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AUTOMATIC MULTI-GRAVITY ASSIST TRAJECTORY DESIGN WITH MODIFIED TISSERAND GRAPHS EXPLORATION

Abstract

Reaching the boundaries of the Solar System has been made possible by Multi-Gravity Assist (MGA) trajectories that reduce the propellant costs by using the gravity of planets to increase or decrease the energy of a spacecraft's orbit. Designing an optimal MGA trajectory constitutes a mixed-integer nonlinear programming (MINLP) problem, which requires a simultaneous combinatorial search of discrete elements (e.g., planets), as well as an optimisation of continuous variables, such as departing date, transfer times, Deep Space Manoeuvres (DSMs), etc., in an exponentially increasing search space. An efficient way to tackle MINLP problems is to first transcribe it into a simplified combinatorial-only problem and, a posteriori, re-optimise the continuous design variables for a subset of promising sequences of discrete elements.

The transcription of an MGA-MINLP problem into a pure combinatorial one can be efficiently explored via Tisserand graphs, which employ Tisserand invariant to map possible flybys as a function of the spacecraft's velocity relative to a given planet. Intersections between contour lines of different relative velocity and planet indicate that a gravity assist is feasible energy-wise and depict how the spacecraft orbit will be perturbed if undergoing that specific gravity assist. Hence, contour line intersections become the nodes of a graph, which can be efficiently explored via tree traversal algorithm.

However, the information obtained from such a Tisserand exploration does not provide launch window or time of flight, and only yields a rough estimate of ΔV. To solve this, a database approach using real ephemerides of celestial objects to correlate initial phase angles of planets with dates and ΔV approximation methods to simulate DSMs was implemented. This allows to successfully establish a list of feasible planetary sequences while providing estimations of propellant costs, launch windows and excess velocities.

The solutions identified are validated by re-optimizing the complete MGA trajectories as sequences of flybys, DSMs and Lambert arcs intersecting the real positions of the planets involved. Mission scenarios to Jupiter and to never-explored objects, e.g. Centaurs or low-perihelion asteroids, are used to validate the accuracy of the Tisserand-based first-guess solutions, as well as the capability to find the global optimum solution in limited computational effort.