Paper ID: 89176
student

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

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INTERPLANETARY TRAJECTORY DESIGN TOOL FOR COMETARY SAMPLE RETURN MISSIONS

Abstract

Comets and primitive asteroids are composed of fragments that originally were part of giant planet cores and other celestial bodies, serving as crucial indicators of the Solar System's formation processes. In the two latest Decadal Surveys, NASA's New Frontiers Program has reaffirmed the paramount scientific importance of retrieving surface samples from cometary nuclei and returning them to Earth for in depth analysis. The growing interest among the scientific community in cometary sample return missions calls for efficient tools to swiftly identify preliminary interplanetary trajectories to these celestial objects and back. The peculiarities of the problem have to be sought for in the high number and variability among the possible targets, coupled with the typically high cometary eccentricities and relative velocities that have to be dealt with. As a result, two interrelated multiple gravity assist transfers need to be addressed and planned.

In this paper a trajectory design methodology is proposed, and evaluated by comparing them with previously flown missions such as Cassini and ESA-Rosetta. Firstly, a survey of accessible short-period comets is conducted to evaluate the feasibility of scientifically relevant targets from the Mission Analysis perspective, using a Tisserand plane analysis. The problem is divided into two segments: the outbound and return trips, linked by the duration of stay at the celestial object. Bellman's principle of optimality ensures the solution's quality remains intact. Promising configurations of planetary gravity assists to be investigated are obtained through a Tisserand-based approach coupled with dynamic programming techniques. For each combination, a sequence is defined as a succession of Gravity Assists, Deep Space Manoeuvres between the current and subsequent bodies, with "body" representing either a planet or the targeted comet, and Lambert arcs connecting each event on a grid of acceptable times of flight. A Particle Swarm Optimisation method is then implemented, incorporating a minimum v constraint, and the solution is retrieved.

To address launcher constraints and offer backup solutions, alternative approaches involving post-launch Earth resonant sequences are explored through an automated search, providing a comprehensive overview of available options.

The proposed approach is applied to the mission design of VESPUCCI, a phase 0 concept for a cryogenic sample return probe. The paper critically examines the obtained solution, effectively demonstrating its feasibility from a mission analysis perspective, and providing an initial demonstration of the tool's viability as a potential approach for complex mission trajectory design.