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| **Lesson 3.2 Orbital Mechanics** |

**Preface**

Many years ago it was common knowledge that the sun revolved around the Earth. Through the work of scientists and scholars new theories were developed and proven through observations and scientific research. These advancements form the basis what is accepted as orbital mechanics today.

This lesson will provide students with an introduction to and basic understanding of laws governing and describing satellite orbits. Students will learn about the Keplerian Element Set and Kepler’s Laws of Motion. They will understand why there are many different types of satellite orbits and how different orbits are well-suited for different satellite missions.

**Concepts**

1.     Orbital mechanics provides a means for describing orbital behavior of bodies.

2.     The same laws that govern satellite orbits also govern celestial body (e.g. comets, planets and moons) orbits.

3.     All objects exert an attraction force to each other.

4.     Objects orbit other objects in a pattern governed by forces exerted on each other.

5.     Objects in orbit are continuously falling toward the body about around which they orbit.

6.     Orbital elements can be used to fully define a satellite’s orbit, allowing the accurate prediction of the precise location of the satellite at a given time.

7.     A satellite’s mission is a major factor when designing its orbit.

**Standards and Benchmarks Addressed**

***Standards for Technological Literacy***

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| **Standard 1:  Students will develop an understanding of the characteristics and scope of technology.** | |
| **BM K:** | The rate of technological development and diffusion is increasing rapidly. |
| **BM L:** | Inventions and innovations are the results of specific, goal-directed research. |
| **BM M:** | Most development of technologies these days is driven by the profit motive and the market. |
| **Standard 2:  Students will develop an understanding of the core concepts of technology.** | |
| **BM W:** | Systems’ thinking applies logic and creativity with appropriate compromises in complex real-life problems. |
| **BM X:** | Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems. |
| **BM Z:** | Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste. |
| **BM AA:** | Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development. |
| **BM BB:** | Optimization is an on going process or methodology of designing or making a product and is dependent on criteria and constraints. |
| **BM CC:** | New technologies create new processes. |
| **BM EE:** | Management is the process of planning, organizing, and controlling work. |
| **BM FF:** | Complex systems have many layers of controls and feedback loops to provide information. |
| **Standard 3:  Students will develop an understanding of the relationships**  **among technologies and the connections between technology and other fields of study.** | |
| **BM G:** | Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function |
| **BM H:** | Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields. |
| **BM J:** | Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology. |
| **Standard 4:  Students will develop an understanding of the cultural, social, economic, and political effects of technology.** | |
| **BM H:** | Changes caused by the use of technology can range from gradual to rapid and from subtle to obvious. |
| **BM I:** | Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects. |
| **BM J:** | Ethical considerations are important in the development, selection, and use of technologies. |
| **Standard 5:  Students will develop an understanding of the effects of**  **technology on the environment.** | |
| **BM H:** | When new technologies are developed to reduce the use of resources, considerations of trade-offs are important. |
| **BM J:** | The alignment of technological processes with natural processes maximizes performance and reduces negative impacts on the environment. |
| **BM L:** | Decisions regarding the implementation of technologies involve the weighing of tradeoffs between predicted positive and negative effects on the environment. |
| **Standard 6:  Students will develop an understanding of the role of society in the development and use of technology.** | |
| **BM H:** | Different cultures develop their own technologies to satisfy their individual and shared needs, wants, and values. |
| **BM I:** | The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures. |
| **BM J:** | A number of different factors, such as advertising, the strength of the economy, the goals of a company and the latest fads contribute to shaping the design of and demand for various technologies. |
| **BM I:** | The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures. |
| **Standard 7:  Students will develop an understanding of the influence of**  **technology on history.** | |
| **BM G:** | Most technological development has been evolutionary, the result of a series of refinements to a basic invention. |
| **BM H:** | The evolution of civilization has been directly affected by, and has in turn affected, the development and use of tools and materials. |
| **BM I:** | Throughout history, technology has been a powerful force in reshaping the social, cultural, political, and economic landscape. |
| **BM M:** | The Renaissance, a time of rebirth of the arts and humanities, was also an important development in the history of technology. |
| **BM O:** | The Information Age places emphasis on the processing and exchange of information. |
| **Standard 8:  Students will develop an understanding of the attributes of design.** | |
| **BM H:** | The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluating the design using specifications, refining the design, creating or making it, and communicating processes and results. |
| **BM I:** | Design problems are seldom presented in a clearly defined form. |
| **BM J:** | The design needs to be continually checked and critiqued, and the ideas of the design must be redefined and improved. |
| **BM K:** | Requirements of a design, such as criteria, constraints, and efficiency, sometimes compete with each other. |
| **Standard 9:  Students will develop an understanding of engineering design.** | |
| **BM I:** | Established design principles are used to evaluate existing designs, to collect data, and to guide the design process. |
| **BM K:** | A prototype is a working model used to test a design concept by making actual observations and necessary adjustments. |
| **BM L:** | The process of engineering design takes into account a number of factors. |
| **Standard 10:  Students will develop an understanding of the role of**  **troubleshooting, research and development, invention and innovation, and experimentation in problem solving.** | |
| **BM I:** | Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace. |
| **BM J:** | Technological problems must be researched before they can be solved. |
| **BM K:** | Not all problems are technological, and not every problem can be solved using technology. |
| **BM L:** | Many technological problems require a multidisciplinary approach. |
| **Standard 11:  Students will develop abilities to apply the design process.** | |
| **BM M:** | Identify the design problem to solve and decide whether or not to address it. |
| **BM N:** | Identify criteria and constraints and determine how these will affect the design process. |
| **Standard 12:  Students will develop the abilities to use and maintain technological products and systems.** | |
| **BM L:** | Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques. |
| **BM M:** | Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it. |
| **BM N:** | Troubleshoot, analyze, and maintain systems to ensure safe and proper function and precision. |
| **BM O:** | Operate systems so that they function in the way they were designed. |
| **BM P:** | Use computers and calculators to access, retrieve, organize and process, maintain, interpret, and evaluate data and information in order to communicate. |
| **Standard 13:  Students will develop the abilities to assess the impacts of products and systems.** | |
| **BM M:** | Design forecasting to evaluate the results of altering natural systems. |
| **Standard 16:  Students will develop an understanding of and be able to select and use energy and power technologies.** | |
| **BM J:** | Energy cannot be created or destroyed; however, it can be converted from one form to another. |
| **BM K:** | Energy can be grouped into major forms: thermal, radiant, electrical, mechanical, chemical, nuclear, and others. |
| **BM N:** | Power systems must have a source of energy, a process, and loads. |
| **Standard 17:  Students will develop an understanding of and be able to select and use information and communication technologies.** | |
| **BM L:** | Information and communication technologies include the inputs, processes, and outputs associated with sending and receiving information. |
| **BM M:** | Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine. |
| **BM O:** | Communication systems are made up of source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination. |
| **BM Q:** | Technological knowledge and processes are communicated using symbols, measurement, conventions, icons, graphic images, and languages that incorporate a variety of visual, auditory, and tactile stimuli. |

***National Science Education Standards***

**Unifying Concepts and Processes:**  As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes.

        **Systems, order, and organization**

        **Evidence, models, and explanation**

        **Change, constancy, and measurement**

        **Evolution and equilibrium**

**Science As Inquiry Standard A:** As a result of activities in grades 9-12, all students should develop

        **Understanding about scientific inquiry**

**Physical Science Standard B:** As a result of activities in grades 9-12, all students should develop an understanding of

        **Structure and properties of matter**

        **Motions and forces**

        **Conservation of energy and increase in disorder**

        **Interactions of energy and matter**

**Earth and Space Science Standard D:** As a result of activities in grades 9-12, all students should develop an understanding of

        **Energy in the earth system**

        **Origin and evolution of the earth system**

        **Origin and evolution of the universe**

**Science and Technology Standard E:** As a result of activities in grades 9-12, all students should develop

        **Abilities of technological design**

        **Understandings about science and technology**

**History and Nature of Science Standard G:** As a result of activities in grades 9-12, all students should develop understanding of

        **Science as a human endeavor**

        **Nature of scientific knowledge**

        **Historical perspectives**

***Principles and Standards for School Mathematics***

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| **Number and Operations** | Instructional programs from pre-kindergarten through grade 12 should enable all students to understand numbers, ways of representing numbers, relationships among numbers, and number systems; understand meanings of operations and how they relate to one another; compute fluently and make reasonable estimates. |
| **Algebra** | Instructional programs from pre-kindergarten through grade 12 should enable all students to understand patterns, relations, and functions; represent and analyze mathematical situations and structures using algebraic symbols;  use mathematical models to represent and understand quantitative relationships; analyze change in various contexts. |
| **Geometry** | Instructional programs from pre-kindergarten through grade 12 should enable all students to analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships; specify locations and describe spatial relationships using coordinate geometry and other representational systems; apply transformations and use symmetry to analyze mathematical situations; use visualization, spatial reasoning, and geometric modeling to solve problems. |
| **Measurement** | Instructional programs from pre-kindergarten through grade 12 should enable all students to understand measurable attributes of objects and the units, systems, and processes of measurement; apply appropriate techniques, tools, and formulas to determine measurements. |
| **Data Analysis and Probability** | Instructional programs from pre-kindergarten through grade 12 should enable all students to formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; understand and apply basic concepts of probability. |
| **Problem Solving** | Instructional programs from pre-kindergarten through grade 12 should enable all students to build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving. |
| **Communication** | Instructional programs from pre-kindergarten through grade 12 should enable all students to organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely. |
| **Connections** | Instructional programs from pre-kindergarten through grade 12 should enable all students to recognize and use connections among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply mathematics in contexts outside of mathematics. |
| **Representation** | Instructional programs from pre-kindergarten through grade 12 should enable all students to create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena. |

***Standards for English Language Arts***

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| **Standard 3** | Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and other texts, their word identification strategies, and their understanding of textual features (e.g. sound-letter correspondence, sentence structure, context, graphics). |
| **Standard 4** | Students adjust their use of spoken, written, and visual language (e.g. conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes. |
| **Standard 7** | Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g. print and non-print texts, artifacts, and people) to communicate their discoveries in ways that suit their purpose and audience. |
| **Standard 8** | Students use a variety of technological and informational resources (e.g. libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge. |

**Performance Objectives**

*It is expected that students will:*

       Describe the contributions to orbital theory of the discipline’s historical figures.

       Define the six orbital parameters that describe an orbit.

       Design and simulate the path of an orbiting body.

       Calculate the energy of an orbiting body.

**Assessment**

*Explanation*

       Students will describe orbital pattern in terms of Keplerian Element Set.

       Describe the historical backgrounds of orbital mechanics.

       Define the different shapes of the conic sections.

*Interpretation*

       Students will draw an orbit based on a Keplerian Element Set.

       Distinguish between the different types of orbits.

       Analyze the ground traces of different satellites to identify the orbital elements.

*Application*

       Students will design a satellite orbit based on its mission.

       Calculate energy required for orbit.

**Essential Questions**

1.     How do satellites impact our daily lives?

2.     What is an orbit and how is it described?

3.     What keeps an object in orbit?

4.     Who is credited with first accurately describing orbits?

5.     What are Kepler’s laws and how are they used in orbital mechanics?

**Key Terms**

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| **Term** | Definition |
| **Apogee** | The point in an orbit that is farthest from Earth. |
| **Argument of Perigee** | Abbreviated as ω. The orientation of the orbit within the orbital plane. |
| **Eccentricity** | Describes the roundness of an orbit. |
| **Ellipse** | The two dimensional shape that is produced by a plane fully intersecting a cone |
| **Geostationary Earth Orbits** | Abbreviated as GEO. Orbits where satellite stays in one spot with respect to Earth |
| **Inclination** | The angle between the earth’s equatorial plane and the plane of the orbit. |
| **Low Earth Orbit** | Abbreviated as LEO. Orbits which are relatively close to the Earth. |
| **Molniya Orbit** | Abbreviated as Moly. A highly inclined, highly elliptical orbit. |
| **Perigee** | The point in an orbit that is closest to earth |
| **Polar Orbit** | The inclination of a polar orbit is 90 degrees. |
| **Right Ascension of the Ascending Node** | Abbreviated as RAAN. The angle measured along the equatorial plane between a vector pointing to a fixed reference point in space and the point on the orbit where the orbital motion is from south to north across the equator. |
| **Semi-major Axis** | Abbreviated as a. Describes the size of the ellipse. |
| **True Anomaly** | The angle between the perigee point and the satellite’s location measured in the direction of the satellite’s motion. |

**Day-by-Day Plans**

*Time:  10 days*

**Day 1:**

       The teacher will present [**Concepts**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital%20Mechanics.htm#Concepts), [**Key Terms**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital%20Mechanics.htm#KeyTerms), and [**Essential Questions**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital%20Mechanics.htm#EssentialQuestions), in order to provide a lesson overview.

       The teacher will present [**Orbital Mechanics Historical Perspective.ppt**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Mechanics_Historical.pptx) while students take notes in their journal.

       The teacher will present **[Satellite Tool Kit.ppt](mk:@MSITStore:C:\\Documents%20and%20Settings\\DAVID_ROEMER\\Desktop\\Aerospace\\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Satellite%20Tool%20Kit.pptx)** while students take notes in their journal.

       The teacher will distribute and introduce [**Activity 3.2.8 Satellite Tool Kit**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/A3_2_8_Satellite%20Tool%20Kit.htm).

       Students will work on and complete Activity 3.2.8 Satellite Tool Kit.

**Day 2:**

       The teacher will present [**Orbital Patterns.ppt**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Patterns.pptx) while students take notes in their journal.

       The teacher will present Orbital Patterns.ppt while students take notes in their journal.

       The teacher will present [**Orbital Mechanics Modeling.ppt**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Mechanics_Modeling.pptx) slide 1-16 while students take notes in their journal. Note:

       The teacher will present Orbital Mechanics Modeling.ppt slide 16-30 while students take notes in their journal. Note Slide 15 will provide a refresher to students for the first part of the presentation.

**Day 3-5:**

       The teacher will present Orbital Mechanics Modeling.ppt slide 30-50 while students take notes in their journal.

       The teacher will distribute [**Activity 3.2.5 Orbital Mechanics Modeling**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/A3_2_5_Orbital%20Mechanics%20Modeling.htm).

       Students will complete Activity 3.2.5 Orbital Mechanics Modeling.

**Day 6-7:**

       The teacher will present [**Orbital Mechanics Physics.ppt**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Mechanics_Physics.pptx) while students take notes in their journal.

       The teacher will distribute and introduce [**Activity 3.2.6 Orbital Mechanics Physics**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/A3_2_6_Orbital_Mechanics_Physics.htm).

       Students will complete Activity 3.2.6 Orbital Mechanics Physics.

**Day 8-9:**

       The teacher will distribute and introduce [**Project 3.2.9 Where is ISS**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/P3_2_9_Wheres_is_ISS.pdf).

       Students will work on and complete Project 3.2.9 Where is ISS.

**Instructional Resources**

Presentations

[**Orbital Mechanics Historical Perspective**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Mechanics_Historical.pptx)

[**Orbital Patterns**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Patterns.pptx)

[**Orbital Mechanics Modeling**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Mechanics_Modeling.pptx)

[**Orbital Mechanics Physics**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Orbital_Mechanics_Physics.pptx)

[**Satellite Tool Kit**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/L3_2_Satellite%20Tool%20Kit.pptx)

Word Documents

[**Activity 3.2.5 Orbital Mechanics Modeling**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/A3_2_5_Orbital%20Mechanics%20Modeling.docx)

[**Activity 3.2.6 Orbital Mechanics Physics**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/A3_2_6_Orbital_Mechanics_Physics.docx)

[**Activity 3.2.8 Satellite Tool Kit**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/A3_2_8_Satellite%20Tool%20Kit.docx)

[**Project 3.2.9 Where is ISS**](mk:@MSITStore:C:\Documents%20and%20Settings\DAVID_ROEMER\Desktop\Aerospace\AE_2011_Teacher.chm::/Lessons/Unit_3/P3_2_9_Wheres_is_ISS.pdf)