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EXTENSION OF FINITE PERTURBATIVE ELEMENTS FOR MULTI-REVOLUTION LOW-THRUST TRANSFER OPTIMISATION

Abstract

This paper presents an extension of the analytical solution for perturbed Keplerian motion of a spacecraft under the effect of a low-thrust action (Zuiani et al., Acta Astronautica, 2011). The new formulation will include the possibility for two different thrusting modes, i.e. with a fixed thrust direction either in a rotating or in a inertial frame. Moreover the contribution of the J2 effect is also included in the analytical formulas. This approach allows for the fast computation of long, many revolution spirals while maintaining adequate accuracy. The proposed approach will be applied to the case of a spacecraft with a hybrid propulsion system comprised of an impulse engine and a low-thrust propulsive system like a solar sail or a low-thrust engine. The spacecraft will be injected as a piggy-back payload into a Geostationary Transfer Orbit (GTO) and will subsequently use its on-board propulsion to transfer to a final high altitude circular orbit around the Earth. The design of the transfer involves a challenging multi-objective optimisation problem since a trade-off has to be made between propellant usage, transfer time and final orbit that can be reached. These performance metrics depend on the optimal allocation of the impulses and the optimal control of the low-thrust system. The completion of the whole transfer might require several spirals and a full multi-objective optimisation would result to be computationally intensive. This makes the use of a full numerical propagation, even in the case of orbit averaging, prohibitive on a sequential machine. In the proposed method, the thrusting pattern, duration and start of each thrusting arc, is defined through a parameterised function. The spiral is then propagated with the above-mentioned analytical approximation. The optimisation provides the definition of the thrust control profile on each arc. In this form, the estimation of the transfer time and propellant consumption is fast enough to be integrated into a multi-objective optimisation loop in which transfer time and propellant mass are minimised for a given attained final orbit.