TOOLBOX FOR OPTIMIZING SPACECRAFT ASCENT TRAJECTORY FROM LAUNCH TO LOWER EARTH ORBIT

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Abstract

The target is to develop a toolbox for the ascent trajectory of a launch vehicle using an analytical/numerical approach. The mission profile would be optimized from Launch to payload delivery in the Lower Earth Orbit (LEO). Reduce launch delays due to inaccuracy in estimating atmospheric and wind profiles.

The toolbox includes trajectory optimization within the atmosphere to achieve LEO, Orbit transfer maneuvers, and Orbit maintenance to counter the effects the atmospheric drag and oblateness to ensure payload delivery to the intended orbit. Input factors are independent (e.g., orbital elements, satellite orientation) and dependent (e.g., engine staging, burn rate, atmospheric drag). They collectively shape the rocket's trajectory and performance throughout the flight.

The toolbox, designed for use in industry for early mission design, uses impulsive movements to accelerate the optimization process.

Introduction

Launch vehicles depend heavily on a strong flight dynamics system. Guidance and navigation are essential elements to counter disturbances caused by the atmosphere and orbital perturbations. The atmosphere makes it difficult to estimate wind profiles accurately, which causes launch delays.

Problem Statement:
- Lack of proper wind profile estimation in causes launch delays
- A hybrid analytical/numerical approach to develop closed-loop guidance system for optimizing ascent trajectory of a launch vehicle from the launch to the target orbit.
- Target: Reduce launch delays, improve burn/coast arcs, incorporating better orbital maneuvers to deliver payloads

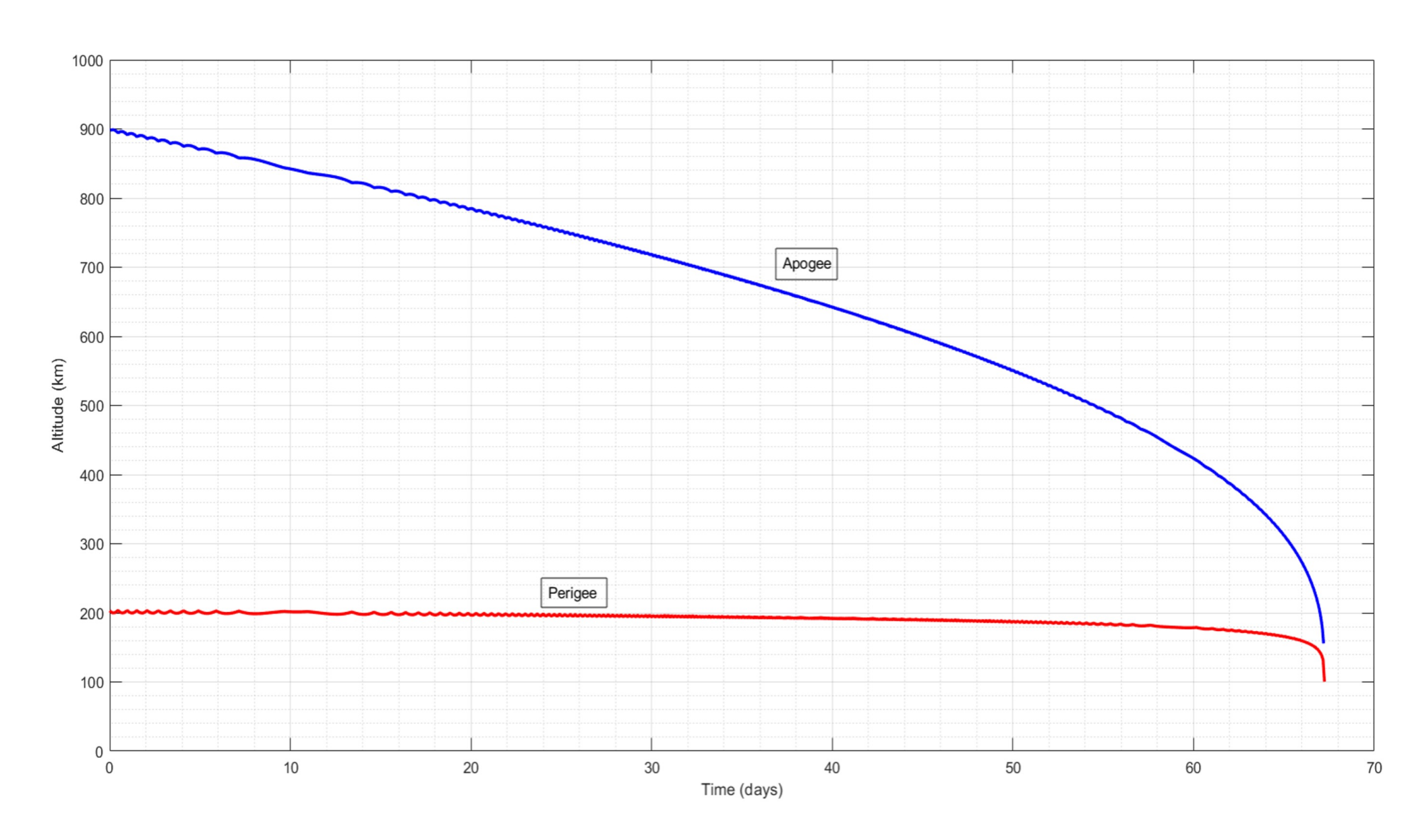


Fig 1. Effect of Atmospheric Drag on Apogee and Perigee Positions of Orbit

Trajectory optimization

- Burn and Coast arcs;
- Normal and drag force estimations; Terminal and path constraints;
- Boundary conditions with free or perigee attachment

SPACE MISSION TOOLBOX

Orbit raising maneuvers

- Impulsive Hohmann transfers
- Estimation of Δv from angular momentum
- Transfer orbit with least total Δv – most efficient transfer orbit

Orbit maintenance

- Perturbations from oblateness and atmospheric drag
- Small impulsive maneuvers at perigee maintain orbit

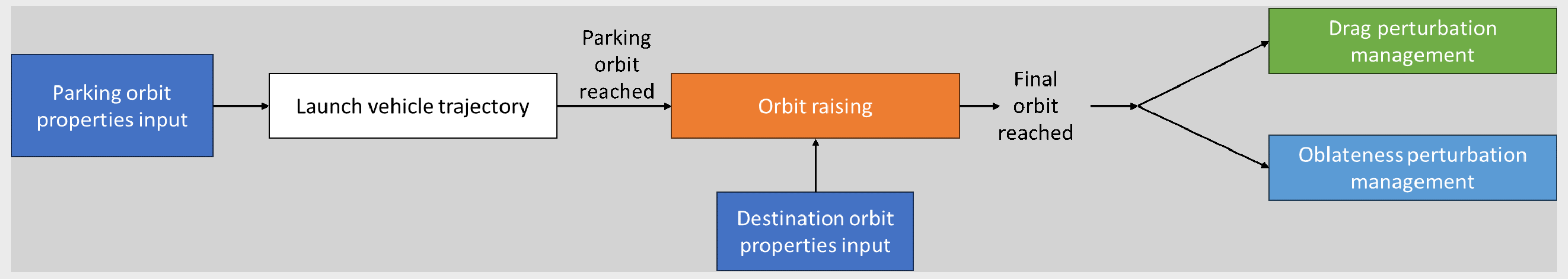


Fig 2. Overview of toolbox solution procedure

Parking orbit properties are user-input. Orbit-raising maneuver used to reach the final orbit of the spacecraft. Detailed calculations for drag and oblateness perturbation management subsystem to find out suitable maneuvers that assist in orbit maintenance over the course of time of the mission.

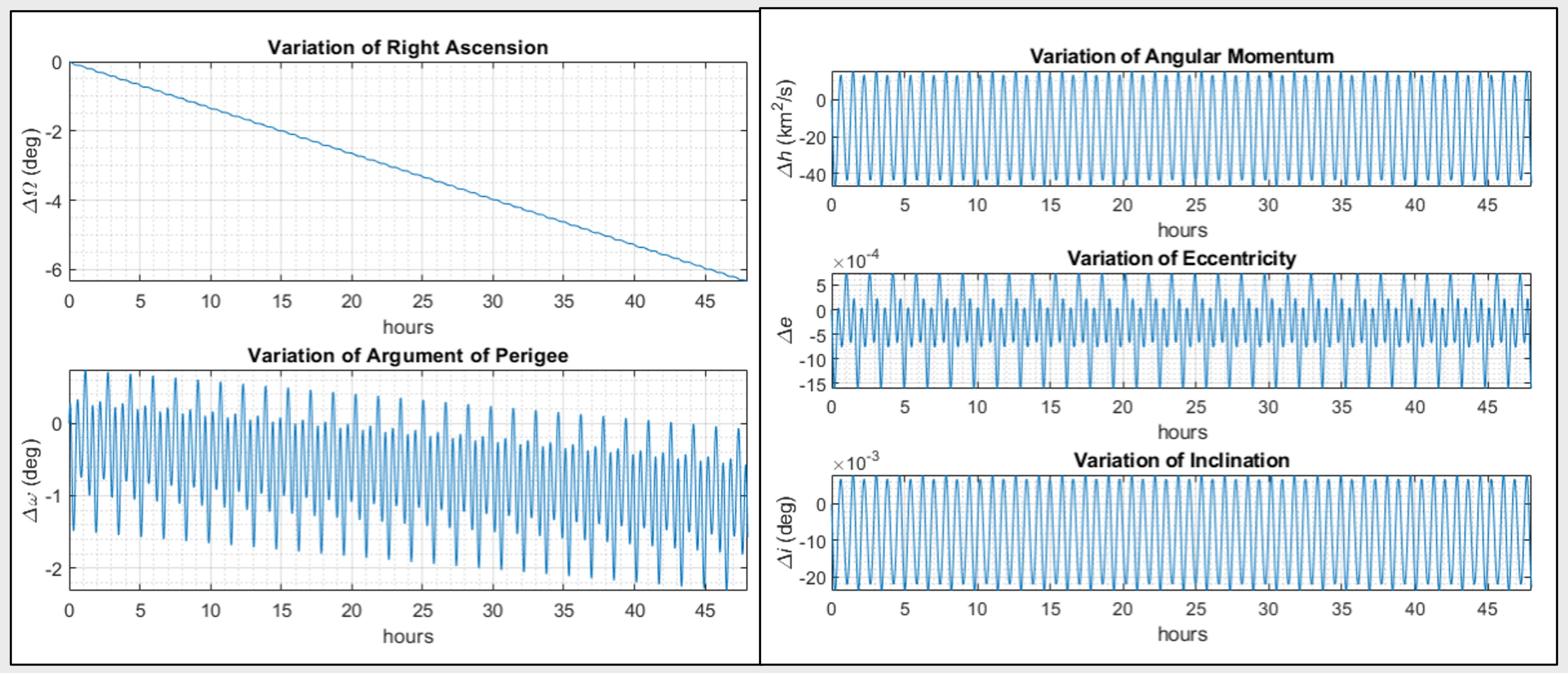


Fig 3. Effect of Earth's Oblateness on Various Orbital Parameters

Reduction of orbit size due to atmospheric drag over 70 days in orbit; with time the drag slowly degenerates the orbit from elliptical to circular

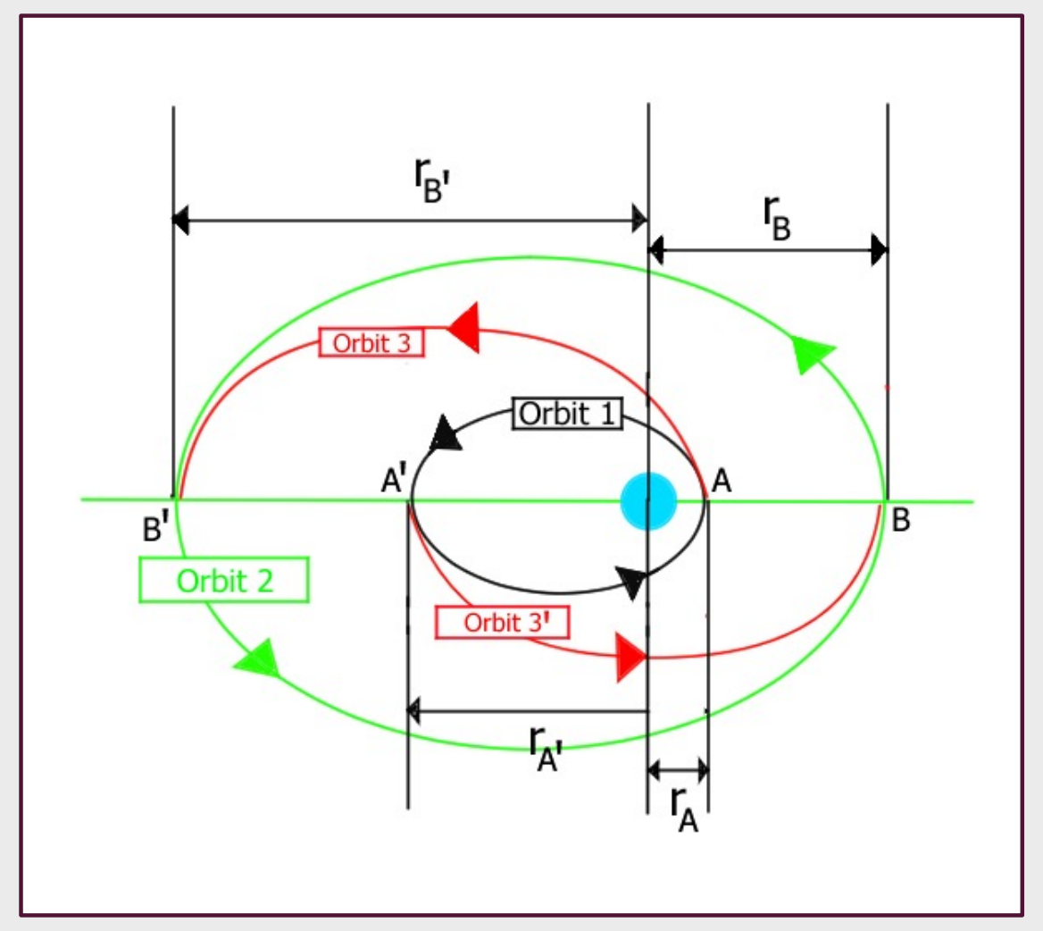
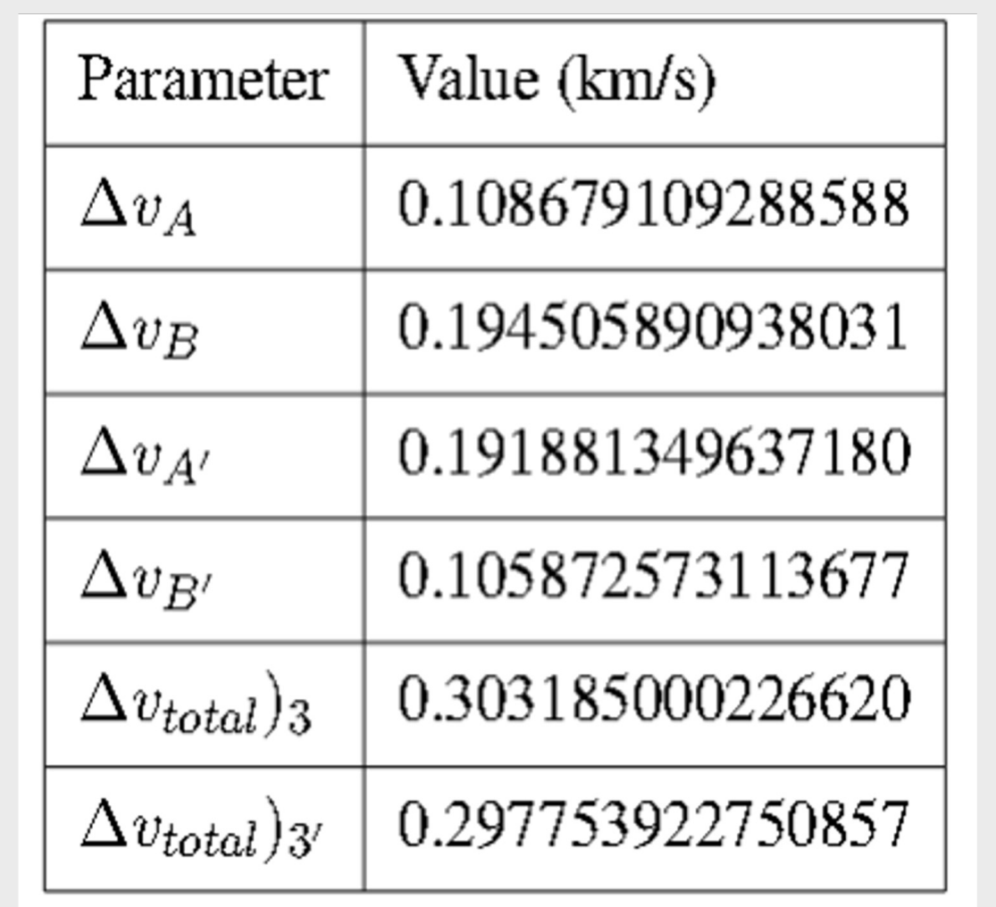


Fig 4. Possible Hohmann Transfer Trajectories (figure not to scale)

Perturbations Caused by Oblateness of Earth over 48 hours in the orbit; Variations of h, e, i are zero-time averaged; Ω,ω advance/ regress based on initial input



Parameter	Value (km/s)
Δv_A	0.108679109288588
Δv_B	0.194505890938031
$\Delta v_{A'}$	0.191881349637180
$\Delta v_{B'}$	0.105872573113677
$\Delta v_{total})_3$	0.303185000226620
$\Delta v_{total})_{3'}$	0.297753922750857

Table1. Calculated Delta-v's for orbit raising maneuver \

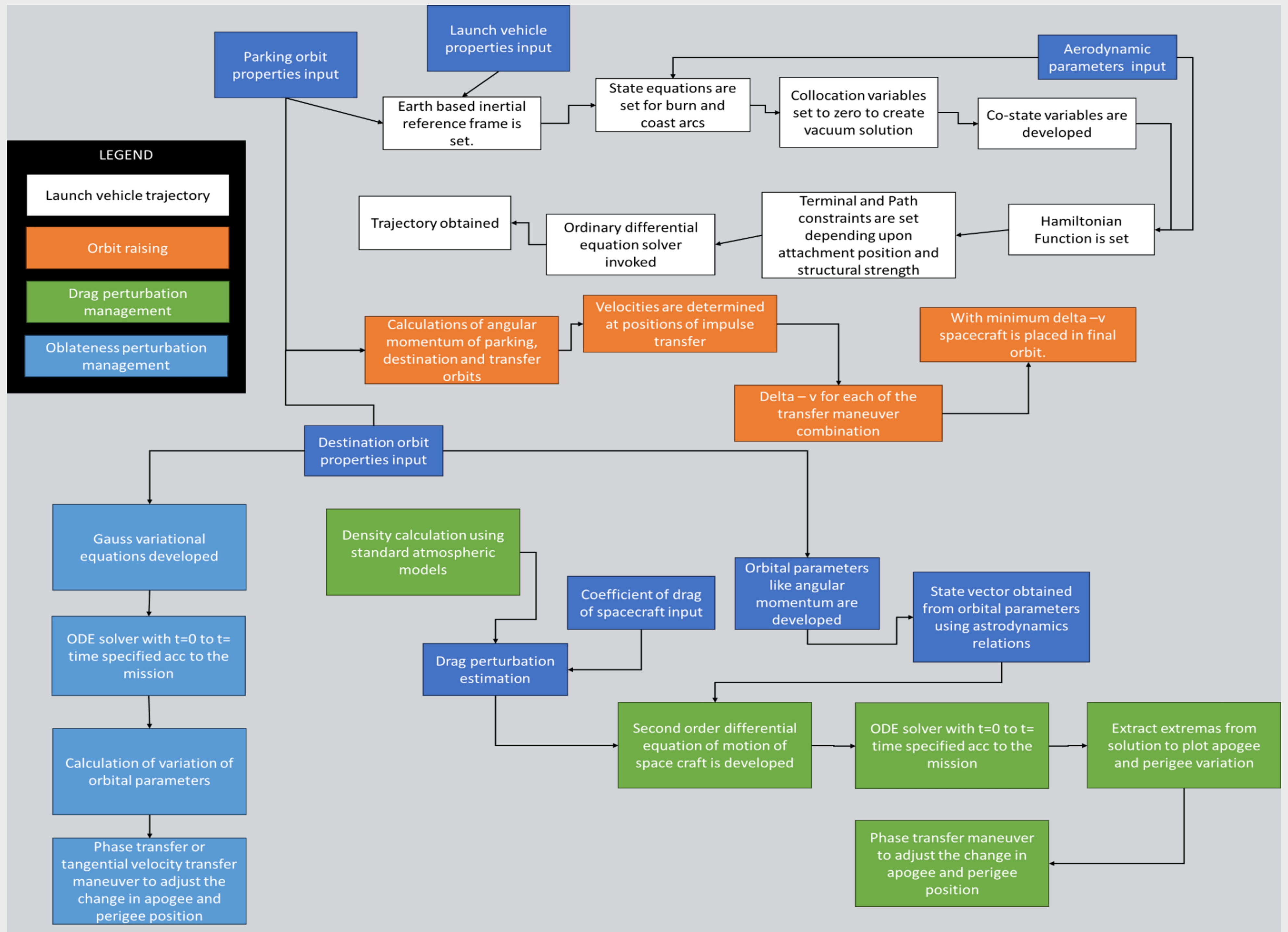
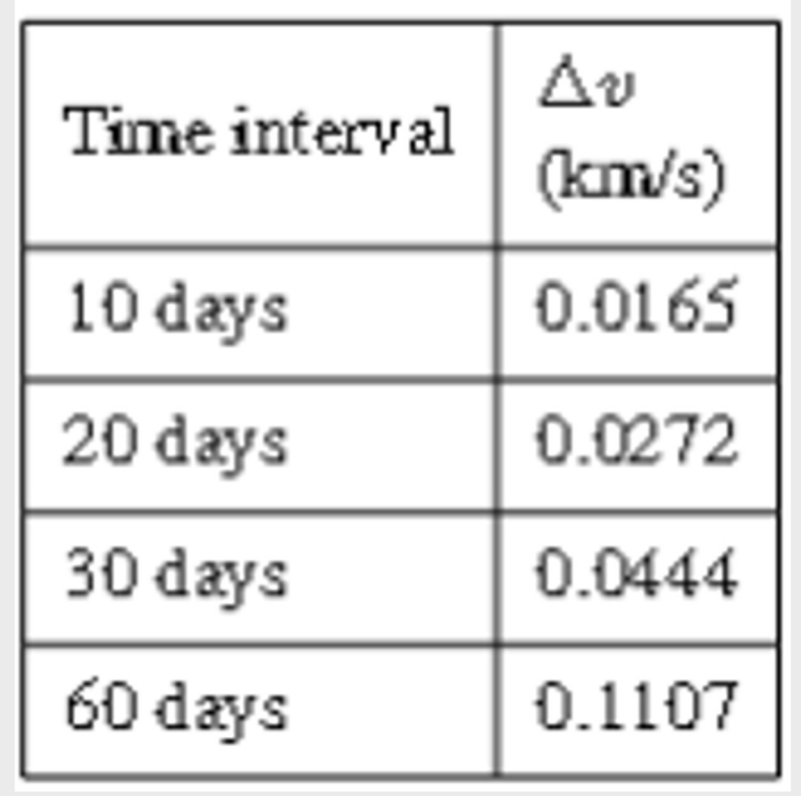


Fig 5. The flowchart describes the entire procedure developed to design a lower earth orbit mission:

Calculated Δvs for orbit raising maneuver.
In this case of raising orbit from altitude 200km by 600km to 200km by 900km Orbit 3' proves to the most efficient transfer orbit.



Time interval	Δv (km/s)
10 days	0.0165
20 days	0.0272
30 days	0.0444
60 days	0.1107

Table 2. Phase maneuver delta-v's for countering perturbations caused by drag force

Phase maneuver Δvs for countering drag-induced perturbations; depending upon the mission requirements phase maneuvers at different time intervals can summed up over the entire mission life to obtain the most efficient orbit maintenance schedule.

Conclusion

The toolbox developed is able to use the inputs provided to create mission profile of a space mission which utilizes a launch vehicle to deliver the payload to parking orbit in the lower earth orbit. From the parking orbit, orbit raising is used to achieve the final orbit. Finally, with orbit maintenance orbit perturbations are studied to deploy appropriate manuevers that can compensate the perturbations to achieve the goal.

References

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