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A Shining Example of Low-Cost Space Exploration: The Success of India's Space Program

Felix Mwiya* and Wisdom Simwila Kalunga†

Chandigarh University Mohali,140414- India

Abstract: India has made progressive strides in space exploration, demonstrating low-cost, highly efficient engineering approaches. The nation has seen advancements in satellite technology that has thus transformed communication and navigation systems and India's overall way of life. This paper will examine the impact of India's space exploration and its journey to this very day, highlighting key achievements, challenges, and future ambitions.

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1. Introduction

The space race is historically marked by one key event: the successful launch of the Russian Sputnik 1, which became the first artificial satellite to orbit Earth. This event ignited fierce competition from the United States, spurring the USA to accelerate its space program, which led to the establishment of NASA and the successful Apollo 11 landing. This competition catalysed advancements in satellite communication, eliminating the need for long cable-based telecommunication and broadcasting, and ushered in progress in material sciences. A new space-exploring country emerged in 1962 when India entered the space arena with the establishment of the Indian Space Research Organisation (ISRO). Since its grand entrance into space exploration, India has made significant advancements. Starting with its first space launch on September 7, 1963, the Nike-Apache sounding rocket from Thumba, near Thiruvananthapuram in Kerala, India has achieved robust progress, including lunar and Martian landings.

2. Early Beginnings

The Indian Space Research Organisation (ISRO) was inaugurated on August 15, 1969, as an evolutionary step following the Indian National Committee on Space Research (INCOSPAR), which was established by the Government of India in 1962, as envisioned by Dr. Vikram Sarabhai [2,3]. The establishment of ISRO marked a significant focus on space research and technology [2,3]. Initially, ISRO's primary focus was on developing launch vehicles, satellite technology, and related ground systems. The organization began with the launch of sounding rockets, known generically as Rohini Sounding Rockets. These rockets were developed to conduct experiments in the upper atmosphere, ionosphere, and near space, as well as to gain knowledge in the basic aspects of rocketry. They served as an experiential learning platform for developing more powerful and complex satellite launch vehicles [1,6,7]. ISRO has significantly enhanced the quality of life through improved communication, television broadcasting, meteorological services, resources monitoring and management, and space-based navigation services such as NAVIC (the Indian Regional Navigation Satellite System), which serves as an alternative to GPS.

*Aeronautics and Astronautics Engineering University Institute of Engineering, Chandigarh University Mohali,140414- India. **Corresponding Author: 21bas1235@cuchd.in.**
† Aeronautics and Astronautics Engineering University Institute of Engineering, Chandigarh University Mohali,140414- India
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3. Rocketry in India

As mentioned earlier, the evolution of rocketry began with sounding rockets such as the RH-75, where "RH" stands for Rohini and "75" refers to the rocket's diameter in millimeters [1]. This rocket was constructed using indigenous materials that were sourced and brought to the Thumba Equatorial Rocket Launching Station (TERLS) [1]. The RH-125 followed the RH-75, incorporating several improvements in propellant formulation, processing, handling and charging of flexible propellant grains, staging, and stage separation techniques [1]. The Satellite Launch Vehicle (SLV-3), a solid propellant rocket with four stages, was introduced after ISRO decided to explore multi-stage rocket systems. SLV-3 utilized indigenous materials and technology, leading to the development of new technologies. Due to its large size [1], a separate remote facility was established for its operations. The first attempt to launch the SLV-3 in 1979 was unsuccessful due to a malfunctioning control thruster. However, a second launch in 1980 succeeded, making India one of only six nations in the world to develop such technology. Subsequent launches were successful and contributed valuable knowledge to the design and development of multi-disciplinary launch vehicle systems and mission management.

4. Chandrayaan 1 to 3

Chandrayaan-1 was India's first planetary exploration mission, designed to perform remote sensing observations of the Moon to enhance our understanding of its origin and evolution [8]. The mission included baseline payloads such as the Terrain Mapping Camera (TMC), a Hyper-Spectral Imager (HySI), a Low Energy X-ray Spectrometer (LEX), a High Energy X-ray Spectrometer (HEX), and a Lunar Laser Ranging Instrument (LLRI), all developed at the Space Applications Centre in Ahmedabad. Although these payloads were indigenous, the mission welcomed contributions from the international research community, such as the Radiation Dose Monitor (RADOM) provided by the Bulgarian Academy of Sciences. These contributions were selected based on their alignment with the objectives of the Chandrayaan-1 mission.

The success of Chandrayaan-1 led to the approval of the second mission, Chandrayaan-2. The technology in Chandrayaan-2 was enhanced to address the challenges encountered by Chandrayaan-1. Additionally, it aimed to gather new data to further our understanding of the Moon’s origin and evolution. The Chandrayaan-2 orbiter was equipped with payloads to investigate the mineralogical, morphological, and chemical properties of the lunar surface. This mission was a collaboration between the Indian Space Research Organisation (ISRO), which was responsible for the launch vehicle, orbiter, and rover, and the Federal Space Agency of Russia, which provided the lander [9].

Chandrayaan-3 built upon the achievements of Chandrayaan-2 with the goal of demonstrating end-to-end capabilities for safe landing and roving on the lunar surface. It also featured a lander and rover configuration. The mission was launched by LVM3 from SDSC SHAR, Sriharikota. The propulsion module carried the lander and rover configuration to a 100 km lunar orbit and included the Spectro-polarimetry of Habitable Planet Earth (SHAPE) payload to study the spectral and polarimetric measurements of Earth from lunar orbit [4,5,10,11].

5. Indians Space Program - Shining example of low-cost space exploration

The U.S. space program during the Apollo era (1960s-1970s) received substantial funding. The Apollo program alone cost about $25.4 billion, which is approximately $150 billion in today’s money. NASA’s budget peaked at around 4.4% of the federal budget in the 1960s. The Soviet Union also made significant investments in its space programs, especially during the early years of the space race. By the mid-1960s, the Soviet space program's budget was estimated to be about 2-3% of the Soviet Union's GDP. Notable expenditures included the development of the Soyuz spacecraft and the Luna series of missions. The total expenditure on the Soviet space program during this period is estimated to be in the tens of billions of dollars.

Post-Space Race Era

United States: After the Apollo program, NASA’s budget declined but remains substantial. For instance, NASA's annual budget for 2023 was approximately $25 billion. Modern missions, such as Mars rovers and the Artemis program, continue to receive significant funding.

Soviet Union (and Russia Post-1991): Following the fall of the Soviet Union, Russia’s space budget fluctuated. In recent years, the Russian space agency Roscosmos has had an annual budget of around $2-3 billion. This is significantly lower than the U.S. budget but still substantial relative to its scale of operations.

Historical Context and Budget for India:

Early Years: India's space program, initiated by the Indian Space Research Organisation (ISRO) in the 1960s, began with relatively modest budgets. Early missions, such as the Aryabhata satellite (1975), were funded with a fraction of the budgets seen in the U.S. and Soviet Union. For example, the development cost of Aryabhata was around $20 million.

Recent Developments: In recent years, India has seen a significant increase in its space budget. For instance, ISRO's budget for 2022-2023 was approximately $2.7 billion. The cost-efficiency of Indian missions is notable; successful missions like the Mars Orbiter Mission (Mangalyaan) cost around $74 million, significantly less than similar missions by other countries. This budget-friendly approach to space exploration pursued by India exemplifies industrial engineering ethics, emphasizing cost reduction while maintaining quality. It is key to efficient manufacturing and reducing costs for human space tourism and space travel [13,14].

6. Conclusion

India has achieved significant milestones that have greatly advanced space exploration and demonstrated that budget-friendly exploration is possible. While India is yet to prove its capability to land humans on a celestial body, this is not a question of "if," but rather "when." India has showcased its space exploration capabilities through missions such as Aryabhata (1975), Chandrayaan-1 (2008)—India's first lunar mission, the Mars Orbiter Mission (Mangalyaan) (2013), and Chandrayaan-2 (2019), which aimed for a soft landing on the Moon. The next ambitious step is the Gaganyaan mission, a human spaceflight program. India has demonstrated high cost efficiency and technical capability with a relatively lower budget. While the U.S. and Russia led early advancements in space exploration, India has made significant strides in recent decades with successful missions and cost-effective solutions that have garnered international recognition. Beyond enhancing India's technical prowess, its space exploration efforts have had a global impact on space research and cooperation.

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8. Conflict of Interest

The author declares no competing conflict of interest.

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