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LOW-THRUST TRAJECTORY OPTIMIZATION AND AUTONOMY ANALYSIS FOR A MEDIUM-EARTH-ORBIT CONSTELLATION DEPLOYMENT

Abstract

Electric propulsion (EP) features a higher propellant efficiency than their chemical counterparts, offering substantial leverage for reducing launch mass, increasing payload capacity or prolonging service life. In addition, a series of successful interplanetary and Earth-Orbiting missions have proven the reliability and versatility of those devices as primary propulsion systems. Therefore, EP is currently considered by all space actors as a key enabling technology for the new generation of telecommunication, Earth-observation and GNSS satellites. Within this scenario, its application to satellite-constellation deployment (including orbit-raising, targeting of the right ascension of the ascending node, and slot-synchronization), slot-relocation, and end-of-life disposal is gaining interest.

However, the low thrust levels provided by EP may require the engine to fire almost continuously for weeks or even months during orbit raising. As a consequence, the control commands need to be re-optimized periodically during operations to cope with unmodeled dynamical perturbations and orbit determination errors, or to account for contingencies or failures that may happen during the long transfer. The updated manoeuvre plan has to comply with the mission constraints, while minimizing the deviation with respect to the nominal trajectory. The frequency of such re-planning and the level of autonomy of the spacecraft are major design parameters for the constellation that impact the operational cost and feasibility of the mission. Notably, in order to reach the target orbital plane, whose ascending node is drifting due to the Earth oblateness, and the specific slot in the constellation when contingencies occur, extra delta-V budget and transfer time must be allocated.

In this paper we present a set of analysis for typical medium-Earth-orbit constellation deployment scenarios using the DEIMOS Orbit-Raising and Autonomy-Simulation tool. To gain robustness against failures during constellation deployment, a slot-synchronization strategy based on altitude checkpoints, which may be user-defined or automatically computed by the tool given a maximum coasting time, will be presented. The reported results include the optimization of the nominal transfer trajectories, i.e., without contingencies, with respect to transfer time. Moreover, an assessment of the impact of perturbations and contingencies will be presented for a satellite with an E2 autonomy level. The analysis includes miss-thrust failures, thruster de-pointing and underperformances, launcher performance uncertainty, orbit determination errors, and the evaluation of the feasibility of reaching the target orbit within the requested tolerance. Finally, statistical information, e.g., average penalties on transfer-time, propellant-mass, or delta-V budget, along with worst-case scenarios will be derived from a Monte-Carlo campaign.