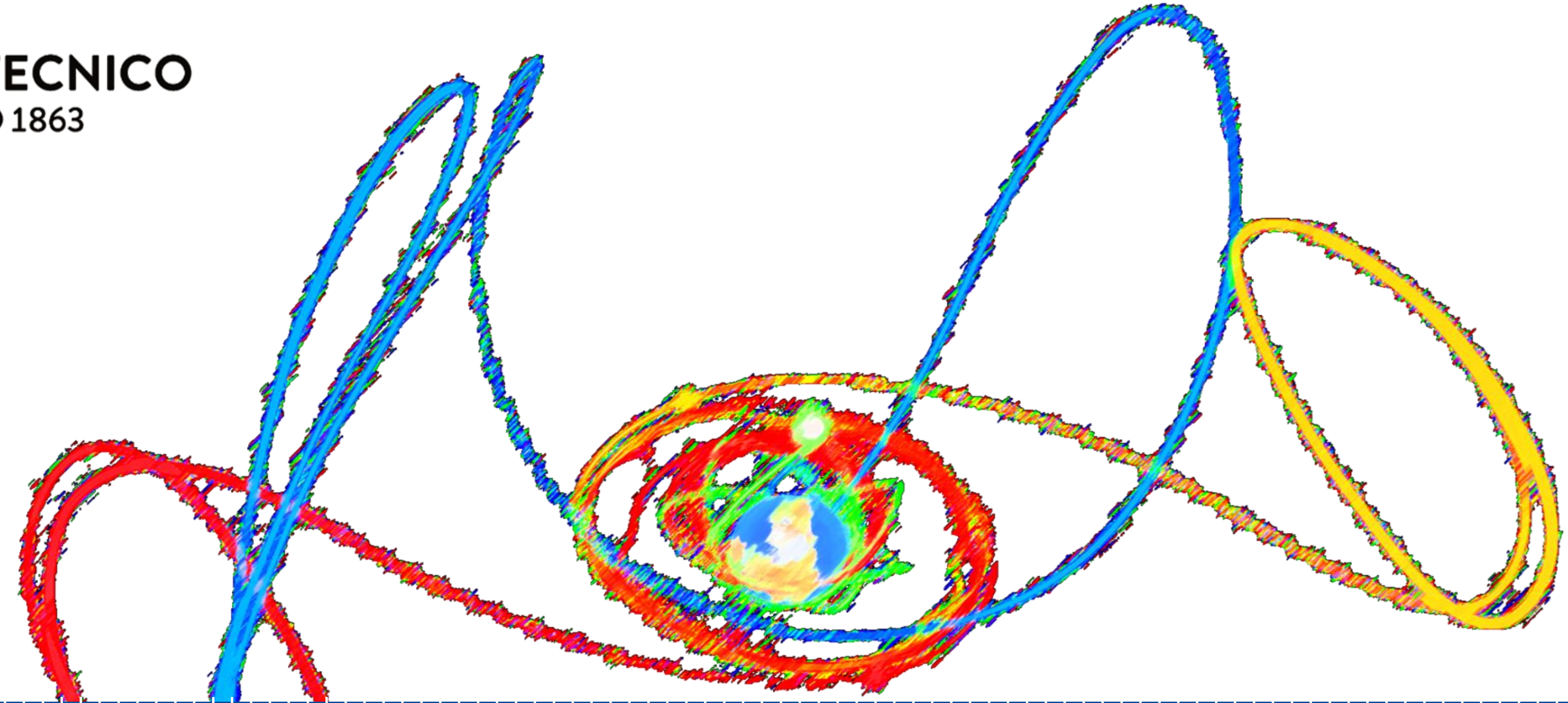
POLITECNICO
MILANO 1863



Orbital Mechanics
Lab Assignments

Giacomo BORELLI, Lorenzo GIUDICI, Mathilda BOLIS, Juan Luis GONZALO GOMEZ, Camilla COLOMBO
Department of Aerospace Science and Technology, Politecnico di Milano

Academic year 2023/24

Contents

Assignments 1 & 2

Assignment 1

INTERPLANETARY EXPLORER MISSION

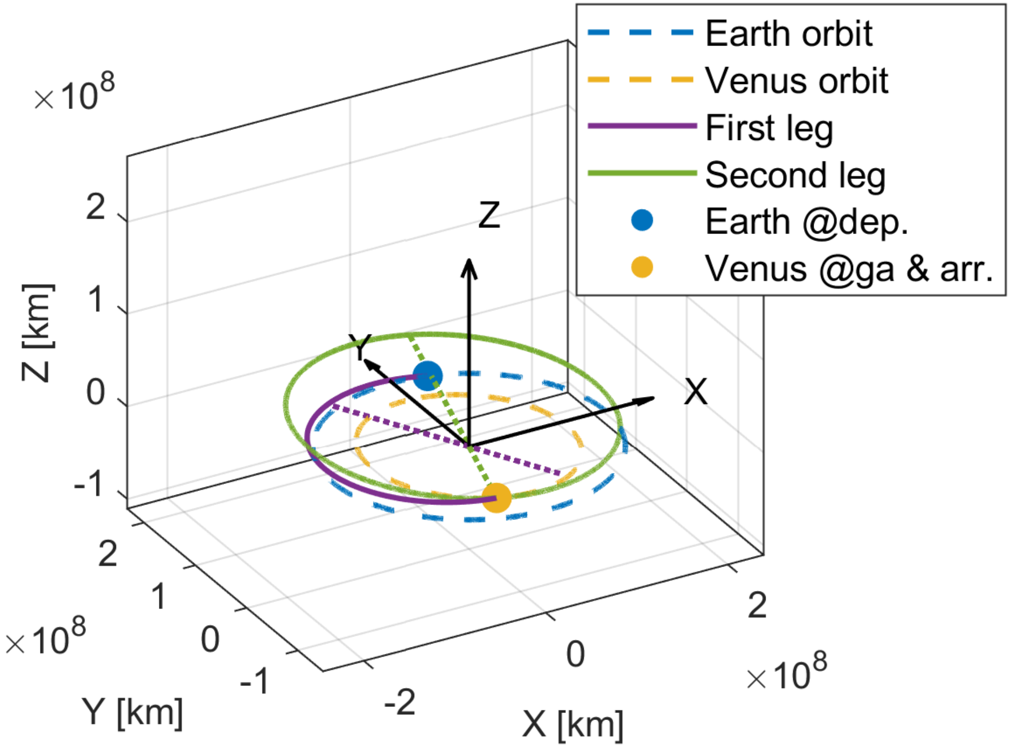
Interplanetary Explorer Mission

First Assignment

The **PoliMi Space Agency** is carrying out a feasibility study for a potential **Interplanetary Explorer Mission** visiting a body in the Solar System (planet or asteroid), with an intermediate flyby on a planet.

As part of the **mission analysis team**, you are requested to perform the **preliminary mission analysis**. You have to study the transfer options from the departure planet to the arrival body, with a powered gravity assist (flyby) at the intermediate planet, and **propose a solution based on the mission cost** (measured through the total Δv).

The departure planet, flyby planet and arrival body have been decided by the science team. Constraints on earliest departure and latest arrival have also been set by the launch provider, the systems engineering team, and the Agency's leadership.



Interplanetary Explorer Mission

Mission requirements

- Each group has the following **mission requirements** (available in WeBeep):
  - Departure planet,
  - Flyby planet,
  - Arrival object: either a planet or a near-Earth object (NEO) identified by its ID in `ephNEO`,
  - Earliest departure and latest arrival dates.
- Use the **method of patched conics.**
- **Do not consider planetary departure and insertion**, that is:
  - Initial heliocentric orbit is equal to that of the departure planet,
  - Final heliocentric orbit is equal to that of the arrival asteroid.
- Use `uplanet` (in WeBeep) to compute the ephemerides of planets, and `ephNEO` (in WeBeep) for the ephemerides of NEOs (see comments in the code for names of NEOs).
- The figure of merit for the mission is the total cost in terms of Δv_{tot}.
  - Other criteria should be taken into account, such as **altitude restrictions during the flyby**.

Interplanetary Explorer Mission

Mission analysis outputs (1/2)

The mission analysis should cover the following points:

1. **Design process**, detailing:
   - Initial choice for the time windows, justifying it based on the characteristics of the mission.
     - Do not just take the whole time interval provided in the mission requirements for both departure and arrival windows. Choose and justify them based on the characteristics of your mission.
   - Additional constraints considered (such as minimum altitude of the closest approach during the flyby).
   - Strategy followed to **explore, analyse and compare** the different transfer options.
   - **Justified selection of a final solution.**
   - **Plots and data supporting your design choices** (e.g., ΔV cost plots, preliminary estimates,…).

Interplanetary Explorer Mission

Mission analysis outputs (2/2)

The mission analysis should cover the following points:

2. **Final solution**, including:
   - **Heliocentric trajectory.**
     - Departure, flyby, and arrival times.
     - Characterization of the interplanetary transfer arcs.
     - Plot of the heliocentric trajectory, together with the orbits of the three celestial objects and their positions at departure, flyby, and arrival.
   - **Flyby (powered gravity assist).**
     - Altitude of the closest approach.
     - Time duration of the flyby (considering a finite SOI).
     - Comparison of the total velocity change due to the flyby Δv_{fb} with the cost of the powered manoeuvre at pericentre Δv_{ga}.
     - Plot of the incoming and outcoming hyperbola arcs.
   - **Cost of the mission in terms of $\boldsymbol{\Delta v_{\text{tot}}}$**
     - Detail the separate values of Δv_{dep}, Δv_{ga}, and Δv_{arr}.

POLITECNICO
MILANO 1863

Assignment 2

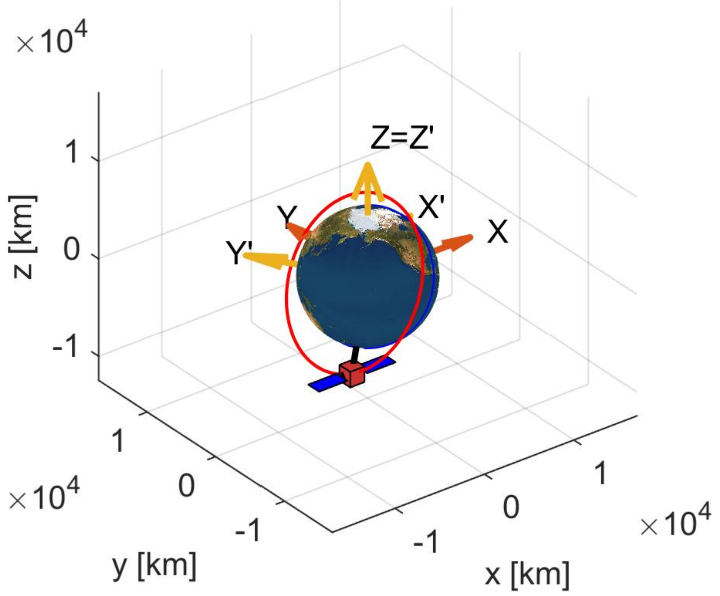
PLANETARY EXPLORER MISSION

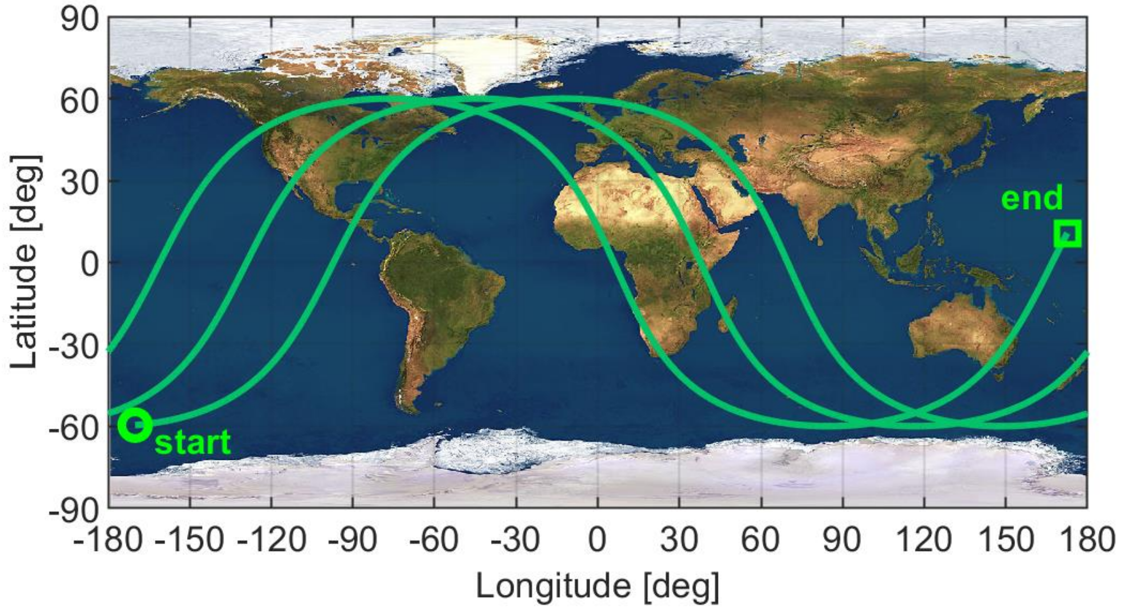
Planetary Explorer Mission

Second Assignment

The **PoliMi Space Agency** wants to launch a **Planetary Explorer Mission**, to perform Earth observation.

As part of the **mission analysis team**, you are requested to carry out the **orbit analysis and ground track estimation.** You have to study the effects of **orbit perturbations**, and compare different **propagation methods**. Also, you have to characterize the **ground track**, and propose an orbit modification to reach a **repeating ground track** (for better communications with our network of ground stations).

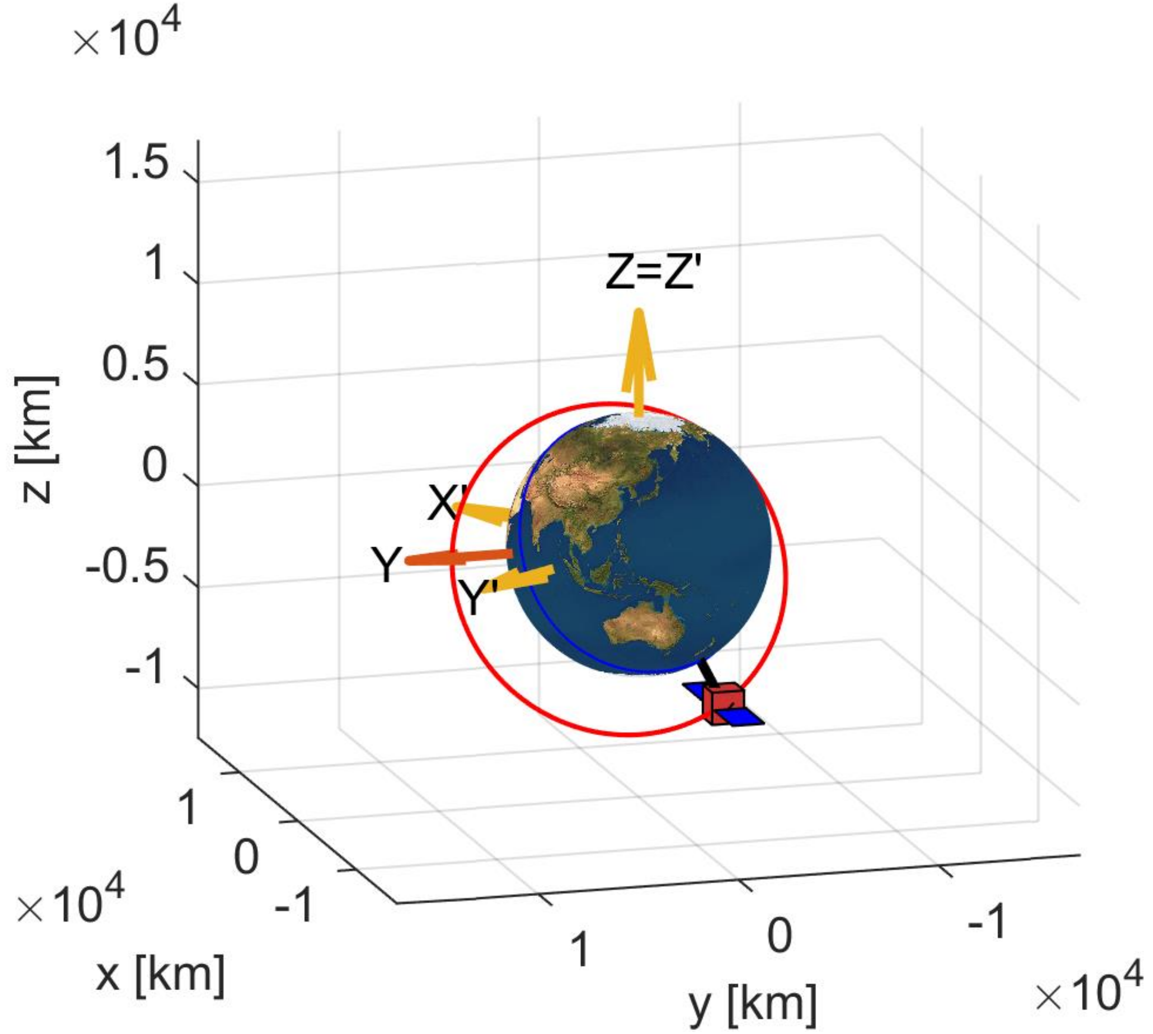




Planetary Explorer Mission

Mission requirements

- Each group has the following **mission requirements** (available in WeBeep):
  - Central planet: Earth,
  - Nominal operational orbit,
  - Orbit perturbations to be considered,
  - Ratio of satellite and Earth revolutions for the repeating ground track.



Planetary Explorer Mission

Mission analysis outputs (1/3)

1. **Nominal orbit,** indicating its initial values and main characteristics.
   - Data in WeBeep does not include Ω, ω, and f_0. You can choose them freely**.**

2. **Ground track**
   a) Plot the ground track of the nominal orbit for the unperturbed 2BP, over different times relevant to your orbit (e.g., 1 orbital period, 1 day, 10 days, pay attention to select times relevant for your orbit).
   b) Modify the semimajor axis to obtain a repeating ground track, and plot it:
      - For the unperturbed 2BP,
      - Use the ratio for satellite and Earth revolutions given in WeBeep.

   c) Plot again the ground tracks for the nominal orbit and for the modified orbit in point **b)**, adding the assigned perturbations to the orbit propagation (J_2 + see table in WeBeep)
      - Does the repeating ground track solution from point **b)** still work under the presence of perturbations? Why?

IMPORTANT: The modified value of semimajor axis should only be used for the ground track analysis. For the rest of the assignment, use the nominal value given in WeBeep.

Planetary Explorer Mission

Mission analysis outputs (2/3)

3. **Propagate the orbit with the assigned perturbations** (J_2 + see table in WeBeep), in:
   a) Cartesian coordinates,
   b) Keplerian elements through Gauss's planetary equations.

4. **Plot the history of the Keplerian elements:**
   a) Choose an adequate and reasoned propagation time based on the assigned perturbations (that is, long enough to observe the effect of all the perturbations),
   b) Choose proper units for time, use degrees for angles,
   c) Compare and analyse the evolution of each element,
   d) Compare both propagation methods (in terms of relative error, computational time, etc).

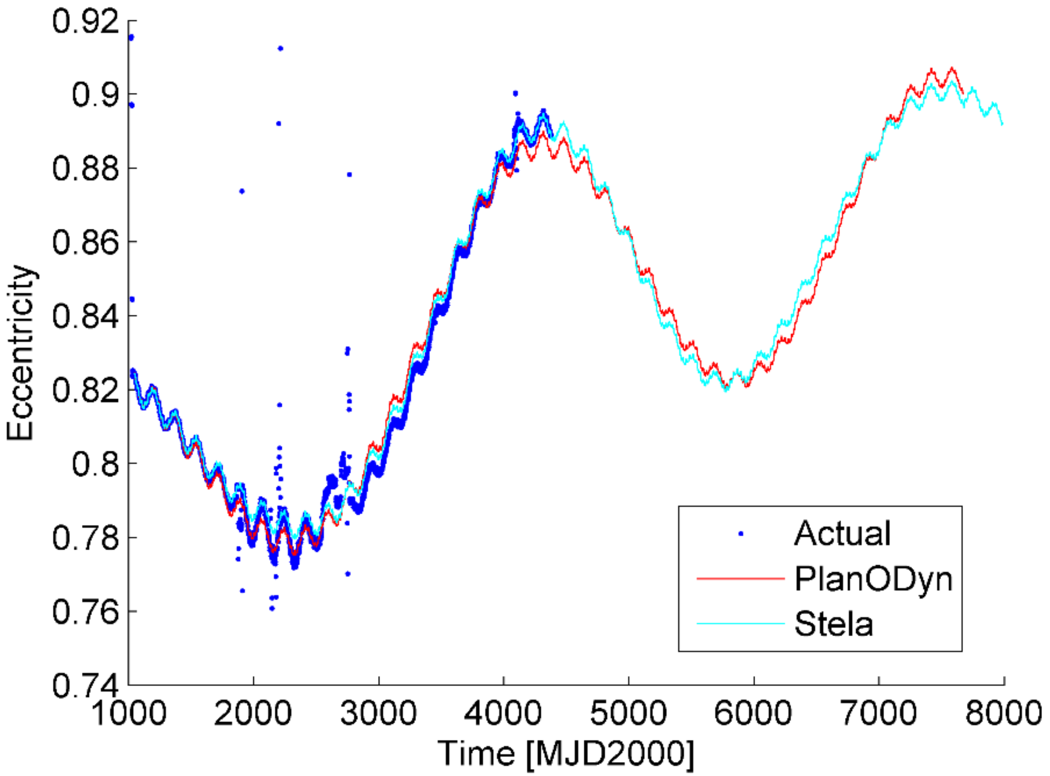
5. **Represent the evolution of the orbit** (image or movie)

Planetary Explorer Mission

Mission analysis outputs (3/3)

6. **Filtering of high frequencies:**
   a) Use a low-pass filter (e.g., `movmean`) to remove high frequencies in the orbital elements, retrieving the long-period and/or secular evolution. You can do more than one filter (i.e., with different cut-off frequencies) for the different time scales.
   b) Plot the results (you can plot together filtered and unfiltered evolution)

7. **Comparison with real data:**
   a) Select an object (i.e., debris, rocket body, satellite, etc.) in the same orbital region, and download its orbital elements (for a significant time span).
   b) Propagate its orbit using your model, using as initial condition the orbital elements for the real object at the initial time.
   c) Compare the downloaded elements with the results from your model.



POLITECNICO
MILANO 1863

GENERAL INSTRUCTIONS

Project

Auxiliar functions available in WeBeep

- For the assignments, you may use the auxiliar MATLAB functions **available in WeBeep**:
  - `astroConstants`: Use it to retrieve common astrodynamics constants (both assignments).
  - `lambertMR`: Use it for solving each Lambert arc (Assignment 1).
  - `uplanet`: Planets' ephemeris (**don't propagate the planets' orbits yourself**).
    - In Assignment 1, use it to compute the ephemerides of departure and flyby planets.
    - In Assignment 2, use it to compute the Sun-Earth position vector for SRP evaluation.
  - `ephMoon`: Analytical ephemeris of the Moon.
    - In Assignment 2, use it to compute the Moon position for third-body perturbation evaluation.
  - `ephNEO`: Ephemerides of several Near-Earth Objects.
    - In Assignment 1, use it to compute the ephemerides of arrival NEO.
  - **timeConversion.zip**: Compressed folder with several time conversion routines

Teamwork

As in a **Mission Analysis team** at **ESA**, you will also work in a group:

- Members of the group must **cooperate**: you are advised to share the work among the team, but **everyone is responsible for all the work done in the project**. This means the work of the team must be checked by the whole team.
- Make decisions towards design solutions based on numerical/analytical/physical evidence and analyses: you must always be able to **motivate your design choices**. *You are supposed to perform the preliminary mission analysis of a real mission*.
- During the final review (oral presentation), **any team member can be questioned about any part of the work**.

Project deliverables and deadlines

Overview

- Project evaluation includes:
  - **Deliverables** (1 submission per group)
    - **Project report**: A single PDF report on the assignments, of maximum **15 pages (total no exceptions)**
    - **Presentation slides**
    - **Simulation codes and results**
    - **Numerical results**, to be submitted via a form
  - **Peer evaluation**
  - **Oral presentation (final review)**
    - **15 minutes** followed by questions about the assignments and the theory of the course
    - All team members must participate in the oral presentation
    - Any student can be questioned about any part of the work

Project deliverables and deadlines

Submission procedure and deadlines

- The deliverables must be submitted through **WeBeep**
  - Submit a **single ZIP file** with **report, slides, and code**, named "`OrbitalMech_group_nnnn.zip`", where `nnnn` is the group ID (e.g., `OrbitalMech_group_2342.zip`).
  - WeBeep **submission file limit is 250MB**. Larger submissions sizes are not allowed (nor needed).
  - **Numerical results for specific questions** and **peer review** submitted via activities in WeBeep.
  - Submissions via any other means will not be considered.
  - Changes to the deliverables after the deadline will not be considered.
- Deadlines:
  - **Deliverables must be submitted by 10 January 2024**.
    - Delivering the project is a must condition for the oral presentation and attending the written exam.
    - The delivery activity in WeBeep closes automatically on 10 January at 23:59.
  - **Oral presentation**
    - Dates will be available during the Winter, Summer and September exam sessions. They will be notified at the beginning of each session.
    - To be done before or within the same exam session (winter/summer/autumn) when the written is done.

Project deliverables and deadlines

Report

- **Single PDF of maximum 15 pages (both assignments in the same report).**
- Include a **front page** with:
  - Title,
  - Group number, academic year,
  - For each member: full name, matriculation number, and person code.
- The report should contain **explanations, data, figures, and tables supporting your design process and final solution.**
  - You may follow the structure in the ‘Mission analysis outputs’ slides.
  - **Properly indicate the units of all numerical data**.
  - **Include labels, legends and titles/captions in all figures**.
  - No need to include theory, but properly introduce/reference all the formulas and models you use.
  - Include a ‘References’ section with a list of all the sources you consulted, and cite them in the text where appropriate.
  - Properly credit all images taken from other sources.

Project deliverables and deadlines

Code

- The codes for both assignments must be included inside a folder named `Code`, with **two separate subfolders for each assignment** as follows:
  - **Assignment 1**: Subfolder `Code\Assignment1\` containing:
    - `InterplanetaryMission_group_N.m`: main script that reproduces your results (`N` is the group ID).
    - `Code\Assignment1\functions\`: subfolder with **all the other functions you developed** for the first assignment.
  - **Assignment 2**: Subfolder `Code\Assignment2\` containing:
    - `PlanetaryMission_group_N.m`: main script that reproduces your results (`N` is the group ID).
    - `Code\Assignment2\functions\`: subfolder with **all the other functions you developed** for the second assignment.
- No need to upload the functions we provide to you in WeBeep, unless you modified them.

Project deliverables and deadlines

Code headers

- Each code file must include a **header** detailing:
  - Inputs and outputs (specify dimensions and units),
  - Authors,
  - Basic usage information

```
function dy = ode_2bp( t, y, muP )
%ode_2bp ODE system for the two-body problem (Keplerian motion)
%
% PROTOTYPE:
%   dy = ode_2bp( t, y, mu )
%
% INPUT:
%   t[1]        Time (can be omitted, as the system is autonomous)  [T]
%   y[6x1]      Cartesian state of the body ( rx, ry, rz, vx, vy, vz ) [ L, L/T ]
%   muP[1]      Gravitational parameter of the primary [L^3/T^2]
%
% OUTPUT:
%   dy[6x1]     Derivative of the state  [ L/T^2, L/T^3 ]
%
% CONTRIBUTORS:
%   Student 1
%   Student 2
%
% VERSIONS
%   2020-11-19: First version
%
```

Project deliverables and deadlines

Final review

The **final review** will take the form of an oral presentation, followed by several questions:

- **Maximum 15 minutes for both assignments combined (not including the questions).**
- All team members have to participate in the oral presentation.
- **Any student can be questioned about any part of the work.**
- Questions can be related to the **report contents, design process, underlying theory, and final results.**

References

- Lecture notes and lab slides.
- Spacecraft orbital elements available at:
  - Space-Track: https://www.space-track.org
  - Celestrack: https://celestrak.com/NORAD/elements/
  - NASA/JPL's HORIZONS: https://ssd.jpl.nasa.gov/horizons/app.html
- Books:

  - D. Vallado, *Fundamentals of Astrodynamics and Applications, 4th Edition*, Springer, 2007, ISBN-13 978-0387718316. Chapters 8 and 9 (very detailed).
  - R. H. Battin, *An Introduction to the Mathematics and Methods of Astrodynamics, Revised Edition*, AIAA Educational Series, Reston, 1999.
    Chapter 10 (Gauss and Lagrange equations derivation).
  - H. Curtis, *Orbital Mechanics for Engineering Students, Second Edition*, Butterworth-Heinemann, 2009, ISBN-13 978-0123747785.
    Chapter 12 (introduction to orbit perturbations).