INTRODUCTION (10 min)

ATTENTION:

<u>Patriot Games</u> (Show Patriots Games movie clip)

MOTIVATION:
So, do you believe that the bad guys have a better idea of our capabilities than we do? Let's put it this way: Do you understand why the bad guys only had to take cover during certain periods of the day? Could you explain it?
For instance, could we place a reconnaissance satellite in an orbit that would give us continuous coverage? What kinds of things do we need to know to answer this question? 1) The kind of resolution we need 2) The kind of orbit that can give us continuous coverage. So, what kind of orbit? Geosynchronous. What does that mean? Why would it give us continuous coverage? What are the disadvantages to such an orbit? These are the kind of things that this class will tell you.
Although "Hollywood-ized" it is clear from the clip that there are definite tactical advantages to understanding our space assets.
This presentation is the first part of Civil Air Patrol’s Intro to Space Course. It is designed to give you an understanding of the ‘how’ and ‘why’ of satellites and their orbits.
Understanding orbital mechanics is critical to understanding the capabilities of satellites we have in space today.

PP Slide 1
PP Slide 2
PP Slide 3
PP Slide 4

OVERVIEW:

a. Without reference, summarize the principles of orbital mechanics, IAW course standards.

(1) Summarize the origins of orbital mechanics.

(2) Explain the physical laws associated with orbital mechanics

(3) Outline the requirements for orbit injection.

(4) Define three ways in which orbits may be classified.

(6) Define the six orbital elements.

(7) Explain satellite ground traces and recall factors that affect them.

(8) Give five examples of commonly experienced perturbations.

(9) Identify 2 launch considerations.

(10) Describe reasons for, types, and methods of orbital maneuvers.

(11) Distinguish between deorbit and decay.

TRANSITION:

Where did it all begin?

BODY (3 hrs 40 mi)

PRESENTATION.	
(1) Summarize the origins of orbital mechanics.	**PP Slide 5** Man has always sought some way to explain the heavens ad the earth. Whether we believe in divine origins or some other form of creation we all acknowledge governing laws or forces Historically speaking these laws often only partially could and sometimes completely inaccurate While the ancient Greeks and Chinese were able to accurately predict planetary motion and celestial phenomena through extremely accurate observations and fanciful explanations, it was not until Copernicus that modem Astronomy finally found some roots in reality.
a) Nicholas Copernicus 1) Polish monk who wrote On the Revolutions-of the Celestial Spheres in 1543 2) Revived the previously proposed heliocentric model 3) Believed orbits were circles whose center were displaced from the center of the sun	**PP Slide 6**
b) Tycho Brahe 1) A son of Danish nobility and a mentor to Johannes Kepler 2) Introduced precision into astronomical measurement through meticulous observation of the celestial bodies	**PP Slide 7** Tycho guarded his data jealously and was in this way able to keep Johannes as his lackey.
c) Johannes Kepler 1) German mathematician 2) Theories were as inaccurate as his predecessors but observed three laws for which he is remembered.	**PP Slide 8** Said of his mentor, " Tycho is superlatively rich, but knows not how to make proper use of it, which is the case with most rich people. One must try to wrest his riches from him." Johannes proposed that the orbits of the planets were inscribed within spheres which enclosed perfect solids. Perfect solids are structures whose faces are identical and regular polygons.

(2) Explain the physical laws associated with orbital mechanics. a) Kepler's 1st Law (Law of Ellipses): The orbits of the planets are ellipses with the sun at one focus	**PP Slide 9** **PP Slide 10** So what does that mean? Okay, let's pull out our geometry hats. **PP Slide 11** Orbital Vocabulary **PP Slide 12** Even the orbit of a ballistic missile is an ellipse, with the center of the Earth as one focus. (ooh, ahh)
b) Kepler's 2nd Law (Law of Equal Areas) The line joining the planet to the center of the sun sweeps out equal areas in equal times. 1) Implies that satellites travel at varying speeds during completion of their orbits	**PP Slide 13, 14, 15** This is fairly easy to visualize for a circular orbit, but for an elliptical orbit, things are slightly more difficult to see.
c) Kepler's 3rd Law (Law of Harmonics) The squares of the periods of revolution for any two planets are to each other as the cubes of their mean distances from the Sun.	**PP Slide 16** Huh? All this is saying is that orbits that have the same semi-major axis will have the same period. This was the first correlation between the size of an orbit and its period. Pretty good for an egghead who was always getting beaten up. Although Kepler had made these observations, it wasn't until Sir Isaac Newton came along that these theories were explained in a consistent and proven way.
d) Sir Isaac Newton 1) Law of Inertia - Every body continues in a state of uniform motion in a straight line, unless it is compelled to change that state by a force impressed upon it 2) Law of Momentum - When a force is applied to a body, the time rate of change of momentum is directly proportional to and in the direction of the force applied 3) Law of Action-Reaction - For every action there is an equal and opposite reaction 4) Newton's Law of Universal Gravitation -Every particle in the universe attracts every other particle with a force proportional to their masses and the distances between them.	**PP Slide 17** **PP Slide 18** **PP Slide 19** F=ma **PP Slide 20** **PP Slide 21** Earth as a point mass: All mass focused at Earth's center. Therefore, any orbital plane must intersect this point

	Through this law, Newton was able to explain all of Kepler's previous observations So why do we care? We care because Newton's law applies to orbital motion - motion of both planets and man made satellites. This is what we'll be talking about next. Any questions?
(3) Outline the requirements for orbit injection.	**PP Slide 22** Before we talk about orbits in more depth, we're going to cover how to get something into orbit in the first place. **PP Slide 23** This picture is a representation of a ball being thrown at varying speeds. If we just drop the ball, it will simply fall the 5m. If we threw the ball with a little bit of horizontal velocity, it will fall 5m down and a couple meters over.
a) Speed 1) If ball is thrown with enough of a horizontal velocity component, the Earth "falls" away from the ball as fast as the ball drops towards it. 2) Speed required depends on height	**PP Slide 24** In other words, at the Earth's surface, if for every 5 meters the ball falls, it travels 8 kilometers across, it will never hit the Earth. Thus, speed is major requirement for orbit insertion. **PP Slide 25** So, do we need more speed or less speed the higher we are? Why?
b) Height 1) From Newton's Law of Gravitation, the force between two objects decreases as the distance between them increases. 2) Hence, the greater the altitude the slower the fall. Less horizontal travel and therefore velocity is required.	**PP Slide 26** For a circular orbit the higher your altitude, the lower the required velocity. The other types of orbits shown also require a specific velocity for that altitude. **PP Slide 27** You can see here that general trend for required velocities at a given altitude. **PP Slide 28** A final aspect to consider when trying to insert an object into a given orbit is the direction you're going to launch in. Does anyone have any idea why?
c) Direction 1) Prograde (east-wardly traveling) orbits require less velocity than retrograde (westerly traveling) orbits.	**PP Slide 29**

2) Retrograde orbits must overcome the velocity associated with the rotation of the Earth.	With this in mind, do you think it matters where we launch from, an addition to the direction we launch in? Think about velocities at the poles versus velocities at the equator.
BREAK!!!!!	**PP Slide 30** Interim Summary When we come back from a break we'll talk about the various types of orbits. **BREAK!!**
(4) Define three ways in which orbits may be classified.	**PP Slide 31** This next section is really to just familiarize you with the terminology you might hear when folks talk about orbits
a) Size/Period. 1) Defined by semi-major or axis 2) Low Earth Orbit (100 - 500 miles) 3) High Earth Orbit (10,000 - 30,000 miles) 4) Semi-synchronous Orbit (12 hr period) 5) Geo-synchronous Orbit (24 hr period)	**PP Slide 32** Remember, what did Kepler say in his third law?
b) Location 1) Equatorial 2) Polar	**PP Slide 33**
c) Shape	**PP Slide 34** All satellite orbits/trajectories may described by using conic sections. The two orbits can be described as circular or elliptical. **PP Slide 35** The two trajectories en be described a parabolic hyperbolic
1) Circular Orbit a) Characteristics 1) Constant Speed 2) Constant altitude	**PP Slide 36** The majority of all existing manmade satellites are in a circular orbit.
b) Typical Missions 1) Reconnaissance/Weather (DMSP) 2) Manned 3) Navigational (GPS) 4) Communications (DSCS 3)	

2) Elliptical Orbit	**PP Slide 37**
a) Characteristics 1) Varying speeds 2) Varying altitudes 3) Asymmetric ground track	
b) Typical missions 1) Deep space surveillance (Pioneer) 2) Communications (Polar) 3) Ballistic Missiles	
3) Parabolic/Hyperbolic Trajectory	**PP Slide 38**
a) Characteristics 1) Escaped Earth's gravitational influence 2) Heliocentric	
b) Typical missions 1) Interplanetary exploration (Galileo, Phobos, Magellan)	There is another way to describe these orbits, and that's what I'll be going into next. To do that, we'll have to define some terms.
d) Orbital Geometry	**PP Slide 39** I know this looks like a pain, but these are the types of terms you're going to be hearing when some space operator are talking about an orbit.
1) Semi-Major axis – Half of the maximum diameter	
2) Semi-Minor axis – Half of the minimum diameter	The ones that are important to remember are the last three: eccentricity, apogee, and perigee.
3) Linear eccentricity - Half the distance between the foci	
4) Eccentricity - The ratio of the linear eccentricity to the semi-major axis	
5) Apogee/Perigee - Points farthest from and nearest to the Earth	
BREAK!!!	**PP Slide 40** This slide shows how the conic sections can be described by eccentricity. Remember we said that all orbits are conic sections. Therefore, in defining eccentricity, you're defining orbit shape. How is it that a circle has an eccentricity of 0? **PP Slide 41** This slide might help you see how that works. Most manmade satellite have orbital eccentricities of 0.1 or less. This means they're fairly circular. **PP Slide 42** These are the various orbital shapes you might get for the eccentricities listed. **PP Slide 43 Break!!!!!**
50 MINUTE MARK	

(5) Describe the various types of coordinate reference systems.	**PP Slide 44** What we'll talk about next is coordinate reference systems. If I said I was from Mililani Town, how many of you would know where I was talking about? How about if I said Mililani was in the county of Honolulu?
a) Purpose 1) Defines positions and directions in a consistent manner, hence allows communication 2) In terms of space a) Defines where satellite is b) Defines where satellite is going 3) Usefulness depends on type selected	What does this mean? How about if I was trying to tell you how to get to McDonalds. Would it be better to use N, S, E and W or longitude and latitude? To pick the most suitable reference system, we need to know what types there are.
	Here's another example of some folks who probably should have used a different coordinate reference system. **(Aliens clip)**
b) Ordinates 1) Origin - Where you're starting from 2) Fundamental Plane - The plane which you're measuring in 3) Principle Direction - The direction which you're measuring from	**PP Slide 45** McDonalds. Example: Origin: Here FP: Earth's surface (it's flat, didn't you know?) PD: North. By using these three ordinates, we could tell someone how to get to McDonalds.
c) Types of Coordinate Reference Systems 1) Inertial a) Non-rotating b) Time independent 2) Non-inertial a) Rotating b) Time Dependent	**PP Slide 46** Using McDonalds, we defined our own reference system, but there are an infinite number out there. Here's a few you'll commonly see in the space world.
d) Examples	**PP Slide 47**
1) Geographic a) Type - Non-inertial b) Purpose - To locate points on the Earth's surface c) Measurements 1) Latitude 2) Longitude	**PP Slide 48**

2) Topocentric a) Type - Non-inertial b) Purpose - To locate a satellite with respect to a tracking station c) Measurements 1) Elevation - Angle between the plane of the Earth's surface and the line connecting site to satellite 2) Azimuth - Angle between true north and elevation plane, measured clockwise 3) Range - Distance from Earth's Surface to satellite	**PP Slide 49** This will tell us where a satellite is on space, BUT only with respect to a specific tracking station. If we were at Hula, and we had info for Pike, we would NOT be able to find the satellite. **PP Slide 50** **PP Slide 51** Mention tracking data
3) Geocentric Inertial	**PP Slide 52**
a) Type- Inertial 1) Origin - Earth's center 2) Fundamental Plane- Equatorial Plane 3) Principle Direction - Vernal Equinox a) Line formed by the intersection of the Equatorial plane and the Earth's orbital Plane	Duh. Who? AKA the First Point of Aries. Constellation which it was pointing to when the reference system was developed. "Was", because this line is actually shifting. So kind of inertial. Right now, the line is leaving Pisces and starting to point towards Aquarius. (Hence that hippie-reject type song about the Dawning of the Age of Aquarius.)
b) Purpose	
1) To determine the exact orientation of an orbital plane and to locate points in space with respect to the Earth	Clearly, this is useful to us for determining where satellites are.
c) Measurements	
1) Declination - Angle between the fundamental plane and the satellite's orbital plane. 2) Right Ascension a) Ascending node - Point where satellite crosses the equatorial plane going from south to north. b) Right Ascension of the ascending node - The angle measured within the equatorial plane From the principle direction to the ascending node	**PP Slide 53** We generally call this inclination **PP Slide 54** Remember that S to N bit. There are two times when the satellite can cross the orbital plane, but only one time when it will go from S to N

4) Orbit Inertial a) Type - Inertial	**PP Slide 55**
b) Purpose - To locate the exact position of a satellite within its orbit at any time	So with the geocentric system, we defined what the satellite's orbit was. With this system we define WHERE in its orbit the satellite is.
c) Measurements 1) Argument of Perigee - Angle from the ascending node to perigee measured within the orbital plane in the direction of satellite travel	These last two are the main reference systems you should try to be familiar with.
	PP Slide 56 Review
	PP Slide 57 Review
	PP Slide 58 So we've talked about a few reference systems, and believe it or not, in doing so, we've talked about 5 of the 6 orbital elements we need to define where a satellite is in space. We said earlier that given three values, Azimuth, Elevation and range, we could define where a satellite was at a particular time. If we wanted to define the satellite's position at any point in time, we would need 6 ordinates, 3 for position and 3 to describe the velocity vector.
(6) Define the six orbital elements	
a) Definition - A set of mathematical parameters that enables us to accurately describe satellite motion	**PP Slide 59**
b)Purpose 1) Discriminates one satellite from other satellites 2) Predicts where a satellite will be in the future or has been in the past 3) Determines necessary distance and direction of maneuver or effect of perturbation	**PP Slide 60**
c) Keplerian Elements 1) Semi-Major or Axis - Size 2) Eccentricity - Shape	**PP Slide 61** Now I know you remember what the first two are. How about the rest?
3) Inclination - Tilt of orbital plane as measured counter-clockwise from the equatorial plane at the ascending node	**PP Slide 62**
4) Right Ascension of the ascending node -The angle measured within the equatorial plane from the principle direction to the ascending nod	**PP Slide 63** **You can think of this as swivel**

5) Argument of Perigee - Angle from the ascending node to perigee measured within the orbital plane in the direction of satellite travel 6) True Anomaly - Angle measured from perigee to satellite within orbital plane in the direction of satellite motion (time dependent)	**PP Slide 64** **PP Slide 65** This is what true anomaly looks like in the orbital plane **PP Slide 66**
7) Epoch Time - Time when true anomaly was measured	Time of perigee passing By using these 6 elements and epoch time, we have completely defined the satellite's orbit and its position.
d) Examples	
This completes the first portion of the Orbital Mechanics lesson plan. **BREAK!!!**	**PP Slide 67** These are some of the orbits you can get just by changing inclination. **PP Slide 68** Interim Summary **BREAK!!!**
BREAK!! This completes the Day One portion of the lesson	
Welcome to Day Two of the Orbital Mechanics lesson plan!! We will pick right where we left off. These are the topics that will be covered today. (1) Explain satellite ground traces and recall factors that affect them.	**PP Slide 1**
a) Definition 1) Subpoint - Point on the Earth's surface defined by an imaginary line connecting the satellite and the Earth's center 2) Ground track is trace of subpoints over time.	**PP Slide 2** Starting simply, you can see that if the Earth does not rotate, the satellite ground track would be the same for any coplanar orbits. In other words, assuming inclination remained the same the other five orbital elements would have no impact on the ground track. (Go through various elements) Unfortunately, the Earth does rotate, and thus we must take the other elements into account.
b) Factors affecting ground traces	**PP Slide 3**

1) Period a) Period defines the westward regression of the ground track. b) Because Earth is rotating east under the satellite, the satellite track appears to "walk" west	**PP Slide 4** For a non-rotating Earth, the ground track of a satellite is a great circle. Since the earth is spinning, and the satellite orbits the earth, the period of both affects the ground track. **PP Slide 5** **PP Slide 6** You can see from the slide that the westward regression is 30*. Because we know that the Earth rotates 360* in 24 hrs, we know that it goes through 15* each hour. A regression of 30* or 2 times 15* implies a 120 minute orbit (every 2 hours!)
2) Eccentricity a) In a highly eccentric orbit, the satellite will be moving much faster at perigee than at apogee b) Satellite will appear to hang over Earth at apogee, but will move faster than Earth at perigee	**PP Slide 7** In addition, ground track will be asymmetrical **PP Slide 8**
3) Inclination Angle a) Defines maximum latitude, North and South that ground track will reach There are special considerations for synchronous or polar orbits-- they will cover all Lat/Longs! b) For a 45* inclined orbit, maximum latitude will be 45* N and 45* S	**PP Slide 9** **PP Slide 10**
4) Argument of Perigee a) Establishes longitude of perigee and apogee	**PP Slide 11** **PP Slide 12** Through these five parameters, we can create almost any ground track we want. This is the key to the capabilities of our space assets.
5) Injection Point a) Assuming no maneuvers after launch, launch sites will determine inclination b) Injection point will determine where ground track will start	**PP Slide 13**
c) Theory	**PP Slide 14**

1) Understanding ground tracks helps determine the best orbit to maximize satellite mission effectiveness 2) Will also help to determine enemy capabilities	Let's think about this a bit. If the injection site is above the Indian Ocean, and the orbital period is 1 hr, the satellite will pass back over IOS exactly 24 revolutions later. However, if its period is not exactly divisible into 24hrs, the satellite might not pass over IOS for several more days.
d) Examples 1) Geostationary Orbit a) Single dot	**PP Slide 15** This is was we saw in Patriot Games. The enemies were using their knowledge of our satellite ground tracks against us. We can see how to pick a satellite orbit depending on its mission by looking at the various ground tracks for some common orbits.
2) Geosynchronous Orbit a) Figure eight 1) Inclination causes satellite speed to vary with respect to Earth's rotational speed; hence the figure 8 2) Equator is crossed from east to west	As the satellite starts to move up from the ascending node a component of velocity is directed upward. This causes the horizontal velocity to be decreased and the satellite to "fall behind" the Earth. At the satellite approaches its highest orbital point it begins to "catch up" to the Earth and eventually overtake it. As the satellite descends, again a component of its velocity is now directed downwards, again taking away from its horizontal motion. The satellite ground track passes through the descending node at the equator and thus completes the top loop of the 8. Similarly the bottom loop is completed.
3) Molnyia Orbit a) Semi-synchronous orbit-> Exactly 180* of westward regression b) Eccentricity causes asymmetrical ground track c) Speed at perigee causes satellite to cover more ground, therefore, want to place apogee over area of interest	Where's apogee? Perigee? Molnyia in Russian means lightning. This describes its motion near perigee. At apogee, you get "hang time." You can see that this would be a good way to provide polar comm. Note that you could choose to place apogee over the south. Of course those penguins would really appreciate CNN.
4) LEO, retrograde a) Westward regression ~22* b) Symmetrical c) Ground track traces from right to left	What kind of orbital elements are we talking about here? This implies what kind of period? Circular orbit Note that even though we're moving in a different direction from the other tracks we've talked about we still have westward regression
5) Polar a) Track appears to "fall off" of map b) Through a given number of revolution, all of the areas Earth will be covered	Note that all orbits intersect at the poles **PP Slide 16**

50 MINUTE MARK	Any questions on ground tracks? Interim summary.
(2) Give five examples of commonly experienced perturbations	**PP Slide 17**
a) Gravitational Perturbations - Earth's asymmetrical mass causes a non-central gravitational pull	**PP Slide 18** Mass asymmetry is also known as the J2 effect
1) Nodal Regression a) Ascending node regresses to the west for prograde orbits, to the east for retrograde orbits b) Sun Synchronous Orbits 1) Takes advantage of nodal regression to keep orbit regressing approximately 1* per day 2) Ensures constant sun angle which is beneficial to reconnaissance missions 3) Can be fixed such that satellite will pass over the same area on the Earth at the same time every day	**PP Slide 19** **PP Slide 20** **PP Slide 21**
2) Apsidal Line Rotation a) Line of Apsides is the line connecting apogee and perigee b) Makes the orbit rotate in its orbital plane 1) 0* ≤ i < 63.4*, 116.6* ≤ I ≤ 360* , eastward rotation 2) 63.4* ≤ i ≤ 116.6 , westward rotation 3) 63.4*, 116.6* stable	**PP Slide 22** a = 1044 mi +rE => T = 2 hrs e=0 i = ~102* Omega=0 Obviously this only applies to elliptical orbits This is why all Molnyia orbits have an inclination of 63.4*
3) Libration - Ellipticity of the Earth causes gravity wells and hills a) Stable points: 75'E, 105*W b) Unstable points: 165-E, 5-W	**PP Slide 23** This perturbation mostly affects equatorial orbits, and therefore comm sats. Stationkeeping is required to keep the birds within certain longitudes. (discuss stationkeeping)
b) Atmospheric Drag -Drag caused by the collision of spacecraft with particles in the atmosphere	**PP Slide 24** Remember from Aerospace education, how many parts of the atmosphere are there? Where does the atmosphere “end”?

1) Drag causes satellite to lose velocity and therefore lowers altitude and increases eccentricity	So when is drag going to be more of a problem? At apogee or perigee?
2) Greatest drag is experienced at perigee where satellite is closest to the Earth	**PP Slide 25** Eventually atmospheric drag can decay a satellite's orbit to the point where re-entry occurs
c) Third Body Effects 1) The gravitational effects of other massive bodies, such as the sun and the moon 2) More significant effects on deep space orbits	**PP Slide 26**
d) Solar Wind/Radiation Effects 1) Solar wind affects satellites like regular winds affect ships 2) Effects are similar to atmospheric drag 3) Effects are more pronounced on satellites with large, flat surface areas	**PP Slide 27** UHF F/O uses the solar wind to provide attitude control
e) Electro-magnetic Interaction between the Earth's magnetic field and the satellite's electromagnetic field results in magnetic drag	**PP Slide 28**
(3) Identify 2 launch considerations	**PP Slide 29** We will now talk launch considerations
a) Launch Windows	**PP Slide 30**
1) Period of time during which a satellite can be launched directly into a specific orbital plane from a specific launch site 2) Driven by safety, minimum fuel requirements, desired injection points, hardware capabilities 3) Will be centered around an optimal time	**PP Slide 31** A launch window can be as small as five minutes or as large as 2 hrs. In reality, though, you don't wait for the optimal time to fire. You start trying as soon as your window opens.
4) Opportunities to launch DIRECTLY into orbit a) 2 per day of latitude of launch site is less than orbit's inclination b) 1 per day if latitude is equal to inclination c) None if latitude is greater than inclination	**PP Slide 32**

b) Azimuth vs. Inclination 1) By launching due East, or on an Azimuth of 90*, you can achieve an inclination equivalent to that of the launch site 2) Proper injection at launch minimizes future plane change requirements 3) Various factors affect how launch are selected a) US will not launch over populated areas b) Launching near the equator gives an initial velocity boost 1) Good for low inclination prograde orbits 2) Bad for retrograde orbits	**PP Slide 33** Note that combined with the launch opportunities this means that the <u>minimum</u> inclination you can ever achieve a direct launch into is equivalent to the latitude of your launch site. All other inclinations must be greater
(4) Describe the reasons for, types and methods of orbital maneuvers	**PP Slide 34** We will now talk about the types of orbital maneuvers
a) Why do them	**PP Slide 35**
1) Maneuver to higher orbit a) Increase satellite field of view b) Counteract atmospheric effects c) Achieve proper area of coverage 2) Maneuver to lower orbit a) Increase imaging resolution b) Satellite rendezvous c) De-orbit	**PP Slide 36**
b) Type of maneuvers	**PP Slide 37**
1) In-plane a) Change in size/period b) Change in argument of perigee c) Change in true anomaly 2) Out-of-plane a) Change in inclination b) Change in Right Ascension of ascending node	

c) In-plane maneuver methods	**PP Slide 38**
1) Hohmann Transfer a) Can be used to change altitudes in either direction b) Most efficient c) Requires completion of one half revolution in transfer orbit d) Method 1) Determine target orbit 2) The transfer orbit is a more elliptical orbit in the same plane with its perigee in the initial orbit and its apogee, in target orbit	
3) To increase altitude, a positive burn, or delta-v is accomplished at perigee to kick satellite into transfer orbit 4) A secondary burn is accomplished at apogee to circularize orbit to final, target orbit 5) To decrease altitude, a negative delta-v at apogee, then perigee is accomplished	**PP Slide 39** In the real world we wait for several revolutions in the transfer orbit before we do another bum. This is so that we sure we have nailed down our orbit before burning into another one.
2) Fast transfer	**PP Slide 40**
a) Does not require set amount of time	
b) Highly inefficient	
c) Prone to error	
d) Driven by time constraints	
e) Method 1) After target orbit is determined, a delta-v of sufficient magnitude to result in intersection with the target orbit is accomplished at any arbitrary point in the initial orbit 2) As soon as the transfer orbit path crosses the target orbit, another delta-v is performed to realign the satellite into desired orbit.	**PP Slide 41**
(5) Distinguish between deorbit and decay	**PP Slide 42** Our last topic we will cover concerns de-orbit and decay

a) De-orbit -Controlled re-entry to a specific location 1) Used to move satellites out of desireable orbits	**PP Slide 43** This is a dumb, really inefficient way of changing orbits.
2) Used to recover manned capsules	Discuss altitude and requirements for burning.
b) Decay - Uncontrolled re-entry 1) Potential impact anywhere along ground track 2) Tracking Impact Prediction (TIP) generated by CMAFB to warn possible victims	**PP Slide 44**

TRANSITION: Are there any questions?
CONCLUSION (10 min)
SUMMARY:
(1) Summarize the origins of orbital mechanics.
(2) Explain the physical laws associated with orbital mechanics
(3) Outline the requirements for orbit injection.
(4) Define three ways in which orbits may be classified
(5) Describe the various type of coordinate reference systems.
(6) Define the six orbital elements.
(7) Explain satellite ground traces and recall factors that affect them.
(8) Give five examples of commonly experienced perturbations
(9) Identify 2 launch considerations
(10) Describe the reasons for, type and methods of orbital maneuvers
(11) Distinguish between deorbit and decay

PP Slide 45

We will now take a break!!

In the next part of the course, we will use the Satellite Tool Kit application to help visually demonstrate some of the concepts you have just learned.