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**Science & Technology**

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### 3.1 Introduction

Space technology is the technology for use in travel or activities beyond Earth's atmosphere, for purposes such as spaceflight or space exploration. Space technology includes space vehicles such as spacecraft, satellites, space stations and orbital launch vehicles; deep-space communication; in-space propulsion; and a wide variety of other technologies including support infrastructure equipment, and procedures.

The limits to space extends to outer space, which is the expanse that exists beyond Earth and between celestial bodies. Outer space does not begin at a definite altitude above the Earth's surface. The *Kármán line*, an altitude of 100 km above sea level, is conventionally used as the start of outer space in space treaties and for aerospace records keeping.

The space environment is a sufficiently novel environment that attempting to work in it often requires new tools and techniques.

Many common everyday services for terrestrial use such as weather forecasting, remote sensing, satellite navigation systems, satellite television, and some long-distance communications systems critically rely on space infrastructure. New technologies originating with or accelerated by space-related endeavours are often subsequently exploited in other economic activities.

The beneficial uses of outer space, including strengthening communications infrastructures, disaster management, education, agriculture, environmental protection and natural resource management, had enormous relevance for human development, especially for developing countries. The wider adoption of beneficial applications would strengthen the goal of maintaining outer space for peaceful purposes

India started its Space endeavours way before independence in the form of contributions and distinct efforts of scientists like C.V.Raman and Meghnad Saha. Initial works were confined to the study of radiations, meteorology, and the study of the upper atmosphere. It got a boost with the establishment of the Department of Atomic Energy (DAE) in 1950 chaired by Homi Bhabha. The department became the sole body to direct funding and look after the research work throughout India.

### 3.2 Orbits

An orbit is the curved path that an object in space (such as a star, planet, moon, asteroid or spacecraft) takes around another object due to gravity.

#### Low Earth Orbit (LEO)

A low Earth orbit is an orbit that is relatively close to Earth's surface. It is normally at an altitude of less than 1000 km but could be as low as 160 km above Earth which is low

compared to other orbits, but still very far from Earth's surface. Earth observation satellites, also known as Remote Sensing Satellites use LEO as they are able to see the surface of the Earth more clearly by being closer to it. The International Space Station is placed at LEO.

#### Medium Earth Orbit (MEO)

Medium Earth Orbit comprises a wide range of orbits anywhere between LEO and HEO (High Earth Orbit) -- between 2,000 km and 35,786 km. It is very commonly used by navigation satellites, like the European Galileo System and Global Positioning System (GPS) constellation. All satellites in MEO have an orbital period of less than 24 hours, with the minimum period (for a circular orbit at the lowest MEO altitude) about 2 hours.

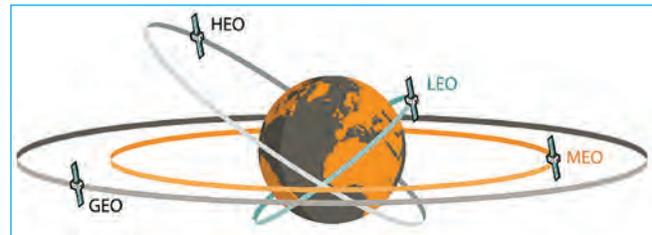


Figure: Different types of Orbit

The orbital periods of MEO satellites range from about two to 12 hours. Some MEO satellites orbit in near perfect circles, and therefore have constant altitude and travel at a constant speed. Other MEO satellites revolve in elongated orbits. The perigee (lowest altitude) of an elliptical-orbit satellite is much less than its apogee (greatest altitude).

The orbital speed is much greater near perigee than near apogee. As seen from a point on the surface, a satellite in an elongated orbit crosses the sky in just a few minutes when it is near perigee, as compared to several hours when it is near apogee. Elliptical-orbit satellites are easiest to access near apogee because the earth-based antenna orientation does not have to be changed often and the satellite is above the horizon for a fairly long time.

#### Geosynchronous Orbit (GSO)

About 35,786 kilometers above the Earth's surface, satellites are in geostationary orbit. This distance puts it in the high Earth orbit category.

A geosynchronous orbit synchronizes with the rotation of the Earth. More specifically, the time it takes for the Earth to rotate on its axis is 23 hours, 56 minutes and 4.09 seconds, which is the same as a satellite takes to complete one geosynchronous orbit. This makes geosynchronous satellites particularly useful for telecommunications and other remote sensing applications.

### Geostationary Orbit (GEO)

Geostationary orbit is a kind of Geosynchronous orbit. This is a circular orbit above the Earth's equator, following the direction of the Earth's rotation. It has an orbital period equal to the Earth's rotational period (one sidereal day), and thus appears motionless, at a fixed position in the sky, to ground observers. Speed at which a satellite orbits the Earth coincides with the speed that the Earth turns and at the same latitude, however, this does not mean that the satellite and the Earth are traveling at the same speed, but rather than the satellite is traveling fast enough so that its orbit matches the Earth's rotation.

When a satellite is in geostationary orbit, its instruments are looking at a certain part of the Earth. That part of the Earth is called a *footprint*. For e.g. India, It is suitable for communication satellites, or meteorological (weather) satellites.

### Semi-Synchronous Orbits

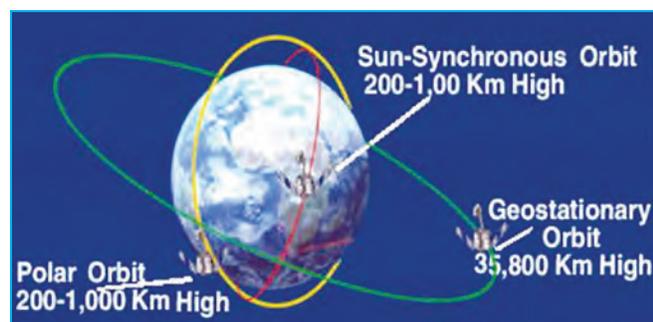
Global Positioning System (GPS) satellites are in another sweet spot known as semi-synchronous orbits. While geosynchronous orbits match the rotation of Earth (24 hours), semi-synchronous orbits take 12 hours to complete an orbit.

Instead of 35,786 kilometers above the Earth's surface, semi-synchronous orbits are approximately 20,200 kilometers above the surface. This puts them in the medium Earth orbit range out of the three classes of orbits. These orbits are close to zero in eccentricity, meaning they are near-circular.

### Polar Orbit

A polar orbit travels north-south over the poles and takes approximately an hour and a half for a full rotation. As the satellite is in orbit, the Earth is rotating beneath it. As a result, a satellite can observe the entire Earth's surface in the time span of 24 hours.

Polar orbits have an inclination of about 90 degrees to the equator. Almost all the satellites that are in a polar orbit are at lower altitudes or in Lower Earth Orbit. They are often used for applications such as remote sensing, monitoring crops, forests and even global security.



### Sun-Synchronous Orbit (SSO)

When a satellite is in a Sun-synchronous orbit, it means that it has a constant Sun illumination through inclination and altitude.

For Sun-synchronous orbits, it passes over any given point on Earth's surface at the same local solar time. Because of the consistent lighting in sun-synchronous orbits, scientists leverage this in various remote sensing applications.

### Transfer Orbit and Geostationary Transfer Orbit (GTO)

A Hohmann Transfer is an orbital maneuver that transfers a satellite or spacecraft from one circular orbit to another. It is the most fuel efficient way to get from one circular orbit to another circular orbit. It is a two-impulse elliptical transfer between two co-planar circular orbits. The transfer itself consists of an elliptical orbit with a perigee at the inner orbit and an apogee at the outer orbit. The fundamental assumption behind the Hohmann transfer, is that there is only one body which exerts a gravitational force on the body of interest, such as a satellite. This is a good model for transferring an earth-based satellite from a low orbit to say a geosynchronous orbit. Inherent in the model is that there is no additional body sharing the orbit which could induce a gravitational attraction on the body of interest.

Geostationary Transfer Orbit (GTO) is a type of **Hoffman transfer orbit**. The Geostationary Transfer Orbit is a highly elliptical orbit with a perigee of 180-200 km above the Earth's surface and an apogee of around 35,900 km.

## 3.3 Satellites

A satellite is any object that orbits a planet or star. Satellite can be both natural and man-made. For example, Earth is a natural satellite of the sun. Likewise, the moon is a natural satellite of Earth. In space Science, the word "satellite" generally refers to a man-made machine that is launched into space and moves around Earth or any other celestial body like Moon or Mars. There are thousands of artificial, or man-made, satellites orbit Earth. Sputnik 1 was the first satellite in space. The Soviet Union launched it in 1957.

### Size of Satellites

The mass based classification of satellites are given below:

- Large satellites: > 1000 kg
- Medium satellites: 500 to 1000 kg
- Small satellites: < 500 kg
  - ◆ Minisatellites: 100 to 500 kg
  - ◆ Microsatellites: 10 to 100 kg
  - ◆ Nanosatellites: 1 to 10 kg
  - ◆ Picosatellites: 100 g – 1 kg
  - ◆ Femtosatellites: 10 g – 100 g
  - ◆ Attosatellites: 1 g – 10 g
  - ◆ Zeptosatellites: 0.1 g – 1 g
- CubeSat sizes:
  - ◆ From ~0.2 kg to ~40 kg
  - ◆ From 0.25U to 27U (1U CubeSat is 10×10×10 cm)

### ISRO NANO SATELLITES

ISRO Nano Satellites (INS) is a versatile system envisioned for future science and experimental payloads. With a capability to carry up to 3 kg of payload and a total satellite mass of 11 kg, it offers immense opportunities for future use.

The INS system is developed as a co-passenger satellite to accompany bigger satellites on PSLV launch vehicle. Its primary objectives include providing a standard satellite bus for launch on demand services and providing opportunity to carry innovative payloads

The primary objectives of INS system are to:

- Design and develop a low cost modular Nano satellite.
- Provide an opportunity for ISRO technology demonstration payloads.
- Provide a standard bus for launch on demand services.
- Provide an opportunity to carry innovative payloads for Universities / R&D laboratories.

### Types of Satellite

Satellites can be classified by their function since they are launched into space to do a specific job.

Generally, there are three different types of satellites i.e. Communications Satellite, Remote Sensing Satellite, and Navigation Satellite.

#### Communication Satellite

Communication satellites are artificial satellites that relay and amplify radio telecommunication signals via a transponder. It creates a communication channel between a source transmitter and a receiver at different locations on Earth. Communications satellites are used for television, telephone, radio, internet, and military applications. Most communications satellites are in geostationary orbit about 35,900 km above the equator, so that the satellite appears stationary at the same point in the sky. Therefore the satellite dish antennas of ground stations can be aimed permanently at one spot.

#### Remote Sensing Satellite / Earth Observatory Satellite

A remote sensing satellite is the one which observes or senses objects or phenomena on Earth. With the help of different payloads like camera, transponders, lasers they acquire information about the Earth and other planets. It is used in numerous fields, including geography, land surveying, Earth science disciplines (for example, hydrology, ecology, meteorology, oceanography, glaciology, geology), military, intelligence, commercial, economic, planning, and humanitarian applications, among others.

#### Navigation Satellite

A navigation satellite is an artificial satellite that, together with other satellites, provide autonomous geo-spatial positioning. It allows electronic receivers to determine their location (longitude, latitude, and altitude/elevation) to high precision using time signals transmitted from satellites. The system can be used for providing position, navigation or tracking something fitted with a receiver (satellite tracking). The group of satellites also calculate the current local time to high precision.

### 3.4 Launch Vehicle Programmes of India

Launchers or Launch Vehicles are used to carry spacecraft to space. India has two operational launchers - Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV). GSLV with indigenous Cryogenic Upper Stage has enabled the launching up to 2 tonne class of communication satellites. The next variant of GSLV is GSLV Mk III, with indigenous high thrust cryogenic engine and stage, having the capability of launching 4 tonne class of communication satellites.

In order to achieve high accuracy in placing satellites into their orbits, a combination of accuracy, efficiency, power and immaculate planning are required.

Vikram Sarabhai Space Centre, located in Thiruvananthapuram, is responsible for the design and development of launch vehicles. Satish Dhawan Space Centre, SHAR, is the *space port of India* and is responsible for integration of launchers.

#### Satellite Launch Vehicle (SLV)

The SLV project was born out of the need for achieving indigenous satellite launch capability for communication, remote-sensing and meteorology. Satellite Launch Vehicle-3 (SLV-3) was the first experimental satellite launch vehicle. It was an all solid, four stage vehicle weighing 17 tonnes with a height of 22m and capable of placing 40 kg class payloads in Low Earth Orbit (LEO). After many successful launches, the SLV project was culminated, paving the way to advanced launch vehicle project such as Augmented Satellite Launch Vehicle (ASLV), Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV).

#### Augmented Satellite Launch Vehicle (ASLV)

The ASLV was made to carry heavier payload than SLV-3. With a lift off weight of 40 ton, the 24m tall ASLV was configured as a five stage, all solid propellant vehicle, with a payload capability of 150 kg into the 400 km LEO. It proved to be a low-cost intermediate vehicle to demonstrate and validate critical technologies like strap-on technology, inertial navigation, bulbous heat shield, vertical integration, closed loop guidance, etc.

#### Polar Satellite Launch Vehicle (PSLV)

Polar Satellite Launch Vehicle is the third generation launch vehicle of India. It is the first Indian launch vehicle to be equipped with liquid stages and the first launcher to gain operational status. It is a 44m tall vehicle, with lift-off mass of 295 ton. It is configured as a four stage, alternate solid and liquid propellant vehicle.

It can take up to 1,750 kg of payload to Sun-Synchronous Polar Orbits of 600 km altitude. 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).



Figure: Profile of Launch Vehicles of ISRO

The PSLV has proven to be a reliable and versatile vehicle for diverse missions. **As of 18 May 2025**, the PSLV had completed 62 launches, with 58 successfully reaching their planned orbits, three outright failures and one partial failure.

The fact that PSLV was used to place Chandrayaan-1 and Mangalyaan to the Moon and the Mars respectively, is a testimony of its versatility and reliability.

**Geosynchronous Satellite Launch Vehicle (GSLV)**

Geosynchronous Satellite Launch Vehicle is the largest launch vehicle developed by India. This fourth generation launch vehicle is a three stage vehicle with indigenously developed Cryogenic Upper Stage (CUS), which is flight proven.

ISRO has renamed the GSLV-Mark III as LVM3 mainly to identify etc of placing satellites into a variety of orbits.

ISRO has designed 3 staged programmes for the development of GSLV, i.e. GSLV-MK I, GSLV- MK II and GSLV- MK III. GSLV MK III is the heaviest and most powerful launch vehicle. It is 43 m tall, with lift off mass of 640 ton.

It has a payload capacity of 4-5 tonnes for Geosynchronous Transfer Orbit (GTO) or about 10 tons to Low Earth Orbit (LEO), which is about twice the capability of the GSLV Mk II. It was used to launch Chandrayaan-2 spacecraft.

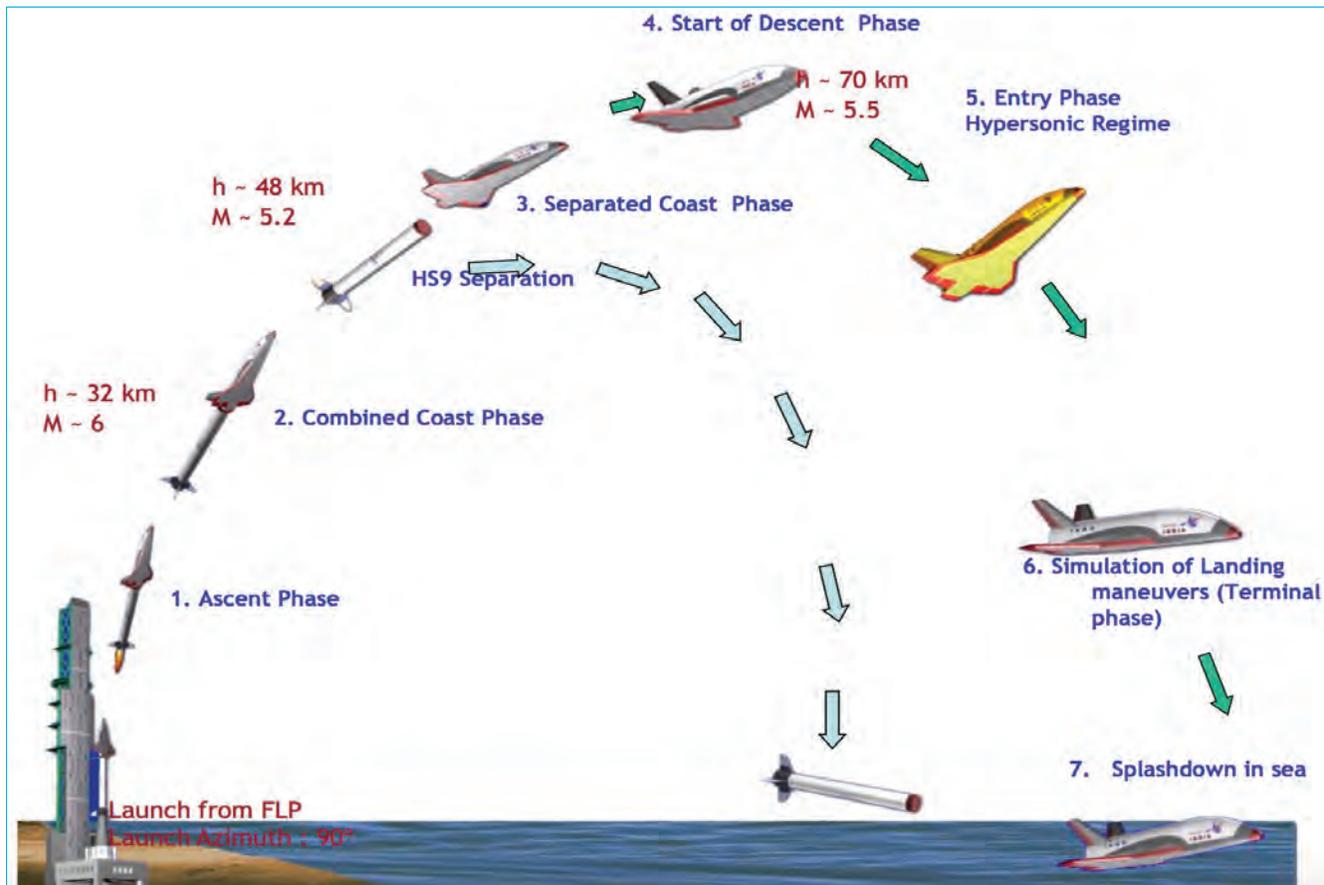
**Reusable Launch Vehicle – Technology Demonstrator (RLV-TD)**

The RLV-TD is a series of technology demonstration missions that have been considered as a first step towards realizing a Two Stage To Orbit (TSTO) fully re-usable vehicle. The Reusable Launch Vehicle is like a winged aircraft that has been configured to act as a flying test bed to evaluate various technologies, namely, hypersonic flight, autonomous landing, powered cruise flight and hypersonic flight using air-breathing propulsion.

This technology is being developed in phases through a series of experimental flights. The first in the series of experimental flights is the Hypersonic Flight Experiment (HEX) followed by the Landing Experiment (LEX), Return Flight Experiment (REX) and Scramjet Propulsion Experiment (SPEX).

**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. The launch of the first sounding rocket from Thumba near Thiruvananthapuram, Kerala on 21 November 1963, marked the beginning of the Indian Space Programme.



### 3.5 Fuels for Launch Vehicle

The propellant used in the Rocket is the chemical mixture burned to produce thrust in rockets and consists of a **fuel and an oxidizer**. Rocket Fuel is a substance that burns when combined with oxidiser for propulsion.

The oxidizer is an agent that releases oxygen for combination with a fuel. The ratio of oxidizer to fuel is called the mixture ratio. There are different types of Fuels for launch vehicles such as:

#### Solid Fuel

Solid propellants are composed of a mixture of granules of solid oxidizer, such as ammonium nitrate, ammonium perchlorate, or potassium nitrate in a polymer binding agent, with flakes or powders of energetic fuel compounds like RDX, aluminium, beryllium. Solid propellant rockets are much easier to store and handle than liquid propellant rockets. In addition, there is minimal sloshing and therefore less turbulence. High propellant density makes for compact size as well. However, Solid fuel rockets have lower specific impulse, a measure of propellant efficiency, than liquid fuel rockets. As a result, the overall performance of solid upper stages is less than liquid stages.

**Specific Impulse:** Specific impulse is a measure of how efficiently a reaction mass engine creates thrust.

#### Advantages

- Can be easily stored and handled in fuelled condition, it is densely packed and Of compact sizer

- Can reach very high speeds quickly
- Simplicity and low cost

#### Disadvantages

- Provides low thrust than liquid fuel.
- No control over combustion. they Start burning cannot be stopped until entire fuel is burnt.

#### Liquid Fuel

Liquid-fuelled rockets have higher specific impulse than solid rockets and are capable of being throttled, shut down, and restarted. However, the combustion chamber of a liquid-fuelled rocket need to withstand high combustion pressures and temperatures.

#### Advantages

- Liquid fuel gives high specific impulse as compare to solid fuel thus provides large thrust
- Propulsion can be controlled restrict ng the fuel flow by using valves and it can also be controlled even under emergency conditions
- Capable of being shut down and restarted (throttle)

#### Disadvantages

- The storage and handling of missile with liquid fuel is difficult and complex
- Preparation of missile takes considerable time
- Requires large storage tanks for fuel thus weighing down the missile

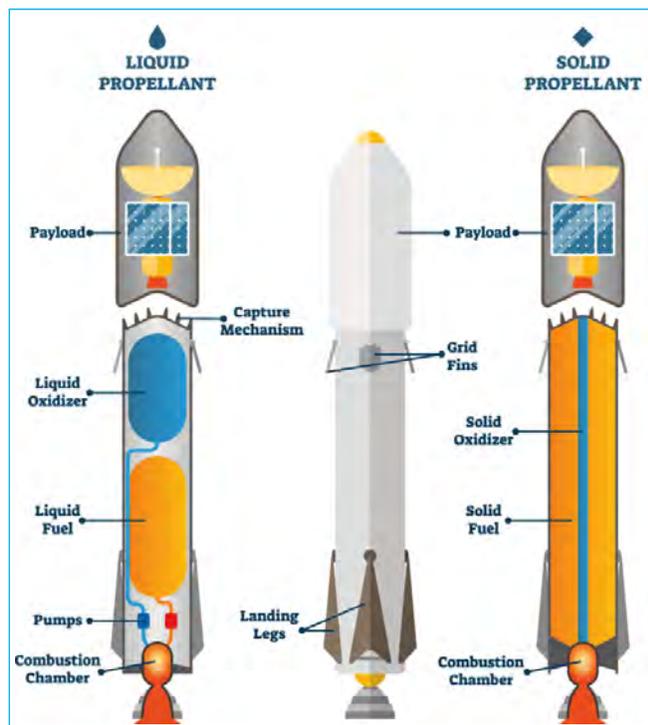


Figure: Mechanism of solid and Liquid propellant usage in rockets

**Hybrid propulsion**

- There are 2 stages in a hybrid propulsion: solid propulsion and liquid propulsion
- This kind of propulsion compensates the disadvantages of both propulsion systems and has the combined advantage of 2 propulsion systems

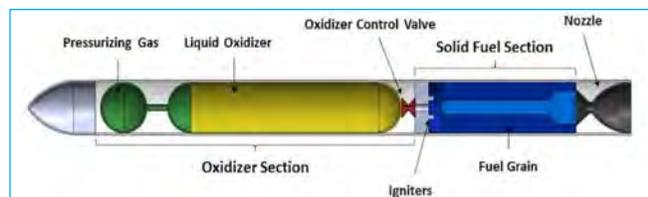


Figure: Hybrid Rocket Engine

**Advantages**

- Throttle or restart possible just like liquid fuel
- Higher specific impulse
- Safe to handle

**Disadvantages**

- Complex to and researched

**Cryogenic Fuel**

Cryogenic fuels are fuels that require storage at extremely low temperatures in order to maintain them in a liquid state. Cryogenic fuels most often constitute liquefied gases such as liquid hydrogen with liquid oxygen (LOX) as an oxidiser. LOX and liquid methane (from Liquefied Natural Gas) as a fuel is also being tested in cryogenic engines.

A cryogenic engine/cryogenic stage is the last stage of space launch vehicles which makes use of cryogenics to store its fuel and oxidiser as liquids instead of gas. In space, there is

a lack of air, including oxygen, which means it is impossible to burn anything. To fix this, rockets carry their own oxygen, known as an oxidiser, mixed with fuel to burn it in space.

- Cryogenic is the study of production and behaviour of material at extremely low temperature
- Cryogenic fuel or oxidiser are gases that are liquefied and stored at very low temperatures (liquefied hydrogen at -253 degrees centigrade and liquid oxygen at -183 degrees centigrade).
- Cryogenic propellants require special insulated containers and vents Which allow gases to escape from the evaporating liquids.
- The liquid fuel and oxidiser are pumped from the storage tanks do an expansion chamber and injected into the combustion chamber where they are mixed and ignited by a flame or spark.
- The fuel expands as it burns and the hot exhaust gases are directed out of the nozzle to provide thrust.
- The combustion of cryogenic fuel provides massive thrust to launch vehicle hence especially used to carry very heavy satellites for space missions.
- Because of their low temperature and need for special insulated container the overall weight is increased thus less desirable in military rockets

**The Indian Space Program and Cryogenic Engines**

ISRO has been spearheading the Indian space program since its inception and has built the capability to launch its satellites. And, ISRO has developed various launch vehicles (rockets) that carry different satellites to different orbits. Satellites revolve around the earth in a fixed path known as orbit. Depending upon the distance from the earth’s surface, there are three types of orbits. The Low Earth Orbit (LEO) is about 160-2000 KM from Earth.

Meanwhile, the Medium Earth Orbit (MEO) is about 5000-10000 KM from Earth. Finally, the Geostationary Earth Orbit (GEO) is about 35800 KM from Earth. In GEO, the satellite’s and the earth’s rotation are the same, so it appears to be in a fixed location from the earth’s surface.

The first few launch vehicles of ISRO, the SLV-3 and the ASLV could only reach the LEO. The PSLV-XL uses solid and liquid fuels instead of only solid fuels like the former two. GSLV Mk II and Mk III use three different kinds of fuels: solid, liquid and cryogenic.

**Semi-Cryogenic Fuel**

Unlike a cryogenic engine, a semi cryogenic engine uses refined kerosene instead of liquid hydrogen. The liquid oxygen is used as an oxidiser. The advantage of using a Semi Cryogenic engine is that it requires Refined Kerosene which is lighter than liquid hydrogen and can be stored in a normal temperature.

A semi-cryogenic engine uses refined kerosene instead of liquid hydrogen. The liquid oxygen is used as an oxidiser. Adding, “The advantage of using a semi-cryogenic engine is that it requires refined kerosene, which is lighter than liquid

fuel and can be stored at a normal temperature. One of the options before ISRO is to replace the liquid core (L110) engine of the GSLV MK III with a semi-cryogenic engine to boost the rocket's payload capacity from four to six tonnes.

ISRO has also developed *ISROSENE*, which is a rocket-grade version of kerosene as an alternative to conventional hydrazine rocket fuel.

### Ion Propulsion

Ion thrusters ionize a neutral gas such as Xenon and create thrust by accelerating the ions (or the plasma) by electric and/or magnetic fields. It is used in auxiliary engines of satellites.

### Green Fuel

Green Fuels are non-hazardous and environment- friendly fuels for rockets and satellites. Space organizations are working to replace its existing hazardous fuel with Green fuels.

ISRO is working on green propulsion through hydrogen peroxide in 'Gaganyaan' mission. ISRO is also developing another green fuel - LOX/Methane- liquid oxygen as oxidiser and methane as fuel.

## 3.6 Engines

Launch Vehicles propelled by rocket engines are commonly called rockets. Rocket engines are reaction engines, producing thrust by ejecting mass rearward, in accordance with Newton's third law.

### ROCKET ENGINES vs JET ENGINES

- Jet engines and rockets work on the same principle they produce thrust through an internal pressure difference and as explained b'/ Newton's 3rd law of motion eject exhaust gases in an equal and opposite direction.
- The main differences are while jets get the oxygen to burn fuel from the air and rockets carry their own oxygen which allows them to operate in space, Jet engines have 2 openings, an intake and exhaust nozzle where as rocket engines only have one opening an exhaust nozzle.



Figure: Rocket and Jet plain

### Need for Jet engines:

- At present the launch vehicles or missiles are usually designed for one time use. Also, their efficiency is low as they are able to carry payloads just 2 to 4% of their lift of Mass.
- Thus, they are expensive and there is a need to reduce launch cost.
- Oxidiser comprises 70% of propellants, Thus, next generation propulsion system must be able to use atmospheric oxygen instead of carrying it. Hence need for air breathing propulsion such as ramjet and scramjet.

ROCKET	JET
It carry both fuel and oxidiser	It carry fuel only and no oxidiser
It does not require atmospheric	It requires atmospheric oxygen
It is NON air breathing	It is air breathing
It works in vacuum and atmosphere	It works only in atmosphere
It uses solid or liquid fuel	It uses liquid fuel
It has simple structure	It has complex structure
It has low efficiency oxygen	It has high efficiency

The main types of jet engines based on how air is compressed in the engine

- **Turbojet:** Turbojet engine is an air breathing jet engine, This is one of the most common type of jet engines. It is still widely used in airplanes.
- **Turbofan engines:** Turbofans differ from the turbo jets in the way they have an additional component - a fan. The fan air and then further compressed and combustion takes place in the burner.
- **DUAL MODE RAMJET(DMRJ):** Type Of jet engine Where a ramjet transforms into scramjet over Mach 4 to 8 range, therefore it can operate both in subsonic and supersonic combustion modes.

### Ramjet Engine

- Ramjet is a form of air breathing jet engine that uses the vehicles high speed (supersonic) forward motion to compress incoming air for combustion (there is no compressor).
- The vehicle carries only the fuel. The fuel injected within the combustion chamber and the incoming compressed hot air is glow down to subsonic speed to mix with fuel and get ignited.
- The expansion of hot gases after fuel injected in combustion accelerates the exhaust air a velocity higher than that at the inlet and creates positive push.
- However, ramjets cannot produce thrust from zero speed or a standstill position. The air entering the engine should be at supersonic speeds.
- Therefore it requires an assisted take off like a rocket to accelerate it to a supersonic speed (Mach 3 to 6), where it begins producing thrust to force air into the inlet.

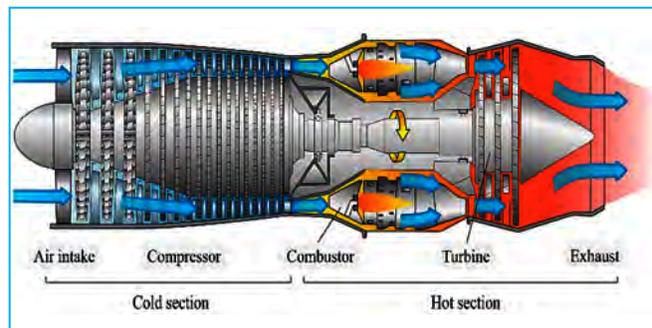


Figure: System of Ramjet engine

Ramjet engine is the most basic type of jet engine available capable of attaining speeds of 3 Mach. Though this engine has no moving parts inside it, there are only three parts:

- Converging Inlet
- Combustion chamber
- A nozzle

At the converging inlet, the air is compressed to a very high ratio and is sent inside. In the combustion chamber, fuel is injected and flame holders burn the fuel-air mixture. Thus combusted mixture has high enthalpy, due to which they flow rapidly towards nozzle.

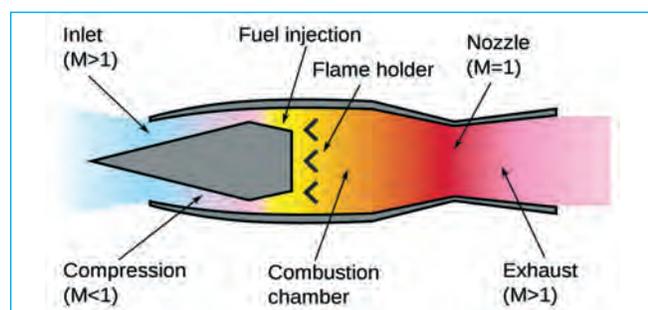


Figure: Working Mechanism of Ramjet engine

After they enter the nozzle, with decrease in pressure the jet velocity will increase to a great extent, majority of thrust is obtained from here.

These have increasing efficiency with increase in their speeds, because higher velocity means higher compression ratio at the inlet. So these are super-efficient at supersonic speeds.

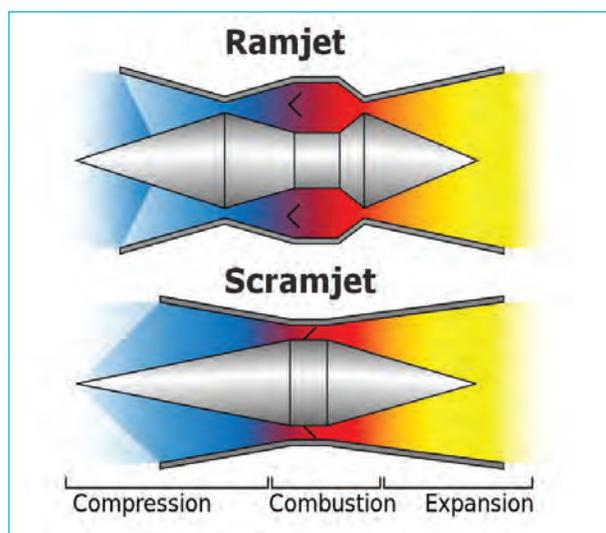
### Solid Fuel Ducted Ramjet Technology

- DRDO had successfully tested 'Solid Fuel Ducted Ramjet (SFDR)' propulsion-based missile system from ITR, Chandipur, Odisha last year.
- The success of SFDR propulsion technology will pave the way for the development Of long-range air-to-air missiles in the country
- The ramjet propulsion system used in the SFDR acts as an oxidiser and the solid propellant reacts as air flows through a solid propellant duct
- Unlike conventional rockets that carry propellant and oxidiser, Ramjet uses the air as an oxidiser just like a jet engine. Therefore, the weight of the fuel required is eliminated.
- SFDR propulsion is designed in such a way that it allows for an up and down throttling. This further lets the missile to amplify its speed until it reaches the terminal phase of the flight.
- The speed increases until the point when sharp turns are required to search for highly manoeuvring targets.
- The first flight of SFDR, developed under a joint Indo-Russian project, was tested in 2018. it had achieved the speed of Mach 3
- The Indian SFDR will be used as variants of missiles such as the advanced version of ASTRA

### Scramjet Engine (supersonic combustion ramjet)

Ramjets work most efficiently at supersonic speeds around Mach 3 (three times the speed of sound) and can operate up to speeds of Mach 6. However, the ramjet efficiency starts to drop when the vehicle reaches hypersonic speeds.

A scramjet engine is an improvement over the ramjet engine as it efficiently operates at hypersonic speeds and allows supersonic combustion. Thus it is known as *Supersonic Combustion Ramjet*, or Scramjet.



- The difference between scramjet and ramjet is that, in scramjet combustion takes place at supersonic air velocities throughout the engine (incoming air is not slow down to subsonic speeds).
- At very high speed (hypersonic), if the air is slow down to subsonic, it would produce unmanageable heat and pressure. Thus, at higher speed there is a need to keep combustion at supersonic speed.
- Theoretical speed of scramjet is Mach 12 to 24

The Scramjet engine designed by ISRO uses *Hydrogen as fuel* and the *Oxygen from the atmospheric air as the oxidiser*. ISRO conducted 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 this recent test of Scramjet engines at supersonic conditions.

**DHAWAN-1**

Skyroot Aerospace, a space technology startup based in Hyderabad, has successfully test-fired Dhawan-1, India's first privately developed fully cryogenic rocket engine. This will power the upper stages of its upcoming Vikram-2 orbital launch vehicle. The rocket engine Dhawan-1 is named after Satish Dhawan, an Indian rocket scientist.

It became the country's first privately (Made-in-India) developed fully cryogenic rocket engine running on two high-performance rocket propellants — liquid natural gas (LNG) and liquid oxygen (LoX). The indigenous engine was developed using 3D printing with a superalloy.

### High thrust Cryogenic Engine

The CE-20 is a cryogenic rocket engine developed by the *Liquid Propulsion Systems Centre* (ISRO subsidiary). It has been developed to power the upper stage of the Geosynchronous Satellite Launch Vehicle Mk III. The engine intakes liquid hydrogen as fuel and liquid oxygen as an oxidizer. The high thrust cryogenic engine is one of the most powerful upper stage cryogenic engines in the world.

### Semi Cryogenic Engine (SCE-200)

The SCE-200 is an indigenously-developed liquid-fuel engine that runs on liquid oxygen (LOX) propellant and highly-refined kerosene, called RP-1 in a combustion chamber. It is developed by the Liquid Propulsion Systems Centre. The new engine will be tested on a GSLV-Mk III. It will help to increase rocket's payload carrying capacity.

## 3.7 Space Research in India

### Indian Space Research Organization (ISRO)

#### History

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.

With the live transmission of Tokyo Olympic Games across the Pacific by the American Satellite 'Syncom-3' demonstrating the power of communication satellites, *Dr. Vikram Sarabhai, the founding father of Indian space programme*, quickly recognized the benefits of space technologies for India.

Since inception, the Indian space programme has been orchestrated well and had three distinct elements: satellites for communication and remote sensing; the space transportation system; and application programmes.

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.

During the 1970s, the *first Indian spacecraft 'Aryabhata'* was developed and was launched using a Soviet Launcher. 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. 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 landmark in our space programme.

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 future communication satellite system.* 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 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 (IRSS)* 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.

#### Mandates of ISRO

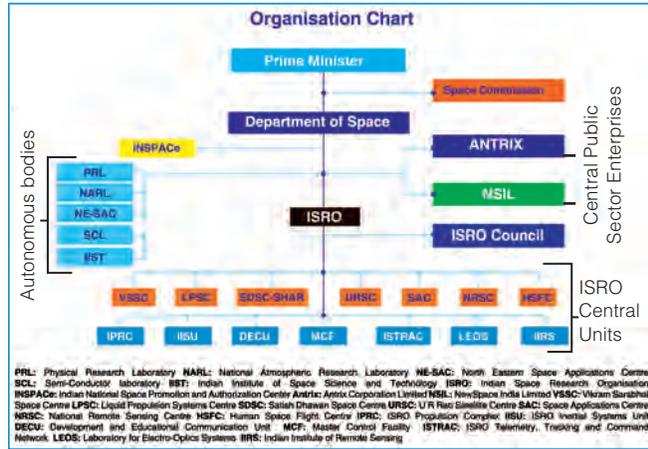
- Design and development of launch vehicles and related technologies for providing access to space.
- Design and development of satellites and related technologies for earth observation, communication, navigation, meteorology and space science.
- Indian National Satellite (INSAT) programme for meeting telecommunication, television broadcasting and developmental applications.
- Indian Remote Sensing Satellite (IRS) programme for management of natural resources and monitoring of environment using space based imagery.
- Space based Applications for Societal development.
- Research and Development in space science and planetary exploration.

#### Objectives of ISRO

- Operational flights of Polar Satellite Launch Vehicle (PSLV).
- Developmental flight of Geo-synchronous Satellite Launch Vehicle (GSLV- Mk II).
- Development of heavy lift Geo-synchronous Satellite Launch Vehicle (GSLV-Mk III).
- Design, Development and Realization of Communication Satellites and Earth Observation Satellites.
- Development of Navigation Satellite Systems.
- Development of satellites for Space Science and Planetary Exploration.
- Earth Observation Applications.
- Space based systems for Societal Applications.
- Advanced Technologies and newer initiatives.
- Training, Capacity building and Education.
- Promotion of Space technology.
- Infrastructure/Facility Development for space research.
- International Cooperation.

**Organisational Structure of ISRO**

The organisational structure of ISRO is given below:



**ISRO Centres**

**Vikram Sarabhai Space Centre (VSSC)**

Vikram Sarabhai Space Centre is the lead Centre of Indian Space Research Organisation (ISRO). It is located in Thiruvananthapuram under the Department of Space (DoS), Government of India. The Centre is named in fond memory of *Dr. Vikram A Sarabhai*, the great visionary and *the father of Indian Space Programme*. VSSC pioneers in rocket research and launch vehicle projects of ISRO. The Centre also pursues research and development activities in associated areas like propellants, solid propulsion technology, aerodynamics, aero structural and aero thermal fields, avionics, polymers and composites, guidance, control & simulation, computer and information, mechanical engineering, aerospace mechanisms, vehicle integration and testing, space ordnance, chemicals and materials.

Systems reliability and quality assurance of all aspects of engineering and operations are studied and evaluated to the levels of perfection required in each field. Programme planning and evaluation, technology transfer and industrial coordination, indigenisation, human resources development, safety and personnel and general administration groups support the Centre for all its activities.

**Satish Dhawan Space Centre (SDSC)**

Satish Dhawan Space Centre SHAR, Sriharikota, the *Spaceport of India*, is responsible for providing Launch Base Infrastructure for the Indian Space Programme. This Centre has the facilities for solid propellant processing, static testing of solid motors, launch vehicle integration and launch operations, range operations comprising telemetry, tracking and command network and mission control centre.

The Centre has *two launch pads* from where the rocket launching operations of PSLV and GSLV are carried out.

The mandate for the centre is to :

- Produce solid propellant boosters for the launch vehicle programmes of ISRO.
- Provide the infrastructure for qualifying various subsystems and solid rocket motors and carrying out the necessary tests.

- Provide launch base infrastructure for satellites and launch vehicles.

**Space Application Centre (SAC)**

Space Applications Centre is one of the major centres of the Indian Space Research Organisation (ISRO). It is located in Ahmedabad. SAC focuses on the design of space-borne instruments for ISRO missions and development and operationalisation of applications of space technology for societal benefits. The applications cover communication, broadcasting, navigation, disaster monitoring, meteorology, oceanography, environment monitoring and natural resources survey.

**ISRO Satellite Centre**

ISRO Satellite Centre is the lead centre of the ISRO responsible for design, development, assembly & integration of communication, navigation, remote sensing, scientific and small satellite missions.

The specialised teams of scientists, engineers and technicians of ISAC have built more than 90 complex & advanced satellites for various applications in areas of telecommunications, television broadcasting, VSAT services, tele-medicine, tele-education, navigation, weather forecasting, disaster warning, search and rescue operations, earth observations, natural resource management, scientific and space science etc.

**Antrix Corporation Limited (ACL)**

Antrix Corporation Limited, is a wholly owned Government of India Company under the administrative control of the Department of Space. It is located in Bengaluru. Antrix Corporation Limited was incorporated as a private limited company owned by Government of India in September 1992 as a Marketing arm of ISRO for promotion and commercial exploitation of space products, technical consultancy services and transfer of technologies developed by ISRO. Another major objective is to facilitate development of space related industrial capabilities in India.

As the commercial and marketing arm of ISRO, Antrix is engaged in providing Space products and services to international customers worldwide. With fully equipped state-of-the-art facilities, Antrix provides end-to-end solution for many of the space products, ranging from supply of hardware and software including simple subsystems to a complex spacecraft, for varied applications covering communications, earth observation and scientific missions; space related services including remote sensing data service, Transponder lease service; Launch services through the operational launch vehicles (PSLV and GSLV); Mission support services; and a host of consultancy and training services.

**NewSpace India Limited (NSIL)**

NewSpace India Limited, incorporated on 6 March 2019 (under the Companies Act, 2013) is a wholly owned Government of India company, under the administrative control of Department of Space (DOS). It is located in Bengaluru.

NSIL is the commercial arm of Indian Space Research Organisation (ISRO) with the primary responsibility of enabling Indian industries to take up high technology space related activities and is also responsible for promotion and commercial exploitation of the products and services emanating from the Indian space programme. To satisfy the needs of its customers, NSIL draws upon the proven heritage of the Indian Space Program and ISRO's vast experience in diverse branches of Space Technology.

**The major business areas of NSIL include:**

- Production of Polar Satellite Launch Vehicle (PSLV) and Small Satellite Launch Vehicle (SSLV) through industry.
- Production and marketing of space-based services, including launch services and space-based applications like transponder leasing, remote sensing and mission support services.
- Marketing spin off technologies and products/ services emanating out of ISRO activities.
- Transfer of technology developed by ISRO centres/ units and constituent institutions of Dept. of Space.
- Building of Satellites (both Communication and Earth Observation) as per user requirements.
- Consultancy services.

**Autonomous Bodies**

**India Deep Space Network**

The Indian Deep Space Network consists of a 18-m and a 32-m antennae that are established at the IDSN campus, Byalalu, Bangalore. The Network is augmented with a couple of stations in the western hemisphere in addition to the 64-m antenna in Bearslake, Russia to improve the visibility duration and to provide support from the antipodal point.

**Physical Research Laboratory (PRL)**

The Physical Research Laboratory, Ahmedabad is an autonomous unit of DoS and a premier research institute engaged in basic research in the areas of Astronomy and Astrophysics, Solar Physics, Planetary Science and Exploration, Space and Atmospheric Sciences, Geosciences, Theoretical Physics, Atomic, Molecular and Optical Physics and Astro-chemistry.

PRL is actively participating in planetary exploration programme and significant progress has been made in the areas of planetary sciences and exploration. Studies of stellar and solar astronomy are conducted from the Infra-red Observatory at Mt. Abu, and a lake site Solar Observatory in Udaipur, respectively. Another campus at Thaltej, Ahmedabad, hosts the planetary exploration (PLANEX) programme. It is Known as the cradle of Space Sciences in India, the Physical Research Laboratory (PRL) was founded in 1947 by Dr. Vikram Sarabhai.

**Semi-Conductor Lab (SCL)**

It is an autonomous body under Department of Space, Government of India. It is engaged in Research &

Development in the area of Microelectronics to meet the strategic needs of the country. SCL is located at *Mohali*.

**National Atmospheric Research Laboratory (NARL)**

NARL is an autonomous research laboratory fully funded by the Department of Space, Government of India and involved in carrying out fundamental and applied research in Atmospheric and Space Sciences. It is located in Tirupati (Andhra Pradesh). A Scientific Advisory Committee consisting of eminent scientists in the field of atmospheric science, monitors the research activities and progress of NARL and provides future directions.

NARL has now become one of the prime centers for atmospheric research in the country and operates a state-of-the-art MST radar, Rayleigh/ Mie Lidar, Boundary Layer Lidar, Sodium Lidar, Lower Atmospheric Wind Profiler, Sodar, Disdrometer, Optical Rain Gauge, Dual frequency GPS receiver, Automatic Weather Station apart from regular launching of the GPS balloon sonde. It is located at *Gadanki near Tirupati*,

**North Eastern Space Applications Centre**

Realising the need of special attention in terms of technological support in managing rich natural resources and improving the poor infrastructure and communication linkages, North Eastern Space Applications Centre (NESAC) was established as a joint initiative of Department of Space (DOS) and the North Eastern Council (NEC) and came into being on 5th of September, 2000. It is located at Shillong, Meghalaya.

**Indian National Space Promotion and Authorization Center (IN-SPACe)**

IN-SPACe is an independent nodal agency under Department of Space for allowing space activities and usage of DOS owned facilities by Non- Government Private Entities(NGPEs) as well as to prioritise the launch manifest. It is located in Ahmedabad, Gujarat.

IN-SPACe is to be established as a single window nodal agency, with its own cadre, which will permit and oversee the following activities of NGPEs:

- Space activities including building of launch vehicles and satellites and providing space based services as per the definition of space activities.
- Sharing of space infrastructure and premises under the control of ISRO with due considerations to on-going activities.
- Establishment of temporary facilities within premises under ISRO control based on safety norms and feasibility assessment
- Establishment of new space infrastructure and facilities, by NGPEs, in pursuance of space activities based on safety norms and other statutory guidelines and necessary clearances.
- Initiation of launch campaign and launch, based on readiness of launch vehicle and spacecraft systems, ground and user segment.

- Building, operation and control of spacecraft for registration as Indian Satellite by NGPEs and all the associated infrastructure for the same.
- Usage of spacecraft data and rolling out of space based services and all the associated infrastructure for the same.

<b>MILESTONES IN INDIAN SPACE PROGRAMME</b>	
<b>1969</b>	Indian Space Research Organization (ISRO) formed (August 15, 1969).
<b>1975</b>	ISRO becomes Government Organization (April 1, 1975). First Indian Satellite, Aryabhata, launched (April 19, 1975). It was launched by u-11 Interkosmos vehicle.
<b>1979</b>	Bhaskara-I, an experimental satellite for earth observations, launched (June 7, 1979). First Experimental launch of SLV-3 with Rohini Technology Payload on board (August 10, 1979). Satellite could not be placed in orbit.
<b>1982</b>	INSAT-1A launched (April 10, 1982). Deactivated on September 6, 1982.
<b>1988</b>	Launch of first operational Indian Remote Sensing Satellite, IRS-1 A (March 17, 1988). Second developmental launch of ASLV with SROSS-2 on board (July 13, 1988). Satellite could not be placed in orbit. INSAT-1 C launched (July 22, 1988). Abandoned in November 1989.
<b>1990</b>	INSAT-1 D launched (June 12, 1990). Identical to INSAT-1A. Still in service. A third stage motor landed from its launch, landed in Australia in 2008. It was launched by Delta 4925 vehicle.
<b>1999</b>	INSAT-2E, the last satellite in the multipurpose INSAT-2 series, launched by Ariane from Kourou Island, French Guiana (April 3, 1999). Indian Remote Sensing Satellite, IRS-P4 (OCEANSAT-1), launched by Polar Satellite Launch Vehicle (PSLV-C2) along with Korean KITSAT-3 and German DLR- TUBSAT from Sriharikota (May 26, 1999).
<b>2001</b>	Successful flight test of Geosynchronous Satellite Launch Vehicle (GSLV) (April 18, 2001) with an experimental satellite GSAT-1 on board. Successful launch of PSLV-C3 (October 22, 2001) placing three satellites - India's TES, Belgian PROBA and German BIRD, into Polar sun-synchronous orbit.
<b>2008</b>	PSLV-C10 successfully launches TECSAR satellite under a commercial contract with Antrix Corporation (January 21, 2008). PSLV-C9 successfully launches CARTOSAT-2A, IMS-1 and foreign nano satellites from Sriharikota (April 28, 2008). PSLV-C11 successfully launches CHANDRAYAAN-1 from Sriharikota (October 22, 2008).
<b>2010</b>	GSLV-D3 launched from Sriharikota (Apr 15, 2010). GSAT-4 satellite could not be placed in orbit as flight testing of the Indigenous Cryogenic Stage in GSLV-D3 Mission was not successful.
<b>2011</b>	Megha-Tropiques, Indo-French Joint Satellite Mission for studying the water cycle and energy exchanges in the tropics.
<b>2012</b>	RISAT-1, first indigenous all-weather Radar Imaging Satellite (RISAT-1), whose images will facilitate agriculture and disaster management weighs about 1858 kg.
<b>2013</b>	The Satellite with ARGOS and ALTIKA (SARAL) is a joint Indo-French satellite mission for oceanographic studies.
	IRNSS-1A Launched by PSLV-C22. It is a satellite in the Indian Regional Navigation Satellite System (IRNSS). It is one of the seven spacecraft constituting the IRNSS space segment.
	The Mars Orbiter Mission (MOM), informally called Mangalyaan is India's first Mars orbiter. Launched by PSLV-C25.
<b>2014</b>	Crew module Atmospheric Re-entry Experiment (CARE) on GSLV MK-III-X.
<b>28 September 2015</b>	ASTROSAT is India's first dedicated multi wavelength space Observatory. It's Launched by PSLV-C30.
<b>22 December 2016</b>	RESOURCESAT-2A, a remote sensing satellite to provide remote sensing data to global users.
<b>15 February 2017</b>	Scripted history by successfully launching a record 104 satellites, including India's earth observation satellite of Cartosat-2 series.
<b>29 November 2018</b>	India's Hyper spectral Imaging Satellite (HysIS) on PSLV-C43. HysIS is to study the earth's surface in the visible, near infrared and shortwave infrared regions of the electromagnetic spectrum.
<b>5 December 2018</b>	GSAT-11, Heaviest spacecraft of India was launched.
<b>24 January 2019</b>	KalamSAT-V2, World's lightest satellite of the time.
<b>1 April 2019</b>	Military satellite EMISAT was launched. This facilitates Electromagnetic intelligence to track any enemy radars for the IAF.

MILESTONES IN INDIAN SPACE PROGRAMME	
22 July 2019	Chandrayaan-2, India's second lunar exploration mission was Launched by GSLV-MkIII M1.
17 December 2020	India's communication satellite CMS-01 was launched on PSLV-C50.
28 February 2021	PSLV-C51, the first dedicated launch for NSIL launched Amazonia-1(optical earth observation satellite Amazonia-1 of Brazil) and 18 Co-passenger satellites including Indian student satellites UNITYsat and Satish Dhawan SAT (SDSAT).
14 February 2022	Student satellite INSPIREsat-1 from Indian Institute of Space Science & Technology (IIST) and Earth Observation Satellite EOS-04 launched on PSLV-C52.
23 Jun 2022	NSIL's 1st Demand Driven Satellite Mission Post Space Sector Reforms: GSAT-24 Communication satellite Successfully launched on-board Ariane-V [ VA 257 flight] from Kourou, French Guiana. NewSpace India Limited (NSIL), a Govt. of India company under Department of Space (DoS) is undertaking GSAT-24 satellite mission as its 1st Demand Driven mission post space reforms. GSAT-24 is a 24-Ku band communication satellite weighing 4180 kg with Pan India coverage for meeting DTH application needs. NSIL has leased the entire satellite capacity to M/s Tata Play.
26 November 2022	PSLV-C54/EOS-06 Mission is accomplished. All the satellites have been in-jected into their intended orbits.
02 September 2023	The Launch of Aditya-L1 by PSLV-C57 accomplished successfully. Aditya L1 shall be the first space based Indian mission to study the Sun. The spacecraft shall be placed in a halo orbit around the Lagrange point 1 (L1) of the Sun-Earth system, which is about 1.5 million km from the Earth.
2 September 2023	The Launch of Aditya-L1 by PSLV-C57 accomplished successfully.
23 August 2023	Chandrayaan-3 mission successfully soft-landed on Moon and Chandrayaan-3 Rover ramped down from the lander. Chandrayaan-3 consists of an indigenous Lander module (LM), Propulsion module (PM) and a Rover with an objective of developing and demonstrating new technologies required for Inter planetary missions. The Lander will have the capability to soft land at a specified lunar site and deploy the Rover which will carry out in-situ chemical analysis of the lunar surface during the course of its mobility.
14 July 2023	LVM3 M4 vehicle successfully launched Chandrayaan-3 into orbit.
29 May 2023	<ul style="list-style-type: none"> <li>GSLV-F12/NVS-01 mission accomplished. The main aim is emonstration of designed Payload capability of SSLV in LEO</li> <li>Injection of EOS-07 satellite and two passenger satellites Janus-1 &amp; AzaadiSAT-2 into 450 km circular orbit.</li> </ul>
10 February 2023	SSLV-D2/EOS-07 Mission is successfully accomplished.
26 November 2023	PSLV-C54/EOS-06 Mission is accomplished. All the satellites have been injected into their intended orbits.
23 June 2023	NSIL's 1st Demand Driven Satellite Mission Post Space Sector Reforms: GSAT-24 Communication satellite Successfully launched on-board Ariane-V [ VA 257 flight] from Kourou, French Guiana. NewSpace India Limited (NSIL), a Govt. of India company under Department of Space (DoS) is undertaking GSAT-24 satellite mission as its 1st Demand Driven mission post space reforms. GSAT-24 is a 24-Ku band communication satellite weighing 4180 kg with Pan India coverage for meeting DTH application needs. NSIL has leased the entire satellite capacity to M/s Tata Play.
30 December 2024	PSLV C60/SPADEX Mission : SpaDeX Deployed! Successful separation of SpaDeX satellites marks another milestone in India's space journey.
19 November 2024	GSAT-N2 (GSAT-20) Satellite was successfully launched November 19, 2024, aboard a Falcon-9 rocket, Florida, USA
16 August 2024	The third developmental flight of SSLV is successfull. The SSLV-D3 placed EOS-08 precisely into the orbit.
17 February 2024	GSLV-F14/INSAT-3DS Mission: The vehicle has successfully placed the satellite into the intended geosynchronous transfer orbit.
6 January 2024	Halo-Orbit Insertion of Aditya-L1 Successfully Accomplished.
1 January 2024	XPoSat satellite is launched successfully
30 July 2025	GSLV-F16/NISAR Mission: GSLV-F16 delivered NISAR to orbit
29 January 2025	The GSLV-F15/NVS-02 mission has been successfully accomplished. India reaches new heights in space navigation.