POLITECNICO DI MILANO

Department of Aerospace Science and Technology

Academic year: 2020/2021

ORBITAL MECHANICS: ASSIGNMENT PRESENTATION

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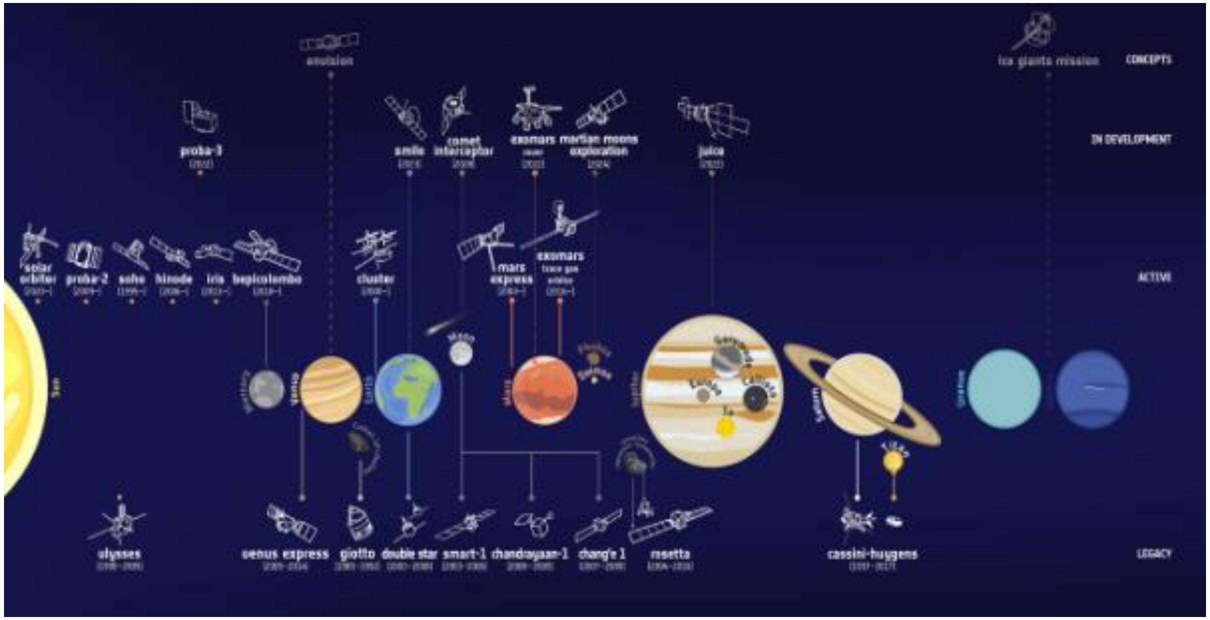
POLITECNICO MILANO

INTERPLANETARY MISSION

MISSION DESCRIPTION:

- Departure planet: Jupiter
- Fly-by planet: Earth
- Arrival planet: Mercury

Figure of merit: Δv_{tot}



DESIGN PROCESS: CONSTRAINTS

- Earliest departure: $01/06/2030$
- Latest arrival: $01/06/2070$
- Fly-by minimum altitude: $h_{min} = 200\ Km$

DESIGN PROCESS: ASSUMPTIONS

- Patched conics method
- Other planets ignored
- SRP neglected
- Initial heliocentric orbit equal to the one of the departure planet
- Final heliocentric orbit equal to the one of the arrival planet

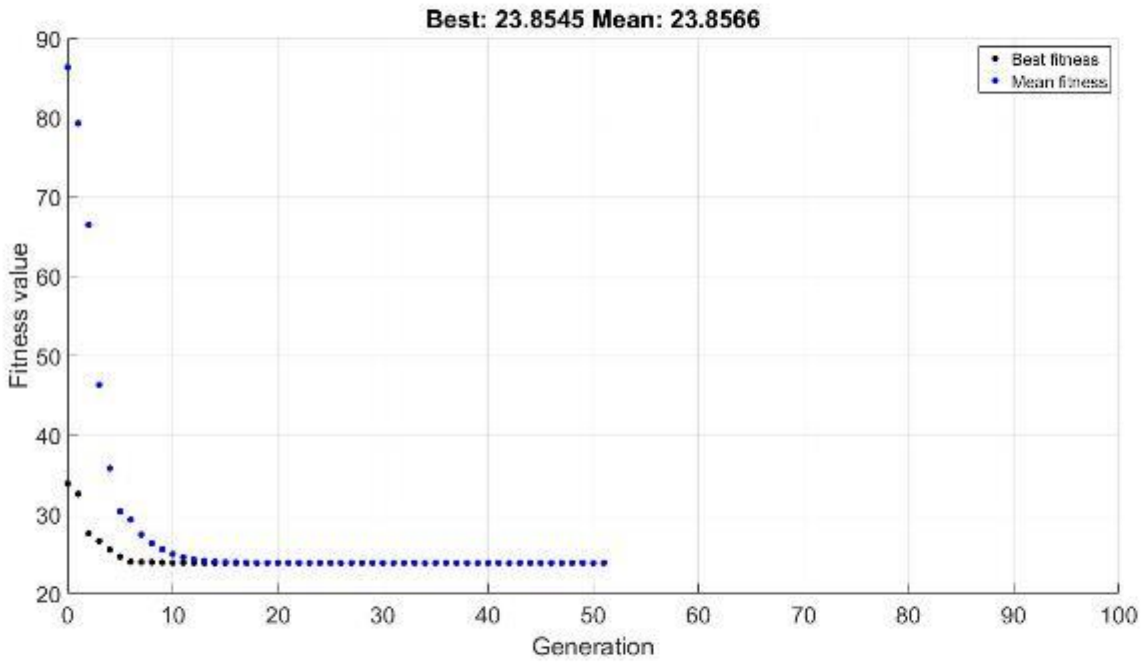
PRELIMINARY ESTIMATIONS

Planets	Relative synodic period
Jupiter and Earth	398.8699 days
Earth and Mercury	115.8774 days
Jupiter and Mercury	89.7916 days

Time window	Earliest date	Latest date
Departure	01/06/2030	13/04/2042
Fly-by	29/04/2032	31/01/2045
Arrival	12/07/2032	17/03/2046

FIRST OPTIMIZATION: GENETIC ALGORITHM

- Heuristic method for search of the minimum
- Number of iterations: 5
- Population size: 1000
- Number of generations: 100



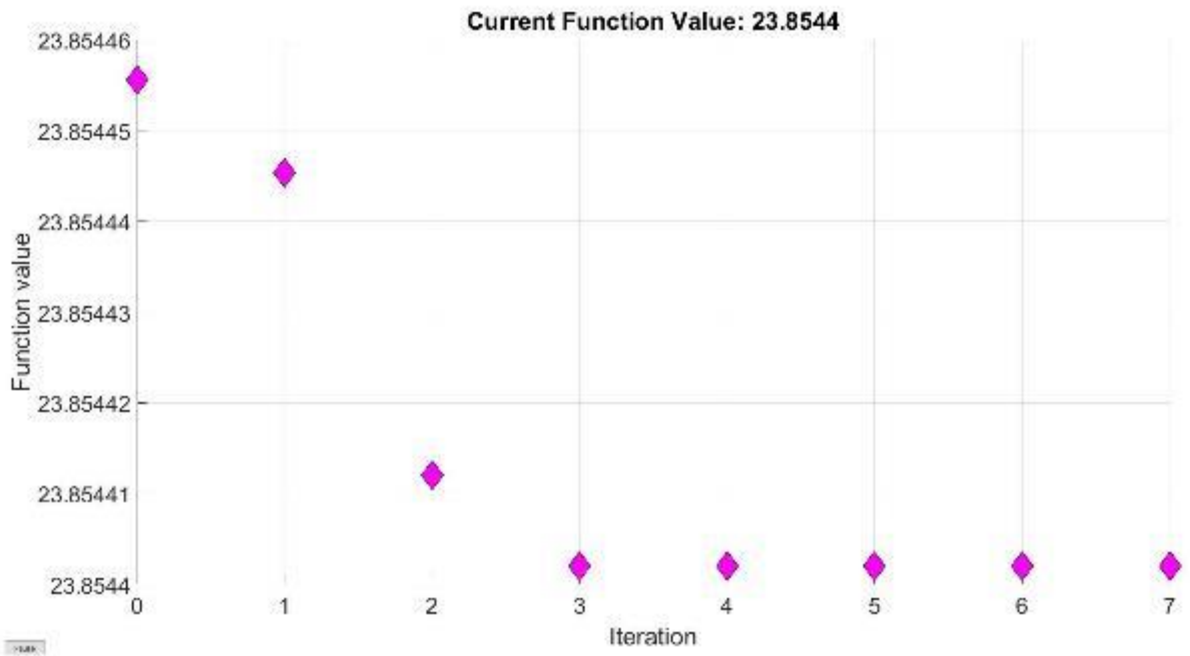
SECOND OPTIMIZATION:

- Refinement of the minimum with:
  1. Gradient-based Optimizer
  2. Grid Search Method

D.O.F	Lower boundary	Upper boundary
Departure Date	$t_{1,ga} - \delta_1$	$t_{1,ga} + \delta_1$
Fly-by Date	$t_{2,ga} - \delta_2$	$t_{2,ga} + \delta_2$
Arrival Date	$t_{3,ga} - \delta_3$	$t_{3,ga} + \delta_3$

SECOND OPTIMIZATION: GRADIENT-BASED OPTIMIZER

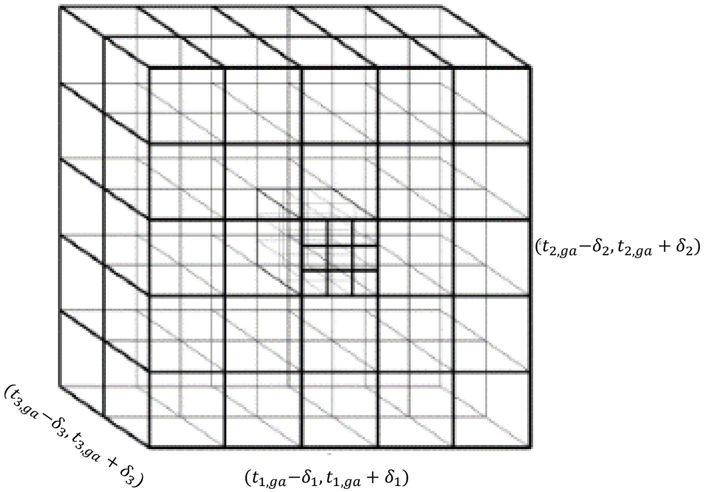
- Search for the minimum of non-linear constrained multi-variable functions
- Initial guess: $x_0 = t_{ga} = \begin{Bmatrix} t_{1,ga} \\ t_{2,ga} \\ t_{3,ga} \end{Bmatrix}$



SECOND OPTIMIZATION: GRID SEARCH METHOD

Three degrees of freedom:

- Departure date
- Fly-by date
- Arrival date



Three nested loop cycles that evaluate the minimum Δv:

for all possible departure dates around $t_{1,ga}$

    for all possible fly-by dates around $t_{2,ga}$

        for all possible arrival dates around $t_{3,ga}$

            calculation of the total Δv of the transfer

        end

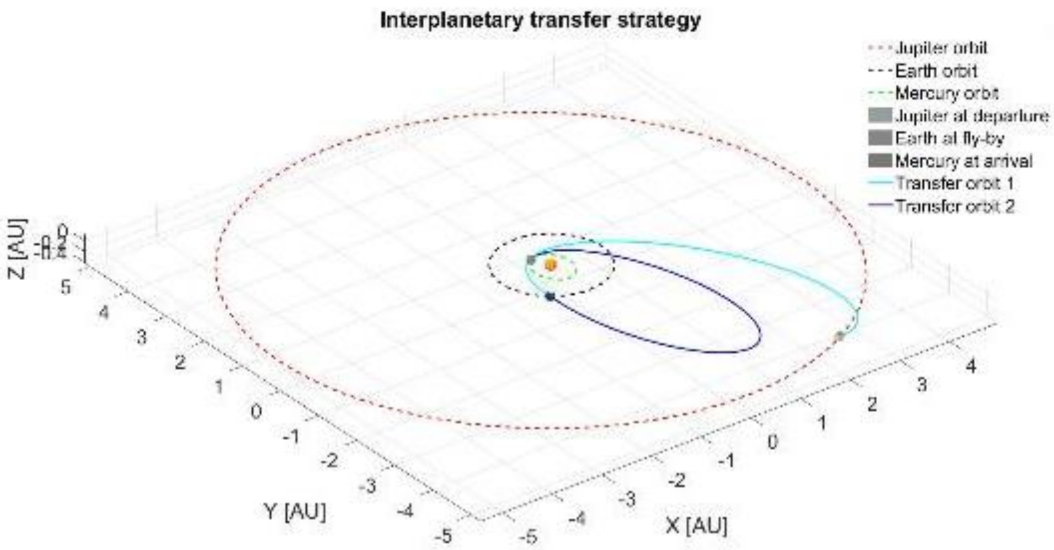
    end

end

OPTIMIZATION RESULTS

Method	t_1 $[mjd2000]$	t_2 $[mjd2000]$	t_3 $[mjd2000]$	Δt $[days]$	Δv $[km/s]$	t_{comp} $[s]$
G.A.	11705.8494	12903.3103	13949.6986	2243.8492	23.8545	104.4523
fmincon	11705.8483	12903.3100	13949.6979	2243.8496	23.8544	0.4215
Grid search	11881.0989	12915.5913	13952.7313	2071.6323	23.6279	396.3988

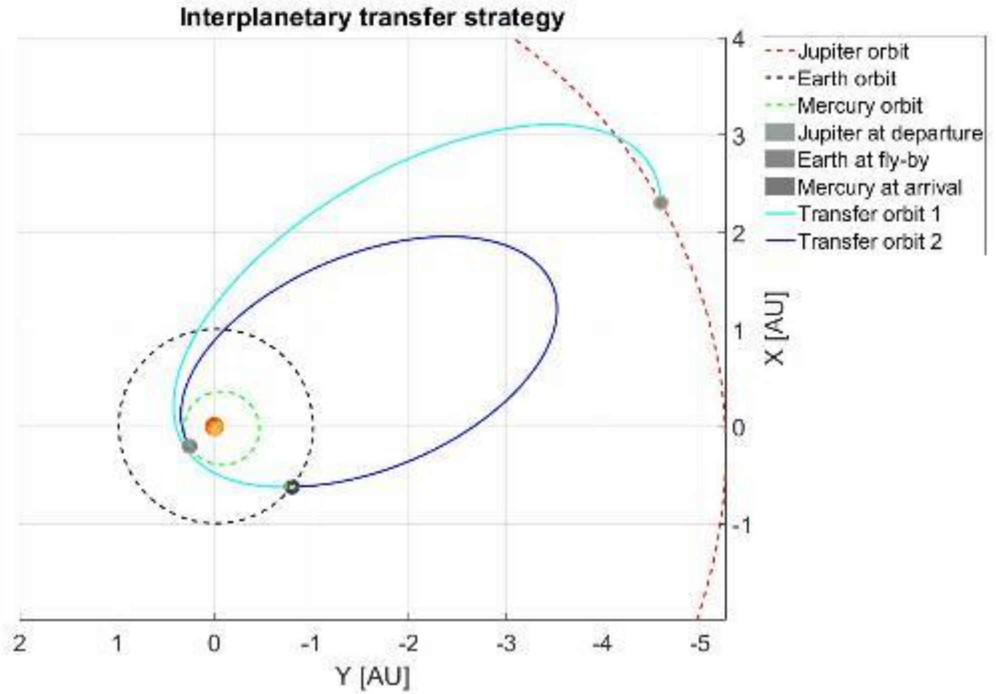
RESULTS: TOTAL TRANSFER



Manoeuvre	Δv cost $[km/s]$
Injection in the first transfer leg	8.8694
Powered gravity assist	0.0063
Injection in the final orbit	14.7523
Total transfer	**23.6279**

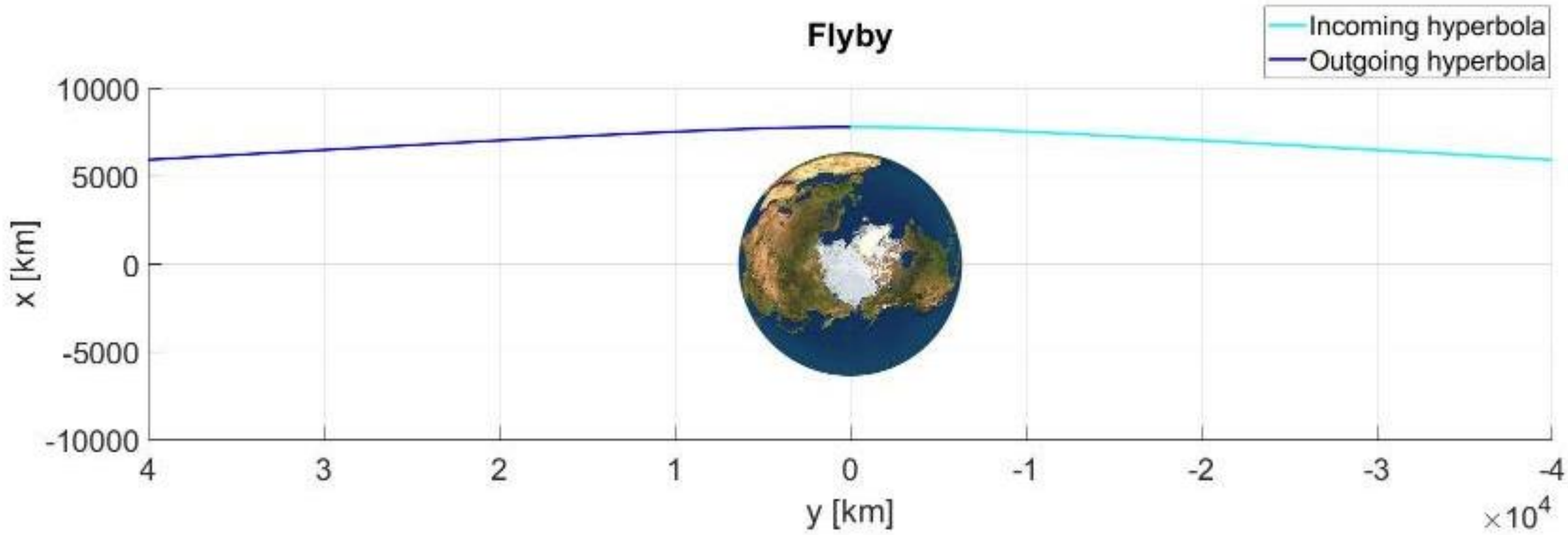
Departure date	$12/07/2032 - 14{:}22{:}30$
Fly-by date	$13/05/2035 - 02{:}11{:}27$
Arrival date	$15/03/2038 - 05{:}33{:}01$

RESULTS: TOTAL TRANSFER



	$a\ [km]$	$e\ [-]$	$i\ [deg]$	$\Omega\ [deg]$	$\omega\ [deg]$	$\vartheta_i\ [deg]$	$\vartheta_f\ [deg]$
First transfer orbit	$4.1868 \cdot 10^8$	0.8680	0.3935	52.1902	68.5723	175.8502	111.4277
Second transfer orbit	$3.0779 \cdot 10^8$	0.8433	7.0936	52.1902	60.7631	119.2369	15.6349

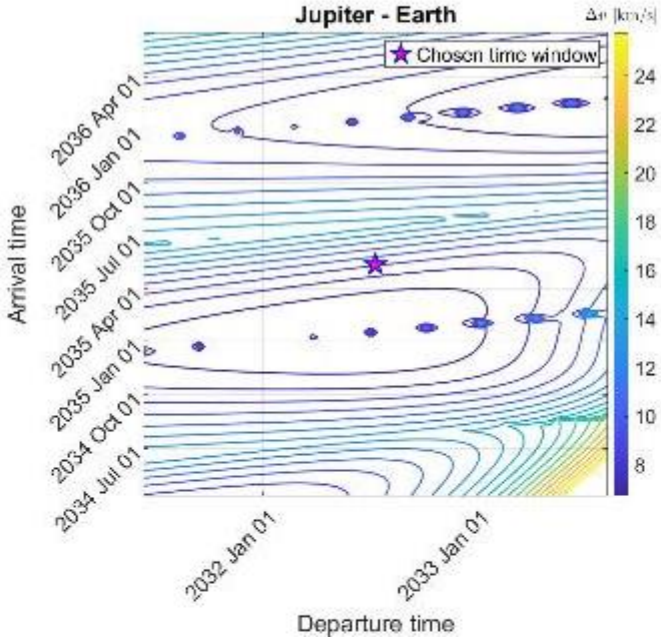
RESULTS: POWERED GRAVITY ASSIST

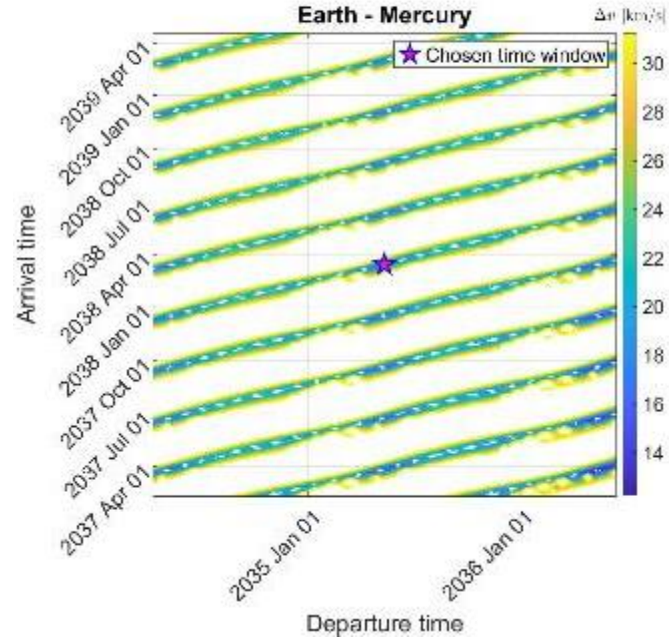


$$\vec{V}^+ = \begin{Bmatrix} 1.5826 \\ -37.9043 \\ -0.1682 \end{Bmatrix} [km/s] \qquad \vec{V}^- = \begin{Bmatrix} 0.3833 \\ -36.2912 \\ -2.8063 \end{Bmatrix} [km/s] \qquad \Delta v_{flyby} = \left\|\vec{V}^+ - \vec{V}^-\right\| = 3.3166\ km/s$$

	$h_p\ [km]$	$v_p\ [km/s]$	$v_\infty\ [km/s]$	$e\ [-]$	$a\ [km]$
Incoming hyperbola	1127.0321	30.7293	29.0206	17.4983	−473.2876
Outgoing hyperbola	1127.0321	30.7356	29.0272	17.5059	−473.0710

DISCUSSION





- Most expensive manoeuvre: injection in Mercury orbit, due to very different orbit inclination.
- Least expensive manoeuvre: powered gravity assist, very efficient.
- The first and last manoeuvres aren’t the best possible, as seen in porkchop plots.
- To obtain a better solution, multiple fly-bys around Earth, Venus or Mercury itself may be considered, as done by ESA’s mission BepiColombo.

MISSION:

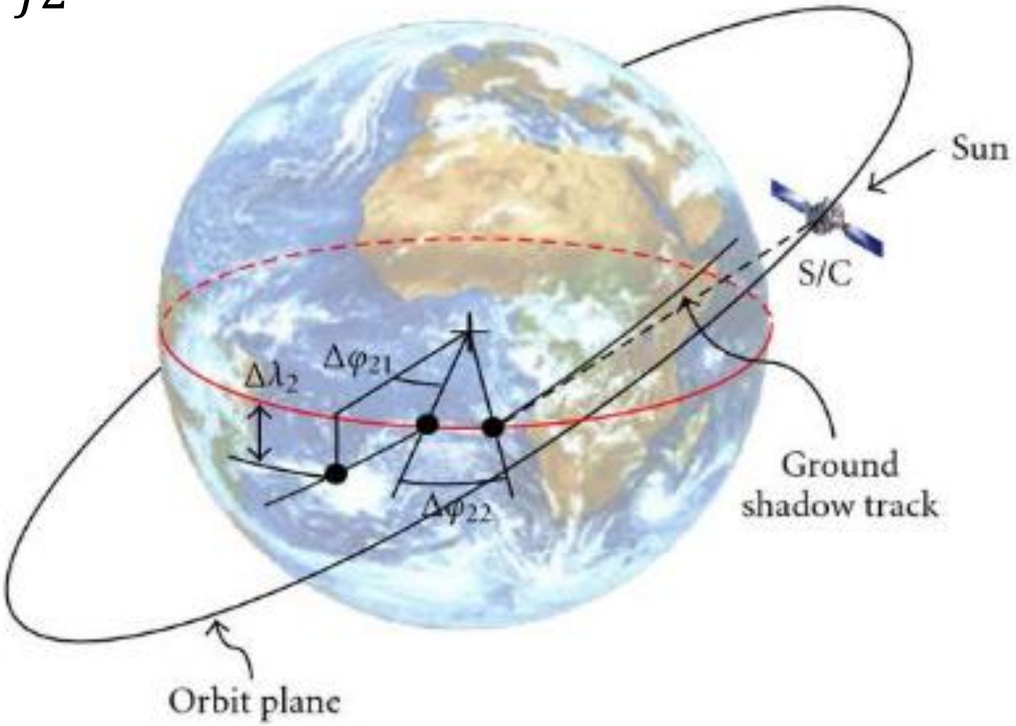
- Examination of given orbit and its ground tracks
- Study of $J2$ and Moon perturbations
- Accuracy comparison of the integration methods used
- Comparison with real case

MISSION DATA:

a $[km]$	e $[-]$	i $[deg]$	Ω $[deg]$	ω $[deg]$	ϑ $[deg]$	rp $[km]$	m/k $[-]$
$3.9899 \cdot 10^4$	0.2510	56.6144	0	0	0	29884.351	1

PERTURBATION MODELLING: J2

- Caused by Earth's oblateness and spheroid structure
- Zonal effect dominated by $J2$



Principal effects:

- Nodal Regression
- Perigee Precession

PERTURBATION MODELLING: MOON PRESENCE

- Causes gravitational attraction

Principal effects:

- Change of e, i and ω

INTEGRATION METHODS:

Integration in Cartesian Coordinates

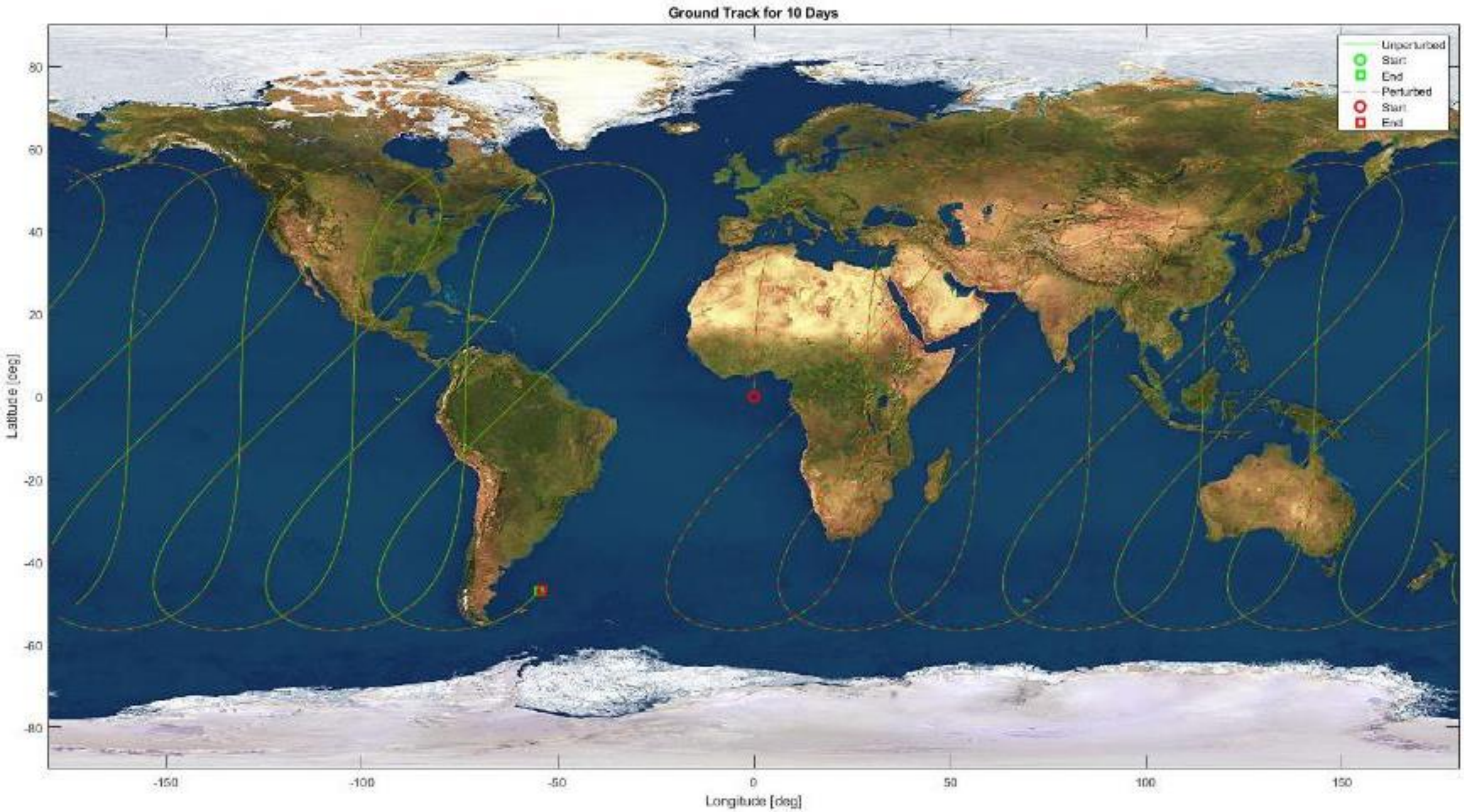
$$\frac{d}{dt}\begin{Bmatrix}\vec{r}\\ \vec{v}\end{Bmatrix} = \begin{Bmatrix}\vec{v}\\ -\frac{\mu}{r^3}\cdot\vec{r} + \overrightarrow{a_{pert}}\end{Bmatrix}$$

Integration of Gauss Planetary Equations

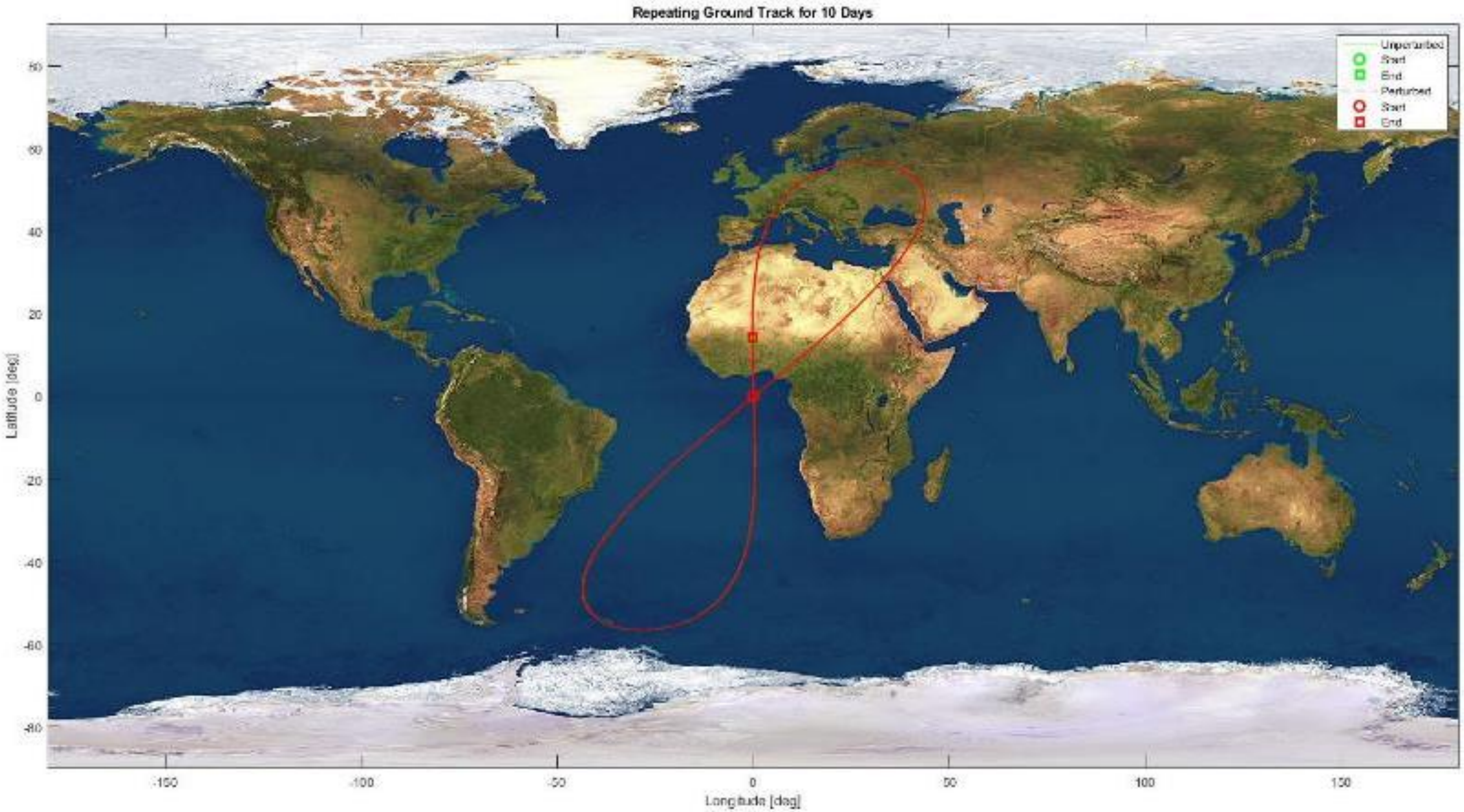
$$\frac{d}{dt}\{\vec{K}\} = fun\left(\overrightarrow{K}, a_{pert}^{RSW}\right)$$

PLANETARY EXPLORER MISSION

GROUND TRACKS:



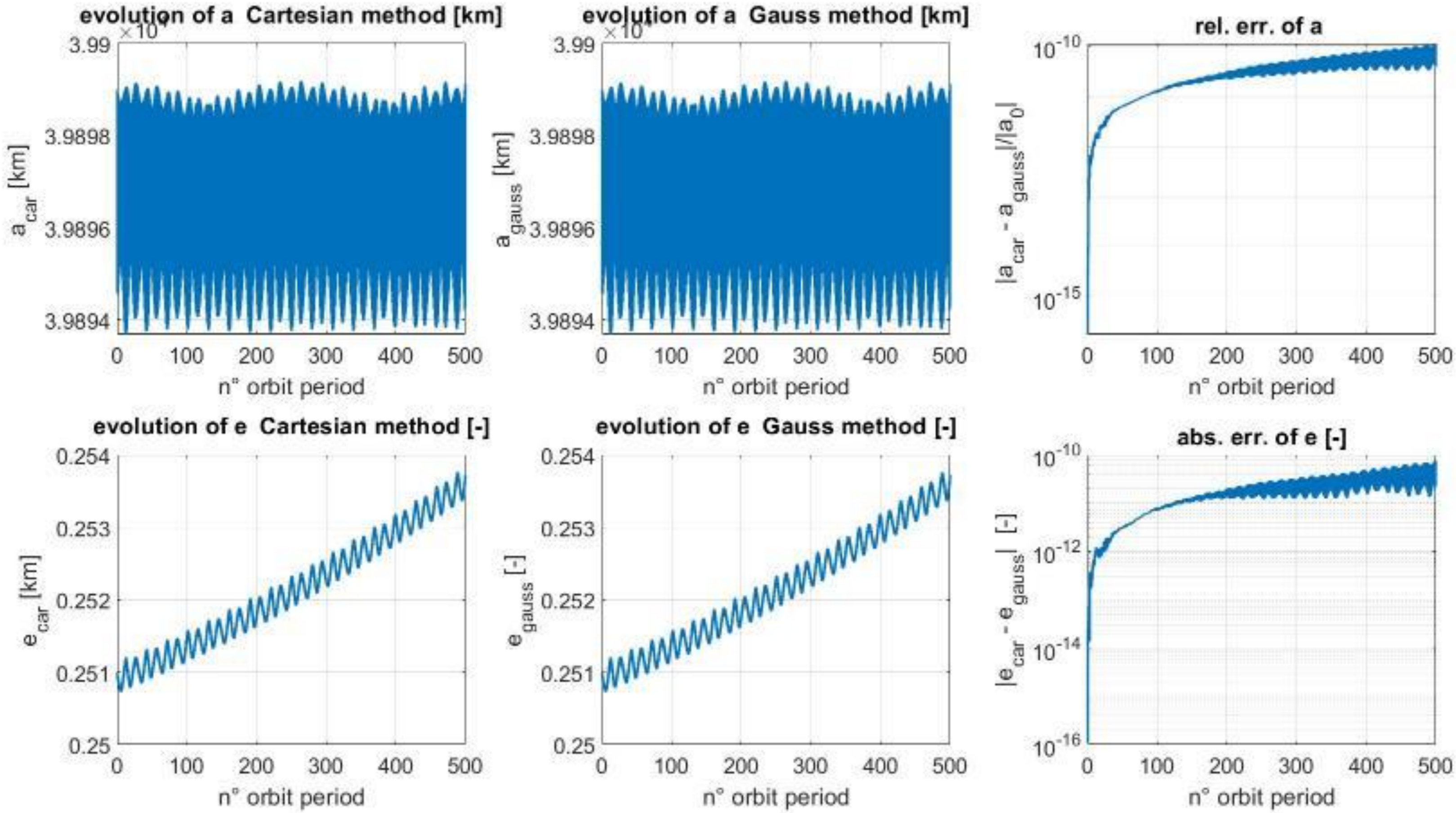
REPEATING GROUND TRACKS:



$a_{rep} = 42166.17\ km$

$a_{rep_{J2}} = 42165.77\ km$

INTEGRATION METHODS COMPARISON



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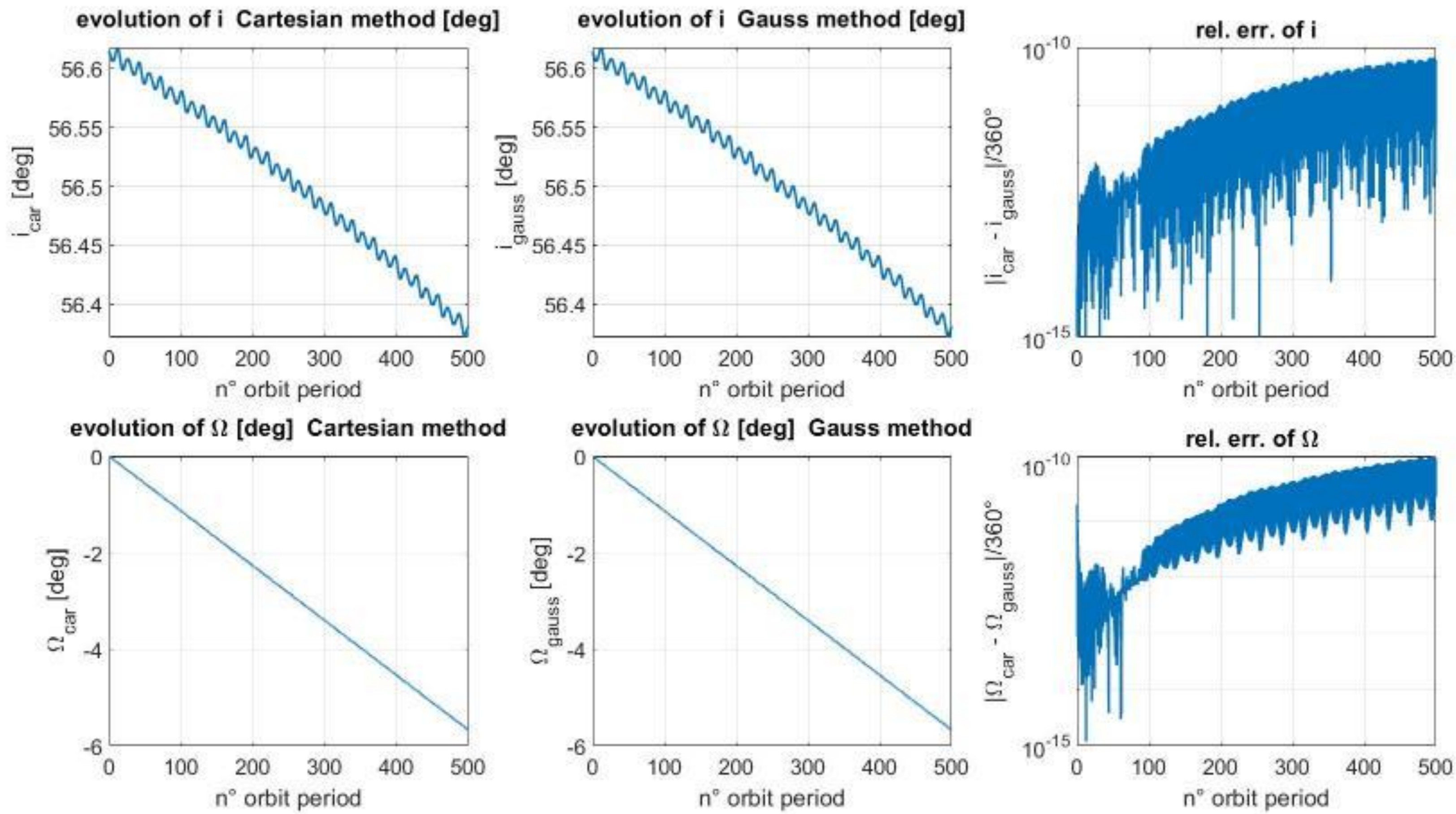

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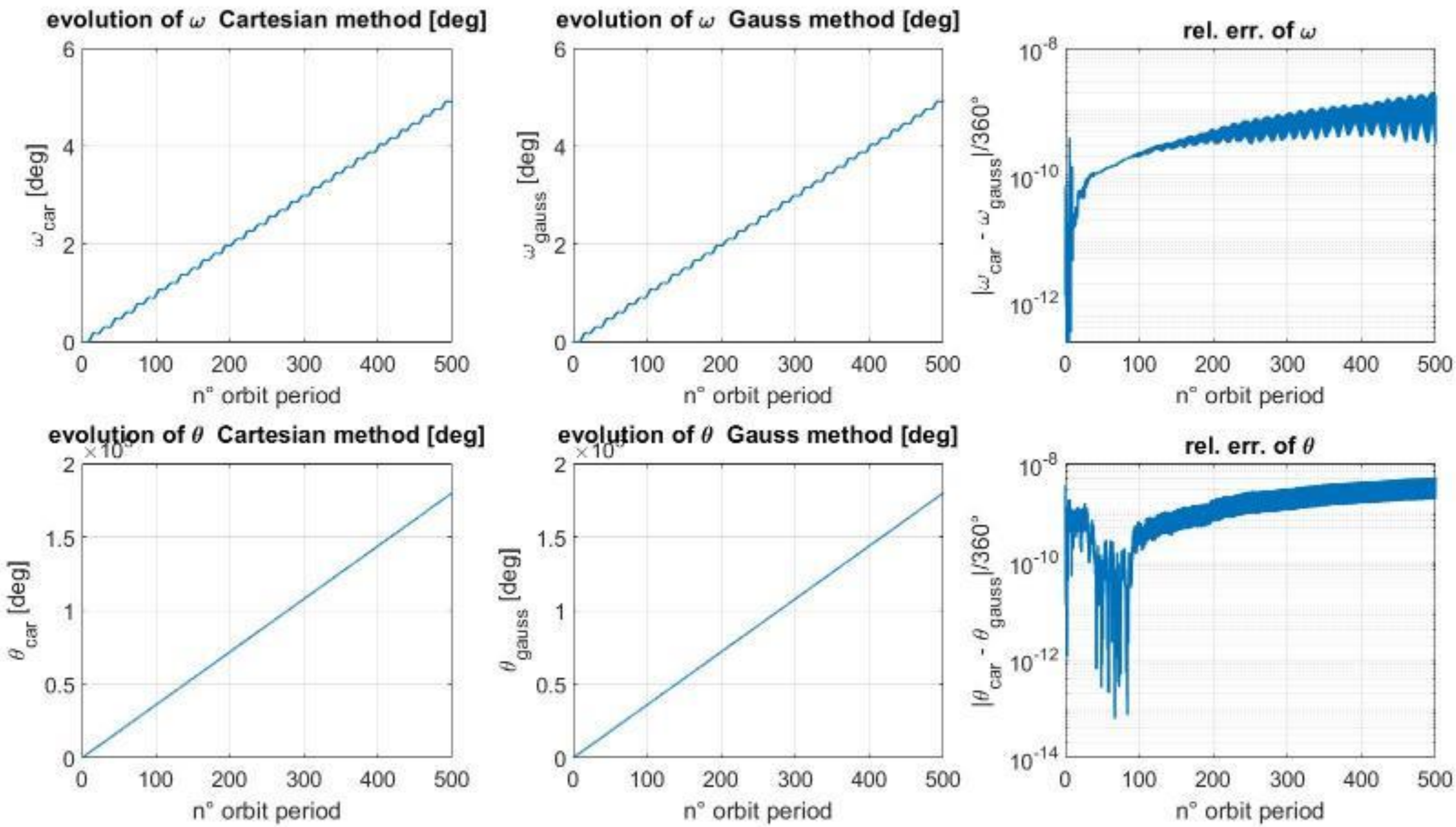
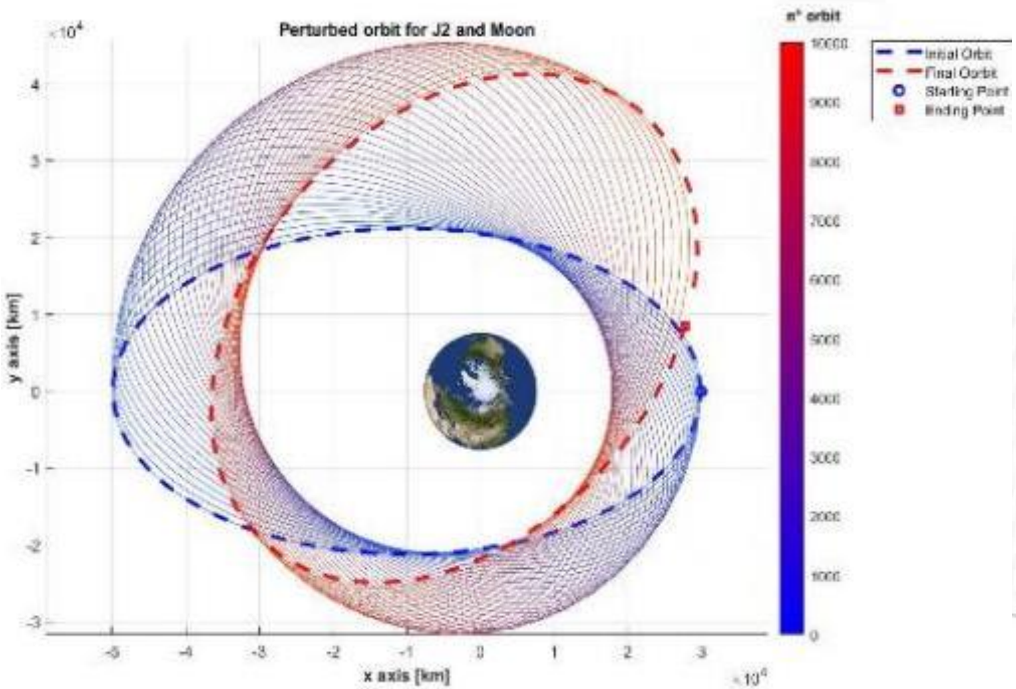
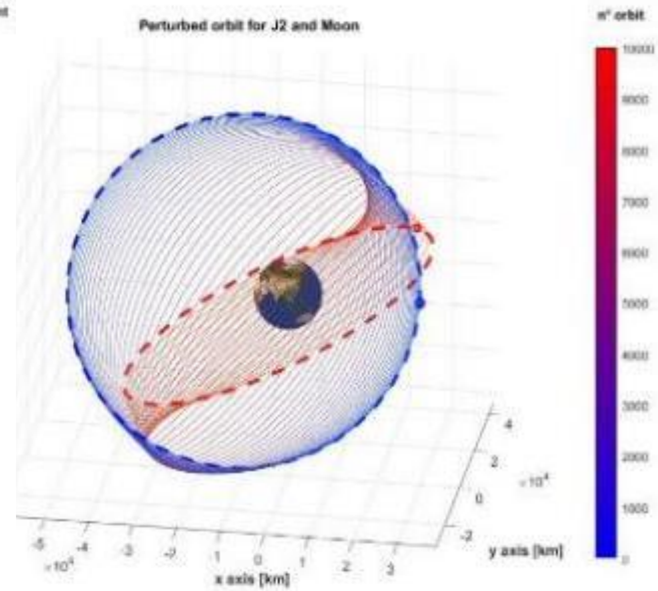


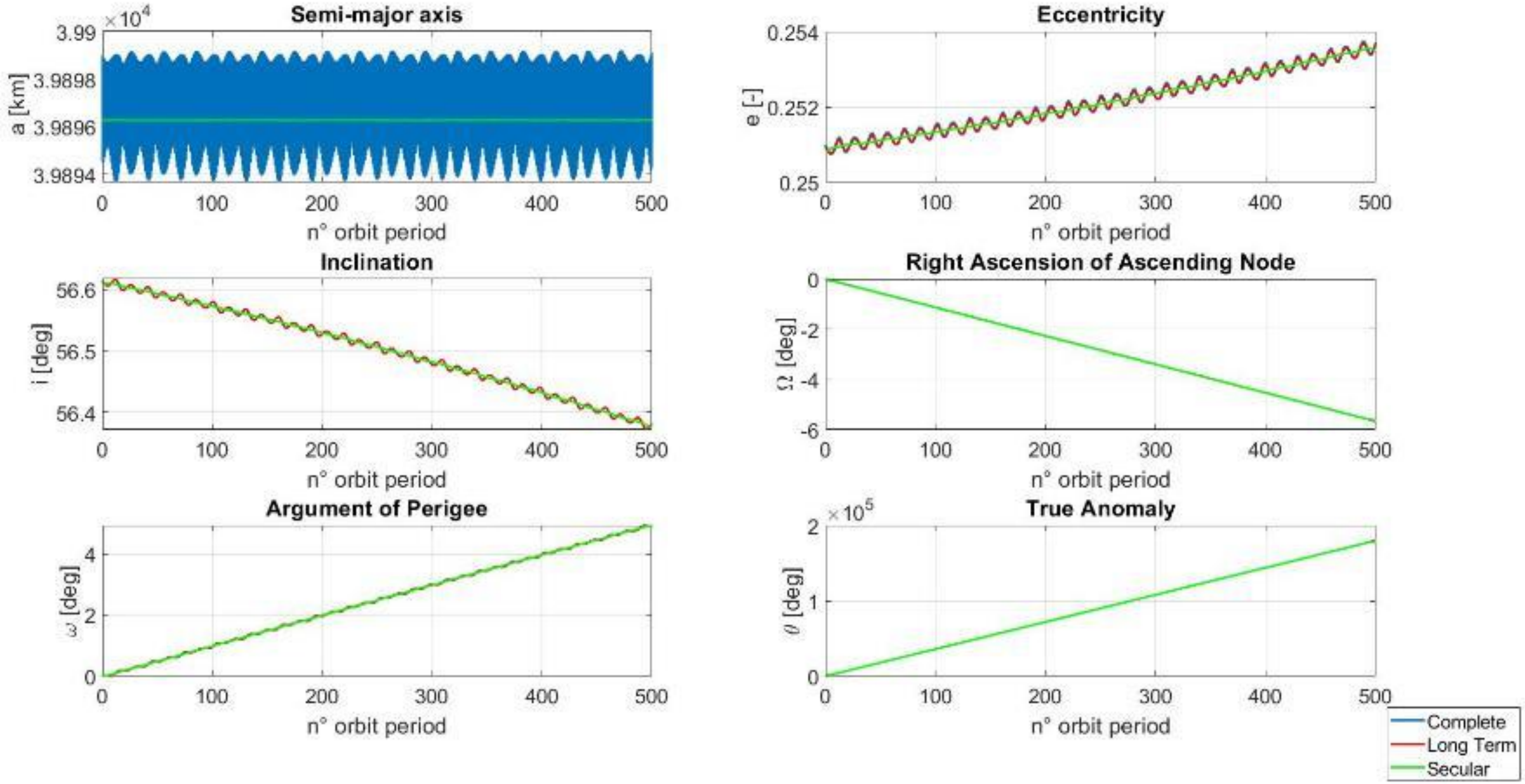
EVOLUTION OF PERTURBED ORBIT:





INITIAL ORBIT PARAMETERS:					
a	e	i	Ω	ω	ϑ
$39899.0\ km$	0.2510	$56.6144°$	$0.0°$	$0.0°$	$0.0°$
FINAL ORBIT PARAMETERS:					
a	e	i	Ω	ω	ϑ
$39897.54\ km$	0.3200	$46.6746°$	$-136.52°$	$76.14°$	$0.0°$

FILTERING OF KEPLERIAN ELEMENTS:



REAL DATA COMPARISON

Satellite used: *ZHONGXING-7*

Properties:

- Telecom satellite
- Set on graveyard orbit
- Almost same altitude as study orbit

REAL DATA COMPARISON