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SURVEY OF LOW-THRUST GRAVITY ASSIST TRAJECTORY OPTIMIZATION METHODS, WITH COMPARISONS TO A NOVEL, MULTI-IMPULSE DISCRETIZATION APPROACH

Abstract

Recent technological advancements in low-thrust electric propulsion (LEP) offer significant performance benefits over other in-space propulsion systems in certain applications. Interplanetary spacecraft stand to benefit significantly from the increased payload mass fraction provided by LEP. The effective use of LEP systems in this mission class requires the development of robust, accurate, and practically implemented methods of computing low-thrust gravity assist (LTGA) trajectories. Unfortunately, finding global optimal solutions for these problems is a formidable task, as no analytic, closed-form solutions exist. Numerical approaches for solving the LTGA problem are often tailored for specific transfers and are sensitive to the chosen initial guess trajectory. This makes available methods difficult to generalize, which greatly restricts the types of transfers that can be computed with regards to changes in inclination, eccentricity and other orbital parameters. Available trajectory optimization methods are surveyed and applied to two orbital transfer problems—a LEO-to-GEO low-thrust transfer with modest eccentricity and high inclination change, and a LEO-to-Mars low-thrust transfer utilizing a lunar gravity-assist. All trajectories are computed numerically and compared with regards to the total delta-V of each transfer, the magnitude of the spacecraft's constant thrust-acceleration, the total flight time, and the ease of adaptability to generic LTGA optimization problems. A novel, multi-impulse discretization method is then introduced and compared to the prior approaches. The method takes an initial guess trajectory and discretizes it into a set of impulsive segments using a non-linear programing solver and perturbation force model to minimize total delta-V. The discretized initial guess trajectory is then fed to an optimal control algorithm that transforms the trajectory back into a continuous numerical curve by finding thrust directions along the path that minimize the difference between the spacecraft's state vector and the discretized waypoints. Results from these two case studies show that the new approach delivers similar or improved performance over the existing methods while incurring significantly reduced computational cost.