



# Robotic Space Exploration Programs

Clayton Turpin

First Edition, 2012

ISBN 978-81-323-4715-6

© All rights reserved.

*Published by:*

**The English Press**

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

Email: [info@wtbooks.com](mailto:info@wtbooks.com)

# Table of Contents

Chapter 1 - Pioneer Program

Chapter 2 - Luna Programme

Chapter 3 - Zond Program

Chapter 4 - Mars Program

Chapter 5 - Ranger Program

Chapter 6 - Mariner Program

Chapter 7 - Surveyor Program

Chapter 8 - Lunar Orbiter Program

Chapter 9 - Viking Program

Chapter 10 - Voyager Program

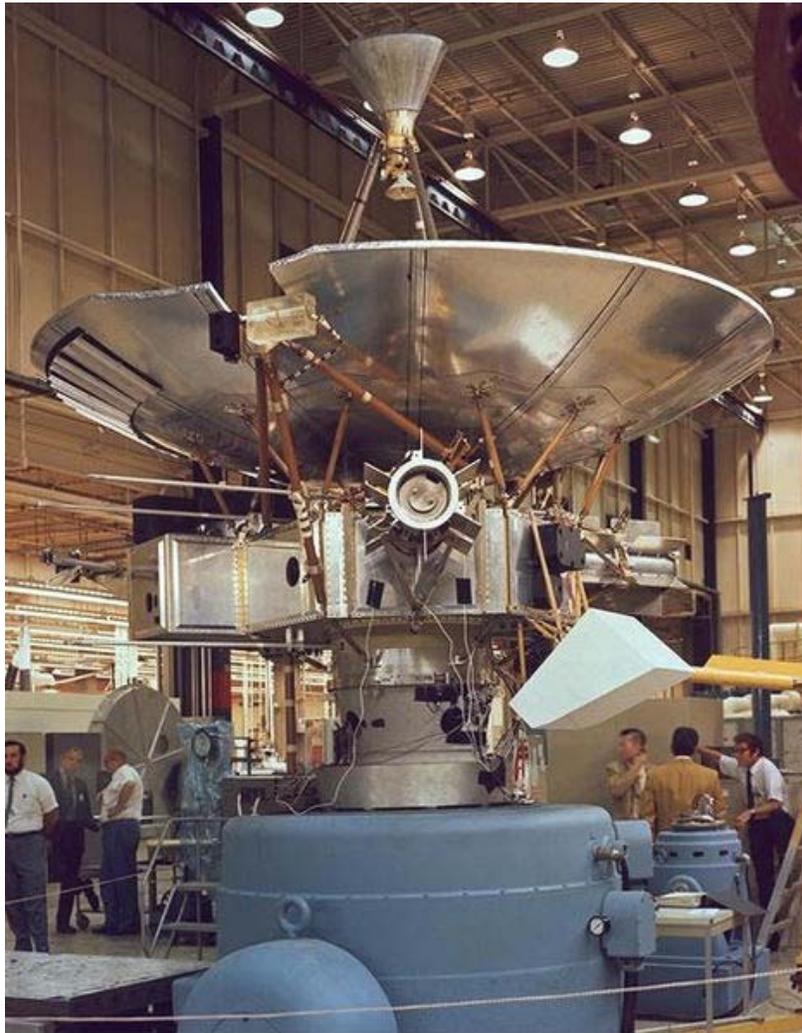
Chapter 11 - Vega Program

Chapter 12 - Chandrayaan-1

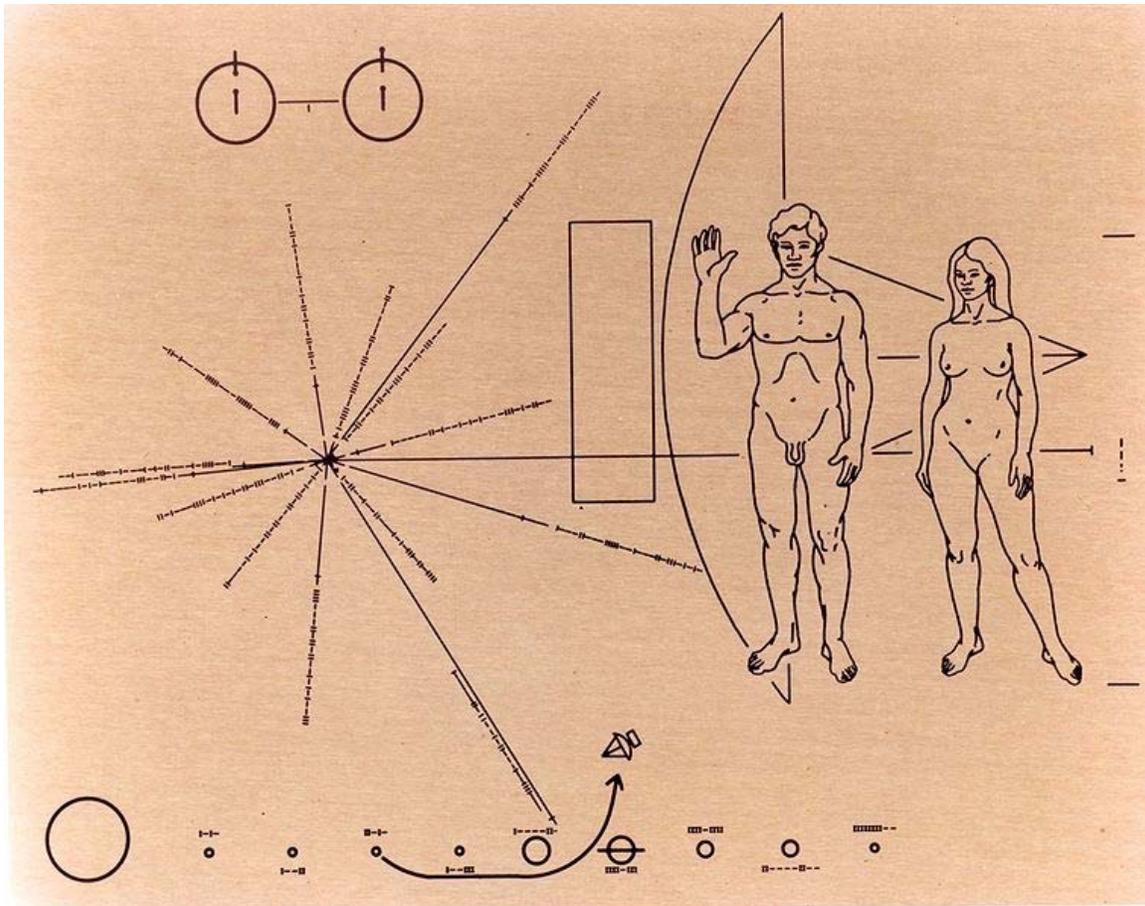
Chapter 13 - Chinese Lunar Exploration Program

## Chapter- 1

# Pioneer Program



Pioneer 10, undergoing construction in 1971. Pioneer 10 and 11 are the most famous probes in the Pioneer program, the first probes to visit the outer planets, and the first to go beyond the orbit of Pluto



The Pioneer plaque

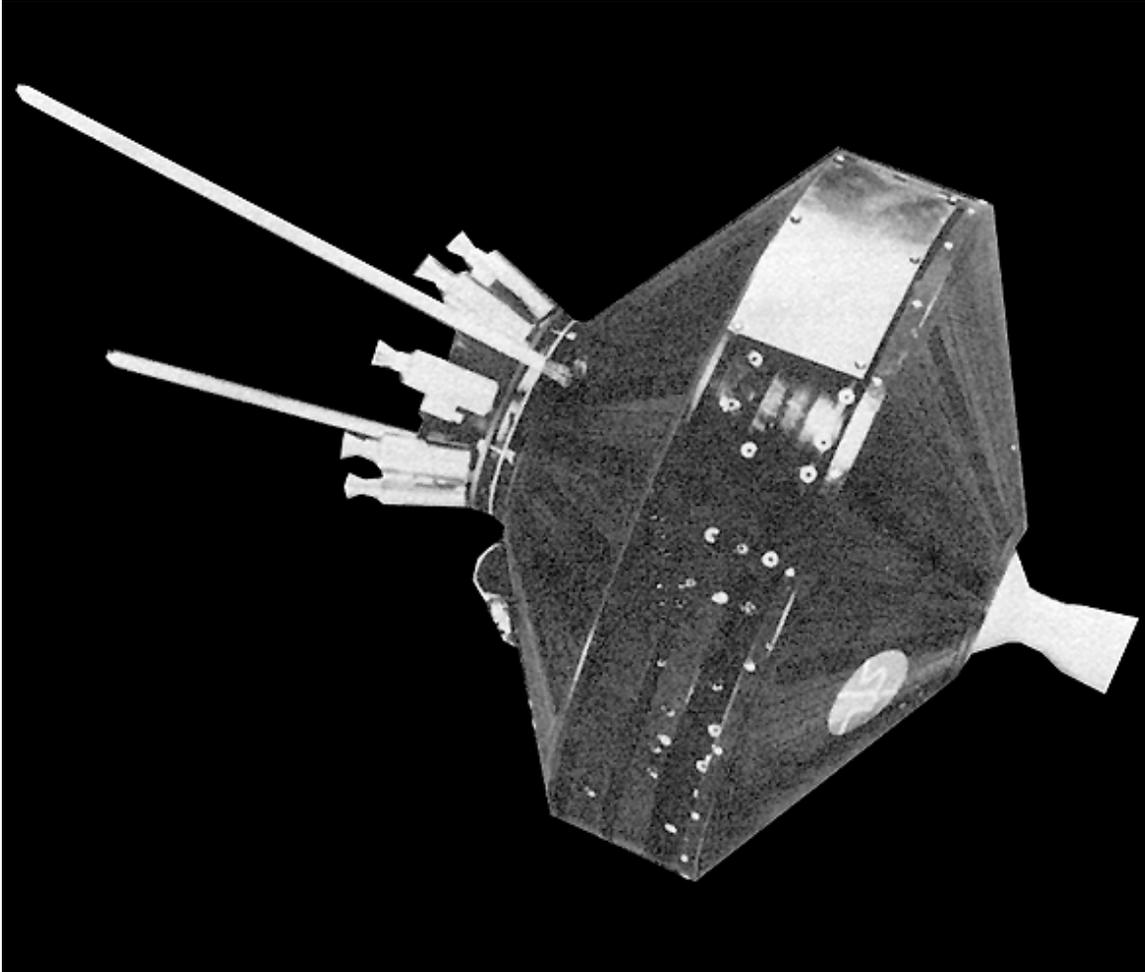
The **Pioneer program** is a series of United States unmanned space missions that was designed for planetary exploration. There were a number of such missions in the program, but the most notable were Pioneer 10 and Pioneer 11, which explored the outer planets and left the solar system. Both carry a golden plaque, depicting a man and a woman and information about the origin and the creators of the probes, should any extraterrestrials find them someday.

Credit for naming the first probe has been attributed to Stephen A. Saliga, who had been assigned to the Air Force Orientation Group, Wright-Patterson AFB, as chief designer of Air Force exhibits. While he was at a briefing, the spacecraft was described to him as a "lunar-orbiting vehicle with an infrared scanning device." Saliga thought the title too long and lacked theme for an exhibit design. He suggested "Pioneer" as the name of the probe since "the Army had already launched and orbited the Explorer satellite and their Public Information Office was identifying the Army as 'Pioneers in Space,'" and by adopting the name the Air Force would "make a 'quantum jump' as to who really [were] the 'Pioneers in space.'"

## Early Pioneer missions

The earliest missions were attempts to achieve Earth's escape velocity, simply to show it was feasible and study the Moon. This included the first launch by NASA which was formed from the old NACA. These missions were carried out by the US Air Force and Army.

## Able space probes (1958-1960)



Pioneer 2

*Most missions here are listed with their most recognised name, and alternate names after in brackets.*

- Pioneer 0 (Thor-Able 1, Pioneer) - Lunar orbiter, destroyed (Thor failure 77 seconds after launch) August 17, 1958
- Pioneer 1 (Thor-Able 2, Pioneer I) - Lunar orbiter, missed Moon (third stage partial failure) October 11, 1958

- Pioneer 2 (Thor-Able 3, Pioneer II) - Lunar orbiter, reentry (third stage failure) November 8, 1958
- Pioneer P-1 (Atlas-Able 4A, Pioneer W), probe lost September 24, 1959
- Pioneer P-3 (Atlas-Able 4, Atlas-Able 4B, Pioneer X) - Lunar probe, lost in launcher failure November 26, 1959
- Pioneer 5 (Pioneer P-2, Thor-Able 4, Pioneer V) - interplanetary space between Earth and Venus, launched March 11, 1960
- Pioneer P-30 (Atlas-Able 5A, Pioneer Y) - Lunar probe, failed to achieve lunar orbit September 25, 1960
- Pioneer P-31 (Atlas-Able 5B, Pioneer Z) - Lunar probe, lost in upper stage failure December 15, 1960

## **Juno II lunar probes (1958-1959)**

- Pioneer 3 - Lunar flyby, missed Moon due to launcher failure December 6, 1958
- Pioneer 4 - Lunar flyby, achieved Earth escape velocity, launched March 3, 1959

## **Later Pioneer missions (1965-1978)**

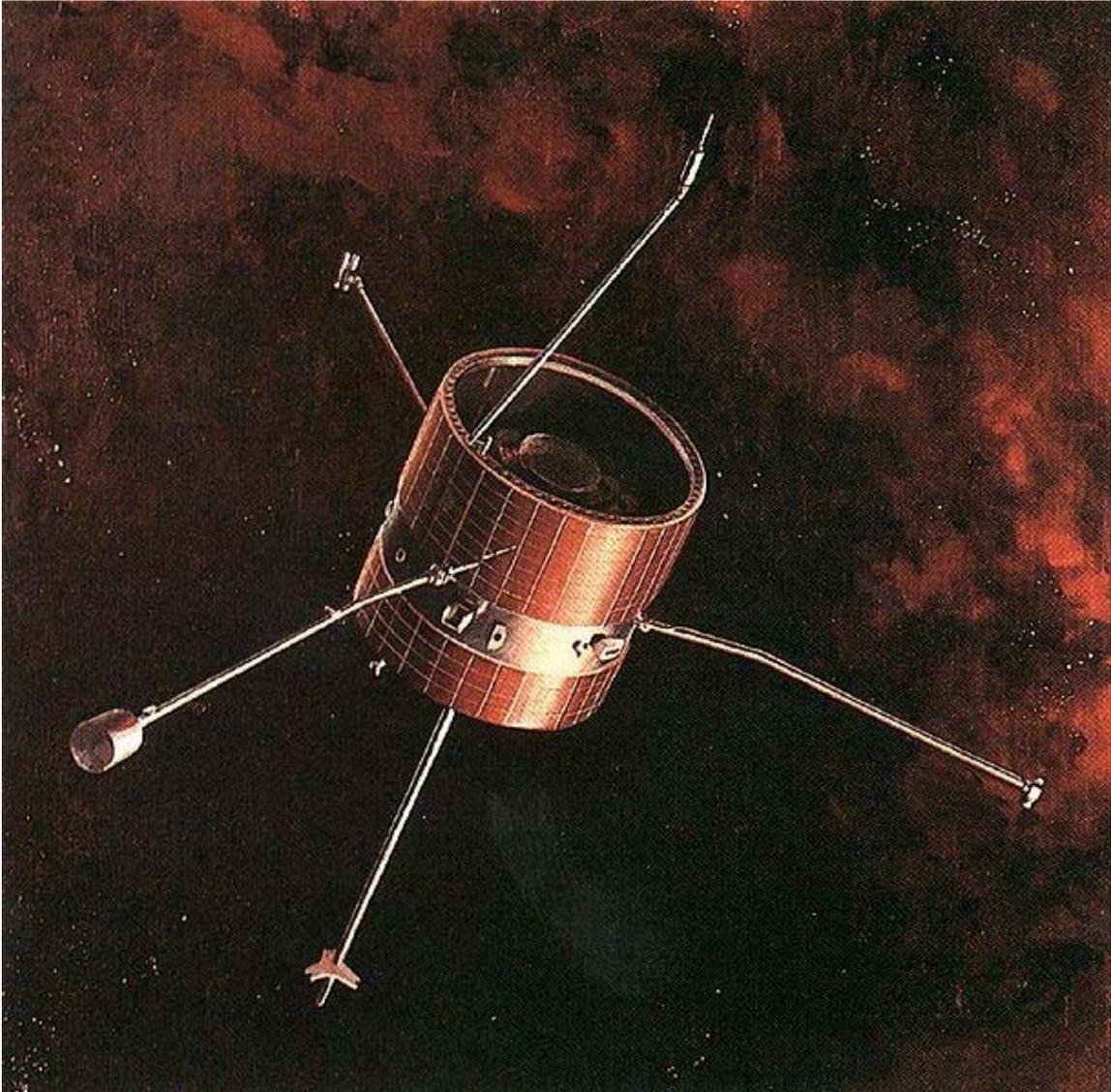


Pioneer 3

Five years after the early Able space probe missions ended, NASA Ames Research Center used the Pioneer name for a new series of missions, initially aimed at the inner solar system, before the bold flyby missions to Jupiter and Saturn. While successful, the missions returned much poorer images than the Voyager's five years later. In 1978, the end of the program saw a return to the inner solar system, with the Pioneer Venus Orbiter and Multiprobe, this time using orbital insertion rather than flyby missions.

The new missions were numbered from Pioneer 6 (*Alternate names in brackets*).

## Pioneer 6, 7, 8, and 9 - interplanetary space "weather network"



Artist's conception of the Pioneer 6-9 spacecraft

The spacecraft in Pioneer missions 6, 7, 8, and 9:

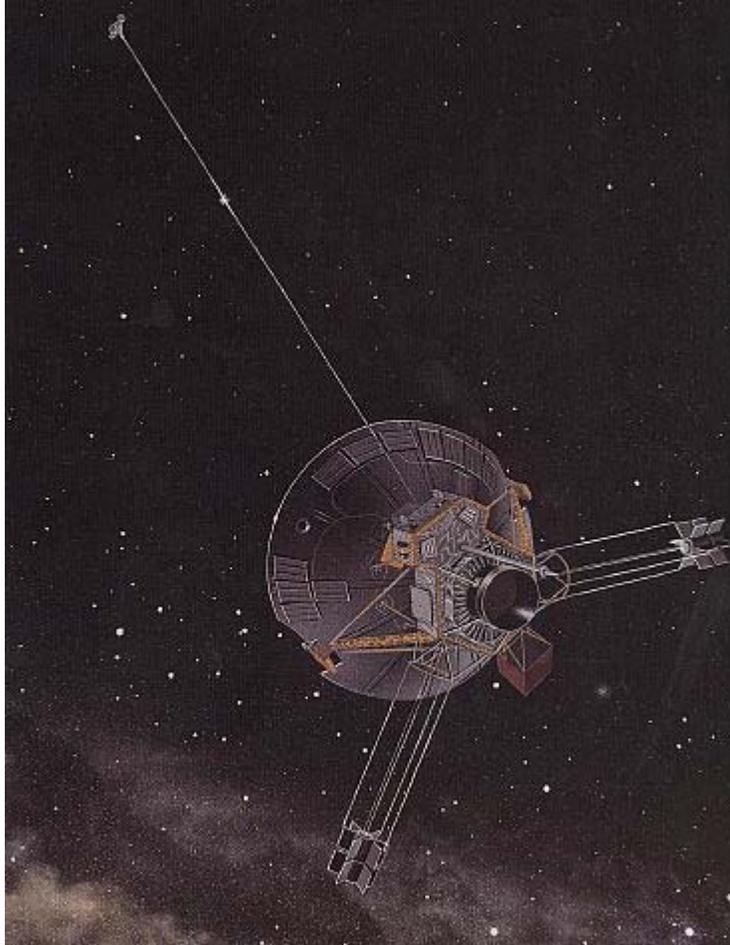
- Pioneer 6 (Pioneer A) - launched December 1965
- Pioneer 7 (Pioneer B) - launched August 1966
- Pioneer 8 (Pioneer C) - launched December 1967
- Pioneer 9 (Pioneer D) - launched November 1968 (*defunct. since 1983*)
- Pioneer E - lost in launcher failure August 1969

Pioneer 6 and Pioneer 9 are in solar orbits with 0.8 AU's distance to the Sun. Their orbital periods are therefore slightly shorter than Earth's.

Pioneer 7 and Pioneer 8 are in solar orbits with 1.1 AU's distance to the Sun. Their orbital periods are therefore slightly longer than Earth's.

Because they orbit the Sun on either side of the Earth's orbital path, some of them are, from time to time, 180° away from Earth. They can sense parts of the Sun several days before the Sun's rotation reveals it to ground based/earth orbiting observatories. If a powerful solar magnetic storm is born, they can warn Earth in advance.

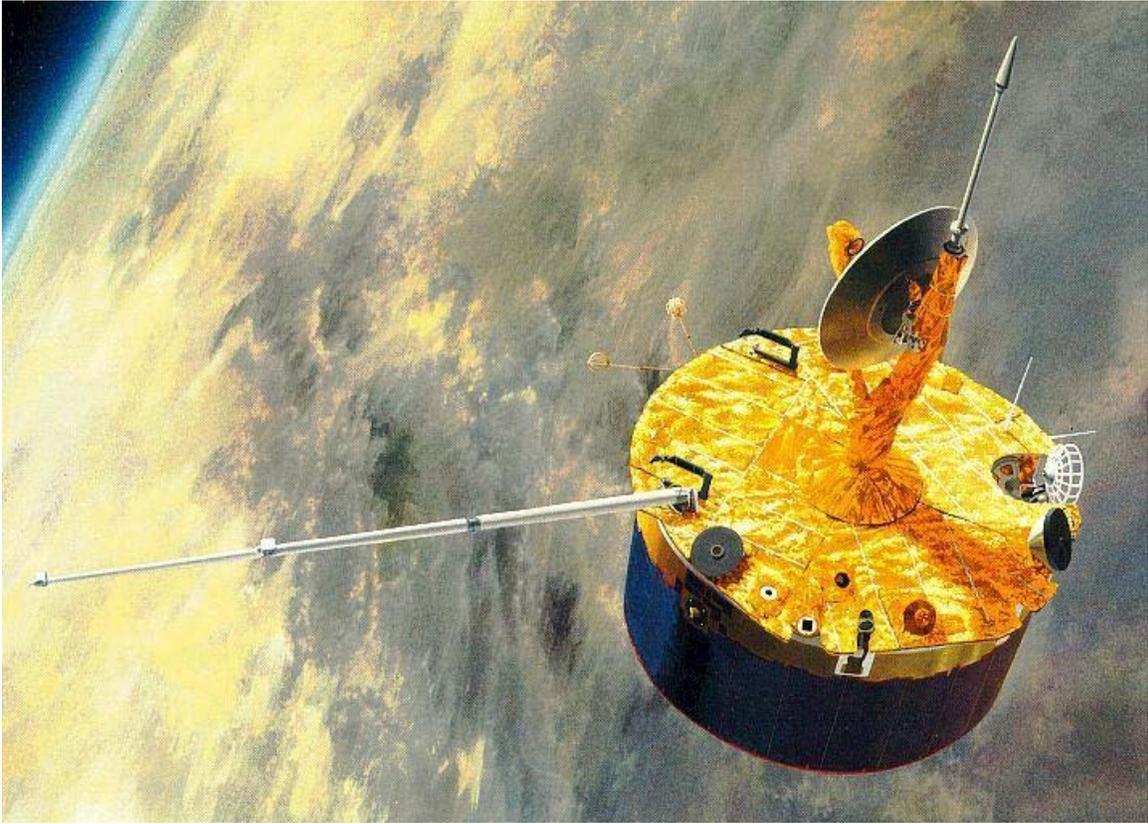
### **Outer solar system missions**



Artist's conception of the Pioneer 10-11 spacecraft

- Pioneer 10 (Pioneer F) - Jupiter, interstellar medium, launched March 1972
- Pioneer 11 (Pioneer G) - Jupiter, Saturn, interstellar medium, launched April 1973
- Pioneer H - identical to Pioneers 10 and 11, but never launched

## Pioneer Venus project



Artist's conception of the Pioneer Venus spacecraft

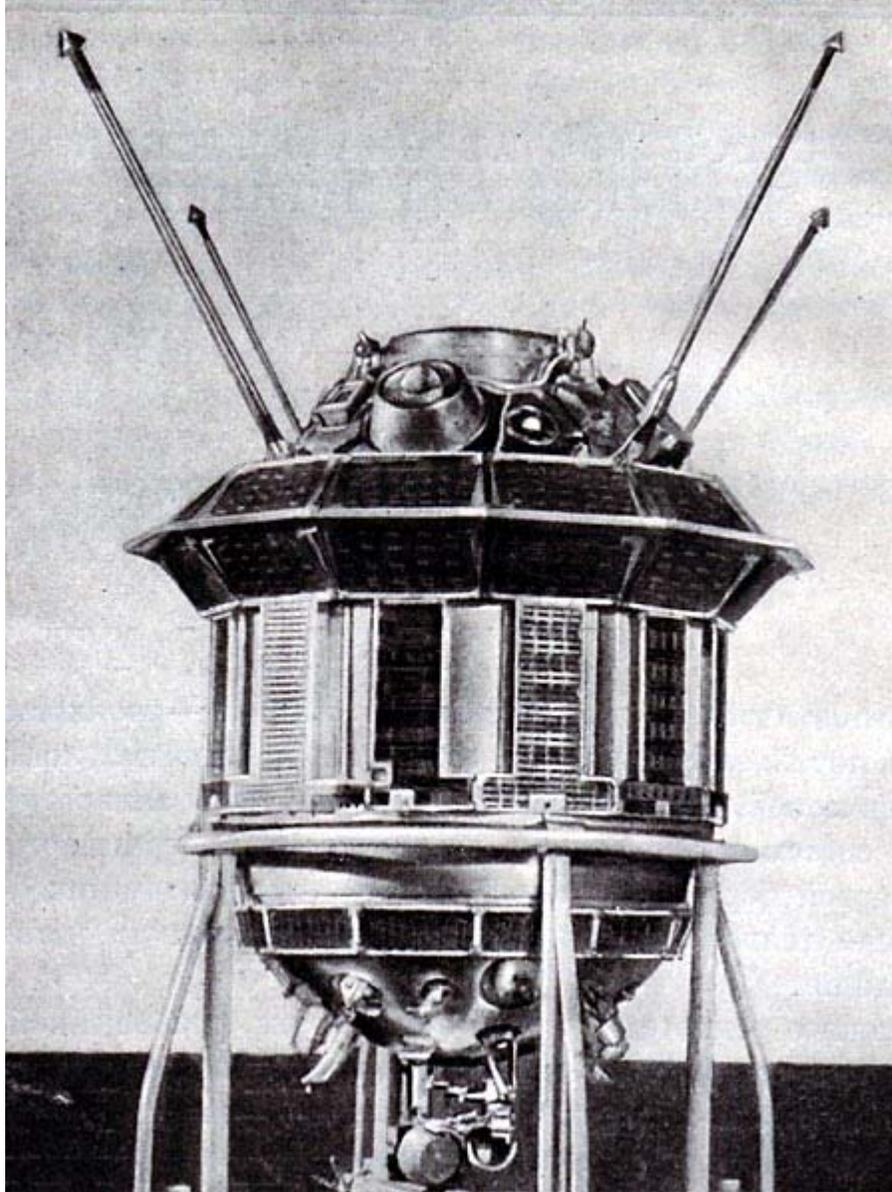
- Pioneer Venus Orbiter (Pioneer Venus 1, Pioneer 12) - launched December 1978
- Pioneer Venus Multiprobe (Pioneer Venus 2, Pioneer 13) - launched August 1978
  - Pioneer Venus Probe Bus - transport vehicle and upper atmosphere probe
  - Pioneer Venus Large Probe - 300 kg parachuted probe
  - Pioneer Venus North Probe - 75 kg impactor probe
  - Pioneer Venus Night Probe - 75 kg impactor probe
  - Pioneer Venus Day Probe - 75 kg impactor probe

## Chapter- 2

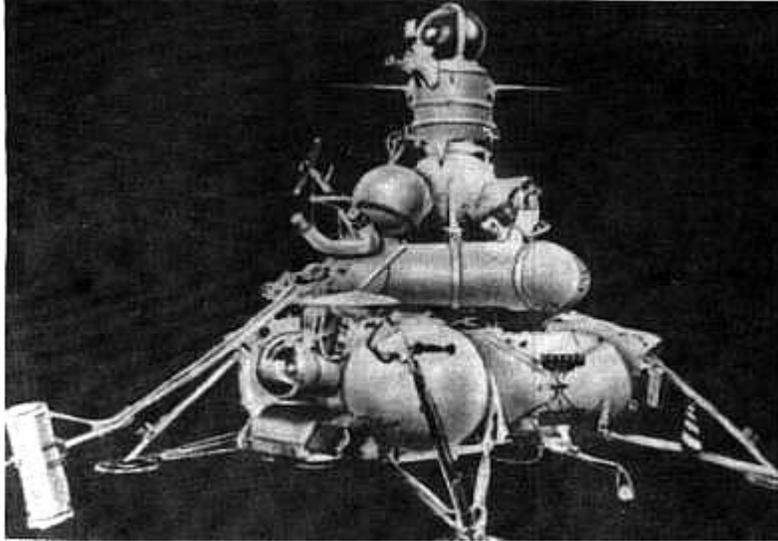
# Luna Programme



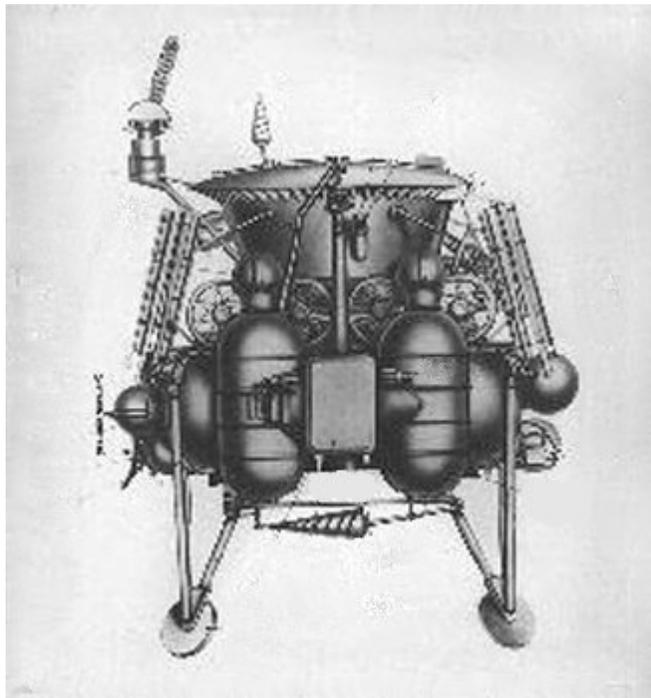
Luna 1



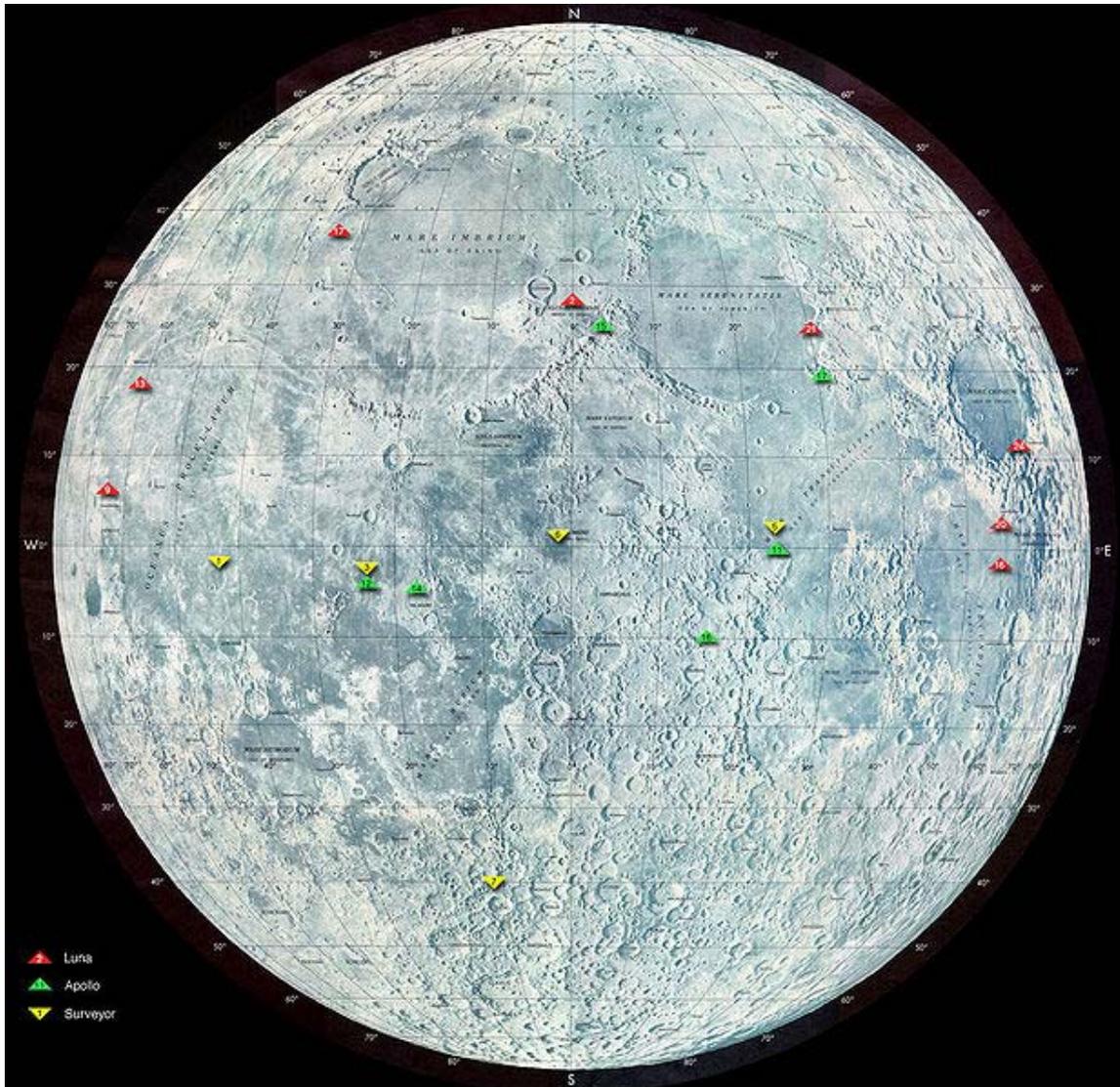
Luna 3



Luna 16



Luna 17



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
- Luna 2
  - Launched September 12, 1959
  - Lunar impact September 14, 1959 at ~07:30:00 UT
  - Latitude 29.10 N, Longitude 0.00 - Palus Putredinis
- Luna 3
  - Launched October 4, 1959
  - Lunar Flyby
- *Luna 1960A*
  - Launch failure April 15, 1960
  - Lunar flyby attempt
- *Luna 1960B*
  - Launch failure April 19, 1960
  - Lunar flyby attempt
- *Luna - Sputnik 25*
  - Launched January 4, 1963 (failed to escape orbit and decayed back into the atmosphere after just one day)
  - Soft landing attempt
- *Luna 1963B*
  - Launch failure February 3, 1963
  - Soft landing attempt
- Luna 4
  - Launched April 2, 1963
  - Lunar Flyby (Soft landing attempt)
- *Luna 1964A*
  - Launch failure March 21, 1964
  - Soft landing attempt

- *Luna 1964B*
  - Launch failure April 20, 1964
  - Soft landing attempt
- *Luna - Cosmos 60*
  - Launched March 12, 1965 (failed to escape orbit and decayed back into the atmosphere after five days)
  - Soft landing attempt
- *Luna 1965A*
  - Launch failure April 10, 1965
  - Soft landing attempt
- Luna 5
  - Launched May 9, 1965
  - Lunar impact (soft landing attempt) - Sea of Clouds
- Luna 6
  - Launched June 8, 1965
  - Attempted Lander - Missed Moon
- Luna 7
  - Launched October 4, 1965
  - Lunar Impact - Oceanus Procellarum
- Luna 8
  - Launched December 3, 1965
  - Lunar Impact - Sea of Storms
- Luna 9
  - Launched January 31, 1966
  - Landed on Moon February 3, 1966 at 18:44:52 UT
  - Latitude 7.08 N, Longitude 295.63 E - Oceanus Procellarum
- *Luna - Cosmos 111*
  - Launched March 1, 1966 (failed to escape orbit and decayed back into the atmosphere after two days)
  - Lunar orbit attempt
- Luna 10
  - Launched March 31, 1966
  - Lunar Orbiter
- Luna 11
  - Launched August 24, 1966
  - Lunar Orbiter
- Luna 12
  - Launched October 22, 1966
  - Lunar Orbiter
- Luna 13
  - Launched December 21, 1966
  - Landed on Moon December 24, 1966 at 18:01:00 UT
  - Latitude 18.87 N, 297.95 E - Oceanus Procellarum
- *Luna 1968A*
  - Launch failure February 7, 1968
  - Lunar Orbiter attempt

- Luna 14
  - Launched April 7, 1968
  - Lunar Orbiter
- *Luna 1969A*
  - Launch failure February 19, 1969
  - Lunar Rover attempt
- *Luna 1969C*
  - Launch failure June 14, 1969
  - Lunar Sample Return attempt
- Luna 15
  - Launched July 13, 1969
  - Lunar Orbiter (attempted lander)
- *Luna - Cosmos 300*
  - Launched September 23, 1969
  - Lunar Sample Return attempt (failed to escape orbit and decayed back into the atmosphere after four days)
- *Luna - Cosmos 305*
  - Launched October 22, 1969
  - Lunar Sample Return attempt (failed to escape orbit and decayed back into the atmosphere after two days)
- *Luna 1970A*
  - Launch failure February 6, 1970
  - Lunar Sample Return attempt
- Luna 16
  - Launched September 12, 1970
  - Landed on Moon September 20, 1970 at 05:18:00 UT
  - Latitude 0.68 S, Longitude 56.30 E - Mare Fecunditatis
  - Lunar Sample Return to Earth September 24, 1970
- Luna 17/Lunokhod 1
  - Launched November 10, 1970
  - Landed on Moon November 17, 1970 at 03:47:00 UT
  - Latitude 38.28 N, Longitude 325.00 E - Mare Imbrium
  - Lunar Rover - Lunokhod 1
- Luna 18
  - Launched September 2, 1971
  - Lunar Impact (Lunar Sample Return attempt)
  - Latitude 3.57 N, Longitude 50.50 E - Mare Fecunditatis
- Luna 19
  - Launched September 28, 1971
  - Lunar Orbiter
- Luna 20
  - Launched February 14, 1972
  - Landed on Moon February 21, 1972 at 19:19:00 UT
  - Latitude 3.57 N, Longitude 56.50 E - Mare Fecunditatis
  - Lunar Sample Return to Earth February 25, 1972
- Luna 21/Lunokhod 2

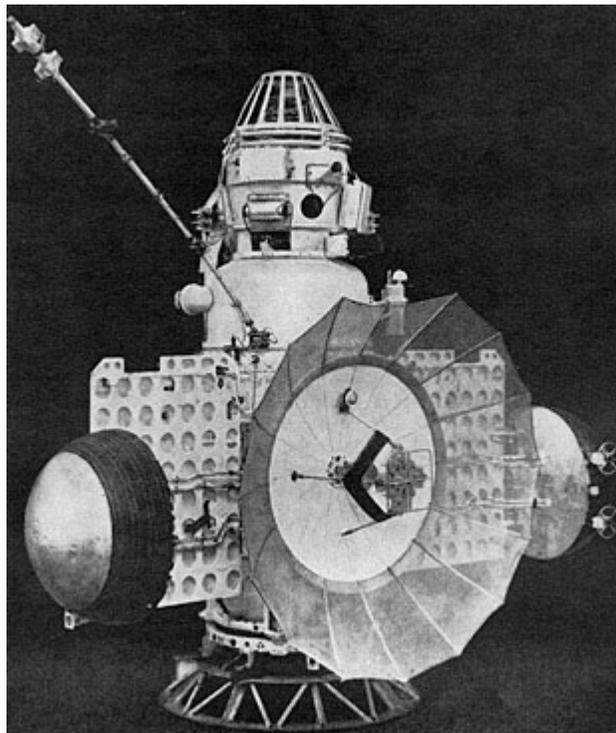
- Launched January 8, 1973
  - Landed on Moon January 15, 1973 at 23:35:00 UT
  - Latitude 25.85 N, Longitude 30.45 E - LeMonnier Crater
  - Lunar Rover - Lunokhod 2
- Luna 22
  - Launched May 29, 1974
  - Lunar Orbiter
- Luna 23
  - Launched October 28, 1974
  - Lunar Lander (Lunar Sample Return attempt) - Mare Crisium
- *Luna 1975A*
  - Launch failure October 16, 1975
  - Lunar Sample Return attempt - Mare Crisium
- Luna 24
  - Launched August 9, 1976
  - Landed on Moon August 18, 1976 at 02:00:00 UT
  - Latitude 12.25 N, Longitude 62.20 E - Mare Crisium
  - Lunar Sample Return- Mare Crisium

## Chapter- 3

# Zond Program

**Zond** (Зонд; Russian for "probe") was the name given to two distinct series of Soviet unmanned space program undertaken from 1964 to 1970. The first series based on 3MV planetary probe was intended to gather information about nearby planets. The second series of test spacecraft being a precursor to manned circumlunar loop flights used a stripped-down variant of Soyuz spacecraft, consisting of the service and descent modules, but lacking the orbital module.

### Missions based on the 3MV planetary probe

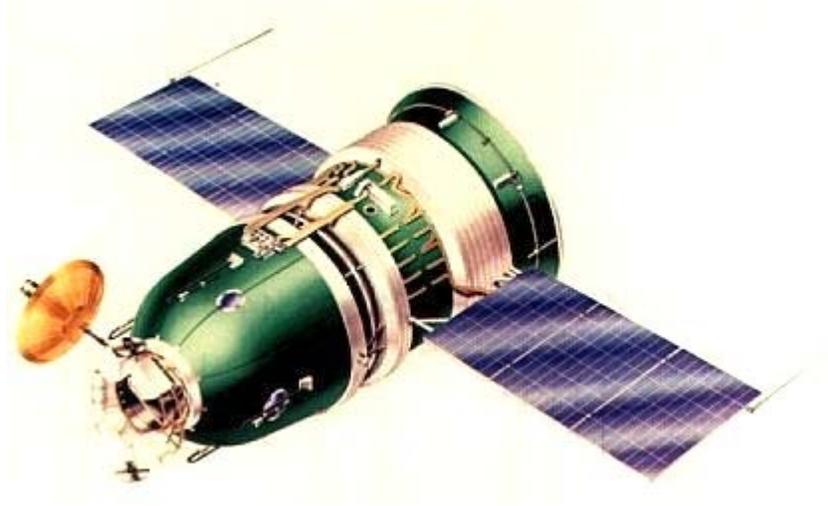


Zond 3 (interplanetary) part of 3MV family

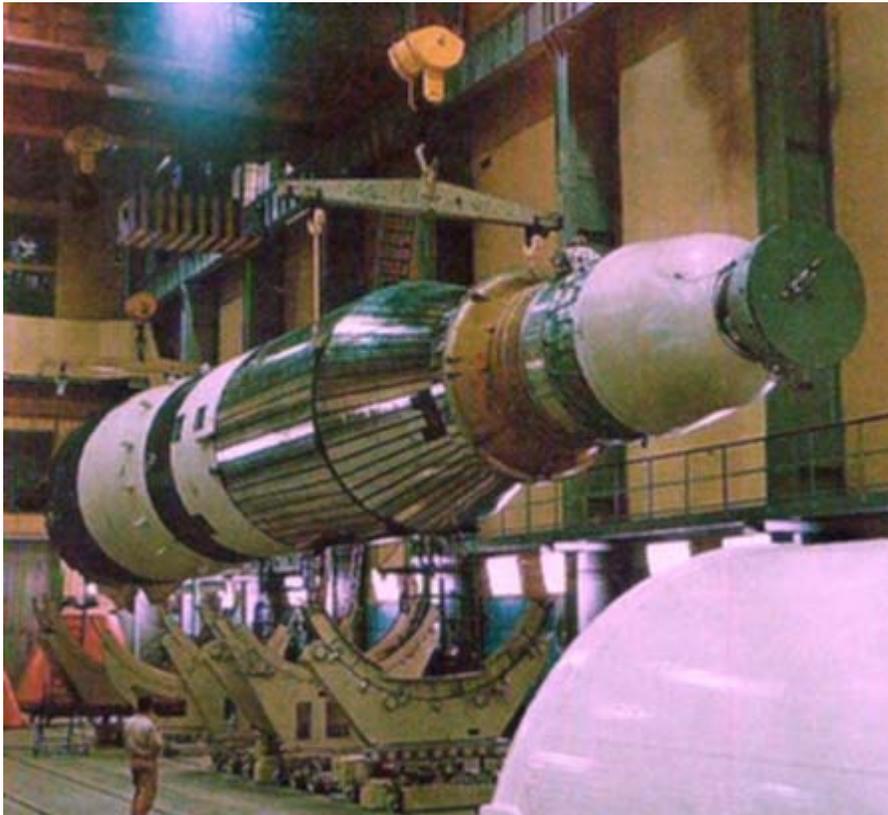
The first three missions were based on the model 3MV planetary probe, intended to explore Venus and Mars. After two failures, Zond 3 was sent on a test mission,

photographing the far side of the Moon (only the second spacecraft to do so) and continuing out to the orbit of Mars in order to test telemetry and spacecraft systems.

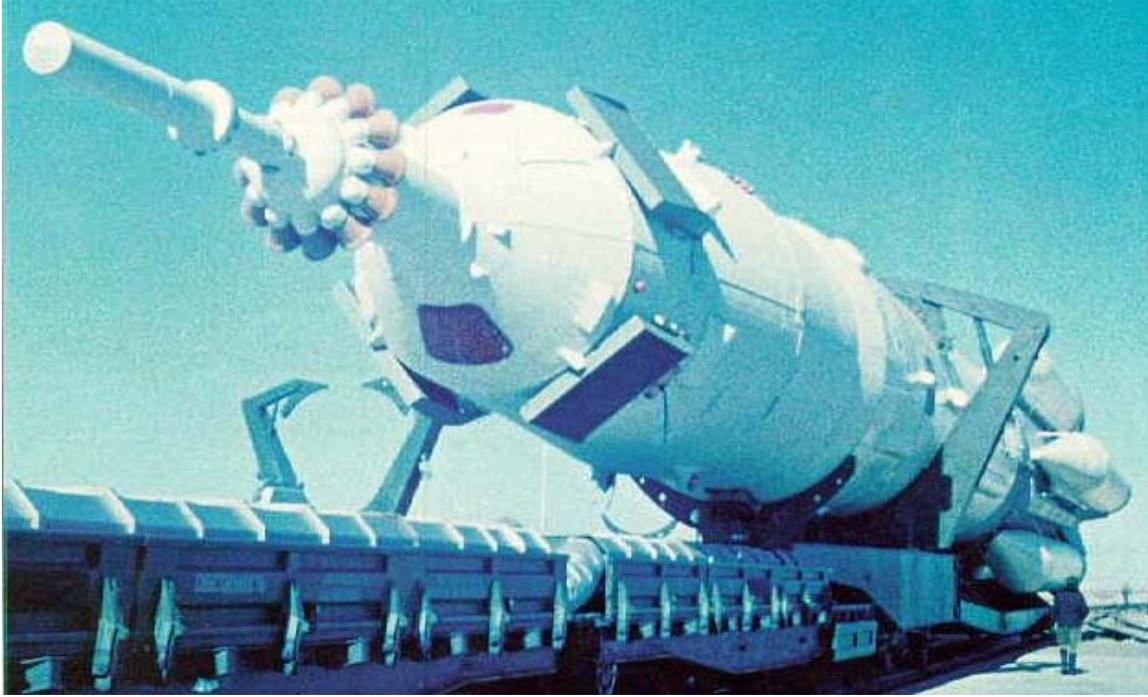
## Circumlunar missions



L1 (Zond) circumlunar spacecraft



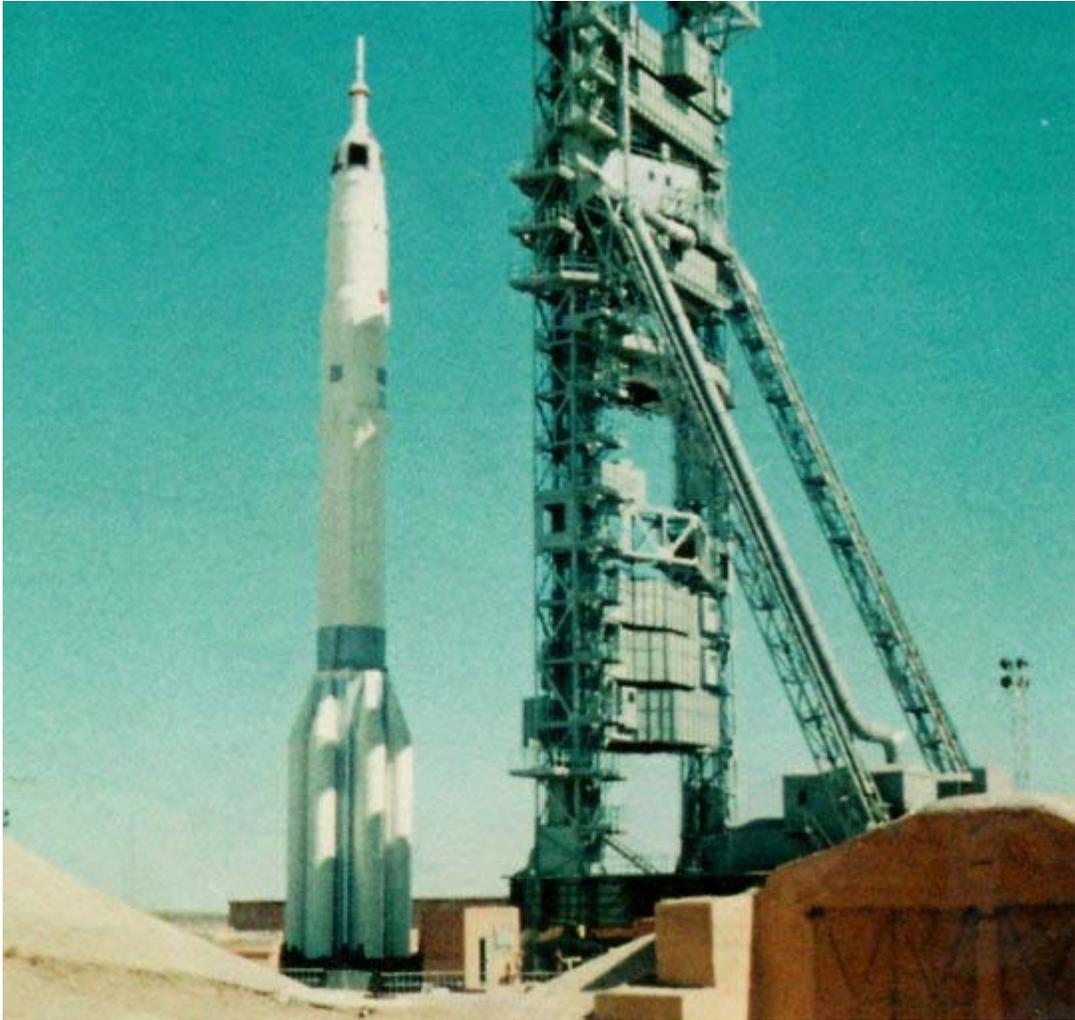
Zond with top stage of Proton booster in assembly hangar



Proton rocket with Zond rollout



Proton with Zond launch



Proton booster with Zond on launchpad



Zond 7 re-entry capsule

The missions 4 through 8 were test flights under for the Soviet Moonshot during the Moon race. The Soyuz 7K-L1 (also mentioned just as L1) spacecraft was used for the moon-aimed missions, stripped down to make it possible to launch around the moon from the Earth. They were launched on the Proton rocket which was just powerful enough to send the Zond on a free-return trajectory around the moon without going into lunar orbit (the same path that Apollo 13 flew in its emergency abort). With minor modification, Zond was capable of carrying 2 cosmonauts.

In the beginning there were serious reliability problems with both the new Proton rocket and the similar new Soyuz spacecraft, but the test flights pressed ahead with some glitches. Then majority of tests flights from 1967-1970 (Zond 4 to Zond 8) showed problems during re-entry.

Zond spacecraft made only unmanned automatic flights. Four of these suffered malfunctions that would have injured or killed any crew. Instrumentation flown on these missions gathered data on micrometeor flux, solar and cosmic rays, magnetic fields, radio emissions, and solar wind. Many photographs were taken and biological payloads were also flown.

# Timetable

## 3MV planetary probe based missions

- Zond 1
  - Launched 2 April 1964
  - Communications lost 14 May 1964
  - Venus flyby 14 July 1964
- Zond 2
  - Launched 30 November 1964
  - Communications lost May 1965
  - Mars flyby 6 August 1965
- Zond 3
  - Launched 18 July 1965
  - Lunar Flyby 20 July 1965

## Soyuz 7K-L1 test missions

- Cosmos 146
  - Launched 10 March 1967
  - Prototype Soyuz 7K-L1P launched by Proton into planned highly elliptical earth orbit.
- Cosmos 154
  - Launched 8 April 1967
  - Prototype Soyuz 7K-L1P launched by Proton and failed into planned translunar trajectory.
- Zond 1967A
  - Launched 28 September 1967
  - Fell off course 60 seconds after launched. Escape tower took Zond capsule safely away. Rocket crashed 65 km downrange.
  - Attempted Lunar flyby
- Zond 1967B
  - Launched 22 November 1967
  - Second stage failure. Zond capsule was safely recovered. Rocket crashed 300 km downrange.
  - Attempted Lunar flyby
- Zond 4
  - Launched 2 March 1968
  - Study of remote regions of circumterrestrial space, development of new on-board systems and units of space stations.
  - Returned to Earth 7 March 1968 - Self destruct system automatically blew up the capsule at 10 to 15 km altitude, 180–200 km off the African coast at Guinea.
- Zond 1968A
  - Launched 23 April 1968
  - Second stage failed 260 seconds after launch.

- Attempted Lunar flyby
- Zond 1968B (Zond 7K-L1 s/n 8L)
  - Launched 21 July 1968
  - Block D stage exploded on pad, killing three people.
- Zond 5
  - Launched 15 September 1968
  - Circumlunar 18 September 1968
  - Returned to Earth 21 September 1968
  - Turtles and other biological specimens were the first lifeforms to travel to lunar orbit and return safely.
- Zond 6
  - Launched 10 November 1968
  - Circumlunar 14 November 1968
  - Returned to Earth 17 November 1968
- Zond 1969A
  - Launched 20 January 1969
  - Stage two shutdown 25 seconds early. Automatic flight abort. Capsule was safely recovered.
  - Attempted Lunar flyby
- Zond L1S-1
  - Launched 21 February 1969
  - First stage failure. Capsule escape system fired 70 seconds after launch. Capsule was recovered.
  - Attempted Lunar orbiter and N1 rocket test
- Zond L1S-2
  - Launched 3 July 1969
  - First stage failure. Zond capsule was recovered.
  - Attempted Lunar orbiter and N1 rocket test
- Zond 7
  - Launched 7 August 1969
  - Lunar flyby 11 August 1969
  - Returned to Earth 14 August 1969
- Zond 8
  - Launched 20 October 1970
  - Lunar flyby 24 October 1970
  - Returned to Earth 27 October 1970
- Zond 9
  - Planned but cancelled
- Zond 10
  - Planned but cancelled

## Chapter- 4

# Mars Program

The **Mars program** was a series of unmanned spacecraft launched by the Soviet Union between 1960 and 1973. The spacecraft were intended to explore Mars, and included flyby probes, landers and orbiters.

Early Mars spacecraft were small, and launched by Molniya rockets. Starting with two failures in 1969, the heavier Proton-K rocket was used to launch larger 5 tonne spacecraft, consisting of an orbiter and a lander to Mars. The orbiter bus design was likely somewhat rushed into service and immature, considering that it performed very reliably in the Venera variant after 1975. This reliability problem was common to much Soviet space hardware from the late 1960s and early 1970s and was largely corrected with a deliberate policy, implemented in the mid-1970s, of consolidating (or "debugging") existing designs rather than introducing new ones.

In addition to the Mars program, the Soviet Union also sent a probe to Mars as part of the Zond program; Zond 2, however it failed en route. Two more spacecraft were sent during the Fobos program. In 1996, Russia launched Mars 96, its first interplanetary mission since the dissolution of the Soviet Union, however it failed to depart Earth orbit.

# Spacecraft

## Mars 1M



Mars 1 stamp

The first Soviet attempts to send a probe to Mars were the two Mars 1M spacecraft, which each had a mass of about 650 kg. Both were launched in 1960 and failed to achieve orbit. The spacecraft were dubbed *Marsnik* by the Western media.

## Mars 3MV

Mars 1 was launched in 1962 but failed en route to Mars. Two other Soviet launches at around the same time, Mars 2MV-4 No.1 and Mars 2MV-3 No.1 were 900-kilogram (2,000 lb) spacecraft, however both failed to leave Earth orbit due to problems with the upper stages of their carrier rockets.

## Mars 2M

Mars 2M No.521 and Mars 2M No.522, known in the West as Mars 1969A and B, were heavier spacecraft with masses of 5 tonnes (4.9 LT; 5.5 ST). They were launched by

Proton-K rockets, and consisted of orbiters and landers similar to late Venera, and Vega spacecraft.

## Mars 4M

The Mars 4M spacecraft; Mars 2 and Mars 3 missions consisted of identical spacecraft, each with an orbiter and an attached lander, which became the first spacecraft to reach the surface of Mars.

The orbiters' primary scientific objectives were to image the Martian surface and clouds, determine the temperature on Mars, study the topography, composition and physical properties of the surface, measure properties of the atmosphere, monitor the solar wind and the interplanetary and Martian magnetic fields, and act as communications relays to send signals from the landers to Earth.

## Mars 2



Mars 2 stamp

- Launch date/time:
  - Mars 2: May 19, 1971 at 16:22:44 UTC
- Launch mass (including fuel):
  - Combined: 4650 kg

- Orbiter: 3440 kg
- Lander: 1210 kg
- On-orbit dry mass: 2265 kg
- Dimensions: 4.1 meters tall, 2 meters across (5.9 meters across with solar panels deployed)

Mars 2 released the descent module 4.5 hours before reaching Mars on November 27, 1971. The descent module entered the Martian atmosphere at roughly 6.0 km/s at a steeper angle than planned. The descent system malfunctioned and the lander crashed at 45°S 30°W / 45°S 30°W, delivering the Soviet Union coat of arms to the surface. Meanwhile, the orbiter engine performed a burn to put the spacecraft into a 1380 x 24,940 km, 18 hour orbit about Mars with an inclination of 48.9 degrees. Scientific instruments were generally turned on for about 30 minutes near periapsis.

### **Mars 3**

- Launch date/time:
  - Mars 3: May 28, 1971 at 15:26:30 UTC
- Launch mass (including fuel):
  - Combined: 4650 kg
  - Orbiter: 3440 kg
  - Lander: 1210 kg
- On-orbit dry mass: 2265 kg
- Dimensions: 4.1 meters tall, 2 meters across (5.9 meters across with solar panels deployed)

Mars 3's descent module was released at 09:14 UT on December 2, 1971, 4 hours 35 minutes before reaching Mars. The descent module entered the Martian atmosphere at roughly 5.7 km/s. Through aerodynamic braking, parachutes, and retrorockets, the lander achieved a soft landing at 45°S 158°W / 45°S 158°W and began operations. However, after 20 seconds the instruments stopped working for unknown reasons, perhaps as a result of the massive surface dust storms raging at the time of landing. Mars 3 lander still managed to transmit a portion of the first picture of Martian surface. Meanwhile, the orbiter had suffered from a partial loss of fuel and did not have enough to put itself into a planned 25 hour orbit. The engine instead performed a truncated burn to put the spacecraft into a long 12 day, 19 hour period orbit about Mars with an inclination thought to be similar to that of Mars 2 (48.9 degrees).

Both landers had a small Mars 'rover' on board, which would move across the surface on skis while connected to the lander with a 15-meter umbilical. Two small metal rods were used for autonomous obstacle avoidance, as radio signals from Earth would take too long to drive the rovers using remote control. Each rover had both a densitometer and a dynamic penetrometer, to test the density and the bearing strength of the soil. Because of the demise of the landers, neither rover saw action.

The Mars 2 and 3 orbiters sent back a large volume of data covering the period from December 1971 to March 1972, although transmissions continued through August. It was announced that Mars 2 and 3 had completed their missions by August 22, 1972, after 362 orbits completed by Mars 2 and 20 orbits by Mars 3. The probes sent back a total of 60 pictures. The images and data enabled creation of surface relief maps, and gave information on the Martian gravity and magnetic fields.

### **Mars 3MS**

Kosmos 419 was launched on May 5, 1971. It consisted of only an orbiter, and was intended to become the first spacecraft to enter areocentric orbit, thereby beating the American Mariner 8 and Mariner 9 spacecraft.

The Mars 4 and Mars 5 orbiters, launched in 1973, were designed to orbit Mars and return information on the composition, structure, and properties of the Martian atmosphere and surface. The spacecraft were also designed to act as communications links to the Mars 6 and 7 landers. Like earlier heavy spacecraft, they were launched by Proton-K rockets.

### **Mars 4**

- Launch date/time:
  - Mars 4: July 21, 1973 at 19:30:59 UTC
- On-orbit mass:
  - Dry: 2270 kg
  - Fully-fuelled: 3440 kg

The Mars 4 orbiter reached Mars on February 10, 1974. Due to a flaw in the computer chip which resulted in degradation of the chip during the voyage to Mars, the retro-rockets designed to slow the craft into Mars orbit did not fire and Mars 4 flew by the planet at a range of 2200 km. It returned one swath of pictures and some radio occultation data which constituted the first detection of the nightside ionosphere on Mars. It continued to return interplanetary data from solar orbit after the flyby.

### **Mars 5**

- Launch date/time:
  - Mars 5: July 25, 1973 at 18:55:48 UTC
- On-orbit mass:
  - Dry: 2270 kg
  - Fully-fuelled: 3440 kg

Mars 5 reached Mars on February 12, 1974 at 15:45 UT and was inserted into an elliptical 1755 by 32,555 km, 24 h 53 min orbit with an inclination of 35.3 degrees. Nearly synchronized with the rotation of the planet, its two phototelevision cameras could be commanded to take 12 pictures during each close approach. The Vega camera

used a wide area 52mm lens with color filters, the Zulfar camera used a telescopic 350mm lens and long-pass orange filter. Images were transmitted in a rapid 220-line mode, and then selected pictures were retransmitted at 880 or 1760 line resolution. Mars 5 collected data for 22 orbits until a loss of pressurization in the transmitter housing ended the mission. About 60 images were returned over a nine day period showing swaths of the area south of Valles Marineris, from 5°N 330°W / 5°N 330°W to 20°S 130°W / 20°S 130°W.

## **Mars 3MP**

The 1973 Mars launch window was inefficient and thus the Proton could not deliver sufficient mass to the necessary trajectory to reach Mars, as had been possible in 1971. To resolve this problem, two landers were launched with orbiter type buses, but without fuel to enter orbit. The Mars 4 and 5 orbiters, which had been launched separately, were used to relay communications, and to complete mission objectives which would have been completed by orbiters launched with the Mars 6 and 7 spacecraft had they been flown.

## **Mars 6**

Mars 6 successfully lifted off on August 5, 1973, into an intermediate Earth orbit on a Proton SL-12/D-1-e booster and then launched into a Mars transfer trajectory. Total fueled launch mass of the lander and bus was 3260 kg. It reached Mars on March 12, 1974. The descent module separated from the bus at a distance of 48,000 km from Mars. The bus continued on into a heliocentric orbit after passing within 1600 km of Mars. The descent module entered the atmosphere at 09:05:53 UT at a speed of 5.6 km/s. The parachute opened at 09:08:32 UT after the module had slowed its speed to 600 m/s by aerobraking. During this time the craft was collecting data and transmitting it directly to the bus for immediate relay to Earth. Contact with the descent module was lost at 09:11:05 UT in "direct proximity to the surface", probably either when the retrorockets fired or when it hit the surface at an estimated 61 m/s. Mars 6 landed at 23°54'S 19°25'W / 23.90°S 19.42°W in the Margaritifer Terra region of Mars. The landed mass was 635 kg. The descent module transmitted 224 seconds of data before transmissions ceased, the first data returned from the atmosphere of Mars. Much of the data was unreadable due to a flaw in a computer chip which led to degradation of the system during its journey to Mars.

## **Mars 7**

Mars 7 successfully lifted off on August 9, 1973, into an intermediate Earth orbit on a Proton SL-12/D-1-e booster and then launched into a Mars transfer trajectory. Total fueled launch mass of the lander and bus was 3260 kg. It reached Mars on March 9, 1974. Due to a problem in the operation of one of the on-board systems (attitude control or retro-rockets) the landing probe separated prematurely (4 hours before encounter) and missed the planet by 1300 km. The early separation was probably due to a computer chip error which resulted from degradation of the systems during the trip to Mars. The

intended landing site was 50°S 28°W / 50°S 28°W. The lander and bus continued on into heliocentric orbits.

### **Mars 4NM and 5NM**

The Mars 4NM and Mars 5NM projects would have seen heavier spacecraft launched by N1 rockets. They would have deployed Marsokhod rovers onto the surface, and conducted sample return missions. The N1 failed on all four of its test flights, and was never used to launch any Mars spacecraft.

## Chapter- 5

# 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.

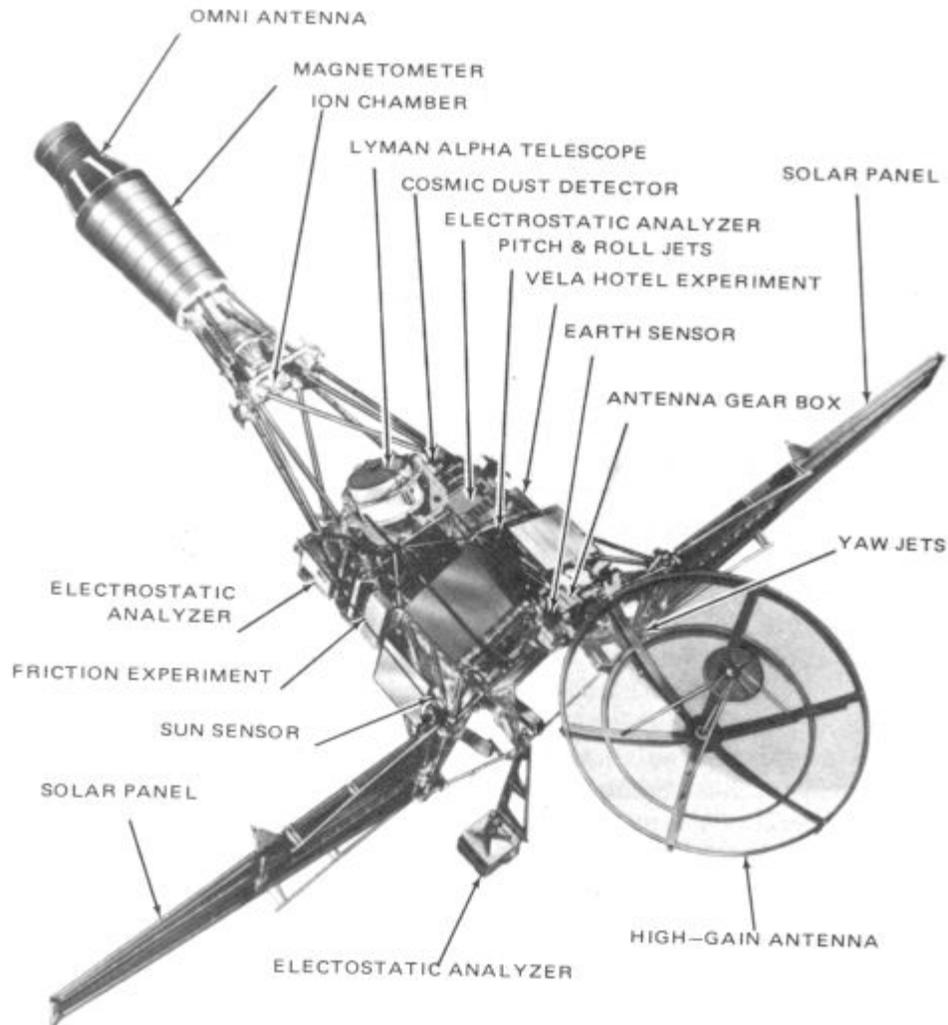
Ranger was originally designed, beginning in 1959, in three distinct phases, called "blocks". Each block had different mission objectives and progressively more advanced system design. The JPL mission designers planned multiple launches in each block, to maximize the engineering experience and scientific 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

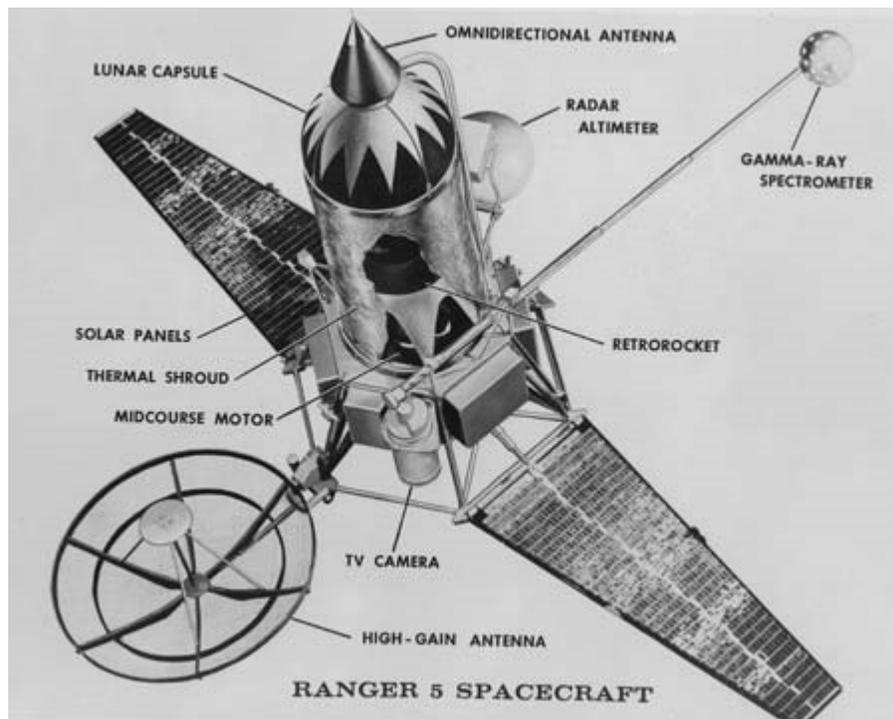
Block 1, consisting of two spacecraft launched into Earth orbit in 1961, was intended to test the Atlas-Agena launch vehicle and spacecraft equipment without attempting to reach the Moon.

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)

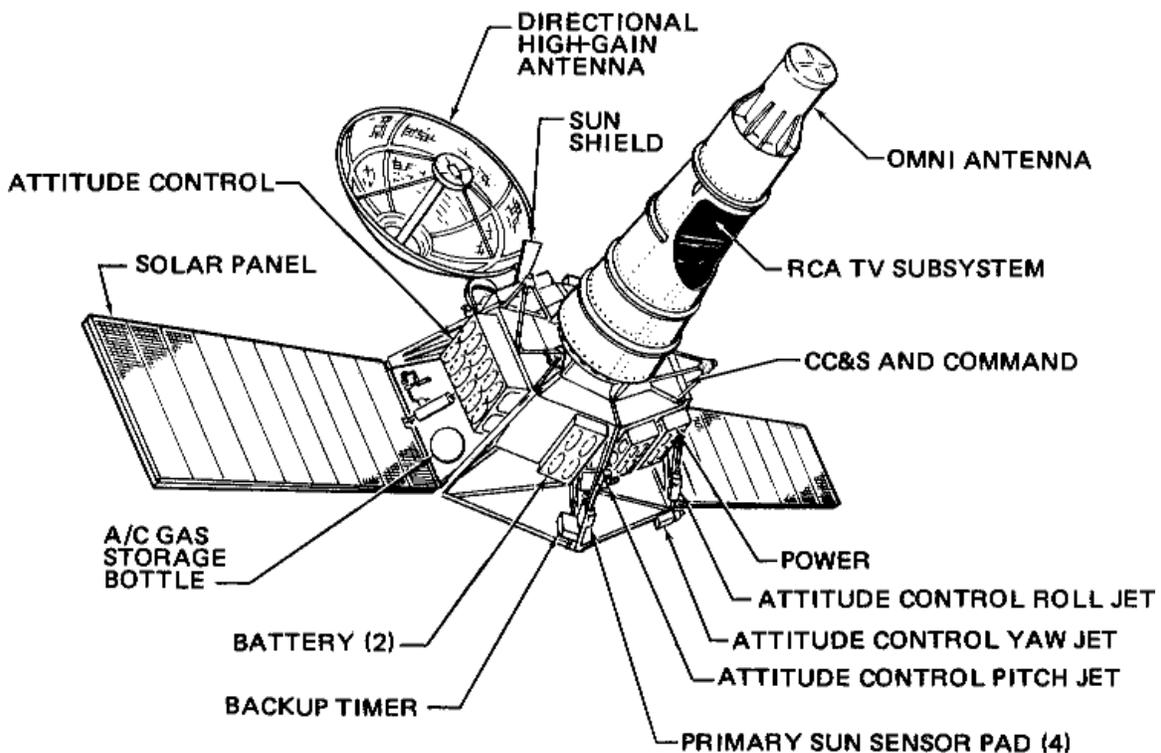
- Ranger 3, launched 26 January 1962, lunar probe, spacecraft failed, missed moon
- Ranger 4, launched 23 April 1962, lunar probe, spacecraft failed, impact
- Ranger 5, launched 18 October 1962, lunar probe, spacecraft failed, missed

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/Agna 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.

## Chapter- 6

# Mariner Program



Launch of Mariner 1 in 1962

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

Of the ten vehicles in the Mariner series, seven were successful and three were lost. The planned Mariner 11 and Mariner 12 vehicles evolved into Voyager 1 and Voyager 2 of the Voyager program, while the Viking 1 and Viking 2 Mars orbiters were enlarged versions of the Mariner 9 spacecraft. Other Mariner-based spacecraft, launched since Voyager, included the Magellan probe to Venus, and the Galileo probe to Jupiter. A

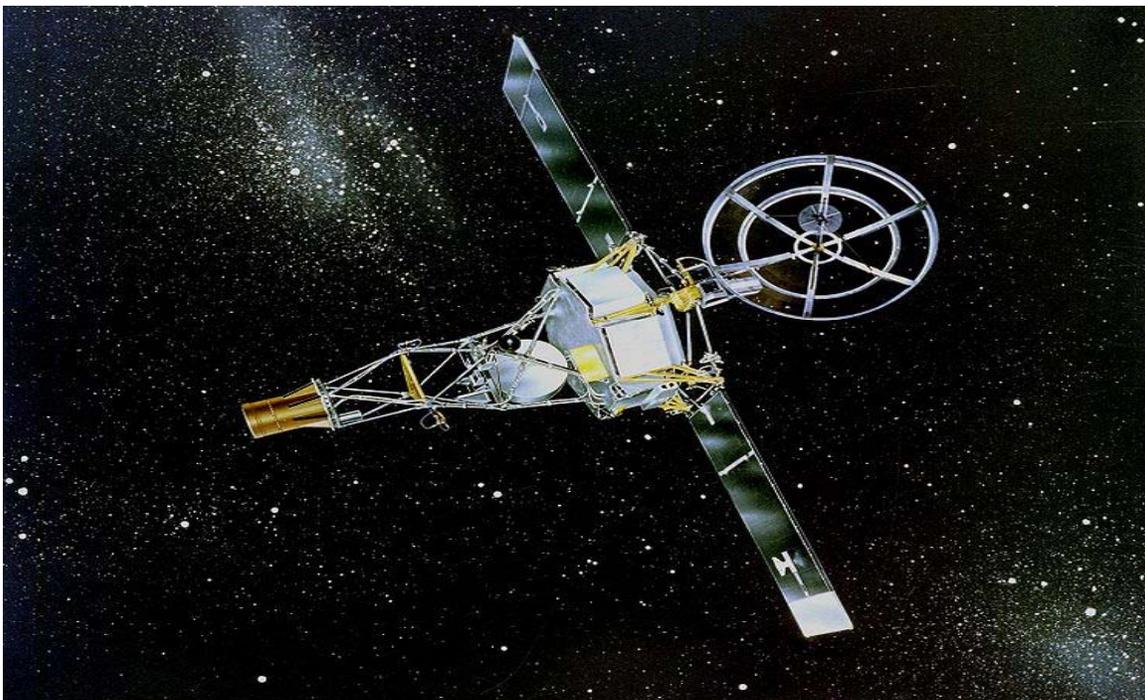
second-generation Mariner spacecraft, called the Mariner Mark II series, eventually evolved into the Cassini-Huygens probe, now in orbit around Saturn.

## Basic layout

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

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

## Mariners 1 and 2



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

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

Status:

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

## Mariners 3 and 4



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

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

Status:

- Mariner 3 – Malfunctioned. Trapped in a Heliocentric orbit.

- Mariner 4 – Unknown. Communications lost after bombardment by micrometeoroids.

## Mariner 5

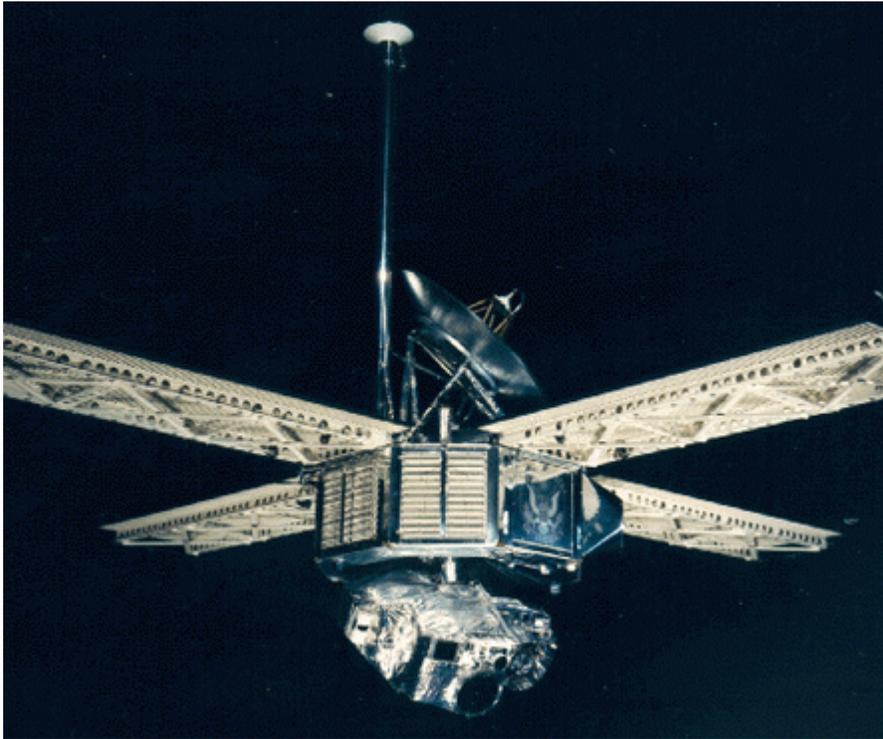


The Mariner 5 spacecraft was launched to Venus on June 14, 1967 and arrived in the vicinity of the planet in October 1967. It carried a complement of experiments to probe Venus' atmosphere with radio waves, scan its brightness in ultraviolet light, and sample the solar particles and magnetic field fluctuations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

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

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

## Mariners 6 and 7



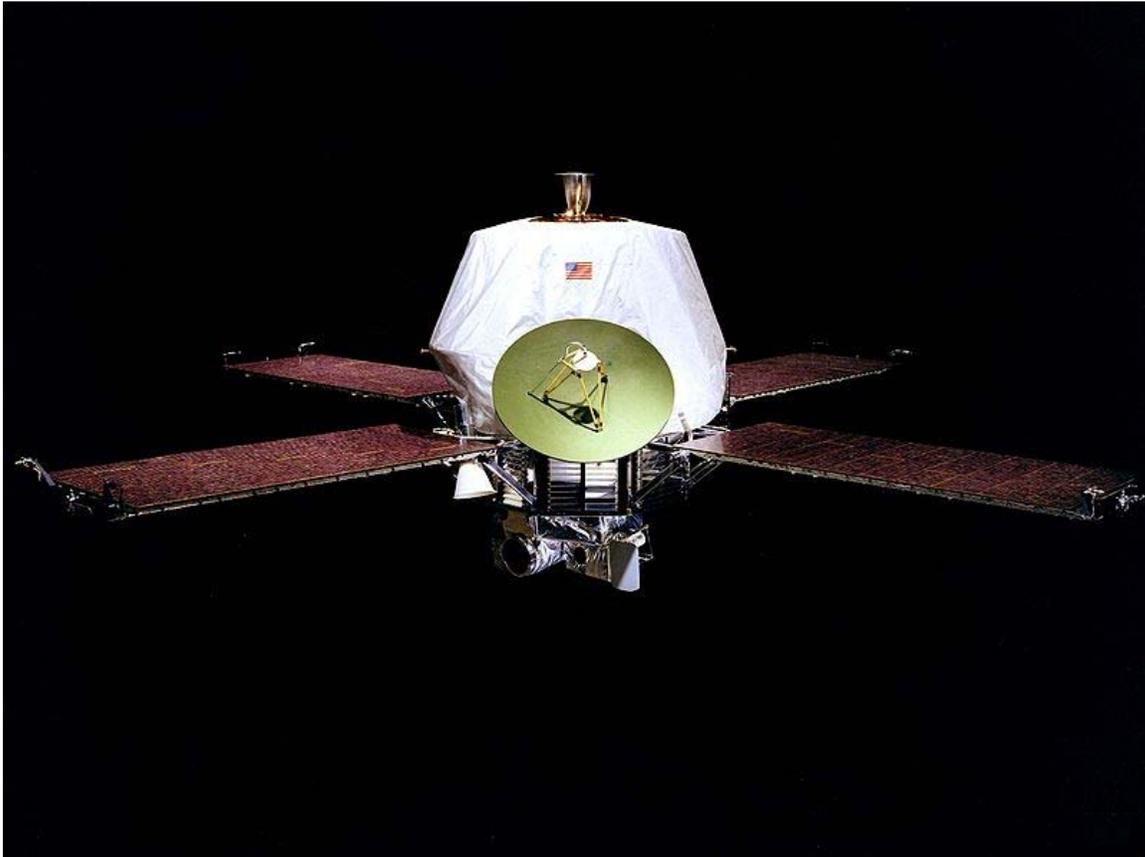
Mariners 6 and 7 were identical teammates in a two-spacecraft mission to Mars. Mariner 6 was launched on February 24, 1969, followed by Mariner 7 on March 21, 1969. They flew over the equator and southern hemisphere of the planet Mars.

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

Status:

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

## Mariners 8 and 9



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

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

Status:

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

## Mariner 10



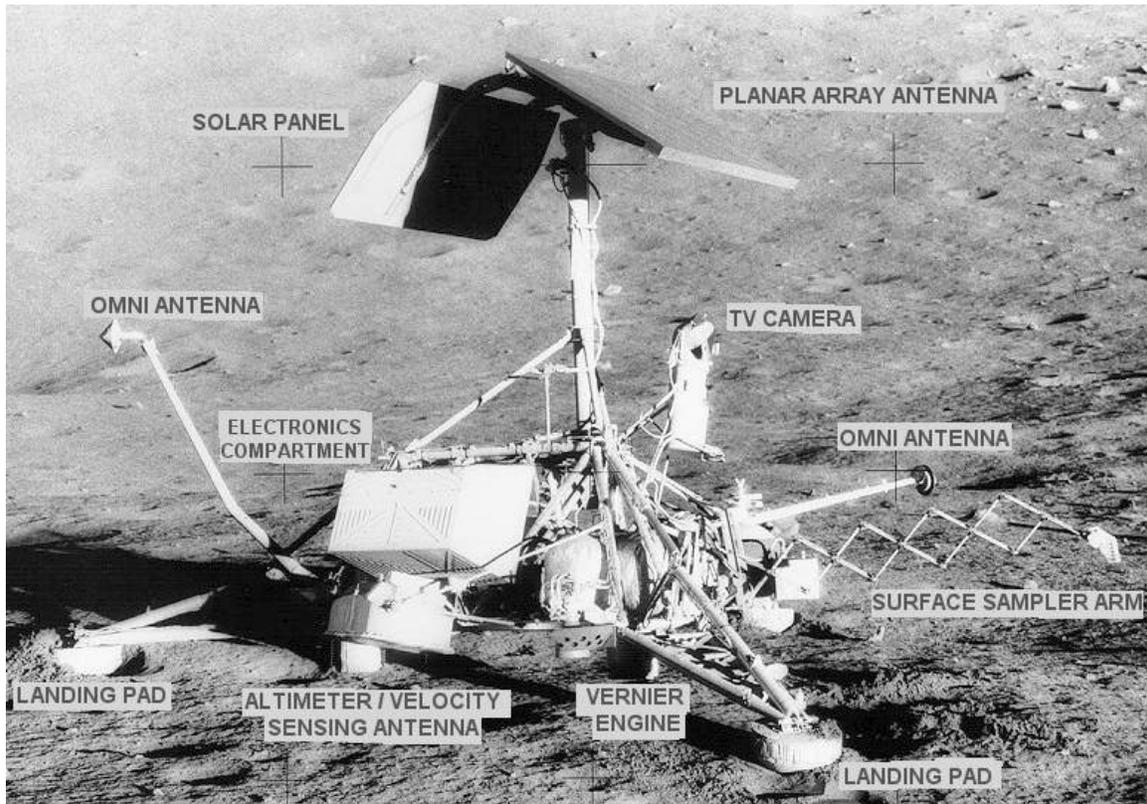
The Mariner 10 spacecraft launched on November 3, 1973 and was the first to use a gravity assist trajectory, accelerating as it entered the gravitational influence of Venus, then being flung by the planet's gravity onto a slightly different course to reach Mercury. It was also the first spacecraft to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

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

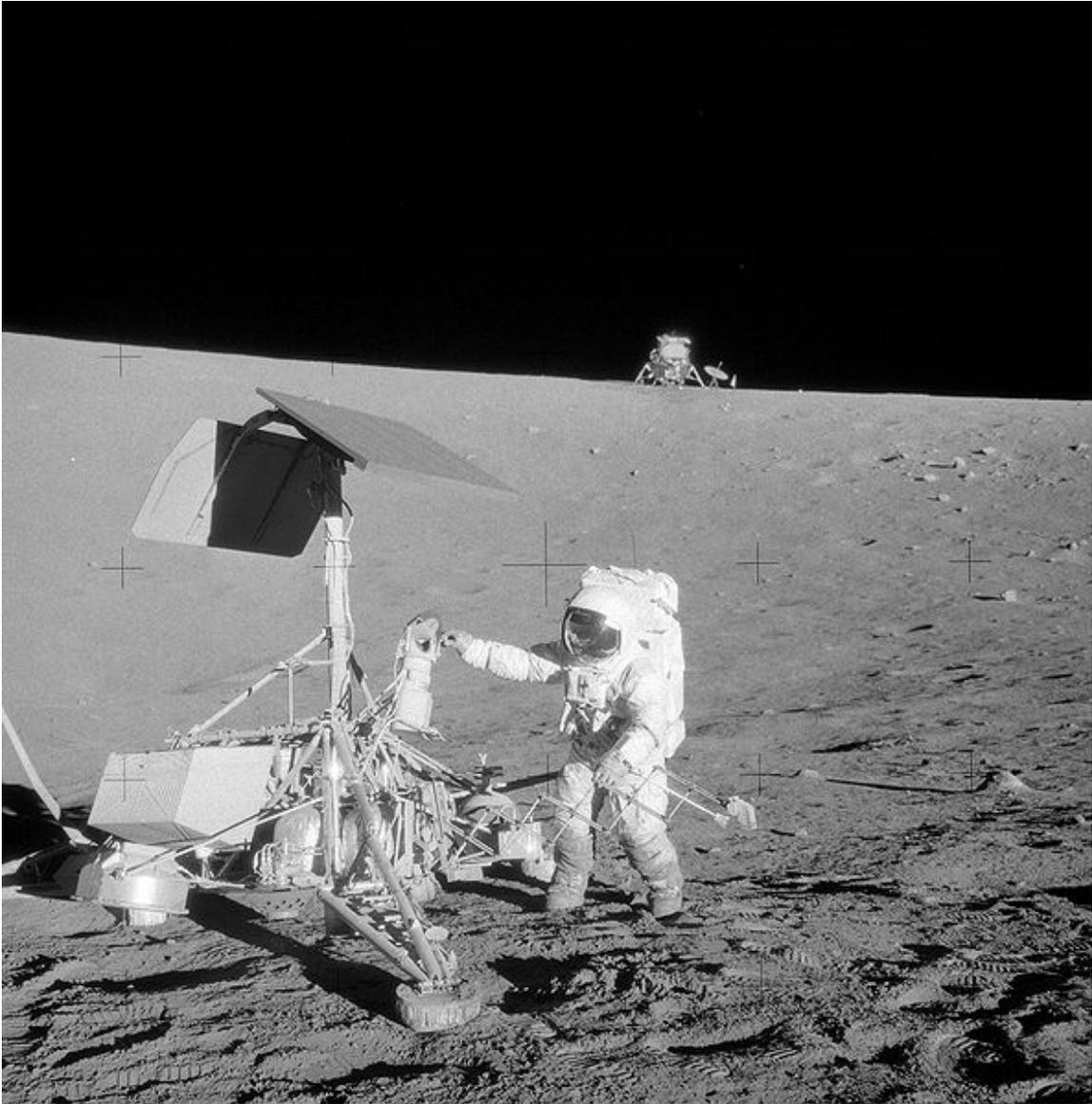
Status: Mariner 10 – Defunct. Trapped in Heliocentric orbit.

## Chapter- 7

# 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 away, in the background. (NASA)

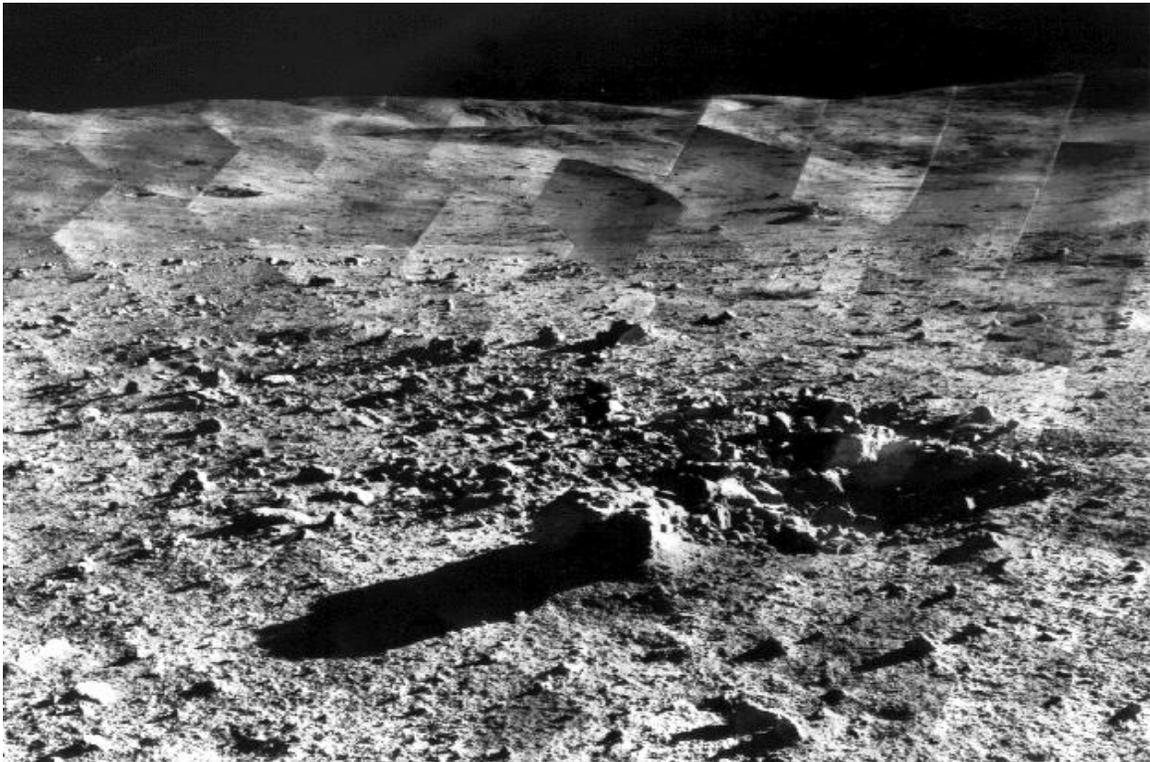
The **Surveyor Program** was a NASA program that, from 1966 through 1968, sent seven robotic spacecraft to the surface of the Moon. Its primary goal was to demonstrate the feasibility of soft landings on the Moon. The mission called for the craft to travel directly to the moon on an impact trajectory, on a journey that lasted 63 to 65 hours, and ended with a deceleration of just over three minutes to a soft-landing. 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 the crew of Apollo 12, which landed near it in 1969. The camera from this craft is on display at the National Air and Space Museum in Washington, DC.

## 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.

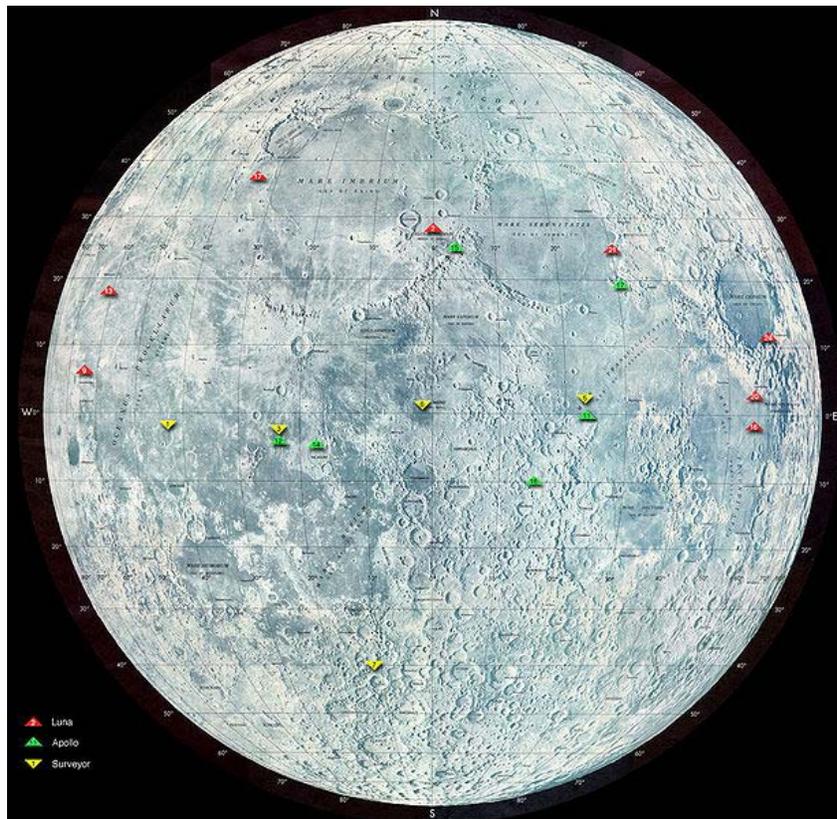
Each Surveyor mission consisted of a single unmanned spacecraft designed and built by Hughes Aircraft Company. The launch vehicle was the Atlas-Centaur which injected the craft directly into trans-lunar flightpath. The craft did not orbit the moon on reaching it, but directly decelerated from impact trajectory, from 2.6 km/s relative to the moon before firing retrorockets, to a soft landing about 3 minutes 10 seconds later.

Each craft was planned to slow 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 fed to them using pressurized helium. (The successful flight profile of Surveyor 5 was given a somewhat shortened vernier flight sequence as a result of a helium leak). 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, and Surveyor 5 required 65 hours (2.7 days). The launch weights (at lunar injection) of the seven Surveyors ranged from 995.2 kilograms (2,194 lb) to 1,040 kilograms (2,300 lb), and their landing weights (minus fuel, jetisoned retrorocket, and radar unit) ranged from 294.3 kilograms (649 lb) to 306 kilograms (670 lb).

## Missions



Location of Surveyor missions on the Moon

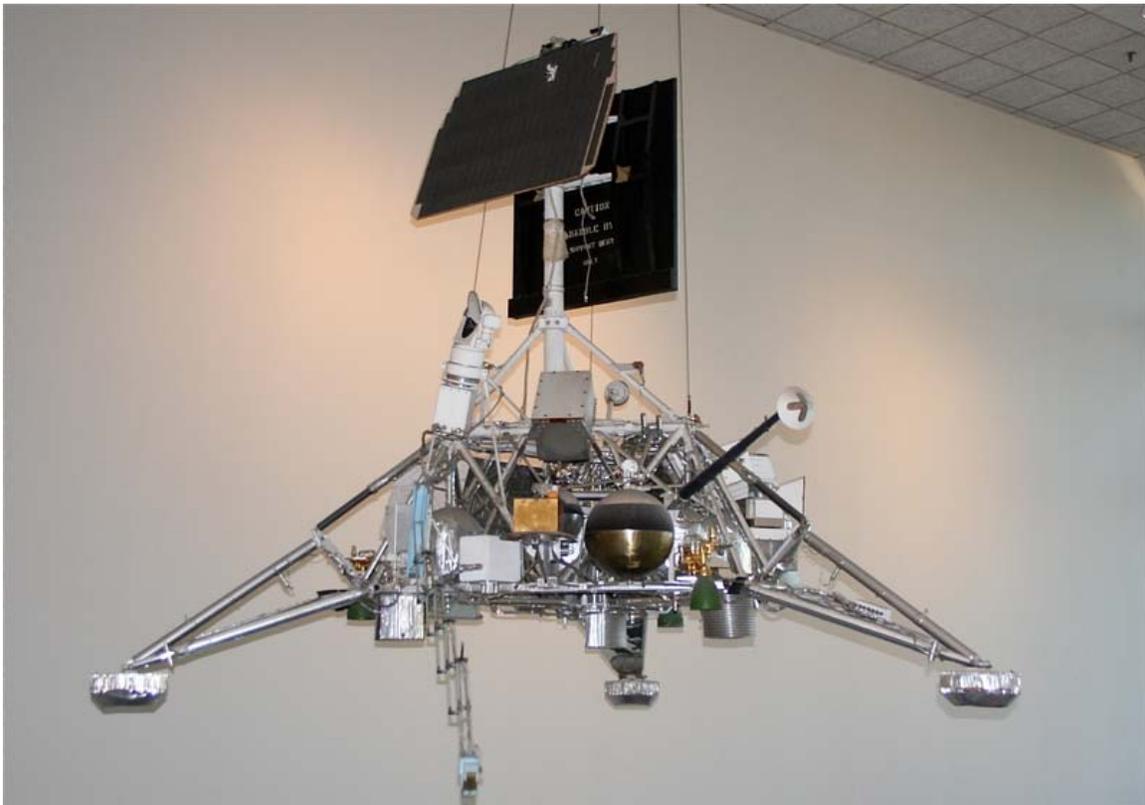
There were seven Surveyor missions; five were successful. Surveyors 2 and 4 failed.

- **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, which it did twice, due to an anomaly with Surveyor's Landing Radar which did not shut off the vernier engines but kept them firing throughout the first touchdown, and after it. Apollo 12's Lunar Module *Intrepid* landed 600 feet from Surveyor 3, as planned. Surveyor 3's TV and telemetry systems were found to have been 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.

## Chapter- 8

# Lunar Orbiter Program



Lunar orbiter spacecraft (NASA)

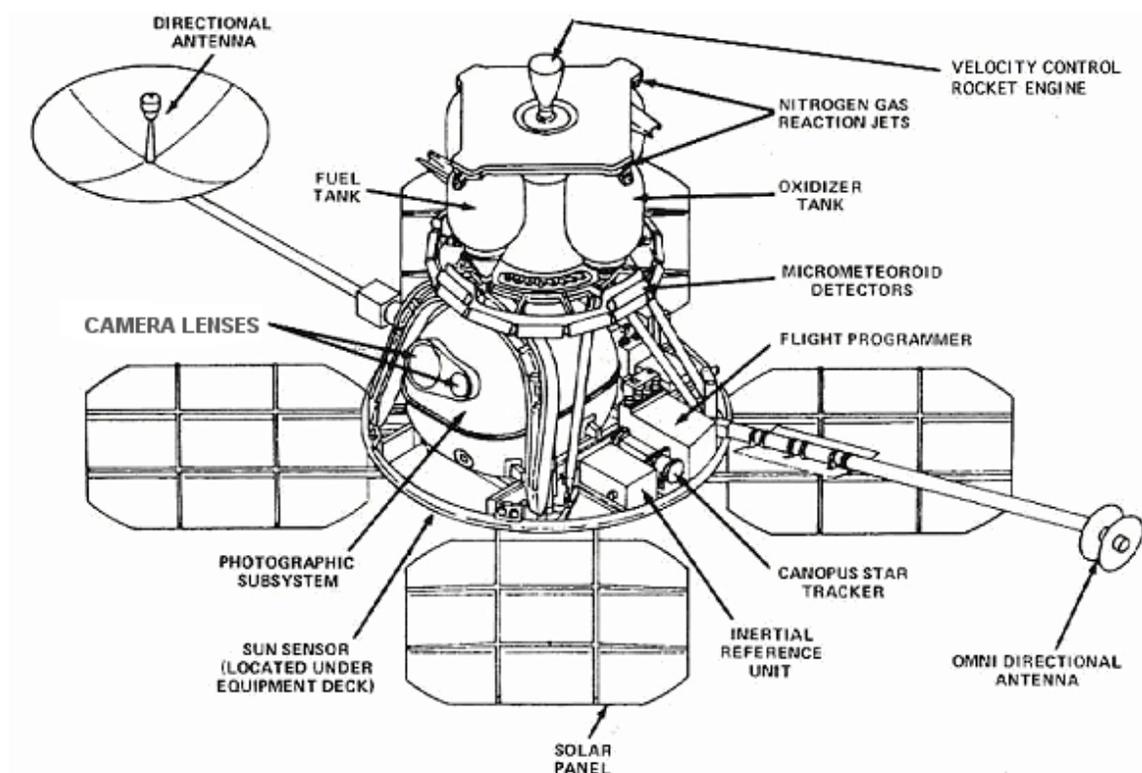
The **Lunar Orbiter program** was a series of five unmanned lunar orbiter missions launched by the United States from 1966 through 1967. Intended to help select Apollo landing sites by mapping the Moon's surface, they provided the first photographs from lunar orbit.

All five missions were successful, and 99 percent of the Moon was mapped from photographs taken with a resolution of 60 meters or better. The first three missions were dedicated to imaging 20 potential manned lunar landing sites, selected based on Earth-based observations. These were flown at low inclination orbits. The fourth and fifth missions were devoted to broader scientific objectives and were flown in high-altitude polar orbits. Lunar Orbiter 4 photographed the entire nearside and 9 percent of the far side, and Lunar Orbiter 5 completed the far side coverage and acquired medium (20 m) and high (2 m) resolution images of 36 pre-selected areas. All Lunar Orbiter craft were launched by an Atlas-Agena D launch vehicle.

The Lunar Orbiters had an ingenious imaging system, which consisted of a dual-lens camera, a film processing unit, a readout scanner, and a film handling apparatus. Both lenses, a 610 mm narrow angle high resolution (HR) lens and an 80 mm wide angle medium resolution (MR) lens, placed their frame exposures on a single roll of 70 mm film. The axes of the two cameras were coincident so the area imaged in the HR frames were centered within the MR frame areas. The film was moved during exposure to compensate for the spacecraft velocity, which was estimated by an electro-optical sensor. The film was then processed, scanned, and the images transmitted back to Earth.

During the Lunar Orbiter missions, the first pictures of Earth as a whole were taken, beginning with Earth-rise over the lunar surface by Lunar Orbiter 1 in August, 1966. The first full picture of the whole Earth was taken by Lunar Orbiter 5 in August, 1967. The second photo of the whole Earth was taken by Lunar Orbiter V on November 10, 1967. This photo was published by Stewart Brand in the first Whole Earth Catalog in the fall of 1968.

## Spacecraft and subsystems



Lunar Orbiter diagram (NASA)

The main bus of the Lunar Orbiter had the general shape of a truncated cone, 1.65 metres tall and 1.5 m in diameter at the base. The spacecraft was composed of three decks supported by trusses and an arch. The equipment deck at the base of the craft held the battery, transponder, flight programmer, inertial reference unit (IRU), Canopus star

tracker, command decoder, multiplex encoder, traveling wave tube amplifier (TWTA), and the photographic system. Four solar panels were mounted to extend out from this deck with a total span across of 3.72 m. Also extending out from the base of the spacecraft were a high gain antenna on a 1.32 m boom and a low gain antenna on a 2.08 m boom. Above the equipment deck, the middle deck held the velocity control engine, propellant, oxidizer and pressurization tanks, Sun sensors, and micro-meteoroid detectors. The third deck consisted of a heat shield to protect the spacecraft from the firing of the velocity control engine. The nozzle of the engine protruded through the center of the shield. Mounted on the perimeter of the top deck were four attitude control thrusters.

Power of 375 W was provided by the four solar arrays containing 10,856 n/p solar cells which would directly run the spacecraft and also charge the 12 A·h nickel-cadmium battery. The batteries were used during brief periods of occultation when no solar power was available. Propulsion for major maneuvers was provided by the gimballed velocity control engine, a hypergolic 100 pound-force (445 N) thrust Marquardt rocket motor. Three axis stabilization and attitude control were provided by four one lbf (4 N) nitrogen gas jets. Navigational knowledge was provided by five Sun sensors, Canopus star sensor, and the IRU equipped with internal gyros. Communications were via a 10 W transmitter and the directional 1 m diameter high gain antenna for transmission of photographs and a 0.5 W transmitter and omnidirectional low gain antenna for other communications. Both antennas operated in S-band at 2295 MHz. Thermal control was maintained by a multilayer aluminized Mylar and Dacron thermal blanket which enshrouded the main bus, special paint, insulation, and small heaters.

The photographic system was provided by Eastman Kodak and derived from a system designed for the U-2 and SR-71 reconnaissance aircraft. The camera used two lenses to simultaneously expose a wide-angle and a high-resolution image on the same film. The wide-angle, medium resolution mode used a 80 mm F 2.8 Xenotar lens manufactured by Schneider Kreuznach, Germany. The high-resolution mode used a 610 mm F 5.6 Panoramic lens manufactured by the Pacific Optical Company. The film was developed on-orbit, and then scanned by a photomultiplier for transmission to Earth.

## **Results**

The Lunar Orbiter program consisted of five spacecraft which returned photography of 99 percent of the surface of the Moon (near and far side) with resolution down to 1 meter. Altogether the Orbiters returned 2180 high resolution and 882 medium resolution frames. The micro-meteoroid experiments recorded 22 impacts showing the average micro-meteoroid flux near the Moon was about two orders of magnitude greater than in interplanetary space, but slightly less than the near-Earth environment. The radiation experiments confirmed that the design of Apollo hardware would protect the astronauts from average and greater than average short term exposure to solar particle events. The use of Lunar Orbiters for tracking to evaluate the Manned Space Flight Network tracking stations and Apollo Orbit Determination Program was successful, with three Lunar Orbiters (2, 3, and 5) being tracked simultaneously from August to October 1967. The

Lunar Orbiters were all eventually commanded to crash on the Moon before their attitude control fuel ran out so they would not present navigational or communications hazards to later Apollo flights. The Lunar Orbiter program was managed by NASA Langley Research Center at a total cost of roughly \$200 million.



Lunar Orbiter camera (NASA)

Below is the flight log information of the five Lunar Orbiter photographic missions:

- Lunar Orbiter 1
  - Launched August 10, 1966
  - Imaged Moon: August 18 to 29, 1966
  - Impact with Moon: October 29, 1966
  - Apollo landing site survey mission
- Lunar Orbiter 2
  - Launched November 6, 1966
  - Imaged Moon: November 18 to 25, 1966
  - Impact with Moon: October 11, 1967
  - Apollo landing site survey mission
- Lunar Orbiter 3
  - Launched February 5, 1967

- Imaged Moon: February 15 to 23, 1967
- Impact with Moon: October 9, 1967
- Apollo landing site survey mission
- Lunar Orbiter 4
  - Launched May 4, 1967
  - Imaged Moon: May 11 to 26, 1967
  - Impact with Moon: Approximately October 31, 1967
  - Lunar mapping mission
- Lunar Orbiter 5
  - Launched August 1, 1967
  - Imaged Moon: August 6 to 18, 1967
  - Impact with Moon: January 31, 1968
  - Lunar mapping and hi-res survey mission

## **Data availability**

The Lunar Orbiter orbital photographs were transmitted to Earth as analog data after onboard scanning of the original film into a series of strips. The data were written to magnetic tape and also to film. The film data were used to create hand-made mosaics of Lunar Orbiter frames. Each LO exposure resulted in two photographs: medium-resolution frames recorded by the 80-mm focal-length lens and high-resolution frames recorded by the 610-mm focal length lens. Due to their large size, HR frames were divided into three sections, or sub-frames. Large-format prints (16 x 20 inches) from the mosaics were created and several copies were distributed across the U.S. to NASA image and data libraries known as Regional Planetary Information Facilities. The resulting outstanding views were of generally very high spatial resolution and covered a substantial portion of the lunar surface, but they suffered from a “venetian blind” striping, missing or duplicated data, and frequent saturation effects that hampered their use. Nevertheless, for many years these images have been the basis of much of lunar scientific research. Because they were obtained at low to moderate Sun angles, the Lunar Orbiter photographic mosaics are particularly useful for studying the morphology of lunar topographic features.

Several atlases and books featuring Lunar Orbiter photographs have been published. Perhaps the most definitive was that of Bowker and Hughes (1971); it contained 675 photographic plates with approximately global coverage of the Moon. In part because of high interest in the data and in part because that atlas is out of print, the task was undertaken at the Lunar and Planetary Institute to scan the large-format prints of Lunar Orbiter data. These were made available online as the Digital Lunar Orbiter Photographic Atlas of the Moon.

## Data recovery and digitization



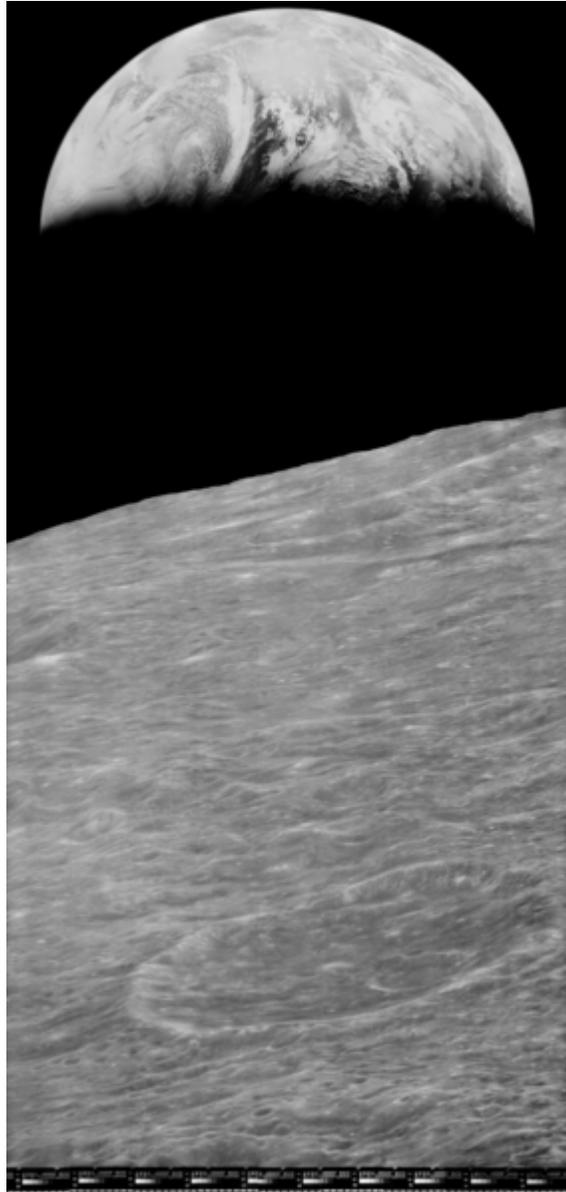
A detail of an original image at the top, compared to a reprocessed version at the bottom created by LOIRP.

In 2000, the Astrogeology Research Program of the US Geological Survey in Flagstaff, AZ was funded by NASA (as part of the Lunar Orbiter Digitization Project) to scan at 25 micrometre resolution archival LO positive film strips that were produced from the original data. The goal was to produce a global mosaic of the Moon using the best available Lunar Orbiter frames (largely the same coverage as that of Bowker and Hughes, 1971). The frames were constructed from scanned film strips; they were digitally constructed, geometrically controlled, and map-projected without the stripes that had been noticeable in the original photographic frames. Because of its emphasis on construction of a global mosaic, this project only scanned about 15% of the available Lunar Orbiter photographic frames. Data from Lunar Orbiter missions III, IV and V were included in the global mosaic.

In addition, the USGS digitization project created frames from very high resolution Lunar Orbiter images for several 'sites of scientific interest.' These sites had been identified in the 1960s when the Apollo landing sites were being selected. Frames for sites such as the Apollo 12 landing site, the Marius Hills, and the Sulpicius Gallus rille have been released.

In 2007, the Lunar Orbiter Image Recovery Project (LOIRP) began a process to convert the Lunar Orbiter Images directly from the original Ampex FR-900 analog video recordings of the spacecraft data to digital image format, a change which provided vastly improved resolution over the original images released in the 1960s. The first of these restored images were released in late 2008.





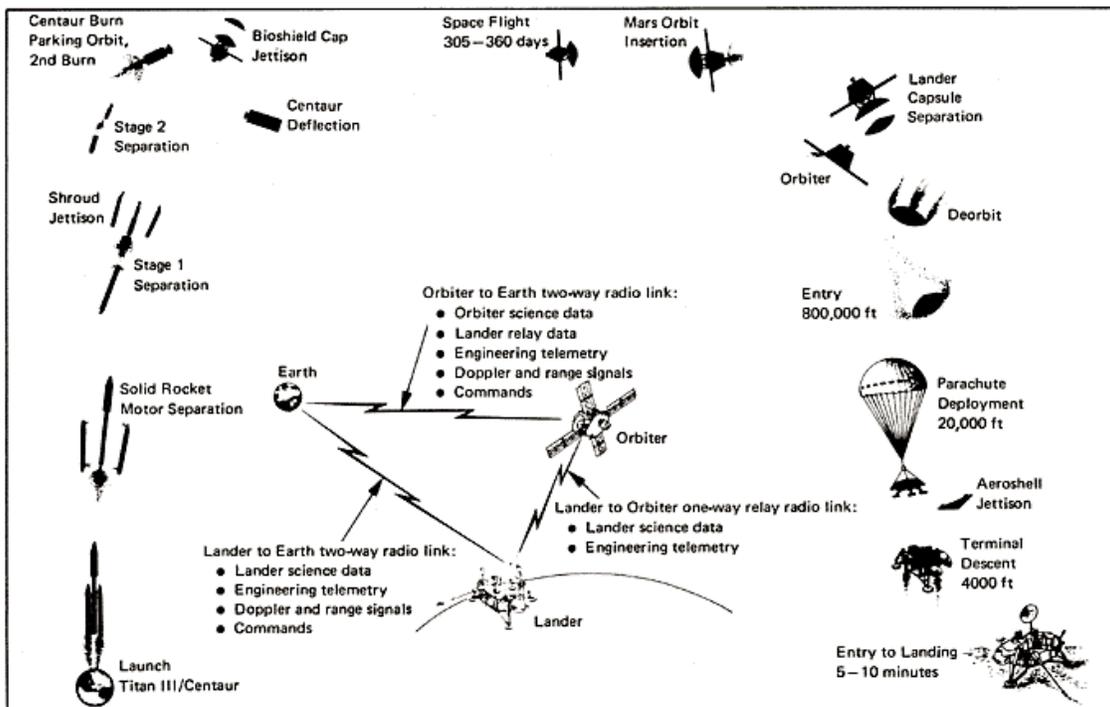
The first image of Earth taken from the Moon. On the left the original and on the right a digitally restored version created by LOIRP

# Chapter- 9

## Viking Program



Viking mission patch



Viking mission profile

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

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

## Viking orbiters



Viking orbiter (NASA)

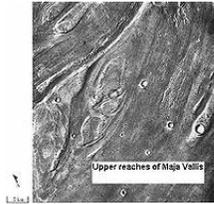
The primary objectives of the Viking orbiters were to transport the landers to Mars, perform reconnaissance to locate and certify landing sites, act as a communications relays for the landers, and to perform their own scientific investigations. Each orbiter, based on the earlier Mariner 9 spacecraft,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

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

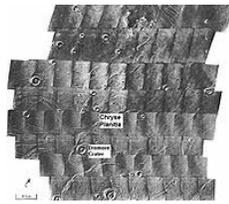
The main propulsion unit was mounted above the orbiter bus. Propulsion was furnished by a bipropellant (monomethylhydrazine and nitrogen tetroxide) liquid-fueled rocket engine which could be gimballed up to 9 degrees. The engine was capable of 1323 N (297 lbf) thrust, translating to a delta-V of 1480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

## Viking Mosaics

The images here, from the Viking Orbiters, are mosaics of many small, high resolution images. Some of the pictures are labeled with place names.



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



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



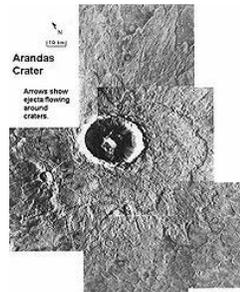
Great amounts of water were required to carry out the erosion shown in this Viking image. Image is located in Lunae Palus quadrangle.



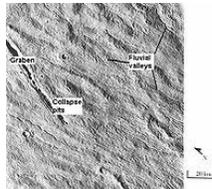
Tear-drop shaped islands caused by flood waters from Maja Valles. Image is located in Oxia Palus quadrangle.



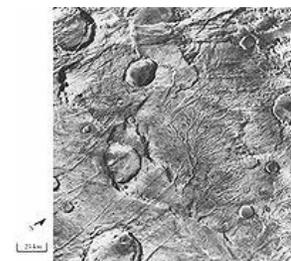
The ejecta from Vedra Vallis, Maumee Vallis, and Maja Valles move from Lunae Planum on the left to Chryse Planitia on the right. Image is located in Lunae Palus quadrangle.



The ejecta from Arandas Crater acts like mud. It moves around small craters (indicated by arrows), instead of falling down on them. Craters like this suggest

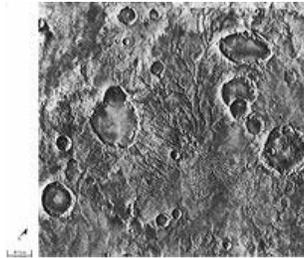


This view of the flank of Alba Patera shows several channels. Some channels are associated with lava flows; others are probably caused by running water. A large trough or



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

that large amounts of frozen water were melted when the impact crater was produced. Image is located in Mare Acidalium quadrangle.



graben turns into a line of collapse pits. Image is located in Arcadia quadrangle.



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

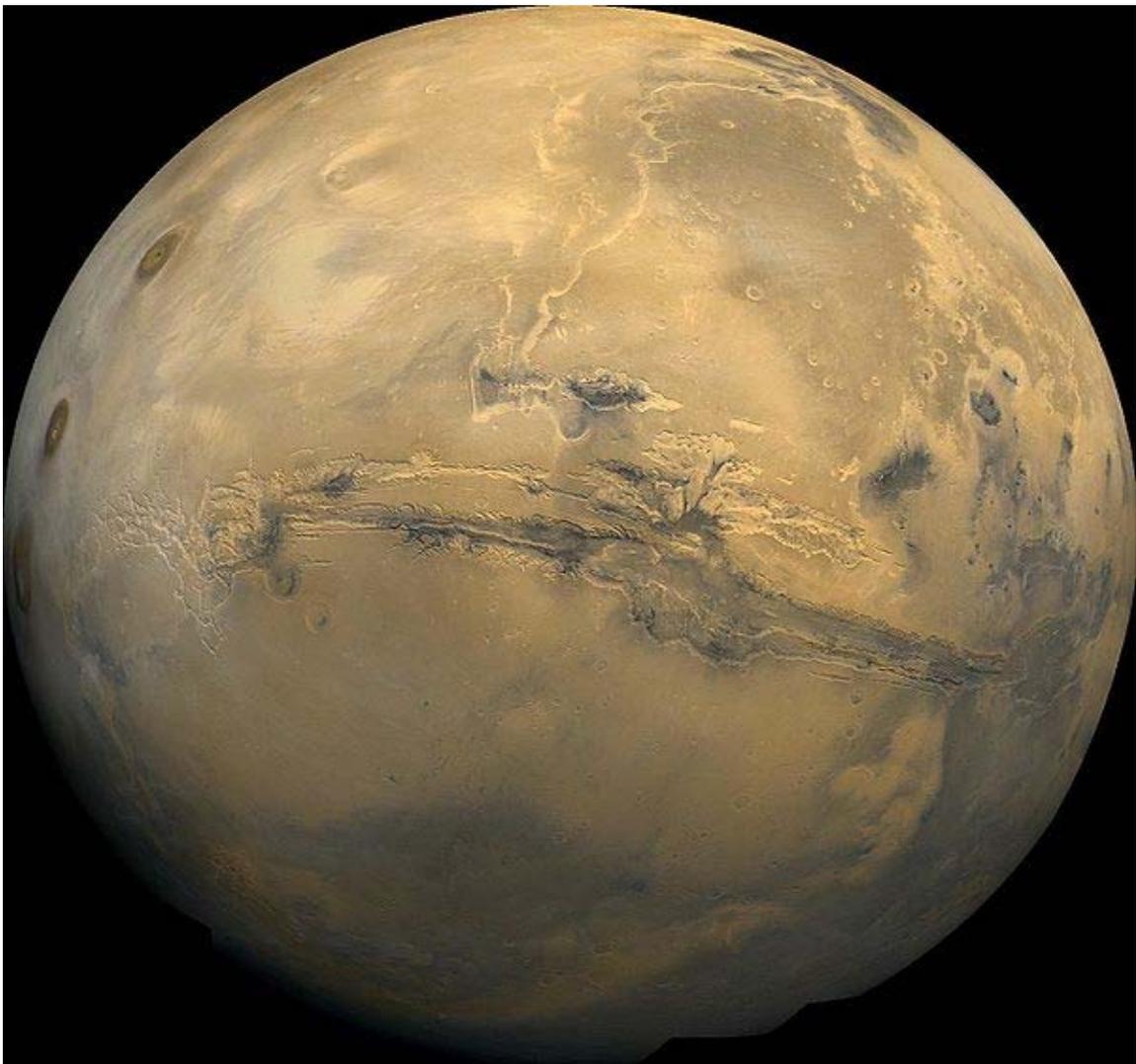
Ravi Vallis. Ravi Vallis was probably formed when catastrophic floods came out of the ground to the right (chaotic terrain). Image located in Margaritifer Sinus quadrangle.

## Viking landers



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

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



Mars from the Viking Orbiter

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

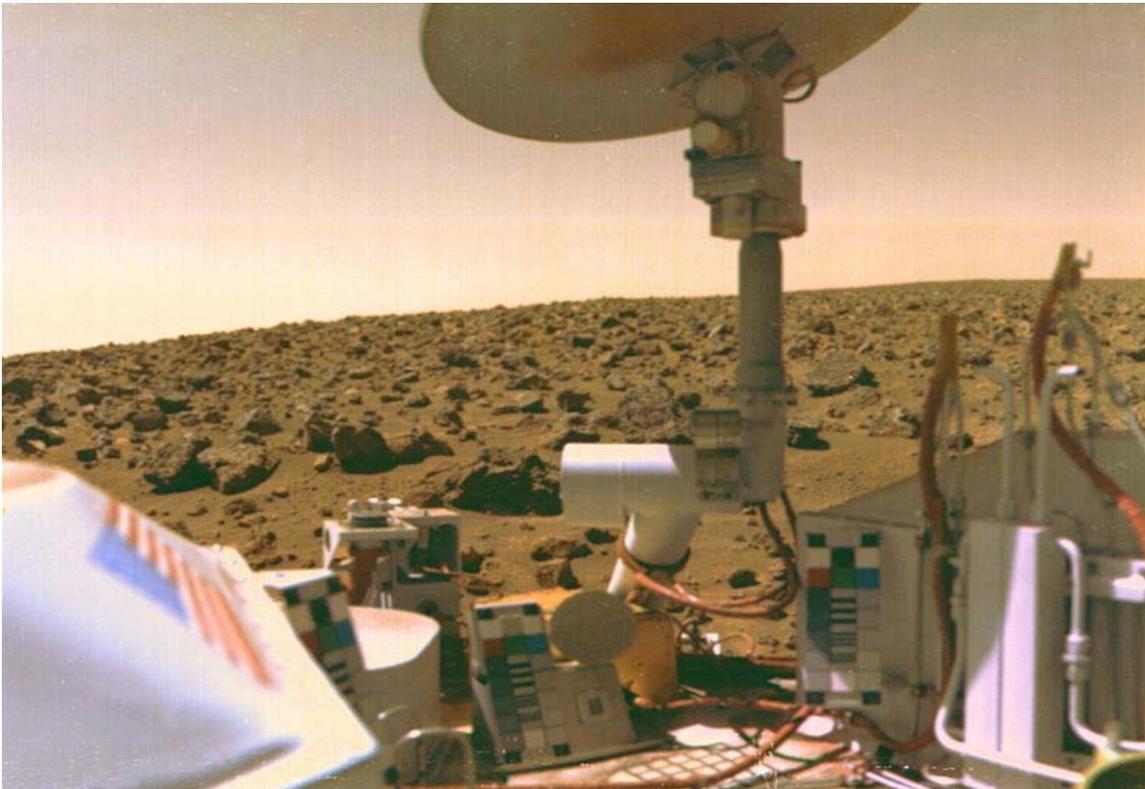


Image from Mars taken by Viking 2

Each lander was covered over from launch until Martian atmospheric entry with an aeroshell heat shield designed to slow the lander down during the entry phase, and also to prevent contamination of the Martian surface with Earthly microbial life that can survive the harsh conditions of deep space (as evident on the Surveyor 3 moon probe). As a further precaution, each lander, upon assembly and enclosure within the aeroshell, were "baked" at a temperature of 250 °F (121 °C) for a total of seven days, after which a "bioshield" was then placed over the aeroshell that was jettisoned after the Centaur upper

stage fired the Viking orbiter/lander combination out of Earth orbit. The methods and standards developed for planetary protection for the Viking mission are still used for other missions.

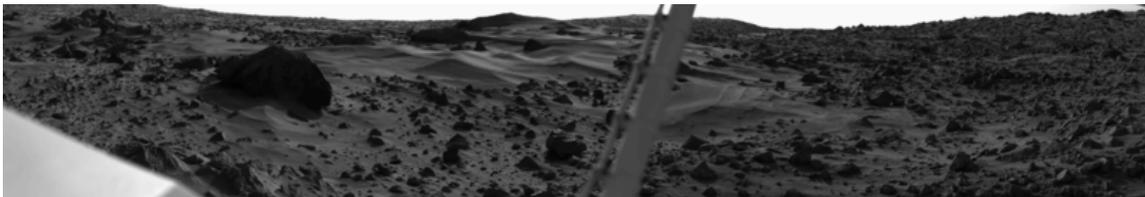
Communications were accomplished through a 20 watt S-band transmitter using two traveling-wave tubes. A two-axis steerable high-gain parabolic antenna was mounted on a boom near one edge of the lander base. An omnidirectional low-gain S-band antenna also extended from the base. Both these antennae allowed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

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

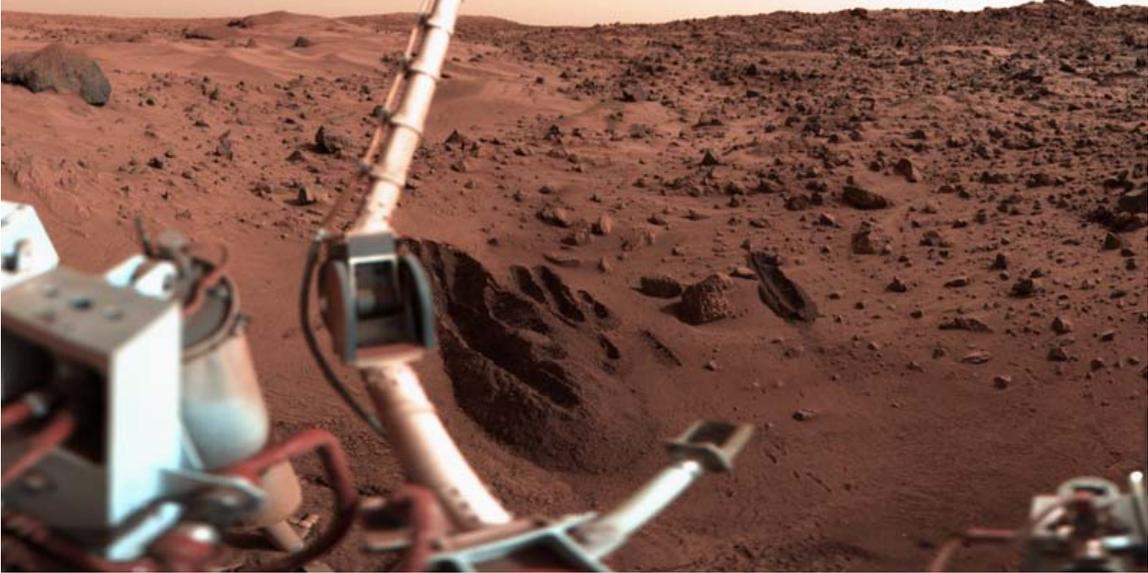
## **Control systems**

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

## **Biological experiments**



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



Trenches dug by the soil sampler of the Viking 1 lander

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

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

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

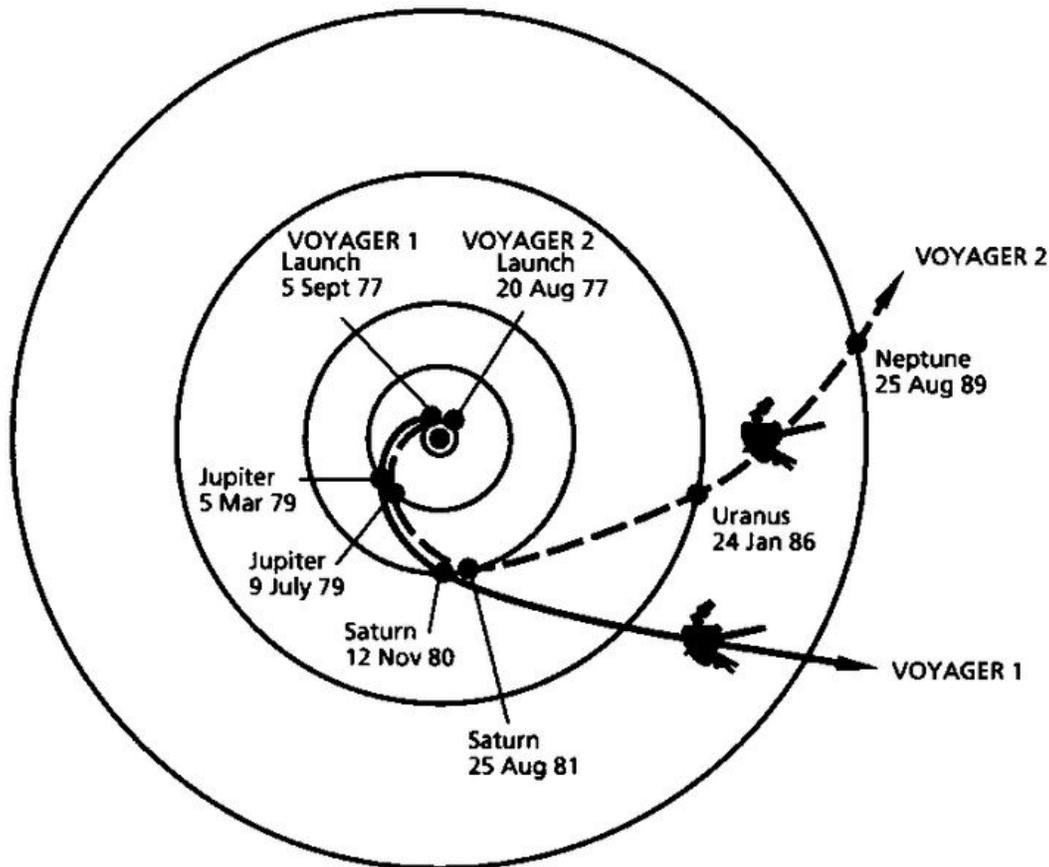
## Mission end

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

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

## Chapter- 10

# Voyager Program

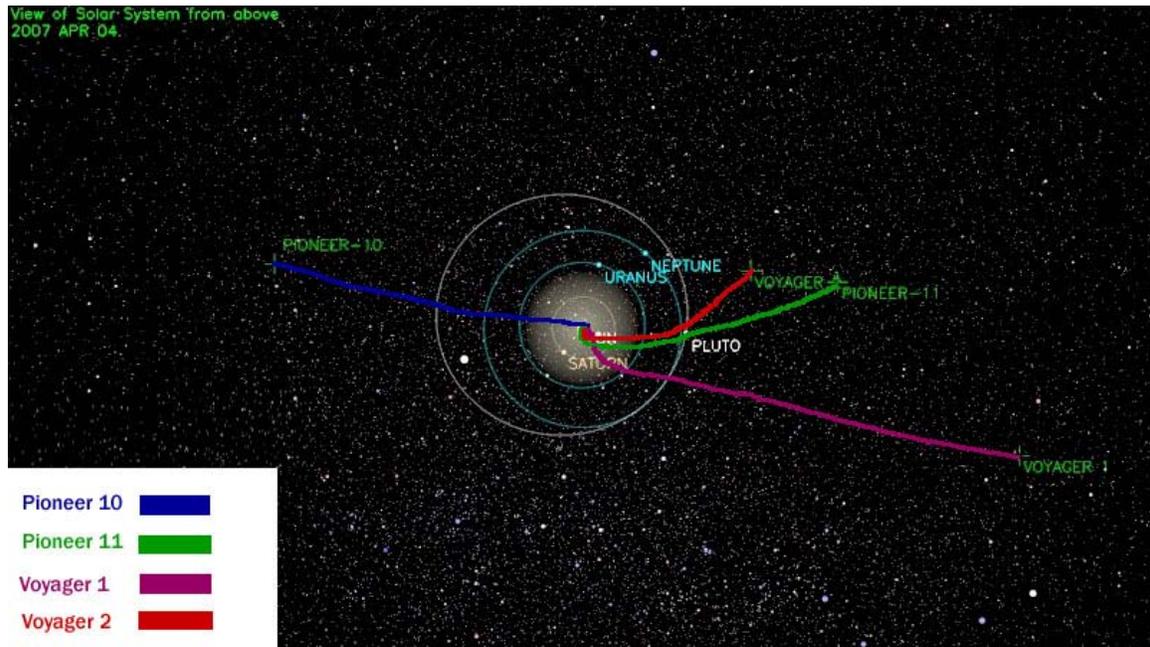


The trajectories that enabled Voyager spacecraft to visit the outer planets and achieve velocity to escape our solar system

The **Voyager program** is a series of U.S. unmanned space missions that consists of a pair of unmanned scientific probes, *Voyager 1* and *Voyager 2*. They were launched in 1977 to take advantage of a favorable planetary alignment of the late 1970s. Although they were officially designated to study just Jupiter and Saturn, the two probes were able to continue their mission into the outer solar system. They are currently on course to eventually exit the solar system. These probes were built at JPL and were funded by NASA. *Voyager 1* is currently the farthest human-made object from Earth.

Both missions have gathered large amounts of data about the gas giants of the solar system, of which little was previously known. In addition, the spacecraft trajectories have been used to place limits on the existence of a hypothetical post-Plutonian Planet X.

## History



Location and approximate trajectories of Pioneer and Voyager spacecraft as of April 4, 2007

The *Voyager* probes were originally conceived as part of the Mariner program, and designated *Mariner 11* and *Mariner 12*, respectively. They were then moved into a separate program named *Mariner Jupiter-Saturn*, later retitled *Voyager* because it was felt that the probes' designs had moved sufficiently far from the Mariner family that they merited a separate name. *Voyager* is essentially a scaled-back version of the Grand Tour program of the late 1960s and early 1970s. The Grand Tour's plan was to send a pair of probes to fly by all the outer planets; it was scaled back because of budget cuts. However, in the end, *Voyager* fulfilled all the Grand Tour flyby objectives except for Pluto, which at the time was considered a planet by the IAU.

Of the pair, *Voyager 2* was launched first. Its trajectory was designed to take advantage of an unusually convenient alignment of the planets allowing the inclusion of Uranus and Neptune flybys in the probe's mission. *Voyager 1* was launched after its sister probe, but on a faster trajectory which enabled it to reach Jupiter and Saturn sooner at the consequence of not visiting the outer planets. Although Pluto was possible in its trajectory, it was eventually decided to make a close fly-by of Titan while examining Saturn instead, which would preclude a later fly-by of Pluto.

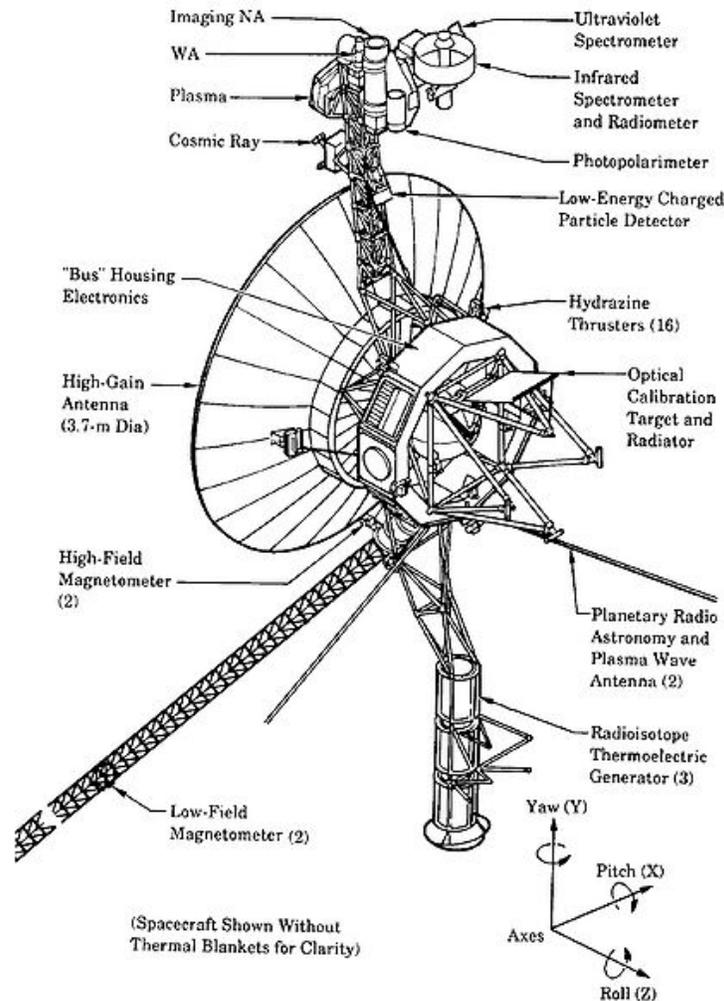
In the 1990s, *Voyager 1* overtook the slower traveling *Pioneer 10* to become the most distant man-made object from Earth. It will keep that record until such time as mankind develops newer, radically-faster forms of space propulsion than are currently known—even the faster (at launch) *New Horizons* probe will not outrace it, since the final speed of *New Horizons* (after maneuvering within the solar system) will be less than the current speed of *Voyager 1*. *Voyager 1* and *Pioneer 10* are also the most widely-separated man-made objects in the universe, because they are traveling in roughly opposite directions from the Sun (and each other).

Periodic contact has been maintained with *Voyager 1* and *Voyager 2* to monitor conditions in the outer expanses of the solar system. The crafts' radioactive power sources are still producing electrical energy, fueling hopes of locating the solar system's heliopause. In late 2003, *Voyager 1* began sending data that seemed to indicate it had crossed the termination shock, but interpretations of this data are in dispute. It is now believed that the termination shock was crossed in December 2004, with the heliopause an unknown distance ahead.

As of August 2009, *Voyager 1* was over 16.5 terameters ( $16.5 \times 10^{12}$  meters, or  $16.5 \times 10^9$  km, 110.7 AU, or 10.2 billion miles) from the Sun, and has thus entered the heliosheath region between solar wind's termination shock and the heliopause (the limit of the solar wind). Beyond heliopause is the bow shock of the interstellar medium, beyond which is interstellar space, a vast area where the Sun's influence gives way to that of the Milky Way galaxy in general. At this distance, light from the Sun takes over 16 hours to reach the probe.

As of August 2009, *Voyager 2* is at a distance of around 89.7 AU (approximately 13.4 terameters) from the Sun, deep in the scattered disc, and traveling outward at roughly 3.3 AU a year. It is more than twice as far from the Sun as Pluto is. On December 10, 2007, instruments on board *Voyager 2* sent data back to Earth indicating that the Solar System is asymmetrical. It has also reached the termination shock, about 10 billion miles from where *Voyager 1* first crossed it.

# Spacecraft design



Voyager spacecraft structure

The identical *Voyager* spacecraft are three-axis stabilized systems that use celestial or gyro referenced attitude control to maintain pointing of the high-gain antennas toward Earth. The prime mission science payload consisted of 10 instruments (11 investigations including radio science).

The diagram at the right shows the 3.7 meter diameter high-gain antenna (HGA) attached to the hollow ten-sided polygonal electronics bus, with the spherical tank within containing hydrazine propulsion fuel.

The Voyager Golden Record is attached to one of the bus sides. The angled square panel to the right is the optical calibration target and excess heat radiator. The three radioisotope thermoelectric generators (RTGs) are mounted end-to-end on the lower boom.

## **Scientific instruments and sensors**

The two planetary radio and plasma wave antennas extend diagonally downwards left and right. The 13 metre long Astromast tri-axial boom extends diagonally downwards left and holds the two low-field magnetometers (MAG); the high-field magnetometers remain close to the HGA.

The instrument boom extending upwards holds, from bottom to top: the cosmic ray subsystem (CRS) left, and Low-Energy Charged Particle (LECP) detector right; the Plasma Spectrometer (PLS) right; and the scan platform that rotates about a vertical axis.

The scan platform comprises: the Infrared Interferometer Spectrometer (IRIS) (largest camera at top right); the Ultraviolet Spectrometer (UVS) just above the UVS; the two Imaging Science Subsystem (ISS) vidicon cameras to the left of the UVS; and the Photopolarimeter System (PPS) under the ISS.

Only five investigator teams are still supported, though data is collected for two additional instruments. The Flight Data Subsystem (FDS) and a single eight-track digital tape recorder (DTR) provide the data handling functions.

The FDS configures each instrument and controls instrument operations. It also collects engineering and science data and formats the data for transmission. The DTR is used to record high-rate Plasma Wave Subsystem (PWS) data. The data is played back every six months.

The Imaging Science Subsystem, made up of a wide angle and a narrow angle camera, is a modified version of the slow scan vidicon camera designs that were used in the earlier Mariner flights. The Imaging Science Subsystem consists of two television-type cameras, each with 8 filters in a commandable Filter Wheel mounted in front of the vidicons. One has a low resolution 200 mm wide-angle lens with an aperture of f/3 (Wide Angle Camera), while the other uses a higher resolution 1500 mm narrow-angle f/8.5 lens (Narrow Angle Camera).

## **Computers**

Unlike the other onboard instruments, operation of the cameras is not autonomous, but is controlled by an imaging parameter table residing in one of the spacecraft computers, the Flight Data Subsystem (FDS). Modern spacecraft (post 1990) typically have fully autonomous cameras.

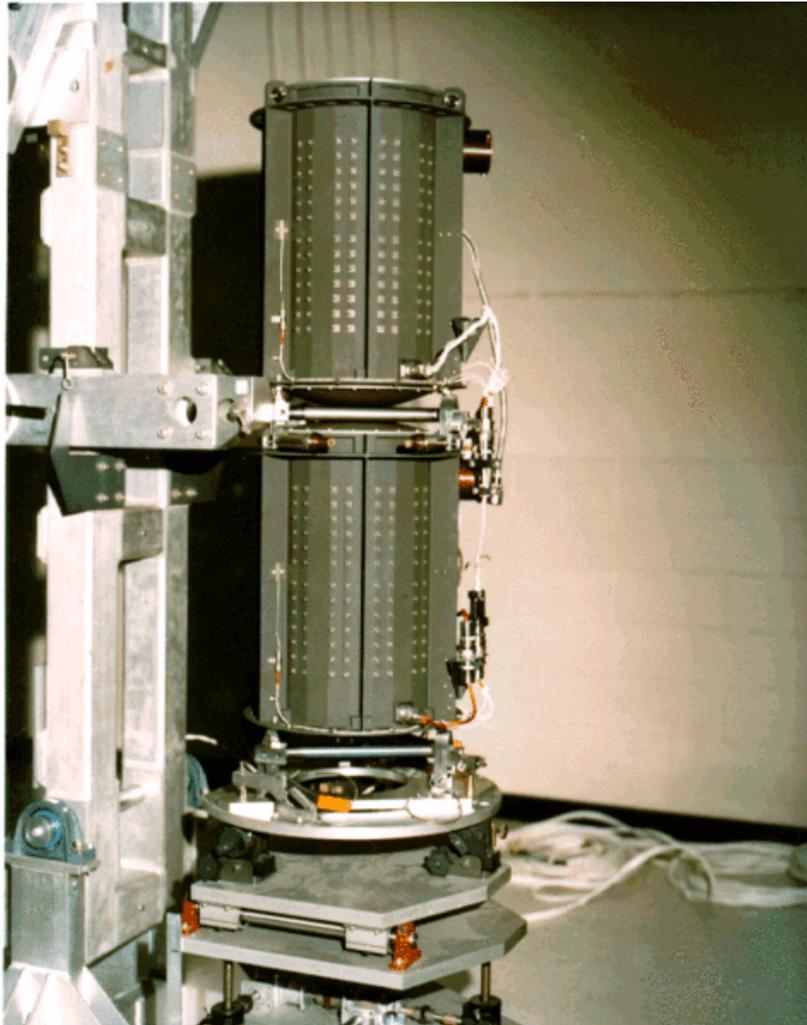
The computer command subsystem (CCS) provides sequencing and control functions. The CCS contains fixed routines such as command decoding and fault detection and corrective routines, antenna pointing information, and spacecraft sequencing information. The computer is an improved version of that used in the Viking orbiter. The custom built CCS systems on both craft are identical. There is only a minor software modification for one craft that has a scientific subsystem the other lacks.

The Attitude and Articulation Control Subsystem (AACS) controls the spacecraft orientation, maintains the pointing of the high-gain antenna towards Earth, controls attitude maneuvers, and positions the scan platform. The custom built AACS systems on both craft are identical.

It is widely reported on the web that the Voyager spacecraft were controlled by a version of the RCA CDP1802 "COSMAC" microprocessor, but such claims are not substantiated by primary references. The CDP1802 was, however, used in the later Galileo spacecraft.

Uplink communications is via S band (16-bit/s command rate) while an X band transmitter provides downlink telemetry at 160 bit/s normally and 1.4 kbit/s for playback of high-rate plasma wave data. All data is transmitted from and received at the spacecraft via the 3.7-meter high-gain antenna.

## Power



Radioisotope thermoelectric generators for the Voyager program

Electrical power is supplied by three radioisotope thermoelectric generators (RTGs). They are powered by Pu-238 (distinct from the Pu-239 isotope used in nuclear weapons) and provided approximately 470 W at 30 volts DC when the spacecraft was launched. Plutonium-238 decays with a half-life of 87.74 years, so RTGs using Pu-238 will lose a factor of  $1 - 0.5^{\{1/87.74\}} = 0.78\%$  of their power output per year.

In 2006, 29 years after launch, such an RTG would produce only  $470 \text{ W} \times 2^{-(29/87.74)} \approx 373 \text{ W}$  — or about 79.5% — of its initial power. Moreover, the bi-metallic thermocouples that convert heat into electricity also degrade, so the actual power will be even lower.

As of September 25, 2009 the power generated by *Voyager 1* and *Voyager 2* had dropped to 276.4 W and 277.6 W respectively. This is about 58% of the power at launch. This level of power output so far has been better than the pre-launch predictions based on a conservative thermocouple degradation model. As the electrical power decreases, spacecraft loads must be turned off, eliminating some spacecraft capabilities.

## Voyager Interstellar Mission

The Voyager primary mission was completed in 1989, with the close flyby of Neptune by *Voyager 2*. The Voyager Interstellar Mission (VIM) is a mission extension, which began when the two spacecraft had already been in flight for over 12 years. The Heliophysics Division of the NASA Science Mission Directorate conducted a Heliophysics Senior Review in 2008. The panel found that the VIM "is a mission that is absolutely imperative to continue" and that VIM "funding near the optimal level and increased DSN (Deep Space Network) support is warranted."

As of the present date, the *Voyager 2* and *Voyager 1* scan platforms, including all of the platform instruments, have been powered down. The ultraviolet spectrometer (UVS) on *Voyager 1* was active until 2003, when it too was deactivated. Gyro operations will end in 2015 for *Voyager 2* and 2016 for *Voyager 1*. Gyro operations are used to rotate the probe 360 degrees six times a year to measure the magnetic field of the spacecraft, which is then subtracted from the magnetometer science data.

The two *Voyager* spacecraft continue to operate, with some loss in subsystem redundancy, but retain the capability of returning scientific data from a full complement of Voyager Interstellar Mission (VIM) science instruments.

Both spacecraft also have adequate electrical power and attitude control propellant to continue operating until around 2020, when the available electrical power will no longer support science instrument operation. At that time, science data return and spacecraft operations will cease. It is possible that one or both craft may have enough RTG energy to last until 2025, but there is only a small probability of this.

# Telemetry

The telemetry comes to the telemetry modulation unit (TMU) separately as a "low-rate" channel and a "high-rate" channel.

Low rate telemetry is 40 bps. Low rate telemetry is routed through the TMU such that it can only be downlinked as uncoded bits (in other words there is no error correction). At High rate, one of a set of rates between 10 bps and 115.2 kbps, is downlinked as coded symbols.

The TMU encodes the high rate data stream with a convolutional code having constraint length of 7 with a symbol rate equal to twice the bit rate ( $k=7$ ,  $r=1/2$ )

Voyager telemetry operates at these transmission rates

- 7200, 1400 bit/s tape recorder playbacks
- 600 bit/s real-time fields, particles, and waves; full UVS; engineering
- 160 bit/s real-time fields, particles, and waves; UVS subset; engineering
- 40 bit/s real-time engineering data, no science data.

Note: At 160 bit/s or 600 bit/s different data types are interleaved.

## The Voyager craft have three different telemetry formats

### High rate

- CR-5T (ISA 35395) Science, note that this can contain some engineering data.
- FD-12 higher accuracy (and time resolution) Engineering data, note that some science data may also be encoded.

### Low rate

- EL-40 Engineering, note that this format can contain some science data, but not all systems represented.
- This is an abbreviated format, with data truncation for some subsystems.

It is understood that there is substantial overlap of EL-40 and CR-5T (ISA 35395) telemetry, but the simpler EL-40 data does not have the resolution of the CR-5T telemetry. At least when it comes to representing available electricity to subsystems, EL-40 only transmits in integer increments—so similar behaviours are expected elsewhere.

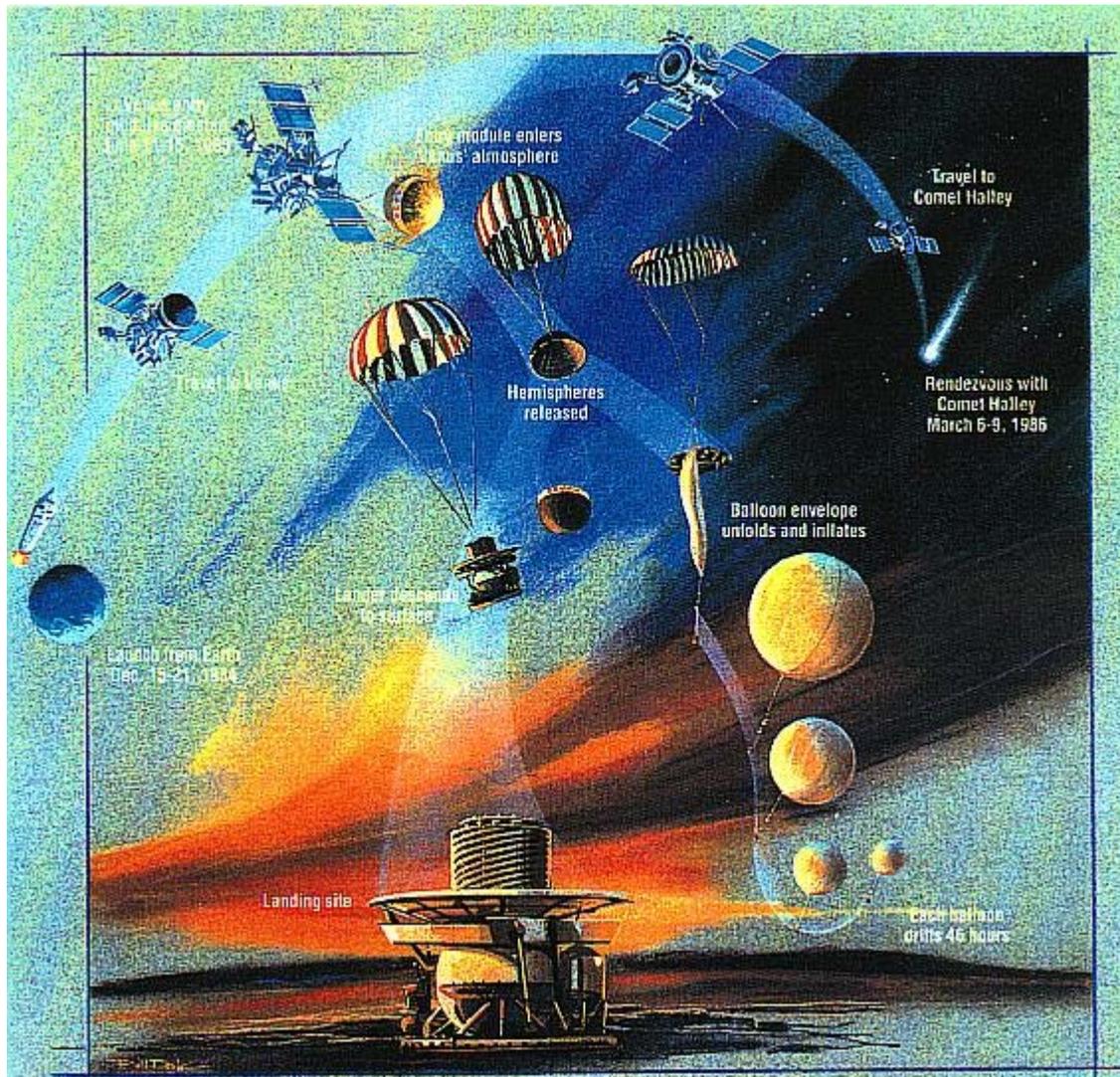
Memory dumps are available in both engineering formats. These routine diagnostic procedures have detected and corrected intermittent memory bit flip problems, as well as detecting the permanent bit flip problem that caused a 2 week data loss event mid-2010.

## **Voyager Golden Record**

*Voyager 1* and *2* both carry with them a golden record that contains pictures and sounds of Earth, along with symbolic directions for playing the record and data detailing the location of Earth. The record is intended as a combination time capsule and interstellar message to any civilization, alien or far-future human, that recovers either of the *Voyager* craft. The contents of this record were selected by a committee chaired by Carl Sagan.

## Chapter- 11

# Vega Program



Vega mission description

The **Vega program** were a series of Venus missions which also took advantage of the appearance of Comet Halley in 1986. Vega 1 and Vega 2 were unmanned spacecraft

launched in a cooperative effort among the Soviet Union (who provided the spacecraft and launch vehicle) and Austria, Bulgaria, Hungary, the German Democratic Republic, Poland, Czechoslovakia, France, and the Federal Republic of Germany in December 1984. They had a two-part mission to investigate Venus and also flyby Halley's Comet.

The flyby of Halley's Comet had been a late mission change in the Venera program following on from the cancellation of the US Halley mission in 1981. A later Venera mission was cancelled and the Venus part of the Vega 1 mission was reduced. Because of this, the craft was designated Vega, a contraction of "Venera" and "Gallei" (Russian words for "Venus" and "Halley", respectively). The spacecraft design was based on the previous Venera 9 and Venera 10 missions.

The two spacecraft were launched on December 15 and December 21, 1984, respectively. With their redesignated dual missions, the Vega probes became part of the Halley Armada, a group of space probes that studied Halley's Comet during its 1985/86 perihelion.

## The Vega spacecraft



Vega solar system probe bus and landing apparatus (model)

Vega 1 and 2 were identical sister ships. The spacecraft was a development of the earlier *Venera* craft. They were designed by Babakin Space Center and constructed as 5VK by Lavochkin at Khimki. The craft was powered by twin large solar panels and instruments included an antenna dish, cameras, spectrometer, infrared sounder, magnetometers (MISCHA), and plasma probes. The 4,920 kg craft was launched by a Proton 8K82K rocket from Baikonur Cosmodrome, Tyuratam, Kazakh SSR. Both Vega 1 and 2 were three-axis stabilized spacecraft. The spacecraft were equipped with a dual bumper shield for dust protection from Halley's comet.

### **Bus Instruments**

1. imaging system
2. infrared spectrometer
3. ultraviolet, visible, infrared imaging spectrometer
4. shield penetration detector
5. dust detectors
6. dust mass spectrometer
7. neutral gas mass spectrometer
8. APV-V plasma energy analyzer
9. energetic-particle analyzer
10. magnetometer
11. wave and plasma analyzers

### **The Venus mission**

Vega 1 arrived at Venus on June 11, 1985 and Vega 2 on June 15, 1985, and each delivered a 1,500 kg, 240 cm diameter spherical descent unit. The units were released some days before each arrived at Venus and entered the atmosphere without active inclination changes. Each contained a lander and a balloon explorer.

### **Descent craft**

The landers were identical to that of the previous five *Venera* missions and were to study the atmosphere and surface, each had instruments to study temperature, pressure, a UV spectrometer, a water concentration meter, a gas-phase chromatograph, an X-ray spectrometer, a mass spectrometer and a surface sampling device.

The Vega 1 lander's surface experiments were inadvertently activated at 20 km from the surface by an especially-hard wind jolt, and so failed to provide results. It landed at 7.5°N, 177.7°E.

The Vega 2 lander touched down at 03:00:50 UT on 15 June 1985 at 8.5° S, 164.5° E, in eastern Aphrodite Terra. The altitude of the touchdown site was 0.1 km above the planetary mean radius. The measured pressure at the landing site was 91 atm and the temperature was 736 K. The surface sample was found to be an anorthosite-troctolite. It transmitted data from the surface for 56 minutes.

## **Payload**

- Meteocomplex T,P sensors
- Sigma-3 gas chromatograph
- LSA particle size spectrometer
- IFP aerosol analyser
- VM-4 hygrometer
- ISAV-A nephelometer / scatterometer
- Malakhit-V mass spectrometer
- ISAV-S UV spectrometer
- GZU VB-02 drill + BDRP-AM25 soil X-ray fluorescence spectrometer
- GS-15-STsV gamma ray spectrometer
- PrOP-V penetrometer
- MSB small solar batteries

## **Balloon**

The two balloon aerobots were designed to float at 54 km from the surface, in the most active layer of the Venusian cloud system. The instrument pack had enough battery power for sixty hours of operation and measured temperature, pressure, wind speed and aerosol density. Both Vega-1 and Vega-2 balloons operated for more than 46 hrs from injection to the final transmission.

The balloons were spherical superpressure types with a diameter of 3.54 meters (11.6 ft) and filled with helium. A gondola assembly weighing 6.9 kilograms (15.2 pounds) and 1.3 meters (4.26 ft) long was connected to the balloon envelope by a tether 13 meters (42.6 ft) long. Total mass of the entire assembly was 21 kilograms (46 pounds).

The top section of the gondola assembly was capped by a conical antenna 37 centimeters (14.6 inches) tall and 13 centimeters ( $5 \frac{1}{8}$  inches) wide at the base. Beneath the antenna was a module containing the radio transmitter and system control electronics. The lower section of the gondola assembly carried the instrument payload and batteries.

The instruments consisted of:

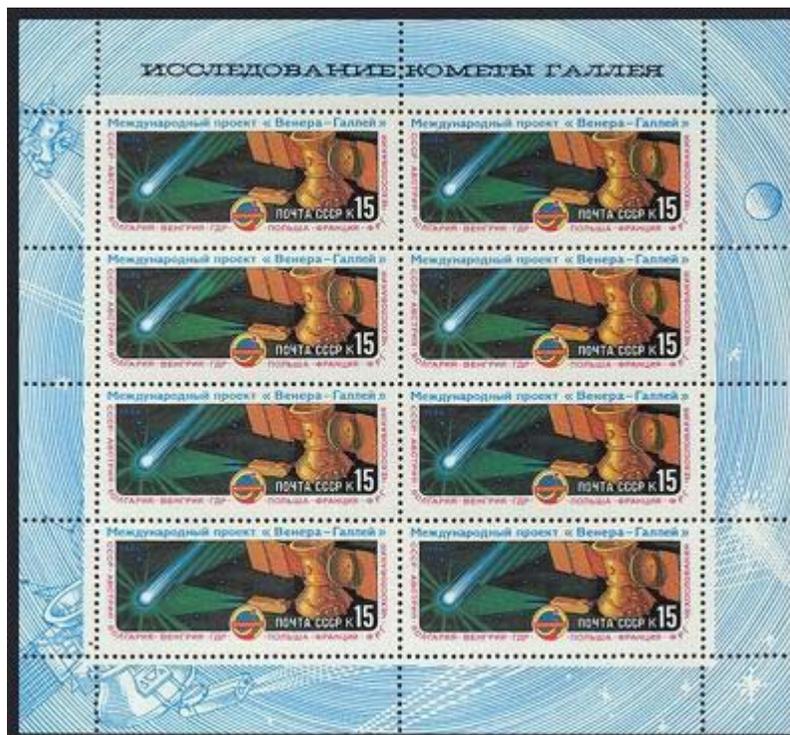
- An arm carrying thin-film resistance thermometers and a velocity anemometer. The anemometer consisted of a free-spinning plastic propeller whose spin was measured by LED-photodetector optointerrupters.
- A module containing a PIN diode photodetector to measure light levels and a vibrating quartz beam pressure sensor.
- A package at the bottom carrying the batteries and a nephelometer to measure cloud density through light reflection.

The small low-power transmitter only allowed a data transmission rate of 2,048 bits per second, though the system performed data compression to squeeze more information through the narrow bandwidth. Nonetheless, the sampling rate for most of the instruments

was only once every 75 seconds. The balloons were tracked by two networks of 20 radio telescopes in total back on Earth: the Soviet network, coordinated by the USSR Academy of Sciences and the international network, coordinated by CNES.

The balloons were dropped onto the planet's darkside and deployed at an altitude of about 50 kilometers (30 miles). They then floated upward a few kilometers to their equilibrium altitude. At this altitude, pressure and temperature conditions of Venus are similar to those of Earth, though the planet's winds moved at hurricane velocity and the carbon dioxide atmosphere is laced with sulfuric acid, along with smaller concentrations of hydrochloric and hydrofluoric acid.

The balloons moved swiftly across the night side of the planet into the light side, where their batteries finally ran down and contact was lost. Tracking indicated that the motion of the balloons included a surprising vertical component, revealing vertical motions of air masses that had not been detected by earlier probe missions.



1985 USSR miniature sheet dedicated to the program, depicting Vega 1 spacecraft, Comet Halley and Intercosmos logo.

## The Halley mission

After their encounters, the Vegas' motherships were redirected by Venus' gravity to intercept Comet Halley.

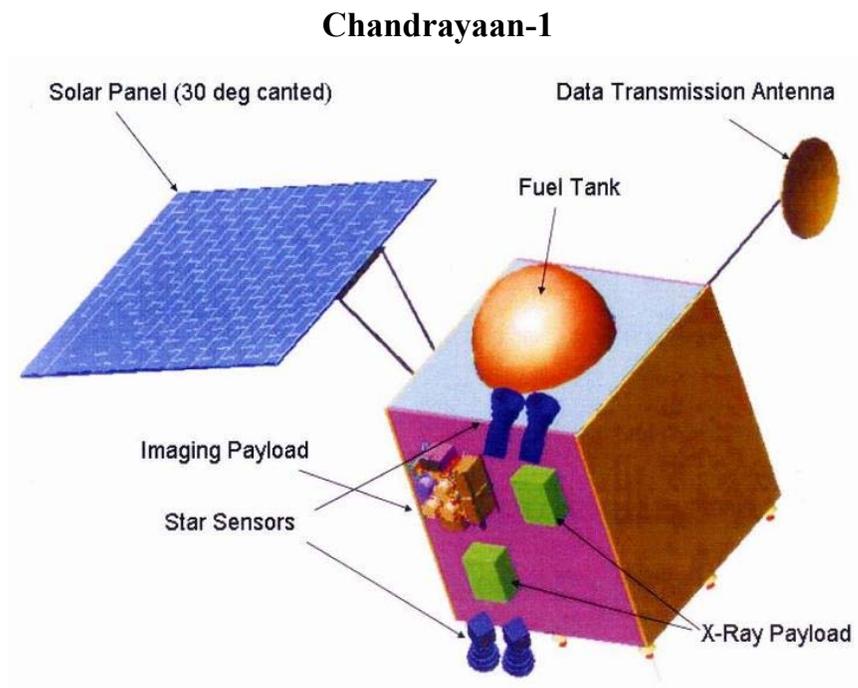
Vega 1 made its closest approach on March 6, around 8,890 km from the nucleus, and Vega 2 made its closest approach on March 9 at 8,030 km. The data intensive examination of the comet covered only the three hours around closest approach. They were intended to measure the physical parameters of the nucleus, such as dimensions, shape, temperature and surface properties, as well as to study the structure and dynamics of the coma, the gas composition close to the nucleus, the dust particles' composition and mass distribution as functions of distance to the nucleus and the cometary-solar wind interaction.

In total Vega 1 and Vega 2 returned about 1,500 images of Comet Halley. Spacecraft operations were discontinued a few weeks after the Halley encounters.

The on-board TV system was created in international cooperation of the scientific and industrial facilities from the USSR, Hungary, France and Czechoslovakia. TV data were processed by international team, including the USSR, Hungary, France, GDR and USA scientists. The basic steps of data acquisition and preprocessing were performed in IKI using the image processing computer system, based on PDP11/40 compatible host.

## Chapter- 12

# Chandrayaan-1



Configuration of Chandrayaan-1 that lift off on the PSLV-C11

<b>Operator</b>	Indian Space Research Organisation
<b>Mission type</b>	Orbiter
<b>Satellite of</b>	Moon
<b>Orbital insertion date</b>	12 November 2008
<b>Orbits</b>	3400 orbits around the Moon.
<b>Launch date</b>	22 October 2008 00:52 UTC

<b>Launch vehicle</b>	PSLV-C11
<b>Launch site</b>	SDSC, Sriharikota
<b>Mission duration</b>	Intended: 2 years Achieved: 312 days
<b>COSPAR ID</b>	2008-052A
<b>Homepage</b>	Chandrayaan-1
<b>Mass</b>	1,380 kg (3,042 lb)

#### **Orbital elements**

<b>Eccentricity</b>	near circular
<b>Inclination</b>	polar
<b>Apoapsis</b>	initial 7,500 km (4,660 mi), final 100 km (62 mi), final (wef 19 May 2009) 200 km (124 mi)
<b>Periapsis</b>	initial 500 km (311 mi), final 100 km (62 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\$80 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,  $^{210}\text{Pb}$ ,  $^{222}\text{Rn}$  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**

- **CIXS 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 results from 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.
- **M<sup>3</sup>, 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 (M<sup>3</sup>), 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 M<sup>3</sup> 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.

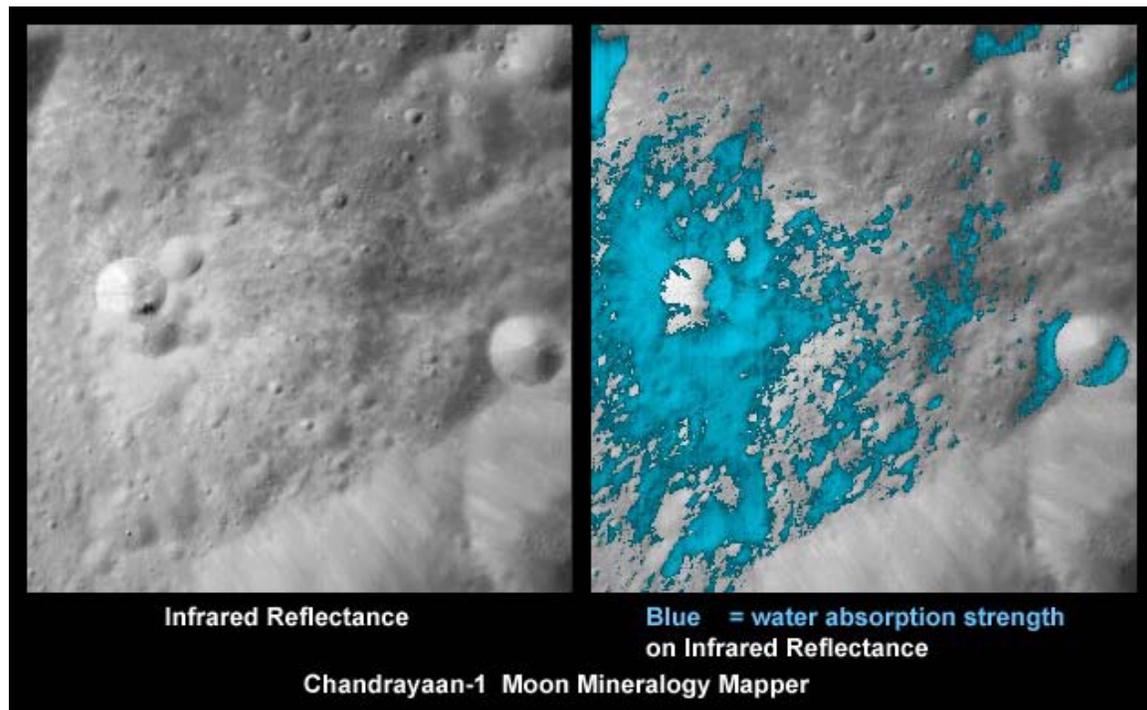
ISRO said scientists from India and participating agencies expressed satisfaction on the excellent performance of Chandrayaan-1 mission as well as the high quality of data sent by the spacecraft.

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 (M<sup>3</sup>) on Chandrayaan-1 has detected water on the moon. M<sup>3</sup> detected absorption features near 2.8-3.0  $\mu\text{m}$  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 M<sup>3</sup> data with neutron spectrometer H abundance data suggests that the formation and retention of OH and H<sub>2</sub>O is an ongoing surficial process. OH/H<sub>2</sub>O production processes may feed polar cold traps and make the lunar regolith a candidate source of volatiles for human exploration.

The Moon Mineralogy Mapper (M<sup>3</sup>), an imaging spectrometer, was one of the 11 instruments on board Chandrayaan-I that came to a premature end on 29 August 2009. M<sup>3</sup> 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, Chandrayan-1
- S. K. Shivkumar – Director - Telemetry, Tracking and Command Network
- Mr. M.Pitchaimani – Operations Director, Chandrayan-1
- Mr. Leo Jackson John – Spacecraft Operations Manager, Chandrayan-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- 13

# Chinese Lunar Exploration Program



Insignia of the program

**Chinese Lunar Exploration Program (CLEP)** (simplified Chinese: 中国探月; traditional Chinese: 中國探月; pinyin: *Zhōngguó Tànyuè*) also known as **Chang'e program** is a program of robotic explorations and human missions to the Moon undertaken by China National Space Administration (CNSA), People's Republic of China's space agency. It uses Chang'e lunar orbiters, rovers and soil return spacecraft and adapted Long March 3A, Long March 5/E and Long March 7 launch vehicles. The launch and the flight are monitored constantly by a TT&C System (Deep Space Tracking Network, with radio antennas of 50 m in Beijing, 40 m in Kunming, Shanghai and Ürümqi, forming a 3000 km VLBI antenna.) and the Ground Application System, responsible for downlink data reception.

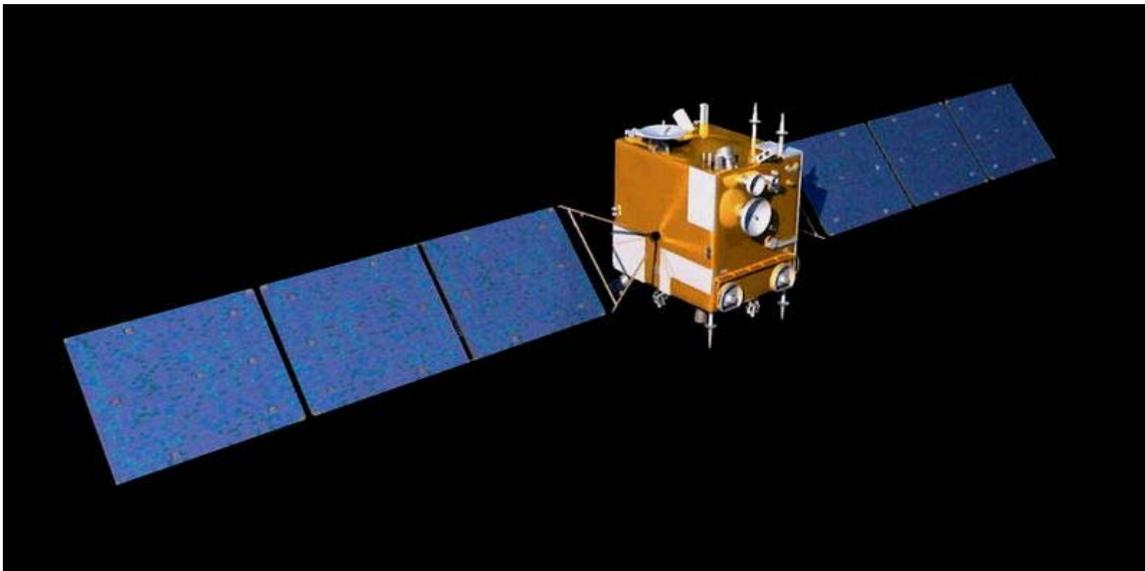
The first spacecraft of the program, Chang'e 1, an un-manned lunar orbiter was successfully launched at Xichang Satellite Launch Center on October 24, 2007 (delayed from 17–19 April 2007).

Ouyang Ziyuan, one of the most prominent Chinese experts in geological research on underground nuclear testing and extraterrestrial materials, was the first to advocate not only the exploitation of the known huge lunar reserves of metals such as iron, but also the mining of lunar helium-3 as an ideal fuel for nuclear fusion power plants. He is now in charge of the Chang'e program. He is known to be one of the strongest supporters of the Chinese human lunar exploration program, and is currently serving as the chief scientist of the program. Another prominent Chinese scientist, Sun Jiadong, was assigned as the general designer, while a younger scientist Sun Zezhou (孙泽州, unrelated to Sun Jiadong) was assigned as the deputy general designer. The program manager was Luan Enjie (栾恩杰).

## Program structure

According to CNSA, the program will go through three phases:

### Phase I: Orbital mission (Chang'e 1 & 2)



Chang'e 2 spacecraft

The first phase of the exploration program starts with the launch of two lunar orbiters.

- Chang'e 1 was the first to be successfully launched as scheduled on October 24, 2007.
- Chang'e 2 was launched on October 1, 2010.

## **Phase II: Soft lander (Chang'e 3)**

In the second phase of the lunar exploration program, two lunar landers will be launched to deploy moon rovers for surface exploration in a limited area. These missions were originally planned for 2012 requiring the use of the CZ-5/E heavy launch vehicle.

Currently, the second and third phases of the program will both require the availability of the heavy-lift Long March 5 (CZ-5) booster. Huang Chunping, the former head of rocket science at China's manned space program, told Xinhua news agency in March 2007 that the Long March 5 (CZ-5) rocket would be ready for launch 'in seven or eight years', which implied that CZ-5 would not be used in the second phase of the Chang'e program. The Hainan Spaceport, fourth and southernmost space center, will be upgraded to suit the new CZ-5 Heavy ELV. It has also been reported that the second phase might use a CZ-3B rocket instead.

It is said that the second phase of the program would include the launch of at least two landers, that will carry small remote-controlled Moon rovers to conduct an inspection of the moon's surface and probe the moon's resources. It would also provide data to determine the selection of a moon base.

On December 14, 2005, many aspects of the above information were confirmed, when it was reported "an effort to launch lunar orbiting satellites will be supplanted in 2007 by a program aimed at accomplishing an unmanned lunar landing. A program to return unmanned space vehicles from the moon will begin in 2012 and last for five years, until the manned program gets underway" in 2017.

A six-wheeled lunar vehicle has been under development since 2002 at the Shanghai Aerospace System Engineering Institute where a specialized testing laboratory has been outfitted to replicate the lunar surface. The 1.5-meter high, 200-kilogram rover is designed to transmit video in real time, dig and analyze soil samples. With an average speed of 100 meters/hour, it can negotiate inclines and has automatic sensors to prevent it from crashing into other objects.

In late 2008, Chen Qiufa (deputy Minister of MIIT and head of SASTIND) indicated that Chang'e 3 Lunar Rover would launch in late 2011 on a Long March 3B rocket. The rover will conduct studies of the Moon's geology, topography, and mineral and chemical composition.

In 2009, the 2013 launch date was confirmed, for a landing craft and rover called Chang'e-3. It will use variable thrusters to make a vertical landing on the surface near the moon's equator area. The lunar rover will leave Chang'e-3 and work on the surface for three months. Energy will be provided by radioisotope thermoelectric generator so that the rover survives lunar nights.

### **Phase III: Automated sample return (Chang'e 4)**

The third phase of the lunar exploration program is planned for 2017 with the use of the CZ-5/E heavy launch vehicle. On the basis of the lander mission, a lunar sample return mission will be undertaken, with up to two kilograms of lunar samples returned to Earth.

After that a manned lunar landing might be possible in 2025–2030.

## **Key technologies (phase I)**

### **Orbit design and flight sequence control**

Under the condition of three-body movement of the earth, the moon and its satellite, the orbit design of lunar exploration satellite is more complicated than that of the previous earth satellite. The lunar satellite will be sent into the highly elliptical earth orbit atop a launch vehicle first. After separating from the launch vehicle it will enter into the earth-moon transfer orbit through three accelerations in the phase-modulated orbit (16h, 24h, 48h) by its own propulsion system, during which it needs to carry out several orbit adjustments and attitude maneuvers so as to ensure to be captured by lunar gravity. After operating in the earth-moon orbit for 4–5 days, it will enter into the lunar acquisition orbit. Then, it will enter into the target lunar orbit and carry out pre-designed missions after three brakings and experiencing three different orbit phases.

### **The three-vector control problem of the lunar satellite's attitude control**

During the flight orbiting the moon the satellite should be always oriented to the earth, the moon and the sun: all the onboard detectors should be kept facing the lunar surface to complete the scientific exploration missions; the transmitting/receiving antennas should be maintained facing the earth to receive the commands from the earth and transfer scientific data to the earth for the ground application research; the solar panels should be oriented to the sun to acquire the power for normal operation. During the flight orbiting the moon, the three bodies of the earth, the moon and the sun rotate relatively, so the attitude control is a three-vector control process.

### **The satellite environment adaptability design**

The complexity of the space environment during the satellite operation has higher requirements of the environment adaptability and reliability for the satellite and its instruments. For instance, the strong radiation environment in the earth-moon space will exert great effect on the electronics; the temperature change ranges greatly from 130°C of the side facing the sun to -170°C of the side back to the sun, so it has stricter requirements of temperature control for the detectors.

## **Long-range TT&C and communication**

The biggest challenge in the Phase I of the Lunar Exploration Program is TT&C system (Telemetry, Tracking and Command), because its transmission capability must have such a long range. China's previous satellite telemetry has a range of as much as 80,000 km, but the distance between the moon and the earth is about 400,000 km, which brings up new challenge to the TT&C system. In addition, the lunar satellite must carry out many attitude maneuvers during its flight to the moon and during operations orbiting the moon. The distance from east to west in China is only 5,000 km, which is also a challenge to TT&C continuity. China hasn't set up a deep space TT&C network. At present, the combination of space TT&C network and astronomical observation network can meet the basic needs of TT&C, but with a small margin.

## **Russian cooperation**

Anatoly Perminov, head of the Russian Federal Space Agency revealed in September 2006 in RIA Novosti that the two countries were indeed working on the Moon as partners, and that the Russian-Chinese space sub-commission's priority was to conclude a joint Moon exploration agreement by the end of that year.