Programming and Mathematics of Astrodynamics and Trajectory Design 2022-2023

IMPORTANT INFORMATION ON THE PRACTICAL ASSESSMENT

- A Turnitin submission of a short practical work (2-3 pages) on trajectory design together with developed code and libraries.
- The list of deliverables is (submissions points for the items below are in canvas):

    1. A report containing technical explanation of the trajectory design methodology and the results. Recommended sections should be: Abstract; Methodology; Results and Conclusions. The maximum allowed length for the report is 3 pages. NOTE the report must describe only one of the ASSESSED EXERCISES.

        The report represents a mission analysis executive report submitted to a space agency. This is; the report should contain a clear description of the analysis done and the scope of it, your conclusions and recommendations for the mission. It should provide sufficient evidences of the reliability of the results.

        Further details on the report and the marking rubrics are given in the introductory presentation of the module. **NOTE the report must be submitted via Turnitin submission point in CANVAS.**

    2. Code: Submit the scripts and functions to run the assessed exercise, at least one exercise from Session 1 (Lambert Arc) and at least one from session 2 (Pork-Chop).

        ✓ You can choose which ones to upload:

        Assessed Exercises: #1, #2 or #3 (only one of the previous)

        Sessions Lambert Arc: #1, #2, #3, #4, #5, #6 or #7 (at least one of the previous)

        Sessions Pork-Chop: #2 (send exercise 2 (i.e. nested-loop))

        ✓ Make sure that the script you send works and that you submit all necessary functions. Note I will need all your libraries to run it, so make sure you upload all the necessary libraries. This is all the functions you created. **NO NEED TO SEND ME MY OWN TOOLBOX, PLEASE.**

        ✓ For ease, zip all your files and submit only one file through Canvas.

        ✓ The assessed exercises increase in difficulty, hence #1 is the simplest. Make sure you complete #1, before challenging yourself with #2. Submitting #1 is perfectly fine.

        ✓ Prepare your report only for the assessed exercise for which you are more confident with (and submit the corresponding report and exercise).

Matlab Guide Assessed Exercises

Assessed Exercise 1. Your space agency is preparing a Mars remote sensing observation mission. The mission is intended to be launched between 1/01/2024 and 31/12/2025. The orbiter has a mass of 1250 kg and a propulsion system with an Isp of 310s. The targeted final orbit is a 400 km circular orbit.

Perform a complete assessment of Earth-Mars direct insertion launch opportunities for a Falcon 9 Heavy launch with booster recovery (see below performance of this launcher). Your space agency programme manager is interested to know the extend of the launch window opportunity and your recommendation as baseline launch date.

Note: Since the objective is to insert the spacecraft in its operational circular orbit, a launch opportunity will be defined as any launch date that allows you to insert the spacecraft dry mass into the 400 km circular orbit. The inclination of the Mars circular orbit is not constrained (which is to say that is ignored at this stage).

Hence, the objective is to construct a script or a function that given a departure date and a time of flight (or an arrival date) it computes how much mass Falcon 9 inserts into interplanetary orbit. Next, with this mass and the Isp, the final mass into the final Mars orbit can be computed.

Note that Falcon 9 launch performance is provided in slide 29. Neglect launch adapter mass.

1. Make sure ATATD-Toolbox is in the Matlab *path*.

2. Initialize the constants that you will need for this exercise. You will certainly need the Sun μ_{Sun}, Mars μ_{Mars}, and Mars' radius R_M.

3. Initialize a matrix where you will store all the Final Mass solutions by assigning it an array of zeros, using the function *zeros*.

4. Create a nested for-loop, such as:

```
for m = 1:j
   for n = 1:k
      <statements>;
   end
end
```

5. Inside the nested for-loop, compute each instance of the Lambert arc by solving the Lambert arc function:

$$[v_1, v_2] = Lambert\left(r_1, r_2, ToF, t_m, \mu_{Sun}\right)$$

6. Be watchful of the two types of transfers you can compute; the long path transfer and the short path transfer. Use the sum of the Excess velocities to distinguish whish one is a better option. Hence, at each iteration of the nester for-loop both cases need to be computed.

$$[v_1^{short}, v_2^{short}] = Lambert\left(r_1, r_2, ToF, +1, \mu_{Sun}\right)$$
$$[v_1^{long}, v_2^{long}] = Lambert\left(r_1, r_2, ToF, -1, \mu_{Sun}\right)$$

7. Compute the Δv for each of the two options:

$$\Delta v^{short} = \left| v_1^{short} - v_{Earth} \right| + \left| v_{Mars} - v_2^{short} \right|$$
$$\Delta v^{long} = \left| v_1^{long} - v_{Earth} \right| + \left| v_{Mars} - v_2^{long} \right|$$

8. Identify which one of the two offers a better transfer option:

```
% Check which of the two transfers is optimal

[~,indexMin]=min([DV_Short DV_long]);
```

9. Using the relevant excess velocity v_∞, compute the wet mass that proton can launch:

```
%% Falcon 9 Heavy - with recovery
    C3_vector=[0 5 10 15 20 25 30 40];
    WetMass_vector=[5750 5000 4250 3600 3000 2400 1900 1000];
    max_vinf=sqrt(40);

if v_inf_Earth<=max_vinf
    C3_Ex4=v_inf_Earth^2;
    massWet = interp1(C3_vector,WetMass_vector,C3_Ex4);
else
    vinfLauncher=max_vinf;
    C3_Ex4=vinfLauncher^2;
    massWet0 = interp1(C3_vector,WetMass_vector,C3_Ex4);

    DV_remaining=v_inf_Earth-vinfLauncher;
    ve=310*9.81;
    massWet=massWet0*exp(-(DV_remaining*1000)/ve);
end
```

10. Compute the final mass at arrival at the Mars' operational orbit. Recall:

Mars Arrival

$$v_{cirM} = \sqrt{\frac{\mu_M}{r_{pM}}} \qquad v_{pM} = \sqrt{\mu_M \left(\frac{2}{r_{pM}} + \frac{v_\infty^2}{\mu_M} \right)}$$

$$\Delta v_2 = v_{pM} - v_{cirM}$$

11. Store the final mass at completion of each loop iteration

```
% Nested for-loop to scan through all the potential Lambert arcs
for iD=1:length(LaunchWindow)
    for iA=1:length(TOF)
%       [...]
        %-----------------------------------------------------------------
        % Storing Solutions
        FinalMass_Matrix(iD,iA)=Mass_final;
    end
end
```

9. Plot the results using contourf.

Assessed Exercise 2. A team of planetary scientist want to propose an exploration mission to a Near Earth Asteroid for the Fast-Class Mission Call from ESA's Science Directorate. The mission boundary conditions state that your spacecraft will be launched together with ESA M-Class Mission ARIEL and piggy-backed to the Sun-Earth L2 point. Your mission will be deployed at the L2 point between 1/1/2028 and 31/12/2028. The total wet mass of your mission cannot be larger than 850 kg and the main propulsion system for the spacecraft has an Isp of 310s. Find a good rendezvous opportunity that is suitable for their mission.

Hint: Using a patched conics approximation, a departure from L2 is equivalent to a departure from the Earth position (in heliocentric coordinates) and a v_∞ =0 km/s.

If their payload weights 20 kg. Can you find any suitable asteroid to rendezvous with? What are the launch window opportunities? Assume that about 15% of the final dry mass is available for payload.

1. Make sure ATATD-Toolbox is in the Matlab *path* (Toolbox available in blackboard under Assessed Exercise material).

2. This new toolbox contain three new files: a new ephNEO a mat-file containing the ephemeris for nearly 20,000 asteroids, and a .cvs file where on top of the ephemeris. The .cvs file can be found under /ATATD-Toolbox and you can use it to see what is the name of the asteroid corresponding to a given "ID of the body".

3. Have a good search!

Assessed Exercise 3. – ***Asteroid Mining Tech Demo***

Search for Asteroid Sample Return mission opportunities for commercial nanosatellite demonstrators for asteroid mining.

The mission should be launched not before 1/1/2030 and completed not later than 31/12/2035. Given the constraints on launch and Δv capability, **ideally**, the nanosat transfer opportunity should satisfy the following requirements:

- The hyperbolic excess velocity of the departure shall be v_∞<1.5 km/s.
- The hyperbolic excess velocity of the arrival shall be v_∞<1.5 km/s.
- The asteroid arrival rendezvous manoeuvre shall be < 500 m/s
- The departure rendezvous manoeuvre shall be < 500 m/s
- Asteroid operation phase should be between 2 to 6 month long.

Provide an analysis of transfer opportunities satisfying the above boundary conditions or challenge the requirements if they turn out to be impossible to satisfy.

1. Make sure ATATD-Toolbox is in the Matlab *path*.

2. This new toolbox contain three new files: a new ephNEO a mat-file containing the ephemeris for nearly 20,000 asteroids, and a .cvs file where on top of the ephemeris. The .cvs file can be found under /ATATD-Toolbox and you can use it to see what is the name of the asteroid corresponding to a given “ID of the body”.

3. Have a good search!