Research Article

Nail Bakhtigaraev*, Polina Levkina, Lidiya Rykhlova, Alexander Sergeev, Gulchekhra Kokhirova, and Vadim Chazov

Features of geosynchronous space objects motion near 75° E

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Abstract: Spacecrafts in geostationary orbit are subject to a complex set of disturbances that involve changes in orbital parameters. Corrections to the orbit are regularly carried out to keep the satellite at a given point of standing. The geostationary satellites must be moved to the disposal orbit after finishing their service life. Otherwise they begin to move towards the nearest stable point of libration and to make oscillatory movements in longitude, regularly approaching different satellites, which creates a threat of collision. The theory of motion for large space objects is well developed and their movement is predictable. However, small-sized fragments of space debris, are highly susceptible to difficult-to-predict non-gravitational disturbances. It is important to study the orbital motion of space objects that perform libration movements near 75° E, where the majority of Russian working geostationary satellites are located. Optical measurements at observatories in Zvenigorod, at the Terskol peak and on Sanglokh Mount (Tajikistan) of some of the librational geosynchronous objects were performed. Results of the analysis of some of the geosynchronous small-sized fragments are given.

Keywords: optical observations of space debris, geostationary orbit, area-to-mass ratio

1 Introduction

Geostationary orbit (GEO) is an near-Earth orbit with zero inclination and zero eccentricity. In this orbit there exists some so-called libration points, due to the difference of the Earth’s equator from the circle. The maximum perturbations in the movement of space objects in GEO are experienced near the longitudes 30° and 120°E, 60° and 150°W.

Minimal perturbations in the movement of objects in GEO are experienced near longitudes 75°E and 105°W, called stable points of libration. Sometimes they are also called potential wells of the geostationary orbit.

If geostationary objects after the termination of their term of service are not moved into graveyard orbits, they begin to move towards the nearest stable libration point and oscillate in longitude around this point which poses a threat of collision with working geostationary satellites. According to the European Space Agency, by the beginning of 2016 in the regime of librational motion around the point of 75°E there were 121 space objects (Classification of Geosynchronous Objects (2016)). In fact, there are a lot more of these space objects.

Our observatories regularly detect not previously observed small-sized fragments of space debris (Bakhtigaraev et al. (2016)). In particular, the limiting magnitude of the telescope Zeiss–2000 of Terskol observatory allows us to detect and track objects down to 22nd stellar magnitude, which corresponds to a size of less than 10 cm. In addition, the observations of space debris are conducted at the Zvenigorod observatory. In 2016, after the restoration of the telescope Zeiss–1000, we started joint observations at the Sanglokh observatory of the Institute of Astrophysics of the Academy of Sciences of the Republic of Tajikistan.
of Tajikistan (Kokhirova et al. (2016); Bakhtigaraev et al. (2017)). The Camera Control module and the Apex II package developed at the Central (Pulkovo) Astronomical Observatory were used to perform the initial image reduction and for time synchronization (Devyatkin et al. (2010)). The numerical-analytical theory of motion of artificial Earth satellites that includes all perturbing factors is used for calculations (Bakhtigaraev & Chazov (2005)).

10 years ago it was shown that the greatest the danger to the functioning geostationary satellites is danger of collision with space objects performing librational motion (Klishin et al. (2007)). Space debris have small dimensions and large values of the area-to-mass ratio. The influence of nongravitational perturbations on the orbital motion and the evolution of the orbits of these fragments requires consideration of the rotation parameters. The pressure of solar radiation causes not only difficult to predict the changes of the orbital parameters, but also leads to changes in the eccentricity. Continuous positional and photometric observations of objects in the region near the libration points of 75°E is required to predict the situation. Below are examples of investigations of the motion of geosynchronous objects around the point at 75°E and the threat of small fragments of space debris.

2 Investigations of geosynchronous objects

The equatorial region in geosynchronous orbit near the longitude 75°E is important for placing spacecrafts performing communication functions and solving scientific and industrial tasks for the Eurasian countries. The fragments of space debris cross this region at high speed. It is dangerous for active satellites approaching this region because they could cease functioning.

Figure 1 shows the location of geosynchronous objects on 08.01.2017 around the point at 75°E in the range of ±2.5°. Circles mark 9 functioning satellites, squares mark 15 space objects according to the two-line elements of the NORAD database (Hoots & Roehrich (1980)), and triangles mark 17 fragments of space debris from the dynamic database of space objects compiled by the Keldysh Institute of Applied Mathematics. A total of 40 objects are in the longitude range 5 degrees.

Figures 2 and 4 show the orbital history of the geostationary satellite Comstar 4 since 1981. It was launched to the point with longitude 233° and has worked with corrections in longitude and angle of inclination. Since 1986, it worked at the longitude 284° without correction of the inclination angle of the orbit. Since the beginning of 2000 up to the present time Comstar 4 is in uncontrolled motion about libration point of 75°E.

3 Investigations of small-sized fragment of space debris Fengyun 2D Deb

The small-sized fragment of space debris Fengyun 2D Deb (33458 NORAD) has been observed since 2007. It was established that this object is a fragment resulting from the launching of the geostationary satellite Fengyun 2D in December 2006 to the longitude 86.5°E. The object moves in the regime of libration near longitude 75°E with an amplitude of 24° and a period of 750 days. According to the results of 12-week sessions of observations at the observatory at the peak Terskol from 2009 to 2014, an empirical model of the motion of this fragment was created. It was found that the area-to-mass ratio (A/m) is variable with a maximum value of 0.18 m²/kg. The model of variations with the A/m with a period of 392 days was proposed.

An important simplifying assumption, that variations of the area-to-mass ratio could be approximated with a smooth function, was made. The model was composed of four curves on the interval of a single period (392 days). Each curve was a section of a sinusoid with a period of 196 days. The following approximation formula for calculating the parameter for a single-period (392 days) interval was derived in the end:

\[
\frac{A}{m} = a + \dot{a}(t - t_0) + [b + \dot{b}(t - t_0)] \sin \left(\frac{\pi(t - t_0)}{98}\right)
\] (1)

Each certain short interval consists of 98 days, while \(t_0\) corresponds to its center. \(a\) is the approximate value of \(A/m\) at \(t_0\), and \(b\) is the amplitude of an ascending or a descending sinusoidal branch (Bakhtigaraev et al. (2016)). The maximum value of the standard deviation of the area-to-
mass ratio that was obtained by least squares method was 0.007 m²/kg.

The graph of this model is given in Figure 5. Knowledge of such features of the movement allowed us to improve the accuracy of the prediction of the orbits of space debris several times. The studies were performed in the framework of the international program “Astronomy in the Elbrus region”.

Observation of a fragment of Fengyun 2D Deb in 2015 and 2017, with the telescope Zeiss–2000 of Terskol observatory and at the telescope Zeiss–1000 of Sanglokh observatory have confirmed the validity of the model. Figure 6 shows a comparison of the value $A/m$ ratio with the observations. Good agreement of observed values with the predictions is seen. Only observations in October–November 2017 are much different from those predicted by old model
Figure 4. The librational motion of Comstar 4 since 2002 near the libration point of 75°E.

Figure 5. Model of variations of the A/m ratio. Squares are observational data (one square is one session for several nights).

Figure 6. Comparison of the A/m ratio with the observed values in 2015–2017.

Figure 7. The change of the eccentricity of the orbit of Fengyun 2D Deb in 2009–2017. The points plotted relate to the two-line orbital elements (TLE). Squares are the observed values. The authors continue the work on further improving of the model parameters.

Figure 7 shows a graph of eccentricity of Fengyun 2D Deb 2006-053D. The points plotted are values of the eccentricity according to the two-lines orbital elements (TLE). Squares are observations from the Terskol (2009-2017) and Sanglok (September 2016) observatories.

The Table 1 shows orbital elements with their accuracy of Fengyun 2D Deb object from observations at the Terskol Peak observatory. Measurements made from 10.10.2017 to 06.11.2017.
Table 1. Orbital elements of Fengyun 2D Deb object from observations at the Terskol Peak observatory.

<table>
<thead>
<tr>
<th>Object</th>
<th>Fengyun 2D Deb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Measurements</td>
<td>1187</td>
</tr>
<tr>
<td>Epoch: date, UT</td>
<td>20.10.2017, 00:00:00.000</td>
</tr>
<tr>
<td>a (km)</td>
<td>42169.650 ± 0.00026</td>
</tr>
<tr>
<td>e</td>
<td>0.00681811 ± 0.00000043</td>
</tr>
<tr>
<td>i (°)</td>
<td>6.12606 ± 0.000019</td>
</tr>
<tr>
<td>ω (°)</td>
<td>311.78971 ± 0.003352</td>
</tr>
<tr>
<td>Ω (°)</td>
<td>57.86529 ± 0.003241</td>
</tr>
<tr>
<td>M (°)</td>
<td>89.51630 ± 0.003318</td>
</tr>
<tr>
<td>n (rev/day)</td>
<td>1.00250565 ± 0.00000009</td>
</tr>
<tr>
<td>A/m (m²/kg)</td>
<td>0.118 ± 0.0002</td>
</tr>
</tbody>
</table>

4 Conclusions

Space objects in geosynchronous orbit of the Earth experience a complex perturbation resulting in changes to the orbital parameters. To hold a geostationary satellite at a given point of standing requires regular orbit corrections. The geostationary satellites must be moved to the disposal orbit after finishing their service life. Otherwise they begin to move towards the nearest stable point of libration and to make oscillatory movements in longitude, regularly approaching different satellites, which creates a threat of collision. The light pressure is a significant perturbing factor in the orbital movement of fragments of space debris. Knowledge of changes of this parameter can improve the prediction accuracy of the orbital elements. That will reduce the likelihood of dangerous encounters of the satellites with the space debris.

Observations from 2015–2017 almost completely coincided with the results of the prediction based on the model of area-to-mass ratio variations of small-size space debris (the model was not improved by observations after 2014).

In all likelihood, V.V. Beletsky’s assumption (see Beletsky (1965)) about the stabilization of the parameters of a space object rotation due to the influence of various forces is confirmed.

References


Beletsky, V. V. 1965, The motion of an artificial satellite relative to the center of mass, Nauka, Moscow, Russia (in Russian).