StellarXplorers

***Understanding Space* Curriculum Guide**

In 2002, I was asked to develop a 4-year high school Aerospace Engineering Magnet Program Curriculum, from scratch, over a 4-year period. During the junior year, I decided to use the *Understanding Space* textbook as the academic foundation. The textbook is used at the Air Force Academy in their Introduction to Space course but much of it is written at the Middle School level. Therefore, StellarXplorers uses it to expose students to the basic principles involved with space and hopefully learn some of the academic basis of space operations. StellarXplorers incorporates scored Team Quizzes into the National High School Space Challenge. For those Quizzes, we provide Study Guides to let teams know what areas to focus on to prepare for the Quizzes. Since these are Multiple Choice questions, it limits what types of questions we can ask. The hope was students would go beyond this and actually explore the textbook. What follows are the "Review Questions" I gave to my students. I primarily gave Quizzes where students had to answer using complete sentences.

Harry Wong is a world famous educator and I was fortunate to hear him speak in person many years ago at a National Education Conference when I was still a relatively new public school teacher. He opened his talk with some advice which I follow even today. While I probably don't have his quote 100% correct, he said "Everything I ever learned about teaching I stole from someone else." His point was few, if any people, create amazing things on their own but instead take information and ideas from others and adapt them to your current situation. That is the purpose of this *Understanding Space* Curriculum Guide. This Guide will hopefully help you give students an overview of space systems engineering and how to apply it to spacecraft subsystems, rockets, and operations systems. Feel free to "steal" this information and use it in whatever way is appropriate for your students. I have even saved the Quizzes I used to give my students and I am willing to share.

Bill Yucuis
StellarXplorers
Chief, Academics and Training
stellarxplorers@afa.org

Chapter 1: Space in Our Lives

1. Explain the advantages of going into space. Give an example for each advantage.
2. Most common space missions fall into four general areas: Communication, Remote Sensing, Navigation, and Science and Exploration. Describe a typical space mission for each area.
3. A mission statement contains the objective, describes the user (customer), and outlines a general operational concept. Write a succinct mission statement for the following two missions:
    A. A return mission to the Moon.
    B. A mission to Mars.
4. Explain the following spacecraft terms: payload and spacecraft bus.
5. Explain the differences between a parking orbit, a transfer orbit, and a final orbit.
6. Explain the purpose of upper-stage rockets and the smaller rockets called "thrusters".
7. Mission management and operations encompasses all activities associated with a space mission from the time it is just an idea until the mission is complete (called "cradle-to-grave"). Give an example of what the mission managers would do. Give examples of what a mission operations team would do.

Chapter 2: Exploring Space

1. Describe how the following people contributed to the advancement of astronomy and our view of the universe:

Aristotle	Copernicus	Galileo Galilei	Ptolemy
Tyco Brahe	Isaac Newton	Arab astronomers	Johannes Kepler

2. State and explain Kepler's Three Laws of Planetary Motion.
3. Explain how spectroscopy radically changed our view of the universe. Describe the discoveries during the 20th Century which further change this view.
4. Describe the contributions to rocketry made by the following people: William Congreve
    Robert Goddard   Konstantin Tsiolkovsky   Werner von Braun
5. Explain the importance of Sputnik. Explain why the Soviet Union (Russia) seemed to have supremacy in space from 1957 – 1965.
6. Explain the chief legacy of the Apollo manned missions to the Moon. Describe the advances made by unmanned space missions from the 1960s through the 1980's.
7. Describe the four major trends in space during the 1990s and continue into the new millennium. Give examples of each.
8. The most ambitious goal for the 21st Century is a manned mission to Mars. Explain how costs of such a mission could be reduced.
9. Give reasons why we should or should not launch humans into space to explore space. Give reasons why we should or should just use probes and Earth-based instruments to explore space.

Chapter 3: The Space Environment

1. Where does Space begin?
2. What is the star closest to Earth? How long would it take to travel there with current technology?
3. List and describe the Sun's two forms of energy output.
4. What are solar flares? How do they differ from solar wind?
5. Describe the six major hazards to spacecraft in the space environment.
6. Why are astronauts in space not in a "zero gravity" environment? What is a better description of their gravity environment?
7. How does the density and pressure of earth's atmosphere change with altitude?
8. What is atmospheric drag?
9. What is atomic oxygen? What effects can it have on spacecraft?
10. What are the major problems in the vacuum environment of space?
11. Describe the hazards to spacecraft from micrometeoroids and space junk.
12. What is the mechanism that protects earth from the effects of solar and cosmic charged particles?
13. What are Galactic Cosmic Rays?
14. What are the Van Allen radiation belts and what do they contain?
15. Describe the potential harmful effects to spacecraft from charged particles.
16. Describe the three physiological changes to the human body during free fall.
17. How are dosages of radiation and charged particles quantified?
18. What are the short-term effects to humans of exposure to radiation and charged particles? What are the long-term effects?
19. How do long space flights affect astronauts psychologically?

Chapter 4: Understanding Orbits

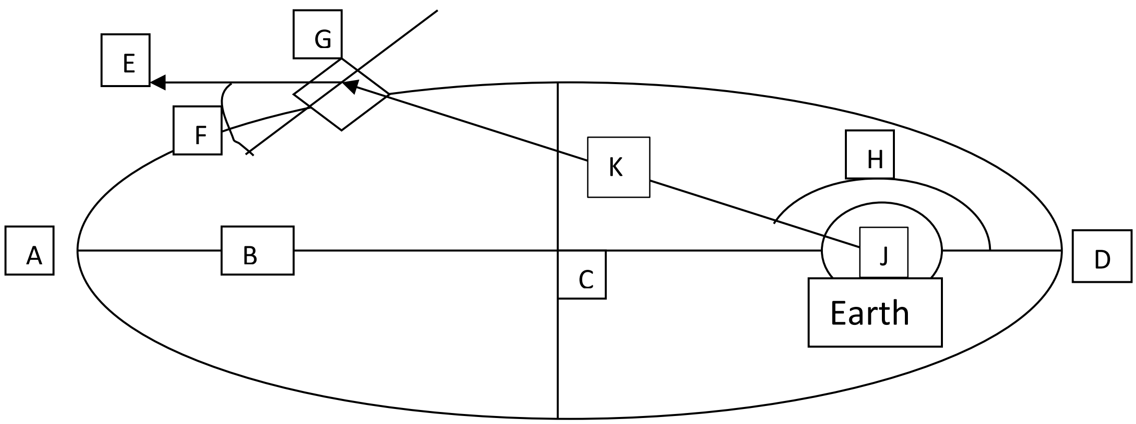
1. Be able to write a definition for the following Key Terms:

Angular Velocity	Total Mechanical Energy	
Angular Momentum	Mass	Gravitational Constant (μ)
Linear Momentum	Inertia	Moment of Inertia

2. Given the six steps in the motion Analysis Process (MAP), be able to describe how each step applies to a real-world problem, such as a straw rocket being launched at a 45^0 angle, a football or baseball player throwing a ball, or a tennis player hitting a ball.
3. Explain why a horizontal velocity of 7.9 km/s, assuming no air resistance, will result in an object orbiting the Earth? What happens if the object goes faster than 7.9 km/s? What happens if it goes slower than 7.9 km/s?
4. What are the only four types of paths a satellite can follow? What path(s) allow the satellite to escape earth's gravity pull?

Chapter 4: Understanding Orbits (continued)

5. For an isolated system (no interactions with its surroundings), what quantities are constant according to the laws of physics?
6. You are inside the ISS and you slowly begin to do somersaults. You tuck into a tight ball. What happens and explain why this happens? You then stretch out your arms. What happens and explain why this happens?
7. You throw a ball straight up. Compare the potential, kinetic, and total mechanical energy of the ball at its highest point to the potential, kinetic, and total mechanical energy when the ball hits the ground.
8. What are the origin, principal direction, and fundamental plane for the geocentric-equatorial coordinate system?
9. What are the three simplifying assumptions we use to "restrict" the two-body equation of motion?
10. Shown below is a drawing of a satellite in an elliptical orbit. Match the letter to the terms:



$\vec{R}$ (radius vector) ______	$\vec{V}$ (velocity vector) ______
F and F' (two foci) ______	$2a$ (*major axis*) ______
R_p (radius of perigee) ______	R_a (radius of apogee) ______
υ (true anomaly) ______	ϕ (flight path angle) ______

Chapter 4: Understanding Orbits (continued)

11. Where is the potential energy of a satellite greater, at perigee or apogee? Why?

12. Know the possible range of values for semimajor axis (a), eccentricity, (e), and specific mechanical energy (ε) for a circle, an ellipse, a parabola, and a hyperbola.

CONIC	a	e	$\mathcal{E}$
Circle			
Ellipse			
Parabola			
Hyperbola			

Chapter 5: Describing Orbits

1. Be able to define the following six Classical Orbital Elements (COE) and tell what it describes about the orbit: Semimajor Axis (a), Eccentricity (e), Inclination (i), Right Ascension of the Ascending Node (Ω), Argument of Perigee (ω), and True Anomaly (υ).
2. Given the six COEs for an orbit, be able to answer the following and explain which COE(s) give you the answer:
   a. Is the orbit a direct or retrograde orbit?
   b. Is the orbit circular, elliptical, parabolic, or hyperbolic?
   c. Is perigee for the orbit located in the Northern or Southern Hemisphere?
   d. On a drawing of an orbit, identify where Earth is located and show where in the orbit the satellite is currently located.
3. Which COE(s) determine if an orbit is a geosynchronous orbit? A sun synchronous orbit? A direct orbit? A retrograde orbit?
4. Explain how a spacecraft's ground track changes due to the rotation of the Earth.
5. Explain how a spacecraft's ground track changes if the orbit size increases or decreases.

Chapter 6: Maneuvering in Space

1. What assumptions allow us to use a Hohmann Transfer?
2. What makes a Hohmann transfer the most energy-efficient maneuver to transfer a spacecraft between coplanar orbits?
3. When going from a smaller circular orbit to a larger circular orbit, why do you speed up twice but end up with a slower velocity once you achieve the final higher orbit?
4. What orbital elements can a simple plane change alter?
5. When changing inclination only, where do we make the velocity change? Why?
6. A satellite is currently in a low-Earth parking orbit (inclination equal to 28^0) and needs to be sent to a geostationary orbit (inclination = 0^0). You have four options:
    a. Option 1: Do a Simple Plane Change at the low-Earth orbit and then do a complete Hohmann Transfer.
    b. Option 2: Do a complete Hohmann Transfer and then do a Simple Plane Change at the geostationary orbit.
    c. Option 3: Do a Combined Plane Change at the low-Earth orbit and then at the geostationary orbit, complete the Hohmann Transfer.
    d. Option 4: Begin a Hohmann Transfer at the low-Earth orbit and then at the geostationary orbit, do a Combined Plane Change.

    Explain, in detail, why Option 4 is the most fuel-efficient option.

Chapter 7: Interplanetary Travel

1. Be able to define the heliocentric-ecliptic coordinate frame. You must define the origin, the primary axis direction, and the primary plane.
2. Be able to explain why we cannot just include all the appropriate gravitational forces for an interplanetary trajectory into a single equation of motion and solve it directly.
3. Be able to explain what a planet's sphere of influence (SOI) represents. What parameters are used to determine the radius of the SOI?
4. Be able to explain what happens if a spacecraft launched from Earth and enters a parabolic trajectory. A hyperbolic trajectory.
5. Be able to answer the following questions about gravity assist:
    a. How do we use gravity assist to get "free velocity changes"?
    b. Is the "free velocity change" actually free?
    c. What is the difference between orbit cranking and orbit pumping?

Chapter 9: Getting to Orbit

1. What is a launch window?
2. What is local sidereal time (LST)?
3. Explain the difference between sidereal time and solar time. Explain why solar time is longer than sidereal time? Approximately how many solar days would pass until the difference between sidereal time and solar time would equal 6 hours? 24 hours?
4. If your current location is 43^0 past the vernal equinox direction, what is LST, written in hours, minutes, and seconds? What if you are 223^0 past the vernal equinox direction?
5. Define the right ascension of the ascending node.
6. Describe the vertical ascent, pitch over, gravity turn, and vacuum phases of a launch vehicle's path from the launch pad to orbit.
7. Explain the advantage of launching a spacecraft on an eastward launch path. Explain the disadvantage of launching a spacecraft on a westward launch path.
8. Define the following terms: $\vec{V}_{\text{loss gravity}}$, $\vec{V}_{\text{launch site}}$, $\vec{V}_{\text{burnout}}$, $\vec{V}_{\text{needed}}$, $\vec{V}_{\text{design}}$, $\vec{V}_{\text{losses}}$

Chapter 10: Returning From Space: Re-entry

1. Be able to describe and explain the three competing reentry requirements.
2. Explain what generates the intense heat during reentry.
3. Be able to define the upper and lower boundaries of a reentry corridor.
4. Explain the forces acting on a vehicle during reentry. Which forces is dominant? Why?
5. Define ballistic coefficient (BC) as a mathematical expression. Describe how the different body shapes will slow down the vehicle due to drag.
6. Explain the two approaches used to balance competing reentry requirements.
7. Explain the deceleration profiles (max g's and altitude of max g's) for increasing reentry velocities? Increasing reentry flight path angles?
8. Define the three types of heat transfer.
9. What causes a shock wave during reentry? What body shapes (ICBM vs Shuttle) have an attached shock wave? a detached shock wave? How is heating different for each shape?
10. Explain the variation in heating rate for increasing reentry velocities? Increasing reentry flight path angles? What parameter(s) determine total heating load during reentry?
11. Explain how the reentry trajectory affects accuracy? The reentry corridor?
12. Explain the deceleration profiles (max g's and altitude of max g's) for an increasing ballistic coefficient? Explain the heating rate profiles (max. heating rate and altitude where it occurs) for an increasing ballistic coefficient?
13. Describe the three approaches to thermal protection systems (TPS) and give their advantages and disadvantages.
14. What are the advantages of using a lifting-reentry vehicle?
15. What is aerobraking? How is it used in interplanetary transfers?

Chapter 14: Rockets and Launch Vehicles

Section 14-1

1. Define rocket thrust and explain where it comes from in terms of Newton's Third Law of Motion.
2. Describe the relationship between rocket thrust, propellant mass, and exhaust velocity.
3. Define specific impulse. Explain why the units are seconds.
4. Write the ideal rocket equation and explain each term.
5. What are the two forms of thermodynamic energy? What forms do electrodynamic energy take?
6. What basic function does a nozzle serve for a thermodynamic rocket?
7. Define the following terms: Isentropic flow, frozen flow, specific enthalpy, and venturi effect.
8. If the exit area of a rocket nozzle is increased, what happens to the effective exhaust velocity? What happens to the pressure thrust?
9. Describe the difference between over-expanded, underexpanded, and ideally expanded rocket nozzles. What is the exit pressure for an ideally expanded nozzle?
10. What two qualities of a thermodynamic rocket engine affect the I_{sp} it can produce? How do we produce the highest I_{sp}?
11. Explain the basic operating principle of a cold-gas rocket. Give an example of one.
12. Describe how an electric field can accelerate ions?
13. Describe the relationship between charge density and thrust.
14. Describe the relationship between electric-field strength and specific impulse.
15. Define plasma and give an every-day example of one. What is the main advantage of using plasma for electrodynamic propulsion?

Section 14-2

1. List the key elements of any propulsion subsystem and describe how they relate to each other. **2.** List the five basic types of thermodynamic rockets and describe their operating principles.
3. Describe the functional differences between bipropellant and monopropellant liquid-chemical rockets. Compare their relative advantages and disadvantages.
4. Describe how the shape of the propellant grain can affect the thrust profile for a solid-rocket motor. Explain why a *slots and tube* pattern produces a neutral burn?
5. Describe the basic operating principle of a solar-thermal rocket. Compare their advantages and disadvantages to chemical bipropellant rockets.
6. Explain the operating principle for nuclear-thermal rockets and discuss the technical and political issues associated with their future applications.
7. Describe the basic operating principles for the two main types of plasma thrusters.
8. Describe the basic operating principle of a solar sail and explain how "thrust" is produced.

Chapter 14: Rockets and Launch Vehicles (continued)

Section 14-3

1. What are the two biggest differences between designing a launch vehicle and designing a spacecraft?
2. Give an example of why a launch vehicle would need to reduce its thrust during the launch phase.
3. The first stage of a launch vehicle is designed to burnout at an altitude of 50,000 meters. What would be the optimum design altitude for the rocket engine?
4. What are the advantages and disadvantages of staging?