ASTRODYNAMICS SYMPOSIUM (C1)
Optimization (1)

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# OPTIMIZATION OF LOW-ENERGY RESONANT HOPPING TRANSFERS BETWEEN PLANETARY MOONS

**Abstract**

In response to the scientific interest in Jupiter's moons, NASA and ESA have recently decided to target in priority Jupiter's largest moons for the next outer planet flagship missions. The proposed missions include two orbiters exploring the Jovian system before settling into orbit around Europa and Ganymede respectively. Trajectory design for these and other similar missions are challenging due to the dynamic complexity of the trade space.

Recent results demonstrate impressive $\Delta$V savings are possible when exploiting the full complexity of the multi-body dynamics of the problem. Multiple resonant gravity assists are the key physical mechanisms that allow the spacecraft to jump between orbital resonances ('resonant hopping'). This phenomenon can steer the orbital energy to achieve desired transfers with reduced propellant requirements. However, existing multi-body approaches often rely on simplified three-body dynamics models and do not involve optimization.

The aim of the current paper is to develop a new systematic methodology to select promising resonant paths and optimize the resulting resonant hopping transfers in higher fidelity models. The proposed approach is to target a predetermined sequence of resonant periodic orbits through small impulsive maneuvers. A good initial guess of the optimal trajectory is generated using a simplified analytical approach in the restricted three-body problem that approximates the impulse provided by the perturbing moon during a flyby. This allows for quick, analytic explorations of the design space in order to identify promising and efficient resonant sequences.

During the optimization process, the problem of directing a trajectory to a target is difficult to solve due to the unstable and chaotic behavior of the multi-body system which results in high numerical sensitivity. A multiple shooting technique is therefore employed that splits the integration interval to limit error propagation and reduce sensitivity accumulation. The resulting optimization problem is then solved using NLP techniques. Targeting successive resonant orbits is also facilitated via a new tool, the Tisserand-Poincaré (T-P) graph, an extension of the Tisserand graph to the three-body problem. Using the T-P graph, the targeting problem for ballistically connecting two orbits between patched three body models can be reduced to two single dimension problems (e.g. one intersection point in the T-P graph).

Preliminary numerical results of tour design in the Jovian system are presented to show the performance of this approach. For example, using only 47 m/s, a spacecraft can transfer between a close resonant orbit of Ganymede and a close resonant orbit of Europa.