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LOW-THRUST VARIABLE-SPECIFIC-IMPULSE TRANSFERS TO LUNAR LIBRATION POINT ORBITS, WITH APPLICATIONS TO MOON EXPLORATION

Abstract

Libration point orbits (LPO) about the L1 and L2 Lagrange points have been the subject of considerable research interest since 1950s. It is found that lunar L1 libration point orbits are connected to orbits around Earth's L1 and L2 via low energy passageways, and the same orbits could reach any point on the surface of the Moon within hours. Thus, the lunar L1 is a perfect location for the Moon exploration, and can be used as an important hub in the future.

Accessing libration point orbits usually requires a transfer from the Earth. This kind of transfer has been investigated extensively since the launch of the International Sun-Earth Explorer (ISEE-3) in 1978. Beginning with the launch of the Small Missions for Advanced Research in Technology (SMART-1) in 2003 and its successful transfer to the Moon through lunar L1 region, highly efficient low-thrust propulsions are now viable options for deep space missions. Among these classes of thruster, variable specific impulse magnetoplasma rocket (VASIMR) is compact, light weight (1-6 kg/kW) and high powered (multi mega watt class), and is expected to be used for future crewed/cargo missions for interplanetary flight. Using this engine, continuous and variable thrust at a constant power is released, and a tradeoff between minimizing the transfer time and maximizing the payload capability can be obtained.

In the present investigation, a design technique for a fuel optimal Earth-to-LPO transfer using VASIMR is proposed. The calculus of variations approach and direct parameter optimization are combined to formulate the trajectory optimization problem. The classic stable manifold, developed in dynamical systems theory, is employed to further reduce fuel consumption. Adjoint control transformation (ACT) is introduced to establish the relationship between the sensitive costates and a set of control related variables that are more meaningful and less sensitive. Particularly, analytical gradients are derived and play a significant role in improving the efficiency and accuracy. Several transfer examples, direct transfers from LEO and MEO to lunar L1 libration point orbits, and indirect transfers with lunar flybys, are presented. Simulations show that the algorithm has very strong convergence properties, and therefore has very wide applicability.

These kinds of transfers may be beneficial for future human missions to the Moon. Several potential applications associated to the exploration of the Moon are proposed. Particularly, the Chinese lunar sample return mission, a follow-up to the Chang'e 3 lunar probe, is discussed and preliminary numerical results are also presented.