Orbit and Kepler's Laws of Planetary Motion

Orbit

- **Definition**: An orbit is a regular, repeating path that one object in space takes around another object.
- **Types of Satellites**:
  - **Natural Satellites**: These include celestial bodies like moons. For example, the Moon orbits Earth.
  - **Man-Made Satellites**: These include space stations, satellites for communication, and observation like the International Space Station.
- **Solar System**: Objects in the solar system, such as planets, comets, and asteroids, orbit the Sun.
- **Ecliptic Plane**: Most objects orbit the Sun along or close to an imaginary flat surface called the ecliptic plane.

Kepler's Laws of Planetary Motion

Kepler's laws describe the motion of planets around the Sun and are applicable to objects in space generally.

1. **Kepler's First Law**:
   - **Statement**: "All planets revolve around the Sun in elliptical orbits, with the Sun at one of the foci."
   - **Ellipse Characteristics**:

- **Perihelion**: The point where the planet is closest to the Sun (approximately 147 million kilometers from the Sun).
- **Aphelion**: The point where the planet is farthest from the Sun (approximately 152 million kilometers from the Sun).
- **Elliptical Path**: The sum of the distances from any point on the ellipse to the two foci is constant.

2. **Kepler's Second Law**:
   - **Also Known As**: The Law of Equal Areas.
   - **Statement**: "A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time."
   - **Implications**:
     - **Variable Speed**: Planets move faster when closer to the Sun (perihelion) and slower when farther (aphelion).
     - **Areal Velocity**: The rate at which the area is swept out by the line segment connecting the planet and the Sun remains constant.
   - **Application**: Used to study the angular speeds and acceleration of planets along their orbits.

3. **Kepler's Third Law**:
   - **Statement**: "The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit."
   - **Formulation**:
     - **Orbital Period**: The time it takes for a planet to complete one orbit around the Sun.
     - **Semi-Major Axis**: The average distance of the planet from the Sun.
   - **Implications**: Planets farther from the Sun have longer orbital periods.

Perigee and Apogee

- **Perigee**:
  - **Definition**: The point in an orbit where a satellite is closest to Earth.
  - **Characteristics**: The satellite moves fastest at this point due to stronger gravitational pull.
- **Apogee**:
  - **Definition**: The point in an orbit where a satellite is farthest from Earth.

- **Characteristics**: The satellite moves slowest at this point due to weaker gravitational pull.

Satellite Motion

Satellites orbit Earth due to a balance between two key forces:

1. **Gravitational Force**:
    - **Direction**: Pulls the satellite towards Earth.
    - **Strength**: Depends on the mass of Earth and the distance of the satellite from Earth.
2. **Centrifugal Force**:
    - **Direction**: Acts outward, countering the gravitational pull.
    - **Cause**: Results from the satellite's orbital motion.

Why Satellites Revolve

- **Balance of Forces**: Satellites revolve to maintain a balance between gravitational pull and centrifugal force.
    - **Falling Back to Earth**: If the satellite's orbital velocity decreases, the centrifugal force becomes less than the gravitational pull, causing the satellite to spiral back towards Earth.
    - **Staying in Orbit**: If the satellite's orbital velocity is adjusted so that the centrifugal force equals the gravitational pull, the satellite remains in a stable orbit.

- **Escaping Earth's Influence**: If the satellite's orbital velocity increases beyond the required speed, the centrifugal force exceeds the gravitational pull, and the satellite can escape Earth's gravitational influence.

Shape of an Orbit

- **Elliptical Orbits**:
  - **Nature**: Most orbits, including Earth's around the Sun, are elliptical rather than perfectly circular.
  - **Kepler's First Law**: States that planets move in elliptical orbits with the Sun at one of the foci.
  - **Earth's Orbit**: Although it appears nearly circular, it is technically elliptical. The Earth's closest point to the Sun is about 147 million kilometers (perihelion), and its farthest point is about 152 million kilometers (aphelion). The difference is about 4%, making the orbit slightly elliptical.

Low Earth Orbit (LEO)

- **Altitude**:
  - **Range**: Typically 160 to 1,000 kilometers above Earth's surface.
  - **Comparison**: Much higher than commercial airplanes (which fly around 14 kilometers).

- **Orbital Characteristics**:
  - **Plane Tilt**: LEO satellites can have tilted orbital planes, offering more routing options compared to Geostationary Orbits (GEO), which are fixed above the equator.
  - **Orbital Period**: Satellites in LEO complete multiple orbits around Earth in a 24-hour period. For example, the International Space Station (ISS) orbits Earth every 90 minutes.
- **Speed**:
  - **Required Speed**: At 200 kilometers altitude, the orbital velocity is approximately 27,400 kilometers per hour. The ISS, at 466 kilometers, orbits every 90 minutes, necessitating a similar high speed.

Advantages of LEO

- **Frequent Visits**: Ideal for missions requiring frequent access, such as the ISS, Hubble Space Telescope, and some observation satellites.
- **Flexibility**: Allows for easier maintenance, instrument updates, and shorter return times to Earth.

Disadvantages of LEO

- **Atmospheric Drag**: Leads to increased fuel consumption and frequent adjustments to maintain orbit.

- **Coverage**: Satellites in LEO do not cover any one part of Earth for long, making them less suitable for continuous communication and weather forecasting.

Issues of Space Debris

- **Congestion**: The increasing number of launches is creating more space debris in LEO.
- **Risks**: Collisions at high velocities can be dangerous, potentially causing further debris and contributing to the Kessler Syndrome—a cascade effect where debris generates more debris.

Initiatives to Tackle Space Debris

1. **International Efforts**:
   - **Inter-Agency Space Debris Coordination Committee (IADC)**: Coordinates international efforts to manage space debris.
   - **North American Aerospace Defense Command (NORAD)**: Monitors space debris.
2. **Specific Missions**:
   - **ClearSpace-1 (2026)**: A mission aimed at removing space debris.
   - **ELSA-d**: ESA's mission focused on debris removal.

- **NEO-01**: A Chinese mission targeting space debris.
- **Terminator Tape**: A project by Tethers Unlimited to address debris.

3. **ISRO Initiatives**:

    - **Project NETRA**: ISRO's program to track space debris.
    - **IS 4 OM**: The System for Safe and Sustainable Operations Management established in 2022.
    - **Collision Avoidance**: ISRO performed 21 maneuvers in 2022 to avoid collisions.
    - **Centre for Space Debris Research**: A facility set up to monitor and mitigate space debris threats.

WEF Guidelines for Space Missions

The World Economic Forum (WEF) provides non-binding guidelines to promote sustainable space practices. These guidelines include:

1. **Post-Mission Disposal (PMD)**:

    - **Objective**: Spacecraft operators should aim to remove satellites from low-Earth orbit (LEO) within 5 years after the mission ends.
    - **Contingency**: If a satellite cannot be controlled and de-orbited, measures should be taken to ensure it does not contribute to space debris.

2. **Collision Avoidance Systems**:
   - **Requirement**: Satellites orbiting above 375 kilometers should have systems to actively manage their orbits.
   - **Technology**: While propulsion-based systems are encouraged, other technologies may be used as appropriate.
3. **Data Sharing and Traffic Management**:
   - **Coordination**: Satellite operators should coordinate with each other and relevant entities to share space situational awareness and operational information.

4. **Financial Measures**:
   - **Insurance**: Liability insurance organizations are encouraged to offer incentives for sustainable missions and implement appropriate safety measures.
5. **Environmental Capacity**:
   - **Research**: The industry is urged to study the objects in orbit, their population, evolution, and interactions.
6. **Long-Term Goals**:
   - **Future Requirements**: Governments should mandate by 2030 that all space missions include capabilities for satellite removal from orbit within 5 years post-mission.

Low Earth Orbit (LEO) Types

1. **Polar Orbits**:
   - **Path**: Satellites in polar orbits travel from pole to pole, perpendicular to the equatorial plane.
   - **Usage**: Ideal for surface mapping and observation due to the ability to cover the entire Earth's surface as the planet rotates below.
   - **Applications**: Often used for Earth observation satellites and mapping services like Google Earth.
2. **Sun-Synchronous Orbits**:
   - **Path**: A type of near-polar orbit where the satellite passes over a specific point on Earth's surface at the same local solar time each day.
   - **Constant Illumination**: Ensures consistent lighting conditions for images, making it easier to observe and compare changes over time.
   - **Applications**: Utilized for remote sensing, imaging, and surveillance due to consistent lighting, which benefits applications like environmental monitoring and agricultural assessments.

Medium Earth Orbits (MEO: 1,000-35,786 km)

- **Characteristics**:
  - MEO covers a range of altitudes between Low Earth Orbit (LEO) and Geostationary Orbit (GEO).
  - Satellites in MEO do not follow specific paths around Earth and can be positioned in various orbital planes.
- **Applications**:
  - **Navigation Satellites**: MEO is frequently used for navigation systems such as GPS (Global Positioning System) and the European Galileo system. These satellites provide positioning, navigation, and timing information to users around the globe.

High Earth Orbits

Geosynchronous Orbits (GSO)

- **Characteristics**:
  - A geosynchronous orbit allows satellites to match Earth's rotation.
  - Located approximately 35,786 km above the equator.
  - Satellites in GSO orbit at the same speed as Earth's rotation, making them appear to stay in a fixed position over a single longitude, though they may drift slightly north or south.

- **Benefits**:
  - **Constant Coverage**: The satellite can observe the same region almost continuously, which is useful for monitoring changes over time.
  - **Military and Surveillance**: Provides constant surveillance of a particular region, beneficial for military and strategic purposes.
  - **Communications**: Ensures reliable communications with a fixed ground location, advantageous for telecommunications and broadcasting.

- **Drawbacks**:
  - **Limited Coverage**: The satellite can only cover a specific area, which means it cannot quickly shift focus to other regions without moving to a different orbit.
  - **Orbital Congestion**: Limited number of positions available can lead to congestion and signal interference.

Geostationary Orbit (GEO) or Geosynchronous Equatorial Orbit

- **Characteristics**:
  - A special type of geosynchronous orbit that is perfectly circular and directly above the equator, matching Earth's rotation precisely.

- The satellite remains fixed over the same spot on Earth's surface, giving it a geostationary characteristic.

- **Applications**:
  - **Weather Monitoring**: Satellites like GOES (Geostationary Operational Environmental Satellites) are used for continuous weather monitoring.
  - **Communication**: Satellites like INSAT (Indian National Satellite System) provide constant communication services, including television broadcasting and weather forecasts.
  - **Search and Rescue**: GEO orbits are also utilized for search and rescue beacons due to their constant visibility over a specific area.
- **Limitations**:
  - **Orbital Traffic**: The limited number of available positions can cause traffic congestion and potential signal interference due to multiple satellites sharing the same orbit.

Geostationary vs. Geosynchronous Orbits

Geostationary Orbit (GEO)

- **Orbital Characteristics**:

- **Path**: Circular orbit directly above the equator.
- **Orbital Period**: Matches Earth's rotation period, 24 hours.
- **Orbital Tilt**: Zero (perfectly equatorial).

- **Visibility**:
  - A satellite in geostationary orbit appears as a fixed point in the sky from any location on Earth, as it remains over the same spot on the Earth's surface.
- **Applications**:
  - Ideal for continuous communication, broadcasting, and weather monitoring due to its constant view of a specific area.

- **Limitations**:
  - **Orbital Congestion**: Limited number of positions available due to safety and maneuvering constraints, which can lead to signal interference and risks from space debris.
  - **Antenna Requirements**: Simple antennas can be used (e.g., for Direct-to-Home (DTH) TV and VSAT services) since the satellite's position is relatively fixed.

Geosynchronous Orbit

- **Orbital Characteristics**:
  - **Path**: Inclined circular or elliptical orbit.

- **Orbital Period**: Also 24 hours, matching Earth's rotation.
- **Orbital Tilt**: Non-zero, resulting in an inclined orbit.

- **Visibility**:
  - A satellite in geosynchronous orbit will appear to trace a figure-eight pattern in the sky due to its inclination and/or eccentricity. It will return to the same spot over Earth's surface once per day.
- **Applications**:
  - Provides coverage over specific regions at different times, with more flexibility in orbital planes and positions.

- **Limitations**:
  - **Orbital Path**: More complex due to inclination and eccentricity, which can cause variability in coverage.
  - **Antenna Requirements**: Typically requires parabolic antennas that may need adjustments to maintain line-of-sight as the satellite's position shifts slightly.

Highly Elliptical Orbits

- **Characteristics**:
  - **Path**: Oval-shaped orbit with varying distances from the Earth.

  - **Velocity**: Satellite speeds up as it approaches the closest point (perigee) and slows down at the farthest point (apogee) due to varying gravitational forces (Kepler's Second Law).
- **Applications**:
  - Suited for satellites that need to spend extended periods over a particular region, such as for specialized communications or Earth observation.
- **Disadvantages**:
  - **Coverage Gaps**: The satellite may experience periods of no coverage over the desired area when it is far from it (high-speed part of the orbit).

Transfer Orbits and Geostationary Transfer Orbit (GTO)

Transfer Orbits

- **Definition**: Transfer orbits are intermediate orbits used to move a satellite or spacecraft from one orbit to another.
- **Purpose**: They are used to transition between different orbital paths with minimal additional propulsion.
- **Types**:

  - **Hofmann Transfer Orbit**: A specific type of elliptical orbit used to move between two circular orbits, often used for interplanetary transfers.
  - **Parking Orbit**: A temporary orbit where the satellite is placed before it is transferred to its final orbit.
- **Usage**:
  - Satellites are initially launched into a transfer orbit, which allows them to reach their final orbit (such as GEO) with less energy compared to launching directly into the final orbit.
  - This approach reduces the requirements and cost of the launch vehicle, as it doesn't need to carry the satellite all the way to its final high-altitude orbit.

Geostationary Transfer Orbit (GTO)

- **Definition**: GTO is a specific type of transfer orbit used to transition a satellite into a geostationary orbit (GEO).
- **Characteristics**:
  - **Elliptical Path**: GTO is an elliptical orbit where the satellite's apogee (farthest point) reaches the altitude of GEO (35,786 km above the equator), and the perigee (closest point) is much lower, often near the Earth's surface.

  - **Energy Requirement**: The satellite is placed into GTO by the launch vehicle. Once the satellite reaches the apogee of GTO, it uses its own propulsion system to adjust its orbit to become a circular geostationary orbit.
- **Process**:
  - **Initial Phase**: After launch, the satellite is inserted into GTO by the launch vehicle.
  - **Final Phase**: At apogee, the satellite's onboard engines fire to increase its velocity and circularize the orbit at the GEO altitude.

- **Applications**:
  - Commonly used for communication satellites and other payloads that need to be positioned in GEO.
- **Examples**:
  - **ISRO Missions**: Recent missions like CYan3 and Aditya-L1 utilized GTO to reach their final orbits.

Miscellaneous Topics

Escape Velocity

- **Definition**: Escape velocity is the minimum speed an object must reach to break free from the gravitational influence of a celestial body without further propulsion.

- **Earth Example**: For a spacecraft to escape Earth's gravity, it must achieve a velocity of about 7 miles per second (approximately 25,000 miles per hour).

Why Launch from Near the Equator?

- **Earth's Rotation Speed**: At the equator, the Earth's surface moves at a speed of about 1670 kilometers per hour (approximately 1040 miles per hour) due to its rotation.
- **Inertia Advantage**: Launching a spacecraft from the equator means the spacecraft benefits from this rotational speed. This initial velocity helps the spacecraft achieve orbit more efficiently.
- **Distance Traveled**: The circumference of the Earth is greatest at the equator, meaning that the surface there travels the most distance in a given period (24 hours) compared to other latitudes.
- **Energy Efficiency**: Utilizing the Earth's rotational velocity reduces the amount of energy (and thus fuel) required to reach orbit, making launches more cost-effective.

Why Launch Satellites and Missiles from the East Coast?

- **Surface Velocity Boost**: The Earth's rotational velocity is fastest at the equator. Launching towards the east provides a boost in the spacecraft's speed, helping it achieve the necessary velocity to enter orbit.

- **Cost Efficiency**: This rotational boost reduces the amount of fuel needed to reach orbit, lowering launch costs.
- **Geostationary Satellites**: Satellites that need to be in geostationary orbit (matching Earth's rotation) benefit most from this eastward launch as they require an orbit aligned with the equator.
- **Polar Orbits**: Satellites in polar orbits (which travel north-south across the Earth) do not benefit from the rotational speed boost in the same way. These satellites are often launched in a northward or southward direction.
- **Safety**: Launch sites are typically located on the eastern coast to minimize risks to populated areas if a launch fails and the spacecraft falls back to Earth.

Space Liability Convention

Overview

- **Full Name**: Convention on International Liability for Damage Caused by Space Objects (Space Liability Convention)
- **Adopted**: 29 March 1972
- **Entered into Force**: 1 September 1972

- **Purpose**: Expands on the liability provisions outlined in the Outer Space Treaty of 1967.

Key Provisions

1. **International Responsibility**:
   - States are liable for damage caused by their space objects, regardless of where the launch occurred. This means that if a space object is launched from a particular country, that country bears the responsibility for any damages caused by the object.
2. **Joint Launches**:
   - In cases where multiple states collaborate on a launch, all involved states are jointly and severally liable for any damage caused. The injured party can seek compensation from any one of the involved states for the full amount of the damage.
3. **Claims Between States**:
   - Claims under the Liability Convention must be filed by one state against another state. Individuals cannot file claims directly under this convention; instead, they must seek assistance from their own government to make a claim on their behalf.

Historical Context

- **Kosmos 954 Incident**: The only claim filed under this convention arose from the crash of the nuclear-powered Soviet satellite Kosmos 954 in Canada in 1978. The incident highlighted the need for clear liability rules for space debris.

International Legal Framework for Space Ventures

Foundational UN Treaties

1. **Outer Space Treaty (1967)**:
   - Often referred to as the "magna carta" of international space law. It establishes fundamental principles governing space activities, including non-appropriation of space, freedom of exploration, and the prohibition of weapons of mass destruction in space.
2. **Rescue Agreement (1968)**:
   - Also known as the Agreement on the Rescue of Astronauts, the Agreement extends the principles of the Outer Space Treaty, emphasizing the obligation of states to assist astronauts in distress and ensure their safe return.
3. **Liability Convention (1972)**:
   - Expands on the liability provisions of the Outer Space Treaty by setting clear rules on liability for damages caused by space objects, as detailed above.
4. **Registration Convention (1976)**:

   - The Convention on Registration of Objects Launched into Outer Space requires states to register space objects with the United Nations, providing transparency about space missions.

5. **Moon Agreement (1984)**:
   - Establishes the Moon and other celestial bodies as the common heritage of all humankind, providing for the exploration and use of the Moon's resources to benefit all countries. It has not been widely adopted.

The Outer Space Treaty (1967)

Overview

- **Full Name**: Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.
- **Effective Date**: October 10, 1967
- **Significance**: Often referred to as the "magna carta" of space law.

Key Provisions

1. **Peaceful Purposes**:
   - Outer space must be used for peaceful purposes. The Treaty prohibits the placement of weapons of mass

destruction in space and bars the establishment of military bases or installations on celestial bodies.

2. **No Sovereignty**:
    - No country can claim sovereignty over the Moon or any other celestial bodies. Outer space, including the Moon and other celestial bodies, is considered the "common heritage of mankind."
3. **Responsibility and Liability**:
    - Countries are responsible for national space activities, whether conducted by governmental or non-governmental entities, and are liable for any damage caused by objects launched into space from their territory.
4. **Assistance to Astronauts**:
    - States must assist astronauts in distress and ensure their safe return. Space installations and vehicles must be open to other nations on a reciprocal basis.
5. **Transparency**:
    - States must conduct space activities in an open manner and avoid any activities that may be harmful to the environment of outer space.

The Rescue Agreement (1968)

Full Name: Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space (ARRA).

Effective Date: December 3, 1968

Key Provisions

1. **Assistance and Rescue**:
   - Obliges states to assist astronauts in distress and provide rescue and safe return if they land in another country's territory.
2. **Return of Space Objects**:
   - Requires the return of space objects that inadvertently land on a foreign country's territory.
3. **Application**:
   - While it has not been used for rescuing astronauts, it has been applied for the recovery and return of space objects.

The Liability Convention (1972)

Full Name: Convention on International Liability for Damage Caused by Space Objects.

Effective Date: September 1, 1972

Key Provisions

1. **Liability**:

- States are liable for damages caused by their space objects on the surface of the Earth and in outer space.

2. **Claims Process**:

    - Claims for damages can be made by one state against another state. The injured party (state) can seek compensation for damages caused by space objects.

The Registration Convention (1976)

Full Name: Convention on Registration of Objects Launched into Outer Space.

Effective Date: September 15, 1976

Key Provisions

1. **Registration**:

    - Requires states to register space objects with the United Nations and provide details about these objects.

2. **Transparency**:

    - Ensures transparency in space activities by maintaining a registry of space objects.

The Moon Agreement (1984)

Full Name: Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.

Effective Date: July 11, 1984

Key Provisions

1. **Peaceful Use**:
   - Reaffirms that the Moon and other celestial bodies should be used for peaceful purposes.
2. **Common Heritage**:
   - States that the Moon and its natural resources are the "common heritage of mankind."
3. **Environmental Protection**:
   - Mandates that the environments of celestial bodies should not be disrupted.
4. **International Regime**:
   - Calls for an international regime to regulate the exploitation of lunar resources and ensure that the benefits are shared with all of humanity.

Indian Space Research Organisation

- **Establishment**: ISRO was founded in 1969, evolving from the Indian National Committee for Space Research (INCOSPAR), which was established in 1962 under Prime Minister Jawaharlal Nehru's initiative.
- **Affiliation**: ISRO operates as the primary research and development arm of the Department of Space (DoS), which is

overseen by the Prime Minister of India. The Chairman of ISRO also serves as the executive of DoS.

- **Capabilities**: ISRO is one of the few government space agencies with comprehensive capabilities, including full launch capabilities, cryogenic engines, extraterrestrial missions, and a large fleet of artificial satellites. It is also one of the agencies with uncrewed soft landing capabilities.

Historical Milestones

- **Early Foundations**:
  - **1920s**: S. K. Mitra conducted early experiments on the ionosphere in Kolkata.
  - **Post-World War II**: Vikram Sarabhai founded the Physical Research Laboratory (PRL) in Ahmedabad, and Homi Bhabha established the Tata Institute of Fundamental Research (TIFR) in 1945.
  - **1950**: The Department of Atomic Energy (DAE) was founded with Bhabha as its secretary, funding space research.
- **Early Institutions**:
  - **1954**: Aryabhatta Research Institute of Observational Sciences (ARIES) was established in the Himalayas.

- **1957**: Rangpur Observatory was set up at Osmania University, Hyderabad.

- **Development of Space Research**:
  - **1962**: INCOSPAR was established by Prime Minister Nehru at the suggestion of Dr. Vikram Sarabhai, marking the beginning of organized space research in India.
  - **1967**: India began upper atmospheric research with the launch of Rohini sounding rockets from the Thumba Equatorial Rocket Launching Station.

Key Achievements

- **Aryabhata**: Launched in 1975 by the Soviet space agency Interkosmos, it was India's first satellite.
- **SLV-3**: In 1980, ISRO launched satellite RS-1, making India the seventh country capable of orbital launches.
- **Launch Vehicles**: ISRO developed various launch vehicles including the Satellite Launch Vehicle (SLV), Augmented Satellite Launch Vehicle (ASLV), and other medium-lift rockets.
- **Satellite Systems**: ISRO operates the world's largest constellation of remote-sensing satellites and has developed the GAGAN and IRNSS (NavIC) satellite navigation systems.

- **Space Missions**: ISRO has successfully sent missions to the Moon (Chandrayaan series) and Mars (Mangalyaan).

Institutional Development

- **1972**: The Indian government established the Space Commission and DoS, institutionalizing space research and incorporating ISRO under it.
- **Advancements**: ISRO has built and launched numerous domestic and foreign satellites, developed rocket engines, and conducted deep space exploration missions.

Key Personnel and Contributions

- **Vikram Sarabhai**: Often considered the father of the Indian space program, his vision led to the establishment of space research in India.
- **Homi Bhabha**: His work and leadership in establishing the DAE provided critical funding and support for early space research.
- **H.G.S. Murthy**: Directed the Thumba Equatorial Rocket Launching Station, starting upper atmospheric research in India.
- **Waman Dattatreya Patwardhan**: Developed propellants for the Rohini sounding rockets.

Indian Space Research Organisation (ISRO): 1970s, 1980s, and 1990s

1970s

- **Institutionalization**:
  - Under Prime Minister Indira Gandhi, INCOSPAR was transformed into ISRO.
  - In 1972, the Indian government established the Space Commission and Department of Space (DoS), bringing ISRO under its oversight and institutionalizing space research in India.
- **Early Achievements**:
  - India joined the Soviet Interkosmos program, which facilitated the launch of India's first satellite, Aryabhata, into orbit using a Soviet rocket.
- **Development of Launch Vehicles**:
  - **Satellite Launch Vehicle (SLV)**: Efforts to develop an orbital launch vehicle began after mastering sounding rocket technology. The SLV, capable of launching 40 kg into a 400-kilometer orbit, had its first launch in 1979, which failed to achieve the desired orbit. A successful launch in 1980 with the Rohini Series-I satellite made India the seventh country to reach Earth's orbit.
  - **Medium-Lift Launch Vehicle**: Development began in 1978 for a vehicle capable of launching 600 kg spacecraft

into a 1,000-kilometer Sun-synchronous orbit. This effort later led to the development of the Polar Satellite Launch Vehicle (PSLV).

- **Other Developments**:
    - **SLV-3**: The SLV-3 had two more launches before being discontinued in 1983.
    - **Liquid Propulsion Systems Centre (LPSC)**: Established in 1985, the LPSC began developing the Vikas engine, based on the French Viking engine. Facilities for testing liquid-fueled rocket engines were also set up.
    - **Augmented Satellite Launch Vehicle (ASLV)**: Developed based on SLV-3, the ASLV had limited success and multiple failures, leading to its discontinuation.
- **Communication and Earth Observation**:
    - Development of technologies for the Indian National Satellite System (INSAT) and Indian Remote Sensing (IRS) satellites began, with launches from overseas initiated.

1990s

- **Polar Satellite Launch Vehicle (PSLV)**:
    - The PSLV's debut in the 1990s significantly boosted the Indian space program. Despite initial failures, it achieved

over 50 successful flights, enabling the launch of low Earth orbit satellites, small payloads to Geostationary Transfer Orbit (GTO), and hundreds of foreign satellites.

- **Geosynchronous Satellite Launch Vehicle (GSLV)**:
    - Development of the GSLV was underway. India sought upper-stage cryogenic engines from Russia but faced US sanctions that blocked this.
    - Instead, KVD-1 engines were imported from Russia under a new agreement, leading to the GSLV Mk.1. Efforts to develop indigenous cryogenic technology began in 1994 and took two decades to realize.

- **US Sanctions and Satellite Navigation**:
    - ISRO faced US government sanctions from May 6, 1992, to May 6, 1994. During this period, the US refused to assist India with Global Positioning System (GPS) technology, prompting ISRO to develop its own satellite navigation system, the Indian Regional Navigation Satellite System (IRNSS), which has been expanded further.

ISRO in the 21st Century

2000s

- **Moon and Mars Missions**:

- **Chandrayaan-1 (2008)**: India's first lunar mission, launched to explore the Moon and confirm the presence of water molecules on its surface. This mission was instrumental in advancing lunar research and international space exploration.
- **Mars Orbiter Mission (Mangalyaan) (2013)**: Launched successfully in November 2013, Mangalyaan became the first Asian spacecraft to reach Mars orbit and India's first interplanetary mission. It achieved this feat on its first attempt, highlighting ISRO's growing capabilities in space exploration.

- **Advancements in Launch Vehicles**:
  - **Cryogenic Upper Stage for GSLV**: By 2008, ISRO's GSLV rocket with cryogenic upper stages became operational. This advancement made India the sixth country globally to possess full launch capabilities, significantly enhancing its ability to deploy heavier payloads and undertake more complex missions.
  - **LVM3 (GSLV Mk III)**: Introduced in 2014, this heavier-lift launcher was designed for launching larger satellites and is planned for future crewed space missions.

2020s

- **Recent Milestones**:

- **Chandrayaan-3 (2023)**: On August 23, 2023, ISRO achieved its first soft landing on the Moon, specifically near the lunar south pole. Chandrayaan-3 marked India's third Moon mission and represented a significant milestone in space exploration, showcasing the nation's capability to land successfully on extraterrestrial bodies.
- **Aditya-L1 (2023)**: Launched on September 2, 2023, Aditya-L1 is India's first solar probe. It aims to study the Sun's outer layers, contributing to our understanding of solar dynamics and space weather.

ISRO Organization Structure and Facilities

Organization Structure

- **Department of Space (DoS)**: The governing body overseeing ISRO, which falls under the Space Commission.
- **Antrix Corporation**: ISRO's marketing arm based in Bengaluru, responsible for promoting and commercializing space products and services.
- **Physical Research Laboratory (PRL)**: Located in Ahmedabad, focuses on fundamental and applied research in space and atmospheric sciences.

- **National Atmospheric Research Laboratory (NARL)**: Based in Gadanki, Andhra Pradesh, dedicated to atmospheric and space science research.
- **NewSpace India Limited**: The commercial wing of ISRO, operating out of Bengaluru, responsible for the commercial arm of space activities.
- **North-Eastern Space Applications Centre (NE-SAC)**: Located in Umiam, it supports space applications in the North-Eastern region of India.
- **Indian Institute of Space Science and Technology (IIST)**: Situated in Thiruvananthapuram, this is India's premier space university, focusing on space science and technology education.

Research Facilities

1. **Vikram Sarabhai Space Centre (VSSC)**
   - **Location**: Thiruvananthapuram
   - **Description**: The largest ISRO base and main technical center for the development of SLV-3, ASLV, and PSLV series. It supports TERLS (Thumba Equatorial Rocket Launching Station) and the Rohini Sounding Rocket program and is involved in developing the GSLV series.
2. **Liquid Propulsion Systems Centre (LPSC)**
   - **Location**: Thiruvananthapuram and Bengaluru

   - **Description**: Handles design, development, testing, and implementation of liquid propulsion systems for launch vehicles and satellites. Testing is conducted at ISRO PRC (Propulsion Complex) at Mahendragiri. Also involved in producing precision transducers.

3. **Physical Research Laboratory (PRL)**
   - **Location**: Ahmedabad
   - **Description**: Focuses on solar planetary physics, infrared astronomy, plasma physics, and more. Operates the Udaipur Observatory.

4. **National Atmospheric Research Laboratory (NARL)**
   - **Location**: Tirupati
   - **Description**: Conducts fundamental and applied research in atmospheric and space sciences.

5. **Space Applications Centre (SAC)**
   - **Location**: Ahmedabad
   - **Description**: Specializes in practical applications of space technology such as satellite communications, remote sensing, and environmental monitoring. Operates the Delhi Earth Station for satellite communications.

6. **North-Eastern Space Applications Centre (NE-SAC)**

- **Location**: Shillong
- **Description**: Supports developmental projects in the North-East region through remote sensing, GIS, satellite communication, and space science research.

Test Facilities

1. **ISRO Propulsion Complex (IPRC)**
   - **Location**: Mahendragiri, Tamil Nadu
   - **Description**: Involved in testing, assembling, and integrating propulsion systems and stages. Known as the "Jet Propulsion Laboratory of India," it conducts tests for all liquid, cryogenic, and semi-cryogenic stages and engines of ISRO’s launch vehicles and satellites.

ISRO Tracking and Control Facilities

1. **Indian Deep Space Network (IDSN)**
   - **Location**: Bengaluru
   - **Description**: Handles the reception, processing, archiving, and distribution of spacecraft health and payload data in real-time. Capable of tracking satellites at very large distances, including beyond the Moon.
2. **National Remote Sensing Centre (NRSC)**
   - **Location**: Hyderabad

- **Description**: Utilizes remote sensing technology to manage natural resources and conduct aerial surveys. Includes centers in Balanagar and Shadnagar and a training facility at Dehradun, which acts as the Indian Institute of Remote Sensing.

3. **ISRO Telemetry, Tracking and Command Network (ISTRAC)**
   - **Location**: Headquarters in Bengaluru, with ground stations worldwide
   - **Description**: Provides software development, ground operations, and Tracking Telemetry and Command (TTC) support. ISTRAC has tracking stations across India and globally in Port Louis (Mauritius), Bearslake (Russia), Biak (Indonesia), and Brunei.

4. **Master Control Facility (MCF)**
   - **Locations**: Bhopal; Hassan
   - **Description**: Manages geostationary satellite orbit raising, payload testing, and in-orbit operations. Includes Earth stations and the Satellite Control Centre (SCC). A second facility, 'MCF-B,' is under construction at Bhopal.

5. **Space Situational Awareness Control Centre**
   - **Location**: Peenya, Bengaluru

- **Description**: Develops a network of telescopes and radars to monitor space debris and safeguard space-based assets. The network includes sophisticated multi-object tracking radar in Nellore, additional radar in Northeast India, and telescopes in Thiruvananthapuram, Mount Abu, and North India.

Human Resource Development

1. **Indian Institute of Remote Sensing (IIRS)**
    - **Location**: Dehradun
    - **Description**: Premier institute for training and education in remote sensing, geoinformatics, and GPS technology. Offers postgraduate and doctoral programs and executes R&D projects. Runs outreach programs including live and interactive sessions and e-learning.
2. **Indian Institute of Space Science and Technology (IIST)**
    - **Location**: Thiruvananthapuram
    - **Description**: Offers undergraduate and graduate programs in Aerospace Engineering, Electronics and Communication Engineering (Avionics), and Engineering Physics.
3. **Development and Educational Communication Unit (DECU)**
    - **Location**: Ahmedabad

- **Description**: Focuses on education, research, and training related to the INSAT programme. Notable projects include GRAMSAT and EDUSAT. Also manages the Training and Development Communication Channel (TDCC).

4. **Space Technology Incubation Centres (S-TICs)**
   - **Locations**: Dr. B. R. Ambedkar National Institute of Technology, Agartala; Bhopal; Jalandhar; Nagpur; Rourkela; Tiruchirappalli
   - **Description**: Set up in premier technical universities to foster startups in space technology and applications. Brings together industry, academia, and ISRO for research and development initiatives.

5. **Space Innovation Centre**
   - **Location**: Veer Surendra Sai University of Technology, Burla, Sambalpur
   - **Description**: Promotes and encourages research and development in space science and technology at VSSUT and other regional institutes.

6. **Regional Academy Centre for Space (RAC-S)**
   - **Locations**: Banaras Hindu University (Varanasi); Gauhati University; Kurukshetra University; Malaviya National Institute of Technology (Jaipur); National Institute of

Technology Karnataka (Mangaluru); National Institute of Technology Patna; Indian Institute of Technology (BHU) Varanasi

- **Description**: Establishes awareness, strengthens academic collaboration, and acts as incubators for space technology, science, and applications. Enhances the use of research potential and infrastructure, facilitates capacity building in tier-2 cities.

Key Organizations and Their Functions in India's Space Program

1. **Antrix Corporation Limited**
   - **Location**: Bengaluru
   - **Description**:
     - **Incorporation**: Established in September 1992 as a wholly-owned Government of India company under the Department of Space.
     - **Primary Role**: Acts as the marketing arm of ISRO for promoting and commercially exploiting space products, technical consultancy services, and technology transfers.
     - **Objectives**:

        - Promote space products and services internationally.
        - Facilitate the development of space-related industrial capabilities in India.
    - **Services Provided**:
        - End-to-end solutions including hardware and software for communications, earth observation, and scientific missions.
        - Space-related services like remote sensing data service, transponder leasing, launch services (using PSLV and GSLV), mission support services, consultancy, and training.

2. **NewSpace India Limited (NSIL)**
    - **Location**: Bengaluru, Karnataka
    - **Description**:
        - **Incorporation**: Formed on March 6, 2019, under the Companies Act, 2013, as a wholly-owned Government of India company.
        - **Primary Role**: Acts as the commercial arm of ISRO, responsible for enabling Indian industries to engage in high-tech space activities and promoting

commercial exploitation of space products and services.

- **Major Business Areas**:
  - Production of Polar Satellite Launch Vehicle (PSLV) and Small Satellite Launch Vehicle (SSLV) through industry.
  - Marketing space-based services such as launch services, transponder leasing, remote sensing, and mission support.
  - Building and marketing satellites for communication and earth observation.
  - Technology transfer and marketing spin-off technologies and products/services from ISRO activities.
  - Consultancy services.

3. **Indian National Space Promotion and Authorization Center (IN-SPACe)**
   - **Description**:
     - **Role**: An autonomous agency within the Department of Space, established to facilitate private sector participation in the space sector.

- **Responsibilities**:
  - Promote, authorize, and supervise non-governmental entities involved in space activities.
  - Oversee the building of launch vehicles and satellites, space-based services, and sharing of space infrastructure.
  - Act as an interface between ISRO and non-governmental entities, assessing the utilization of space resources and addressing private sector needs.
  - Explore accommodation of requirements from private players, including educational and research institutions.

4. **Human Space Flight Centre (HSFC)**
   - **Location**: Bengaluru
   - **Description**:
     - **Role**: Coordinates the Indian Human Spaceflight Programme.
     - **Primary Responsibility**: Implement the Gaganyaan project, which aims to conduct India's first crewed spaceflight.

- **Upcoming Mission**: The first crewed flight is planned for 2024, utilizing a home-grown LVM3 rocket.

ISRO's Launch Vehicles

1. Polar Satellite Launch Vehicle (PSLV)

- **Overview**: PSLV is a third-generation, indigenously-developed expendable launch system.
  - **Expendable vs. Reusable**:
    - **Expendable**: Used only once for carrying payloads into space (e.g., PSLV, GSLV).
    - **Reusable**: Designed for recovery and later reuse (e.g., SpaceX Falcon 9).
- **Development**: Developed in the 1990s to place satellites into polar and near-polar orbits.
- **Capabilities**:
  - **Low Earth Orbit (LEO)**: Can place up to 1,750 kg payloads into Sun-Synchronous Orbits (SSO).
  - **Geosynchronous Transfer Orbit (GTO)**: Can place up to 1,425 kg payloads.
- **Configurations**:
  - Varies with the number of solid rocket boosters:

- **PSLV-C**: Core Alone (no additional boosters).
- **PSLV-DL**: Two boosters.
- **PSLV-QL**: Four boosters.
- **PSLV-XL**: Six boosters.

- **Stages**:
  - **First Stage**: Solid-fueled.
  - **Second Stage**: Liquid-fueled (Vikas engine, derived from France's Viking engine).
  - **Third Stage**: Solid-fueled.
  - **Fourth Stage**: Liquid-fueled.
- **Performance**:
  - **Launch History**: As of September 2023, 60 launches with 57 successful missions, 2 failures, and 1 partial failure (95% success rate).
  - **Satellites Launched**: Includes IRS (Indian Remote Sensing) satellites and the IRNSS satellite constellation.

2. Geosynchronous Satellite Launch Vehicle (GSLV)

- **Overview**: A fourth-generation expendable launch system.
- **First Flight**: April 18, 2001.
- **Capabilities**:

  - **Low Earth Orbit (LEO)**: Can place up to 5,000 kg payloads.
  - **Geosynchronous Transfer Orbit (GTO)**: Can place up to 2,500 kg payloads.
- **Stages**:
  - **First Stage**: Solid-fueled.
  - **Second Stage**: Liquid-fueled.
  - **Third Stage**: Cryogenic.
- **Features**:
  - Uses solid rocket boosters and liquid strap-on motors for additional thrust.
- **Launch History**:
  - **Total Flights**: 15, with 4 unsuccessful flights.
  - **Recent Launch**: GSLV-F12/NVS-01 Mission (2023) carried navigation payloads and an indigenous atomic clock.
  - **Recent Failure**: GLSV-F10 (2021).

Additional Details

- **Strap-on Motors**:

  - GSLV uses four liquid strap-on motors, each powered by a Vikas engine.
- **Recent Advances**:
  - The GSLV-F12/NVS-01 Mission included an indigenous atomic clock, highlighting advancements in technology for navigation and timekeeping.

ISRO's Launch Vehicles and Technologies

1. Launch Vehicle Mark-3 (LVM3)

- **Overview**:
  - **Type**: Three-stage heavy-lift launch vehicle.
  - **Primary Uses**: Designed to launch communication satellites into geostationary orbits and support crewed missions under the Indian Human Spaceflight Programme.
  - **Payload Capacity**:
    - **Geosynchronous Transfer Orbit (GTO)**: 4 tons.
    - **Low Earth Orbit (LEO)**: 8 tons.
- **Development**:
  - **First Orbital Test**: 5 June 2017.
  - **Notable Missions**: Chandrayaan-2, Chandrayaan-3, CARE (space capsule recovery experiment), and planned Gaganyaan crewed mission.

- **Recent Developments**:
    - **OneWeb Agreement**: In March 2022, ISRO began launching OneWeb satellites due to disruptions in Roscosmos services. The first launch with LVM3 took place on 22 October 2022, successfully placing 36 satellites into Low Earth Orbit.
- **Launch Record**:
    - **Total Launches**: 7 as of 19 July 2023.
    - **Success Rate**: 100% with all missions successful.

2. Cryogenic Engines / Technology

- **Cryogenic Definition**: Technology involving extremely low temperatures.
- **Cryogenic Fuels**:
    - **Liquid Oxygen (LOX)**: Used as an oxidizer, maintained below -183°C.
    - **Liquid Hydrogen (LH2)**: Used as fuel, maintained below -253°C.
- **Advantages**:
    - **Efficiency**: Provides high specific impulse, meaning more thrust per unit of propellant.

- **Applications**: Useful for space launches and for low-temperature storage applications.

- **Cryogenic Engine (CE20)**:
  - **Development**: Result of over three decades of research.
  - **Design**: Based on advanced processes similar to those used in Ariane rockets.
  - **Challenges**: Involves handling supercooled fuels and materials capable of withstanding high temperatures and pressures.

3. Semi-Cryogenic Engine-200 (SCE-200)

- **Overview**:
  - **Type**: Liquid rocket engine with a thrust class of 2 MN.
  - **Development**: By ISRO's Liquid Propulsion Systems Centre (LPSC).
  - **Features**: Uses liquid oxygen (LOX) and RP-1 kerosene.
- **Purpose**:
  - **Current Use**: To replace the L110 stage (powered by Vikas engines) in LVM3.
  - **Future Use**: Expected to power ISRO's Next Generation Launch Vehicle (NGLV) and future reusable rockets.
- **Expected Benefits**: Enhanced payload capacity and efficiency.

4. Vikas Engine

- **Overview**:
  - **Development**: Designed by ISRO's Liquid Propulsion Systems Centre in the 1970s.
  - **Name**: Named after Vikram Ambalal Sarabhai, a pioneer in India's space program.
- **Fuel**:
  - **Components**: Uses 40 metric tons of UDMH (Unsymmetrical Dimethylhydrazine) as fuel and Nitrogen Tetroxide (N_2O_4) as an oxidizer.
  - **History**: Early engines involved imported components which have since been replaced by domestic equivalents.

ISRO's Small Satellite Launch Vehicle (SSLV) and Related Technologies

1. Small Satellite Launch Vehicle (SSLV)

- **Overview**:
  - **Type**: Small-lift launch vehicle.
  - **Payload Capacity**:
    - **Low Earth Orbit (LEO)**: 500 kg.
    - **Sun-synchronous Orbit (SSO)**: 300 kg.

- **Features**:
  - Designed for cost-efficiency and minimal turnaround time.
  - Launch-on-demand flexibility with minimal infrastructure requirements.

- **Development**:
  - **Maiden Flight**: SSLV-D1 on 7 August 2022 (failed to reach orbit).
  - **Successful Flight**: SSLV-D2 on 10 February 2023 (successfully delivered payloads to orbit).

- **Future Plans**:
  - A dedicated launch site for SSLV at Kulasekharapatnam, Tamil Nadu, for handling launches to Sun-synchronous orbits.
  - Production and launch operations to be managed by a consortium of Indian firms and NewSpace India Limited (NSIL) once operational.

2. Sounding Rockets

- **Overview**:

- **Purpose**: Probe upper atmospheric regions and conduct space research; also used to test new components or subsystems.

- **Historical Context**:
  - **Establishment of TERLS**: 1963 in Thumba, near the magnetic equator, enhancing atmospheric science capabilities in India.
  - **First Launch**: 21 November 1963 from Thumba.
  - **ISRO's Involvement**: Began launching indigenous sounding rockets in 1965.

- **Programs**:
  - **Rohini Sounding Rocket (RSR) Program**: Consolidated in 1975.
- **Current Versions**:
  - **RH-200**: Payload range of 8-100 kg, apogee up to 475 km.
  - **RH-300-Mk-II**: Enhanced version.
  - **RH-560-MK-II**: Advanced version with higher payload and apogee capabilities.

3. Reusable Launch Vehicle – Technology Demonstrator (RLV-TD)

- **Objective**:

- Develop space planes/shuttles for low Earth orbit missions with the ability to return and be reused.

- **RLV-TD Tests**:
  - **First Trial**: 23 May 2016.
  - **Tests Remaining**:
    - Return Flight Experiment (REX)
    - Powered Cruise Flight
    - Scramjet Propulsion Experiment (SPEX)
- **Features**:
  - **Design**: Aircraft-like with fuselage, nose cap, double delta wings, and twin vertical tails.
  - **Advantages**: Low-cost, reliable, on-demand space access.
- **Global Context**:
  - **NASA**: Space shuttles have been in use for human space flights.
  - **SpaceX**: Demonstrates partially reusable Falcon 9 and Falcon Heavy rockets; developing fully reusable Starship.

4. Air Breathing Engines

- **Overview**:

- **Function**: Use atmospheric oxygen for combustion; more efficient and cost-effective than traditional rocket engines.

- **Types**:
  - **Ramjet**: Compresses incoming air using vehicle's forward motion; efficient at supersonic speeds but not hypersonic.
  - **Scramjet**: Operates efficiently at hypersonic speeds (Mach 6 and above) with supersonic combustion.
- **Scramjet Engine - TD**:
  - **First Mission**: 28 August 2016.
  - **Achievements**:
    - Demonstrated ignition and stable combustion at supersonic speeds.
    - Successful air intake and fuel injection systems.
  - **Fuel**: Hydrogen used as fuel, with atmospheric oxygen as the oxidizer.