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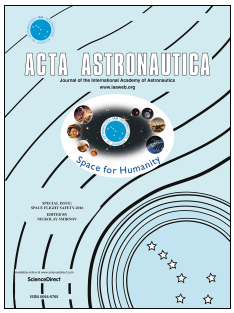

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Optimal Injection Point for Launch Trajectories with Parametric Thrust Profile

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Abstract

The problem of finding the optimal thrust profile of a launcher upper stage is analyzed. The engine is non-re-ignitable and it is continuously thrusting, following either a linear or a bilevel parametric profile, until reaching the targeted coplanar orbit. This problem differs from the classical rocket problem where the thrust level is a time-dependent function varying freely between prescribed bounds. Applying the maximum principle yields an analytical closed-loop solution for the thrust direction. Furthermore the final point is found to be necessarily at an apsis, reached from above in the case of a perigee injection. The optimal control problem reduces to a nonlinear problem with only the thrust profile parameters as unknowns. This formulation eases preliminary design studies aiming at defining the optimum upper stage thrust profile. An application case targeting a geostationary transfer orbit illustrates the solution method.

Keywords: Launch Trajectory; Thrust Level; Optimal Control; Closed-Loop Control

1. Introduction

The thrust levels of the engines are key parameters of a launch vehicle design. They drive the loads met during the flight, the fuel required to reach the targeted orbit, and finally the launcher gross mass and cost. The problem of finding the best thrust levels is thus intensively investigated since Goddard's pioneering work [1-4].

The thrust levels are defined during preliminary design studies. Once chosen, they can generally not be changed or modulated without major evolutions of the launcher features regarding structural design, on-board control and overall reliability. For an operational launcher, the ascent trajectory is controlled through the thrust orientation.

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