ASEN 3200 Orbit Mechanics and Attitude Dynamics - Spring 2021

LABORATORY O-2

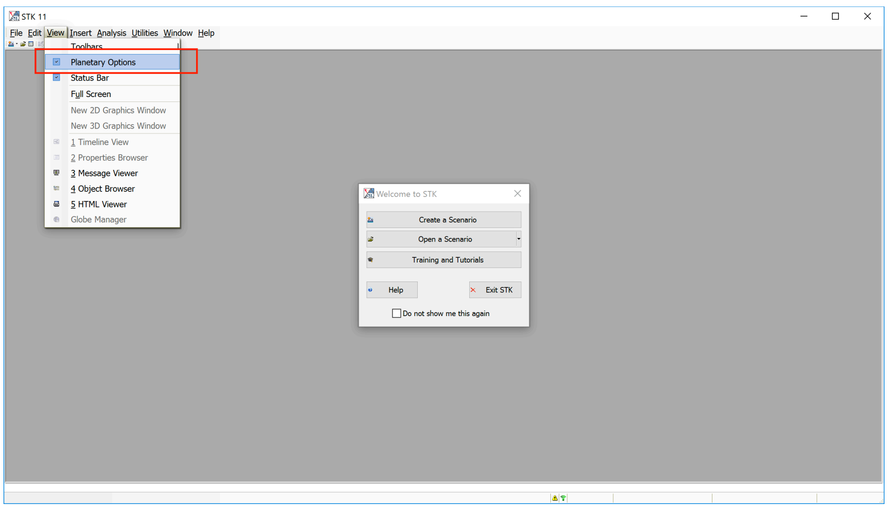
Assigned: Week of February 1, 2021

Due: February 18 or 19, 2021 at start of lab

PART I: Mars Orbiter

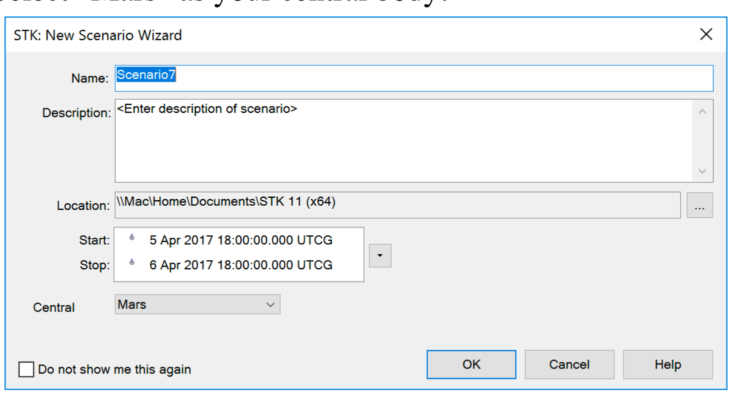
Using STK 12/Astrogator, create a scenario with a satellite orbiting Mars. Follow the outlined procedure and answer the questions presented throughout:

1) Open STK. Before selecting "Create New Scenario", from the "Welcome to STK" popup screen, navigate to the "View" option in the main toolbar. Click the "Planetary Options" item in the dropdown, as displayed below:

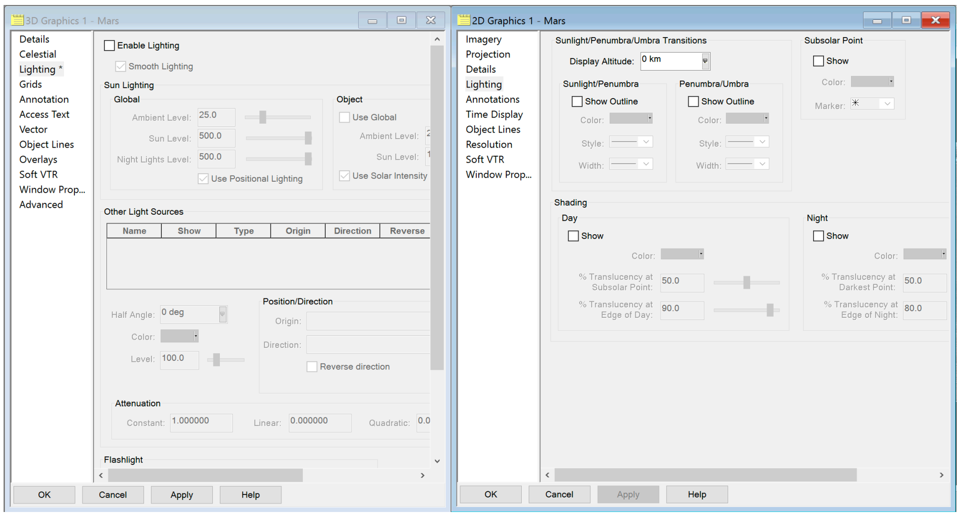


By clicking this option, we can automatically create a scenario with a central body that is not Earth, without having to manually change it in multiple locations.

2) Then, create a new scenario with a start date equal to February 1, 2020 19:00:00.000 UTCG and an end date of March 1, 2020 19:00:00.000 UTCG. You should also see an option to choose the central body. The window you see will look *similar but not exactly the same* as the figure displayed below. Select "Mars" as your central body.



3) In the 3D graphics and 2D graphics windows, you should notice that Mars has automatically been set as the central body. In each of the two graphics windows, remove the day/night lighting by using the graphics window properties panel (click the small yellow notepad icon in the toolbar within each graphics window). Then, navigate to the "Lighting" tab. In the 3D graphics window properties, uncheck the "Enable Lighting" box. In the 2D graphics window properties, under the "Lighting" tab uncheck the "Show" checkbox under "Shading"→"Day" and "Shading"→"Night" (if it is not already unchecked). By removing these options, we can gain a much clearer view of Mars.



4) Consider a space habitat on the surface of Mars. For infrastructure purposes, this habitat is accompanied by a vehicle that remains in Martian orbit. At the initial epoch of the scenario, the vehicle's state can be extracted from the following information, expressed in a Mars Inertial coordinate system:

   a. $\vec{r} = -3424.7\hat{x} - 47.5\hat{y} + 1172\hat{z}\ km$
   b. $|\vec{v} \cdot \hat{x}| = 0.4250$ km/s, $\vec{v} \cdot \hat{y} = -3.333$ km/s
   c. $\vec{h} = 3{,}948.694\hat{x} - 3{,}556.357\hat{y} + 11{,}394.338\hat{z}\ \text{km}^2/\text{s}$ (Hint: use this quantity to find $\vec{v} \cdot \hat{z}$)

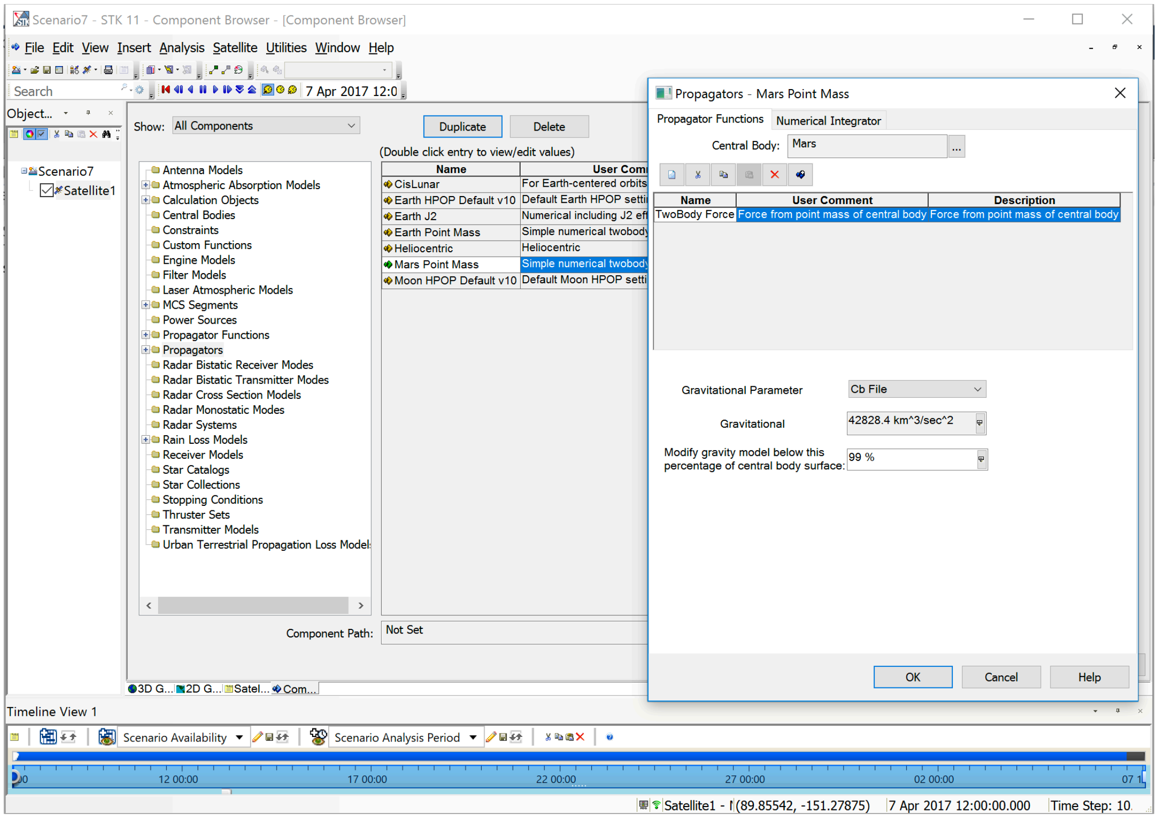
Question 1: First calculate the complete velocity vector in the Mars Inertial coordinate system. Use the position and velocity information to determine the Keplerian orbital elements $(a, e, i, \omega, \Omega, \theta)$ in this coordinate system as well as the orbital period for the Mars orbiter. Use the gravitational parameter for Mars given in the textbook: $\mu = 42828 km^3/s^2$. Show your working and justify any quadrant choices for angular quantities.

5) Determine if you need to create a new propagator using the same method as the previous lab: open the component browser from the utilities option in the menu. The component browser houses each of the items necessary to set up a scenario for the satellite. Navigate to the "Propagators" item in the lefthand panel.

   a. **If the "Mars Point Mass" propagator appears in the list**, double click it and check that it only features a "TwoBody Force" and the gravitational parameter for

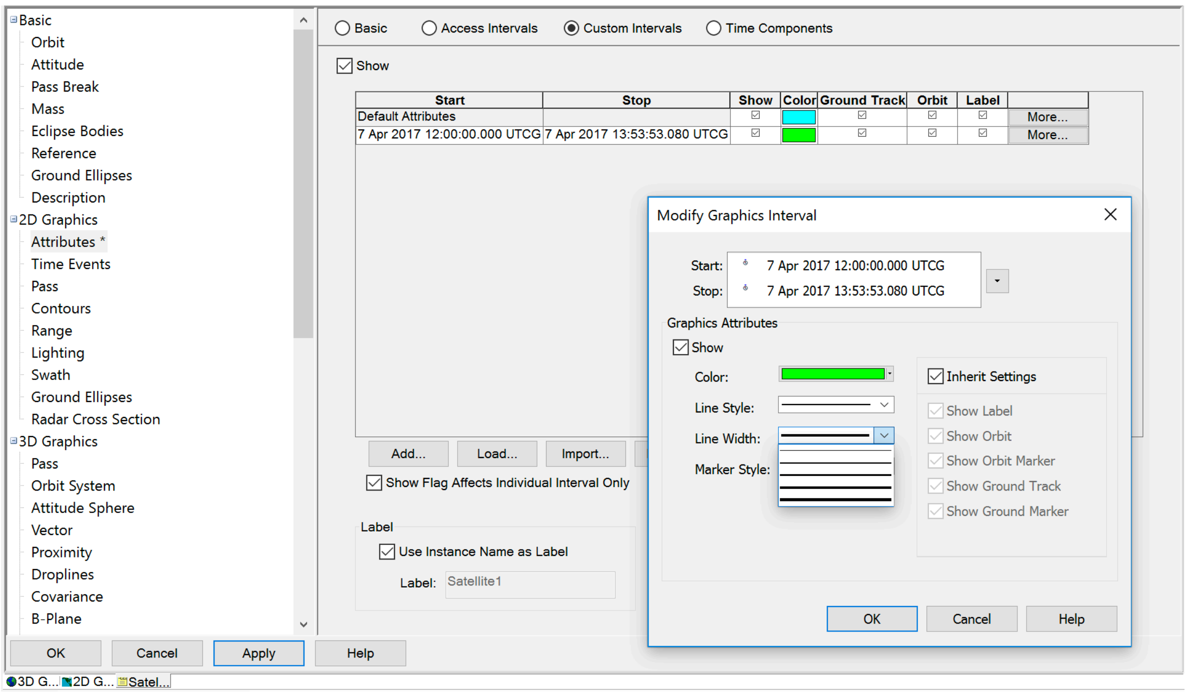
Mars is close to the value in the textbook.

b. **If the "Mars Point Mass" propagator does not appear in the list**, single click on the "Earth Point Mass" model in the righthand panel. Then, click the "Duplicate" button. Change the name to "Mars Point Mass" in the popup window. Double click the "Mars Point Mass" entry and a new popup window will appear. Change the central body to "Mars" and click ok. You have now created a propagator that reflects a relative two-body problem around Mars.



6) Create a satellite in orbit about Mars with Astrogator selected as the "propagator" in the satellite properties window. In this example, be sure to select "Mars Inertial" as the "Coord. System" (coordinate system) when inputting Keplerian orbital elements in the "Initial State" segment of the MCS. Double click the initial state item in the MCS and also change the coordinate system to "Mars Inertial" in the popup window. This coordinate system is used by STK when reporting orbital information using its summary feature, which we will use later. Set the initial condition of the spacecraft using the **Keplerian orbital elements** calculated in Question 1, with the initial epoch equal to the scenario start time. Ensure that you see the text "Central Body: Mars" next to the Propagator drop-down menu (at the top of the window).
7) Double click the Propagate segment in the MCS and change the coordinate system to "Mars Inertial". Customize the propagate segment to use the Mars Point Mass propagator (ensuring the dynamics governing the spacecraft are modeled via the two-body problem using Mars as the central body). Set the time stopping condition to precisely one orbital period, as computed in Question 1. Run the MCS.

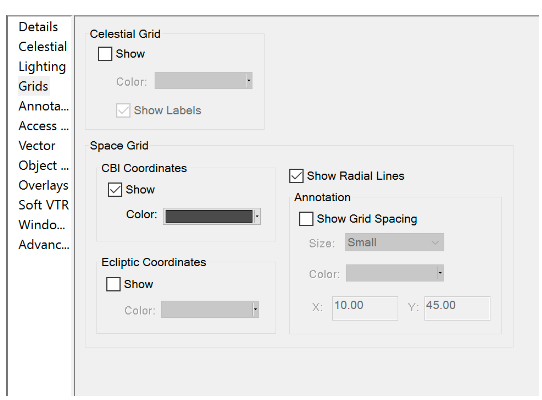
8) Increase the width of the line plotted in the graphics windows to represent the satellite orbit. To perform this task in the satellite properties window, select the “Attributes” item under “2D Graphics”. Then, in the second line of the table, click the “More…” button, highlighted below (If you do not see a second line appear, run the MCS, close the satellite properties window and reopen it). Change the line width using the line width drop-down menu. (You may need to come back to this step multiple times as you rerun the MCS and the line width resets to the default)



9) If needed, rerun the MCS to propagate the Mars orbiter for a single orbital period.

10) Customize the perspective in the 3D graphics window to get a useful three-dimensional perspective of the orbit.

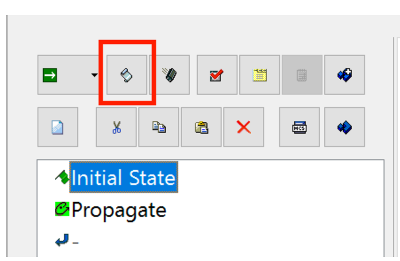
11) Add a grid representing the equatorial plane to the 3D graphics window by accessing the “Grids” page in the 3D graphics window properties. Then check “Show” under the “Space Grid” / “CBI Coordinates”, and choose a color that appears clear against a dark backgroun. The value in using this grid is that we can better visualize the orbit orientation relative to the equatorial plane.



12) Add the following vectors in the "Vector" page of the **3D Graphics properties window** (not in the spacecraft properties window!). In the "Add Components" window that appears when selecting vectors, change "Filter By" to "All Objects". The vectors that should be added include: Mars Inertial XYZ axes (to add each vector select Mars as the object, and expand the "Inertial" option on the right panel by clicking the "+" button and then add the X, Y and Z vectors under "Axes"), "Orbit_AngMomentum" (for the spacecraft, ensure that your satellite is selected in the lefthand panel), "Ecc" (for the spacecraft, the eccentricity vector) and "LineofNodes" (for the spacecraft). For the latter three vectors, choose the vector that does not have a (…) note after them, to ensure that these vectors are calculated using Mars as the central body. You can double check this by right-clicking and selecting "Properties" for each vector before selecting it, and noting the "Central Body" in the properties popup that appears. Ensure that each vector is a different color and the labels are shown. You may want to update the size of the vectors as you see fit, to ensure that they are clear.

Question 2: Visually verify that each vector is in a direction that is consistent with your expectations and their definitions. Mark on this figure the angles: i, Ω, ω. You can draw in STK on the 3D graphics window by using the "Grease Pencil" tool located in the 3D graphics toolbar as indicated below. Note, however, that these markings do not move when you change your view perspective in the 3D graphics window. Take a snapshot of the orbit. Then, remove each of these annotations by using the erase option in the "Grease Pencil" tool.

13) Use STK to calculate the Mars Inertial coordinates for the initial state. To straightforwardly determine this information, navigate to the Astrogator MCS within the satellite properties window. Next to the green arrow to run the MCS is a white scroll icon, that produces a summary of the spacecraft state and orbital information in the specified coordinate system at the end of a segment that you must highlight. For an initial state segment, the initial and final state along this segment are identical. However, for a propagate segment, the summary will be provided at the end of the propagated trajectory. To run this summary for the initial state, first double-click once on the "Initial State" segment in the MCS and change the coordinate system to "Mars Inertial" and click OK (in case you did not do this in an earlier step). Click the "Initial State" segment once. It should be highlighted in blue now as displayed below. Then, click the white scroll icon above the MCS.

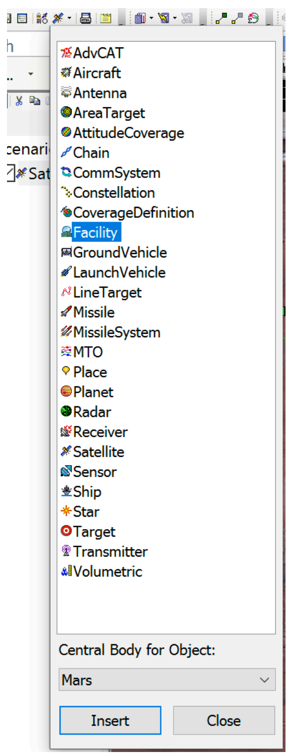


14) A summary will then appear as a new window. Double check that the "State Vector in Coordinate System" line item near the beginning of the summary indicates "Mars Inertial" as

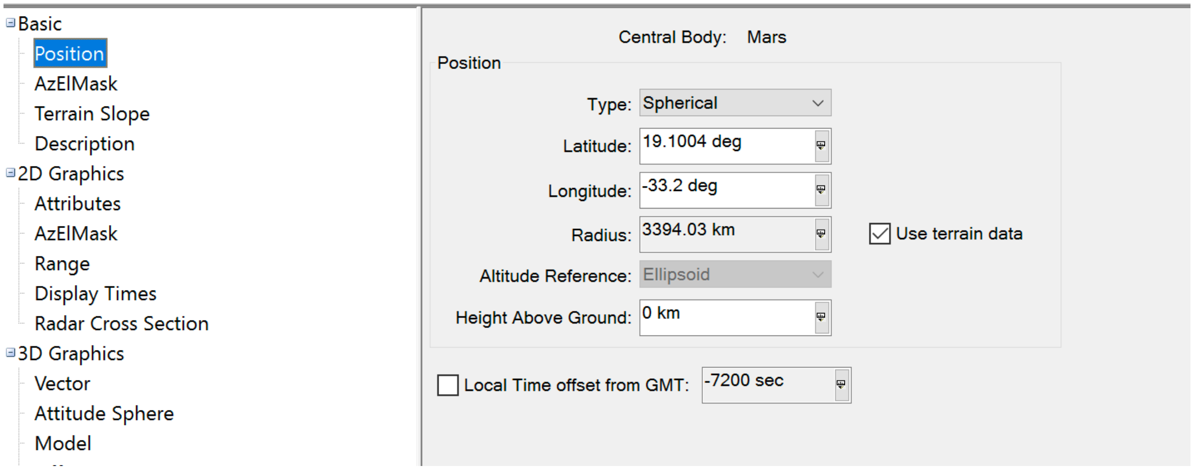
the coordinate system. If you scroll through the summary, you will be provided with the Cartesian coordinate description in the specified coordinate system, the Keplerian orbital elements, a set of spherical state components, elliptical orbit parameters.

Question 3: Take a screen shot / copy the text of the summary only including the sections with the Cartesian state components and the orbital elements. Is there a discrepancy between the specified position and velocity vectors at the beginning of this lab and STK's reported values? How large is this discrepancy? What do you think contributed to any observed difference?

15) Consider a space-based habitat on the surface of Mars, at the 1997 Pathfinder landing site. This landing site is located at 19.1 degrees north latitude and 326.8 degrees east longitude. Create a facility on the surface of Mars to indicate the location of the Mars habitat. To insert a facility, 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: "Facility". Ensure that the central body is selected as Mars. Then, click the "Insert" button.



16) Double click on the new facility object to access its properties window. In the coordinate type dropdown, select "Spherical" and ensure that you see "Central Body: Mars" directly above the dropdown menu. Then, input the longitude and latitude for the human habitat as listed in the previous step. Then, click apply and "OK".



17) To ensure that the groundtrack of the spacecraft orbit appears on 2D Graphics view, navigate to the satellite properties window and then to the "2D graphics"→"Pass" page. Ensure that under the "Ground Track Central Body Display" list, the checkbox next to Mars is selected to "Show" the ground track on the Mars surface picture. Then, ensure that under the "Leading/Trailing" panel on this page, the "Ground Track" "Lead Type" option is selected to "All". By changing this property, you are indicating that you want STK to plot the ground track for as many orbital periods as the satellite path is integrated for.

Question 4: Navigate to the 2D graphics window. For one orbit, does the groundtrack form a closed curve on the surface of Mars? Why or why not?

Question 5: Suppose the orbiter must pass directly over the habitat to capture an image of its location. Does the path of the Mars orbiter pass over the location of the habitat on the Martian surface during its first revolution around the orbit? If not, iteratively modify one single orbital element of the initial state until the groundtrack passes over the Mars habitat during the first revolution. Which orbital element did you modify and why? What value of this orbital element resulted in the orbiter passing directly over the habitat? Take a screenshot of the 2D graphics window, displaying the groundtrack and facility/habitat.

Question 6: Update the propagate segment of the satellite to integrate its path for an entire day and rerun the MCS. How many times in one day does the spacecraft fly over the Mars habitat? Include a screenshot of the 2D graphics window.

PART II: Orbit Determination for Near Earth Objects

In addition to the planets and moons located within our solar system, there are a large variety of celestial bodies such as comets and asteroids. Some of these bodies, named Near-Earth Objects (NEOs) approach the vicinity of Earth. The composition and dynamics of these bodies can provide a wealth of information into the processes that formed our solar system. However, some objects may pose a risk of collision with the Earth or Moon. Accordingly, there have been efforts to characterize NEOs in terms of their orbits, size, composition and dynamics. Let's consider how observational data of a NEO can be converted to a preliminary prediction of the orbit.

Using STK 12/Astrogator, you will create a scenario with a satellite in a heliocentric orbit, i.e. the central body for your scenario should be the Sun. You will use a "satellite" object in STK to model a NEO. Follow the outlined procedure and answer the questions presented throughout:

1) Astrometric observations of a NEO produce the following three position vectors in Sun-centered ICRF coordinates:
    a. At t_1: $\vec{r}_1 = 0.5887\hat{x} - 0.2206\hat{y} + 0.0239\hat{z}\ AU$
    b. At t_2: $\vec{r}_2 = 0.5027\hat{x} + 0.2289\hat{y} + 0.0436\hat{z}\ AU$
    c. At t_3: $\vec{r}_3 = 0.3243\hat{x} + 0.4560\hat{y} + 0.0453\hat{z}\ AU$

Question 7: Write a Matlab script that implements Gibb's method to use the three position vectors to compute the Sun-centered ICRF velocity vector at the second observation time. Include your code in your report.

Question 8: Convert the position and velocity vector at the second observation time to Keplerian orbital elements $(a, e, i, \omega, \Omega, \theta)$ as well as the orbital period. Show your working.

2) Create a new scenario with a start time of 19 October 2017 18:00:00.000 UTCG, and an end date of 19 October 2018 18:00:00.000 UTCG, with the Sun as the central body.
3) In the 3D graphics window, confirm that the central body is the Sun. We will not use the 2D graphics window in this example, so you may close it. In the 3D graphics window properties page, navigate to the "Advanced" tab. Change the "Max Visible Distance" to 1e+012 km to ensure that you can view the objects added to the 3D graphics window from far away.
4) Determine if you need to create a new propagator using the same method as the previous lab: open the component browser from the utilities option in the menu. Navigate to the "Propagators" item in the lefthand panel.
    a. **If the "Sun Point Mass" propagator appears in the list**, double click it and check that it only features a "TwoBody Force" and the gravitational parameter for Sun is close to the value in the textbook.
    b. **If the "Sun Point Mass" propagator does not appear in the list**, single click on the "Earth Point Mass" model in the righthand panel. Then, click the "Duplicate" button. Change the name to "Sun Point Mass" in the popup window. Double click the "Sun Point Mass" entry and a new popup window will appear. Change the

central body to "Sun" and click ok. (Note that there is a heliocentric propagator preset in STK. However, this is not a Sun point mass model)

5) Add a new satellite, with Astrogator selected as the propagator. Ensure that the central body is set to "Sun" at the top of the Astrogator panel. This satellite will represent the NEO that has been observed. Double click the initial state item in the MCS and change the coordinate system in the popup window to Sun ICRF. Set the initial condition of the spacecraft to the Keplerian orbital elements calculated for the second observation time in Question 8, with the initial epoch equal to the scenario start time.
6) Update the representation of the satellite to look like a NEO, by navigating in the satellite properties window to the "3D graphics"-> "Model" page. First, drag the bars on the "Maximum Viewing Distance" panel all the way to the right to 1e+012km. Then, in the "Model" panel on this page, change the "Model File" from "Satellite.dae" to use any picture that corresponds to a natural body, e.g. "eros.mdl". Then, increase the size of the object so that it is big enough to see in its orbit (but of course it will not be to scale!) by changing the "Log Scale" value in the "Model" panel. You may need to press "Apply" and then rerun the MCS for it to be visible.
7) Propagate the satellite using the Sun Point Mass propagator for an entire orbital period (i.e. change the "trip" value for the duration stopping condition.
8) Double click the Propagate segment in the MCS and change the coordinate system to "Sun ICRF".
9) Run the MCS.
10) Add the Earth as an extra "Planet" object via the "Insert Default Object" menu you used to add a satellite earlier.
    a. To define which celestial body this object represents, double-click the Planet in the scenario panel and navigate to the "Central Body" dropdown menu within the "Basic"→"Definition" page of the planet object properties window. Then, select Earth, and leave the ephemeris source as default. Then, click "Apply" to save your changes. The planet object label will update automatically
    b. Next, customize the appearance of the Earth on 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 following boxes: Show inertial position, show orbit, and show position label. Ensure that the "Inherit from 2D Planet Graphics" box is unchecked. You can change the color of the Earth's orbit in the "2D graphics"→"Attributes" panel

Question 9: In the 3D graphics window, add three vectors indicating the Sun ICRF X, Y, and Z directions. Take a screenshot of a useful three-dimensional view of the orbit. Also include a screenshot of the NEO's heliocentric orbit looking down on the plane of motion of the Earth's orbit. Describe the geometry of the NEO's orbit in your own words. Name one perturbation that might affect the motion of this NEO in its heliocentric orbit and explain why you chose this force.

Question 10: Using a three-dimensional perspective of the NEO's orbit, do you think that it crosses the Earth's heliocentric orbit? Assuming this object is an asteroid, what group of NEOs does this object belong to? Use the following website to answer this question: https://cneos.jpl.nasa.gov/about/neo_groups.html Select from the list: Atiras, Atens, Apollos, Amors. Why did you choose this group classification?

Question 11: Play the animation in the 3D graphics window for the first orbit of the NEO from the initial scenario state date. During the first revolution around the orbit, is the timing of the Earth and the NEO in their heliocentric orbits such that a close approach occurs? How would you define a close approach? If there is a close approach, on what approximate date does this occur?

ASEN 3200 Lab O-2 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, etc

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

PART I: Mars Orbiter (40 pts)

- Description of scenario setup and initial parameters
- Theory – explain, with equations, how you converted a set of inertial position and velocity state components to orbital elements. Justify the sign/quadrant of any angles.
- Results and Analysis – show all plots and summarize output generated from STK, 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.
- Results and Analysis – justify reason for any discrepancies between original inertial position and velocity state components and STK computed values.
- Results and Analysis – justify why ground track on Mars surface is not closed curve.

PART II: Near Earth Objects (30 pts)

- Description of scenario setup and initial parameters
- Theory – explain, with equations, how Gibb's method is used to convert three position vector observations to a full state at one time.
- Theory – explain, with equations, how you converted the inertial state vector to orbital elements. You may reference equations used in Part I, if desired.
- Results and Analysis – include your Matlab code with a brief description.
- 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.
- Results and Analysis – 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 did what in the group and any outside assistance

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)