Bharath

INSTITUTE OF HIGHER EDUCATION AND RESEARCH

Declared as **Deemed-to-be-University** u/s 3 of the UGC Act, 1956

B.Tech- Aerospace Engineering

U20ASPL02 - Satellite Design

Lab Manual

Vision of the institute

"Bharath Institute of Higher Education & Research (BIHER) envisions and constantly strives to provide an excellent academic and research ambience for students and members of the faculties to inherit professional competence along with human dignity and transformation of community to keep pace with the global challenges so as to achieve holistic development."

Mission of the institute

- To develop as a Premier University for Teaching, Learning, Research and Innovation on par with leading global universities.
- To impart education and training to students for creating a better society with ethics and morals.
- To foster an interdisciplinary approach in education, research and innovation by supporting lifelong professional development, enriching knowledge banks through scientific research, promoting best practices and innovation, industry driven and institute oriented cooperation, globalization and international initiatives.
- To develop as a multi-dimensional institution contributing immensely to the cause of societal advancement through spread of literacy, an ambience that provides the best of international exposures, provide health care, enrich rural development and most importantly impart value based education.
- To establish benchmark standards in professional practice in the fields of innovative and emerging areas in engineering, management, medicine, dentistry, nursing, physiotherapy and allied sciences.
- To imbibe human dignity and values through personality development and social service activities.

B.Tech- Aerospace Engineering

Vision of the Department

Department of Aeronautical Engineering will endeavor to accomplish worldwide recognition with a focal point of Excellence in the field of Aeronautics by providing quality Education through world class facilities, enabling graduates turning out to be Professional Experts with specific knowledge in Aeronautical & Aerospace engineering.

Mission of the Department

- To be the state of art Teaching and Learning center with excellent infrastructure and empowered Faculties in Aeronautical & Aerospace Engineering.
- To foster a culture of innovation among students in the field of Aeronautics and Aerospace with updated professional skills to enhance research potential for sponsored research and innovative projects.
- To Nurture young individuals to be knowledgeable, skilful, and ethical professionals in their pursuit of Aeronautical & Aerospace Engineering.

B.Tech- Aerospace Engineering

Program Educational Objectives Statements (PEO)

PEO 1: Demonstrate a solid grasp of fundamental concepts in Mathematics, Science, and Engineering, essential for effectively addressing engineering challenges within the Aerospace industry.

PEO 2: Involve in process of designing, simulating, fabricating, testing, and evaluating in the field of Aerospace.

PEO 3: Obtain advanced skills to actively engage in research and development endeavors within emerging domains, while also pursuing further education opportunities.

PEO 4: Demonstrate efficient performance both as independent contributors and as valuable team members in diverse multidisciplinary projects.

PEO 5: Embrace lifelong learning and career advancement while adapting to the evolving social demands and needs.

B.Tech- Aerospace Engineering

Programme Outcomes (PO's)

PO1: Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and Engg. Specialization to the solution of complex engineering problems.

PO2: Problem analysis: Identify, formulate, research literature, and analyze engineering problems to arrive at substantiated conclusions using first principles of mathematics, natural, and engineering sciences.

PO3: Design/development of solutions: Design solutions for complex engineering problems and design system components, processes to meet the specifications with consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: Use research-based knowledge including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9: Individual and teamwork: Function effectively as an individual, and as a member or leader in teams, and in multidisciplinary settings.

PO10: Communication: Communicate effectively with the engineering community and with society at large. Be able to comprehend and write effective reports documentation. Make effective presentations and give and receive clear instructions.

PO11: Project management and finance: Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team. Manage projects in multidisciplinary environments.

PO12: Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

B.Tech- Aerospace Engineering

Program Specific Outcomes (PSO) - R2020

PSO1: Design and analyze aerospace components/systems for aerospace industries.

PSO2: Acquire the concepts of spacecraft attitude dynamics for the prediction of spacecraft motion.

Course Outcomes (COs)

CO1	**Acquire** knowledge about satellite mission requirements, payload requirements, and its constraints. **(Manipulation)**
CO2	**Demonstrate** the ability to design various satellite subsystems, including power systems, communication systems, attitude control, and thermal management. (**Precision**)
CO3	**Demonstrate** the ability to integrate on-board control system. (**Precision**)

Mapping/Alignment of COs with PO & PSO

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	H	H	H		H	M	M	H	H	H	-	H	H	H
CO2	H	H	H		H	M	M	H	H	H	-	H	H	H
CO3	H	H	H		H	M	M	H	H	H	-	H	H	H

(Tick mark or level of correlation: H-High, M-Medium, L-Low)

1.Introduction to Satellite Design

OVERVIEW OF SATELLITE COMPONENTS

Structural Components:

Frame: The structural framework of a satellite provides support and protection to internal components. It is typically constructed from lightweight yet durable materials such as aluminium or composite materials to withstand launch forces and thermal stress.
Thermal Control Systems: Satellites employ thermal blankets, radiators, and heat pipes to manage internal temperatures in the vacuum of space, preventing overheating or freezing of sensitive equipment.

Power Systems:

Solar Panels: Most satellites utilize solar panels to harness solar energy, which is then converted into electrical power using photovoltaic cells. These panels must be positioned strategically to maximize exposure to sunlight.
Batteries: Batteries serve as a crucial power source during periods of eclipse or when solar energy is insufficient. They store excess energy generated by solar panels for use when the satellite is not in direct sunlight.

Communication Components:

Antennas: Satellites rely on antennas for transmitting and receiving signals to and from Earth. These antennas come in various types, including dish, horn, and phased-array antennas, depending on the specific communication requirements.

Transponders: Transponders onboard satellites receive signals from ground stations, amplify them, and retransmit them back to Earth at a different frequency, enabling long-distance communication.

Propulsion Systems:

Thrusters: Thrusters are essential for maintaining the satellite's orbit, adjusting its position, and performing trajectory corrections. They can be powered by chemical propellants, ion engines, or other advanced propulsion technologies.
Reaction Wheels: Reaction wheels generate torque by spinning rapidly, allowing satellites to control their orientation without expending propellant. They play a crucial role in stabilizing the satellite and pointing its instruments accurately.

Payload Instruments:

Imaging Systems: Satellites equipped with cameras and imaging sensors capture high-resolution images of Earth's surface for various applications, including remote sensing, environmental monitoring, and urban planning.
Scientific Instruments: Some satellites carry scientific instruments such as spectrometers, magnetometers, and particle detectors to study phenomena such as atmospheric composition, magnetic fields, and cosmic rays.

MISSION TYPES AND APPLICATIONS:

Satellites are deployed for a wide array of missions, each designed to serve specific purposes and functions. Here's an overview of some common satellite mission types:

Communication Satellites: These satellites facilitate various types of communication, including television broadcasts, internet services, telephone calls, and data transmission. They operate in geostationary or low Earth orbit (LEO) to provide global coverage.

Earth Observation Satellites: These satellites are equipped with sensors and cameras to monitor and observe Earth's surface, atmosphere, oceans, and other environmental parameters. They are used for weather forecasting, environmental monitoring, agriculture, urban planning, and disaster management.

Navigation Satellites: Navigation satellites provide positioning, navigation, and timing (PNT) services to users on the ground, air, and sea. Global Navigation Satellite Systems (GNSS) like GPS (U.S.), Galileo (EU), GLONASS (Russia), and BeiDou (China) fall into this category.

Weather Satellites: These satellites specialize in observing and monitoring weather patterns, atmospheric conditions, and climate changes. They provide data for weather forecasting, storm tracking, and climate research.

Scientific Research Satellites: Satellites designed for scientific research purposes are equipped with instruments and sensors to study various phenomena in space, such as cosmic rays, radiation, magnetic fields, and the behaviour of celestial bodies.

Surveillance and Reconnaissance Satellites: Military and intelligence agencies deploy these satellites for monitoring and gathering information about ground activities, troop movements, and potential threats. They are also used for maritime surveillance and border control.

Space Exploration Satellites: These satellites are launched for exploring celestial bodies within the solar system and beyond. They include probes, rovers, and orbiters sent to study planets, moons, asteroids, and comets.

Space Debris Monitoring Satellites: With the increasing congestion of space debris, satellites dedicated to monitoring and tracking space debris help prevent collisions and ensure the safety of space operations.

Technology Demonstration Satellites: These satellites test new technologies and concepts in space, such as propulsion systems, materials, communication protocols, and power generation methods.

Search and Rescue Satellites: These satellites are equipped with distress beacons and receivers to detect and locate signals from emergency transmitters carried by ships, aircraft, or individuals in distress, aiding in search and rescue operations.

Commercial Imaging Satellites: Operated by private companies, these satellites capture high-resolution images of Earth's surface for various commercial purposes like agriculture, urban planning, infrastructure monitoring, and land management.

Educational and Amateur Radio Satellites: Some satellites are launched for educational purposes or amateur radio enthusiasts. They often carry payloads for experiments conducted by students or provide opportunities for amateur radio operators to communicate via space.

SATELLITE ORBITS AND LAUNCH CONSIDERATIONS:

Types of Orbits:

Low Earth Orbit (LEO): Situated at altitudes below 2,000 kilometres, LEO is ideal for Earth observation, satellite communication, and space stations like the International Space Station (ISS).
Geostationary Orbit (GEO): Positioned at an altitude of approximately 35,786 kilometers, GEO satellites orbit at the same rate as Earth's rotation, appearing stationary from the ground. GEO is commonly used for telecommunications and weather monitoring.
Polar Orbit: Passes over the Earth's poles, providing global coverage and ideal for remote sensing and mapping missions.
Molniya Orbit: High eccentricity orbit used for communication satellites serving high latitudes.

Orbital Mechanics:

Kepler's laws and Newtonian mechanics govern the motion of objects in orbit, determining parameters like orbital period, eccentricity, and inclination.
Orbital maneuvers, such as inclination changes and altitude adjustments, are conducted using onboard propulsion systems to achieve desired orbits.

Launch Considerations:

Successful launch operations require meticulous planning and consideration of various factors:

Launch Vehicle Selection:

Launch vehicles are chosen based on payload mass, destination orbit, and mission requirements. Common options include expendable rockets like the Falcon 9, Atlas V, and Delta IV, as well as reusable systems like the SpaceX Starship.

Trajectory Planning:

Trajectory planning involves calculating the optimal path from launch to desired orbit, considering factors like orbital mechanics, atmospheric conditions, and payload constraints.
Launch trajectories may involve multiple stages, each optimized for specific phases of the ascent.

Launch Site Selection:

Launch sites are chosen based on factors such as proximity to desired orbital inclinations, safety considerations, and geopolitical factors.
Common launch sites include Kennedy Space Center in the United States, Baikonur Cosmodrome in Kazakhstan, and Guiana Space Centre in French Guiana.

Challenges and Future Directions:

Despite advancements in space launch technology, several challenges persist:

Cost Reduction: Launch costs remain a significant barrier to space access. Efforts to develop reusable launch systems aim to lower costs and increase accessibility to space.

Debris Mitigation: Orbital debris poses risks to operational spacecraft and satellites. Strategies for debris mitigation and removal are essential for ensuring long-term space sustainability.

Next-Generation Launch Systems: Innovations such as electric propulsion, spaceplanes, and small satellite launchers are poised to revolutionize space launch capabilities, enabling more frequent and cost-effective access to space.

2. Mission Analysis and Requirements
SATELLITE MISSION OBJECTIVES REQUIREMENTS AND CONSTRAINTS

Satellite missions play a crucial role in various domains, including communication, Earth observation, navigation, and scientific exploration. The success of these missions heavily relies on welldefined objectives, meticulous requirements, and careful consideration of constraints. Satellite missions are designed to achieve specific goals, ranging from scientific research to commercial applications. The objectives of a satellite mission serve as the guiding principles, driving the design, implementation, and operation of the satellite system.

Objectives of Satellite Missions:

Scientific Exploration: Some satellite missions are launched to explore celestial bodies, study the universe, or conduct experiments in microgravity environments.

- Earth Observation: Satellites are deployed to monitor the Earth's surface, atmosphere, oceans, and climate systems for various purposes, including environmental monitoring, disaster management, and urban planning.
- Communication: Communication satellites facilitate global communication networks, enabling voice, data, and video transmission across vast distances.
- Navigation: Navigation satellites provide precise positioning, timing, and navigation services essential for applications such as aviation, maritime navigation, and location-based services.
- Technology Demonstrations: Satellite missions may aim to demonstrate new technologies, test novel concepts, or validate innovative spacecraft components.

Requirements for Satellite Missions:

- Functional Requirements: Functional requirements define what the satellite system must do, encompassing tasks such as data collection, processing, transmission, and control.
- Performance Requirements: Performance requirements specify the desired levels of accuracy, reliability, and efficiency for various subsystems and mission operations.
- Environmental Requirements: Environmental requirements address the conditions and challenges that the satellite must withstand during launch, in orbit, and throughout its operational lifetime.
- Regulatory Requirements: Regulatory requirements include compliance with international treaties, national regulations, spectrum allocation, and licensing for satellite operations.
- Cost and Schedule Requirements: Cost and schedule constraints dictate the budgetary limitations and timeline milestones for the satellite mission, influencing design decisions and project management strategies.

Constraints on Satellite Missions:

- Technical Constraints: Technical constraints arise from limitations in technology, materials, resources, and engineering capabilities, impacting the design, performance, and operational feasibility of satellite missions.
- Orbital Constraints: Orbital constraints relate to the selection of orbital parameters, including altitude, inclination, eccentricity, and orbital plane, influenced by mission objectives, orbital dynamics, and collision avoidance considerations.
- Payload Constraints: Payload constraints encompass limitations on payload mass, volume, power consumption, and data bandwidth, affecting the selection and integration of instruments, sensors, and communication systems.
- Regulatory Constraints: Regulatory constraints encompass spectrum allocation, frequency coordination, orbital slot assignments, and space debris mitigation requirements, governed by international agreements and national legislation.

SELECTION AND DESIGN OF SATELLITE PAYLOADS:

Satellite payloads play a crucial role in achieving mission objectives, whether it's for communication, remote sensing, scientific research, or any other purpose. This report delves into the intricate process of selecting and designing satellite payloads, emphasizing the importance of aligning them with mission goals. It explores various factors and considerations involved in this process, including mission requirements, payload types, technology constraints, and budgetary considerations. Additionally, the report discusses the significance of optimizing payload design to maximize efficiency and performance while ensuring reliability and cost-effectiveness.

1. *Introduction:*

   - Overview of Satellite Payloads

   - Importance of Mission Goals in Payload Selection and Design

2. *Mission Analysis and Requirements:*

   - Defining Mission Objectives and Goals

   - Identifying Payload Requirements based on Mission Objectives

   - Analyzing Environmental Factors and Operational Constraints

3. *Payload Types and Technologies:*

   - Overview of Different Payload Categories (Communication, Remote Sensing, Navigation, etc.)
   - Selection Criteria for Payload Technologies (RF, Optical, SAR, etc.)

- Advantages and Limitations of Various Payload Types

4. *System Architecture and Integration:*

- Integration of Payload with Satellite Bus

- Compatibility and Interoperability Considerations

- Power, Thermal, and Data Handling Requirements

5. *Payload Design Optimization:*

- Maximizing Performance while Minimizing Weight, Size, and

Power Consumption

- Reliability and Redundancy Strategies - Cost-Effectiveness Analysis and Trade-offs

6. *Testing and Validation:*

- Simulation and Testing of Payload Systems

- Environmental Testing (Thermal, Vibration, Radiation, etc.)

- Validation against Mission Requirements

7. *Case Studies:*

- Examples of Successful Payload Selection and Design for Different

Mission Types

- Lessons Learned and Best Practices

8. *Future Trends and Challenges:*

- Emerging Technologies and Innovations in Satellite Payloads

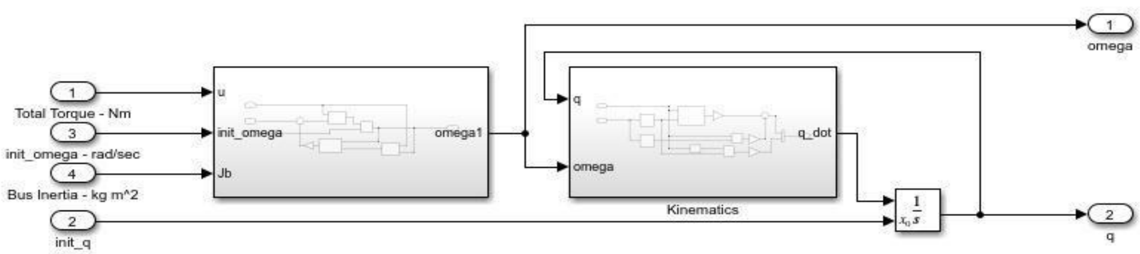
- Challenges in Meeting Evolving Mission Requirements

- Regulatory and Policy Implications.

3.Attitude Determination and Control System
PRINCIPLES OF SATELLITE ATTITUDE DETERMINATION AND CONTROL

Attitude determination is the process of combining available sensor inputs with knowledge of the spacecraft dynamics to provide an accurate and unique solution for the attitude state as a function of time, either onboard for immediate use, or after the fact (i.e. post-processing). With the powerful microprocessors now available for spaceflight, most attitude algorithms that formerly were performed as post-processing can now be programmed as onboard calculations.

Attitude control is the combination of the prediction of and reaction to a vehicle's rotational dynamics. Because spacecraft exist in an environment of small and often highly predictable disturbances, they may in certain cases be passively controlled. That is, a spacecraft may be designed in such a way that the environmental disturbances cause the spacecraft attitude to stabilize in the orientation needed to meet mission goals.
The following Simulink model represents the satellite attitude determination and control system. It embodies the Quaternion based Satellite Attitude dynamics and control system.



POWER SUBSYSTEM DESIGN:

Satellites are essential for various applications such as communication, weather monitoring, navigation, and scientific research. Designing a satellite involves meticulous planning, especially regarding its power generation, storage, and distribution system. This report provides an overview of the design considerations and components involved in ensuring efficient power management for a satellite.

Design Considerations:

Power Requirements: Determining the power needs of the satellite based on its payload, instruments, and operational requirements.
Reliability: Ensuring robustness and reliability of power systems to withstand harsh space conditions and prolonged operation.
Weight and Size Constraints: Minimizing the weight and size of power components to optimize the satellite's overall mass and volume.
Adaptability: Designing a flexible power system capable of adapting to varying power demands and environmental conditions.

Power Generation:

Solar Panels: Most satellites rely on solar panels to generate electrical power. Photovoltaic cells on the panels convert sunlight into electricity.
Deployable Arrays: To maximize power generation, satellites often feature deployable solar arrays that can extend after launch to increase surface area exposed to sunlight.
Energy Conversion Efficiency: Utilizing high-efficiency solar cells to maximize the conversion of solar energy into electrical power.
Orientation Control: Implementing mechanisms for orienting the solar panels towards the sun to optimize energy capture.

Power Storage:

Battery Systems: Batteries are used to store excess energy generated by solar panels for use during eclipse periods when the satellite is not exposed to sunlight.
Types of Batteries: Lithium-ion batteries are commonly used in satellites due to their high energy density, long cycle life, and reliability.
Battery Management System (BMS): Implementing a BMS to monitor and control the charging, discharging, and temperature of the batteries to ensure safe and efficient operation.

Power Distribution:

Power Regulation: Voltage regulation circuits ensure that the electrical power supplied to satellite subsystems remains within specified limits.

Power Conditioning: Conditioning circuits filter and stabilize the power supply to remove noise and fluctuations that could affect sensitive electronic components.

Redundancy: Incorporating redundant power distribution pathways to enhance reliability and fault tolerance.

Subsystem Isolation: Isolating subsystems to prevent power fluctuations or failures in one subsystem from affecting others.

4. Communication Subsystem

DESIGNING THE SATELLITE SYSTEM FOR UPLINK AND DOWNLINK DATA TRANSMISSION

Satellite communication systems are crucial for providing connectivity across vast distances, enabling global communication, broadcasting, and data transmission. The design of such systems involves careful consideration of various factors to ensure efficient and reliable uplink and downlink transmissions. This report outlines the key components and considerations involved in designing a satellite communication system for both uplink and downlink transmission, covering aspects such as system architecture, frequency bands, modulation techniques, and link budget analysis.

Satellite communication systems serve as vital infrastructure for connecting remote locations, facilitating communication in areas where terrestrial networks are impractical or unavailable. The design of these systems encompasses both the uplink (transmission from ground stations to the satellite) and downlink (transmission from the satellite to ground stations), each presenting unique challenges and requirements.

- System Architecture:

The architecture of a satellite communication system typically consists of ground stations, satellites, and associated infrastructure. Ground stations are equipped with antennas and transceivers for transmitting and receiving signals to and from the satellite. Satellites act as relay stations, receiving signals from ground stations on the uplink and retransmitting them to designated downlink coverage areas.

- Frequency Bands:

Satellite communication systems operate across various frequency bands, including L-band, C-band, Ku-band, and Ka-band, each offering different characteristics and suitability for different applications. Lower frequency bands like L-band and C-band provide better penetration through atmospheric conditions and are suitable for applications requiring reliable communication under adverse weather conditions. Higher frequency bands like Ku-band and Ka-band offer higher data rates and greater bandwidth, making them suitable for broadband internet and multimedia services.

- Modulation Techniques:

Modulation techniques play a crucial role in encoding information onto the carrier signal for transmission. Common modulation schemes used in satellite communication systems include phase-shift keying (PSK), quadrature amplitude modulation (QAM), and frequency-shift keying (FSK). The choice of modulation technique depends on factors such as bandwidth efficiency, power efficiency, and susceptibility to noise and interference.

- Link Budget Analysis:

Link budget analysis is essential for evaluating the performance and feasibility of a satellite communication link. It involves accounting for various factors such as transmit power, antenna gains, path loss, atmospheric attenuation, and noise figure to determine the received signal strength at the receiver. By ensuring that the received signal power exceeds the minimum required threshold, link budget analysis helps ensure reliable communication under different operating conditions.

Design of Satellite communication system for uplink and downlink transmission using MATLAB.

```
>> % Parameters
N = 1000;                      % Number of bits
Eb_No_dB = 10;                 % Energy per bit to noise power spectral density ratio (Eb/No) in dB
Eb_No_lin = 10^(Eb_No_dB/10); % Convert Eb/No from dB to linear scale
SNR_dB = Eb_No_dB + 10*log10(1/2); % Calculate SNR (signal-to-noise ratio) in dB
SNR_lin = 10^(SNR_dB/10);     % Convert SNR from dB to linear scale

% Generate random binary data
data = randi([0 1], 1, N);

% BPSK Modulation
s = 2*data - 1;                % Map binary 0 to -1 and binary 1 to 1
x = s;                         % BPSK modulation

% Add AWGN (Additive White Gaussian Noise)
n = sqrt(1/(2*SNR_lin))*(randn(1,N) + 1i*randn(1,N)); % Generate AWGN
y = x + n;                     % Received signal at the receiver

% BPSK Demodulation
z = real(y);                   % BPSK demodulation (coherent detection)

% Decision
received_data = z > 0;         % Decision thresholding: 0 if z < 0, 1 if z >= 0

% Bit Error Rate (BER) Calculation
BER = sum(data ~= received_data) / N; % Calculate bit error rate

% Display results
disp(['Eb/No (dB) = ' num2str(Eb_No_dB)]);
disp(['SNR (dB) = ' num2str(SNR_dB)]);
disp(['Bit Error Rate (BER) = ' num2str(BER)]);
Eb/No (dB) = 10
SNR (dB) = 6.9897
Bit Error Rate (BER) = 0.002
```

Also, it is open to create and simulate satellite communication system for uplink and downlink data transmission using MATLAB toolbox.

THERMAL CONTROL DESIGN

Satellites operate in an extreme thermal environment in space, where they are subjected to significant temperature variations ranging from extreme cold in shadowed regions to intense heat in direct sunlight. Effective thermal control design is crucial to ensuring the proper functioning and longevity of satellite systems. This report discusses the principles and strategies involved in managing the thermal environment of satellites through proper design.

Thermal Environment in Space:

Sunlight Exposure: Satellites experience direct solar radiation, which can cause overheating of components and systems.
Eclipse Periods: During eclipse periods when the satellite is in Earth's shadow, temperatures can drop drastically, leading to cold-soak conditions.

Radiative Heat Transfer: Heat is exchanged through radiation, conduction, and convection between the satellite and its surroundings **Thermal Control Design Strategies:**

Passive Thermal Control: Utilizing passive techniques such as insulation, surface coatings, and radiators to manage heat flow without the need for active components.

Active Thermal Control: Employing active systems like heaters, louvers, and thermal blankets to actively regulate temperatures as needed.

Multi-Layer Insulation (MLI): MLI blankets consisting of multiple layers of reflective foil and insulation material are commonly used to minimize heat transfer between the satellite and space environment.
Thermal Radiators: Deployable radiators or heat pipes are used to dissipate excess heat generated by onboard electronics or other systems.

Thermal Mass: Incorporating materials with high thermal mass to buffer temperature fluctuations and stabilize thermal conditions within the satellite.

Thermal Analysis and Modelling:

Finite Element Analysis (FEA): Conducting thermal simulations using FEA software to predict temperature distributions and evaluate the effectiveness of thermal control measures.

Thermal Cycling Tests: Subjecting satellite components and systems to thermal cycling tests to assess their performance under simulated space conditions and verify thermal control design.

Integration and Testing:

Thermal Vacuum Testing: Conducting thermal vacuum tests to simulate the thermal environment of space and validate the thermal control design under actual operating conditions.

Component-Level Testing: Testing individual components and subsystems to ensure they meet thermal performance requirements and interface properly with the overall thermal control system.

5. Structural Design for satellite

STRUCTURAL REQUIREMENTS AND MATERIAL SELECTION

Material selection is of primary importance when considering small spacecraft structures. Requirements for both physical properties (density, thermal expansion, and radiation resistance) and mechanical properties (modulus, strength, and toughness) must be satisfied. The manufacture of a typical structure involves both metallic and nonmetallic materials, each offering advantages and disadvantages.

Spacecraft commonly contain onboard devices whose function are based on mechanical movement (i.e.: slide, roll, rotate, separate, unfold, or spin) to either modify part of the spacecraft's geometry or to ensure operational function of a component or instrument. These devices are known as mechanisms, and as spacecraft become more sophisticated with the advances in miniaturization of electronics and systems, their reliance of mechanisms greatly increases.

Life of a spacecraft that include the moving parts associated in each phase:

- Deployment: dispensing spacecraft into orbit
- Beginning of mission life: deployments of solar arrays, booms, antennas, instrumentation, etc
- Mission maintenance: sun tracking, pointing antennas and instruments, active doors or shields, gyroscopes and reaction wheels, thrusters, etc.
- End-of-life: deorbiting methods.

Types of Satellite Mechanisms:

Type of Mechanism	**Description**	**Technology Examples**
Separation and Release	Reliable stowage and release of spacecraft and deployable components upon an external command (active) or springloaded (passive)	Clamp band systems, Frangibolts, release nuts, pin pullers, bolts, burn wire, hinges, and passive spring-loaded switches

Motorized	Allows for rotatory motion of spacecraft components.	Solar Array Drive Assembly, directional antennas, combination of dampeners and absorbers
Attitude Control	Provides pointing accuracy and stability for spacecraft and components	Reaction (momentum) wheel assembly, gimbals, component pointing, passive methods

Actuators:

Actuators are devices that convert electrical, thermal, hydraulic, and/or pneumatic energy into mechanical motion when said energy is allowed to flow. Active, or commanded, actuators use onboard data links and electrical transistors to determine the transfer of energy; whereas passive, or reactive, actuators allow the spacecraft environment (including external launch systems) to dictate actuator energy transfer. Spacecraft actuators are used for a variety of purposes, including:

Attitude control and gimbaling: to control the orientation of either part (gimbaling), or all (attitude control), of a spacecraft in space. This is important for pointing sensors, instruments, and/or communications antennas in a direction required for their use.

- *Attitude control general types*: reaction control thrusters, momentum wheels, control moment gyros, magnetic torquers, aerodynamic control surfaces, solar sails, and gravity gradient stabilizers.
- *Gimbal general types*: single-axis, dual-axis, and triple-axis system.

Propulsion: supporting attitude control system operations, manoeuvring to a new orbit, or reducing orbital velocity to begin atmospheric re-entry.

General types: chemical rocket engines (which can be the same as the upper stage launch vehicle engines), reaction control thrusters, and electric propulsion systems. These systems typically require actuated valves to operate.

Deployment, docking and separation: extend and unfold solar panels, antennas, and other spacecraft components requiring unpacking to function.

Deployment general types: hinge-&-spring based, linear-actuator-&scissor-frame based, roll-out systems, and inflatable structures.

Docking general types: probe-and-drogue, peripheral, and soft-capture systems.

Separation general types: spring-powered or gas-powered systems.

- *Thermal control*: manage all or part of the spacecraft's temperature. This is important for protecting internal components from extreme temperatures.

General types: louvers, heat pipes, thermoelectric/Peltier devices, and pumped thermal fluid systems.
Mechanical actuation methods/techniques that are found in many of the above systems include:

- *Electric & electromagnetic*: AC/DC motor, piezoelectric ceramics, and push/pull & rotary solenoids (including solenoid valves), and microelectromechanical systems (MEMS).

- *Thermal & thermoelectric*: Shape memory alloys (SMA), phasechange liquids/solids (paraffin wax, liquid metals), thermofluidic gas systems, thermal bimorph structures, harmonic drive micro actuators (HMAs), thermal knife cutters, and magnesium alloy band systems.

The following image provides some commercial actuators that are being used in the satellite actuator design market.

Manufacturer	Product	Mass (Kg)	Size (mm)	Power Consumption	Actuation method
Ensign-Bickford Aerospace & Defense Company	TiNi™ FD04 Frangibolt	0.007	13.72x10.16	15 W @ 9 VD	SMA
Ensign-Bickford Aerospace & Defense Company	TiNi™ ML50	0.015		-	SMA
Moog	Type 2 Side-Drive Solar Array Drive Mechanism (SADM)	5	234x278.6	15	-
Honeybee and MMA Design	Solar Array Drive Actuator (SADA)	3.1	127x210	-	Stepper Motor
Comat Space	Solar Array Drive Mechanism - 400	0.465	83x62x46	4	Geared motor
Comat Space	Solar Array Drive Mechanism - 1500	3.5	201x132	13	Geared motor
DHV Technology	MicroSADA-10	<0.25	100x100x100	-	Stepper motor
DHV Technology	MicroSADA-18	<0.95	226x80x18	-	Stepper motor
DCUBED	Micro Pin Puller (uD3PP)	0.08	25.5x25.5 x 25.5	-	SMA
DCUBED	Nano Pin Puller (nD3PP)	0.025	17x17x17	-	SMA
DCUBED	Micro Release Nut (uD3RN)	0.078	25x25x25	-	SMA
Beyond Gravity	Separation Nut PSM 3/8B	0.23	58.5x36x56	-	-
Revolv Space	Solar Array Rotary Actuator (SARA)	<0.35	97x97x23	1 W (average)	-
Nimesis Technology	Triggy	0.004-0.271	*	*	SMA

Integration and Testing:

Integration and testing are crucial phases in satellite structural design, ensuring that the satellite structure meets all design requirements and can withstand the harsh environments encountered during launch and in-orbit operations. Here's a brief explanation of integration and testing in satellite structural design:

1. *Structural integration:*

- The various structural subsystems, such as the primary structure, solar array supports, antenna supports, and payload platforms, are integrated and assembled together.
- Precise alignment and interface compatibility between the subsystems are verified during this stage.
- Structural integration also involves the installation of deployment mechanisms, thermal control hardware, and other structural components.

2. *Structural model testing:*

- Structural model testing is performed on engineering models or structural qualification models to verify the design and validate analytical models.
- This includes static load testing, modal surveys, and vibration testing to evaluate the structure's strength, stiffness, and dynamic behavior.
- Testing may also involve thermal cycling and acoustic testing to simulate launch and space environments.

3. *Deployment testing:*

- Deployment mechanisms, such as solar array deployment, antenna deployment, and reflector deployment, are thoroughly tested to ensure reliable and precise operation.
- Deployment testing may involve ground-based functional tests, as well as simulated zero-gravity or vacuum testing to replicate space conditions.

4. *Structural flight acceptance testing:*

- The flight model, which is the actual satellite structure intended for launch, undergoes acceptance testing to verify its readiness for flight.
- This may include static load tests, modal surveys, and vibration testing at acceptance levels to screen for any workmanship or manufacturing defects.

5. *Mass properties verification:*

- The mass properties of the satellite structure, including its mass, center of gravity, and moments of inertia, are carefully measured and verified against design requirements.
- Proper mass properties are essential for accurate attitude control and orbital maneuvers.

6. *Integration with other subsystems:*

- The satellite structure is integrated with other subsystems, such as propulsion, avionics, and payloads, to ensure compatibility and identify any potential interference or clearance issues.

- System-level testing may be performed to validate the overall satellite performance.

6.Software and onboard systems

DESIGNING SATELLITE ONBOARD SOFTWARE AND CONTROL SYSTEM

Satellites play a crucial role in various fields such as communication, navigation, weather forecasting, and scientific research. The effectiveness of a satellite heavily depends on its onboard software and control system, which are responsible for managing its operations, controlling its movements, and ensuring its functionality throughout its mission duration.

Requirements Analysis:

Before embarking on the design process, it's essential to gather and analyze the requirements for the satellite's onboard software and control system. These requirements typically include:

- Mission objectives and goals
- Payload specifications
- Orbit characteristics
- Environmental constraints
- Communication requirements
- Power and thermal constraints
- Reliability and fault tolerance requirements

System Architecture:

Based on the requirements analysis, the system architecture for the onboard software and control system is designed. This architecture encompasses the following components:

- Flight software: responsible for executing mission-specific tasks, handling payload operations, and managing subsystems.
- Guidance, Navigation, and Control (GNC) system: responsible for determining the satellite's position, velocity, and attitude, and executing maneuvers to maintain desired orbits.
- Command and Data Handling (C&DH) system: responsible for receiving commands from ground stations, processing data from sensors and payloads, and storing telemetry and scientific data.

- Communication subsystem: responsible for establishing communication links with ground stations and other satellites for data transfer and telemetry.

- Fault detection, isolation, and recovery (FDIR) system: responsible for detecting anomalies, isolating faults, and executing recovery procedures to ensure mission continuity.

Software Development:

The software development process involves:

- Writing code for various software modules using programming languages such as C, C++, and Python.

- Implementing algorithms for guidance, navigation, and control.

- Testing software modules individually and integrating them into the overall system.

- Validating software through simulations and hardware-in-the-loop testing.

Control System Design:

The control system design involves:

- Determining control algorithms for attitude determination and control, orbit control, and propulsion system management.

- Implementing redundant and fault-tolerant control schemes to ensure reliability.

- Conducting simulations and analysis to evaluate the performance of the control system under different operating conditions.

Integration and Testing:

Once the software and control system components are developed, they are integrated into the satellite hardware. Integration and testing activities include:

- Hardware-software integration testing to ensure compatibility and functionality.

- Environmental testing to validate performance under simulated space conditions.

- Functional testing to verify compliance with requirements and specifications.

- Mission simulation testing to validate overall system behavior and performance.

Verification and Validation:

Verification and validation processes ensure that the onboard software and control system meet the specified requirements and perform reliably in the intended operational environment. This involves:

- Conducting formal reviews and audits of design documentation and software code.

- Performing ground-based testing and simulation exercises to validate system functionality and performance.

- Conducting in-orbit testing and calibration to verify performance in the actual space environment.

UNDERSTANDING AND ENVIRONMENTAL TESTING OF SATELLITES

Satellites are crucial components of modern space exploration, communication, and scientific research. They operate in harsh environmental conditions, including extreme temperatures, vacuum, and mechanical stresses. Therefore, comprehensive understanding and rigorous environmental testing are essential to ensure their reliability and functionality in space.

Vibration Testing:

Vibration testing is conducted to simulate the mechanical stresses experienced during launch and in-orbit operations. The objectives of vibration testing are to assess the structural integrity, verify component mounting, and identify potential points of failure. Typically, satellites undergo sine, random, and shock vibration tests.

Sine Vibration Test: Involves subjecting the satellite to sinusoidal vibrations at various frequencies and amplitudes to simulate different launch and operational conditions.

Random Vibration Test: Mimics the random vibrations experienced during launch and in-orbit maneuvers, ensuring the satellite's resilience to unpredictable mechanical stresses.

Shock Vibration Test: Simulates sudden shocks and impacts that can occur during launch or deployment, ensuring the satellite's components can withstand such events without damage.

Thermal Testing:

Thermal testing is crucial for evaluating a satellite's ability to withstand extreme temperature variations encountered in space. Thermal cycling, vacuum bakeout, and thermal vacuum tests are commonly performed.

Thermal Cycling: Involves subjecting the satellite to repeated cycles of extreme temperatures to assess its thermal stability and the integrity of materials under thermal stress.

Vacuum Bakeout: Removes residual moisture and volatile substances from satellite components by exposing them to high temperatures in a vacuum chamber, preventing outgassing and potential contamination in space.

Thermal Vacuum Test: Combines vacuum conditions with thermal cycling to simulate the thermal environment of space accurately. This test ensures that the satellite's components function reliably under vacuum conditions while exposed to temperature extremes.

Vacuum Testing:

Vacuum testing is essential for evaluating the performance and behavior of satellite components in the near-zero pressure environment of space. It helps identify potential outgassing, material degradation, and thermal management issues.

Chamber Testing: Involves placing the satellite or its components in a vacuum chamber to simulate the near-vacuum conditions of space. Various parameters such as pressure, temperature, and radiation can be controlled to replicate specific space environments.

Leak Testing: Ensures the integrity of satellite seals and joints by subjecting them to vacuum conditions and monitoring for any pressure drop, indicating the presence of leaks.

Outgassing Evaluation: Determines the rate at which satellite materials release gases in a vacuum, which can affect optical surfaces and electronic components.