BULGARIAN ACADEMY OF SCIENCES

SPACE RESEARCH IN BULGARIA, 5

Sofia . 1986

The Ceodetic Experiment of the Satellite INTERCOSMOS-BULGARIA-1300

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On August 7, 1981, within the framework of the INTERCOSMOS international programme of space research, an artificial earth's satellite INTERCOSMOS-BULGARIA-1300, dedicated to the 1300th anniversary of the Bulgarian State, was launched into the space.

Although the satellite INTERCOSMOS-BULGARIA-1300 was not specifically designed for geodynamic and geodetic studies, it was supplied with a system for laser location. This was the first satellite of this type, since due to their significant weight and dimensions such systems were so far installed on specialized satellites only. Firm restrictions on the weight and dimensions of the laser tracking systems were imposed already in the design stage, since apart from the OLSS system (optical laser light-reflecting system), 11 other instruments were to be housed aboard the satellite. Throughout two years of intensive efforts (1979-1980) this difficult task was successfully resolved in the Central Laboratory for Geodesy at the Bulgarian Academy of Sciences [1,2]. A reflective system of 4,5 kg weight was designed for the satellite, using its very good and stable orientation on the vertical and circular orbit. The shape of a tetrahedral truncated pyramid was selected due to size restrictions, and 12 prisms were located at the small base, 16 at the lateral faces, and the large base was used to fix the system at the satellite bottom. Such an angle was selected between the lateral faces and the base so as to ensure the energy of the reflected signal by the retroreflectors of the base up to zenith angles of $Z=35°$, and at a larger angle up to $Z=\pm 55°$ by the lateral panels. Due to this configuration of the retroreflectors dead zones up to 20 % of the circular view occur at $Z=35°$. In order to improve the performance of the OLSS system at the extreme angles of tracking, tripleprisms of coverage and of different divergence were used. The experimental tests on the reflectance capacity of the system, made conjointly by the Central Laboratory for Geodesy and the Astrocouncil of the Soviet Academy of Sciences, had shown that the OLSS system provides a sufficiently powerful signal, up to $Z=60°$, and that the dead

Table 1

Maxim. errors (m)	Duration of tracking interval			
	1 day	7 days	14 days	1 month
Along the orbit	7,4	364	1460	6690
range	5,3	262	1050	4820

Table 2

Interval of observations (MJD)	Epoch of the observations (MJD)	Number of points in the series	Number of points with 50 m	Tracking stations	Mean motion $(n)\frac{\text{rotat.}}{\text{day}}$	Empirical atmosph. coeff. $\left(\frac{n}{3}\right)\frac{\text{rotat.}}{\text{day}}$
44833 —44837	44833.91	160	156	Riga Simeiz	14.138376	5.83E-6
44836 —44840	44836.95	164	163	Potsdam Riga Simeiz	14.138412	9.42E-6
44846 —44850	44846.93	31	27	Potsdam	14.138639	6.33E-6
44850 —44855	44850.89	80	67	Potsdam Riga Zvenigorod	14.138691	10.85E-6
44869 —44875	44869.72	247	214	Riga Simeiz Zvenigorod	14.139016	8.71E-6
44875 —44883	44875.73	245	245	Simeiz	14.139155	6.17E-6
44884 —44890	44886.70	136	136	Potsdam Riga	14.139243	3.54E-6
		1063	1008			

zones made up 17 % of the circular view. The observations, made by 12 laser tracking stations, had confirmed this experiment.

The satellite BULGARIA-1300 is subject to atmospheric drag, in spite of its comparatively high altitude 850 km. This is caused by the considerable size of the solar batteries and by the fact that the satellite was in orbit during a period of high solar activity. Unaccountable fluctuations of atmospheric density could therefore influence the accuracy of determination of the orbital elements.

Possible errors (due to the fluctuations of density not taken into account) of the determination of the satellite position along the orbit and on the slant range are shown in Table 1. These values are determined by the consistent square polynomial method [3] on condition that variations of density are distributed in the worst possible way.

Laser observations of the satellite from four stations — Riga, Simeiz, Zvenigorod, Potsdam — have been processed at the Astronomical Council for estimation of the atmospheric influence on the speed of the satellite motion during the first two months when large splashes of solar activity were observed (Table 2).

One passage a day was observed at each station, if meteorological conditions permitted. Observations were united in series of 5 days. The analytic theory of satellite motion used for the calculations provided an accuracy of the orbit determination at a 5-day interval no better than 50 m. The discrepancies between measured and computed ranges, after average orbital elements based on all series of observations have been determined, are less than 50 m. The mean value of the average motion (n) and the atmospheric coefficient $\left(\frac{\dot{n}}{2}\right)$ were computed for all arcs. The variations of the index of solar activity F 10.7 and

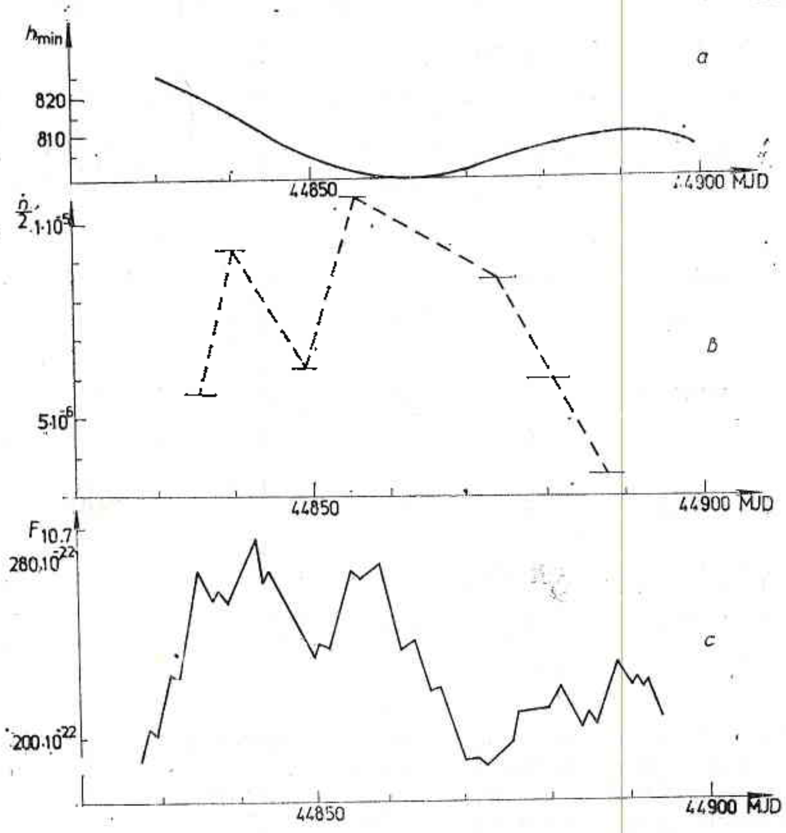

Fig. 1. Graphs of the changes in: a — the minimum height h_{min} (km); b — the atmospheric coefficient $\dot{n}/2$; and c — the index of solar activity F 10.7, as functions of the time T (in mean Julian days — MJD) for a chosen period of the motion of the artificial Earth's satellite INTERCOSMOS-BULGARIA-1300

values of the atmospheric coefficient $\left(\frac{\dot{n}}{2}\right)$ are presented in Fig. 1, showing the dependence of changes in $\left(\frac{\dot{n}}{2}\right)$ on variations in F 10.7. The change of the satellite height is shown in the upper part of Fig. 1 for the same period of time.

A method of differential improvement of the orbit, using the analytical theory developed by [4], was applied for the calculations of more precise values of the orbital elements of the satellite from laser observations for the same period at the State Astronomical Institute (USSR) [3]. The intermediate orbit is an orbit of the generalized problem of two fixed centres. The algorithm of filtration is the least squares method. The theory of motion takes into account perturbations from the geopotential up to the 20th order harmonics. Lunar and solar perturbations and secular perturbations are in the atmospheric drag. The model of the geopotential is GEM-10.

Six elements of the intermediate satellite orbit and the coefficient of the secular change of the mean motion were improved parameters. Unlike other analogous programs, the secular changes of the other elements are found from theory.

Eleven series of observations at intervals from 3 to 5 days have been used to study perturbations in the satellite INTERCOSMOS-BULGARIA-1300 motion.

Following conclusion can be made from the results obtained:

1. The theory of the motion for the satellite BULGARIA-1300 gives a satisfactory accuracy at intervals up to 5 days, the mean square discrepances between measured and theoretical ranges being about 3 to 10 m. It is necessary to take more precisely into account perturbations of the atmospheric drag, including variations of atmospheric density with time at intervals longer than 5 days, in order to increase the accuracy of the theory. Theoretically, the accuracy of determination of the angular orbital elements, obtained by the least squares method, is about 0,3 seconds of arc. The actual accuracy, as estimated from two nearby determinations, is 4 seconds of arc. This may be explained by the instability of the atmospheric density, and perturbations that were not taken into account, as well as by the small number of stations that took part in laser observation of the satellite INTERCOSMOS-BULGARIA-1300.

2. The accuracy of laser observations utilized in our work for various passages of the satellite and for various stations varies from 0,8 to 5 m.

3. The obtained laser observations of the satellite INTERCOSMOS-BULGARIA-1300 can be used for studying orbital changes and factors influencing its motion. These observations can be used for positioning by dynamical methods in an accuracy limit 2-5 m. A joint processing of laser and photographic observations of the satellite, obtained at stations Riga, Zvenigorod and Simeiz at a two-day interval in June 1982 in a period of solar activity ($F_{10.7}=160\times10^{-22}$), has been carried out at the Astronomical Council within the ORBITA program [5], founded on the numerical integration of the motion equation. Perturbations of the gravitational field were taken into account only for harmonics up to the order 8. As estimation shows very large errors [6] in the determination of the satellite radius-vector (see below) appear, if changes of the atmospheric density are not taken into account, as compared with calculations based on the atmospheric model DTM 7.

$t=0{,}5$ days	$\Delta r=16$ m
$t=1$ day	$\Delta r=62$ m
$t=1{,}5$ days	$\Delta r=135$ m

The mean square errors of the forecast of the orbital elements on a two-day interval, as computed by the ORBITA program, are:

$m_a=1$ m; $m_e=5\,.\,10^{-6}$; $m_i=5^\circ\,.\,10^{-4}$; $m_n=4^\circ\,.\,10^{-4}$; $m_{\dot{n}}=4^\circ\,.\,10^{-2}$.

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Геодезический эксперимент со спутником ИНТЕРКОСМОС-БОЛГАРИЯ-1300

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(Резюме)

В работе даны первые результаты лазерных наблюдений спутника „Интеркосмос-Болгария-1300". На основе полученных результатов станциями Рига, Симеиз, Звенигород и Потсдам сделаны количественные оценки влияния атмосферы на скорость движения спутника. На основе анализа результатов сделаны выводы о качествах используемых аналитических теорий обработки наблюдений и возможностей спутников с общим предназначением с целью решения вопросов, связанных с определением влияния верхней атмосферы на движение спутников.