Creation of a Trajectory Framework that is Sustainable for a Continuous Exploration of Mars and its Moons

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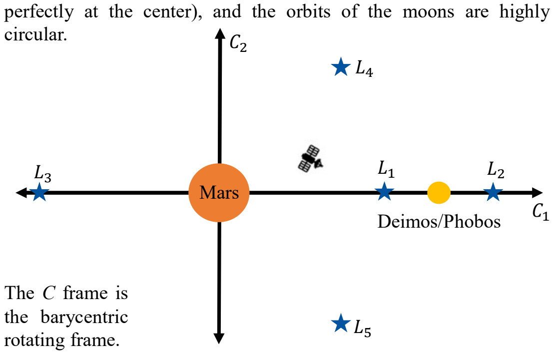
ABSTRACT: As humanity looks to the Cislunar region in recent space flight operations, the question remains: where will technology advance next? Mars is of particular interest with both the public and private sector aiming to get humans on the planet in the coming decades. Investigating stable trajectories in the Mars-Phobos-Deimos system for telecommunications and observation is the next step in developing future mission plans. Innovations in orbital mechanics must be considered, neither the two-body problem (2BP) nor the circular restricted three-body Problem (CR3BP) are sufficient to effectively model satellite motion. Instead, in similar fashion to the patched-conics solution of transfers between the influence of celestial bodies, a patched CR3BP-2BP-CR3BP method of propagating the orbits is proposed. To begin, assumptions about Deimos and Phobos will be made—co-planar orbits and spherical symmetry to name a few. Once the problem has been successfully modeled, each assumption will be undone methodically to increase modeling accuracy. Impulsive maneuvers will be considered, as well as low, continuous thrust maneuvers. The aim of this project is to develop a robust, sustainable trajectory framework that can be used in future missions.

Background

The circular restricted three-body problem (CR3BP) is a widely used dynamical framework in the field of astrodynamics. This is a simplified model that relies on the assumption of one large gravitational primary, one small gravitational primary, and a spacecraft that is small in comparison to the other two bodies in the system. This small third body assumption essentially assumes all gravitational forces that the spacecraft would enact on the two primaries are assumed to be negligible. In the case of the Cislunar region, the Earth is the large primary and the Moon is the small primary. In the case of the Martian system, Mars is the large primary, and either Deimos or Phobos is the small primary. In the CR3BP, the two gravitational primaries are in circular orbits about the system's barycenter; a good assumption for the Mars-Phobos and Mars-Deimos system as the barycenter falls within Mars (though not perfectly at the center), and the orbits of the moons are highly circular.



The C frame is the barycentric rotating frame.

Methodology

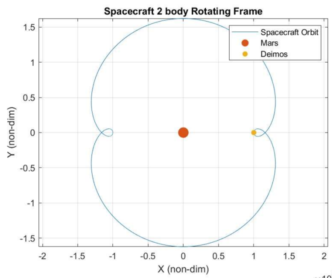
Primarily, the methodology to approaching this research has been to focus on searching for orbital resonance. This is crucial for designing transfers and missions, as it maximizes the change in trajectory for some chosen ΔV. The addition of spherical harmonics may affect resonance; modeling quasi-satellite orbits in proximity to the moons will alter the trajectories. However, this will allow for more robust station-keeping to be planned.

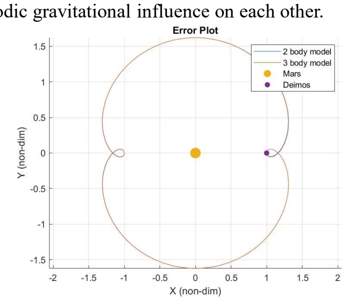
Orbital resonance found in 2BP → Orbital resonance found in CRB3P → Spherical harmonics added to model → Models are assessed against one another

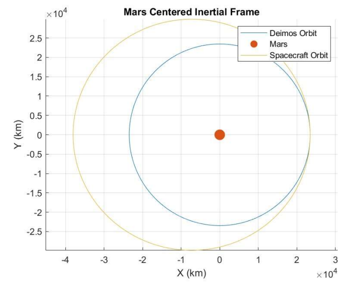
Orbital Resonance

What is orbital resonance?

Orbital resonance occurs when bodies in orbit exert periodic gravitational influence on each other.







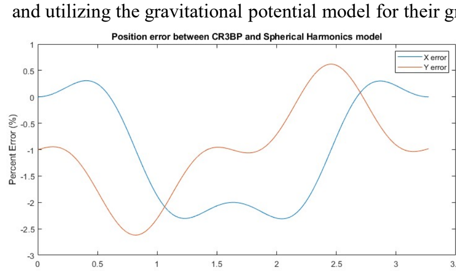
How are resonant orbits obtained?

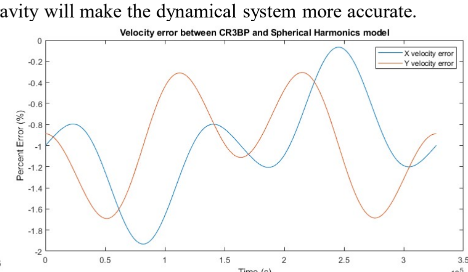
First, the 2BP is leveraged. The conics that describe the spacecraft orbit and the moon's orbit are considered. Then, the eccentricity of the spacecraft's orbit is varied, until the periapsis of the spacecraft's orbit and the orbit of the moon are close within some chosen tolerance. This is used as an initial guess for orbital resonance in the CR3BP.

Spherical Harmonics

What are spherical harmonics?

In the CR3BP, the assumption is that the all bodies in the system can be modeled as point masses. However, in the Mars-Phobos and Mars-Deimos systems this does not hold well. Phobos and Deimos are irregularly shaped moons, and utilizing the gravitational potential model for their gravity will make the dynamical system more accurate.





Future Goals

For the future of this project the team will begin to design trajectories around the Mars-Phobos-Deimos system for the purpose of scientific research and observation. This will be done by increasing the complexity of the problem.

Spherical Harmonics

- Higher order spherical harmonics terms will be considered in future work.

2BP-CR3BP

- Patching between the Mars-Phobos and Mars-Deimos system is needed in order to design transfers between them.
- Moon-to-Moon Analytical Transfer (MMAT) method is explored as a method of designing these transfers.

Inclination of moons

- Currently, the dynamical model assumes coplanar orbits for Phobos and Deimos, which is untrue.
- The refined model will consider the inclination of each of the moons' orbits.

Trajectory Optimization

- Identification of key regions of interest in Mars-Phobos-Deimos system.
- Optimization of trajectories such that these regions can be reached with minimal ΔV.

References

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[2] B. Baker-McEvilly, S. Doroba, A. Gilliam, F. Criscola, D. Canales, C. Frueh, and T. Henderson, "A Review on Hot-Spot Areas Within the Cislunar Region and Upon the Moon Surface, and Methods to Gather Passive Information from these Regions," 33rd AAS/AIAA Space Flight Mechanics Meeting, January 15-19, 2023.

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