POLITECNICO
MILANO 1863

Orbital Mechanics
Assignments

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Assignment 1

INTERPLANETARY EXPLORER MISSION

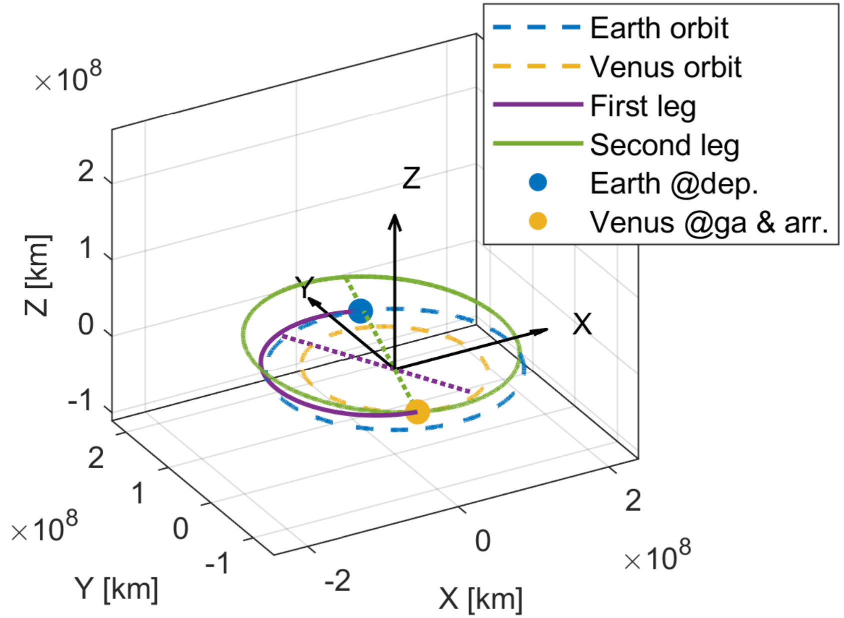
Interplanetary Explorer Mission

First Assignment

The **PoliMi Space Agency** is carrying out a feasibility study for a potential **Interplanetary Explorer Mission** visiting three planets in the Solar System.

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 planet, 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, flyby, and arrival planets 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 Beep):
  - Departure planet,
  - Flyby planet,
  - Arrival planet,
  - Minimum departure and maximum 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 planet.
- 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 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. porkchop or similar 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.
     - Plot of the heliocentric trajectory, together with the orbits of the three planets 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).
     - Compare total flyby Δv with the cost of the manoeuvre Δv_{ga}.
     - Plot of the incoming and outcoming hyperbola arcs.
   - **Cost of the mission in terms of $\boldsymbol{\Delta v_{tot}}$**
     - Detail the separate values of Δv_{dep}, Δv_{ga}, and Δv_{arr}.

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Assignment 2

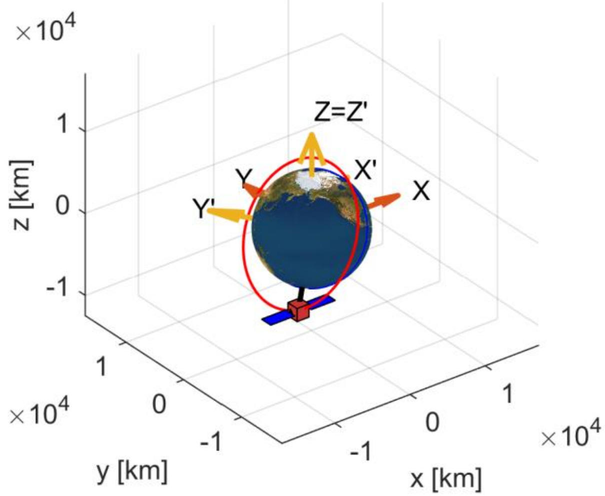
PLANETARY EXPLORER MISSION

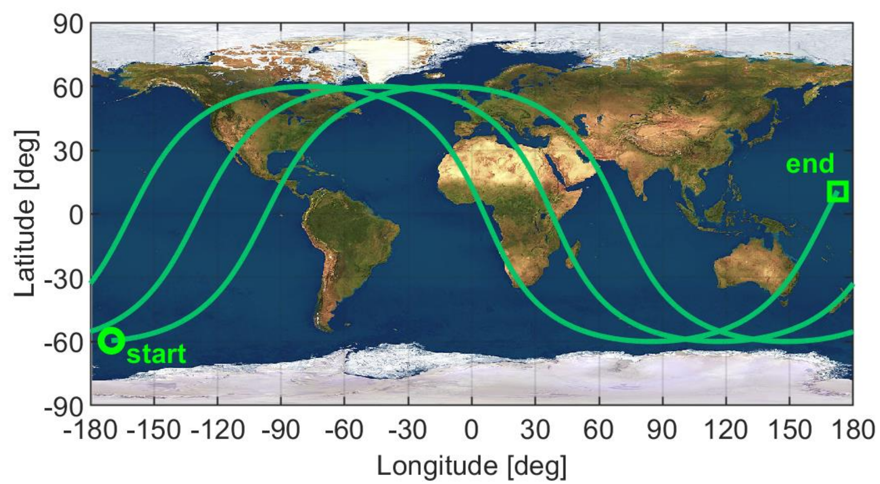
Planetary Explorer Mission

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).

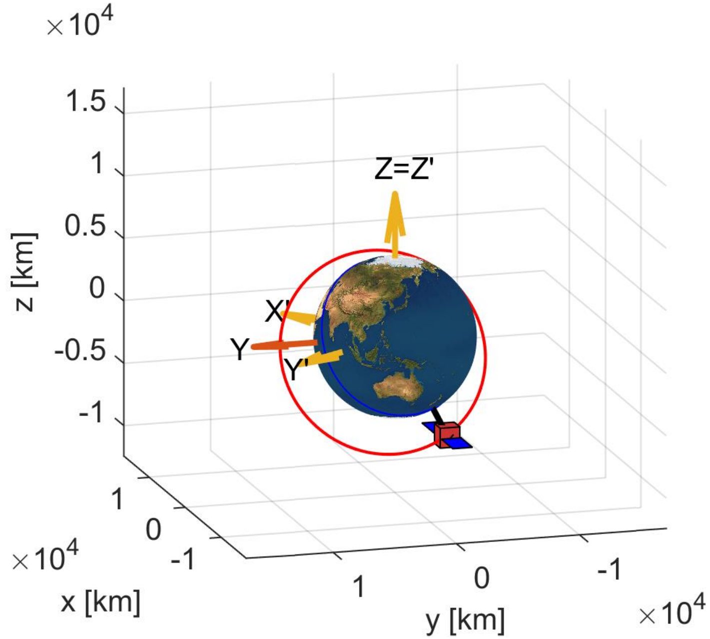




Planetary Explorer Mission

Mission requirements

- Each group has the following **mission requirements** (in Beep):
  - 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 Beep does not include Ω, ω, and f_0. You can choose them freely.

2. **Ground track** (considering only J_2 as perturbation)
   a) Plot the ground track over 1 orbit, 1 day, and 10 days
      - For unperturbed 2BP and for the 2BP perturbed by J_2.

   b) Modify the semimajor axis to obtain a repeating ground track:
      - For the unperturbed case (rotation of Earth) and with secular J_2.
      - Use the ratio for satellite and Earth revolutions given in Beep.
      - Represent the results. Does the ground track repeat exactly? If not, what could be the reasons?
      - *IMPORTANT: The modified values of semimajor axis should only be used for the ground track analysis. For the rest of the assignment, use the nominal value given in Beep.*

Planetary Explorer Mission

Mission analysis outputs (2/3)

3. **Introduce the assigned perturbations** (J_2 + see table in Beep).

4. **Propagate the orbit**, in:
   a) Cartesian coordinates,
   b) Keplerian elements through Gauss' planetary equations.

5. **Plot the history of the Keplerian elements:**
   a) Choose proper units for time, use degrees for angles,
   b) **Compare and analyse** the evolution of each element,
   c) Compare both propagation methods (in terms of accuracy, computational time, etc).

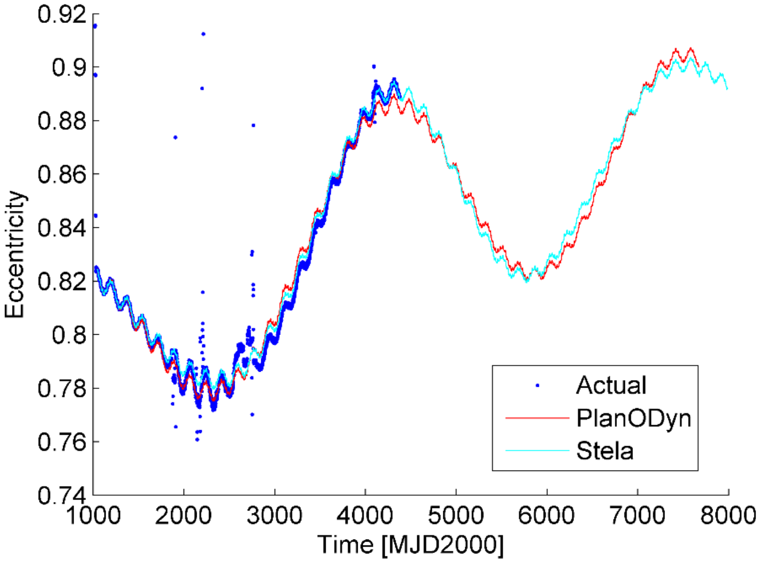
6. **Represent the evolution of the orbit** (image or movie)

Planetary Explorer Mission

Mission analysis outputs (3/3)

7. **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.
   b) Plot the results (you can plot together filtered and unfiltered evolution)

8. **Comparison with real data:**
   a) Select a satellite 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 its orbital elements at the initial time.
   c) Compare the downloaded elements with the results from your model.



GENERAL INSTRUCTIONS

Auxiliar functions available in Beep

- For the assignments, you may use the auxiliar MATLAB functions **available in Beep**:
  - `astroConstants`: Use it to retrieve common astrodynamic constants (both assignments).
  - `lambertMR`: Use it for solving each Lambert arc (Assignment 1).
  - `uplanet`: Planets' ephemeris (**don't propagate the planets' orbits yourself**).
  - `ephMoon`: Analytical ephemeris of the Moon (needed in Assignment 2 if you have the Moon as third-body perturbation).
  - **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 distribute the work among the team, but **everyone is responsible for all the work done in the project**.
- 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

As with any **real-life engineering project,** your team has to produce several **deliverables**:

1. A report,
2. The code developed,
3. A final review (oral presentation),

and comply with **deadlines**:

- All deliverables **(report, code, and slides for the presentation)** must be submitted through Beep at least **five days** before the **final review**.
- The final review must be passed before the end of the exam session in which you plan to do the written exam (or on a previous session).

Project deliverables and deadlines

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**.
  - There is 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.
- **Maximum 22 pages for both assignments combined (including front pages).**

Project deliverables and deadlines

Code

- The Beep submission must include **two different folders** with the codes of each assignment:
  - **Assignment 1**: Folder named `Assignment1` containing:
    - `InterplanetaryMission_group_N.m`: main script that reproduces your result.
    - `Assignment1\functions\`: subfolder with **all the other functions you developed**.
  - **Assignment 2**: Folder named `Assignment2` containing:
    - `PlanetaryMission_group_N.m`: main script that reproduces your results.
    - `Assignment2\functions\`: subfolder with **all the other functions you developed.**
- No need to upload the functions we have provided to you in Beep, 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.cgi
- 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).