

Low-Thrust Inclination Control on Elliptical Orbits with Constant Orbital Period

Alexey Ivanyukhin

Abstract. This study addresses the problem of low-thrust control aimed at modifying the orbital geometry while maintaining the orbital period. More specifically, the control strategy focuses on altering the orbital eccentricity and inclination while keeping the semi-major axis constant. This problem formulation is relevant for combined insertion schemes into geostationary and high elliptical orbits. The problem is analogous to Edelbaum's problem, but it differs significantly due to a more complex strategy for changing the orbital geometry. New analytical feedback control laws have been derived for the considered problem. The efficiency of the obtained control laws has been evaluated.

Introduction

Many spacecraft employ low-thrust propulsion systems (electric thrusters) for interorbital transfers, orbit maintenance, and correction in near-Earth space. Combined launch strategies utilizing both high-thrust and low-thrust propulsion for delivering spacecraft to target orbits are of significant interest, as such transfer schemes can substantially increase the spacecraft mass delivered to the target orbit while maintaining acceptable transfer durations. In practical implementations of combined transfer schemes, cases with a constant orbital period are of particular interest.

A key feature of spacecraft control with low-thrust propulsion systems is the significant dominance of gravitational acceleration over thrust acceleration, typically differing by several orders of magnitude. This low acceleration level results in long transfer durations and necessitates determination of the control at each instant.

The analysis of interorbital transfers and combined launch strategies requires the development of efficient and simple control laws for executing typical orbital

maneuvers with low-thrust propulsion. A number of special cases admitting analytical solutions are known, including acceleration with transverse or radial thrust [?]. Of significant practical importance is the solution obtained by Edelbaum for transfers between non-coplanar circular orbits [?].

1. Optimal Control Problem

For qualitative analysis of orbital evolution under low-thrust acceleration, it is convenient to employ the planetary Lagrange equations [?]. In this study, the averaged equations of motion in Gauss form are considered, and an analysis of secular variations of orbital elements under low-thrust acceleration is conducted in both orbital and Cartesian coordinate systems.

Following the ideas of Spitzer and Pollard [?, ?], optimal control problems for the yaw angle are formulated for transfers between elliptical orbits while maintaining a constant value of the semi-major axis, with the objectives of minimizing transfer time and maximizing final spacecraft mass. In contrast to the known works [?, ?] and similar studies, continuous yaw angle control and a long active arc per revolution are considered.

The solution of the optimal control problem is reduced to an isoperimetric problem, analogous to the Edelbaum problem [?]. The formulations considered involve a more complex strategy for modifying the orbital geometry. For the time-optimal case, a closed-form solution in terms of Legendre elliptic integrals has been obtained, while for the problem of maximizing final mass, a numerical-analytical solution requiring neither numerical integration nor optimization has been derived.

Conclusion

New analytical feedback control laws have been derived for the problems under consideration. Efficiency assessments of the obtained control laws demonstrate a reduction in the required ΔV by 10 % compared to analogous, previously known control laws.

The study was supported by the Russian Science Foundation grant No 25-79-30009, <https://rscf.ru/project/25-79-30009/>.

References

- [1] G.L. Grodzovskii, Yu.N. Ivanov, V.V. Tokarev, *Mechanics of Spaceflight Low-Thrust*, Israel Program for Scientific Translations Ltd., Jerusalem, 1969, p. 679.
- [2] T.N. Edelbaum, *Propulsion requirements for controllable satellites*, ARS J., 1961, Vol. 31, No. 8, pp. 1079-1089.
- [3] A. Spitzer, *Novel orbit raising strategy makes low thrust commercially viable*, 24th International Electric Propulsion Conference, Moscow, 1995, Paper IEPC-95-212, pp. 1429-1436.

- [4] J.E. Pollard, *Simplified approach for assessment of low-thrust elliptical orbit transfers*, 25th International Electric Propulsion Conference, Cleveland, 1997, Paper IEPC-97-160, pp. 979-986.
- [5] M. Konstantinov, V. Svtina, *Analysis for feasibility of spitzer's schemes complication for spacecraft nal insertion into geostationary orbit by electric propulsion*, Procedia Engineering, 2017, Vol. 185, pp. 304-311.

Alexey Ivanyukhin

Research Institute of Applied Mechanics and Electrodynamics of Moscow Aviation institute

Peoples Friendship University of Russia (RUDN University)

Moscow, Russia

e-mail: `ivanyukhin.a@yandex.ru`