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Application of electric propulsion for motion control of spacecraft which function on non Keplerian orbits

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Abstract

This article discusses the design-ballistic optimization for spacecraft, which move under the influence of the gravitational fields of complex configuration and electric propulsion. Such conditions exist near asteroids, for example in the systems of two gravitating bodies, in the vicinity of the libration points. In this paper, we propose to use a method of iterative mission optimization for electric propulsion spacecraft, using sequences of the mathematically specified models of movement and the spacecraft design. The previously obtained analytical results, which describes the planar movement of spacecraft with solar electric propulsion, allows the initial approach in the iterative scheme of optimization to be constructed. A method of modeling and optimization of interplanetary missions ballistic schemes is developed, based on a combination of Pontryagin's maximum principle formalism conditions of transversality and methods of mathematical programming, allowing restriction characteristics for real interplanetary missions to be considered. Recommendations for the choice of the design-ballistic parameters of the interplanetary mission's spacecraft are obtained taking into account the features of a nuclear and solar power plant for purposes of the delivery of a payload to the required heliocentric orbit, to the Moon and near asteroid.

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Keywords: spacecraft; electric propulsion; non Keplerian orbit.

1. Introduction

Space exploration programs are very expensive and do not give quick feedback. One of the possible ways to solve this problem is to use the perspective propulsion system with high performance, for instance, using electric propulsion or a solar sail.

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Nomenclature

$m_0 = m(t_0)$	=	the mass of the space tug in the parking orbit at the t_0 time
m_{pl}	=	the payload mass
m_{pp}	=	the power plant mass
m_{ps}	=	the propulsion system mass
m_{f1}, m_{f2}	=	the fuel masses of forward and back flights
m_t	=	the tank mass, including the propellant distribution system
m_c	=	the construction mass
α_{pp}, α_c	=	the specific mass coefficients on power of the power plant and of the construction
γ_{ps}, γ_c	=	the specific mass coefficients on thrust of the propulsion system and of the construction
η_{pp}, η_{ps}	=	the power and the thrust efficiency coefficient
k	=	the specific mass coefficient of the tank
$\delta \in \{0, \ 1\}$	=	the function of thrust switching
T	=	the total mission duration
$\chi(\mathbf{x})$	=	the dependence the specific fuel consumption of the phase vector $\mathbf{x}$
$\mathbf{x}$	=	the phase vector, when consist of the radius-vector $\mathbf{r}$, the velocity vector $\mathbf{V}$ and the relative weight of fuel consumed $\overline{m}$
$\mathbf{a}$	=	the currently vector acceleration of propulsion
a_0	=	the nominal acceleration of spacecraft
$\mathbf{e}$	=	the trusting direction unit vector
$\mathbf{g}$	=	the gravity acceleration
$\mathbf{f}$	=	the total perturbation acceleration vector
μ_{pl}	=	the relative payload mass
$\mathbf{r}_i$	=	the radius-vectors of attraction center
j_{sp}	=	the specific impulse of engine

The application of electric propulsion is one of the most promising research areas for future space missions. For example, some theoretical and technical aspects of low thrust application are described in the articles [1-4, 10]. The areas of the search for the optimal control laws are shown in the works [2-9].

The problem of integrated design-ballistic optimization of the electric propulsion missions is a non-classical search problem of the criteria's extremum on parametric variables and unknown functions. The search for the optimal control function and the corresponding trajectory is called the ballistic problem of the mission's optimization. The search for the spacecraft design parameters is known as the design problem of the mission's optimization. Unfortunately, these problems cannot be separated from electric propulsion spacecraft, and this fact significantly complicates the solution process.

The issue of ballistic optimization of a low thrust mission is reduced to the two-point boundary value problem [3-6, 9]. However, this problem is complicated by the necessity to allow continuous control action, the magnitude of which is comparable with other disturbances [2, 4-6, 8]. Therefore, the motion of spacecraft with low thrust, has to be described in non-Keplerian motion.

In recent years, research regarding the designing optimal trajectories of the spacecraft motion in complex gravitational fields has grown significantly These fields surround points of the libration, neighborhoods of the planet-satellite system and regions near asteroids of irregular shape. For example, the optimal interplanetary trajectories and the trajectories of flights to the Moon pass near the libration point L1 Earth-Moon system as shown in works [3, 5-6]. Since an acceleration rate is less than the gravitational acceleration, the optimal control laws