# CIVIL AIR PATROL

## INTRO TO SPACE

## STK LESSON PLAN ONE:

## *ORBITAL MECHANICS*

## PART II - STK SCENARIOS

This portion of the lesson plan illustrates the satellite concepts you just learned about. To do this, you will run six self-guided scenarios using STK/VO software. Each scenario will help you visualize the characteristics associated with the six orbital elements. As you recall, the major concepts were:

1. The six classical elements uniquely characterize an orbit.
2. The classical elements have an influence on the satellite ground track pattern.

The instructions below are a step-by-step guide to help you view and understand the scenarios.

**SCENARIO ONE**

Scenario One helps you visualize the semi-major axis influences on an orbit. Specifically:

1. Changes in the semi-major axis change the altitude of an orbit.
2. Changes in the semi-major axis alter the satellite's field of view (FOV).
3. Changes in the semi-major axis alter the satellite's geographic point location on a flat map.



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1. Execute Scenario One by following the **STARTING AND USING SATELLITE TOOL KIT** instructions and loading **Scenario\Lesson3\axisR\semi-major_axisR.sc**
   - Select the **VO** map and rotate the earth until Korea is centered on the earth
   - Depicted in **blue** is a LEO satellite with a 6700 km semi-major axis.
2. Select **START.**
   - Observe the speed of the satellite. The semi-major axis determines the altitude, which in turn determines how long it takes the satellite to complete an orbit.
3. Select **PAUSE**
   - The next few steps will enable you to change the semi-major axis and observe the effects.
4. Select the **Satellite Tool Kit** window.
5. Highlight **LEO**. Be sure the **+ (plus)** symbol is indicated. Thus, this action will enable all linking files to be copied in the next step. If the **- (minus)** symbol is displayed, click once **ON** the minus sign to get the plus sign back.
6. Select **EDIT**, and **COPY.**
7. Highlight **semi-major_axisR**.
8. Select **EDIT** and **PASTE**.
9. A **LEO1** file will appear. Change the name to **MEO**.
   - To Change The Name
     - Click ONCE on the center of the name. **LEO1** will be highlighted in blue and the cursor will flash.
     - Type in **MEO,** then point to the icon before the name and click once
10. Select **PROPERTIES** and then **GRAPHICS**.

11. Change the **blue** color to **magenta**.

12. Select **APPLY** and **OK.**

13. At the MEO icon, click on the **+**. A **Sensor1** icon appears.

14. Highlight **Sensor1.**

15. Select **PROPERTIES** and then **BASIC.**

16. Change the outer half angle parameter to 15.0 degrees. This action is required to ensure the satellite's FOV is an appropriate size for the visual representation.

17. Select **APPLY** and **OK.**

18. Once again, highlight **MEO**.

19. Select **PROPERTIES** and then **BASIC**.

    - Displayed are all the basic orbital elements necessary to define an orbit. Currently the **MEO** orbital elements are a carbon copy of the **LEO** orbital data.

20. Now change the semi-major axis to **20372 km**. This value reflects an appropriate **MEO** altitude.

21. Select **APPLY** and **OK**.

22. Toggle to the **VO** MAP and select **RESET**.

23. Select **START**.

    - In addition to the **LEO**, the **MEO** is depicted in **magenta**. Compare the relative speeds of each orbit. The **LEO** satellite travels faster than the **MEO** satellite because the **LEO** semi-major axis is smaller. Consequently, the smaller the semi-major axis, the lower the altitude and the shorter orbital period.

24. At time **15:03**, select **PAUSE.**

- Also note that the semi-major axis (altitude) influences the field of view size (FOV). The **MEO** satellite FOV is comparatively larger than the **LEO** satellite FOV. Again, as described in lesson 1, the greater the altitude or semi-major axis, the larger the satellite's FOV.

25. Select the **2D** map.
    - The **2D** map view is a mercator projection map. Basically it is the globe projected on a flat map. The unique characteristic of a mercator projection is that the distance between latitude lines is equal, making it easy to perform any calculations. Earth view map 1 is used to show the satellite's orbit projected over geographic areas. The semi-major axis affects the ground track in a few ways. First, it shows the speed of a satellite. Note how quickly the **LEO** satellite, depicted in **blue**, moves across its track compared to the **MEO** satellite. Second, it determines the ground track repeating pattern. Note the **LEO** satellite moves slightly west with each pass, giving the appearance of successive ground tracks.
26. Select **PAUSE.**

27. Review the scenario as often as necessary. Repeats steps 4-25 to change the value of the semi-major axis again to different altitudes. Once complete with the scenario, select **PAUSE.**
28. View the scenario as often as needed. Close out according to the instructions in **STARTING AND USING SATELLITE TOOL KIT.** Do not save the file.

## SCENARIO TWO

Scenario Two helps you visualize how eccentricity affects the shape of the orbit. Specifically:

1. Changes to the eccentricity value from zero to one changes an orbit from circular to eccentric.
2. The eccentricity values describes the symmetry of the orbit.

This scenario will illustrate these concepts by having you make changes to the eccentricity value. To initiate the scenario, complete the following steps.

1. Load **Scenario\Lesson3\eccentricityR\eccentricityR.sc**
2. Select the **VO** map. Now select **RESET**.
3. Orient the globe so the African continent is at the nine o'clock position. Then select **START.**
   - Depicted in **red** is the **MEO1** orbit. The eccentricity value is 0.01, representing a circular orbit. Because the orbit is circular, the earth is at the center of the orbit.
4. The next few steps will enable you to change the eccentricity value to a 0.5 value
5. Select the **Satellite Tool Kit** window.
6. Highlight **MEO_1.**
7. Select **EDIT** and **COPY.**
8. Select **EDIT** and **PASTE**. A **MEO_11** file will appear. Change the name to **MEO_2**. Refer to step 9 of Scenario One if you need instructions on how to do this.
9. Select **PROPERTIES** and **GRAPHICS**. Change the color **red** to **magenta**.
10. Select **APPLY** and **OK.**
11. Select **PROPERTIES** and **BASIC**.

- Displayed are all the basic orbital elements necessary to define an orbit. Currently, the **MEO_2** orbit has the same orbital data as **MEO_1**.

12. Change the eccentricity value to **0.5.**
13. Select **APPLY** and then **OK**.
14. Toggle to the **VO** map.
15. Select **RESET,** then **START.**

    - The **magenta** orbit depicting an eccentricity value of .5 represents an elongated orbit. Compare the two orbits. For the **MEO_2** orbit, the earth is no longer in the center of the orbit, illustrating its elongated orbit.

16. The remaining steps will change the eccentricity value from .5 to .65.
17. Select the **Satellite Tool Kit** window.
18. Select the **MEO_1** icon.
19. Select **EDIT** and **COPY**. A **MEO_11** will appear.
20. Change the **MEO_11** name to **MEO_3.**
21. Select **PROPERTIES** and then **GRAPHICS**. Change the color **red** to **Dark Sea Green**.
22. Select **APPLY** and then **OK.**
23. Select **PROPERTIES** and then **BASIC**.
24. Change the Eccentricity value from **0.0** to **0.65**.
25. Select **APPLY** and then **OK.**
26. Toggle to the **VO** map and select **RESET**.

    - The **Dark Sea Green** orbit represents the highly eccentric orbit. Observe how elongated the orbit is compared to the previous orbits.

27. Select the **2D** map and select **RESET.**

- Eccentricity determines a ground track's symmetry. In turn, it defines how much ground will be covered in a period of time throughout the orbit. For example, if the eccentricity parameter equals zero, a satellite will sweep over equal areas in equal time. In contrast, if the eccentricity parameter is close to one, the satellite will dwell over the apogee point. Thus, the area covered in this portion of the orbit is small. Conversely, the satellite will move through its perigee point rapidly and cover more surface area in an equal amount of time.

28. Select **START.**

29. At time **2 Jan 00:10**, all three satellites will be in view.

- The earth map shows each satellite's ground track for one complete pass, specifically, pass number three. The **MEO_1** orbit will sweep out an equal area in equal time. However, **MEO_3**, representing the highly eccentric orbit will initially move out quickly until its apogee point, where it dwells for a long time over one geographic spot, approximately 20 degrees longitude.

At time **2 Jan 08:05** select **PAUSE.**

- All satellites have completed one pass and are in the same approximate position to each other. Each orbit completes its pass in the same amount of time. Only the speed during the orbit varies for the more eccentric orbit.

30. Review the scenario as often as needed. Close out according to the instructions in **STARTING AND USING SATELLITE TOOL KIT.** <u>Do not save the file</u>.

## SCENARIO THREE

Scenario Three helps you visualize how the inclination affects the orientation of the orbit. Specifically, the scenario illustrates the following:

1. Changes to the inclination value changes the tilt of an orbit from the equatorial plane.
2. From a flat perspective, the extreme northern and southern latitudes a satellite will cover equates to the inclination value. For example, if a satellite's inclination is 28.5 degrees, it will travel no further north than 28.5 degrees north latitude and no further south than 28.5 degrees south latitude.

This scenario will illustrate these concepts by having you make changes to the inclination value. To initiate the scenario, complete the following steps.

1. Load **Scenario\Lesson3\inclinationR\ inclinationR.sc**
2. Select the **VO** map and maximize the window.
3. Select **RESET.**
4. Orient the globe so that the African continent is at nine o'clock position.
5. Zoom in on the globe until the word **LEO_1** is visible.
   - You are viewing a LEO orbit at a zero inclination.
   - Observe its relation to an imaginary equatorial line. The **LEO_1** satellite, having a zero inclination, parallels the equator. It does not tilt away from the equator.
6. The next few steps will enable you to change the inclination value.
7. Select the **Satellite Tool Kit** window.
8. Highlight the **LEO_1** icon. Ensure the + sign appears before you do the next step.
9. Select **EDIT** and then **COPY**.

10. Select **EDIT** and then **PASTE**. **LEO_11** will appear. Change the name to **LEO_35.**

11. Select **PROPERTIES** and **GRAPHICS**. Change the color **red** to **magenta**.

12. Select **APPLY** and **OK**.

13. Select **PROPERTIES** and **BASIC**. This orbit tab represents all the parameters required to define the orbit. Currently, the **LEO_35** parameters are the same as **LEO_1**.

14. Change the inclination value to **35.0 degrees.**

15. Select **APPLY**, then **OK**.

16. From the **LEO_1** icon, click on the **+**. **Sensor1** will appear.

17. Highlight **Sensor1**.

18. Select **PROPERTIES** and **GRAPHIC**. Change the color from **red** to **Medium Orchid**.

19. Select **APPLY** and **OK**.

20. Toggle to the **VO** map.

21. Select **RESET**, then **START.**

    - By observation, you can view the 35-degree tilt of the orbit with respect to the imaginary equatorial line or the **LEO_1** orbit. As **LEO_35** travels in its orbit, it is able to view 35 degrees above and below the **LEO_1** orbit.

22. Select **PAUSE.**

23. The next few steps will enable you to compare a highly inclined orbit to the previous two orbits.

24. Select the **Satellite Tool Kit** window.

25. Highlight **LEO_35**. Ensure the **+** symbol is indicated. Thus, this action will enable all linking files to be copied in the next step.

26. Select **EDIT** and **COPY**.

27. Select **EDIT** and **PASTE**. **LEO_351** will appear. Change the name to **LEO_80.**

28. Select **PROPERTIES** and **GRAPHICS**. Change the color from **magenta** to **Dark Sea Green.**

29. Select **APPLY** and **OK**.

30. Select **PROPERTIES** and **BASIC**. The orbit tab is displayed. Presently, the orbital parameters reflect the same values as the **LEO_35**.

31. To define a highly inclined orbit, change the inclination value to **80.0** degrees.

32. Select **APPLY** and **OK**.

33. Highlight **Sensor1** under the **LEO_80** icon**.**

34. Select **PROPERTIES** and **GRAPHICS**. Change the color from **red** to **white**.

35. Select **APPLY** and **OK**.

36. Select the **VO** map and select **RESET**.

    - In view are all three orbits. The **LEO_80** orbit is tilted 80 degrees from the equator. It is nearly perpendicular to the equator and nearly parallels the north and south poles. The advantage to a highly inclined orbit is the satellite will travel over higher latitudes.

37. Select **START**.

    - Observe that the distance north and south of the equator that a satellite can cover is a function of orbital inclination. The greater a satellite's orbital inclination, the greater the satellite's coverage of northerly and southerly latitudes.

38. Select **PAUSE.**

39. Select the **2D** map, then select **RESET.**

- The map illustrates the concept of how inclination bounds the satellite's ground track to its equivalent inclination value. Simply stated, it shows how much area above and below the equator the satellite views.

40. Select **START**.

- In this scenario, **LEO_1**, depicted in **red** has a zero inclination. Thus, it will remain at the equator, at zero degrees latitude. By comparison, the **LEO_35** satellite, depicted in **magenta**, will travel north to 35 degrees and then to 35 degrees south, equivalent to it's inclination value. Finally, the **LEO_80** illustrates that the ground track will cover latitudes up to 80 degrees north and south.

41. Select **PAUSE.**

42. View the scenario as often as needed. Close out according to the instructions in **STARTING AND USING SATELLITE TOOL KIT.** Do not save the file.

## SCENARIO FOUR

Scenario Four helps you visualize the influences of argument of perigee on an orbit. Specifically, the lesson addresses the primary influence of perigee point placement. To help visualize this concept, you will make changes to a HEO satellite's argument of perigee. To run the scenario, complete the following steps.

1. Load **Scenario\Lesson3\argperigee\ArgperigeeR.sc**.

2. Select the **VO** map and **RESET**.

3. Orient the globe so that the North American continent is centered on your screen.

4. Zoom out until three-fourths of an orbit is in view.

5. Displayed is a HEO orbit. The argument of perigee value is 270 degrees, resulting in a perigee point in the southern hemisphere.

   - By definition, the argument of perigee is measured from the ascending node to the perigee point in the direction of satellite motion. Now look at your display and imagine a horizontal line around the center of the earth. This line represents the equator. The point at which that line crosses the orbit is the ascending node. From the ascending node, use a pointer and trace a movement around the orbit 270 degrees in a counter clockwise direction. Your pointer is now at the southern point in the orbit, representing the perigee point.

6. Select **START**.

   - The satellite will travel fastest at its perigee point. Thus the south pole region will have very little coverage.

7. The next few steps will have you change the argument of perigee value.

8. Select the **Satellite Tool Kit** window.

9. Highlight **HEO270**.

10. Be sure the + symbol is indicated. This action will allow all linking files to be copied in the next step.

11. Select **EDIT** and **COPY**.

12. Select **EDIT** and **PASTE**. A **HEO2701** will appear. Change the name to **HEO90**.

13. Select **PROPERTIES** and then **GRAPHICS**. Change the color from **red** to **magenta**.

14. Select **APPLY** and **OK.**

15. If the + symbol appears next to **HEO90,** click on it. **Sensor1** appears. If the + symbol isn't there, **Sensor1** will already be visible.

16. Highlight **Sensor1**.

17. Select **PROPERTIES** and then **GRAPHICS**.

18. Change the color to **Hot Pink**.

19. Highlight **HEO90.**

20. Select **PROPERTIES** and then **BASIC**. The orbit tab displays all the parameters defining this orbit. However the **HEO90** orbit is a duplicate of the **HEO270**. Observe the effects when you change the argument of perigee.

21. Change the Argument of Perigee value to **90 degrees**.

22. Select **APPLY** and **OK**.

23. Toggle to the **VO** map.

24. Select **START**.

    - In comparing the two orbits, the perigee points are directly opposite from each other. The **magenta** orbit, represents a satellite with a 90 degree argument of perigee. The majority of its coverage will be in the southern latitudes as it approaches apogee.

25. Select **PAUSE.**

26. Toggle to **2D** map.

- Observe where the perigee points are for each satellite. The perigee point defines the point in the orbit at which the satellite will spend the least amount of time. In selecting a satellite orbit, you should consider how much time a particular point on the earth needs to be viewed. Note: a circular orbit does not have a defined argument of perigee. Can you explain why? Hint: The apogee and the perigee are equal values.

27. View as often as needed. When complete, select the **PAUSE** button. Close out according to the instructions in **STARTING AND USING SATELLITE TOOL KIT.** Do not save the file.

## SCENARIO FIVE

Scenario Five illustrates how the Right Ascension of the Ascending Node (RAAN) influences an orbit. Specifically, the changes in RAAN change the orientation of the orbital plane along the equatorial plane. This scenario will illustrate this concept by having you make changes to the RAAN of a LEO satellite. To run the scenario, complete the following steps.

1. Load file **Scenario\Lesson3\Raanr\RAAN.sc**
2. Select **VO** map and expand the screen. Select **RESET**.

3. Orient the globe so that North American continent is at the nine o'clock position.

Zoom in until the words **LEO** and **equator line** are visible.

- Depicted in **red** is a LEO orbit inclined to 28.5 degrees. The white horizontal line represents the equator. The ascending node is the intersection of the **red** orbit and the equator line. The RAAN is measured from the first point of Aries to the ascending node. In this case, the RAAN is located at the same point as Aries, 0.0 degrees.

4. Select **START.**

- Observe the satellite in its orbit. Every time the satellite completes a pass at the ascending node, the earth's position underneath it is different. Thus the ascending node of a LEO orbit shifts west with each satellite revolution.

5. Select **PAUSE.**
6. Select the **Satellite Tool Kit** window.
7. The next few steps will enable you to change the RAAN value and determine its affects on the orbit.
8. Highlight **LEO**. Be sure the **+** symbol is indicated. This action will enable you to copy all linking files in the next step.
9. Select **EDIT** and **COPY**.
10. Select **EDIT** and **PASTE**. A **LEO1** will appear. Change the name to **LEO90**.
11. Select **PROPERTIES** and **GRAPHICS**. Change the color **red** to **magenta.**
12. Select **APPLY** and **OK.**

13. Select **PROPERTIES** and **BASIC**.

- The Orbit Tab displays include all the orbital elements necessary to define an orbit. Currently, the **LEO90** data is the same as the **LEO** data.

14. Change the RAAN value to **90 degrees**.
15. Select **APPLY** and **OK**.
16. Select the + symbol under **LEO90**. The **Sensor1** icon appears.
17. Highlight **Sensor1**.
18. Select **PROPERTIES** and **GRAPHICS**. Change the color to **HotPink.**
19. Select **APPLY** and **OK**.
20. Toggle to the **VO** map.

    - Observe where the **magenta** orbit, **LEO90**, intersects the equator line. It is 90 degrees east of the **LEO** orbit. The **LEO** ascending node represents the Aries position at zero degrees. The angle distance from **LEO** to **LEO90** is RAAN. You can observe that the RAAN parameter orients the orbital plane along the equatorial plane.

21. Select the **2D** map.

    - One complete satellite revolution is represented for each orbit. Depicted in **red** is the orbit with a RAAN value of zero, while depicted in **magenta** is the orbit with a RAAN value of 90 degrees. Additionally, each orbit has labels 1 and 2, representing the ascending node for each satellite pass. Taking a closer look, the **LEO** ascending node at pass 1 is at approximately –100 degrees longitude. In comparison, the **LEO90** is at approximately –10 degrees longitude. Thus the difference in longitude is 90 degrees, indicating the difference in RAAN values between the orbits. Again the scenario illustrates the RAAN parameter influences where the orbit will cross the equator measured from the first point of Aries.

22. Select **START**.

23. At time **01:30** select **PAUSE**.

    - At this point, each satellite has completed one pass and will initiate the second pass measured from the ascending node. Observe the ascending node for each satellite pass shifts to the west as a result of the earth's rotation.

24. Select **RESET**.

25. Review the scenario as often as necessary. Repeat steps **7-22** to change the RAAN value once again. Once you have completed the scenario, select **PAUSE**.

26. Close out according to the instructions in **STARTING AND USING SATELLITE TOOL KIT.** Do not save the file.

## SCENARIO SIX

Scenario Six illustrates how true anomaly influences an orbit. This lesson will focus on the true anomaly parameter determining the specific satellite location in the orbit. The scenario will illustrate this concept by having you make changes to the true anomaly of a LEO satellite. To run the scenario, complete the following steps.

1. Load **Scenario\Lesson3\trueanomR\eccentricityR.sc**.

2. Select the **VO** map and maximize the window.

3. Select **RESET.**

4. Orient the South American continent to the center of the display.

5. Zoom in until the **MEO_1** label is visible. The label is located at the three o'clock position.

6. **MEO_1** represents a slightly inclined, slightly eccentric orbit. At time 1 Jan 1997 00:00, this satellite is located in a position where the true anomaly is zero degrees. The true anomaly parameter enables satellites to co-exist within the same plane. The parameter defines the space between the two satellites. Spacing between satellites is very important because it prevents interference and defines area visibility.

7. Select **START.**

8. Observe **MEO_1**'s orbit.

9. Select **PAUSE.** To examine the influence of the true anomaly value on an orbit, follow these steps.

10. Select the **Satellite Tool Kit** window.

11. Highlight **MEO_1**. Be sure the **+** symbol is indicated. This action will enable you to copy all linking files in the next step.

12. Select **EDIT** and **COPY**.

13. Select **EDIT** and **PASTE**. A **MEO_11** will appear. Change the name to **MEO_2.**

14. Select **PROPERTIES** and **GRAPHICS**. Change the color from **red** to **gold**. Also change the line width to **2.**

15. Select **APPLY** and **OK**.

16. Select **PROPERTIES** and then **BASIC**. The orbit tab describes the current parameters for **MEO_2**. They are the same as **MEO_1**.

17. Change the True Anomaly value to **300.0 degrees.**

18. Select **APPLY** and then **OK**.

19. Select the **+** marker at the **MEO_2** icon. **Sensor1** will appear.

20. Highlight **Sensor1**.

21. Select **PROPERTIES** and then **GRAPHICS**. Change the color to **yellow**.

22. Select **APPLY** and then **OK**.

23. Toggle to the **VO** map.

    - Observe the satellite orbits lie upon each other. The only distinction between the two orbits is that the **MEO_1** is in front of **MEO_2**. The spacing is determined by the true anomaly value. In this case, the difference is 300 degrees in the direction of satellite motion.

24. Select **START.**

    - **MEO_2** will cover the same geographic points, but at a later point in time.

25. Select **PAUSE.**

26. Select the **2D** map.

    - Observe both satellites follow the same ground track and thus cover the same geographic area. The only difference is **MEO_2** will cover the same geographic point at a later time.

27. Select **START**. View as often as needed. When complete select **PAUSE.**

28. View the scenario as often as needed. Close out according to the instructions in **STARTING AND USING SATELLITE TOOL KIT.** <u>Do not save the file</u>.

# Part III - Student Problem

This portion of the lesson plan provides an opportunity for you to apply the concepts you have learned in Part 1 and Part 2 by solving a problem.



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**Problem**

You work for a large television affiliate in the year 2000. You are very excited to learn that you will be the chief coordinator for bringing live television to the U.S. coverage of the 2000 Summer Olympics in Sydney Australia. However, due to last minute notice, you discover that all satellite links in the area have already been leased. You have informed your supervisors of the problem and have been given money to launch a new satellite in orbit. Funds are limited; thus, a geostationary orbit is out of the question. In addition, the TV station is willing to accept short periods of gap in the coverage. What type of orbit will best suit your needs to ensure you have coverage of the summer Olympics? Describe the orbit in terms of the 6 elements discussed in this lesson. Use STK to illustrate your solution.

**Proposed Solution**

The constraints of the problem prevent you from using a GEO satellite orbit. However a HEO satellite provides the next best type of orbit to provide long periods of coverage. Additionally, since continuous coverage is not required, a HEO satellite would meet your needs.

To visualize the proposed solution load the following file:

**Scenario\Lesson3\student_problem\student_problem.sc** and proceed with the following steps.

The terms to describe the orbit are as follows:

| | | |
|---|---|---|
| 1. | Semimajor Axis: | 26553 km |
| 2. | Eccentricity: | .7 |
| 3. | Inclination: | 45.0 degrees |
| 4. | Argument of Perigee: | 270.0 degrees |
| 5. | RAAN: | 71.0 degrees |
| 6. | True Anomaly: | 0.0 degrees |