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Title

Sensitivity analysis of collision avoidance manoeuvre with low thrust propulsion

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Abstract
As the number of objects in Space increases, so does the number of Conjunction Data Messages (CDMs) for potential Close Approach (CA) events. As a consequence, one of the pillars of space traffic management requires deriving operational concepts suitable for collision avoidance operations in low-thrust missions.
The ELECTROCAM project, funded by ESA and carried out by GMV, Politecnico di Milano and Universidad Carlos III de Madrid, has the objective of advancing the state of the art in two main aspects of low-thrust collision avoidance activities: conjunction screening under different sources of uncertainty, including those of the thruster, and low-thrust Collision Avoidance Manoeuvre (CAM) design and execution. Furthermore, operational constraints must also be considered in CAM design and decision-making. To meet these goals, suitable concepts are identified for each of the different scenarios where low thrust is used, including ballistic, disposal and orbit-raising scenarios, and tested against a large conjunction dataset.
As part of this analysis, Politecnico di Milano is responsible for developing analytical and semi-analytical manoeuvre optimisation methods tailored to each proposed scenario and the preliminary computation of the optimal CAM employing a low-thrust engine. Moreover, these models also enable the efficient execution of sensitivity analyses on different key parameters of CA and CAM.

In this study, the proposed analytical and semi-analytical techniques are briefly described, and some application cases are shown. A large amount of CDM dataset is created by GMV, simulating real conjunctions. These are derived from a screening against a background TLE population in different orbit scenarios: early Geostationary transfer and insertion into GEO, GEO Graveyarding, Low Earth orbit (LEO) to high-LEO transfer, and typical Station Keeping activities in LEO (Starlink's orbit) and GEO. Covariance information of the secondary is derived from statistical analysis on JSpOC CDMs from ESA missions. For the primary, improved operational concepts are simulated in order to manage the large uncertainty associated to the long-thrusting arcs present in the different orbit scenarios considered. This way, the predicted state better matches the flown trajectory, and the covariance growth is kept within limits reasonable for an accurate risk analysis. These concepts are compared against current or nominal operational concepts.
On all these cases the CA is first analysed, in terms of miss distance, relative velocity and position on the b-plane, and the probability of collision at time of close approach. Then, the focus shifts to how CAM influences the displacement in the b-plane, expense for the manoeuvre and efficacy of it. For each of them, different Accepted Collision Probability Level (ACPL) thresholds and conjunction notification times are tested for CAM design. We analyse the convergence of

the proposed methods and the capabilities to achieve the required ACPL for a given operational scenario. In case the required ACPL cannot be fulfilled, due to a short warning time, a minimisation of the probability of collision is ensured through a semi-analytical solution.