INVESTIGATION OF ALTERNATIVE RETURN STRATEGIES FOR ORION TRANS-EARTH INJECTION DESIGN OPTIONS

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The purpose of this study is to investigate alternative return strategies for the Orion trans-Earth injection (TEI) phase. A dynamical systems analysis approach considers the structure of the stable and unstable Sun perturbed Earth-Moon manifolds near the Earth-Moon interface region. A hybrid approach, then, combines the results from this analysis with classical two-body methods in a targeting process that seeks to expand the window of return opportunities in a precision entry scenario. The resulting startup arcs can be used, for instance, to enhance the block set of solutions available onboard during an autonomous targeting process.

Introduction and Motivation

The purpose of this study is to investigate alternative return strategies for the Orion trans-Earth injection (TEI) phase. A dynamical map of the flow in the Earth-Moon system[1] is of particular interest to expand the window of opportunities in a precision entry scenario. The insight from this analysis can then be applied in constructing an enhanced set of return options that serve as startup solutions to targeting and optimization algorithms.

Gradient based targeting and optimization methods share several elements in common. For instance, they each require a reasonably accurate initial guess, and the solutions identified are confined to the immediate vicinity of the startup arc. In either approach, the startup solution itself need not be entirely feasible, but the quality of the initial guess can have a significant impact on the convergence process. A feasible trajectory, in this case, refers to one that satisfies the necessary continuity, path, and entry constraints.

The Orion trans-Earth injection sequence begins with a departure from low-lunar orbit, specifically a polar orbit. The baseline return strategy employs a three-maneuver sequence, including a plane change maneuver, to achieve precision entry without exceeding the available fuel budget. In identifying startup arcs for this three-maneuver return sequence, some methods consider the use of two-body approximations.[2] However, the startup arcs generated from this approach lead to infeasible startup arcs. Specifically, a state and time discontinuity exists at the interface between the Earth and Moon trajectory segments. The magnitude of this discontinuity varies greatly depending on the

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entry site targeted on Earth, and the location of the Moon along its path during the lunar cycle. This type of discontinuity can slow down the convergence process for either targeting or optimization processes. This is of particular concern in an onboard determination process, where computational resources are limited and time is of the essence in identifying a feasible return path. Furthermore, since gradient based methods only explore the vicinity of the initial guess, the resulting trajectories do not fully exploit the rich dynamical structure of the Sun perturbed Earth-Moon system.

The present investigation seeks to explore alternative return strategies that take advantage of the invariant manifold structure in the Sun perturbed Earth-Moon system. The study is divided into two main steps. First, the quality of the startup arcs derived from two-body approximations[2] is investigated through dispersion analysis. For a select group of entry sites, constraint coupling and its impact on the resulting error at the interface with the sphere of influence is investigated. Subsequently, the natural dynamical structure[1] within the context of a multi-body model is used to investigate hybrid return strategies that also offer low cost transfers while preserving the general timing constraints involved in human space flight.

Proposed Approach

The first step in this study is to investigate the parameters that most significantly impact the quality of the startup arc derived from two-body analysis.[2] This is accomplished by (a) systematically introducing perturbations in the entry constraints, (b) identifying the associated inertial state, (c) propagating the resulting state backwards in time towards the lunar sphere of influence, and (d) investigating how each constraint contributes to the dispersion at the lunar sphere of influence, the coupling factors between constraints, the impact of entry time, and the combined impact on the overall dispersions at the interface with the lunar sphere of influence. The results of this study are used to identify the nature of the state and time discontinuities in the resulting startup arcs and to improve the process of designing return trajectories used as startup arcs during targeting and optimization processes.

A different perspective may enhance understanding of the design space. Thus, once the most sensitive cases are identified, alternative design strategies for return options are considered based on a global geometrical approach. A dynamical map of the flow near the lunar interface region serves as a geometrical basis to examine the natural flow and identify overlaps with any of the dispersion trajectories. One of the possible structures considered in this study corresponds to the stable and unstable manifolds associated with quasi-periodic L_2 Lissajous trajectories in the Sun perturbed Earth-Moon systems. Of particular interest are sections of these manifolds that cross through the interface region. While it is understood that these trajectories are generally low velocity paths, and that they may not satisfy the time of flight constraints usually associated with this type of mission, a hybrid approach considers the combination of "conic" arcs near the Earth and Moon with segments along the existing manifold structure near the interface region. A robust differential corrections process can subsequently blend both segments into a single continuous feasible path. Alternative return strategies may then emerge that offer better alignments for meeting the desired entry constraints.

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