Open Final Exam

DUE Tue 2025-12-09 @ **23:59**

Guidelines

- Take home exam; open until to Tue 2025-12-09 @ 23:59
- ***Open book*** including:
  - Use of course textbook (*Curtis*) either in print or electronic
  - Use of all class materials available on Canvas for *this* course (AA310 AU25)
  - Use of *your* own functions in Matlab/Python
  - Use of computers/calculators/etc to help with math processing
  - Use of *your* own “cheat sheets”, notes, summaries, etc.
  - Use of online **general** information (such as size/mass of planets, radius of planet orbits, etc), but…
- ***NOT permitted***:
  - Searching online for a solution
  - Use of any “AI” or similar tools to ask for a solution or check
  - Collaboration of any kind
  - Use of someone else’s notes
  - Previous solutions to AA310 or equivalent classes
- **Reminder: show your work!**
  - The “correct answer” is worth ~30% of the credit - showing your work is 70%!
  - Show and comment all your code
    - If you use code from a previous HW, exam, or project, state that (you do *not* have to explain it again or even include the source, if it has not changed at all since then)
  - Reference equations from class (either “Lecture # Slide #”, or “Curtis #.##”, etc)
  - All questions that say “explain”, “conclude”, “analyze”, etc, require written explanations in addition to numerical answers
- **Turn-in:**
  - Submit PDF document/scan on Canvas by Tue 2025-12-09 @ 23:59

1. ESCAPADE

On 2025-Nov-13 Blue Origins launched its second New Glenn Booster carrying a mission to Mars that follows a unique and innovative trajectory. With your knowledge of AA310 ***you*** can make sense of this new trajectory!

a. New Glenn 2

i. The New Glenn 2 booster completed its firing approximately at T+00:03:10, at an altitude of 252,287ft at a speed of 4,674mph. Ignoring the effects of the atmosphere, and assuming that speed is all tangential[1], what would be the parameters [a, e, r_p, r_a, v_p, v_a, b, h, T, en] of the "orbit" for the booster? (if Earth did not get in its way)

ii. How does the value of e (eccentricity) relate to HW1 Problem 2 (reduced gravity airplane)?

iii. Comment on some of the other "interesting" results

b. The "parking" orbit

ESCAPADE, an un-manned mission, will *not* have a traditional circular parking orbit. It will "loiter" around the Earth-Sun L2 Lagrangian point. That point is approximately 1.5 million kilometers beyond the Earth.

i. Draw (by hand, computer, or plot if you want) an approximate figure of the L2 Lagrangian point showing the Earth, the Sun, and the L2 point.

ii. What trajectory (what e (eccentricity), approximately) should ESCAPADE take so that it can reach the Lagrangian point with almost 0 speed?

iii. The *argument of perigee* of the mission was -179.7°. Why?

iv. Given that the booster sped ESCAPADE to 4,674mph, how much more Δv must the 2nd stage impart to get it to L2 from 200km altitude[2]? (In other words: what velocity must ESCAPADE have at the end of the 2nd stage firing to reach L2?) - Do this *approximately* with the trajectory from point (iii) above.

[1] Which is not correct, the rocket was still increasing altitude.
[2] Stage 2 continued to increase altitude after the stage 1 booster.

c. Aligning the orbit

New Glenn launched at an inclination of 29.5°. The Earth equator is inclined 23.45° to the Earth-Sun orbital plane. For simplicity, lets assume that the correction is the difference between those: 6.05° [3].

Assuming that the Earth-Sun inclination correction must happen on its own (not at the same time as the other Δv's):

i. What is the Δv's required if it is done "immediately" after reaching v_{esc}?
ii. What if it could be done immediately after Stage 1 separation?

d. Waiting for Mars

Escapade will wait at L2 for a whole year, before leaving to Mars in November 2026. Approximating the wait as 365 days: where was Mars with respect to Earth when New Glenn 2 launched? Provide both the math and a drawing (by hand, using the computer, plot if you want). (Only use information in this question and previous AA310 work, you may **not** use an online search, simulator, or any other method.)

e. Using Earth to go to Mars

After waiting around L2 for a year, ESCAPADE will do a fly-by of Earth to enter its Hohmann[4] trajectory to Mars.

i. If we assume a *straight* trajectory from L2 back to Earth[5], then Earth needs to impart a turn angle of $\delta=\pi/2$. What is the eccentricity needed for this turn?

To minimize the possibilities of ESCAPADE affecting current satellites, it cannot come closer than 40,000km above the surface of the Earth[6] (farther away than GEO satellites).

ii. What is all the other information about the orbit? (r_p, r_a, a, b (= Δ), h, θ_∞, β, δ, v_∞, v_{esc}, v_p, ε)

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[3] This would depend on the time of year and location and direction of departure, if done wrong, it could mean adding the two!
[4] ESCAPADE is using electric propulsion, so the real trajectory will not be exactly a Homann transfer, but we will approximate that for this exercise.
[5] Which is *not* what ESCAPADE is doing, it is using the *instability* of L2 to get pulled by Earth, but that is beyond AA310.
[6] I made this one up.

iii. What does v_∞ have to do with ESCAPADE?

iv. Comment on the aiming radius.

v. Would this maneuver actually get you on the way to Mars? If yes: show that you have everything you need; if not, show what is missing.

f. The real thing…

The ESCAPADE mission is actually **two** satellites that will orbit Mars. Initially they will be in the same orbit with an offset in their true anomaly. Then they will change to two orbits with different apse lines. This will require yet more Δv's!

But because all of those maneuvers will be done with electric propulsion, **you are done with this problem**! (Please do not miss Problem 2 below!)

And OK, you did not truly analyze the full mission. There are a lot of details skipped, and a lot of these parts are not the actual ESCAPADE orbital trajectories. They were heavily simplified for the test.

You are strongly encouraged to go see more about the real mission:

NASA Mission homepage
`https://science.nasa.gov/mission/escapade/`
Berkeley (PI) Mission
`https://escapade.ssl.berkeley.edu/`
Simulation trajectories
`https://svs.gsfc.nasa.gov/14915`
(this last one is the most fun WRT AA310, especially the L2 "loiter" simulation!)

2. Assumptions and more Assumptions

Throughout the **whole** class many assumptions were made.

List what you consider to be **the 3 <u>most important</u> assumptions made <u>as part of the derivations and analysis in the class</u>** (directly related to the orbital mechanics work we did in the class) that you believe need to be corrected before you use the materials you learned in this class on an actual mission.

For **each** of the **3** assumptions provide the following parts in your explanation:

a. Identify the assumption in a couple words (give it a "title")
b. Provide a technical explanation (ie, related to physics, math, etc) of the assumption *in terms of orbital mechanics*
c. Explain why you believe the assumption *must* be corrected before using the results in a full mission (i.e., what quantitative error has an effect substantial enough that it cannot be ignored)

Valid answers must be:
(i) an assumption discussed in class and/or as part of a homework/project
(ii) technically correct - i.e., the technical explanation is correct and based on math/physics
(iii) the effect of the assumption must be substantial, such that it must be corrected before a real mission

Change Log

2025-11-05 13:35	alvarso@uw.edu	Problem 1a - clarified "speed is all perpendicular to Earth" to "speed is all tangential".