AN OPTICAL SEARCH FOR SMALL-SIZE DEBRIS IN GEO AND GTO

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Abstract. *At the present time, due to the results of observations and calculations, ten exploded geostationary objects have been revealed. This circumstance has essentially complicated the debris situation in the geostationary area, and has determined the necessity of the design of a statistical model for the allocation of space debris of small-size. The constructed model contains classification and quantitative assessment of orbital objects of small-size, and also allocation of orbital parameters of their motions. The model allows one to obtain the necessary initial data for the study the influence of orbital debris on the stability of geostationary spacecraft elements.*

CLASSIFICATION AND ESTIMATION OF THE QUANTITATIVE STRUCTURE OF ORBITAL DEBRIS OF SMALL-SIZE

The explosions of geostationary space objects were determined by the results of observations of the large fragments having the sizes of 0.5 - 1 m and more [1]. At the same explosions plenty of small-sized fragments, which represent particular danger to functioning space vehicles, are formed. This danger depends on the size of the fragments and the relative velocity of the collision with a space vehicle. In this connection a build-up is conducted of a statistical model of an orbital debris classification based on their sizes and is listed in table 1.

Table 1. Classification of small-sized fractions debris

Class number	Size interval (m)	Eq. size (m)	Eq. mass (kg)
1	0.3-1.0	6.5E-1	3.882E+2
2	0.1-0.3	2.0E-1	1.131E+1
3	0.03-0.1	6.5E-2	3.882E-1
4	0.01-0.03	2.0E-2	1.131E-2
5	0.003-0.01	6.5E-3	3.882E-4
6	0.001-0.003	1.55E-3	1.131E-5

For an estimate of the quantity of debris of the various classes, formed as a result of a space object explosion, models of fragmentation are surveyed. The most comprehensible, as a solved problem, is the model shown in [2]. It has passed experimental checkout and most fully reflects the pattern of a splinter formation of damages of a space vehicle. On this model, the quantity of the debris of various masses m is determined by following the empirical functions:

$$N(m) = 1.71 * 10^{-4} M_e \exp\left(-Am^{1/2}\right), \quad \text{A= 0.02056 if m > 1936 g;}$$
$$N(m) = 8.69 * 10^{-4} M_e \exp\left(-Am^{1/2}\right), \quad \text{A= 0.0576 if m < 1936 g,} \tag{1}$$

where M depends on the mass of the blown up object and the density of a substance.

If class i actuates fragments in mass from m_1 up to m_2, then the quantity of such fragments at the explosion is:

$$N_i = N(m_{i2}) - N(m_{i1}). \tag{2}$$

Then the relation of the quantity of the debris, classes j and i, can be written as:

$$K_{ij} = \frac{\exp\left(-A\sqrt{m_{j2}}\right) - \exp\left(-A\sqrt{m_{j1}}\right)}{\exp\left(-A\sqrt{m_{i2}}\right) - \exp\left(-A\sqrt{m_{i1}}\right)}. \tag{3}$$

From the ratio of masses of objects, it is possible to proceed to their sizes. If we assume that debris of small-size has a spherical form of radius R, then

$$m = \frac{4}{3}\pi R^3 \rho, \tag{4}$$

where ρ - density of debris substance.

As an estimation of the quantity of the debris formed as a result of the explosions of 10 space objects, it was supposed that:

1. all spacecraft explosions are equivalent;

2. the quantity of apparent fragments with mass about 350 kg and the size of 1 m of 1-st class is equal to one or two;

3. the gross weight, formed at the explosion of one object, of the debris is equal to its weight, which is about 1700 kg.

The results of modeling fragmentation of 10 space objects at their explosions are listed in table 2.

Table 2. Quantity of fragments of various classes

Class number	1	2	3	4	5	6
Quantity of fragments	**119**	**944**	**3450**	**1370**	**320**	**50**

The objects caused by a fragmentation at the activations of geostationary space vehicles are divided up in a structure of objects of classes 1 and 2, besides the debris formed at explosions. Their quantitative structure is determined from the data of the catalogue of activations.

The data analysis listed in table 2 shows, that the basic share of the fragments formed at explosions is debris of classes 3 and 4. They should be taken into account in a statistical orbital debris model in the geostationary area. The influence of objects of a smaller size s can be neglected, because of their rather small quantity and the much greater area of possible allocation.

ALLOCATIONS OF SPACE DEBRIS ORBITAL PARAMETERS

Allocations of debris orbital parameters formed from exploded objects are determined by parameters of the motion of the spacecraft at the moment of fragmentation [1] and the incremental velocity of the debris, caused by the explosion. The ratio of the mass of debris and the increment of its velocity can be determined from the equality of their kinetic energies at the moment of explosion. We shall receive for debris of various masses

$$\Delta V_2 / \Delta V_1 = \left(m_1 / m_2\right)^{1/2}. \qquad (5)$$

This ratio is valid for the debris of approximately 0.1 m^2 size. Otherwise, the area of effect of a shock wave becomes very small, that reduces the efficiency of its effect on such debris. For an observation of large debris of class 1, the increment of their velocity, which is about 1 m/s, is determined. The increment of velocities of more small-sized debris, up to the sizes about 10 mm, was determined by the use of the above mentioned ratio.

It was supposed, that all space object explosions to the present time were spherically symmetrical. After fragmentation, under Moon and solar activity disturbances and the unsymmetrical gravity field of the Earth, changes occur to debris orbital elements. It is possible to assume, that an obliquity i of the planes of orbits, and eccentricities e practically do not change after object fragmentation. Arguments of the latitude of the debris, and arguments of a perigee ω in a steady mode are distributed uniformly in limits from 0 to 2π. The analysis of the area of the fragments motion of explosions, conducted in [2] allows one to assume, that the longitude of the ascending node Ω of the debris orbits have a distribution law close to the distribution law of the ascending nodes of the catalogued objects. It is given in figure 1.

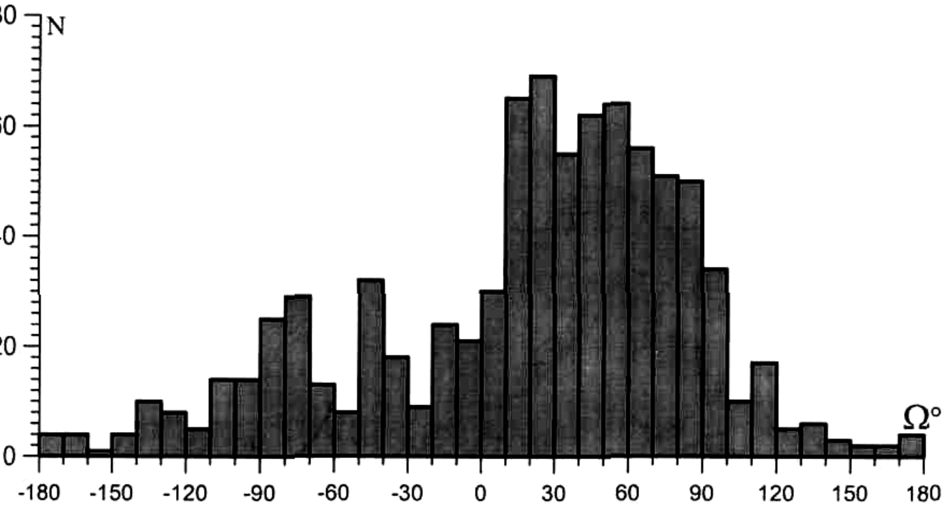

Figure 1. Distribution of the longitude of the ascending node of catalogued objects

Adopted guesses of distribution laws of objects' orbital parameters of various classes are determined.

For an adopted model of damage and an adopted initial background, incremental velocities of standard objects of various classes at symmetrical explosions are specified, pursuant to a ratio (5), and are listed in table 3.

Table 3. Incremental debris velocities of various classes

Class	1	2	3	4	5	6
ΔV[m/s]	**1.0**	**5.8**	**31.6**	**185.2**	**1000.0**	**1000.0**

The greatest interest in the map of examination of "clogging" of the geostationary area due to explosions is represented by debris of classes 3 and 4. Distribution laws of the obliquity of their orbits, of eccentricities, and semi-major axes under data of mean representatives, are shown in figures 2 - 7. It is possible to assume, that in the process of changes of the orbit evolution after fragmentation, arguments of latitude and arguments of perigees of these debris are distributed uniformly in limits from 0 to 2π.

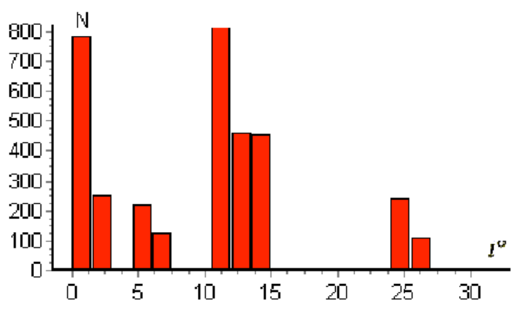

Figure 2. Allocation of objects of the third class on an obliquity of orbits

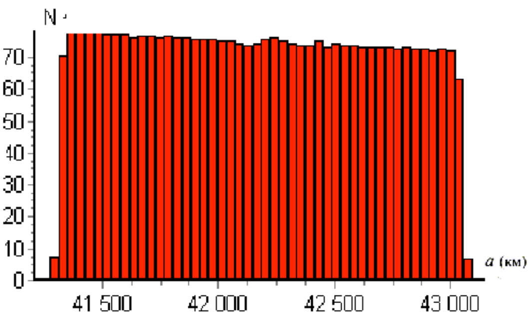

Figure 3. Allocation of objects of the third class on the semimajor axis

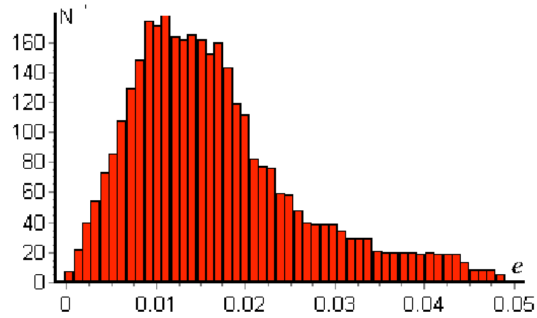

Figure 4. Allocation of objects of the third class on eccentricity

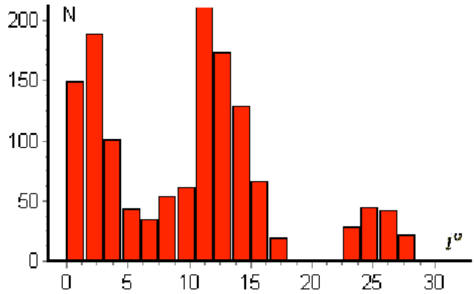

Figure 5. Allocation of objects of the fourth class on an obliquity of orbits

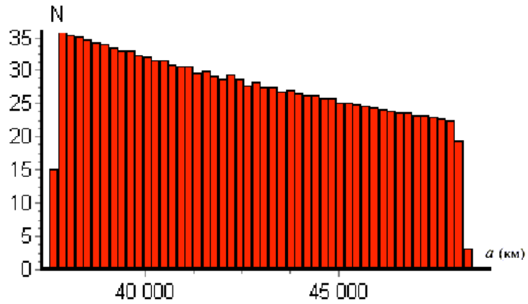

Figure 6. Allocation of objects of the fourth class on the semimajor axis

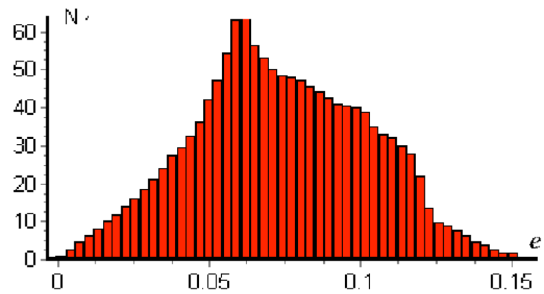

Figure 7. Allocation of objects of the fourth class on eccentricity

The data on the quantitative structure of small-sized orbital debris and the allocation of orbital parameters of their motion allows one to estimate a statistical model for the various classes of objects, influencing exterior configuration of space vehicles and to explore stability of these vehicles.

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