

THE INFLUENCE OF SOLAR LIGHT PRESSURE TO GEO OBJECTS. EVOLUTION ASPECTS.

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ABSTRACT

The surface of a satellite or space debris object re-emits solar light, thus giving rise to a reactive force. In the case of an asymmetry of the scattering field this force caused secular variations of the semi-major axis. A method for considering the asymmetry of solar light scattered by satellite or fragment's surface based on analysis of the light curve obtained from photometric observations of GEO objects is developed. The lasting evolution (500 years) of five geostationary satellite's orbits were studied based on that data. It is worth noting that for all satellites under investigation their semi-major axes are decreasing. The decrease reaches values of 100 to 400 km for several satellites. Due to the effect of radiation pressure on the evolution of fragments of GSS and their carriers (space debris objects), these fragments tend to move to non-libration orbits rather than to group near the libration point. This effect is especially strong for small satellites with a high ratio of effective area to mass. It appears like a mechanism of "self-purification" of GEO as well as LEO.

INTRODUCTION

It is known, that the greatest influence on a movement geosynchronous satellites (GSS) renders a gravity field of the Earth. Gravity forces from the Moon and the Sun influence mainly orientation of an orbit GSS concerning equator, causing long-period variation of an inclination and longitude of ascending node.

The light pressure is the basic perturbation factor of a ungravity type. For GSS with $s/m = 0.1 \text{ cm}^2/\text{g}$ (s - middle cross-section square, m - weight) it causes a perturbing acceleration in 1000 times of smaller than perturbative influence of polar ellipticity of the Earth and in 5 times smaller than influences of earthly equator ellipticity. The account of light influence collides with significant difficulties, as the satellites have the rather complex form. Besides for an estimation of influence of light pressure the precise knowledge of orientation of object is essential.

The light pressure on the satellite, is composed

from a number of components. The vector of force of light pressure is the sum of vectors of separate components:

- a. Pressure of direct falling light, parallel to a vector of solar radiation. The value of this pressure is proportional to a middle cross section square of the satellite (s) and the value of solar constant.
- b. Force caused by a Pointing-Robertson effect. The force works towards to a movement of the satellite;
- c. Pressure of solar light, scattered by satellite's surface. The value of this pressure is proportional to an albedo of a surface of the satellite, its middle cross section square and solar constant.
- d. Pressure of light reflected by a surface of the Earth and an own infrared radiation of the Earth.
- e. Pressure by a scattered surface GSS of Earth's radiation.
- f. Pressure of an own infrared radiation of a surface of the satellite.

The influence of direct solar pressure is well known. It does not result in variations of a semi-major axis of an orbit on time ranges essentially exceeding duration of one year. The Pointing-Robertson effect, bringing to such variations, is smallest. The pressure of radiation scattered by surface of the satellite is usually taken into account or as the additive to direct light pressure proportional to an albedo of the satellite, or is calculated on the basis of the known shape and distribution of an albedo on a surface. In case of discrepancy of a vector of force of a scattered radiation with a direction of a direct solar pressure vector the occurrence long-period and secular variations of a semi-major axis of an satellite orbit is possible. The calculation of effect is possible only for objects of rather simple shape. Besides the reflective properties of a surface of the satellites change under influence of the factors connected to space properties.

SCATTERED RADIATION PRESSURE

A number of papers of A.M.Mikisha and M.A.Smirnov have been devoted to the study of

long-term evolution of high orbit space objects due to solar radiation pressure (Ref. 1, 2). We suggest a technique of definition from photometric observations of light pressure force caused by a scattered radiation on the satellite surface.

Effective direction vector of pressure force of a scattered radiation in equatorial geocentric coordinates will be written down as:

$$\vec{n}_e = \frac{1}{B} \begin{pmatrix} \iint J(t_o, \delta_o, t, \delta) \cos^2(\delta) \cos(t) d\delta dt \\ \iint J(t_o, \delta_o, t, \delta) \cos^2(\delta) \sin(t) d\delta dt \\ \iint J(t_o, \delta_o, t, \delta) \cos(\delta) \sin(\delta) d\delta dt \end{pmatrix},$$

here $B = \iint J(t, \delta) \cdot \cos(\delta) d\delta dt$.

Field of a scattering of solar light by the satellite surface $J(\vec{s}, \vec{r})$ is function 4-th variable - two coordinates of a direction on the sun and two coordinates of a direction of a scattered radiation. As the field of a scattering has property of invariancy concerning permutation of the first and second vector arguments, that, entering variable $p = \alpha - \alpha_0$ and $q = \delta - \delta_0$, the components of a vector \vec{n}_e can be expressed through value these variable:

$$B_1 = \iint J(p, q) \sin(q) dp dq$$

$$B_6 = \iint J(p, q) \cos(p) dp$$

$$B_2 = \iint J(p, q) \cos(q) dp dq$$

$$B_7 = \iint J(p, q) \sin(p) \sin(2q) dp dq$$

$$B_3 = \iint J(p, q) \sin(2q) dp dq$$

$$B_8 = \iint J(p, q) \cos(p) \sin(2q) dp dq$$

$$B_4 = \iint J(p, q) \cos(2q) dp dq$$

$$B_9 = \iint J(p, q) \sin(p) \cos(2q) dp dq$$

$$B_5 = \iint J(p, q) \sin(p) dp dq$$

$$B_{10} = \iint J(p, q) \cos(p) \cos(2q) dp dq$$

These 10 variables characterize completely a field of a scattering of solar light and are used for calculation of a vector of pressure of light scattered by the satellite surface.

Such approach to the description of light pressure

force scattered by surface of object is applied for the first time for research of perturbation in a movement of celestial bodies caused by light pressure. This approach has resulted in development the averaged theory of evolution of an orbit GSS under effect of the specified force, which essence consists in the following.

Substituting the obtained value \vec{n}_e we obtain expressions for projections of perturbation force, which we substitute in the differential equations describing time variations of elements of an orbit. Averaging of the right sections of the differential equations of a movement on one revolution of the satellite, we obtain, that in the right sections of the averaged equations there are members bringing in appearance of long-period and secular variations of a semi-major axes, eccentricity and inclination. These variations in a semi-major axis and eccentricity occur even for a circular orbit ($e = 0$).

SATELLITES ORBIT EVOLUTION

On photometric observations of the GSS the fields of a scattering of solar light by their surface were obtained with completeness sufficient for definition a force vector of a scattered radiation for 5 objects (GSS 81050A, 81069A, 85015A, 85087A, 89006A). For these objects the coefficients $B_1 - B_{10}$ used for calculation of orbits evolution were computed. For 5 model satellites that have observed scattering fields the evolution of a semi-major axis, an eccentricity and an inclination of all orbits on time interval equal 500 years was calculated (the ratio of the effective middle cross-section square for them was equal to unit, and the initial elements of an orbit were set as $\Omega = \omega = i = 0$; $e = 0.0003$; $a = 42164$ km). Besides light pressure were taken into account of perturbation from the second zone harmonic of geopotential (her influence on a longitude of an ascending node and an argument of perigee) and influence of gradients of a gravity field of the Moon and the Sun on evolution of an inclination of an orbit and orientation of a plane of an orbit (Ref. 3). The influence of light pressure is most essential for evolution of a semi-major axis of an orbit (for which a secular variation under the gravity forces is absens). The influence of light pressure on an eccentricity and inclination of an orbit is essential less, than influence of gravity field. In a Fig. 1 the evolution of a semi-major axis on the interval 500 years for these 5 objects is given. It is visible, that for all objects there is a secular reduction of a semi-major axis of an orbit.

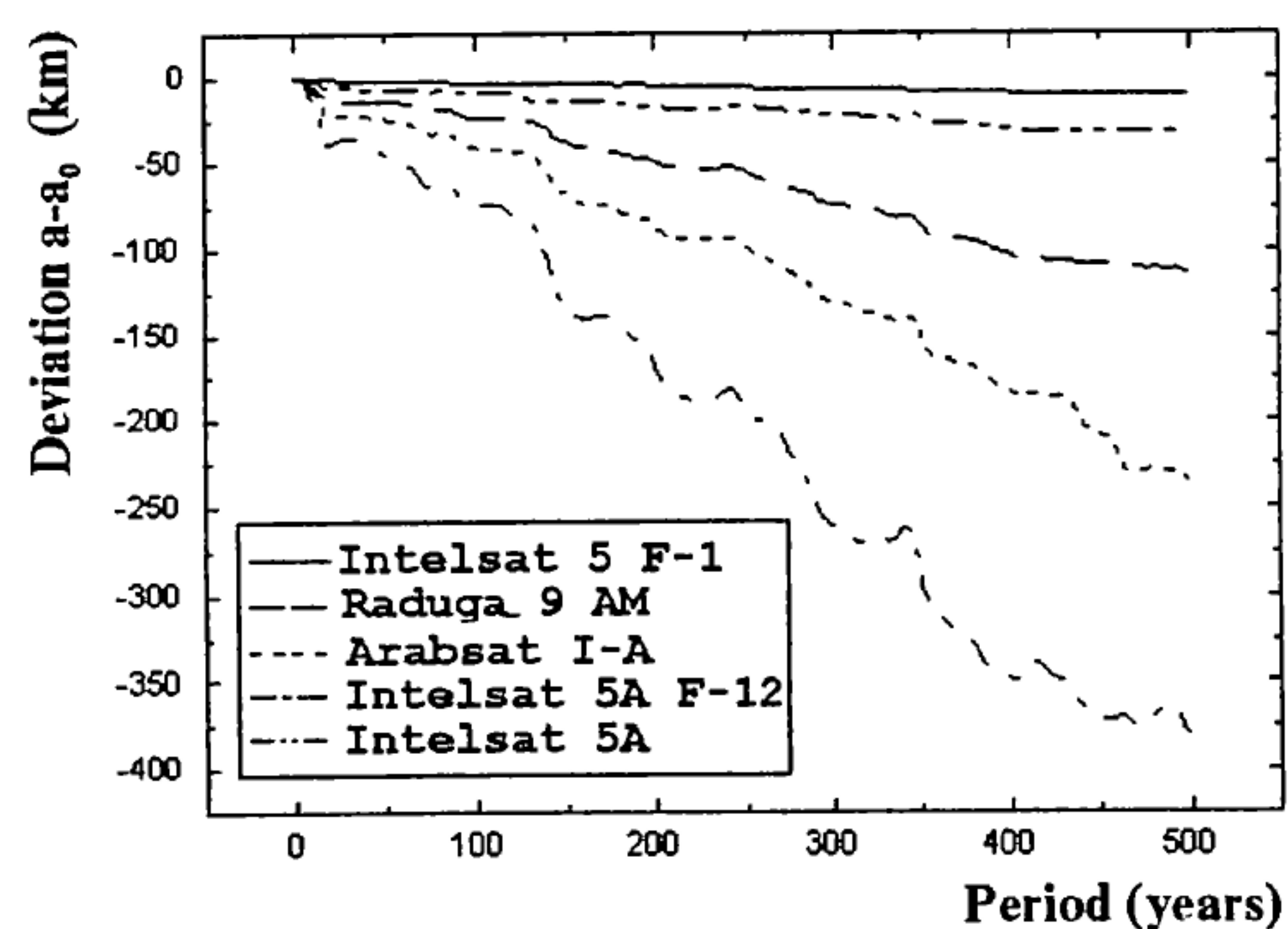


Figure 1. Evolution of a semi-major axis of an orbit for five model geosynchronous satellites.

The satellites which have ceased active to work, ceases to support constant orientation. If the asymmetry of a scattering field is occurred the expense of constant in relation to the orientation of the Sun, that on rotation of object around the centre of weights the scattering will be symmetrical and coefficients B_i with odd indexes will be equal to a zero. That will result in sharp reduction of secular influence of light pressure by a semi-major axis of an orbit. If the asymmetry of a scattering field is caused by properties of reflecting surfaces of a satellite, that during the rotation of object around of centre of weights the asymmetry of a scattering field of light will be kept.

CONCLUSIONS

For the overwhelming majority of the artificial satellites of the Earth the ratio (relation) of a middle cross section square of the satellite to weight lays in a range of $0.1 - 1 \text{ cm}^2/\text{g}$. Therefore secular variations of height of an orbit for geosynchronous satellites are rather insignificant also such satellites will occupy approximately same volume of space during a long period of time. But with destruction of space vehicles in result both internal and external reasons formed fragments have the much larger ratio of a middle cross section square of the object to weight - up to $10 - 100 \text{ cm}^2/\text{g}$. As it is visible from a Figure 1, the light pressure will render essential influence on secular evolution of a semi-major axis of an orbit of such fragments. Variations can achieve several kilometers per one year, that will result in appreciable change of spatial distribution of elements of space debris. Due to the effect of radiation pressure on evolution of the fragments of the GSSs and their carriers, these fragments tend to pass on non-librational orbits rather than to group near libration points. This means

that mechanism of self-purification is effective on the GEO.

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