Efficient design of optimal low-energy trajectories to Near Earth Objects⋆

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Abstract. An efficient and effective technique to design spacecraft transfers from the Earth's vicinity to Near Earth Objects (NEOs) is proposed. The method exploits the natural dynamics of the circular restricted three-body problem (CR3BP) and the analytical solutions provided by two-body approximations. The current version of the method is applied to the design of trajectories to low-inclination NEOs. Unstable invariant manifold trajectories or transit orbits emanating from planar Lyapunov orbits around L_1 or L_2 of the Sun-Earth CR3BP often intersect the orbits of NEOs. Two-body approximations of these trajectories far from the Earth yield a simple analytical model to compute rendezvous opportunities. Preliminary results prove the validity of the method. The contribution will illustrate the technique and its advantages, and will discuss the use of low-thrust propulsion to reduce the propellant consumption to reach the targets.

Keywords: Circular restricted three-body problem · Libration points · Hyperbolic invariant manifolds · Two-body problem · Orbit transfers.

1 Introduction

A Near Earth Object (NEO) is any small Solar System body (asteroid, comet, meteoroid) whose orbit has a perihelion lower than 1.3 astronomical units, hence leading to proximity with Earth. There are over 25000 known near-Earth asteroids (NEAs) and more than a hundred listed short-period near-Earth comets (NECs). Exploring these objects is key to expand our understanding of the origin and evolution of the solar system. In recent years, NEOs have gained importance also in the context resource utilization. Past missions to NEOs (e.g.,

NEAR, Hayabusa, ICE, Deep Impact, Giotto) were designed using the conventional patched-conics technique in combination with high- or low-thrust propulsion. The present contribution proposes a novel, simple and efficient methodology to design transfers from LEO or from a planar Lyapunov orbit (PLO) around L_1 or L_2 to one or more targets in the NEO category by leveraging the invariant structures of the Sun-Earth circular restricted three-body problem (CR3BP).

2   Objectives and methodology

The hyperbolic invariant manifolds (HIMs) of periodic orbits around the Sun-Earth Lagrange points L_1 and L_2 expand into the co-orbiting region of the Earth and approach at low relative speed objects in a similar regime of motion. The objective of the present work is to prove a strategy to identify low-cost trajectories departing either a low Earth orbit or a planar Lyapunov orbit (PLO) around L_1 or L_2 and reaching low-inclination ($\leq 5°$) NEOs. The approach is 2D, i.e., the orbit of the candidate targets are projected on the ecliptic plane. The unstable HIM trajectories of families of PLOs around the two equilibrium positions are propagated to intersection with the sphere of influence (SoI) of the Earth. Transit orbits (TOs) passing through the HIMs are propagated both forward (to the SoI) and backwards (to search for intersections with a LEO) in time. At the SoI, the states of either type of objects are collected and expressed with respect to a heliocentric reference frame with fixed axes to yield osculating orbital elements. This two-body approximation of CR3BP trajectories is illustrated and justified in [1]. The shape of the resulting osculating orbits are determined by the specific departure position on or inside the PLO (for HIMs and TOs, respectively), whereas the longitude of the perihelion varies depending on the orbital phase of the Earth at the time of SoI crossing. The intersection of these orbits with the orbits of the selected NEOs depends on time. The requirement that the target and the spacecraft (s/c) encounter at the intersection point translates into an additional time constraint, which can only be satisfied approximately, yet results can be obtained with an accuracy compatible with the model errors.

3   Results

Preliminary results obtained from the propagation of HIM trajectories prove that the technique can yield solutions with ΔVs (i.e., the magnitudes of the velocity difference between the s/c and the target at encounter) as low as 60 m/s and times of flight in the range between 1 and 2 years. The contribution will discuss the case of HIMs as well as TOs and the possibility of achieving zero relative-speed rendezvous by employing low-thrust propulsion.

References

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