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COMPUTATIONALLY EFFICIENT SIMULATION OF LOW-THRUST TRAJECTORIES

Abstract

The paper presents the results of the application of a method based on singular perturbation theory to the study of the motion of a body under the action of a constant low thrust. The use of low-thrust propulsion system for orbit maneuvers allows one to exploit renewable electric energy with a significantly more efficient use of fuel, specific impulse being one order of magnitude larger (and possibly more, with novel technologies currently under development) with respect to more conventional high thrust chemical propulsion system. On the technological side, such an advantage comes at the cost of very high power required by the system. On the mission analysis and design side, it is no longer possible to represent orbit maneuver by means of a simplified impulsive model, provided that the low-thrust propulsion system is switched on for time interval which are a non-negligible fraction of orbital period. In many envisaged applications, such as Earth-Moon transfers, a multi-revolution low-thrust trajectory is envisioned as a means for reaching the Earth's satellite by minimum fuel, to maximize mission payload, at the expenses of longer transfer times. In this respect, the computational effort necessary for simulation of a low-thrust trajectory can be demanding. This in turn makes overall mission optimization a numerically and computationally demanding problem. In this respect, approximate solutions allow one to select a promising region of the search space at a reduced computational cost. In this paper, such an approximation is pursued by means of a singular perturbation approach. Singular perturbation theory is a widely used method adopted in many fields of applied mathematics, physics and engineering. It allows one to approximate the solution of a set of differential equations by means of a perturbative series, the elements of which are determined by a combination of (lower order) differential equations and algebraic equations. In Astrodynamics it has already been used in diverse applications such as the analysis of the effects on orbit propagation of non-symmetrical gravitational field, atmospheric drag, solar radiation pressure and of a third or possibly also a fourth body. In this work a two-timescale behavior of the resulting evolution of motion variables under low-thrust is highlighted and an approximation for the zeroth and first order perturbation terms of orbital parameters is derived. The resulting solution is compared and validated with respect to a numerically accurate one obtained by means of numerical integration of Gauss's planetary equations.