IAF ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimization (1) (6)

Author: Mr. Alessandro Beolchi
Khalifa University of Science and Technology (KUST), United Arab Emirates

Dr. Elena Fantino
Khalifa University of Science and Technology (KUST), United Arab Emirates
Dr. Mauro Pontani
Sapienza University of Rome, Italy
Prof. Kathleen Howell
Purdue University, United States
Ms. Chiara Pozzi
Khalifa University of Science and Technology (KUST), United Arab Emirates

LOW-ENERGY ROUND-TRIP TRAJECTORIES TO NEAR-EARTH OBJECTS USING SOLAR ELECTRIC PROPULSION

Abstract

Near-Earth Objects (NEOs) represent valuable targets for space exploration, due to their accessibility, scientific significance, and potential for in-situ resource utilization. Advances in low-energy trajectory design have uncovered efficient routes to these bodies. However, the use of low-energy transfers for direct connections between Earth and NEOs remains largely unexplored, particularly when combined with low-thrust propulsion. This work aims to develop a systematic and streamlined methodology for designing spatial low-energy trajectories for the scientific exploration of NEOs, encompassing both one-way and round-trip transfers. An effective approach based on the combined use of the Sun-Earth-spacecraft Circular Restricted Three-Body Problem (CR3BP) and the Sun-spacecraft Two-Body Problem (2BP) is adopted. Within the CR3BP, invariant manifold trajectories (MTs) and associated transit orbits (TOs) traverse the Earth realm, acquiring a phase difference relative to the Earth. Beyond a certain distance from Earth, as the terrestrial gravitational influence becomes negligible, the Sun-spacecraft 2BP is used to approximate MTs and TOs. The 2BP simplifies the identification of spacecraft-NEO encounters, which are determined either through intersection of the respective heliocentric elliptical orbits or by solving a Lambert problem. Impulsive trajectories serve as the backbone of the analysis, and are subsequently replaced by low-thrust arcs, improving propellant efficiency. Because the axes of the Sun-Earth synodic frame rotate, the same MT or TO is approximated by infinitely many 2BP orbits, which differ only by their orientation in space, determined by the departure epoch. This property provides a degree of freedom that can be leveraged in the design of both the outbound (Earth-NEO) and inbound (NEO-Earth) leg of a round-trip trajectory, thus enabling the selection of the preferred solution according to custom design criteria such as mission duration and propellant budget. The solid foundation of the methodology at hand was demonstrated in a previous contribution, which successfully applied this strategy to identify low-energy solutions for NEO rendezvous missions, leveraging the departure epoch as a free parameter. This work extends the range of applicability of the method to round-trip trajectories by incorporating the stay-time at the NEO as the additional design parameter associated with the inbound leg of the transfer.