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MINIMUM-PROPELLANT DIRECT, ASSISTED, AND SLINGSHOT RETURN TRAJECTORIES FROM MARS, JUPITER, AND THEIR MOONS

Abstract

For future space missions, exploiting a planet's moons to escape from its sphere of influence can significantly improve the performance of the mission itself. In fact, being able to return to Earth while saving the maximum amount of propellant possible allows us, at the preliminary stage, to design the mission with more mass to be allocated to the payload, which means being able to carry out more detailed explorations that will allow us to gain a greater understanding of our planetary system.

This study focuses on identifying the minimum-propellant mission architectures for future return missions from planets with moons to Earth. In particular, Mars and Jupiter are selected as the central bodies, and their moons, including Phobos, Deimos, and the four most massive moons of Jupiter, are taken into consideration.

The analysis explores various escape strategies, such as direct escape trajectories from each gravitational body and either gravity assists or powered flybys. The study considers more than 100 different mission architectures, which include direct escape trajectories and all the possible permutations with one or two additional moons. A detailed analysis narrows the search space for the best gravitational body combinations and identifies the most promising candidate strategies for escape. Different dynamical models are implemented, including a three-body dynamical model and a bi-circular four-body problem, respectively for when one or two moons are considered along with the more massive primary. The heliocentric phase follows Keplerian motion and is patched to the escape conditions from the primaries at the sphere of influence. JPL's DE432s ephemerides are implemented to retrieve the celestial bodies' states over time.

A Lambert's problem for the return trajectory explores launch windows between January 1, 2025, and December 31, 2050. Results show significant differences between the Mars and Jupiter frameworks, with an evident cut-off convenience threshold for considering moons to escape when a bigger primary to smaller primary flyby is implemented. In contrast, solutions that exploit trajectories from a smaller primary towards the bigger one to take advantage of its gravitational pull or the Oberth effect are promising regardless of the specific primary's mass ratio. Notably, the solutions exhibit periodicity over the years due to the combined planetary ephemerides.