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ANALYSIS OF BALLISTIC ESCAPE OPPORTUNITIES VIA MULTIPLE LUNAR SWINGBYS FOR FAST AND FLEXIBLE MISSIONS

Abstract

All interplanetary missions begin with a hyperbolic escape trajectory that allows them to escape the gravity well of the Earth-Moon system and, so, it begins its true interplanetary adventure. Typically, the upper stage of a launcher may insert the spacecraft in such an initial condition, and the spacecraft may then be woken up (i.e., commissioned) to perform correction manoeuvres to recover from launcher dispersion errors. Such process to escape the gravity well of the Earth would typically require medium-to-heavy, as well as dedicated, launch capabilities. However, together with the context of Space 4.0 and the so-called democratization of space, a larger number of mission proposals are in need of lower-cost, more flexible and efficient Earth escape routes.

The Moon may offer such an effective interplanetary gateway, with the potential to reduce propellant costs up to a third or allow for a 50% increase in payload capacity. To reap the benefits of the Moon's gravitational perturbation, one or multiple timely lunar swingbys are necessary. This is operationally complex, requiring longer and navigationally challenging cislunar spaceflight. Nevertheless, such procedures have been proven by past missions such as ISEE-3/ICE.

Techniques to design such departure process vary from the implementation of planar patched restricted three body problem (PCR3BP) to complex leveraging of multi-body equilibria and manifold dynamics. However, while techniques are available for bespoke design of complex three and four body gymnastics, the application of these techniques to the overall statistical understanding necessary for preliminary mission design purposes is less than optimal.

This paper revises the state-of-the-art of ballistic escape and endgame (i.e. capture) trajectory design. It presents a pipeline of solution refinement which begins on a simple Sun-Earth PCR3BP with Moon swing-bys modelled as a linked conic. This seed solution is subsequently refined into ephemeris model, which validates the simplified dynamical framework. The refinement process confirms the scope of the Monte-Carlo analysis run within the PCR3BP. The results of the Monte-Carlo allow to understand the availability of Lunar Swing-bys for different escape directions and magnitudes as a function of the launch date. This is particularly relevant to understand the opportunities offered by single or multiple lunar swing-by escape and capture opportunities for missions benefiting of ride-share or piggyback launch opportunities and/or subjected to programmatic and launch delays.