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Design guidelines for spacecraft launch window

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FOREWORD

The standard is translated from the Chinese version of Standard on GB/T 29078-2012 released by Standardization Administration of China (SAC) under the management of State General Administration of Quality Supervision and Inspection and Quarantine. TC 425 is responsible for the translation. In case of any doubt about the contents of English version, the Chinese original shall be considered authoritative.

This standard is drafted in accordance with rules given in GB/T 1.1-2009.

This standard is proposed by China Aerospace Science and Technology Corporation.

This standard is under the jurisdiction of National Technical Committee on Space Technology and Operation of Standardization Administration of China (SAC/TC 425).

INTRODUCTION

This standard belongs to the National Standard System of China Space. The National Standard System of China Space is applicable to the formulation, revision, and management of national standards in the field of space, covering three sectors of space management, space technology, and space application and services and serving as the basis for guiding spacecraft and launch vehicle project management, engineering, space launch services, and in-orbit satellite applications.

Launch window design is a part of spacecraft system design. Calculate launch window through analyzing spacecraft operation conditions as well as considering launch time constraints, which can provide guideline for spacecraft launching. Spacecraft should be launched in the specific launch window to satisfy its mission. This standard specifies the constraints and general calculate methods of launch window design, and it provides reliable parameters for spacecraft system and its subsystem design.

Design guidelines for spacecraft launch window

1 Scope

This standard specifies the task, design methods and relevant requirements of spacecraft launch window design.

This standard is applicable to launch window design for all kinds of satellites, spaceships, space stations and deep space probes.

2 Terms and definitions

For the purposes of this document, the following terms and definitions are applied.

2.1

launch window

the allowed time range for spacecraft launching, which can meet the scheduled flight conditions and mission requirements.

2.2

orbital maneuver

transferring spacecraft from one to another scheduled orbit by orbit control.

2.3

attitude maneuver

adjusting spacecraft from one to another scheduled attitude by attitude control.

2.4

ecliptic time

duration of spacecraft in the shadow of the Earth.

2.5

sub-satellite point

the intersection of earth reference ellipsoid and connection line from spacecraft to earth center.

2.6

ascending node

the intersection of spacecraft orbit and equatorial plane, directing from south to north.

2.7

sun elevation

an angle between the local horizontal plane and the connection line of observer and the Sun, and be positive (+) above the horizon or negative (-) below the horizon.

2.8

transit

the phenomenon that the passage of a spacecraft across the face of sun. The observer, spacecraft and the Sun align in a line in this case.

3 Task of launch window design

According to the spacecraft mission and constraints of spacecraft and related systems, the revolution principles of spacecraft and related celestial bodies, as well as the flight time and orbit injection parameters of launch vehicle, determine the time range of spacecraft to be launched (generally in Beijing Time).

The launch window design provides the basis for spacecraft launching and relevant design parameters referenced by the spacecraft system and its subsystems.

4 Methods for launch window design

4.1 Analysis on constraints of launch window

Analyze the mission and the environment requirements of spacecraft operating, and provide the constraints of launch window design. The constraints originate from the following requirements and factors:

a) Solar illumination requirements for ground targets;
b) Direction of sunlight on solar arrays for satisfying normal power supply of spacecraft;
c) Geometrical relationship of the Earth, spacecrafts and the Sun by attitude control;
d) Direction of sunlight on spacecraft by thermal control system;
e) The incident direction requirements of specific spacecraft equipment (such as sun sensor) for sunlight, earth reflected light and moon reflected light;
f) Ecliptic time limit;
g) Position of spacecraft into and out of the shadow of the Earth;
h) Geometric relationship of spacecraft and the Sun relative to the observation station;
i) Landing time requirements of returnable spacecrafts;
j) Requirements for spacecrafts rendezvous and docking;
k) Space constellation requirements of spacecrafts;
l) Requirements for capturing the target orbits of deep space probes;
m) Other constraints.

For specific mission, the necessity and rationality of each launch window constraints shall be analyzed through the system engineering methods, and the factors which contradict with each other shall be coordinated, so that the constraints for launch window calculation are determined.

4.2 Calculation of launch window

4.2.1 General

According to related constraints specified in 4.1, establish formulas corresponding to these constraints, achieve the allowable launch time ranges through calculation, and take the intersection of all calculated time ranges as the launch window.

The launch window calculation involves the calculation of 4.2.2~4.2.9, which can be selected according to specific mission.

According to the specific mission, the following factors shall also be considered in launch window calculation:

a) Orbit parameter variations caused by orbit maneuver;
b) Attitude changes caused by attitude maneuver;
c) Orbit error;
d) Attitude error;
e) Position changes of the Sun and the Moon during spacecraft operating period;
f) The duration of active phase of launch vehicle and its deviation.

4.2.2 Calculation of the sun and the moon position

The positions of the Sun and the Moon can be calculated according to that positions listed in astronomical almanac, or other verified calculation methods to meet accuracy requirements.

4.2.3 Calculation of spacecraft position and sub-satellite point position

The position of spacecraft can be calculated according to the spacecraft orbit perturbation and motion equation, and the calculation accuracy shall meet the mission requirements.

The spacecraft position can be calculated in the earth center fixed coordinate frame is in the earth center. The sub-satellite position, that is, the geocentric latitude and longitude can be derived from spacecraft position.

The positions of spacecraft and sub-satellite point can also be calculated through other verified methods to meet accuracy requirements.

4.2.4 Calculation of earth shadow

The calculation of earth shadow mainly includes the calculation of ecliptic time and orbit positions when spacecraft goes in and out of earth shadow. It can be calculated through other verified methods to meet accuracy requirements.

4.2.5 Calculation of sun elevation at spacecraft sub-satellite point

The sun elevation at spacecraft sub-satellite point can be calculated with Formula (1):

$$\sin E = \sin \delta_S \sin \delta + \cos \delta_S \cos \delta \cos(\alpha_S - \alpha) \quad \cdots\cdots (1)$$

Wherein,

E - Sun elevation in radian (rad);

δ_S - Solar declination in radian (rad);

δ - Spacecraft declination in radian (rad);

α_S - Solar right ascension in radian (rad);

α - Spacecraft right ascension in radian (rad).

4.2.6 Calculation of angle between the spacecraft and the sun to ground station

The angle of the spacecraft and the Sun to ground station can be calculated with Formula (2).

$$\cos\theta = \frac{\vec{U}_S \cdot (\vec{r} - \vec{p})}{\left|\vec{r} - \vec{p}\right|} \qquad (2)$$

Wherein,

θ - Angle between the spacecraft and the sun to ground station in radian (rad);

$\vec{U}_S$ - Unit vector pointing to the Sun from the earth center;

$\vec{r}$ - Vector pointing to spacecraft from the earth center, scale in kilometer (km);

$\vec{p}$ - Vector pointing to ground station from the earth center, scale in kilometer (km).

When θ closes to 0, there will be a transit phenomenon that may affect the normal ground station operation.

4.2.7 Calculation of launch time in the case of space rendezvous, docking and constellation

In the case that spacecraft implement the space rendezvous, docking or networking, carry out launch window analysis and calculation not only according to the launch constraint of single spacecraft, but also according to the constraint of orbit plane. With the given orbit inclination and the right ascension of ascending node, the launch time shall be calculated with Formula (3).

$$t = \frac{\Omega_0 - \alpha_{G0} - \lambda_N + 2n\pi}{\omega_e - \dot{\Omega}} - T_L \qquad (3)$$

Wherein,

t - Launch time calculated from the reference time t_0 in second (s);

Ω_0 - Right ascension of ascending node at the reference time (t_0) in radian (rad);

α_{G0} - Right ascension of Greenwich Mean Time at the reference time (t_0) in radian (rad);

λ_N - Ascending node longitude at orbit injection time in radian (rad) that can be calculated according to Formula (4) or (5);

n - An integer, different values corresponding to different launch time;

ω_e - Earth rotation rate, 7.2921158×10^{-5} rad/s;

$\dot{\Omega}$ - Change rate of right ascension of ascending node, rad/s;

T_L - Launching phase flight time of launch vehicle in seconds (s).

When the orbit injection point is in the ascending arc, see Formula (4).

$$\lambda_N = \lambda - \arcsin\left(\tan\phi / \tan i\right) \quad (4)$$

When the orbit injection point is in the descending arc, see Formula (5).

$$\lambda_N = \lambda + \arcsin\left(\tan\phi / \tan i\right) - \pi \quad (5)$$

Wherein,

λ - Longitude of orbit injection point in radian (rad);

ϕ - Geocentric latitude of orbit injection point in radian (rad);

i - Orbit inclination in radian (rad);

In the case of space rendezvous or networking, it generally needs some time to carry out phase adjustment till spacecraft reaches the target orbit. During the process of phase adjustment, there is a relative drift of right ascension of ascending node between spacecraft orbit plane and target orbit plane. There exists relationship between relative drift of right ascension of ascending node and phase adjustment, see Formula (6).

$$\Delta\Omega = -\frac{7}{2} J_2 \left(\frac{R_e}{a}\right)^2 \frac{\cos i}{(1-e^2)^2} \Delta u \quad (6)$$

Wherein,

$\Delta\Omega$ - Relative drift for right ascension of ascending node in radian (rad);

J_2 - Second order harmonic coefficient of the Earth's gravitational potential, and its value is 1.08263×10^{-3};

R_e - Radius of the Earth's equator in kilometer (km);

a - Semi-major axis of target orbit in kilometer (km);

e - Eccentricity of target orbit;

i - Orbit inclination in radian (rad);

Δu - Phase adjustment in radian (rad);

Calculate the relative drift for right ascension of ascending node according to the phase adjustment requirements of spacecraft, and carry out pre-bias for right ascension of ascending node so as to determine the launch time of spacecraft.

4.2.8 Calculation of launch time for deep space probe

In general, the mechanism of capturing the target orbit for deep space probe is similar to that of space rendezvous. In the case that the orbit inclination and the right ascension of ascending node at orbit injection are given, the calculation of launch time can be referred to 4.2.7.

When the deep space probe is used for exploring other celestial body (such as lunar exploration, mars exploration, etc.), generally, it is needed to implement the orbit rendezvous with the target celestial body, and an optimal rendezvous point with the most minimum energy consumption is existed. In engineering, the orbit rendezvous shall be operated near these optimal points. In order to determine the feasible launch time duration in engineering, it is necessary to consider the relationship among transferring orbit time from the Earth to target celestial body, target celestial orbit period and its phase in the orbit. On this basis, carry out specific analysis and calculation of launch window according to initial orbit plane capture and other spacecraft engineering constraints.

4.2.9 Calculation of the specific axis

The specific axis in spacecraft body coordination shall be described in equatorial inertial coordinate system. The direction of the specific axis is denoted by celestial right ascension and declination. The orient of the specific axis of spacecraft is related to the attitude stabilization mode. The coordinate of spin axis in the inertial system is constant for the spin stable spacecraft. The coordination in the celestial inertial system is satisfied with some principle for the three-axis stabilized spacecraft.

5 Preparation for design document of launch window

In different stages of spacecraft research and development, the technical reports on analyzing and calculating the launch window shall be presented.

The technical report shall include constraint analysis, calculation formula, and calculation results. The begin time and the end time which the launch vehicle is allowed to takeoff in this duration shall be illustrated in the calculation results. If necessary, the corresponding parameters shall be given.