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AN ANALYTICAL APPROACH FOR CONSTELLATION LOW-THRUST REPLENISHMENT EXPLOITING J2 EFFECT

Abstract

In recent years, the surge in large constellations brings the fore various challenges to constellation studies. One of the major challenges is the great computational effort involved in mission analysis and design for constellations containing a large number of satellites. Given the aim to reduce the computational load, this work proposes an analytical approach for designing a constellation replenishment mission with low-thrust propulsion, where the constellation replenishment is a key mission phase in constellation life-cycle. In the constellation replenishment mission, some spare satellites are moved from the parking orbit to the operational orbit, to replace the unfunctional satellites. Such a procedure includes the changes in semi-major axis, Right Ascension of the Ascending Node (RAAN) and inclination of the spare satellites, where the RAAN change can be facilitated by exploiting the J2 effect. The development of this analytical approach is divided into two steps. In the first step, we derive the analytical solutions for circular low-thrust transfer subject to two predefined control laws: an in-plane tangential thrusting to change the semi-major axis and an out-of-plane yaw thrusting to change the RAAN and inclination. A difficulty for deriving the analytical solutions is that the motion of orbital elements is coupled by short-term oscillations. In order to decouple the motion, we employ the orbital averaging technique to filter out the short-term oscillations and keep the long-term and secular motion. In the second step, we minimise the time and fuel consumption at the same time in an analytical way, described detailly as bellow. Due to the fact that the out-of-plane thrusting is inherently expensive, two parameters are introduced to control the fuel consumption: one to adjust the contributions of J2 and thrust effects to the RAAN change, and the other to adjust the length of burning arcs per revolution in the out-of-plane thrusting phase. With the analytical solutions having been derived, the time and fuel consumption can be analytically expressed in terms of the parameters. Then a multi-objective optimisation problem is formulated, in which the design variables are the two parameters and the objectives are the time and fuel consumption. Through a mapping from the design variable space to the objective space, the optimal design variables are found to be the solution of singular transformation, and they can be analytically described by setting the determinant of the transformation matrix to zero.