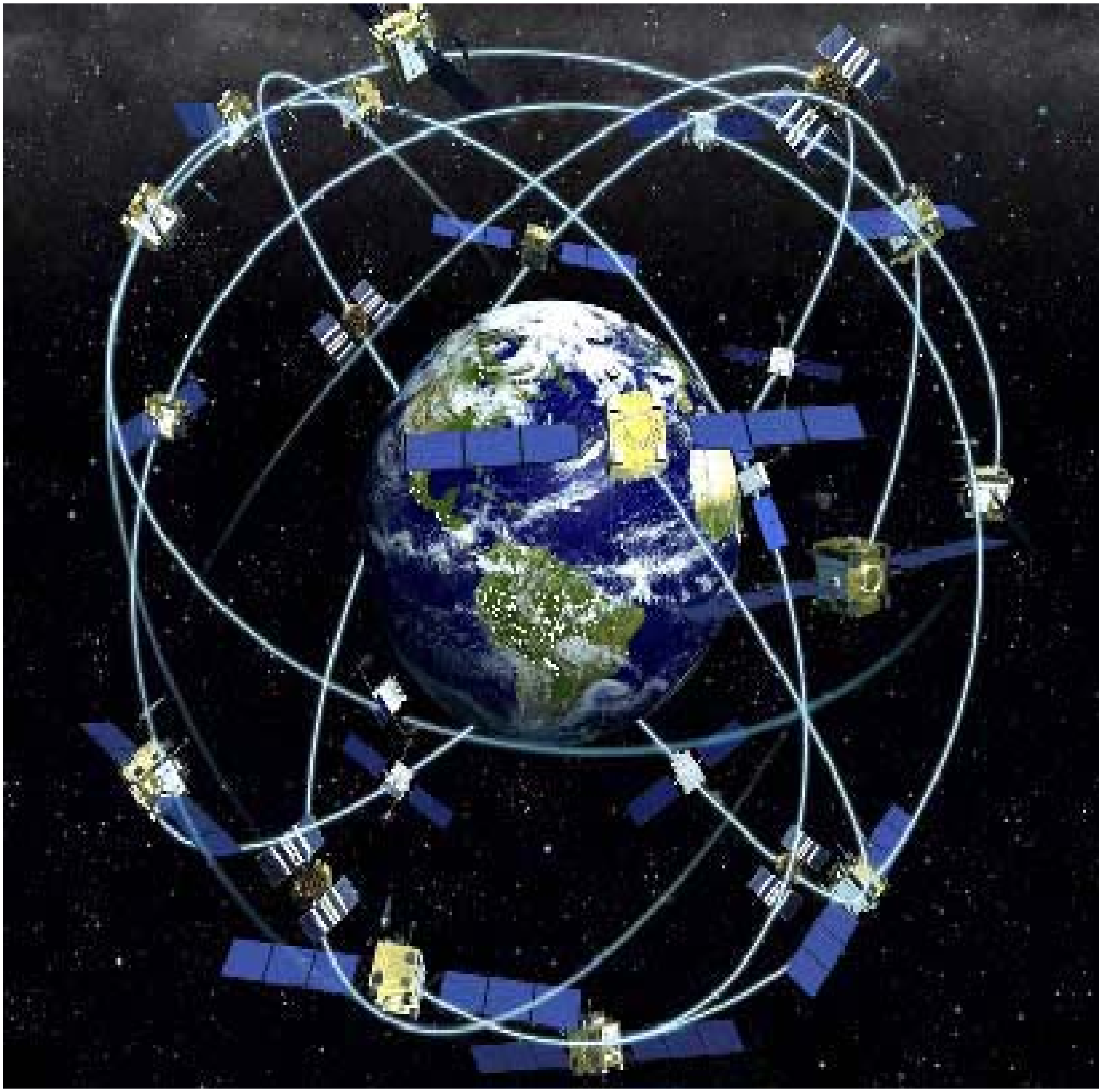
CIVIL AIR PATROL – SATELLITE TOOLKIT (CAP-STK) AEROSPACE PROGRAM



CIVIL AIR PATROL
United States Air Force Auxiliary
Maxwell Air Force Base, Alabama

INTRODUCTION

The CAP-STK Aerospace Education Program is designed to educate cadets on the exciting aspects of satellites, satellite orbits, the types and locations of orbits, and satellite missions using Analytical Graphics Incorporated (AGI) state of the art computer application, Satellite ToolKit (STK). For this version of the curriculum, STK 9.0 will be the software utilized in the lesson plans. STK is the same software that space companies use to determine where to place satellites on orbit and to find their satellites once launched.

Satellites and their missions play a critical part in our everyday lives. Everything we do somehow is now connected to satellites in space. We use satellites to communicate, conduct banking transactions, tell the time, navigate our way around a city – or the country for that matter, forecast the weather, protect our national security, create precise maps, examine the oceans, analyze the sun, map the galaxy, the list is practically endless! The more we know about how satellites work and the environment they operate in, the better we will be in determining additional ways we can use these unique assets in the future. STK will excite cadets about space and space operations, and should motivate them want to learn more about this critical part of our infrastructure.

This program, will be divided into several chapters and twenty scenarios, and is designed to build on itself as cadets go through the program. STK should be loaded and licensed on the computers to be used for this instruction, prior to starting the program. To obtain a license, go to National's AE website at www.capmembers.com/ae and click on the STK button. It will show you how to obtain a license.

For each block of instruction, a scenario will be presented. The instructor, or cadets themselves, if multiple computers are available, should then use STK to create the scenario presented. When completed, you can then compare your results with the proposed "book" answer created by the author. Understand that because there are an infinite number of possible solutions, there is no one "right" answer. Cadets will be educated on, and come to understand these important aspects of space and satellite operations using STK:

-- Orbital mechanics and the six orbital (Keplerian) elements used to find or place a satellite in orbit.

-- The altitudes satellites operate in and the missions satellites perform at those altitudes.

-- Linking different segments of a space system together and how we communicate with and operate spacecraft from the ground.

-- Creating satellite constellations.

-- Launching rockets into space and have them join up with orbiting spacecraft

-- Determining when a satellite will overfly your location

-- Linking ground, airborne, and space segments together, and creating linkages around the world.

As part of this curriculum, the CAP-STK Aerospace Program PowerPoint presentation should be presented prior to continuing.

LEARNING OUTCOMES

Chapter One – Orbital Mechanics

After completing the chapter, you should be able to:

- Define the size of an orbit.
- Define the shape of an orbit.
- Define the inclination of an orbit.
- Define right ascension.
- Define argument of perigee.
- Define true anomaly.
- Demonstrate each orbital element for a satellite using STK

Chapter Two – Orbit Orientations

After completing this chapter, you should be able to:

- Describe the characteristics of a low Earth orbit (LEO)
- Describe the characteristics of a medium Earth orbit (MEO)
- Describe the characteristics of a highly elliptical orbit (HEO)
- Describe the characteristics of a geosynchronous orbit (GEO)
- Describe the characteristics of a sun-synchronous orbit
- Demonstrate each orbital altitude in STK.

Chapter Three – Space Operations

After completing this chapter, you should be able to:

- Describe how to find satellites in the satellite database and display in STK.
- Describe how to launch a satellite from a specific location to meet up with an orbiting object.
- Describe how to display the planets and planet moons in the solar system.
- Describe how to link ground and space objects together in a chain, using constellations.
- Demonstrate each topic above using STK.

Chapter Four – Space and a System of Systems

- Describe how to connect STK space, air, sea, and ground assets for a specific mission.
- Describe how to connect STK space, air, and sea assets to monitor Earth's polar regions.
- Describe how to connect STK assets to accomplish a specific mission: humanitarian relief.
- Describe how to connect STK assets to accomplish a global reconnaissance operation.
- Demonstrate thorough knowledge and understanding of STK by performing an integrated scenario using all aspects of STK presented in this program.

1 ORBITAL MECHANICS

Important Terms

Field of View: The area of the Earth that can be seen by a satellite, based on the size/type of sensor viewing the Earth.
Apogee: In an elliptical orbit, apogee occurs when the satellite's pass is the farthest away from Earth in its orbit track. At apogee, the satellite is traveling at its slowest.
Perigee: In an elliptical orbit, perigee occurs when the satellite's orbit pass is closest to the Earth. At perigee, the satellite is traveling really fast.
Dwell time: The amount of time a satellite spends over a particular area of Earth. When a satellite is at apogee, traveling slowly, it is said to have a long "dwell time" over a particular spot of the Earth.
Pro-grade Orbit: A satellite in an equatorial orbit, moving from west to east as it orbits the Earth. The orbit inclination will be less then 90 degrees.
Retro-grade Orbit: A satellites orbit that seems to move from east to west. Usually a polar orbit, its inclination is greater than 90 degrees.
Satellite Constellation: A grouping of satellites arranged in specific orbital planes accomplishing the same mission. Example: the GPS constellation of 24 satellites accomplishes the navigation mission.
Revisit Time: The time it takes a satellite to come back over the same spot of Earth in its orbit. To take more frequent images of the same area of Earth, you need to place more satellites in orbit to increase "revisit time."
Look Angle: The angle a satellite sensor has to look to view a spot on the Earth, offset from the vertical. It can be to the left, right, to the front or behind the satellite. The higher the angle, the more distorted the view, due to the higher atmospheric interference.
First Point of Aries: The fixed point in space that is used as a reference to measure right ascension and argument of perigee

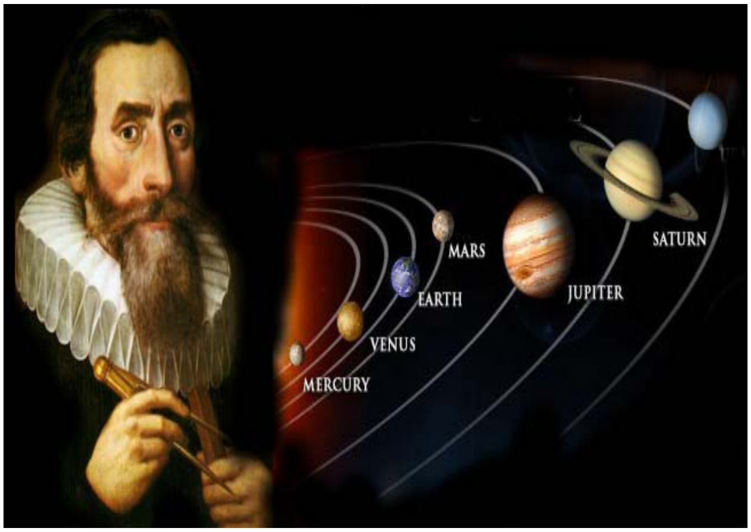
The Six Orbital Elements

An astronomer by the name of Johannes Kepler in the early 1600s derived 3 laws base on his observations of planetary motion: the Law of Ellipses, the Law of Equal Areas, and the Law of Harmonics.

Law of Ellipses: The orbits of the planets are ellipses with the sun at one focus.

Law of Equal Areas: The line joining the planet to the center of the sun sweeps out equal areas in equal times.

Law of Harmonics: The squares of the periods of two planets orbits are proportional to each other as the cubes of the semi-major axes. (Or, orbits with the same semi-major axis will have the same period.)



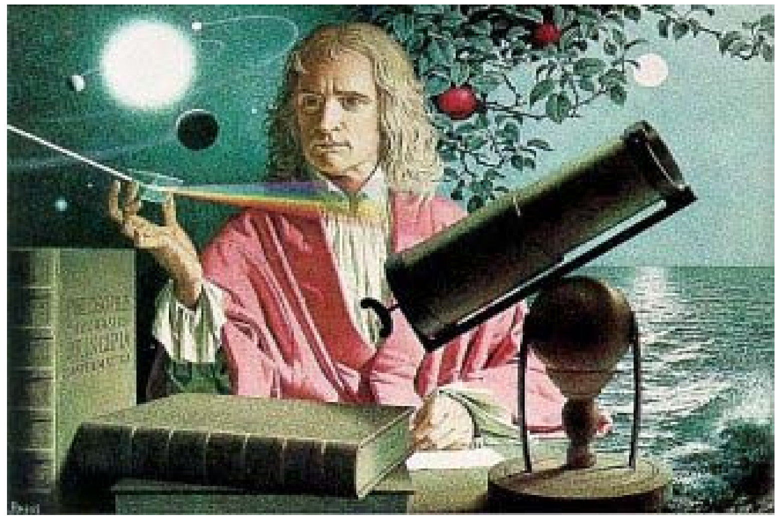
Johannes Kepler

Then came along someone you may have heard about: Sir Isaac Newton. Many people think Newton discovered gravity. He actually didn't discover it – gravity was there all along!!! But he helped explain it. After many careful observations, Newton came up with three laws of motion, and this helped explain why Kepler's laws worked. These laws are the Law of Inertia, the Law of Momentum, and the Law of Action-Reaction.

Law of Inertia: Every body continues in a state of uniform motion unless it is compelled to change that state by a force imposed upon it.

Law of Momentum: Change in momentum is proportional to and in the direction of the force applied.

Law of Action-Reaction: For every action, there is an equal, and opposite, reaction.



Sir Isaac Newton

Newton also came up with something called the law of universal gravitation, which helped explain what gravity actually was – why do things always fall to the ground?? Why?? In his gravity law, he stated that "between any two objects there exists a force of attraction that is proportional to the product of their masses and inversely proportionate to the square of the distance between them."

In other words, Newton was saying that every object has a mass and weighs a certain amount. Because an object has mass, it attracts other bodies. But how much it attracts other bodies depends on the how far away or how close those bodies are to each other.

Example: You pick a rock, hold it out and drop it. What happens? Of course, it falls to the Earth. Why? Given what was just said, we need to compare the mass of the Earth to the mass of the rock. Which has more mass? The Earth wins!! It attracts the rock! The Earth tries to pull everything in to its center.

Now, place a satellite in orbit around the Earth, The Earth has mass, the satellite has mass. The Earth's attraction on the satellite is tremendous. What is the only thing that keeps a satellite up in space? Speed! It has to be going very fast, or it would drop to Earth just like the previously mentioned rock.

It is through both the works of Kepler and Newton that the orbits of objects in space can be determined. Through careful analysis, scientists came up with six elements used to define an orbit. These six elements are:

1. Size – How big or small the orbit is
2. Shape – Is your orbit circular or an ellipse
3. Inclination – What kind of tilt does the orbit have

4. Right Ascension – Where does your orbit pass the equator on the ascending pass, as measured from a fixed point in space
5. Argument of Perigee – Where does perigee occur in your orbit as measured from a fixed point in space
6. True Anomaly – Where your object actually is in the orbit

Get to know these terms well. We will now be using them throughout the rest of the course. These are the fundamental elements by which you can determine any orbit of any object in space.

We will now examine each of these orbital elements in detail. We will be using STK to do this. For each specific topic (Example: Size, MEO, Constellation, etc) there will be a scenario presented, and instructions on how to complete the scenario using STK. Do the best you can!! Once you are done, open and review the proposed solution scenario. How close did you come??

SCENARIO #1: The Size of an Orbit

The mission your satellite will perform is going to determine where it is placed in orbit. Is it going to take pictures of the Earth? Is it going to provide communications? Is it going to relay banking transactions? For the first part of this scenario, your satellite is to take detailed pictures of the Earth. So where are you going to place it?? Right: LEO!

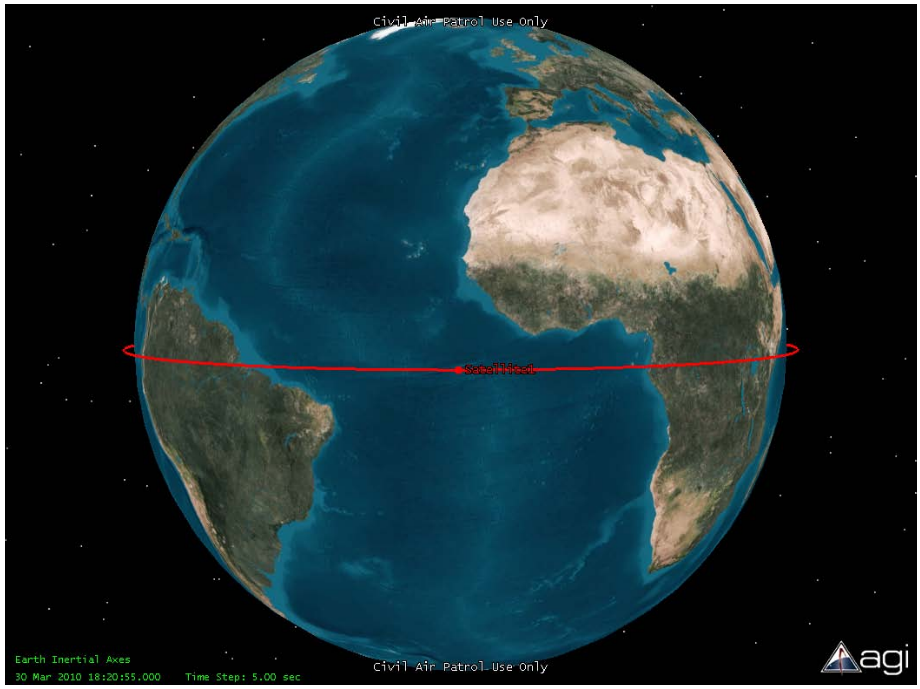
-- Open STK.
-- Since this is the first time using STK, There is some set up required to get you configured for the scenario. These are things you will need to do for every new scenario created.

-- A window will appear about scenarios.
-- Click "Create a New Scenario."
-- Name your scenario "SIZE 1."
-- Type in a description if you want.
-- Note that the analysis period is one day. You can make it longer than a day if you want.
-- Click "OK."
-- Four windows will appear. The one in the very background is the master scenario window, where you will input and change your data. Then there are 2 windows in front of that: your 3D window and 2D window. The very front window will allow you to place an object into the scenario.
-- Until you become comfortable creating satellites, we will be using the "Orbit Wizard" to assist us. On the right side of the front window, under "Select a Method," highlight "Orbit Wizard" and click on "Insert."
-- A new window appears. This is how we will create out first satellite.
-- At the top left, you can select the type of orbit. For now, we will stick with "Circular."
-- There is also a box on the left labeled "Definition." In it, you can set the inclination of your orbit, the altitude or size of your orbit, and RAAN. RAAN is right ascension. (The technical name of it is Right Ascension of the Ascending Node – or RAAN!) And in STK, you will only see it as RAAN.
-- For this first scenario, set inclination to zero.
-- Altitude can be measured in several different ways. To keep it simple, set altitude to miles by clicking on the little box in the altitude section and setting to "mi" for miles.
-- Change altitude to 120 miles.
-- Leave RAAN at 0 degrees.
-- The upper right section of the larger window is where you can change the color of your satellite track. For purposes of this scenario, change the color to red.
-- Click "OK" to close the box.
-- Click "Close" to close the "Insert Object" window.
-- For the vast majority of STK scenarios, we will be using the 3D Graphics 1 – Earth map.
-- Maximize the 3D map.

You may also want to increase the thickness of the orbit track to better see your satellite orbit. You do that by:

-- Double click on your satellite. Go to "2D Attributes" and click on "Attributes." Go to "Line Width" and increase the thickness of the line. For most scenarios depicted, the 3rd line is used. Click "OK."

Your scenario should look something like this. →



Your map shows a satellite in low Earth orbit, orbiting the equator. Its orbital parameters are:

Size: 120 miles
Shape: Circular
Inclination: 0 deg
RAAN: 0 deg
Argument of Perigee: 0 deg
True Anomaly: 0 deg

-- Slowly move the mouse button over each icon on the screen, to familiarize yourself with the name of each button.
-- Start the scenario by clicking on the "Start" button located towards the top left corner, above the icon labeled "Properties." This properties icon will become important for future scenarios, so remember where it is.
-- You can slow down the satellite's movement by clicking on the "Decrease Time Step" icon near the play button. You can make your satellite go faster by clicking the "Increase Time Step" icon
-- To pause the scenario, hit "Pause."
-- Use the left mouse button to move the globe. It will move in any direction you wish.
-- Use the right mouse button to zoom in/out.

One thing you will want to do for most scenarios is to increase the ambient light levels so you can see the Earth and your satellite better. You do this by:

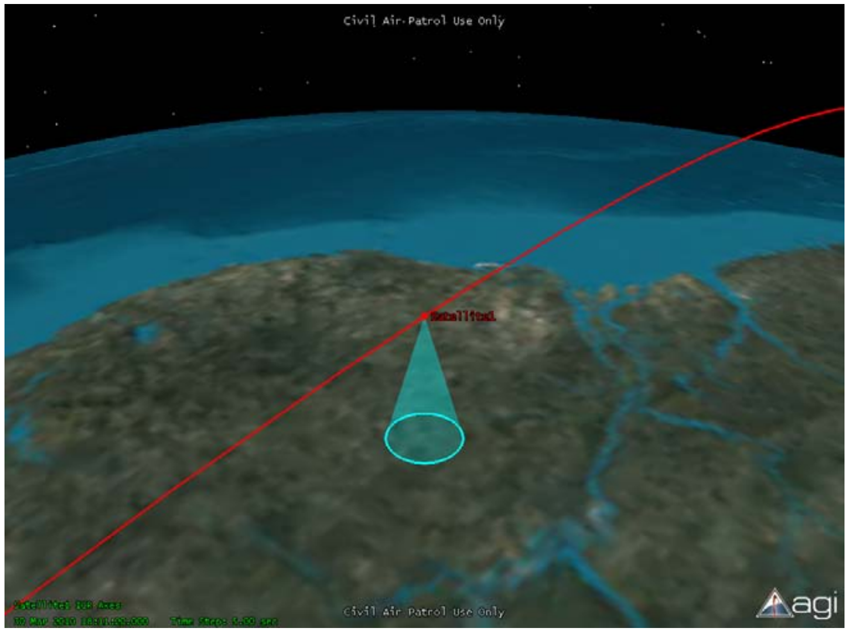
-- Click on the "Properties" icon in the upper left hand corner of the 3D Map. A new window opens.
-- Click on "Lighting." In the area called "Sun Lighting," there are 5 slide bars. Slide them all to the right to increase the lighting around the Earth! Click "OK."

DIFFERENT VIEWS

-- Go to the first row of icons above the screen and click on the first eyeball. (This will be the eyeball with a little arrow pointing to the left.) It is labeled "View From/To."
-- Another window will appear. Since we have not named our satellite yet, it has a default name of "Satellite1." In this window, click on "Satellite1" to highlight it, and then click "OK."
-- Your view has now changed to that of the satellite.
-- Zoom in and out, and change the orientation of the satellite.
-- Note the track of the satellite in relation to the size of the Earth.
-- Since this orbit is only 120 miles high, it is good for taking photos of the Earth. But since the Earth is so close, it is like looking through a soda straw. You have a very limited field of view or FOV.   At this altitude, the satellite will orbit Earth 16.29 times a day.
-- To demonstrate this limited FOV in a LEO orbit, we will now place a sensor on your satellite.
-- Under "Object Browser" on the left hand side of the screen, click once on "Satellite1" to highlight.

-- Then go up to the second row of icons and find the “New Object” icon. Click on the down arrow within the icon.
-- Find “Sensor.” Highlight it. Click “Insert.”
-- Your satellite now has a sensor! …or, for our scenario, a camera
-- Double click on “Sensor1” under satellite one. A new window appears.
-- Change cone angle to 15 degrees and click “Apply.”
-- While you have this window open, go to “2D Graphics” “Attributes.”
-- This is where you can change the color of your sensor. Change the color to light blue.

Your scenario should look something like this. →



-- Orient your satellite and hit “Start.”
-- You will now see photos that your satellite is taking.

QUESTION: Why can’t this satellite take photos of North America?
Answer: Its inclination is zero! You only can take photos of what is along the equator with this set of orbital elements.

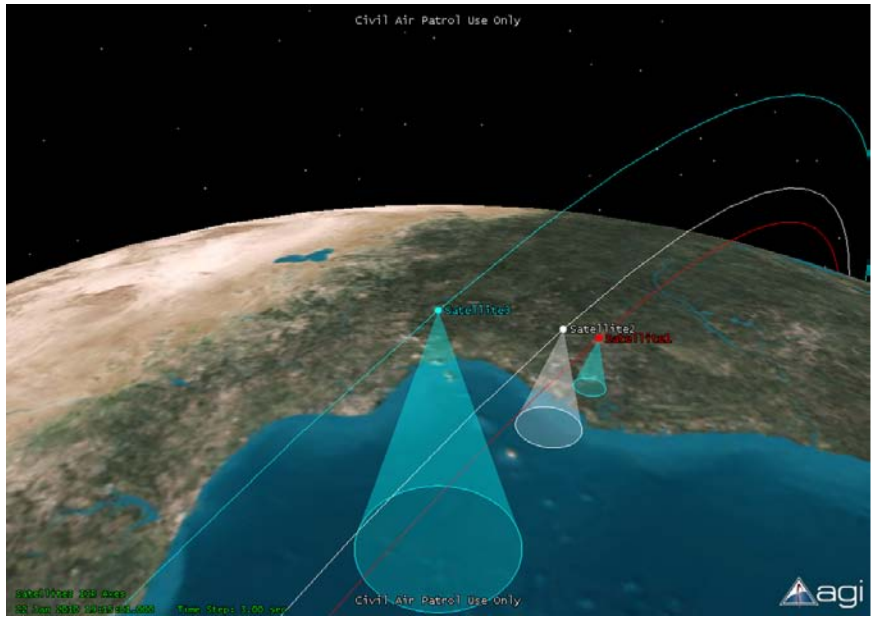
-- Go down to the bottom of the map, under the time stamp. Click on “2D Graph.”
-- This is the 2D map where you can view your ground track. Go back to “3D graph.” Hit “Pause.”

CHANGING SIZE

-- We are now going to change the size of the orbit.
-- But first we need to change your view. Go back to the eyeball (View From/To) and open it. Click on “Earth” on the left hand side, and then click “OK.”
-- Go to the very top of the screen and click on the “Insert” that is between “View” and “Analysis;” then “New,” and then double click on the “Orbit Wizard.”
-- Change inclination to 0 degrees.
-- Change altitude format to miles, and insert 230 miles in the box. Leave RAAN alone, and click “OK.”
-- 230 miles is the orbital altitude of the International Space Station.
-- Close the wizard.
-- Go back to the 3D map and hit the red “Reset” icon, then “Start.”
-- Follow the satellites as they orbit. What starts to happen?

QUESTION: Why are the satellites traveling at different speeds?
Hint: At this altitude, the satellite will orbit Earth 15.66 times a day. (Compare with Satellite1…)
Answer: The closer to the Earth, the faster you need to be going to stay in orbit. Why, because, in essence, the closer to the Earth, the more gravity there is! Review Newton’s law of universal gravitation.

-- Let's make one more satellite in LEO.
-- Go to "Insert," "New," and open the "Orbit Wizard."
-- Change inclination to 0 deg, change altitude format to miles, and insert 500 miles in the box. Leave RAAN alone, and hit "OK."
-- Close the wizard.
-- Hit the red "Reset" icon, then "Start."
-- What happens now? Satellite 3 seems to fall further behind…..
-- Attach sensors to Satellites 2 and 3 following the instructions above. Change the cone angle to 15 degrees on both sensors.
-- Hit "Reset" and "Start."



The view to the right is taken from the Satellite 3 view.

QUESTION: Why is the Satellite 3 cone larger? It is the same 15 degrees as the other 2….
Answer: The higher the altitude, the bigger the FIELD OF VIEW (FOV)!

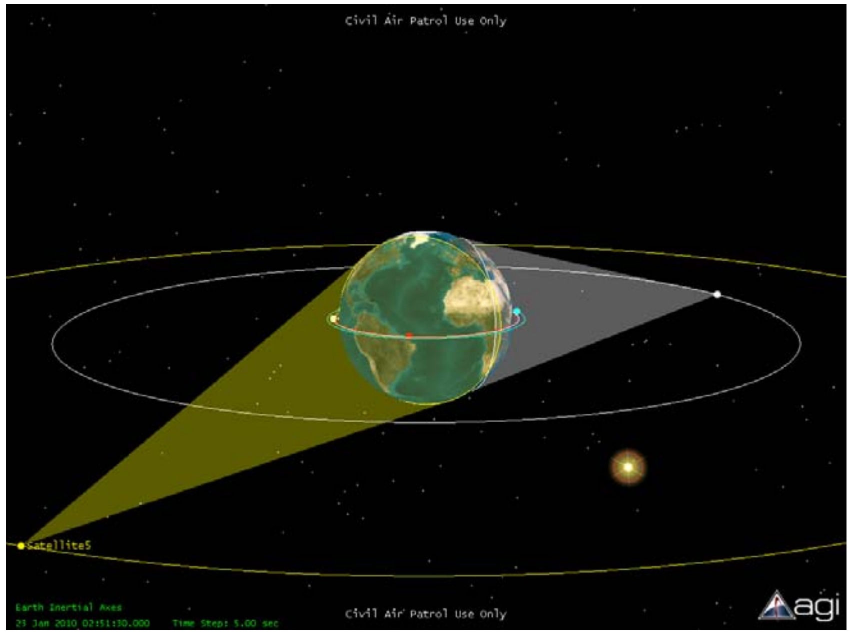
-- We are now going to move further out in space and create a satellite in semi-synchronous orbit, then synchronous orbit.
-- Go to the "Orbit Wizard" and create another new satellite: "Satellite4."
-- Change inclination to 0 deg. Change altitude to miles, and enter 12000 in the block. Leave RAAN alone.
-- Go to the upper right and change the color of the orbit to white so you can see it better, click "OK." -
-- Close the wizard.
-- You will need to zoom out fairly far to see this satellite's orbit.
-- Hit "Start." Move the Earth around and observe the orientation of your new satellite.

QUESTION: The satellite is in semi-synchronous orbit, which means it orbits the Earth twice a day. What is another name for this orbit?
Answer: MEO

-- The satellite travels through space slower – because it can! If it was traveling faster, it would move further out into space. It might even achieve escape velocity and leave the Earth's gravity pull completely! If the satellite was traveling slower, its orbit would decay and it would start coming back to Earth.
-- Create a sensor for your satellite. Change cone angle to 14 degrees and hit "OK."
-- Note what your FIELD OF VIEW is now! You can cover almost the entire Earth facing you!
-- Go to the "Orbit Wizard" and create "Satellite5."
-- Change inclination to 0 deg, set altitude to miles and insert 22300 in the block. Leave RAAN alone! Change the color to yellow and hit "OK." Close the wizard.
-- Hit "Start." Satellite 5 is now twice as far away as Satellite 4. It is at the orbiting at the exact same rotational speed as that of the Earth.

-- Go to the 2D graph. Observe Satellite 5's movement!
-- Go back to the 3D graph.
-- Create a sensor for your satellite. Change cone angle to 8.6 degrees. Run the scenario.

Your scenario should look something like this.



QUESTION: What do you call a satellite's orbit that travels at the same speed of the Earth's rotation?
Answer: geosynchronous

QUESTION: What is the difference between geosynchronous and geo-stationary?
Answer: A geostationary orbit has an inclination of 0 degrees. Its ground track is just a dot on the 2D map.

-- Go to the "Object Browser" in the upper left and highlight "Size1." Hit "File" and then "Save." Then close the scenario.

AN IMPORTANT POINT:
Before leaving SIZE, you need to know that in STK, you will not see "Size" listed as an orbital element. Size is always referred to as "Semi-major axis." So from now on, to change the size of an orbit you will need to change its semi-major axis.
The Earth has a diameter of 7926 miles. Half of that is 3963 miles. The semi-major axis is half the longest distance across an ellipse. (It's one half the major axis.) In a circular orbit, to find a satellite's altitude you would need to start with half of the Earth's diameter (3963 miles, then add the satellite altitude you want to set. So for our first satellite in the previous scenario, it has a semi-major axis of 4083 miles. (3963 miles plus the 120 miles we set = 4083 miles)
When talking about an elliptical orbit, it's different! So for now, we will always start with a circular orbit; then turn it into an ellipse.

RETRIEVING A STK SCENARIO

-- You can view a completed scenario by clicking on "Open a Scenario" when you open STK. For the scenario just completed, as an example, go to "File Folder SIZE1" and click on the file called "Size1.sc," and click "Open."
-- The scenario should now be displayed in STK, and you can review it.

IMPORTANT NOTE: STK scenario files always end with the suffix ".sc."

-- Now that we are familiar with STK and the orbital element of "size," let's move on the scenario 2!!

SCENARIO #2: The Shape of an Orbit

We know from Kepler that satellite orbits can have different shapes. Your mission in this scenario is to provide communications for a polar outpost. Usually, communications satellites are placed in a GEO orbit at the equator. But that won't be possible for this scenario. So we are going to create satellites that are in a highly elliptical orbit with their apogee at the North Pole. Why? It is because satellites travel slowest at apogee. They have what is called a long "dwell time" over the area. We will be able to provide as much communications as possible while the satellites travel through apogee.
Remember, we are focusing on SHAPE. We might have to manipulate some of the other orbital elements, but focus on the shape of the orbit.

-- Another word for an orbit's shape is eccentricity. That's what it is called in STK, so, let's go!
-- Open STK. Click on "Create a New Scenario."
-- Name your scenario "SHAPE 2." Click "OK."
-- Open the "Orbit Wizard."
-- Change inclination to 90 degrees, change altitude to miles, and set the altitude at 12000, leave RAAN alone. Change color to red, and click "OK."
-- Close the wizard and maximize the 3D window. Zoom out so you can see the entire orbit.

QUESTION: What type of an orbit is this?
Answer: a polar, MEO orbit

-- Go to the "Object Browser" in the left hand corner and double click on "Satellite1."
-- A new window appears that lists the 6 orbital elements.
-- Go to the semi-major axis window and change km to miles. You will note that your semi-major axis is 15,963.2 miles. That would be 3963 mi radius of the Earth we talked about before x the 12000 miles we selected as the altitude = 15, 963 miles. (rounded!!)
-- Now we will change our orbit from a circle into an ellipse.
-- Go to the "Orbit Wizard" and create "Satellite2." Change inclination to 90 deg, and set altitude to 12,000 miles.
-- Double click on "Satellite 2." Go to 2D graphics and click on "Attributes." Change the color to white.
-- Then go to "Basic" and "Orbit." Change eccentricity to .5; change argument of perigee to 270, and click "OK."
-- Start the scenario.

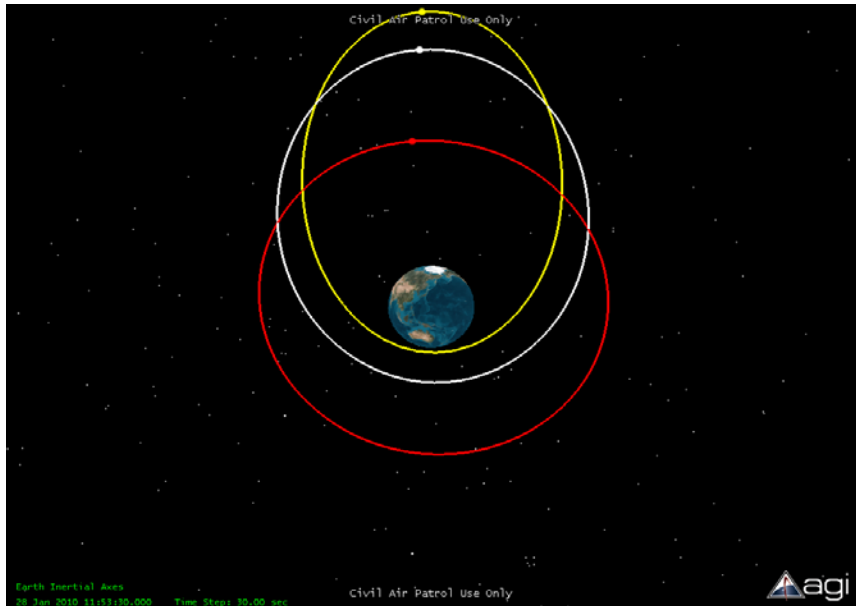
QUESTION: Are the satellites still traveling at the same speed? If no, why?
Answer: Review Kepler's Second Law!

-- Reset the scenario. (Red arrow to the left of Start…)
-- Create a "Satellite3" using the wizard. Set inclination and altitude parameters the same as Satellite 2.
--- Double click on it; go to "2D Attributes" and change the color to yellow. Then select "Basic," "Orbit," and change eccentricity to .7.   Change argument of perigee to 270 and click "OK."
-- Increase the step time to make the satellites move a little faster.
-- Does apogee occur over the North Pole? If yes, we are providing good communications!

Question: What happens as we make the orbit more eccentric?

Answer: We are increasing the satellite's apogee and perigee. Which means the satellite will travel slower at apogee and faster at perigee.

Your scenario should look something like this.



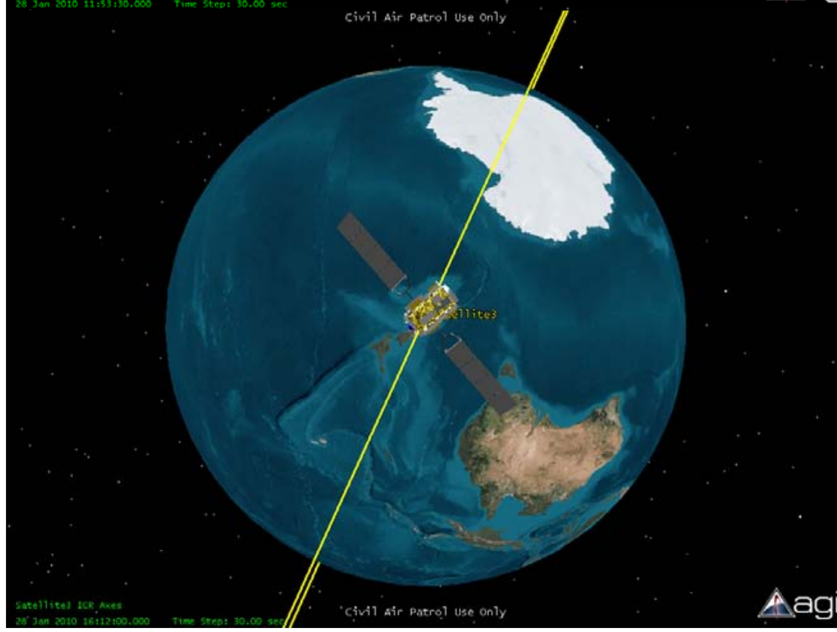
-- Pause the scenario when the satellites are at apogee and then again at perigee. What do you observe?

QUESTION: Why do the satellites seem to be in the relative same orbital locations at apogee and perigee?
Answer: Kepler's second law again! It is the Law of Equal Areas in action.

-- Start the scenario and continue to observe from different angles.

-- Pause the scenario. Go to the eyeball (View From/To). Scroll down to "satellite3." Highlight it and hit "OK."

-- You have just become satellite 3. Orient the satellite so that you can see the globe, depicted at right.



Note what happens as the satellite goes through apogee and perigee.

-- This is a highly elliptical orbit! It is also known as a Molniya orbit, because the Russians use this orbit frequently.

-- Create a "Satellite4." Change its eccentricity to .8. What happened?? STK won't let you do this because at .8, the orbit is too eccentric. Your satellite would be flying through the earth twice each orbit. Not happening…..

QUESTION: How eccentric can you make the orbit and still have the satellite orbiting in space?
Answer: .7517

-- Go back to the eyeball, click on it, then click on the Earth; click "OK."
-- Continue to orient the map to get some different views of eccentric orbits.
-- Save your scenario!
-- You can also review this scenario by going to folder "SHAPE2" and opening the "SHAPE2.sc" file located there.

Once complete with this scenario, it's time to look at inclination!

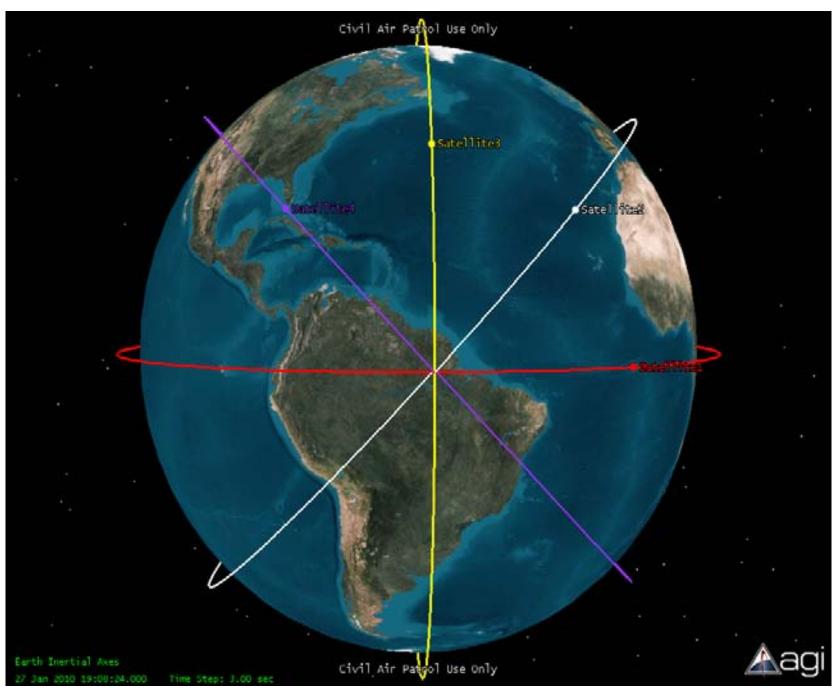
SCENARIO #3: Inclination

How do we get satellites to do more than take pictures of the equator? We need to change the orbital element of inclination. Inclination is the tilt of your orbit as viewed from the equator. Your mission for Scenario 3 is to take photos of the continent of Africa.

-- Create a New Scenario in STK and name it “Inclination 3.” (Hopefully, you are not having problems navigating your way around STK. If you are, please go back and review the first 2 scenarios on how to do things…)
-- Open the “Orbit Wizard” and create “Satellite1” in a circular orbit, orbiting the equator (Inclination: 0 deg), at 300 miles altitude. Make the satellite’s orbit red.
-- This satellite will only orbit the equator.
-- Create “Satellite2” using the “Orbit Wizard.” Make its Inclination 45 degrees at 300 miles. Change its color to white.
-- Start the scenario.
-- Satellite 2 will now incline to 45 degrees above the equator, and 45 degrees below the equator.
-- Go to the 2D Graphics Map. Note the ground track looks like a sine wave.
-- Also note that the satellite is moving from west to east. This is known as a pro-grade orbit.
-- Hit “Pause.”

IMPORTANT NOTE: When the satellite is traveling from the south latitudes to the north latitudes, this is known as the Ascending Pass. On the back side of the pass, the satellite will be making a Descending Pass.

Many people get confused when they see the orbit sine wave on a 2D map. They think the satellite is moving up and down through the orbit. In reality, the satellite is just going round and round in its orbit. It is the tilted Earth rotating underneath the satellite that gives it the appearance of moving up and down.



For our scenario, 45 degrees of inclination is not good enough. We will need a polar orbit!
-- Create Satellite 3 using the “Orbit Wizard.” Change its inclination to 90 degrees at 300 miles. Change its color to yellow.
-- Start the scenario. Now we have 100% global coverage! Pause the scenario.

-- Create “Satellite4” using the “Wizard.” Change its inclination to 135 degrees at 300 miles. Change its color to purple.
-- Start the scenario. Go to the 2D graphics map.
-- What is Satellite4 doing? It appears to be going backwards!

QUESTION: What is an orbit called that is beyond 90 degrees of inclination?
Answer: A Retrograde Orbit.

Note that you also have created a mini constellation of satellites.

IMPORTANT NOTE: In low Earth orbit, when a specific satellite will pass over head could vary greatly. How often a particular satellite passes over head is called its Revisit Time.

QUESTION: How could you increase revisit time of a particular constellation of satellites in low Earth orbit?
Answer: Place more satellites in orbit!

-- Pause the scenario.
-- Insert a sensor on to each of your satellites. Make the Satellite1 sensor's cone angle 15 degrees, Satellite 2 sensor's cone angle 30 degrees, Satellite 3 45 degrees and Satellite 4 60 degrees. While you have this window open changing the cone angle, you can also change the type of sensor
-- You can also change the color of your sensor by double clicking on your sensor and going to 2D graphics, then "Attributes."
-- You can make your sensor pulse by going to "3D Graphics," "Pulse."
-- Change each of your sensors so they are doing something different!
-- Start your scenario! Observe where each of your satellites is going, and how much ground it can cover based on the cone angle of your sensor.

Question: Which is the better sensor?
Answer: It depends, on the mission of your sensor, and what you are trying to image.

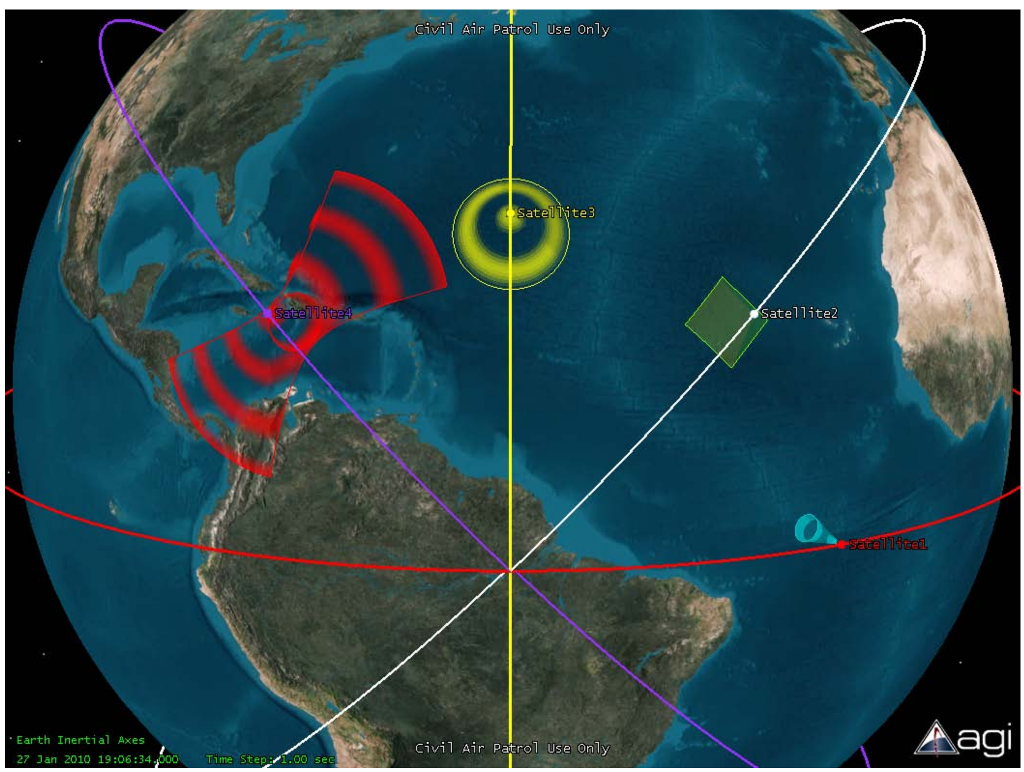
Depicted at right:

Satellite 1: cone angle 15 degrees.
Simple conic sensor, light blue.

Satellite 2: cone angle 30 degrees.
Rectangular sensor, green

Satellite 3: cone angle 45 degrees.
Complex conic sensor, yellow.

Satellite 4: cone angle 60 degrees.
It is a SAR sensor, color red.



Task!: Take an image of the western most part of the continent of Africa. Which satellite will image that part of Africa first? How long did it take? Why did it take so long?

One of the main missions for satellites in low Earth orbit is taking images of the Earth. There are 3 main types of imaging: Electro-Optical or EO, which a visible images (like taking a digital image of the globe); Infra-red images, which are thermal images looking for heat sources; and Synthetic Aperture Radar (SAR), which are radar images of the Earth. (Radar can see through clouds!)
The type of sensor you have on your satellite and the inclination of your orbit is going to be critical to getting a good "picture." Given the depiction above, you might come to the conclusion to always use a "wide angle lens," or us much of a large cone angle as possible, but you don't.

Question: Why would you not want as wide an angle as possible when taking pictures of Earth?
Answer: The wider your look, the more atmosphere you have to look through. Too much atmosphere will distort your picture!

How far to the right or left, or forward or backwards, your sensor has to look to take an image is called "Look Angle."

If you want to take really sharp pictures, you want to be looking almost straight down at your object. That is why it is important to get your inclination right so you will overfly your target at the orientation you want.

-- Continue to manipulate STK and view various inclinations of orbits until you feel comfortable with the concept.
-- Save your scenario!

You can also view the above depiction by going to folder "Inclination3" and opening the "Inclination3.sc" STK scenario file.

Once your review is complete, let's now transition to something you have been waiting for: right ascension!!

SCENARIO #4: Right Ascension of the Ascending Node (RAAN)

How do we place satellites in orbit at different points around the earth so we don't have to wait forever for our satellite to orbit over head? It's all in the swivel! Right ascension (now to be called only RAAN) is the angle of your inclined orbit passing the equator on the ascending pass, as measured from a fixed point in space. Your mission for this scenario is to place satellites in orbit, spaced equally apart, to minimize revisit time as much as possible.

-- Open STK; Create a new scenario and name it RAAN 4.
-- Open the "Orbit Wizard."
-- Leave inclination at 45 degrees. Change altitude to 300 miles, leave RAAN at 0 degrees, select color red, hit "OK."
-- Close "Insert Objects" and maximize the 3D Graphics window.
-- Start the Scenario. Your satellite is now in a LEO, 45 degree inclined orbit with a RAAN of 0 degrees.
-- Pause and reset the scenario.
-- Open the "Orbit Wizard" and create "Satellite2." Keep inclination at 45 degrees, set altitude to 300 miles, and set RAAN to 90 degrees. Change you color to white, hit "OK." Close "Insert Objects."
-- Orient the 3D map and find Satellite 2. What happened?

Satellite 2 has "swiveled" 90 degrees to the east.

-- Start the scenario and not the coverage these 2 satellites now provide.
-- Pause and reset the scenario.
-- Open the wizard and create Satellite 3. Leave inclination alone, change altitude to 300 miles, change RAAN to 180 degrees, change color to yellow and hit "OK." Close "Insert Objects."
-- Orient the 3D map and find "Satellite3." Would you expect Satellite 3 to be 90 degrees to the east of Satellite 2? Yes! You have swiveled another 90 degrees to the east.

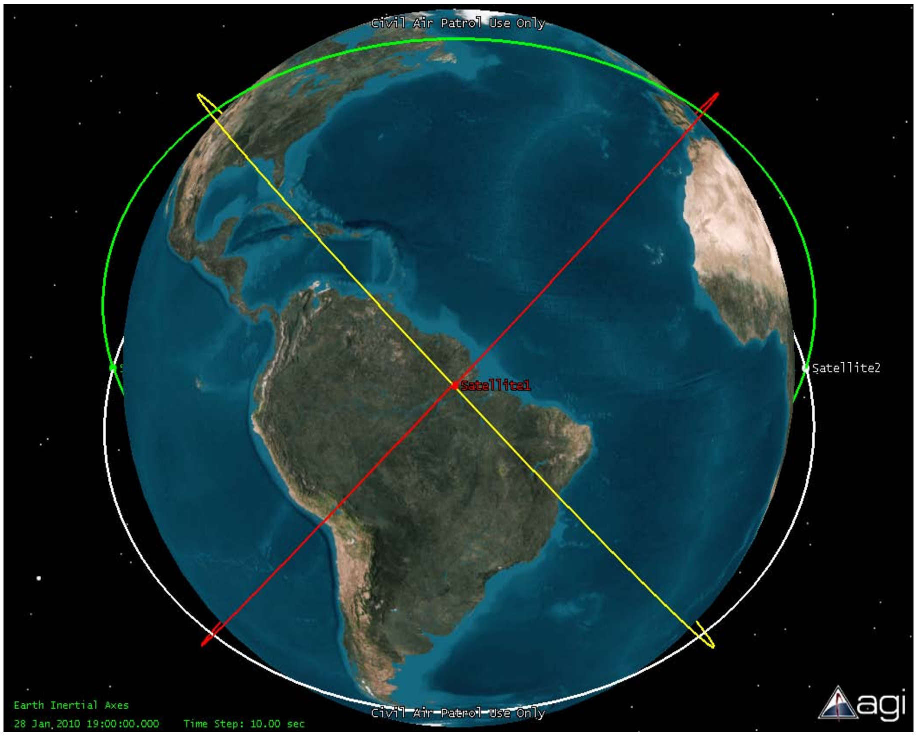
--Start the scenario and note what the satellites are doing.

-- Go to the 2D map and observe. Go back to the 3D map.

-- Pause and reset the scenario.

-- Open the wizard and create "Satellite4." Leave inclination alone, change altitude to 300 miles, change RAAN to 270 degrees, change color to green, hit "OK." Close "Insert Objects."

Your map should look like something like this. →



You now have 4 satellites spaced the same distance apart. This is giving us decent coverage.

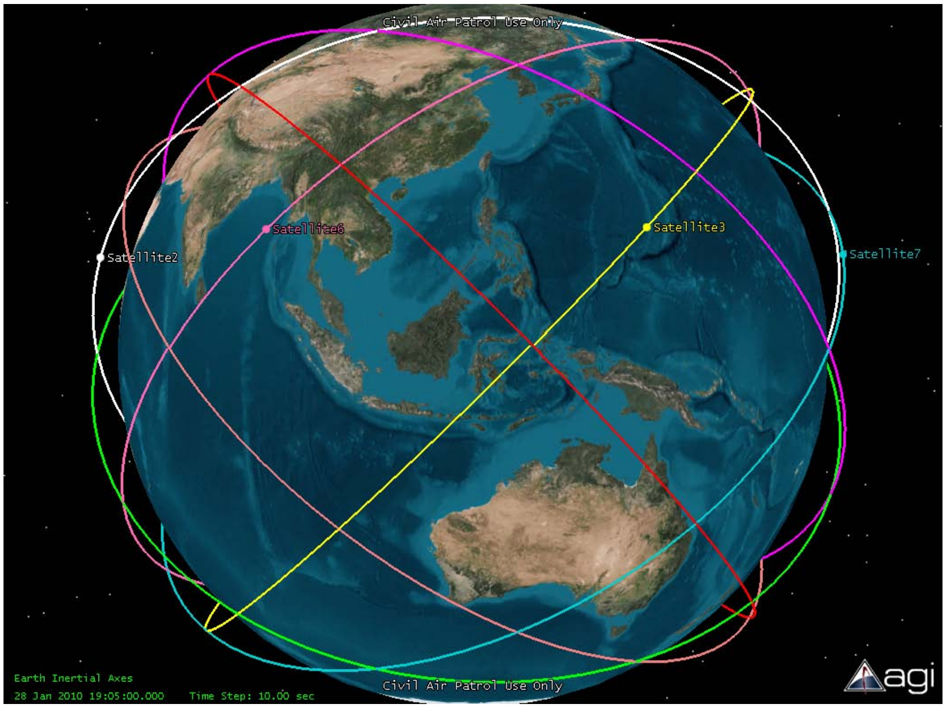
QUESTION: If given 4 more satellites, how could we increase coverage even more?
Answer: Space out your satellites at every 45 degrees of RAAN. The RAAN of those 4 satellites would need to be 45 degrees, 135 degrees, 225 degrees and 315 degrees.

-- Create 4 more satellites using the Wizard with the RAANS of 45,135, 225, and 315, with all other parameters the same.
-- Run the scenario and observe the orientation of the satellites. Now the revisit times have been cut almost in half!

-- Go to the 2D graphic map and review. Go back to the 3D map.

-- Your map should look something like this. →

-- Pause and reset the scenario.



-- Task!! Select a country, like India or Australia. Determine when and how often a satellite will overfly the country – any part of it.
Use the clock in the bottom left part of your screen.

QUESTION: What kind of revisit times do you come up with?
Answer: Will depend on the country selected.

-- Continue to manipulate STK and view the various RAAN of orbits until you feel comfortable with the concept.
-- Save your scenario!

You can also view the above depiction by going to folder RAAN4 and opening the RAAN4.sc STK scenario file.

Once your review is complete, let's now transition to something that is quite mysterious to a lot of people: argument of perigee!!

SCENARIO #5 Argument of Perigee

Argument of perigee has everything to do with elliptical orbits, and where you want apogee to occur in your orbit. At apogee, your satellite will have a long dwell time, which would be good for communications, viewing a specific area of the Earth for a long time, etc. Argument of perigee is defined as where perigee will occur in the orbit as measured from a fixed point in space. Once you have defined where perigee will occur – apogee will be on the opposite side, 180 degrees from perigee! Your mission for this scenario is to set an argument of perigee to occur over the North Pole, to watch the ice cap melt.

-- Open STK and Create a new scenario. Name it “ArgumentofPerigee 5.”
-- Open the “Orbit Wizard” and make Satellite1 with the following parameters: Inclination: 0 degrees, Altitude: 12000 miles, leave RAAN alone, set color to red, hit “OK.”
-- Close the “Insert Objects” window and then maximize the 3D graphics window.

Depicted is a satellite in an MEO, circular orbit. We need to make this orbit an ellipse!

-- Double click on Satellite1 and change eccentricity to .5; hit “OK.”

Satellite1 is now in an elliptical orbit. Its argument of perigee is 0 degrees.

-- Start the scenario.
-- Orient the Earth so you can see where apogee will occur in the orbit.
-- Hit “Pause” when the satellite is at apogee.

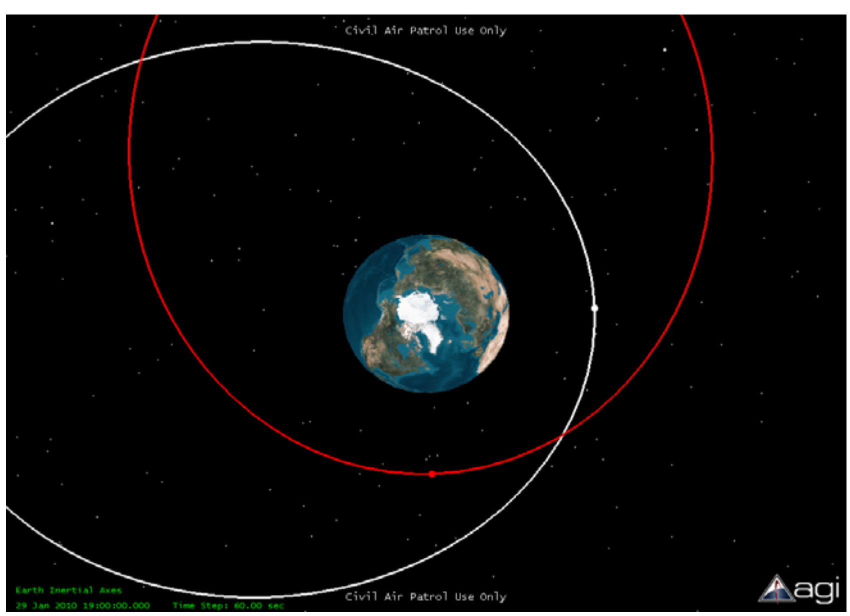
QUESTION: At the start of the scenario, where would apogee occur?
Answer: off the north coast of Australia

-- Go to the “Orbit Wizard” and create “Satellite2.” Inclination: 0 degrees, Altitude: 12000 miles, leave RAAN alone, change color to white, hit “OK.” Close the “Insert Objects” window.
-- Double click on “Satellite2” and change eccentricity to .5 and argument of perigee to 90 degrees; hit “OK.”
-- Start the scenario and observe the satellites. What did we do?

We have moved where perigee will occur for “Satellite2” 90 degrees to the east!

QUESTION: Where does apogee occur for “Satellite2” at the start of the scenario?
Answer: Over the middle of the Pacific.

-- Pause the scenario. Your map should look something like this. →



-- Go to the wizard and create “Satellite3.”

Inclination: 0 degrees, Altitude: 12000 miles, leave RAAN alone, change color to yellow; hit “OK.” Close the “Insert Objects” window.

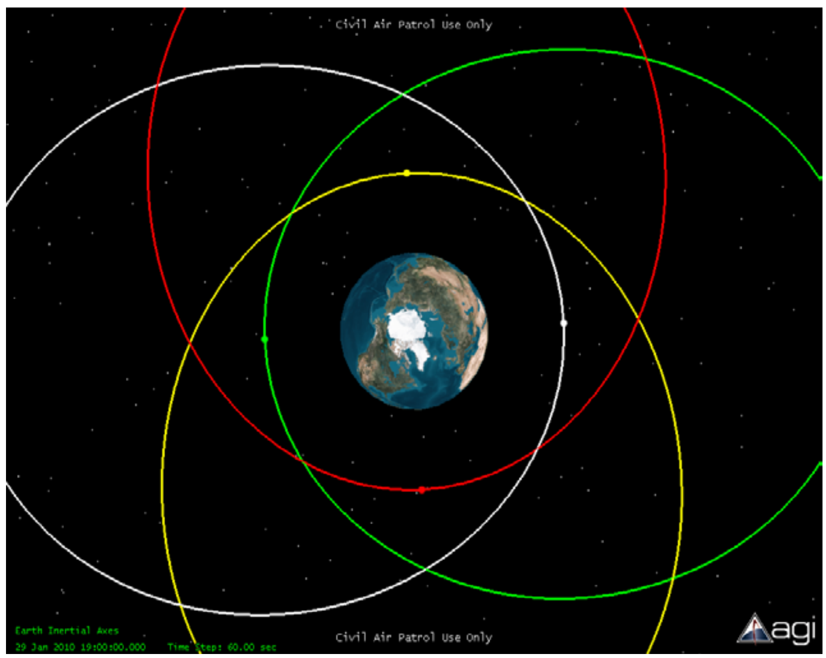
-- Double click on “Satellite3” and change eccentricity to .5 and argument of perigee to 180 degrees; hit “OK.”
-- Start the scenario.

QUESTION: Where does apogee occurs for Satellite 3?
Answer: over South America

-- Pause and reset the scenario.
-- Go to the wizard and create “Satellite4.” Inclination: 0 degrees, Altitude: 12000 miles, leave RAAN alone, change color to green, hit “OK.” Close the “Insert Objects” window.
-- Double click on “Satellite4,” change eccentricity to .5 and argument of perigee to 270 degrees.
-- Start the scenario and observe.

Question: At the start of the scenario, where is apogee?
Answer: Over the eastern part of Africa.

Your map should look something like this, as viewed from the North Pole. →



There are now 4 different satellite apogees occurring. But where are they all occurring?
along the equator!

QUESTION: Which orbital element will we have to change to get apogee to occur someplace other then the equator?
Answer: inclination

Now comes the hard part. Which satellite do we need to change its inclination for apogee to occur over the North Pole to complete the scenario?

-- Double click on “Satellite1” and change its inclination to 90 degrees.
-- Run the scenario.

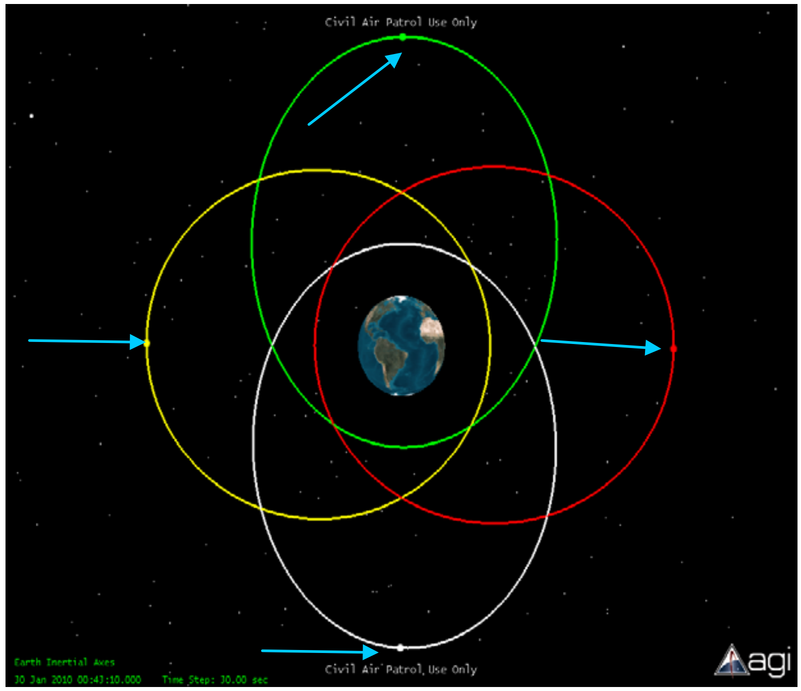
QUESTION: Does apogee occur over the North Pole for Satellite 1?
Answer: No!

-- Hit “Pause” and “Reset.”
-- Change the inclination of satellites 2-4 (one at a time).
-- Run the scenario for each satellite after you have changed the inclination. (IE: change Satellite2 inclination, run the scenario; Change Satellite3, run the scenario, etc.)
-- Run the scenario.
-- Pause the scenario when satellite apogee is achieved.

QUESTION: Which satellite achieves apogee over the North Pole?
Answer: Satellite4!

Why? Because in an eccentric orbit, to achieve apogee over the North Pole, the inclination needs to be 90 degrees, and the argument of perigee needs to be 270 degrees. Look closely at your 3D map when all the satellites are at apogee.

Satellite4 (green) at Apogee over the North Pole!



Satellites 1 and 3 apogee occurs at the equator, even with 90 degrees of inclination and Satellite 2 apogee occurs at the South Pole! Is this a coincidence? No! It's all about determining argument of perigee!

Highly Elliptical Orbits (HEO) are sometimes used because the latitudes of launch sites are high. Example: The latitude of the primary Russian launch site at Tyuratam (also known as the Baikonur Cosmodrome) is located at 46 degrees north latitude. It is almost impossible for the Russians to place a communications satellite into a geosynchronous orbit around the equator from that latitude. Instead, they place their satellites into HEO orbits, which the Russians call Molniya orbits.

QUESTION: What would you have to do to Satellites1, 2 and 3 to get their apogees to occur over the North Pole?
Answer: Change their argument of perigees to 270 degrees!

Try it and see what happens. Remember this for future scenarios.

-- Continue to manipulate STK and view the various argument of perigee orbits until you feel comfortable with the concept.
-- Save your scenario!

You can also view the above depiction by going to folder "ArgumentofPerigee5" and opening the "ArgumentofPerigee5.sc" STK scenario file.

Once your review is complete, let's now transition to actually finding your satellite and the orbit you have selected: True Anomaly!!

SCENARIO #6 True Anomaly

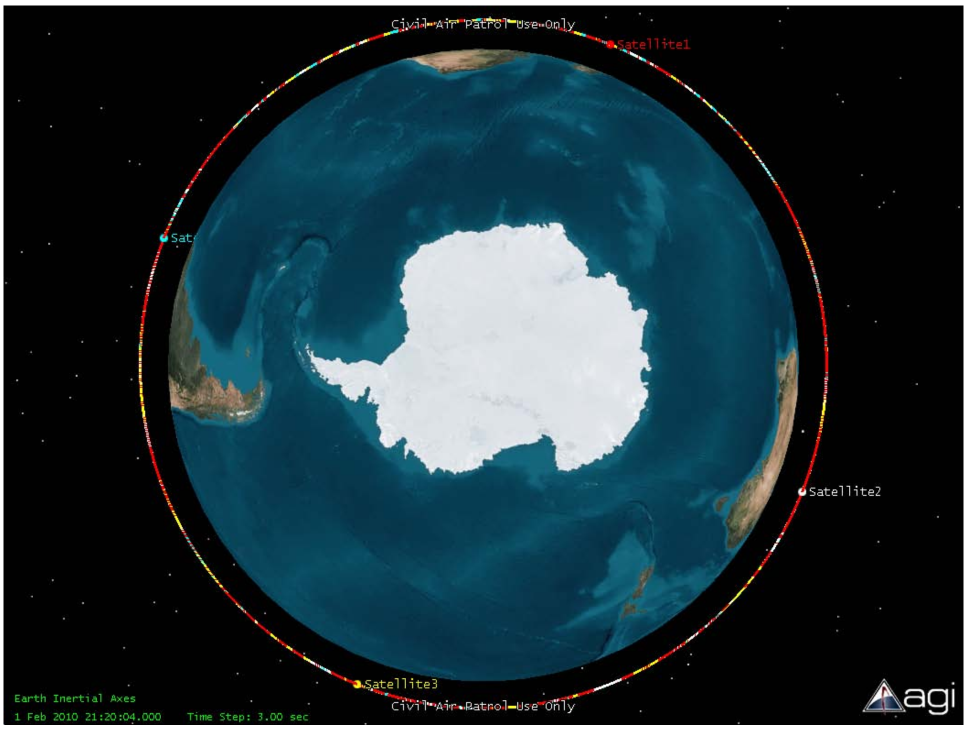
The previous 5 orbital parameters defined the actual orbit. Now we need to determine where your satellite actually is in that orbit! True anomaly is the angle, measured in degrees, where your actual satellite is, as determined from a fixed point in space. Your mission for this scenario is to set 4 satellites in one orbital plan, spaced equally apart to monitor the Amazon River in Brazil.

-- Open STK. Create a "New Scenario" and call it "TrueAnomaly 6."
-- Open the "Orbit Wizard" and create "Satellite1" using the following specifications: Inclination 0 degrees, Altitude 500 miles, leave RAAN alone, change color to red; hit "OK." Close the "Insert Objects" window and maximize the 3D window.
-- We now have "Satellite1" in a LEO orbit, orbiting the equator.
-- Open the wizard and create Satellite2: Inclination: 0 degrees, Altitude 500 miles, leave RAAN alone, change color to white; hit "OK. "Close the "Insert Objects" window.
-- Double click on "Satellite2." Change "True Anomaly" to 90 degrees; hit "OK."
-- Now create Satellites 3 and 4 using the same parameters. Make Satellite 3 yellow, and Satellite 4 light blue.
-- Set Satellite 3 true anomaly to 180 degrees, and Satellite 4 true anomaly to 270 degrees.

What has happened?
With all other orbital elements the same, you have placed 4 satellites in this one orbital plane, all spaced equal distances apart (90 degrees). That's what true anomaly does – it sets your satellite's specific position in the orbit.

-- Run the scenario and observe.

Your screen should look something like this. →



It is a view from the South Pole looking up at the equator.

-- Now place a sensor on each satellite, simple conic, with an angle of 45 degrees.

QUESTION: Per the scenario, how often are we monitoring the Amazon River?
Answer: Your revisit time is every 25-30 minutes.

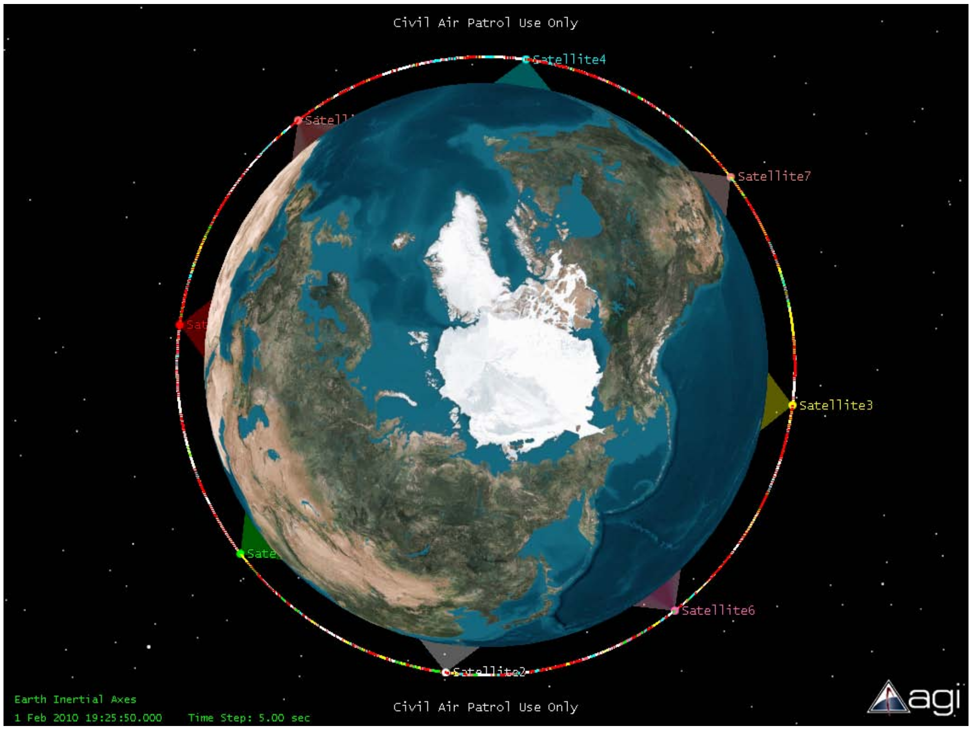
QUESTION: How could we increase the revisit time?
Answer: Place more satellites in the orbital plane!

-- Hit “Pause” then “Reset.”
-- Place 4 more satellites in the same orbital plane.
-- Set their true anomaly at 45 degrees, 135 degrees, 225 degrees and 315 degrees.
-- Once complete, add sensors to these 4 new satellites.

-- Run your scenario.

QUESTION: What is the revisit time now?
Answer: Approximately every 12 minutes.
Good job!

There are now 8 satellites in this one plane.



But satellites are expensive!
They are expensive to build and expensive to launch. It typically costs about $200 million to launch a medium sized rocket into space. So sometimes just putting more satellites up in space is not an option – it just costs too much! One way companies reduce costs is to launch several satellites on one rocket and insert them all into the same orbital plane. As the delivery platform (or bus) makes it orbit, it drops the satellites off at the proper true anomaly location. That is how the GPS and Iridium constellations were built.

-- Continue to manipulate STK and view various true anomaly orbits until you feel comfortable with the concept.
-- Save your scenario!

You can also view the above depiction by going to folder “TrueAnomaly6” and opening the “TrueAnomaly6.sc” STK scenario file.

Once your review is complete, let’s move on to the next chapter, where we will examine orbit altitudes and the different missions satellites perform at those altitudes.

2 ORBIT ORIENTATIONS

Important Terms

One Meter Resolution: The highest resolution imaging satellites can produce in a low Earth orbit traveling at 17, 500 mph.
Semi-Synchronous Orbit: A satellite in a medium Earth orbit that circles the Earth every 12 hours.
Van Allen Radiation Belt: An area of space around the Earth consisting of intense, ionizing radiation and high energy particles, mainly protons and electrons, held in place by the Earth's magnetic field.
NAVSTAR: The official name of the U.S. Global Positioning System (GPS) navigation satellites.
Molniya Orbit: A type of highly elliptical orbit frequently used by the Russians. They place their satellites in this type of orbit due to the high latitude of their launch locations.
Tandem Satellites: 2 satellites spaced closely together in the same orbital plane that work together to provide a stereo, high resolution, detailed image of an area of the Earth.
Geosynchronous Orbit: A satellite that orbits the earth once a day. Its velocity matches the speed of the Earth's rotation. Its inclination is not zero, tracing an hour glass shape ground track.
Geostationary Orbit: A satellite that orbits the earth once a day. Its orbital velocity matches the speed of the Earth's rotation. Its orbital inclination is zero, creating a dot for a ground track.
Sun-Synchronous Orbit: A satellite in a LEO, polar orbit that will pass over the same part of the Earth at close to the same time each day.
Dawn-to-Dusk Orbit: A satellite in an orbit that trails close to the Earth's shadow. The sun's light is always on the satellite allowing the satellite to have its solar panels in the sun all the time.

This chapter will focus on the different orientations satellites operate at by focusing on 5 major orbits. Chapter 2 assumes a certain level of knowledge of STK, as presented in chapter one. We will continue to demonstrate more features of the space application as the chapter progresses.

Low Earth Orbit (LEO)

As previously mentioned, LEO is defined as the area 120 – 1200 miles above the Earth. This is really close to the earth, and your satellite needs to be going really fast to stay in orbit. The typical velocity of a LEO satellite is 17,500 mph. At this speed, your satellite will complete one trip around the Earth every 90 minutes, or about 15 revolutions per day! Being so close to the Earth is good for taking photos. The best picture-taking satellites in orbit today can provide you with less than one meter resolution. They can actually take pictures of people on the ground (or the license plate of your car) – from space! This is truly a remarkable capability. But LEO satellites perform many other missions; they provide communications, remote sensing (observing the environment, etc), and let's not forget the manned missions. For LEO satellites to provide communications, there are going to have to be quite a few of them, since they can only provide coverage for a relatively short distance – and because they are moving quite fast. Iridium and Globalstar are examples of 2 LEO communications constellations.

QUESTION: Why bother create a constellation of LEO communications satellites when you could just put a few communications satellites out at GEO?
Answer: Think altitude! It is much easier, and less expensive to place a satellite into a LEO orbit than a GEO orbit – 22,300 miles away. LEO COMSATs are smaller and more lightweight. GEO satellites have to be bigger, because they need much more powerful transmitters to transmit from 22,300 miles away.

<u>SCENARIO #7 Low Earth Orbit</u>

Your mission for Scenario 7 is to create a constellation of LEO communications satellites at an altitude of 1000 miles. Create a scenario that uses 6 orbital planes, with 4 satellites in each plane. As part of this scenario, we will also demonstrate how to provide a communications link from a satellite to a ground station.

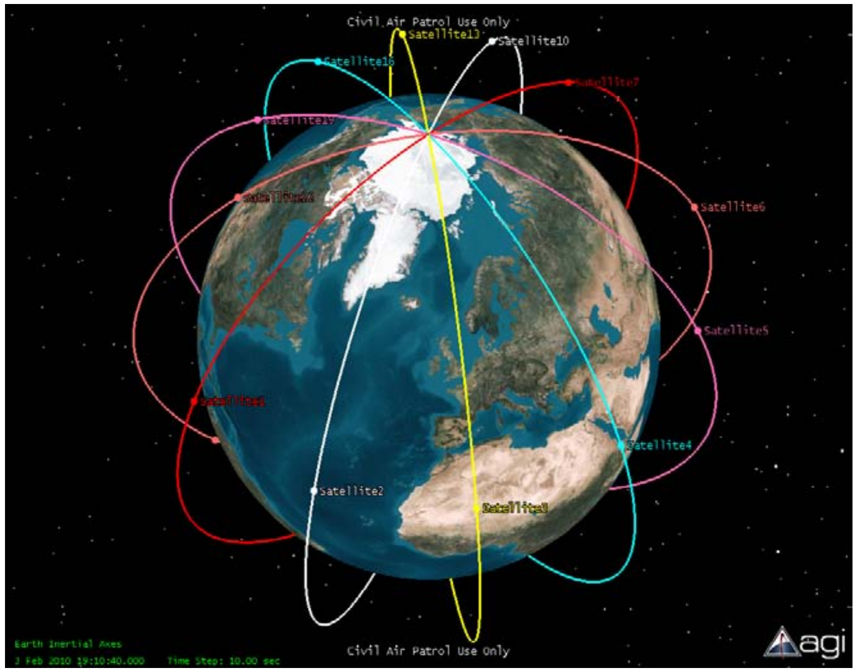
-- Create a new scenario and name it “LEO 7.”

-- Use the “Orbit Wizard” to create your satellites.

Hint: Polar orbits will probably work best. Adjusting right ascension and true anomaly will be crucial to building a successful constellation.

-- Create your satellites in 6 planes, 4 satellites to a plane for a total of 24 satellites

Your scenario should look something like this. →



Be careful how you construct your orbital planes. Initially you would think to divide 6 into 360 to get planes of 0, 60, 120, 180, 240 and 300 degrees. But if you build it this way, you actually only end up with 3 planes! Because 0 and 180 degrees would be the same plane, 60 and 240 are the same, etc.
The scenario wants 6 separate orbital planes.

QUESTION: What do you set your right ascension at to get 6 planes, as indicated in the above picture?
Answer: 0, 30, 60, 90, 120 and 150 degrees.

QUESTION: What do you set your true anomaly at to space your satellites equally?
Answer: 0, 90, 180 and 270 degrees.

-- Run your scenario.

What do you observe? Since all other orbital parameters are the same, your constellation has symmetry. 6 satellites will arrive at the North Pole and South Pole, and 12 satellites will arrive at the equator all at the same time.

Question: How could you stagger the satellites to provide more robust communications coverage?
Answer: Change the locations of the satellites in each plane. (true anomaly) Instead of satellites being in their orbits at 0, 90, 180, and 270 degrees, you could move some to 45, 135, 225 and 315 degrees.

-- Pause and reset your scenario.

Now that you have your communications constellation built, we need the satellites to talk to the ground! Here is how you do that:

First you need to create a ground facility. STK let's you access a database to set either a city or a facility on the map:

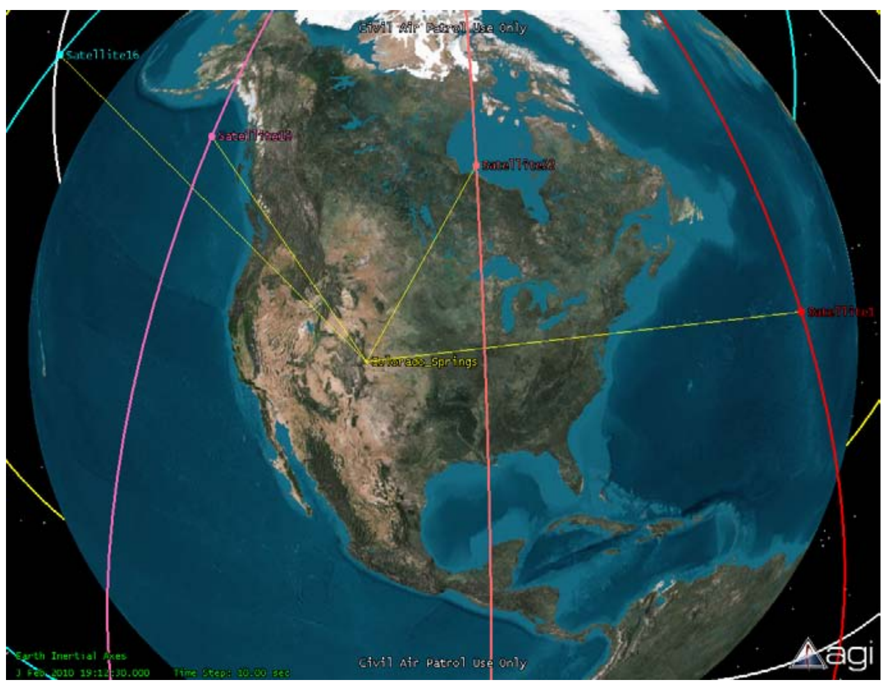
-- Click "Insert" at the top of the screen. Instead of going to the wizard, it gives you the option to either click "Facility from City Database" or "Facility from Facility Database." We are going to start with a city, so click on "Facility from City Database." A new window appears.
-- In the "City Name" block at the top, type in Colorado Springs and hit "Search."
-- Highlight "Colorado Springs" in the block and hit "Insert," then close the window.

You now have the city of Colorado Springs in your scenario and highlighted on your map.

-- Double click on Colorado Springs in the "Object Browser," go to "2D Graphics," then "Attributes," and change the color to yellow; hit "OK."
-- Orient the map so the USA is in front of you. Colorado Springs should be on the map, in yellow.

How do we get the satellites to communicate with Colorado Springs?

-- At the top of your screen, next to "Insert," click on "Analysis," then "Access." A new window appears.
-- Highlight all of the satellites in the "Associated Objects" block. (Highlight the first satellite, scroll down to the last satellite, hold the shift key and highlight the last satellite)
-- Hit "Compute," then "Close."
-- Reset and run your scenario.



What do you see?
Every time the yellow lines appear, the satellites are providing communications to Colorado Springs.
(Technically these are not communications lines; these are lines of access – when Colorado Springs can view the satellites overhead.)

Is there 100% coverage? No.

Question: What could we do to provide better coverage?
Answer: Move the satellites in the orbital plane as previously discussed.

OPTIONAL: Try changing the location of some satellites to try to attain 100% communication coverage with Colorado Springs.
-- Create a new city. You can select your hometown, or just pick a city anywhere in the world.

-- Compute Access to this new city.

Does communications coverage improve or is it about the same as Colorado Springs?

Remember how to compute access from ground facilities to satellites. You will be doing this quite a bit in future.

-- Continue to manipulate STK and view various LEO orbits until you feel comfortable with the concept.
-- Save your scenario!

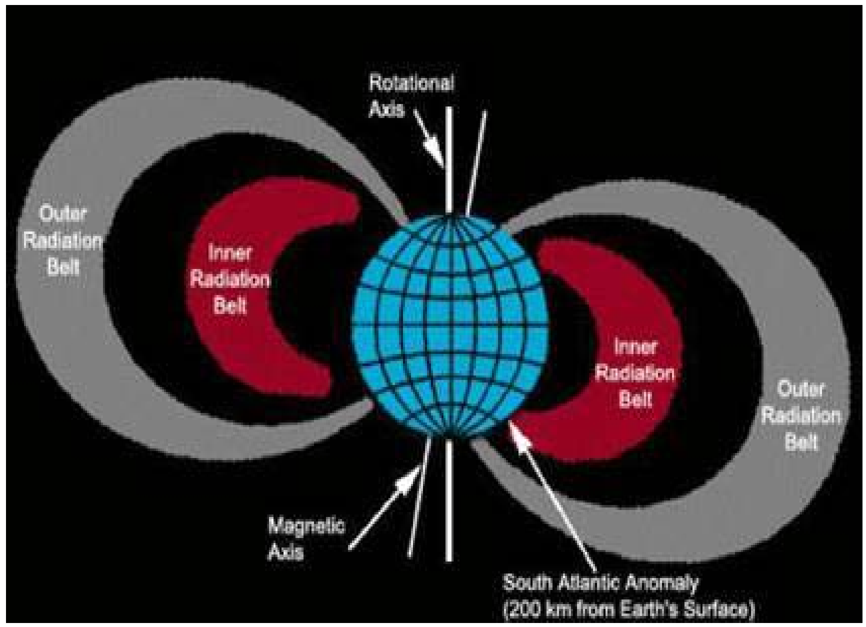
You can also view the above depiction by going to folder “LEO7” and opening the “LEO7.sc” STK scenario file.

Once your review is complete, we will now move further away in altitude from the Earth – to MEO!

Medium Earth Orbit (MEO)

A MEO orbit is approximately 1000 - 12,000 miles in altitude. Most satellites in a MEO orbit are at 12,000 miles in altitude. At this altitude, the satellite orbits the Earth twice a day. Another word for this orbit is semi-synchronous. One of the primary missions of satellites in a medium Earth orbit (MEO) is to provide a navigation signal. To provide a precise signal, the orbital shape of MEO satellites should be circular. Another mission for satellites at MEO is to provide communications. The first communications satellite, TELSTAR was launched in 1962 into a MEO orbit. It was designed to provide high-speed telephone signals across the Atlantic Ocean. Because it was placed in a lower MEO orbit, it could only provide trans-Atlantic communications for 20 minutes each orbit! The solution was to increase the altitude of future communications satellites!

One of the main concerns of placing satellites in a MEO orbit, especially lower MEO orbit, is the Earth's radiation belt. This area of space, called the Van Allen Radiation Belt, consists of intense, ionizing radiation and high energy particles, mainly protons and electrons, held in place by the Earth's magnetic field. The inner belt is produced by cosmic rays striking the upper atmosphere, and is about 3,700 miles in altitude. The outer belt, which includes some helium ions from the solar wind, can range out to 12,000 miles.



The Earth's Radiation Belts

The radiation belt is one of the main reasons you do not see many satellites between the altitudes of 1,000 – 11,000 miles. The radiation is just too intense! You would have to build a satellite to withstand operating in the environment of constant radiation bombardment, by adding shielding. This shielding would add a lot of weight to your satellite, making it more expensive to launch. Depicted at right is a GPS satellite, built to withstand operating in a harsh radiation environment.
Its altitude of 12,000 miles is at the upper limit of the Van Allen belt.

NAVSTAR

SCENARIO #8 Medium Earth Orbit

For Scenario 8, your mission is to create your own navigation constellation. Place satellites in a MEO orbit, at 12,000 miles in altitude, to provide precise navigation for Earth users. Place a total of 32 satellites in your constellation.

QUESTION: What is the current navigation constellation, built by the USA, called?
Answer: Global Positioning System (GPS)

QUESTION: What type of a signal does GPS satellites transmit?
Answer: a timing signal

QUESTION: What are the GPS satellites called?
Answer: NAVSTAR

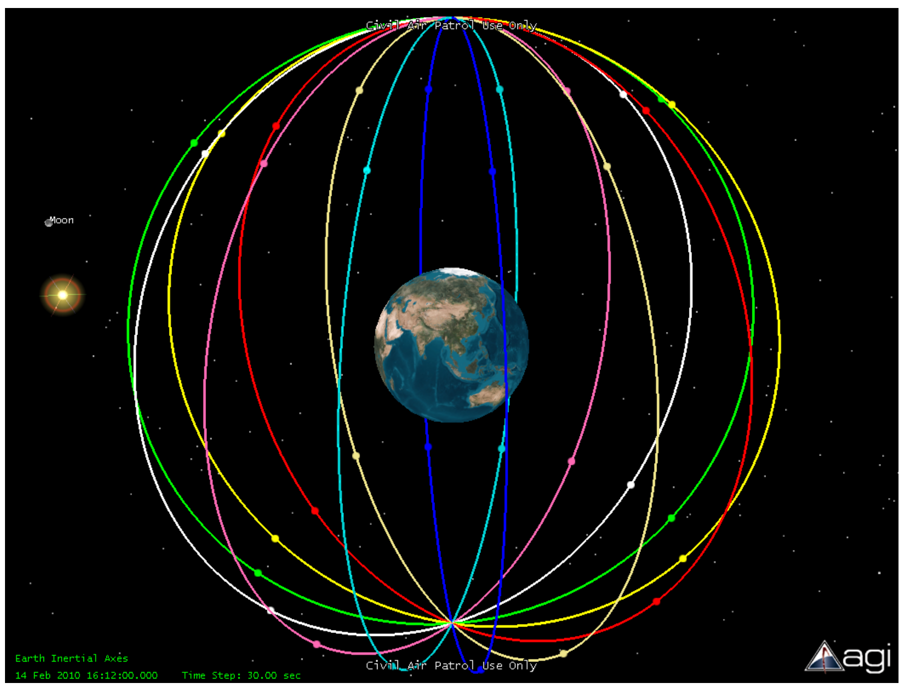
For this scenario, create 8 orbital planes, with 4 satellites in each plane.

-- Create a new scenario and name it “MEO 8.”
-- Use the orbit wizard to create your satellites.
-- You might want to review Scenario 7, to ensure you construct your orbital planes properly.

Did you remember to space your orbital planes equidistant apart?

QUESTION: What degrees of RAAN should your orbital planes be set to?
Answer: 0, 22.5, 45, 67.5, 90, 112.5, 135, and 157.5 degrees.

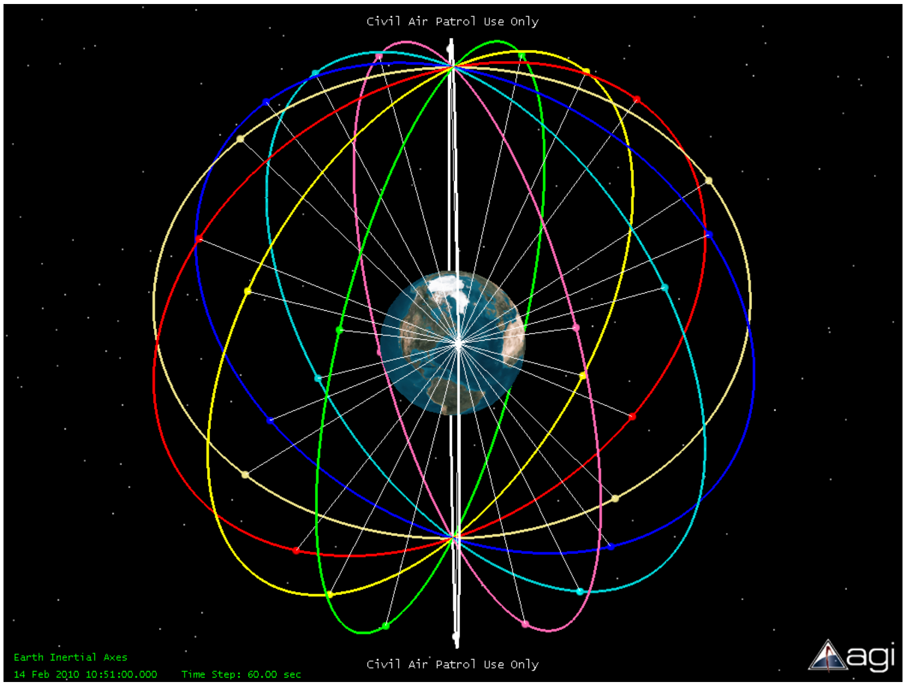
Your navigation constellation should look something like this. →



A unique feature among some satellite constellations is the ability for satellites to talk to each other while in orbit. This feature is called a cross-link. You can demonstrate this ability by computing access from satellite to satellite.

You have already established a satellite – ground station link in a previous scenario. Establishing a satellite – satellite link is very similar.
-- Open your MEO 8 scenario.
-- Click once on any satellite in the “Object Browser” list.
-- At the top of the window, click “Analysis” and then “Access.”
-- Click on the first satellite in the “Associated Objects” window. Scroll down to the bottom, press the shift key and click on the last satellite in the list.

-- Click on “Compute.” Close the window.
-- Go to the 3D map and run the scenario. Observe the map closely.



Displayed is the satellite you selected communicating with every other satellite in the constellation.

You map should look something like this. →
What your map will actually look like will depend on which satellite you selected to communicate with the other satellites.

QUESTION: Does your satellite communicate with all 31 satellites?
Answer: No!

Why?

In order to have constant communication, your satellites need to have line-of-sight. Is there 100% line of sight with the other satellites?

QUESTION: What is getting in the way?
Answer: The Earth is blocking the communications link.

-- Pause your scenario.

You can deselect and select another satellite to provide communications.

-- Go to “Analysis” and “Access.”
-- Highlight the first satellite listed in “Associated Objects.” Scroll down, hold the shift key, and highlight the last satellite in the list. Click on “Remove All.” Close the window.
-- Go to the 3D map, click on a different satellite in the “Object Browser.”
-- Then go to “Analysis” and then “Access.” Compute access for this different satellite.
-- Close and run your scenario. Observe your access from this different satellite.

-- Continue to manipulate STK and view various MEO orbits until you feel comfortable with the concept.
-- Save your scenario!

You can also view the above depiction by going to folder “MEO8” and opening the “MEO8.sc” STK scenario file.

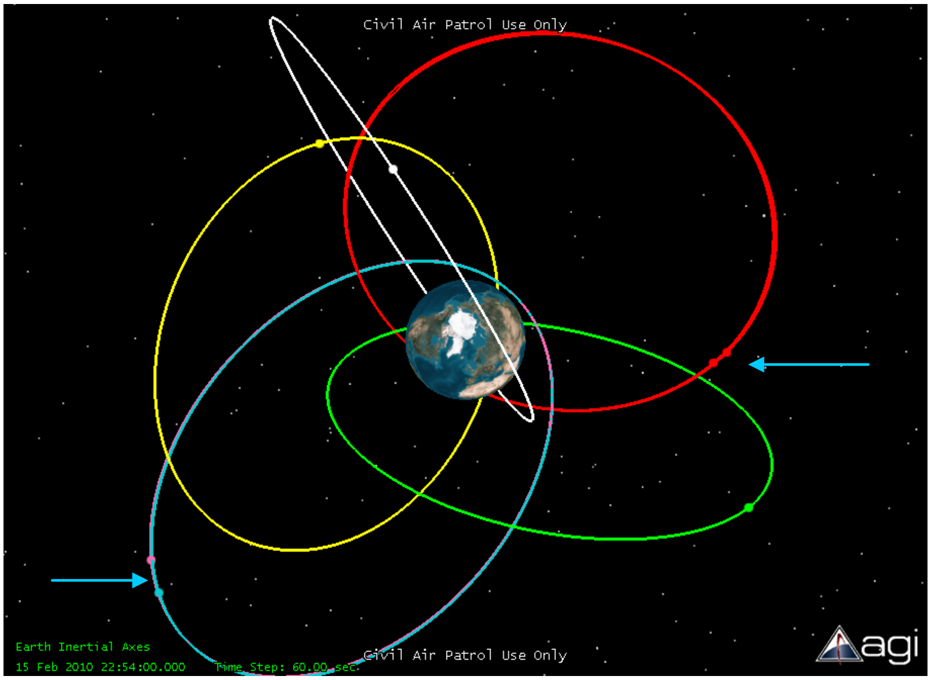
Once your review is complete, we will now visit the strange orbits of highly elliptical orbits!

Highly Elliptical Orbit (HEO)

The distinguishing characteristic of a HEO orbit is that the satellite will move at different speeds! At apogee, it will have a long dwell time over a specific location of the Earth, and then will swing rapidly through perigee. The Russians use this Molniya orbit frequently, to provide communications to their country, due to the high latitude of their launch location. The Russians have also been known to place a satellite in a Molinya orbit with apogee over the center of the United States. Why would they do that? They wouldn't be spying on us, would they?

At right are depicted several HEO orbits used by different countries.

- Depicted in yellow and green are 2 Russian military COSMOS satellites.
- Depicted in red are 2 Russian Molinya satellites. Note they are traveling in tandem, right next to each other!
- Depicted in light blue and purple are 2 French satellites, Spirale A and B. They are also traveling in tandem.
- Depicted in White is a Chinese space surveillance satellite called Doublestar.



These are actual satellites pulled out of satellite database. You will learn how to pull satellites out of the database in a future scenario.
If you want to run this scenario, go to folder "HEO9" and open STK file "HEO9.sc" and observe the different orientations of HEO satellites.

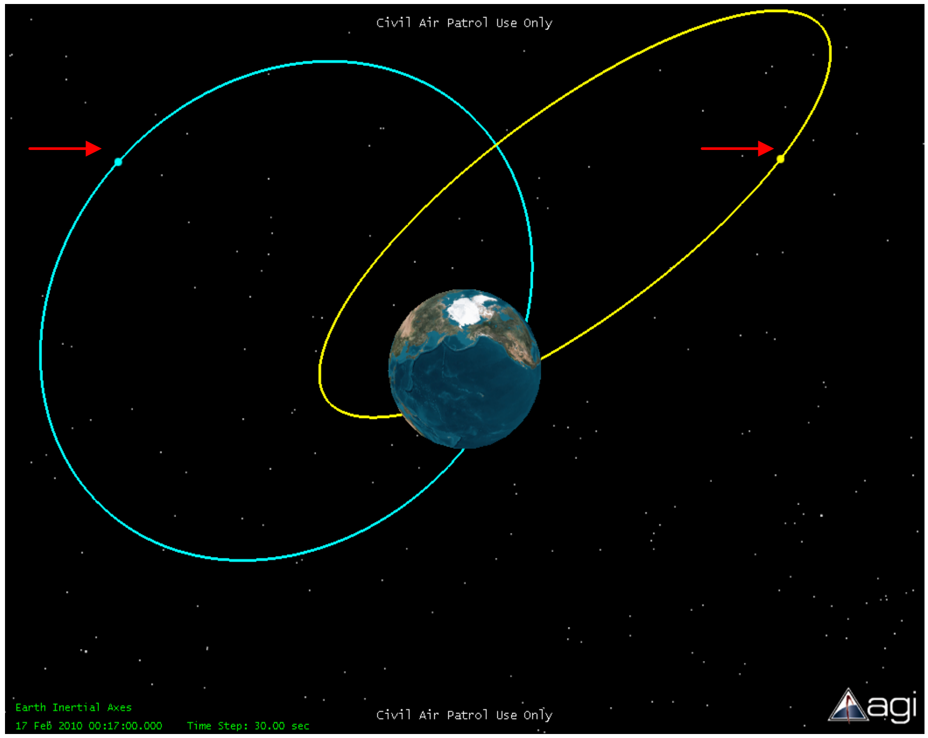
QUESTION: In the picture above, there are 2 satellites in the same orbital planes traveling really close together. Why?
Answer: When 2 satellites travel close to each other in the same orbit, they are working together in tandem, and are called tandem satellites. They take images of the same area of Earth, and you get much better resolution. These stereo, high resolution, images are more detailed then just a single image.

Example: Tandem satellites are used to measure the height and temperature of the ocean surface.

SCENARIO #9 Highly Elliptical Orbit (HEO)

California needs more HD TV! Your mission for Scenario 9 is to place 2 satellites in a HEO orbit, with apogee to occur over California. These two satellites must provide HD TV to California for as long a time as possible. How close can you get to 100% coverage? You will be using all six of the orbital elements to create this scenario.
The second part of the scenario will be to compute access to a city in California to verify access.

You scenario should look something like this. →



Remember, when setting your orbits, the Earth is going to rotate!

You must make your orbit large, at least the size of a MEO orbit.

You need to make your orbit highly eccentric.

You must offset inclination, RAAN, and argument of perigee.

Finally, you need to offset your satellites (true anomaly) for constant coverage!

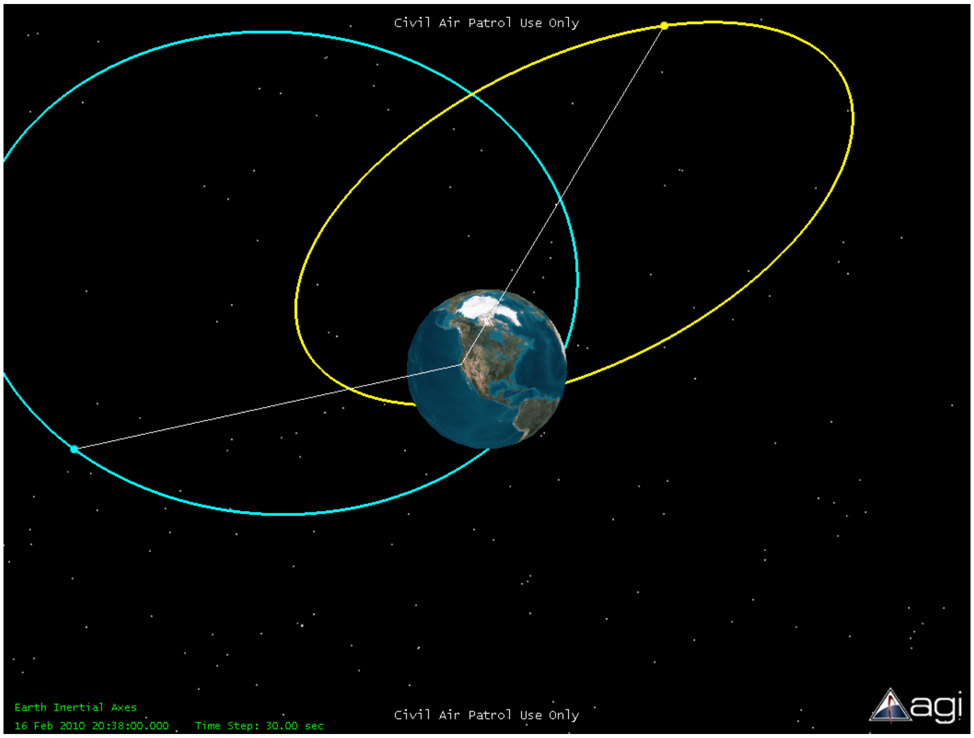
Now we need to compute access to a California city to see what kind of coverage you have.

-- Go to “Insert” at the top of the screen, then select “Facility from City Database.”
-- In the “Search Option” box, type in “Sacramento,” or another CA city if you want, and click on “Search.”
-- Highlight the city you want, then hit “Insert.”
-- In the “Object Browser” box, highlight your city, then go to the top of the screen and select “Analysis” and then “Access.”
-- Highlight “Satellite1” and hit “Compute.”
-- Then highlight “Satellite2” and hit “Compute.” Then, close the window.

Your communications lines will now be displayed between your city and the satellites.
Do you have 100% coverage?
If no, you need to re-orient your satellite orbits!
This is quite a difficult scenario. Had a higher latitude location for communications been selected, it would have been easier, but a mid-latitude location like California is harder…..
You will need to move inclination, RAAN, argument of perigee, and true anomaly. If you can get this right, you can do anything in the CAP-STK Program!!

Remember, there is no one right answer.

Keep trying to get 100% coverage!



One possible solution is depicted at right.

Go to folder “HEO9,” open STK Scenario File “HEO9_California.sc” and run the scenario.

Manipulate the screen so that California and your city are always in view.

100% coverage for a 24 hour period is possible!

You must offset your orbits and take into account the rotation of the Earth.
You then need to move your satellites in the orbits to get 100% coverage.

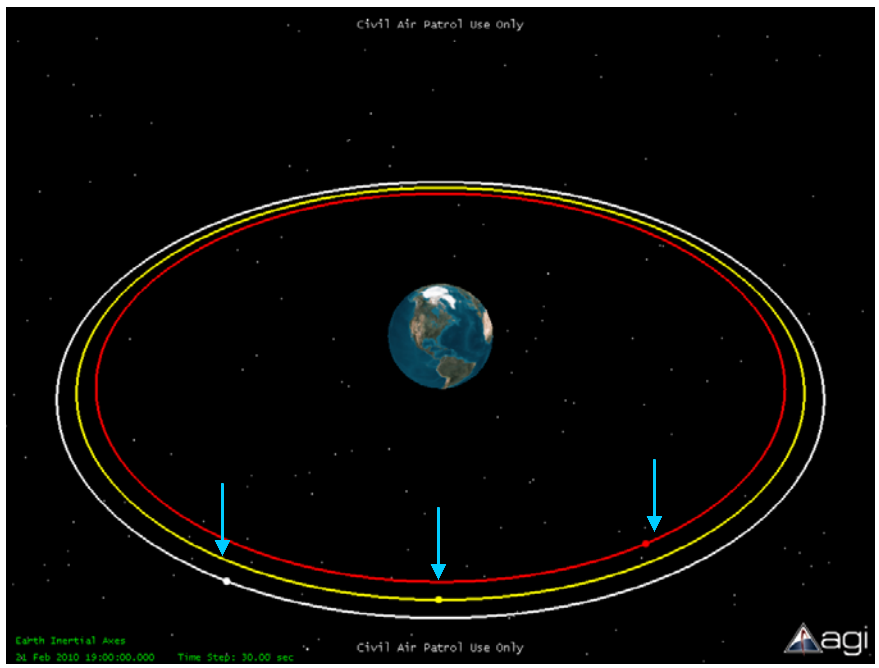
-- Continue to manipulate STK and view the various HEO orbits until you feel comfortable with the concept.
-- Save your scenario!

Once your review is complete, we will now move on to GEO!!

Geosynchronous Orbits (GEO)

Why does the satellite dish on the side of your house not move? It seems to always be pointed to the same point in space…. The answer is that your dish is tracking a communications satellite that is orbiting at the exact same speed the Earth, and your house, is rotating. These satellites, located at or near the equator's latitude, take 1 day to orbit the Earth. That concept is called geosynchronous. The altitude the satellite needs to be at is an amazing 22,300 miles. This is about a tenth of the distance to the moon! That is how far your satellite TV signal is traveling to get to you. Obviously, it is best to have the satellite "parked" directly over the country it is providing communications to, or as close to the country as possible.

These "parking slots" at GEO are very valuable. They have to be at the proper altitude and longitude. If they are parked to low, the satellite will orbit faster than the Earth is rotating. If it is too high in altitude, the Earth's orbit will be faster than the satellites orbit. In either case, you will soon find your satellite somewhere other than where you want it to be, and you will lose signal lock. Poof! No more NFL football! You also need to have your satellite parked in the proper longitudinal spot (example: 98.5 degrees), or you risk colliding with another GEO satellite – not good!



The picture at right depicts 3 satellites. The satellite in red is at 21,000 miles, the satellite in yellow is at GEO, the satellite in white is at 23,600 miles. The picture depicts the location of the satellites after just one 24 hour period! The satellite in red is orbiting too fast, white is too slow. Go to file "GEO10" and run the "GEO10.sc" STK scenario to view the above depiction. Where are the satellites after 5 days? The red and white satellites are providing service to customers for free somewhere else on Earth!

You need to be at or near the equator at the proper altitude. But there are only so many slots! You don't want to place communications or weather satellites too close together. If you did, their powerful transmitters would interfere with each other. So, these parking slots are controlled and allotted on an international basis, controlled by an agency called the International Tele-communications Union (ITU). The ITU also ensures frequencies are coordinated, especially on satellites adjacent to each other, to ensure that service is not disrupted.

At GEO, satellites are prone to drift. They are subjected to many of the perturbations mentioned in the opening PowerPoint presentation. They will also tend to drift either east or west towards the Earth's gravitational stable points. You can't have your satellite drift out of its slot! So you have to do what is called station-keeping. Station-keeping means you use your on board thrusters to move your satellite back where it belongs. Newton tells us that if you thrust in one direction, you must then thrust in the other direction to stop the satellite where you want it. All of this thrusting is using up fuel! What happens when you run out of fuel? You can't move your satellite anymore and it will drift out of position – time to send up a new satellite! But before your satellite runs out of fuel (you constantly monitor your satellites fuel status so you know exactly how much is left), you need to move it out of the way to make room for the new satellite. This is done by thrusting the satellite to a higher altitude to get it out of the way. This is called super-syncing the satellite. You move it up higher to where it is out of the way of everything else.

Geosynchronous versus Geostationary. What is the difference?

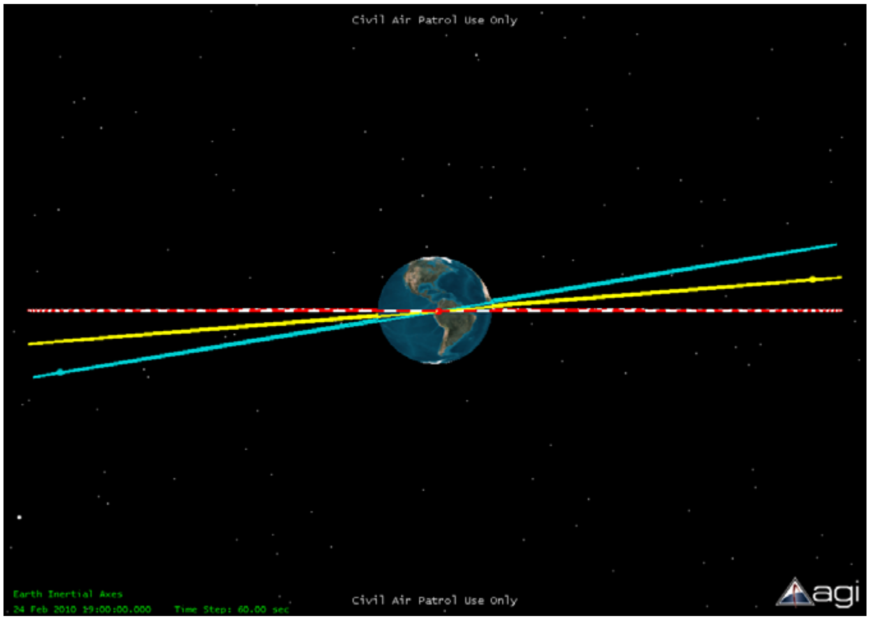
A geostationary satellite is parked right on the equator. Its orbit has 0 degrees of inclination at the proper altitude (22, 300 miles). Its ground track is just a dot on the map – it never moves!
A geosynchronous satellite has an orbit that has a slight inclination – it is something other than 0 degrees. (Example: 8.5 degrees of inclination) It traces a ground track that looks like a figure 8. Why? Because with an inclination, your satellite's orbit is going to travel above the equator, then below the equator, as the Earth rotates, tracing a figure 8. Let's now see this in STK.

SCENARIO #10 Geosynchronous Orbit (GEO)

Your mission for Scenario 10 is to place four satellites at GEO. Place two satellites in geostationary orbit 180 degrees apart. Place 2 satellites in geosynchronous orbit; one with an inclination of 5 degrees and the other with an inclination of 10 degrees, and also 180 degrees apart.
Once that is complete, place a sensor on each satellite; cone angle of 8.5 degrees.

You can use the orbit wizard to create your satellites. Name your scenario "Geo 10."

Your scenario should look something like this. ⟶



The 2 geostationary satellites should be opposite each other, and the 2 geosynchronous satellites should be opposite each other.

-- Run your scenario.
-- Go to the 2D map.

Note that the geostationary satellites do not move at all!

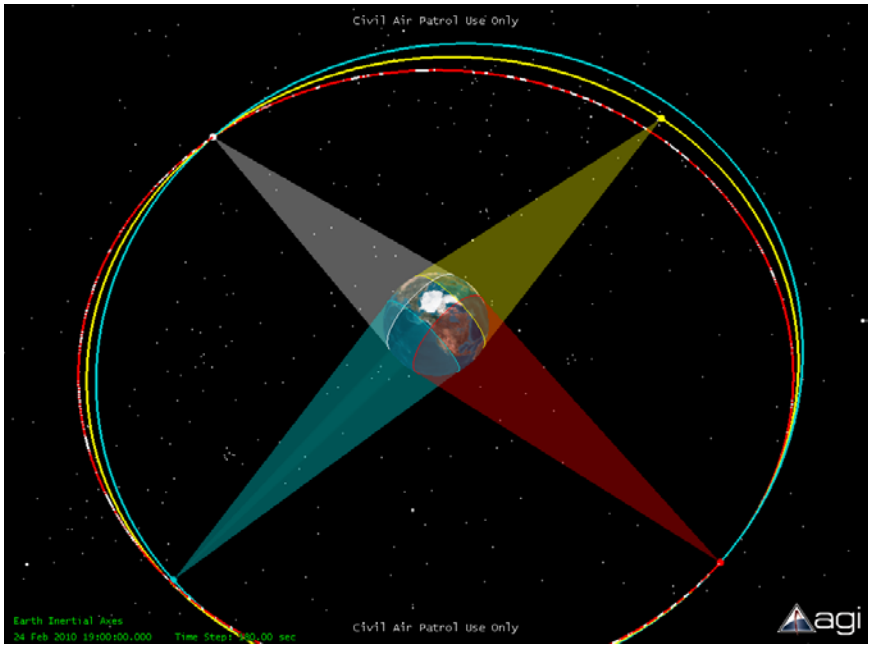
The geosynchronous satellites slowly trace a figure 8.

-- Go back to the 3d map.

Note your field of view!

-- Pause your scenario and create a sensor for each satellite.

Your scenario should now look something like this. ⟶

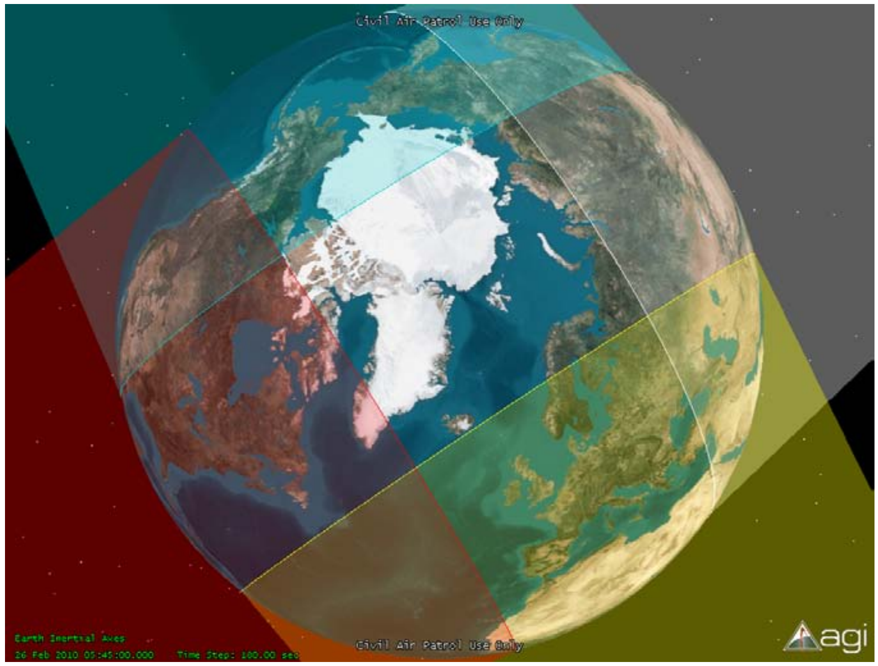


-- Run your scenario.

Look closely at the coverage each satellite provides.
The coverage for the geostationary satellites does not change. Now look closely at the coverage for the geosynchronous satellites. What do you notice?

Now zoom in to the North Pole and observe closely the coverage of the geosynchronous satellites.

Make your 3D map view look something like this. ⟶



-- Run your scenario with this view and watch the coverage provided.
-- Pause your scenario.
-- Change the inclination of the satellite you had at 10 degrees to 15 degrees.
-- Run your scenario and observe the coverage.

QUESTION: What would be the advantage of placing a satellite in geosynchronous orbit?
Answer: There are times when you would want to purposely place your satellite into an inclined, geosynchronous orbit, to provide better coverage at high latitudes.

-- Pause your scenario.

There is another way to view the Earth and satellite orbits. STK has the ability to stop the rotation of the Earth and have just the satellites orbit.

-- On the 3D Map, click on the first eyeball (View From/To).
-- Under Earth, click on the "+" sign next to "Axes," then click on "Fixed," and hit "OK."

You have now stopped the Earth!

-- Run your scenario and not the orbits and coverage of the satellites.

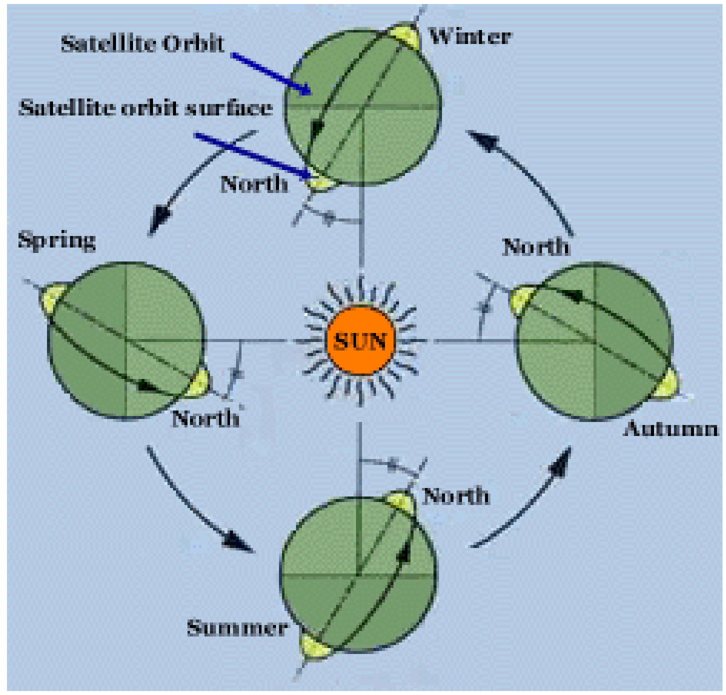
You might need to zoom out and re-orient the 3D Map for the best views.
-- When complete, go back to the eyeball, and under "Earth," "Axes," click on "Inertial," then "OK." This will start the Earth rotating again.

-- Continue to manipulate STK and view the various GEO orbits until you feel comfortable with the concept.
-- Save your scenario!

You can also view the above depiction by going to folder "GEO10" and opening the "GEO10_1.sc" STK scenario file.
Once your review is complete, we will now see what sun-synchronous orbits are all about!

Sun-Synchronous Orbits

Another type of orbit you need to be familiar with is called a sun-synchronous orbit. This is a LEO, polar orbiting satellite, but its unique feature is that it will pass over the same part of the Earth at close to the same time each day. The positioning between the satellite and the Sun are always the same, so the area the satellite orbits over always gets the same angle from the Sun. This is important for data collection and measuring environmental conditions of the same part of the Earth at the same time of day. A Sun-synchronous orbit is always a retro-grade orbit.



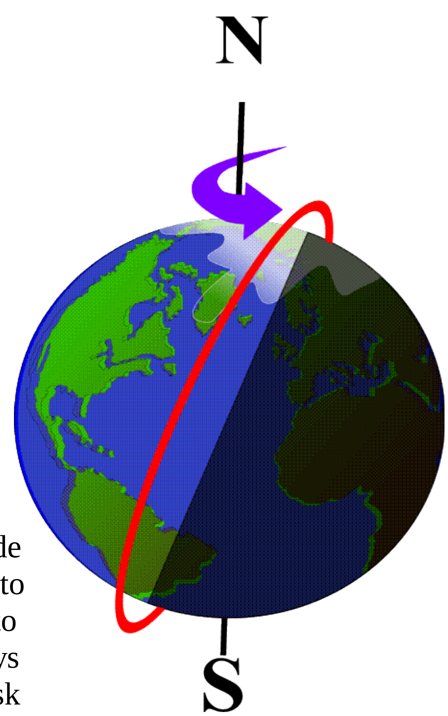
Sun-Synchronous Orbit – passes over the same part of the Earth at the same time every day

Example: You have the requirement to measure the ocean reflectivity in the Gulf of Alaska at roughly noon every day. A sun-synchronous orbiting satellite is made to order for you!

Another type of sun-synchronous orbit is called a sub-recurrent orbit. In this orbit, after a certain number of days, the satellite repeats its original orbit.

Example: Satellite MOS-1 will come back to the exact same orbit every 17 days.

This orbit also enables the satellite to observe the same area at regular intervals. (Partly exacted from: www.eorc.jaxa.jp/en/hatoyama/experience/rm_kiso/satellit_type_orbit_e.html)



RADARSAT 1 satellite's orbit is a dusk-dawn polar orbit

Another type of sun-synchronous orbit is called a dawn-to-dusk orbit. In a dawn-to-dusk orbit, the satellite trails close to the Earth's shadow. When the sun shines on one side of the Earth, it casts a shadow on the opposite side of the Earth. This shadow on the other side of the Earth is called night time!! Because the satellite never moves into this shadow, the sun's light is always on it. Since the satellite is close to the shadow, the part of the Earth the satellite is directly above is always at sunset or sunrise. That is why this kind of orbit is called a dawn-dusk orbit. This allows the satellite to always have its solar panels in the sun! (Partly extracted from www.satellites.spacesim.org/english/.../orbit/sunsynch.html)

SCENARIO #11 Sun-Synchronous Orbits

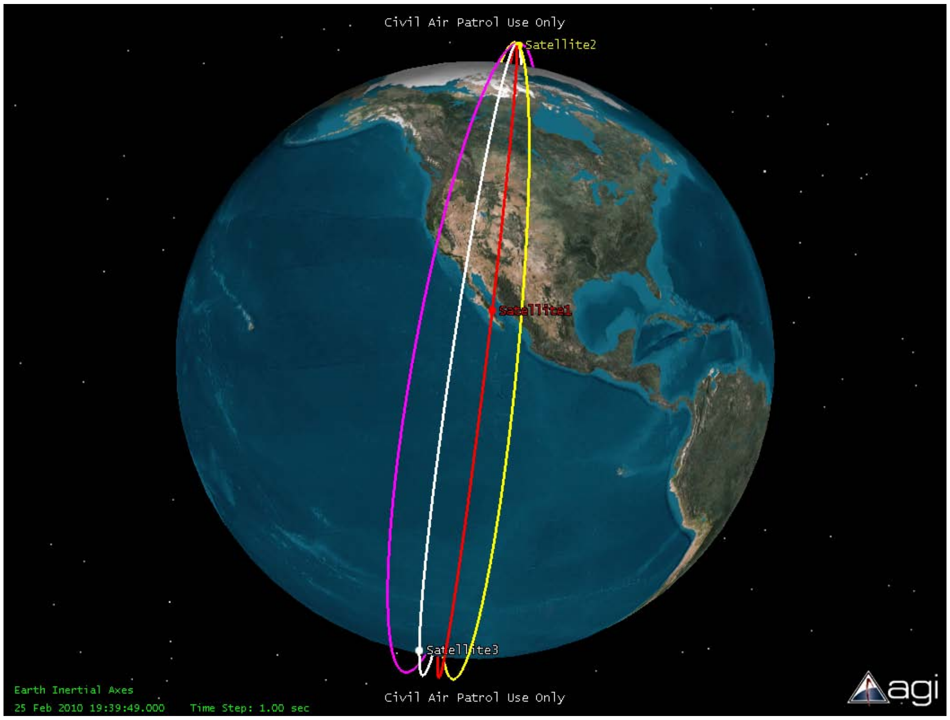
Your mission for Scenario 11 is to create multiple satellites in a sun-synchronous orbit to monitor the waters off the Baja peninsula of Mexico to see when the whales return from their migration!

-- Create your scenario in STK and name it “Sun_Sync 11.” Also change the time for the scenario to run for several days.
-- When you open the “Orbit Wizard,” in the upper left corner, instead of “Type of Orbit” of circular, you can go in here and change it to “Sun-Synchronous!”
-- Note that when you do this, the boxes below change to “Geometry Definition” and “Node Definition.”
-- Leave inclination and altitude alone! STK has already set your altitude and inclination to be sun-synchronous.
-- Leave the “Node Definition” time alone as well.
-- Close the wizard, enlarge the 3D map and run the scenario.
-- Don’t change the “Lighting Settings” this time for this scenario.

You will need to note the times in the bottom left corner. You can speed up the time step sequence to make the scenario run faster.

QUESTION: Does the satellite pass over the same area of Earth at roughly the same time of day?
Answer: most of the time!

-- Now create 3 more satellites to pass over the Baja Peninsula at different times of the day.



NOTE: The satellites need to pass over the area in the day time! (That’s why we didn’t change the lighting, so you can really see when it is dark in that area…)

QUESTION: What orbital element needs to be changed to keep up with the rotation of the Earth and have your satellite pass over the same area?
Answer: RAAN.

Depicted at right are 4 satellites. Satellite 3 (white) has already passed over the area, Satellite 1 is right on top of the area, and Satellite 2 is getting ready. By changing RAAN, you can keep up with the rotating Earth and have the satellites pass over the same area.

Go to folder “Sun-Sync11” and run STK scenario file “Sun_Sync11.sc” to view this scenario.
Remember – there is no one right answer.

In this scenario, you could continue to create satellites and change their RAAN to the right, to pass over the Baja Peninsula, until the shadow of darkness enveloped you!

-- Run your scenario for several time-step days. You are really only interested in the particular time of day the satellites actually pass over the area of interest.

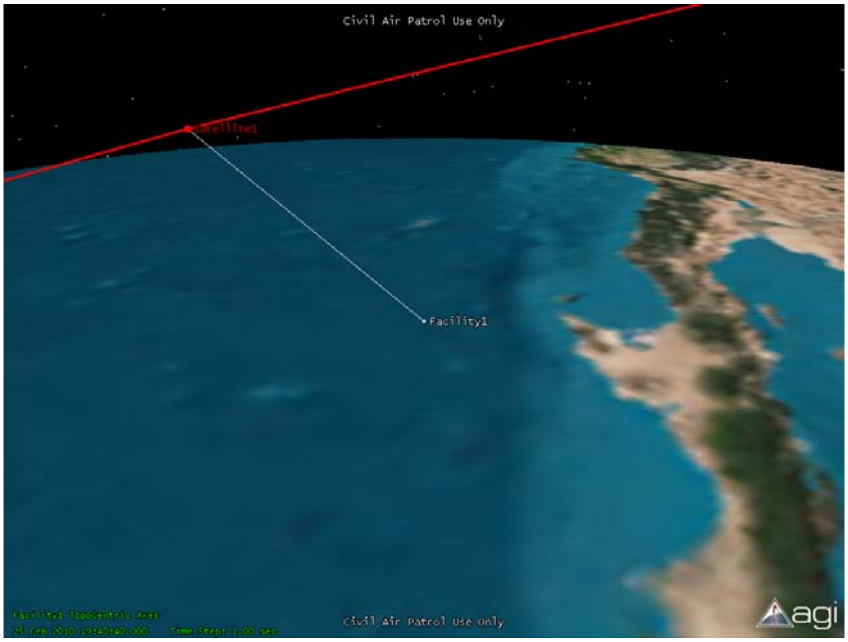
We will now create a facility on the ocean to the west of Baja to compute access to your satellites to see your coverage.

-- In the "Object Browser," highlight your scenario name.
-- At the top of the screen, click on the icon called "New Object." This is the same button used to create a sensor on your satellite.
-- Open the window, then click on "Facility." This will insert a facility into your scenario.
-- Go to "Object Browser" and double click on your facility. In the window that opens, you will need to change the latitude and longitude to put the facility where you want it!
-- Change latitude to 26.75 degrees. Change longitude to -116.0 degrees.

This should put a facility on the ocean off the coast of Baja. Consider it a floating monitoring station for migrating whales!

-- Compute access from the facility to each satellite. (Click on "Analysis" at the top of the screen, then "Access," then highlight "Satellite1," then compute; highlight "Satellite2," then compute, etc., and then close.)

Your scenario should look something like this. →



You don't need to have continuous access! With each once-a-day pass, your look angle to the point on the ocean should be relatively the same…

How did I get the screen to the right? Go to the eyeball (View From/To) and make yourself the "Facility!" You now have a view from the ground up. You will need to zoom out and re-orient the globe to get different views from the ground

-- Continue to manipulate STK and view the various sun-synchronous orbits until you feel comfortable with the concept.
-- Save your scenario!

You can also view the above depiction by going to folder scenario "Sun-Sync11" and opening the "Sun_Sync11_1.sc" STK scenario file.

This now concludes the chapter of Orbital Orientations. We are now ready to move on to the exciting world of space operations!

3 SPACE OPERATIONS

Important Terms

Two Line Element: A set of data that defines the orbital parameters of a satellite.
Launch Window: When to launch a rocket to meet up with an object in space. The launch must be timed to occur close to the time the satellites orbital plane intersects the launch site.
Plane of the Ecliptic: Planets orbiting the Sun almost all in the same orbital plane.
Asteroid Belt: The area of the solar system between Earth and Mars containing many large rocks and space debris.
Ceres: The largest and most massive body in the asteroid belt. It is considered a dwarf planet. It contains almost a third of the asteroid belt's total mass.
Cross-link: The ability of satellites in orbit to communicate with each other and pass information back and forth for relay to Earth.
Globalstar: A constellation of satellites in low Earth orbit that relays voice and data communications. Civil Air Patrol uses Globalstar as part of the Satellite Digital Imaging System (SDIS) to transmit photos from CAP aircraft to mission base.
Iridium: Another constellation of satellites in low Earth orbit used to provide voice and data coverage to satellite phones, pagers and integrated transceivers over Earth's entire surface.

How to find and display satellites from the STK database, launch rockets, view the solar system and link objects together

This chapter will focus on existing satellites currently in orbit, how to launch rockets to meet up with satellites using STK, how to display different objects in the Solar System and how to use STK chains to link various objects together. Chapter 3 assumes even a greater level of knowledge of STK, as presented in previous chapters. We will continue to demonstrate even more features of the space application as the chapter progresses.

Up to this point, you have been creating your own satellites using the "Orbit Wizard." In this chapter, we will use existing satellites pulled out of the STK satellite database. When displayed, you will see the actual orbits of these operational satellites, and for LEO satellites, you will be able to compute access to these satellites for possible viewing as the satellites orbit overhead.

EXAMPLE: The International Space Station (ISS) is by far the largest man-made orbiting object in space. STK will allow you to compute access from your location allowing you to see the ISS orbit in space.

STK also has the capability to demonstrate how to launch rockets from any location on Earth, and to display other objects in the solar system.

STK can also link various platforms together! In the final scenario of this chapter, you will be shown how to link various ground, air, and space objects together to communicate information around the globe.

SCENARIO #12: The STK Satellite Database

Your mission for scenario 12 is to display certain satellites from the database!

-- Create a new scenario in STK, and name it “Database 12.”

Instead of using “Orbit Wizard” to create satellites, we are going to pull them out of the database!

-- When STK opens, instead of clicking on “Orbit Wizard,” click “Insert Satellite from Database.”

This will open a new window. All satellites in the database will be displayed alphabetically. There are over 1,000 of them! We will be finding various satellites using the satellite’s “Common Name.”

-- At the top of this window you will see an area where you can enter the satellites name, next to “Common Name.” All you do is type in the name of the satellite.
-- Type in “ISS” and click on “Search.” ISS with an SCC number of 25544 will appear in the window.

That’s the Space Station! SCC is a number that’s assigned to each object in space to track it.
You can also change the color of the orbit track it.

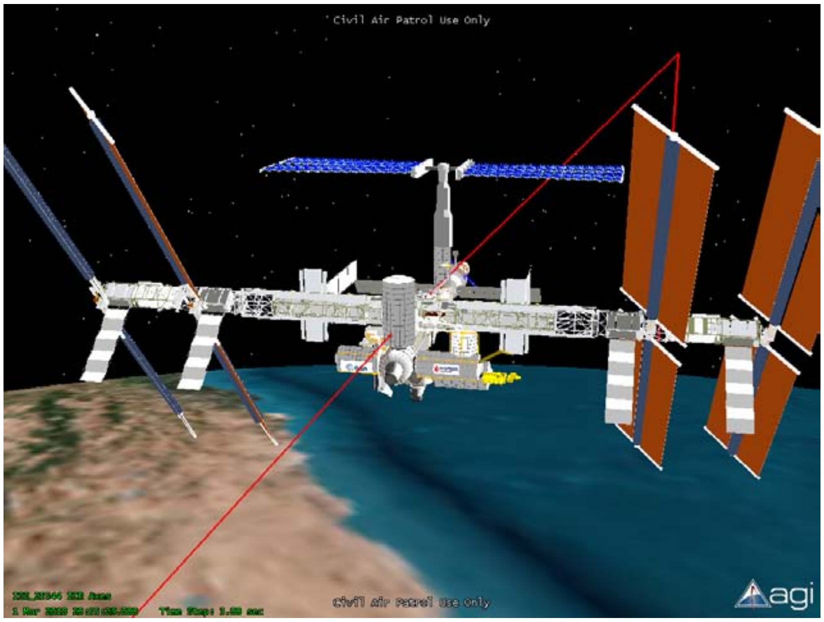
-- Highlight “ISS” in the window and click “Insert.” Then close the window, and close the “Insert STK Objects” window.
-- Enlarge the 3D map window.
-- Run the scenario.

This is the actual track of the space station in real time!

-- Pause your scenario, go to the eyeball and make yourself the ISS.
-- Zoom in until you can see the ISS.

Displayed is a model of the completed ISS.

It should look something like this. ⟶



-- Move around the satellite and view it from various positions.
-- Zoom in real close and observe each of the modules of the ISS.

-- Run the scenario.

Note that the solar panels move to track the sun.

-- Click on the eyeball and make yourself the Earth again.

You also have the ability to view, even change the orbital parameters of existing satellites!

-- Go to "Object Browser" and double click on "ISS_25544."
-- A new window appears. In the "TLE Source" box, ensure "Automatic Update" is selected, the click on "Preview."

This opens up the "TLE" data for the satellite. TLE stands for "Two Line Element," and it is the six orbital parameters! Another word for TLE is "El Set" data. El Set stands for Element Sets.

Note the eccentricity, inclination, RAAN and argument of perigee of the ISS! Semi-major axis and true anomaly are listed here as "mean." This is complicated, but it is more a measure of time - how far the space station travels given a set of parameters….

-- Close the window when done. You can also view a similar depiction by going to folder "Satellite Database 12" and opening the "Database12.sc" STK scenario file.

You will now display other satellites from the database.

-- At the top of the screen, click "Insert" and then "Satellite from Database."

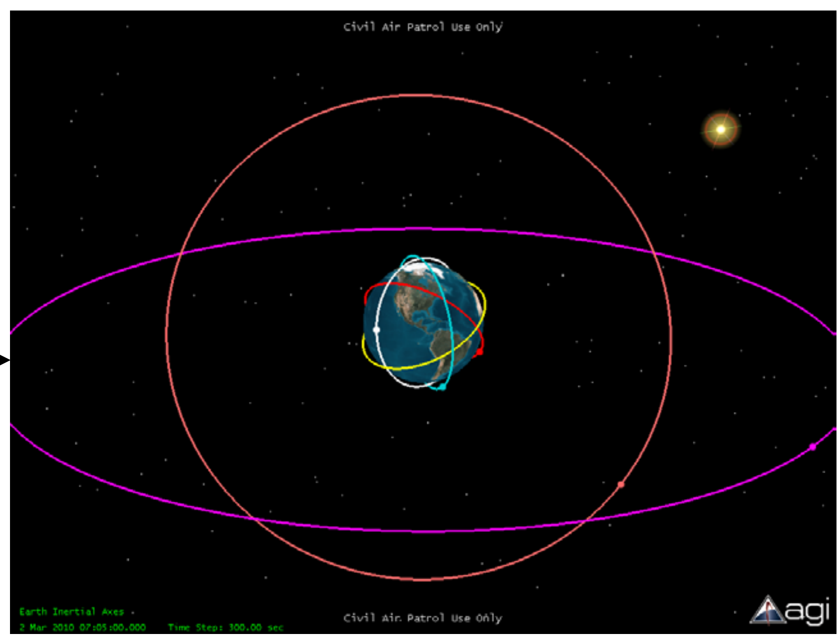
Find the following satellites and insert them into your scenario:
(Sometimes you might have to type a "*" after the common name. This sets the wild card in the database, which allows it to search for names that are close to what you typed.)

- The Hubble Space Telescope (Hubble*)
- The Quickbird imaging satellite (Quickbird*)
- One Iridium communications satellite (Iridium*)
- One GPS satellite (Navstar*)
- One Relay satellite (TDRS*)

Once all satellites are displayed, run your scenario and observe the different satellites.

-- Go to the eyeball and make yourself each satellite.

Note that each satellite model is different. Each model is a representation of that specific satellite.
Your map should look something like this.



QUESTION: What kind of an orbit is the Quickbird imaging satellite in?
Answer: A LEO, polar, circular orbit

Quickbird takes very high resolution images (photos) of the Earth.

QUESTION: What kind of an orbit is the Hubble in?
Answer: an LEO, inclined, circular orbit.

The Hubble Space Telescope takes high resolution images of the universe!
The GPS satellite is in a semi-synchronous orbit, and the TDRS satellite is out at GEO.

Double-click on each satellite in the object browser and review the orbital parameters for each.

-- Click on the eyeball and give yourself the "Earth-view" then "Inertial."

For satellites at LEO, you can compute access to see when that satellite will orbit overhead. In case you don't remember, here is how you do that:

-- Go to "Object Browser" and highlight the scenario name "Database 12."
-- Go to the top of the screen, click "Insert," and then "Facility from City Database."
-- Type in a city and click on "Search." When your city comes up, highlight it and click on "Insert." Then, close the window.
-- In the "Object Browser" highlight your city. Then, at the top of the screen, click on "Analysis." Then click "Access."
-- Click on the satellite you want to access. Let's make it the ISS. Highlight ISS. Then, click "Compute".
-- To the right of the "Compute" button is a box labeled "Reports." In this box, there are 2 icons you could click. Click the one that says "AER."

A new window appears listing all the times the ISS can be seen from your city. The time is in UTCG, or Zulu, you need to convert this to your local time.

-- Scroll down and review the different access times.

The "azimuth" column is the degrees (direction) the ISS is coming from when it appears over the horizon, to the degrees it will go to when it disappears over the horizon again.
The "elevation" column is how high in the sky the ISS will appear, measured in degrees off the horizon. You need to select a time where the elevation angle is fairly high, or you will never see it, it will be too close to the horizon.
The "range" column is simply how far away the ISS at various time steps from your location!

-- Select a few times where the elevation angle is fairly high, and write these access times down.
-- When your review of the AER report is complete, go back to the 3-D map.
-- Run your scenario. Watch the time when the AER report says the ISS will pass over you. STK will model that access for you! It will show you the direction from which the ISS is coming!
-- When complete, save and close your scenario.

You can also view a "Compute Access" depiction by going to folder "Satellite Database 12" and opening the "Database12_1.sc" STK scenario file.

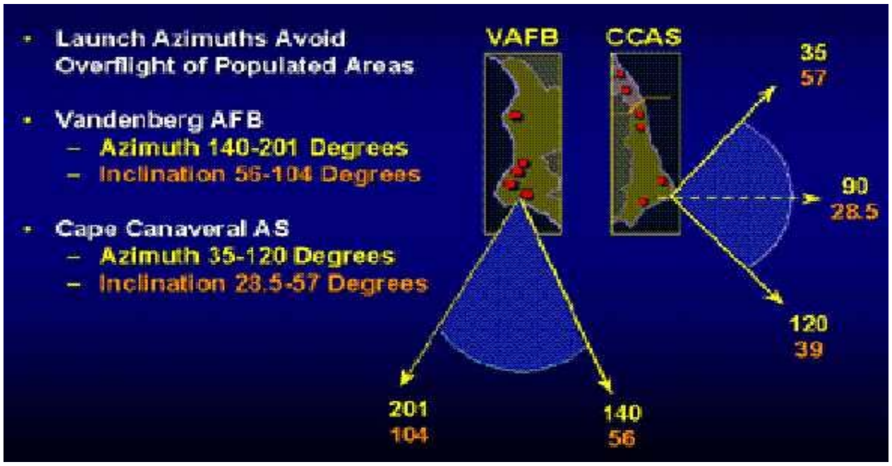
RECOMMENDATION: Make a squadron project out of computing access times to the ISS!

Obviously, you are only going to see the ISS at night, when it is backlit by the sun.
Try this out at various times during the month.

Now it time to launch rockets!

Launching Rockets

There are 2 primary launch locations in the United States: Cape Canaveral and the Kennedy Space Center (KSC) in Florida, and Vandenberg Air Force Base in California. There are also 2 other launch sites in the US: Wallops Island on the Virginia coast, officially called the Goddard Space Flight Center, Wallops Flight Facility, and Ft Greeley in Alaska. The topography of the U.S. makes these launch locations ideal. We can place satellites into a pro-grade, equatorial inclined orbits from the east coast, and polar, retrograde orbits from the west coast.



Launch Azimuths for the 2 primary US launch sites.

You have seen the picture on the right before! It outlines the launch sites and launch inclinations that are possible.

Kennedy Space Center launches have an allowable path no less than 35 degrees northeast and no greater than 120 degrees southeast. These are azimuth degree readings based on due east from KSC as 90 degrees.
A 35-degree azimuth launch places a satellite in an orbital inclination of 57 degrees. A launch path from KSC at an azimuth of 120 degrees will place a satellite in an orbital inclination of 39 degrees (it will be above or below 39 degrees north or south of the equator).
These two azimuths, 35 and 120 degrees, represent the launch limits from the KSC. Any azimuth angles further north or south would launch a rocket over a habitable land mass, adversely affecting safety provisions for an abort in the event of a rocket malfunction where the rocket would have to be intentionally destroyed, or present the undesirable possibility that the first and second stages of the rocket could land on foreign land or sea space.

Launches from Vandenberg have an allowable launch path suitable for polar insertions south, southwest and southeast. The launch limits at Vandenberg are 201 and 140 degrees. At a 201 degree launch azimuth, the spacecraft would be orbiting at a 104 degree inclination, which is a retrograde orbit. At a launch azimuth of 140 degrees, the spacecraft would be orbiting at a 56 degree inclination. Like KSC, Vandenberg has allowable launch azimuths that do not pass over habitable areas or involve safety, abort, separation and political considerations.

Mission requirements and payload weight penalties also are major factors in selecting a launch site. The Earth rotates from west to east at a speed of approximately 900 nautical miles per hour (1,035 mph). A launch to the east uses the Earth's rotation somewhat as a springboard.
(Extracts in part from NASA's web site)

If you are launching a spacecraft to meet up with a satellite, when you launch is critical! The launch must be timed to occur close to the time the satellites orbital plane intersects the launch site. This is called the launch window. For example: when launching a rocket to meet up with the ISS from KSC, the launch window is only 10 minutes long!

SCENARIO #13: Launching Rockets

The International Space Station is running out of MREs!! Your mission for scenario 13 is to launch a rocket from the Kennedy Space Center to rendezvous with the ISS to resupply them with critical rations. To launch a rocket using STK:

-- Create a new scenario and name it "Rocket_Launch 13."
-- Go into the satellite database and insert the ISS in your scenario.
-- Go to the top of the page, click on the little arrow next to the "New Object" icon, then click on "Launch Vehicle," and click "Insert."
-- Go to "Object Browser," and double click on "Launch Vehicle1."
-- A new window opens. You will now need to set launch latitude and launch longitude. This will set your launch site. You will need to know the latitude and longitude of the KSC.
(Latitude: N28.5 degrees; Longitude: W -80.55 degrees)
-- The launch altitude will be 0; we are launching from sea level.

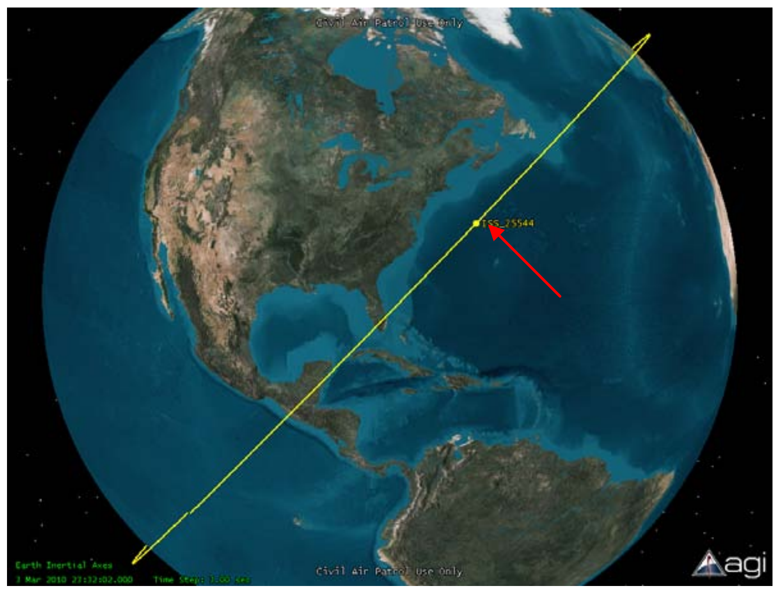
Now you need to decide when to launch!

After you have decided when to launch, you will need to calculate your burn out latitude, longitude, and altitude to meet up with the ISS.

Don't worry about burn out velocity.

Good luck!

Hint: When to launch. The ISS should be in approximately this position. →



You must launch into the proper orbital plan!

The ISS must be on an ascending pass.

In past shuttle launches, the ISS would pass overhead of the KSC, then the shuttle would launch after it.

-- Create your launch location, and determine the azimuth to launch.

Hint: Do you remember what the orbital altitude and inclination of the ISS is?

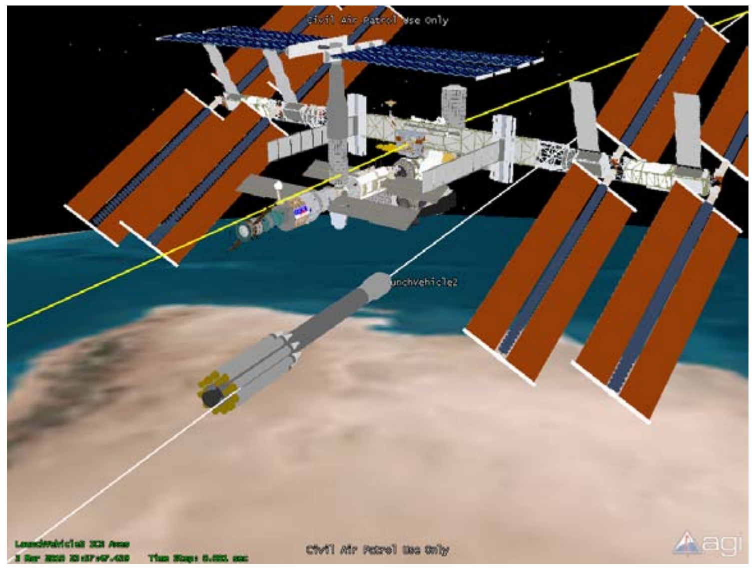
Your azimuth should look initially something like this. →

You will need to set the specific time to launch your rocket. To do that:

-- When you have the window open manipulating your burnout location, go up to the “Use Scenario start time” box and deselect it.
-- Then enter the start time of your launch and the stop time for booster burnout.

You will need to keep changing burnout latitude, longitude, and altitude so that your rocket rendezvous with the ISS. How close can you get it? When you think you have the solution, go to the eyeball and make yourself the rocket. Watch the launch, and see the ISS approach!

When complete, the view should look something like this. →



The default rocket STK uses, depicted at right is a Delta II. You can also change rocket models. You will learn how to do this below.

When complete, go to folder Rocket Launch13 and open STK scenario file Rocket_Launch13.sc to view the possible solution to your right.

How close did you come?

Of course, in the real world, as the rocket approached, it would start firing its thrusters to slow down, and align itself with the space station.

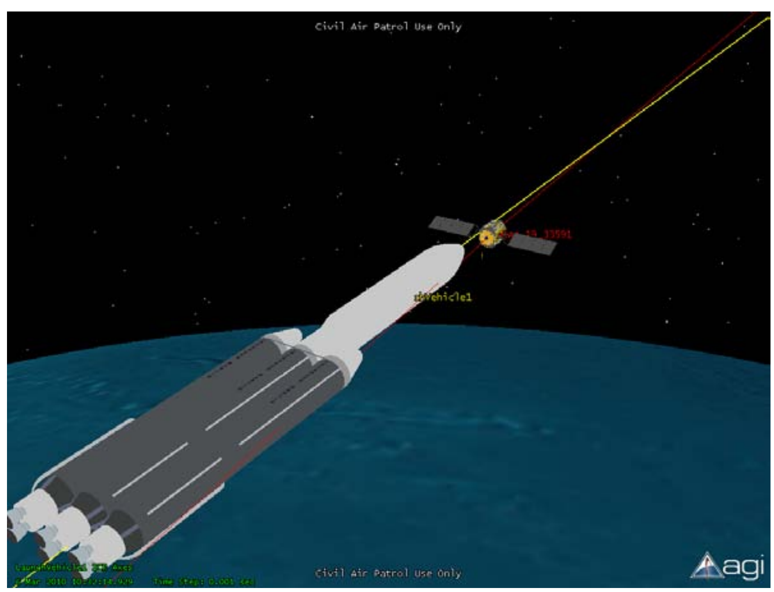
Once complete with that scenario, here is the next one:

Launch a rocket from Vandenberg AFB in California to rendezvous with a satellite in polar orbit.

Use a National Oceanic and Atmospheric Administration (NOAA) environmental satellite: NOAA 19, as your target satellite. It is running out of fuel, and you need to replace the fuel cell!

This is all the help you will get for this one…. This will be harder because the satellite is smaller, and it’s at a higher altitude…

Your solution should look something like this. →



You will notice the rocket model has changed! The model depicted here is an Atlas V Heavy rocket.

How do you change models?

-- Go to “Object Browser” and double click “Launch Vehicle.”
-- Under “3D graphics,” click on “Model.” This will open another window.
-- In the upper left corner, next to the “Model File” box, there is an icon with 3 dots in it.
-- Click on that icon, and you get a list of models. Some of these are rocket models, some are satellite models.
-- If you want to change your model, select one, and click on “Open.” Then close the window.

Reset and run your scenario.

-- Go to the eyeball and make yourself the rocket. Observe the rendezvous.

You will need to decrease the time step sequence significantly to observe when the 2 spacecraft meet…

Go back to the Earth view.

QUESTION: What could you do to slow down the intercept velocity?
Answer: lower your “burnout velocity” in the window where you change the burnout latitude and longitude.

Careful! If you change your “burnout velocity”, it will change your point in space where the intercept will take place.

If you want to view the rendezvous depicted above, go to folder “Rocket_Launch 13” and click STK scenario file “Rocket_Launch13_1.sc.”

-- Continue to manipulate STK and view your rocket launches until you feel comfortable with the concept.
-- Save your scenario!

You can create additional rocket launches within this scenario if you desire.

When you are ready to move on, go to the next scenario and learn about the solar system!

<u>SCENARIO #14: STK and the Solar System</u>

STK also has the capability to help you understand the solar system! It has the ability to display the planets, and then lets you become the planet to see the solar system orbits from each planet's perspective. It also has some unique features that can be displayed to enhance your understanding of how the planets orbit the Sun.

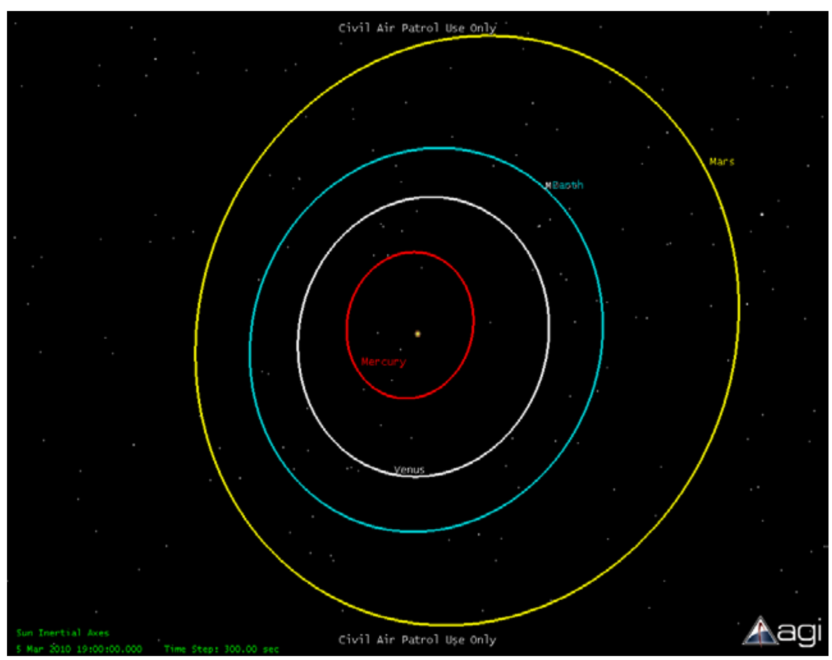
Your mission for Scenario 14 is to create the solar system, and view the orbits of each planet, the Sun, and the Moon, from different perspectives.

-- Open STK and create scenario "Solar_System 14."
-- Open the "Properties" icon at the top left corner of the 3D window.
-- Click "Advanced." Change "Max Visible Distance" to the following: "1e+012 km." Click "OK" to close the window.
-- Go to the "New Object" icon (under "Insert") at the top of the window and open it. (Click on the little arrow to the right of it.)
-- Click the "Planet" icon to highlight it, and then click "Insert." Then close the window.

You have now just created a generic planet. Here's how to change it into a planet you will recognize:

-- Under "Object Browser," double-click on "Planet1" to open its properties.
-- In the window next to "Central Body," which should be selected, there is a scroll-down list. Click on the down arrow and a list of solar system bodies is displayed. Highlight "Mercury."
-- In the same window, go to "2D Graphics," "Attributes," and change the color to one you want. Increase the line width. Then click "OK."

You have just created the planet Mercury's orbit!



Now continue to go to the "New Object" icon and insert more planets into your scenario. Insert all planets into the scenario, including the Earth. Also, include the dwarf planet Pluto. Also insert the Earth's moon into your scenario.

Your screen should look something like this, displaying the inner planets. ⟶

What do you notice?

Some planets orbits are elliptical, not circular!

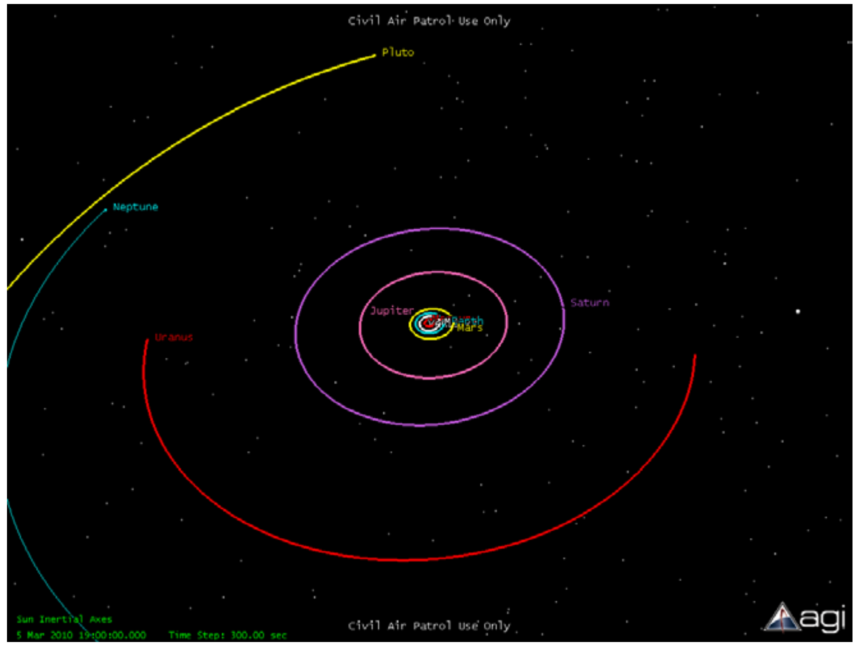
QUESTION: What is the significance of the planets being in elliptical orbits?
Answer: They travel around the Sun at different speeds!

-- Go to the eyeball and make yourself the Sun, and click “OK.”
-- Run your scenario and view the planets orbiting the Sun.

You will need to zoom out to see the planets!
You will probably need to speed up the time step sequence to get the planets moving.

-- Orient your screen to view the solar system from different angles.

If you zoom out to display all of the planets, it should look something like this. →



Note that the orbital tracks for Uranus, Neptune and Pluto are not complete. The reason for this is that STK can only accurately extrapolate the proper orbit so far into the future.

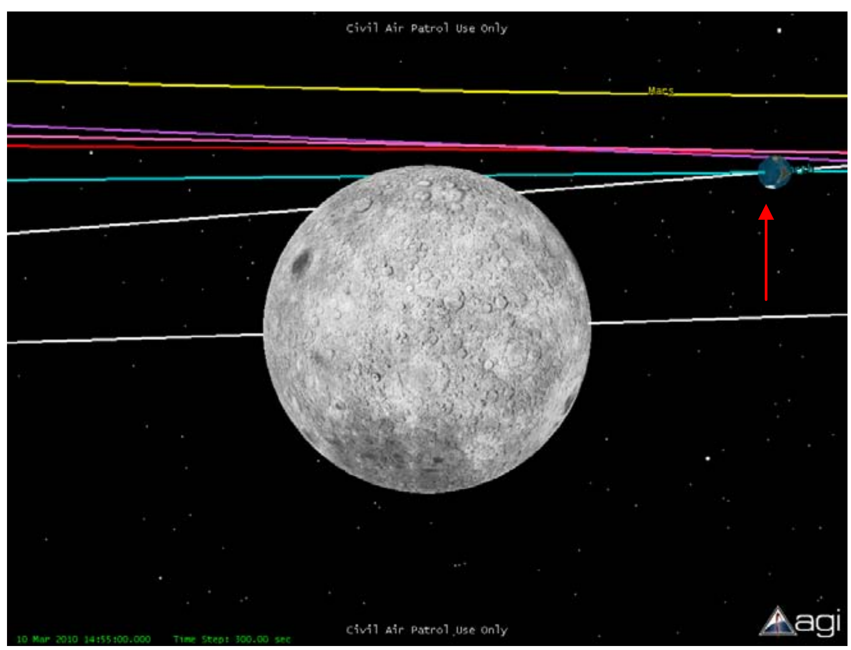
QUESTION: How long does it take Neptune to orbit the Sun once?
Answer: 165 Earth years!

-- Pause the scenario.
-- Go to the eyeball and make yourself Mercury. When you open the eyeball, ensure you scroll down to the planets and click on the planet Mercury.
-- Run your scenario and view the solar system from Mercury’s perspective.
-- When complete, make yourself Venus and run the scenario and view…
-- Continue this process for each planet.

QUESTION: What do you observe the further out in the solar system you are?
Answer: Planets orbit slower!

-- Now make yourself the Moon, run the scenario, and observe the Earth from various viewpoints.

Orient your map so it looks like this, with the Earth in the background rotating from right to left. →



What do you notice?

First, the view of the moon here is one you will never see from Earth! Depicted is the other side of the Moon…. (the “Dark Side”??)

-- Run the scenario.

Note that the Moon rotates at the exact speed that the Earth orbits the Sun. The same side of the Moon always faces the Earth.

If you want to see this exact scenario, go to folder “Solar_system14” and open the “Solar_System14.sc” STK scenario file.

-- Now orient the map so the Moon is between the Earth and the Sun and zoom in to enlarge the Moon.

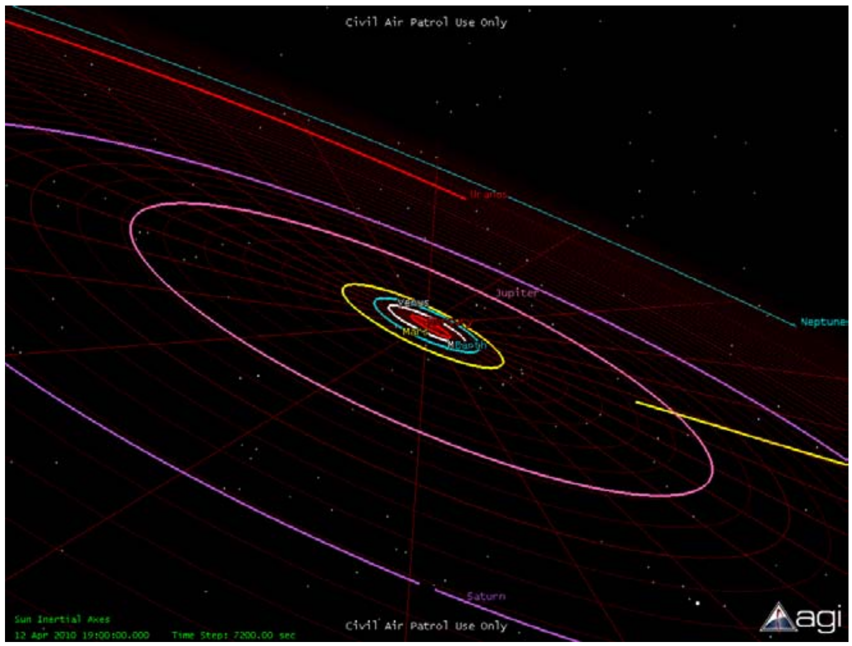
This is the view of the Moon you are used to seeing. Note where the Sun is in the background.

-- Continue to run the scenario observing various aspects of the Earth, Moon, Sun orientations.
-- Reset the scenario.

QUESTION: What is the plane of the ecliptic?
Answer: The planets orbit the Sun almost all in the same orbital plane! STK can display this.

-- Go to the eye and make yourself the Sun.
-- Click on the “Properties” icon in the upper left corner of the 3D map.
-- Click on “Grids” to highlight it. Click in the box next to “Ecliptic Coordinates.” Set the color to red and hit “OK.”

The 3D map now displays the plane of the ecliptic. Your map should look something like this. →



-- Run the scenario,

-- Zoom out so you can see all of the orbital planes. Note that most planets are all in the same plane, except the former planet Pluto. (Maybe that’s why they kicked Pluto out of the planet club.)

Note that the ecliptic plane is tilted.

If you want to see this particular scenario, go to the “Solar_System 14” folder and open the “Solar_System14-1.sc” STK scenario file and run it.

At various times of the year, if you look up in the sky, you will see many of the planets all in the same line. Now you know why…..

-- Go to the eyeball and make yourself Saturn.

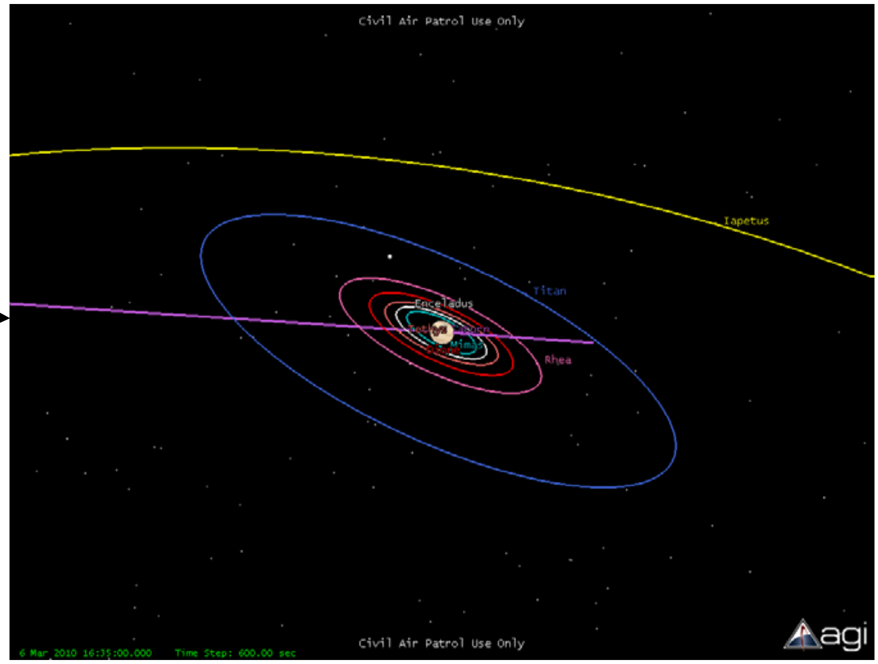
In STK, you can also model the moons orbiting Saturn (or any other planet that has moons….)

-- Go to the "New Object" icon and create another planet. Double click on it, and next to "Central Body," open the pull down menu and select a Saturn moon; hit "OK."
-- Create each of Saturn's 7 major moons.

QUESTION: What are the names of Saturn's 7 major moons?
Answer: Dione, Encelatus, Lapetus, Mimas, Rhea, Tethys and Titan.

-- When all 7 moons are displayed, run your scenario.

It should look something like this.



Saturn has its own mini solar system! Note that these major moons are almost all on the same orbital plane…

Titan, Saturn's largest moon is bigger than the planet Mercury!

Note that Saturn has 62 moons total, 53 of which have names!

To view this scenario, you also can go to the solar system folder and load and run the "Solar_System14-2.sc" STK scenario file.

Now let's do the same thing for Jupiter's moons.

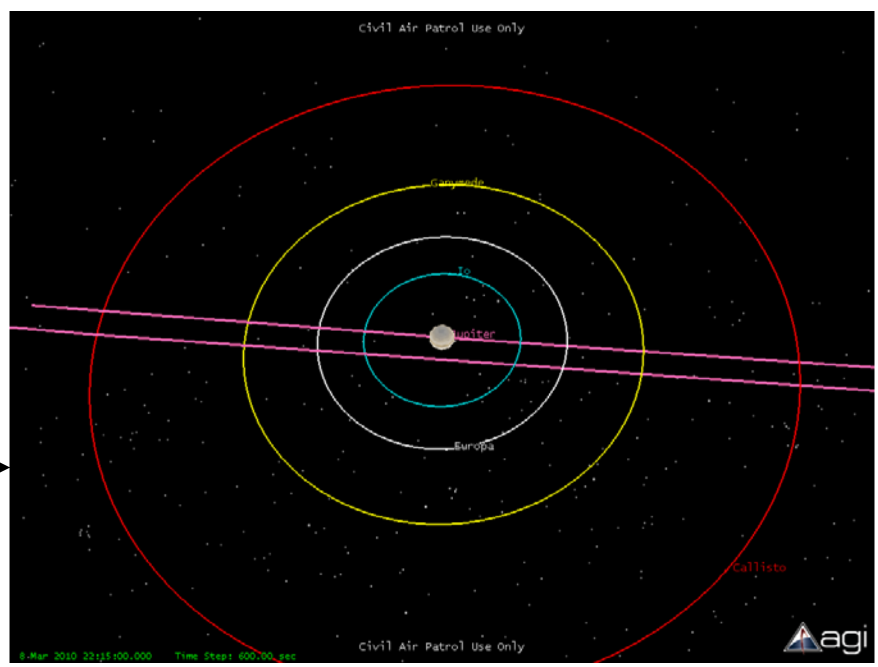
-- Make your self Jupiter, then go into "New Objects" and create the 4 largest moons of Jupiter.

QUESTION: What are the names of Jupiter's 4 largest moons?

Answer: IO, Europa, Ganymede, and Callisto. They are called the Galilean moons because they were discovered by Galileo in 1610.

-- When all 4 moons are displayed, run your scenario.

It should look something like this.



Jupiter has 63 moons total!

QUESTION: Why does Jupiter have so many moons?

Answer: Think Newton's law of universal gravitation. Jupiter is so massive, with an intense gravitational field; it has attracted and captured many other celestial bodies over the millennia.

To view this scenario, you also can go to the solar system folder and load and run the "Solar_System14-3.sc" STK scenario file.

QUESTION: Are all the moons of Jupiter in the same orbital plane?
Answer: Yes!

QUESTION: Is the orbital plane of the moons the same orbital plane of all the planets?
Answer: Yes.

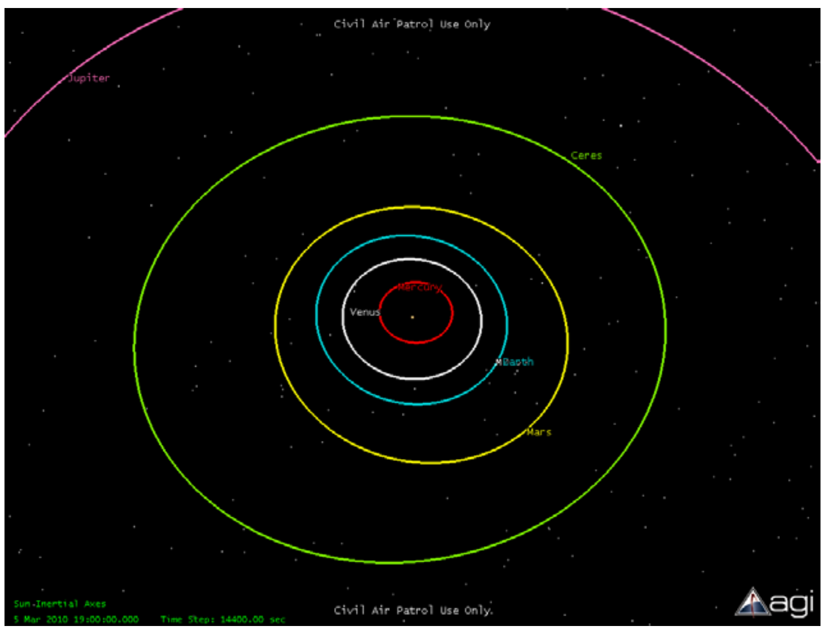
QUESTION: Why does there seem to be only one orbital plane in the solar system?
Answer: When the sun was formed and captured the planets, and everything else in the sun's gravitational field, this matter must have streamed in from one direction. Thus, only one plane where all the matter lines up!

STK also lets you display other moons in the solar system.

OPTIONAL: What planets do they following moons belong to? Once you find out, create them for the corresponding planet: Ariel, Charon, Deimos, Hyperion, Phobos, Phoebe, Titania, and Triton.

If you create all of these moons for their corresponding planets, you will have almost our complete solar system built! What about the celestial body Ceres?

OPTIONAL: Go into STK and create/display Ceres.



QUESTION: What kind of a celestial body is displayed?
Answer: Ceres is the largest and most massive body in the asteroid belt. It is considered a dwarf planet. It contains almost a third of the asteroid belt's total mass.

Depicted at right in green is Ceres' orbit: between the orbits of Mars and Jupiter, in the asteroid belt!

Go to STK file "Solar_System14-4" to review.

-- Continue to manipulate STK and view different views of the solar system until you feel comfortable with the concept.
-- Save your scenario!

When you are ready to move on, go to the next scenario and learn how to create a complete space system using STK chains.

SCENARIO #15: Space as a System: Constellations and Chains

When conducting satellite operations, you use all elements of the space system: the ground, space, and data link segments. You command and control satellites from the ground. When the satellite is overhead, that is easy to do. What happens when you do not have line of sight to the satellite? You use other satellites as cross-links, or to relay commands to other ground stations to then uplink to selected satellites (data-link).

Your mission for scenario 15 is to use an existing satellite constellation to conduct space operations to relay information from one area of the Earth to another area. You will learn how to use a chain to conduct these operations. Specifically, you must relay vital White Tiger information from the Mumbai Zoo in India to the National Zoo in Washington DC, whose offices are located in Arlington, Virginia. These rare tigers are depending on you!

STK allows you to easily create entire constellations. We will start with a GEO constellation, then move to MEO, then finally LEO. As you move closer to the Earth, you will need more satellites, and completing chains will become more difficult.

-- Open STK.
-- Create a new scenario and name it “Constellations 15.”
-- In the “Orbit Wizard,” click “Select from Satellite Database.”

We are going to use satellites whose specific function is to relay communications from GEO.

-- Type “TDRS*” in the box and click “Search.”
-- Highlight all of the TDRS satellites and click “Insert.” Close the window.
-- Change the color of the orbit of each satellite if you want.
-- Insert the cities of Mumbai and Arlington into your scenario.

We will now establish a chain. In STK, a chain is a specific sequence of satellites, airborne, seaborne, and ground stations.
It is different than “Computing Access.” When you compute access, STK will display any access to any satellite. In a chain, you tell STK what the sequence of access should be.

Example: Ground Station 1 to Satellite 3 to Satellite 6 to Ground Station 2.

Here is how you do it:

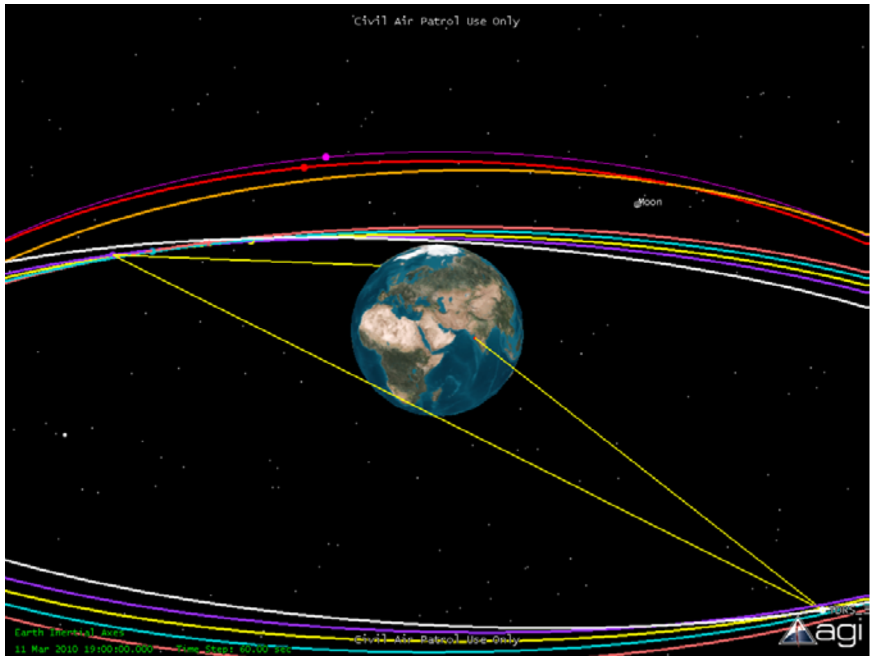
-- Go to “New Object” and open the pull down menu.
-- Click on the “Chain” icon, and click “Insert.”
-- Double click on “chain” in the “Object Browser” window. This will open a new window.
-- In the “Available Objects” window, you need to select your sequence of “objects,” and hit the arrow to bring them over to the 2nd window.

It is imperative that you select objects that have line of sight to each other! The ground station must have line of sight to a satellite overhead. Satellites must have line of sight to each other in space.

-- So for this scenario, select Mumbai, then the arrow pointing to the right, then TDRS 3, hit the arrow, TDRS 7 hit the arrow, then Arlington hit the arrow. Click “OK.”
-- Reset then run the scenario.

Your chain should link the 4 objects you have selected!

Your scenario should look something like this. ⟶



This is a relatively simple chain, because we used satellites at GEO that have a huge FOV.

-- Pause and reset your scenario.

If you want to review this scenario, go to the “Constellation15” folder and open and run the “Constellation15.sc” STK scenario file.

-- Close your scenario.

We will now create a new constellation in a MEO orbit. We will use the GPS constellation for this!

-- Open STK and name your scenario “Constellation 15_1.” Go to the “Wizard” and “Select from Satellite Database.”
-- Type in “NAVSTAR*” and hit “Search.”
-- Select all of the NAVSTAR satellites and click on “Insert.” Then, close the window, and close the wizard window.
-- Create ground stations Mumbai and Arlington.
-- Create a chain.

Displayed is the current GPS constellation! A full-up GPS constellation consists of 6 orbital planes with 4 satellites in each plane. You will note there are more than 24 satellites. The U.S. Air Force continues to launch GPS satellites as replacements for those already on orbit. But GPS satellites are lasting longer than expected! So those satellites become spares.

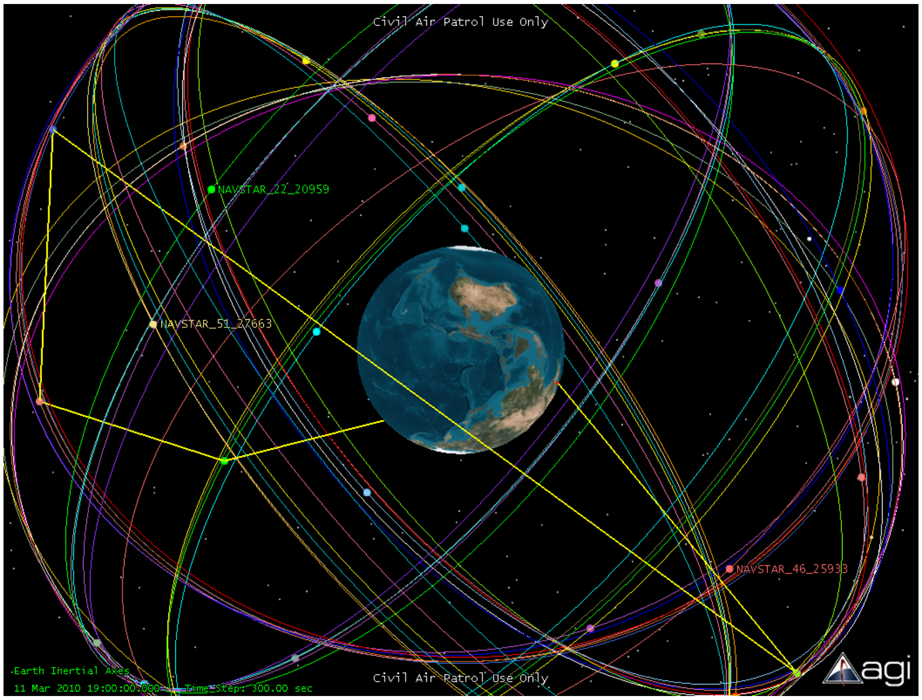
The scenario is the same! Establish a chain from Mumbai to Arlington. It will be more difficult using MEO satellites.

You should be able to establish a chain at least at the start of your scenario…. Then what happens?

The Earth is going to block the line of sight of certain satellites, and you lose the Chain.

QUESTION: What can you do allow more communication from Mumbai to Arlington?
Answer: Create more chains!

It would be really complicated to try to figure out the exact sequence of satellites to keep one continuous chain linked up (You can try if you want!), so let's make more chains! When you initially establish your chain, the link should look something like (link is yellow).



When you lose the communication, make another chain!

QUESTON: How many separate chains do you need to make to ensure 100% access from Mumbai to Arlington in a 24 hour period?

Answer: It depends! There are an infinite number of possible sequences of chains you can make.

One of the solutions is at “Constellation15” folder, STK scenario file “Constellation15_1.sc.” That particular scenario used 7 chains to achieve almost 100% coverage in a 24 hour period. Can you do it with fewer chains?

Continue to work with this scenario until you are certain you have the least amount of chains possible for the given time period.

-- Save and close your scenario.

Now we will move on to the most complex chain sequence: establishing a chain with a constellation in low Earth orbit! You will need to establish a continuous chain for a 1 hour period.

-- Create a new scenario and name it “Constellation 15_2.”
-- Go to the “Wizard” and the satellite database and search for “Globalstar” satellites.
-- Insert them into your scenario.
-- Create your 2 ground stations: Mumbai and Arlington.

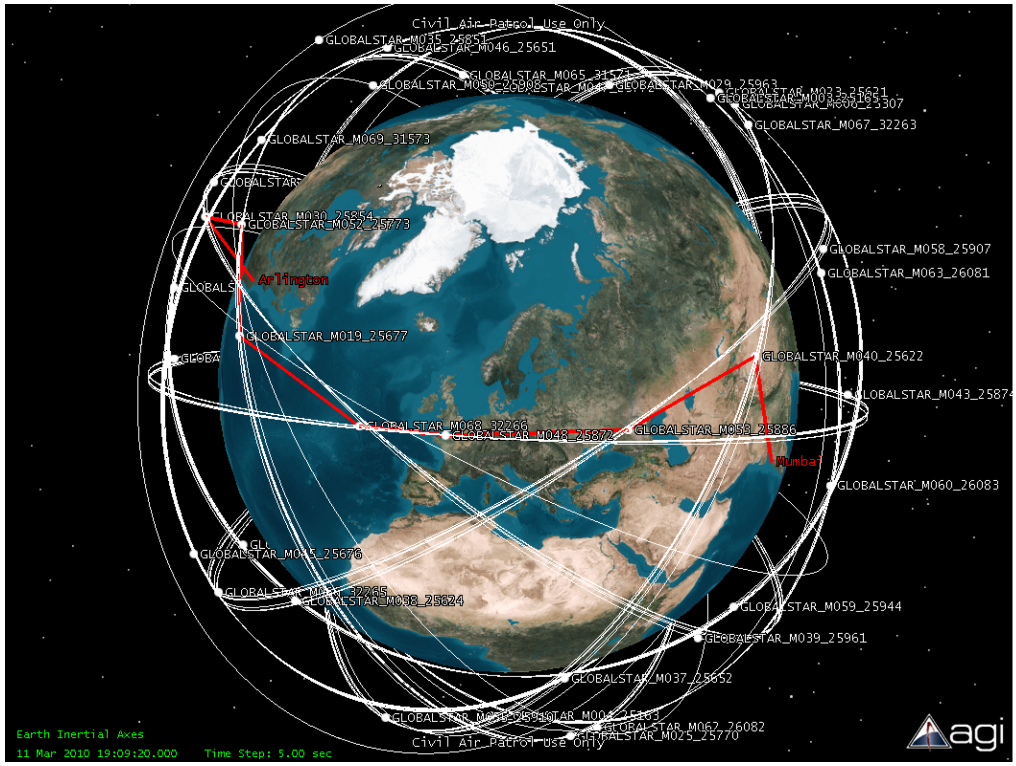
Displayed is the Globalstar constellation. Globalstar is the constellation of satellites Civil Air Patrol uses to conduct Satellite Digital Imaging System (SDIS) operations. CAP uses the system to transmit photos of disaster sites from the aircraft to a designated location on the ground (usually mission base).

You will need to analyze the satellite positions closely. A LEO constellation has only a limited FOV. How you set your chain up will be critical to keeping the link up.

Hint: You will definitely need to have more satellites in each chain!

-- Create your first chain and establish a communications link between Arlington and Mumbai. The White Tigers continue to need your help!

IMPORTANT: You need to note closely the direction the satellites are orbiting. Don't establish a link with a satellite that is about to disappear over the horizon! Also, there are many satellites in a retrograde orbit. Establishing a link with them will reduce your total contact time….



When your chain is intact, you should have a continuous link between the 2 cities.
Depicted at right is the completed link (in red).

In LEO orbits, your chain will not last long.
Note closely the satellite orbits, and establish another one!

You might not be able to get 100% coverage for a 24 hour period….
Sometimes the satellites just don't line up like you want them to…..
Do the best you can!

If you would like to see a possible solution, go to the "Constellations15" folder and open the "Constellations15-2.sc" STK scenario folder and view the scenario.

How many chains do you think it would take to provide 100% coverage?

OPTIONAL: Close this scenario. Open a new scenario and this time use the Iridium constellation of LEO communications satellites. Pull the Iridium satellites out of the database.

The **Iridium satellite constellation** is a large group of satellites used to provide voice and data coverage to satellite phones, pagers and integrated transceivers over Earth's entire surface. Iridium Satellite LLC owns and operates the constellation and sells equipment and access to its services. The constellation requires 66 active satellites in orbit to complete its constellation and additional spare satellites are kept in-orbit to serve in case of failure. Satellites are in low Earth orbit at a height of approximately 485 miles and inclination of 86.4 degrees. Orbital velocity of the satellites is approximately 17,000 mph. Satellites communicate with neighboring satellites via K_a band inter-satellite links. Each satellite can have four inter-satellite links: two to neighbors fore and aft in the same orbital plane, and two to satellites in neighboring planes to either side. The satellites orbit from pole to pole with an orbit of roughly 100 minutes. (Extracted in part from http://en.wikipedia.org/wiki/Iridium_satellite_constellation)

As you can see, providing global coverage in a LEO orbit takes many satellites constantly communicating with each other. They do this in the real world by using computers to determine which satellites are within view of the ground stations and each other, and automatically switching satellites to ensure 100% communications at all times. You also should see the utility of using satellites at geosynchronous orbit – much easier to communicate with, but usually at a greater cost!

Continue to work with this scenario until you are certain you have the least amount of chains possible for the given time period, while providing as close to 100% coverage as possible.

-- Save and close your scenario.

When you are ready to move on, we will now go to the final chapter, with the most exciting STK scenarios of all!

4 SPACE and a SYSTEM OF SYSTEMS

Important Terms

Bandwidth: The amount of data that can be transmitted on a specific channel. Think of it as a pipe. The bigger the pipe, the more data that can be transmitted.
Unmanned Aerial Vehicles (UAVs): Aerial vehicles that are remotely piloted from a ground station. They perform a variety of mission from photo reconnaissance to communications relay.

How to link all aspects (ground, air, sea, space) of the system together to accomplish a specific mission

STK has the capability to connect any number of platforms, be they in space, in the air, on the sea, or on the ground. This is a unique feature of STK that allows you to view the entire spectrum of space operations, something we call "Space as a System". It allows you to communicate from any platform anywhere in the world, through multiple platforms anywhere in the world, to any platform, anywhere! For this final chapter of the STK program, you will be given challenging scenarios that require you to link multiple platforms together to perform a specific mission. It assumes a high level of knowledge of STK. Only specific aspects of STK that have not been presented before will be stepped through.

SCENARIO #16: Space, Air, Sea, Ground Connectivity

For scenario 16, you are the CEO of the MTM Corporation. Your company's mission is to establish a global network for aircraft and ship communications. The MTM Express Air Shipping and Containership Corporation (MTMEASCC), has the requirement to be able to communicate with their aircraft and ships on a regular basis. These aircraft and ships are scattered all over the globe. The base of operations for shipping is in Long Beach, California. The aircraft hub is based in New York City. You need to establish your network using the following assets: Space: 1 GEO satellite, 2 MEO satellites; Ground Stations: 1 at Long Beach, CA, and 1 at New York City; there are currently 4 ships at sea, locations are: 1 is in the Indian Ocean, 1 is traveling from New Zealand to Australia, 1 is in the South Atlantic, and 1 is traversing the Bering Sea. The aircraft locations are as follows: 1 is airborne between Hong Kong and Singapore, 1 is airborne over Turkey, 1 is airborne over Chile, and 1 is airborne in the Hawaiian Islands. The ships must establish connectivity with Long Beach, the aircraft with NYC.

Create your scenario and then compare against the one in the folder "Space_Air_Sea_Ground16.sc" file.

-- Open STK and create your scenario.

You should already know how to create satellites and ground stations! To create ships and aircraft:

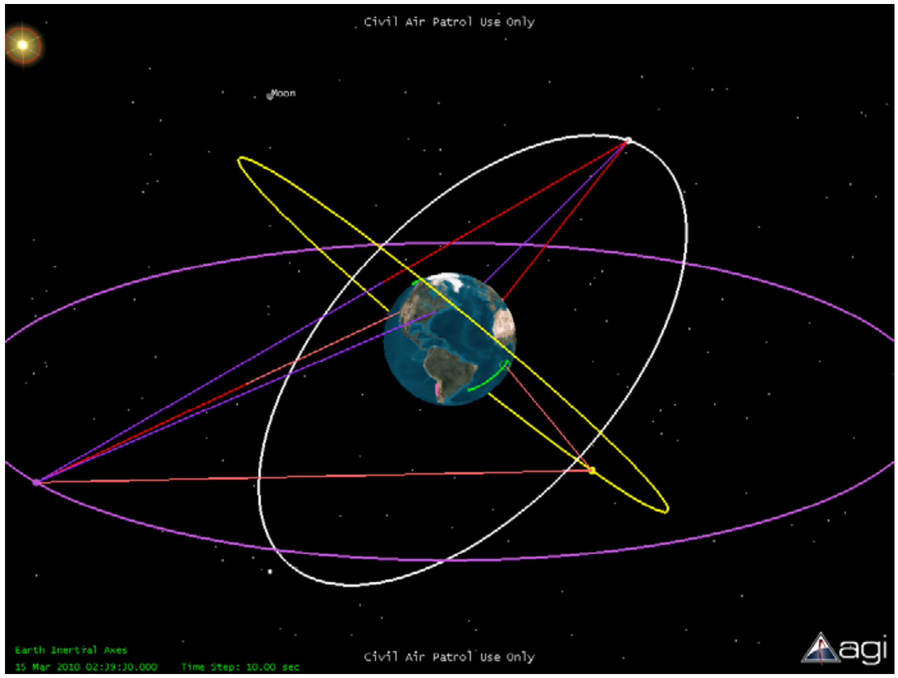
-- Go to the "New Object" icon, highlight "Ship," and click "Insert."
-- Go to the "Object Browser" and double click on the ship. A new window appears.
-- On the right side of the window, click on "Insert Point." This will allow you to place your ship on the ocean at the latitude and longitude you input in the window.
-- This also allows you to move your ship on the ocean by placing multiple latitude and longitude points in this window. When you start the scenario, your ship will travel from point to point!
-- When complete, hit "OK."
-- You can also go to the 3D map and double click on the map anywhere in the ocean, and it will give you the latitude and longitude of the point at the cursor. This will facilitate figuring out the latitude and longitude to place your ships.

NOTE: This also works when placing aircraft or ground stations into a scenario! Just click on the map where you want to place something, and STK will give you the latitude and longitude of that location.

-- To insert an aircraft, go to the "New Object" icon and click on the "Airplane" icon.
-- Double click on the aircraft in the "Object Browser" and insert the latitude and longitude of where you want your aircraft to be and/or traveling to/from.
-- When complete, hit "OK."
-- Now create your entire system. You can either pull satellites out of the satellite database, or create you own satellites

-- When complete, run your scenario.

Your completed system should look something like this. ⟶



As you can see, some satellites get quite busy. That’s why communications satellites need to be able to have the bandwidth to receive and transmit a large amount of data. Some new communications satellites that will be launched soon will have the capability to relay data at the rate of 10 gigabytes per second!

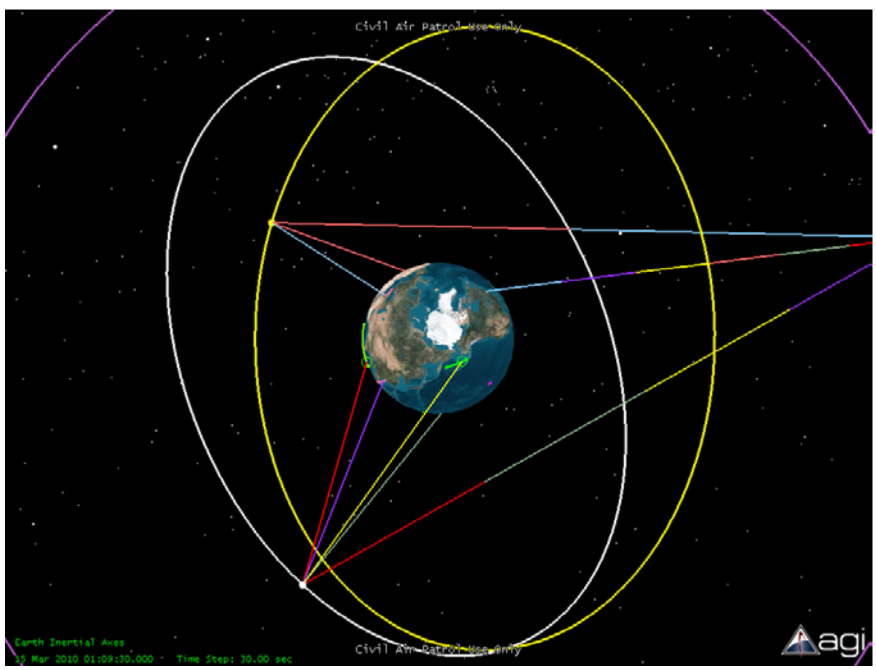
You can also view this scenario by going to folder “Space_Air_Sea_Ground16” and opening the STK scenario file “Space_Air_Sea_Ground16.sc” file and run the scenario.

Then catastrophe strikes! Your facility in Long Beach has gone down indefinitely due to an earthquake!

Your next task is to now re-route your ship communications to the New York City facility.

When complete, all ship and air communications should be go through NYC.

Your scenario should now look something like this. ⟶



Displayed are 6 of the 8 aircraft/ships communicating with the 2 MEO satellites, then the GEO satellite, then NYC.

When you have re-established you net, run your scenario.

QUESTION: How often does each of your ships and aircraft communicate with NYC?

Answer: It depends on how you built your system.

QUESTION: Which asset (ship or aircraft) has the longest single communications link?
Answer: It depends on how you built your system and positioned your satellites.

QUESTION: How could you increase total communication time?
Answer: Reposition your MEO satellites.

You can also view the scenario by opening the STK scenario “Space_Air_Sea_Ground16_1.sc” file.

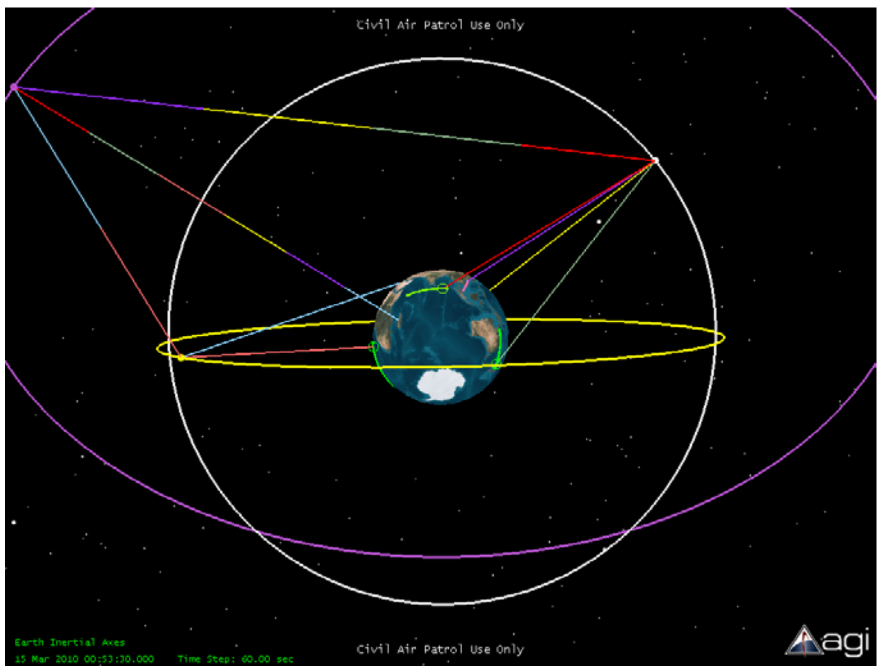
-- Try repositioning your MEO satellites to optimize the total time each asset can communicate with New York.

Oh no, disaster strikes again! Your facility in NYC has been flooded by a water pipe breaking! You must now switch all communication links to the backup facility in Antananarivo, Madagascar!

-- Re-align your space system so that all assets communicate with a ground facility in Madagascar, the world corporate headquarters for the MTMEASCC consortium.

QUESTION: What is the one satellite that you MUST reposition for this scenario to work?
Answer: the GEO satellite!

When complete, your scenario should look something like this.



You might need to reorder the satellite sequence in your chain to optimize the amount of time your assets can communicate with the new ground facility.

You can also view the scenario by opening the STK scenario “Space_Air_Sea_Ground16_2.sc” file.

Continue to work with this scenario until you are certain you have the most communication time established for each asset.

-- Save and close your scenario.

When you are ready to move on, we will now go to a scenario where you get to closely monitor the polar icecaps. Are they melting or aren’t they??

SCENARIO #17: Polar Monitoring

The polar icecaps are important! We need to know what is going on at the top and bottom of the world. As the CEO of the MTM Consortium, your mission is to link a system together to report on the status of both the North Pole and South Pole ice.

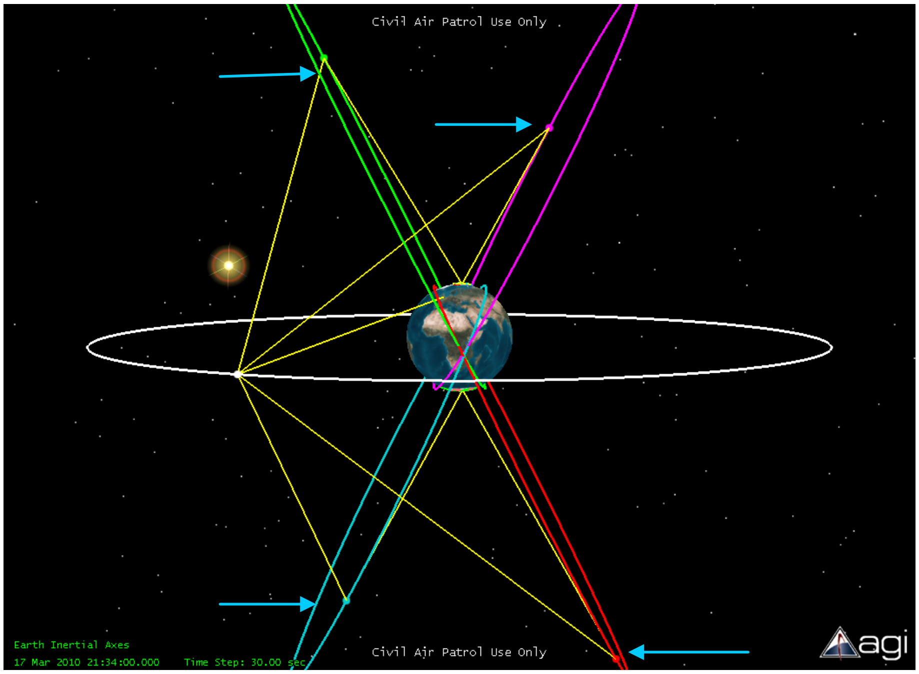
The assets you will use to accomplish this mission are as follows: 3 Ground Stations (1 at the North Pole, 1 at the South Pole, and a home station located London, England), 4 Unmanned Aerial Vehicles (UAV) (2 north, 2 south), a sensors on each UAV, 4 HEO satellites (2 north, 2 South) offset 180 degrees to provide as close to 100% coverage as possible, and 1 GEO satellite.

You will need to cover 100% of the polar icecap using the UAVs. You will need to create a "search pattern", setting latitude and longitude points for your aircraft to fly back and forth across the ice. The UAV must then transmit the data collected to the ground station located near the pole, the ground station will then uplink the data to the HEO satellites, to crosslink it to the GEO satellite, then to London. There does not need to be one complete chain from UAV-ground station-HEO-GEO-London. The UAV needs to communicate with the ground station when it can; the ground station needs to communicate with the HEO satellite as much as possible!

For this scenario, when you go to create your aircraft, you will have to change your aircraft model to a UAV! You will also need to create a "Ground Facility" that is not a city. To do that:

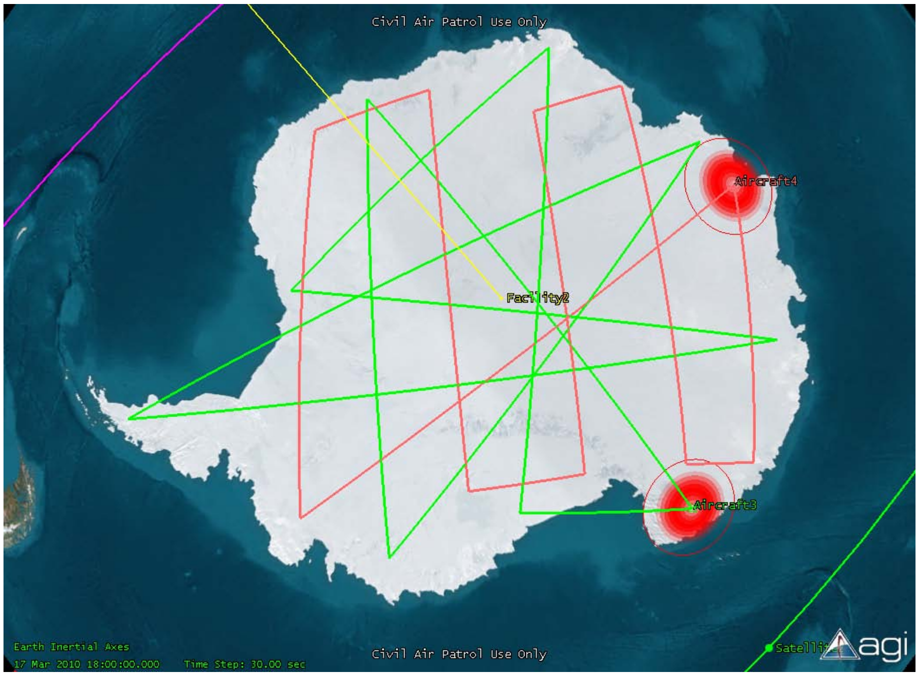
-- Create your scenario in STK.
-- Insert an aircraft into your scenario. Double click on your aircraft in the "Object Browser."
-- Go to "3D Graphic," then "Model."
-- Next to "Model File," click on the box with the 3 dots in it.
-- Select a UAV from the list! (Those would be Predator, Pioneer, Global Hawk or Hunter.)
-- Once you have created your aircraft, you will need to create your grid to cover 100% of the pole.
-- To create a ground station, in the "New Object" icon, click on "Facility." Then double click on it in the "Object Browser," and set the latitude and longitude of your facility.
-- Now create the rest of your scenario, using the assets listed above.

When complete, your scenario should look something like this. →



Note that in the snapshot at right, the facilities at the North and South Poles are communicating with both HEO satellites, which in turn are linked to the GEO satellite which is communicating with London.

You need to offset your HEO satellites so as one is coming out of apogee, one is entering!



The pattern traced to cover the entire area is up to you.

At right Aircraft 3 (the green pattern) is tracing some sort of star pattern. With this pattern, you will fly over the ground station more frequently to download your data.

Aircraft 4 (the orange pattern) is tracing a more traditional “search pattern” flying north/south.

Continue to manipulate your latitude and longitude points until you get the pattern you want.

-- Run your scenario and see if you have 100% coverage of the ground, and 100% contact between the ground station and the HEO satellites.

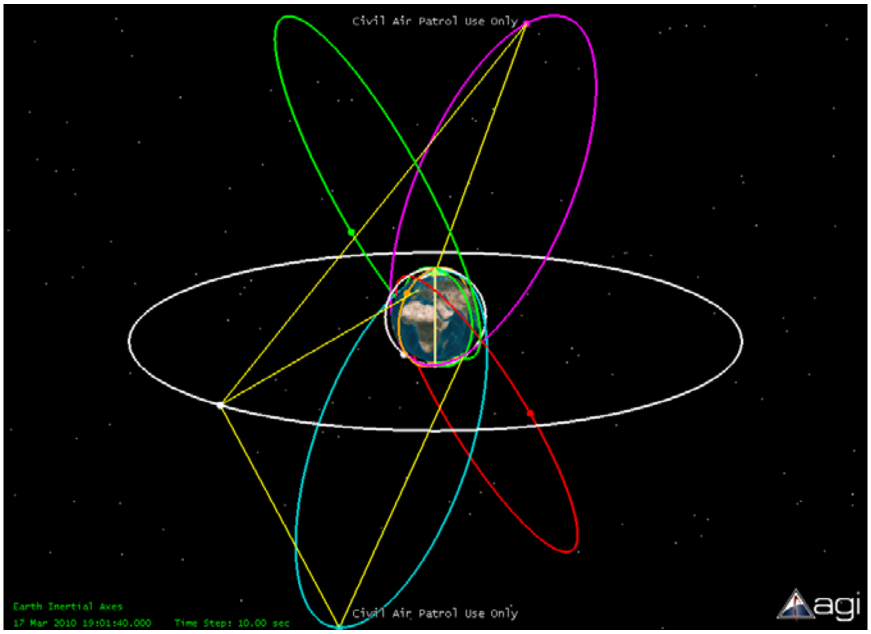
You can also view the current scenario by going to folder “Polar_Monitoring17” and opening the “Polar_Monitoring17.sc” STK scenario file.

How does your scenario compare?

Disaster strikes! Both of your ground facilities have lost their uplink signal to the MEO satellites due to simultaneous blizzards at the north and south poles! What do you do?
Since the MTM Consortium has deep pockets, it has leased 4 LEO satellites!

-- For the next part of this scenario, create 4 LEO, polar orbiting satellites spaced 90 degrees apart at the equator. These LEO satellites will have the capability to communicate directly with your UAVs!
-- Re-establish a communication link with London. (Aircraft, Leo Sat, MEO Sat, GEO Sat, London)

Your scenario should look something like this. →



Ensure you establish connectivity with both aircraft in the north, and both in the south.

You will need to analyze your scenario closely to ensure you optimize which LEO satellite communicates with which MEO satellite. Some will have a longer connection time than others.

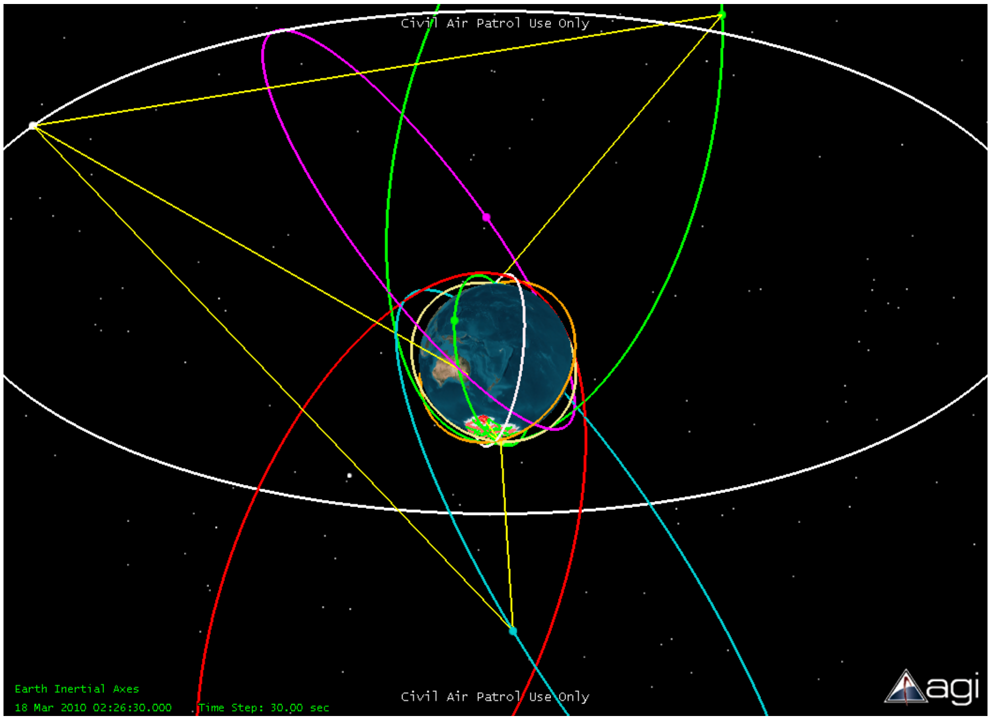
Try to get your connections as long as possible!

You can also view this scenario by going to folder "Polar_Monitoring17" and opening the "Polar_Monitoring17_1.sc" STK scenario file.

This is just not a good day…. Now the main facility in London has gone down!

-- Switch communications to the backup facility in Sydney, Australia!
-- Create a facility in Sydney, and re-route your communications.

Your scenario should now look something like this. →



You will need to move your GEO satellite.

You need to remove the London link in the chain and establish a Sydney one.

QUESTION: Did your connectivity times change with the move from London to Sydney? Answer: They should change a little, based on how your MEO satellite now communicates with the newly-positioned GEO satellite.

Good job! The icecap continues to be monitored for any changes.

You can also view this scenario by going to folder "Polar_Monitoring17" and opening the "Polar_Monitoring17_2.sc" STK scenario file.

Continue to work with this scenario until you are certain you have the most communication time established for each asset.

-- Save and close your scenario.

When you are ready to move on, we will now go to a scenario where you get to provide humanitarian relief for a country in trouble.

SCENARIO #18: Humanitarian Relief

A huge volcano has just erupted on the island nation of Sri Lanka. Colombo, the capital, is being buried in rocks and ash. Lava is flowing everywhere. The country has asked for our help!

Your mission for Scenario 18 is to provide land, air, sea, and space assistance. First, you will need to provide a continuous communications link for use within the country using space assets. You will then need to create several LEO satellites to take images of the country. You will need to relay these images back to the USA rescue coordination center in Miami, Florida. You will need to deploy at least 2 aircraft carriers to the area. At scenario start time, these aircraft carriers are at least 36 hours away. One is coming from the western part of the Indian Ocean, the other from the east. When the carriers arrive, you will launch and recover 1 aircraft from the carrier. This aircraft will overfly Sri Lanka and take detailed photos of the destruction. As the aircraft take these pictures, they also need to uplink them to a satellite and send them back to Miami. You will need to fly 2 C-130s from our base in Qatar to arrive in the capital city. On these 2 aircraft will be 4 Humvees you will then use to reconnoiter the city. These ground vehicles will also relay the information the get back to the Miami center using space assets.

For this scenario, you are being introduced to another STK feature – the ability to place vehicles on the ground and have them move from place to place. To place vehicles on the ground, go to the "New Objects" icon and click on "Ground Vehicle." Then double click on the vehicle and insert latitude and longitude points for where you want your vehicle to go.

NOTE: The vehicles will not be on the ground in country at the scenario start time. They don't arrive until the C-130s arrive! So you need to start the vehicles moving at the appropriate time.

NOTE: Similarly, the aircraft on the carrier can not launch until the carriers arrive off the coast. Start your carrier aircraft moving at the appropriate time. (Set the first latitude and longitude point for the aircraft at the carrier's location!)

Good luck. The citizens of Sri Lanka are counting on you.

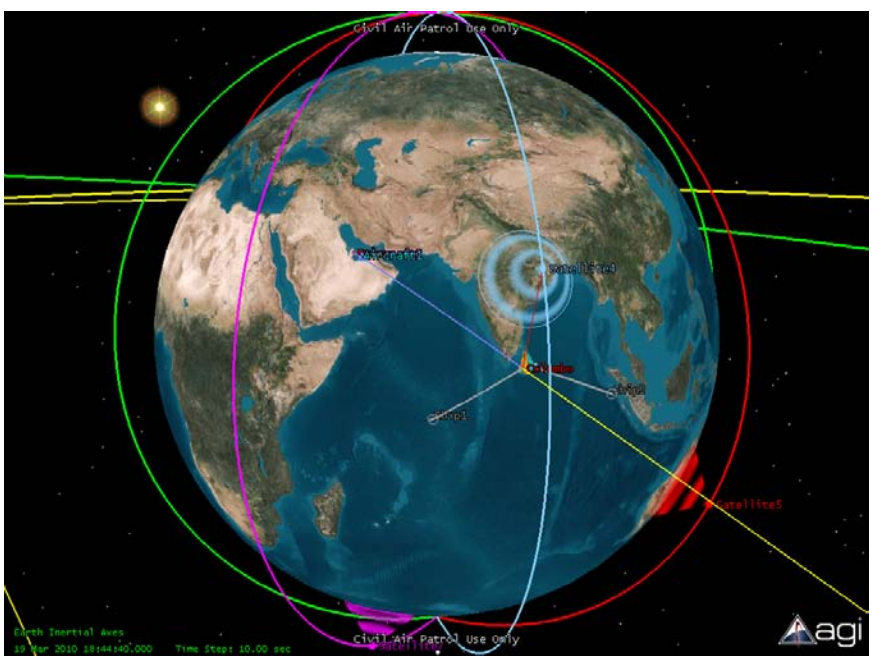
Initially, your scenario should look something like this. →

A link has been established with a GEO satellite that provides communications.

A link has been established with the Miami coordination center.

A LEO satellite is imaging the capitol city.

The ships and aircraft are enroute.

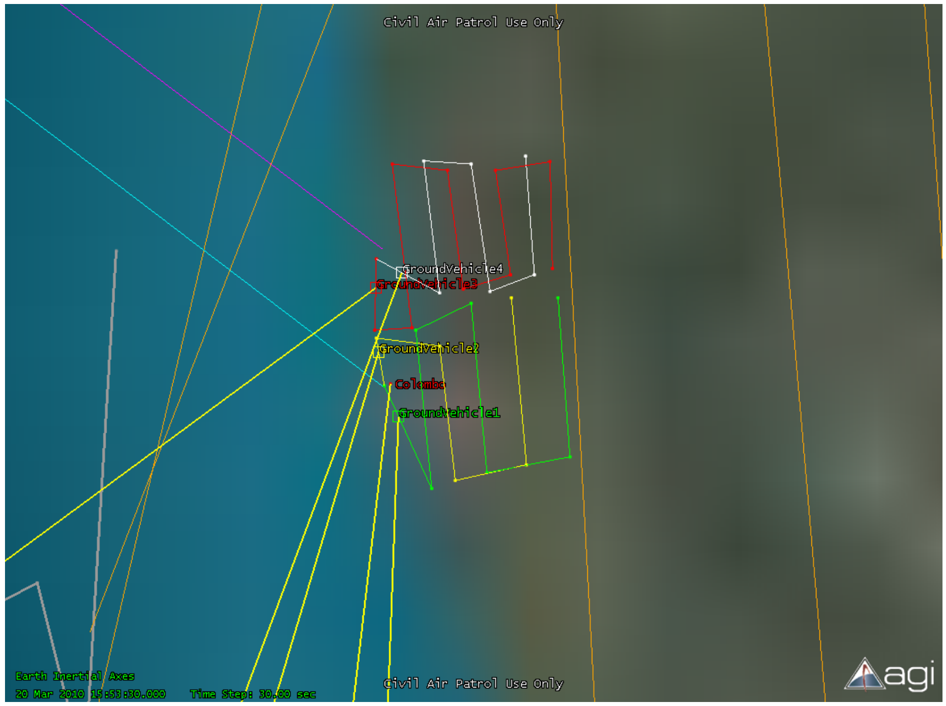


The 4 aircraft should arrive first from QATAR. You should have preset routes for them to reconnoiter the capital city.

The scenario at right then has the aircraft fly back and forth from Qatar to Colombo dropping off relief supplies.

The yellow lines are the uplink signals to the GEO satellite.

Note that the ships have not arrived yet.



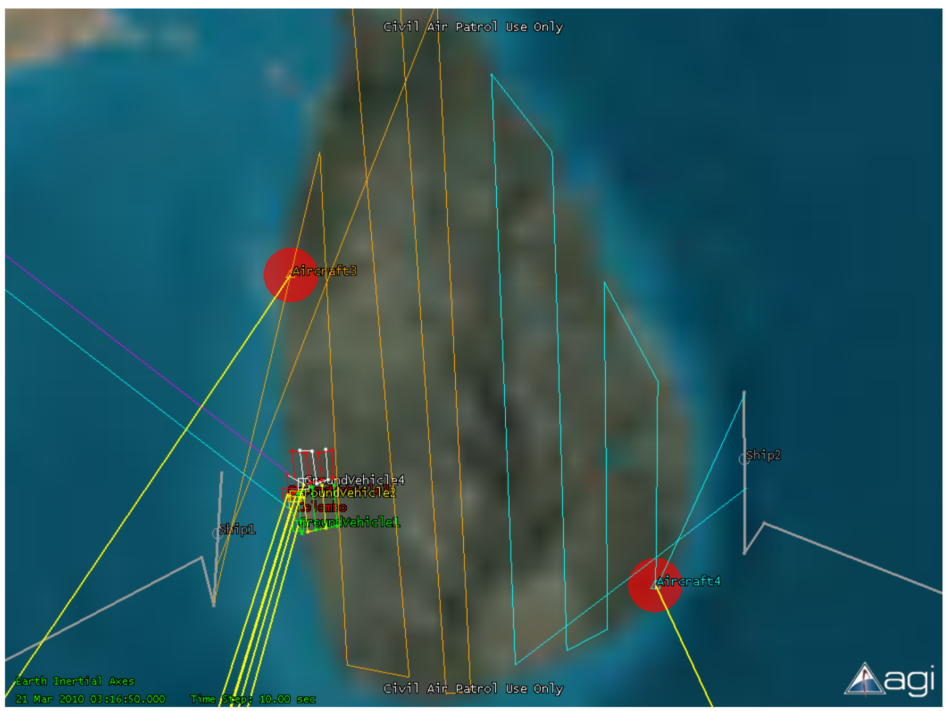
When the ships arrive off the coasts, they should launch their aircraft to image the country.

The brown lines are the search pattern for the aircraft launched from Ship 1 off the west coast.

The blue lines are the search pattern for the aircraft launched from Ship 2 off the east coast.

Note that the aircraft should fly back to the carrier!

The yellow lines are the uplinks to the GEO satellite.



How does your scenario compare?

You can also view this scenario by going to folder "Humanitarian_Relief18" and opening the "Humanitarian_Relief18.sc" STK scenario file.

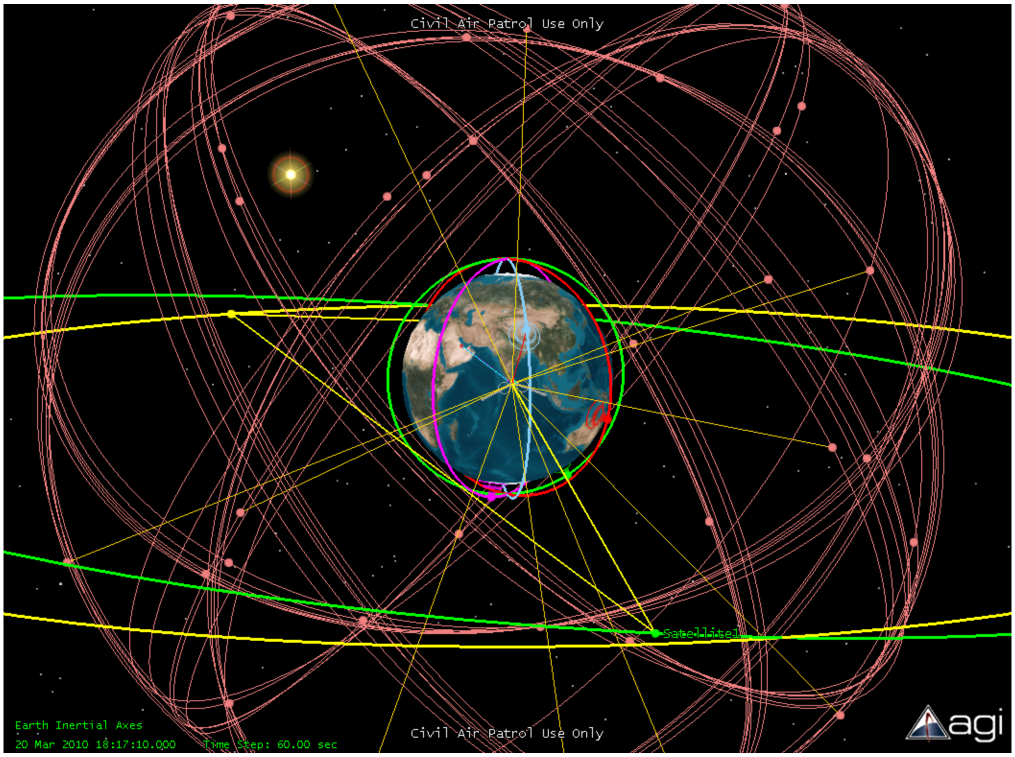
QUESTION: What is another important mission that is being accomplished from space for this relief operation?
Answer: the navigation mission!

Task: Insert the GPS constellation into your scenario. Compute access to the constellation from one of your ground vehicles.

Your scenario should now look something like this. →

Access lines from the ground vehicle to the GPS satellites are in yellow.

As you can see, the more complex the scenario, the more difficult it is to see individual features on the screen.



You can also view this scenario by going to folder "Humanitarian_Relief18" and opening the "Humanitarian_Relief18_1.sc" STK scenario file.

Continue to work with this scenario until you have your relief operations running smoothly…

-- Save and close your scenario.

When you are ready to move on, we will now go under cover on a covert operation!

SCENARIO #19: Reconnaissance Operations

The military uses space assets on a daily basis to conduct its operations. The military counts on satellites to communicate in the field, navigate their way around the battle space, take images of potential targets, command and control UAVs (most UAVs flying over battle zones today are controlled from facilities located in New Mexico in the US!), conduct weather forecasting, relay data to aircraft, the list is almost endless.

Your mission for Scenario19 is to put an operation together to conduct reconnaissance of several areas of the globe. There is a global smuggling operation going on, and you must provide information on where the smugglers are. You have Intelligence that suggests you need to be focusing on the following areas: Banjul, Gambia; Mogadishu, Somalia; Madang, Papa New Guinea; and San Salvador, El Salvador.

How you conduct your operation is totally up to you. Similar to the last scenario, you can use space, air, sea, and ground assets. For space assets, **you can only use satellites in the STK database**! You cannot create your own satellites using the wizard. Additionally, the satellites you select can only perform the mission of that satellite.

Example: If you want to use Globalstar satellites, those satellites can only be used for communications. You can not put a sensor on it and have it takes images. Globalstar is not an imaging satellite!

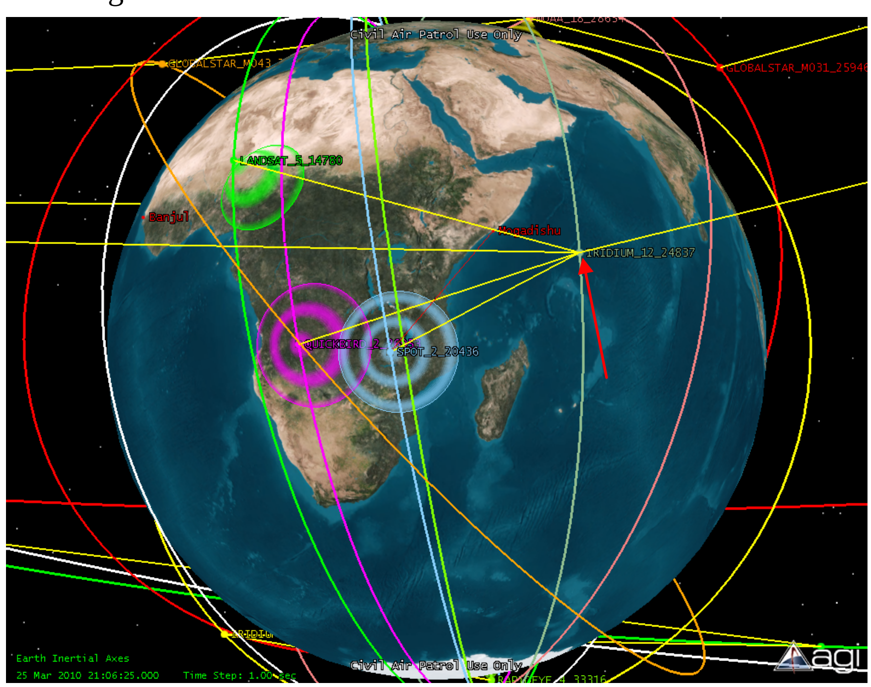
Any communications satellite can talk to any other communications satellite. A sensoring satellite can talk to a communications satellite.

Additionally, you can only use a maximum of 3 of any one type of satellite. If you want to use Iridium satellites, you can only use 3 of them, NOT the entire constellation!

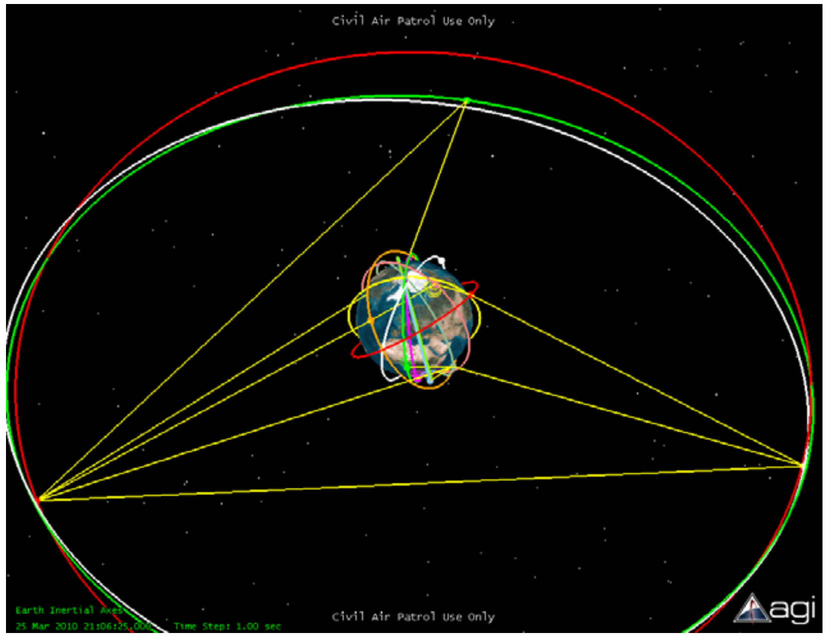
Be careful! Some of these countries will not allow you to occupy or overfly their land. These countries are Gambia, Somalia, and Papa New Guinea. You might be shot, or shot down! However, you can probably fly close to their coasts. You will need to link as many of the assets you use together and communicate your information back to Washington D.C.

QUESTION: Does a country's air sovereignty rights (over flight rights) apply to satellites?
Answer: No! International space law says that outer space is free for use by all countries. This is similar to the right of innocent passage on the high seas.

Depicted at right are 3 sensor satellites uplinking the info they have collected to the communications satellite Iridium 12.



The picture on the right shows the scenario partially constructed, with the space portion complete.



You need to ensure each sensoring satellite can link with each communications satellite, if possible.

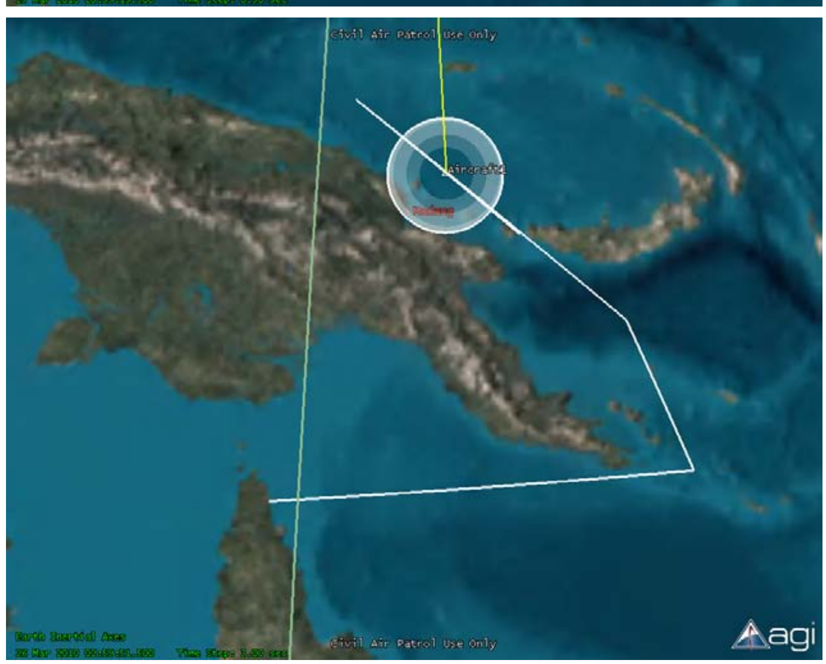
This scenario utilizes 3 Tracking and Data Relay Satellites (TDRS) at GEO to crosslink data uploaded from the communications satellites.

If you would like to review this scenario, go to folder “Recce_Ops19,” and open the “Recce_Ops19.sc” STK scenario file.

Depicted at right is a close-up view of the Recce Operation being conducted of Mogadishu.

An aircraft launched from a ship, and is flying its mission off the coast.

The yellow line indicates the uplink with one of the communications satellites, to relay information through the TDRS satellites back to Washington.

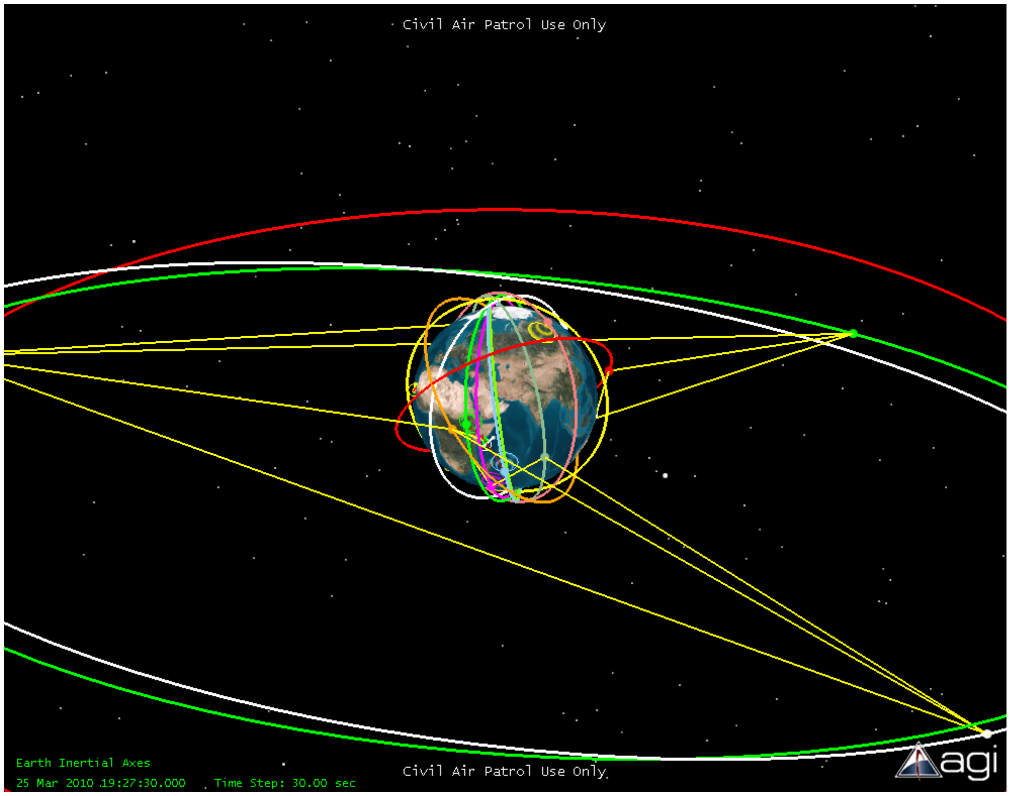


Depicted at right is a close-up view of the operation being conducted in Indonesia.

For this part of the scenario, we did not have to use a ship because Australia gave us permission to use one of their airfields for an aircraft to fly the mission.

So this aircraft takes off from Australia, flies its mission and returns to Australia.

As you can see in this complex scenario, sometimes there is a tremendous amount of data that must be linked through satellites. That is why communications relays satellites have a lot of bandwidth to pass data. When one of these satellites fail, the data stops: no images, no voice or data transmitted, cell phones stop working, no text messages received, no ATM transactions; the world almost grinds to a halt!



Depicted at right is the entire scenario. It is difficult to see, but all sensoring satellites are taking images of their targets (the red line – this was done by "computing access" from the city to the satellite). These satellites then uplink to communications satellites when they can, while the aircraft also uplink their data. The TDRS satellites are very important! Since they have excellent line of sight, they are able to link up with the communications satellites, and each other, to crosslink information. There is one key satellite positioned above Washington to receive all of the data and downlink it. Then there are analysts in Washington trying to interpret the data to find out what the smugglers are doing. They are analyzing photos and decoding intercepted communications to figure out how to stop the bad guys…

If you would like to review this scenario, go to folder "Recce_Ops19," and open the "Recce_Ops19_1.sc" STK scenario file.

There is no one right answer to this scenario!

One thing you can do is go to the eyeball and make yourself each asset to get a different perspective of how your scenario operates. Did you change your models to more accurately depict each asset? (as an example, in the scenario highlighted above, one of the ships is an Aegis class cruiser, and the aircraft flying from it is a helicopter!)

Continue to work with this scenario until you have your reconnaissance operation running the way you want it.

-- Save and close your scenario.

When you are ready to move on, we will now move to the last scenario, the graduation scenario!

SCENARIO #20: Space and a System of Systems

For your final scenario, you will put it all together! You will demonstrate a thorough knowledge and understanding of STK by performing one last mission.

For this mission, you must link 2 ground stations together using the following assets: 1 LEO, 1 MEO, 1 HEO, and 1 GEO satellites, 1 aircraft, 1 ship, and 1 ground vehicle. They must all link together to form one continuous chain. You can create your own satellites or pull them out of the database. Before creating the LEO satellite, you must launch a rocket into the orbital plane of the LEO satellite you will create. The ground stations must be on separate continents.

Scenario: You must relay vital information about an ongoing conflict, at a place of your choosing. 2 separate ground stations need this information.
Some possible locations for you to consider are: Afghanistan, North Korea, Taiwan, or a place of your choosing.

QUESTION: How long can you hold the chain together?

QUESTION: How many times can you get the chain to link together in a 24 hour period?

Remember, there is no one right answer.

You will not be given a possible solution for this scenario! You are now on your own for this and any other STK scenario you create.

CONCLUSION

This concludes the CAP-STK Aerospace Education Program. Hopefully, you now have a greater understanding of space and how satellites perform their missions. As stated at the outset, satellites and their missions play a critical part in our everyday lives. The more we know about how satellites work and the environment they operate in, the better we will be in determining additional ways we can use these unique assets in the future.

The more we become dependent on satellites, the more we will need to develop redundant capabilities to ensure access is always available.

The goal of this program was to educate and excite cadets about space and space operations. Cadets completing this course hopefully are now motivated to want to learn more about this critical part of our everyday lives.

Continue to use STK as part of your CAP Aerospace Program! It has an infinite variety of uses, and helps easily explain some of the more complex concepts relating to space and satellites.

Good luck!