

Accident in orbit

N. Parkhomenko [1], V. Shargorodsky [1], V. Vasiliev [1], V. Yurasov [1],
[1] Open Joint-Stock Company Research-and-Production Corporation
“Precision Systems and instruments

Late January 2013, the BLITS nanosatellite has been lost - supposedly as a result of its collision with a small uncatalogized fragment of space debris. The collision caused a change in the BLITS orbit parameters as well as in its spin rate and spin axis orientation. The BLITS optical retroreflector cross-section value has decreased more than 500,000 times, thus preventing its use as a laser ranging target.

Currently, the OJC “RPC “PCI” has started a development of a new spherical retroreflector nanosatellite where zero signature is combined with a considerably enhanced efficiency. Introduction into the ball lens structure of an intermittent layer of a high-refraction glass for spherical aberration correction will, as follows from calculations, increase the cross-section value by nearly an order of magnitude with only modest (20 percent) increase of the ball lens external diameter relative to the BLITS.

The primary goal of the first space flight of a laser ranging satellite designed as a glass ball retroreflector was technology testing, and its results completely confirmed the correctness of this innovative approach to development of geodetic nanosatellites for high-accuracy laser ranging with use of ball-lens retroreflectors providing a near-zero target error. The OJC Research and Production Corporation “Precision Systems and Instruments” (OJC RPC “PSI”) has now started a development of a new modified autonomous ball-lens satellite.

The BLITS nanosatellite is a passive spacecraft made as a composite glass-ball retroreflector having a diameter of 17 cm and mass of 7.5 kg. It consists of an internal glass ball and two external meniscus-type glass components fastened by glue joints [1]. One half of the composite ball external surface has a reflective coating (Figure 1). The satellite has been developed and manufactured by the OJC RPC “PSI” to support solving of scientific and applied problems in space geodesy, geodynamics, and laser ranging instrument calibration with an unprecedented accuracy. The nanosatellite has been launched on September 17, 2009 into a nearly circular 830-km-high orbit with a 98.6 degree inclination as a piggyback load on the Meteor-M spacecraft; the nanosatellite international number is 2009-049007, and its NORAD number is 35871.

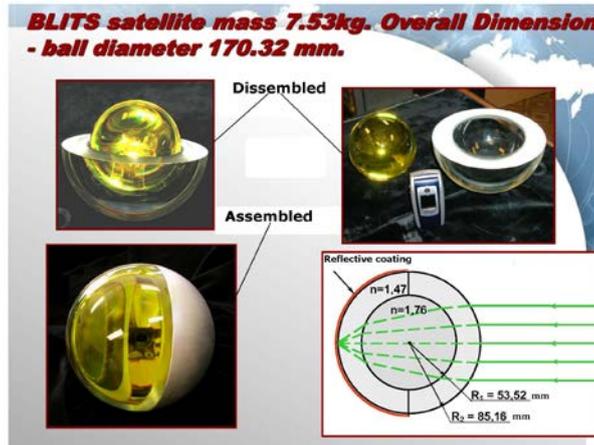


Figure 1. BLITS nanosatellite design

Traditionally, the satellites used as targets for laser ranging are equipped with a number of cube corner retroreflectors fastened on the satellite external surface; the equivalent reflection point of such a target is subject to some variations relative to the satellite center of mass (from few millimeters to several centimeters, depending on the satellite design and size).

For the BLITS nanosatellite, having a full central symmetry, this variation is less than 0.1 mm, thus providing potential submillimeter accuracy of laser ranging for space geodesy, geodynamics, and other application areas where highest accuracy is needed. The clue for its design was the Luneberg lens principle [2].

The BLITS satellite was included in the laser station observation list with a high priority. Its launching has provided a basis for a technological breakthrough in laser ranging station design towards achievement of a submillimeter accuracy level, which, in turn, opens new potentialities for research in geodynamics requiring precision range measurements

The Russian Laser Ranging Network and the International Laser Ranging Network (ILRS) have continued successfully using the BLITS spacecraft during 40 months for high-accuracy ranging. Last successful BLITS ranging sessions were made at the beginning of day January 22, 2013. The Changchun station (China) had a short measurement session from 01:20:51 to 01:21:22 UTC, while the Yarragadee station (Australia) had a longer session from 01:40:06 UTC to 01:45:21 UTC. The last session which took place a few hours before the supposed collision does not show any degradation of the satellite cross-section, meaning that at this time still nothing happened. However, all the subsequent attempts to get return signals from BLITS, starting from January 22, 2013, appeared unsuccessful.

Later, as a result of an express analysis of the BLITS orbit evolution, made with use of TLE data, it was found that on January 22, 2013 there was an abrupt decrease of the BLITS orbit major semiaxis by 120 meters. At the same time, the BLITS orbiting period and velocity were decreased by 0.17 sec (see Figure 2) and 0.067 m/s correspondingly.

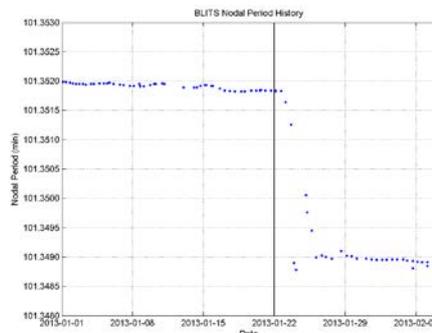


Figure 2. BLITS nodal period history

The most probable cause of such an abrupt change in the BLITS orbit parameters could be a collision with a space debris object. Another argument in favor of this hypothesis is an early March detection, by the US Space Command, of a new space object near the new BLITS orbit classified as a BLITS fragment (NORAD number 39119, international number 2009-049009). As estimated by US Joint Space Command (www.space-track.org) [3], the radar cross-section (RCS) of this object is 0.0018m^2 , which is more than 40 times less than the BLITS radar cross-section. It should be noted that the BLITS radar cross-section has practically remained the same as before the event, and is about $0.0823\text{-}0.0829\text{ m}^2$.

A search for catalogized space objects which may be the cause of that collision requires localization of the time of the supposed collision. To estimate this moment, we assumed that a short impulse of force was applied to the BLITS satellite at the moment of collision. Therefore, a following step sequence was used to estimate the time of collision.

1. Using TLE data, a BLITS orbit parameter determination updating is made for the time before the supposed orbit change moment. The updating is made by smoothing the orbit using TLE data over a week-long interval [4].

2. Using TLE data, just the same as above is made for the time after the supposed orbit change moment.

3. At the time interval January 22-23, 2013, the relative distance is determined between the predicted BLITS positions calculated from the orbit parameters before and after orbit change moment. As the sought moment, the time is chosen when the minimum relative distance is achieved between the predicted spacecraft positions.

A possible object which may be the cause of collision with BLITS has been found from the results of express estimations when the calculated time of collision was localized between 07:56:41 and 07:59:04 UTC on January 22, 2013. The minimum relative distance calculated with use of this method has been found to be about 200 meters. With an account for possible errors of the smoothed orbit parameters determination, the obtained estimation of the BLITS orbit change moment may be considered as accurate enough.

According to data from the Center for Space Standards and Innovations (CSSI) which is regularly tracking dangerous events at close approach to catalogized space objects, within this time interval a collision was possible between BLITS and a fragment of the Chinese «Fengyun 1C» (№30670, international number 1999-025939), generated as a result of antisatellite weapon testing in 2007. In accordance with the CSSI estimation (also obtained from TLE data), the fragment came on January 22, 2013, to a close approach with BLITS (at distance of about 2.5 km). The relative velocity of approach was than 9676 m/s. The angle between the object velocity vectors by the approach was 81 deg, i.e. the fragment approached BLITS from the side. The approach geometry is shown in Figure 3. The BLITS path is here in the East-West direction while the fragment path is in the South-North direction. The crossing point was over the Arctic Ocean, near Novaya Zemlya Island.

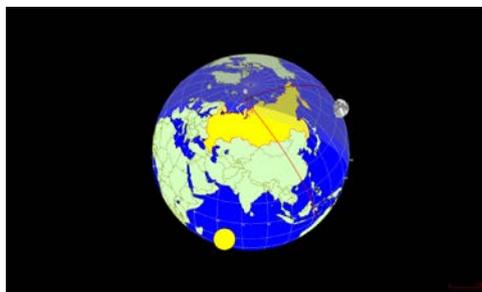


Figure 3. Geometry of close approach between BLITS and fragment of Chinese satellite

From data published in www.space-track.org, the Fengyun 1C fragment radar cross-section is 0.0187 m^2 . Hence, the fragment is probably several times less in size and mass than BLITS. To

confirm the BLITS collision with the Fengyun 1C fragment, TLE data concerning the Chinese satellite fragment within few weeks before and after January 22, 2013 have been collected and analyzed. The Chinese fragment motion parameters analysis does not show any considerable unpredicted variations of its orbit, while such variations should be seen in case of a collision because the orbit of BLITS (which is comparable to the fragment in mass) has substantially changed. So we could not obtain any definite facts confirming the BLITS collision with the Fengyun 1C fragment.

In the Figure 5, the space debris flux characteristics are presented relatively to the BLITS spacecraft, in a moving satellite coordinate system. From the azimuthal distribution of the approach directions, it is clear that frontal collisions are the most probable ones. The mean velocity of collision is 12.3 km/sec in that case.

Besides this, in the upper right corner of this Figure estimation is presented for the catalogized space objects flux density relative to this spacecraft. It is $Q=0.00001117 \text{ m}^{-2}$ per year. From this estimation, one can easily determine the mean number of objects (flux) crossing a spherical volume of a radius r during a unit of time. As a radius $r=2.5 \text{ km}$, we take the minimum distance between BLITS and the Fengyun 1C fragment (at close approach). We get the estimated value:

$$\text{Flow} = \pi \cdot r^2 \cdot Q = 215 \text{ dangerous approaches per year.}$$

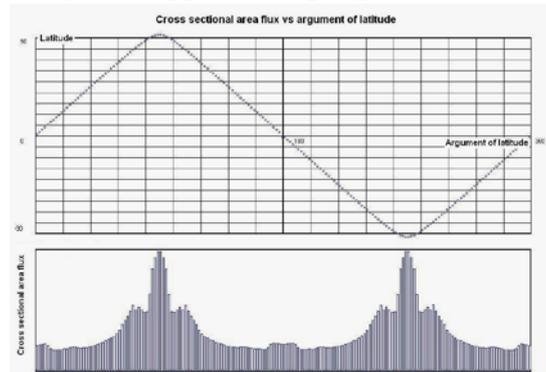


Figure 4. Space debris flux variations along the BLITS track

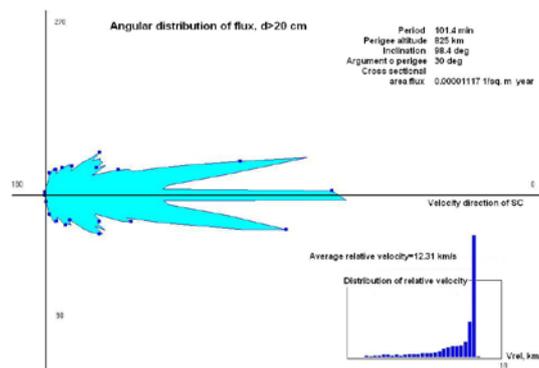


Figure 5. Catalogized space object flux relative to BLITS

From our point of view, the most probable event is a collision of BLITS with a small uncatalogized space debris fragment. To estimate the mass and size of an object which could cause the collision we take the BLITS velocity variation estimated value -0.067 m/s . Let us consider a most simple case when two objects with mass values m_1 and m_2 having equal velocities V are moving opposite to each other. Let us assume that at the moment of collision they press one into another and remain moving with a velocity of V_{col} . Using the conservation of momentum law:

$$m_1 \cdot V - m_2 \cdot V = (m_1 + m_2) \cdot V_{col} \quad (1)$$

we obtain the velocity change of the first object:

$$\Delta V = V_{col} - V = -2 \cdot \frac{m_2}{m_1 + m_2} \cdot V. \quad (2)$$

With known values of $m_1=7.53$ kg, $V=7.43$ km/sec, and ΔV it is easy to determine the second object mass $m_2=0.000034$ kg which is a small value. So, the observed changes in BLITS orbit parameters may be caused by BLITS collision with a very small space debris fragment: $m=0.034$ g, corresponding to a size of a few millimeters.

The number of such small space debris fragments is several orders of magnitude more than the number of cataloged fragments, and they cannot be tracked by current radars or optical sensors. The BLITS orbit having a height of ~ 800 km and inclination of 98.6 degrees is passing through space areas with maximum concentration of space debris (see Figure 6).

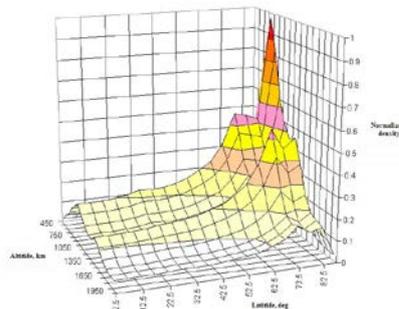


Figure 6. Normalized distribution of LEO space debris over latitude and height

To check the BLITS collision hypothesis and to estimate its current state, several sessions of BLITS photometric observations have been taken in the Altay Optical and Laser Center. The measurement results show an abrupt decrease of the BLITS brightness variation period relative to its value during the past regular operation.

For example, in Figures 7 and 8 typical BLITS brightness variation during its normal mode are shown. In the Figure 7, photometry observation results are presented taken during a BLITS pass on September 11, 2012; in Figure 8, one can see a part of this pass. The BLITS spin period was the ~ 5.6 seconds, which is clearly seen from the curve.

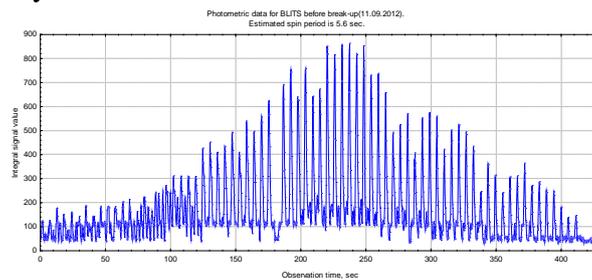


Figure7. BLITS brightness variation curve prior to destruction (full observation interval)

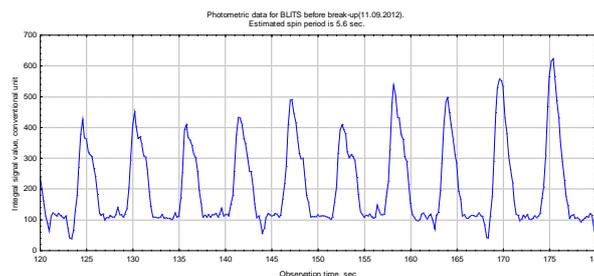


Figure 8. BLITS brightness variation curve prior to destruction (part of the observation interval)

In Figures 9 and 10, the results are presented of BLITS photometric observations made after January 22, 2013. In the Figure 9, the brightness curve is shown for the full pass on February 16, 2013; in the Figure 10 a part of this pass is presented. One can see a considerable change in the brightness variations. The brightness variation period is considerably less than before (about 2.1 – 2.2 sec). This is confirmed by results of several observation sessions taken on various dates.

This is an additional confirmation of the hypothesis of BLITS destruction as a result of collision.

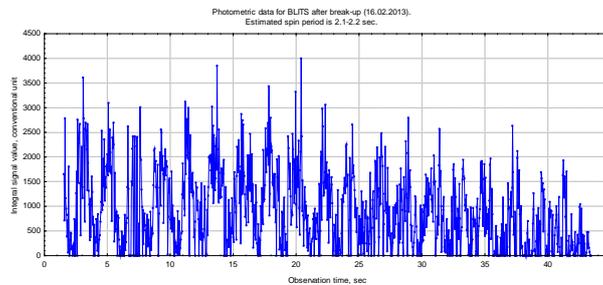


Figure 9. BLITS brightness variation curve after destruction (full observation interval)

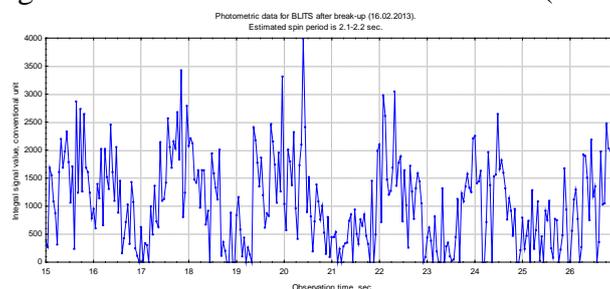


Figure 10. BLITS brightness variation curve after destruction (part of the observation interval)

Additional laser ranging sessions where a more powerful laser installation in the Northern Caucasus was used have provided an opportunity to determine the BLITS optical radar (lidar) cross-section after destruction: it has been found that its value has decreased more than 500,000 times relative to its initial value. The BLITS nanosatellite is no more a retroreflector providing a high concentration of the reflected laser radiation. Therefore, the BLITS observation campaign has been canceled on March 5, 2013.

The BLITS accident is another demonstration of the increasing space debris danger for space activities in low Earth orbits. It shows the necessity of urgent actions for space monitoring and reduction of space pollution. It is also evident that further BLITS-type nanosatellites should be launched into higher and less polluted orbits.

CONCLUSIONS

It is clear that some event occurred to cause the observed changes in semi-major axis and spin rate for BLITS—a satellite with no propulsion system or moving parts. Analysis has shown [10] that the event occurred somewhere around 03:06:50 UTC on 2013 Jan 22 and a comprehensive search of all tracked objects showed no objects which came within 20 km of BLITS on Jan 22 had any observed change in their orbit, which would be an indication of a possible collision.

Examination of a simple mechanical failure hypothesis [10] where BLITS might have come apart along its glued seam showed that such an event would not produce a sufficient change in velocity for the larger of two pieces to account for the observed decrease in semi-major axis nor would it result in a significant increase in the spin rate to match the observed photometric observations. When considered together with the relative size of the only debris object cataloged

from the event based on the RCS measurements, it is also clear that a breakup that produced these two pieces would produce an even smaller change in velocity and spin rate of the main object—effectively ruling out all possible breakup modes.

Finally, a thorough examination of the mass required to produce the observed change in semi-major axis for an object in an orbit similar to BLITS showed that most encounter geometries could produce the effects with an object far too small to be tracked by the SSN[10].

As a result, it is the authors’ belief that the most likely cause of this event was a collision with an object too small to be tracked by the SSN. This analysis demonstrates the difficulty in determining what actually occurred, due to the complexity of the problem and limitations of the data, but highlights the advantages of collaboration and data sharing in coming to a sound conclusion based on the evidence.

FUTURE

Currently, the OJC “RPC “PCI” has started a development of a new spherical retroreflector nanosatellite where zero signature is combined with a considerably enhanced efficiency. Introduction into the ball lens structure of an intermittent layer of a high-refraction glass for spherical aberration correction will, as follows from calculations, increase the cross-section value by nearly an order of magnitude with only modest (20 percent) increase of the ball lens external diameter relative to the BLITS. A schematic drawing of the improved spherical satellite - the retroreflector is shown in Fig. 11

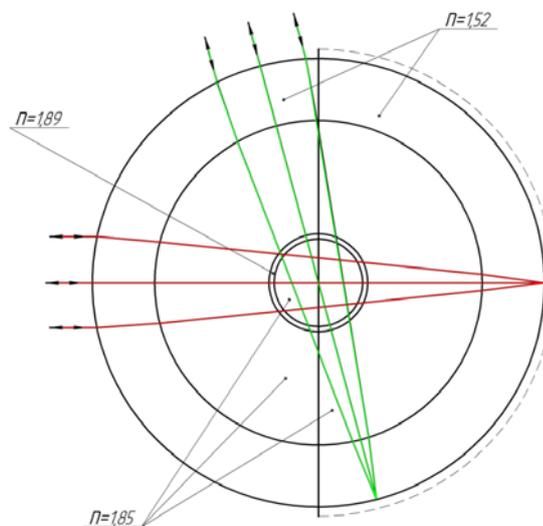


Figure 11. Spherical glass nanosatellite “BLITS-M”

Expected target parameters of the “BLITS-M” nanosatellite

Target error	no more than 0.1 mm
Cross-section	$0.3 \cdot 10^6 - 1 \cdot 10^6 \text{ m}^2$
Flight lifetime	at least 10 years
Orbital altitude	1500 km – 3000 km
Diameter	210.4 mm
Mass	16.1 kg

REFERENCES

1. http://ilrs.gsfc.nasa.gov/missions/satellite_missions/current_missions/blit_general.html
2. Luneburg, R.K. (1944) *Mathematical Theory of Optics*, Providence, Rhode Island, Brown University. pp.189-213
3. <https://www.space-track.org>.
4. Cefola, P.J., Proulx, R. J., Nazarenko, A.I., and Yurasov, V.S. "Atmospheric Density Correction Using Two Line Element Sets as the Observation Data," *Proceedings of the 2003 AAS/AIAA Astrodynamics Conference, Advances in the Astronautical Sciences*, Vol. 116, Part 3, Univelt, pp. 1953 - 1978.
5. Report of the Committee on the Peaceful Uses of Outer Space. General Assembly Official Records Fifty-fourth Session Supplement No. 20 (A/54/20). New York, 1999.
6. A. Nazarenko. The Development of the Statistical Theory of a Satellite Ensemble Motion and its Application to Space Debris Modeling. Second European Conference on Space Debris, ESOC, Darmstadt, Germany 17-19 March 1997.
7. A. Nazarenko. Simulation of man-made pollution in near space. *Journal Astronomicheskij Vestnik* , Volume 36, 2002, pp. 555-564 (in Russian).
8. A. Nazarenko et al. GOST R. 25645.167-2005 Space environment (natural and artificial). Model of spatial and temporal distribution for space debris flux density in LEO, Moscow, Standardinform, 2005 (in Russian).
9. A. Nazarenko, I. Usovik. Space debris environment modeling with allowance for mutual collisions of objects larger than 1 cm in size. 6th European Conference on Space Debris. Darmstadt, April 2013.
10. T.S. Kelso et al, What Happened to BLITS? An Analysis of the 2013 Jan 12 Event, The Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, September 2013.