INDIAN SPACE PROGRAMME – A BRIEF OVERVIEW

Deepak Mishra

Satnav Payload Electronics Division (SNED)
Satcom and Navigation Payload Area (SNPA)
Space Application Centre (SAC), ISRO, Ahmedabad, India
Email: deepakmishra@sac.isro.gov.in

India is now a leading player in the international space arena. However, the beginnings of the country's space missions were modest. Early milestones included the first rocket launch of Rohini-75 from Thumba near Thiruvananthapuram in Kerala in 1969 and fabrication of the first Indian satellite Aryabhata in a work shed at Peenya Industrial Estate, Bengaluru in 1975. In 1967, the first 'Experimental Satellite Communication Earth Station (ESCES)' located in Ahmedabad was operationalised, which also doubled as a training centre for the Indian as well as international scientists and engineers. INCOSPAR subsequently grew and became ISRO on August 15, 1969, also under the Department of Atomic Energy (DAE). In 1972 Government of India set up a Space Commission and the Department of Space (DOS), bringing ISRO under the DOS. ISRO subsequently developed two other rockets: the Polar Satellite Launch Vehicle (PSLV) for launching satellites into polar orbits and the Geosynchronous Satellite Launch Vehicle (GSLV) for placing satellites into geostationary orbits. These rockets have launched numerous communications satellites and Earth observation satellites. Satellite navigation systems like GAGAN and IRNSS have been deployed. In January 2014, ISRO used an indigenous cryogenic engine in a GSLV-D5 launch of the GSAT-14. Another milestone in the history of ISRO is sending a lunar orbiter, Chandrayaan-1, on October 22, 2008 and a Mars orbiter, Mars Orbiter Mission, on November 5, 2013, which entered Mars orbit on September 24, 2014, making India the first nation to succeed on its first attempt to Mars, and ISRO the fourth space agency in the world as well as the first space agency in Asia to reach Mars orbit. On June 18, 2016, ISRO launched twenty satellites in a single vehicle, and on February 15, 2017, ISRO launched 104 satellites in a single rocket (PSLV-C37), a world record. ISRO launched its heaviest rocket, Geosynchronous Satellite Launch Vehicle-Mark III (GSLV-Mk III), on June 5, 2017 and placed a communications satellite GSAT-19 in orbit. With this launch, ISRO became capable of launching ton heavy satellites. Future plans of ISRO include development of the Unified Launch Vehicle, Small Satellite Launch Vehicle and development of a reusable launch vehicle, human spaceflight, a space station, controlled soft lunar landing, interplanetary probes and a solar spacecraft mission.

Keywords: GSLV, PSLV, DAE, IRNSS, GAGAN

Introduction

India is now a leading player in the international space arena. However, the beginnings of the country's space missions were modest. Early milestones included the first rocket launch of Rohini-75 from Thumba near Thiruvananthapuram in Kerala in 1969 and fabrication of the first Indian satellite Aryabhata in a work shed at Peenya Industrial Estate, Bengaluru in 1975.

Space research activities were started in India during the early 1960s. Even advanced countries were only conducting experiments on the applications of satellites at that time. When the live transmission of Tokyo Olympic Games in 1964 across the Pacific by the American Satellite 'Syncom-3' displayed the power of communication satellites, Dr. Vikram Sarabhai, the founder of Indian space programme, recognised the benefits of space technologies for India. Sarabhai realized that the resources in space have the potential to address the real problems of people. He had already set up Physical Research Laboratory (PRL) in Ahmedabad, where a big team of brilliant scientists, anthropologists, communicators and social scientists were ready to spearhead the Indian space programme.

But even earlier, modern space research in India can be traced to the 1920s, when scientist, S K Mitra, conducted a series of experiments leading to the sounding of the ionosphere by applying ground-based radio methods in Kolkata. Later, Indian scientists like C V Raman and Meghnad Saha contributed to scientific principles applicable in space sciences.

The period after 1945 saw important developments in space research. Two scientists led the initiatives, Vikram Sarabhai and Homi Bhabha. Bhabha established the Tata Institute of Fundamental Research in 1945. Initial experiments in space sciences included the study of cosmic radiation, high altitude and airborne testing, deep underground experimentation at the Kolar mines and studies of the upper atmosphere. Studies were carried out at research laboratories, universities and independent locations.

In 1950, the Department of Atomic Energy was founded with Bhabha as its Secretary. The department provided funding for space research throughout India. During this time, tests continued on aspects of meteorology and the Earth's magnetic field. In 1954, the Uttar Pradesh state observatory was established at the foothills of the Himalayas. The Rangpur Observatory was set up in 1957 at Osmania University, Hyderabad. Space research was further encouraged by the government of India. In 1957, the Soviet Union launched Sputnik 1 and opened up possibilities for the rest of the world to conduct a space launch. Subsequently the Indian National Committee for Space Research (INCOSPAR) was set up in 1962 by the efforts of India's first Prime Minister, Jawaharlal Nehru. Since its inception, the Indian space programme has maintained three distinct elements: Satellites for communication and remote sensing, the space transportation system and application programmes.

In 1967, the first 'Experimental Satellite Communication Earth Station (ESCES)' located in Ahmedabad was operationalised, which also doubled as a training centre for Indian as well as international scientists and engineers. INCOSPAR subsequently grew and became ISRO on August 15, 1969, also under the Department of Atomic Energy (DAE). In 1972, the Government of India set up a Space Commission and the Department of Space (DOS), bringing ISRO under the DOS. The establishment of ISRO thus institutionalised space research activities in India. It is managed by the Department of Space, which reports to the Prime Minister of India. Realising that a satellite system can contribute to the national development and that it need not wait for its own satellites to begin application development, ISRO used foreign satellites in the initial stages. Accordingly, a TV programme on agricultural information to farmers 'Krishi Darshan' was started and it received good response. The next step was the Satellite Instructional Television Experiment (SITE), hailed as 'the largest sociological experiment in the world' during 1975-76. This experiment benefited around two lakh people, covering 2,400 villages of six states and transmitted development-oriented programmes using the American Technology Satellite (ATS-6). It also trained 50,000 science teachers in primary schools in one year. SITE was followed by the Satellite Telecommunication Experiments Project (STEP), a joint project of ISRO and, Post and Telegraphs Department (P&T) using the Franco-German Symphonie satellite during 1977–79. Conceived as a sequel to SITE which focused on television, STEP was for telecommunication experiments. STEP was aimed to provide a system test of using geosynchronous satellites for domestic communications, enhance capabilities and experience in the design, manufacture, installation, operation and maintenance of various ground segment facilities and build up requisite indigenous competence for the proposed operational domestic satellite system, INSAT, for the country.

SITE was followed by the 'Kheda Communications Project (KCP)', which worked as a field laboratory for need-based and locale specific programme transmission in the Kheda district of Gujarat State. KCP was awarded the UNESCO-IPDC (International Programme for the Development of Communication) award for rural communication efficiency in the 1984. Meanwhile, the first Indian satellite 'Aryabhata' was developed and launched using a Soviet launcher. The ISRO-built satellite was sent to space by the Soviet Union on April 19, 1975. It was named after the mathematician Aryabhata. In 1980, Rohini became the first satellite to be placed in orbit by an Indian-made launch vehicle, SLV-3.

ISRO subsequently developed two other rockets: the Polar Satellite Launch Vehicle (PSLV) for launching satellites into polar orbits and the Geosynchronous Satellite Launch Vehicle (GSLV) for placing satellites into geostationary orbits. These rockets have launched numerous communications satellites and Earth observation satellites. Satellite navigation systems like GAGAN and IRNSS have been deployed. In January 2014, ISRO used an indigenous cryogenic engine in a GSLV-D5 launch of the GSAT-14.

Another milestone in the history of ISRO is sending a lunar orbiter, Chandrayaan-1, on October 22, 2008 and a Mars orbiter, Mars Orbiter Mission, on November 5, 2013, which entered Mars orbit on September 24, 2014, making India the first nation to succeed on its first attempt to Mars and ISRO the fourth space agency in the world as well as the first space agency in Asia to reach Mars orbit. On June 18, 2016, ISRO launched twenty satellites in a single vehicle, and on February 15, 2017, ISRO launched 104 satellites in a single rocket (PSLV-C37), a world record. ISRO launched its heaviest rocket, Geosynchronous Satellite Launch Vehicle-Mark III (GSLV-Mk III), on June 5, 2017 and placed a communications satellite GSAT-19 in orbit. With this launch, ISRO became capable of launching ton heavy satellites.

Future plans of ISRO include development of the Unified Launch Vehicle, Small Satellite Launch Vehicle and development of a reusable launch vehicle, human spaceflight, a space station, controlled soft lunar landing, interplanetary probes and a solar spacecraft mission.

Fig. 1: Dr. Vikram Sarabhai — Architect

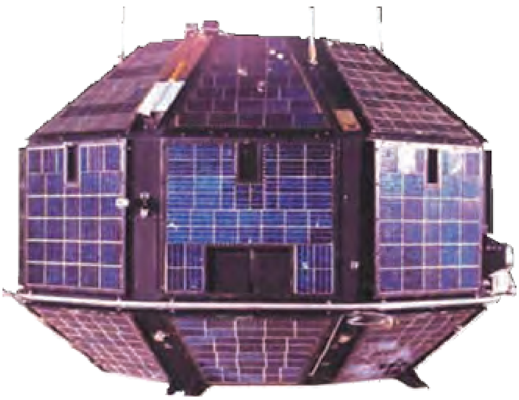

Fig. 2: First Indian Satellite Aryabhata of India's Space Programme

Early Landmarks

An early landmark of ISRO was the development of the first launch vehicle SLV-3 with a capability to place 40 kg in Low Earth Orbit (LEO), which had its first successful flight in 1980. Through the SLV-3 programme, competence was built up for the overall vehicle design, mission design, material, hardware fabrication, solid propulsion technology, control power plants, avionics, vehicle integration checkout and launch operations.

Development of multi-stage rocket systems with appropriate control and guidance systems to orbit a satellite was a major milestone. In the experimental phase during 1980s, end-to-end capability demonstration was done in the design, development and in-orbit management of space systems together with the associated ground systems for the users.

Bhaskara-I & II missions were pioneering steps in the remote sensing area whereas 'Ariane Passenger Payload Experiment (APPLE)' became the forerunner for future communication satellite systems. Development of the complex Augmented Satellite Launch Vehicle (ASLV), also demonstrated newer technologies like use of strap-on, bulbous heat shield, closed loop guidance and digital autopilot. This paved the way for learning many nuances of launch vehicle design for complex missions, leading the way for realisation of operational launch vehicles such as PSLV and GSLV. During the operational phase in 1990s, major space infrastructure was created under two broad classes: one for the communication, broadcasting and meteorology through a multi-purpose INSAT and the other for IRS system. The development and operationalisation of Polar Satellite Launch Vehicle (PSLV) and development of Geo-synchronous Satellite Launch Vehicle (GSLV) were significant achievements during this phase.

Some ISRO Success Stories

Vikram Sarabhai, the founder of the Indian space programme, had realised the potential of space communication systems in putting television to use as a mass education tool throughout the country. He visualised and suggested this as early as 1966–67, just three years after the first geosynchronous satellite, Syncom, was launched. In 1967 he initiated studies with a view to using space communication systems for operational television broadcasting. A joint study by ISRO and the National Aeronautics and Space Administration (NASA) of the United States was conducted in 1967 which recommended a hybrid system of direct broadcast by satellite combined with terrestrial TV transmitters as the most effective means of countrywide TV coverage.

In 1968, a National Satellite Communication (NASCOM) study group was set up by the government. These studies and deliberations paved the way for the acceptance in 1969 by the government of the proposal to conduct the Satellite Instructional Television Experiment (SITE) with NASA's ATS-6 satellite. In 1969 studies were also conducted on the use of communication satellites for meteorological earth observations.

Based on these studies and a joint study with the Massachusetts Institute of Technology (MIT) in 1970, ISRO evolved in the early 1970s the unique multipurpose nature of the INSAT system that included direct TV broadcasting, communications and meteorological observations and it was firmed up during 1975–77. Laboratory for Electro-Optics Systems (LEOS) is situated at Peenya Industrial Estate, Bengaluru where the first Indian Satellite Aryabhata was fabricated in 1975.

The Experimentation Phase

The 1980s were times for experimentation for launch vehicle technologies to demonstrate the country's ability to develop Augmented Satellite Launch Vehicle (ASLV) with a payload capability of 150 kg into Low Earth Orbit, a more capable launch vehicle compared to SLV-3 which was capable of putting a 40 kg satellite into a low earth orbit.

During the same period, ISRO acquired extensive experience in the design, development, building, launching and in-orbit maintenance of a variety of satellites including communication and remote sensing satellites. INSAT-1B, India's first multipurpose operational satellite launched in 1983, demonstrated the country's ability to bring about a rapid and major revolution in India's telecommunications, television broadcasting and weather forecasting. Today, communication satellites are an integral part of our economic infrastructure.

The world got an inkling of India's ability to design, build and maintain a complex remote sensing satellite in 1988 when IRS-1A, the first operational satellite built in India, started imaging the earth from orbit. The images sent by satellite circling the Earth from its 900-km-high polar orbit were utilised in diverse fields such as agriculture, groundwater prospecting, mineral survey, forestry, etc.

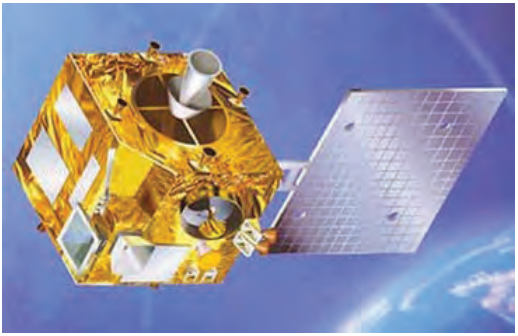

Fig. 3: IRS-1A Satellite

The Growth Phase

During the 1990s, ISRO began building the INSAT-2 series of multipurpose satellites indigenously. At the same time, systematic usage of imagery from our remote sensing satellites for tasks like crop yield estimation, groundwater and mineral prospecting, forest survey, urban sprawl monitoring and wasteland classification, and fisheries development began.

Today, India has a fleet of advanced remote sensing satellites equipped with high resolution and multispectral cameras dedicated to cartography, resource survey and ocean and atmospheric applications. Apart from these, polar orbit-based observation satellites, weather watching satellites INSAT-3D and INSAT-3DR—circling the earth in the 36,000 km high geosynchronous orbit, are providing valuable inputs for weather forecasting.

The Indian National Satellite (INSAT) system today is one of the largest domestic communication satellite systems in the Asia-Pacific region and has become an integral part of our telecommunications and TV broadcasting infrastructure including DTH services driving the country's communications revolution. Besides, our geostationary satellites are providing vital inputs to the task of nationwide weather forecasting, especially in the provision of advance warning of cyclones, saving lives and mitigating the loss of property. One of them

Fig. 4: Communication Satellites (Image credit: ISRO)

carries a satellite-aided Search and Rescue transponder and has helped in speedy rescue of people in distress in the open seas.

High throughput satellites such as GSAT-11, GSAT-29 and GSAT-19 are supporting the Digital India campaign by boosting broadband connectivity to the rural and inaccessible Gram Panchayats in the country. The transponders on these satellites will also bridge the digital divide of users including those in Jammu & Kashmir and North-Eastern regions of India.

Perfecting the launch vehicle technology is an immensely difficult and challenging task, which only a few countries possess. Till now ISRO has developed five launch vehicles (SLV-3, ASLV, PSLV, GSLV and GSLV Mk III, which is also known as LVM3) and mastered the technology of rockets that use solid, liquid as well as cryogenic propellants.

Polar Satellite Launch Vehicle (PSLV) is the third generation launch vehicle of India. It is the first Indian launch vehicle to be equipped with liquid stages. With 51 successful flights over the years, PSLV has emerged as the reliable and versatile workhorse launch vehicle of India. In fact, it has launched 342 foreign satellites as on 22 June 2021 and has carved out a niche in the commercial satellite launch arena.

On 15 February 2017, PSLV created a world record by successfully placing 104 satellites in orbit during a single launch. Well, as numbers go, it was undoubtedly a record, but the real significance is the immense confidence reposed by foreign countries, including the USA, in the capability of ISRO. This success was the result of meticulous planning and flawless execution of the mission by ISRO.

Expanding the Horizon

In the early twenty first century, the Indian launch vehicle programme has ventured beyond the PSLV resulting in the development of the Geosynchronous Satellite Launch Vehicle (GSLV) with more payload capability, efficiency and sophistication. GSLV, with the capability to launch two-ton satellites into Geosynchronous Transfer Orbit (GTO), employs cryogenic propulsion technology in its third stage.

Geosynchronous Satellite Launch Vehicle Mark II (GSLV Mk II) is the fourth generation launch vehicle having three stages (including the cryogenic upper stage) with four liquid strapons. Cryogenic technology involves storage of liquid hydrogen and liquid oxygen at very low temperatures. Materials used to operate at these very low temperatures, chilling processes and interplay of engine parameters make the development of cryogenic stage a very challenging and complex task.

With the successful qualification of the indigenously developed Cryogenic Upper Stage (CUS) in the GSLV-D5 flight on 5 January 2014, ISRO demonstrated its mastery of cryogenic rocket propulsion. Since January 2014, the vehicle has achieved six consecutive successes.

GSLV Mk III, India's fifth-generation satellite launch vehicle has two solid strapons, a core liquid booster and a cryogenic upper stage. The vehicle is designed to carry four-ton class of satellites into Geosynchronous Transfer Orbit (GTO) or about ten tons to Low Earth Orbit (LEO). LVM3-X/ CARE Mission, the first experimental suborbital flight of GSLV Mk III on 18 December 2014 injected the Crew

Module Atmospheric Re-entry Experiment (CARE) in December 2014. The CARE module began its return journey and a little later, re-entered the earth's atmosphere. It was successfully recovered over the Bay of Bengal about 20 minutes after its launch.

Subsequently, after two successful developmental flights and with the successful injection of Chandrayaan-2 into the Earth Parking Orbit in July 2019, GSLV Mk III successfully entered into its operational phase. Besides these, India's Reusable Launch Vehicle Technology Demonstrator (RLV TD) was successfully flight tested in May 2016 and several critical technologies were successfully validated. The first experimental mission of ISRO's Supersonic Combustion Ramjet (SCRAMJET) engine towards the realisation of air breathing propulsion system was also successfully conducted in August 2016. With this, India became the fourth country to flight test the SCRAMJET engine.

The Indian space programme has always focused on the development and utilisation of space technologies to achieve overall development of the country. Despite its emphasis on applications, ISRO has pursued many space science projects in earnest to perform meaningful exploration of space. India's first satellite Aryabhata was a scientific satellite.

After Aryabhata, ISRO entered into the realm of science missions again with a unique mission that caught the attention of the world—the Space Capsule Recovery Experiment-1 (SRE-1). Launched by PSLV in January 2007, SRE-1 with its scientific experiments orbited the Earth for 12 days and was successfully de-orbited and recovered over the Bay of Bengal. This proved several technologies necessary for reusable launch vehicles and human spaceflight.

Fig. 5: GSLV MK III

Fig. 6: PSLV XL LAUNCH

Venturing into Space

The space science missions of India—Chandrayaan-1, Mars Orbiter Mission, Astrosat and Chandrayaan-2, have caught the attention of millions of Indians as well as the outside world.

Launched by PSLV on 22 October 2008, the 1380 kg Chandrayaan-1 spacecraft was successfully navigated to the Moon in three weeks and was put into an orbit around the moon. On 14 November 2008, when a TV set sized 'Moon Impact Probe' separated from Chandrayaan-1 spacecraft and successfully impacted on the surface of the Moon, India became the fourth country to send a probe to the lunar surface after the United States, the Soviet Union and Japan and the fifth individual country to put a spacecraft into an orbit around the Moon. Later, when Chandrayaan-1 conclusively discovered water molecules on the lunar surface, it was widely hailed as a pathbreaking discovery. Encouraged by the success of Chandrayaan-1, ISRO endeavoured to realise the Mars Orbiter Mission for demonstrating India's capability to build, launch and navigate an unmanned spacecraft to Mars. Launched by PSLV on 5 November 2013, the 1340 kg Mars Orbiter Spacecraft encountered Mars on 24 September 2014. With this, ISRO became the fourth space agency to successfully send a spacecraft to Mars orbit. Achieving success in the first such mission itself is yet another accomplishment of ISRO.

AstroSat launched by PSLV in September 2015 is the first dedicated Indian astronomy mission aimed at studying celestial sources in X-ray, optical and UV spectral bands simultaneously. AstroSat recently made a major breakthrough by discovering one of the earliest galaxies in extreme-Ultraviolet light.

The Chandrayaan-2 mission, India's second mission to the moon, was successfully

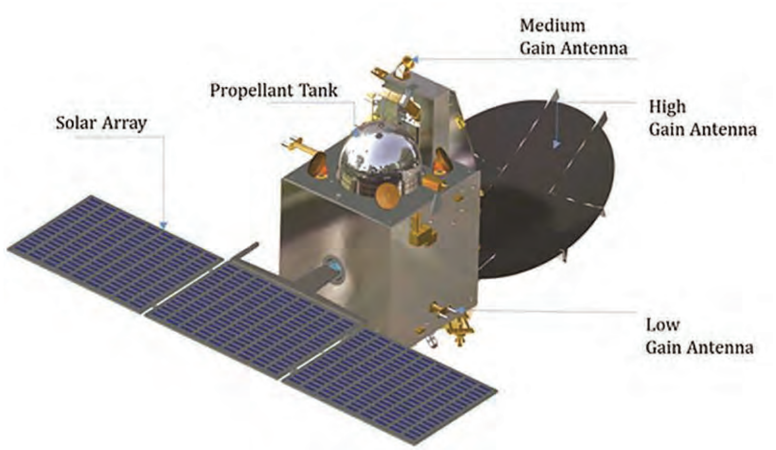

Fig. 7: AstroSat (Image Credit: isro.gov.in)

launched on 22 July 2019. Chandrayaan-2 Orbiter spacecraft was placed in its intended orbit. The eight instruments onboard the Orbiter are continuously providing useful science data which will enrich our understanding of the Moon's evolution and mapping of the minerals and water molecules in the Polar regions.

Having successfully built many communications, meteorological (weather monitoring), remote sensing and scientific satellites, ISRO has successfully established and operationalised the Navigation with Indian Constellation (NavIC) with eight satellites in orbit, which are providing accurate position, navigation and time information to users in India and its surroundings. Further, through GPS Aided GEO Augmented Navigation (GAGAN), ISRO is providing satellite-based navigation services with accuracy and integrity required for civil aviation applications and to provide better Air Traffic Management over Indian Airspace.

Fig. 8: Mars Satellite (Image Credit: isro.gov.in)

Apart from this, ISRO has also facilitated students in building and launching satellites for various applications. So far, 14 student satellites have been launched by ISRO.

Human Space Flight Endeavour

The 'Gaganyaan Programme' approved by the Government of India in 2018 is a point of inflexion in the growth profile of India's space endeavour. With the Gaganyaan Programme, a new vertical has been created within ISRO and a new ISRO centre namely Human Space Flight Centre (HSFC) was established on 10 January 2019 and started functioning.

Gaganyaan is a national programme wherein ISRO is leveraging the domain expertise of various national agencies like Indian Armed Forces, DRDO labs, CSIR labs, academic institutions, partners. MoUs or contracts are also in effect with concerned participating agencies. ISRO has organised various Industry meets and workshops to apprise the industries about the requirements of Gaganyaan. The crew selection and basic space flight training of four astronaut trainees have been completed at the Gagarin Cosmonaut Training Centre (GCTC), Russia and ISRO are gearing up for the mission-specific training in India. The preliminary design of major subsystems has been completed and ISRO has entered into the realisation phase. The test plan for various systems is also finalised.

Fig. 9: Human Space Flight Mission (Image Credit: isro.gov.in)

ISRO has initiated the process of encouraging micro-gravity research in academic institutes. Five microgravity experiment proposals have been shortlisted for flying in Gaganyaan unmanned flights. ISRO will be supporting the activities of payload design and qualification. In addition, to meet the programmatic schedule targets, foreign collaboration is being planned in areas that require establishing large infrastructure and long lead research and development. The major areas of collaborations are astronaut training, life support systems, spacesuit, wind tunnel testing, flight surgeon training, etc. ISRO has entered into contracts and agreements with various international agencies like M/s Glavkosmos Russia; NRC Canada; INCAS Romania and CNES France. In the framework of ISRO-CNES collaboration, a three-week training programme for flight surgeons was conducted at ISRO. An International Symposium on Human Space Flight and Exploration was organised by ISRO in Association with the International Academy of Astronautics (IAA) to bring together national and international experts, scientists, professionals and academicians for the exchange of technical information and policy details on human space flights.

Future Challenges

The Indian space programme has many challenges ahead. There are plans to build heavier, more capable and efficient satellites. And, space science missions like Chandrayaan-3, Aditya-L1, Mission to Venus to further explore the solar system, are in progress. Pursuit of research and development activities pertaining to small satellite launch vehicle, air-breathing rocket propulsion and demonstration of reusable rocket technology, are also progressing.

The space programme in the country is poised for several major breakthroughs in the development of advanced technology needed for the realisation of the future launch vehicle and spacecraft missions in the coming years. Efforts are on to establish the necessary infrastructure for casting large boosters, liquid-propellant engines, heavy cryo-boosters for advanced heavier launchers and missions in the area of remote sensing, communications and navigational satellites as well as space science systems. Necessary ground infrastructure for providing mission support during the launch phase and in-orbit support for the planned missions is under realisation.

The continuing expansion of space applications programmes like Village Resources Centres, telemedicine, tele-education, disaster management support and outreach through Direct-To-Home (DTH) television, reiterates the increasing role played by the Indian space systems in providing direct benefits to society.

The Indian space programme continues to pursue successful goals on all fronts in meeting the objectives of achieving self-reliance in space technology and its applications for national development.