Paper ID: 31045
oral
student

ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimization (2) (2)

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OPTIMAL RENDEZVOUS IN CURVILINEAR COORDINATES

Abstract

Proximity rendezvous maneuvers are very important for many practical operational scenarios. A field of application are Active Debris Removal missions, where the initial orbit of the chaser spacecraft is normally close but not equal to the one of the target debris. This is especially true when launched as a piggyback payload, or when a multiple target mission is considered. A phasing maneuver is also required to place the chaser at the required operational distance. Those issues are capital in the mission design of LEOSWEEP (improving LEO Security With Enhanced Electric Propulsion), an EU-funded project aiming at the contactless manipulation of non-cooperative targets using specifically designed ion beams.

Optimization of a general rendezvous problem is very complex. It was studied in the classical book by Marec, obtaining closed solutions only for a small set of conditions. As in many optimization problems, an appropriate choice of the dynamics formulation can ease their treatment to a great extent. The key idea behind this article it to employ a novel relative motion formulation based on curvilinear coordinates.

The minimum-time rendezvous maneuver between two close, non-coplanar and quasi-circular orbits is studied, using the aforementioned formulation for dynamics and both the Direct and Indirect Methods for Optimal Control Problems. The former leads to an extensive set of numerical solutions, while the analytical expressions in the latter provide greater insight on the physical characteristics of the maneuver.

The numerical solutions obtained for a wide range of thrust values reveal that the optimal transfer undergoes fundamental qualitative changes as the non-dimensional thrust parameter varies. It is possible to distinguish two different regimes for very high and very low thrust parameters, with nearly bang-bang thrust orientation control laws, and a transition zone between them. Additionally, a direct relation between mission time and thrust is identified for both regimes. These behaviors are further investigated by applying perturbation techniques to obtain approximate analytic solutions to the first order optimality conditions given by the Indirect formulation. This study confirms and justifies the qualitative behaviors detected through the numerical tests, provides an estimate on the values of thrust at which the transition zone appears, and gives an analytical approximation for the relation between maneuver time and thrust parameter.

References:

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