DOUBLY-SATELLITE-AIDED PLANETARY CAPTURE WITH INTERPLANETARY TRAJECTORY CONSTRAINTS

Christopher J. Scott,[(1)] **Martin T. Ozimek,**[(2)] **Amanda Haapala**[(3)] **and Brent B. Buffington**[(4)]

[(1)]*Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd. Laurel, Maryland, 20723, (240) 228-5120, Christopher.Scott@jhuapl.edu*

[(2)]*Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd. Laurel, Maryland, 20723, (240) 228-1569, Martin.Ozimek@jhuapl.edu*

[(3)]*Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd. Laurel, Maryland, 20723, (240) 228-2382, Amanda.Haapala.Chalk@jhuapl.edu*

[(4)]*Jet Propulsion Laboratory, 4800 Oak Grove Drive Pasadena, California, 91109, (818) 393-7964, Brent.B.Buffington@jpl.nasa.gov*

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ABSTRACT

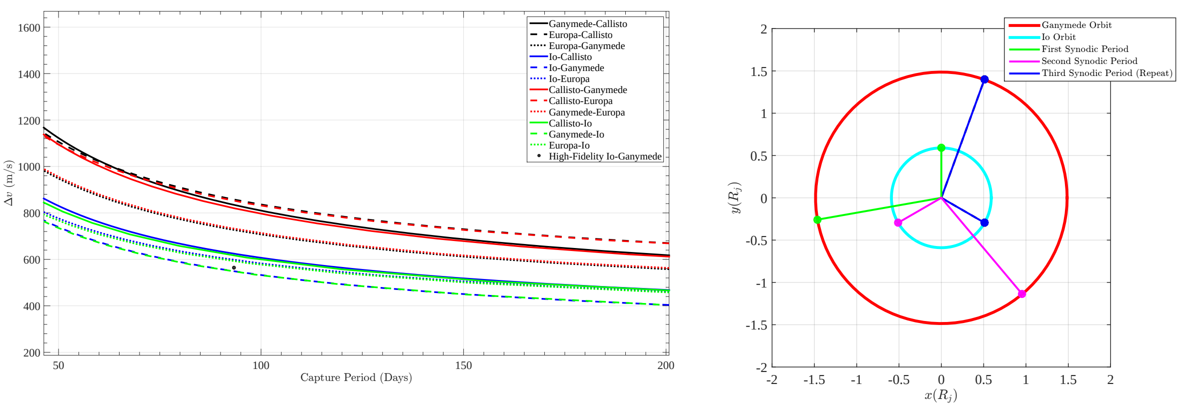
The system entry problem entails the capture of a spacecraft about a planet by way of maneuver(s) or flyby(s) of a satellite(s), or both. Generally, a global search for an optimal interplanetary transfer results in a fixed arrival date and a nearly fixed incoming excess velocity, both in terms of magnitude and asymptote inertial direction. This search opens a trade space, usually explored numerically, and involves the complexities and relative benefits of satellite-aided capture. Within this trade space, in the case of the Jovian system, a balance is sought between the capture maneuver magnitude and radiation dose. This paper introduces the analytical equations necessary to solve the phase-free singly-aided and doubly-aided capture problems, with a focus on the doubly-aided capture problem in the Jovian system. An analytical approximation for the required phasing is derived and the implications of the Laplace resonance are discussed. Analytical approximations are used to seamlessly seed a multiple-shooting algorithm in order to arrive at the converged high-fidelity solution space for the Europa Clipper Mission.

Efforts to develop the analytical approximation stem from a desire to rapidly identify enabling trajectories and possible Δv cost/savings. The assumptions made in this study reduce the design space to a small region of interest by automatically omitting infeasible solutions. Key assumptions of the phase-free approximation are listed as follows: 1) Orbits of the moons are circular. 2) The maneuver is applied at the planetary periapsis. 3) The maneuver is tangential to the velocity 4) Zero sphere-of-influence flybys are modeled. 5) The flybys minimize energy with respect to Jupiter. 6) The asymptote into the system is fixed. 7) A flyby-maneuver-flyby sequence is assumed.

The flyby-maneuver-flyby sequence is the most likely for a finite excess velocity declination with respect to the central body. In other sequences, the first flyby must zero the inclination with respect the orbital plane of the moons. The phase-free doubly-aided solution is analytically calculated in seven steps with an estimation for the phasing comprising the seventh: 1) Select a value for the perijove radius after the first flyby. 2) Define the location of the node of the incoming hyperbola such that the hyperbola intersects the orbit of the first flyby body. 3) Calculate the orbital elements of the incoming hyperbola, subject to the node, asymptote, and perijove constraints. 4) Based on a B-plane target that minimizes energy, calculate the orbital elements after the first flyby. 5) Find the orbital elements after the maneuver subject to the node and tangential maneuver constraints. 6) Based on a B-plane target that minimizes energy, calculate the orbital elements after the second flyby. 7) Calculate the time of flight of each segment to provide a relative and absolute phasing guess. The phase-free singly aided solution is constructed as follows: 1) Follow steps 1–4

for the doubly-aided problem. 2) Compute the maneuver that yields the desired orbital period. 3) Calculate the time of flight of each segment to provide the phasing guess for the flyby moon.

The phase-free results for every flyby combination in the Jovian system are summarized in Fig. 1(a). The resonant conditions provide a set of advantages and disadvantages over the non-resonant solutions: 1) For a given phase-free solution, if the phasing condition is not satisfied, then the solution will never exist for that specific interplanetary trajectory. 2) For a given phase-free solution, if the phasing condition is satisfied, then it will always repeat at the appropriate number of synodic periods over a timescale much smaller than the orbital period of Jupiter. Therefore, in the resonant moon situation, a given arrival epoch will immediately rule out sets of phase-free solutions. This behavior is especially desirable for practical considerations such as finding trajectory configurations that yield suitable communications access. The resonance pattern for Io and Ganymede is represented in Fig. 1(b), while a high-fidelity solution with the sequence Io-maneuver-Ganymede, converged from the analytical estimation, appears in Fig. 2.



(a) Phase-Free Solutions

(b) Io-Ganymede Resonance

Figure 1: The Phase-Free Trade Space and the Io-Ganymede Resonance

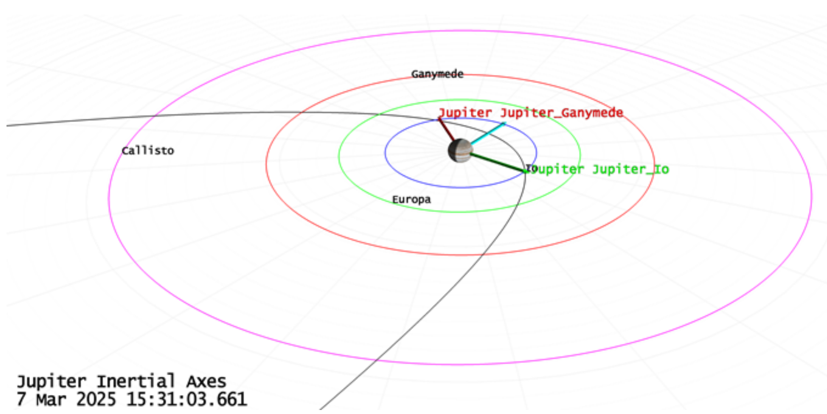


Figure 2: High-Fidelity Solution Seeded from the Analytical Estimation