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India's Space Programme

Capabilities, Organisations and Warfighting Potential

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Introduction

Space presents an inexhaustible potential for exploration, discovery, and diverse uses that modern society demands. Space technology can be leveraged for enhancing human welfare, disaster management, and conflict prevention, as also for quenching mankind's thirst for exploration and, in the long term, offer a means of survival for the human race as the earth progressively becomes less habitable.

Notably, the national security implications of space can no longer be ignored. Space has already been designated as a war fighting domain, together with the traditional domains of land, sea, air, and cyber[1]. The major world powers are moving ahead vigorously towards developing military space and counter-space capabilities. With China, a daunting adversary sitting next door, India cannot afford to be complacent while trying to keep pace with these significant developments, which have grave implications for our national security.

Another key facet that needs to be taken note of is the recent commercialisation of the space sector. The term *NewSpace* refers to the initiatives being taken in this direction. While earlier, the state used to have a monopoly over this sector, private actors now play an increasingly important role; a notable example being *SpaceX* in the United States. The world today is seeing the emergence of *NewSpace* as a revolution in the space industry, with private industries leading the way in applying the expertise acquired by space agencies as commercial value propositions. Currently, India contributes barely two percent of the approximately $360 billion-dollar global space economy[2]. Policy formulation for space commerce, especially with regard to the private sector's role in this all-important domain, is extremely relevant for the growth of India's space endeavours.

India's space programme over the years has played a significant role in the socio-economic development of India and has supported both civilian and military requirements. It has been steered primarily by the Indian Space Research Organisation (ISRO), which is one of the six government space agencies in the world that possesses full launch capabilities, deploys cryogenic engines, launches extra-terrestrial missions, and operates large fleets of artificial satellites.

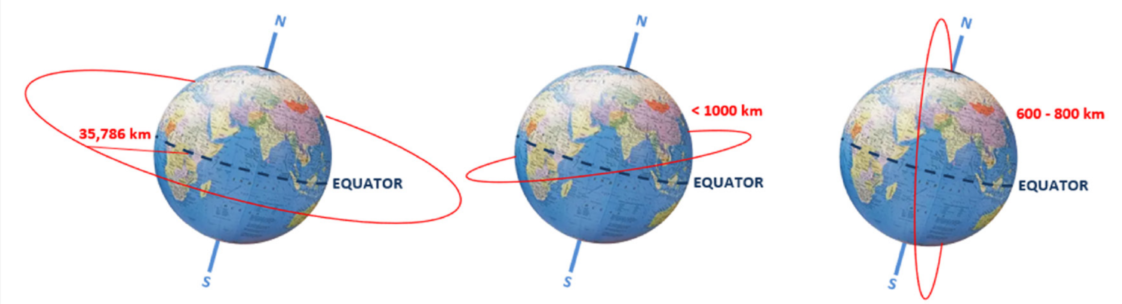
This paper commences by giving an overview of various types of satellite orbits and the most common space applications. Subsequently, it outlines India's achievements in these application areas. A brief look is then taken at India's launch vehicles, exploration missions, and future plans. Thereafter**,** the paper reviews organisations which have so far steered India's space endeavours, including some new establishments which will spur these endeavours to newer heights. This is followed by a brief insight into the important aspect of commercialisation of the space sector. Finally, the national security implications of this important war fighting domain are discussed, with a focus on counter-space capabilities of leading military powers.

Types of Orbits

The most commonly used orbits are the Geostationary Orbit (GEO), Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and the Polar Orbit with the Sun-Synchronous Orbit (SSO) as its special case[3, 4].

Geostationary Orbit (GEO). Satellites in GEO circle earth above the equator from west to east following earth's rotation, taking 23 hours, 56 minutes, and 4 seconds (a sidereal day[5]), travelling at exactly the same rate as earth. This makes satellites in GEO appear to be 'stationary' to a ground observer. The speed of the GEO satellite is about 3 km per second at an altitude of 35,786 km. The GEO is used by telecommunication satellites so that an antenna on earth can be fixed always to stay pointed towards that satellite without moving. Satellites in GEO cover an extensive range of earth, hence, as few as three equally spaced satellites can provide near global communication coverage. Satellites in GEO are also used by weather monitoring satellites to observe weather trends over specific areas.

Low Earth Orbit (LEO). Satellites in Low Earth Orbit are at an altitude ranging from 160 to 1000 km. By comparison, most commercial aeroplanes do not fly at altitudes much greater than approximately 15 km. Satellites in this orbit travel at a speed of around 8 km per second, taking approximately 90 minutes to circle the earth. Unlike GEO that must always orbit along earth's equator, the planes of LEO can be tilted, giving more available routes, which is one of the reasons why LEOs are commonly used. The LEO's lower altitude makes it useful for satellites to achieve a higher image resolution and also for communications, since lesser power is needed. However, LEO satellites used for communications require complex tracking from ground stations, because they move very fast across the sky. In order to provide constant coverage, communications satellites in LEO work as part of a large constellation.



GEOSTATIONARY ORBIT (LEO) LOW EARTH ORBIT (LEO) SUN-SYNCHRONOUS ORBIT (SSO)

Medium Earth Orbit (MEO). Medium Earth Orbits are usually at altitudes between 10,000 km and 20,000 km, taking between two and eight hours to orbit the earth, and requiring between 8 and 20 units to provide complete coverage of the earth. For example, a constellation with 24 MEO satellites, could have four of these covering any given spot on the earth at any time during the day, which caters for communications outages caused by inclement weather, as also achieves greater accuracy in position tracking. Satellites in MEO are popularly used for navigation purposes or for communications with lower power requirements, higher throughput, and lower latency. All popular navigation constellations, namely, US's GPS, Russia's GLONASS, Europe's Galileo, and China's Beidou, mostly use satellites in MEO. Notably, the Indian Navigation with Indian Constellation (NavIC) system is based on GEO, and not MEO, satellites.

Polar Orbit and Sun-Synchronous Orbit (SSO). Satellites in polar orbits usually travel past Earth from north to south, passing roughly over Earth's poles, with altitudes ranging between 200 and 1000 km, thus making them part of the LEO class. North-south orbits with an inclination of up to 30 degrees are still classified as polar orbits. Polar orbits provide coverage of the full globe because of the Earth's rotation. SSO is a particular kind of polar orbit. Being synchronous with the sun means that satellites in these orbits are always in the same 'fixed' position relative to the Sun, i.e., the satellite always visits the same spot at the same local time, allowing imaging under the same lighting and angular conditions over a period of time. This helps to predict the weather or storms, monitor emergencies like forest fires or flooding, or accumulate data on long-term problems like deforestation or rising sea levels.

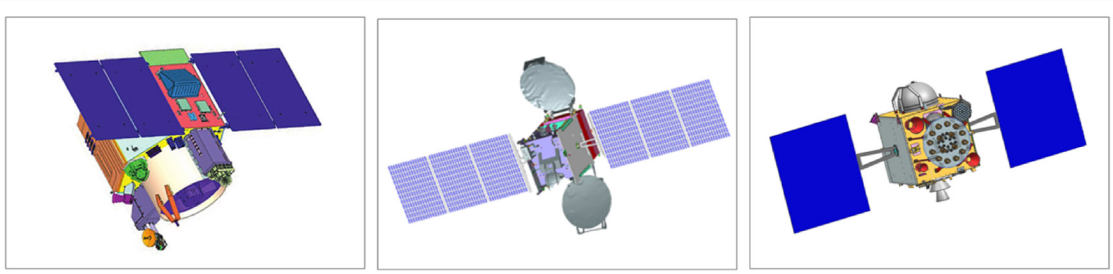
India's Satellite Applications

Space applications can broadly be grouped into the following categories: earth observation, communications, navigation, scientific & exploration, and experimental. This section explains each of these in brief in the context of India's space programme.

Earth Observation (Remote Sensing) Applications. Earth observation satellites are equipped with remote sensing technology and are thus also known as remote sensing satellites. These are used to study vegetation conditions, ground and sea surface temperatures, ground elevation, cloud conditions, water distribution, urban and rural development, disaster management, etc. Various sensors equipped on these satellites are as follows:-

- **Optical Sensors**. These sensors observe the reflection of sunlight, including invisible ultraviolet and infrared rays and the Earth's radiation[6].

- **Microwave Sensing**. Because of their long wavelengths compared to the visible and infrared spectrum, microwaves can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall, as the longer wavelengths are not susceptible to


EARTH OBSERVATION: CARTOSAT-3 COMMUNICATION: GSAT-30 NAVIGATION: IRNSS (NavIC) 1G

atmospheric scattering. Microwave sensors can be active or passive. Active microwave sensors transmit microwaves to the target and receive the reflected microwaves. This method is not affected by clouds and does not require sunlight, hence it can be used in all weather conditions and also during the night. Passive microwave sensing is similar in concept to thermal remote sensing. All objects emit microwave energy, though in small amounts. These are detected by passive microwave sensors[7].

The Indian Remote Sensing (IRS) Series. Starting with IRS-1A in 1988, ISRO has launched many remote sensing satellites, making India's remote sensing constellation the largest in operation today globally, which provides data in diversified spatial, spectral, and temporal resolutions. All remote sensing satellites are placed in polar SSO (except for Geo Imaging Satellites (GISATs), the first of which is scheduled to be launched in Aug 2021). The initial versions were named as IRS 1 (A, B, C, D), while the later versions were divided into sub-classes and named based on their function, e.g., Oceansat, Cartosat (for cartography applications), Hyper Spectral Imaging Satellite (HySIS), Electro-Magnetic Intelligence Satellite (EMISAT) and ResourceSat (for resource management). The nomenclature was changed to "EOS" in 2020. Presently, there are 18 remote sensing satellites in operation[8,9].

Communications Applications. Satellite communications have become ubiquitous globally for such diverse applications as Television, Direct to Home (DTH) Broadcasting, Digital Satellite News Gathering (DSNG), and Very Small Aperture Terminal (VSAT) satellites for mobile applications. The technology has matured substantially over the past three decades. A communications satellite relays and amplifies radio telecommunication signals using a transponder, i.e., it creates a communications channel between a source transmitter and a receiver at different locations on Earth. Out of the approximately 3000 satellites in operation today, nearly half are communications satellites. Most communications satellites are in geostationary orbit; therefore, tracking is a trivial function. As stated earlier, only three satellites in GEO are needed to provide global communications coverage.

The Indian National Satellite (INSAT) Series. ISRO's INSAT system is one of the largest domestic communications satellite systems in the Asia-Pacific Region, with a large number of operational communications satellites placed in GEO. Established in 1983 with the commissioning of INSAT-1B, this system initiated a major revolution in India's communications sector and sustained the same subsequently. The INSAT system is a joint venture of the Department of Space (DOS), Department of Telecommunications, India Meteorological Department, All India Radio, and Doordarshan. The nomenclature of this satellite series was shifted to *GSAT* (Geostationary Satellite) from *INSAT* in 2001, which was further changed to CMS (Communications Satellite) from 2020 onwards. These satellites have been in use by Indian Armed Forces as well. GSAT-9, also referred to as the *SAARC Satellite*, is a notable example of providing communications services for India's smaller neighbours. Presently there are 5 INSAT, 19 GSAT, and 1 CMS series satellites in operation[10,11].

Navigation Applications. ISRO has operationalised two navigation satellite systems; namely, the GPS Aided Geo Augmented Navigation (GAGAN) and Navigation with Indian Constellation (NavIC) systems, described below[12, 13, 14]:-

- **GAGAN.** GAGAN has been jointly developed by ISRO and the Airport Authority of India to provide accurate navigational services over the Indian Flight Information Region (FIR). GPS alone does not meet the navigational requirements of the International Civil Aviation Organization (ICAO) for accuracy, integrity, and availability. GAGAN augments the GPS for providing better position accuracy. It consists of a set of ground reference stations positioned across various locations in India, which gather GPS satellite data. The reference stations help in generating GPS correction messages, which are rebroadcast via three geostationary satellites (GSAT-8, GSAT-10, and GSAT-15). GAGAN has been fully functional since 2015.

- **NavIC.** NavIC is the operational name for the Indian Regional Navigation Satellite System (IRNSS), which is designed to provide position information service to users in India, as well as the region extending up to 1500 km from its borders. NavIC provides two types of services, namely, Standard Positioning Service (SPS) and Restricted Service (RS). The RS is encrypted and provides a higher accuracy (1-5 metres). It is a regional satellite navigation system developed by ISRO, which is under the total control of the Indian government. The requirement of such a navigation system is driven by the fact that access to global navigation systems like GPS is not guaranteed in hostile situations. The constellation consists of eight active satellites (including a partially active one). Three of these are located in GEO and five in inclined GSO (IGSO). The system is intended to provide an absolute position accuracy of better than 10 metres throughout the Indian landmass and better than 20 metres in the balance area of operation. The GPS, for comparison, had a position accuracy of 20-30 metres. In 2020, Qualcomm launched four new 4G chipsets and one 5G chipset with support for NavIC.

Scientific Satellites. The Indian space programme encompasses research in areas such as astronomy, astrophysics, planetary and earth sciences, atmospheric sciences, and theoretical physics. Balloons, sounding rockets, space platforms, and ground-based facilities support these research efforts.

Experimental Satellites. ISRO has launched many small satellites for experimental purposes. India's first satellite, Aryabhata, launched by a Soviet rocket in April 1975, was an experimental satellite carrying x-ray, astronomy, and solar physics-related payloads. The Ariane Passenger Payload Experiment (APPLE) was ISRO's first indigenous experimental communication satellite. The Indian Nano Satellite-1C (INS-1C), launched in Jan 2018, is the most recent experimental satellite which is designed to carry out multi-spectral imaging.

India's Satellite Launch Vehicles

Today India has two operational launchers or launch vehicles: the Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV). However, India's first launcher, which successfully put a satellite into orbit, was termed simply as the Satellite Launch Vehicle (SLV)[15].

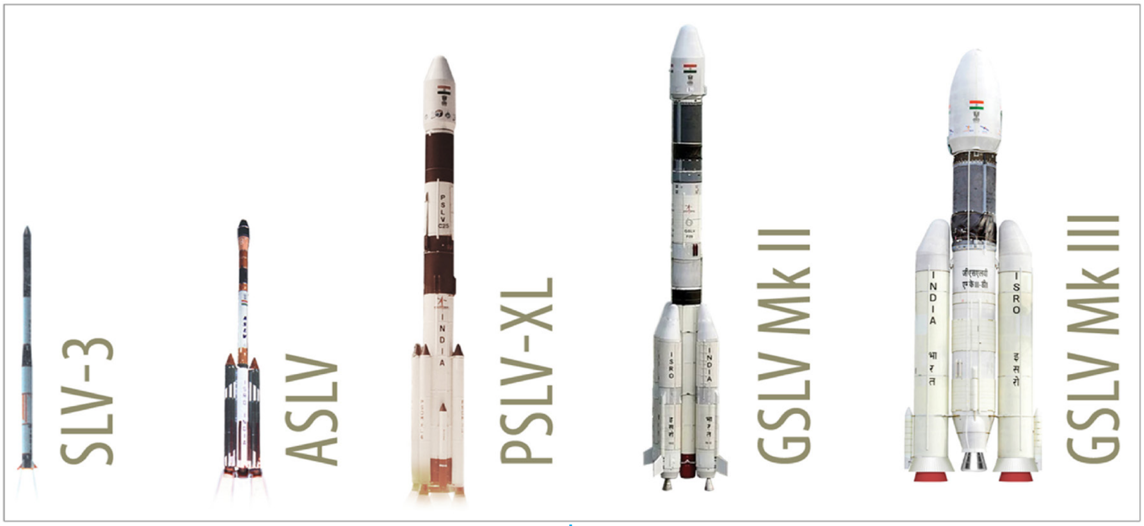
The Vikram Sarabhai Space Centre is responsible for the design and development of launch vehicles. Two more ISRO establishments, the Liquid Propulsion Systems Centre and ISRO Propulsion Complex develop the liquid and cryogenic stages for these launch vehicles. The Satish Dhawan Space Centre is responsible for the integration of launchers. It houses two operational launch pads from where all GSLV and PSLV flights take place. An overview of India's launch vehicles is given out in the succeeding paragraphs.

Satellite Launch Vehicle (SLV). The SLV (more specifically, SLV-3) was the first space rocket to be developed by India. The initial launch in 1979 was a failure, followed by a successful launch in 1980, which carried the 35 kg Rohini-RS1 satellite into orbit, making way for India into the club of countries with orbital launch capabilities. The SLV had a total of four launches, two of which were successes, with the last launch carried out in 1987[16].

Augmented Satellite Launch Vehicle (ASLV). The ASLV was another launch vehicle being developed in the 1980s to place satellites into geostationary orbit. However, due to repeated failures and lack of funds, this project was dropped in favour of the PSLV project, which was also ongoing at the time[17].

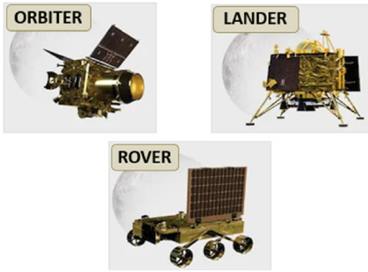
Polar Satellite Launch Vehicle (PSLV). The PSLV was the first medium-lift launch vehicle that enabled India to launch all its remote-sensing satellites into LEO. It can take up to a 1.75-ton payload to Sun-Synchronous Orbits. Its first successful launch was in 1994. Due to its unmatched reliability, the PSLV has also been used to launch various satellites into GEO and Geo-Synchronous Orbit (GSO, which are similar to GEO but not directly above the equator), e.g., satellites from the NavIC constellation. Despite two partial failures, the PSLV has become the primary workhorse for ISRO with more than 50 successful launches, and has placed hundreds of Indian and foreign satellites into orbit. Besides, the vehicle has successfully launched two spacecraft as well, namely, Chandrayaan-1 in 2008 and Mars Orbiter Spacecraft in 2013[18].

Geosynchronous Satellite Launch Vehicle (GSLV). The GSLV was envisaged in the 1990s for transferring significant payloads to GEO. ISRO initially faced problems in the development of the GSLV, as the US had blocked India from obtaining cryogenic technology from Russia. This encouraged India to develop its own cryogenic engines. GSLV Mk II, now referred to simply as GSLV, has an indigenously developed cryogenic upper stage (CE-7.5), which can carry 2-ton payloads to GEO and 5-ton payloads to LEO. GSLV's primary payloads are the INSAT communications satellites. After its first launch in 2001, GSLV has achieved more than ten successful launches so far[19].

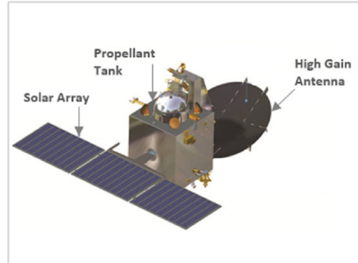


GSLV Mark III. The GSLV Mk III is the heaviest launcher in operational service with ISRO. Equipped with a more powerful cryogenic engine (CE-20) than the GSLV, GSLV Mk III is designed to carry 4-ton payloads to GEO or 10-ton payloads to LEO which is about twice the capability of the GSLV Mk II. It has had three successful launches so far (with GSAT-19, GSAT-29, and Chandrayaan-2 as payloads). It is also expected to carry India's first manned mission to space, which is now delayed to 2023.

CHANDRAYAAN I - BLASTOFF



CHANDRAYAAN II



MANGALYAAN

Extra-Terrestrial Exploration

There are three missions for extra-terrestrial exploration which have been undertaken by India so far: Chandrayaan I & II and the Mars Orbiter Mission (MOM).

Chandrayaan-1. Chandrayaan-1 was India's first mission to the Moon. It included a lunar orbiter and an impactor called the Moon Impact Probe. ISRO launched the spacecraft on 22 Oct 2008 using a PSLV, and it entered into lunar orbit about two weeks later. It carried 11 high-resolution remote sensing equipment for visible, near-infrared, and X-ray frequencies, five of which were Indian, while six were from NASA, the European Space Agency (ESA), and other American and European Institutes. Although it was planned for two years, the mission was operational for a little over ten months. During this period, it surveyed the lunar surface to produce a complete map of its chemical characteristics and three-dimensional topography, focussing on the Polar Regions which were expected to have ice deposits. Thus, Chandrayaan-1 became the first lunar mission to discover the existence of water on the Moon[20].

Chandrayaan-2. Chandrayaan-2, India's second moon mission, was launched using GSLV Mk-III on 22 Jul 2019 and consisted of a lunar orbiter, the Vikram lander, and the Pragyan lunar rover, all of which were developed in India. It was the first moon mission meant to explore the South Pole region. The main objective of the Chandrayaan-2 mission was to demonstrate ISRO's ability to soft-land on the lunar surface and operate a robotic rover on its surface, in addition to some scientific aims. The Vikram lander, carrying the Pragyan rover, was scheduled to land on the near side of the Moon. However, the lander deviated from its intended trajectory at the very last moment, starting from an altitude of about 2 km, and telemetry was lost seconds before touchdown. A review board concluded that the crash-landing was caused by a software glitch. The lunar orbiter, on the other hand, was efficiently positioned in an optimal lunar orbit, extending its expected service time from one year to seven years. There will be another attempt for a soft landing on the moon but without an orbiter. This was earlier scheduled in 2021 but has now been postponed to 2022 due to the COVID pandemic[21].

Mars Exploration: Mangalyaan. The Mars Orbiter Mission (MOM), also known as Mangalyaan, was launched into Earth orbit on 5 Nov 2013 by ISRO using a PSLV. The MOM probe spent about a month in earth orbit, where it made a series of seven apogee-raising orbital manoeuvres before being injected towards Mars on 30 Nov, i.e., 25 days later. After a 298-day transit to Mars, it was put into Mars orbit on 24 Sep 2014. It carried a payload of 15 kg comprising five scientific instruments for atmospheric and surface imaging studies. Mangalyaan was India's first interplanetary mission, and it made India the fourth space agency to achieve Mars orbit, after Roscosmos, NASA, and the European Space Agency. India also became the first country to enter Mars orbit on its first attempt, and the mission was completed at a record low cost of Rs 450 crore. On 24 Sep 2020, MOM completed six years in orbit around Mars and is still operational[22].

Future Projects

In the coming years, in addition to a number of communication and earth observation satellites, ISRO plans to send humans into space (Gaganyaan, scheduled in 2023) and later establish a space station to facilitate a few weeks long stay of astronauts. ISRO aims to develop and operationalise more powerful and less pollutive rocket engines, deploy telescopes in space and develop satellite navigation systems with global coverage. Long-term plans may include manned landings on the moon and on other planets as well. A brief insight into some of the near-term projects is given out in succeeding paragraphs.

Launch Vehicles and Engines. Notable development projects undertaken by ISRO include the semi-cryogenic engine, reusable launchers, and small satellite launch vehicles, as explained below:-

- **Semi-Cryogenic Engine**. The engine (SCE-200) will be less pollutive and more powerful than the current cryogenic engine CE-20. When mated with GSLV Mark III, the engine will boost its payload capacity from the existing 4-ton to possibly 6-ton[23].

- **Methalox Engine**. Methane and liquid oxygen-based engines are being developed to achieve the reusability of engines. Methane is less pollutive, leaves no residue, and hence the engine can be re-used.

- **Reusable Launchers**. There are two reusable launcher projects ongoing at ISRO. One is the

ADMIRE test vehicle, conceived as a vertical take-off vertical landing (VTVL) system, and another is the Reusable Launch Vehicle Technology Demonstrator (RLV-TD)[24], similar to the American space shuttle, which will be launched vertically but will land like a plane. The latter will also act as a test bed to evaluate various technologies such as hypersonic flight, autonomous landing, and powered cruise flight.

- **Small Satellite Launch Vehicle (SSLV).** The SSLV is a compact small lift launch vehicle primarily aimed at tapping the small satellites market. This launcher has been designed for quick assembly with low power requirements and hence would facilitate far higher launch frequency. The planned SSLV can place a 500 kg payload into a 500 km LEO. Its maiden flight is expected sometime in 2021[25].

- **Extra-Terrestrial Probes.** Several extra-terrestrial probes are also being planned, as under[26]:-

- **Lunar Exploration.** Chandrayaan-3 is India's planned second attempt to soft-land on the moon after the failure of Chandrayaan-2, now postponed to 2022 due to the pandemic. The mission will only include a lander-rover set and will communicate with the orbiter of Chandrayaan-2.

- **Mars Exploration.** Mangalyaan-2 has been proposed for launch in 2024. The newer spacecraft will be significantly heavier and better equipped than its predecessor.

- **Venus Exploration.** ISRO is planning an orbiter mission to Venus called Shukrayaan-1 to study its atmosphere. Scheduled for 2025, it will include a payload of 100 kg comprising instruments from India and other countries, including France, Russia, and maybe the US.

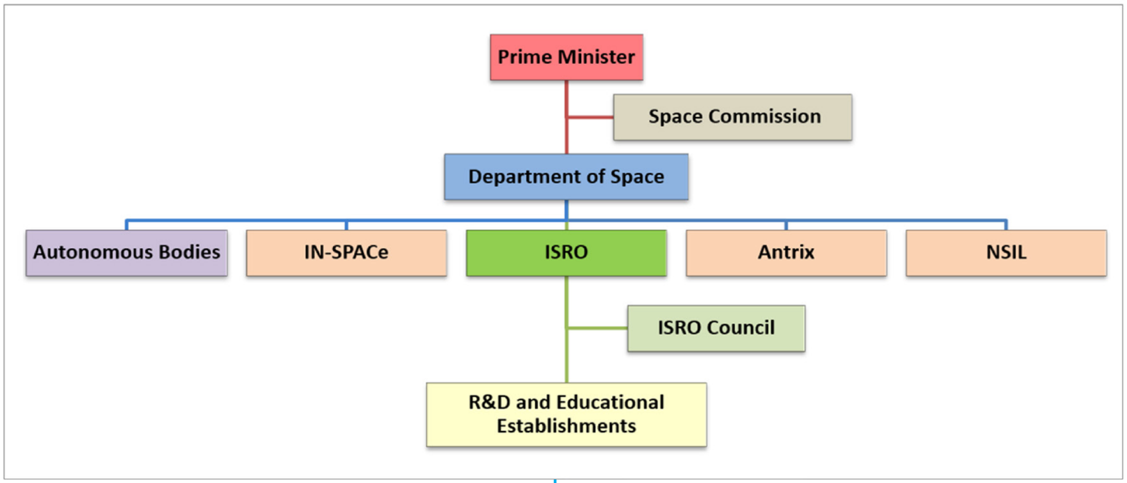
- **Solar Probes.** India's first solar mission, named Aditya L1, to study the solar corona is due for launch in 2022.

This work so far has reviewed the essentials of India's space program. It will now delve into two important facets associated with the space sector, namely, the NewSpace phenomenon, i.e., the commercialization of the space sector and the militarization of space. But first, the next section surveys the organisations which are steering India's forays in the space sector

Organisation

The Department of Space (DOS) and ISRO. ISRO is India's national space agency, headquartered in Bengaluru. It operates under the DOS, which is directly overseen by the prime minister of India. ISRO is the primary agency in India to perform tasks related to space-based applications, space exploration, and the development of related technologies. To trace its history, the Indian National Committee for Space Research (INCOSPAR) was established under the Department of Atomic Energy (DAE) in 1962. INCOSPAR grew and became ISRO in 1969, within the DAE. In 1972, the Government of India (GoI) set up a Space Commission and the DOS, bringing ISRO under the DOS. Since then, it has been managed by the DOS, which also governs various other institutions in India in the domain of astronomy and space technology. ISRO is one of the largest space agencies in the world. It has completed 111 spacecraft missions, 80 launch missions and has placed in orbit 342 foreign satellites from 34 countries so far. ISRO's launch systems have earned the reputation of being among the world's most reliable and cost-effective solutions in the world[27].

Antrix. Antrix Corporation Limited (ACL), Bengaluru, is a wholly-owned GoI enterprise under the administrative control of the DOS. Antrix was set up in 1992 as a marketing arm of ISRO for commercial exploitation of space products and transfer of technologies developed by ISRO. Another major objective was to facilitate the development of space-related industrial capabilities in India. Antrix is engaged in providing space products and services to international customers worldwide. It provides end-to-end solutions for many of the space products, ranging from simple subsystems to a complex spacecraft; space-related services including remote sensing data service; transponder lease service; launch services; mission support services including the establishment of ground



infrastructure; and a host of consultancy and training services[28,29].

New Space India Limited (NSIL). NSIL was set up by the DOS in March 2019. It aims to boost the growth of the Indian industry by taking up more technologically advanced space-related work. Its charter is to empower the industry in India. It facilitates the transfer of technology from ISRO to the industry; provision of launch services for customer satellites; manufacture of SSLVs in collaboration with the private sector; production of PSLV through industry; and production and marketing of space-based services. In general, while Antrix will facilitate ISRO's commercial deals with foreign customers, NSIL will handle the capacity building of local industry for space manufacturing[30].

Indian National Space Promotion and Authorization Centre (IN-SPACe). IN-SPACe is an independent nodal agency under the DOS, establishment of which was announced as recently as Jun 2020. It is meant to act as a facilitator and regulator for Non-Governmental Private Entities (NGPEs). A licensing, authorisation, and supervisory regime for space activities have been put in place through IN-SPACe, as required vide the Outer Space Treaty, which India ratified in 1982[31].

Mission Support Infrastructure. There are several establishments of ISRO which provide different services for satellite missions. Some of the major ones are[32]:-

- Satish Dhawan Space Centre at Sriharikota in Andhra Pradesh is the only spaceport in India.
- Master Control Facilities at Hassan in Karnataka and Bhopal in Madhya Pradesh monitor and control all communication and navigation satellites.
- National Remote Sensing Centre at Hyderabad manages the remote sensing satellites, including the dissemination of data.
- ISRO Telemetry, Tracking and Command Network, Bengaluru is entrusted with providing tracking support for all the satellite and launch vehicle missions.

Research and Educational Institutes. There are a number of research and academic institutes which provide design, development, and capacity-building support to ISRO, such as the Vikram Sarabhai Space Centre at Thiruvananthapuram, the Liquid Propulsion Systems Centre at Trivandrum, Space Applications Centre at Ahmedabad, amongst several others. In addition, the Indian Institute of Remote Sensing (IIRS) at Dehradun is a premier institute for capacity building in Remote Sensing through postgraduate programmes.

Defence Space Agency (DSA). In June 2010, India established an Integrated Space Cell within the Integrated Defence Headquarters to look after defence-specific space capability requirements. Soon thereafter, the Naresh Chandra Task Force, set up in 2011 to revisit the recommendations of the Kargil Review Committee, advocated the creation of an Aerospace Command. The DSA is a downsized version of the Aerospace Command and was approved by Prime Minister in Sep 2018. The Defence Imagery Processing and Analysis Centre (DIPAC) in Delhi and the Defence Satellite Control Centre in Bhopal were subsumed by the DSA. The DSA is headquartered in Bengaluru and is manned by about 200 personnel from all three Services of the Indian Armed Forces. Its charter is to operate systems to protect Indian interests in outer space and deal with potential space wars. The agency also has the responsibility of developing a space warfare strategy[33].

Defence Space Research Agency (DSRA). The DSRA is the scientific organisation responsible for developing space-warfare systems and technologies for the DSA. It was approved by the GoI in June 2019. It is composed of scientists who undertake research and development in close coordination with the Armed Forces. Various types of anti-satellite weapon systems are currently under development[34].

Commercialisation of Space

In India, space activities have traditionally been driven by the government to meet national needs with a high focus on self-reliance and security. Commercial activities till recently were driven by ISRO through its commercial arm, Antrix Corporation, closely regulated and controlled by the Department of Space (DOS). However, with the setting up of the NSIL and IN-SPACe, commercial activities are bound to get a fillip, which today account for merely about 2% of the $360 billion global space economy. This is intended to be achieved by incentivising private players to participate across the space value chain[35].

ISRO is currently, working to bring in more private industry participation in both launch systems and satellite manufacturing in order to build capacity and reach its designated targets and goals. India has a large base of Small and Medium-Scale Enterprises (SMEs) involved in supplying parts and components for satellite and launch vehicle manufacturing, contracted by ISRO for meeting its demands. Over the last four decades, an ecosystem of approximately 500 Indian companies has been developed. As per ISRO, 80% of the PSLV production is outsourced to private industries, while in the case of major satellite missions such as the Mars Orbiter Mission (MOM), over 120 companies contributed to manufacturing[36]. In recent times, ISRO has adopted public private partnership policies to encourage companies to take up more production activities rather than being merely part/ component manufacturers. ISRO has also built a facility spread over 25 acres in Bengaluru, where the amenities have been set up for use by the industry[37].

As already brought out, while Antrix handles ISRO's commercial deals for satellites and launch vehicles with foreign customers, NSIL is chartered to deal with capacity building of local industry for space manufacturing, although there is considerable overlap in the functions of these two public sector entities. IN-SPACe has been set up to act as a single-point interface between ISRO and everyone who wants to participate in space-related activities by regulating space activities and facilitating usage of ISRO facilities by Non-Government Private Entities (NGPEs). It will also handhold and guide the private industries in space activities through incentives and a friendly regulatory environment.

The GoI has also released a draft Spacecom Policy-2020 in Oct 2020[38], which seeks to foster the promotion of Indian industry as a co-traveller along with DOS towards meeting the growing demands of space-based communication.

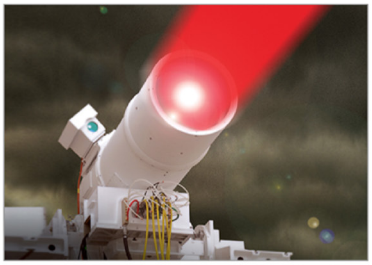
With these initiatives, private industry, including start-ups in the country, should be able to leapfrog by piggybacking on five decades of experience and expertise gathered by ISRO and come up with offerings that complement the efforts of ISRO. This would empower them to integrate into the global space supply chain and compete internationally.

Militarisation of Space

From a security perspective, an increasing number of countries are relying on space to enhance their military capabilities and national security by developing counter-space capabilities that can be used to provide military advantages in this new war fighting domain. This section provides an insight into the nature of counter-space capabilities that are being pursued globally, the expertise achieved by major world powers, and finally, the Indian perspective and capability status in this area.

Counter-Space Capabilities. Counter-space capabilities are of four types: kinetic physical counter-space weapons, non-kinetic physical counter-space weapons; electronic counter-space weapons; and cyber weapons[39]. These are explained below.

Kinetic Physical Counter-Space Weapons. These are weapons that attempt to strike directly or detonate a warhead near a satellite or ground station. The three main forms of kinetic physical attack are direct-ascent Anti-Satellite (ASAT) weapons, co-orbital ASAT weapons, and ground station attacks. Direct-ascent ASAT weapons are launched from earth to strike a satellite in orbit, while co-orbital ASAT weapons are first placed into orbit and then later maneuvered into or near their intended target. Attacks on ground stations target those sites which are responsible for the command and control of satellites. Kinetic physical attacks tend to cause irreversible damage to the systems affected and demonstrate a strong show of force that would likely be attributable and publicly visible. A successful kinetic-physical attack in space produces orbital debris, which can indiscriminately affect other satellites in similar orbits. Four countries, namely, the United States, Russia, China, and India, have successfully tested direct-ascent ASAT weapons.


LASER WEAPONS


HIGH POWER MICROWAVE WEAPONS


ELECTRONIC WEAPONS

- **Non-Kinetic Physical Counter-Space Weapons.** These are weapons that have physical effects on satellites or ground systems without making physical contact. These may be discussed under three heads: Lasers may be used to temporarily dazzle or permanently blind the sensors on satellites; High-Powered Microwave (HPM) weapons can disrupt a satellite's electronics or cause permanent damage to electronic circuits; and a nuclear device detonated in space can create an electromagnetic pulse (EMP) that would have indiscriminate effects on satellites in orbit. These attacks operate at the speed of light and are more difficult to attribute. Lasers and HPM weapons may be mounted on the ground, ship, or airborne platforms, as also other satellites. A laser can only be effective against a sensor on a satellite if it is within the field of view of the sensor, making it possible to attribute the attack to its approximate geographical origin. HPM attacks can be more difficult to attribute because the attack can come from a variety of angles, including from other satellites passing by in orbit. The use of a nuclear weapon in space would likely be attributable and publicly visible. However, the detonation of nuclear weapons in space is banned under the Partial Test Ban Treaty of 1963.

- **Electronic Counter-Space Weapons.** These are weapons that target the usage of the electromagnetic spectrum for data transmission through jamming. An uplink jammer interferes with the signal going from earth to a satellite, while a downlink jammer targets the signal from a satellite to users on earth. In both cases, it is the receiver which is targeted. Spoofing is a form of electronic attack where the attacker tricks a receiver into believing that a fake signal produced by the attacker is the real signal. A spoofer can be used to inject false information into a data stream or could even issue false commands to a satellite. Electronic forms of attack can be difficult to detect or distinguish from accidental interference, making attribution more difficult. Both jamming and spoofing are reversible forms of attack because once they are turned off, communications can return to normal. The technology needed for jamming and spoofing is commercially available and inexpensive, making it relatively easy for it to proliferate among state and non-state actors.

- **Cyber Weapons**. Cyber-attacks target the data itself as well as the systems that use, transmit, and control the flow of data. These attacks can target ground stations, end-user equipment, or the satellites themselves. While cyber-attacks require a high degree of understanding of the systems being targeted, significant resources are not always required to carry them out. Cyber-attacks can be conveniently contracted out to private groups or individuals when the barrier to entry is relatively low. Accurate and timely attribution of a cyber-attack can be very difficult because attackers can use a variety of methods to conceal their identity.

Global Space Powers. The assessed capabilities of major global space powers are briefly reviewed as under[40]:-

- **The United States**. The US has conducted multiple tests for rendezvous and proximity operations (RPO) in both LEO and GEO that could lead to a co-orbital ASAT capability. It has operational midcourse missile defence interceptors that have been demonstrated in an ASAT role against low LEO satellites. The US has an operational EW offensive counter-space system, which is deployed globally to provide uplink jamming capability against geostationary communications satellites. It also has the capability to jam global navigation satellite services (GPS, GLONASS, Beidou) within a local area of operation. Over the past several decades, the US has conducted significant R&D on the use of ground-based high energy lasers for counter-space and other purposes. It has evolved doctrine and policy on counter-space capabilities over several decades, although not always publicly expressed. Its setting up of the Space Force in 2019 demonstrates the determination of the US to maintain its domination in this new warfighting domain[41].

- **China**. There is sufficient evidence to indicate that China is making a sustained effort to develop a broad range of counter-space capabilities. Like the US, it has conducted multiple tests of technologies for RPO in both LEO and GEO that could lead to a co-orbital ASAT capability. China dramatically demonstrated DA-ASAT capability in 2007 by destroying a satellite in polar orbit at an altitude of 865 km. China likely has significant electronic warfare (EW) counter-space capabilities against navigation and communication satellites and is also assessed to be developing directed energy weapons (DEW) for counter-space use. Setting up of Space Segment Department under newly raised PLA Strategic Support Force is a major organisational transformation carried out by China towards the militarisation of space[42].

- **Russia**. There are strong reasons to believe that Russia has been testing technologies for RPO in both LEO and GEO, especially over the last couple of years. It is almost certainly capable of some limited DA-ASAT operations. Russia has operational experience in the use of counter-space EW capabilities from recent military campaigns. Russian ground-based satellite laser ranging facilities could be used to dazzle the sensors of optical imagery satellites. The Russian Space Forces are a branch of the Russian Aerospace Forces, which are chartered to defend its space assets and secure its interests in this domain[43].

Space Security: The Indian Perspective

Shifts in India's Position on the Militarization of Space. India's traditional approach to outer space emphasized non-militarization of space. However, this began to change in the early 2000s, driven by the evolving security threats that India faced, especially in relation to Pakistan and China. Pakistan's acquisition of ballistic missiles has led India to pursue ballistic missile defences. In addition, China's successful ASAT test in January 2007 brought to the fore the vulnerability of India's space-based assets. As a result, India has since adopted a much more determined approach to how it wants to protect its space assets and develop its own ASAT capability as a deterrent[44].

Growing Synergies between Space Initiatives and the Indian Military. Some concrete actions have been taken by India to integrate its space program more fully with the military. The creation of the Integrated Space Cell, the DSA, and the DSRA have been referred to above. In addition, for the first time, India conducted a space security table-top war game called *IndSpaceEx* in July 2019, which was attended by stakeholders from the military and the scientific establishment. The Ministry of Home Affairs has also established the Space and Technology Cell to monitor border areas to check for intrusion from Pakistan and China. Pakistan's expanding nuclear weapons program has also prompted India to develop suitable space-based assets for surveillance of Pakistan's nuclear forces. The growing competition with China is leading to greater cooperation between India and a number of space powers in the Indo-Pacific, such as Japan, Australia, and France, all of whom feel threatened by China. These partnerships are likely to gather greater momentum given the recent aggressive stance adopted by China in its neighbourhood and beyond[45].

India's Military Space Assets. India currently has several operational remote sensing satellites which can be used for civil as well as military purposes. Among these, RISAT-2 has a day-night, all-weather monitoring capability with one-metre resolution; the CARTOSAT-2 with a camera in the visible region is a dedicated satellite for the Indian Armed Forces, which, because of its high agility, can be steered to facilitate imaging of any area at short notice. The Indian Navy uses GSAT-7, launched in 2013, for real-time communication among its warships, submarines, aircraft, and land systems. GSAT-7A, or 'angry bird', an advanced military communications satellite, was launched in December 2018 and is being utilised by the Indian Air Force (IAF) and the Indian Army (IA) on a 70:30 sharing basis. For the IAF, it facilitates enhanced network-centric warfare capabilities by interlinking the ground radar network and Airborne Early Warning and Control (AEW&C) aircraft. It is used by the Aviation Corps and some other elements of the IA. GSAT-6A was launched in 2018 for the Indian Armed Forces, but communication with it was lost before it reached its orbit. GSAT-32 is planned as its replacement. The Electromagnetic Intelligence-gathering Satellite (EMISAT) was launched in Apr 2019 to detect enemy radar signatures. In all, India has upwards of 14 satellites with military applications[46].

India's Counter-Space Weapons. A brief overview of India's counter-space weapon capabilities is as under[47, 48]:-

- **Kinetic Physical.** India conducted a successful direct-ascent ASAT test in March 2019. As per Chairman DRDO, while this test was conducted at a low altitude (283 km) to limit space debris, the missile system used in the test was capable of reaching most satellites in LEO. He also stated that India is working on technologies related to co-orbital weapons.

- **Non-Kinetic Physical.** In late 2020, Chairman DRDO announced a program for the development of high-energy lasers and high-powered microwaves, which could be adapted as counter-space weapons. India reportedly has two laser-based weapon systems capable of striking short-range aerial targets such as drones by jamming command and control links.

- **Electronic.** India has indigenously developed the fully mobile Samyukta EW system, which is capable of jamming communications and radar signals over a wide range of frequencies. Himshakti, another such system, is the most recent electronic warfare system in India's arsenal, capable of jamming frequencies over 10,000 square kilometre. India reportedly jammed Pakistani radars and communications during the 2019 Balakot airstrike.

- **Cyber.** As the country's cyber capabilities grow, its most frequent targets are the governments of Pakistan and China. However, there is no evidence to indicate that India has tested or employed its cyber capabilities against space systems.

Conclusion

After a brief explanation of the different types of orbits, this paper reviewed ISRO's commendable achievements over the years in the three main types of space applications, as also the different types of launch vehicles that ISRO has developed. It then touched upon India's exploration missions, i.e., the Chandrayaan and Mangalyaan, and went over some of its future development and exploration plans. The work also gave an overview of the main government organisations involved in developing its space sector, which, apart from ISRO, includes the DOS, Antrix, NSIL, IN-SPACe, DSA, DSRA, and several other establishments providing mission support services as well as R&D support. Finally, two important facets of the space sector were discussed: the commercialisation of the sector and the increasingly important role of private industry in this endeavour, and the vital aspect of militarisation of space, including India's initiatives in this area.

India's achievements in the space sector over the years have indeed been commendable. Recent steps taken by the GoI to give a fillip to NewSpace initiatives are also noteworthy. However, with the increasing strategic importance of space, it is imperative that much more attention be devoted to this domain, especially from a national security perspective.

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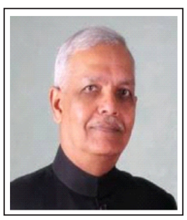

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