(U) B01 – Orbital Mechanics
(U) Lesson Overview

(U) Lesson Title: Orbital Mechanics
(U) Unit: National Reconnaissance Operations Center (NROC) 201 B01

(U) Instructional Method: Informal Lecture
(U) Instructional Aids: PowerPoint slides, animated videos
(U) Instruction Time: 2 hours

(U) Student Preparation/Reading Assignment:

1. Completion of the Orbital Mechanics CBT on CLEON
2. AU-18: Space Primer, Air University Press, 2009, chapter 6 & 7, pgs 89-135

(U) References:

1. Air Force Weather Agency (AFWA) Space Environment Primer
2. Air Force Weather Web Services, *Events and Impacts Product Help.* [redacted] (b)(3)
3. AU-18: Space Primer, Air University Press, 2009, chapter 6, 7.
4. Joint Tactical Exploitation of National Systems (JTENS), 2011, Main Appendix B.
5. Orbital Mechanics, [redacted] (b)(3)
6. "Satellite Orbits 101: How High do they fly?" Earthwide Communications, LLC, March/April 2010, pgs 28-32.
7. Space debris [redacted] (b)(3)
8. Understanding Space: An Introduction to Astronautics, 3rd ed. McGraw-Hill Companies. Chap 3, pgs 79-90.

(U) Knowledge Objective: The objective of this lesson is for each student to comprehend the principles of orbital mechanics.
(U) Performance Objective: n/a

(U) Main Points:

B01A Understand Classical Orbital Elements
B01B Understand Orbit Types
B01C Understand Orbital Perturbations

(U) Samples of Behavior:

1. Describe the principles of orbital mechanics.
2. Recognize low earth (LEO), geosynchronous orbits (GEO), highly elliptical orbits (HEO) and medium earth orbits (MEO).
3. Describe the advantages and limitations of LEO, HEO, GEO and MEO orbits.
4. Match NRO satellites to their launch location
5. Identify impacts of solar activity on satellite operations
6. Identify impacts of charged particles on satellite operations
7. Identify impacts of geomagnetic effects on satellite operations
8. Identify man-made operational concerns

(U) STRATEGY STATEMENT: This lesson is important to introduce students who will work with satellite operations to comprehend the motion of satellites matched with their missions.

(U) The lesson will be taught by informal lecture, allowing for a conversational tone and student questioning that will set the stage for a conversation between the instructor and students. The lesson will use the topical method of organization to allow for ease of understanding, beginning with the basics of satellite orbits, then translate the basics to four orbits in use today (low earth orbit (LEO), highly elliptical orbit (HEO), geosynchronous orbit (GEO) and medium earth orbit (MEO)) and close with a discussion of common space weather and other operational concerns.

(U) The instructor will introduce the lecture by using an appropriate attention step which will have students think about how frequently we use satellite technology without even realizing it. This can be done by asking the students who used a GPS receiver to plot their drive to the course. This lesson is important to understand because of the satellite technologies frequently used today: satellite maps, radio, TV and images. The overview will cover the objective of comprehending the principles of orbital mechanics. The force keeping satellites in orbit, components of orbits, purpose, advantages and disadvantages of LEO, HEO, GEO and MEO orbits will be discussed.

(U) Transition into the main point will follow by showing the students the video from Family Guy, describing a fictional orbit and the force of gravity exerted by the character in the video. Another option would be to toss an object in the air, let it fall and then ask the students why it fell. The anticipated response (AR) would be "Gravity" which would transition to main point one.

Main Point One is "Principles of Orbit." Main point one will be covered by the principles of orbits. This topic is important because an understanding of orbital mechanics should begin with the parts of orbits and then apply those parts. PowerPoint slides will be used to provide visual references of an orbital diagram, providing examples and subtypes of the orbital elements. The sub points in main point one will be (1) force of gravity, (2) shape of an orbit (eccentricity), (3) size of an orbit (orbital altitude/semi-major axis), (4) period of an orbit (related to altitude), (5) tilt of an orbit (inclination), (6) twist of an orbit (Right ascension of the ascending node), (7) position of orbit in orbital plane (argument of perigee) and (8) spacecraft location (true anomaly, attitude and ephemeris), (9) orbital perturbations and (10) space weather. Questions will be asked to evaluate the students' comprehension of the aspects of each sub point. Transition into main point two will be made by using an external transition: "Before we move on to applying these orbital principles to space missions, are there any questions on the parts of an orbit? Now that we've discussed the parts of an orbit, let's look at four common orbits in use today and how gravity, the orbital elements, orbital perturbations and space weather impact their missions.

Main Point Two is "Orbit Types." Main point two will be covered by discussing LEO, HEO, GEO and MEO orbits respectively. The orbits will be discussed with respect to their orbital elements from Main Point One. PowerPoint slides will be used to provide visual references of orbits around the earth and nadir point references, providing clear examples of the force of gravity, shape, size, period, inclination and impacts of perturbations and space weather of each orbit. The sub points in main point two will be (1) orbital elements, (2) advantages, (3) disadvantages and (4) common missions. Questions will be asked to evaluate the students' comprehension of the orbits discussed. Transition into the next point will be made by admitting that the orbit types are ideal cases and now we will discuss forces that negatively affect an orbit.

Main Point Three is "Orbital Perturbations." Main point three will be covered by discussing the forces that negatively affect a satellite in its orbit. This is important to understand how the orbits we discuss are ideal cases and that in practice other forces (both kinetic and electromagnetic) are at play. PowerPoint slides will be used to provide visual references of the perturbations and space weather. The sub points in main point two will be (1) orbital perturbations, (2) space weather. Questions will be asked to evaluate the students' comprehension of the forces discussed. Transition into the conclusion will be made by reviewing the topics discussed.

Conclusion will be done with a summary of the main points, emphasizing the force of gravity in keeping satellites in orbit, the elements that describe orbits, the functions of LEO, HEO, GEO and MEO orbits and the orbital perturbations. Remotivation will remind students of the prevalence of satellites in our lives today. Closure will be accomplished by Douglas Adams "Space is big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the drug store, but that's just peanuts to space."

LESSON OUTLINE:

(U) MP1: Orbital Elements
- (U) Principles of orbital mechanics.
- (U) Key components of an orbit.

(U) MP2: Orbital Types
- (U) Low Earth Orbit (LEO)
- (U) Highly Elliptical Orbit (HEO)

- (U) Geosynchronous Orbit (GEO)
- (U) Medium Earth Orbit (MEO)

(U) MP3: Orbital Perturbations
- (U) Orbital Perturbations
- (U) Space Weather

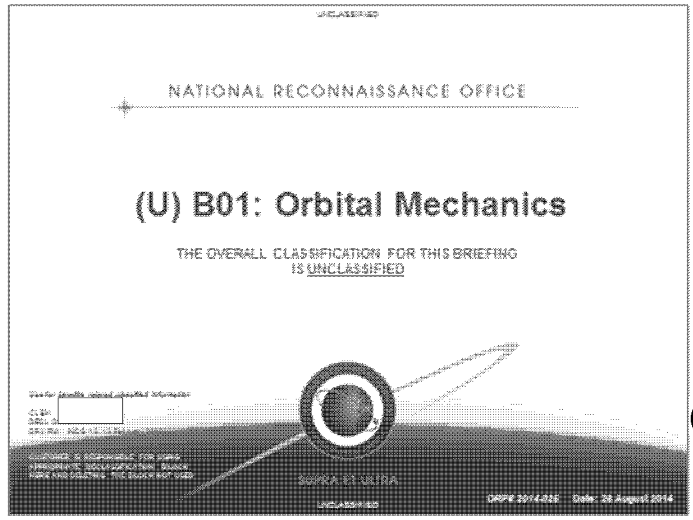
UNCLASSIFIED

(U) B01A – Orbital Mechanics
(U) Instructional Guide

(U) Introduction

Slide #1: (U) ORBITAL MECHANICS

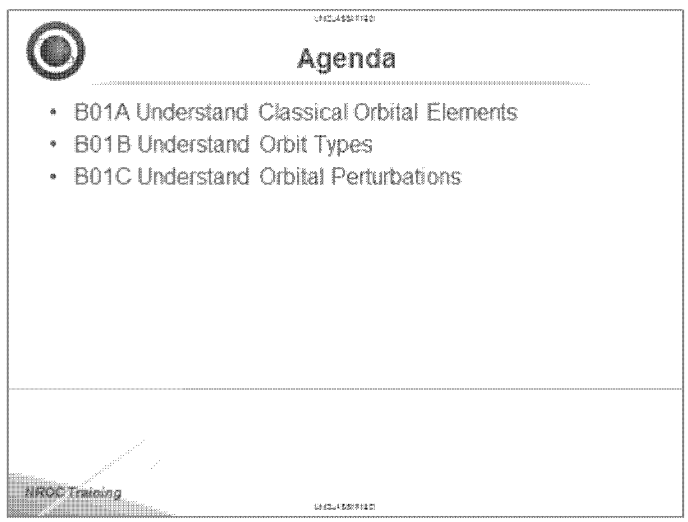
(U) Satellite technology is very common today, not only in navigation systems, but in radio, television and commercial imagery of the earth. It's important that we understand the fundamental principles behind satellite operations to better appreciate the work of scientists, engineers and other nerds in the space industry over the past 60+ years.



(b)(3)

Slide #2: (U) AGENDA

(U) This slide shows the three points on the agenda for this lesson

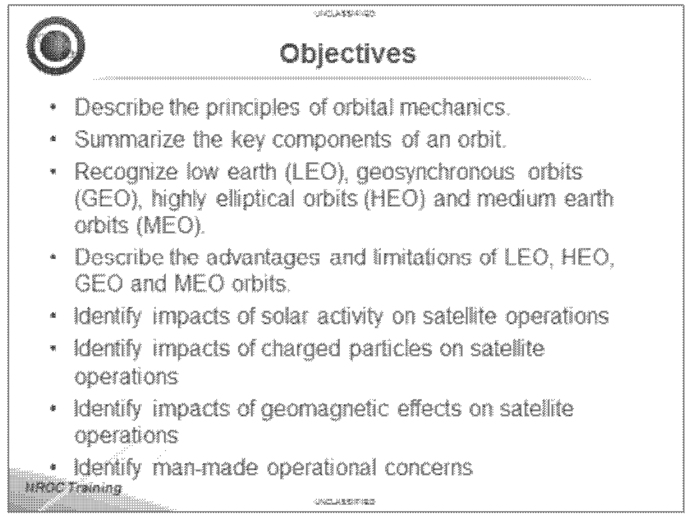


ORP#: 2014-027	Date: 26 August 2014

UNCLASSIFIED

Slide #3: Objectives

(U) These are the things you should expect to be able to do at the end of this lesson. They are also the things you can expect to be tested on.

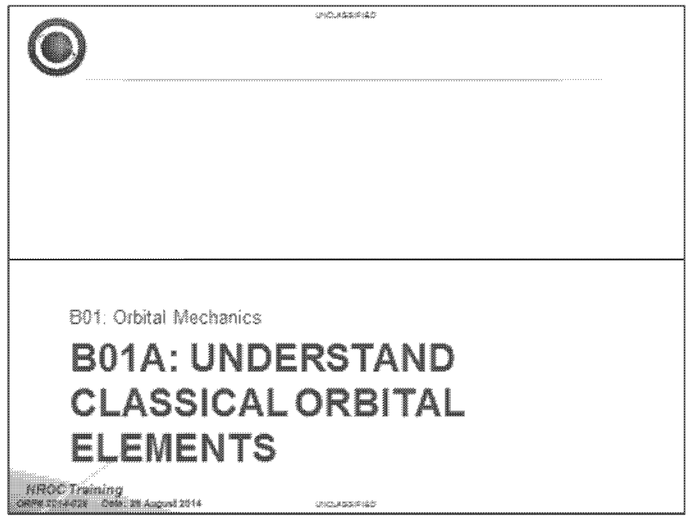


(U) B01A – Understand Classical Orbital Elements
(U) Instructional Guide

Position	Level of Learning
All Positions	B

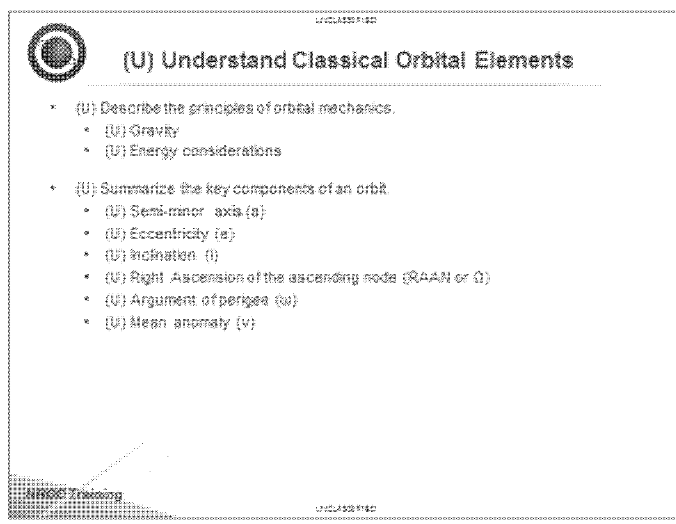
Slide #4: (U) B01A UNDERSTAND CLASSICAL ORBITAL ELEMENTS

(U) Let's start with discussing the basics of the classical orbital elements.

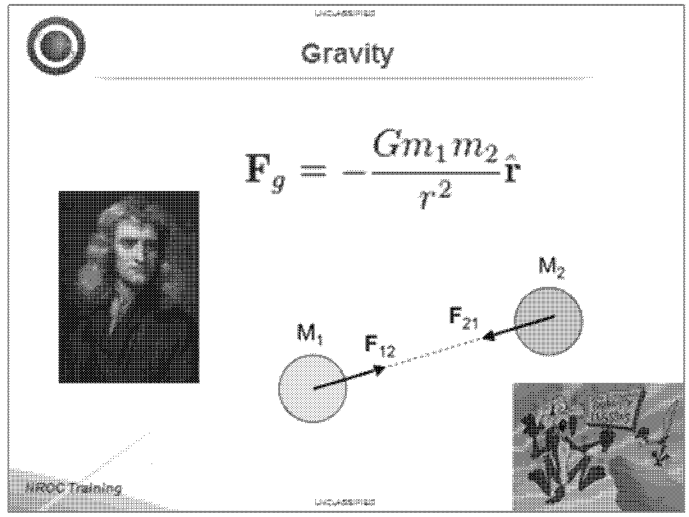


Slide #5: (U) Understand Classical Orbital Elements

(U) This is the map of the Westfields campus. You already saw this in NRO 100 and you have a copy of it in the book you received that day. We are going to towers the facilities so that you will have experienced where these places are located and I'll show you a few more important locations as well.



Slide #6: Gravity



(U) Who knows what physical property causes gravity?

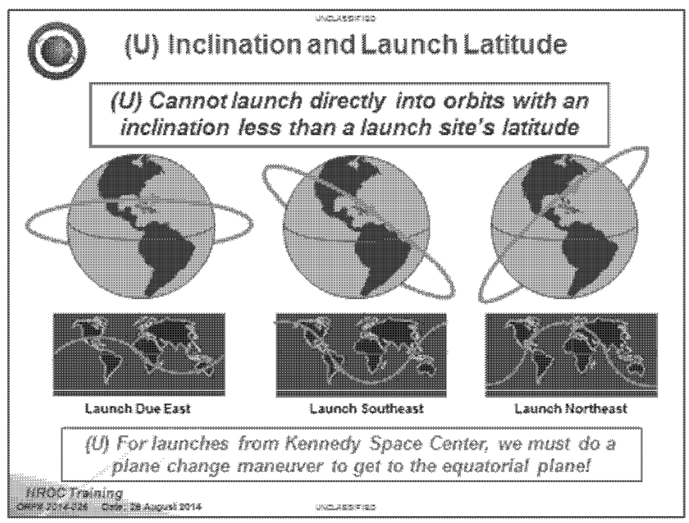
(A): Mass aka stuff

(Q): What other factor affects the *force* of gravity, exerted by that mass?

(A): distance

(U)Isaac Newton developed this equation (show F_g equation on screen) to determine the force of gravity one object (in our case the Earth) exerts on another (the satellite). The mass of the earth exerts its gravitational force on satellites and the satellites use the energy from their launch boosters, thrusters, gyros and reaction wheels to keep them in their proper orbit. The satellites themselves are truly *falling* around the earth. We'll discuss more about orbital perturbations that negatively impact the designed orbit of satellites.

Slide #7: (U) Inclination and Launch Latitude



(U) Explain why the energy needed for the space launch vehicles determines which orbit the satellite will go. Efficiency is the name of the game

(U) Depending on their initial launch energy, satellites can be in one of four orbits (listed from lowest to highest total energy): circle, ellipse, parabola or hyperbola. We are primarily concerned with circular and elliptical orbits as these orbits allow satellites to revolve around the earth. Hyperbolic orbits are used to remove a vehicle from orbit around the earth in what is called a super-synchronous orbit.

Slide #8: (U) NRO Vandenberg Air Force Base (VAFB)

(b)(3)

[redacted]

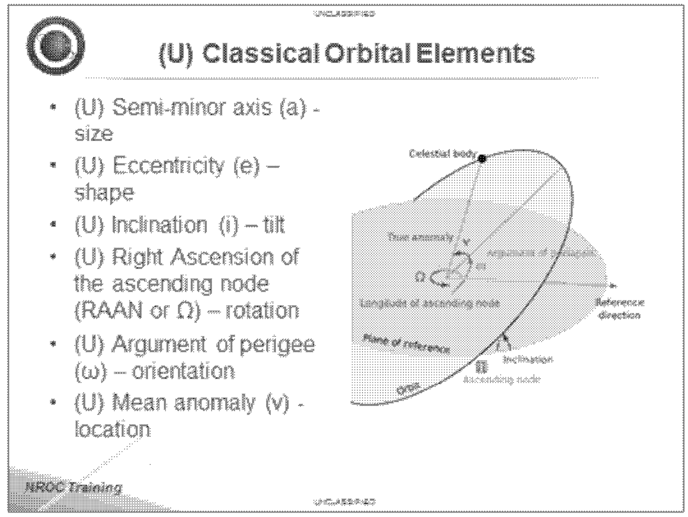
Slide #9: (U) NRO Cape Canaveral Air Force Station (CCAFS)

(b)(3)

[redacted]

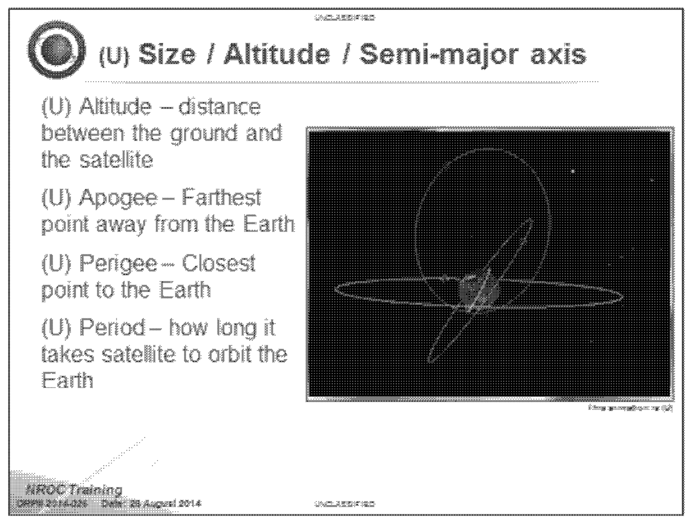
Slide #10: (U) Classical Orbital Elements

(U) Here are the elements we will be discussing.



Slide #11: (U) Size / Altitude / Semi-major axis

(U) The size of an orbit is related to shape and the amount of energy used to put the satellite there. The shape is characterized by the semi-major axis of the orbit. More typically, we refer to a satellites orbital altitude, which is the distance a satellite is above the surface of the earth (expressed in nautical miles, statute miles or kilometers). Two locations in a satellites orbit used to describe the satellites size are apogee and perigee. An easy way to remember the difference is that at apogee, the satellite is "away" from the earth. Therefore, at perigee, a satellite is closest to the earth.



(Q): Because it is based on distance, what can you tell me about the force of gravity on a satellite at its perigee? At its apogee?

(A): Perigee F_g is highest; Apogee lowest

(Q): Can anyone infer the locations of the apogee and perigee in a circular orbit?

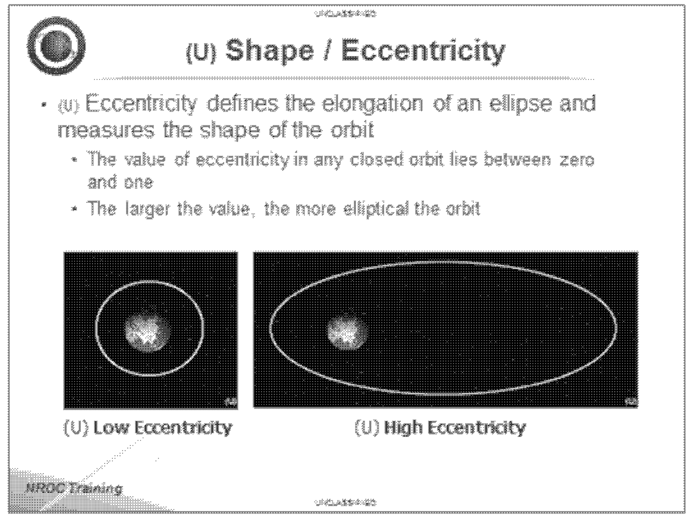
(A): In a circular orbit, these two properties are equal.
It is useful to note the time it takes the satellite to revolve around the earth, which we refer to as the orbital period.

(Q): What is the orbital period of the earth around the sun?

(A): one year or 365 days.
Period cans range from 90 minutes to 24 hours (same rotation as the earth).

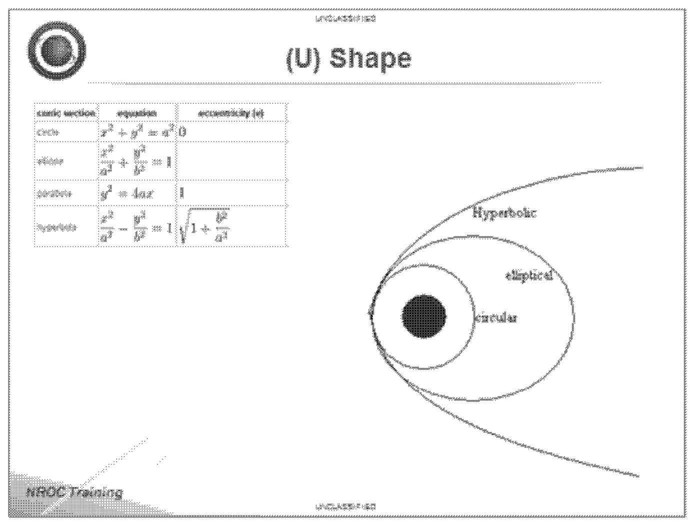
Slide #12: (U) Shape / Eccentricity

(U) Eccentricity refers to how stretched or non-circular an orbit is. Here are two examples of orbits, one with a low e and one with a high e.



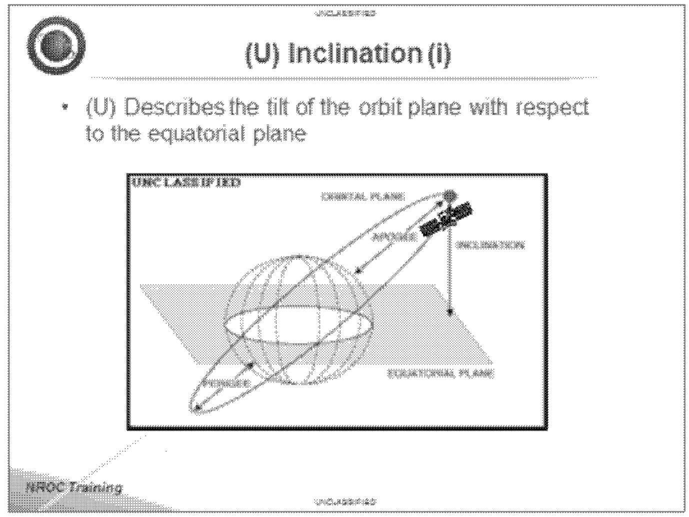
Slide #13: (U) Shape

(U) Here is another look at four orbits with eccentricities ranging from 0 to greater than



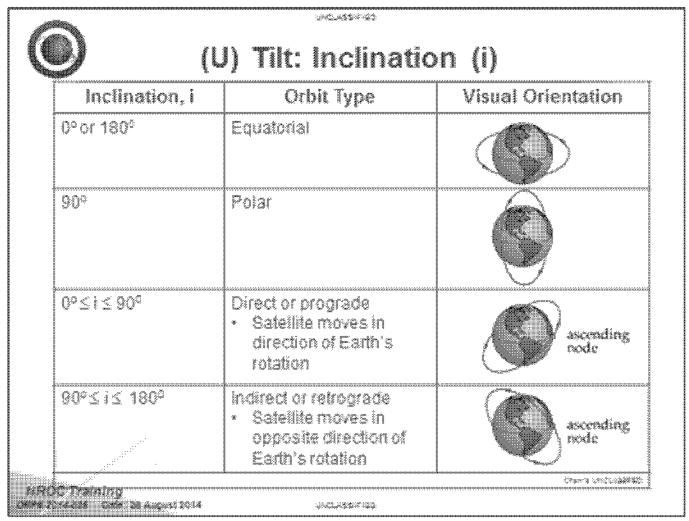
Slide #14: (U) Inclination (i)

(U) The next aspect of a satellite's orbit that is pertinent to our discussion is inclination. Inclination is imply the 'tilt' of an orbit with respect to the equator. We can describe the inclination of a satellite with the amount of degrees it is above or below 0°.

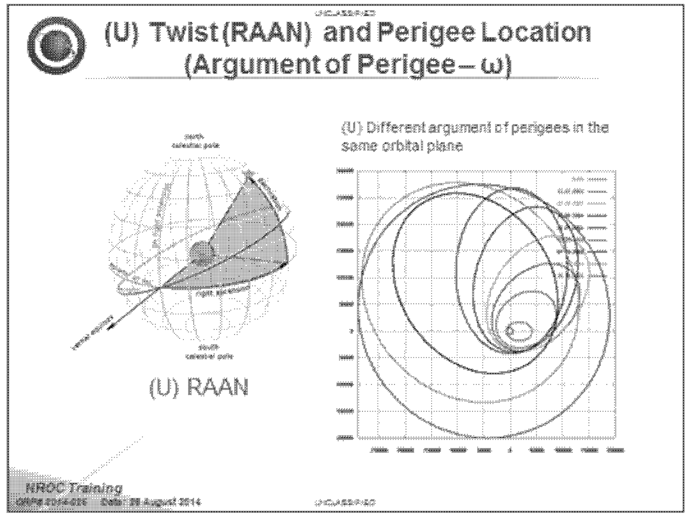


Slide #15: (U) Tilt: Inclination (i)

(U) Inclinations from 0° to 90° are considered prograde orbits (where the satellite's velocity vector is with the direction of the earth's rotation); 90° to 180° are retrograde orbits (where the satellite's velocity vector is against the rotation of the earth), at or near 90° are polar orbits and at or near 0° or 180° are called equatorial orbits.



Slide #16: (U) Twist (RAAN) and Perigee Location (Argument of Perigee – ω)

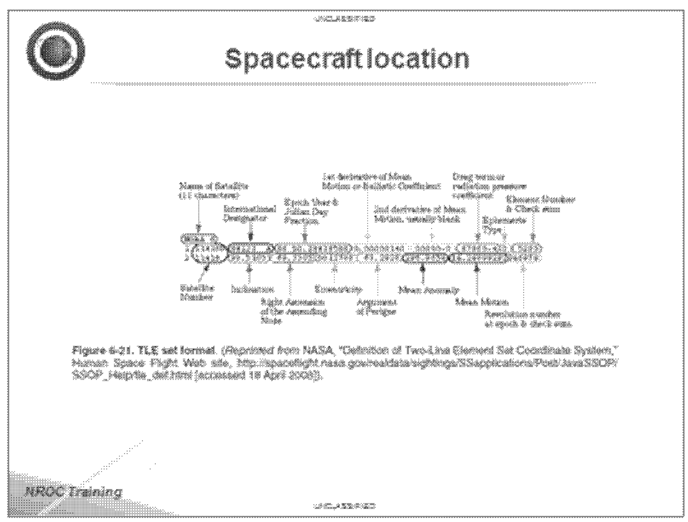


(U) The next aspect of a satellite's orbit that is pertinent to our discussion is right ascension of the ascending node (RAAN or Ω). This element describes the twist of the orbit from a reference point. For Earth orbiting satellites, we use the First Point of Aries as the reference point. From the perspective of the Earth, the First Point of Aries does not move.

(U) So the eccentricity (e), semi-major axis (a), inclination (i) and right ascension of the ascending node (RAAN or Ω) all define the orbital plane of the satellite's orbit. You can think of the orbital plane as a sheet extending to infinity in all directions. You could have many different satellites with the same e, a, i and Ω (same orbital plane), but with different true anomalies or argument of perigees, keeping the vehicles safe from colliding. Next we'll look at a set of elements that describe the specific location of a satellite at a point in time.

(U) The argument of perigee (ω) locates the perigee point of the orbit within the plane, calculated from the RAAN. One could consider this the spin of the orbit within the inclined plane. Again, you could design multiple orbits within one plane with phased arguments of perigee. This phased perigee location is useful to give multiple look angles for the same target location on the Earth. We'll see this used in a later lesson on some of the NRO missions.

Slide #17: Spacecraft location



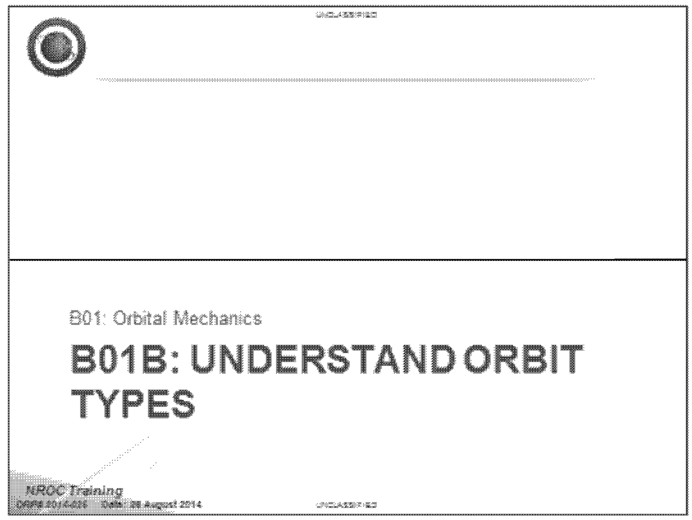
(U) We need to place the actual satellite in the orbit! The true anomaly (v, Greek letter nu) locates the vehicle in its orbit with respect to the perigee location. Typically, we can associate an epoch, aka timestamp to the true anomaly to effectively state, "The satellite was at location X in its orbit at time Y." Satellite engineers and operators will use ephemeris data (show example of two line element set) to understand a satellite's space catalog number (SCC#), velocity, and location. Another crucial aspect of the satellite's location in space is its attitude, or its orientation with respect to the earth.

(U) B01B Understand Orbit Types
(U) Instructional Guide

Position	Level of Learning
All Positions	B

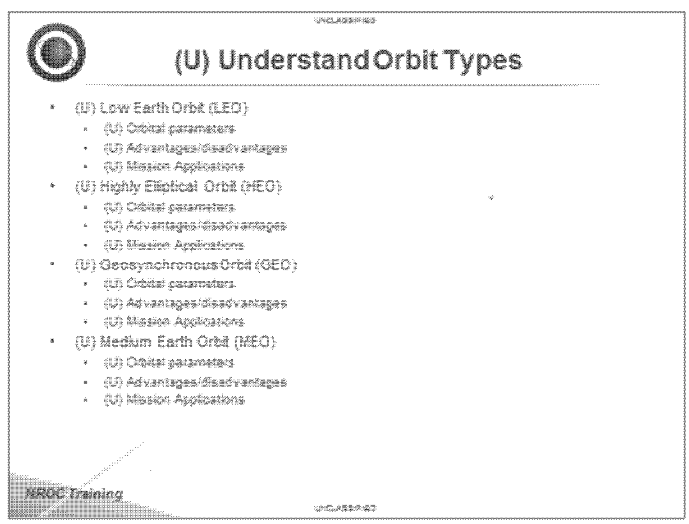
Slide #18: B01B Understand Orbit Types

(U) In this section, orbit types will be defined.

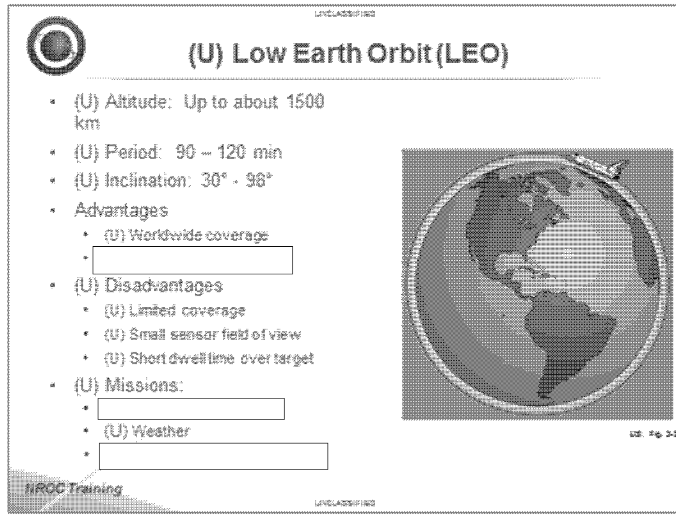


Slide #19: Understand Orbit Types

(U) The orbits covered in this section as they pertain to NRO systems, are LEO, HEO, GEO, and MEO orbits.



Slide #20: (U) Low Earth Orbit (LEO)



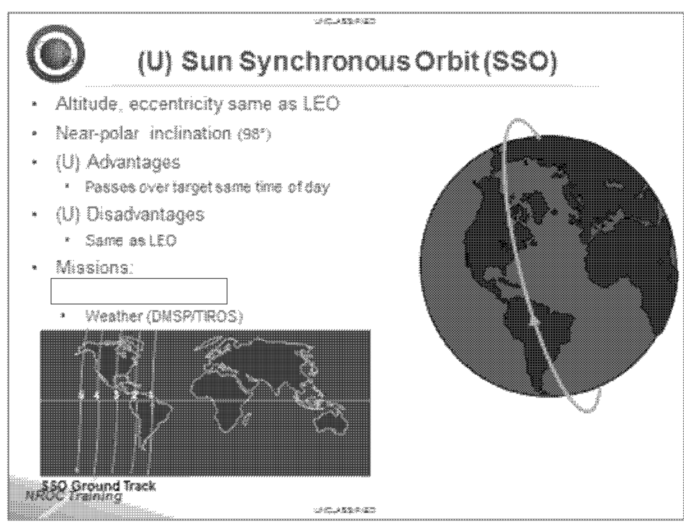
(b)(3)

(U) We'll begin with systems in low earth orbit, called LEO for short (nothing to do with lions here). The force of gravity is strong on LEO systems due to their close proximity to the earth. The shape of LEO orbits can be circular or elliptical, depending on the mission. LEO orbits range in altitude from 150-1000km. If you live in America, that's about 93 to 621 miles. The period of LEO orbits is typically around 90 minutes. The inclinations of LEO orbits can also range from slightly inclined (50°) to near polar (90-100°).

(U)The close proximity to the earth is one of the main factors when considering satellite missions in a LEO orbit. [redacted] (b)(3)

(U) The closeness to the earth can also be a disadvantage. Being very close to the earth means the satellite [redacted] (b)(3)

Slide #21: (U) Sun Synchronous Orbit (SSO)

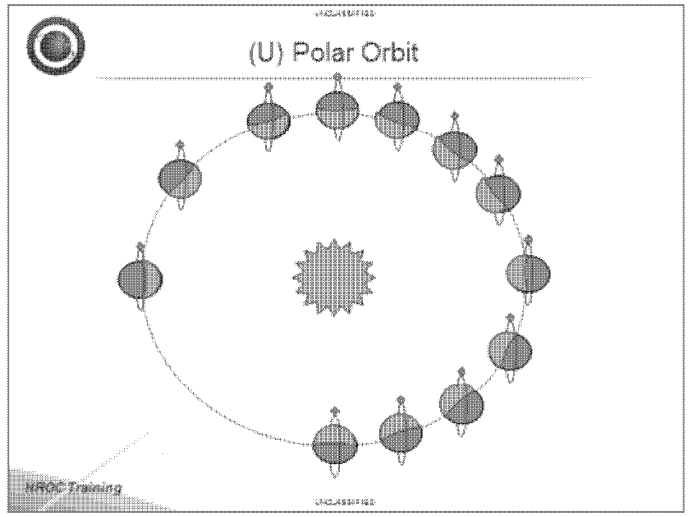


(b)(3)

(U) SSO is a special type of LEO. One type of LEO orbit is the sun-synchronous orbit (SSO). This orbit has an inclination of ~98° and range in altitude from 100-560 miles. This orbit will pass over a specific point on the earth at the same time each day, by taking advantage of the J2 effect and allowing the orbital plane to drift on par with the rate the earth orbits the sun.

Slide #22: (U) Polar Orbit

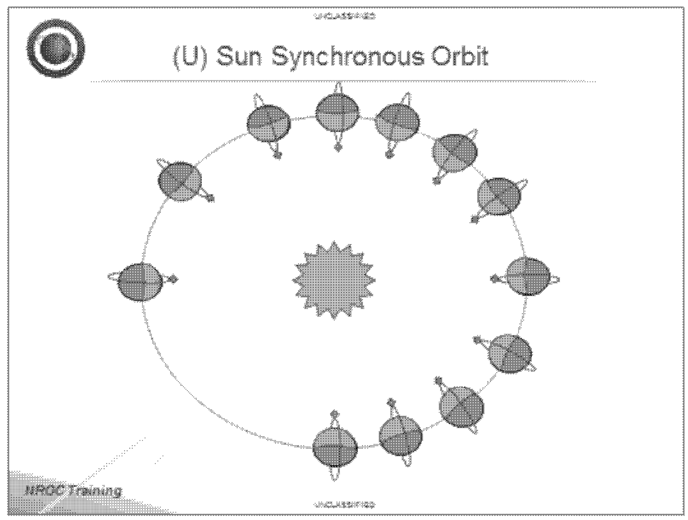
(U) This slide shows a satellite's orbit around the earth with respect to the sun, with a polar (90° inclination) orbit.



Slide #23: (U) Sun Synchronous Orbit (SSO)

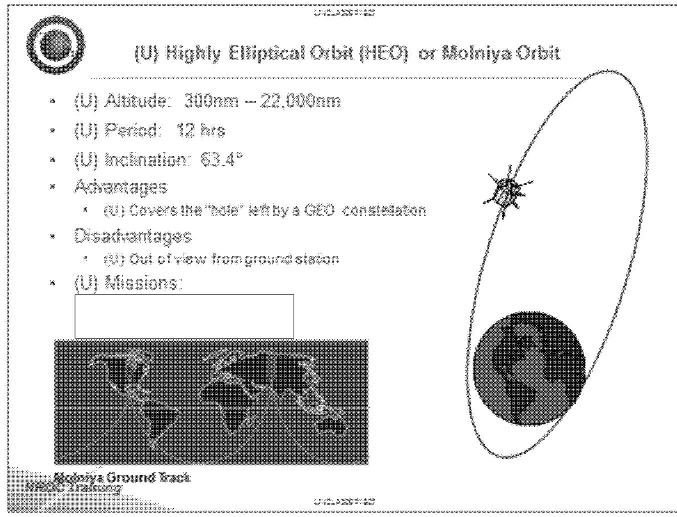
(U) By comparison, this slide shows a satellite's orbit around the earth with respect to the sun, with a SSO (98.6° inclination) orbit

(U) Now that we've examined the facets of low earth orbiting systems, let's look at satellites a little farther from the earth.



Slide #24: (U) Highly Elliptical Orbit (HEO) or Molniya Orbit

(U) Our second orbit for discussion is the highly elliptical orbit, called HEO for short. We'll use the term Molniya orbit synonymously with HEO orbit. The Russians started using the HEO orbit for their communication and missile warning satellites.



(b)(3)

(Q): Does anyone know the meaning of the word *Molniya*?

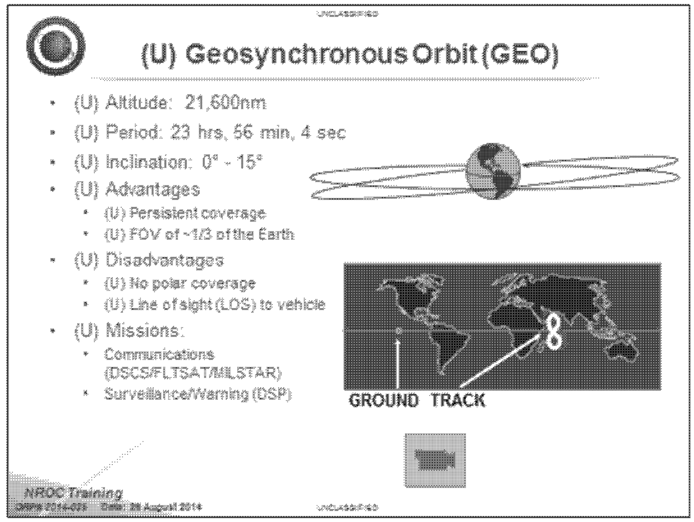
(A): Lightning. The Russians named their satellites in this orbit lightning due to the speed with which a satellite travels at perigee.

(U) The force of gravity on HEO systems is much less than that on LEO systems due to their distance from the earth at apogee (approximately 22,000 miles above the surface). The eccentricity of a HEO orbit is approximately .72, thus very stretched. The period of a HEO orbit is referred to as semi-synchronous, meaning half of the time it takes the earth to rotate on its axis (12 hours). HEO orbits are inclined at 63.4° to take advantage of the J2 effect's apsidal rotation. At this inclination, the orbit does not rotate within the orbital plane so the perigee location will stay in the southern hemisphere.

(U) The purpose of the HEO orbit is maintaining a view of the northern hemisphere. Common missions [redacted] (b)(3)

(U) One disadvantage of the HEO orbit is the fact that satellites in the orbit will traverse the South Atlantic Anomaly four times per day.

Slide #25: (U) Geosynchronous Orbit (HEO)



(U) Our third orbit for discussion is the geosynchronous orbit, called GEO for short. The force of gravity on GEO systems is much less than that on LEO systems due to their distance from the earth (approximately 22,000 miles above the surface). GEO orbits are typically circular. Geosynchronous orbits can be slightly inclined (0-15 degrees); however, GEO orbits at exactly 0 degrees inclination are referred to as geostationary orbits. As the name implies, the period of GEO orbits is approximately 24 hours (geo=earth; syn=same; chronous=time).

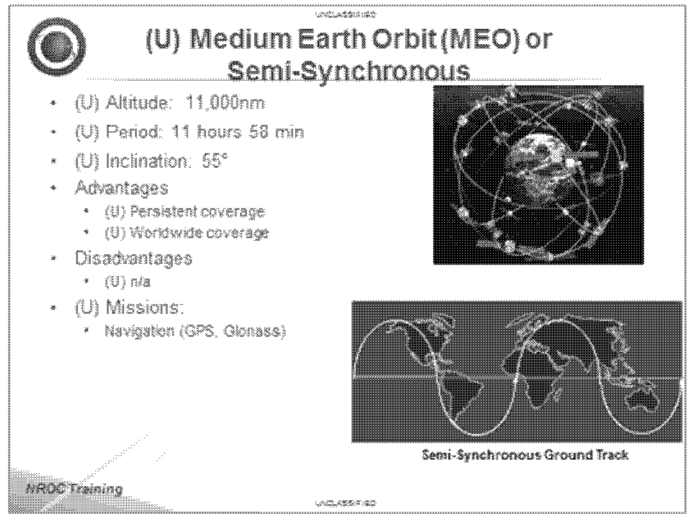
(U) The continuous coverage area is the main factor to consider for satellite missions in GEO orbit. Common GEO missions are early warning and communications. More specifically, the Defense Support Program (DSP) is an early warning system used by the DoD and the United Kingdom's Skynet.

(U) The primary advantage of the GEO orbit is its distance from the earth, allowing for its access to ⅓ of the earth from one satellite. In addition to coverage, the continuous staring (related to the orbital period) allows for comparison of data across time. [redacted] (b)(3)

(U) The access area of GEO systems is also a limitation of the system. One GEO satellite does not have worldwide access and no GEO satellite can collect or broadcast to the polar regions.

Slide #26: (U) Medium Earth Orbit (MEO) or Semi-Synchronous

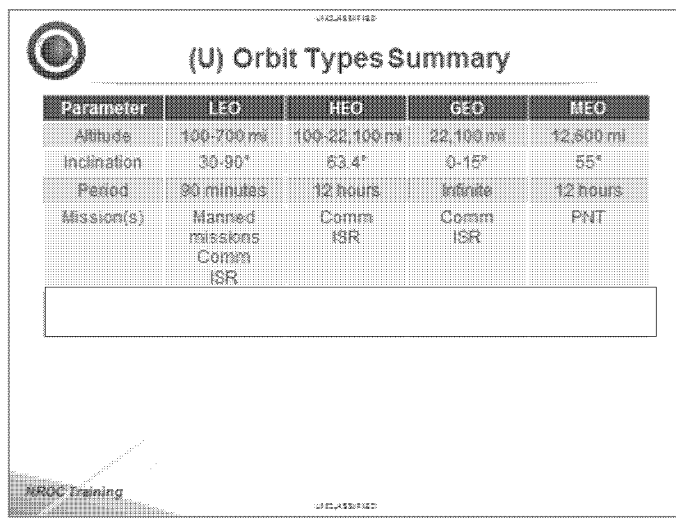
(U) Our final orbit for discussion is medium earth orbit, called MEO for short. We are most interested in the orbit of the Global Positioning System (GPS) constellation, which is inclined at 55°. The MEO orbits are typically circular, at an altitude of 12,600 miles above the surface of the earth. The period of the orbits is semi-synchronous, meaning they orbit the earth twice in one day.



(U)The field of view of the satellites in MEO is advantageous for its line of sight to a large portion of the earth. A disadvantage of MEO is its traversing the outer Van Allen radiation belt and thus being subject to a high density ionized particle environment. [redacted] (b)(3)

Slide #27: (U) Orbit Types Summary

(U) This table provides brief summary of key attributes pertaining to each orbit type discussed.

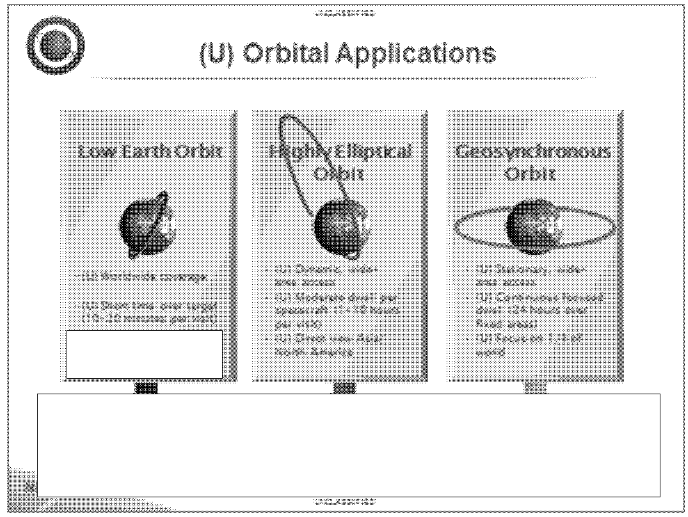


Parameter	LEO	HEO	GEO	MEO
Altitude	100-700 mi	100-22,100 mi	22,100 mi	12,600 mi
Inclination	30-90°	63.4°	0-15°	55°
Period	90 minutes	12 hours	Infinite	12 hours
Mission(s)	Manned missions Comm ISR	Comm ISR	Comm ISR	PNT

[redacted] (b)(3)

Slide #28: (U) Orbital Applications

(U) This slide summarizes the advantages and disadvantages of the LEO, HEO and GEO orbit.



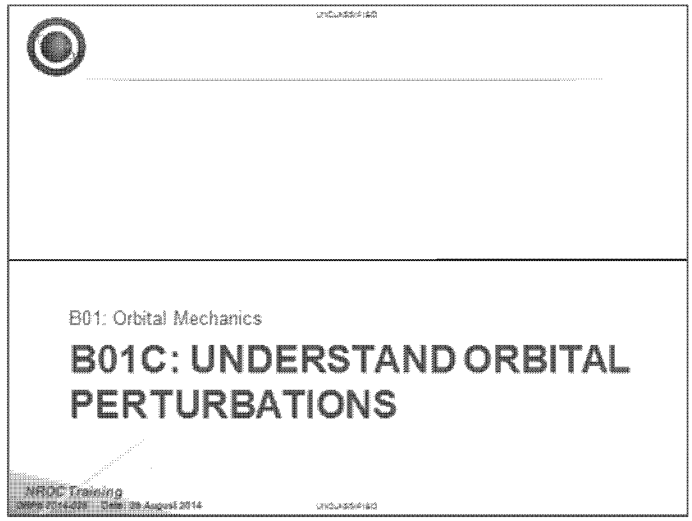
(b)(3)

(U) B01C Understand Orbital Perturbations
(U) Instructional Guide

Position	Level of Learning
All Positions	B

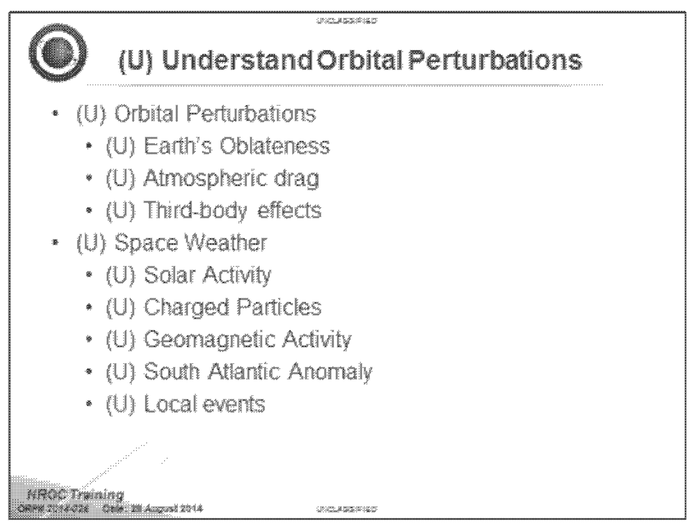
Slide #29: (U) B01C Understand Orbital Perturbations

(U) This section will cover what orbital perturbations are and their importance.



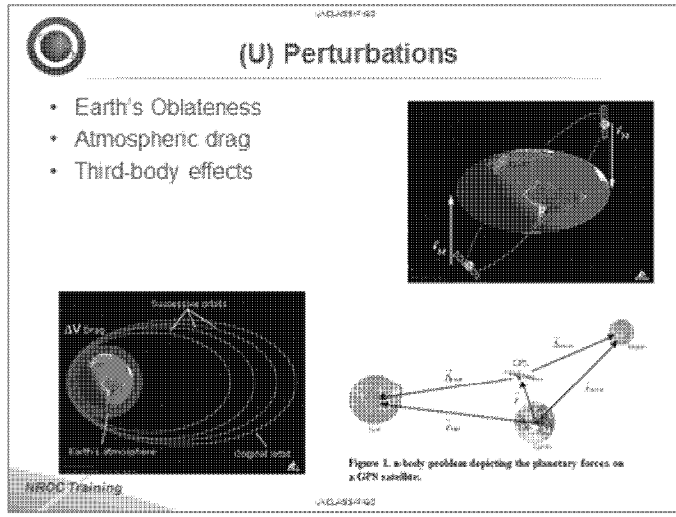
Slide #30: (U) Understand Orbital Perturbations

(U) Next, we need to be concerned with those forces that negatively impact a satellite's motion, called orbital perturbations. A perturbation is a disturbance of a satellite's orbit, attitude, or state of equilibrium in space. The major perturbations that are usually included in satellite orbit determinations include Gravitation Gradients, Magnetic Gradients, Solar Pressure and Atmospheric Drag.



Slide #31: (U) Perturbations

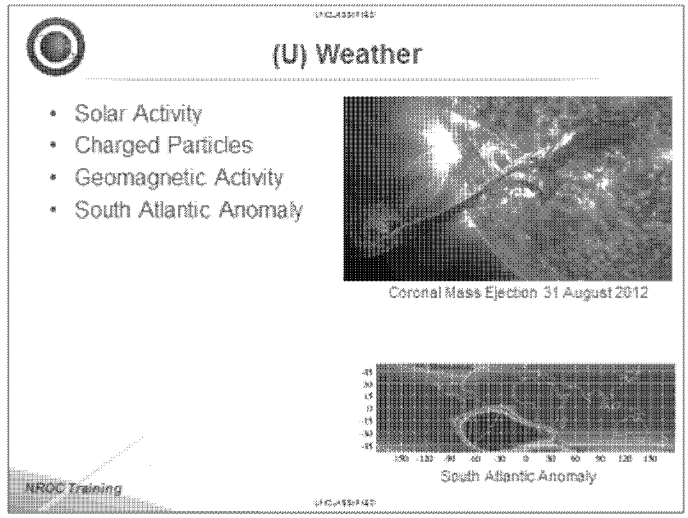
(U) In the world of terrestrial satellites, the Earth is not perfectly spherical, has an atmosphere and magnetosphere, and reflects a significant amount of sunlight. The sun and moon also exert gravitational forces on the system, along with additional light energy. The net result is a complex gravitational problem with a multitude of forces, the sum of which is generally modeled as perturbations from the ideal perfect-sphere two-body system. A "secular" perturbation is a slow drift in an orbital parameter. Each parameter is affected differently, depending on the source of the perturbation.



(U) The non-spherical nature of the Earth (J2 effect or oblateness) imparts drifts to the right ascension of the ascending node (RAAN) and the argument of perigee, both of which are functions of the semi-major axis, the inclination, and the eccentricity. The J2 effect will cause the argument of perigee to rotate, causing the orbit to rotate within its plane. We'll discuss how this can positively impact one orbit later (HEO at 63.4° inclination is a stable orbit with regards to the J2 effect). The ellipticity of the equator (the Earth has a beer belly) can cause orbital misalignments due to increased or decreased gravitational pull at certain nodal locations.

(U) Separately, the gravity of the sun and moon affect the mean anomaly, the right ascension of the ascending node, and the argument of perigee; for near-circular orbits, the latter two are functions of inclination and period.

Slide #32: (U) Weather



(U) Solar pressures are complex to model and depend critically upon both the ratio of projected area to mass of the vehicle and the vehicles surface characteristics. In certain situations the solar pressures can be used to offset the other perturbations that a satellite encounters. One example would be a solar sail.

(U) For low-altitude orbits, atmospheric drag imparts a significant drift to the altitude of perigee. As the satellite flies through the atmosphere, its velocity is reduced, and its perigee altitude is dropped by a corresponding amount; as a result, the orbit ultimately circularizes. Without intervention, the orbit will ultimately intersect the planet (catastrophically) somewhere in the orbital plane.

(U) **Solar Activity** is the overall activity level of the sun and its likelihood to impact systems. Criteria analyzed to determine the state of this category are the occurrence of moderate or greater x-ray flares and significant solar radio bursts.

(U) **Charged particles** show the observed or forecast potential for system impacts from charged particles significantly above normal background levels. Charged particle enhancements occur due to solar events or enhanced geomagnetic activity.

(U) Spacecraft can suffer a buildup of electrons on surfaces even sub-surface, such as in cabling or conductors on subsystem circuit boards. Charging, if not mitigated, can cause damage to components.

(U) Vehicle charging is also known by other common terms.

- Internal charging
- Deep dielectric charging
- Surface charging
- Hybrid charging

(U) Vehicle charging can last a very short time on spacecraft surfaces, seconds to minutes. Sub-surface charging buildup can last hours.

(U) **Geomagnetic activity** shows the overall geomagnetic activity level of the Earth's magnetic field. A measured or forecast planetary geomagnetic activity index is used to determine the likelihood of system impacts.

(U) The middle portion of this slide reports probable (unconfirmed) space environment impacts to

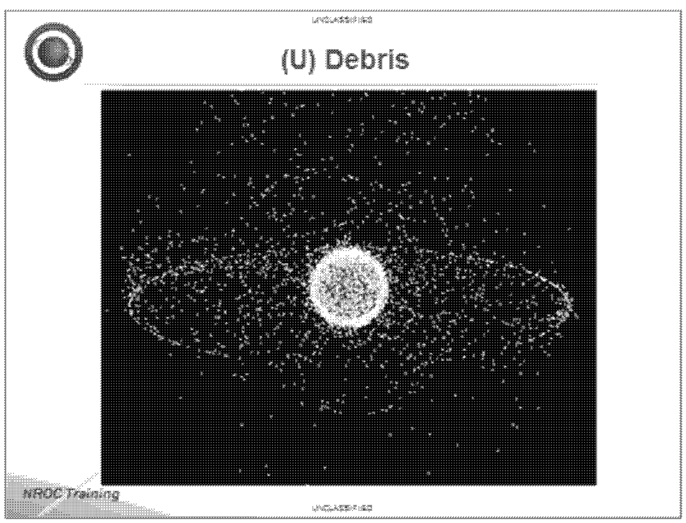
(b)(3)

(U) The bottom portion of the slide highlights reported space environment impacts from users. It is divided into six categories; the five from above and UHF SATCOM Communications.

(U) **The South Atlantic Anomaly (SAA)** is the only non-polar region where the radiation from the Van Allen Radiation Belts is experienced at high densities relatively near the sensible atmosphere. Plans for operation of satellites, especially the use of imaging sensors, must take account of the high dose rate of radiation in the SAA. A high rate of radiation produces many false triggering of semiconductor imaging electronics, and introduces both false counts and imaging noise. For many satellite applications, such as using star sensors used to fix position, operation in the SAA is operationally excluded to avoid complications. Geographically, the SAA appears to be centered above the part of the Atlantic Ocean just south of Brazil.

(U) The Van Allen Radiation Belts are regions that of high proton and electron density surrounding the earth. The radiation belts would be close-to-spherical if not for the effects of the solar wind. Satellites/spacecraft entering the VAB are bombarded by protons with energies exceeding 10 million electron volts at a rate of 3000 hits per square centimeter per second. The Van Allen Radiation Belts follow the field patterns of the earth's magnetic field, which is essentially a large dipole with an axis along the earth's magnetic poles (which are not coincident with the geographic poles of rotation). Where the Van Allen belts enter the atmosphere, near the magnetic poles, an oval pattern of aurorae are common. At lower latitudes, the belts are usually found at altitudes above 1000 km. But there are several complications to this simple first-order picture. The earth's magnetic field is not a simple dipole, and the mean axis is not along a primary diameter of the earth. Therefore there is a region -- the SAA -- where the high-intensity of the belts comes down to within a few hundred kilometers of the earth's surface. And since the belt is itself an abstraction -- the high-energy-density region of a wide spread of trapped radiation -- increased electron dose rates in the SAA can be detected at altitudes as low as 100 nautical miles

Slide #33: (U) Debris



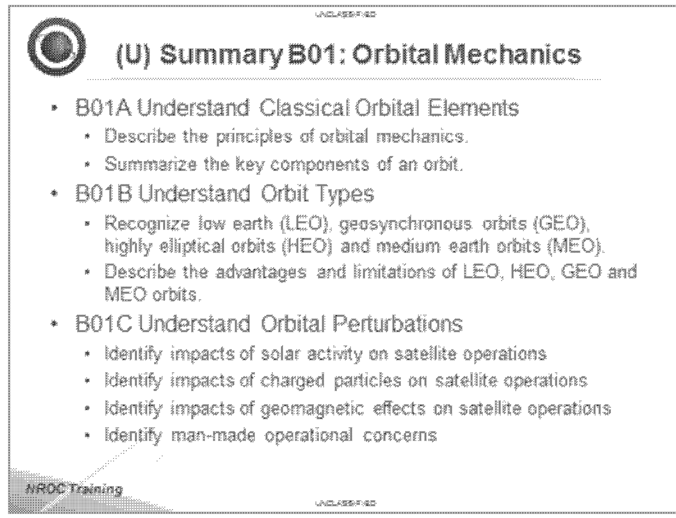
(U) Finally, orbital debris will also cause problems for satellite missions. Space debris is the collection of objects in orbit around Earth that were created by humans but no longer serve any useful purpose. These objects consist of everything from spent rocket stages and defunct satellites to explosion and collision fragments. The debris includes slag and dust from solid rocket motors, surface degradation products such as paint flakes, coolant released by satellites, clusters of small needles, and objects released due to the impact of micrometeoroids or fairly small debris onto spacecraft. As the orbits of these objects often overlap the trajectories of spacecraft, debris is a potential collision risk.

(U) The vast majority of the estimated tens of millions of pieces of space debris are small particles, like paint flakes and solid rocket fuel slag. Impacts of these particles cause erosive damage, similar to sandblasting. The majority of this damage can be mitigated through the use of a technique originally developed to protect spacecraft from micrometeorites, by adding a thin layer of metal foil outside of the main spacecraft body. Impacts take place at such high velocities that the debris is vaporized when it collides with the foil, and the resulting plasma spreads out quickly enough that it does not cause serious damage to the inner wall. However, not all parts of a spacecraft may be protected in this manner, e.g. solar panels and optical devices and these components are subject to constant wear by debris and micrometeorites.

(U) Due to the density of satellites and other space objects in LEO, most close approaches with other space objects occur in satellites in LEO orbits.

Slide #34: (U) Orbital Mechanics

(U) This slide is a summary of topics covered in this lesson.



Slide #35: (U) Questions