ASEN 5050 – Spaceflight Dynamics

Homework #3

Assigned: Tuesday, February 2, 2021
Due: Tuesday, February 9, 2021 at 8.59pm MT

Notes:

- Use the following planetary constants (from Vallado, D., 2013, "Fundamentals of Astrodynamics and Applications, 4th Edition"):
  - $Gm_{Mars} = 4.305 \times 10^4 km^3/s^2$
  - $Gm_{Saturn} = 3.794 \times 10^7 km^3/s^2$
  - Equatorial radius of Mars: 3,397.2 km
  - Equatorial radius of Saturn: 60,268 km

Problem 1:

Recall that the Cassini mission ended with the spacecraft descending into Saturn's atmosphere. To explore the end of the mission in a manner that is solveable at this point in the semester, assume that the spacecraft does not break up during atmospheric entry – but, rather, impacts the surface of Saturn. Also assume that Saturn is a perfect sphere with a radius equal to the equatorial radius.

At a time t_1, during the final orbit, the position and velocity vectors of the spacecraft are expressed as follows in a Saturn-centered inertial frame $(\hat{X}, \hat{Y}, \hat{Z})$ that uses Saturn's equatorial plane as the reference plane:

$$\bar{r}_1 = -720{,}000\hat{X} + 670{,}000\hat{Y} + 310{,}000\hat{Z} km$$
$$\bar{v}_1 = 2.160\hat{X} - 3.360\hat{Y} + 0.620\hat{Z} km/s$$

a) Calculate the position and velocity vectors of the spacecraft at impact, expressed in the Saturn-centered inertial frame.
b) If the spacecraft really did impact the surface of Saturn, do you think that your prediction of the state vector at impact is accurate? Justify and explain.

Problem 2:

Please install either STK or GMAT on your computer following the instructions that are available on Canvas as soon as you can; alternatively, you can access STK or GMAT via the Cloud Computing site setup by the College of Engineering. I recommend that you complete the installation before the STK/GMAT support session on Thursday 2/4 in case you have questions about STK/GMAT. It may take up to an hour to download and install STK, depending on your internet connection.

Answer the following questions while working through the instructions in the HW 3 Supplement Document, available on Canvas for each software package.

Notes:

- Some of the steps, parameters and answers may be different for each type of software.
- Be sure to show your working for any questions that ask you to calculate quantities

a) (ungraded, optional) Why did you choose to use either GMAT or STK?

b) Use the initial state information to calculate the orbital period and periapsis altitude in the two-body problem (in a useful set of units).

c) On your own and outside of STK/GMAT transform the orbital element description of the initial state to a Cartesian state vector in the Mars-centered inertial frame. Compare the values you computed to the state vector computed by STK or GMAT and, if applicable, speculate on the reason for any differences.
   - In STK, open the initial state segment in the MCS and change the "Coordinate type" to Cartesian.
   - In GMAT, open the spacecraft property window and change the "State Type" to Cartesian.

   On your own and outside of STK/GMAT, transform the calculated Cartesian state vector back into orbital elements and verify that the recovered quantities match the original values provided to you in the lab statement.

d) Include two snapshots of the 3D graphics window in your report, displaying only the "MAVEN" spacecraft orbit computed in the Mars point mass dynamical model: one looking down on the orbital plane, and the other providing a useful three-dimensional perspective.

e) Run the simulation for the "MAVEN" spacecraft and describe its orbit propagated in the Mars point mass dynamical model in your own words, discussing its geometry, orientation and characteristics in as much detail as possible.

f) How do the eccentricity and specific angular momentum evolve over time when you run the simulation for the "MAVEN" spacecraft using the Mars point mass dynamical model for 10 full orbital periods? Is this observation consistent with your expectations?
   - In STK, comment both on the vector directions via the 3D view and the magnitude via the time history plot.
   - In GMAT, comment on the magnitude only via the time history plot.

g) Include two snapshots of the 3D graphics window in your report, displaying only the trajectory of the "MAVEN" spacecraft, propagated in a dynamical model that reflects a higher-fidelity model of Mars' dynamical environment (in STK, incorporating atmospheric drag; in GMAT, a more complex model of the gravitational field): one looking down on the orbital plane, and the other providing a useful three-dimensional perspective.

h) Run the simulation for the "MAVEN" spacecraft and describe its motion in your own words, discussing how the higher fidelity model of Mars' dynamical environment has impacted the geometry, orientation and characteristics of the trajectory during the integration time period.

i) How do the eccentricity and specific angular momentum evolve over time when you run the simulation for "MAVEN" with the higher fidelity dynamical model? Is this observation consistent with your expectations? When, in the orbit, do the values change most significantly and why do you think that is?
   - In STK, comment both on the vector directions via the 3D view and the magnitude via the time history plot.

- In GMAT, comment on the magnitude only via the time history plot.

j) Use the MAVEN website (http://lasp.colorado.edu/home/maven/) to determine the activities being conducted by the MAVEN spacecraft on the epoch corresponding to the initial condition given in this lab statement. Using your research from this website, do you think that the relative two-body problem is a sufficiently good approximation of the dynamical environment to reliably design the trajectory of the MAVEN spacecraft?

Suggestion: Take some time this week to use STK/GMAT to supplement your understanding of the geometry of orbits in three-dimensional space. Try modifying the orbital elements and see how the orbit changes. Or identify a concept that you may be struggling with and try to use the software to investigate further.