TEST SATELLITE FOR CALIBRATION OF LARGE-SIZE ACTIVE OPTICAL IMAGING SYSTEMS

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The REFLECTOR microsatellite development is a result of a joint effort of IPIE (Russia) and AFRL (USA). The microsatellite, successfully launched December 10, 2001, is a spatial test object carrying several groups of retroreflectors with specified spacing between them, intended for testing and calibration of high-resolution ground-based optical telescopes when laser illumination of targets is used.

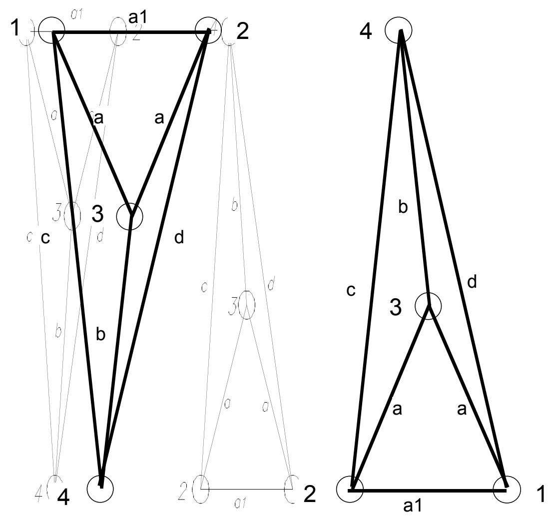
Due to an extensive support campaign of the ILRS network, data have been obtained for determination of the satellite oscillations in space. It was first demonstrated that ranging might be used for determination of spatial attitude of objects provided with cube corner reflectors.

Data are presented on the REFLECTOR satellite oscillation period measurements during the initial phase of observations; on the basis of the data, it is also possible to estimate the efficiency of the passive oscillation damping system used on the REFLECTOR microsatellite.

December 10, 2001, the Meteor-3M(1) satellite has been launched, carrying four microsatellites as a piggyback load; one of the four was the REFLECTOR microsatellite [1]. REFLECTOR means **R**etroreflector **E**nsemble **F**or **L**aser **E**xperiments, **C**alibration, **T**esting and **O**ptical **R**esearch. The launching was successful, as planned. The REFLECTOR satellite (COSPAR ID: 0105604, SIC Code: 5556, NORAD SSC Code: 27004) is in orbit with the following parameters:

Inclination: .... 99.64 degrees
Eccentricity: 0.0008
Perigee:... 1020 km
Period: .... 104.5 minutes

The REFLECTOR microsatellite carries 32 retroreflectors (cube corner prisms) arranged so that return signals can be obtained from any side when the microsatellite is stabilized along the vertical direction, forming a test image shown in Figure 1. The photo and drawing of the microsatellite are shown in Figures 2a and 2b. The optical parameters of the microsatellite are listed in Table 1.



a_1 = 0.07 arc. sec.*	b/a = 1.37
a = 0.09 arc. sec.*	∠1-3-4 = 150.6°
b = 0.12 arc. sec.*	c/a = 2.294
c = 0.20 arc. sec.*	d/a = 2.345
d = 0.21 arc sec.*	

* For everage observation conditions: elevation 45°

Figure 1. REFLECTOR test image geometry

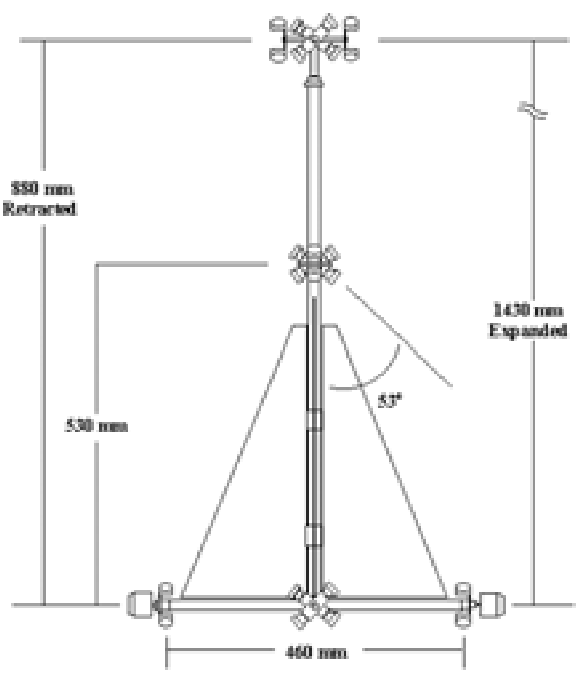


Figure 2a. REFLECTOR microsatellite (photo)

Figure 2b. REFLECTOR microsatellite (drawing)

Table 1

Optical parameters of the REFLECTOR microsatellite

Parameter	Value
Operating wavelength, μm	0.532
Total number of cube corner prisms	32
Number of cube corner prisms with λ/4-plates at the face	8
Cube corner prism aperture size, mm	28.2
Cube corner prism height, mm	18.9
Fused silica refraction index	1.4607
Retroreflector transparency at normal incidence	0.57
Reflection pattern angular width (FWHM) along the microsatellite velocity vector, arc. sec.	5.7
Retroreflector axis tilt relative to the microsatellite vertical axis, deg.	45

To make REFLECTOR more useful to the general laser ranging and remote sensing community, the group of retros at the mid-section of the vehicle were modified to cause a polarization change to the reflected light. For REFLECTOR, _ wave plates were placed the over entrance apertures of the center retros. The fast axis of the _ wave plate was aligned with the vehicle's central body tube. Light returned from these retros will pass through the _ wave plate twice, once on the way in (to the retroreflector) and once on the way out. The polarization change imparted to the light will depend on the incident angle, which will be a relatively complicated but predictable function of the vehicle orbit parameters and the ground site position.

After separation from the carrier satellite and extension of the boom carrying 8 cube corner prisms, the microsatellite attitude is controlled by a passive stabilization/damping system. The oscillation damping duration may be as long as several months. After final stabilization, the extendable boom should be pointed towards the Zenith or Nadir.

Gravitational stabilization is achieved due to different moments of inertia along the three orthogonal directions; oscillation damping is achieved due to interaction between the Earth magnetic field and built-in rods of magnetically soft material with a wide hysteresis loop [2].

On the IPIE request, starting from December 21, 2001, regular tracking of the REFLECTOR satellite is conducted by the ILRS laser tracking network. The REFLECTOR precision orbit determination (POD) is provided by the MCC (Russia). Currently, the REFLECTOR satellite orbit is determined with an accuracy better than 1 meter at the processing interval (tracking data), and 10÷15 m at a 24-hour interval (orbit prediction). The microsatellite passes observed up to September 2002 are listed in Table 2.

Table 2

REFLECTOR passes observed by SLR stations till September, 2002

Station number	**Station name**	**Number of passes**	**Station number**	**Station name**	**Number of passes**
7090	Yarragadee	259	8834	Wettzell	27
7839	Graz	132	1873	Simeiz	19
7110	Monument Peak	132	7837	Shanghai	19
7840	Herstmonceux	121	7838	Simosato	18
7501	Hartebeesthoek	108	7849	Mount Stromlo	15
7105	Greenbelt	92	7836	Potsdam	13
-	Shelkovo	84	1870	Mendeleevo	12
7824	San Fernando	78	1864	Maidanak	11
7835	Grasse	72	7249	Beijing	8
7237	Changchun	67	1863	Maidanak	7
7080	McDonald	65	1884	Riga	5
7832	Ryiadh	49	1868	Komsomolsk	4
7810	Zimmerwald	48	7405	Concepcion	4
7210	Haleakala	41	7806	Metsahovi	2
7403	Arequipa	38	1893	Katzively	1
7124	Papeete	35	7820	Kunming	1
				Total	**1587**

Ranging as well as photometrical data have been used to estimate the microsatellite status (its attitude, and oscillation damping). A conclusion can be drawn from the data, that the microsatellite boom has been normally deployed, and the oscillation damping process is going on; the boom seems to be pointed towards the Earth center.

The REFLECTOR microsatellite should be used basically as a calibration target, to determine the resolution of ground-based imaging and remote sensing systems using laser light for target illumination; to achieve this goal, the attitude changes should be slow, with a period much longer than calibration session duration.

Based on the Herstmonceux SLR station data, the REFLECTOR microsatellite oscillation period duration has been plotted versus time from December 23, 2001 to February 6, 2002 (Figure 3).

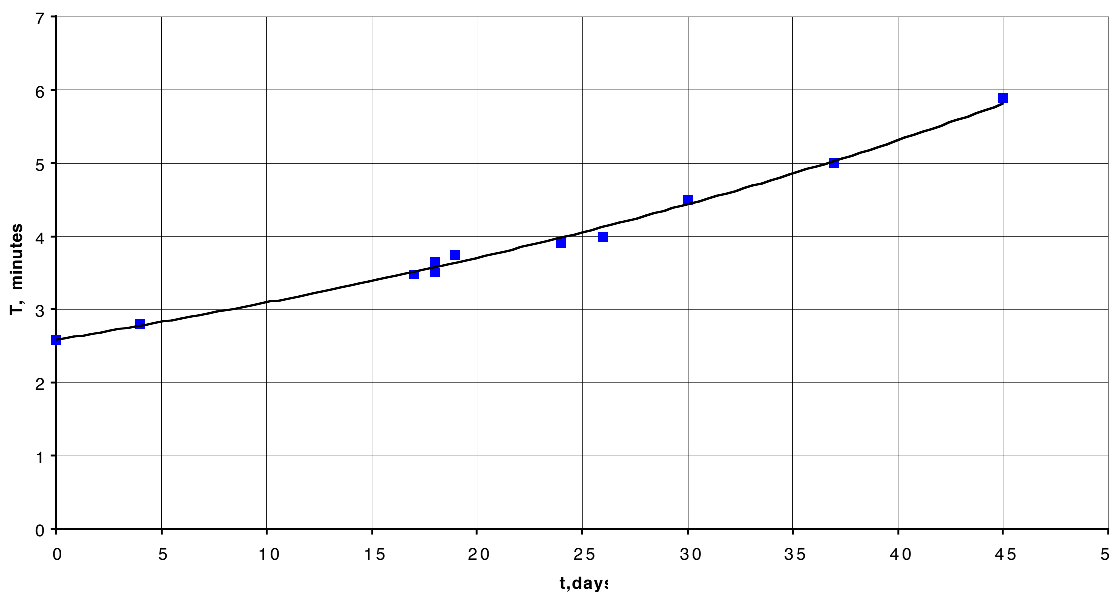


Figure 3. REFLECTOR microsatellite oscillation (tumbling) period duration versus time from December 23, 2001 to February 6, 2002

Some examples of REFLECTOR observation data obtained by SLR stations with multistop time interval counters (Yarragadee, Mount Stromlo, Herstmonceux, and Riga) are presented in Figures 4,5,6,and 7.

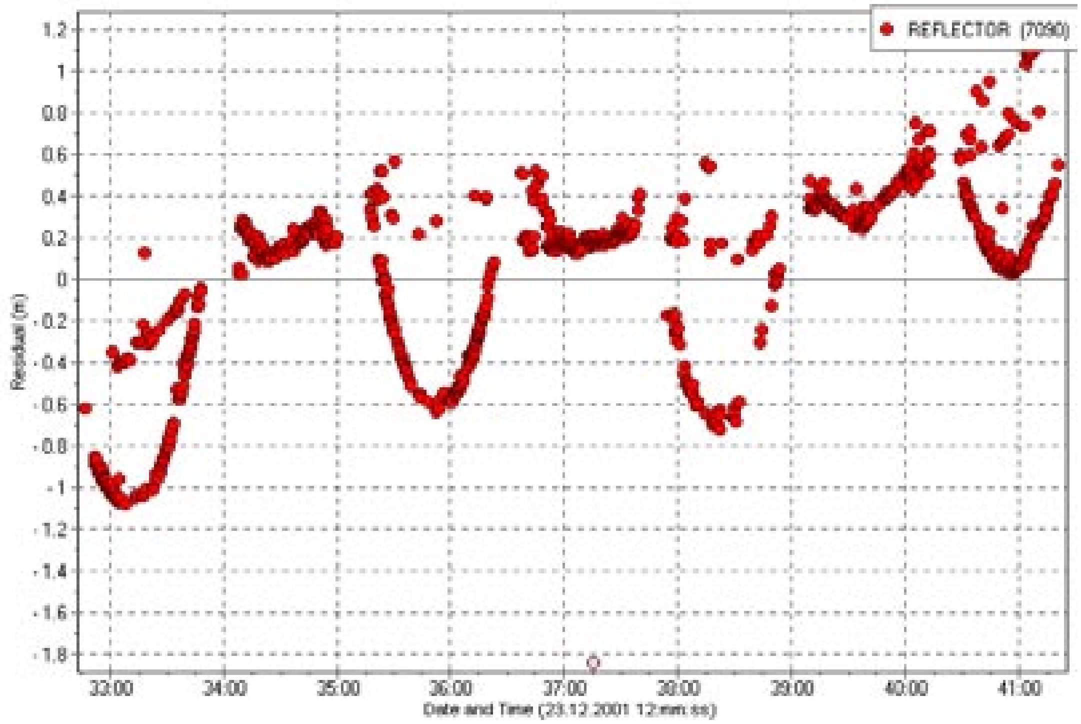


Figure 4. Observations of SLR station Yarragadee (7090)

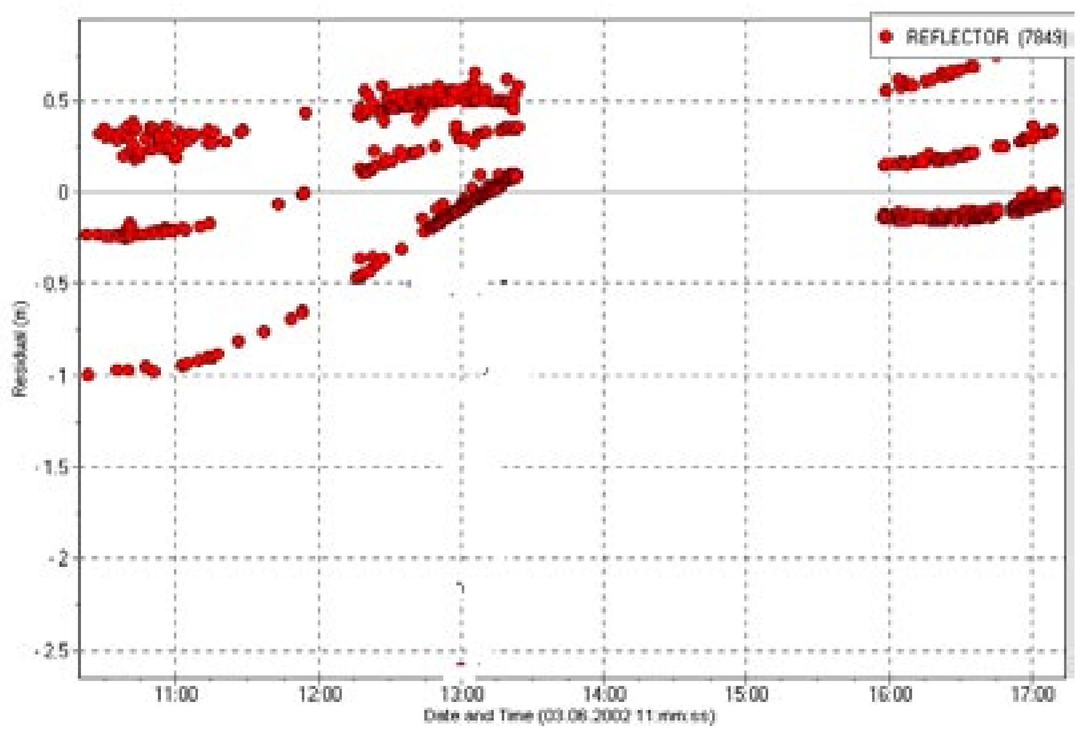


Figure 5. Observations of SLR station Mount Stromlo (7849)

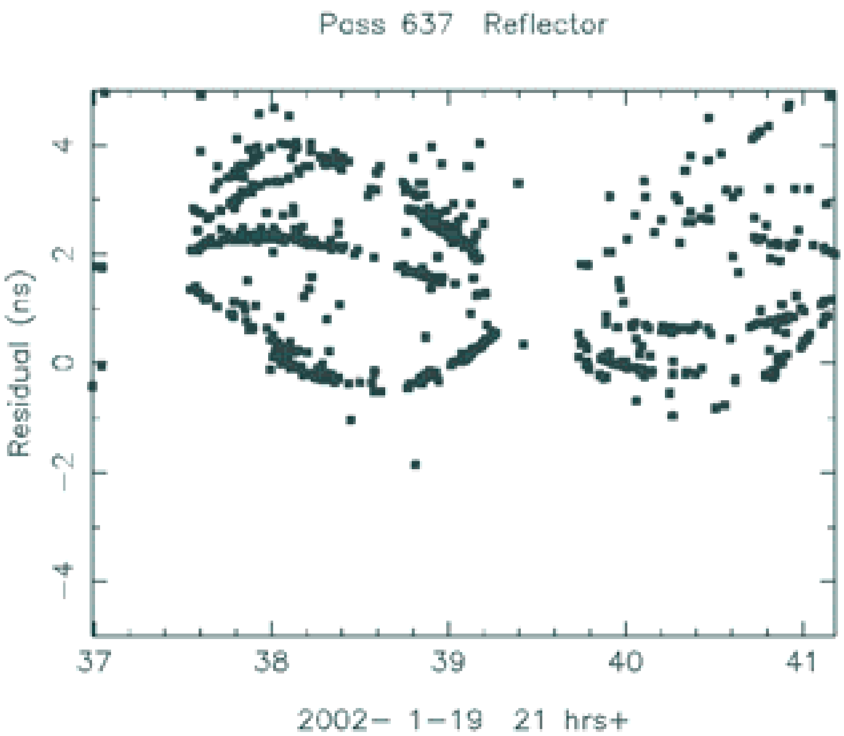


Figure 6. Observations of SLR station Herstmonceux (7840)

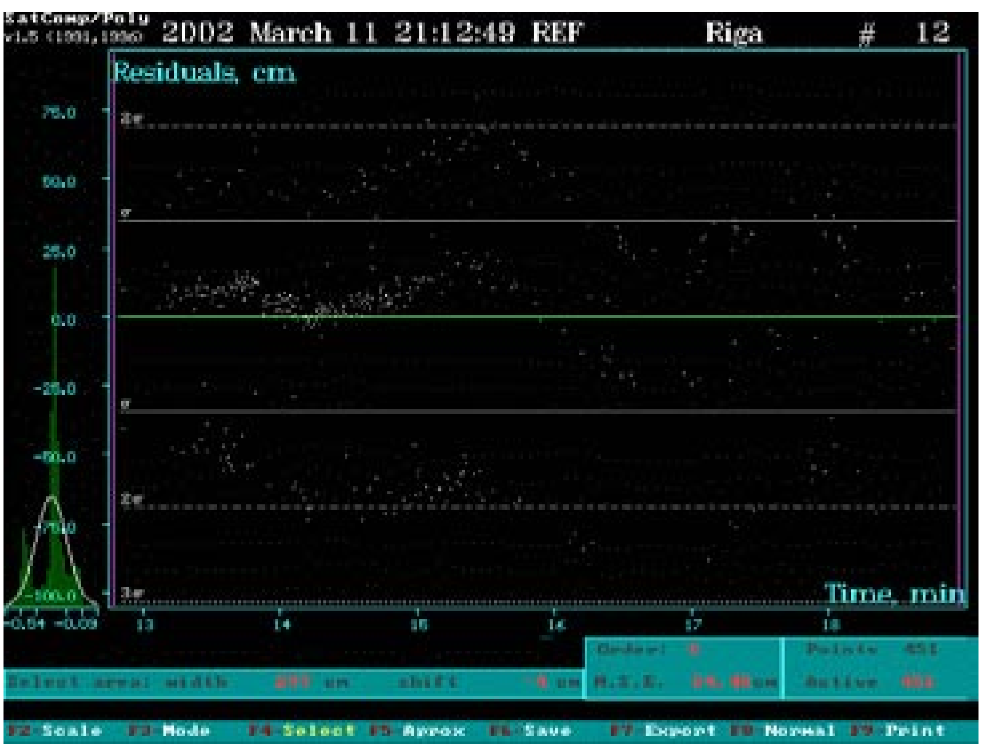


Figure 7. Observation of SLR station Riga (1884)

Observations made March to May 2002 showed that the microsatellite oscillation period is much more than 6 min. A further analysis of satellite laser ranging data (especially of data from SLR stations using multistop time counters) shows that currently this period is no less then several tens of minutes. The pass observation time being only a small fraction of the oscillation period, it is now difficult to estimate the oscillation amplitude from range measurements without a detailed physical or mathematical simulation.

The REFLECTOR microsatellite SLR data analysis shows that ranging with multistop time counters is a new and efficient technique for determination of a spacecraft attitude; it can be used if several retroreflectors are mounted in properly selected positions at the spacecraft. The technique may be used to solve various scientific and applied problems (e.g. to determine the value of range correction relative to the spacecraft center of mass, etc.). For an efficient use of this technique, it is advisable to develop a method of attitude determination from range differences between separate retroreflectors, based on mathematical or physical simulation.

Acknowledgement

We are very grateful to the International SLR Network, and especially to the most active Yarragadee station, for the REFLECTOR mission support. We are also most grateful to the stations which provided multistop ranging data, first of all to the Herstmonceux SLR station and personally to Dr. Roger Wood for help with data and for fruitful discussion.

References

1. D. Voelz, J. Sellers, S. Hanes, J. Rotge, V. Shargorodsky, V. Shevchenko, V. Vasiliev and V. Burmistov. US/Russian micro-satellite for calibration of active ground-based optical collectors. Reported at the 12-th Workshop on Laser Ranging, Matera, Italy, 2000.

2. V. Shargorodsky, V. Shevchenko, M. Ovchinnikov, V. Penkov, S. Mirer, and R. Nemuchinsky. Nanosatellite reflector for optical calibrations: attitude control and determination aspects. Advanced Space Research, vol. 30, No. 2, pp. 337-343, 2002.