ENAE 791 PROBLEM SET 2 – SPRING, 2022

DUE 3/1/22 (OR WHENEVER...)

Revised 2/28/2022 – The original form of this problem set is in error, in that the orbit of Orion produces a hypervelocity entry - that is, the spacecraft skips out of the atmosphere due to excess energy. While it is a bounded entry (it's not going to escape, but enter the atmosphere again later), the entry is considerably off-nominal. I apologize for not checking this earlier.

At this point, you have three options:

- You can propagate the trajectory from entry to exit and call it good enough
- You can continue to propagate the trajectory through subsequent entry and descent
- You can redo (2) from a low Earth orbital entry starting with a circular orbit at an altitude of 350 km

Whichever option you choose will receive full credit. Take any extra time you need before turning in the problems. Again, sorry about this.

(1) A spacecraft is in orbit around the Earth. Its position and velocity can be expressed in an inertial Cartesian frame centered on the gravitational center of the Earth with the Z axis oriented through the north pole as $\bar{X}$={0, 11681, 0} (km) and $\bar{V}$={5.134, 4.226, 2.787} (km/sec). Write a computer routine (program, MatLab script, or Excel spreadsheet, whatever works for you) to numerically integrate the planar state equations derived in class. Starting with the state specified, propagate the orbit forward through one orbital period. What are the position and velocity errors in your numerical prediction as compared to the calculated orbital state? (Note: we're going to be adding on to this program throughout the term to incorporate atmospheric drag, lift, and launch thrust, as well as out-of-plane motions. It's in your enlightened self-interest to write the code cleanly enough you can continue to modify and reuse it throughout the term.)

(2) Extend your computer routine from (1) to incorporate aerodynamic lift and drag and numerically integrate the planar state equations derived in class as necessary for the following problems.

(a) The Orion test flight on December 4, 2014, involved a test of the heat shield for the Orion spacecraft. The spacecraft reached an apogee *altitude* of 5800 km and reached entry interface at an altitude of 122 km. If the desired flight path angle at entry interface was -2.5^o, find the entry velocity for the spacecraft.

(b) The Orion spacecraft had a mass of 10,400 kg, a base diameter of 5 meters, and a hypersonic c_D of 1.2. Find the ballistic coefficient for the entry vehicle.

(c) Calculate the trajectory of the Orion spacecraft undergoing a ballistic entry under these conditions. Plot (a) altitude vs. velocity, (b) altitude vs. time, (c) altitude vs. downrange distance, and (d) deceleration vs. altitude for this trajectory. What is the peak deceleration? What is terminal velocity?

(d) Repeat (c) for a lifting entry with the lift vector pointed upwards and an L/D of 0.25.