A MODEL OF DISTRIBUTION OF GEOSTATIONARY SATELLITE FRAGMENTS AFTER EXPLOSION

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ABSTRACT

The influence of the velocity changes $\Delta\overline{V}$ originated after a satellite explosion, on initial orbits of satellite fragments have been examined. These orbits have been expressed through orbital element of parent body and $\Delta\overline{V}$. The obtained formulas have been tested with the use of observable fragments of satellite 77092A (Ekran 2). Taking into account the orbital evolution of fragments it has been shown that the volume of the region of their distribution is significantly larger than the volume of the geostationary ring where the all observable objects move.

INTRODUCTION

Since 1957 more than 4000 satellites and rocket upper stages have been put into near Earth's space. Especially intense conditions on the Geostationary Earth Orbit (GEO) were created, where now about 240 controlled apparatuses work. The satellites are periodically replaced by other, but they remain in a vicinity of GEO for ever, thus increasing risk of collisions.

However the more important source of space debris formation is occasional explosion of geostationary satellite (GS). In [1] it has been shown, that after the explosion of GS its fragments are distributed to thousands of kilometers.

We constructed model for orbits of fragments for spherical symmetric distribution of velocity changes ($\Delta\overline{V}$). The evolution of the obtained orbits allows determine the size and form of area in which the fragments can move. Such method can be applied to both low and high orbital objects.

1. DEFINITION OF ORBITS OF FRAGMENTS

Let's take system of coordinates, in which the axis x is directed to the point of an equinox, and for the basic plane the plane of equator of date [2] is accepted. A position of the satellite in the moment of an explosion is determined by vector r_0 and velocity V_0. In this moment all fragments get additional velocity ΔV .

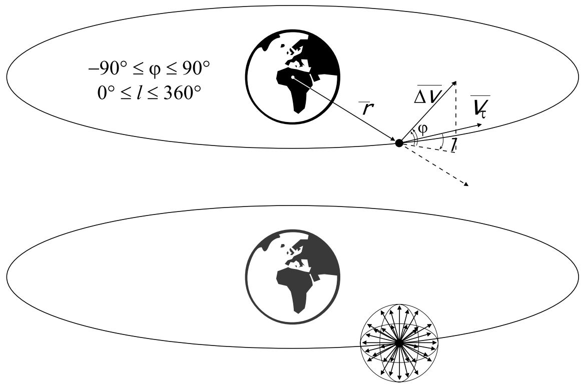

Fig. 1. Spherical model of explosion

In case of spherically symmetric explosion (Fig. 1) any directions of motion are equal in rights, therefore ΔV are represented by following way:

$$\Delta\overline{V} = \Delta V \begin{Bmatrix} \cos\varphi \cos l \\ \cos\varphi \sin l \\ \sin\varphi \end{Bmatrix},$$

where ΔV - module of velocity changes, which varies within the limits of 1 – 250 m/sec, depending on the weights of fragments, l - angle measured from the direction of transversal velocity from 0° up to 360°, the angle φ is measured from an orbital plane from 0° up to ±90°.

Using integrals of a two bodies problem, we determine the elements of an orbit referred to a plane of equator and expressed through orbital elements of the satellite on the moment t_0 and ΔV , φ and l.

Introduction of a Laplace plane is convenient for research of evolution of geostationary objects, as relative to this plane the inclination of an orbit varies a little, and, therefore, the coefficients of the secular members of argument of perigee and longitude of orbital ascending node remain practically constant.

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2. THE EXAMPLES OF REAL EXPLOSIONS ON THE GEOSTATIONARY ORBIT

The demonstrated algorithms were tested on modeling of real explosions of the 77092A Ekran 2, having observable fragments.

For the Ekran 2 we have small numbers of the TLE before and after the explosion of June 21, 1978 (43680.6328 MJD), and also orbital elements for the period 1993-1998. On an interval about one year within 1998 there are similar data for the fragment 77092H.

The theory of motion of geostationary object without of occasional changes in the rate of drift allows to represent evolution of its longitude on intervals about 10 000 day with accuracy of 0.°1.

Using the data for the Ekran 2 we have obtained the following results. At the moment of explosion the agreeable orbital elements of parent body before and after explosion, and the same data for its fragments are determined. The results of calculations are given in Table 1. Because of errors in elements the calculated radiuses *r* differ on 1 - 3 km/sec.

Table 1. Elements of orbits of the Ekran 2 and its fragments referred to the Laplace plane, before explosion and after explosion of June 21, 1978

	77092A Ekran 2 before explosion	77092A Ekran 2 after explosion	77092H fragment
T_0	43680.632778 MJD	43680.632778 MJD	43680.632778 MJD
Λ	7.°3419	7.°3419	7.°3419
I	7.°3073	7.°3123	7.°2800
Ω	178.°9713	178.°9215	178.°0993
E	.1952E-03	.3366E-02	.1268E-02
ω	204.°9680	154.°5339	346.°9343
V	211.°8141	262.°2506	70.°9298
Ω	56.°7821	56.°7845	57.°8841
$\lambda_v = v+\omega+\Omega-S$	98.°4926	98.°4452	98.°7226
$D\lambda_v/dt$ °/day	-0.08513	0.04766962	-0.34311901
A	42172.6 km	42162.1 km	42193.2 km
P	42172.6	42161.4	42193.1
R	42179.6	42180.5	42175.7
ΔV		9.9 m/sec	10.3 m/sec
φ		0°	-71.°4
		92.°5	283.°2

Crossing of orbits of fragments with the geostationary orbit increases probability of their collision with the functioning satellites and can serve as an explanation of the found changes of rates of drift for uncontrolled objects.

3. THE FORMING OF THE REGION OF CHOKING UP BY THE FRAGMENTS

Basing on the analytical estimations of changes of orbital elements and the data of Table 1 it can be described the size and shape of the debris region in which the fragments of an exploded object move.

The maximum changes of orbital elements of fragments Δi and $\sin i\, \Delta\Omega$ relative to orbit of the parent body for ΔV=250 m/sec do not exceed ±4.°7. The perigee and apogee distances of fragment orbits vary in the limits of 4.8 to 9.6 R .E.

All the orbits of fragments intersect the point of an explosion. This point is determined by osculating orbit of GS at the moment of the event in the adopted system of coordinates.

In a result of an explosion the parent body also changes its orbit and it can be considered as one of the largest fragments. Usually the velocities of the largest fragments are varied from 1 to 10 m/sec. The changes of orbital elements of these fragments are small and their evolutions are similar. On contrary, the small fragments are ejected with $\Delta V > 100$ m/sec and they spread far from parent body and their orbits have large eccentricities.

In the equatorial geocentric co-ordinates the region of motion of all known GS (RMAKGS) is limited by the belt with the width about 15°, inclined relative to equator on 7°. The width of region (across the radius) is equal to nearly 5000km. In Fig. 2a are represented RMAKGS and the region of the motion of exploded GS 77092A (Ekran 2) fragments after one-day time interval. The large variety of orbital radii of created fragments leads to the essential diversity of their Laplace planes. Because of the orbital evolution the inclination relative to equator for distant objects can reach the maximum values equal to 28°. The arguments of perigee due to secular perturbations make a whole cycle along the orbit in 20-35 years, but according to the same cause the period of secular variation of longitudes of orbital nodes is equal to 40-70 years. In 20 years after the explosion the region of the motion of small-size model fragments of GS Ekran 2, ejected with the rate 100-250 m/sec is shown in Fig. 2b.

In Fig. 2c RMAKGS and the region of the motion of exploded GS 77092A (Ekran 2) (and additional GS 68081E Transtage 13, 67066G, 73100D and 78113D) fragments at present days are shown.

Thus, the region occupied by fragments in comparison with the geocentric ring increases twice in height and five times - in width. The maximum density of debris is concentrated in vicinity of GEO.

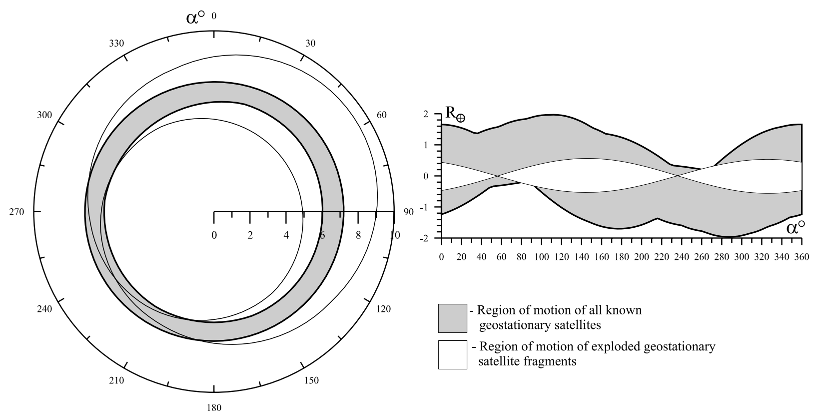

Fig. 2a. RMAKGS and the region of the motion of exploded GS 77092A (Ekran 2) fragments after one-day time interval (22.06.1978)

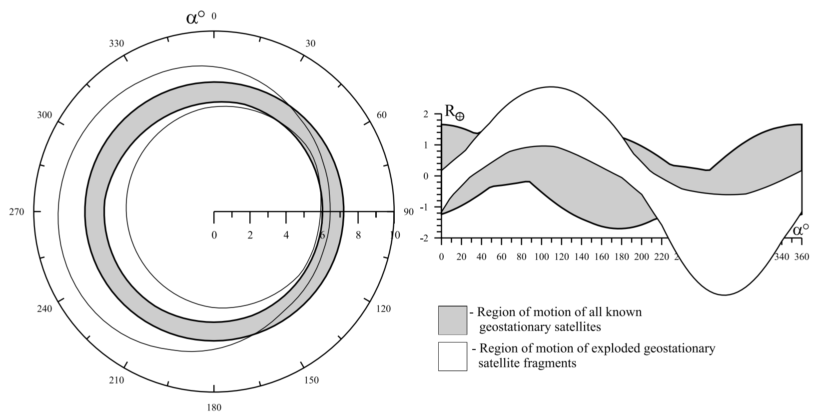

Fig. 2b. RMAKGS and the region of the motion of exploded GS 77092A (Ekran 2) fragments after 20 years (21.03.2001)

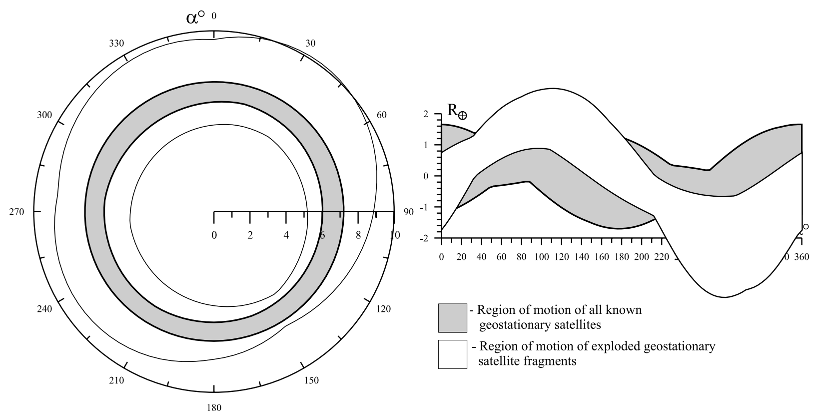

Fig. 2c. Region of motion of exploded satellites (77092A, 68081E, 67066G, 73100D and 78113D) fragments in present days (21.03.2001)

CONCLUSION

On the base of the investigations of the space region formation in which the fragments of exploded GS move can be made the following conclusions.

1. The fragments can move off away GEO to both sides on distances 11500 and 17500 km.

2. The maximum changes of the fragment inclinations can be about 5dg and depends on the explosion place in orbit of parent body. Taking into account of their orbital evolutions, the inclination of orbits with the maximum semi major axis referred to equator can reach 28 dg. These fragments are especially dangerous because the collision with them can provoke the process of permanent fragmentation [1].

3. For elaboration of effective methods for the safety of controlled satellites in GEO the first step is to know a real situation in this region or a precise number of moving and exploded objects. For this purpose it is necessary to calculate orbital evolution of all launched objects in GEO and all the dangerous objects.

In order to receive the constant and certain information about the population of GEO region it is useful to introduce the more powerful equipment of ground observational means and launch the satellite in the GEO region with telescope on board for observations of small-size objects.

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