



Case Number: 2024CBC/AGK/033

Date: 27 February 2025

MITRA SOM SAHA
NARENDRA M. AGRAWAL
NISIGANDHA BHUYAN
MAJOR RAVI KHANNA
RAJIV AGARWAL
ASHITA AGGARWAL

Chandrayaan 3: ISRO's Incredible Odyssey into Space

'Anyone who goes to space tries to look at his own country first, but soon it appears that there is no boundary between the countries and the entire world is one family where our destinies are integrated.'

– Rakesh Sharma¹

It was 5:43 pm on August 23, 2023. The atmosphere at the Mission Operations Complex at ISRO Telemetry, Tracking, and Command Network (ISTRAC) in Bengaluru, India was electric. It was a mix of confidence laced with some apprehension. Anxiety was palpable as scientists bore the weight of their nation's expectations. Indian Space Research Organisation (ISRO) Chairman, Dr S. Somanath, and his colleagues, had their eyes glued to the large consoles as Vikram, the lander, began its descent. The Automatic Landing Sequence (ALS) was initiated. All four throttleable engines were activated for a powered descent. With everything working seamlessly, India was poised to create history in the next 20 minutes.

Rewind to September 7, 2019, when the situation was no different. Every parameter was on target during the first phase of the descent, called the Rough Braking Phase. Scientists cheered as the Vikram lander successfully descended to 2.1 km above the lunar surface. However, the jubilation was short-lived. Tense moments followed as everyone witnessed Vikram deviating from its path while transitioning between the final two critical phases – the Absolute Navigation Phase (also known as the camera coasting phase) and the Fine Braking Phase. What unfolded next shattered the dreams of 1.4 billion people. Earlier that day, while addressing journalists, then ISRO Chairman, Dr K. Sivan's description of the last phase of Vikram's landing as '15 minutes of terror' became prophetic. The nation stood silent, yet resolute, as it witnessed a teary-eyed Dr Sivan being consoled by the Prime Minister.

Four years later, India once again stood on the cusp of scripting history. Would everything go as planned tonight? Considering the vast number of landing tests and simulations completed before the launch of Chandrayaan-3 Dr Somanath felt confident. However, such odysseys into unknown realms were always fraught with uncertainties. No number of successful tests could guarantee the success of such hugely complex missions. Just three days earlier, the Russian Luna 25 had crash-landed near the lunar south polar region, a sobering reminder of the mission's risks. (See **Exhibit 1**).

¹ Rakesh Sharma is the first Indian astronaut to orbit in space. In April 1984, he flew aboard Soyuz T-11, as part of the Soviet Interkosmos programme.

India held its breath as Vikram entered the terminal descent after completing the Fine Braking Phase. Schools across the country were live streaming the event. Finally, at 6:03 p.m., young school children of Bharat witnessed the nation's moment of glory as they watched the dust rise from the lunar surface. Vikram had achieved a perfect touch down on the lunar south pole. Spontaneously, scientists, engineers, and technicians at the Mission Operation Complex (MOX) erupted in joy. The smile on Dr Somanath's face as he rose from his seat to shake hands with his team members captured the nation's elation. As the first country to land on the challenging region of the lunar south pole, India had achieved a milestone hitherto unaccomplished by mankind.

The Genesis

The legacy of ISRO since its inception in August 1969 – or even earlier when the Government of India set up the Indian National Committee for Space Research (See **Exhibit 2**) under the Department of Atomic Energy in 1962 – has been shaped by the vision of legendary leaders like Vikram Sarabhai, MGK Menon, U.R. Rao, and Satish Dhawan.² Each of these individuals contributed not just to the space programme but also to the national cause, propelling India to the global high table through soft knowledge power.

'ISRO's future is no longer a future for India alone. It is a future for humanity. It is a future for humankind, how it will move out of the planet called Earth', proclaimed Dr K. Kasturirangan, former Chairman of ISRO.³

The journey of ISRO, becoming a beacon of hope and dreams not only for Indians but for all of mankind, has been arduous. The nature of challenges might have changed, but the determination to overcome them remains steadfast. This resoluteness is now an inherent characteristic of the organisation embedded in its very DNA. Time and again, this persistence has left the world enthralled by ISRO's ability to manoeuvre complexities despite resource constraints.

'Add up all the money that we have spent on ISRO since its inception, and still, it would be less than the annual NASA budget,' said Dr A.S. Kiran Kumar, former Chairman of ISRO. Even the cost of launching Chandrayaan-3, at approximately US \$74 million, was considerably lower than production costs of many Hollywood or Bollywood blockbusters.

Resourcefully Reimagining Restraints ISRO's innovative thinking has been an enabler in transforming its dreams into reality. Where else could one see rockets meant for transportation into space being carried on bicycles and old, creaking bullock carts?ⁱ (See **Exhibit 3**). In 1981, the American magazine NEWSWEEK published a picture showing APPLE, India's first indigenously built experimental communication satellite, which was developed in *'just two years, with limited infrastructure in industrial sheds',*ⁱⁱ being transported on a bullock cart from a hangar to the test centre (See **Exhibit 4**). The photograph was captioned: *'Collision of Centuries'*.ⁱⁱⁱ

Even today, this spirit of overcoming resource limitations through ingenuity endures. The absence of a powerful rocket did not deter ISRO scientists from launching the Mars Orbiter Mission and Chandrayaan-1. They overcame the shortcoming using the sling-shot mechanism (See **Exhibit 5**), to harness Earth's gravity in transferring the orbiter to the lunar or Martian gravitational field. Inventive thinking and

² All these personalities are former Chairmen of ISRO.

³ This quotation by Dr K. Kasturirangan, and other subsequent quotations attributed to Dr Kasturirangan, Dr A.S. Kiran Kumar, and Dr S. Somanath – all of whom have headed ISRO as Chairman – have been sourced from the interviews conducted by Dr R. Balasubramaniam, Member – Human Resource, Capacity Building Commission, Govt. of India.

resilience in the face of technology or resource constraints have been ISRO's hallmark, a legacy instilled by its founding leaders.

Chandrayaan 3: India Rises like a Phoenix

'Nobody gets Mars right on the first try. The US didn't, Russia didn't, the Europeans didn't. But on September 24, 2014, India did. That's when the Mangalyaan...went into orbit around the Red Planet, a technological feat no other Asian nation has yet achieved.'

– 'Time' American News Magazine^{iv}

ISRO, however, did not always get everything right on the first try. No space agency does. A failure study conducted by NASA observed that 41.3% of all small satellites launched by space agencies between the years 2000 and 2016 were unsuccessful.^v The study implies that almost one out of every two modern small satellite missions will result in either a total or a partial mission failure. ISRO's success rate was better. From 2000 until February 2024, out of 83 launches, ISRO succeeded in all but five, which equates to a failure rate of only 6.02% (See **Exhibit 6**), which is comparable with NASA. However, the pressure on ISRO to deliver is significantly higher, given that India, a developing country, is often criticised for investing in expensive space programmes when countrymen living below the poverty line are struggling to make ends meet.

Failure Analysis: 'Everything will Fail'

The criticism was unforgiving when, in 1979, the satellite launch vehicle, SLV-3 failed to place the Rohini satellite into orbit. It plunged into a watery grave instead. The harshest criticism, nonetheless, was encountered in 1987, when, after a gap of four years, ASLV-1, described as a 'quantum jump' in space, plunged into the Bay of Bengal. The cash loss was assessed at ₹6 crore.

'It is only a setback in time. It is only when you stumble that you can get up and walk better,' the then Prime Minister of the country said.^{vi} However, within 15 months, when the Augmented Satellite Launch Vehicle (ASLV-2) could not achieve orbit, it was the toughest time for ISRO, as India also faced an embargo from the developed nations.

ISRO set up high-profile failure analysis committees each time after a mission failure. These committees included not just ISRO scientists but multiple external experts too. A thorough diagnostic examination was undertaken, and each time, India rose like a phoenix. The ambitious launch vehicle ASLV-3, in which ISRO introduced the 'closed-loop guidance system', was finally successfully launched in 1992.

'For any organisation, especially a space agency, success and failures are an integral part. How the organisation deals with that success and failure is very important. This is where culture plays a role. At ISRO, we have looked for what caused the failure rather than who caused the failure,' explained Dr Kiran Kumar.^{vii}

ISRO uses the same analysis process even today. With refinements and enhanced follow-up actions, the possibility of failure is reduced over time.

'Moon cannot be created on earth, especially the gravity field cannot be replicated. One cannot create the absence of atmosphere or other perturbations like radiation. When Chandrayaan-2 was executed, there were certain shortcomings in terms of the absence of sufficient data. ISRO had no data about the moon other than what Chandrayaan-1 had sent. But someone must take the first steps into unknown realms. So, the process began with the help of various other players. Even the gravity model of the moon was borrowed,' elaborated Dr Somanath. Yet, there will always be a certain level of uncertainty in such missions, which one can only attempt to minimise.

To increase the probability of success for Chandrayaan-3, ISRO initiated reviews at multiple levels, including peer-level reviews. Greater participation from academia was facilitated to elevate the rigour of understanding a complex problem in its entirety. Global experts were invited to review the scientific approaches and scrutinise the entire scenario sceptically. Software rigour testing, like helicopter drop tests and crane-based testing, was conducted on a large scale across domains.

'This is the culture that we have created internally: we do not assume everything will succeed; we rather assume that everything will fail. Many failure modes were addressed, but none occurred in the real flight. This is the beauty of this system: Your ability to visualise numerous possibilities of failure saves you from real catastrophe,' Dr Somanath contended.

Using Failure as a Springboard

The analysis of what went wrong during the soft landing of the Chandrayaan-2 mission went on for almost a year. This understanding was synthesised into a case where success could be achieved under all possible conditions. After the first year of understanding, scientists considered the necessary design modifications. Additional sensors were included, and more fuel was added to effectively manage various scenarios while simultaneously decreasing the number of throttleable engines from five to four. The entire model was rigorously tested in the third year, considering numerous perturbations. Test cases were increased, and the boundaries of performance were extended. Newer assessments like ground tests and simulations, on orbit testing, and evaluations were introduced and extensively implemented. These evaluations were a game changer and marked a clear improvement over Chandrayaan-2.

For the first time, ISRO also introduced a cross-functional review system. Satellites were built in the satellite centre, and rockets in the rocket centre. The new review system ensured that the scientists at the rocket centre analysed the work of the satellite centre, and vice versa. Simulation test beds were created in other centres, and data was cross verified to ensure no mistakes were made.

As India celebrated the success of Chandrayaan-3, Dr Somanath reflected on the capacity-building process undertaken over the past three years, a classic example of using failures as springboards to success. He also attributed the achievement to a culture of continual learning and being in sync with the overarching purpose of ISRO.

A Strong Sense of Purpose

'There is a larger purpose that drives people in ISRO...everybody who is working, whether he is working for a satellite, working for a rocket, or working for an application; all of them see the big picture of space technology serving specific national requirements. And that itself is a great motivator, affirmed Dr Kiran Kumar.

Dr Sarabhai, as the first ISRO chairman and a visionary leader, was convinced that space science had immense societal applications in a developing nation like India where agriculture was the mainstay. As Dr U.R. Rao, former ISRO Chairman mentioned:

'When remote sensing was unheard of in the country, Sarabhai got us to get into a helicopter to record visuals of wilting coconut trees in Trivandrum. He showed it to Prime Minister Indira Gandhi and told her, 'See, a satellite picture can show you much more about agriculture.' He convinced her.'^{viii}

Dr Vikram Sarabhai not only laid down the vision but also secured approval at the national level. The country accepted the national blueprint with a broad agenda covering remote sensing, scientific, and communication satellites at the August 1972 seminar.^{ix}

A book about ISRO titled *ISRO, A Personal History*, documents the long-term vision of planetary exploration laid down two decades ago.^x Every mission, every capacity-building effort is aligned with ISRO's ubiquitous vision: to *'harness, sustain and augment space technology for national development while pursuing space science research and planetary exploration.'*^{xi}

'We were the only country that started the space programme for a purpose other than military,' said Dr Kiran Kumar.

Thus, at ISRO, it is not only about being strongly aware of the vision in every single mission but about living it every day, in every moment, in every decision.

Collaborate Globally, Build Indigenously for Self-reliance

'Dr Sarabhai was a well-known figure internationally. He approached NASA with a bold request, 'I want to move the Advanced Technology Satellite, ATS 6, to the Indian Ocean region. Give it to us as a loan for two years; we would like to use it for our developmental purposes.' recollected Dr Kasturirangan.

Whether for communication or remote sensing, building a satellite at that point in time was a formidable challenge for India. Hence, the strategy adopted was to procure what was available, collaborate with willing global players, and simultaneously build ground systems. This is evident throughout the history of ISRO, starting from the Satellite Instructional Television Experiment that enabled India to broadcast television to an audience of millions of viewers⁴ to ISRO joining hands with the USSR to launch its first experimental satellite, Aryabhata, in 1975. (See **Exhibit 7**).

During Chandrayaan-1 for instance, several payloads like the Near Infrared Spectrometer (SIR-2) and Miniature Synthetic Aperture Radar (Mini SAR) were sourced from global institutes like the Max-Planck-Institute for Solar System Science, Germany, Applied Physics Laboratory, Johns Hopkins University and Naval Air Warfare Centre, in the USA.^{xii} Chandrayaan-2, in the true spirit of ISRO's evolving self-reliance, was an entirely indigenous endeavour. Most of the instruments on board, including all the sensors, were Indian, designed, built and tested in India. ISRO was determined to carve its own path in the cosmos.

'From 2019, India's space power has seen a remarkable surge, attributed to both striking scientific missions and military capability demonstrations^{xiii} and today the country is seen as a 'great space power.'^{xiv} (See **Exhibit 8**). The successful launch of Chandrayaan-3 is simply the culmination of decades of careful mission planning, to achieve one goal at a time – from Bhaskara to IRS, from INSAT to GSAT, from SLV to ASLV to PSLV and GSLV and now to LVM3, continually upgrading scientific capability within the country.

NASA and ISRO, in February 2014, entered into an agreement for a joint Earth-observing mission *'with the goal to make global measurements of the causes and consequences of land surface changes using advanced radar imaging.'*^{xv} Scheduled for launch in 2024, this collaboration, named NISAR for NASA ISRO Synthetic Aperture Radar, marks the first time cooperation on hardware development between NASA and ISRO on an equal footing. The state-of-the-art earth-observing radar satellite has already been successfully tested at ISRO facilities.^{xvi}

⁴ With the support of NASA ISRO launched the *'greatest communications experiment until that time',* the Satellite Instructional Television Experiment (SITE) in 1975-76. *'India became the world's first nation to broadcast television to an audience of millions of viewers.'* National Aeronautics and Space Administration (2023) Nasa History News & Notes. Vol 40, Number 4, Winter 2023. Pg. 22. Available at: <https://www.nasa.gov/wp-content/uploads/2023/12/newsnotes-40-4-winter-2023.pdf> (Accessed on 14th July 2024)

In February 2017, PSLV-C37, on its 39th flight, launched a record 104 satellites, 101 of which were for international customer satellites, with 96 belonging to the USA alone.^{xvii} A country once criticised for piggy-back riding on the achievements of the US, Russia (erstwhile USSR), and the European Space Agency (ESA), was today launching satellites for developed nations. The tables had turned.

Mission Mode at ISRO

During ISRO's formative years, Prof. Dhawan (former Chairman of ISRO) instituted a stringent review mechanism, holding the entire organisation accountable to the chairman periodically. Every three months, he reviewed design documents, critical designs, secondary critical designs, flight readiness, and many other parameters of a programme's progress within the context of technology, maturity, and development. These reviews were never closed-door affairs.^{xviii} Anyone could attend and raise an issue, regardless of seniority. The person presenting was bound to answer and offer the necessary explanation. Youngsters, in particular, have a voice at ISRO. Such openness ensured that fresh ideas and critical feedback were always welcomed, reinforcing a culture where every voice matters. This inclusive culture of review remains a cornerstone of ISRO even today.

Given the complexity and multi-disciplinary nature of space missions, Prof. U. R. Rao, who succeeded Dhawan, introduced the matrix management structure^{xix} to optimise available resources and enable seamless coordination. This mission mode of work at ISRO inherently demands accountability within specific time frames, budgets and precisely defined specifications. It necessitates identifying uncertainties and potential contingencies and curating the workaround plan that mandates a robust structural system to enable people to group together, collaborate and also work jointly with the leadership. Prof. Rao '*steadfastly brought in high levels of professional competence, mutual respect, and team spirit with trust that became the organisational norm and continues to be the guiding force.*'^{xx}

Analysing the critical path, preparing an overall master schedule, managing supply chain, and finance management are all conducted formally, and adhere to the principles of project management. However, ISRO being a technology-driven organisation, the risks involved are high. Thus, it is left to the leadership to decide on priorities, albeit after necessary deliberations.

'A decision is taken after discussion, but once a decision is taken - like a launch date is fixed - it is not left to anybody's discretion. If that translates to working 24 hours, one must work 24 hours.' Dr Somanath affirmed.

Thus, at ISRO, 'centralisation, decentralisation, and recentralisation'⁵ intertwine to create a tapestry of a dynamic and efficient organisational culture that is nurtured through a shared vision, where the comprehensive goals of the organisation are the guiding principles. Each project team operates with a high degree of autonomy. Yet, these independent efforts are brought back into alignment through a rigorous review mechanism, to ensure coherence and quality. This integrated approach – centralised shared vision, decentralised execution and recentralisation through collective review – has crystallised into what is known as the 'ISRO culture.' A culture that stands as a beacon for any public service organisation, exemplifying how meticulous planning, strict adherence to deadlines, and promoting an ecosystem of

⁵ CDR, the abbreviated form for 'Commander' (Cdr), was interpreted by an Indian Army General as a three-step process: Centralisation, Decentralisation, and Recentralisation. Case Study Reference No. IIMC-CRC-2023-04. Indian Institute of Management, Calcutta (November 2021) Building an Ethical Organisation. Available at: Available at:

https://www.iimcal.ac.in/sites/default/files/case_studies_portal/1711700739_iimccrc_ruddefine_excellence_consulting-sneak_peek.pdf Pg 13 (Accessed on July 14, 2024)

innovative thinking through people empowerment across all ranks can coexist to drive groundbreaking achievements.

Nurturing leaders

ISRO has always been about exemplary leadership—individuals who have not only been luminaries in their academic accomplishments but institution builders, true '*karmayogis*'⁶ who have exemplified the virtues of *Vikas* (development), *Garv* (pride), *Kartavya* (duty), and *Ekta* (unity) in their thoughts and dedicated service to ISRO and the nation.

Dr Sarabhai hand-picked individuals to lead India's nascent space programme, bringing in talents like Prof. Bhawsar, Chitnis, H.G.S. Murthy, Kalam et al. He entrusted Dr U.R. Rao with preparation of the blueprint for developing space technology in India, drawing on his experience of working with NASA in Massachusetts. Prof. Dhawan was away on a sabbatical at Caltech—California Institute of Technology—when he was offered the Chairmanship of ISRO, by the then Prime Minister.^{xxi} Together, these individuals evolved as the who's who of India's early space programme.

Dr Kasturirangan recalled the time when he was considering a postdoctoral fellowship when Dr Sarabhai heard about the possibility of him moving to Berkeley. Dr Sarabhai passionately elaborated the space programme he envisioned for the country and told Dr Kasturirangan, '*There are many things that one can do in life, but nothing compares to working for your own country and on a programme with great potential for the future, benefitting the country, and simultaneously bringing prestige to the people involved. You will leave a legacy.*'^{xxii}

He was so persuasive with his arguments that the young Dr Kasturirangan decided to stay back. This *Guru Shishya*⁷ tradition at ISRO has successfully ignited the minds of young recruits, emboldening them with the freedom of thought and action. (See **Exhibit 9, 10**)

'At ISRO, we have been successful in creating an inspirational ecosystem. Ultimately, human beings exist for a certain level of satisfaction. What exactly is this satisfaction? It is not money or power – neither is abundant here. It is the possibility of transforming what you visualise into reality. When I joined this project as a young engineer, I had a sketch of the current launch vehicle on an A4 sheet of paper. After 12 years I could launch it as a project director. For me, it was sheer magic,' emphasised Dr Somanath.

From sponsoring the higher studies of young recruits, creating opportunities for them to pursue their Master and PhD degrees to nurturing them through comprehensive internal capacity-building programmes and honing their managerial capabilities by virtue of courses at the country's top-notch institutions like IIMs, these graduates, who are rarely from premier institutions like the IITs, are transformed into individuals capable of handling complex space missions. Now regarded as one of the finest space agencies globally, ISRO's story is not just of technological triumph but also of a deep and abiding commitment to its people. ISRO not only invests in technology; it invests in its people.

⁶ Karmayogi, a Sanskrit word, as explained in the Hindu scripture, '*Bhagwad Gita*', describes a person who performs selfless actions for the benefit of others.

⁷ The '*Guru-Shishya*' tradition, refers to The Mentor-Disciple or Teacher-Student Relationship. It is a centuries-old educational and spiritual system in Indian culture, where the '*Guru*' (mentor or teacher) imparts knowledge, wisdom, and skills to the '*Shishya*' (disciple or student) in a deeply personal and holistic manner. This tradition emphasizes a bond of mutual respect, trust, and commitment, transcending the mere exchange of information to nurture character, values, and spiritual growth.

The Road Ahead

On the evening of August 23, 2023, as Dr Somanath soaked in the achievement of being the first nation to successfully soft land on the lunar south pole, he could not help but reflect on the achievements of ISRO. Yet, there were areas that required substantial improvement. ISRO was established with the aim of serving society. Has ISRO been 100 percent successful in that? Dr Somanath believed that although ISRO was engaged in conceptualisation, building, launching, assimilating data, connecting ministries, and departments, ensuring that data from various missions was available to users, and contributing to national causes like crop forecasting and more precise weather predictions, it still had a long way to go. What systemic changes could he bring about to ensure that the purpose for which ISRO was established was optimally realised?

ISRO is also an organisation hailed for promoting gender equality. All that matters is merit and competency. From the Mangalyaan to Chandrayaan missions, the world witnessed female trailblazers like Nandini Harinath, Ritu Karidhal, Moumita Dutta, Minal Sampat and T.K. Anuradha leading from the front. Chandrayaan-2 had M. Vanitha as the Project Director, while Chandrayaan-3 had K. Kalpana serving as the Associate Project Director. Today, the female workforce at ISRO is about 25% and steadily growing, with many women at the level of Project Directors, Deputy Directors, and Associate Directors. By deliberately encouraging women to move into core decision-making levels, ISRO could perhaps become the first space agency in the world to be led by a woman chairperson.

Furthermore, with planetary exploration poised to dominate the 21st century, ISRO is preparing to push the boundaries of space research. The Aditya-L1 mission is currently studying the Sun, while XPoSat is observing bright X-ray sources. Projects such as the Chandrayaan-4 mission – aimed at returning lunar samples – and an orbiter mission to Venus have already received approval. These are not merely scientific pursuits but bold strides toward strengthening India's position as a global space power. As the Honourable Prime Minister of India, Shri Narendra Modi, proclaimed in his address following Chandrayaan-3's historic landing:

*"This achievement of the Chandrayaan Mission will propel India's journey beyond the Moon's orbit. We will test the limits of our solar system and continue working to realize the infinite possibilities of the universe for humanity. We have set many big and ambitious goals for the future. Soon, ISRO will launch the 'Aditya L-1' mission for an in-depth study of the Sun. Following that, Venus is also on ISRO's agenda. Through the Gaganyaan mission, the country is diligently preparing for its first human spaceflight mission. India is repeatedly proving that the sky is not the limit."*⁸

Indeed, for ISRO, the sky has never been the limit – even now, it remains merely the starting point of a greater journey.

With the space sector witnessing growing participation from private players like SpaceX and Blue Origin, ISRO is prepared to accelerate its capacity-building efforts, drive innovation at an unprecedented pace, and reduce the turnaround time between critical missions. Recognizing the need for a robust space ecosystem, the Indian government opened the space sector to private entities in 2020. In April 2023, the Union Cabinet approved the Indian Space Policy 2023, encouraging private sector investment and collaboration. Recent policy shifts have further amplified these opportunities. The Foreign Direct Investment (FDI) cap for satellite manufacturing and operations has been increased to 74% under the automatic route, paving the

⁸ <https://www.pib.gov.in/PressReleasePage.aspx?PRID=1951491&utm> (Accessed on February 27, 2025)

way for greater international partnerships and technological advancements.⁹ ISRO is set to harness these developments, transforming challenges into opportunities and scaling new heights in space exploration. Another significant milestone is the establishment of a ₹1,000 crore Venture Capital Fund for the space sector under the aegis of IN-SPACe.¹⁰ This initiative provides ISRO with a strategic boost, enabling deeper private sector participation and reinforcing India's leadership in global space technology.

Having completed the project design for Chandrayaan-4 and Chandrayaan-5,¹¹ ISRO has firmly established itself as a dominant force in solar system exploration. Dr Somanath believes these advancements will not only reinforce ISRO's pioneering role but also ensure that India remains an indispensable player at the high table of global space exploration.

⁹ The Economic Times (May 2024) Now India can hope to have its own SpaceX and Blue Origin. Available at: <https://economictimes.indiatimes.com/news/science/now-india-can-hope-to-have-its-own-spacex-and-blue-origin/articleshow/110570418.cms?from=mdr> (Accessed on July 14, 2024)

¹⁰ https://www.isro.gov.in/UnionCabinetapprovesestablishment_INSPACe.html (Accessed on February 27, 2025)

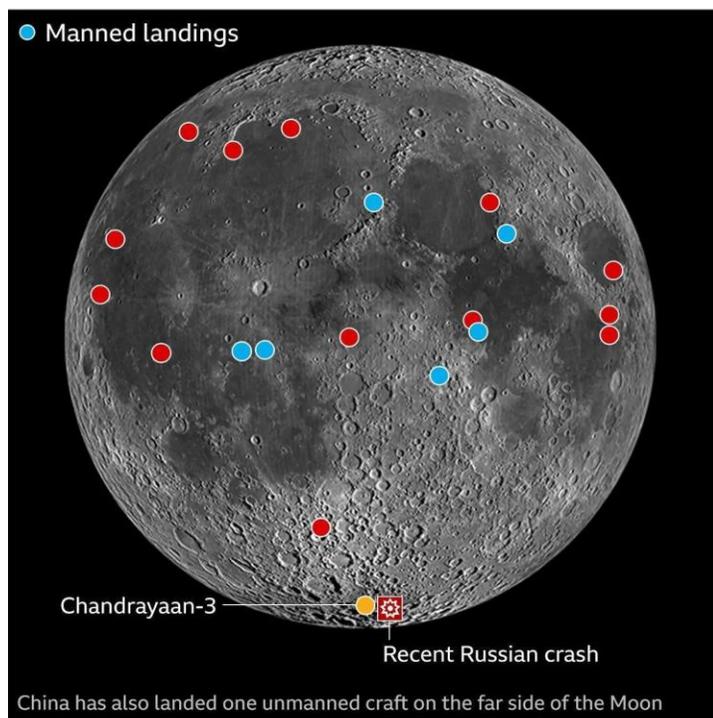
¹¹ The Hindu (August 2024), Chandrayaan 4 and 5 design complete; 70 satellites likely to be launched in 5 years: ISRO chief. Available at: <https://www.thehindu.com/sci-tech/science/chandrayaan-4-and-5-design-complete-70-satellites-likely-to-be-launched-in-5-years-isro-chief/article68546904.ece> (Accessed on: September 29, 2024)

EXHIBITS

Exhibit 1: Sites of Successful Moon Landings

Sites of successful Moon landings

Near side of the Moon



Source: Nasa

BBC

Source: <https://www.bbc.com/news/world-asia-india-66594520> (Accessed on July 14, 2024)

Exhibit 2: The Inception of ISRO

'Space research activities were initiated in our country during the early 1960's, when applications using satellites were in experimental stages even in the United States. With the live transmission of Tokyo Olympic Games across the Pacific by the American Satellite 'Syncom-3' demonstrating the power of communication satellites, Dr Vikram Sarabhai, the founding father of the Indian space programme, quickly recognised the benefits of space technologies for India.

Dr Sarabhai was convinced and envisioned that the resources in space have the potential to address the real problems of man and society. As Director, Physical Research Laboratory (PRL) located in Ahmedabad, Dr Sarabhai convened an army of able and brilliant scientists, anthropologists, communicators and social scientists from all corners of the country to spearhead the Indian space programme.

To spearhead the space research activities, Indian National Committee for Space Research (INCOSPAR) was set up in 1962 under the Department of Atomic Energy. Subsequently, Indian Space Research Organisation (ISRO) was established in August 1969, in place of INCOSPAR. The Government of India constituted the Space Commission and established the Department of Space (DOS) in June 1972 and brought ISRO under DOS in September 1972.'

Source: <https://www.isro.gov.in/genesis.html> (Accessed on July 14, 2024)

Exhibit 3: Rockets being carried on bicycles



Source: <https://www.indiatimes.com/technology/science-and-future/from-bicycle-to-a-billion-dreams-the-inspiring-history-of-isro-powering-india-s-space-fantasy-371930.html> (Accessed on 14th July 2024)

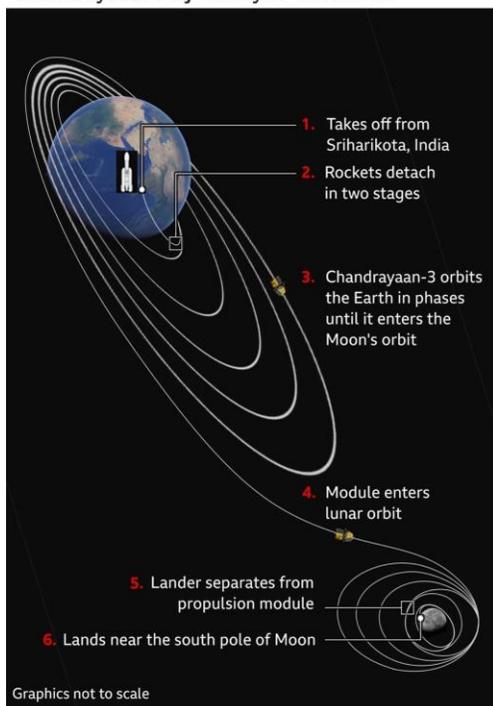
Exhibit 4: APPLE being transported on a bullock cart



Source: <https://www.thehindu.com/news/cities/Hyderabad/india-and-france-in-space-isro-cnes-a-common-history-a-virtual-exhibition/article32610320.ece> (Accessed on July 14, 2024)

Exhibit 5: The slingshot mechanism used for Chandrayaan Missions

Chandrayaan-3's journey to the Moon



Source: Indian Space Research Organisation



Source: <https://www.bbc.com/news/world-asia-india-66594520> (Accessed on July 14, 2024)

Exhibit 6: Launch Missions at ISRO - 1979 till February 2024

Year	LVM	GSLV	PSLV	SSLV	ASLV	SLV	OTHERS	TOTAL	SUCCESS	FAILED
2021- Feb 2024	3	3	8	2	0	0	0	16	15	GSLV -1
2016-2020	0	8	19	0	0	0	3	30	29	PSLV 1
2011-2015	1	2	16	-	-	-	-	19	19	0
2006-2010	-	6	5	-	-	=	=	11	8	GSLV- 3
2001-2005	-	3	4	-	-	-	-	7	7	0
1979-2000	-	-	5	4	4	-	-	13	9	PSLV- 1 ASLV- 2 SLV - 1
1979- Till Date	4	22	57	6	4	0	3	96	87	9

Source: Developed by Authors based on data from the ISRO website. Available at:
<https://www.isro.gov.in/LaunchMissions.html#> (Accessed on July 10, 2024)
<https://ntrs.nasa.gov/api/citations/20190002705/downloads/20190002705.pdf> (Accessed on July 10, 2024)

A failure study of all small satellites launched by NASA during the period 2000 to 2016 suggests that 41.3% of all small satellites launched were unsuccessful. The launch vehicle failure rate at NASA during the above period was 6.1%. From the year 2000 till February 2024, out of a total of 83 launches in the last 24 years, ISRO had five failures, which is about 6.02%, similar to the launch vehicle failure rates at NASA.

In 2022, there were 186 space launches globally and out of them, about eight failed, which was about 4.3%. BBC, (2023), Available at:
<https://www.bbc.com/future/article/20230518-what-are-the-odds-of-a-successful-space-launch>
 Downloaded on Jun 28, 2024

'Seradata's (<https://www.seradata.com/>) (Accessed on July 10, 2024) understanding of failure also includes the rocket's payload not reaching the intended orbit or it being significantly damaged in the launch, not just failing to achieve orbit. If one looks at launches in the 1950s, in those first stumbling leaps of the space race, the failure rates are shockingly different – more than 70%. It was not until the early 1960s when this number started falling, and it has hovered around the same point ever since – around 7% (9% if satellite-related launch failures are included).'

Exhibit 7: Additional Note on ISRO's strategy for International Collaboration for technology transfer or purchase.

NASA agreed to support ISRO, albeit for a year, and that paved the way for the '*the greatest communications experiment until that time,*' Satellite Instructional Television Experiment (SITE) in 1975-76. *India became the world's first nation to broadcast television to an audience of millions of viewers.*¹²

Given the importance of remote sensing, India entered into an agreement with NASA¹³ in January 1978, even before starting to build its own remote sensing satellite. '*Indian Space Scientists took advantage of the 'LANDSAT System' which was made available by the United States and developed ground stations and analysis capabilities to make full use of data from these satellites.*'¹⁴

*Dr Werner von Braun, the mind behind America's Saturn-5 rockets, had advised ISRO scientists in 1973 not to invest in an independent launch vehicle because India lacked the necessary industrial and military infrastructure.*¹⁵ History is witness to the fact that India persevered without being deterred by the lack of appropriate resources. While Bhaskara-1¹⁶, India's first experimental remote sensing satellite, was being launched from the Volgograd Launch Station (in the erstwhile USSR) in June 1979, here at Sriharikota in August of the

¹² NASA History (Winter 2023) Volume 40, Number 4. Page 22. Available at:<https://www.nasa.gov/wp-content/uploads/2023/12/newsnotes-40-4-winter-2023.pdf> (Accessed on July 14 2024)

¹³ Ministry of External Affairs, Government of India (January 1978) Memorandum of Understanding between the GoI and the Government of the United States of America regarding Landsat satellites. Available at:
<https://www.mea.gov.in/Portal/LegalTreatiesDoc/US78B1734.pdf> (Accessed on July 14, 2024)

¹⁴ ISRO India (1995) Space India, The Indian Space Programme. Page 3. Available at:
[https://www.isro.gov.in/media_isro/pdf/ResourcesPdf/SpaceIndia/publication\(36\).pdf](https://www.isro.gov.in/media_isro/pdf/ResourcesPdf/SpaceIndia/publication(36).pdf) (Accessed on July 14, 2024)

¹⁵ India Today (January 2015) SLV-3 launch fails, plunges into Bay of Bengal seconds after take-off. Available at:
<https://www.indiatoday.in/magazine/science-and-technology/story/19790915-slv-3-launch-fails-plunges-into-bay-of-bengal-seconds-after-take-off-822576-2014-02-24> (Accessed on July 14, 2024)

¹⁶ ISRO, Department of Space. Bhaskara-I. Available at: https://www.isro.gov.in/Bhaskara_I.html?timeline=timeline (Accessed on July 14, 2024)

same year, India was simultaneously attempting the maiden flight of its indigenously built launch vehicle SLV-3. Although 317 seconds after the launch, a faulty valve in the second stage of the launch vehicle caused it to plunge into the Bay of Bengal,¹⁷ it was the stepping stone to the successful flight of SLV-3 in July 1980 when Rohini RS-1 was put into orbit.

*'The reaction control system, solar panels, thermal paints, chemical battery and tape recorders'*¹⁸ for Bhaskara-1 & 2 were supplied by the USSR in addition to launching them free of any cost. ISRO used these experiences to indigenously build the state-of-the-art Indian Remote Sensing Satellite IRS1A in March 1988, becoming 'the first developing country to have its own space-based system for natural resource management.'¹⁹

In the words of Dr Kasturirangan, *'The most sophisticated camera systems were built, and electronic scanning for imaging using Charge-Coupled Devices (CCD) was introduced instead of the mechanical scanners used by US LANDSAT missions.'*²⁰ *Many of the control systems, like the gyroscope, reaction wheels and propulsions, were designed and built in India. It was a fabulous mission, launched after six years of effort, producing results comparable to the best two satellites in the world, the French SPOT and the American LANDSAT.'*

In the domain of communication satellites, ISRO demonstrated grit and determination by building the Ariane Passenger Payload Experiment (APPLE) and launching it from French Guyana in 1981.²¹

One can identify the commonality in the strategy over ISRO's timeline when Prof. Dhawan boldly decided to buy four satellites from Ford Aerospace Communication Corporation, USA, paving the way for the INSAT-1 series.²² This series, one of the largest domestic Geostationary Communication Satellite systems in the Asia-Pacific region, was custom-designed and made according to India's unique requirements and launched from the USA. Successfully deployed in 1983, INSAT-1A beautifully weaved together communication, broadcasting, and meteorology into a single mission. The process of going to the USA for test and evaluation allowed Indian engineers to learn the nitty-gritty details of satellite technology, paving the way for INSAT-2A, the first multipurpose satellite built by India, and the later INSAT and GSAT series of communication satellites.²³

While IRS-1, 2, and 3 were launched in collaboration with Russia (then USSR), ISRO kept enhancing its launch vehicle capacity. After the successful flight of SLV-3²⁴ in 1980, the ASLV was tested successfully in 1992,²⁵ tripling the payload capacity. PSLV, designed to launch 1000 kg class IRS satellites,²⁶ became India's

¹⁷ ABP Live (August 2022) This Day In History: 43 Years Ago, ISRO Conducted Maiden Flight Of India's First Experimental Satellite Launch Vehicle. Available at: <https://news.abplive.com/science/this-day-in-history-43-years-ago-isro-conducted-maiden-flight-of-india-s-first-experimental-satellite-launch-vehicle-1547417> (Accessed on July 14, 2024)

¹⁸ ISRO, Department of Space (March 2023), Indian Remote Sensing Satellite, IRS-1A. Available at: https://www.isro.gov.in/ISRO_HINDI/Indian_Remote_Sensing_Satellite_1A.html (Accessed on July 14, 2024)

¹⁹ Available at: <https://www.nature.com/articles/332296a0.pdf> Accessed on 14th July 2024

²⁰ Kasturirangan K and Jayaraman V, ISRO. Indian Remote Sensing Satellite, IRS-1A A forerunner for operational era. Available at: https://www.isro.gov.in/media_isro/pdf/FlashNews/IndianRemoteSensingSatellite_IRS_1A.pdf Pg 3. (Accessed on July 14, 2024)

²¹ ISRO, Department of Space. APPLE. Available at: <https://www.isro.gov.in/APPLE.html> (Accessed on July 14, 2024)

²² National Aeronautics and Space Administration, INSAT 1A. Available at: <https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1982-031A> (Accessed on July 14, 2024)

²³ ISRO, Department of Space. Communication Satellites. Available at: <https://www.isro.gov.in/CommunicationSatellitenNew.html#> (Accessed on July 14, 2024)

²⁴ ISRO, Department of Space. SLV. Available at: <https://www.isro.gov.in/SLV.html> (Accessed on July 14, 2024)

²⁵ ISRO, Department of Space. ASLV. Available at: <https://www.isro.gov.in/ASLV.html> (Accessed on July 14, 2024)

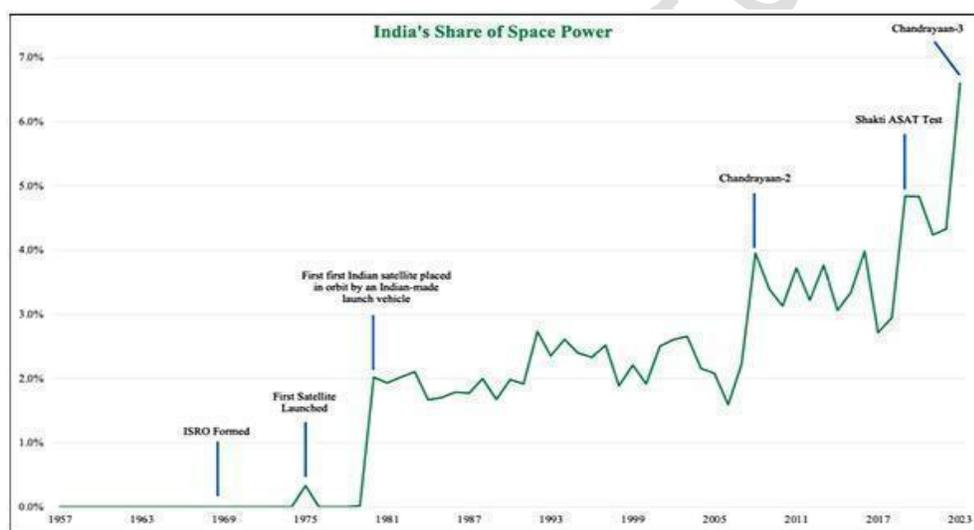
²⁶ ISRO (1989) Space India. The Indian Space Programme. Page 4. Available at: [https://www.isro.gov.in/media_isro/pdf/ResourcesPdf/SpaceIndia/publication\(54\).pdf](https://www.isro.gov.in/media_isro/pdf/ResourcesPdf/SpaceIndia/publication(54).pdf) (Accessed on July 14, 2024)

first launch vehicle with liquid stages. Famed as the '*workhorse of ISRO*' for its versatility and reliability, PSLV has launched numerous Indian and foreign satellites since its successful first flight in October 1994. India's Chandrayaan-1 in 2008 and Mars Orbiter Mission in 2013 are among the prestigious accomplishments of PSLV.²⁷

Similarly, when the world was transitioning to Cryogenic engines, Prof. Dhawan once again decided to start building a 1-tonne engine internally. '*Thus, when our engineers discussed obtaining the cryogenic engine with the Soviets, they deliberated on equal terms. The Soviets were surprised that Indians knew so much about cryogenics without having built one,*' recalled Dr Kasturirangan.

ISRO's journey to mastering advanced rocket technology is again a testament to its relentless pursuit of excellence. In 2001, ISRO built and tested a superior three-stage launch vehicle equipped with the Russian cryogenic engine. Fast forward to January 2014, when GSLV²⁸ made its maiden flight with an indigenously built cryogenic engine. Today, ISRO has successfully designed, built, and tested LVM3 (Geosynchronous Satellite Launch Vehicle Mk III)²⁹ powered by India's largest cryogenic engine with a fuel capacity of 28 tonnes and capable of placing 4-tonne GSAT satellites in geosynchronous orbit with remarkable cost-effectiveness. From the 40 kg payload capability of SLV-3 in a Low Earth Orbit to a 4-tonne payload capability in a Geosynchronous Orbit (8 tonnes in a Low Earth Orbit), ISRO has come a long way.

Exhibit 8: India's Share of Space Power



Source: <https://www.thespacereview.com/article/4702/1> (Accessed on July 14, 2024)

²⁷ ISRO, Department of Space. PSLV. Available at: https://www.isro.gov.in/PSLV_CON.html (Accessed on July 14, 2024)

²⁸ ISRO, Department of Space. Geosynchronous Satellite Launch Vehicle Mark II. Available at: https://www.isro.gov.in/GSLV_CON.html (Accessed on July 14, 2024)

²⁹ ISRO, Department of Space. LVM3(Geosynchronous Satellite Launch Vehicle Mk III). Available at: https://www.isro.gov.in/GSLVmk3_CON.html (Accessed on July 14, 2024)

Exhibit 9: A letter by Dr K. Kasturirangan to his teacher and mentor at ISRO, Prof. P D Bhawsar

रामन अनुसंधान संस्थान
सी. वी. रामन एवेन्यू, सदाशिवनगर, बेंगलूर - 560 080, भारत

RAMAN RESEARCH INSTITUTE
C. V. Raman Avenue, Sadashivanagar, Bangalore - 560 080, India

K.KASTURIRANGAN
Former Chairman, ISRO
Former Chairman, National Education Policy Committee
Chairman, National Steering Committee for National Curriculum Frameworks August 08, 2022

Prof P D Bhawsar
No. 4 Rohini Society
Bhudarpura
Ambawadi Vistar Post
Ahmedabad 380015

Respected Prof Bhawsar,

On the eve of your 97th Birthday, I offer my heartfelt pranams with prayers to Almighty to give me the privilege of your blessings and guidance for many years to come. Respected sir, I am what I am today, because of the care and concern that you personally have about me. Further, you extended that very important gesture to a youngster who was your student at that time, in terms of freedom of thinking and action, which in turn created special attributes in my life like original thinking and creative approaches. Also, you gave me lot of freedom which made me bold to act in all subsequent years of my life in different capacities. It is very rare that such an opportunity endowed with magnanimity is available to all youngsters who are being supervised by their seniors. The problems you suggested in Physics and Astrophysics, the experimental techniques that you thought me to master, the freedom and flexibility with which I could interact with many other academics and my contemporaries and above all gave me support and encouragement in times of despondency all of which made me prepare myself for a future which in retrospect today only make me realise how much I owe to you in my life.

Sir, only providence and blessings of the Almighty could've brought me to your attention and made you adopt me as your student. From then onwards, it was a question of things going right by my association with

Phone : Off + 91 80 2361 0122 Fax : 91 80 2361 0492 e-mail : root@rri.res.in

Source: Dr K. Kasturirangan letter to Prof. P. D. Bhawsar on his 97th Birthday.

https://www.sac.gov.in/data/Highlight/777/Felicitaton%20of%20Prof.%20P.D.%20Bhavsar_17-8-2022.pdf

Exhibit 10: ISRO Chairman Satish Dhawan thanking Dr APJ Abdul Kalam, Project Director of Satellite Launch Vehicle (SLV), for the successful launch of SLV-3

A Beautiful Day

18th July 1980 is a memorable day for the entire space community of India. This was the day the space scientists put a 40 Kg Rohini satellite in a low earth orbit through SLV-3 which took off at 0805 hrs; within minutes the satellite was in orbit. This was a great accomplishment for our scientists, especially after an unsuccessful earlier mission on 10th August 1979.

There was jubilation all around. People were thrilled. They were shouting, hugging and lifting each other and were emo-

HAL Hindustan Aeronautics Limited, Bangalore

SLV – Satellite Launch Vehicle

ISRO Indian Space Research Organization

INSAT – Indian National Satellite IRS-2 Indian Remote Sensing Satellite.

DRDO Defence Research and Development Organization, Hyderabad

DRDL Defence Research and Development Laboratory

RESONANCE | October 2003

57

GENERAL | ARTICLE

tionally charged. This was the time Prof. Dhawan took me aside and said that we should go to a silent place. Both of us went to the launch pad and sat on the launcher. We watched the waves of the Bay of Bengal in silence.

After a few minutes Prof. Dhawan said to me: “Kalam, you know you have been working hard for the last eight years. You encountered a number of problems and failures. You faced them all with utmost courage, patience and perseverance. For all the efforts that you put in, today we have got the results. I want to thank you for your excellent work. I will remember it and cherish it”.

I had never come across such a beautiful day till then. In the din of loud external jubilation of the entire space community, Prof. Dhawan and I were enjoying the intrinsic beauty of the mega event.

Source: Satish Dhawan - A Creative Teacher by APJ Abdul Kalam. Available at: <https://www.ias.ac.in/article/fulltext/reso/008/10/0056-0062> (Accessed on: July 14, 2024)

About the Authors

Ms Mitra S. Saha is an alumna of IIM Calcutta and has been in the field of education for the last 28 years. Specialising in Theoretical Physics during her master's degree, Mitra served as a Lecturer in Physics at St. Anne's Junior College, Mumbai, for 16 years before taking up her current position as head of a K-12 school. A 'CCS - Dharampal Fellow,' Mitra is currently pursuing a Fellowship Programme at the Academy of HRD, Ahmedabad.

Prof. Narendra M. Agrawal completed his doctorate at Indian Institute of Management, Ahmedabad and retired as a Professor of Organisational Behaviour and Human Resource Management from the Indian Institute of Management (IIM) Bangalore. He currently serves as Adjunct Faculty at IIM Bangalore, IIM Amritsar, IIM Sambalpur, and the Academy of HRD, Ahmedabad. He was a visiting professor at St. Gallen University, Switzerland, from 2002 until 2020. A mechanical engineer by training, he worked for 24 years with Hindustan Aeronautics Limited in Nashik and Bangalore.

Dr Nisigandha Bhuyan is a full professor of Business Ethics at the Indian Institute of Management, Calcutta. She has nearly two decades of teaching experience in the field of business ethics. She has worked extensively in areas such as the philosophical foundations of business ethics, Indian philosophy, the stakeholder theory approach to business ethics, contractarian business ethics, and the ethics of technology. She is currently the convener of the Management Centre for Human Values (MCHV) and the editor of the Journal of Human Values (MCHV), published by Sage at IIM Calcutta. She holds a Ph.D. from the Indian Institute of Technology, Kanpur, and conducted her post-doctoral research at ISB Hyderabad and the Wharton School of Business, University of Pennsylvania.

Major Ravi Khanna served a successful decade in the Indian Army. As a Business Excellence and Strategic HR&OD Evangelist currently, he is an expert in Organisational Development, Talent Management, Family Constitutions & Business Continuity and Coaching. An alumna of IIM Lucknow, he has been serving the corporate world in the capacity of an OD Practitioner, Head-HR and Strategic Advisor, over the past two decades. Founder and Chief Belief Officer (CBO) of RuDefine Excellence Consulting, he has led several impactful assignments, including a distinguished tenure as the Global Head - HR Office for a prominent UAE-based conglomerate..

Rajiv Agarwal is the Department Chair and Professor of Strategy at S. P. Jain Institute of Management and Research. Over a career spanning 30 years, he has held senior executive roles and contributed articles in journal publications besides authoring books and periodicals. With a PhD on Family Managed Businesses in India, from Birla Institute of Technology & Science, Pilani, he has also pursued the Owner / President Management Programme from Harvard Business School.

Ashita Aggarwal is Professor, Marketing at S. P. Jain Institute of Management and Research. She is also a researcher and brand consultant with international teaching experience at the State University (USA) of New York and Hamburg University, Germany. She has led administrative leadership roles in a career spanning 21 years and won several awards for excellence in teaching and publishing case studies. She holds a PhD in management and is a gold medallist for her MBA (PGDM).

The following members of the Capacity Building Commission contributed to the development of the case study: Aasha Gulrajani Swarup, Richa Gupta, and Meena Priyadarsnee.

Authors' Note

The authors are grateful to Dr Kasturirangan, Dr Kiran Kumar, Dr Somanath (Former Chairmen of ISRO) for the valuable insights they provided during their interviews with Dr R. Balasubramaniam, Member – Human Resource, Capacity Building Commission (CBC), Govt. of India. Apart from the quotations attributed to them, specific information and details shared about ISRO without any mention of external references have also been extracted from the transcript of these three interviews. Copies of the interviews can be requested from the CBC, New Delhi. We are grateful to CBC and Dr R. Balasubramaniam for the permission to use the interview transcripts for this case.

ENDNOTES

- ⁱ The Times of India (December 2013) Rocket was ferried in bullock cart. Available at: <https://timesofindia.indiatimes.com/city/ahmedabad/rocket-was-ferried-in-bullock-cart/articleshow/28117058.cms> (Accessed on: September 29, 2024)
- ⁱⁱ ISRO, Department of Space, APPLE. Available at: <https://www.isro.gov.in/APPLE.html> (Accessed on July 14, 2024)
- ⁱⁱⁱ *Down to Earth (July 2017) Obituary: U R Rao laid foundation for self-reliance in satellite building.* Available at: <https://www.downtoearth.org.in/science-technology/obituary-u-r-rao-laid-foundation-for-self-reliance-in-satellite-building-58331> (Accessed on July 14, 2024)
- ^{iv} Business Insider (2014) Mangalyaan makes its way to Time's 'best inventions of 2014' list. Available at: <https://www.businessinsider.in/mangalyaan-makes-its-way-to-times-best-inventions-of-2014-list/articleshow/45260385.cms> (Accessed on July 14, 2024)
- ^v NASA (March 2019), Small-Satellite Mission Failure Rates, Available at: <https://ntrs.nasa.gov/api/citations/20190002705/downloads/20190002705.pdf> (Accessed on: 31 January 2025)
- ^{vi} India Today (April 1987) Failure of ASLV mission comes a major blow to India's ambitious space programme. Available at: <https://www.indiatoday.in/magazine/science-and-technology/story/19870415-failure-of-aslv-mission-comes-a-major-blow-to-india-ambitious-space-me-798754-1987-04-14> (Accessed on July 14, 2024)
- ^{vii} Dr Kiran Kumar, A. S. 2024. *Interview by Dr R. Balasubramaniam*, January 15, 2024. Audio Recording Available.
- ^{viii} The Times of India (September 2014) From a small fishing village to Mars, pioneers saw future. Available at: <https://timesofindia.indiatimes.com/india/from-a-small-fishing-village-to-mars-pioneers-saw-future/articleshow/43469291.cms> (Accessed on July 14, 2024)
- ^{ix} Dr Kasturirangan, K. 2024. *Interview by Dr R. Balasubramaniam*, January 15, 2024. Audio Recording.
- ^x ISRO, A Personal History, by R. Aravamudan and Gita Aravamudan, Book. HarperCollins Publishers India (2017)
- ^{xi} ISRO, Department of Space. Available at: <https://www.isro.gov.in/Vision-Mission-Objectives.html> (Accessed on July 14, 2024)
- ^{xii} ISRO, Department of Space. Available at: https://www.isro.gov.in/Chandrayaan-1_science.html (Accessed on July 14, 2024)
- ^{xiii} The Space Review (December 2023), Enter India, the fifth great space power. Available at: <https://www.thespacereview.com/article/4702/1> (Accessed on July 14, 2024)

-
- ^{xiv} NASA History (Winter 2023) Working Together, Volume 40, Number 4, Page 26. Available at: <https://www.nasa.gov/wp-content/uploads/2023/12/newsnotes-40-4-winter-2023.pdf> (Accessed on July 14, 2024)
- ^{xv} California Institute of Technology. NASA-ISRO SAR (NISAR) Mission. NASA partnership with the Indian Space Research Organisation (ISRO). Available at: <https://nisar.jpl.nasa.gov/mission/isro-partnership/> (Accessed on July 14, 2024)
- ^{xvi} NASA-ISRO SAR Mission (NISAR) (2014) NASA partnership with the Indian Space Research Organisation (ISRO). Available at: <https://nisar.jpl.nasa.gov/mission/isro-partnership/> (Accessed on July 14, 2024)
- ^{xvii} ISRO, Department of Space (2017) PSLV-C37 Successfully Launches 104 Satellites in a Single Flight. Available at: <https://www.isro.gov.in/SuccessfullyLaunches104.html> Accessed on 14th July 2024
- ^{xviii} Dr Kasturirangan, K. 2024. *Interview by Dr R. Balasubramanium*, January 15, 2024. Audio Recording.
- ^{xix} Outlook (July 2017) UR Rao – Pioneering Satellite Technologist And Proponent Of ‘ISRO Culture’. Available at: <https://www.outlookindia.com/national/ur-rao-pioneering-satellite-technologist-and-proponent-of-isro-culture-news-299759> (Accessed on July 14, 2024)
- ^{xx} ISRO, Department of Space (2017) A Tribute to Prof U R Rao. Available at: <https://www.isro.gov.in/TRIBUTE.html> (Accessed on July 14, 2024)
- ^{xxi} Dr Kasturirangan, K. 2024. *Interview by Dr R. Balasubramanium*, January 15, 2024. Audio Recording Available.
- ^{xxii} Dr Kasturirangan, K. 2024. *Interview by Dr R. Balasubramanium*, January 15, 2024. Audio Recording Available.