Operational Concept for Orbit Raising with Low Thrust

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Missions performing long orbit transfers with low-thrust electric propulsion systems have become increasingly popular in recent years. A recent example of such mission is the ABS-3A mission, launched in March 2015: a fully-electric communications satellite in a geostationary orbit with a Boeing 702SP satellite bus. The satellite made the transfer from a super-synchronous transfer orbit to the final geostationary orbit using electric propulsion only.
Using a low-thrust electric propulsion system, such a transfer from a satellite's initial orbit to the final operational orbit can take between several months to one year. During this period, the satellite fires its thruster(s) almost continuously. There are several challenges associated with such transfers, not the least of which is the optimization of the transfer trajectory. The optimal transfer problem has been studied actively over the last decades and many solutions exist, most of which rely on solving some large optimization problem to determine optimal steering laws over the course of the transfer. Problems less studied are related to the operational implementation of such a transfer, which is the topic of this paper.
During the transfer with continuous low thrust, the orbit prediction errors are significantly larger than without such continuous thrust. These errors are dominated by the combination of orbit determination errors and errors arising from the propulsion system itself – the execution of the maneuvers differs significantly from the planned maneuvers. This paper presents an error model considering these two dominant error sources and a method for propagation of the covariance of error resulting from these sources.
Two particular challenges result from the errors due to orbit determination and maneuver execution. The first is that the planned trajectory differs from the actual trajectory. This introduces the need for feedback, consisting of a re-optimization of the transfer trajectory, as well as generating and uploading new thruster and steering commands to the satellite. The frequency of such re-planning is an important operational consideration, as well as the execution of the commands on-board the satellite. The usual approach is a time-tagged execution of such profiles, however, when an on-board orbit determination capability is present, such commands can also be "anomaly-tagged", reducing the impact of orbit prediction errors.
The second challenge is collision avoidance. Typical launch orbits have high apogees, at or above the apogee of the target operational orbit, where usually the density of other satellites is low and the risk of collisions is acceptable. However, the perigee is usually in the Low Earth Orbit (LEO) regime. During a low thrust transfer, it may take the satellite several weeks to raise its perigee to an altitude above LEO altitude (~2000 km). The density of objects in the LEO regime is significant, providing a need for conjunction analysis and collision avoidance strategies.
These challenges are addressed in this paper. An analysis of the orbit prediction errors is performed and the results of this analysis are used in the synthesis of an operational concept for orbit raising using a low thrust propulsion system.