | |
|---|---|
| **Launch date** | May 30, 1966 at 14:41:00 UTC |
| **Launch vehicle** | Atlas-Centaur |
| **Mission duration** | 65 hours |
| **Orbital decay** | Landed on moon June 2, 1966, 06:17:37 UTC at 2°27′S 43°13′W / 2.45°S 43.22°W |
| **Landing site** | |
| **COSPAR ID** | 1966-045A |
| **Mass** | 292 kg after landing |

**Surveyor 1** was the first lunar lander in the American Surveyor program that explored the Moon. The program was managed by the NASA Jet Propulsion Laboratory, utilizing spacecraft designed and built by Hughes Aircraft.



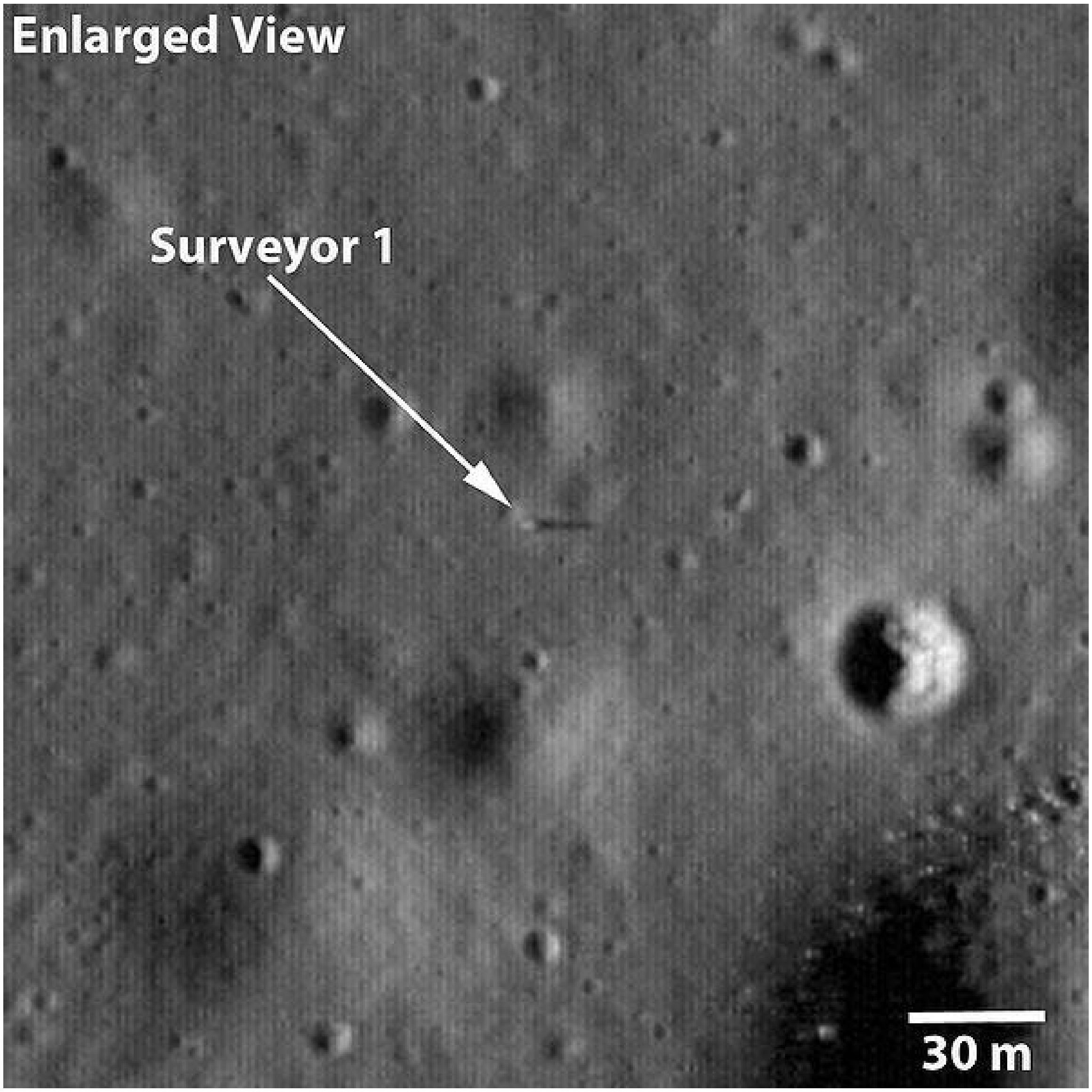
- Launched May 30, 1966; landed June 2, 1966
- Weight on landing: 596 lb (270 kg)

A total 11,237 images were transmitted to Earth.

The successful soft landing in the Ocean of Storms was the first ever by the U.S. on an extraterrestrial body, and came just four months after the landing of the Soviet Luna 9 mission.

## Mission description

Launch of the Atlas-Centaur AC-10 rocket carrying the Surveyor spacecraft.




Surveyor 1 photographed by the Lunar Reconnaissance Orbiter.

The Surveyor spacecraft was designed to attain the engineering objectives of the Surveyor program, which included the first lunar soft landing by an American spacecraft. No instrumentation was carried specifically for scientific experiments, but considerable scientific information was obtained. The spacecraft carried two television cameras - one for approach, which was not used, and one for operations on the lunar surface. Over 100 engineering sensors were on board. The television system transmitted pictures of the spacecraft footpad and surrounding lunar terrain and surface materials. The spacecraft also acquired data on the radar reflectivity of the lunar surface, bearing strength of the lunar surface, and spacecraft temperatures for use in the analysis of the lunar surface temperatures. The spacecraft was launched May 30, 1966, directly into a lunar impact trajectory. Engines were turned off at a height of 3.4 m above the lunar surface. The spacecraft fell freely from this height, landing on the lunar surface on June 2, 1966, in

Oceanus Procellarum - 2.45 deg s latitude, 43.22 deg w longitude (selenographic coordinates). The spacecraft transmitted data from shortly after touchdown until July 14, 1966, with an interval of no operation during lunar night (June 14 to July 7, 1966). Engineering interrogations continued until January 7, 1967.

## Science instruments

Surveyor 1's shadow against the lunar surface.

## Television

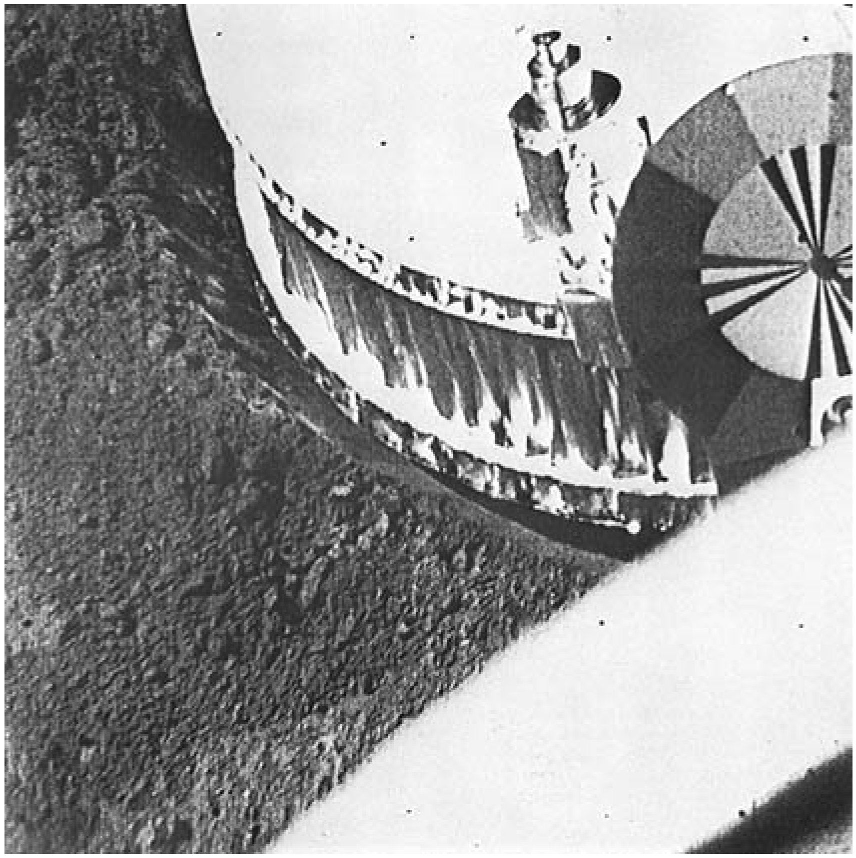


Image from Surveyor 1 of its footpad in order to study soil mechanics in preparation for the Apollo manned landings.

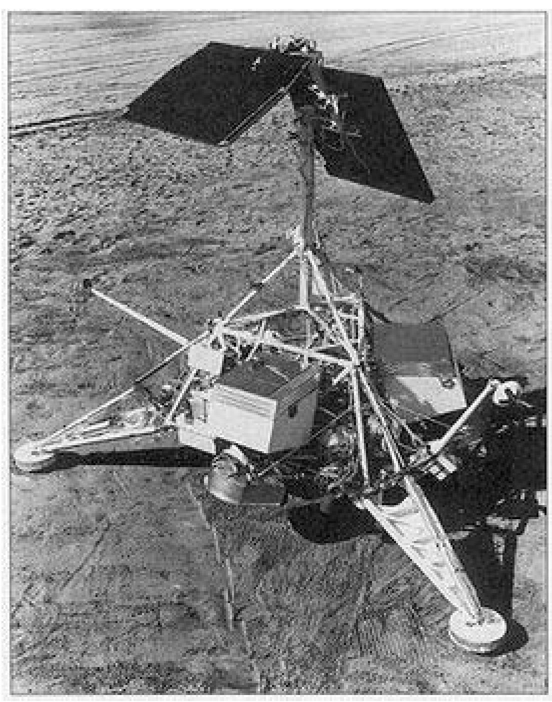
The TV camera consisted of a vidicon tube, 25 and 100 mm focal length lenses, shutter, filters, and iris mounted along an axis inclined approximately 16 deg to the central axis of the spacecraft. The camera was mounted under a mirror that could be moved in azimuth and elevation. Camera operation was totally dependent upon the receipt of the proper command structure from earth. Frame by frame coverage of the lunar surface was obtained over 360 deg in azimuth and from +40 deg above the plane normal to the camera Z axis to -65 deg below this plane. Both 600 line and 200 line modes of operation were used. The 200 line mode transmitted over an omnidirectional antenna for the first 14 photos and scanned one frame every 61.8 seconds. The remaining transmissions were of 600 line pictures over a directional antenna, and each frame was scanned every 3.6 seconds. Each 200 line picture required 20 seconds for a complete video transmission and utilized a bandwidth of 1.2 kHz. Each 600 line picture required nominally 1 second to be read from the vidicon and required a 220 kHz bandwidth for transmission. The data transmissions were converted to a standard television signal for closed circuit and public broadcast television. The television images were displayed on earth on a slow scan monitor coated with a long persistency phosphor. The persistency was selected to optimally match the nominal maximum frame rate. One frame of TV identification was received for each incoming TV frame and was displayed in real time at a rate compatible with the incoming image. These data were recorded on a video magnetic tape recorder. Over 10,000 pictures were taken by the Surveyor 1 camera before lunar sunset on June 14, 1966. Included were wide and narrow angle panoramas, focus ranging surveys, photometric surveys, special area surveys, and celestial photography. The spacecraft responded to commands to activate the camera on July 7 and, by July 14, 1966, returned nearly another 1000 frames.

### Strain gauge

Strain gauges were mounted on each leg shock absorber to record the peak axial forces at landing impact of the spacecraft. They were designed to accept a force of approximately 800 kgf (7.8 kN).

## Surveyor 2

**Surveyor 2**



Surveyor model on Earth

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Hughes Aircraft |
| **Mission type** | Lander |

| | |
|---|---|
| **Launch date** | September 20, 1966 12:32:00 UTC |
| **Launch vehicle** | Atlas-Centaur |
| **Mission duration** | 62 hours 46 minutes |
| **Orbital decay** | Impacted on moon September 23, 1966, 03:18:00 UTC at 4°00′S 11°00′W / 4.0°S 11.0°W |
| **Landing site** | |
| **COSPAR ID** | 1966-084A |
| **Mass** | 292 kg after fuel used |

**Surveyor 2** was the second American lunar lander in the Surveyor program intended to explore the Moon.

It was launched September 20, 1966 from Cape Kennedy aboard an Atlas-Centaur rocket. A mid-course correction failure resulted in the spacecraft losing control. Contact was lost with the spacecraft at 9:35 UTC, September 22.

# Background

On February 3, 1966 **Luna 9** spacecraft was the first spacecraft to achieve a lunar soft landing and to transmit photographic data to Earth. Several months after, **Surveyor 1** launched on May 30, 1966; landed on Oceanus Procellarum, June 2, 1966, also transmitting photographic data back to Earth.

Surveyor 1 is a tough act to follow

This spacecraft was the second of a series designed to achieve a soft landing on the moon and to return lunar surface photography for determining characteristics of the lunar terrain for Apollo program lunar landing missions. Besides transmitting photos, Surveyor 2 was planned to perform a 'bounce', to photograph underneath its own landing site. It was also equipped to return data on radar reflectivity of the lunar surface, bearing strength of the lunar surface, and spacecraft temperatures for use in the analysis of lunar surface temperatures.

# Failure

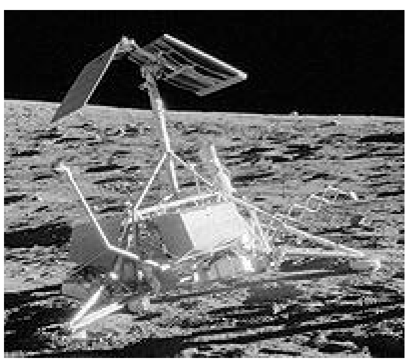
The target area proposed was within Sinus Medii. The Atlas-Centaur had placed Surveyor 2 on a path to the moon that was only 130 km from its aim point. During the midcourse correction maneuver, one vernier engine failed to ignite, resulting in an unbalanced thrust that caused the spacecraft to tumble for its remaining 54 hours. Attempts to salvage the mission failed. Contact was lost with the spacecraft at 9:35 UTC, September 22. The spacecraft was targeted at Sinus Medii, but crashed near Copernicus crater. The spacecraft was calculated to have impacted the lunar surface at 03:18 UTC, September 23, 1966. Its weight on impact was 644 lb (292 kg), and speed was about 6000 miles an hour (2.6 km/sec = 5840 mph), slightly over lunar escape velocity (2.4 km/sec) and similar to the impact velocities of the Ranger program spacecraft.

# Aftermath

The next Soviet mission, Cosmos 111, was launched on March 1, 1966. The mission was also a failure. Surveyor 3 soft-landed on April 20, 1967 at the Mare Cognitum portion of the Oceanus Procellarum. It transmitted a total of 6,315 TV images to the Earth. There were seven Surveyor missions; five were successful. Surveyors 2 and 4 failed. Each consisted of a single unmanned spacecraft designed and built by Hughes Aircraft Company. The current condition and location of Surveyor 2 is unknown.

## Surveyor 3

**Surveyor 3**



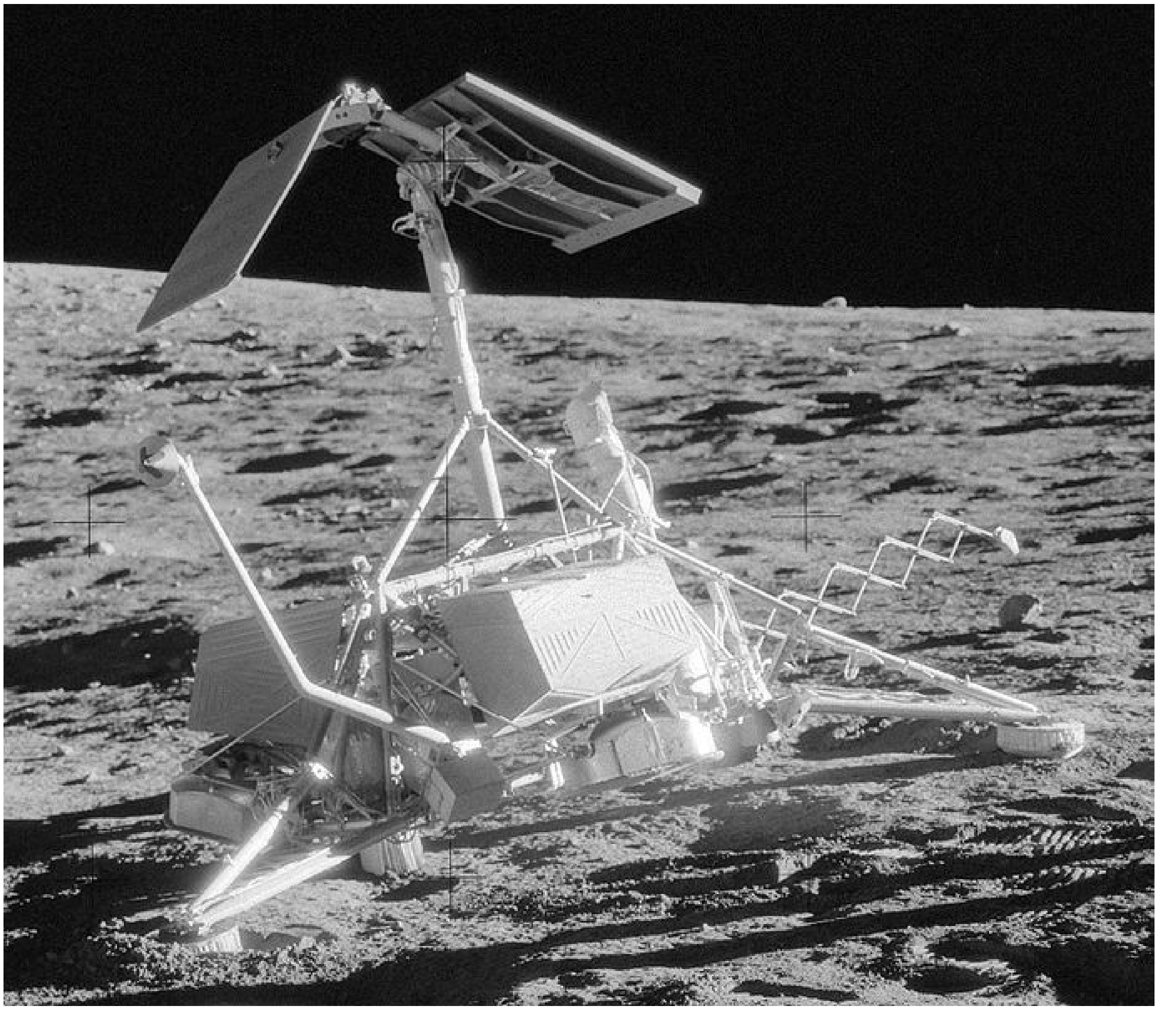
Surveyor 3 on the Moon, photographed by Alan Bean over two years after it landed

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Hughes Aircraft |
| **Mission type** | Lander |
| **Launch date** | April 17, 1967 at 07:05:00 UTC |
| **Launch vehicle** | Atlas-Centaur |

| | |
|---|---|
| **Mission duration** | 65 hours |
| **Orbital decay** | Landed on Moon April 20, 1967, 00:04:53 UTC at 2°56′S 336°40′E / 2.94°S 336.66°E |
| **Landing site** | |
| **COSPAR ID** | 1967-035AFDGTRFYG |
| **Mass** | 302 kg after landing |

**Surveyor 3** was the third lander of the Surveyor program sent to explore the surface of the Moon. Launched on April 17, 1967, Surveyor 3 landed on April 20, 1967 at the Mare Cognitum portion of the Oceanus Procellarum (S3º 01' 41.43" W23º 27' 29.55") . It transmitted a total of 6,315 TV images to the Earth.

As Surveyor 3 was landing (in a crater, as it turned out ), highly reflective rocks confused the spacecraft's lunar descent radar. The engines failed to cut off at 14 feet (4.3 meters) in altitude as called for in the mission plans, and this delay caused the lander to bounce on the lunar surface twice. Its first bounce reached the altitude of about 35 feet (10 meters). The second bounce reached a height of about 11 feet (three meters). On the third impact with the surface — from the initial altitude of three meters, and velocity of zero, which was below the planned altitude of 14 feet (4.3 meters), and very slowly descending — Surveyor 3 settled down to a soft landing as intended.



This Surveyor mission was the first one that carried a surface-soil sampling-scoop, that can be seen on its extendable arm in the pictures. This mechanism was mounted on an electric-motor-driven arm and was used to dig four trenches in the lunar soil. These trenches were up to seven inches (18 centimeters) deep. Samples of soil from the trenches were placed in front of the Surveyor's television cameras to be photographed and the pictures radioed back to the Earth. When the first lunar nightfall came on May 3, 1967, Surveyor 3 was shut down because its solar panels were no longer producing electricity. At the next lunar dawn (after 14 terrestrial days, or about 336 hours), Surveyor 3 could not be reactivated, because of the extremely cold temperatures that it had experienced. This is in contrast with the Surveyor 1, which was able to be reactivated twice after lunar nights, but then never again.

## Science instruments

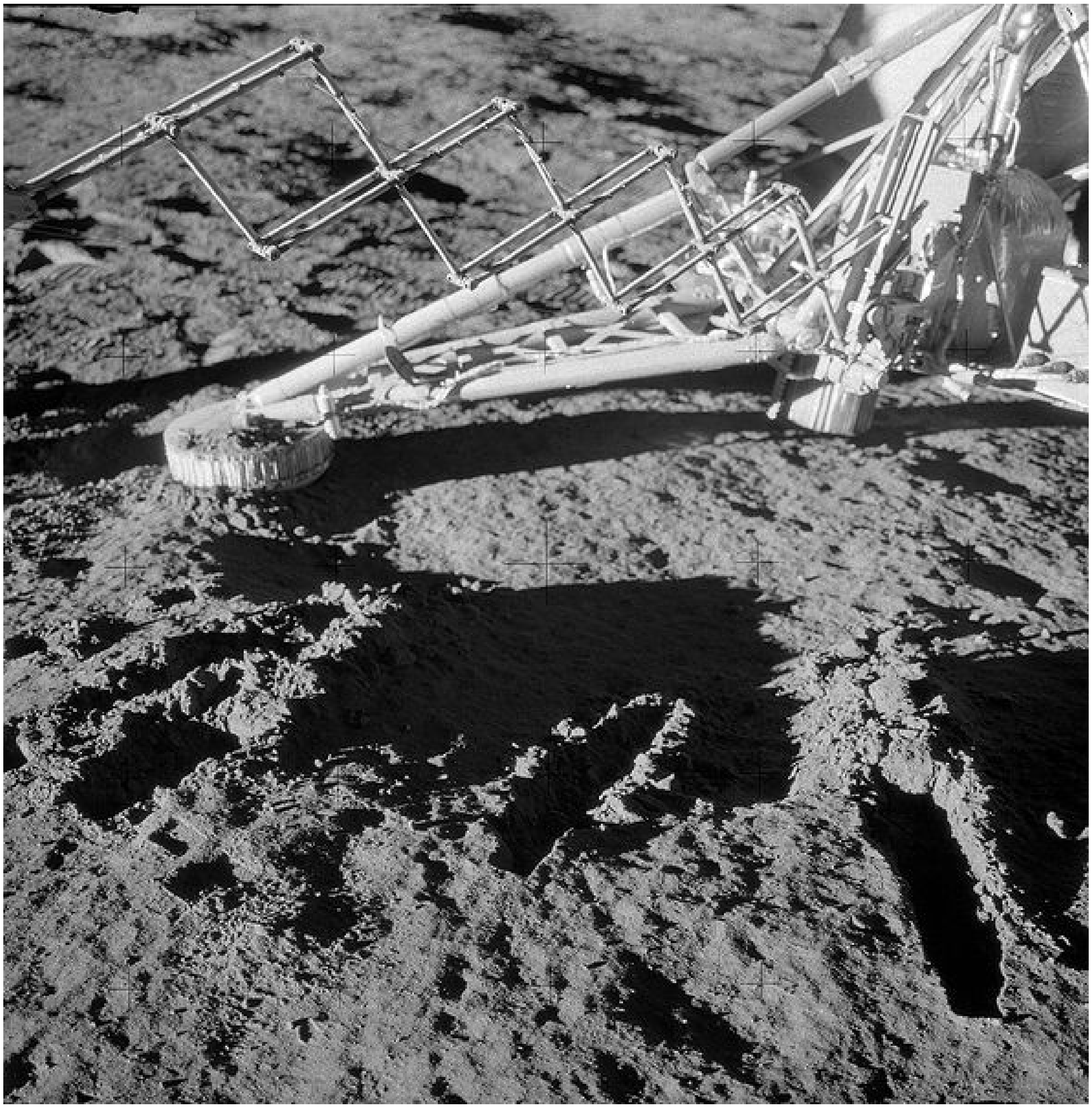
## Television


Surveyor 3 camera brought back from the Moon by Apollo 12, on display at the National Air and Space Museum

The television camera on Surveyor 3 consisted of a vidicon tube, two 25 and 100 millimeter focal length lenses, shutters, filters, and an iris mounted along an axis inclined about 16 degrees to the central axis of the spacecraft. The TV camera was mounted under a mirror that could be moved in azimuth (horizontally) and elevation (vertically). The operation of the camera was completely dependent upon the receipt of proper commands from the Earth. Frame-by-frame coverage of the lunar surface was obtained over the complete 360 degrees in azimuth, and from +40 degrees above the plane normal to the camera's Z-axis to -65 degrees below this plane. Both 600-line and 200-line modes of TV camera operation were used. The 200-line mode transmitted over an omnidirectional antenna and scanned one frame every 61.8 seconds. A complete video transmission of each 200-line picture required 20 seconds and used a bandwidth of 1.2 kHz. The 600-line pictures were transmitted over a directional antenna. These pictures were scanned as often as once every 3.6 seconds. Each 600-line picture required a nominal one second to be read from the image vidicon, and its transmission required a 220 kHz bandwidth, using digital picture transmission. The TV photos were displayed back on the Earth on a slow-scan TV monitor that was coated with a long-persistency phosphor. Its persistency had been selected to match the nominal maximum frame rate. One frame of TV identification was received for each incoming TV photo, and the picture was displayed in real-time at a rate compatible with that of the incoming image. These data were recorded on a video magnetic-tape recorder. The camera returned 6315 pictures between April 20 and May 3, 1967, including views of the spacecraft itself, panoramic lunar surveys, views of the mechanical surface digger at work, and of the Earth itself during a solar eclipse.

The Apollo 12 Lunar Module landed near Surveyor 3 in November 1969. Astronauts Conrad and Bean examined the spacecraft, and they brought back about 10 kg of parts of the Surveyor to the Earth, including its TV camera, which is now on permanent display in the National Air and Space Museum in Washington, D.C.

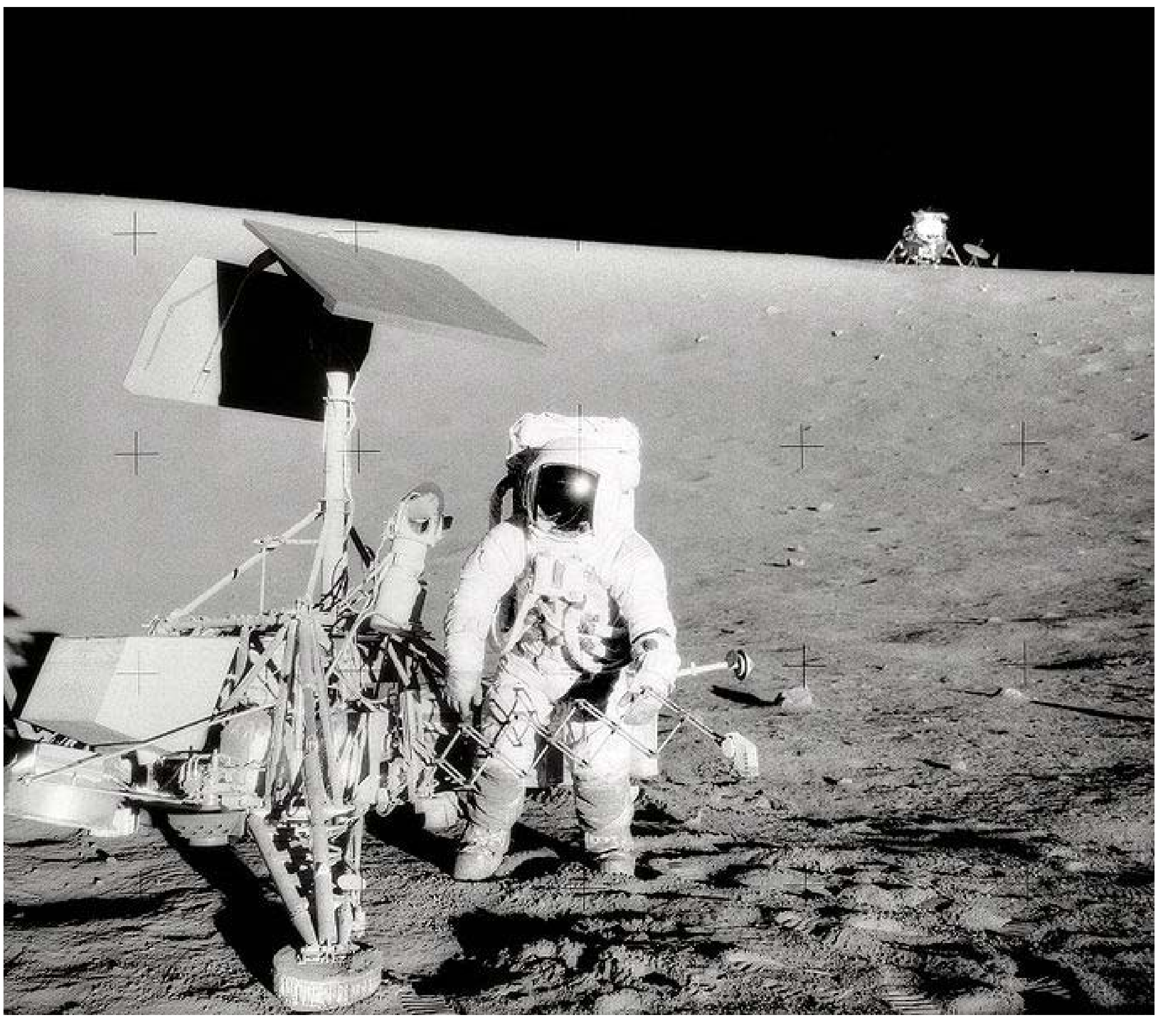
### Soil mechanics surface sampler



Surveyor 3 scoops, photographed by the Apollo 12 astronauts

The soil mechanics surface sampler was designed to dig, scrape, and trench the lunar surface and to transport lunar surface material while being photographed so that the properties of the lunar surface could be determined. The sampler was mounted below the television camera and consisted primarily of a scoop approximately 120 mm long and 50 mm wide. The scoop consisted of a container, a sharpened blade, and an electric motor to open and close the container. A small footpad was attached to the scoop door to present a flat surface to the lunar surface. The scoop was capable of holding a maximum quantity of approximately 32 mm diameter of solid lunar material and a maximum of 100 $cm^3$ of granular material. The scoop was mounted on a pantograph arm that could be extended about 1.5 m or retracted close to the spacecraft motor drive. The arm could also be moved from an azimuth of +40 to -72 degrees or be elevated 130 mm by motor drives. It could also be dropped onto the lunar surface under force provided by gravity and a spring. The surface sampler performed seven bearing tests, four trench tests, and 13 impact tests. The total operating time was 18 hours, 22 minutes on 10 separate occasions. Measurements of motor currents and forces applied to the surface were not obtained due to the state of the spacecraft telemetry following landing on the lunar surface. However, estimations were possible. The small spring constant of the torque spring precluded the determination of density from the impact tests. Penetrations of 38 to 50 mm were obtained from the bearing tests, and a 175 mm depth was reached during trenching operations. The design of the mechanism and its electronic auxiliary was more than adequate for the lunar surface operations.

## Apollo 12 and the remote possibility of interplanetary contamination



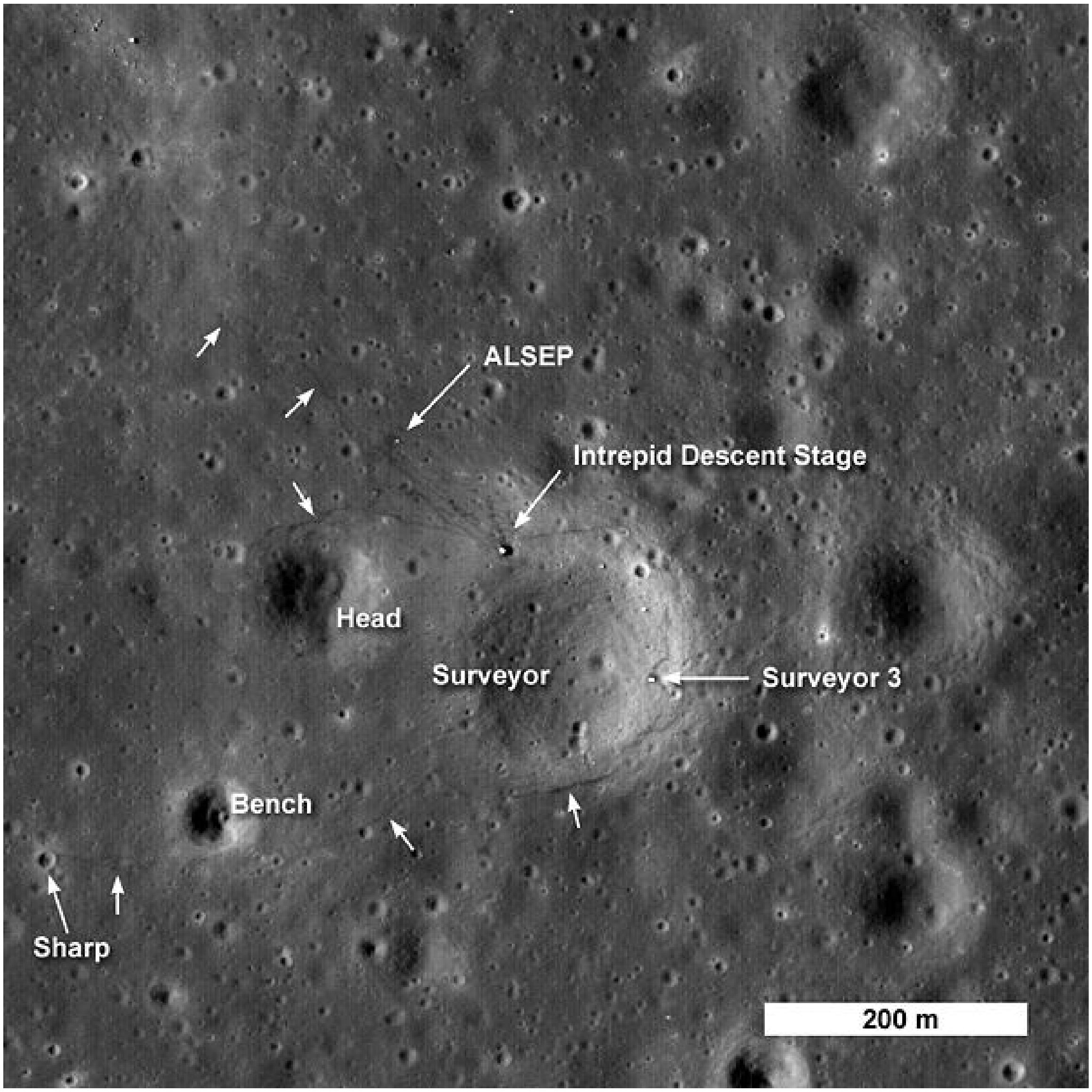
Alan L. Bean, the Lunar Module pilot of Apollo 12, stands next to the Surveyor 3 lander. In the background is the Apollo 12 Lunar Module, "Intrepid"

The Surveyor 3 landing site was later selected also as the landing target for the Lunar Module of the Apollo 12 manned lunar mission in 1969. Several components of the Surveyor 3 lander were collected and returned to the Earth for study of the long-term exposure effects of the harsh lunar environment on man-made objects and materials. Although space probes have returned to Earth in the decades since Apollo 12, this remains the only occasion in which humans have visited a probe that had been sent to another world.

It is widely claimed that a common type of bacteria, *Streptococcus mitis*, accidentally contaminated the Surveyor's camera prior to launch, and that bacteria survived dormant in the harsh lunar environment for two and one-half years, supposedly then to be detected when Apollo 12 brought the Surveyor's camera back to the Earth. This claim has been cited by some as providing credence to the idea of interplanetary panspermia, but more importantly, it led NASA to adopt strict abiotic procedures for space probes to prevent contamination of the planet Mars and other astronomical bodies that are suspected of having conditions possibly suitable for life. Most dramatically, the Galileo spacecraft was removed from orbit around Jupiter to avoid the possibility of contaminating the Jovian moon Europa with bacteria from earth.

However, independent investigators have challenged the claim of surviving bacteria in Surveyor 3 on the Moon.

## Lunar Reconnaissance Orbiter

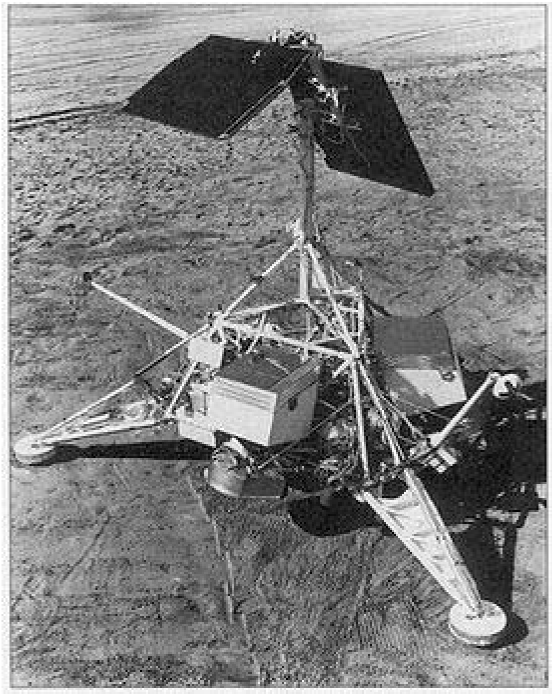



Landing site photographed by Lunar Reconnaissance Orbiter

In 2009, the Lunar Reconnaissance Orbiter photographed the Surveyor 3 landing site in some detail, in which surrounding astronaut foot tracks could be seen.

## Surveyor 4

**Surveyor 4**



Surveyor model on Earth

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Hughes Aircraft |
| **Mission type** | Lander |
| **Launch date** | July 14, 1967 11:53:29 UTC |
| **Launch vehicle** | Atlas-Centaur |
| **Mission duration** | 65 hours |
| **Orbital decay** | Impacted on moon July 17, 1967, 02:05:00 UTC at 0°27′N 1°23′W / 0.45°N 1.39°W |
| **Landing site** | |
| **COSPAR ID** | 1967-068A |
| **Mass** | 282 kg after fuel used |

**Surveyor 4** was the fourth lunar lander in the Surveyor program sent to explore the surface of the Moon.

- Launched July 14, 1967; landed July 17, 1967
- Weight on landing: 625 lb (283 kg)

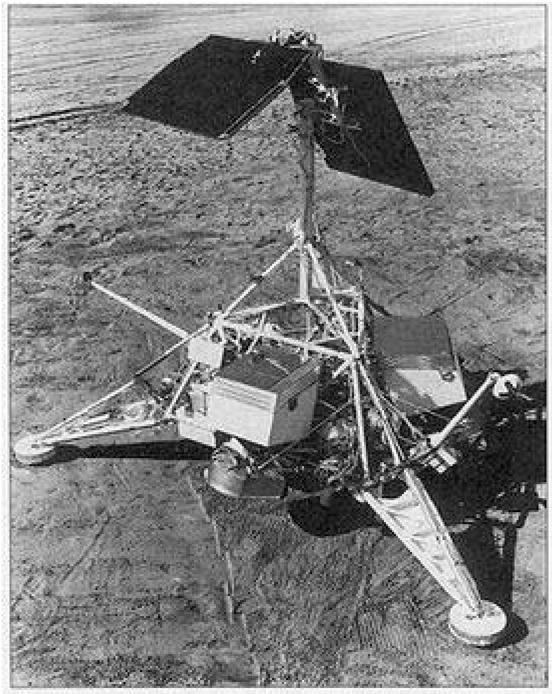
This spacecraft crashed after an otherwise flawless mission; telemetry contact was lost 2.5 minutes before touchdown.

This spacecraft was the fourth in a series designed to achieve a soft landing on the moon and to return photography of the lunar surface for determining characteristics of the lunar terrain for Apollo lunar landing missions. Equipment on board included a television camera and auxiliary mirrors, a soil mechanics surface sampler, strain gauges on the spacecraft landing legs, and numerous engineering sensors. After a flawless flight to the moon, radio signals from the spacecraft ceased during the terminal-descent phase, approximately 2.5 min. before touchdown. Contact with the spacecraft was never reestablished, and the mission was unsuccessful. The solid fuel retro rocket may have exploded near the end of its scheduled burn.

Like Surveyor 3, Surveyor 4 was equipped with a surface claw (with a magnet in the claw) to detect and measure ferrous elements in the lunar surface. The mission was completely successful until all communications were abruptly lost 2 seconds prior to retrorocket cutoff at 02:03 UT on 17 July 1967, with only 2.5 minutes left to landing on the Moon. The landing target was Sinus Medii (Central Bay) at 0.4° north latitude and 1.33° west longitude. NASA concluded that the lander might have exploded when contact was lost.

## Surveyor 5

**Surveyor 5**



Surveyor model on Earth

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Hughes Aircraft |
| **Mission type** | Lunar Science |
| **Launch date** | September 8, 1967 at 07:57:00 UTC |
| **Launch vehicle** | Atlas-Centaur |
| **Mission duration** | 65 hours |
| **Orbital decay** | Landed on moon September 11, 1967, 00:46:44 UTC at 1°25′N 23°11′E / 1.41°N 23.18°E |
| **Landing site** | |
| **COSPAR ID** | 1967-084A |
| **Mass** | 303 kg after landing |

**Surveyor 5** was the fifth lunar lander of the Surveyor program sent to explore the surface of the Moon.

- Launched September 8, 1967; landed September 11, 1967
- Weight on landing: 303 kg (668 lb)

Surveyor 5 landed on Mare Tranquillitatis. A total of 19,049 images were transmitted to Earth.

The mission experienced a helium leak that could have resulted in failure. An improvised landing sequence was successful and data was received for 2 weeks after the landing. A miniature chemical analysis lab using an alpha particle backscatter device was used to determine the lunar surface soil consisted of basaltic rock. A similar instrument, the APXS, was used onboard several Mars missions.

Surveyor 5 was the third spacecraft in the Surveyor series to achieve a successful lunar soft landing. The spacecraft had a basic triangular structure of aluminum tubing that provided mounting surfaces for engineering and scientific equipment. The objectives were to obtain postlanding television pictures of the lunar surface, conduct a Vernier engine erosion experiment, determine the relative abundance of the chemical elements in the lunar soil, obtain touchdown dynamics data, and obtain thermal and radar reflectivity data. Instrumentation for this spacecraft was similar to that of the previous Surveyors and included landing legs, a Vernier propulsion system, and numerous engineering sensors. An alpha-scattering instrument was installed in place of the surface sampler, and a small bar magnet attached to one footpad was included to detect the presence of magnetic material in the lunar soil. The spacecraft landed at 00:46:44 UT on September 11, 1967 (7:46 p.m. EST September 10) in Mare Tranquillitatis, at 1.41° N latitude and 23.18° E longitude (selenographic coordinates), within the rimless edge of a small crater on a slope of about 20 deg. The spacecraft transmitted excellent data for all experiments from shortly after touchdown until October 18, 1967, with an interval of no transmission from September 24 to October 15, 1967, during the first lunar night. Transmissions were received until November 1, 1967, when shutdown for the second lunar night occurred. Transmissions were resumed on the third and fourth lunar days, with the final transmission occurring on December 17, 1967. Pictures were transmitted during the first, second, and fourth lunar days.

# Science instruments

## Television

The TV camera consisted of a vidicon tube, 25 and 100 mm focal length lenses, shutters, color filters, and iris mounted along an axis inclined approximately 16° to the central axis of the spacecraft. The camera was mounted under a mirror that could be moved in azimuth and elevation. Camera operation was totally dependent upon receipt of the proper command structure from earth. Frame by frame coverage of the lunar surface was obtained over 360° in azimuth and from +40° above the plane normal to the camera *z*-

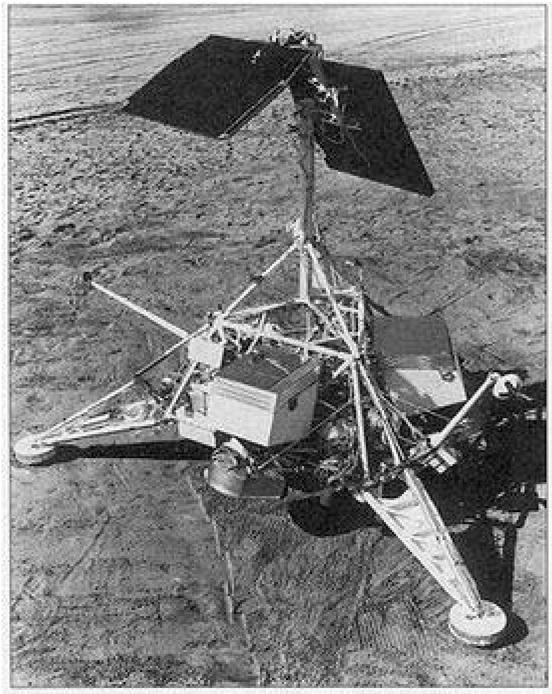
axis to 65° below this plane. Both 600-line and 200-line modes of operation were used. The 200-line mode transmitted over an omnidirectional antenna and scanned one frame each 61.8 seconds. A complete video transmission of each 200-line picture required 20 seconds and utilized a bandwidth of 1.2 kHz. Most transmissions consisted of the 600-line pictures, which were telemetered by a directional antenna. These frames were scanned each 3.6 seconds. Each 600-line picture required nominally 1 second to be read from the vidicon and utilized a 220 kHz bandwidth for transmission. The television images were displayed on a slow scan monitor coated with a long persistency phosphor. The persistency was selected to optimally match the nominal maximum frame rate. One frame of TV identification was received for each incoming TV frame and was displayed in real time at a rate compatible with that of the incoming image. These data were recorded on a video magnetic tape recorder and on 70 mm film. During the first lunar day, which ended on September 24, 1967, 18,006 high quality television pictures were transmitted. After being shut down during the lunar night, more than 20 days, the camera responded to commands and transmitted an additional 1,048 pictures between October 15 and October 23, 1967. Another 64 pictures were transmitted on the fourth lunar day, but the quality of pictures taken after the first lunar day was poor due to camera degradation resulting from the lunar night temperatures.

### Alpha-scattering surface analyzer

The alpha-scattering surface analyzer was designed to measure directly the abundances of the major elements of the lunar surface. The instrumentation consisted of six alpha sources (curium 242) collimated to irradiate a 100 mm diameter opening in the bottom of the instrument where the sample was located and two parallel but independent charged particle detector systems. One system, containing two sensors, detected the energy spectra of the alpha particles scattered from the lunar surface, and the other, containing four sensors, detected energy spectra of the protons produced via reactions (alpha and proton) in the surface material. Each detector assembly was connected to a pulse height analyzer. A digital electronics package, located in a compartment on the spacecraft, continuously telemetered signals to earth whenever the experiment was operating. The spectra contained quantitative information on all major elements in the samples except for hydrogen, helium, and lithium. The experiment provided 83 hours of high quality data during the first lunar day. During the second lunar day, 22 hours of data were accumulated. However, detector noise posed a problem in the reduction of data from this second day.

## Surveyor 6

**Surveyor 6**



Surveyor model on Earth

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Hughes Aircraft |
| **Mission type** | Lander |
| **Launch date** | November 7, 1967 at 07:39:00 UTC |
| **Launch vehicle** | Atlas-Centaur |
| **Mission duration** | 65 hours |
| **Orbital decay** | Landed on moon November 10, 1967, 01:01:06 UTC at 0°29′N 1°24′W / 0.49°N 1.40°W |
| **Landing site** | |
| **COSPAR ID** | 1967-112A |
| **Mass** | 299.6 kg after landing |

**Surveyor 6** was the sixth lunar lander of the Surveyor program that reached the surface of the Moon.

- Launched November 7, 1967; landed November 10, 1967
- Mass on landing: 299.6 kg (660.5 lb)

Surveyor 6 landed on the Sinus Medii. A total of 30,027 images were transmitted to Earth.

This spacecraft was the fourth of the Surveyor series to successfully achieve a soft landing on the moon, obtain post landing television pictures, determine the abundance of the chemical elements in the lunar soil, obtain touchdown dynamics data, obtain thermal and radar reflectivity data, and conduct a Vernier engine erosion experiment. Virtually identical to Surveyor 5, this spacecraft carried a television camera, a small bar magnet attached to one footpad, and an alpha-scattering instrument as well as the necessary engineering equipment. It landed on November 10, 1967, in Sinus Medii, 0.49 deg in latitude and 1.40 deg w longitude (selenographic coordinates) - the center of the moon's visible hemisphere. This spacecraft accomplished all planned objectives. The successful completion of this mission satisfied the Surveyor program's obligation to the Apollo project. On November 24, 1967, the spacecraft was shut down for the 2 week lunar night. Contact was made on December 14, 1967, but no useful data were obtained.

Lunar soil surveys were completed using photographic and alpha particle backscattering methods. A similar instruments, the APXS, was used onboard several Mars missions.

In a further test of space technology Surveyor 6's engines were restarted and burned for 2.5 seconds in the first Lunar liftoff on November 17 at 10:32 UTC. This created 150 lbf (700 N) of thrust and lifted the vehicle 12 feet (4 m) from the Lunar surface. After moving west 8 ft (2.5 m) the spacecraft was once again successfully soft landed. The spacecraft continued functioning as designed.

# Science experiments

## Television

The TV camera consisted of a vidicon tube, 25 and 100 mm focal length lenses, shutters, polarizing filters (as opposed to color filters used on the previous Surveyor cameras), and iris mounted nearly vertically and surmounted by a mirror that could be adjusted by stepping motors to move in both azimuth and elevation. The polarizing filters served as analyzers for the detection of measurement of the linearly polarized component of light scattered from the lunar surface. An auxiliary mirror was used for viewing the lunar surface beneath the spacecraft. The frame by frame coverage of the lunar surface provided a 360 deg azimuth view and an elevation view from approximately +90 deg above the plane normal to the camera z axis to -60 deg below this same plane. Both 600 line and 200 line modes of operation were used. The 200 line mode transmitted over an omnidirectional antenna and scanned one frame each 61.8 seconds. A complete video transmission of each 200 line picture required 20 seconds and utilized a bandwidth of 1.2 kHz. Most transmissions consisted of the 600 line pictures, which were telemetered by a directional antenna. The frames were scanned each 3.6 seconds. Each frame required nominally one second to be read from the vidicon and utilized a 220 kHz bandwidth for transmission. The optical surfaces were the cleanest of any mission because of a redesigned mirror hood. The television images were displayed on a slow scan monitor coated with a long persistence phosphor. The persistence was selected to optimally match the nominal maximum frame rate. One frame of TV identification was received for each incoming TV frame and was displayed in real time at a rate compatible with that of the incoming image. These data were recorded on a video magnetic tape recorder and on 70 mm film. The camera performance was excellent in terms of both the quantity and quality of pictures. Between lunar landing, lunar 'second' landing, and the lunar first day sunset on November 24, 1967, 29,914 pictures were taken and transmitted.

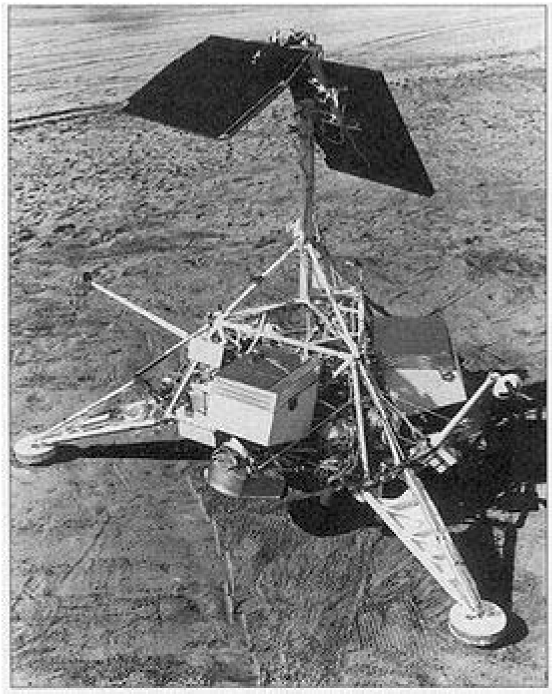
## Alpha-Scattering Surface Analyzer

The alpha-scattering surface analyzer was designed to measure directly the abundances of the major elements of the lunar surface. The instrumentation consisted of an alpha source (curium 242) collimated to irradiate a 100 mm diameter opening in the bottom of the instrument where the sample was located and two parallel but independent charged particle detector systems. One system, containing two sensors, detected the energy spectra of the alpha particles scattered from the lunar surface, and the other, containing four sensors, detected energy spectra of the protons produced via reactions (alpha and protons) in the surface material. Each detector assembly was connected to a pulse height analyzer. A digital electronics package, located in a compartment on the spacecraft, continuously telemetered signals to earth whenever the experiment was operating. The spectra contained quantitative information on all major elements in the samples except for hydrogen, helium, and lithium. Curium collected on the collimator films and was scattered by the gold plating on the inside bottom of the sensor head. This resulted in a gradually increasing background and reduction of the sensitivity technique for heavy elements. One proton detector was turned off during the second day of operation because of noise. A total of 43 hours of data was obtained from November 11 to November 24, 1967. The final data was obtained 4 hours after local sunset. However, after the spacecraft 'hopping' maneuver on November 17, 1967, the sensor head was upside down. Measurements were continued in order to obtain information on solar protons and cosmic rays. Therefore, data for the purpose of the chemical analysis of lunar surface material were obtained only during the first 30 hours of operation. During this period, 27 hours and 44 min of data were known to be noise free.

## Accomplishments

Surveyor 6 was the first rocket launch from the moon's surface which was monitored by the Jet Propulsion Laboratory in Pasadena. It used its liquid-fuelled vernier engines to lift itself from its original landing site to a position some 10 feet away.

# Surveyor 7

| Surveyor 7 | |
|---|---|
|  | |
| Surveyor model on Earth | |
| **Operator** | NASA |
| **Major contractors** | Hughes Aircraft |
| **Mission type** | Lander |
| **Launch date** | January 7, 1968 at 06:30:00 UTC |
| **Launch vehicle** | Atlas-Centaur |
| **Mission duration** | 65 hours |
| **Orbital decay** | Landed on moon January 10, 1968, 01:05:36 UTC at 41°01′S 348°35′E / 41.01°S 348.59°E |
| **Landing site** | |
| **COSPAR ID** | 1968-001A |

**Mass** 305.7 kg after landing

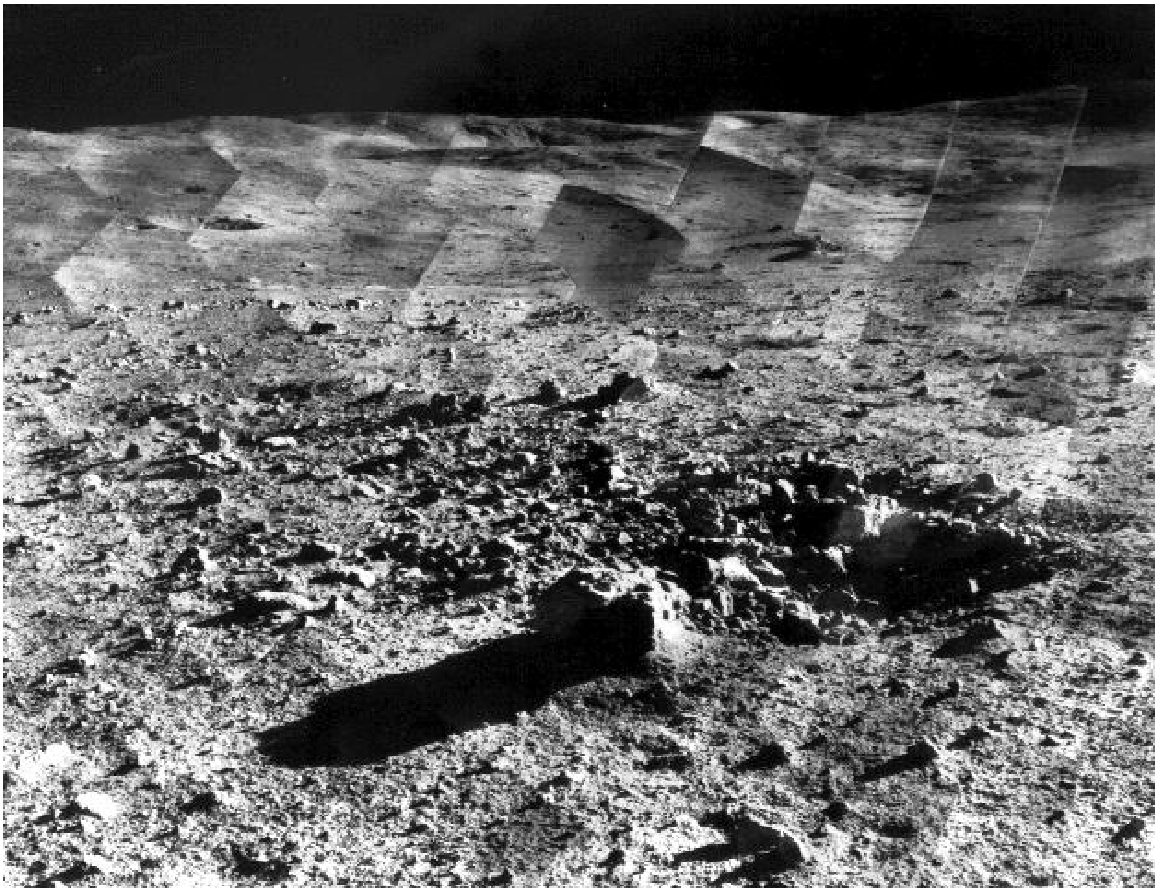
**Surveyor 7** was the seventh and last lunar lander of the Surveyor program sent to explore the surface of the Moon.

- Launched January 7, 1968; landed January 10, 1968
- Weight on landing: 305.7 kg (674.0 lb)

A total of 21,091 pictures were transmitted to Earth.

Surveyor 7 was the fifth and final spacecraft of the Surveyor series to achieve a lunar soft landing. The objectives for this mission were to: (1) perform a lunar soft landing (in an area well removed from the maria to provide a type of terrain photography and lunar sample significantly different from those of other surveyor missions); (2) obtain postlanding tv pictures; (3) determine the relative abundances of chemical elements; (4) manipulate the lunar material; (5) obtain touchdown dynamics data; and, (6) obtain thermal and radar reflectivity data. This spacecraft was similar in design to the previous Surveyors, but it carried more scientific equipment including a television camera with polarizing filters, a surface sampler, bar magnets on two footpads, two horseshoe magnets on the surface scoop, and auxiliary mirrors. Of the auxiliary mirrors, three were used to observe areas below the spacecraft, one to provide stereoscopic views of the surface sampler area, and seven to show lunar material deposited on the spacecraft. The spacecraft landed on the lunar surface on January 10, 1968, on the outer rim of the crater Tycho. Operations of the spacecraft began shortly after the soft landing and were terminated on January 26, 1968, 80 hours after sunset. Operations on the second lunar day occurred from February 12 to 21, 1968. The mission objectives were fully satisfied by the spacecraft operations.

The spacecraft landed near the large lunar crater Tycho, named for the famous astronomer. This crater is visible to the naked eye from Earth with luminous rays of impact ejected material emanating radially from it. Surveyor 7 was the final spacecraft in the Surveyor program. It landed perfectly, less than two miles (3 km) from the navigational target. The alpha backscattering instrument failed to deploy properly. Mission controllers successfully used the surface soil sampler claw to push the alpha backscattering instrument into the proper position to conduct its experiments. Battery damage was suffered in the first lunar night and transmission contact was subsequently sporadic. The spacecraft was last in contact on 20 February 1968.



Photomosaic of a panorama taken by Surveyor 7 of its landing site.

Surveyor 7 was the first probe to detect the faint glow on the lunar horizon after dark that is now thought to be light reflected from electrostatically levitated moon dust.

# Science instruments

## Television

The TV camera consisted of a vidicon tube, 25 and 100 mm focal length lenses, shutters, polarizing filters, and iris mounted nearly vertically and surmounted by a mirror that could be adjusted by stepping motors to move in both azimuth and elevations. The polarizing filters served as analyzers for the detection of measurements of the linearly polarized component of light scattered from the lunar surface. The frame by frame coverage of the lunar surface provided a 360 deg azimuth view and an elevation view from approximately +90 deg above the plane normal to the camrea A axis to -60 deg below this same plane. Both 600 line and 200 line modes of operation were used. The 200 line mode transmitted over an omnidirectional antenna and scanned one frame each 61.8 seconds. A complete video transmission of each 200 line picture required 20 seconds and utilized a bandwidth of 1.2 kHz. Most transmissions consisted of 600 line pictures, which were telemetered by a directional antenna. The frames were scanned each

3.6 seconds. Each frame required nominally one second to be read from the vidicon and utilized a 220 kHz bandwidth for transmission. The dynamic range and sensitivity of this camera were slightly less than those on the Surveyor 6 camera. Resolution and quality were excellent. The television images were displayed on a slow scan monitor coated with a long persistency phosphor. The persistency was selected to optimally match the nominal maximum frame rate. One frame of TV identification was received for each incoming TV frame and was displayed in real time at a rate compatible with that of the incoming image. These data were recorded on a video magnetic tape recorder and on 70 mm film. The camera transmitted 20,961 pictures during the first lunar day, January 10 to January 22, 1968. From February 12 to February 14, the camera was operated in the 200 line mode because of loss of horizontal sweep in the 600 line mode. During the second lunar day, 45 pictures were transmitted before loss of power caused suspension of camera operation.

## Alpha-Scattering Surface Analyzer

The alpha-scattering surface analyzer was designed to measure directly the abundances of the major elements of the lunar surface. The instrumentation consisted of an alpha source (curium 242) collimated to irradiate a 10 mm diameter opening in the bottom of the instrument where the sample was located and two parallel but independent charged particle detector systems. One system, containing two sensors, detected the energy spectra of the alpha particles scattered from the lunar surface, and the other, containing four sensors, detected energy spectra of the protons produced via reaction (alpha and proton) in the surface material. Each detector assembly was connected to a pulse height analyzer. A digital electronics package, located in a compartment on the spacecraft, continuously telemetered signals to earth whenever the experiment was operating. The spectra contained quantitative information on all major elements in the samples except for hydrogen, helium, and lithium. The experiment provided 46 hours of data accumulated from three lunar surface sample measurements. These measurements were of a portion of undisturbed local lunar surface, a lunar rock, and an extensively trenched area of the lunar surface. Data were obtained during the first and second lunar days, January 12 to 23 January 1968, and February 13 to 20 February 1968.

## Soil Mechanics Surface Sampler

The soil mechanics surface sampler was designed to pick up, dig, scrape, and trench the lunar surface, and transport lunar surface material while being photographed so that the properties of the lunar surface could be determined. The sampler consisted primarily of a scoop with a container, a sharpened blade, and an electric motor to open and close the container. The flat foot of the scoop incorporated two embedded rectangular horseshoe magnets. The scoop was mounted on a pantograph arm that could be extended about 1.5 m or retracted close to the spacecraft motor drive. The arm could also be moved from an azimuth of +40 deg to -72 deg or be elevated 130 mm by motor drives. It could also be dropped onto the lunar surface under force provided by gravity and a spring. The scoop was mounted below the television camera in a position that allowed it to reach the alpha-scattering instrument in its deployed position and redeploy it to another selected location.

The instrument performed 16 bearing tests, seven trenching tests, and two impact tests. It also freed the alpha-scattering instrument when it failed to deploy on the lunar surface, shaded this instrument, and moved this instrument for evaluation of other samples. Performance was flawless during 36 hours of operation between January 11 and January 23, 1968. The instrument responded to commands on February 14, 1968, which verified that it had survived the lunar night. The power system, however, was unable to support any operations.

## Chapter- 7

# Lunar Orbiter Program

## Lunar Orbiter 1

**Lunar Orbiter 1**

| | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Langley Research Center |
| **Mission type** | Orbiter |
| **Satellite of** | Moon |
| **Orbits** | 577 |
| **Launch date** | August 10, 1966 at 19:31 UTC |
| **Launch vehicle** | Atlas-Agena D |
| **Mission duration** | 80 days |
| **Orbital decay** | Impacted lunar farside on October 29, 1966, at 6°21′N 160°43′E / 6.35°N 160.72°E |

| | |
|---|---|
| **Landing site** | |
| **COSPAR ID** | 1966-073A |
| **Mass** | 385.6 kg (850 lb) |
| | **Orbital elements** |
| **Semimajor axis** | 2,694 km (1,674 mi) |
| **Eccentricity** | .33 |
| **Inclination** | 12° |
| **Apoapsis** | 1,866.8 km (1,160.0 mi) |
| **Periapsis** | 40.5 km (25.2 mi) |
| **Orbital period** | 208.1 minutes |

The **Lunar Orbiter 1** robotic (unmanned) spacecraft, part of the Lunar Orbiter Program, was designed primarily to photograph smooth areas of the lunar surface for selection and verification of safe landing sites for the Surveyor and Apollo missions. It was also equipped to collect selenodetic, radiation intensity, and micrometeoroid impact data.

The spacecraft was placed in an Earth parking orbit on August 10, 1966 at 19:31 (UTC). The Trans lunar injection burn occurred at 20:04 (UTC). The spacecraft experienced a temporary failure of the Canopus star tracker (probably due to stray sunlight) and overheating during its cruise to the Moon. The star tracker problem was resolved by navigating using the Moon as a reference and the overheating was abated by orienting the spacecraft 36 degrees off-Sun to lower the temperature.

Lunar Orbiter 1 was injected into an elliptical near-equatorial lunar orbit 92.1 hours after launch. The initial orbit was 189.1 by 1,866.8 kilometres (117.5 × 1,160.0 mi) and had a period of 3 hours 37 minutes and an inclination of 12.2 degrees. On August 21 perilune was dropped to 58 kilometres (36 mi) and on August 25 to 40.5 kilometres (25.2 mi). The spacecraft acquired photographic data from August 18–29, 1966, and readout occurred through September 14, 1966.

A total of 42 high resolution and 187 medium resolution frames were taken and transmitted to Earth covering over 5 million square km of the Moon's surface, accomplishing about 75% of the intended mission, although a number of the early high-res photos showed severe smearing. It also took the first two pictures of the Earth ever from the distance of the Moon. Accurate data were acquired from all other experiments throughout the mission.

Orbit tracking showed a slight "pear-shape" to the Moon based on the gravity field, and no micrometeorite impacts were detected. The spacecraft was tracked until it impacted the lunar surface on command at 7 degrees N latitude, 161 degrees E longitude (selenographic coordinates) on the Moon's far side on October 29, 1966 on its 577th orbit. The early end to the nominal one year mission was due to the small amount of remaining attitude control gas and other deteriorating conditions and was planned to avoid transmission interference with Lunar Orbiter 2.

# Lunar Orbiter 2

| Lunar Orbiter 2 | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Langley Research Center |
| **Mission type** | Orbiter |
| **Satellite of** | Moon |
| **Orbits** | 2,346 |
| **Launch date** | November 6, 1966 at 23:21:00 UTC |
| **Launch vehicle** | Atlas-Agena D |
| **Mission duration** | 339 days |
| **Orbital decay** | Impacted lunar surface on October 11, 1967, at 3°00′N 119°06′E / 3.0°N 119.1°E |
| **Landing site** | |
| **COSPAR ID** | 1966-100A |
| **Mass** | 385.6 kg (850 lb) |
| **Orbital elements** | |
| **Semimajor axis** | 2,694 km (1,674 mi) |
| **Eccentricity** | .35 |
| **Inclination** | 11.9° |
| **Apoapsis** | 1,850 km (1,150 mi) |
| **Periapsis** | 52 km (32 mi) |
| **Orbital period** | 208.07 minutes |

The **Lunar Orbiter 2** spacecraft was designed primarily to photograph smooth areas of the lunar surface for selection and verification of safe landing sites for the Surveyor and Apollo missions. It was also equipped to collect selenodetic, radiation intensity, and micrometeoroid impact data.

The spacecraft was placed in a cislunar trajectory and injected into an elliptical near-equatorial lunar orbit for data acquisition after 92.5 hours flight time. The initial orbit was 196 by 1,850 kilometres (122 × 1,150 mi) at an inclination of 11.8 degrees. The perilune was lowered to 49.7 kilometres (30.9 mi) five days later after 33 orbits. A failure of the amplifier on the final day of readout, December 7, resulted in the loss of six photographs. On December 8, 1966 the inclination was altered to 17.5 degrees to provide new data on lunar gravity.

The spacecraft acquired photographic data from November 18 to 25, 1966, and readout occurred through December 7, 1966. A total of 609 high resolution and 208 medium resolution frames were returned, most of excellent quality with resolutions down to 1 metre (3 ft 3 in). These included a spectacular oblique picture of Copernicus crater, which was dubbed by the news media as one of the great pictures of the century. Accurate data were acquired from all other experiments throughout the mission. Three micrometeorite impacts were recorded. The spacecraft was used for tracking purposes until it impacted upon the lunar surface on command at 3.0 degrees N latitude, 119.1 degrees E longitude (selenographic coordinates) on October 11, 1967.

## Lunar Orbiter 3

| Lunar Orbiter 3 | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Langley Research Center |
| **Mission type** | Orbiter |
| **Satellite of** | Moon |
| **Orbits** | 1,702 |
| **Launch date** | February 5, 1967 at 01:17:00 UTC |
| **Launch vehicle** | Atlas-Agena D |
| **Mission duration** | 246 days |
| **Orbital decay** | Impacted lunar surface on October 9, 1967, at 14°18′N 97°42′W / 14.3°N 97.7°W |
| **Landing site** | |
| **COSPAR ID** | 1967-008A |
| **Mass** | 385.6 kg (850 lb) |

| | Orbital elements |
|---|---|
| **Semimajor axis** | 2,694 km (1,674 mi) |
| **Eccentricity** | .33 |
| **Inclination** | 20.9° |
| **Apoapsis** | 1,847 km (1,148 mi) |
| **Periapsis** | 55 km (34 mi) |
| **Orbital period** | 208.1 minutes |

The **Lunar Orbiter 3** was a spacecraft launched by NASA in 1967, designed primarily to photograph areas of the lunar surface for confirmation of safe landing sites for the Surveyor and Apollo missions. It was also equipped to collect selenodetic, radiation intensity, and micrometeoroid impact data.

The spacecraft was placed in a cislunar trajectory and injected into an elliptical near-equatorial lunar orbit on February 8 at 21:54 UT. The orbit was 210.2 by 1,801.9 kilometres (130.6 × 1,119.6 mi) with an inclination of 20.9 degrees and a period of 3 hours 25 minutes. After four days (25 orbits) of tracking the orbit was changed to 55 by 1,847 kilometres (34 × 1,148 mi). The spacecraft acquired photographic data from February 15 to February 23, 1967, and readout occurred through March 2, 1967. The film advance mechanism showed erratic behavior during this period resulting in a decision to begin readout of the frames earlier than planned. The frames were read out successfully until March 4 when the film advance motor burned out, leaving about 25% of the frames on the takeup reel, unable to be read.

A total of 149 medium resolution and 477 high resolution frames were returned. The frames were of excellent quality with resolution down to 1 metre (3 ft 3 in). Included was a frame of the Surveyor 1 landing site, permitting identification of the location of the spacecraft on the surface. Accurate data were acquired from all other experiments throughout the mission. The spacecraft was used for tracking purposes until it struck the lunar surface on command at 14.3 degrees N latitude, 97.7 degrees W longitude (selenographic coordinates) on October 9, 1967.

## Lunar Orbiter 4

| | Lunar Orbiter 4 |
|---|---|
| **Operator** | NASA |
| **Major** | Langley Research Center |

| | |
|---|---|
| **contractors** | |
| **Mission type** | Orbiter |
| **Satellite of** | Moon |
| **Orbits** | 360 |
| **Launch date** | May 4, 1967 at 22:25:00 UTC |
| **Launch vehicle** | Atlas-Agena D |
| **Mission duration** | 180 days |
| **Orbital decay** | Impacted lunar surface no later than October 31, 1967, near 22--30 degrees W. |
| **Landing site** | |
| **COSPAR ID** | 1967-041A |
| **Mass** | 385.6 kg (850 lb) |
| **Orbital elements** | |
| **Semimajor axis** | 6,152.5 km (3,823.0 mi) |
| **Eccentricity** | .28 |
| **Inclination** | 85.5° |
| **Apoapsis** | 6,111 km (3,797 mi) |
| **Periapsis** | 2,706 km (1,681 mi) |
| **Orbital period** | 721 minutes |

**Lunar Orbiter 4** was designed to take advantage of the fact that the three previous Lunar Orbiters had completed the required needs for Apollo mapping and site selection. It was given a more general objective, to "perform a broad systematic photographic survey of lunar surface features in order to increase the scientific knowledge of their nature, origin, and processes, and to serve as a basis for selecting sites for more detailed scientific study by subsequent orbital and landing missions". It was also equipped to collect selenodetic, radiation intensity, and micrometeoroid impact data. The spacecraft was placed in a cislunar trajectory and injected into an elliptical near polar high lunar orbit for data acquisition. The orbit was 2,706 by 6,111 kilometres (1,681 × 3,797 mi) with an inclination of 85.5 degrees and a period of 12 hours.

After initial photography on May 11, 1967 problems started occurring with the camera's thermal door, which was not responding well to commands to open and close. Fear that the door could become stuck in the closed position covering the camera lenses led to a decision to leave the door open. This required extra attitude control maneuvers on each orbit to prevent light leakage into the camera which would ruin the film. On May 13 it was discovered that light leakage was damaging some of the film, and the door was tested and partially closed. Some fogging of the lens was then suspected due to condensation resulting from the lower temperatures. Changes in the attitude raised the temperature of the camera and generally eliminated the fogging. Continuing problems with the readout drive mechanism starting and stopping beginning on May 20 resulted in a decision to terminate the photographic portion of the mission on May 26. Despite problems with the readout drive the entire film was read and transmitted. The spacecraft acquired photographic data from May 11 to 26, 1967, and readout occurred through June 1, 1967. The orbit was then lowered to gather orbital data for the upcoming Lunar Orbiter 5 mission.

A total of 419 high resolution and 127 medium resolution frames were acquired covering 99% of the Moon's near side at resolutions from 58 to 134 metres (190 to 440 ft). Accurate data was acquired from all other experiments throughout the mission. Radiation data showed increased dosages due to solar particle events producing low energy protons. The spacecraft was used for tracking purposes until it struck the lunar surface due to the natural decay of the orbit no later than October 31, 1967, between 22--30 degrees W longitude.

| Instruments | |
|---|---|
| **Lunar Photographic Studies :** | Evaluation of Apollo and Surveyor landing sites |
| **Meteoroid Detectors :** | Detection of micrometeoroids in the lunar environment |
| **Caesium Iodide Dosimeters :** | Radiation environment en route to and near the moon |
| **Selenodesy :** | Gravitational field and physical properties of the moon |

## Lunar Orbiter 5

| Lunar Orbiter 5 | |
|---|---|
| **Operator** | NASA |
| **Major contractors** | Langley Research Center |
| **Mission type** | Orbiter |
| **Satellite of** | Moon |
| **Orbits** | 1,380 |

| | |
|---|---|
| **Launch date** | August 1, 1967 at 22:32:00 UTC |
| **Launch vehicle** | Atlas-Agena D |
| **Mission duration** | 183 days |
| **Orbital decay** | Impacted lunar surface on January 31, 1968, at 2°47′S 83°06′W / 2.79°S 83.1°W |
| **Landing site** | |
| **COSPAR ID** | 1967-075A |
| **Mass** | 385.6 kg (850 lb) |
| | **Orbital elements** |
| **Semimajor axis** | 4,846.8 km (3,011.7 mi) |
| **Eccentricity** | .26 |
| **Inclination** | 85° |
| **Apoapsis** | 6,023 km (3,743 mi) |
| **Periapsis** | 194.5 km (120.9 mi) |
| **Orbital period** | 510.08 minutes |

**Lunar Orbiter 5**, the last of the Lunar Orbiter series, was designed to take additional Apollo and Surveyor landing site photography and to take broad survey images of unphotographed parts of the Moon's far side. It was also equipped to collect selenodetic, radiation intensity, and micrometeoroid impact data and was used to evaluate the Manned Space Flight Network tracking stations and Apollo Orbit Determination Program. The spacecraft was placed in a cislunar trajectory and on August 5, 1967 was injected into an elliptical near polar lunar orbit 194.5 by 6,023 kilometres (120.9 × 3,743 mi) with an inclination of 85 degrees and a period of 8 hours 30 minutes. On August 7 the perilune was lowered to 100 kilometres (62 mi), and on August 9 the orbit was lowered to a 99-by-1,499-kilometre (62 × 931 mi), 3 hour 11 minute period.

The spacecraft acquired photographic data from August 6 to 18, 1967, and readout occurred until August 27, 1967. A total of 633 high resolution and 211 medium resolution frames at resolution down to 2 metres (6 ft 7 in) were acquired, bringing the cumulative photographic coverage by the five Lunar Orbiter craft to 99% of the Moon's surface. Accurate data were acquired from all other experiments throughout the mission. The spacecraft was tracked until it struck the lunar surface on command at 2.79 degrees S latitude, 83 degrees W longitude (selenographic coordinates) on January 31, 1968.

Instruments

| | |
|---|---|
| **Lunar Photographic Studies :** | Evaluation of Apollo and Surveyor landing sites |
| **Meteoroid Detectors :** | Detection of micrometeoroids in the lunar environment |
| **Caesium Iodide Dosimeters :** | Radiation environment en route to and near the Moon |
| **Selenodesy :** | Gravitational field and physical properties of the Moon |