ASEN 3200 Orbit Mechanics and Attitude Dynamics - Spring 2021

LABORATORY O-1

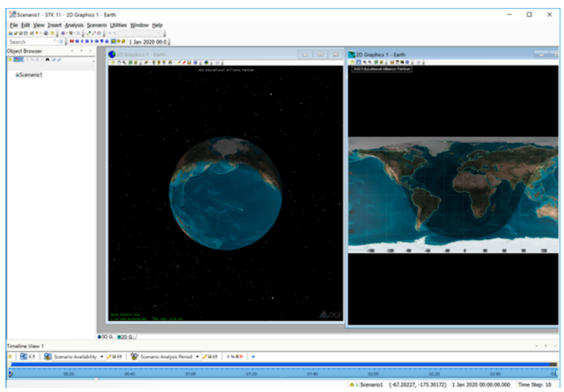
Assigned: Week of January 18, 2021

Due: February 4 or 5, 2021 at start of lab

PART I

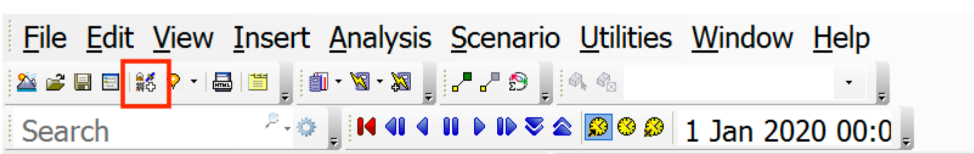
Using STK/Astrogator, create a scenario with a satellite orbiting the Earth. Follow the outlined procedure and answer the questions presented throughout. Helpful hints: **SAVE YOUR SCENARIO REGULARLY! Save each scenario in a *separate* folder. If you save multiple scenarios in the same folder, STK may overwrite data and you could lose your work.**

1. Open STK and create a scenario using a start time of 1 Jan, 2020 00hr 00min 00s UTCG and stop time that is 1 day later by entering this information in the New Scenario Wizard screen. Select any name for your scenario, then click "OK". The STK window will then update to appear as follows:



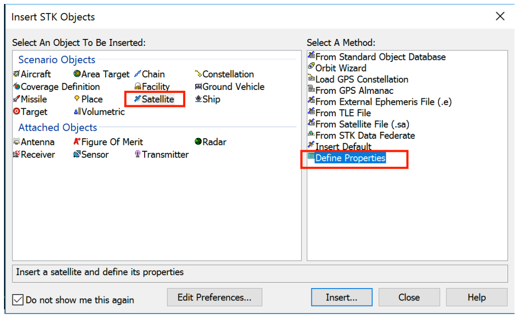
   This window features both a 3D graphics window and a 2D ground track view (a projection of the satellite's location on a body's surface), with a panel on the left indicating the objects available within the STK scenario. Be sure to save this scenario by clicking the "Save" button or using the "File"→"Save" options within the menu. **Be sure to press the save button regularly!**

2. Insert a satellite either by clicking the button highlighted by a red square in the figure below, located within the toolbar at the top of the window or accessing the "Insert"→"New…" option in the menu bar.

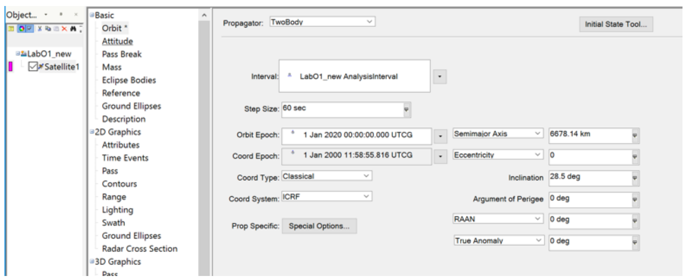


3. An "Insert STK Objects" popup should appear. Select the "Satellite" object on the left panel of this window and click the "Define Properties" method for inserting the object. These options are highlighted in the picture below. Once the desired object and insertion method have been

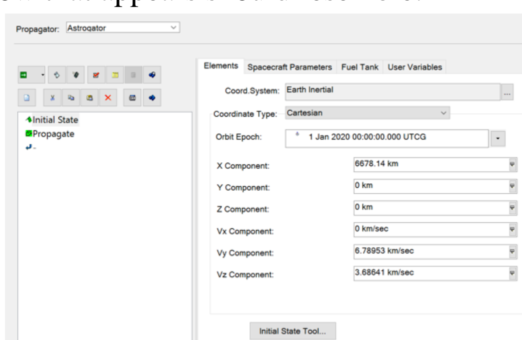
selected, click “Insert…”.



4. The satellite’s properties window then appears as displayed below. On the “Basic”→ “Orbit” page of this window, select the “Propagator” dropdown menu and click the “Astrogator” label.



The new Astrogator window that appears should resemble:

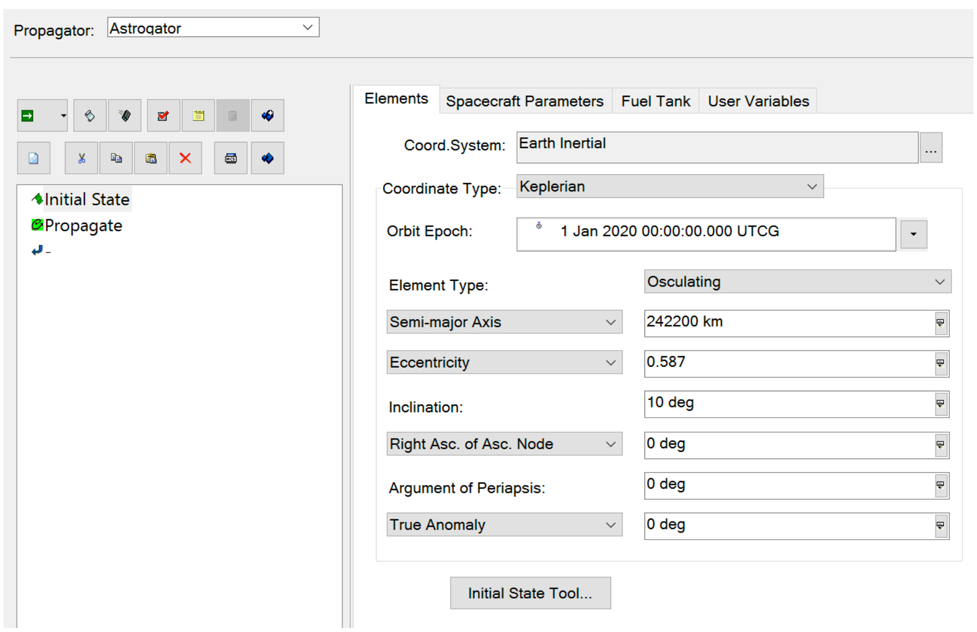


Astrogator is a powerful feature of STK that enables the construction of a Mission Control Sequence (MCS) and offers a lot of flexibility for configuration. An MCS is a sequence to define the various phases of a mission: initial condition, propagation over some time interval or until an event is reached, application of maneuvers, etc. When propagating a satellite in Astrogator, we can define various force models, add vectors of interest, perform propagations near a variety of bodies, generate reports describing the satellite state at various locations along the trajectory, and even target transfers. In this lab, we will explore the fundamental features of Astrogator.

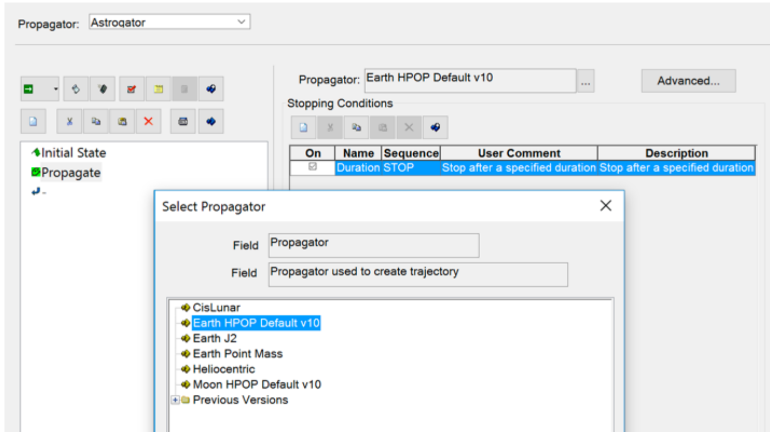
5. Configure the MCS (which appears on the lefthand side of the Astrogator panel, displayed in the figure above). By default, STK adds two components to the MCS: an initial state, and a propagation segment. Keep these two segments.

6. Click on the "Initial State" segment in the MCS. Use the following parameters to define the satellite's orbit in the "Elements" tab in the panel on the righthand side:
   a. *Coord. System: Earth Inertial*
   b. *Coordinate Type: Keplerian*
   c. *Element Type: Osculating (this term means the orbital elements at the specified epoch)*
   d. *Orbit Epoch: 1 Jan 2020 00:00:00.000 UTCG*
   e. *Semimajor axis, a =* 37.9735 Re *(Earth radii, use the ruler icon to change units)*
   f. *Eccentricity, e = 0.587*
   g. *Inclination, i =* 10° (*this variable orients the orbit plane*)
   h. *Right Ascension of ascending node, Ω = 0° (this variable orients the orbit's intersection with the Earth equator)*
   i. *Argument of periapsis, ω =* 0° *(this variable orients the orbit's periapsis within the orbital plane)*
   j. *The initial condition is located at a true anomaly of 0 degrees.*

   Once these values have been entered to define the initial state of the spacecraft, click the "Apply" button to save your changes. The window should resemble the figure below:

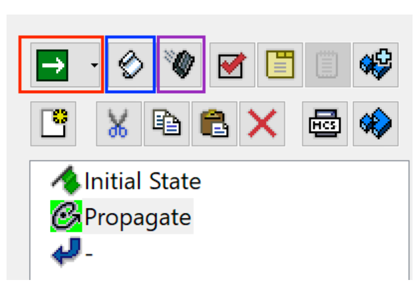


7. You may also choose to rename the satellite by right-clicking on the "Satellite1" label on the left panel of the STK window and selecting "Rename".
8. Next, configure the "Propagate" segment by clicking its label in the MCS. A new panel should appear on the righthand side of the Astrogator page. Click the "…" button next to the Propagator selection box which, by default, reads "Earth HPOP Default v10". A new popup window should appear as follows:



Select the "Earth Point Mass" propagator from the list and then click "Ok". This propagator only includes the point mass model of the Earth's gravity, allowing us to integrate the motion of the satellite in the two-body problem. Once you have returned to the "Propagate" configuration panel and the "Propagator" textbox has updated, click "Apply". This panel also enables configuration of the time interval, or other condition, over which the spacecraft is integrated. For this example, let's define the "Propagate" segment to integrate over a given time interval – the orbital period. Calculate this value using the orbital elements of the satellite. (What value of the gravitational parameter will you use in this calculation?) Then, click on the "Duration" line in the "Stopping Conditions" list. Below this list are some textboxes. In the "Trip" box, enter the orbital period you calculated. You may change the units by clicking the ruler icon at the right of the textbox and selecting the desired unit format. In the "Sequence" textbox, ensure that "STOP" appears. This property tells the propagator to stop integrating the motion of the spacecraft after a time interval equivalent to the orbital period. Once you have configured these properties, click the "Apply" button.

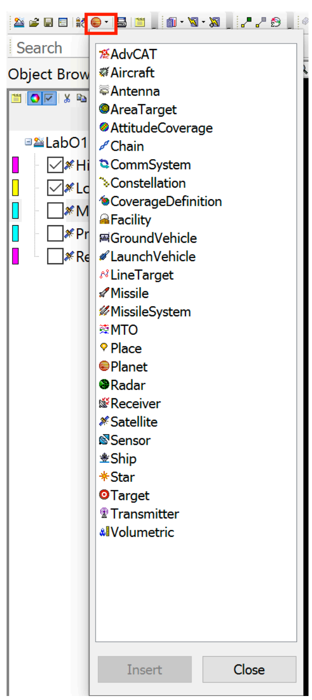
9. Change the color of the satellite orbit by double-clicking on the "Propagate" segment in the MCS to reveal an "Edit Segment" popup window. Change the color in the "Color" dropdown menu. Choose a color that will appear clearly on a dark background!
10. Run the MCS and generate the path of the spacecraft for one orbital period by clicking the "Run Entire Mission Control Sequence" button highlighted in red on the left below. To clear the graphics from the 3D graphics window at any time, simply click the "Clear Graphics" button highlighted by the purple box below. The summary button highlighted by a blue box below will allow us to generate reports providing information about the satellite's trajectory.



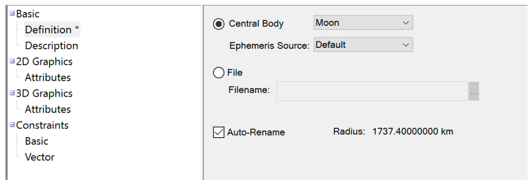
11. Once you have run the MCS, navigate to the 3D graphics window to view the orbit in three

dimensions near the Earth. You may need to zoom out to view the entire orbit – this can be achieved by holding the right click button on your mouse while dragging the mouse towards or away from you. To rotate the view, click the left button on your mouse on a region in the 3D graphics window and drag. To remove the Earth shadow from the 3D graphics window, navigate to the 3D graphics properties window by clicking the yellow notepad icon at the top of the left of the toolbar within the 3D graphics window and select the “Lighting” page. Then, uncheck the “Enable Lighting” property.

12. Navigate back to the Satellite Properties window. Select the “3D Graphics”→ “Model” page. In the “Details Threshold” panel, increase the value in the “Marker Label” textbox by a couple of orders of magnitude (you could also drag the blue bar to the very right). This will allow you to see the spacecraft within its orbit, even when zoomed out in the 3D Graphics window. Then, under the “Model” panel within this page, ensure that the “Show” checkbox is selected and drag the blue bar next to the “Log Scale” to the right. Then, click “apply” and see if the spacecraft is big enough to see clearly in the 3D graphics window. Complete this step slowly and in small increments until you find a value that displays the satellite as large enough to be visible, but not too large that it overwhelms the entire picture (start with ~7).
13. Depending on the type of orbit, and the analysis of interest, it may be useful to add other bodies to the 3D graphics window. For this example, the satellite has a large semi-major axis. Accordingly, it can be useful to view the orbit of the Moon as a reference. To add another body to the scenario, navigate to the “Insert Default Object” located in the main STK toolbar. Note, that this icon is often represented by a graphic corresponding to the last object you inserted, so it may look different as you work through each scenario. Click on the small arrow to the right of this icon to select the object of interest within the drop-down menu: “Planet”. Then, click the “Insert” button.



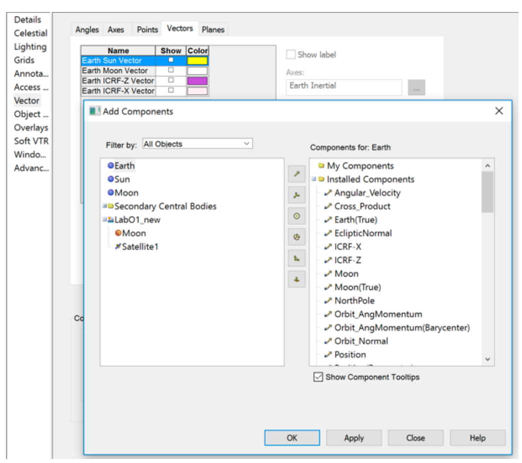
14. An additional object is then added to the scenario, named using the default "Planet". Either double click the planet object in the lefthand scenario panel, or right-click and select "Properties". To define which celestial body this object represents, navigate to the "Central Body" dropdown menu within the "Basic"→"Definition" page of the planet object properties window. Then, select Moon, and leave the ephemeris source as default. Then, click "Apply" to save your changes. The planet object label will update automatically.



15. Next, customize the appearance of the Moon in the 3D graphics window by navigating to the "3D Graphics"→"Attributes" panel of the planet object properties window. Uncheck the box near the label "Inherit from 2D Planet Graphics", and check the "Show Orbit" box.

    You can change the color of the Moon's orbit in the "2D graphics"→ "Attributes" panel.

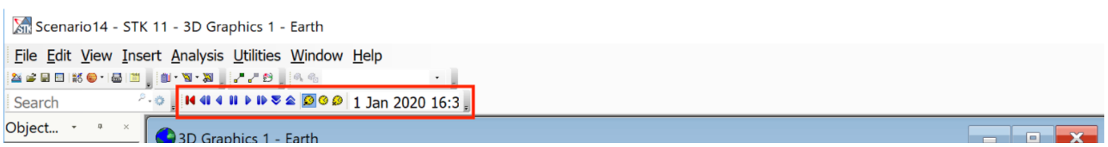
16. Other information can also be added to the 3D graphics window. For instance, we can add a vector representing the angular momentum of a satellite as it orbits the Earth. In this example, let's add the angular momentum vector for the satellite in the 3D graphics window. To add this vector, open the **3D graphics properties window** (Although you can also add this vector using the properties page of the satellite as well, the vector does not always size well through that approach. Hence, I suggest using the 3D graphics window). Navigate to the "Vector" page in the lefthand panel. Some sample vectors are already available in the Vector list on this page. However, to add a different vector, click the "Add…" button. Then, a new popup window will appear as shown below:



17. Select your spacecraft from the lefthand panel, indicating which object the vector will be computed for, and then "Orbit_AngMomentum" from the righthand side panel. Click "Ok" and return to the Vector page of the 3D graphics properties window. Now, "Satellite1 Orbit_AngMomentum" appears on the vector list, and the checkbox under "Show" should be

checked. You can modify the color of this vector by double-clicking the colored square next to the vector label and then clicking the small drop-down arrow that appears. Then, select the color of interest.

18. Retain the default properties for the vector indicating the satellite's angular momentum, ensuring that the "Show label" box has been checked. You may wish to modify the vector size by changing the value in the "Scale" box within the "Component Size" panel and then clicking "Apply". To view the time evolution of this vector, return to the 3D graphics window, change the view perspective, and reset the scenario time via the red reset button in the animation toolbar. You will notice that the orbit angular momentum vector is centered at the Earth – with a basepoint that is fixed in this view. This configuration helps to visualize any changes in the vector over time. Then, click play and watch the satellite/s, planet/s, and vector/s evolve through the scenario window. You can increase the time step to speed up the animation by using the "Increase Time Step" button (which appears as two upward facing arrows) within the animation toolbar. If the vector disappears, it means the scenario has ended. In this case, press the red reset button to return to the initial scenario time.



Question 1: Follow a similar process to add the Eccentricity vector for the spacecraft orbit to the 3D graphics window. Include two snapshots of the 3D Graphics window in your report: one looking down on the orbital plane, and the other providing a three-dimensional perspective with the angular momentum vector clearly displayed. How do the eccentricity and angular momentum vectors evolve over time when you run the simulation for a full orbital period? Is this consistent with your expectations, and why?

Question 2: This orbit was propagated using a two-body point mass model of the Earth. What do you think are the two significant perturbations acting on a spacecraft in this orbit and why?

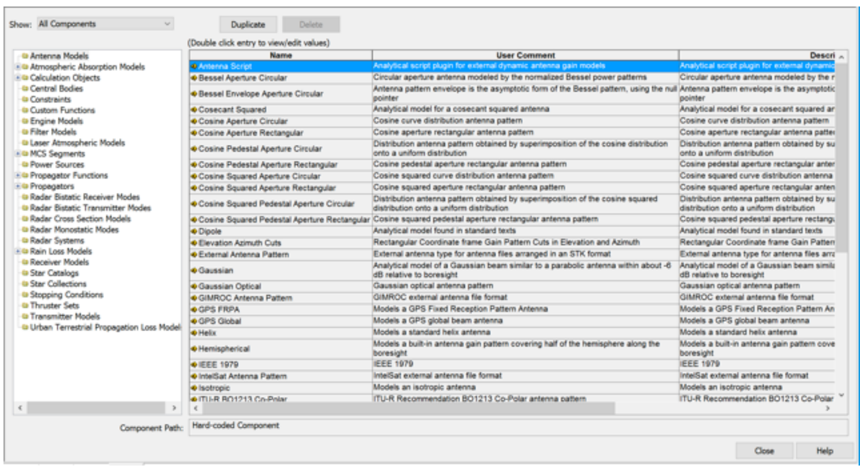
Question 3: Does the spacecraft's orbit ever intersect the orbit of the Moon? Use a figure with an appropriately selected three-dimensional perspective to justify your response.

Question 4: In Matlab, write a script to integrate the motion of this spacecraft for one orbit period. Create a plot of the path of the spacecraft within the orbit plane, locating the following: the Earth, initial location of the spacecraft, and eccentricity vector. Compare this plot to the one you created in STK. Are they consistent? Describe, in your own words, how you set up your Matlab code and justify your integrator choice, how you defined your initial conditions, and the value of the gravitational parameter used (is it the same as the value used in STK?). Create another plot displaying the magnitude of the eccentricity and angular momentum vectors over one orbit period and comment on the time evolution of each quantity, as well as whether/why the result is consistent with your expectations.

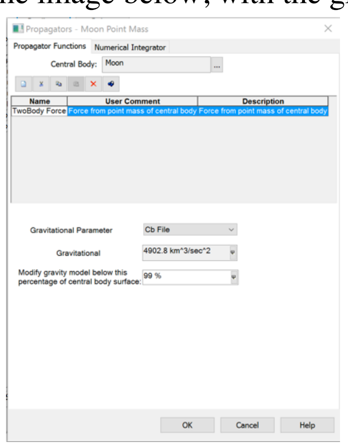
PART II

Using STK/Astrogator, you will create a scenario with a satellite orbiting the Moon to perform surface observations.

1. In the main STK toolbar, navigate to "View" and click "Planetary Options". Then, close the previous scenario (after saving!) and start a new scenario with an analysis start date of Jan 1 2020 00:00:00.000 UTCG, and end date one day later. In the dropdown box next to "Central Body", ensure that the Moon is selected.
2. Since the satellite you will be modeling will be orbiting the Moon, ensure that the central body in both the 2D and 3D graphics windows is set to the Moon. Turn off the shadow for the Moon using the 3D graphics properties window.
3. Let's create a propagator that models only the point mass gravity of the Moon (there is already one in STK, but this is an opportunity to learn how to create the propagator yourself). Navigate to the "Utilities"→ "Component Browser" option in the main menu. A new window should appear as below:



4. Select "Propagators" from the lefthand panel, and single click on the "Earth Point Mass" model in the righthand panel. Then, click the "Duplicate" button. Change the name to "Moon Point Mass Custom" in the popup window. Double click the "Moon Point Mass Custom" entry and a new popup window will appear. Change the central body to "Moon" and click ok. Your popup window should resemble the image below, with the gravitational parameter updated:



Click “Ok” and close the component browser.

5. Add a new satellite using the same procedure as the previous portion of this lab, with Astrogator selected as the propagator. In this example, be sure to select a “Moon Inertial” coordinate system when inputting orbital elements in the “Initial State” segment of the MCS. Set the initial condition of the spacecraft using the Keplerian “Coordinate Type” after converting the following information into orbital elements as instructed in Question 5 below:
    a. Orbital Period of 6.3 hrs
    b. Periapsis radius of r_p=1840 km
    c. Polar orbit (Hint: this constraint sets the inclination, an angle which orients the orbital plane, and should be selected to ensure that the spacecraft passes over the poles. You can use the 2D and/or 3D graphics windows to find a feasible value using guess and check with visual verification)
    d. Right Asc. Of Asc. Node = 0 deg
    e. Argument of Periapsis = 0 deg
    f. Initial location of spacecraft such that r = 2400 km, moving away from periapsis.

Question 5: Show your working to convert information in (a), (b), (f) in the above question to the following quantities: a, e, θ.

6. Define the propagate segment to use the new Moon Point Mass Custom propagator you created. Set the Duration stopping condition to integrate the satellite for one period. After setting these values, double-click the “Propagate” segment and change the satellite orbit color if you wish. Run the MCS to generate the orbit of the spacecraft.
7. Navigate to the 3D Graphics window and change the perspective to look down on the orbital plane. Using the same method as part I, ensure that the spacecraft marker is large enough to be visible when the animation is run.
8. Navigate to the spacecraft properties window and access the “2D Graphics”→”Attributes” page. Here, you can increase the line thickness of the path of the spacecraft. Under the last row in the table on this page, click the “More…” button. In the “Modify Graphics Interval” panel, use the “Line Width” dropdown to select the thickest line. Click the “Apply” button to apply these changes. Note, sometimes when you rerun the MCS, this property may reset.

Question 6: In the 3D graphics properties page, add a vector indicating the “Moon”→”NorthPole” direction.

Question 7: Include a snapshot of the satellite orbit in the 3D graphics window, taken from a useful perspective.

Question 8: The spacecraft is designed with equipment that is only able to clearly make surface observations between altitudes of 200 and 500 km. From the specified initial condition, calculate the time in hours that the spacecraft must wait until its first opportunity to observe the surface, subject to the equipment constraints. Use Kepler’s equation and include your calculations in your lab report.

Question 9: Use the conic equation to calculate the value of the true anomaly at the beginning and end of this first surface observation window. Use Kepler's equation to calculate the time interval corresponding to this observation window. Show your work in your lab report. Verify your results in STK by modifying the true anomaly of the initial state to equal the true anomaly at the beginning of this first surface observation window. Modify the propagate segment duration stopping condition to reflect the time interval you calculated. Run the MCS again and include a screenshot of the portion of the spacecraft trajectory for which an observation window occurs.

Question 10: Navigate to the 2D Graphics window, which displays a projection of the satellite's position over the Moon's surface (we will learn more about this projection soon!). Then, on the Satellite properties window, navigate to the "2D Graphics"→ "Pass" panel and on the "Ground Track Central Body Display" list, ensure that the checkbox for "Moon" is checked. Also ensure that in the "Leading/Trailing" panel, the "Ground Track" "Lead Type" is set to "All". You may need to run the MCS again. Include a screenshot of the 2D graphics window in your report. Report the approximate range of values of the longitude and latitude of the spacecraft during the observation window. (Definition of these angles is in Chapter 1 of the textbook, page 32). Visually compare the groundtrack (the path of the spacecraft projected onto the Moon's surface) over the observation window to the Image Map of the Moon located at the following website:

https://pubs.usgs.gov/sim/3316/downloads/sim3316_sheet1_lo_res.pdf

Name a crater near the spacecraft's lunar groundtrack during this observation window.

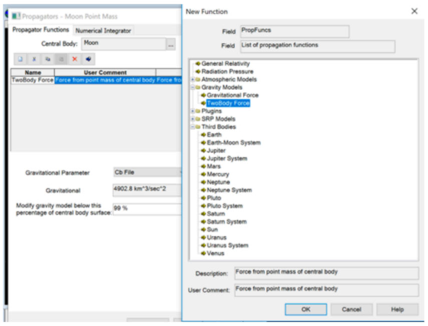
Question 11: Use MATLAB to write a script that solves Kepler's equation iteratively for an elliptical orbit. Include a copy of your group's code in your report. Explain in your own words how the code works as well as how you selected any tolerance values and the initial guess.

Question 12 For the lunar orbit constructed in this example, consider an instantaneous location for the spacecraft 13.5 minutes past periapsis – at this instant, is the spacecraft within the allowable range of altitudes, 200-500km, for surface observation to occur? Justify your answer by showing working and using the MATLAB script you wrote.

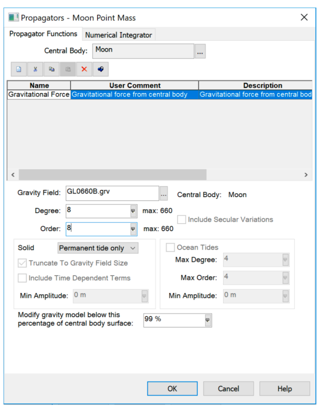
Question 13: This orbit was propagated using a two-body point mass model of the Moon. What do you think are the two most significant perturbations acting on a spacecraft in this orbit and why?

Question 14: Pick one of these perturbations and add it to your propagator function in the "Component Browser", where you can double-click the "Moon Point Mass Custom" propagator to edit it. To add additional force contributions (more information available here:

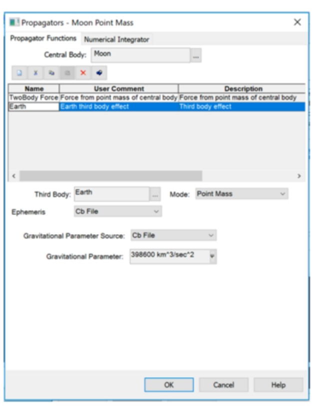
http://help.agi.com/stk/#gator/ab-propfunction.htm?Highlight=propagator
http://help.agi.com/stk/#gator/ab-prop.htm#propfunc), click the blank page icon above the list of forces which currently only contains "TwoBody Force" as displayed below.



To model the gravitational field using a nonspherical model of the Moon, for example, you will need to first delete the “TwoBody Force” and replace it with “Gravitational Force” and select nonzero values for the “Degree” and “Order” of the gravitational model, e.g., 8x8. If modeling the Moon as an object that is not a point mass, your propagator should resemble:



To add the gravity due to other bodies, for example, do not delete “TwoBody Force” – rather, add a “Third Body”. If adding other gravitational contributions, your propagator should resemble:



Once you have configured the propagator to include an additional contribution of your choosing, propagate the spacecraft path for 100 orbit periods. Do this by updating the propagation time in the Astrogator MCS and re-running the simulation. Include a screenshot of your orbit, from a clear and useful perspective. Comment on whether the perturbation you selected results in a significant impact on the path of the spacecraft, in comparison to the previous results for the two-body problem.

ASEN 3200 Lab O-1 Spring 2021 Rubric

Title Page (1 pt.) – Lab, Course Number, Group Members, Date
Abstract (5pts) – short summary of objectives, experiment, results, and analysis
Introduction (5pts) – brief introduction to this lab, what you plan to investigate, how this could be applied

Within the writeup in the below sections, using subheadings such as "Question X" to clearly identify your answer to each question.

PART I: Earth Satellite Simulation (25 pts)

- Description of scenario setup and initial parameters
- Results and Analysis - for each question, show plots and summarize output generated from STK/Matlab, describe results, and briefly explain the theory (with equations as necessary).
- Results and Analysis – include your Matlab code with a description of the script and justify choices for parameters/setup. Include a copy of your code in your report.

PART II: Lunar Surface Observation (45 pts)

- Description of scenario setup and initial parameters
- Theory – explain, with equations, how the initial condition is determined via calculations for the semi-major axis, eccentricity and true anomaly. Justify the sign of the true anomaly.
- Theory – explain, with equations, the conversion between orbit position / true anomaly and time, where relevant. Include, where appropriate, a discussion to justify the sign of the true anomaly.
- Results and Analysis – include your Matlab code with a description of the method used to solve Kepler's equation and a description of the equations used. Be sure to justify any selected tolerances or initial guesses. Include a copy of your code in your report.
- Results and Analysis - for each question, show all plots and summarize output generated from STK and describe results. Ensure that any plots are clear and 3D graphics views provide a useful perspective of the orbit. Justify your responses to any questions.

Conclusions and Recommendations (4 pts)

- What did you learn from this lab?
- What would you be interested in exploring beyond the given objectives or STK features?

Acknowledgements (1 pt.) List who in the group completed each task and any outside assistance you received

References (1 pt) Must cite all external sources, including images

Style & Clarity (13 pts)
Organization (3) – clear flow, follows required outline, numbered pages
Figures (2.5) – clear figures, appropriate axes, informative titles, clearly labeled units
Tables (2.5) – clear tables, significant figures, headings, informative titles, clearly labeled units
Spelling & Grammar (5)