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Characterization of low-energy orbits for the exploration of Enceladus

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Abstract

This investigation proposes a set of orbits in the Saturn-Enceladus system in the Circular Restricted Three-Body Problem and analyses their performance for the exploration of the south polar region of the moon, where several gas ejecta are observed. Parameters that are essential in the design of an *in situ* observational programme, such as orbital periods, distance ranges from the surface, orbital inclinations, speeds in the synodic and the moon-centered inertial reference frames, surface latitude coverage and times of overflight are determined and discussed. The dynamical properties (periodicities, robustness) of the proposed trajectories make them particularly suitable to design of a complex observational tour of the moon.

1 Introduction

In the framework of the future generation of solar system exploration missions, high priority is given to the observation of the so-called Inner Larger Moons of Saturn, namely, Mimas, Enceladus, Tethys and Dione [1]. In particular, the geyser-like jets (observed by Cassini in 2005, 2008 and 2015) from the Enceladus's south polar surface, venting water vapor, ammonia, salts, hydrogen and organics, have placed this moon among the targets to search for life and habitability features [2, 3]. Near-polar science orbits around planetary satellites are unstable and they can only be reached by expensive change-of-plane orbital maneuvers [4]. Previous mission studies for planetary orbiters have managed to identify long-term stable orbits around planetary moons with altitudes near 200 km, but the highest inclinations reached are in the range $\sim 40°$ to $\sim 60°$ [5, 6, 7]. This investigation proposes a set of periodic orbits around Enceladus to be employed for the robotic *in situ* exploration of its south polar region.

2. Methodology

The dynamical model employed is the Circular Restricted Three-Body Problem (CR3BP), with Saturn and Enceladus as primaries. Halo orbits, a specific set of periodic Libration Point Orbits (LPOs), around the Lagrange points L_1 and L_2 of the system are considered, owing to their significant out-of-plane motion. The stable and unstable hyperbolic invariant manifolds (HIMs) of these orbits (see Figure 1) are used to design homoclinic and heteroclinic transfers. In a homoclinic loop, the probe leaves the Halo orbit by its unstable HIM and goes back to it by means of the stable HIM, and the connection between the two segments is computed at a suitable symmetry plane in the synodic reference frame, in such a way that the maneuver needs no propellant (zero ΔV). A heteroclinic transfer links two Halo orbits around L_1 and L_2, respectively, and it does so by connecting orbits of the respective stable and unstable HIMs. The cost of the connection is a function of the energy difference between the involved Halo orbits.

By following heteroclinics and homoclinics, the probe executes loops around the moon and approaches its surface. The coverage offered by these trajectories is analysed, with particular focus on the observability of the south polar regions. Properties such as orbital periods, distance ranges from the surface, orbital inclinations, speeds relative to the synodic and the moon-centered inertial reference frames, surface latitude coverage and times of overflight are computed and discussed.

3. Discussion and conclusions

The proposed exploration orbits offer several advantages over classical two-body solutions. Firstly, their appealing performance features, especially concerning the orbital inclinations and the close-approach distances to the moon. Then, since the CR3BP takes

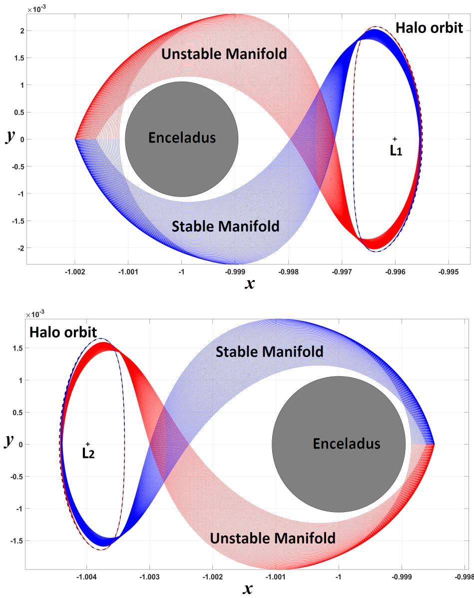

Figure 1: Projection of the three dimensional stable and unstable HIMs of Halo orbits on the (x, y) plane. The Halo orbits are about L_1 and L_2 in the Saturn-Enceladus system in the synodic reference frame.

into account the gravitational effects of both primaries (i.e., Enceladus and Saturn) simultaneously, and, since the influence of the other moons is negligible (owing to their small masses and large distances), this model offers very good approximations to n-body solutions. Hence, the transfer trajectories here considered should require negligible navigation corrections. The periodic character of the Halo orbits makes them convenient parking orbits in the framework of a complex observation tour of Enceladus, in which several homoclinic and heteroclinic paths are followed consecutively. Finally, the same Halo orbits can be employed as departure gates to other destinations, i.e., other moons in the system, thus extending to 3D the low-energy inter-moon connections found in previous work by the same and other authors [8, 9, 10].

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