

Robotic Spacecrafts and Robotic Space Exploration



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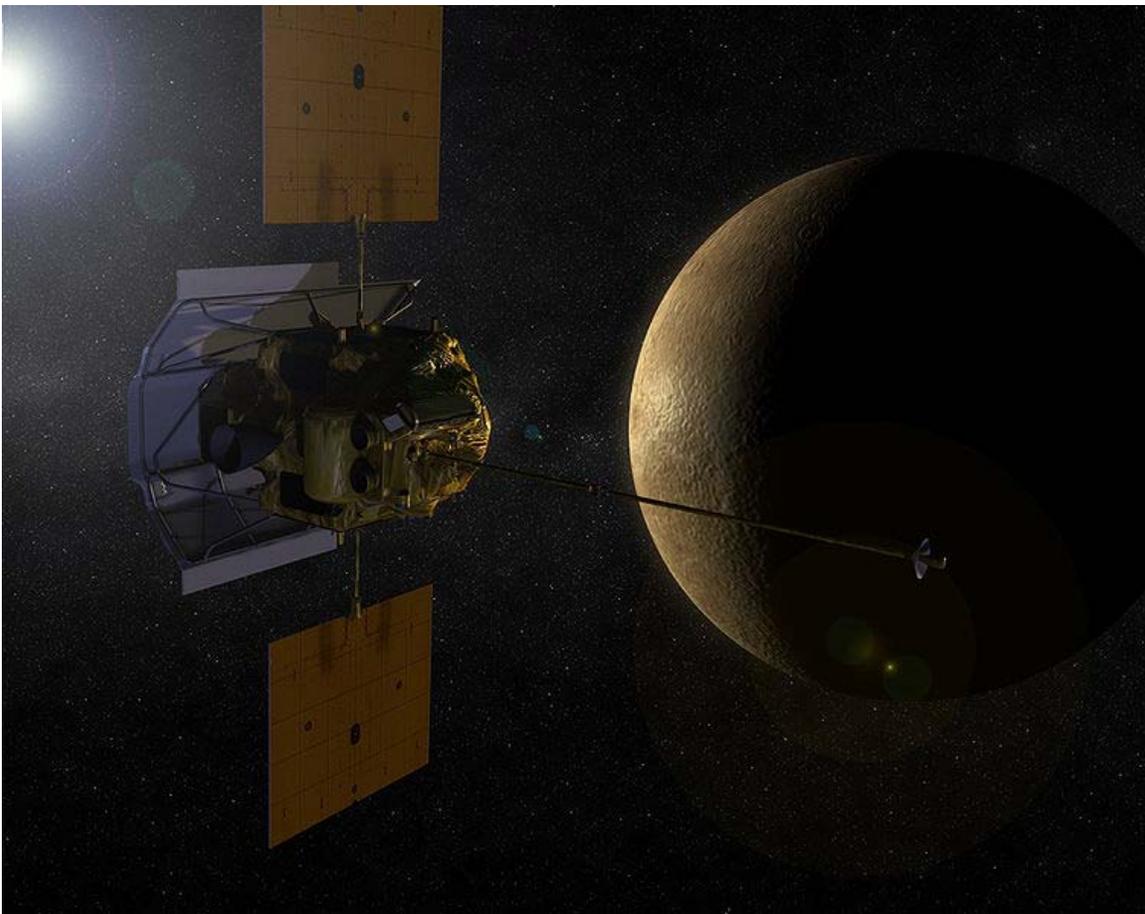
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Chapter- 1

Introduction to Robotic Spacecraft



An artist's interpretation of the MESSENGER spacecraft at Mercury

A **robotic spacecraft** is a spacecraft with no humans on board, that is usually under telerobotic control. A robotic spacecraft designed to make scientific research measurements is often called a space probe. Many space missions are more suited to telerobotic rather than crewed operation, due to lower cost and lower risk factors. In addition, some planetary destinations such as Venus or the vicinity of Jupiter are too

hostile for human survival, given current technology. Outer planets such as Saturn, Uranus, and Neptune are too distant to reach with current crewed spaceflight technology, so telerobotic probes are the only way to explore them.

Many artificial satellites are robotic spacecraft, as are many landers and rovers.

History

The first space mission, Sputnik 1, was an artificial satellite put into Earth orbit by the USSR on 4 October 1957. On 3 November 1957, the USSR orbited Sputnik 2, the first to carry a living animal into space – a dog.

Only seven other countries have successfully launched orbital missions using their own vehicles: France (1965), Japan (1970), China (1970), the United Kingdom (1971), India (1981), Israel (1988).

Design

In spacecraft design, the United States Air Force considers a vehicle to consist of the mission payload and the bus (or platform). The bus provides physical structure, thermal control, electrical power, attitude control and telemetry, tracking and commanding.

JPL divides the "flight system" of a spacecraft into subsystems. These include:

Structure

This is the physical backbone structure. It:

- provides overall mechanical integrity of the spacecraft
- ensures spacecraft components are supported and can withstand launch loads

Data handling

This is sometimes referred to as the command and data subsystem. It is often responsible for:

- command sequence storage
- maintaining the spacecraft clock
- collecting and reporting spacecraft telemetry data (e.g. spacecraft health)
- collecting and reporting mission data (e.g. photographic images)

Attitude and articulation control

This system is responsible for the spacecraft's orientation in space (attitude) and the positioning of movable parts (articulation). Attitude and articulation are controlled in order to:

- point an antenna at Earth for communications
- point onboard instruments for collection of data (possibly in some other direction)
- adjust for the heating effects of sunlight
- provide guidance during propulsive maneuvers

Telecommunications

Components in the telecommunications subsystem include radio antennas, transmitters and receivers. These may be used to communicate with ground stations on Earth, or with other spacecraft.

Electrical power

The supply of electric power on spacecraft come from photovoltaic (solar) cells or from a radioisotope thermoelectric generator. Other components of the subsystem include batteries for storing power and distribution circuitry that connects components to the power sources.

Temperature control and protection from the environment

Spacecraft are often protected from temperature fluctuations with insulation. Some spacecraft use mirrors and sunshades for additional protection from solar heating. They also often need shielding from micrometeoroids and orbital debris.

Propulsion

Mechanical devices

Mechanical components often need to be moved for deployment after launch or prior to landing. In addition to the use of motors, many one-time movements are controlled by pyrotechnic devices.

Control

Robotic spacecraft use telemetry to radio back to Earth acquired data and vehicle status information. Although generally referred to as "remotely-controlled" or "telerobotic", the earliest orbital spacecraft - such as Sputnik 1 and Explorer 1 - did not receive control signals from Earth. Soon after these first spacecraft, command systems were developed to allow remote control from the ground. Increased autonomy is important for distant probes where the light travel time prevents rapid decision and control from Earth. Newer probes

such as Cassini-Huygens and the Mars Exploration Rovers are highly autonomous and use on-board computers to operate independently for extended periods of time.

List of space probes

Lunar probes

- Luna program — USSR Lunar exploration (1959–1976).
- Ranger program — US Lunar hard-landing probes (1961–1965).
- Zond program — USSR Lunar exploration (1964–1970).
- Surveyor program — US Lunar soft-landing probe (1966–1968).
- Lunar Orbiter program — US Lunar orbital (1966–1967).
- Lunokhod program — USSR Lunar Rover probes (1970–1973).
- Muses-A mission (*Hiten* and *Hagoromo*) — Japanese Lunar orbital and hard-landing probes (1990–1993).
- *Clementine* — US Lunar orbital (1998).
- *Lunar Prospector* — US Lunar orbital (1998–1999).
- *Smart 1* — European Lunar orbital (2003).
- *SELENE* — Japanese lunar orbiter (2007).
- *Chang'e 1* — Chinese lunar orbiter (2007).
- *Chandrayaan 1* — Indian lunar orbiter (2008).
- *Lunar Reconnaissance Orbiter* — US Lunar orbiter (2009).
- *LCROSS* — US Lunar hard-landing probe (2009).
- *Chang'e 2* — Chinese lunar orbiter (2010).
- *Gravity Recovery and Interior Laboratory* — US Lunar orbiters, to be launched 2011

Mars probes

- Zond program — failed USSR flyby probe
- Mars probe program — USSR orbiters and landers
- Viking program — Two NASA orbiters and landers (1974)
- Phobos program — Failed USSR orbiters and Phobos landers
- *Mars Pathfinder* — NASA lander and rover (1997)
- Mars Surveyor '98 program (*Mars Climate Orbiter* and *Mars Polar Lander*) — Failed NASA probes
- Mars Global Surveyor - NASA orbiter
- Mars Odyssey — NASA orbiter, reached Mars on October 24, 2001
- Mars Observer — failed NASA Mars orbiter
- Mars Express (*Mars Express Orbiter* and *Beagle 2*) — European orbiter and failed lander 2003
- Mars Exploration Rovers — NASA rovers (2004)
- *Mars Reconnaissance Orbiter* — NASA orbiter, entered Martian orbit March 10, 2006
- *Phoenix* — NASA lander, landed May 25, 2008
- *Mars Science Laboratory* — NASA rover, to be launched 2011

Venus probes

- Venera program — USSR Venus orbiter and lander (1961–1984)
- Pioneer Venus project — US Venus orbiter (1978)
- Vega program — USSR mission to Venus and Comet Halley (1984)
- Magellan probe — US Venus orbiter (1989)
- Venus Express — ESA probe sent for the observation of the Venus's weather (2005)
- MESSENGER - US Fly-by/Orbiter (2004)

Gas giant probes

- Pioneer program — US Jupiter and Saturn flybys
- Voyager program — US Jupiter, Saturn, Uranus and Neptune flyby and study of interstellar medium
- Galileo probe — US Jupiter orbiter and atmosphere probe
- *Cassini-Huygens* — US-European Saturn orbiter and Titan lander Huygens (1997–present)

Comet and asteroid probes

- International Cometary Explorer — passed through gas tail of comet 21P/Giacobini-Zinner (1985)
- Giotto mission — European — flyby of comet 1P/Halley (1986)
- Vega 1 & 2 — USSR — flyby of comet 1P/Halley (1986)
- Sakigake probe — Japanese — flyby of comet 1P/Halley (1986)
- Suisei probe — Japanese — flyby of comet 1P/Halley (1986)
- *NEAR Shoemaker* — US — asteroid 433 Eros orbiter, which later landed on the asteroid's surface, launched 1996
- *Deep Space 1* — US — comet 19P/Borrelly and asteroid flyby, 1998–2000
- Stardust probe — US — comet 81P/Wild flyby and sample return, launched 1999, flied-by 2004, returned January 15, 2006
- *CONTOUR* — US — comet flyby mission (comets 2P, 73P and 6P); lost due to solid rocket motor failure shortly after launch in 2002
- *Hayabusa* — Japanese — asteroid orbiter, lander and sample return, launched 2003, returned June 13, 2010
- *Rosetta* — European — comet 67P/Churyumov-Gerasimenko orbiter and lander (Philae); launched 2004
- Deep Impact — successful US comet 9P/Tempel impactor, launched 2005
- Deep Impact/EPOXI — US — comet 103P/Hartley flyby (extended Deep Impact mission) — 2010
- Stardust/NEXT — US — comet 9P/Tempel flyby (extended Stardust mission) — 2011

Solar observation probes

- Ulysses — Solar particles and fields
- Genesis — First solar wind sample return mission, 2001–2004 (crash)
- *Interstellar Boundary Explorer* (IBEX) — launched October 19, 2008.
- Advanced Composition Explorer — Solar particles and fields observation at Earth-Sun L₁ point
- STEREO — Pair of probes in solar orbits providing 3D observations of sun

Other solar system probes

- Zond program — USSR flyby missions to the Moon, Venus, and Mars
- Mariner program — US Mercury, Venus and Mars flybys
- MESSENGER — US Mercury orbiter, launched 2004
- *New Horizons* — US launched on January 19, 2006 — First probe to visit Pluto (in July 2015)
- *Dawn* — US launched on September 27, 2007 — First probe to visit Vesta and Ceres (in 2011 and 2015 respectively)

Chapter- 2

Robotic Exploration of the Moon

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 duration	?
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
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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.

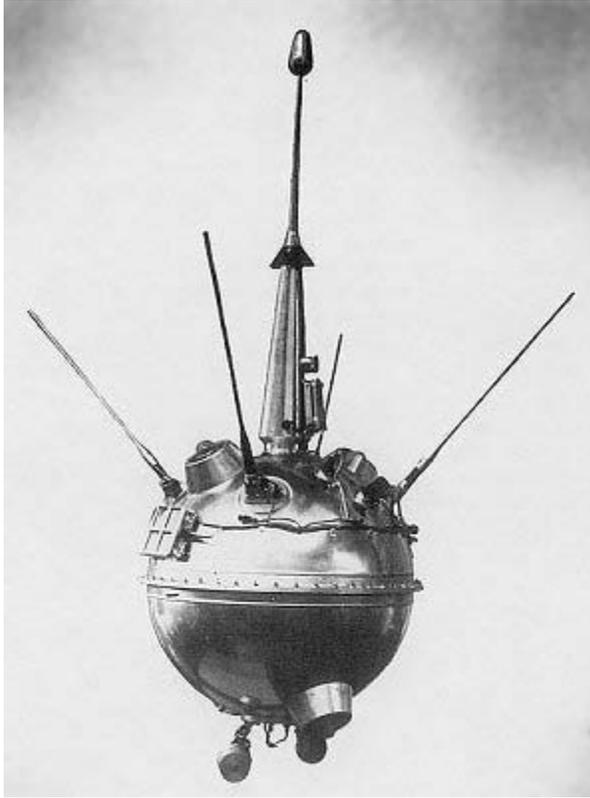
The flight

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 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
Landing site	
COSPAR ID	1959-014A
Mass	390.2 kg (860.2 lb)

Lunar landing

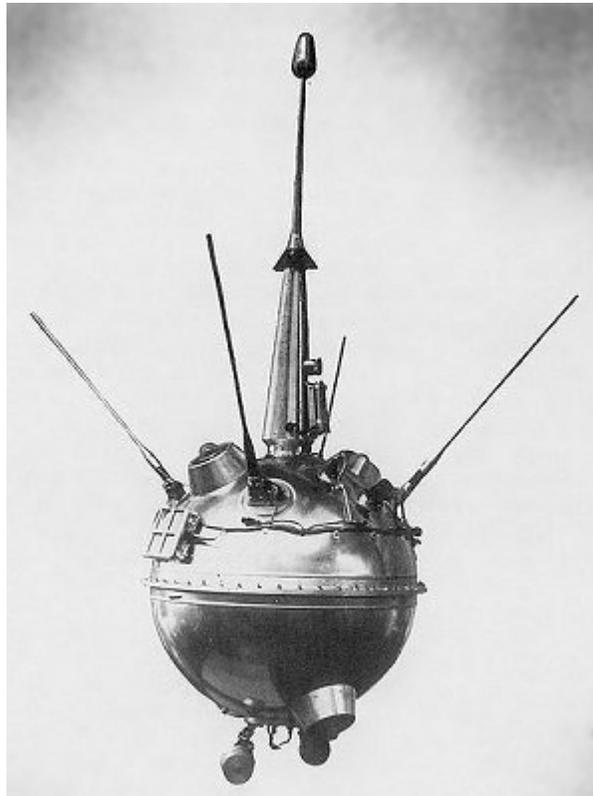
Date Lunar collision
September 13, 1959, 21:02:24 UTC

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

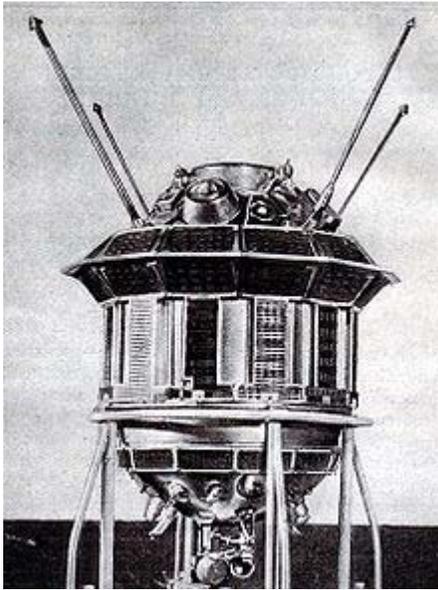
The spacecraft also carried Soviet pennants. Two of them, located in the spacecraft, were sphere-shaped, with the surface covered by identical pentagonal elements. In the center of this sphere was an explosive for the purpose of slowing the huge impact velocity. This was designed as a very simple way 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 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	~207 days

duration

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

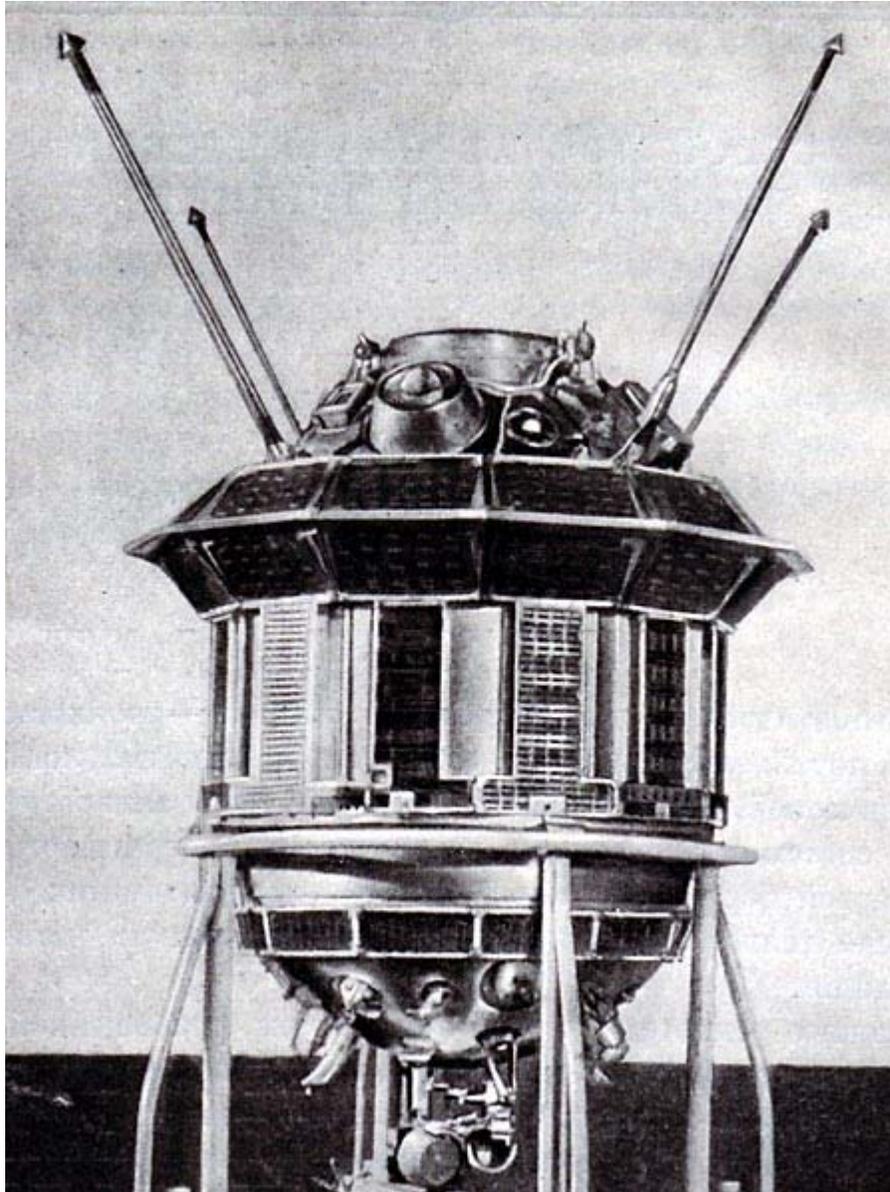
Periapsis 40,638 km

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 cylindrical 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 cylindrical 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



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).

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)

Instruments	
Television :	transmit closeup pictures of the lunar surface
Seismometer :	determine the presence or absence of lunar seismicity

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 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 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.

Clementine (spacecraft)

Clementine

	
Organization	BMDO / NASA
Major contractors	Naval Research Laboratory
Mission type	Lunar science

Satellite of	Moon
Launch	January 25, 1994 at 16:34:00 UTC
Launch vehicle	Titan 23G
End of mission	Signal too weak to receive: June 1994
Mission duration	115 days
Mass	227 kg
NSSDC ID	1994-004A
Webpage	NASA NSSDC Master Catalog
Orbital elements	
Semimajor axis	5,116.0 km
Eccentricity	0.36
Inclination	90°
Orbital period	300 minutes
Apoapsis	4,594 km
Periapsis	2,162 km
Orbits	360

Instruments	
Charged particle telescope	Measure the flux and spectra of energetic protons and electrons
Ultraviolet/Visible camera	Study the Moon and 1620 Geographos at five different wavelengths in the ultraviolet spectrum
Near-Infrared CCD camera (NIR)	Study the Moon and 1620 Geographos at six different wavelengths in the near-infrared spectrum
Laser Image Detection and Ranging (LIDAR) system	Measure the distance from the spacecraft to a point on the surface of the Moon
High-resolution camera (HIRES)	Study selected portions of the Moon and asteroid

Clementine (officially called the **Deep Space Program Science Experiment (DSPSE)**) was a joint space project between the Ballistic Missile Defense Organization (BMDO, previously the Strategic Defense Initiative Organization, or SDIO) and NASA. Launched on January 25, 1994, the objective of the mission was to test sensors and spacecraft components under extended exposure to the space environment and to make scientific observations of the Moon and the near-Earth asteroid 1620 Geographos. The Geographos observations were not made due to a malfunction in the spacecraft.

The lunar observations made included imaging at various wavelengths in the visible as well as in ultraviolet and infrared, laser ranging altimetry, gravimetry, and charged particle measurements. These observations were for the purposes of obtaining multi-spectral imaging of the entire lunar surface, assessing the surface mineralogy of the Moon, obtaining altimetry from 60N to 60S latitude, and obtaining gravity data for the near side. There were also plans to image and determine the size, shape, rotational characteristics, surface properties, and cratering statistics of Geographos.

Clementine carried seven distinct experiments on-board: a UV/Visible Camera, a Near Infrared Camera, a Long Wavelength Infrared Camera, a High Resolution Camera, two Star Tracker Cameras, a Laser Altimeter, and a Charged Particle Telescope. The S-band

transponder was used for communications, tracking, and the gravimetry experiment. The project was named Clementine after the song "Oh My Darling, Clementine" as the spacecraft would be "lost and gone forever" following its mission.

Spacecraft design

The spacecraft was an octagonal prism 1.88 m high and 1.14 m across with two solar panels protruding on opposite sides parallel to the axis of the prism. A 42-inch-diameter (1,100 mm) high-gain fixed dish antenna was at one end of the prism, and the 489 N thruster at the other end. The sensor openings were all located together on one of the eight panels, 90 degrees from the solar panels, and protected in flight by a single sensor cover.

The spacecraft propulsion system consisted of a monopropellant hydrazine system for attitude control and a bipropellant nitrogen tetroxide and monomethyl hydrazine system for the maneuvers in space. The bipropellant system had a total capability of about 1,900 m/s with about 550 m/s required for lunar insertion and 540 m/s for lunar departure.

Attitude control was achieved with 12 small attitude control jets, two star tracker cameras, and two inertial measurement units. The spacecraft was three-axis stabilized in lunar orbit via reaction wheels with a precision of 0.05 deg in control and 0.03 deg in knowledge. Power was provided by gimbaled, single axis, GaAs/Ge solar panels which charged a 15 A·h, 47 W·h/kg Nihau (Ni-H) common pressure vessel battery.

Spacecraft data processing was performed using a MIL-STD-1750A computer (1.7 MIPS) for savemode, attitude control, and housekeeping operations, a RISC 32-bit processor (18 MIPS) for image processing and autonomous operations, and an image compression system provided by the French Space Agency CNES. A data handling unit sequenced the cameras, operated the image compression system, and directed the data flow. Data was stored in a 2 Gbit dynamic solid state data recorder.

Mission



Clementine launch

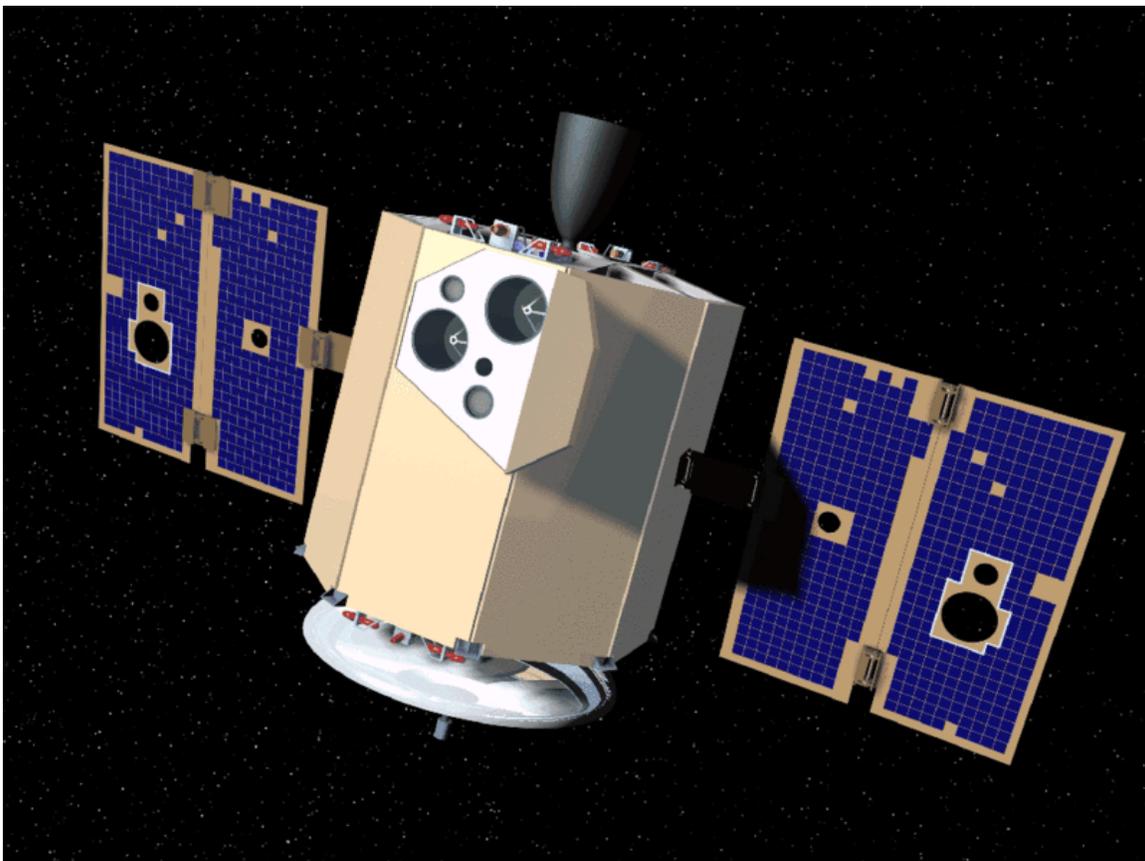
On January 25, 1994, Clementine was launched from Space Launch Complex 4 West at Vandenberg Air Force Base, California using a Titan II launch vehicle. The mission had two phases. After two Earth flybys, lunar insertion was achieved approximately one month after launch. Lunar mapping took place over approximately two months, in two parts. The first part consisted of a five hour elliptical polar orbit with a periapsis of about 400 km at 30 degrees south latitude and an apoapsis of 8300 km. Each orbit consisted of an 80 minute lunar mapping phase near periapsis and 139 minutes of downlink at apoapsis.

After one month of mapping the orbit was rotated to a periapsis at 30 degrees north latitude, where it remained for one more month. This allowed global imaging and altimetry coverage from 60° south to 60° north, over a total of 300 orbits.

After an Earth to moon transfer and two more Earth flybys, the spacecraft was to head for Geographos, arriving three months later for a flyby, with a nominal approach closer than 100 km. Unfortunately, on May 7, 1994, after the first Earth transfer orbit, a malfunction aboard the craft caused one of the attitude control thrusters to fire for 11 minutes, using up its fuel supply and causing Clementine to spin at 80 rpm. Under these conditions, the asteroid flyby could not yield useful results, so the spacecraft was put into a geocentric orbit passing through the Van Allen radiation belts to test the various components on board.

The mission ended in June 1994 when the power level onboard dropped to a point where the telemetry from the spacecraft was no longer intelligible.

NASA announced on March 5, 1998 that data obtained from Clementine indicated that there is enough water in polar craters of the moon to support a human colony and a rocket fueling station. Doubt has since been cast on this interpretation, however.



Artist's conception of Clementine fully deployed

Science instruments

Charged Particle Telescope (CPT)

The Charged Particle Telescope (CPT) on Clementine was designed to measure the flux and spectra of energetic protons (3–80 MeV) and electrons (25–500 KeV). The primary goals of the investigation were to: (1) study the interaction of the Earth's magnetotail and interplanetary shocks with the Moon; (2) monitor the solar wind in regions far removed from other spacecraft as part of a multimission coordinated study; and, (3) measure the effects of incident particles on the operating ability of the spacecraft solar cells and other sensors.

In order to meet the stringent limit on the mass of the instrument (<1 kg), it was implemented as a single element telescope. The telescope had a 10 degree half-angle field of view. The detector, a silicon surface-barrier type with an area of 100 mm² and a thickness of 3 mm, was shielded so as to prevent protons below 30 MeV from reaching it from directions other than via the aperture. The aperture was covered by a very thin foil to prevent light impinging on the detector and generating noise. The signal from the detector was broken up into nine channels, the lowest six dedicated to electron detection and the highest three to protons and heavier ions.

Ultraviolet/Visible camera

The Ultraviolet/Visible camera (UV/Vis) was designed to study the surfaces of the Moon and the asteroid Geographos at five different wavelengths in the ultraviolet and visible spectrum. The Geographos rendezvous was canceled due to equipment malfunction. This experiment yielded information on the petrologic properties of the surface material on the Moon, as well as giving images useful for morphologic studies and cratering statistics. Most images were taken at low Sun angles, which is useful for petrologic studies but not for observing morphology.

The sensor consisted of a catadioptric telescope with an aperture of 46 mm and fused silica lenses focused onto a coated Thompson CCD camera with a bandpass of 250–1000 nm and a six-position filter wheel. The wavelength response was limited on the short wavelength end by the transmission and optical blur of the lens, and on the long end by the CCD response. The CCD was a frame transfer device which allowed three gain states (150, 350, and 1000 electrons/bit). Integration times varied from 1–40 ms depending on gain state, solar illumination angle, and filter. The filter center wavelengths (and bandpass widths (FWHM)) were 415 nm (40 nm), 750 nm (10 nm), 900 nm (30 nm), 950 nm (30 nm), 1000 nm (30 nm), and a broad-band filter covering 400–950 nm. The field of view was 4.2×5.6 degrees, translating to a cross-track width of about 40 km at a nominal 400 km lunar altitude. The image array was 288×384 pixels. Pixel resolution varied from 100–325 m during a single orbit mapping run at the Moon. At Geographos the pixel resolution would have been 25 m at the 100 km closest approach, giving an image size about 7×10 km. The camera took twelve images in each 1.3 s image burst, which occurred 125 times over the 80-minute mapping span during

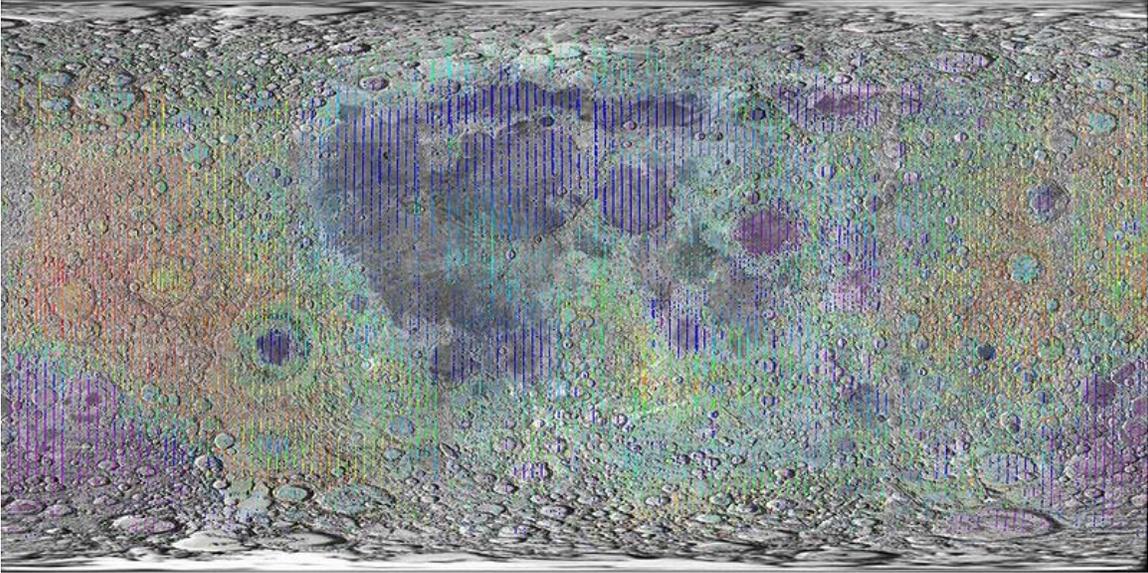
each five-hour lunar orbit. The Moon's surface was covered completely during the two month lunar mapping phase of the mission. The dynamic range was 15,000. The signal-to-noise ratio varied from 25–87 depending on the surface albedo and phase angle, with a relative calibration of 1% and an absolute calibration of 15%.

Near-Infrared CCD Camera (NIR)

The Clementine Near-Infrared camera (NIR) was designed to study the surfaces of the Moon and the near-Earth asteroid 1620 Geographos at six different wavelengths in the near-infrared spectrum. This experiment yielded information on the petrology of the surface material on the Moon. The rendezvous with Geographos was canceled due to equipment malfunction.

The camera consisted of a catadioptric lens which focused on a mechanically cooled (to a temperature of 70 K) Amber InSb CCD focal-plane array with a bandpass of 1100–2800 nm and a six-position filter wheel. The filter center wavelengths (and bandpass widths (FWHM)) were: 1100 nm (60 nm), 1250 nm (60 nm), 1500 nm (60 nm), 2000 nm (60 nm), 2600 nm (60 nm), and 2780 nm (120 nm). The aperture was 29 mm with a focal length of 96 mm. The field of view was 5.6×5.6 degrees, giving a cross-track width of about 40 km at a nominal 400 km lunar altitude. The Moon had complete mapping coverage during the two month lunar phase of the mission. The image array is 256×256 pixels, and pixel resolution varied from 150–500 m during a single orbit mapping run at the Moon. (At Geographos the pixel resolution would have been 40 m at closest approach, giving an image size about 10×10 km.) The camera took twelve images in each 1.3 s image burst, which occurred 75 times over the 80 minute mapping span during each five hour lunar orbit. The dynamic range was 15,000. The signal-to-noise ratio varied from 11–97 depending on the surface albedo and phase angle, with a relative calibration of 1% and an absolute calibration of 30%. The gain varied from 0.5X to 36X.

Laser Image Detection and Ranging (LIDAR) System



Relief measurements made by LIDAR

The Clementine Laser Image Detection And Ranging (LIDAR) experiment was designed to measure the distance from the spacecraft to a point on the surface of the Moon. This will allow an altimetric map to be made, which can be used to constrain the morphology of large basins and other lunar features, study stress and strain and flexural properties of the lithosphere, and can be combined with gravity to study the density distribution in the crust. The experiment was also designed to measure distances to the surface of Geographos, but this phase of the mission was canceled due to a malfunction.

The LIDAR system consisted of a 180 mJ, 1064 nm wavelength Nd-YAG (Yttrium-Aluminum-Garnet) laser transmitter which transmitted pulses to the lunar surface. The laser produced a pulse with a width less than 10 ns. At 1064 nm wavelength, the pulse had an energy of 171 mJ with a divergence less than 500 microrad. At 532 nm, it had a 9 mJ pulse with a 4 millirad divergence. The reflected pulse travelled through the High-Resolution Camera telescope, where it was split off by a dichroic filter to a silicon avalanche photodiode detector. The detector was a single 0.5×0.5 mm cell SiAPD receiver with a field of view of 0.057 square degrees. The laser had a mass of 1250 g, the receiver was housed in the 1120 g HIRES camera. The travel time of a pulse gave the range to the surface. The LIDAR memory could save up to six return detections per laser firing, with a threshold set for the best compromise between missed detections and false alarms. The returns were stored in 39.972 m range bins, equal to the resolution of the 14-bit clock counter. The LIDAR has a nominal range of 500 km, but altimetric data was gathered for altitudes up to 640 km, which allowed coverage from 60 degrees south to 60 degrees north by the end of the lunar phase of the mission. The vertical resolution is 40 m, and the horizontal spot resolution is about 100 m. The across track spacing of the measurements at the equator was about 40 km. One measurement was made each second over a 45 minute period during each orbit, giving an along track spacing of 1–2 km.

High-Resolution Camera (HIRES)

The Clementine High-Resolution Camera consisted of a telescope with an image intensifier and a frame-transfer CCD imager. The imaging system was designed to study selected portions of the surfaces of the Moon and the near-Earth asteroid 1620 Geographos, although the asteroid rendezvous was canceled due to a malfunction. This experiment allowed the detailed study of surface processes on the Moon and, combined with spectral data, allowed high-resolution compositional and geologic studies.

The imager was an intensified Thompson CCD camera with a six position filter wheel. The set of filters consisted of a broad-band filter with a bandpass of 400 to 800 nm, four narrow-band filters with center wavelengths (and bandpass width (FWHM)) of 415 nm (40 nm), 560 nm (10 nm), 650 nm (10 nm), and 750 nm (20 nm), and 1 opaque cover to protect the image intensifier. The field of view was 0.3 x 0.4 degrees, translating to a width of about 2 km at a nominal lunar altitude of 400 km. The image array is 288 x 384 pixels, (pixel size of 23 x 23 micrometers) so the pixel resolution at the Moon was 7–20 m depending on the spacecraft altitude. (At Geographos the resolution would have been <5 m at closest approach.) The clear aperture was 131 mm and the focal length was 1250 mm. The nominal imaging rate was about 10 frames per second in individual image bursts covering all filters at the Moon. The high resolution and small field of view only allowed coverage of selected areas of the Moon, in the form of either long, narrow strips of a single color or shorter strips of up to four colors. The instrument has a signal to noise ratio of 13 to 41 depending on the albedo and phase angle, with a 1% relative calibration and a 20% absolute calibration, and a dynamic range of 2000.

The telescope of the High-Resolution Camera was shared by the LIDAR instrument. The 1064 nm laser return was split to the LIDAR receiver (an avalanche photodiode detector) using a dichroic filter.

Imagery from the HIRES can be viewed in NASA World Wind software.

Chapter- 3

Chandrayaan-1

Chandrayaan-1

Operator Indian Space Research Organisation

Mission type Orbiter

Satellite of Moon

**Orbital
insertion date** 12 November 2008

Orbits 3400 orbits around the Moon.

Launch date 22 October 2008
00:52 UTC

Launch vehicle PSLV-C11

Launch site SDSC, Sriharikota

**Mission
duration** Intended: 2 years
Achieved: 312 days

Landing site

COSPAR ID 2008-052A

Homepage Chandrayaan-1

Mass 1,380 kg (3,042 lb)

Orbital elements

Eccentricity near circular

Inclination polar

Apoapsis initial 7,500 km (4,660 mi), final 100 km

(62 mi), final (wef 19 May 2009) 200 km
(124 mi)
initial 500 km (311 mi), final 100 km (62
Periapsis mi), final (wef 19 May 2009) 200 km (124
mi)

Chandrayaan-1 (Sanskrit: चंद्रयान-१, lit: moon vehicle) was India's first unmanned lunar probe. It was launched by the Indian Space Research Organisation in October 2008, and operated until August 2009. The mission included a lunar orbiter and an impactor. India launched the spacecraft with a modified version of the PSLV, PSLV C11 on 22 October 2008 from Satish Dhawan Space Centre, Sriharikota, Nellore District, Andhra Pradesh, about 80 km north of Chennai, at 06:22 IST (00:52 UTC). Former prime minister Atal Bihari Vajpayee announced the project on course in his Independence Day speech on 15 August 2003. The mission was a major boost to India's space program, as India researched and developed its own technology in order to explore the Moon. The vehicle was successfully inserted into lunar orbit on 8 November 2008.

On 14 November 2008, the Moon Impact Probe separated from the Chandrayaan orbiter at 20:06 and struck the south pole in a controlled manner, making India the fourth country to place its flag on the Moon. The probe impacted near Shackleton Crater at 20:31 ejecting underground soil that could be analysed for the presence of lunar water ice.

The estimated cost for the project was ₹386 crore (US\$ 90 million).

The remote sensing lunar satellite had a mass of 1,380 kilograms (3,042 lb) at launch and 675 kilograms (1,488 lb) in lunar orbit. It carried high resolution remote sensing equipment for visible, near infrared, and soft and hard X-ray frequencies. Over a two-year period, it was intended to survey the lunar surface to produce a complete map of its chemical characteristics and three-dimensional topography. The polar regions are of special interest as they might contain ice. The lunar mission carries five ISRO payloads and six payloads from other space agencies including NASA, ESA, and the Bulgarian Aerospace Agency, which were carried free of cost.

After suffering from several technical issues including failure of the star sensors and poor thermal shielding, Chandrayaan stopped sending radio signals at 1:30 AM IST on 29 August 2009 shortly after which, the ISRO officially declared the mission over. Chandrayaan operated for 312 days as opposed to the intended two years but the mission achieved 95 percent of its planned objectives. Among its many achievements was the discovery of the widespread presence of water molecules in lunar soil.

Objectives

The stated scientific objectives of the mission were:

- to design, develop, launch and orbit a spacecraft around the Moon using an Indian-made launch vehicle
- to conduct scientific experiments using instruments on the spacecraft which would yield data:
 - for the preparation of a three-dimensional atlas (with high spatial and altitude resolution of 5–10 m) of both the near and far side of the Moon
 - for chemical and mineralogical mapping of the entire lunar surface at high spatial resolution, mapping particularly the chemical elements magnesium, aluminium, silicon, calcium, iron, titanium, radon, uranium, and thorium
 - to increase the scientific knowledge
 - to test the impact of a sub-satellite (Moon Impact Probe — MIP) on the surface on the Moon as a fore-runner to future soft-landing missions

Specifications

Mass

1,380 kg at launch, 675 kg at lunar orbit, and 523 kg after releasing the impactor.

Dimensions

Cuboid in shape of approximately 1.5 m

Communications

X band, 0.7 m diameter dual gimbaled parabolic antenna for payload data transmission. The Telemetry, Tracking & Command (TTC) communication operates in S band frequency.

Power

The spacecraft is mainly powered by its solar array, which includes one solar panel covering a total area of 2.15 x 1.8 m generating 750 W of peak power, which is stored in a 36 A·h lithium-ion battery for use during eclipses.

Propulsion

The spacecraft uses a bipropellant integrated propulsion system to reach lunar orbit as well as orbit and altitude maintenance while orbiting the Moon. The power plant consists of one 440 N engine and eight 22 N thrusters. Fuel and oxidizer are stored in two tanks of 390 litres each.

Navigation and control

The craft is 3-axis stabilized with two star sensors, gyros and four reaction wheels. The craft carries dual redundant bus management units for attitude control, sensor processing, antenna orientation, etc.

Specific areas of study

- High-resolution mineralogical and chemical imaging of the permanently shadowed north- and south-polar regions

- Searching for surface or sub-surface lunar water-ice, especially at the lunar poles
- Identification of chemicals in lunar highland rocks
- Chemical stratigraphy of the lunar crust by remote sensing of the central uplands of large lunar craters, and of the South Pole Aitken Region (SPAR), an expected site of interior material
- Mapping the height variation of features of the lunar surface
- Observation of X-ray spectrum greater than 10 keV and stereographic coverage of most of the Moon's surface with 5 m resolution
- Providing new insights in understanding the Moon's origin and evolution

Payloads

The scientific payload had a total mass of 90 kg and contained five Indian instruments and six foreign instruments.

Indian Payloads

- **TMC** or the **Terrain Mapping Camera** is a CCD camera with 5 m resolution and a 40 km swath in the panchromatic band and was used to produce a high-resolution map of the Moon. The aim of this instrument was to completely map the topography of the Moon. The camera works in the visible region of the electromagnetic spectrum and captures black and white stereo images. When used in conjunction with data from Lunar Laser Ranging Instrument (LLRI), it can help in better understanding of the lunar gravitational field as well. TMC was built by the ISRO's Space Applications Centre (SAC) at Ahmedabad. The TMC was successfully tested on 29 October 2008 through a set of commands issued from ISTRAC.
- **HySI** or **Hyper Spectral Imager** performed mineralogical mapping in the 400-900 nm band with a spectral resolution of 15 nm and a spatial resolution of 80 m.
- **LLRI** or **Lunar Laser Ranging Instrument** determines the height of the surface topography by sending pulses of infrared laser light towards the lunar surface and detecting the reflected portion of that light. It operated continuously and collected 10 measurements per second on both the day and night sides of the Moon. It was successfully tested on 16 November 2008.
- **HEX** is a **High Energy alpha/gamma x-ray spectrometer** for 30 – 200 keV measurements with ground resolution of 40 km, the HEX measured U, Th, ^{210}Pb , ^{222}Rn degassing, and other radioactive elements.
- **MIP** or the **Moon Impact Probe** developed by the ISRO, is an impact probe which consisted of a C-band Radar altimeter for measurement of altitude of the probe, a video imaging system for acquiring images of the lunar surface and a mass spectrometer for measuring the constituents of the lunar atmosphere. It was ejected at 20:00 hours IST on 14 November 2008. The Moon Impact Probe

successfully crash landed at the lunar south pole at 20:31 hours IST on 14 November 2008. It carried with it a picture of the Indian flag. India is now the fourth nation to place a flag on the Moon after the Soviet Union, United States and Japan.

Payload from other countries

- **C1XS or X-ray fluorescence spectrometer** covering 1- 10 keV, mapped the abundance of Mg, Al, Si, Ca, Ti, and Fe at the surface with a ground resolution of 25 km, and monitored solar flux. This payload is collaboration between Rutherford Appleton laboratory, U.K, ESA and ISRO. It was activated on 23 November 2008.
- **SARA, The Sub-keV Atom Reflecting Analyser** from the ESA mapped mineral composition using low energy neutral atoms emitted from the surface.
- **M³, the Moon Mineralogy Mapper** from Brown University and JPL (funded by NASA) is an imaging spectrometer designed to map the surface mineral composition. It was activated on 17 December 2008.
- **SIR-2**, A near infrared spectrometer from ESA, built at the Max Planck Institute for Solar System Research, Polish Academy of Science and University of Bergen, also mapped the mineral composition using an infrared grating spectrometer. The instrument is similar to that of the Smart-1 SIR. It was activated on 19 November 2008 and scientific observations were successfully started on 20 November 2008.
- **miniSAR**, designed, built and tested for NASA by a large team that includes the Naval Air Warfare Center, Johns Hopkins University Applied Physics Laboratory, Sandia National Laboratories, Raytheon and Northrop Grumman; it is the active Synthetic Aperture Radar system to search for lunar polar ice. The instrument transmitted right polarised radiation with a frequency of 2.5 GHz and monitored scattered left and right polarised radiation. The Fresnel reflectivity and the circular polarisation ratio (CPR) are the key parameters deduced from these measurements. Ice shows the Coherent Backscatter Opposition Effect which results in an enhancement of reflections and CPR, so that water content of the Moon's polar regions can be estimated.
- **RADOM-7, Radiation Dose Monitor Experiment** from the Bulgarian Academy of Sciences maps the radiation environment around the Moon. It was successfully tested on 16 November 2008.

Space flight

Chandrayaan-1 was launched on 22 October 2008 at 6.22 am IST from Satish Dhawan Space Centre using the ISRO's 44.4 metre tall four-stage PSLV launch rocket. Chandrayaan-1 was sent to the Moon in a series of orbit-increasing manoeuvres around

the Earth over a period of 21 days as opposed to launching the craft on a direct trajectory to the Moon. At launch the spacecraft was inserted into geostationary transfer orbit (GTO) with an apogee of 22,860 km and a perigee of 255 km. The apogee was increased with a series of five orbit burns conducted over a period of 13 days after launch.

For the duration of the mission, ISRO's telemetry, tracking and command network (ISTRAC) at Peenya in Bangalore, tracked and controlled Chandrayaan-1. Scientists from India, Europe, and the U.S. conducted a high-level review of Chandrayaan-1 on 29 January 2009 after the spacecraft completed its first 100 days in space.

Earth orbit burns

First orbit burn

The first orbit-raising manoeuvre of Chandrayaan-1 spacecraft was performed at 09:00 hrs IST on 23 October 2008 when the spacecraft's 440 Newton Liquid Engine was fired for about 18 minutes by commanding the spacecraft from Spacecraft Control Centre (SCC) at ISRO Telemetry, Tracking and Command Network (ISTRAC) at Peenya, Bangalore. With this Chandrayaan-1's apogee was raised to 37,900 km, and its perigee to 305 km. In this orbit, Chandrayaan-1 spacecraft took about 11 hours to go around the Earth once.

Second orbit burn

The second orbit-raising manoeuvre of Chandrayaan-1 spacecraft was carried out on 25 October 2008 at 05:48 IST when the spacecraft's engine was fired for about 16 minutes, raising its apogee to 74,715 km, and its perigee to 336 km, thus completing 20 percent of its journey. In this orbit, Chandrayaan-1 spacecraft took about twenty-five and a half hours to go round the Earth once. This is the first time an Indian spacecraft has gone beyond the 36,000 km high geostationary orbit and reached an altitude more than twice that height.

Third orbit burn

The third orbit raising manoeuvre was initiated on 26 October 2008 at 07:08 IST when the spacecraft's engine was fired for about nine and a half minutes. With this its apogee was raised to 164,600 km, and the perigee to 348 km. In this orbit, Chandrayaan-1 took about 73 hours to go around the Earth once.

Fourth orbit burn

The fourth orbit-raising maneuver took place on 29 October 2008 at 07:38 IST when the spacecraft's engine was fired for about three minutes, raising its apogee to 267,000 km and the perigee to 465 km. This extended its orbit to a distance more than half the way to the Moon. In this orbit, the spacecraft took about six days to go around the Earth once.

Final orbit burn

The fifth and final orbit raising manoeuvre was carried out on 4 November 2008 04:56 am IST when the spacecraft's engine was fired for about two and a half minutes resulting in Chandrayaan-1 entering the Lunar Transfer Trajectory with an apogee of about 380,000 km.

Lunar orbit insertion

Chandrayaan-1 successfully completed the lunar orbit insertion operation on 8 Nov 2008 at 16:51 IST. This manoeuvre involved firing of the liquid engine for 817 seconds (about thirteen and half minutes) when the spacecraft passed within 500 km from the Moon. The satellite was placed in an elliptical orbit that passed over the polar regions of the Moon, with 7502 km aposelene (point farthest away from the Moon) and 504 km periselene (nearest to the Moon). The orbital period was estimated to be around 11 hours. With the successful completion of this operation, India became the fifth nation to put a vehicle in lunar orbit.

First orbit reduction

First Lunar Orbit Reduction Manoeuvre of Chandrayaan-1 was carried out successfully on 9 November 2008 at 20:03 IST. During this, the engine of the spacecraft was fired for about 57 seconds. This reduced the periselene from 504 km to 200 km while aposelene remained unchanged at 7,502 km. In this elliptical orbit, Chandrayaan-1 took about ten and a half hours to circle the Moon once.

Second orbit reduction

This manoeuvre, which resulted in steep decrease in Chandrayaan-1's aposelene from 7,502 km to 255 km and its periselene from 200 km to 187 km, was carried out on 10 November 2008 at 21:58 IST. During this manoeuvre, the engine was fired for about 866 seconds (about fourteen and half minutes). Chandrayaan-1 took two hours and 16 minutes to go around the Moon once in this orbit.

Third orbit reduction

Third Lunar Orbit Reduction was carried out by firing the on board engine for 31 seconds on 11 November 2008 at 18:30 IST. This reduced the periselene from 187 km to 101 km, while the aposelene remained constant at 255 km. In this orbit Chandrayaan-1 took two hours and 9 minutes to go around the Moon once.

Final orbit

Chandrayaan-1 spacecraft was successfully placed into a mission-specific lunar polar orbit of 100 km above the lunar surface on 12 November 2008. In the final orbit reduction manoeuvre, Chandrayaan-1's aposelene was reduced from 255 km to 100 km

while the periselene was reduced from 101 km to 100 km. In this orbit, Chandrayaan-1 takes about two hours to go around the Moon once. Two of the 11 payloads – the Terrain Mapping Camera (TMC) and the Radiation Dose Monitor (RADOM) – have already been successfully switched on. The TMC successfully acquired images of both the Earth and the Moon.

Impact of the MIP on the lunar surface

The Moon Impact Probe (MIP) crash-landed on the lunar surface on 14 November 2008, 15:01 UTC (20:31 Indian Standard Time (IST)) near the crater Shackleton at the south pole. The MIP was one of eleven scientific instruments (payloads) on board Chandrayaan-1.

The MIP separated from Chandrayaan at 100 km from lunar surface and began its nosedive at 14:36 UTC (20:06 IST) going into a free fall for thirty minutes. As it fell, it kept sending information back to the mother satellite which, in turn, beamed the information back to Earth. The altimeter then also began recording measurements to prepare for a rover to land on the lunar surface during a second Moon mission planned for 2012.

Following the successful deployment of MIP, the other scientific instruments were turned on, starting the next phase of the mission.

After scientific analyses of the received data from MIP, Indian Space Research Organisation confirmed presence of Water on Lunar soil and published the finding in a press conference addressed by its then Chairman Sri.G.Madhavan nair.

Rise of spacecraft's temperature

ISRO had reported on 25 November 2008 that Chandrayaan-1's temperature had risen above normal to 50°C, scientists said that it was caused by higher than normal temperatures in lunar orbit. The temperature was brought down by about 10°C by rotating the spacecraft about 20 degrees and switching off some of the instruments. Subsequently ISRO reported on 27 November 2008 that the spacecraft was operating under normal temperature conditions. In subsequent reports ISRO says, since the spacecraft was still recording higher than normal temperatures, it would be running only one instrument at a time until January 2009 when lunar orbital temperature conditions are said to stabilise. The spacecraft was experiencing high temperature because of radiation from the Sun and infrared radiation reflected by the Moon.

Mapping of minerals

The mineral content on the lunar surface was mapped with the Moon Mineralogy Mapper (M³), a NASA instrument on board the orbiter. The presence of iron was reiterated and changes in rock and mineral composition have been identified. The Oriental Basin region

of the Moon was mapped, and it indicates abundance of iron-bearing minerals such as pyroxene.

Mapping of Apollo landing sites

ISRO claims that the landing sites of the Apollo Moon missions have been mapped by the orbiter using multiple payloads. Six of the sites have been mapped including that of Apollo 11, the first mission that brought humans on the Moon.

Images acquisition

The craft completed 3000 orbits acquiring 70000 images of the lunar surface, which many in ISRO believe is quite a record compared to the lunar flights of other nations. ISRO officials estimated that if more than 40,000 images have been transmitted by Chandrayaan's cameras in 75 days, it worked out to nearly 535 images being sent daily. They were first transmitted to Indian Deep Space Network at Byalalu near Bangalore, from where they were flashed to ISRO's Telemetry Tracking And Command Network (ISTRAC) at Bangalore.

Some of these images have a resolution of up to 5 metres, providing a sharp and clear picture of the Moon's surface, while many images sent by some of the other missions had a 100-metre resolution.

On 26 November, the indigenous Terrain Mapping Camera, which was first activated on 29 October 2008, acquired images of peaks and craters. This came as a surprise to ISRO officials because the Moon consists mostly of craters.

Detection of X-Ray signals

The X-ray signatures of aluminium, magnesium and silicon were picked up by the C1XS X-ray camera. The signals were picked up during a solar flare that caused an X-ray fluorescence phenomenon. The flare that caused the fluorescence was within the lowest C1XS sensitivity range.

Full Earth image

On 25 March 2009 Chandrayaan beamed back its first images of the Earth in its entirety. These images were taken with the TMC. Previous imaging was done on only part of the Earth. The new images show Asia, parts of Africa and Australia with India being in the center.

Orbit raised to 200 km due to malfunctions

After the completion of all the major mission objectives, the orbit of Chandrayaan-1 spacecraft, which was at a height of 100 km from the lunar surface since November 2008, had to be raised to 200 km due to malfunctions. The orbit raising manoeuvres were

carried out between 09:00 and 10:00 IST on 19 May 2009. The spacecraft in this higher altitude enabled further studies on orbit perturbations, gravitational field variation of the Moon and also enabled imaging lunar surface with a wider swath. However, it was later revealed that the true reason for the orbit change was that it was an attempt to keep the temperature of the probe down. It was "...assumed that the temperature [of the spacecraft subsystems] at 100km above the Moon's surface would be around 75 degrees Celsius. However, it was more than 75 degrees and problems started to surface. We had to raise the orbit to 200km."

Altitude sensing due to Star Sensor failure

The star sensor, a device used for direction finding of which the mission carried two, failed in orbit after nine months of operation. Afterward, the direction of Chandrayaan was determined using a back-up procedure using a two axis Sun sensor and taking a bearing from a ground station. This was used to update three axis gyroscopes which enabled spacecraft operations, although some failures may have reduced the craft's lifetime. The first of the sensors failed on 26 April. The second failure, detected on 16 May, was attributed to excessive radiation from the Sun.

Bistatic RADAR experiment with LRO

On 21 August 2009 Chandrayaan-1 along with the Lunar Reconnaissance Orbiter was used to perform a bistatic radar experiment to detect the presence of water ice on the lunar surface. In this experiment, Chandrayaan emanated RADAR pulses which, after reflection from the surface, were picked up by the receivers of both the Chandrayaan and the LRO. Both receivers, Mini-SAR in Chandrayaan and Mini-RF in LRO, were pointed at the Erlanger crater for four minutes during which the observations were made. In March 2010, it was reported that the Mini-Sar experiment onboard the Chandrayaan-1 had discovered cold dark spots which are hypothesized to contain an estimated "at least 600 million metric tonnes" of water-ice held within northern polar craters.

End of the mission

The mission was launched in 22 October 2008 and expected to operate for 2 years. However, at 09.02 (UTC) on 29 August 2009 communication with the spacecraft was suddenly lost. The probe had operated for 312 days. The craft will remain in orbit for approximately another 1000 days, eventually crashing into the lunar surface.

A member of the science advisory board of Chandrayaan-1 said that it is difficult to ascertain reasons for the loss of contact. ISRO Chairman -Madhavan Nair- said that due to very high radiation, power-supply units controlling both the computer systems on board failed, snapping the communication connectivity. However, information released later showed that the power supply failed due to overheating.

Completion of primary objectives

Although the mission was less than 10 months in duration, and less than half the intended 2 years in length, a review by scientists termed the mission successful, as it had completed 95% of its primary objectives, consisting of:

- To construct the complex spacecraft with 11 scientific instruments.
- To place the spacecraft in a circular orbit around the Moon by orbit raising manoeuvres from a near Earth orbit.
- To place the Flag of India on the Moon.
- To carry out imaging operations and to collect data on the mineral content of the lunar soil.
- To set up a deep space tracking network and implement the operational procedures for travel into deep space.

The data collected from the mission have been disseminated to Indian scientists and also the partners from Europe and U.S.A. for analysis.

Data collected analysis result

Chandrayaan's Moon Mineralogy Mapper has confirmed the magma ocean hypothesis, meaning that the moon was once completely molten. "It proves beyond doubt the magma ocean hypothesis. There is no other way this massive rock type could be formed," said Carle Pieters, science manager at the NASA-supported spectroscopy facility at Brown University in the US.

The Terrain mapping camera Camera on board Chandrayaan-1 , besides producing more than 70,000 three dimensional images, has recorded images of the landing site of US spacecraft Apollo 15, rubbishing conspiracy theories that the US mission to land on the moon four decades back was a hoax.

"TMC and HySI payloads of ISRO have covered about 70 per cent of the lunar surface, while M³ covered more than 95 per cent of the same and SIR-2 has provided high-resolution spectral data on the mineralogy of the moon", ISRO said.

Indian Space Research Organisation said interesting data on lunar polar areas was provided by Lunar Laser Ranging Instrument (LLRI) and High Energy X-ray Spectrometer (HEX) of ISRO as well as Miniature Synthetic Aperture Radar (Mini-SAR) of the USA.

LLRI covered both the lunar poles and additional lunar regions of interest, HEX made about 200 orbits over the lunar poles and Mini-SAR provided complete coverage of both North and South Polar Regions of the moon.

Another ESA payload - Chandrayaan-1 imaging X-ray Spectrometer (C1XS) - detected more than two dozen weak solar flares during the mission duration. The Bulgarian payload called Radiation Dose Monitor (RADOM) was activated on the day of the launch itself and worked until the mission's end.

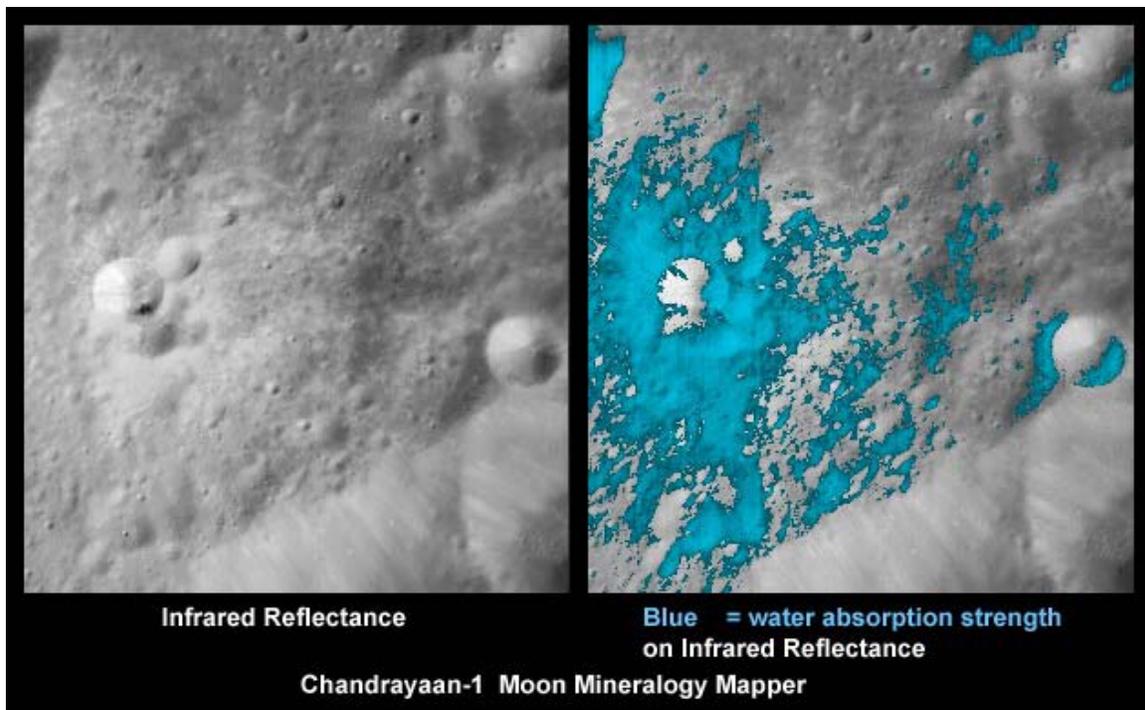
ISRO said scientists from India and participating agencies expressed satisfaction on the excellent performance of Chandrayaan-1 mission as well as the high quality of data sent by the spacecraft.

They have started formulating science plans based on the data sets obtained from the mission. It is expected that in the next few months, interesting results about lunar topography, mineral and chemical contents of the moon and related aspects are expected to be published, ISRO said.

A Chandrayaan-1 moon mission payload has enabled scientists to study the interaction between the solar wind and a planetary body like moon without a magnetic field, a meeting convened by ISRO was told.

In its 10-month orbit around the moon, Chandrayaan-1's X-ray Spectrometer (C1XS) has detected titanium, confirmed the presence of calcium, and gathered the most accurate measurements yet of magnesium, aluminium and iron on the lunar surface.

Water discovered on moon



These images show a very young lunar crater on the side of the moon that faces away from Earth, as viewed by NASA's Moon Mineralogy Mapper. ISRO found water on the moon 10 months ago.

This was confirmed on 24 September 2009, when Science Magazine reported that NASA's Moon Mineralogy Mapper (M³) on Chandrayaan-1 has detected water on the moon. M³ detected absorption features near 2.8-3.0 μm on the surface of the Moon. For

silicate bodies, such features are typically attributed to hydroxyl- and/or water-bearing materials. On the Moon, the feature is seen as a widely distributed absorption that appears strongest at cooler high latitudes and at several fresh feldspathic craters. The general lack of correlation of this feature in sunlit M³ data with neutron spectrometer H abundance data suggests that the formation and retention of OH and H₂O is an ongoing surficial process. OH/H₂O production processes may feed polar cold traps and make the lunar regolith a candidate source of volatiles for human exploration.

The Moon Mineralogy Mapper (M³), an imaging spectrometer, was one of the 11 instruments on board Chandrayaan-I that came to a premature end on 29 August 2009. M³ was aimed at providing the first mineral map of the entire lunar surface.

Lunar scientists have for decades contended with the possibility of water repositories. They are now increasingly “confident that the decades-long debate is over,” a report says. “The moon, in fact, has water in all sorts of places; not just locked up in minerals, but scattered throughout the broken-up surface, and, potentially, in blocks or sheets of ice at depth.” The results from the NASA’s Lunar Reconnaissance Orbiter are also “offering a wide array of watery signals.”

How The Moon Produces Its Own Water

A scientific instrument on Chandrayaan-1 — the Sub keV Atom Reflecting Analyser or SARA — made this discovery that was published in the latest edition of the Planetary and Space Science journal.

According to European Space Agency (ESA) scientists, hydrogen nuclei from solar winds are absorbed by the lunar regolith (a loose collection of irregular dust grains making up the moon’s surface). An interaction between the hydrogen nuclei and oxygen present in the dust grains are expected to produce hydroxyls and water.

SARA, developed by the ESA and the Indian Space Research Organisation, was designed to study the moon’s surface composition and solar wind-surface interactions. Recently, another instrument on the Indian spacecraft, the Moon Mineralogy Mapper — an imaging spectrometer developed by the U.S. National Aeronautics and Space Administration — first found water molecules on the lunar surface.

SARA’s results also highlight a mystery: not every hydrogen nucleus is absorbed. One out of every five rebounds into space, combining to form an atom of hydrogen. “We didn’t expect to see this at all,” said Stas Barabash of the Swedish Institute of Space Physics, who is the European Principal Investigator for SARA.

Hydrogen shoots off at speeds of around 200 km per second and escapes without being deflected by the moon’s weak gravity, the team found.

This knowledge provides timely advice for scientists who are readying ESA’s BepiColombo mission to mercury. The spacecraft will carry two instruments similar to

SARA and may find that the innermost planet is reflecting more hydrogen than the moon because the solar wind is more concentrated closer to the sun.

Discovery of Caves on Moon

Chandrayaan-1 has discovered large caves on the lunar surface that can act as human shelter on moon. The tunnel, which has been discovered near the lunar equator, is an empty volcanic tube, measuring about two km in length and 360 metres in width. According to AS Arya, scientist SF of Ahmedabad-based Space Application Centre (SAC), this could be a potential site for human settlement on moon. Earlier, Japanese Lunar orbiter Kaguya (SELENE) had also discovered a cave on moon.

Award for Chandrayaan-1



The American Institute of Aeronautics and Astronautics (AIAA) has selected ISRO's Chandrayaan-1 mission as one of the recipients of its annual AIAA SPACE 2009 awards, which recognizes key contributions to space science and technology.

The International Lunar Exploration Working Group (ILEWG) chose the Chandrayaan-1 team for giving the International Cooperation award, M, Annadurai, project director, Chandrayaan-1. The Chandrayaan team of the Indian Space Research Organisation (ISRO) was chosen for the award for accommodation and tests of the most international lunar payload ever (from 20 countries consisting of India, the European Space Agency representing 17 European countries, NASA and Bulgaria) and the successful launch of the probe on PSLV rocket on 22 October and the lunar insertion of the spacecraft carried out subsequently.

Team

The scientists considered instrumental to the success of the Chandrayaan-1 project are:

- G. Madhavan Nair – Chairman, Indian Space Research Organization
- Dr. T. K. Alex – Director, ISAC (ISRO Satellite Centre)
- Mylswamy Annadurai – Project Director, Chandrayaan-1
- S. K. Shivkumar – Director - Telemetry, Tracking and Command Network
- Mr. M. Pitchaimani – Operations Director, Chandrayaan-1
- Mr. Leo Jackson John – Spacecraft Operations Manager, Chandrayaan-1

- Dr. K. Radhakrishnan (scientist) – Director, VSSC
- George Koshy – Mission Director, PSLV-C11
- Srinivasa Hegde – Mission Director, Chandrayaan-1
- M C Dattan – Director of the Satish Dhawan Space Centre, Sriharikota
- Prof. J N Goswami – Director of Physical Research Laboratory and Principal Scientific Investigator of Chandrayaan-1
- Rajendra Masanta - Server Operation Lead Specialist - Pool - 19 Space Satellite
- Anil Prasad - Server Operation Specialist - Pool - 19 Space Satellite

Public release of Data

ISRO has stated recently, that the voluminous data gathered by Chandrayaan-I would be made available to the public by the end of the year 2010. The data would be eventually split into two seasons with the first season going public by the end of 2010 and the second going public by the mid of 2011. The data would contain rare pictures of the moon and also data from the chemical and mineral mapping of the lunar surface.

Chandrayaan-2

ISRO is also planning a second version of Chandrayaan named Chandrayaan II. According to former ISRO Chairman G. Madhavan Nair, "The Indian Space Research Organisation (ISRO) hopes to land two motorised rovers- one Russian and another Indian - on the Moon in 2013, as a part of its second Chandrayaan mission. The rover will be designed to move on wheels on the lunar surface, pick up samples of soil or rocks, do on-site chemical analysis and send the data to the mother-spacecraft Chandrayaan II, which will be orbiting above. Chandrayaan II will transmit the data to Earth."

Lunar outpost

Chandrayaan's imagery will be used to identify regions of interest that will be explored in detail by the NASA Lunar Reconnaissance Orbiter. The interest lies in identifying lunar water on the surface that can be exploited in setting up a future lunar outpost. The Mini-SAR, one of the U.S payloads on Chandrayaan, was used to determine the presence of water ice.

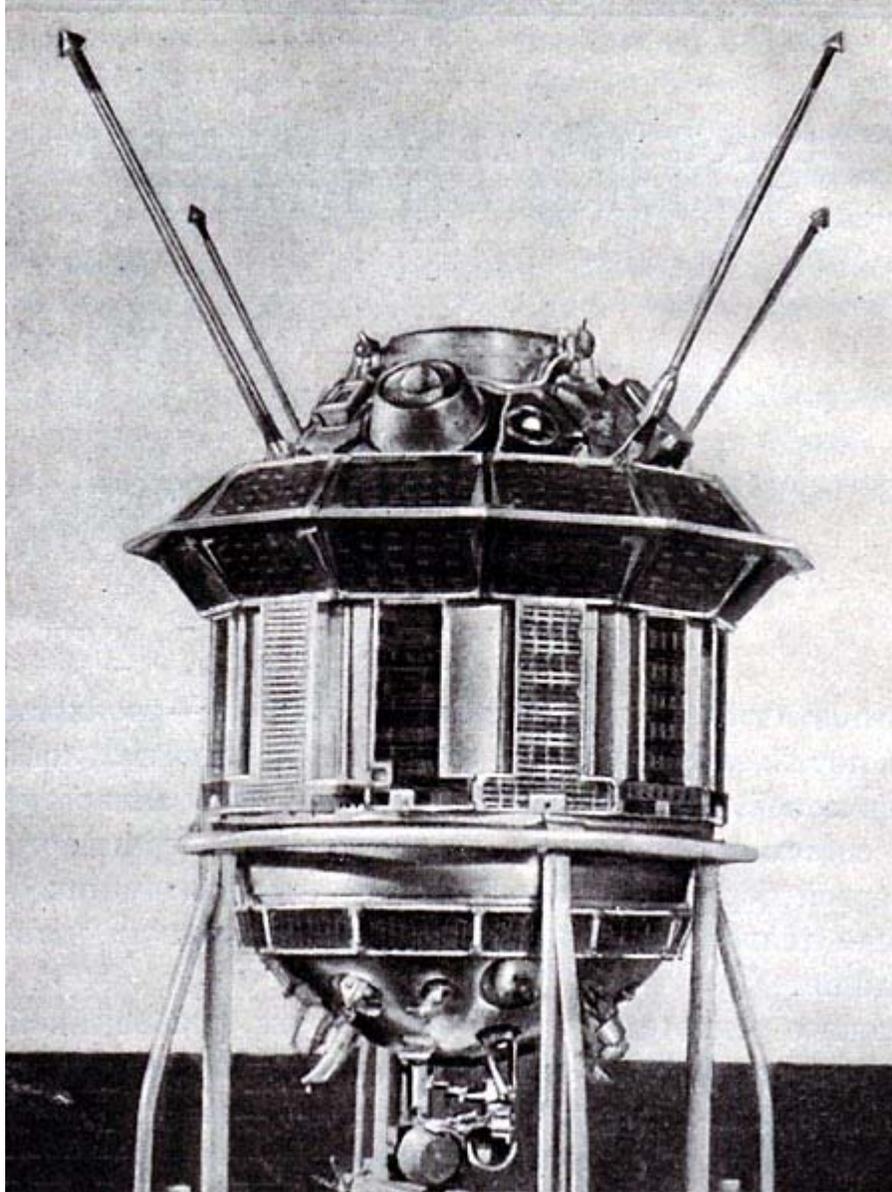
Chapter- 4

Robotic Spacecraft Missions

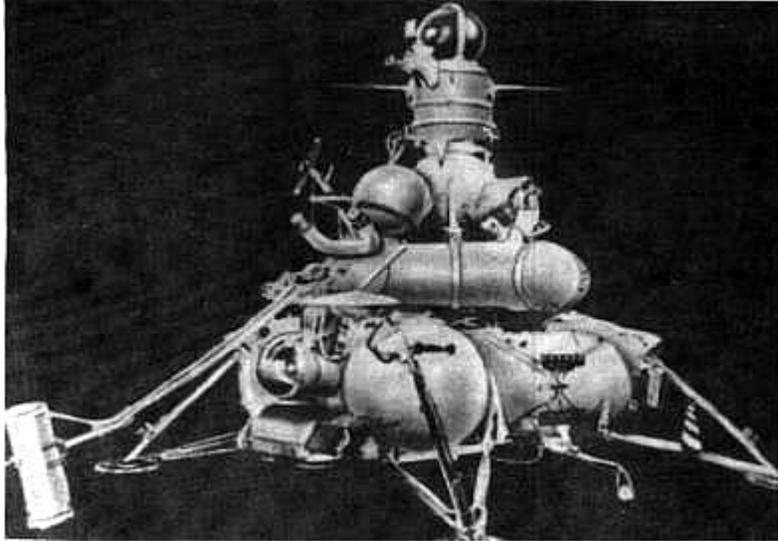
Luna programme



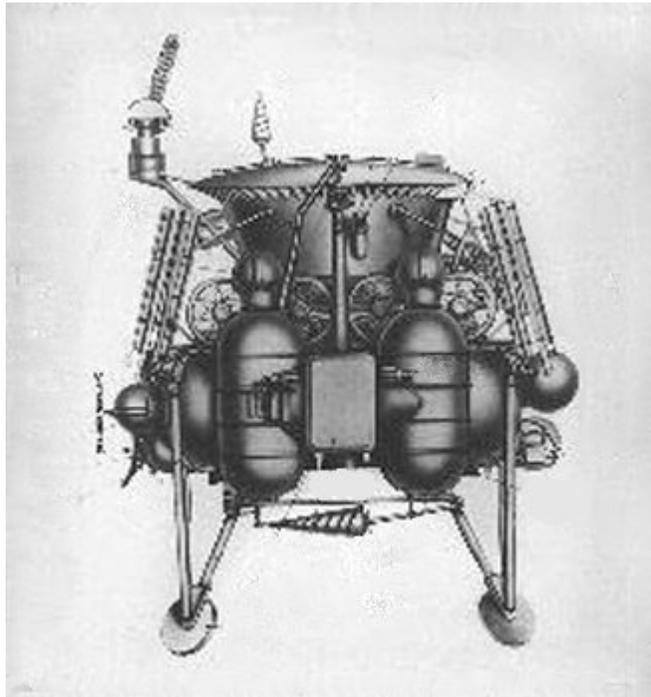
Luna 1



Luna 3



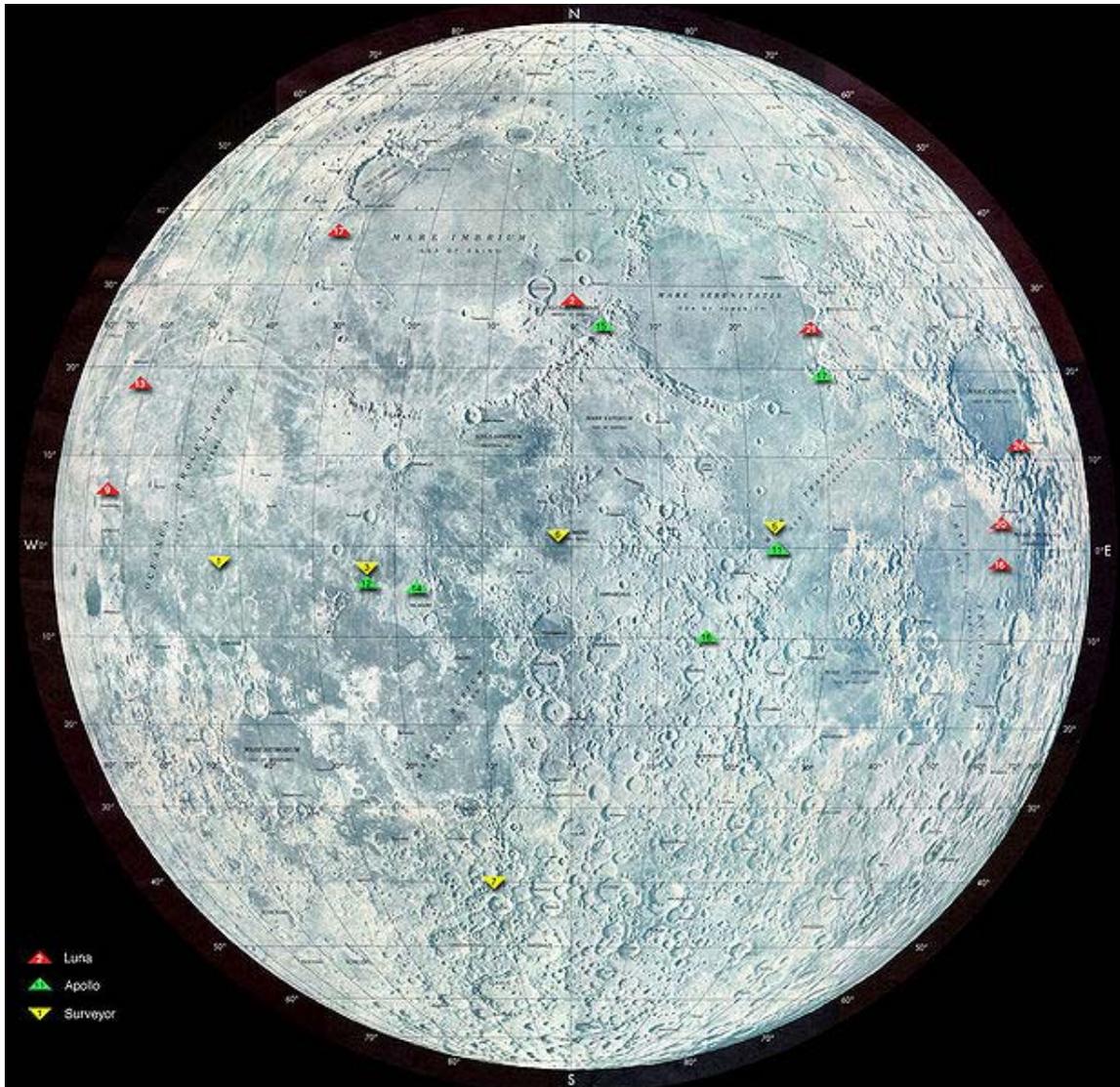
Luna 16



Luna 17



Luna 24



Location of Luna missions on the Moon

The **Luna programme** (from the Russian word Луна "Luna" meaning "Moon"), occasionally called **Lunik** or **Lunnik**, was a series of robotic spacecraft missions sent to the Moon by the Soviet Union between 1959 and 1976. Fifteen were successful, each designed as either an orbiter or lander, and accomplished many firsts in space exploration. They also performed many experiments, studying the Moon's chemical composition, gravity, temperature, and radiation. Twenty-four spacecraft were formally given the Luna designation, although more were launched. Those that failed to reach orbit were not publicly acknowledged at the time, and not assigned a Luna number. Those that failed in low Earth orbit were usually given Cosmos designations. The estimated cost of Luna Program was about \$4.5 billion.

Achievements

Luna 1 missed its intended impact with the Moon and became the first spacecraft to fall into orbit around the Sun.

In 1959, the **Luna 2** mission successfully impacted upon the lunar surface, becoming the first man-made object to reach the Moon.

Luna 3 rounded the Moon later that year, and returned the first photographs of its far side, which can never be seen from Earth.

Luna 9 became the first probe to achieve a soft landing on another planetary body (February 1966). It returned five black and white stereoscopic circular panoramas, which were the first close-up shots of the Lunar surface.

Later that year **Luna 10** became the first artificial satellite of the Moon.

Luna 17 and **Luna 21** carried vehicles that roamed around on the Moon's terrain.

Another major achievement of the Luna programme, with **Luna 16**, **Luna 20** and **Luna 24** spacecrafts, was the ability to collect samples of lunar soil and return them to Earth, by 1970. The program returned 0.326 kg of lunar samples. The **Luna** missions were the first space-exploration sample return missions to rely solely on advanced robotics.

Other notable missions

Luna 15, also designed to return soil samples from the lunar surface, holds the significance of undergoing its mission at the same time as the historic Apollo 11 mission. Arguably a last-ditch attempt to steal thunder from the potential American success, it would have returned lunar samples to Earth before the Apollo astronauts could do so. However, Neil Armstrong and Buzz Aldrin were already on the lunar surface when Luna 15 began its descent, and the spacecraft crashed into a mountain minutes later.

Failed missions

Whilst the programme was active, it was Soviet practice not to release any details of missions which had failed to achieve orbit. This resulted in Western observers assigning their own designations to the missions, for example Luna E-1 No.1, the first failure of 1958 which NASA believed was associated with the Luna programme was known as *Luna 1958A*.

NASA identified a spacecraft which it referred to as Luna 1966A as having launched on 30 April 1966, a spacecraft which it referred to as Luna 1969B as having launched on 15 April 1969, and a spacecraft which it referred to as Luna 1970B as having launched on 19 February 1970. When details of Soviet launches were later disclosed, no launches of Luna spacecraft were found to have occurred on those dates.

Missions

- *Luna 1958A*
 - Launch failure September 23, 1958
 - Lunar impact attempt
- *Luna 1958B*
 - Launch failure October 11, 1958
 - Lunar impact attempt
- *Luna 1958C*
 - Launch failure December 4, 1958
 - Lunar impact attempt
- Luna 1
 - Launched January 2, 1959
 - Lunar (Impact) Flyby
- *Luna 1959A*
 - Launch failure June 18, 1959
 - Lunar impact attempt

Ranger program



First image of the moon returned by a Ranger mission (Ranger 7 in 1964)

The **Ranger program** was a series of unmanned space missions by the United States in the 1960s whose objective was to obtain the first close-up images of the surface of the Moon. The Ranger spacecraft were designed to impact the lunar surface, returning imagery until they were destroyed upon impact. A series of mishaps, however, led to the failure of the first six flights beginning in 1961 until Ranger 7 successfully returned images in July 1964, followed by two more successful missions.

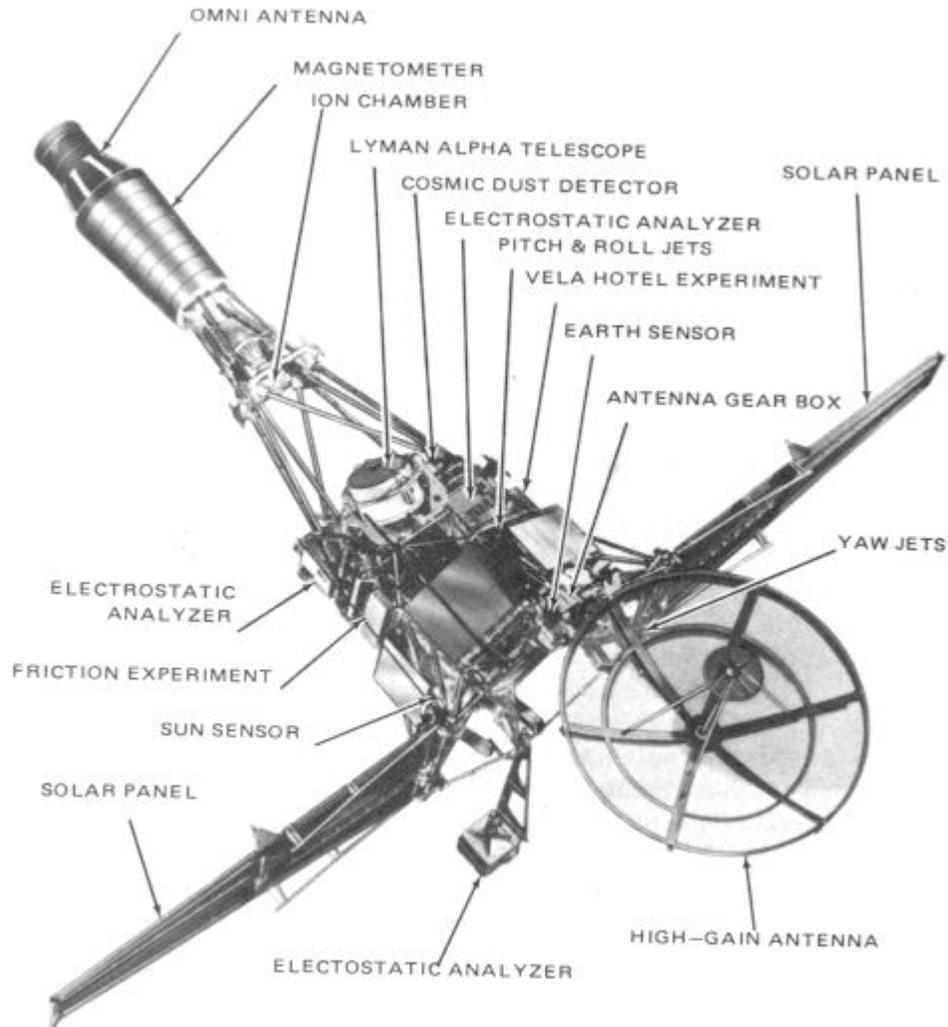
Ranger was originally designed, beginning in 1959, in three distinct phases, called "blocks". Each block had different mission objectives and progressively more advanced system design. The JPL mission designers planned multiple launches in each block, to maximize the engineering experience and scientific value of the mission and to assure at least one successful flight. Total research, development, launch, and support costs for the Ranger series of spacecraft (Rangers 1 through 9) was approximately \$170 million.

The Ranger spacecraft

Each Ranger spacecraft had six cameras on board. The cameras were fundamentally the same with differences in exposure times, fields of view, lenses, and scan rates. The camera system was divided into two channels, P (partial) and F (full). Each channel was self-contained with separate power supplies, timers, and transmitters. The F-channel had two cameras: the wide-angle A-camera and the narrow angle B-camera. The P-channel had four cameras: P1 and P2 (narrow angle) and P3 and P4 (wide angle). The final F-channel image was taken between 2.5 and 5 seconds before impact (altitude about 5 km) and the last P-channel image 0.2 to 0.4 seconds before impact (altitude about 600 m). The images provided better resolution than was available from Earth based views by a factor of 1000.

Mission list

Block 1 missions



Ranger block I spacecraft diagram. (NASA)

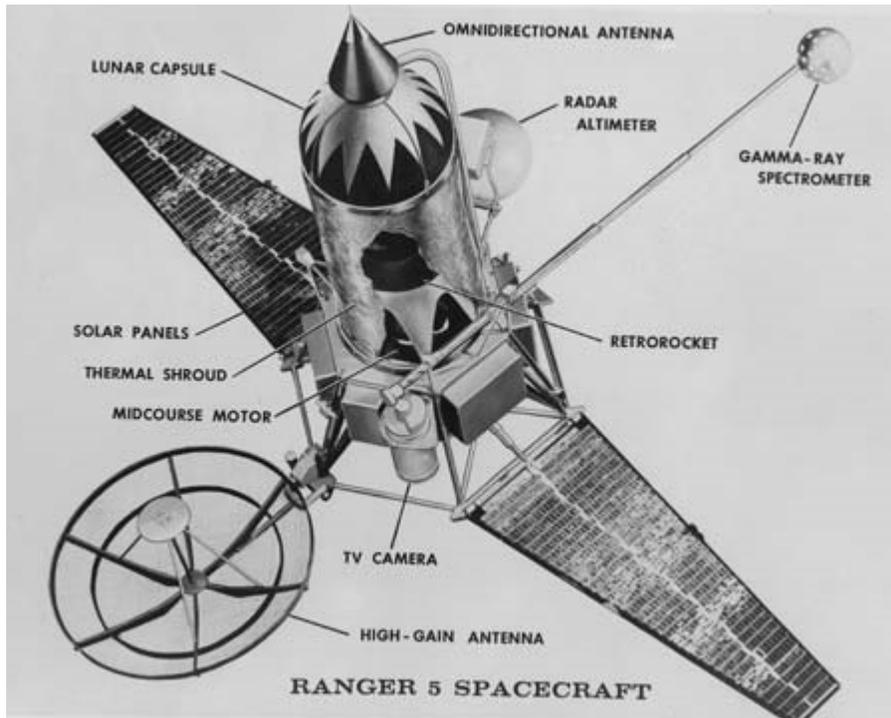
- Ranger 1, launched 23 August 1961, lunar prototype, launch failure
- Ranger 2, launched 18 November 1961, lunar prototype, launch failure

Block 1, consisting of two spacecraft launched into Earth orbit in 1961, was intended to test the Atlas-Agena launch vehicle and spacecraft equipment without attempting to reach the Moon.

Most elements of spacecraft technology taken for granted today were untested before Ranger. Perhaps the most important of these was three-axis attitude stabilization, meaning that the spacecraft is fixed in relation to space instead of being stabilized by spinning. This would permit pointing large solar panels at the Sun, a large antenna at Earth, and cameras and other directional scientific sensors at their appropriate targets. Rocket propulsion carried aboard the spacecraft was another critically important new technology, needed for accurate targeting at the Moon or distant planets.

In addition, two-way communication and closed-loop tracking, requiring spacecraft and ground system development, and the use of on-board computing and sequencing combined with commands from the ground, all had to be developed and tried out in flight. Unfortunately, problems with the early version of the launch vehicle left Ranger 1 and Ranger 2 in short-lived, low-Earth orbits in which the spacecraft could not stabilize themselves, collect solar power, or survive for long. In 1962, JPL utilized the Ranger 1 and Ranger 2 design for the failed Mariner 1 and successful Mariner 2 deep-space probes to Venus.

Block 2 missions



Ranger block II spacecraft diagram. (NASA)

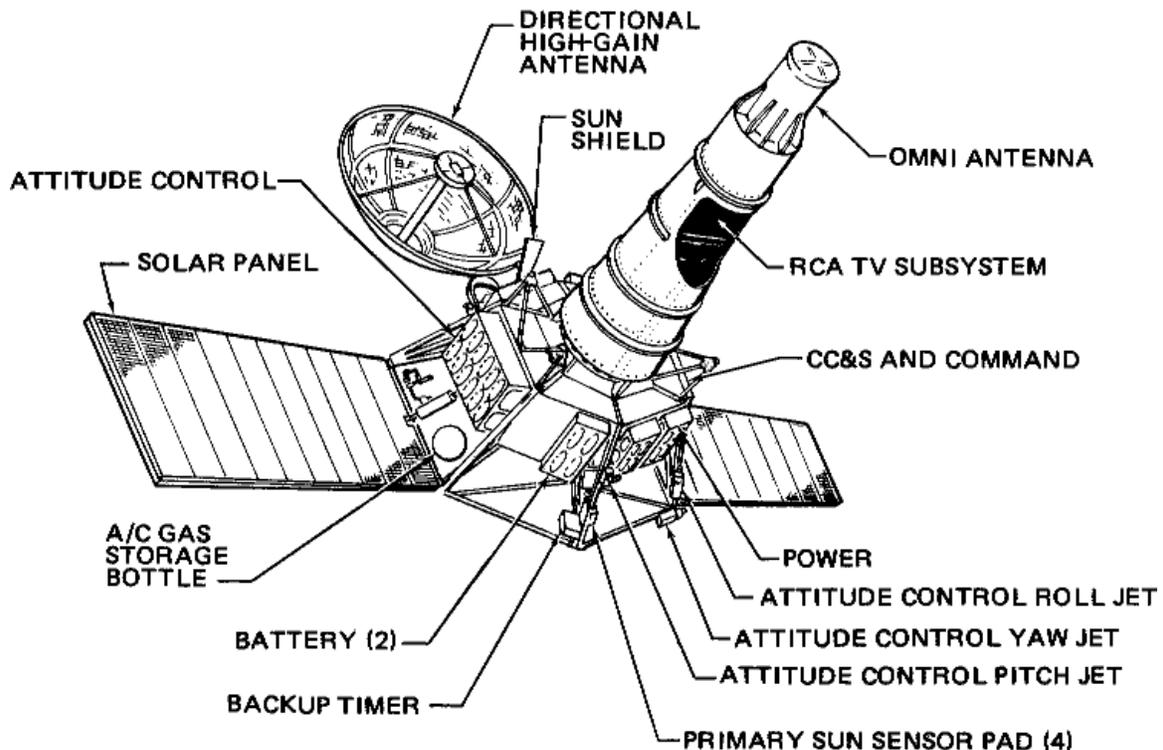
- Ranger 3, launched 26 January 1962, lunar probe, spacecraft failed, missed moon
- Ranger 4, launched 23 April 1962, lunar probe, spacecraft failed, impact
- Ranger 5, launched 18 October 1962, lunar probe, spacecraft failed, missed

Block 2 of the Ranger project launched three spacecraft to the Moon in 1962, carrying a TV camera, a radiation detector, and a seismometer in a separate capsule slowed by a rocket motor and packaged to survive its low-speed impact on the Moon's surface. The three missions together demonstrated good performance of the Atlas/Agena B launch vehicle and the adequacy of the spacecraft design, but unfortunately not all on the same attempt. Ranger 3 was launched into deep space, but an inaccuracy put it off course and it missed the Moon entirely. Ranger 4 had a perfect launch, but the spacecraft was completely disabled. The project team tracked the seismometer capsule to impact just out of sight on the lunar far side, validating the communications and navigation system.

Ranger 5 missed the Moon and was disabled. No significant science information was gleaned from these missions. The craft weighed 331 kg.

Around the end of Block 2, it was discovered that a type of diode used in previous missions produced problematic gold-plate flaking in the conditions of space. This may have been responsible for some of the failures.

Block 3 missions



Ranger block III spacecraft diagram. (NASA)

- Ranger 6, launched 30 January 1964, lunar probe, impact, cameras failed
- Ranger 7
 - Launched 28 July 1964
 - Impacted Moon 31 July 1964 at 13:25:49 UT
 - 10°21'S 339°25'E / 10.35°S 339.42°E - Mare Cognitum
- Ranger 8
 - Launched 17 February 1965
 - Impacted Moon 20 February 1965 at 09:57:37 UT
 - 2°40'N 24°39'E / 2.67°N 24.65°E - Mare Tranquillitatis (Sea of Tranquility)
- Ranger 9
 - Launched 21 March 1965
 - Impacted Moon 24 March 1965 at 14:08:20 UT

- 12°50'S 357°38'E / 12.83°S 357.63°E - Alphonsus crater

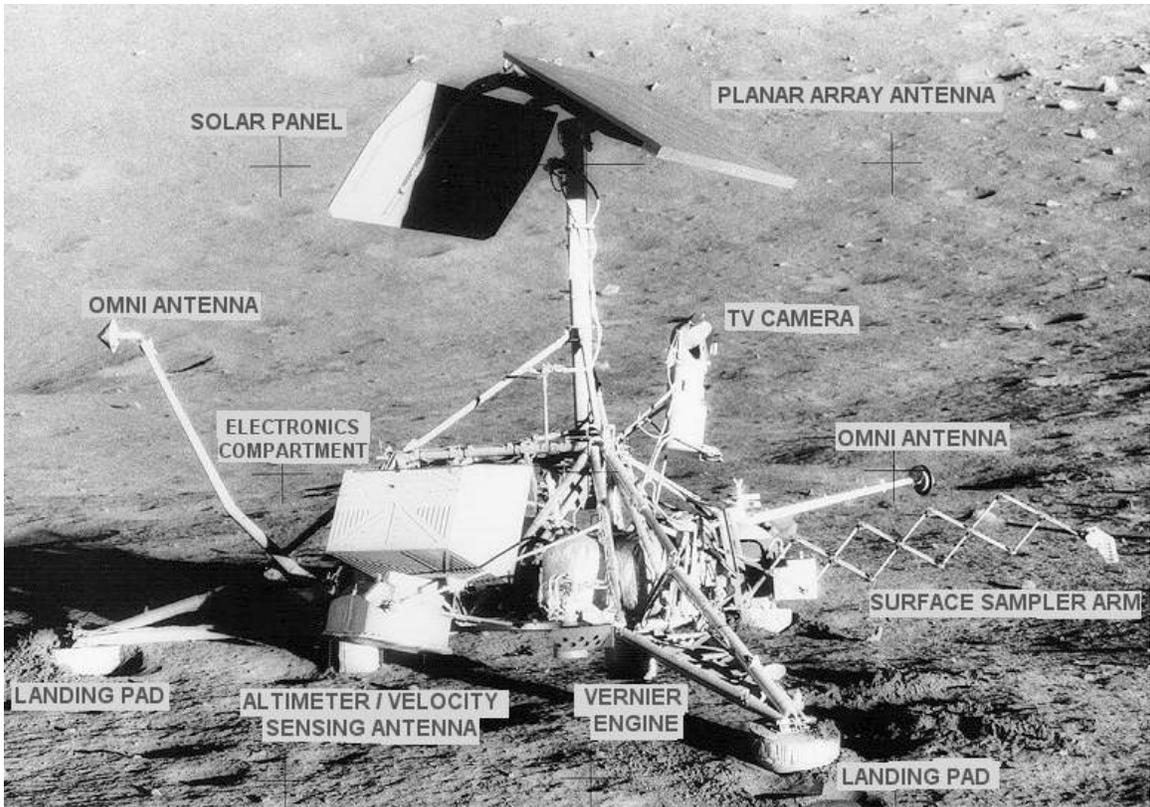
Ranger's Block 3 embodied four launches in 1964-65. These spacecraft boasted a television instrument designed to observe the lunar surface during the approach; as the spacecraft neared the Moon, they would reveal detail smaller than the best Earth telescopes could show, and finally details down to dishpan size. The first of the new series, Ranger 6, had a flawless flight, except that the television system was disabled by an in-flight accident and could take no pictures.

The next three Rangers, with a redesigned television, were completely successful. Ranger 7 photographed its way down to target in a lunar plain, soon named Mare Cognitum, south of the crater Copernicus. It sent more than 4,300 pictures from six cameras to waiting scientists and engineers. The new images revealed that craters caused by impact were the dominant features of the Moon's surface, even in the seemingly smooth and empty plains. Great craters were marked by small ones, and the small with tiny impact pockmarks, as far down in size as could be discerned—about 50 centimeters (16 inches). The light-colored streaks radiating from Copernicus and a few other large craters turned out to be chains and nets of small craters and debris blasted out in the primary impacts.

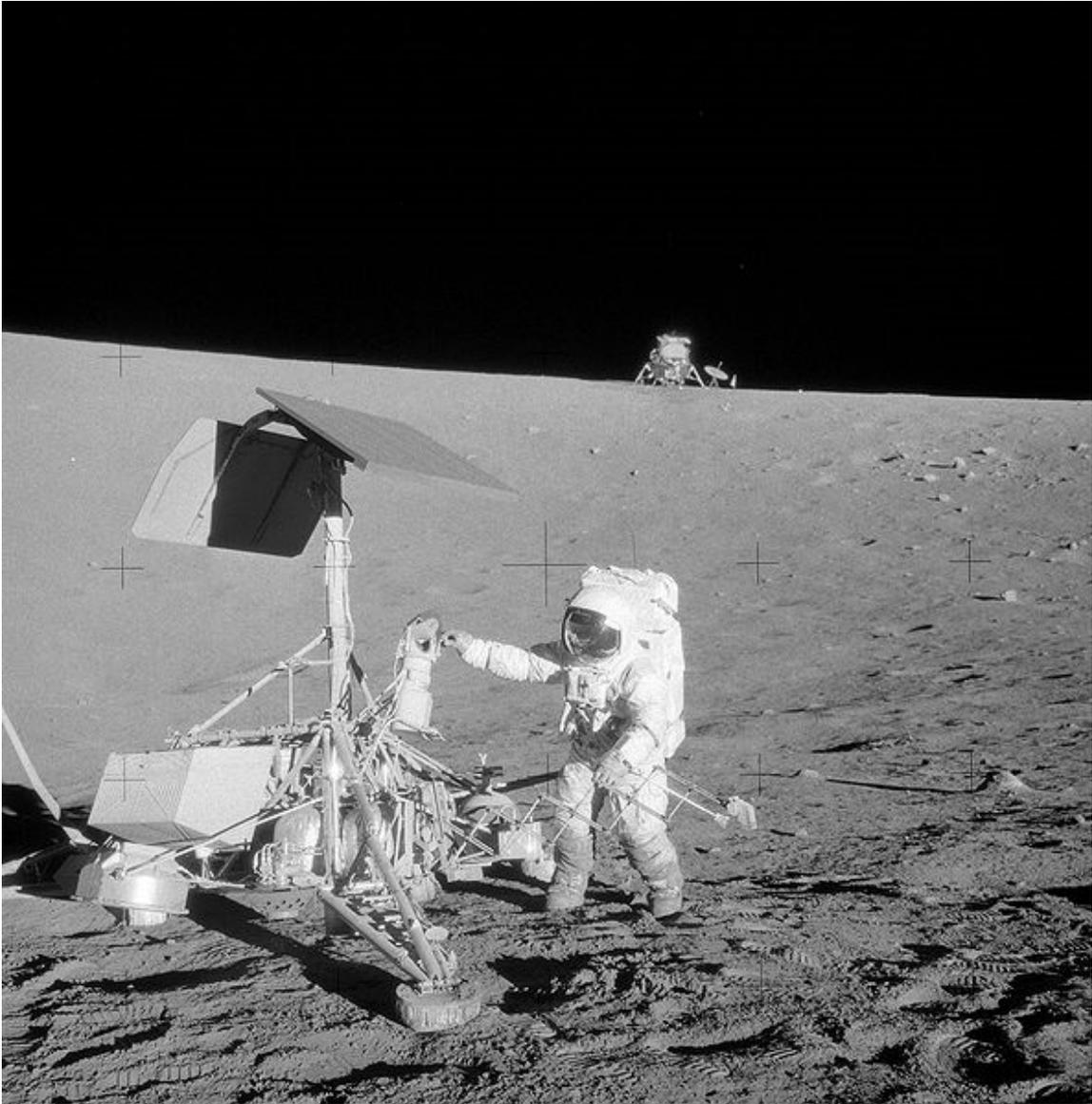
In February 1965, Ranger 8 swept an oblique course over the south of Oceanus Procellarum and Mare Nubium, to crash in Mare Tranquillitatis where Apollo 11 would land 4½ years later. It garnered more than 7,000 images, covering a wider area and reinforcing the conclusions from Ranger 7. About a month later, Ranger 9 came down in the 90 km diameter (55 mile) crater Alphonsus. Its 5,800 images, nested concentrically and taking advantage of very low-level sunlight, provided strong confirmation of the crater-on-crater, gently rolling contours of the lunar surface.

Thus, after a long trouble-plagued start that taught the system engineers a great deal and the scientists very little, Project Ranger finished with three flights that greatly advanced the lunar scientists' knowledge of the surface and whetted their appetites for a closer look.

Surveyor Program



Photograph of the Surveyor 3 spacecraft resting on the surface of the Moon, taken by Apollo 12 astronauts (descriptions added). Not seen are the main retrorocket and radar unit, which are jettisoned before landing. (NASA)



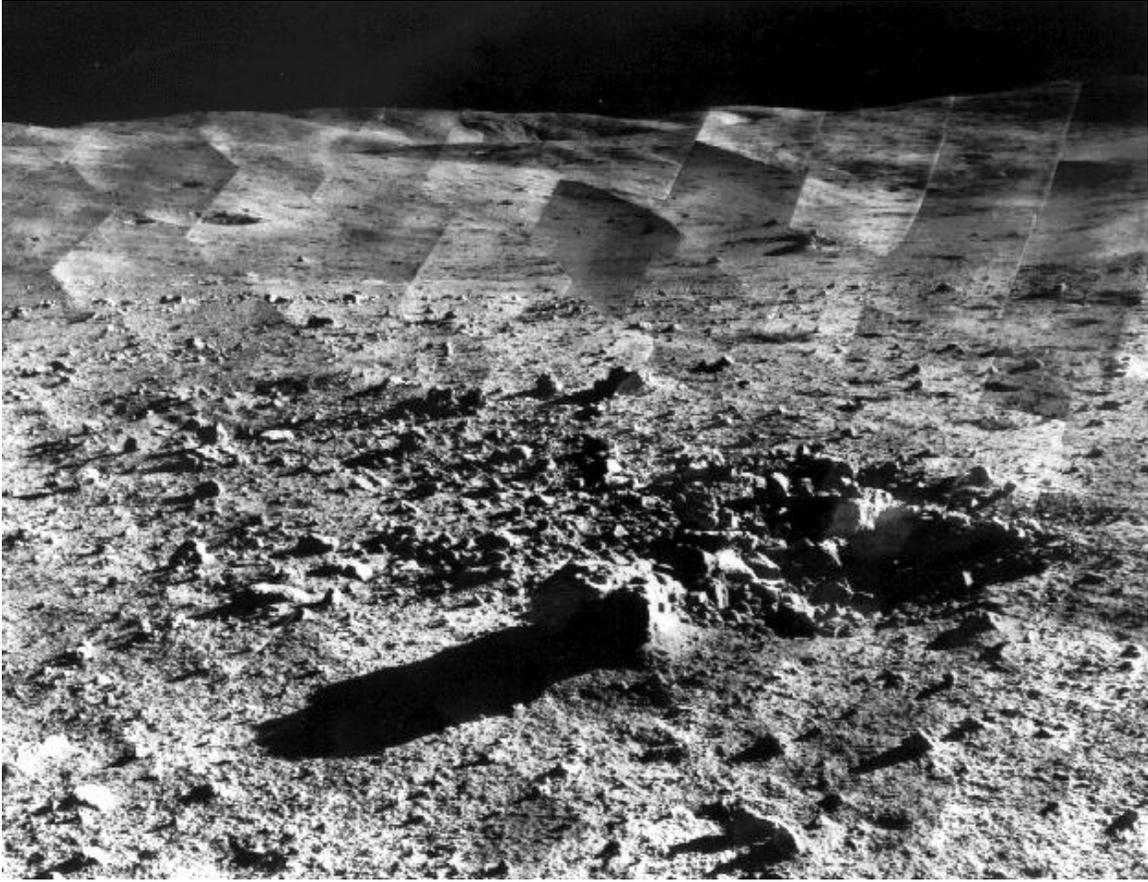
Astronaut Pete Conrad jiggles the Surveyor 3 craft. Human scale demonstrates typical lander height of 3 meters. Lunar module is about 200 meters in the background. (NASA)

The **Surveyor Program** was a NASA program that, from 1966 through 1968, sent seven robotic spacecraft to the surface of the Moon. Its primary goal was to demonstrate the feasibility of soft landings on the Moon. The program was implemented by NASA's Jet Propulsion Laboratory (JPL) to prepare for the Apollo Program. The total cost of the Surveyor program was officially \$469 million dollars.

Five of the Surveyor craft successfully soft-landed on the moon, including the first one. The other two failed: Surveyor 2 crashed at high velocity after a failed mid-course correction, and Surveyor 4 was lost to contact (possibly exploding) 2.5 minutes before its scheduled touch-down.

All seven spacecraft are still on the Moon; none of the missions included returning them to Earth. Some parts of Surveyor 3 were returned to Earth by Apollo 12, which landed near it. The camera from this craft is on display at the National Air and Space Museum.

Goals



Surveyor 7 landing site landscape

The program performed several other services beyond its primary goal of demonstrating soft landings. The ability of spacecraft to make midcourse corrections was demonstrated, and the landers carried instruments to help evaluate the suitability of their landing sites for manned Apollo landings. Several Surveyor spacecraft had robotic shovels designed to test lunar soil mechanics. Before the Soviet Luna 9 mission (landing four months before Surveyor 1) and the Surveyor project, it was unknown how deep the dust on the Moon was. If the dust was too deep, then no astronaut could land. The Surveyor program proved that landings were possible. Some of the Surveyors also had alpha scattering instruments and magnets, which helped determine the chemical composition of the soil.

The simple and reliable mission architecture was a pragmatic approach to solving the most critical space engineering challenges of the time, namely the closed-loop terminal descent guidance and control system, throttleable engines, and the radar systems required

for determining the lander's altitude and velocity. The Surveyor missions were the first time that NASA tested such systems in the challenging thermal and radiation environment near the Moon.

Launch and lunar landing



Launch of the Atlas-Centaur AC-10 rocket carrying the Surveyor 1 spacecraft, 30 May 1966.

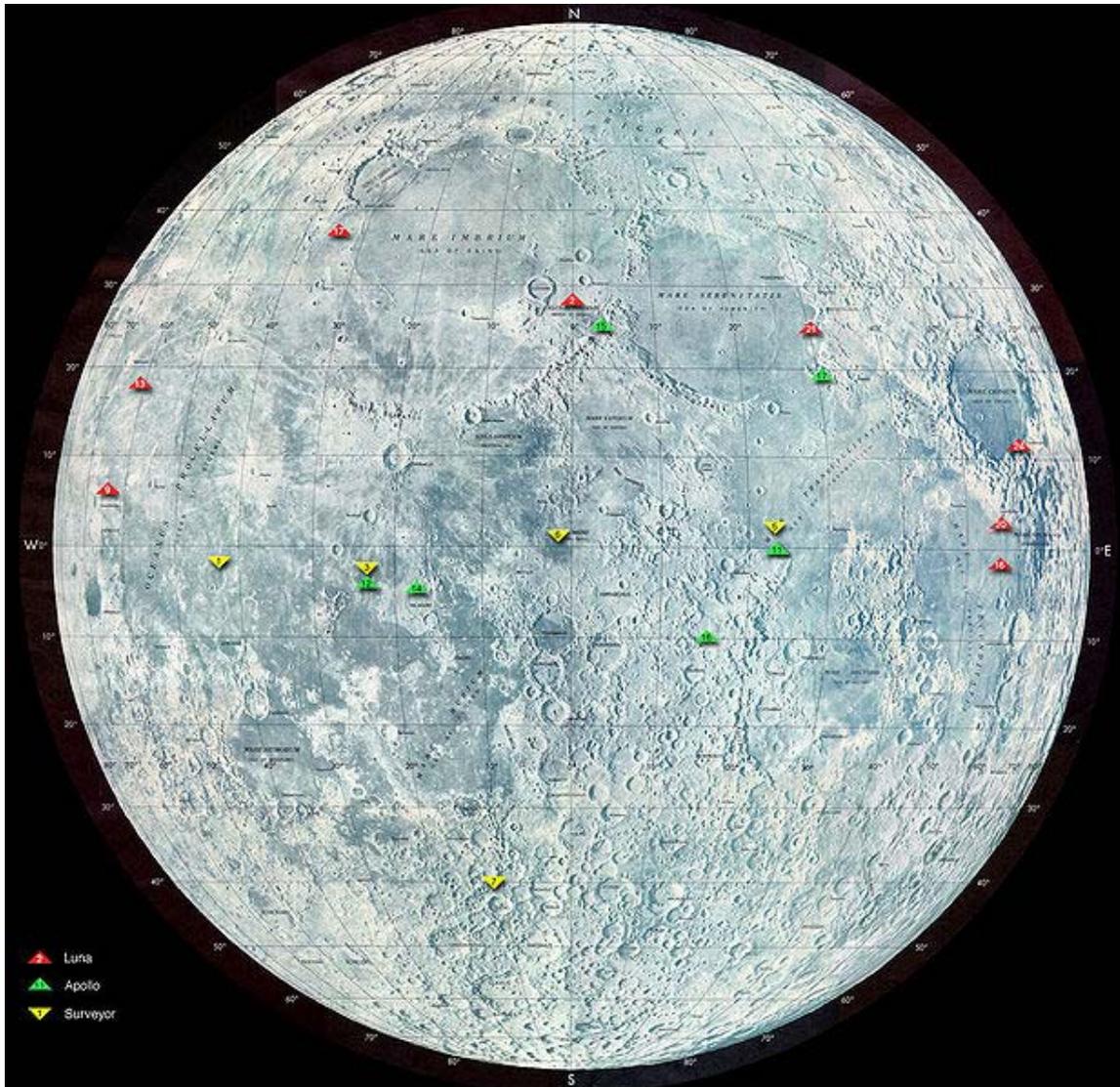
Each Surveyor mission consisted of a single unmanned spacecraft designed and built by Hughes Aircraft Company. The launch vehicle was the Atlas-Centaur which injected the craft directly into trans-lunar flightpath. The craft did not orbit the moon on reaching it,

but directly decelerated, from 2.6 km/s relative to the moon before firing retrorockets, to a soft landing.

Each craft was slowed to about 110 m/s (4% of speed before retrofire) by a main solid fuel retrorocket, which fired for 40 seconds starting at an altitude of 75.3 km above the Moon, and then was jettisoned along with radar unit, 11 km from the surface. The remainder of the trip to the surface, lasting about 2.5 minutes, was handled by smaller doppler radar units and three vernier engines running on liquid fuels. The last 3.4 meters to the surface was accomplished in free-fall from zero velocity at that height, after the vernier engines were turned off. This resulted in a landing speed of about 3 m/s.

Surveyor 1 required a total of about 63 hours (2.6 days) to reach the moon. Its launch weight was 995.2 kilograms (2,194 lb), and its landing weight (minus fuel, jettisoned retrorocket, and radar unit) was 294.3 kilograms (649 lb).

Missions



Location of Surveyor missions on the Moon

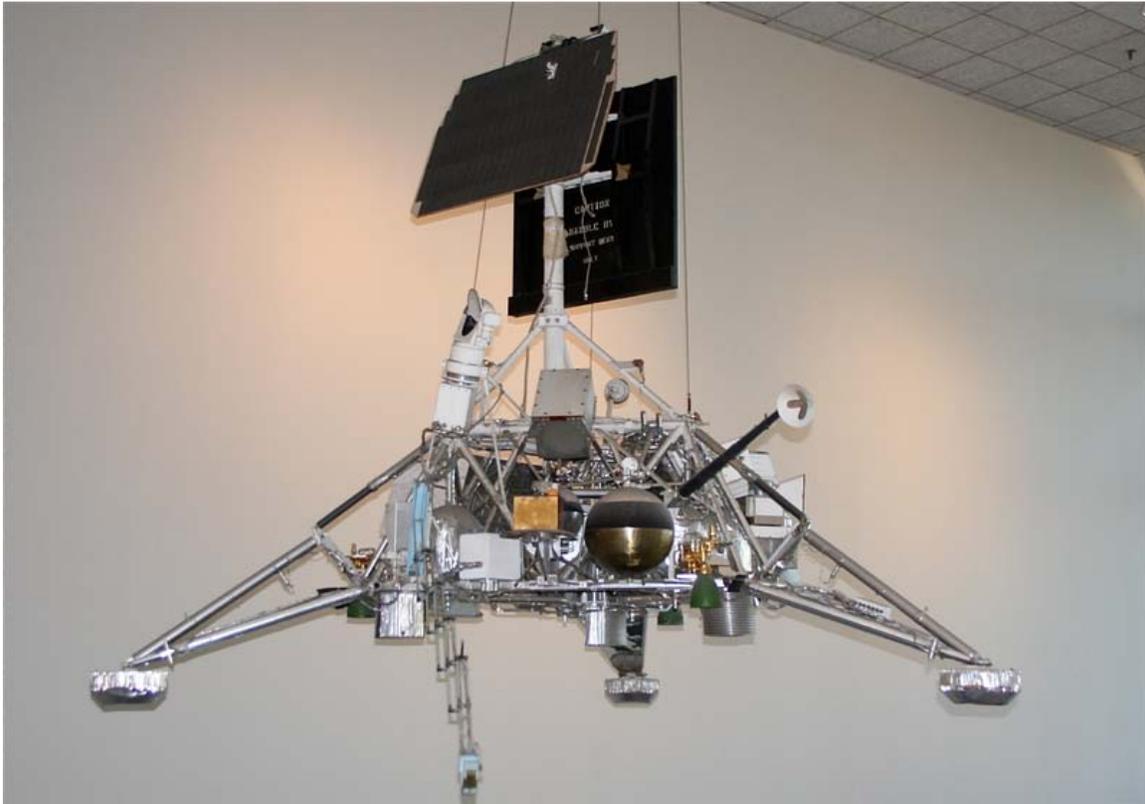
There were seven Surveyor missions; five were successful. Surveyors 2 and 4 failed.

- **Surveyor 1** - Launched May 30, 1966; landed on Oceanus Procellarum, June 2, 1966
- **Surveyor 2** - Launched September 20, 1966; crashed near Copernicus crater, September 23, 1966
- **Surveyor 3** - Launched April 17, 1967; landed on Oceanus Procellarum, April 20, 1967
- **Surveyor 4** - Launched July 14, 1967; crashed on Sinus Medii, July 17, 1967
- **Surveyor 5** - Launched September 3, 1967; landed on Mare Tranquillitatis, September 11, 1967
- **Surveyor 6** - Launched November 7, 1967; landed on Sinus Medii, November 10, 1967

- **Surveyor 7** - Launched January 7, 1968; landed near Tycho crater, January 10, 1968

Surveyor 6 was the first spacecraft planned to liftoff from the Moon's surface. Surveyor 3 was the first spacecraft to unintentionally liftoff from the Moon's surface, twice, due to an anomaly with Surveyor's Landing Radar. Apollo 12's Lunar Module *Intrepid* landed 600 feet from Surveyor 3, as planned. Surveyor 3's TV and telemetry systems were damaged by the multiple unplanned landings and liftoffs.

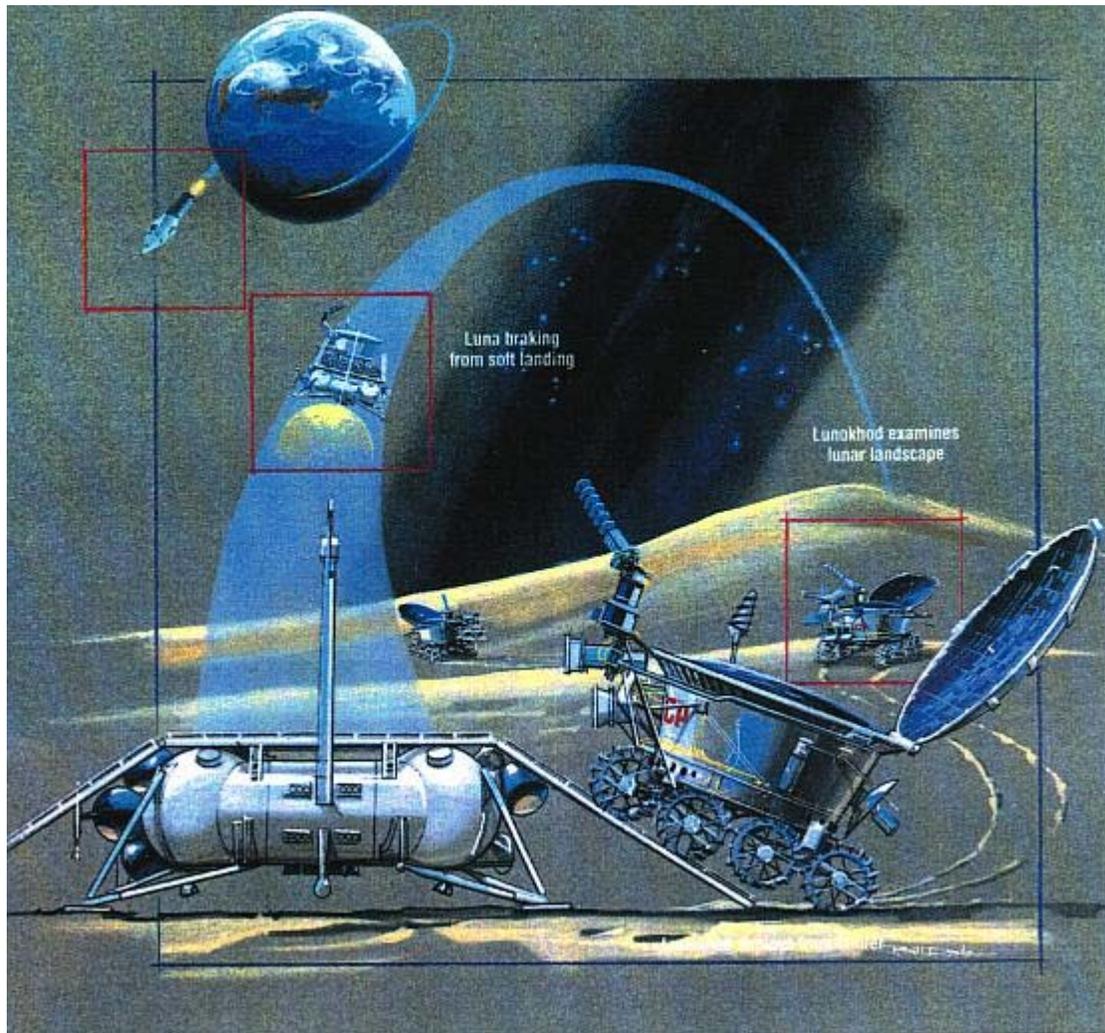
Space Race competition



Surveyor lander on display at the National Air and Space Museum

During the time of the Surveyor missions, the United States was actively involved in a Space Race with the Soviet Union. Thus, the Surveyor 1 landing in June 1966, only four months after the Soviet Luna 9 probe landed in February, was an indication the programs were at similar stages.

Lunokhod programme



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

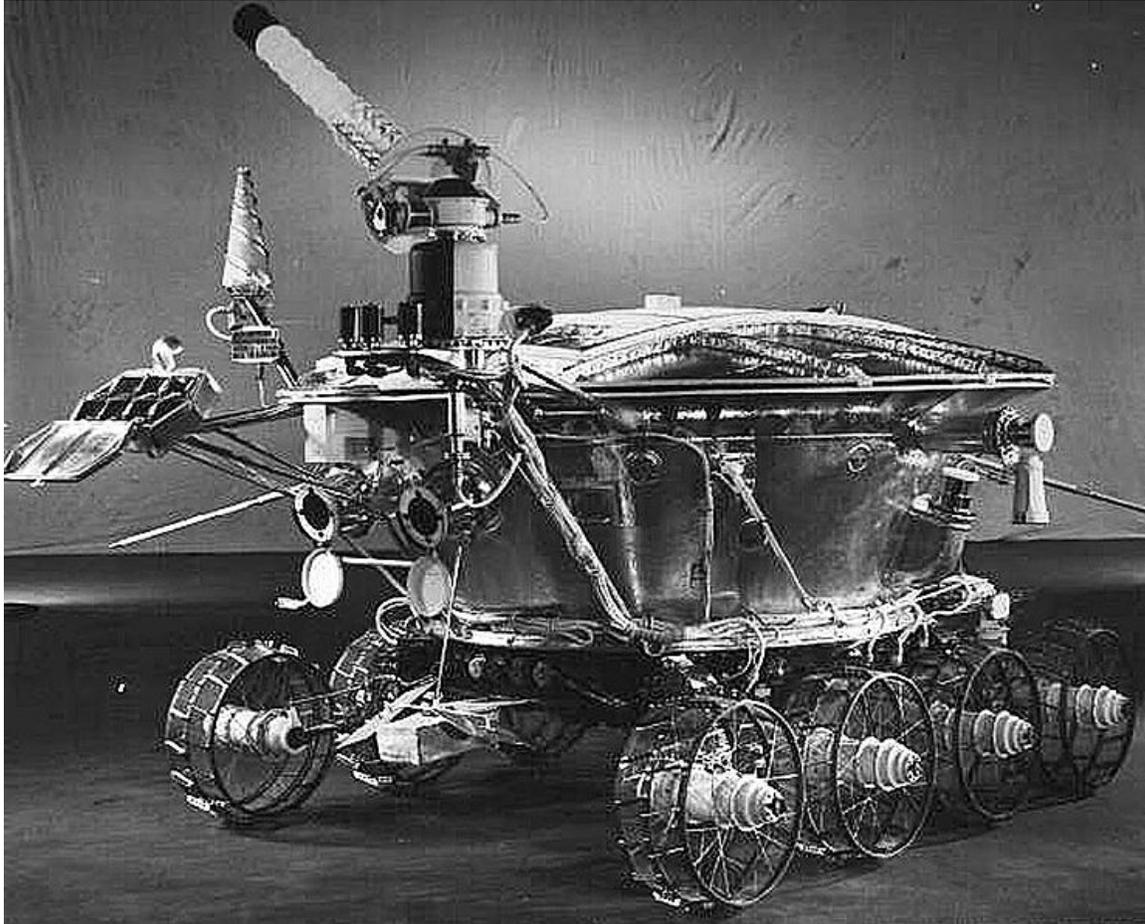
Lunokhod's original primary mission was the survey of sites for later manned landings and lunar bases. It was intended that the spacecraft would provide a radio beacon for precision landings of manned spacecraft. Also, the vehicle was designed to be used by a single cosmonaut to move from the primary 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.

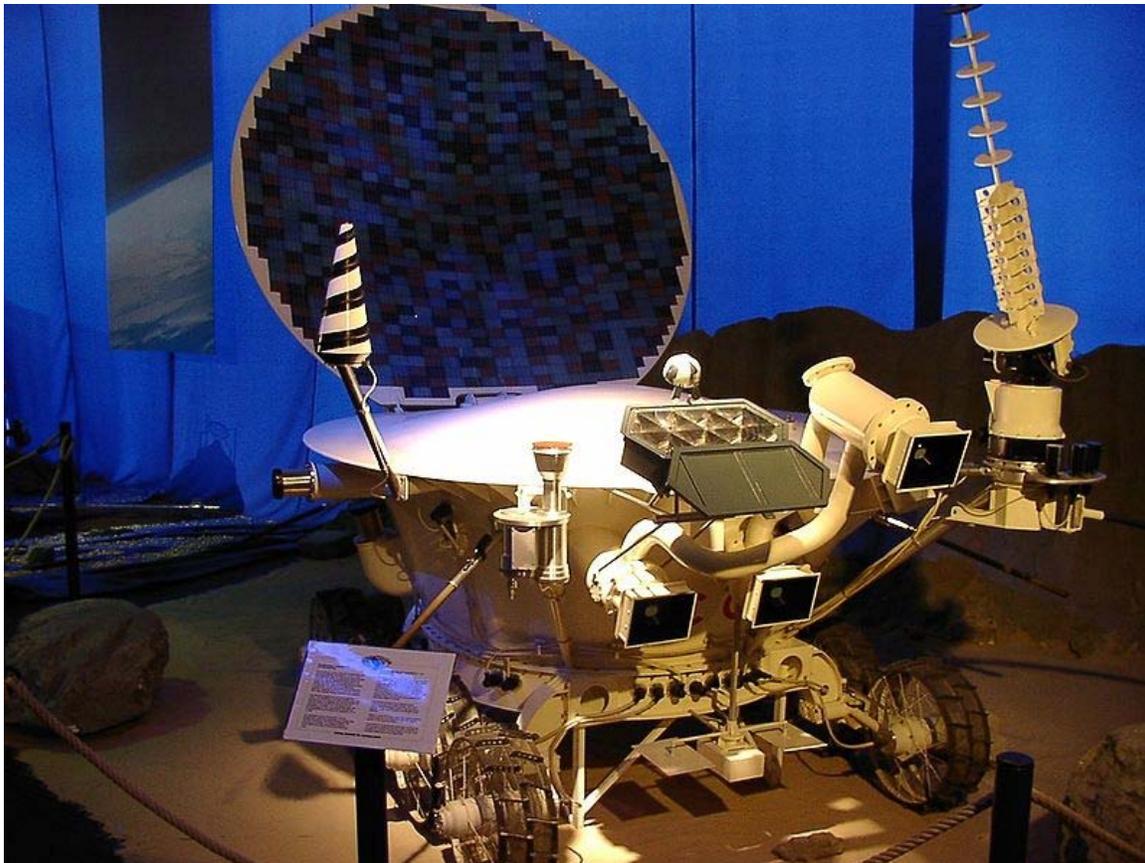
Luna 17 was launched on November 10, 1970 at 14:44:01 UTC. After reaching Earth parking orbit, the final stage of Luna 17's launching rocket fired to place it into a trajectory towards the Moon (November 10, 1970 at 14:54 UTC). After two course correction manoeuvres (on November 12 and 14) it entered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

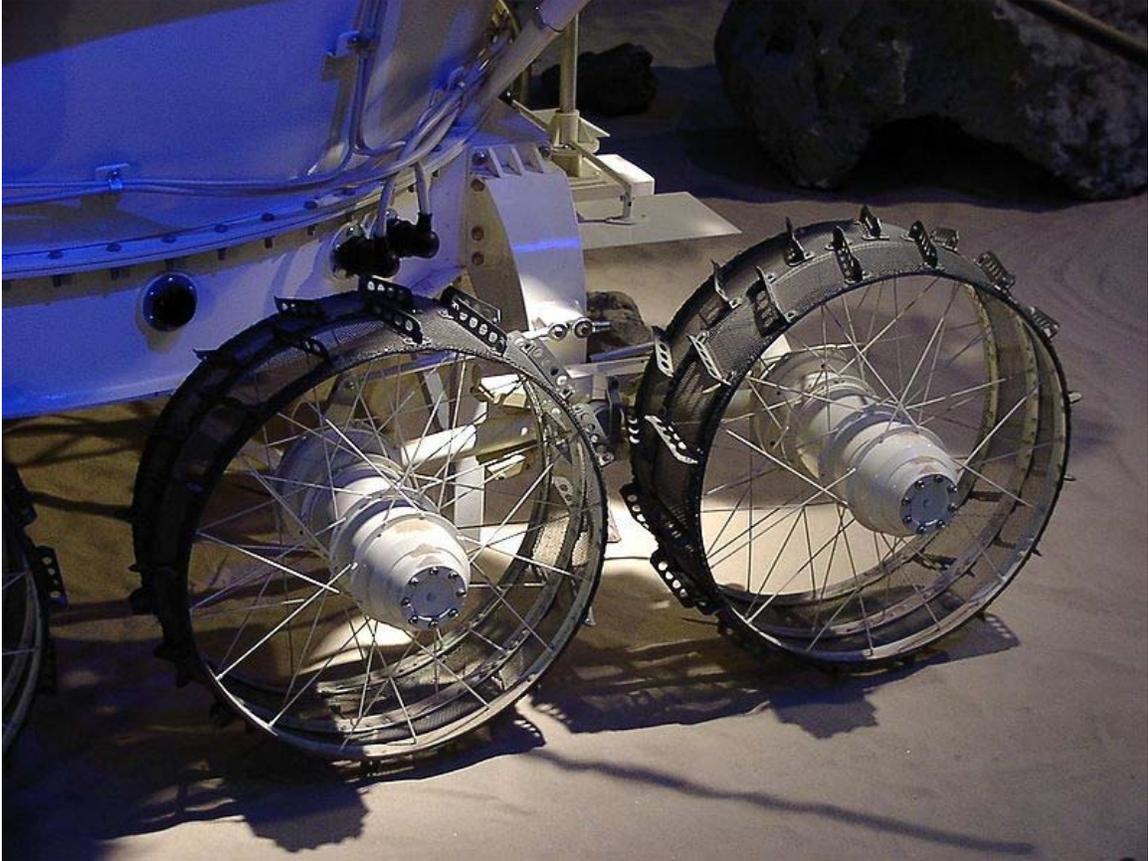
To be able to work in vacuum a special fluoride based lubricant was used for the mechanical parts and the electric motors (one in each wheel hub) were enclosed in pressurised containers.

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.

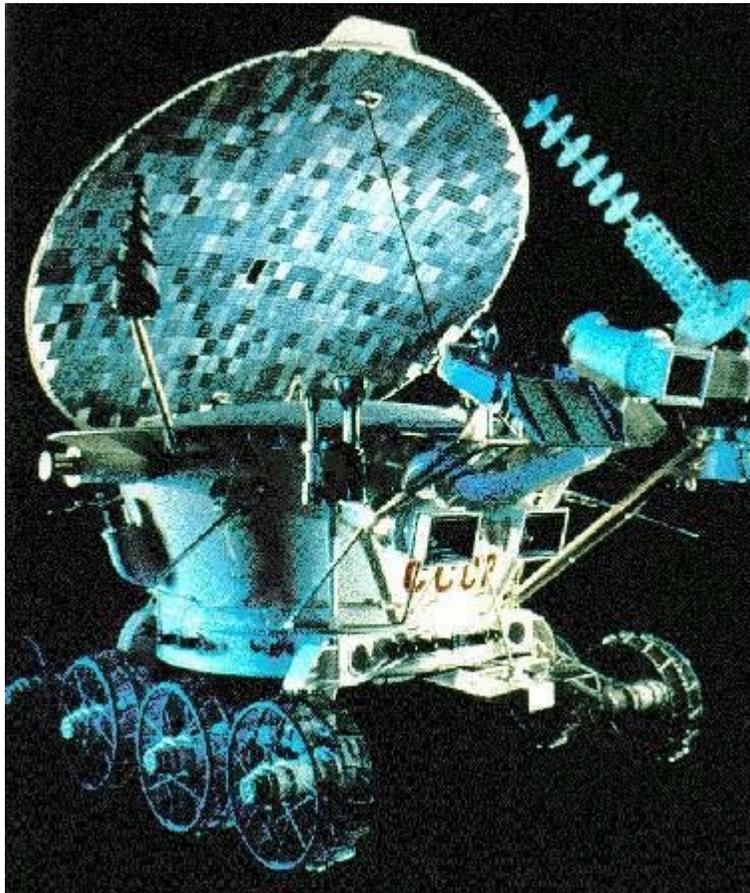
The rover stood 135 cm (4 ft 5 in) high and had a mass of 840 kg (1,850 lb). It was about 170 cm (5 ft 7 in) long and 160 cm (4 ft 11 in) wide and had eight wheels each with an independent suspension, motor and brake. The rover had two speeds, ~1 km/h and ~2 km/h (0.6 mph and 1.2 mph).

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.

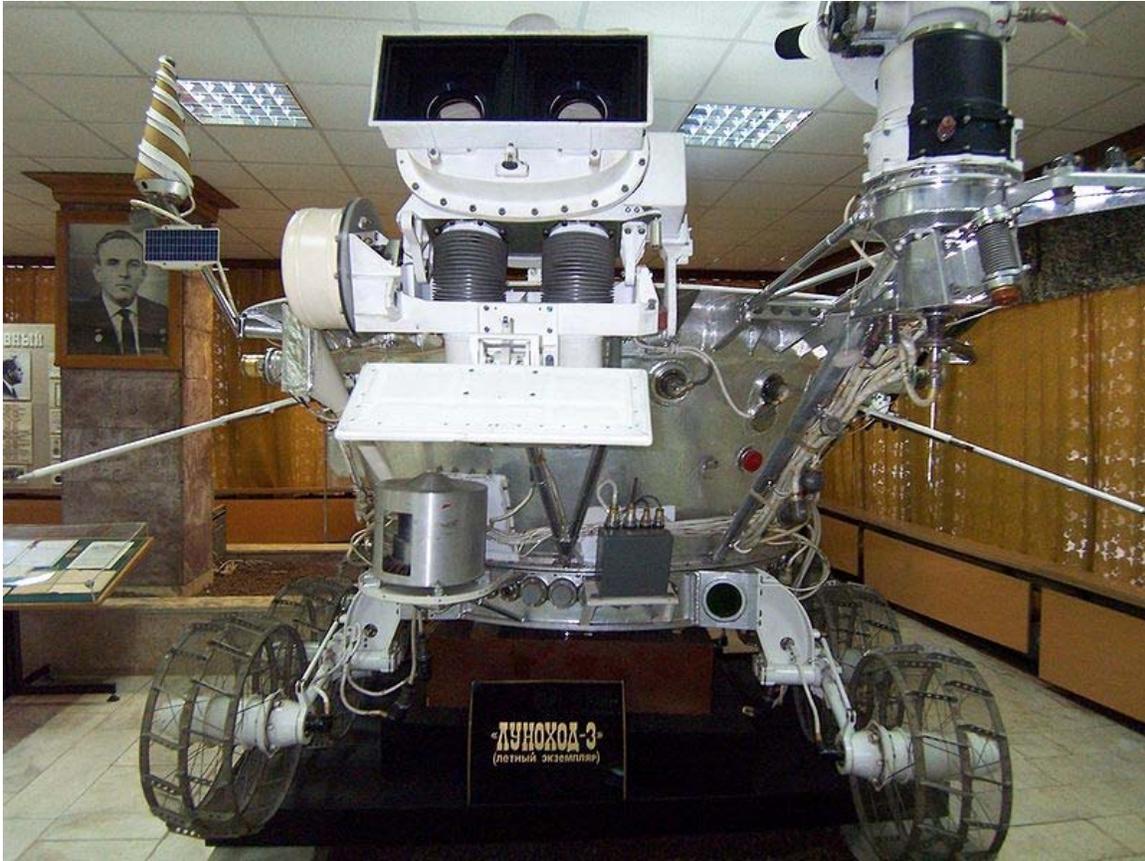
Payload

- 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 heat sources 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.

LCROSS

LCROSS



LCROSS spacecraft, artist's rendering

Operator	NASA/Ames Research Center
Mission type	Impactor
Launch date	2009-06-18 21:32:00 UTC
Launch vehicle	Atlas V 401
Launch site	Cape Canaveral SLC-41
Mission duration	June 18, 2009 – October 9, 2009 Elapsed: 1 year, 5 months, and 19 days
Landing site	
COSPAR ID	2009-031B
Mass	LCROSS Shepherding Spacecraft: 621 kg (1,369 lb) (min.); Centaur at impact: 2,249 kg (4,958 lb) (min.)

Orbital elements

Regime Highly elliptical

Orbital period 37 days

The **Lunar Crater Observation and Sensing Satellite (LCROSS)** was a robotic spacecraft operated by NASA. The main LCROSS mission objective was to explore the presence of water ice in a permanently shadowed crater near a lunar polar region. It was successful in discovering water in the southern lunar crater Cabeus.

It was launched together with the Lunar Reconnaissance Orbiter (LRO) on June 18, 2009, as part of the shared Lunar Precursor Robotic Program, the first American mission to the Moon in over ten years. Together, LCROSS and LRO form the vanguard of NASA's return to the Moon, and are expected to influence United States government decisions on whether or not to colonize the Moon.

LCROSS was designed to collect and relay data from the impact and debris plume resulting from the launch vehicle's spent Centaur upper stage (and data collecting Shepherding Spacecraft) striking the crater Cabeus near the south pole of the Moon.

Centaur had nominal impact mass of 2,305 kg (5,081 lb), and an impact velocity of about 10,000 km/h (6,200 mph).

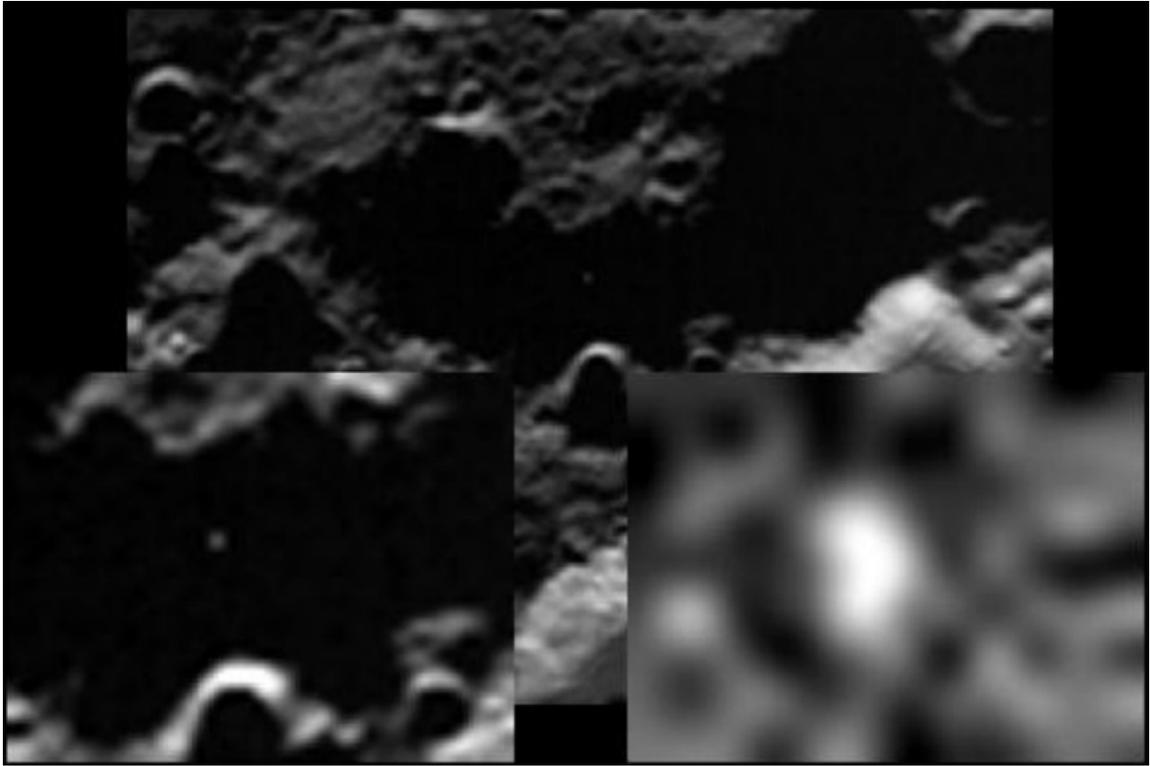
LCROSS suffered a malfunction on August 22, depleting half of its fuel and leaving very little fuel margin in the spacecraft.

Centaur impacted successfully on October 9, 2009, at 11:31 UTC. The Shepherding Spacecraft descended through Centaur's ejectate plume, collected and relayed data, impacting six minutes later at 11:37 UTC.

Mission

LCROSS was a fast-track, low-cost companion mission to the LRO. The LCROSS payload was added after NASA moved the LRO from the Delta II to a larger launch vehicle. It was chosen from 19 other proposals. LCROSS's mission was dedicated to late American broadcaster Walter Cronkite.

LCROSS launched with the LRO aboard an Atlas V rocket from Cape Canaveral, Florida, on June 18, 2009, at 21:32 UTC (17:32 EDT). On June 23, four and a half days after launch, LCROSS and its attached Centaur booster rocket successfully completed a lunar swingby and entered into polar Earth orbit with a period of 37 days, positioning LCROSS for impact on a lunar pole.



The flash from the LCROSS Centaur impact.



The Atlas V rocket carrying LRO and LCROSS.

Early in the morning on August 22, 2009, LCROSS ground controllers discovered an anomaly caused by a sensor problem, which had resulted in the spacecraft burning through 140 kilograms (309 pounds) of fuel, more than half of the fuel remaining at the time. According to Dan Andrews, the LCROSS project manager, "Our estimates now are if we pretty much baseline the mission, meaning just accomplish the things that we have to [do] to get the job done with full mission success, we're still in the black on propellant, but not by a lot."



An illustration of the LCROSS Centaur rocket stage and shepherding spacecraft as they approach impact with the lunar south pole on October 9, 2009.

Lunar impacts, after approximately three orbits, occurred on October 9, 2009, with the Centaur crashing into the Moon at 11:31 UTC and the Shepherding Spacecraft following a few minutes later. The mission team initially announced that Cabeus A would be the target crater for the LCROSS dual impacts, but later refined the target to be the larger, main Cabeus crater.

On its final approach to the Moon, the Shepherding Spacecraft and Centaur separated October 9, 2009, at 01:50 UTC. The Centaur upper stage acted as a heavy impactor to create a debris plume that rose above the lunar surface. Following four minutes after impact of the Centaur upper stage, the Shepherding Spacecraft flew through this debris

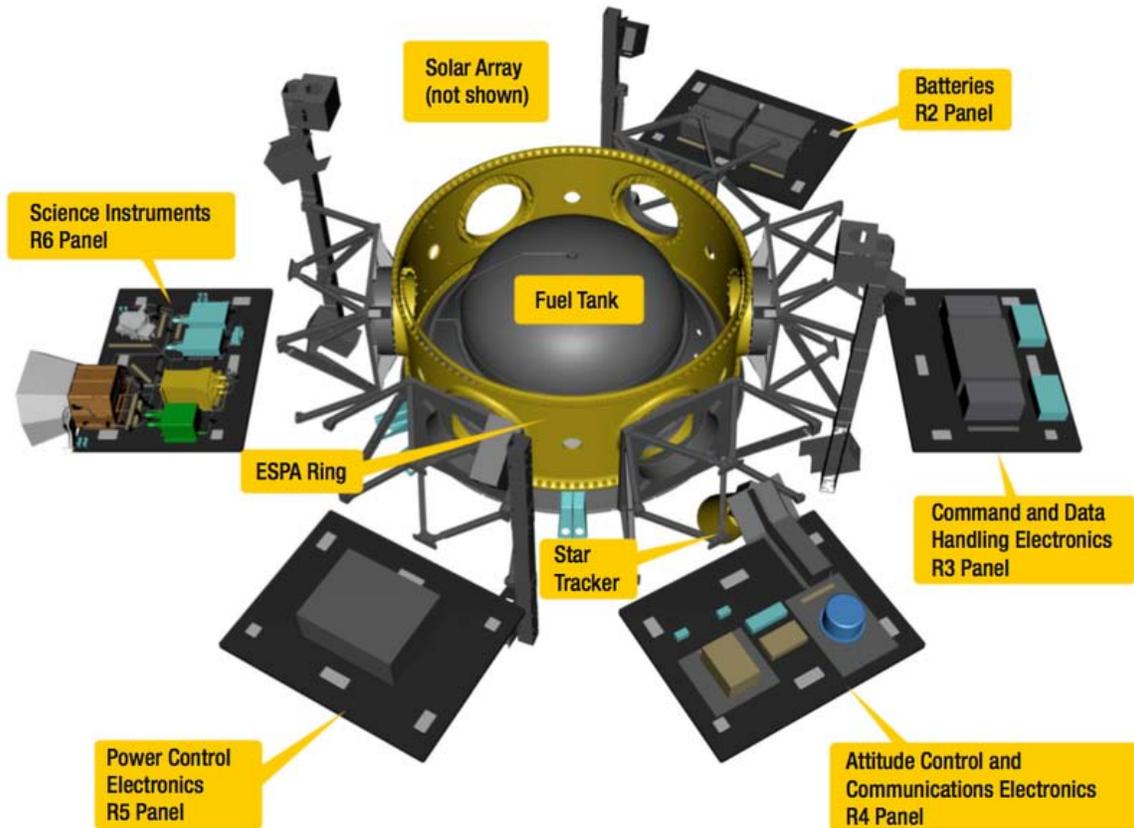
plume, collecting and relaying data back to Earth before it struck the lunar surface to produce a second debris plume. The impact velocity was projected to be 9,000 km/h (5,600 mph). The actual impact was later calculated to have been over 10,000 km/h (6,200 mph).

The Centaur impact was expected to excavate more than 350 metric tons (390 short tons) of lunar material and create a crater about 20 m (65 ft) in diameter to a depth of about 4 m (13 ft). The Shepherding Spacecraft impact was projected to excavate an estimated 150 metric tons (170 short tons) and create a crater 14 m (46 ft) in diameter to a depth of about 2 m (6 ft). Most of the material in the Centaur debris plume was expected to remain at (lunar) altitudes below 10 km (6 mi).

It was hoped that spectral analysis of the resulting impact plume would help to confirm preliminary findings by the Clementine and Lunar Prospector missions which hinted that there may be water ice in the permanently shadowed regions. Mission scientists expected that the Centaur impact plume would be visible through amateur-class telescopes with apertures as small as 25 to 30 cm (10 to 12 inches). But no plume was observed by such amateur telescopes. Even world class telescopes such as the Hale telescope, equipped with adaptive optics, did not detect the plume. The plume may have still occurred but at a small scale not detectable from earth. Both impacts were also monitored by Earth-based observatories and by orbital assets, such as the Hubble Space Telescope.

Whether or not LCROSS would find water had been stated to be influential in whether or not the United States government pursues creating a Moon base. On November 13, 2009, NASA confirmed that water was detected after the Centaur impacted the crater.

Spacecraft



LCROSS spacecraft (exploded view)

The LCROSS mission took advantage of the structural capabilities of the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring used to attach LRO to the Centaur upper stage rocket. Mounted on the outside of the ESPA were six panels that hold the spacecraft's science payload, command and control systems, communications equipment, batteries, and solar panels. A small monopropellant propulsion system was mounted inside of the ring. Also attached were two S Band omnidirectional antennas and two medium-gain antennas. The mission's strict schedule, mass, and budget constraints posed difficult challenges to engineering teams from NASA Ames Research Center (ARC) and Northrop Grumman. Their creative thinking led to a unique use of the ESPA ring and innovative sourcing of other spacecraft components. Usually, the ESPA ring is used as a platform to hold six small deployable satellites; for LCROSS, it became the backbone of the satellite, a first for the ring. LCROSS also took advantage of commercially available instruments and used many of the already-flight-verified components used on LRO.



LRO (top, silver) and LCROSS (bottom, gold) prepared for fairing

LCROSS is managed by NASA's ARC and was built by Northrop Grumman. The LCROSS preliminary design review was completed on September 8, 2006. The LCROSS mission passed its Mission Confirmation Review on February 2, 2007, and its Critical Design Review on February 22, 2007. After assembly and testing at Ames, the instrument payload, provided by Ecliptic Enterprises Corporation, was shipped to Northrop Grumman on January 14, 2008, for integration with the spacecraft. LCROSS passed its review on February 12, 2009.

Instruments

The LCROSS science instrument payload, provided by NASA's ARC, consisted of a total of nine instruments: one visible, two near infrared, and two mid-infrared cameras; one visible and two near-infrared spectrometers; and a photometer. A data handling unit (DHU) collected the information from each instrument for transmission back to LCROSS Mission Control. Because of the schedule and budget constraints, LCROSS took advantage of rugged, commercially available components. The individual instruments went through a rigorous testing cycle that simulated launch and flight conditions, identifying design weaknesses and necessary modifications for use in space, at which point the manufacturers were allowed to modify their designs.

Results

The impact was not as visually prominent as had been anticipated. Project manager Dan Andrews believed that this was due to pre-crash simulations that exaggerated the plume's prominence. Because of data bandwidth issues, the exposures were kept short, which made the plume difficult to see in the images in the visible spectra. This resulted in the need for image processing to increase clarity. The infrared camera also captured a thermal signature of the booster's impact.

Presence of water

On 13 November 2009, NASA reported that multiple lines of evidence show water was present in both the high-angle vapor plume and the ejecta curtain created by the LCROSS Centaur impact. As of November 2009, the concentration and distribution of water and other substances required more analysis. Additional confirmation came from an emission in the ultraviolet spectrum that was attributed to hydroxyl fragments, a product from the break-up of water by sunlight. Analysis of the spectra indicate that a reasonable estimate of the concentration of water in the frozen regolith is on the order of one percent. Evidence from other missions suggests that this may have been a relatively dry spot, as thick deposits of relatively pure ice appear to present themselves in other craters. A later, more definitive, analysis found the concentration of water to be " $5.6 \pm 2.9\%$ by mass."