UNIVERSITY OF SCIENCE AND TECHNOLOGY OF HANOI

DEPARTMENT OF SPACE AND APPLICATIONS

SPACE SYSTEM DESIGN I

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Final Exam Report

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Contents

1 Question 1

Each group of 3 or 4 students shall design and present about one Earth Observation (EO) mission.

My group, Group 1, have decided to design and implement an Earth observation satellite mission capable of monitoring global environmental changes, including deforestation, urban expansion, and land-use alterations, with secondary objectives to assess vegetation health, track natural disasters, and study climate change indicators. The mission aims to provide high-resolution, near-real-time data to support global decision-making processes in disaster management, urban planning, and environmental conservation. In my group's design, I'm in charge of **launch vehicle** and **ground segment**.

1.1 Launch Vehicle

Selected Launch Vehicle: SpaceX Falcon 9.

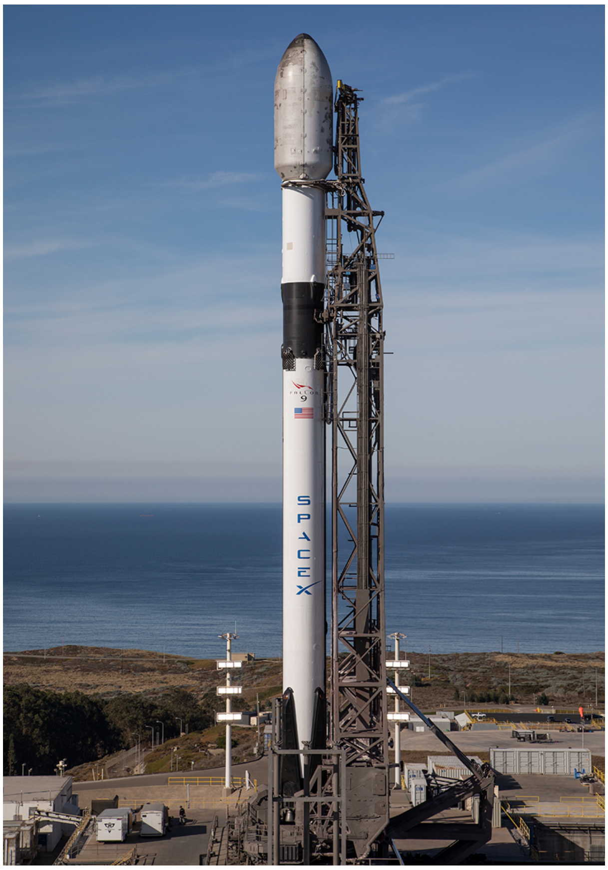

Figure 1: Falcon 9

Rationale for Selection:

1. Cost-Effectiveness:

   - The Falcon 9's reusable first stage significantly lowers operational expenses, reducing the cost per kilogram for payload delivery.

- Its competitive pricing structure provides a cost-efficient solution for medium-class satellite launches.

2. Proven Reliability:

   - Falcon 9's extensive track record of over 200 successful launches highlights its operational reliability.
   - Its demonstrated ability to handle diverse payloads ensures compatibility with complex satellite designs.

3. Payload Capacity and Compatibility:

   - The vehicle can carry up to 22,800 kg to Low Earth Orbit (LEO), accommodating the primary satellite payload and any secondary instruments.
   - Its payload fairing dimensions (5.2m diameter, 13.1m height) provide sufficient space to house the satellite securely during launch.

4. Mission-Specific Benefits:

   - Falcon 9's adaptability to sun-synchronous orbit (SSO) launch trajectories aligns with the satellite's mission design.
   - The rocket's launch scheduling flexibility ensures alignment with mission timelines.

Launch Site: Vandenberg Space Force Base, USA.

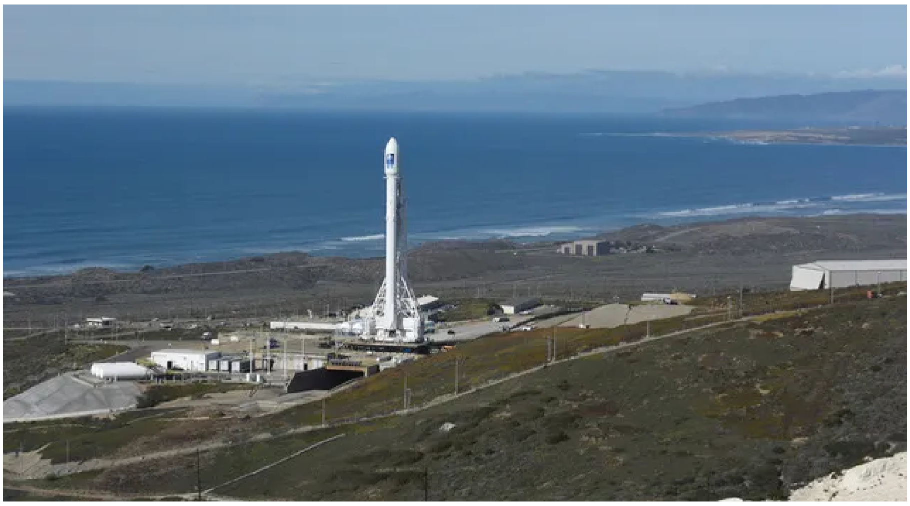

Figure 2: Vandenberg Space Force Base, USA

Advantages:

1. Geographical Location:

   - Strategically positioned for polar and sun-synchronous orbit insertions, which are critical for global environmental monitoring missions.

- Low population density in the surrounding areas minimizes safety risks during launch.

2. Infrastructure and Support:

  - Equipped with advanced facilities for payload integration, environmental testing, and pre-launch operations.
  - Provides experienced personnel and streamlined logistics to ensure efficient mission preparation.

Launch Preparations:

- Detailed pre-launch assessments, including vibration, thermal, and electromagnetic interference (EMI) tests, will validate the satellite's readiness for flight.
- Integration with the launch vehicle will be conducted using precision alignment tools to minimize structural stress during liftoff.
- A redundant series of checks will confirm the readiness of all subsystems, ensuring a high probability of mission success.

1.2 Ground Segment

Ground Stations:

Primary Stations:

1. Kourou, French Guiana:

  - Serves as the central hub for data reception, leveraging its equatorial location for optimal communication coverage.

Figure 3: Kourou, French Guiana

2. Kiruna, Sweden:

   - Provides vital support for high-latitude data reception, ensuring comprehensive global coverage.

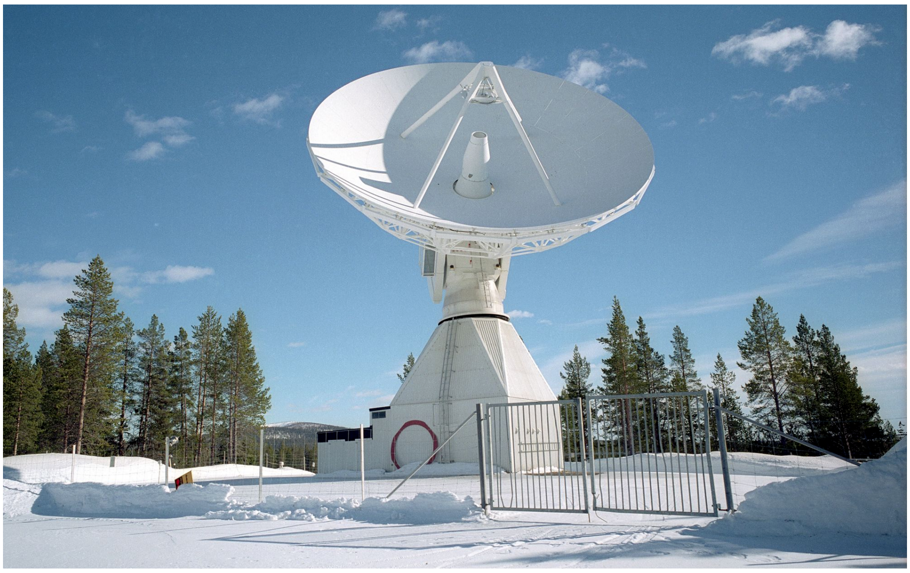

Figure 4: Kiruna, Sweden

Backup Stations:

1. Bangalore, India:

   - Enhances redundancy for uninterrupted data reception and command uplink.

Figure 5: Bangalore, India

2. Alaska, USA:

   - Offers additional support for operations in polar regions, critical for Earth observation missions.

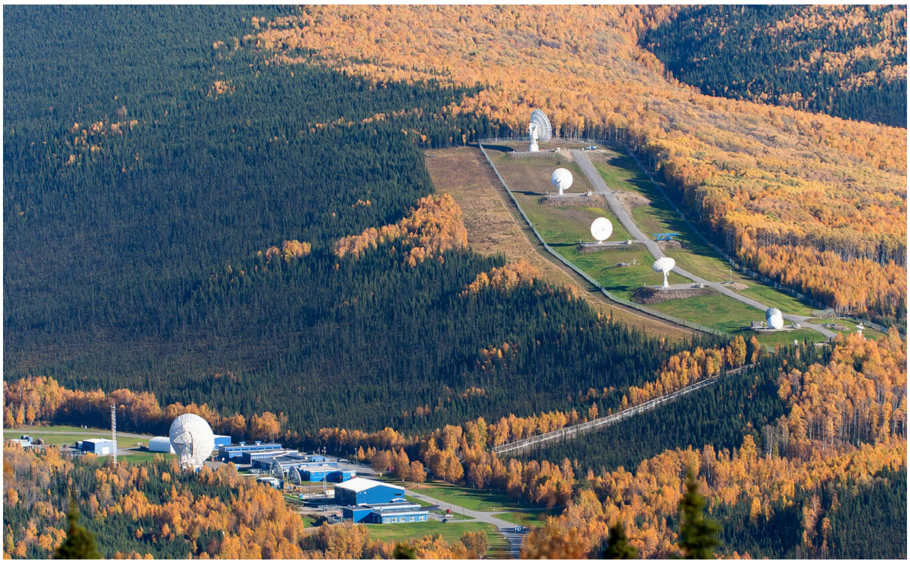

Figure 6: Alaska, USA

Equipment and Capabilities:

- High-gain parabolic antennas (10m diameter) equipped for rapid data reception at rates exceeding 1 Gbps.
- Real-time telemetry systems for continuous monitoring of satellite health and operational status.

Mission Control Center:

Location: Darmstadt, Germany.

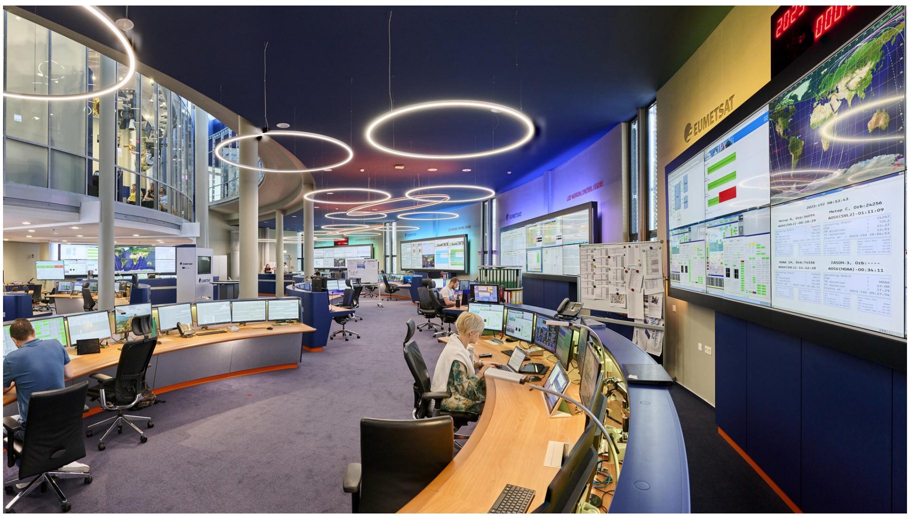

Figure 7: European Space Operations Centre at Darmstadt, Germany

Functions:

- Oversees 24/7 satellite operations, including command uplinks and real-time telemetry data analysis.
- Manages anomaly detection and resolution, ensuring mission continuity and performance.
- Coordinates data dissemination to the processing center and end-users.

Data Processing Center:

Cloud-Based Architecture:

- Implements scalable infrastructure capable of handling petabyte-scale datasets generated by the satellite.
- Utilizes advanced machine learning algorithms to automate data classification, anomaly detection, and trend analysis.

End-User Accessibility:

- Provides web-based Geographic Information System (GIS) tools for data visualization and environmental modeling.
- Offers comprehensive Application Programming Interfaces (APIs) for seamless integration of satellite data into third-party applications, enabling customized analysis and decision support.

Mitigation of Political and Logistical Challenges:

1. **International Collaboration**:
   - Establishes shared ownership agreements for ground station facilities, fostering cooperative cost-sharing and operational responsibility.
   - Drafts comprehensive legal frameworks to address data-sharing protocols, dispute resolution mechanisms, and jurisdictional rights.
2. **Engagement with Private Sector**:
   - Partners with private entities to leverage existing infrastructure and expertise, minimizing setup costs and accelerating deployment timelines.
   - Develops shared usage models for ground station facilities, ensuring operational efficiency and adaptability to geopolitical changes.

By integrating a robust network of ground stations, a dedicated mission control center, and advanced data processing systems, the ground segment ensures seamless communication, reliable data acquisition, and efficient dissemination to stakeholders worldwide.

2 Question 2

2.1 Name some typical types of orbits and their use for satellite applications.

1. **Low Earth Orbit (LEO):**
   - **Altitude**: 160–2,000 km (100–1,240 miles)
   - **Orbital Period**: ~90–120 minutes
   - **Inclination**: Varies (polar, equatorial, or inclined)
   - **Key Characteristics**:
     - High spatial resolution for Earth observation due to proximity.
     - Limited ground coverage per pass; requires constellations for global coverage.
     - Subject to atmospheric drag, requiring periodic station-keeping.
   - **Applications**:
     - **Earth Observation**: High-resolution imagery (e.g., Landsat, Sentinel).
     - **Communications**: Low-latency internet constellations (e.g., Starlink, OneWeb).
     - **Scientific Research**: Microgravity experiments (e.g., ISS), astronomy (e.g., Hubble Space Telescope).
     - **Military Surveillance**: Reconnaissance satellites (e.g., KH-series).
2. **Medium Earth Orbit (MEO):**
   - **Altitude**: 2,000–35,786 km (1,240–22,236 miles)
   - **Orbital Period**: 2–12 hours
   - **Inclination**: Typically ~55° for GPS
   - **Key Characteristics**:
     - Intermediate ground coverage and latency compared to LEO and GEO.
     - Relatively stable orbits with lower station-keeping requirements than LEO.
   - **Applications**:
     - **Navigation Systems**: GPS (U.S.), Galileo (EU), GLONASS (Russia), BeiDou (China).
     - **Communications**: Some regional satellites use MEO for broader coverage without requiring GEO.
3. **Geostationary Orbit (GEO)**
   - **Altitude**: 35,786 km (22,236 miles) above the equator.

- **Orbital Period**: 23 hours, 56 minutes, and 4 seconds (synchronous with Earth's rotation).
- **Inclination**: 0° (equatorial).
- **Key Characteristics**:
  - Satellite appears fixed relative to a ground observer.
  - Large field of view (~42% of Earth's surface per satellite).
  - High latency (~250 ms round trip) due to altitude.
- **Applications**:
  - **Telecommunications**: Global internet backbones, television broadcasting (e.g., DirecTV).
  - **Weather Monitoring**: Continuous Earth imaging for weather forecasting (e.g., GOES).
  - **Surveillance**: Early-warning missile detection (e.g., SBIRS).

4. **Polar Orbit**
   - **Altitude**: Typically 500–800 km (subset of LEO).
   - **Inclination**: ~90° (passes over both poles).
   - **Key Characteristics**:
     - Near-complete Earth coverage over multiple passes as Earth rotates beneath.
     - Sun-synchronous variants provide consistent solar illumination angles for imaging.
   - **Applications**:
     - **Environmental Monitoring**: Global data collection for climate studies (e.g., NOAA-20).
     - **Reconnaissance**: Intelligence gathering over all latitudes.
     - **Meteorology**: Polar weather satellites (e.g., MetOp).

5. **Sun-Synchronous Orbit (SSO)**
   - **Altitude**: ~600–800 km.
   - **Inclination**: 97–98° (retrograde to achieve precession rate).
   - **Key Characteristics**:
     - Orbital precession synchronizes with the Sun, ensuring consistent lighting conditions for imaging.
     - Ideal for comparing time-series data (e.g., vegetation, urban growth).
   - **Applications**:

  - **Earth Observation**: High-resolution imaging (e.g., Sentinel-2, Landsat).
  - **Scientific Research**: Atmospheric composition (e.g., Aura satellite).

6. **Highly Elliptical Orbit (HEO)**

   - **Altitude**: Perigee ~500–1,000 km; Apogee ~20,000–50,000 km.
   - **Orbital Period**: 12–24 hours.
   - **Key Characteristics**:
     - Asymmetric orbit with long dwell time at apogee.
     - Suited for high-latitude coverage (e.g., Arctic regions).
   - **Applications**:
     - **Communications**: Molniya orbits for Russian coverage.
     - **Science**: Observations of Earth's magnetosphere (e.g., THEMIS).

7. **Geostationary Transfer Orbit (GTO)**

   - **Altitude**: Highly elliptical, perigee ~200–1,000 km, apogee ~35,786 km.
   - **Inclination**: Matches launch latitude.
   - **Key Characteristics**:
     - Transition orbit used to move satellites from LEO to GEO using onboard propulsion.
   - **Applications**:
     - Intermediate orbit for GEO deployments.

8. **Cislunar Orbits**

   - **Types**:
     - Low Lunar Orbit (LLO): ~100–300 km above the Moon.
     - Near Rectilinear Halo Orbit (NRHO): Gateway orbits for lunar missions.
   - **Key Characteristics**:
     - Used for lunar surface missions or as staging points for deep space exploration.
   - **Applications**:
     - **Lunar Exploration**: Artemis program Gateway.
     - **Deep Space Missions**: Staging for Mars missions.

2.2 The altitude of perigee and apogee of a Sun-synchronous satellite orbit are 629 and 650 km, respectively. Calculate the required inclination to put the satellite in the orbit. How many orbits does the satellite move around the Earth per day?

J_2 constant of the Earth = 1.08263 x 10^{-3}.

The earth's gravitational parameter $\mu_{Earth} = 398,600km^3/s^2$.

To calculate the inclination required to put the satellite in the orbit, we use the formula:

$$i = arccos(-\frac{2}{3} \cdot \frac{R_e^2 J_2}{a^{\frac{7}{2}} \cdot \sqrt{\mu}} \cdot \omega \cdot (1-e^2)^2)$$

$$= arccos(-\frac{2}{3} \cdot \frac{(6387km)^2 \cdot 1.083x10^{-3}}{(7017.5km)^{\frac{7}{2}} \cdot \sqrt{398600km^3/s^2}} \cdot \frac{360}{365.25x86400} rad/s \cdot (1-0.0164^2)^2)$$

$$= 90°$$

The orbital period:

$$T = 2\pi\sqrt{\frac{a^3}{\mu}} = 5850.39s$$

Orbits per day = $\frac{86400}{T} = 14.77$

List of Figures

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