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SPACE SCIENCE & TECHNOLOGY

The Supplementary Physics Textbook for Class XI & XII

June 2023

Centre for School Curriculum Development
Department of School Education
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Royal Government of Bhutan

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"Your parents, relatives, and friends would be very proud of what you haveachieved. At your age, to have completed your studies is your personal accomplishment. Your knowledge and capabilities are a great asset for thenation. I congratulate you for your achievements. Finally, your capabilities and predisposition towards hard work will invariably shape the future of Bhutan. You must work with integrity, you must keep learning, keep working hard, and you must have the audacity to dream big."

- His Majesty Jigme Khesar Namgyel Wangchuck

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FOREWORD

Bhutanese science education system has come a long way. Guided by the noble vision of His Majesty The King and the philosophical foundations of 21st century educational paradigms, Bhutanese science education system is making continuous progress. Bhutanese science education system has undergone many reforms such as refinement of, and changes to theories, ideas, and beliefs over time. Therefore, the current Bhutanese science curriculum is a product of years of initiatives undertaken over the past several decades.

As the world today is confronted with multitude of real-world issues, there is a grand call to upscale and enhance the relevancy of education in itself. As far as the Ministry of Education and Skills Development (MoESD) is concerned, Bhutanese education system cannot afford to sit back and wait for the optimal time and space to come. The MoESD is, therefore, in full pursuit to diversify and enhance the relevancy of the science curriculum. This is no exception with classes 9 to 12 physics curriculum.

Today, as evident in the curriculum, the MoESD as never before, endeavours to bring in space technology as the new elements of science. While it may not be new, perhaps, it is largely motivated, in part, by a general consensus around the notion to upscale learners' abilities in science and STEM particularly in the contexts of space technology. At the heart, such notion stems from the view that engaging in scientific practices not only helps learners to acquire a robust understanding of space technology but also develops their scientific temper and scientific habits of mind. In addition, the book, both by and of itself, aspires to capture students' sense of wonder; pique interest; spark curiosity; or motivate them to remain constantly engaged in activities related to space technology.

As the book is first of its kind, especially in Bhutanese science education, I am quite confident that it will inherently serve as a springboard to further the quality of teaching and learning. Overall, I believe that the book, as it aspires, would certainly serve as a strong foundation of science education in equipping learners with the abilities to think critically, analyse information, and solve complex problems —the skills needed to pursue opportunities both within and beyond the STEM fields.

Karma Galay
(Director General)

INTRODUCTION

Science education in Bhutan was largely started with a curriculum adapted from other established education systems.By 1986, however, the Royal Government of Bhutan (RGoB) started to implement a localised science curriculum. Since then, science education in Bhutan witnessed a series of evolution, including the refinement of, and changes to, theories, ideas, and beliefs over time. The present classes 9 to 12 physics curriculumis, thus, shaped by numerous initiatives undertaken in the pastseveral decades.

To further the quality and the relevancy of the classes 9 to 12 physics curriculum, the erstwhile Royal Education Council (REC) initiated a major reform since 2009. The curriculum reform, forthe most part, was informed partly or wholly by the noble visionof His Majesty the King; and the contemporary approaches of the 21st century educational paradigms. As never experienced before, the curriculum reform then felt the urgency to strengthen the aspects of space technology in classes 9 to 12 physics curriculum. Thus, the erstwhile REC in collaboration with the Department of Information, Telecom, and Technology (DITT) endeavored to raise the standards of space technology inclasses 9 to 12 physics curriculum.

Today, the classes 9 to 12 physics curriculum presents a range of concepts and skills on space science and technology. These broadly include but are not limited to the universe, space, satellites, and rockets. Simply put, space technology is directly aimed to enhance learners' scientific abilities, scientific habits of mind, or spirits and practices of STEM in making informed decisions, evaluating policy matters, or weighing over scientific pieces of evidence. Beyond this, however, the inclusion of spacetechnology is generally aimed to capture students' interest andsense of wonder, pique curiosity, or encourage learners to remainincreasingly involved in space science.

This supplementary textbook for key stage 5 (classes XI & XII),like key stage 4, mainly focuses on the aspects drawn from thecurricular intentions of the classes 9 to 12 physics curriculum. Expanded from key stage 4, this supplementary textbook focuses on space-related scientific laws and principles; deep space and outer space exploration; applications of space technology; design and the development of rockets; launching of satellites and future prospects in space technology.

To dig deeper into the above said aspects of the book, it contains a blend of concepts and activities that require learners as to how to deepen or sophisticate their understanding. More importantly perhaps, the book contains many, if not, most activities that require technology to be used as means. For each activity or the chapter, the book contains follow-up questions and chapter-end questions that relate either directly with theconcepts or just demand the application of concepts in a contextual scenario.

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CLASS XI

Space Technology in Our Lives

SPACE TECHNOLOGY IN OUR LIVES

Space technology has revolutionized our way of life by providing innovative solutions to global challenges. The development of rockets and satellites has played a crucial role in space exploration, and their design is based on the laws and theories of physics. The universal law of gravitation, which describes the attraction between two objects, is fundamental in designing rockets and satellites that are capable of overcoming Earth's gravitational pull. The concepts of acceleration due to gravity, escape velocity, and orbital velocity are used to understand the behavior of satellites in orbit. Satellites based on their payloads, orbits, and sizes have transformed the way we communicate, forecast weather, navigate, and observe our planet.

Moreover, satellite data analysis is critical in gaining knowledge about our world and space, providing valuable insights into global phenomena like climate change, natural disasters, and land use. As a result, the in-depth understanding of space technology has become an integral part of our daily lives, and its influence can be observed in many aspects of modern life. Therefore, it is vital to continue developing and advancing space technology to address global challenges and to improve the quality of life for all.

1. Universal Law of Gravitation

Objective

- Describe the effect of gravitational force on centripetal force to comprehend the motion of satellites in the orbit.

1.1 Acceleration due to Gravity on the Earth

Do rockets launched from the equator and poles of the Earth require the same thrust? Rockets launched from different geographical locations on the Earth require different velocities. This is due to the variation of Earth's gravitational force. Figure 1.1 shows the launch of ELaNA-XII on October 8, 2015.

Figure 1.1 Rocket launch

According to Newton's universal law of gravitation, the gravitational force between any two bodies with masses separated by a distance is given by:

$$F_g = G\frac{M \times m}{r^2}$$

Where,

G = universal gravitational constant

F_g = the gravitational force

M = mass of one of the bodies (e.g., earth)

m = mass of the other body (e.g., rockets)

r = distance between the two bodies

The force of gravity experienced by a body of mass 'm' is equalto the weight of the body. Therefore,

$$mg = G\frac{Mm}{r^2}$$

Where, g = acceleration due to gravity

$$g = G\frac{M}{r^2}$$

Acceleration due to gravity of the Earth varies from one point toanother. It is affected by various factors such as altitude, depthfrom the surface of the Earth, shape of the Earth, or rotation ofthe Earth.

Activity 1: Determining how acceleration due to gravity changes with depth, height, shape and rotation of the Earth

To determine how the acceleration due to gravity changes with the altitude and the depth below the surface of the Earth, explore the link https://bit.ly/3nRN5VO or scan the QR code to complete Table 1.1. You may also explore information from other relevant sources, if any.

Table 1.1 Variation of acceleration due to gravity

Factor	Variation in gravity
1. Altitude or height abovesea level	
2. Depth below the surface ofthe Earth	
3. Shape of the Earth	
4. Rotation of the Earth	

Questions

1. A spaceship is orbiting the Earth at an altitude of 500 kilometers. Calculate the acceleration due to gravity at that altitude.

2. A mining tunnel is dug 500 meters below the surface of the Earth. Calculate the acceleration due to gravity at this location.

1.2 Escape Velocity

Objects that are thrown upwards typically descend back to the Earth because they are influenced by the gravitational attraction exerted by the Earth. However, if objects are projected into space with a force greater than the Earth's gravitational pull, then they would not fall back. Thus, the minimum velocity required by objects to escape the Earth's gravitational pull is commonly referred to as escape velocity.

Factors affecting the escape velocity are given in the followingformula

$$v_e = \sqrt{\frac{2GM}{r}}$$

where,

v_e= escape velocity

G = Gravitational constant

M = mass of the attracting body

r = radius of the attracting body

Activity 2: Understanding factors affecting escape velocity

Complete Table 1.2 to understand the factors affecting escape velocity and answer the following questions.

Table 1.2 Factors affecting escape velocity

Attracting body	Mass (kg)	Radius (km)	Escape velocity km/s)
Earth	5.972 × 1024	6371	
Moon	7.342 × 1022		2.4
Jupiter		70,000	59.5

Questions

1. How does the mass and radius of an attracting bodyimpact its escape velocity?
2. The escape velocity of Jupiter is greater than the escapevelocity of Mars. Do you agree? Justify your answer.

1.3 Orbital Velocity

Objects revolve around a celestial body in a fixed orbit with a velocity called orbital velocity. It is the minimum velocity required for the satellite to orbit around the celestial body. Figure 1.3 shows a satellite orbiting the Earth.

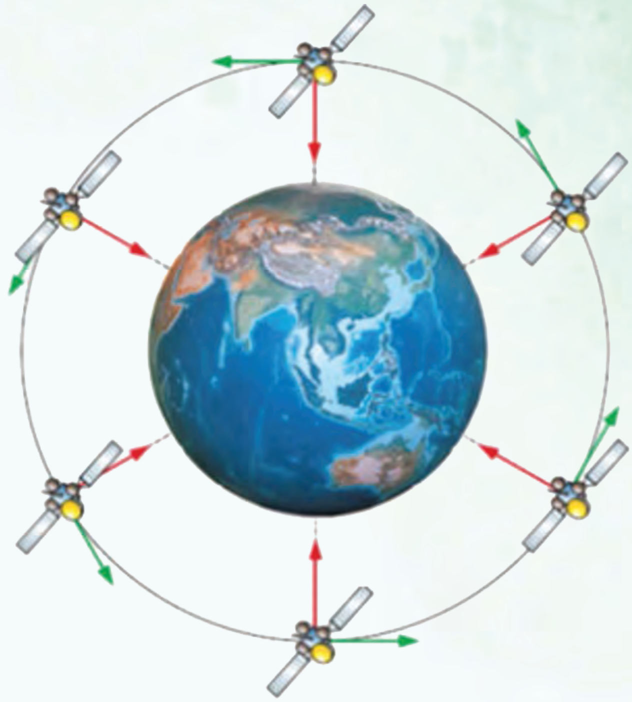


Figure 1.3 Satellite orbiting the Earth.

Centripetal force plays an essential role for a satellite to orbit around a planet (e.g. Earth). This force is provided by gravity, which acts on the satellite. The necessary centripetal force required by the satellite to revolve in a particular orbit must beequal to the force of gravity at that orbit. Consider a satellite with mass 'm' revolving around the Earth in a circular orbit at a distance 'r' at height 'h' from the Earth's surface. If 'M' and 'R' arethe mass and radius of the Earth respectively as shown in Figure1.4.

Thus,

$$F_c = F_g$$

$$\frac{mX(V_0)^2}{r} = G\frac{Mxm}{r^2}$$

$$v_o = \sqrt{\frac{GM}{r}}$$

since r = R+h

$$v_o = \sqrt{\frac{GM}{R+h}}$$

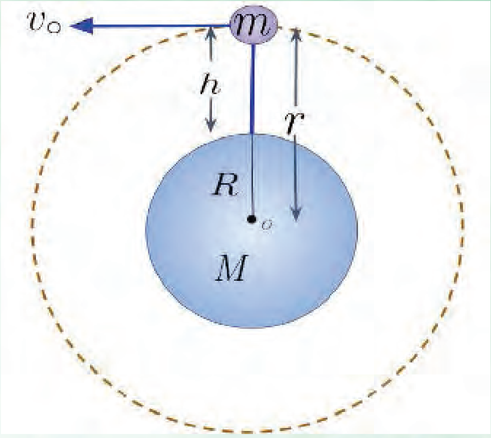


Figure 1.3 Satellite orbiting the Eartg

Where,

F_g= force of gravity

F_o= centripetal forcev_0= orbital velocity

M = mass of the Earth

m = mass of the satellite

r = distance between the Earth and the satellite

h = distance of satellite from the surface of the Earth

R = radius of the Earth

Therefore, we can conclude that the orbital velocity of a satellite depends on ‘r’ and ‘h’.

Activity 3: Understanding the orbital velocity of a satellite in different orbits

What we need:

- narrow rigid tube (ballpoint pen barrel, straw, etc.)
- piece of string about 50 cm
- objects
- weights
- paper clip

What to do:

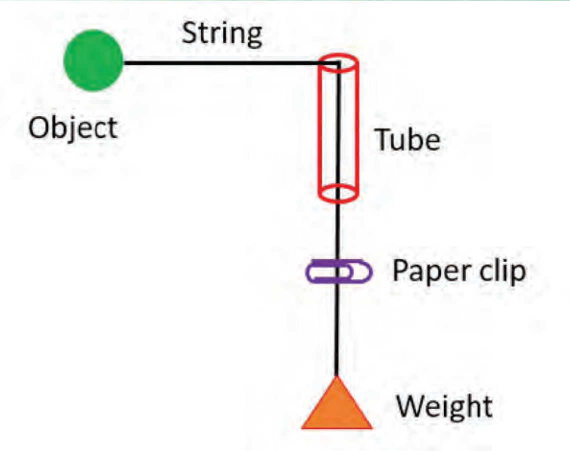


Figure 1.5 Velocity of object in a circular motion

1. Build the demonstration model as shown in Figure 1.5. The object represents a satellite and the weight is to supply the centripetal force to the object. The narrow tube is to provide a grip to control the motion of the object.
2. Keep the distance between the object and the tube 30 cm.
3. Attached a paper clip to the string about 3 cm below thetube.
4. Spin the object without letting the paper clip to shift up ordown.
5. Once the object spins smoothly, record the time taken for10 revolutions.
6. Repeat the steps from 2 - 5 twice by decreasing thedistance and record your observation in Table 1.3.
7. Repeat steps 1- 5 by changing the objects and recordyour observation in Table 1.4.
8. Draw at least two conclusions from the activity.

Table 1.3 Time Period of an Object in a CirculaMotion

Sl.No.	Distance (cm)	Time taken for 10revolutions (s)	Time period (s)
1	30		
2	20		
3	10		

Table 1.4 Time Period of Objects in a CirculaMotion

Sl.No.	Objects	Time taken for 10revolutions (s)	Time period (s)
1	First object		
2	Second object		
3	Third object		

Questions

1. How do mass and distance affect the time period of asatellite?
2. How would you design a satellite based on its mass to achieve optimal performance in space?
3. A typical shuttle orbits 200 km above the Earth. How fast does a satellite at this distance have to move to stay in orbit? Calculate its period of revolution (Mass of the Earth
4. $=5.972 \times 10^{24}$ kg and its radius = 6.371×10^{3} m,$G=6.67\times10^{-11}Nm^{2}kg^{-2}$)

Activity 4: Demonstrating interplanetary travel

What we need:

- a piece of paper
- a pencil

What to do:

1. On a piece of paper, draw the Sun and the eight planets bykeeping sufficient distance between the Earth and Mars.
2. Draw a satellite revolving around the Earth.
2. Draw a path to send the satellite to Mars.
3. Use the link
   https://shorturl.at/ozIJT/https://shorturl.at/jotFQ to exploreinterplanetary travel.
5. Explain Hohmann transfer orbit.

Questions

1. How are the mechanics and dynamics of interplanetarytravel influenced by centripetal force?
2. What is a Hohmann transfer orbit, and how does it facilitateinterplanetary travel?

Fun Fact

Escape velocity does not depend on the mass or shape of the object trying to escape. It only depends on the celestial body being escaped from.

2. Satellite

Objective

- Describe different types of satellites based on payload,orbit, and size.

2.1 Types of Satellites

Have you seen a satellite? A satellite is a body that orbits aroundcelestial bodies in space. Generally, satellites are classified asnatural and artificial. Examples of natural satellites are the Earth and the Moon. The Earth revolves around the Sun and the Moonrevolves around the Earth.

An artificial satellite is a man-made machine that is launched into space and orbits around a celestial body. Artificial satellites are designed in many shapes and sizes. They have different payloads to perform different functions in space.

Fun Fact

As of March 8, 2023 there are 4500 satellites.

Activity 5: Exploring types of satellites

What to do:

1. Explore different types of satellites. Use the link or QR code to understand the types of satellites https://eos.com/blog/types-of-satellites/
2. Classify the satellites as per the format of Table 2.1.

Table 2.1 Types of Satellites

Types of Satellite		Name of Satellite
Based on orbit	1. LEO (160 - 2000 km)	
	2. MEO (2000 - 35786 km)	
	3. GEO (above 35786 km)	
Based on Payload	1. Communication	
	2. Earth observation	
Based on size	1. Small satellite (<500kg)	
	2. Medium-sized satellite(500 - 1000kg)	
	3. Large Satellite (>1000kg)	

Questions

1. How do communication satellites differ from Earth observation satellites in terms of their functionality and design?
2. In which orbit is the BHUTAN-1 satellite deployed?
3. What are the potential future advancements andapplications for small satellites, such as CubeSats, and howmight they impact space missions and scientific research?

3. Space Technology Applications and Satellite Data Analysis

Objectives

- Explain the applications of satellite technology for variouspurposes.
- Analyze satellite data to study local and global phenomenasuch as global warming, natural disaster, land use, etc.

Space technology has become vital in our daily lives, enabling space exploration and groundbreaking discoveries. In the future, it will revolutionize transportation, agriculture, healthcare, and address climate change. With diverse applications, the importance of space technology will only increase.

3.1 Applications of Satellite Communication

Satellites relay signals for long-distance communication, allowing real-time voice calls, video conferencing, and data transmission globally. They transmit signals to receiving antennas enabling the distribution of television, radio, and other broadcasting services. Satellites play a significant role in providing internet connectivity, especially in remote areas where there are no othermeans of communication. This enables telemedicine, allowing the provision of remote healthcare services, consultations, and diagnoses, bridging the gap between urban and rural areas. In education, satellite communication in remote areas ensures access to quality education enabling distance learning programs and connecting students with expert teachers. Satellite navigation systems enhance transportation, logistics, and navigation by providing precise positioning and tracking services.During disasters, satellite communication establishes communication networks, supports coordination efforts, and aids in rescue operations, while also facilitating damage assessmentand efficient disaster management.

Overall, satellite communication plays a pivotal role in connectingpeople, empowering various sectors and connecting the society as shown in Figure 3.1.

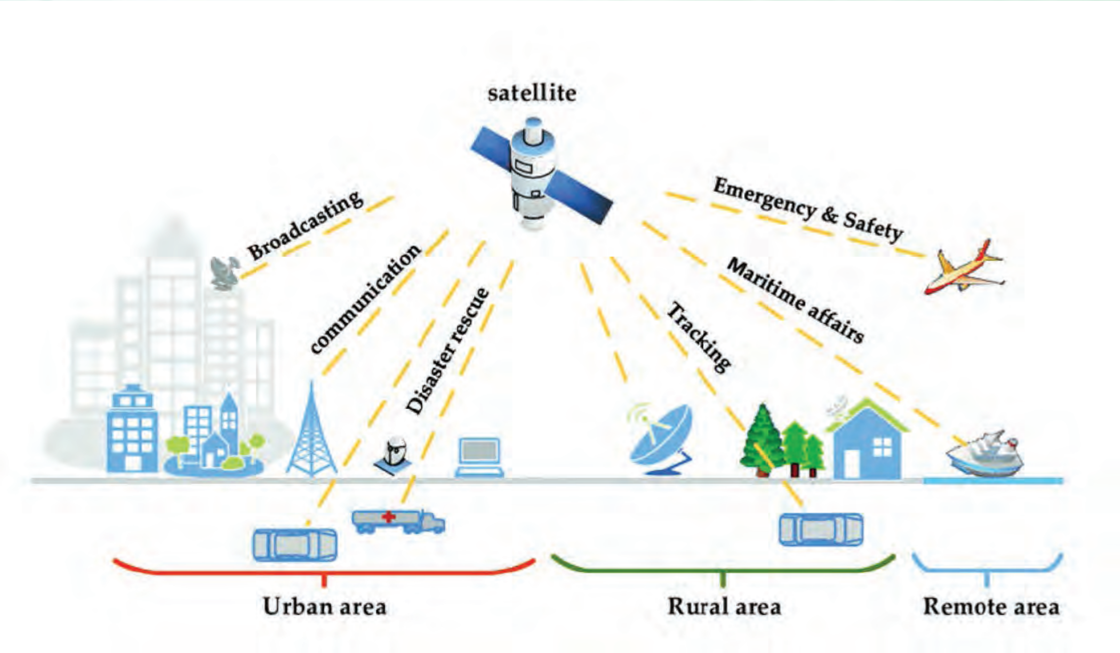


Figure 3.1 Satellite communication

Activity 6: Exploring Satellite Coverage

What we need:

- flashlight
- meter ruler
- chart paper

What to do:

1. Use the chart paper as a screen and focus light on it froman appropriate distance as shown in Figure 3.2.

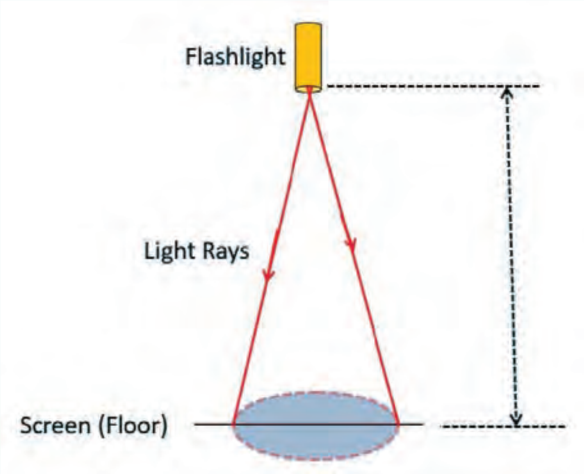


Figure 3.2 Satellite coverage

2. Calculate the area covered by the light source on thescreen and record in Table 3.1.
3. Repeat steps and 2 for four more times by changing the distance between the light source and the screen.

Table 3.1 Satellite coverage

Sl.No	Distance between the screenand the light source (m)	Area covered by thelight source (m^2)
1		
2		
3		
4		
5		

Questions

1. Satellites near the Earth have more coverage. Do you agree? Give reason(s).
2. What is the minimum number of geosynchronous satellitesneeded in a constellation to provide complete coverage of the entire Earth, if each satellite is positioned at an orbitalheight of 35,786 km and has a maximum coverage distanceof 19.5 km? (Radius of Earth: 6371 km)

3.2 Earth Observation

Remote sensing is employed by the Earth observation satellites to acquire detailed images and data of the Earth's surface, atmosphere, and oceans, as shown in Figure 3.3. Various remotesensors are utilized, each with its own unique strengths and capabilities, catering to diverse research inquiries, applications,and goals, by furnishing extensive data for analysis. The collected data, including satellite imagery, is examined to offer insights into weather prediction, urban planning, infrastructure advancement, mapping, agriculture, and ensuring food security.

Figure 3.3 Observation of the Earth by satellite

Activity 7: Observing changes in land pattern

What to do:

1. Identify a specific place of your interest to observe the changes in land pattern.
2. Use Google Earth timelapse feature using the linkhttps://tinyurl.com/22283w4k to see the changes over time.

Questions

1. How does remote sensing contribute to our understandingof alterations in land patterns?
2. Analyze the satellite image timelapse of the selected location and data archived over the period of time andprovide inference based on the analysis.
3. How do satellite images of the Earth enable us to address global challenges and make informed decisions regarding issues such as climate change, natural resource management, and disaster response?

Fun Fact

BHUTAN-1 was first launched to the ISS before releasing into the Earth's orbit.

CHECK YOUR UNDERSTANDING

1. Read the question carefully and choose the correctoption.

   i. The strength of acceleration due to gravity varies withthe

      A. size of the rocket.

      B. speed of the rocket.

      C. weight of the rocket.

      D. altitude of the rocket

   ii. Which of the following statements best compares the escape velocity and orbital velocity of an object?

      A. The escape velocity is greater than the orbitalvelocity.

      B. The orbital velocity is greater than the escapevelocity.

      C. The escape velocity and orbital velocity arealways equal.

      D. The escape velocity depends on mass whereas orbital velocity does not.

   iii. The equilibrium of the following two factors enables asatellite to remain in orbit.

      A. Satellite weight and speed

      B. Centripetal force and mass

      C. Gravitational pull and inertia

      D. Satellite weight and the pull of the moon and sun

iv. Low earth orbit satellites are not used forcommunications because they

A. heat up and melt.

B. make a lot of noise.

C. produce sonic booms.

D. provide 24 hour contact to the users

v. Which technology is employed by Earth observation satellites to acquire detailed images and data of the Earth's surface, atmosphere, and oceans?

A. Robotics

B. Virtual reality

C. Remote sensing

D. Artificial intelligence

2. State whether the following statements are 'True' or 'False'.

Statement	True/False
i. The acceleration due to gravity increasesas you move closer to the center of the Earth.	
ii. The centripetal force required to keep anobject in orbit increases as the mass of the object increases.	
iii. If the orbital velocity of an object decreases, it falls back to the surface ofthe celestial body.	
iv. Geostationary orbit is ideal for Earth observation due to its closer proximity tothe Earth's surface.	
v. Satellite data analysis relies on visible lightimagery and does not utilize other parts of the electromagnetic spectrum.	

3. Answer the following questions.

i. What role does acceleration due to gravity play in thepositioning and movement of satellites, and how does itaffect the launch velocity and trajectory required to place a satellite into orbit?

ii. What would happen to a satellite if the gravitational force suddenly disappeared?

iii. Why is it important to place communication satellites ina specific orbit and which orbit is the most suitable?

iv. How can satellite communication technologies aid in responding to emergencies during natural disasters?

v. What are potential applications that satellite communication technology may have in the future?

vi. A black hole is a body from which nothing can escape.What conditions must be met for a uniform spherical body of mass M to be a black hole? What should the radius of a black hole be if it has a mass nine times that of the Earth?

(Mass of Earth $M_E=6x10^{24}$kg and $G=6.67x10^{-11}Nm^2kg^{-2}$).

vii. A rocket is launched from Earth with the goal of reachinga stable orbit around the planet. The mass of the Earth isapproximately $6x10^{24}$kg, and its radius is approximately 6,371 km. Calculate the following:

a. the escape velocity required for the rocket to leaveEarth's gravitational pull

b. the orbital velocity needed for the rocket to maintain a stable orbit around Earth.

c. if the rocket reaches an altitude of 200 km abovethe Earth's surface, calculate its distance from the center of the Earth.

CLASS XII

Developing a Satellite

SATELLITE

The exploration, usage, and understanding of space and celestialbodies are made possible by a variety of scientific, technical, andtechnological advancements. Satellite-based space explorationand understanding have played a significant role in understanding the mysteries of outer space. However, there are challenges faced in the development of satellites, such as mission definition, funding, engineering, and regulatory concerns. Additionally, it is crucial to understand the orbital mechanics based on Kepler's laws, spacecraft components, the launch procedures, and the importance of internationalcooperation and collaboration in the satellite development sector. It is crucial to consider how satellite technology develops in the future, including new developments like miniaturized satellites, reusable launch vehicles, and satellite constellations, and to weigh the possible advantages and risks of these new developments and innovations.

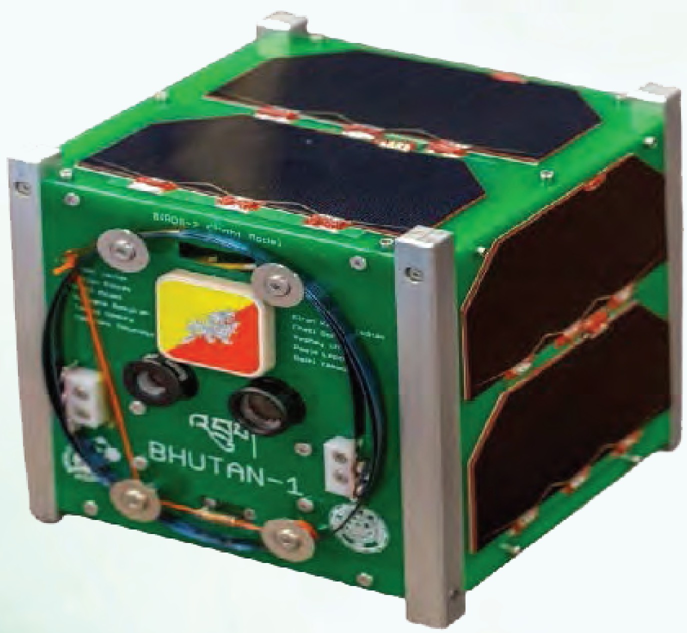


Figure 1.1 Bhutan's first stellite, BHUTAN-1

1. Processes of Satellite Development

Objective

- Explain satellite development processes to develop amodel of an artificial satellite.

Build a Satellite: Launch your Dreams

Have you ever wondered what it takes to build a satellite and send your dreams soaring among the stars? The phases of the satellite development process is shown in Figure 1.1 followed by explaination of each phase.

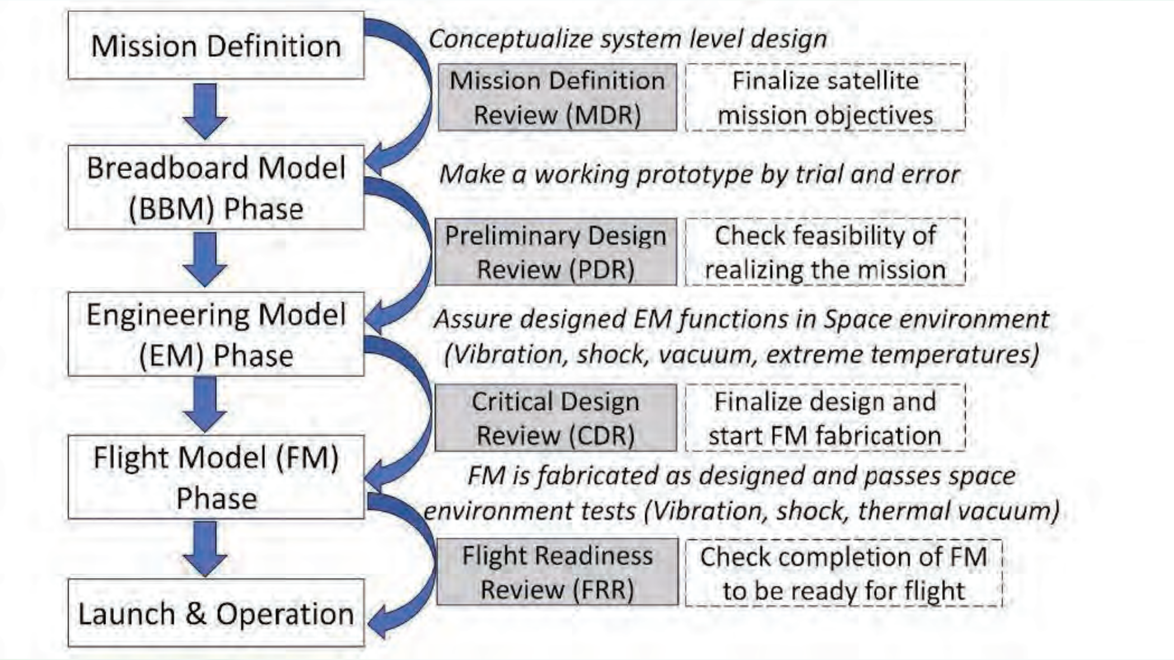


Figure 1.1 Design process in building a satellite

a. Mission Definition

During the mission definition phase, the goals, objectives, andrequirements of the satellite mission are identified and defined.The system level design of the satellite is also conceptualized.This phase includes determining the purpose of the satellite, itstarget orbit, payload requirements, expected mission duration, and other key mission parameters. The end result of this phase is the Mission Definition Review (MDR), where the mission objectiveis reviewed and finalized.

b. Breadboard Model (BBM) Phase

The Breadboard Model (BBM) phase follows the missiondefinition phase. In this phase, the satellite design is developed further, and a functional prototype in a breadboard is built. The BBM phase includes design, prototyping, and testing. The completion of this phase is marked by the Preliminary Design Review (PDR), where the satellite design is assessed for its feasibility, functionality, and compliance with requirements.

c. Engineering Model (EM) Phase

The Engineering Model (EM) phase starts after the successfulPDR. In this phase, the satellite design is refined, and an engineering model is fabricated, assembled, integrated, and tested. The engineering model is closest to the final design andincorporates the intended features and functionalities of the satellite. The EM must pass through a series of rigorous qualification tests in an emulated space environment (vacuum, extreme temperature, vibration, shock) to ensure the proper functionality of the satellite when it is launched to space. The Critical Design Review (CDR) is conducted to ensure the design is feasible, and meets the necessary requirements for proceedingto development of the flight model (FM).

d. Flight Model (FM) Phase

The Flight Model (FM) phase follows the CDR. This phase involves fabrication, assembly, integration, and testing of the flight model, which is the actual satellite that will be launched into space. The satellite undergoes a series of space environmentaltests (vacuum, extreme temperatures, vibration, shock) to simulate the conditions it will experience during launch and operation. The completion of this phase is marked by the FlightReadiness Review (FRR), where the satellite's readiness for launch is assessed.

e. Launch and Operation

The final phase of satellite development is the launch and operation phase. Once the satellite is deemed ready for launch, itis transported to the launch site and prepared for integration with the launch vehicle. After a successful launch, the satellite is deployed into its designated orbit. During the operation phase,the satellite's systems and payloads are activated, and it beginsits intended mission. Throughout its operational life, the satellite is monitored and controlled from a ground station to ensure itsproper functioning and mission success.

Activity 1: Designing Satellite Mission

Bhutan plans to launch a satellite with an Earth Observation payload. Work in groups to research and gather information forwhat is required to be done in each phase for the defined mission. Each group presents their findings to the class, explaining the significance and key aspects of the assigned phase.

Questions

1. What are the main objectives and activities involved in the Mission Definition phase of satellite development?
2. How does the EM phase differ from the BBM phase in termsof design and testing?
3. What are some key considerations and challenges duringthe Launch and Operation phase of a satellite mission?

2. Orbital Mechanics and Satellite Launch

Objective

- Explain the concept of rocket launch technology.

There are numerous spacecraft in orbit around the Earth, servingvarious purposes. If the orbit is a circle, its motion can be readily estimated. However, when the orbit is an ellipse, which is the case for most orbits, the task becomes more challenging.

2.1 Demystifying the motion of objects in orbit

What does it take to know the mysteries of orbital mechanics?

Understanding orbits is crucial for the placement of satellites, mission planning, and space exploration. It enables researchers and engineers to plan complex activities to ensure the successof space missions, including computing launch trajectories andpredicting satellite placements. When an object such as a satellite or spacecraft is orbiting around a planet, it remains at afixed distance from the planet's surface when the centripetal force is equal to the gravitational force.

Activity 2: Exploring orbital elements and planetary motion

Use the simulation link https://shorturl.at/apFR4 to explore orbital elements and planetary motion.

Questions

1. How does the gravitational force affect the motion ofobjects in an orbit?
2. What are the fundamental principles of orbital mechanics?
3. Identify the variables associated with the orbit andplanetary motion as shown in the simulation.

2.2 Kepler's Laws of Planetary Motion

These laws, formulated by Johannes Kepler in the 17th century, describe the motion of objects in orbit.

a. Kepler's First Law

Planets revolve around the sun in elliptical orbits having the sunat one of the foci. It is characteristic of an ellipse that the sum ofthe distances of any planet from two foci is constant. Figure 2.1 shows the explanation to Kepler's first law.

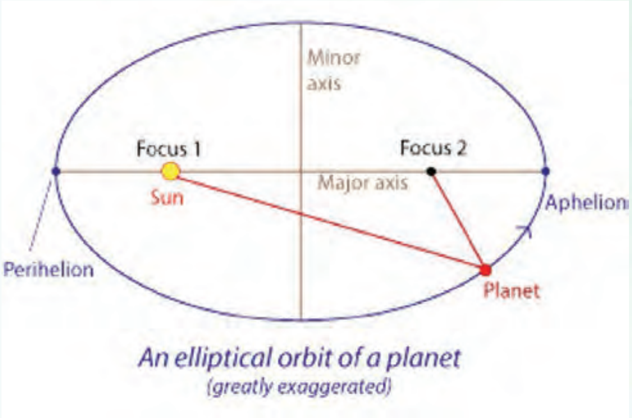


Figure 2.1 Kepler's first law

Activity 3: Understanding Kepler's First Law

Consider f_1 and f_2 as the position of the Sun as shown in Figure 2.2.

Refer to the figure and answer the following questions.

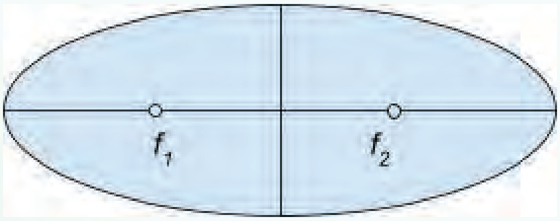


Figure 2.2 Sample elliptical orbit

Questions

1. Prove that the sum of the distances of any planet on thecircumference of the circle from two foci, f1 and f2 is constant as given in the figure.

2. How can you relate the geometry of a planetary orbit toKepler's first law?
3. Describe the significance of a planet following the ellipsein its orbit.

b. Kepler's Second Law

The law describes the speed of a planet traveling in an ellipticalorbit around the Sun. It states that a line between the Sun andthe planet sweeps equal areas in equal times. Thus, the speed ofthe planet increases as it nears the Sun and decreases as it moves away from the sun.

Activity 4: Investigating Kepler's second law

What we need:

- twine thread (approximately 1 m)
- bob

What to do?

1. Attach a twine thread securely to the bob.
2. Whirl it around in a circular path as shown in Figure 2.3
3. After a few revolutions allow the twine to wind itself uparound the finger.

Figure 2.3 Whirl of twine thread

4. Record the observations and answer the questions.

Questions

1. What happened to the speed of the bob when the lengthof the twine thread was shortened?
2. How can you relate the speed of the Earth at different positions (A, B, and C) with respect to the Sun as shown inFigure 2.4?

3. What is the pattern in climatic conditions on the Earth's surface when it is positioned at A and C in the figure?

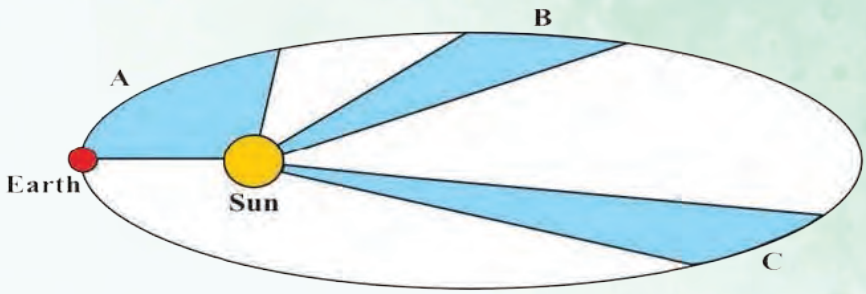


Figure 2.4 Position of the Earth with respect to the sun

c. Kepler's Third Law

The square of the orbital period of the planet is directly proportional to the cube of the semi-major axis of its orbit. Itimplies that the period for a planet to orbit the Sun increasesrapidly with the radius of its orbit.

Activity 5: Examining the Kelper's Third Law

The hypothetical data for distance between Jupiter and its moons along with the orbital period is provided in Table 1. Use thedata for calculations to prove Kepler's third law and answer thefollowing questions.

Table 1 Distance between Jupiter and Moons

Moon	Distance from center of Jupiter (10^3 km)	Orbital period/day	$\frac{(radius\ of\ the\ orbit)^3}{(time\ period\ of\ orbit)^2}$
Io	420	1.8	
Europa	670	3.6	
Ganymede	1070	7.2	
Callisto	1890	16.7	

Questions

1. What is the relation between distance and orbital period inthe activity?

2. How can you relate the conclusion with Kepler's third lawas shown in Figure 2.5?

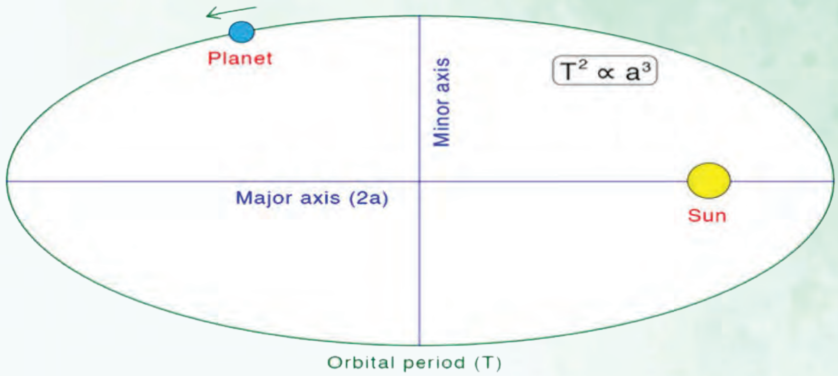


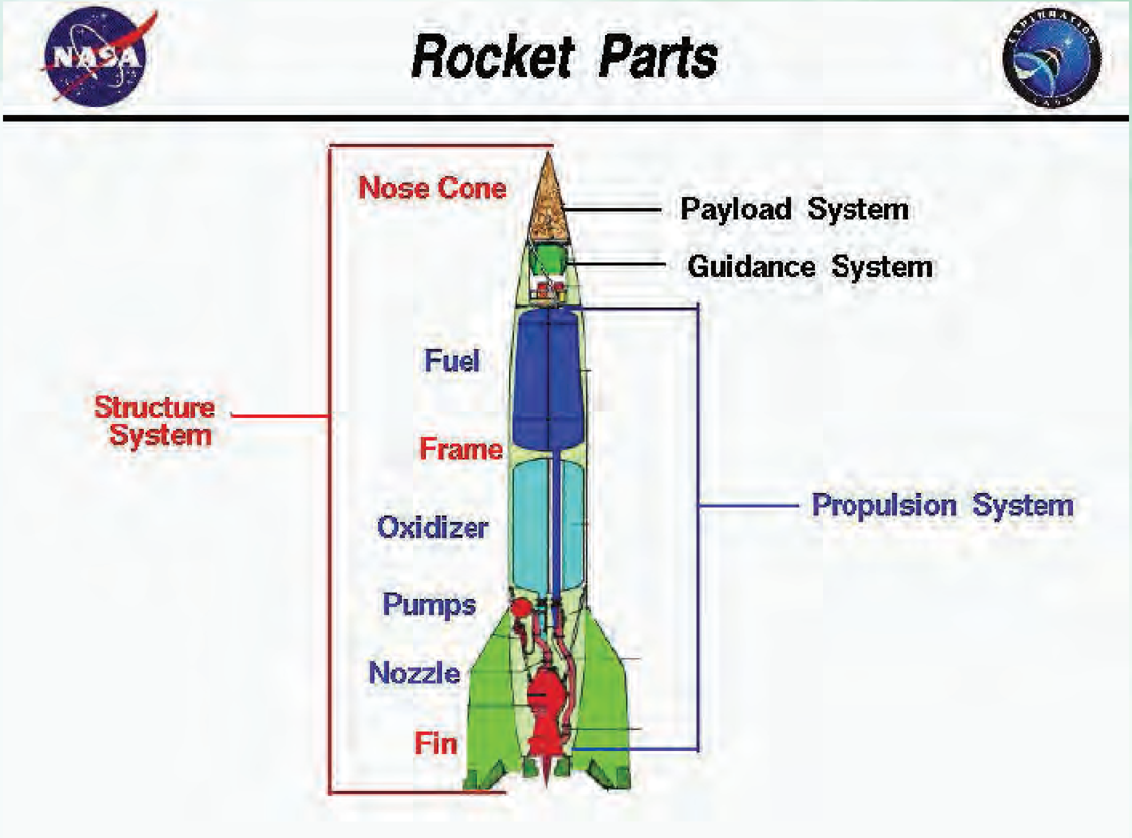
Figure 2.5 Kepler's third law

2.3 Rocket: The Space Car

Did you ever wonder how humans manage to explore space and reach distant celestial bodies? There is an incredible world of rockets and technology that can take humans on a journey beyond the Earth's atmosphere.

A rocket is a vehicle that is used to launch satellites and send supplies or humans to space. Rocket works on the principle ofNewton's third law of motion. The exhaust, which is

flames, hot gases, and smoke that comes from the burning of therocket's propellants, propels the rocket forward. Rockets come in a variety of shapes and sizes. The basic components of a rocket consist of the structural system, propulsion system, guidance system, and payload system as shown in Figure 2.6.



Fiure 2.6 Basic components of rocket

Activity 6:Discovering the wonders of rocket launch

Use the simulation link https://t.ly/L5lh to launch a rocket to themaximum height. Attempt till the rocket reaches space and successfully deploys its payload. Record your observations in Table 2 and answer the questions that follow.

Table 2: Rocket launch

Attempt	Mass (kg)	Thrust (N)	Thrust time (s)	Maximum speed (m/s)	Height (km)	Remark
1						
2						
3						

Questions

1. What are some of the challenges encountered during rocket launch?
2. What are the crucial factors that must be taken into account to ensure the successful launch of a rocket?
3. What potential safety, environmental and risk-related impacts might arise during the design and launch of a rocket?

Rocket flight profile

During liftoff, the rocket's engine generates thrust greater than its weight, launching it from the launch pad. Initially, it ascends vertically, driven by powerful thrust and decreasing weight. As the rocket gains altitude, it escapes Earth's atmosphere with minimal drag and adjusts its flight path away from vertical as shown in Figure 2.7.

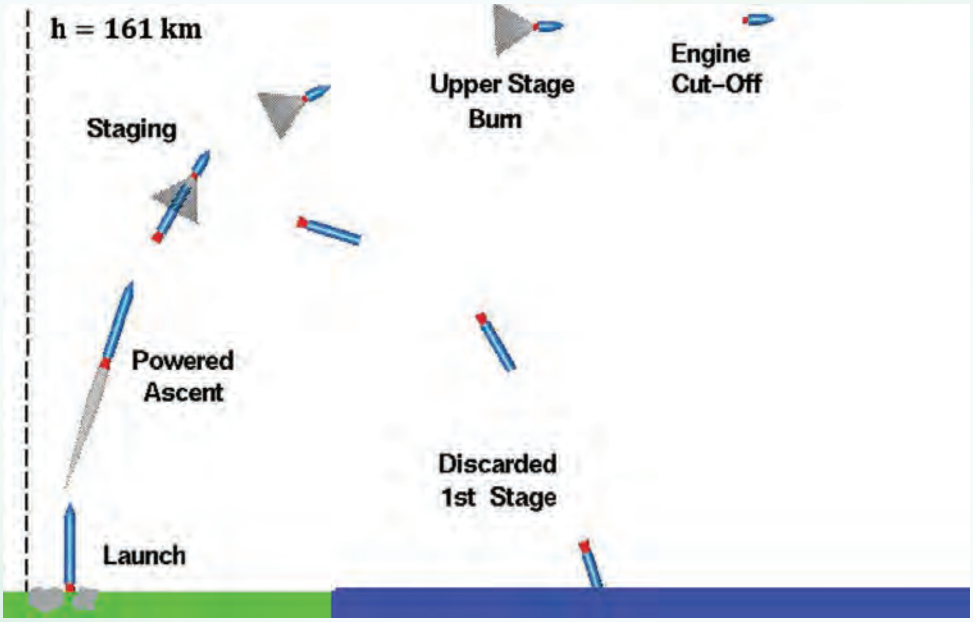


Figure 2.7 Flight to Orbit

After a few minutes, staging occurs, shedding the first stage and igniting the upper stage engine. The discarded first stage is either discarded completely or follows a ballistic trajectory back to Earth. The upper stage continues accelerating, gradually tilting horizontally. At a specific altitude and velocity, the upperstage engine is deactivated, placing the payload into Earth's orbit. The required orbital velocity of the payload is determined by Kepler's equation.

Activity 7: Designing a Rocket

1. Use the information given in the link https://tinyurl.com/v7zdr8du or app https://openrocket.info/ to design a rocket in groups.
2. Share your design with the other groups.
3. With reference to the design, answer the followingquestions.

Questions

1. What challenges did you face during the design process,and how did you overcome them?
2. Describe any safety measures or precautions you implemented in your design.
3. How can your design contribute to improving rocketdesigns?

3. Space and Ground Segment

Objectives

Describe space segment subsystems to comprehend how satellites are stationed in a particular orbit.

- Explain Earth segment subsystems to investigate transmission and reception of signals from satellites.

Have you ever wondered how we capture stunning images of the Earth from space?

In the vastness of space, high above the Earth's atmosphere lies the space segment, from where satellites can capture images of the Earth. The captured images by the satellite in the space segment can be retrieved by the ground segment as shown in Figure 3.1. It is at the ground segment where technology and human expertise come together to guide, control, and communicate with the satellite.

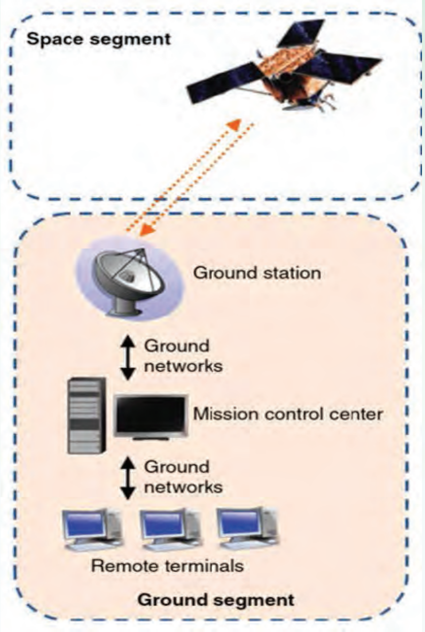


Figure 3.1 Space and groud segment

3.1 Cosmic Connection: Understanding the Space Segment

Satellite is composed of the payload bus and the satellite bus. The combination allows the satellite to fulfill its intended missions. Each component plays a vital role in ensuring the satellite's functionality and successful operation in the space environment.

Payload is the equipment or instrument carried by the satellite which is crucial for determining the satellite's mission. Satellite payload includes communication, Earth observation, navigation, and weather instruments. For example, BHUTAN-1 carried a 5MPcamera for Earth observation.

Satellite bus is the main framework of satellite, providing support and essential systems. It consists of various subsystems that maintain structural stability, proper functioning and thermal resilience in space. Subsystems vary based on the satellite's sizeand mission. Some of the fundamental subsystems are as follows:

a. Structure and Mechanism

The structure provides a robust framework to house payloads,instruments and subsystems, ensuring their protection during launch, and in the harsh conditions of space. Mechanisms are onboard devices whose function is based around movement. They include motors, reaction wheels and deployment systemsfor folded-down antennas or solar arrays. Figure 3.2 shows thesatellite structure and internal components of BHUTAN-1.

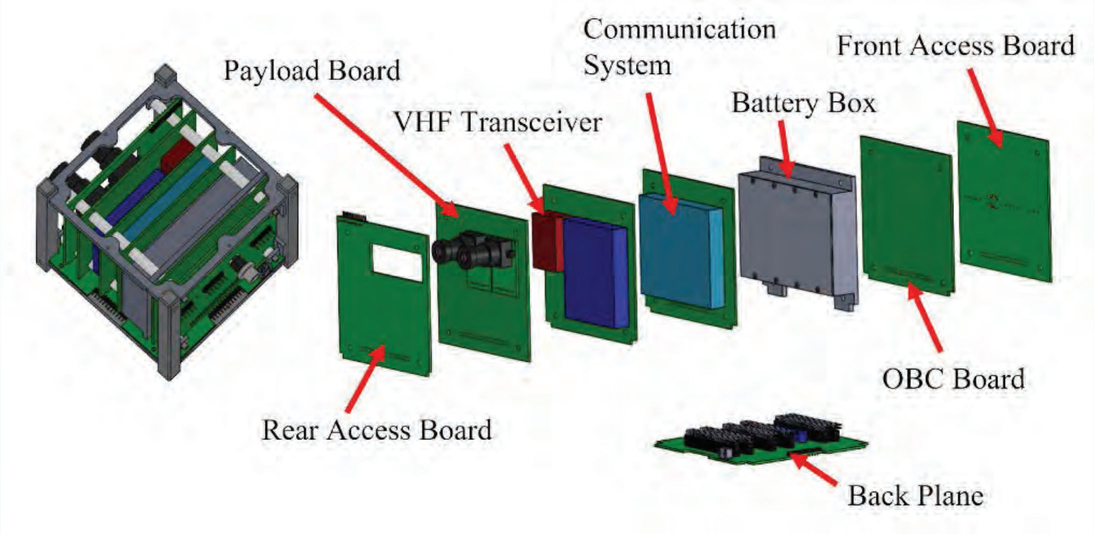


Figure 3.2 Satellite structure and internal component of BHUTAN-1

b. Command and Data Handling (C&DH) System

C&DH system is responsible for spacecraft control, managing data and facilitating communication between different subsystems. It consists of processors, memory for software execution, mass storage for data storage, and interfaces for internal communication. It relies on an on-board computer (OBC)as its central processing unit and requires robust components to withstand the space environment and ensure mission reliability.

c. Electrical Power System (EPS)

The EPS is the source of electrical power to all the subsystemsthat require electrical power as indicated in Figure 3.3.

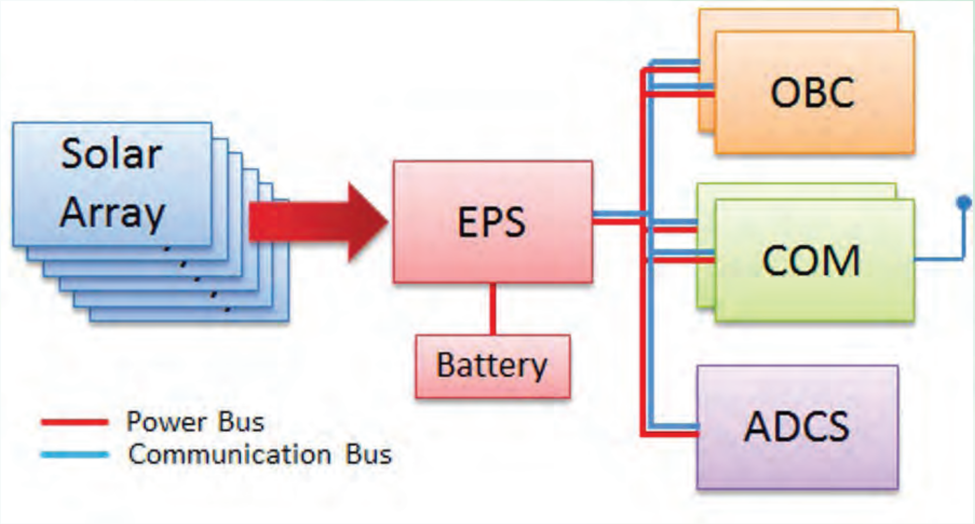


Figure 3.3 EPS in satellite

The electrical power system comprises a power generation unit (solar panels), power storage unit (rechargeable batteries) and power conditioning and distribution circuit. The solar panels generate power during the sunlight phase and supply it to the satellite subsystems and also charge the batteries. During satellite eclipse, the battery supplies power to the satellite subsystems. The solar panels consist of solar cells connected in series and/or parallel, depending on the power requirement of the satellite. BHUTAN-1 utilized a configuration where two solarcells are connected in series on each side, and the solar panels on five sides are connected in parallel, as depicted in Figure 3.4.

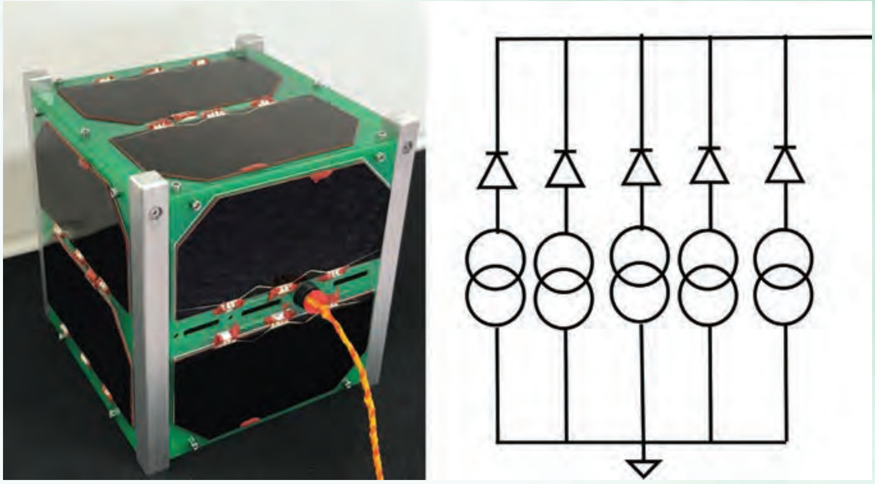


Figure 3.4 Solar cell connectioninBHUTAN-1

d. Attitude Determination and Control System (ADCS)

ADCS of a satellite consists of sensors, actuators, and algorithmsto control and maintain the satellite's attitude (orientation) and orbit. It ensures accurate pointing, stability and maneuverability, allowing the satellite to fulfill its mission objectives effectively.

e. Propulsion system

Satellite propulsion systems use thrusters, such as electric, chemical, or ion engines, to generate force and change the satellite's velocity, position, and orientation in space. These systems enable satellite maneuverability and orbit adjustmentsfor precise positioning and mission requirements.

f. Telemetry, Tracking and Command (TT&C) System

The TT&C system manages the satellite in space. Tracking determines the spacecraft's position and movement, whiletelemetry collects health information and transmits it to the Earth. The command element receives and executes remote control commands for changes in the satellite's functions, configuration, position, and velocity.

g. Thermal Control System

The thermal control subsystem manages and regulates temperature in a satellite, which faces extreme temperature variations in space. Various thermal control systems, such as insulation blankets and radiators, are used to maintain the right temperatures for different spacecraft components. This is crucial for the optimal performance of satellite electronic equipment.

Activity 8:Designing your own Satellite Subsystem

What we need:

- Paper, pencil
- 3D designing tools (optional)

What to do?

1. Explore more information about the subsystem components that constitute a satellite from relevant resources.

2. Choose one subsystem and sketch your design using paper and pencil or 3D designing tools.
3. Present your design to the class and explain how yoursubsystem will contribute to the overall functioning of thesatellite.

Questions

1. Which subsystem did you choose to design and why?What factors influenced your decision?
2. If Bhutan is awarded to manufacture any satellite component, which component would you prefer tomanufacture based on availability of raw materials and economic return?
3. Describe the key components and features of your designed subsystem and how they contribute to the overall functioning of the satellite.

3.2 Ground Segment: Satellite Ground Station and Satellite Tracking

Ground station enables two-way communication between satellite and the station as shown in Figure 3.5 (a). The groundstation uses antennas to transmit and receive radio signals, facilitating data exchange. It sends commands (uplinks) to control satellite operations, collect telemetry data for satellite health assessment, download (downlink) mission data, and determine satellite positions. Figure 3.5 (b) shows the S-band antenna at Ground Station in Thimphu. Satellite tracking relies onTwo-Line Element (TLE) data, which includes position, velocity, and orbital elements.

[a] [b]

Figure 3.5 Communication between satellite ad ground station

Activity 9: Tracking a Satellite

Do you want to track and see the satellite? Bigger satellites like the International Space Station (ISS) can be seen with the nakedeye.

What to do?

1. Download a satellite tracking app like “look4sat” or any other similar app.
2. Set your station position using GPS.
3. Navigate to the satellite selection menu and choose the satellite named ISS ZARYA.
4. Determine the Acquisition of Signal (AOS) and Loss of Signal (LOS) timing of the satellite, along with its elevation, as indicated in Figure 3.6. Use the app’s filtering feature to view passes that occur within your desired hours.

Figure 3.6 AOS and LOs timing with elevator

5. Utilize the app's interactive features to locate the path, direction, and position of the satellite a few minutes before AOS by pressing on the screen shown in Figure 3.7.
6. During the AOS and LOS timing, use the radar feature in the app to track the path, direction, and position of the satellite, as illustrated in Figure 3.8.

Figure 3.7 Locating the direction, path and the position of the satellite

7. Record a video of the satellite passing using a recordingdevice. For better visibility, choose satellite passes with an elevation above 50 degrees during the early morning or late evening.

Questions

1. Share your video with other friends or on any social mediaplatform.
2. State the factors that need to be considered in order toobtain the clear view of the satellite.
3. After this activity, select two other satellites; Iridium and India-Bhutan Sat (INS-2B) and check their visibility similarly. Describe your observations.

4. The Space Environment

Objective

- Identify the elements of the space environment tominimize space hazards.

4.1 Major Hazards of the Space Environment

What lies beyond our blue planet? Understanding and adapting to the space environment is crucial for space exploration missions and the development of spacecraft. It poses unique challenges that scientists, engineers, and astronauts mustaddress to ensure safe and successful exploration beyond theEarth. The elements of the space environment are as follows:

1. **Vacuum:** Space is a vacuum devoid of air or atmosphericpressure.

2. **Microgravity:** Gravity is significantly reduced in space,leading to a state of weightlessness or microgravity.

3. **Extreme Temperatures:** Space experiences extreme temperature variations due to the absence of atmospheric regulation. Areas without direct sunlight can becomeextremely cold, while regions exposed to sunlight can reach very high temperatures.

4. **Cosmic Radiation:** Space is permeated by cosmic radiation, including high-energy particles from various sources such as the Sun and distant celestial bodies.

5. **Solar Radiation:** The Sun emits various forms of radiation,including harmful ultraviolet (UV) radiation and X-rays, which can impact spacecraft systems and human health.

6. **Magnetic Fields:** Earth's magnetic field and magnetic fields generated by celestial bodies influence the space environment, interacting with charged particles and shaping the behavior of plasma.

7. **Plasma:** Space contains ionized gas called plasma, consisting of charged particles, which plays a significantrole in space physics and astrophysics.

8. **Electromagnetic Waves:** Space is filled with various forms of electromagnetic waves.

4.2 Living and Working in Space

In the microgravity environment of space, astronauts experience weightlessness and can float freely inside the spacecraft as shown in Figure 4.1. They adapt to the environment by pushing off surfaces to move around. Living in microgravity has effects on the human body, such as muscle and bone weakening due to the minimal gravity.

The ISS has a special toilet. Astronauts secure themselves using straps to prevent floating off. Instead of a flush toilet, there is a suction tube that carries waste away in an airstream, with solid waste compressed and stored for disposal later. Urine is collected and recycled.

Nutrition plays a vital role in maintaining astronauts' health. Food for space missions is specially treated to last long and be low in mass. Carrying heavy food supplies is expensive, so everything needs to be lightweight and easily stored. Mealtimes also serveas important social occasions for astronauts far away from theirfamilies and friends.

Figure 4.1 Astronauts in ISS

Activity 10: Preparing Space Food.

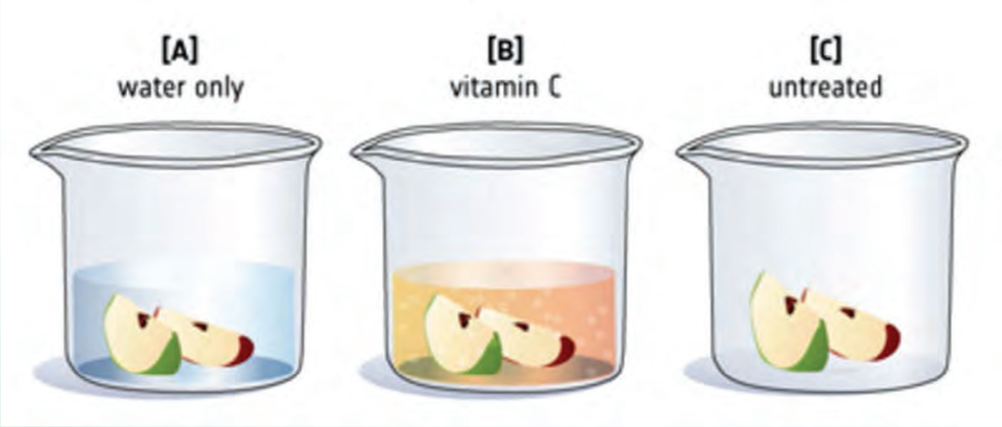


Figure 4.2 Fruit wedges placed in different solutions

What we need:

- distilled water
- Apple, banana, celery stick, carrots
- vitamin C tablet
- beakers
- knife
- spoon
- paper plate

What to do?

1. Add water in 2 beakers. Dissolve a vitamin C tablet in one ofthe beakers and leave the other as plain water. Label both beakers accordingly.
2. Cut a piece of fruit into six equal slices. Place 2 slices ineach of the two prepared liquids and beaker marked with
3. 'untreated' as shown in Figure 4.2. Make sure they areimmersed completely and leave for 10 minutes.
4. Remove each slice with a spoon and place in separate paper plates.
5. Repeat with different fruits and vegetables.
6. Let all 3 plates stand for an hour and observe for anybrowning.
7. Answer the following questions based on the observation from the experiment.

Questions

1. Which fruit and vegetable did not turn its colour? Why?
2. Suggest any other chemical inhibitor which can be used to preserve fruits and vegetables.
3. Learn about life in space from the link https://tinyurl.com/2djmd7tm and compare it with life on the Earth.

5. Satellite Disposal

Objective

- Explain the ways of satellite disposal and its management.

5.1 Satellite Lifespan

Satellites have varying lifespans depending on factors like design, purpose and operational conditions. On average, they are designed to last between 1 to 15 years, although some satellites exceed this range. Lifespan is influenced by fuel availability for propulsion, battery life and component degradation due to radiation and micrometeoroids. Once a satellite reaches the end of its operational lifespan, it may cease to function.

5.2 Satellite Disposal

When satellites reach the end of their operational lifespan, they need to be passivated and disposed of to prevent them from becoming space debris. Passivation involves shutting down the satellite's systems, depleting any remaining fuel, and making it inactive. There are different methods for satellite disposal:

a. Design for Demise: Satellites are intentionally brought down into Earth's atmosphere where they burn up upon reentry. This is common for low Earth orbit (LEO) satellites.

b. Graveyard Orbit: Satellites are moved to a higher, less-trafficked orbit where they can remain for centuries without posing a threat to other spacecraft. This method is often used for geosynchronous Earth orbit (GEO) satellites. Figure 5.1 shows the illustration of the graveyard orbit.

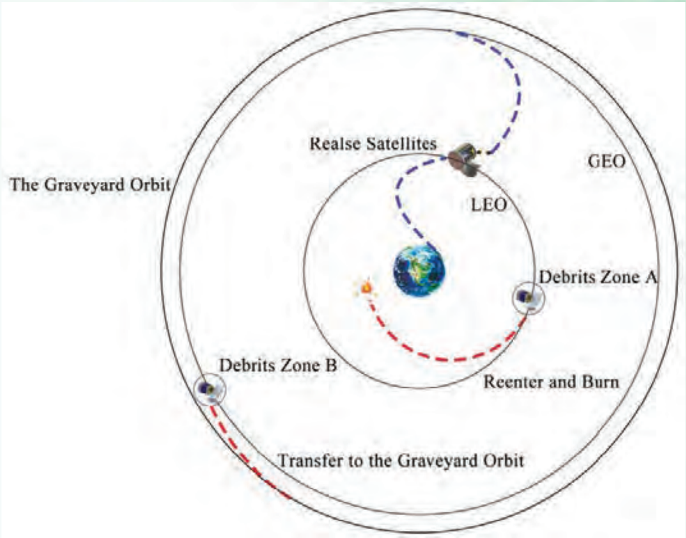


Figure 5.1 Graveyard orbit.

c. Direct Deorbit: Satellites are intentionally brought down into a designated ocean location. This method is used for large satellites that have reached the end of their lifespan.

5.3 Space Debris Management

Managing space debris involves a range of strategies aimed atmitigating the risks posed by the growing population of defunctsatellites and other debris in orbit around the Earth. It involvestracking systems to predict potential collisions by providing data for avoidance maneuvers. It also involves debris removal techniques including capturing objects with robotic arms, nets, or harpoons, and deorbiting them. Efforts are also made to address the issue at its source by designing satellites and rockets for post-mission disposal and promoting sustainable space practices.

Fun Fact

Over 128 million known space debris objects orbit Earth. Space debris travels at 28,000 kilometers per hour. The Kessler Syndrome is a scenario where collisions between debris generate more debris, rendering some orbits unusable.

6. Space Laws and Regulations

Objective

- Study the space laws and regulations to create awareness that all nations have equal opportunity and accountability to explore space.

6.1 Cosmic Governance: Navigating Space Laws and Regulations

Space law regulates human activities in space and consists of international treaties, conventions, and resolutions of the UN General Assembly, along with national laws. It covers various topics such as environmental protection, liability for space objects, conflict resolution, astronaut recovery, risk sharing, technology use, and international cooperation.

The fundamental principles of space law are:

1. Common Heritage of Mankind: Outer space is shared by all humanity for the common benefit.
2. Freedom of Exploration and Use: All nations have equal rights to explore and use space without discrimination.
3. Non-Appropriation: No country can claim sovereignty over outer space or celestial bodies.
4. Peaceful Purposes: Space activities should be conducted peacefully, without the use of force.
5. International Cooperation: Nations are encouraged to collaborate and share resources for mutual benefit in space exploration.

Activity 11: Evaluating the Norms for Satellite Launch

What to do?

Imagine that you plan to launch a research satellite from Bhutan. Evaluate the international and national space laws to which it has to adhere.

Questions

1. What measures should be taken to ensure compliance withthe guidelines outlined in the Outer Space Treaty duringsatellite launches?
2. Can you provide details on specific regulations or guidelines concerning space debris mitigation that must be followed during satellite launches?
3. Should Bhutan have its own National Space Law? Justify.

CHECK YOUR UNDERSTANDING

1. Read the question carefully and choose the correct option.

   i. The purpose of the on-board computer system in a satellite among its various subsystems is to

      A. collect data only.

      B. provide power to the satellite.

      C. control the satellite's orbit only.

      D. control all subsystems of the satellite.

   ii. A satellite signal transmitted from a satellite transponderto ground station is

      A. Uplink.

      B. Downlink.

      C. Terrestrial.

      D. Earthbound.

   iii. When a satellite orbits the Earth, one of the foci of theellipti-cal orbit is the

      A. Sun.

      B. Earth.

      C. Moon.

      D. Satellite.

iv. Kepler's second law is known as

A The Law of Orbits.

B. The Law of Areas.

C. The Law of Periods.

E. The Law of Gravity.

v. What is the purpose of the upper stage engine during the launch of a satellite?

A. To ignite the first stage engine.

B. To communicate with the ground station.

C. To provide initial thrust and propel the rocketoff the launch pad.

D. To shed the weight of the first stage andcontinue accelerating the satellite.

2. Read the following statement and state True/False.

Statement	True/False
i. When astronauts are in space, they experience the microgravity environment.	
ii. The space environment is characterized by high atmospheric pressure.	
iii. The method of intentionally bringing the satellite down into the Earth's atmosphere where it will burn up upon reentry is called Design for Demise.	
iv. Bhutan launched the first satellite BHUTAN-1 in 2015.	
v. The International Space Station is subject to laws of the country that owns the module or where the astronauts are from.	

3. Answer the following questions.
   i. Explain the process of satellite development.
   ii. Explain the significance of space debris management and why it is important in your opinion?
   iii. How do Kepler's laws of planetary motion provide insights into the fundamental principles governing the motion of celestial bodies within our solar system?
   iv. What are the potential benefits and drawbacks of launching rockets in Bhutan from economic, scientific, geographical and technological perspectives?
   v. Solar irradiance is the power per unit area received from the Sun. In space the solar irradiance is 1366 W/m^2. Assuming you have a solar panel with 12 solar cells, each with length 8 cm and width 4 cm, the efficiency of the solar cell is 30%. Calculate the power generated by the solar panel.
   vi. A remote sensing satellite revolves in Earth's orbit at a height of 25×10^6 m. Find the orbital speed and the periodof revolution of the satellite. (Earth radius, $R_e = 6.38\times 10^6$ mand $g = 9.8$ ms^{-2})
   vii. What could be the reason for some satellites having wing-like deployments as shown in the image, while BHUTAN-1 does not possess such features?