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DESIGN OF OPTIMAL SPATIAL LOW-ENERGY TRAJECTORIES TO NEAR-EARTH OBJECTS

Abstract

Near Earth Objects (NEOs) are small Solar System bodies (asteroids, comets, meteoroids) on heliocentric orbits with perihelion below 1.3 astronomical units, leading to occasional proximity with Earth. With over 30000 known asteroids and approximately 100 listed short-period comets, the NEO population represents an inventory of exploration targets reachable with significantly lower cost than the objects of the Main Asteroid Belt. Similarly to the latter, NEOs are primordial bodies, hence their study can provide insight into the origins of our planetary system. Furthermore, the materials present in these objects can be used to resupply spacecraft on course to other destinations. Past missions to NEOs (e.g., NEAR, Hayabusa, ICE, Deep Impact, Giotto) were designed using the patched-conics approximation, in combination with impulsive and/or low-thrust maneuvers. This contribution builds on previous work in which we proposed a design technique that leverages the invariant structures (hyperbolic invariant manifolds) of the planar circular restricted three-body problem (CR3BP) combined with the simplicity and efficiency of the Keplerian approximation to connect the vicinity of the Earth with NEOs in nearly circular, low-inclined heliocentric orbits through planar Lyapunov orbits around the collinear points L1 and L2 of the Sun-(Earth+Moon) CR3BP. The resulting trajectories follow low-energy paths; therefore they naturally minimize both the launch cost and the V to rendezvous with selected targets. In this contribution, we develop an extension of the technique to the 3D domain, using libration point orbits with their hyperbolic invariant manifolds and an adaptation of a trajectory design method called MMAT to approach NEOs on inclined orbits. We analyze the time of flight, launch energy and V to perform rendezvous with a variety of targets, and we compare our results with the performance of existing solutions and past missions. Finally, we present a methodology to reshape the rendezvous maneuver through low-thrust arcs, and we compare times of flight and propellant consumption in equivalent impulsive and continuous-thrust scenarios.