Paper ID: 14664
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ASTRODYNAMICS SYMPOSIUM (C1)
Orbital Dynamics (2) (7)

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LOW-ENERGY EARTH-MOON TRANSFERS INVOLVING MANIFOLDS VIA ISOMORPHIC MAPPING

Abstract

Analysis and design of low-energy transfers to the Moon has been a subject of great interest for decades. Exterior and interior transfers, based on the transit through the regions where the collinear Lagrange points L1 and L2 are located, have been studied for a long time and some space missions have already taken advantage of the results of these studies. Examples of this kind of missions are represented by the European Smart-1, the Japanese Hiten, and the recent NASA GRAIL missions. This paper is concerned with an isomorphic mapping for low-energy Earth-to-Moon mission analysis. If the Birkhoff's equations of motion are employed, the phase space associated with trajectories in the circular restricted three-body problem can be represented through a convenient set of cylindrical coordinates. This isomorphic mapping of trajectories allows a visual, intuitive representation of periodic orbits and of the related invariant manifolds, which correspond to tubes that emanate from the curve associated with the periodic orbit. Two types of Earth-to-Moon missions are considered. The first mission is composed of the following arcs: (i) transfer trajectory from a circular low Earth orbit to the stable invariant manifold associated with the Lyapunov orbit at L1 (corresponding to a specified energy level) and (ii) transfer trajectory along the unstable manifold associated with the Lyapunov orbit at L1, with final injection in a periodic orbit around the Moon. The second mission is composed of the following arcs: (i) transfer trajectory from a circular low Earth orbit to the stable invariant manifold associated with the Lyapunov orbit at L1 (corresponding to a specified energy level) and (ii) transfer trajectory along the unstable manifold associated with the Lyapunov orbit at L1, with final injection in a capture (non-periodic) orbit around the Moon. In both cases three velocity impulses are needed to perform the transfer: the first at an unknown initial point along the low Earth orbit, the second at injection on the stable manifold, the third at injection in the final (periodic or capture) orbit. The final goal is in finding the optimization parameters, which are represented by the locations, directions, and magnitudes of the velocity impulses such that the overall delta-v of the transfer is minimized. This work proves how the isomorphic mapping can be profitably employed to optimize such transfers, by determining in a geometrical fashion the desired optimization parameters that minimize the delta-v budget required to perform the transfer