Paper ID: 22317
oral
student

ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations and Optimization (1) (8)

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A HOMOTOPY-BASED METHOD FOR OPTIMIZATION OF HYBRID HIGH-LOW THRUST TRAJECTORIES

Abstract

Space missions require increasingly more efficient trajectories to provide payload transport and mission goals by means of lowest fuel consumption, a strategic mission design key-point. Recent works demonstrated that the combined (or hybrid) use of chemical and electrical propulsion can give important advantages in terms of fuel consumption, without losing the ability to reach other mission objectives: as an example the Hohmann Spiral Transfer, applied in the case of a transfer to GEO orbit, demonstrated a fuel mass saving between 5-10% of the spacecraft wet mass, whilst satisfying a pre-set boundary constraint for the time of flight. Nevertheless, methods specifically developed for optimizing space trajectories considering the use of hybrid high-low thrust propulsion systems have not been extensively developed, basically because of the intrinsic complexity in the solution of optimal problem equations with existent numerical methods. The study undertaken and presented in this paper develops a numerical strategy for the optimization of hybrid high-low thrust space trajectories. An indirect optimization method has been developed, which makes use of a homotopic approach for numerical convergence improvement. Indirect optimization methods are generally more precise and faster than direct and especially than heuristic methods; nevertheless, in the case under study, they suffer from numerical problems due to discontinuities in the equations defining the optimal problem and in the narrow convergence radius that typically has the shooting function, so that a solution with current numerical solvers is really hard or even impossible to obtain. The adoption of a homotopic approach provides a relaxation to the optimal problem, transforming it into a simplest problem to solve in which the optimal problem presents smoother equations and the shooting function acquires an increased convergence radius: the original optimal problem is then reached through a homotopy parameter continuation. Moreover, the use of homotopy can make possible to include high thrust impulses (treated as velocity discontinuities) to the low thrust optimal control obtained from the indirect method. The number of impulses, as well as their magnitude, is obtained in order to minimize the problem cost function. The initial study carried out in this paper is finally correlated with existing solutions found in the literature using hybrid thrust transfers, in order to show the effectiveness in the adoption of this kind of propulsion systems for future space missions. At last, a case for a possible future mission application is shown and preliminary results are obtained.