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OPTIMUM DESIGN OF POWER-LIMITED PROPULSION SYSTEMS WITH APPLICATION TO FAST EARTH-TO-MARS TRANSFER

Abstract

Power-limited systems with variable Isp, which have been studied theoretically since the beginning of astronautics, are getting closer to practical applications thanks to recent technological advances in the field of magnetosplasma rockets, such as Ad-Astra's VASIMR concept. Such concepts are considered for high-speed interplanetary transfers, such as Mars missions, with demanding payload fractions that would be compatible with manned missions.

This paper explores the problem of the optimization of a power-limited propulsion system through simple performance models, and investigates the trade-off between the technological requirements, the transfer time and the payload fraction. Following previous works existing in literature, we model the technological characteristics of the vehicle through a small number of design parameters, the most important of which being the specific weight (or mass-to-power ratio) of the power generation system. Also, we use in our models the classical "trajectory characteric" parameter (defined as the integral over time of the squared thrust acceleration) which represents - under certain hypotheses – the propulsion requirements for an interplanetary mission with a given transfer time and a given transfer strategy. In this paper, we first give a review of existing methods in literature, then we present the equations of two new classes of optimal designs. The first one corresponds to the maximum payload-mass design, considering a fixed value for the power source. We show that, for a given power level, there exists two different vehicle designs that deliver the same payload mass while satisfying the same propulsion requirements. The second class of solutions corresponds to the optimal design that maximizes the payload fraction, the input power being free. This class of optimal design is described through very simple equations that make possible to study – more straightforwardly than existing calculations - the links between the main mission requirements (transfer time and payload fraction) and the main technological requirements (specific weight of the power generation and structure mass ratio of the whole vehicle, excluding the power generation system). One important result obtained from these equations is a simple expression that yields the estimated theoretical upper limit of the power source's specific weight as a function of transfer time, considering a null payload mass. In the last part of this paper, we apply this simple performance model to discuss the feasibility of a fast Earth-to-Mars transfer using a power-limited system.

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