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Author: Dr. Viacheslav Petukhov
RIAME, Russian Federation, vgpetukhov@gmail.com

MINIMUM-THRUST PROBLEM AND ITS APPLICATION TO TRAJECTORY OPTIMIZATION WITH THRUST SWITCHINGS

Abstract

It is considered an indirect approach to the finite-thrust trajectory optimization based on Pontryagin maximum principle. Namely, it is considered problem of thrust magnitude minimization for fixed-time transfer between two fixed points. The thrust magnitude is assumed to be invariable along trajectory and the thrust direction is unconstrained. This problem is dual to the minimum-time problem. In particularity, all necessary optimality conditions for both problems are identical besides the same transversality condition using for thrust magnitude computation in case of the minimum-thrust problem instead computation of transfer duration otherwise. Solution of the minimum-thrust problem corresponds to the minimum-time trajectory for thrust magnitude providing given transfer duration. It is easy to show the minimum-thrust problem is smooth due to absence of thrust switchings and fixed boundary conditions even in case of moving initial and final points (for example, planets) while initial and final times are fixed. This problem can be used to calculate domain of existence for optimal trajectory with thrust switchings. Obviously, solution of last problem exists if minimal thrust of corresponding minimum-thrust problem is less or equals to available thrust. Unfortunately, minimum-thrust problem itself has constrained domain of existence restricted by required propellant mass. To avoid numerical singularities, it is considered minimum thrust acceleration problem. Minimum thrust acceleration problem is extreme case of minimum-thrust problem corresponding to zero propellant flow rate (or infinite specific impulse). Solution of the minimum thrust acceleration problem exists for any non-singular boundary conditions. This problem can be easy solved using power-limited trajectory or Lambert solution as an initial guess and numerical continuation. It is proposed a technique to compute optimal finite-thrust trajectory starting from corresponding minimum thrust acceleration problem with following numerical continuation with respect to propellant flow rate to the minimum-thrust problem and then to the trajectory optimization with thrust switchings. Proposed technique allows to detect singularities caused either by lack of thrust magnitude or by insufficient specific impulse. In fact, this technique allows to calculate boundaries of domain of existence for trajectory optimization problem with thrust switchings. Proposed technique allows, at first, to design very robust numerical solvers and, at second, to find launch windows reliably.