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Analysis of meteoroid risk in circumterrestrial space

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Abstract

A model of the meteoroid-spacecraft collision risk in near Earth space is presented.
The risk from dangerous meteoroids in main meteor showers is calculated. Its level is shown to be close to maximal allowable risk.

1. Introduction

One of the hazards to space technology and humans in near-Earth space is the hazard coming from impacts of micrometeoroids ranging from 1 mm to tens of centimeters in size [1, 2].
Here, streams of meteoroid particles (1 mm to 1 cm) have been and remain difficult to monitor using modern technology. Observable are only meteors they cause.

2. Model of meteoroid risk in near Earth space

Meteoroid risk is the probability (a measure of hazard) that a spacecraft will collide with hazardous meteoroids capable of having a destructive effect on the spacecraft and stop (fully or partly) its operation for a certain number of collisions.
Our physical model of meteoroid risk consists of the following components [3]:
(1) hazardous directions, i.e., distribution of meteor streams and sporadic meteors in space; (2) distribution of meteor streams by seasons of year and by the length of action within these seasons; (3) distribution of meteor streams by velocities and masses; (4) spatial distribution of meteoric particles in the stream itself; (5) effect of the gravitational attraction of meteoric particles by the Earth; (6) effect of shading of meteoroids by the Earth from the observer; (7) orientation of the entire spacecraft as well as its constructive elements relative to the meteoroid arrival direction; (8) time of spacecraft residence on the orbit and time of meteoric stream influence on the spacecraft.

3. Calculating the number of collisions

The expected rate of collision of meteoroids with the spacecraft averaged over the observation interval where t_1 is the moment of start and t_2 is the moment of end of observations, can be taken to be

$$\boldsymbol{N = C \int_{t_1}^{t_2} f(t) dt}. \qquad (1)$$

Most often, activity factors (profiles) of meteor showers are analytically (despite their diversity) described by expressions of the form

$$\boldsymbol{F_\lambda = F_0 \cdot e^{-A(\lambda-\lambda_0)^2}}, \qquad (2)$$

where F_0 is the density of the meteor stream at the maximum (on the axis of the meteor swarm) at solar longitude λ_0.
The total collision number was calculated as their sum during the shower's maximum activity

$$N = \int_{\lambda_1}^{\lambda_2} F_0 \cdot e^{-A(\lambda-\lambda_0)^2} d\lambda. \qquad (3)$$

The current collision number was calculated with regard to the location geometry of a satellite, the Earth, and the shower radiant at that very moment. (Fig. 1) [3, 5].
On the celestial sphere of the spacecraft in a satellite centered coordinate system [3,5] (Fig. 1), the Earth's disc moves along the equator of the spacecraft orbit, and the radiant of a meteor stream describes a small circle, the plane of which is parallel to the equatorial plane of the system. Here, *R*, E, ⊙, ♈, are the directions to the meteor stream radiant, the Earth, the Sun, and the vernal equinox, respectively; *b* is the ecliptic latitude; and ☊ is ascending node of the spacecraft orbit. This means that the Earth's coordinates are characterized by the spacecraft's position on the orbit.

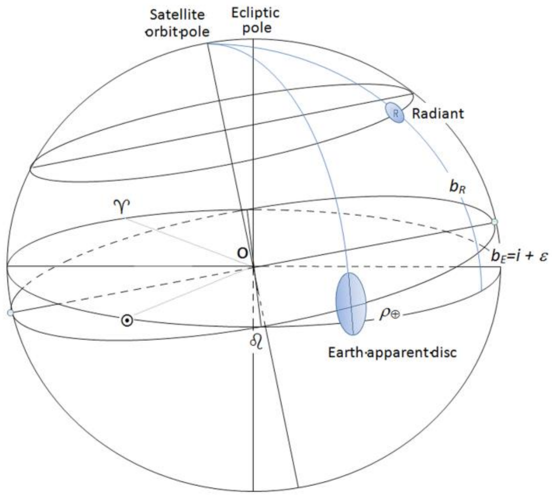

Figure 1: Satellite-centric reference system for calculation the number of collisions

The satellite-centered latitude of the center of the Earth's disk and the stream radiant can be easily determined as

$$\phi_R = b_R - i - \varepsilon;\ \phi_E = 0, \quad (4)$$

where i is the inclination of the satellite orbit to the ecliptic and $\varepsilon = 23°27'$ is the inclination of the ecliptic to the equator. Then, the condition that the spacecraft falls into the Earth's shadow is described by the inequality

$$b_R - i - \varepsilon \le \rho_E, \quad (5)$$

where ρ_E is Earth's angular radius visible from the spacecraft.

4. Meteoroid risk for main meteor showers

Here, the risk was estimated as the number N of collisions of dangerous meteoroids with the normal to the meteoroid flux flat unit during the maximum shower activity (3).

We calculated the provided model using both the IMO's and our own observation data [6].

During the maximum activity of meteor shower (half-width of the shower) the dangerous meteoroid flux rises steeply:

Quadrantids: during 0.25^d $N=1.2\cdot10^{-2}$ km^{-2} – 1 collision per 1 km^2 on the average during $21^{\mathbf{d}}$**;**

Eta Aquariids: during 1.0^d $N=5\cdot10^{-2}$ km^{-2} – 1 collision per 1 km^2 on the average during 20^d;

Perseids: during 1.0^d $N=1.2\cdot10^{-2}$ km^{-2} – 1 collision per 1 km^2 on the average during 80^d;

Geminids: during 0.25^d $N=1\cdot10^{-2}$ km^{-2} – 1 collision per 1 km^2 on the average during 25^d.

5. Summary and Conclusions

Thus, for a satellite with the midsection of 10 m^2, the meteoroid risk during most active meteor showers is about $R=(1\text{-}5)\cdot10^{-7}$. It is noticeably dangerous because the maximum allowable risk is defined as $R_{Lim.}=10^{-6}$, and such danger should not be neglected.

Of course, the risk from dangerous meteoroids in space is not very big but the circumterrestrial space is highly populated with satellites; therefore their total area of collisions is rather large. So the total risk for the whole of the satellite population may become significant.

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