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Calculating launch windows for transfers of solar powered EP spacecraft between low-Earth non-coplanar circular orbits

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Abstract

The paper considers the problem of finding such conditions for launch of a low thrust electric propulsion (EP) spacecraft from circular low orbit that the passage through Earth shadow along the transfer trajectory would be minimized. An approximate method of calculating shadow intervals on the loops of a near circular oscillating orbit is suggested. A precise method, based on numerical integration of the equations of motion and calculation of Sun's ephemerides is developed. A series of trajectories for transfers to geostationary orbit (GEO) were computed for various launch dates and longitudes of ascending node. Based on the calculations, isolines of aggregate shadow time were built. They allow an optimal launch date and initial position of ascending node.

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Keywords: spacecraft; low thrust; optimal launch date; ephemerides; isolines of aggregate shadow time.

1. Introduction

The most common problem for ballistic development of inter-orbital transfers is to determine the time that the spacecraft spends in the shaded and lighted parts of the orbit. This problem is especially important for solar-powered low thrust spacecraft. The efficiency of the electric power system, and, by extension, that of the constantly firing thrusters, depends considerably on the mutual position of the spacecraft, the Sun and the Earth, specifically on the passage of the spacecraft through lighted and shaded parts of the orbit. In addition, astronomic and ballistic conditions, specifically lighting, often have a decisive influence on the thermal conditions of the spacecraft's elements and instruments and operation of orientation sensors [1].

The problems of controlling a spacecraft with solar powered electric propulsion have been discussed in detail in the review [2], and also in [3], [4] and [5].

The analysis of the length of time that a spacecraft spends in the Earth's shadow while it is lifted to GEO was done in [6].

An approximate method for calculating transfer time for low thrust spacecraft is described in the monograph [7].

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In a general case, the shadow of a planet consists of two areas - full shadow and half-shadow. The Full shadow area is a cone on the side directly opposed to the Sun. Half-shadow area is the area between the full shadow and completely lighted area. Depending on the initial position of the Sun and the orbital plane, an inter-orbital transfer for a solar-powered spacecraft can be characterized by different shadow time. For fixed boundary conditions of the transfer the light and shadow characteristics of the trajectory will ultimately depend on the launch date (the position of the Sun) and the initial value of the longitude of ascending node.

Let us state the problem of finding such conditions for the launch under which the total shadow time of the spacecraft would be minimized.

2. Approximated method of calculating total length of shaded parts of a multi-loop quasi-circular inter-orbital transfer orbit

Consider a model describing the motion of a spacecraft through lighted and shaded areas of orbit. Introduce a geocentric system of coordinates $O\xi\eta\zeta$ (Fig. 1).

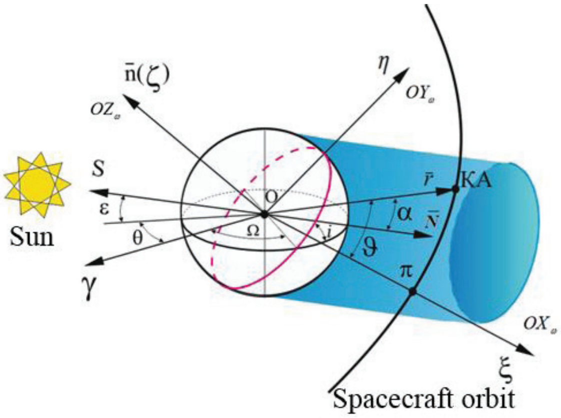

Fig. 1. Geocentric orbital system of coordinates

The axis $O\xi$ is in the plane of the orbit and pointed at the periapsis, the axis $O\zeta$ is along the vector of the integral of the planes, the axis $O\eta$ compliments the system to right-handed. Let us now define in this system the following vectors: $\bar{S}$ is the direction to the Sun, $\bar{N}$ is the direction along the axis of the cylinder of the shadow, $\bar{r}$ is the radius vector of the spacecraft's center of mass, $\bar{n}$ is normal to the orbital plane. Also in Fig. 1 we introduce the following symbols: Θ for the angle between spring equinox point and the line from the Earth to the Sun; ϑ for the angle of the true anomaly of the spacecraft; π for orbit periapsis; Ω for longitude of ascending node; i for orbit inclination; Ω for the angle between the equatorial plane and the ecliptics plane; α for the angle between the axis of the shadow cylinder and the radius vector of the spacecraft.

For a circular orbit the condition of the orbit being shaded will be written as:

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