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From Discovery to Soft Landing: A Comprehensive Review of the Chandrayaan Mission Series

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ABSTRACT

From orbital discovery missions to cutting-edge soft-landing technologies, the Indian Space Research Organization's (ISRO) Chandrayaan mission series symbolizes a forward-thinking and revolutionary path in lunar exploration. Beginning with Chandrayaan-1 in 2008, India's first lunar mission accomplished important scientific firsts, such as high-resolution lunar mapping and the discovery of hydroxyl and water signals on the Moon, which profoundly altered the world's perception of lunar resources. Launched in 2019 to deploy a rover and demonstrate India's first soft-landing capability, Chandrayaan-2 continues to deliver important scientific data and validate technologies, even though the lander encountered a mission anomaly during descent.

This paper examines the evolution of mission architectures, payload instruments, navigation and landing technologies, scientific discoveries, and the wider implications of the Chandrayaan program for planetary science, space exploration policy, and future human and robotic lunar missions. The Chandrayaan series exemplifies India's methodical approach to deep-space exploration, highlighting incremental technological maturation, international collaboration, and the growing role of emerging spacefaring nations in lunar science and exploration—Chandrayaan-3, which successfully demonstrated a safe and accurate soft landing in 2023.

Keywords: Chandrayaan-1, Chandrayaan-2, Chandrayaan-3, Vikram Lander, Pragyan Rover, Importance of Chandrayaan Programs, Difference between Chandrayaan 2 and Chandrayaan 3.

INTRODUCTION

India's lunar exploration program, Chandrayaan, consists of a number of lunar exploration projects. India's first lunar mission, Chandrayaan 1, was launched in 2008; it was followed by Chandrayaan 2 in 2019 and Chandrayaan 3 in 2023. These missions are a part of India's attempts to investigate the geology, mineral content, and surface of the Moon, supporting international lunar research initiatives.

A lunar orbiter, an impactor, a soft lander, and a rover spacecraft are all part of the Indian Lunar Exploration Program. Three missions have been completed thus far; the first two involved orbiters, landers, and rovers. But the third mission, Chandrayaan 3, lacked an orbiter.

Lunar exploration has long been a key component of planetary research and the advancement of space technology, providing a means of comprehending the Solar System's formation and evolution as well as opening the door for upcoming deep-space expeditions. Since the early space race, lunar missions have advanced spaceship engineering, navigation, and landing capabilities in addition to offering vital data on lunar geology, surface composition, and possible resources. The 21st century has seen a resurgence of interest in the Moon due to scientific curiosity, technical advancements, and the strategic significance of lunar resources for long-term space travel.

The Indian Space Research Organization (ISRO) produced the Chandrayaan mission series, which marked India's first foray into lunar exploration. Starting with an orbital mission and progressing toward autonomous soft-landing and rover operations, the Chandrayaan program is an example of a methodical and forward-thinking approach to deep-space exploration. India's first successful lunar mission, Chandrayaan-1, was launched in 2008 and achieved important advances in lunar research, including the identification of chemicals associated with water on the lunar surface.

Building on this foundation, Chandrayaan-2 was launched in 2019 to continue high-resolution orbital studies, deploying a robotic rover, and demonstrating India's first soft landing capabilities. Despite the lander's unsuccessful landing, the mission taught important scientific and technological insights. These lessons culminated in the 2023 launch of Chandrayaan-3, which became one of the few countries to accomplish this difficult milestone by successfully executing a precision soft landing close to the Moon's south pole.

A concept of progressive technological advancement, risk minimization, and information gathering is reflected in the Chandrayaan mission series. These missions have made substantial contributions to global lunar research, including surface mineralogy, topography, exosphere studies, and the evaluation of polar water ice deposits, in addition to their technological accomplishments. Chandrayaan-3's achievement has also reinforced international cooperation and brought attention to the expanding importance of developing spacefaring nations in planetary exploration.

The Chandrayaan series of lunar exploration missions is presently being carried out by the Indian Space Research Organization (ISRO). The series includes:

Table 1. Mission Series

Mission	Craft	Landing Date
Chandrayaan 1	Moon Impact Probe	14 November, 2008
Chandrayaan 2	Vikram	6 September, 2019
Chandrayaan 3	Vikram, Pragyan	23 August, 2023

1. **Chandrayaan 1**
   Chandrayaan 1, India's first lunar mission, was successfully launched from SDSC SHAR, Sriharikota, on October 22, 2008. The orbit was raised to 200 kilometers in May 2009 following the accomplishment of all major mission objectives. The mission ended on August 29, 2009, when the satellite lost contact with the spacecraft after completing more than 3400 moon orbits.

2. **Chandrayaan 2**
   The Chandrayaan 2 mission was successfully launched by the GSLV MkIII-M1 from the Satish Dhawan Space Centre (SDSC), Sriharikota, on July 22, 2019, at 14:43. On September 7, an attempt was made to land Vikram, which dropped from its orbit of 35 km to about 2 km above the ground in accordance with the planned trajectory. The ground station and the lander were no longer in contact.

3. **Chandrayaan 3**
   Chandrayaan 3 was introduced by LVM3 from SDSC SHAR in Sriharikota on August 23, 2023. As a follow-up to Chandrayaan 2, Chandrayaan 3 aims to demonstrate that it is feasible to land and explore the lunar surface safely from beginning to end. For ISRO, this mission was a huge success [1].

Chandrayaan 1: Beginning of India's Space Odyssey

The Chandrayaan missions have expanded our knowledge of the Moon's mysteries and elevated India's space program to the international arena. The launch of Chandrayaan 1 on October 22, 2008, marked the start of India's lunar trip. The mission's objectives were to perform mineralogical and chemical investigations and image the Moon's surface in great detail. The remarkable discovery of water molecules on the lunar surface resulted from Chandrayaan 1's amazing accomplishment of its goals. On November 14, 2008, the spacecraft's payload, known as MIP (Moon Impact Probe), broke apart and made a controlled impact with the lunar South Pole.

Figure 1. Chandrayan 1 at SHAR (Image credit from ISRO)

Subsequently, India produced discoveries on the detection of hydroxyl (OH) and water (H_2O) on the lunar surface. Additionally, the results showed that their abundance was higher in the polar zone. It also discovered ice in the Moon's north polar region.

Long-held beliefs about the Moon's aridity were refuted by this discovery, which also created new opportunities for future research and even human habitation. The mission has left a lasting impact by providing key information about the Moon's composition.

Payloads of Chandrayaan-1

Table 2. Payloads of Chandrayaan 1 [2]

Payloads	Functions
Chandrayaan-1 X-ray Spectrometer (C1XS)	To perform high-resolution X-ray spectroscopy of the lunar surface to determine the mineral abundances of Mg, Al, Si, Ca, Fe, and Ti.
Near IR Spectrometer (SIR-2)	To study surface-related aspects of the moon and find the vertical distribution of crustal material, investigate the process of basin, maria & crater formation on the moon.
Miniature Synthetic Aperture Radar (Mini SAR)	For observing the moon's permanently shaded region at the right angle and without sunlight.
Sub keV Atom Reflecting Analyzer (SARA)	For imaging the moon's surface, including areas that are perpetually shadowed.
Radiation Dose Monitor Experiment (RADOM)	To examine particle flux, dosage rate, and deposited energy spectrum in the vicinity of the moon's surface both numerically and qualitatively.
Moon Mineralogy Mapper (M3)	To locate evidence of lunar evolution and mineralogy on the lunar surface
Terrain Mapping Camera (TMC)	For employing high spatial and altitude resolution to map the topography of the moon's near and far sides.
Hyper Spectral Imager (HySI)	To gather spectroscopic information for mapping the lunar surface's minerals.
Lunar Laser Ranging Instrument (LLRI)	to create an altimetric map of the moon.
High Energy X-ray Spectrometer (HEX)	To carry out spectral studies on the planetary surface using hard X-ray radiation.
Moon Impact Probe (MIP)	For creating, developing, and showcasing the technology needed to influence a probe at the intended site.

Chandrayaan 2: New Learnings and Aspirations

Chandrayaan 2 set out on an even more ambitious journey, building on the success of its predecessor. It had an orbiter, a lander called Vikram, and a rover called Pragyan. It was launched on July 22, 2019. The main goal was to perform scientific research and make a soft-landing close to the south pole of the Moon. Vikram's landing attempt encountered unanticipated difficulties, yet the orbiter continued to flourish and provide useful data. The lander and rover were left stranded on the lunar surface due to technical difficulties and system malfunctions that hindered a successful landing.

Figure 2. Chandrayan 2 at SHAR (Image credit from ISRO)

What caused Chandrayaan 2 to fail?

The July 2019 launch of Chandrayaan 2, which sought to use an orbiter, lander, and rover to investigate the Moon's south pole, was partially unsuccessful. Unfortunately, equipment malfunctions caused the lander Vikram and rover Pragyaan to crash on the lunar surface on September 7 of that year. Vikram was supposed to slow down as it got closer to the Moon, but mistakes caused it to continue traveling at a high speed, which resulted in the collision. In spite of this obstacle, the Orbiter was able to gather data and identify water signals throughout latitudes, building on the discovery of water by Chandrayaan 1.

The crash caused opportunities to be lost. The opportunity to demonstrate effective soft-landing technology in space was squandered. According to ISRO scientists, the mishap was caused by a tiny, fixable fault. The goal of the Chandrayaan-3 mission was to perfectly demonstrate this technology. With their equipment, Vikram and Pragyaan were able to make surface observations that provided information about the composition, minerals, and topography. They will provide a variety of data in conjunction with the Orbiter to create a more complete depiction of the Moon.

Payloads of Chandrayaan-2

Table 3. Payloads of Chandrayaan 2 [3].

Payloads	Functions
Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS)	To determine the presence of key elements, including Mg, Al, Si, Ca, Na, Fe, and Ti, by measuring moon fluorescence (XRF) spectra.
Solar X-ray Monitor (XSM)	X-rays from the sun and its corona are detected, their intensity is measured, and the CLASS payload is supported.
Chandra’s Atmospheric Compositional Explorer-2 (CHAECE-2)	In order to conduct an in-situ investigation of the composition, distribution, and variability of the lunar neutral exosphere, Chandrayaan-1 is being expanded.
Dual Frequency Synthetic Aperture Radar (DFSAR)	Chandrayaan-1 S-band micro-SAR advancement. Dual frequency (L & S) SAR is used. It offers twice as much depth (about 5 meters) as the S band alone.
Imaging Infra-Red Spectrometer (IIRS)	It is a hyperspectral optical imaging tool for mapping the moon's mineralogy and geomorphology.
Terrain Mappin Camera (TMC)	Map the lunar surface over a 20-kilometer swath at a high spatial resolution of 5 meters in the panchromatic spectral band (0.5-0.8 microns). Understanding the moon's evolution and creating 3-D maps will be beneficial.
Orbiter High Resolution Camera (OHRC)	To give a dual-angle view of the landing site in order to shield the lander from rocks.
Dual Frequency Radio Science (DFRS) Experiment	To determine the electron density's temporal evolution in the lunar ionosphere. Ground stations receive the two signals it transmits in the (X & S) band.

Chandrayaan 3: A Great Success for India

In order for the lander to make a smooth landing at a designated lunar spot, the ISRO conducted a second deboosting operation on August 20th after the lander slowed down to bring it to a lower orbit. Chandrayaan-3 successfully underwent a deboosting operation to deploy the rover after being detached from the propulsion module.

The goal is to send a rover to the moon and investigate the lunar south pole following the Chandrayaan 3 landing.

Figure 3. Rover module of Chandrayan 2 (Image credit from ISRO)

India prepared for Chandrayaan 3 despite the difficulties of Chandrayaan 2, and the landing proved to be a significant win for our nation.

With strengthened landing legs, updated software, and improved redundancy mechanisms to guarantee a smooth and controlled landing, this mission was created to address the shortcomings of its predecessor. With a mission length of one lunar day, or fourteen Earth days, Chandrayaan 3 was able to maximize scientific observations [4].

Payloads of Chandrayaan-3

Table 4. Payloads of Chandrayaan 3 [5]

Lander Payloads	Functions
RAMBHA- LP (Langmuir Probe)	To quantify the density of near-surface plasma (ions and electrons) and how it varies over time
Chandra's Surface Thermo-Physical Experiment (ChaSTE)	To gauge the lunar surface's thermal characteristics close to the polar regions.
Instrument for Lunar Seismic Activity (ILSA)	To identify the structure of the lunar crust and mantle and detect seismicity around the landing site.
Rover Payloads	**Functions**
Alpha Particle X-Ray Spectrometer (APXS)	To ascertain the lunar surface's mineralogical and chemical makeup.
Laser Induced Breakdown Spectroscope (LIBS)	To determine the lunar surface's elemental composition.

Overview of Chandrayaan 2 over Chandrayaan 1

Unlike Chandrayaan-1, Chandrayaan-2 sent Pragyaan, a six-wheeled rover, to the moon to carry out several scientific studies after carefully landing its Vikram module. Chandrayaan-1 had a lift-off mass of 1380 kg, whilst Chandrayaan-2 weighed 3850 kg. In September 2019, Chandrayaan-2 failed to make the intended soft landing. It was intended to demonstrate a variety of skills, such as entering the moon's orbit, softly landing over its south pole with a lander, and doing surface research with a rover.

Overview of Chandrayaan 3 over Chandrayaan 2

Instead of landing gently, the rover and lander aboard Chandrayaan-2 smashed onto the lunar surface. The chairwoman clarified that the lander's five engines produced a little higher thrust than anticipated, which was the primary cause of the touchdown. The lander had to take pictures while staying still in order to identify the landing location. The mistakes happened at that point. However, all of these mistakes were taken into account while designing the present objective. The expansion of the landing area is the first modification that warrants notice.

The current mission has been told to make a safe landing anywhere within an area of 4 x 2.4 km^2, instead of trying to reach a specific 500 x 500 m^2 patch for landing as was done by the previous Chandrayaan-2. The landing site is another element that is highlighted. While Chandrayaan 3 is designed to land on the moon's South Pole, Chandrayaan 2 landed on the moon's near side. Because it is believed to be rich in water ice, the South Pole is a crucial area for lunar study. Lastly, compared to Chandrayaan 2, Chandrayaan 3 will be a more independent mission. Once Chandrayaan 3 lands on the moon, human intervention will be impossible, allowing the lander and rover to function more autonomously [6-11].

Importance of Chandrayaan Programmes

1. **Scientific Exploration**

The Chandrayaan missions seek to investigate the Moon's surface, composition, and mineralogy. These missions advance our knowledge of lunar geology and planetary science.

2. **Technological Advancement**

Modern spacecraft design, navigation, propulsion, and communication technologies are incorporated throughout every Chandrayaan mission. Space exploration and satellite technologies can benefit from these developments.

3. **National Prestige**

India's standing in the international space community is improved by completing lunar missions. It shows that India is capable of carrying out challenging space missions on its own.

4. **International Collaboration**

Chandrayaan missions frequently involve international cooperation from space organizations in the US, Europe, and Australia, among other countries. This fosters collaborations with other space agencies and advances worldwide scientific cooperation.

5. **Resource Potential**

Future space exploration and colonization initiatives may be impacted by investigating the Moon's resources, including water, ice, and minerals. If hydrogen is collected from water (on the moon), it might be a renewable energy source.

6. **Inspiration and Education**

Young scientists, engineers, and students in India and around the world are motivated to pursue professions in science and technology by the Chandrayaan missions. Additionally, they increase public interest in and knowledge of space exploration.

Chandrayaan 1

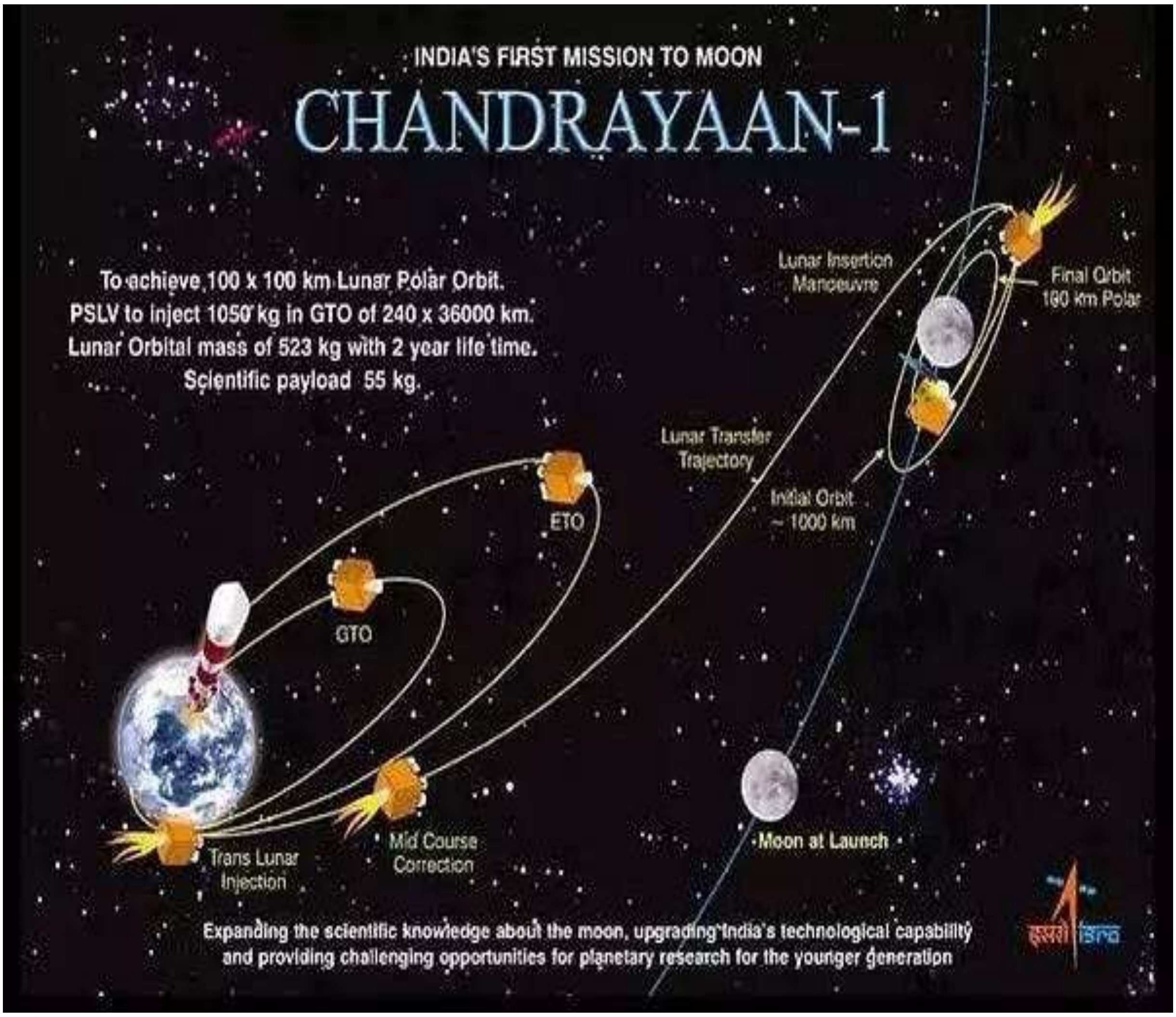

Figure 4. Chandrayan 1 details of in orbit function at SHAR (Image credit from ISRO)

- Launched by the ISRO in 2008, Chandrayaan-1 is India's first lunar mission.
- The Polar Satellite Launch Vehicle (PSLV) was used to launch it.
- The mission was mainly orbiter-based. Following its launch, it entered lunar orbit and started to circle the Moon in order to collect data and examine its surface.
- The Moon Impact Probe (MIP), another impact probe included in the mission, detached from the orbiter and executed a controlled crash landing on the lunar surface close to the south pole.

Findings
- Verified that water is present in lunar soil.
- Found iron, magnesium, titanium, calcium, and aluminum on the moon.
- Proof that an old lunar lava flow created lunar caves.
- The lunar surface's previous tectonic activity.

Chandrayaan 2
- India's second lunar mission is called Chandrayaan-2.
- The Orbiter, Lander (Vikram), and Rover (Pragyan) were all entirely indigenous.
- Launch Vehicle Mark-III (LVM3) or GSLV Mark III rockets were used to launch it.
- It was aimed at the moon's uncharted South Polar area.
- Finding the location and quantity of lunar water is the goal.

Findings
- The results of Chandrayaan-1 were validated by Chandrayaan-2.
- The Rover-carrying Vikram Lander crashed on the moon's surface while attempting a soft landing.

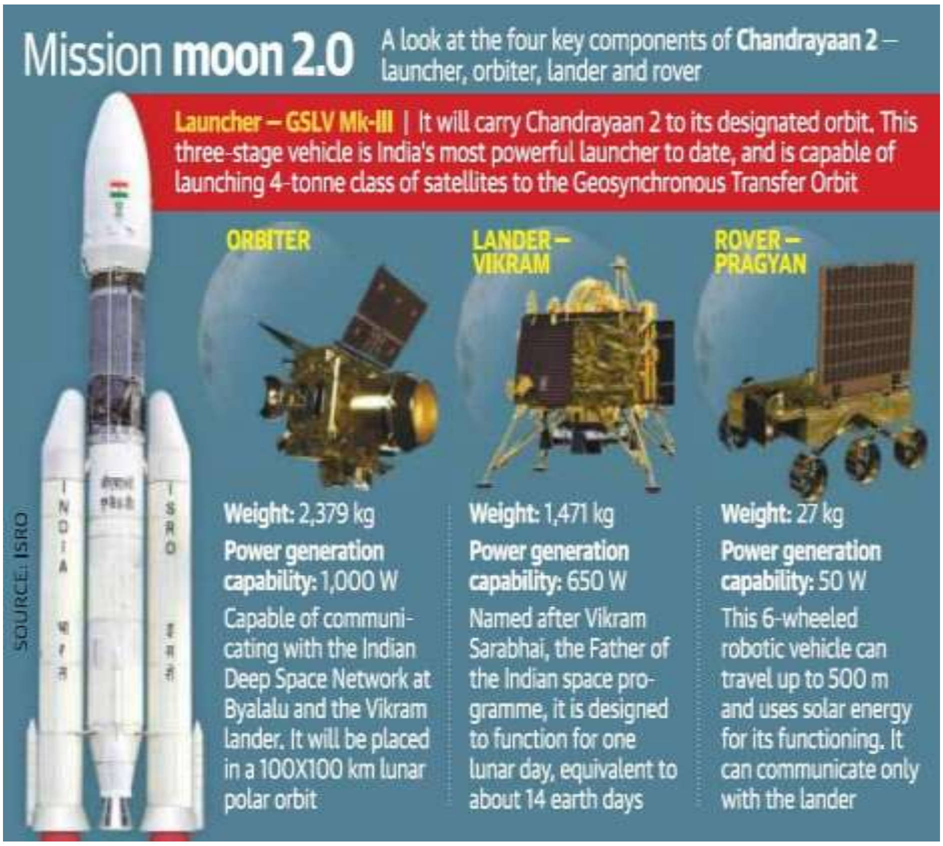

Figure 5. Chandrayan 2 specification and modules (Image credit from ISRO)

Chandrayaan 3 (LVM3-M4)

- The Chandrayaan-3 mission is an extension of Chandrayaan-2. Mission duration: 14 Earth days, or one lunar day. [The moon completes one revolution around the Earth and one rotation on its axis in around 28 Earth days].
- It is made up of a Rover (Pragyan), a Propulsion module, and an indigenous Lander module (Vikram).
- Launch Vehicle Mark-III (LVM3) or GSLV Mark III rockets were used to launch it.
- Solid fuel, liquid fuel, and cryogenic fuel engines will power Chandrayaan-3.

Aims

- To show off India's capacity for a peaceful landing on the moon
- To show off Rover's lunar wandering
- To carry out scientific investigations in-situ
- After the US, Russia, and China, India will be the fourth nation in the world to accomplish this if the soft landing is successful.

Difference between Chandrayaan 2 and Chandrayaan 3 [12, 13]

Basis	Chandrayaan 2	Chandrayaan 3
Launch Date	22 July, 2019	14 July, 2023
Approach	Three main parts of Chandrayaan 2 were the orbiter, the Vikram Lander, and the Pragyan Rover. It used a success-based strategy, hoping to land successfully in a 500 m x 500 m rectangle.	A failure-based strategy was the foundation for Chandrayaan 3 to guarantee the project's success. It was missing the orbiter and consisted of a rover named Pragyan and a lander named Vikram. It aimed to safely land in a 4 km × 2.4 km region.
Aim	Studying the lunar terrain, mineralogy, elemental abundance, and exosphere was the main goal of Chandrayaan 2, along with looking for water ice in the polar regions.	The objectives of Chandrayaan 3 were to soft land on the lunar surface, send a rover from the lander to explore the south pole, investigate the composition and distribution of water on the

		surface, examine the surface's mineralogy and geology, and investigate the lunar environment and its role in the evolution of the moon.
Design	It comprises the Indian-produced Pragyan rover, the Vikram lunar lander, and the lunar orbiter. The purpose of the lander was to carry out India's first-ever gentle lunar landing. Chandrayaan 2 had five legs and a central push.	The goal of Chandrayaan 3 is to develop and demonstrate new technologies needed for interplanetary missions. It consists of an indigenous Lander module (LM), a Propulsion module (PM), and a Rover.
Apparatus	The Chandrayaan 2 orbiter carried nine instruments. Chandrayaan 2 had a single computer on board.	The Spectro-Polarimetry of Planet Earth is the only instrument carried by the Chandrayaan 3 satellite. Chandrayaan 3 had two computers on board.
Payloads and Scientific Instruments	Science-related packages on Orbiter, Lander, and Rover were part of the Chandrayaan 2 mission. The Lander’s payload consists of LP, RAMBHA, ChaSTE, and ILSA.	The shape payload carried by Chandrayaan 3 is in addition to the NASA-supplied RAMBHA, ChaSTE, LP, and ILSA payloads, while the Rover payloads are unchanged.
Mission Components	Orbiter, Lander (Vikram), Rover (Pragyan)	No Orbiter, Lander (Vikram), Rover (Pragyan)
Landing Objective	Soft landing on the lunar surface	Soft landing on the lunar surface
Landing Site	Plain approximately 600 km from the South Pole	South Pole of the Moon
Software Glitch	Communication was lost due to a software glitch	NA
Orbiter’s Role	Studying the Moon's atmosphere, surface mapping, etc.	Studying the Moon's atmosphere, surface mapping, etc.
Objective	Exploring the Moon and expanding lunar knowledge	Focused on spectral and polarimetric measurements of Earth to assess the habitability of exoplanets
Launch Vehicle	Geosynchronous Satellite Launch Vehicle Mark III (GSLV Mk III)	Geosynchronous Satellite Launch Vehicle Mark III (GSLV Mk III)

CONCLUSION

The Chandrayaan series demonstrates India's capacity to grow from technical failures. Chandrayaan-3 made India a pioneer in polar exploration, whereas Chandrayaan-1 placed the country on the lunar map. This "Discovery-to-Landing" foundation will be expanded upon by further missions, such as LUPEX (Chandrayaan-4), to investigate lunar night survival and sample returns. From Chandrayaan-1's orbital finding of lunar water to Chandrayaan-3's dramatic soft landing at the South Pole, the Chandrayaan mission series represents a remarkable evolution in planetary exploration. ISRO has improved autonomous landing technologies and changed the scientific focus from remote mapping to crucial in-situ analysis by methodically resolving the technical difficulties of Chandrayaan-2 using a "failure-based" design strategy. In the end, this comparative analysis highlights that India's lunar mission is a worldwide standard for economic innovation, demonstrating that strategic perseverance and iterative learning can transform past setbacks into a definite template for future deep-space exploration.

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