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Distance Learning Programme

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Science & Technology

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SCIENCE & TECHNOLOGY

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Space Science & Technology

Chapter 2

Outer Space refers to the void that exists between celestial bodies. There is no boundary where outer space said to begin, but according to space treaties Kármán line located at an altitude of 100 km above sea level is conventionally used as the start of outer space. Space can also be regarded as a resource available for exploitation because it forms part of man's environment similar to land, air and water. Space research involves dual use technology with application in both civilian and defence sectors. Indian space research also involves dual use technology and other countries that possess this technology include Russia, USA, European Union, Israel, Japan and China.

What is an Orbit?

An orbit is a regular and repeating curved trajectory of an object in space. An object in an orbit is called a Satellite, it can be artificial satellite or natural satellite like earth and other planets. The earth, like any other planets in space, rotates around the sun, in its own orbital path at a constant speed.

How an Orbit is formed?

Orbit is a result of perfect balance between the momentum of an object and the force of gravity. " When an object is in motion, it will be in motion unless some external forces applied to it- Newtons First Law". When an object is released into space, it follows a straight trajectory, but due to the earths gravity the object is pulled towards it and the trajectory become curved shaped and due this repeated action, it becomes an orbit.

Object speeds by a planet with a lot of momentum	Gravity attracts the object to the planet and vice versa	Object continues to try to move forward, but is pulled down by gravity.	The result is a balance of forces pushing the object out and pulling it in, making a circular orbit.

Note: *The trajectory of an orbit can be circular or elliptical.*

Types of Orbits

On the Basis of Altitude

- **Near Earth Orbit (NEO):** Being the orbit closest to the Earth, satellite orbiting here has to overcome greater gravitational pull of the earth. Generally experimental satellites are launched in the NEO. Ex. Aryabhatt and Rohini.

- **Low Earth Orbit (LEO):** This orbit lies at an altitude between 160 Km to 2000 Km above the earth's surface. Objects that are in the Low Earth Orbit are subject to atmospheric drag. " Atmospheric Drag is a process of reduction of the altitude of a satellite's orbit due to frequent collision of gas molecules and it is a cause of orbital decay." So, Higher the orbital altitude, lower will be the atmospheric density and drag.

  However, beyond 1000 Km above the earth's surface, objects will be subject to Earth's "Van Allen Radiation Zone"- It is a very sensitive zone, filled with energetic charged particles from solar winds and cosmic rays, that are captured by the earths magnetic field leading to varying levels of radiations. So, to avoid catastrophes, missions to LEO aims for altitude between 160 Km to 1000 Km above the earths surface.

  LEO is the circular orbit in which Remote Sensing Satellites (RSS) are launched. Remote Sensing Satellites follow a circular orbit moving from North pole to South pole, therefore this orbit is also known as Polar Orbit. In a 24 hour period, polar orbiting satellites will view most of the Earth twice: once in daylight and once in darkness. Moreover, Within LEO, high bandwidth communication can be experienced with low time lag.
- **Middle Earth Orbit (MEO):** MEO is also called Immediate circular Orbit, lies at an altitude between 2000 Km to 35786 Km, but most commonly satellite operates at an altitude between 20200 Km to 20650 to avoid unwanted hazards. Satellite in this orbit has an orbital period of 2-24 hours and an orbital period of 12 hours can be achieved by satellites in this region, thus this will allow these satellites to orbit the earth twice a day. The most common use of satellites in this region is for navigation, such as the GPS, Glonass and Galileo constellations. Communications satellites that cover the North and South Pole are also put in MEO. On the contrary, due to comparatively high altitude more ground coverage can be achieved.

  Nevertheless, MEO has disadvantages too. With the increase in altitude as compared to LEO, propagation delay will begin to creep into the transmission of signals. Thus the power required to transmit the signal will increase.
- **Geosynchronous Earth Orbit (GEO):** A Geosynchronous Earth orbit lies at the highest altitude of approximately 36000 Km above the earth's equator. The orbital period is equal to the earth's rotational period around its axis, which allows satellites to match Earth's rotation. This position is a valuable spot for monitoring weather, communications and surveillance. A Satellite in the Geosynchronous orbit can see or track one spot of the planet all the time. Satellites in this orbit can be used for military and commercial purposes such as telephone, internet and television. It also ensures a stable connectivity as it can spot a single area over months or years.

On the Basis of Application

- **Geostationary Orbit (GSO):** The geostationary orbit is a special case of geosynchronous orbit in which a satellite moves in a circular geosynchronous orbit in the equatorial plane in the direction of the earth's rotation. The satellite in this orbit has the same orbital period as the rotation of the earth around its axis, making it appear stationary relative to a fixed spot on the earth. This allows for them to provide constant coverage of an area. This orbit is good for providing television broadcasting, weather monitoring and communication services.
- **Sun Synchronous Orbit (SSO):** It is a special type of polar orbit. Here the orbital plane of the satellite is always at the same constant angle relative to the sun-earth line during all seasons. A sun-synchronous orbit crosses over the equator at approximately the

same local time each day (and night). This orbit keeps the angle of sunlight on the surface of the earth as consistent as possible, though the angle will change from season to season. This consistency means that scientists can compare images from the same season over several years. Generally, remote sensing satellites are launched in this orbit.

- **Highly Elliptical Orbit (HEO):** Satellites in Highly Elliptical Orbit have orbits that are close to the earth at one point of their orbit, but are much farther away from the earth at other times. Often highly-elliptical orbits are used to serve areas to the far north or south of the earth, which cannot be reached using geostationary satellites.
- **Transfer Orbit (TO):** Transfer orbit is an intermediate orbit into which a spacecraft is first launched and from where the satellite subsequently lifts off, with the help of its propulsion system, to its designated orbit.
  - **Polar Transfer Orbit (PTO):** It is an orbit at an altitude of about 100 km below the Polar or Low Earth Orbit. Remote Sensing satellites are launched into this orbit first and then using its own propulsion, system it lifts itself to the desired orbit.
  - **Geostationary Transfer Orbit (GTO):** This orbit is located at a height of about 200 km below the geostationary orbit. GSS are first launched in GTO and then lifts itself using its own propulsion system to the desired orbit.

Indian Space Programme

Genesis

The 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. Dr. Vikram Sarabhai, the founding father of Indian space programme, recognized 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. He 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.

The INCOSPAR (Indian National Committee for Space Research) was initiated under the leadership of Dr. Sarabhai and Dr. Ramanathan. In 1967, the first 'Experimental Satellite Communication Earth Station (ESCES)' located in Ahmedabad was operationalized, which also doubled as a training centre for the Indian as well as international scientists and engineers.

The Satellite Instructional Television Experiment (SITE), was hailed as 'the largest sociological experiment in the world' during 1975-76. It benefited around 200,000 people, covering 2400 villages of six states and transmitted development oriented programmes using the American Technology Satellite (ATS-6).

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.

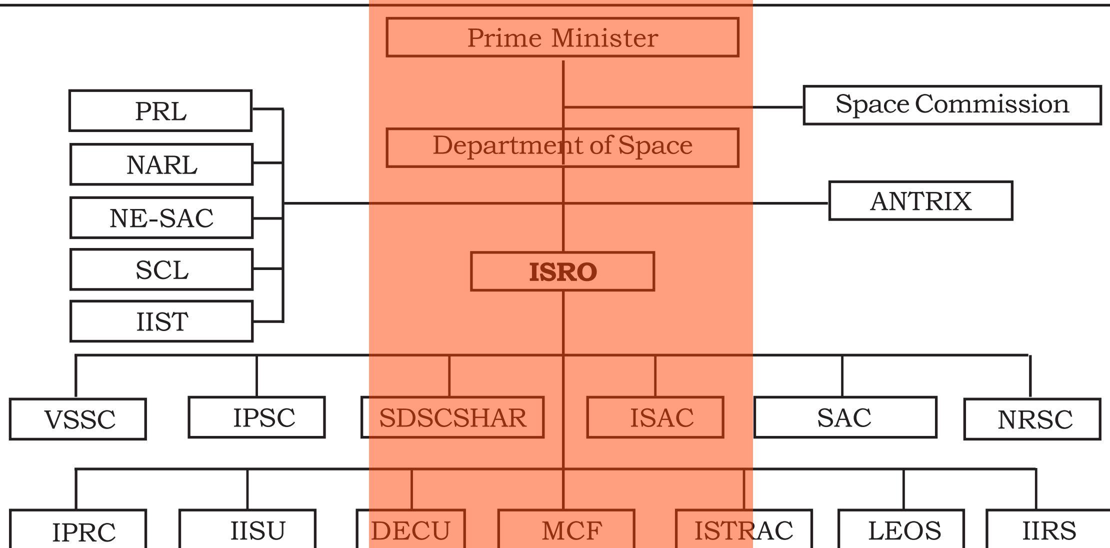
The first Indian spacecraft 'Aryabhata' was developed and was launched using a Soviet Launcher in 1975. Another major landmark was the development of the first launch vehicle SLV-3 with a capability to place 40 kg in Low Earth Orbit (LEO), which had its first successful flight in 1980.

In the experimental phase during 80's, 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 the future communication satellite system. Development of the complex Augmented Satellite Launch Vehicle (ASLV), also demonstrated newer technologies like the use of strap-on, bulbous heat shield, closed loop guidance and digital autopilot. This paved the way for learning the many nuances of launch vehicle design for complex missions, leading the way for the realisation of operational launch vehicles such as PSLV and GSLV.

During the operational phase in 90's, major space infrastructure was created under two broad classes: one for the communication, broadcasting and meteorology through a multi-purpose Indian National Satellite system (INSAT), and the other for Indian Remote Sensing Satellite (IRS) system. The development and operationalisation of Polar Satellite Launch Vehicle (PSLV) and development of Geosynchronous Satellite Launch Vehicle (GSLV) were significant achievements during this phase.

Organizational Setup

The Space Commission formulates the policies and oversees the implementation of the Indian space programme to promote the development and application of space science and technology for the socio-economic benefit of the country.



PRL: Physical Research Laboratory, **NARL:** National Atmospheric Research Laboratory, **NE-SAC:** North Eastern Space Applications Centre, **SCL:** Semi-Conductor Laboratory, **IIST:** Indian Institute of Space Science and Technology, **ISRO:** Indian Space Research Organisation, **Antrix:** Antrix Corporation Limited, **VSSC:** Vikram Sarabhai Space Cenre, **LPSC:** Liquid Propulsion Systems Centre, **SDSC:** Satish Dhawan Space Centre, **ISAC:** ISRO Satellite Centre, **SAC:** Space Applications Centre, **NRSCL:** National Remote Sensing Centre, **IPRC:** ISRO Propulsion Complex, **IISU:** ISRO Inertial Systems Unit, **DECU:** Development and Educational Communication Unit, **MCF:** Master Control Facility, **ISTRAC:** ISRO Telemetry, Tracking and Command Network, **LEOS:** Laboratory for Electro-optic Systems, **IIRS:** Indian Institute of Remote Sensing.

Department of Space (DOS) implements these programmes through, mainly Indian Space Research Organisation (ISRO), Physical Research Laboratory (PRL), National Atmospheric Research Laboratory (NARL), North Eastern-Space Applications Centre (NE-SAC) and Semi-Conductor Laboratory (SCL).

ISRO

The Indian Space Research Organisation (ISRO) is the space agency of the Government of India headquartered in Bangalore. Its vision is to harness space technology for national development while pursuing space science research and planetary exploration.

ISRO was formed in 1969 and it superseded the erstwhile Indian National Committee for Space Research (INCOSPAR) established in 1962 by the efforts of then PM of India, Jawaharlal Nehru, and his close aide and scientist Vikram Sarabhai. The establishment of ISRO thus institutionalized space activities in India. It is managed by the Department of Space, which reports to the Prime Minister of India.

Indian Launch Vehicles

The first experimental Satellite Launch Vehicle (SLV-3) was developed in 1980. An Augmented version of this, ASLV, was launched successfully in 1992. India has made tremendous strides in launch vehicle technology to achieve self-reliance in satellite launch vehicle programme with the operationalisation of Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV).

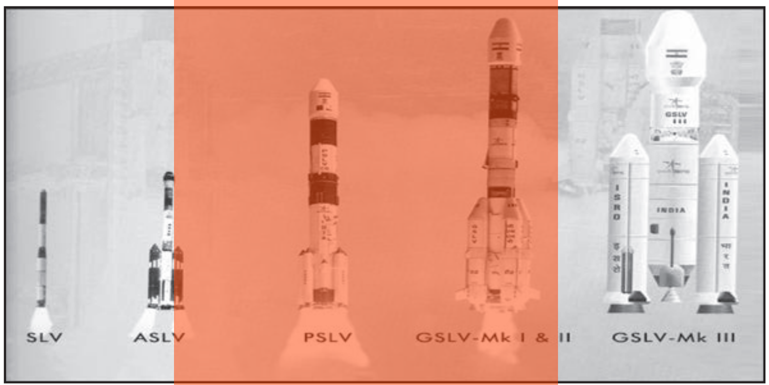


Fig. *Satellite Launch Vehicles*

Initial Launch Vehicles of India

- **Satellite Launch Vehicle (SLV):** Satellite Launch Vehicle-3 (SLV-3) was India's first experimental satellite launch vehicle, which was an all solid fuel, four stage vehicle capable of placing 40 kg class payloads in Low Earth Orbit (LEO). It was first launched in 1980 when Rohini satellite, RS-1, was placed in orbit, thereby making India the sixth member of an exclusive club of space-faring nations.
- **Augmented Satellite Launch Vehicle (ASLV):** The ASLV is a five stage, all-solid propellant vehicle, capable of placing 150 kg class satellites into 400 km circular orbits. The ASLV Programme was designed to augment the payload capacity to 150 kg, thrice that of SLV-3, for Low Earth Orbits (LEO). Under the ASLV programme, four developmental flights were conducted.

Operational Launch Vehicles of India

Polar Satellite Launch Vehicle (PSLV)

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. After its first successful launch in October 1994, PSLV emerged as the reliable and versatile workhorse launch vehicle of India. The vehicle successfully launched two spacecraft – Chandrayaan-1 in 2008 and Mars Orbiter Spacecraft in 2013 – that later travelled to the Moon and Mars respectively.

PSLV earned its title 'the Workhorse of ISRO' through consistently delivering various satellites to Low Earth Orbits, particularly the IRS series of satellites. It can take up to 1,750 kg of payload to Sun-Synchronous Polar Orbits of 600 km altitude. Due to its unmatched reliability, PSLV has also been used to launch various satellites into Geosynchronous and Geostationary orbits, like satellites from the IRNSS constellation.

PSLV has four stages using solid and liquid propulsion systems alternately. In the first stage, PSLV uses the S139 solid rocket motor that is augmented by 6 solid strap-on boosters. In the second stage, an Earth storable liquid rocket engine known as the Vikas engine is used. The third stage of PSLV is a solid rocket motor that provides the upper stages high thrust after the atmospheric phase of the launch. The fourth or uppermost stage of PSLV, comprises two Earth storable liquid engines. PSLV uses 6 solid rocket strap-on motors to augment the thrust provided by the first stage in its PSLV-G and PSLV-XL variants. However, strap-ons are not used in the core alone version (PSLV-CA).

Geosynchronous Satellite Launch Vehicle (GSLV)

Geosynchronous Satellite Launch Vehicle Mark II (GSLV Mk II) is the largest launch vehicle developed by India, which is currently in operation. This fourth generation launch vehicle is a three stage vehicle with four liquid strap-ons. The indigenously developed cryogenic Upper Stage (CUS), which is flight proven, forms the third stage of GSLV Mk II. From January 2014, the vehicle has achieved four consecutive successes.

GSLV's primary payloads are INSAT class of communication satellites that operate from Geostationary orbits and hence are placed in Geosynchronous Transfer Orbits by GSLV. Further, GSLV's capability of placing up to 5 tonnes in Low Earth Orbits broadens the scope of payloads from heavy satellites to multiple smaller satellites.

The first stage of GSLV was also derived from the PSLV's first stage. The 138 tonne solid rocket motor is augmented by 4 liquid strap-ons. One Vikas engine is used in the second stage of GSLV. The stage was derived from the second stage of PSLV where the Vikas engine has proven its reliability. The third stage uses CE-7.5, India's first cryogenic engine, developed under the Cryogenic Upper Stage Project (CUSP). CE-7.5 has a staged combustion operating cycle.

Sounding Rockets

Sounding rockets are one or two stage solid propellant rockets used for probing the upper atmospheric regions and for space research. They also serve as easily affordable platforms to test or prove prototypes of new components or subsystems intended for use in launch vehicles and satellites. With the establishment of the Thumba Equatorial Rocket Launching Station (TERLS) in 1963 at Thumba, a location close to the magnetic equator, there was a quantum jump in the scope for aeronomy and atmospheric sciences in India. The launch of the first sounding rocket from Thumba near Thiruvananthapuram, Kerala on 21 November 1963, marked the beginning of the Indian Space Programme.

ISRO started launching indigenously made sounding rockets from 1965 and experience gained was of immense value in the mastering of solid propellant technology. In 1975, all sounding rocket activities were consolidated under the Rohini Sounding Rocket (RSR) Programme. RH-75, with a diameter of 75mm was the first truly Indian sounding rocket, which was followed by RH-100 and RH-125 rockets. The sounding rocket programme was the bedrock on which the edifice of launch vehicle technology in ISRO could be built.

Future Launchers

GSLV Mk III

GSLV Mk III is a three-stage heavy lift launch vehicle developed by ISRO. The vehicle has two solid strap-ons, a core liquid booster and a cryogenic upper stage.

GSLV Mk III is designed to carry 4 ton class of satellites into Geosynchronous Transfer Orbit (GTO) or about 10 tons to Low Earth Orbit (LEO), which is about twice the capability of GSLV Mk II.

The first experimental flight of LVM3, the LVM3-X/CARE mission lifted off from Sriharikota on December 18, 2014 and successfully tested the atmospheric phase of flight. Crew module Atmospheric Reentry Experiment was also carried out in this flight. The module reentered, deployed its parachutes as planned and splashed down in the Bay of Bengal. The first developmental flight of GSLV Mk III, the GSLV-Mk III-D1 successfully placed GSAT-19 satellite into a Geosynchronous Transfer Orbit (GTO) on June 05, 2017 from SDSC SHAR, Sriharikota.

Indigenous Cryogenic Upper Stage (CUS)

A cryogenic rocket stage is more efficient and provides more thrust for every kilogram of propellant it burns compared to solid and earth-storable liquid propellant rocket stages. Specific impulse (a measure of the efficiency) achievable with cryogenic propellants (liquid Hydrogen and liquid Oxygen) is much higher compared to liquid and solid propellants, giving it a substantial payload advantage.

ISRO's Cryogenic Upper Stage Project (CUSP) envisaged the design and development of the indigenous Cryogenic Upper Stage to replace the stage procured from Russia and used in GSLV flights. However, the cryogenic rocket stage has certain advantages and disadvantages:

- **Advantages:** High energy per unit mass, clean fuel, economical in long run.
- **Disadvantages:** Storage, huge initial capital investment, very sophisticated technology requiring high level of technical expertise.

RLV-TD

Reusable Launch Vehicle – Technology Demonstrator (RLV-TD) is one of the most technologically challenging endeavours of ISRO towards developing essential technologies for a fully reusable launch vehicle to enable low cost access to space. The configuration of RLV-TD is similar to that of an aircraft and combines the complexity of both launch vehicles and aircraft. The winged RLV-TD has been configured to act as a flying test bed to evaluate various technologies, namely, hypersonic flight, autonomous landing and powered cruise flight. In future, this vehicle will be scaled up to become the first stage of India's reusable two stage orbital launch vehicle.

RLV-TD was successfully flight tested on May 23, 2016 from Satish Dhawan Space Centre SHAR, Shriharikota, validating the critical technologies such as autonomous navigation, guidance & control, reusable thermal protection system and re-entry mission management.

Scramjet Engine -TD

The first experimental mission of ISRO's Scramjet Engine towards the realisation of an Air Breathing Propulsion System was successfully conducted on August 28, 2016 from Satish Dhawan Space Centre SHAR, Sriharikota.

The Scramjet engine designed by ISRO uses Hydrogen as fuel and the Oxygen from the atmospheric air as the oxidiser. This test was the maiden short duration experimental test of ISRO's Scramjet engine with a hypersonic flight at Mach 6. ISRO's Advanced Technology Vehicle (ATV), which is an advanced sounding rocket, was the solid rocket booster used for the test of Scramjet engines at supersonic conditions.

Indian Satellites

ISRO has established two major space systems, the Indian National Satellite System (INSAT) series for communication, television broadcasting and meteorological services which are Geostationary Satellites, and Indian Remote Sensing Satellites (IRS) system for resources monitoring and management which are Earth Observation Satellites.

Communication Satellites

The Indian National Satellite (INSAT) system is one of the largest domestic communication satellite systems in Asia-Pacific region with nine operational communication satellites placed in geostationary orbit. Established in 1983 with commissioning of INSAT-1B, it initiated a major revolution in India's communications sector and sustained the same later. GSAT-17 joins the constellation of INSAT System consisting 15 operational satellites, namely -INSAT-3A, 3C, 4A, 4B, 4CR and GSAT-6, 7, 8, 9, 10, 12, 14, 15, 16 and 18.

The INSAT system with more than 200 transponders in the C, Extended C and Ku-bands provide services to the telecommunications, television broadcasting, satellite news gathering, societal applications, weather forecasting, disaster warning and search and rescue operations.

ISRO's New Communication Satellites to Usher in High-speed Internet Era

Recently, ISRO has launched India's high throughput communication satellite GSAT-31 from a spaceport in French Guiana followed by GSAT-7A. These Satellites will augment the Ku-band transponder capacity in Geostationary Orbit and is planning to usher in an age of high-speed internet connectivity in the country with the launch of heavy-duty communication satellites. GSAT-11 & GSAT-20 will be launched from Europe & India respectively. GSAT-29 will be launched through the GSLV MK III from India. On June 5, 2017 ISRO had launched GSAT-19, which too carried Ka-band and Ku-band high bandwidth communication transponders. The satellites will use multiple spot beams (a special kind of transponder that operates at a high frequency) that will increase internet speed and connectivity. Together, all these satellites will provide high bandwidth connectivity of up to 100 gigabit per second. These satellites will reuse beams (signals) several times in order to cover the entire country. In contrast, traditional satellite uses a broad single beam (not concentrated) to cover wide regions.