Analysis of ILRS data from STPSat-2 Retro-reflector after Second Test Campaign

July 2016

Richard E. Preston, Robert W. Crow, Katherine M. Crow (Sensing Strategies), Elizabeth A. Beecher (AFRL), Linda M. Thomas (NRL)

The authors wish to acknowledge the contributions of the following: Mr Kenneth Reese, STPSat-2 Program Manager and the Space Test Program STPSat-2 operations team, Dr Lawrence Schmitt (AFRL), David McCormick and Carey Noll (NASA GSFC), and the ILRS community. Sensing Strategies Inc performed this work under AFRL contract FA8650-12-D-1380.

1.0 Summary

This report documents results of a second ILRS[1] campaign to characterize a small (1/2-inch diameter), commercial hollow retro-reflector on the STPSAT-2 satellite flown by the USAF Space Test Program (STP). The original campaign was carried out in 2013, and the goal of the present effort was to evaluate if any changes or aging of the retro-reflector affected its performance. The AF is interested in using this style of retro-reflector on future small satellites, and a verification that its properties are maintained over multiple years is of considerable interest. The second campaign confirms that the angular and amplitude signals received by the ground sites were comparable to the original results.

Initial experiments were carried out over a six-month period and measured returns from four different International Laser Ranging Service (ILRS) sites were reported. The data showed that the retro-reflector's angular response fall-off was the limiting factor in obtaining returns. This suggests that the devices are useful for ILRS ranging, but this size would have greater utility when the mission can support active tracking of a ground station.

2.0 Background

The STPSAT-2 satellite was launched in November 2010. STPSAT-2 is in a circular orbit at an altitude of 650 km with an inclination angle of 72 degrees. The STP office included a small, hollow RR on the satellite to allow for the possibility of laser ranging experiments. AFRL and NRL approached NASA about including the STPSAT-2 satellite on the ILRS target list to facilitate an evaluation of the retro-reflector and whether the devices might have utility on smaller, cubesat-size satellites for geodesy purposes.

In 2013, NASA submitted an ILRS support request, and a six-month period of satellite illuminations was executed and the return data from the ILRS ground stations was analyzed. The published results[2] show that the ½-inch diameter device resulted in a return beam divergence that exceeded the velocity aberration, and that it is suitable to support tracking experiments.

In early 2016, a new campaign was requested to assess if the retro-reflector had changed over the three years since the last characterization.

3.0 Technical Approach

The evaluation makes use of reported laser pulse returns from sites illuminating the satellite. The returns are used to map out the field of view of the retro-reflector and, if possible, characterize the relative return amplitudes as a function of range to the satellite. In this context, it is significant if a site is illuminating the satellite and not getting returns because that helps define the angles and ranges for which the device is useable. So the data sets selected for this analysis were ones in which the return signals strengths were reported.

3.1 Summary of Retro-Reflector Description and Expected Utility (from Previous Report)

The hollow retro-reflector, shown in Figure 1, is a PLX Omni Wave which has a ½ inch diameter, 5 arc second beam deviation and has a protected-silver coating with a reflectivity of 0.98 at 1064 nm and 0.96 at 532 nm. The device was mounted on the STPSAT-2 satellite NADIR face.

---

[1] Pearlman, M.R., Degnan, J.J., and Bosworth, J.M., "The International Laser Ranging Service", Advances in Space Research, Vol. 30, No. 2, pp. 135-143, July 2002, DOI:10.1016/S0273-1177(02)00277-6.

[2] "Analysis of ILRS Data from STPSat-2 Retro-reflector," Richard E. Preston, Robert W. Crow, Elizabeth A. Beecher, Linda M. Thomas, 19th International Workshop on Laser Ranging, September 2014

Figure 1: The 1/2" diameter retro-reflector used on STPSat-2

The field of view profile for the retro-reflector is shown in Figure 2. A folded path optical analysis for this device was provided in the report from the 2013 test campaign. A typical pass from that campaign is shown in Figure 3.

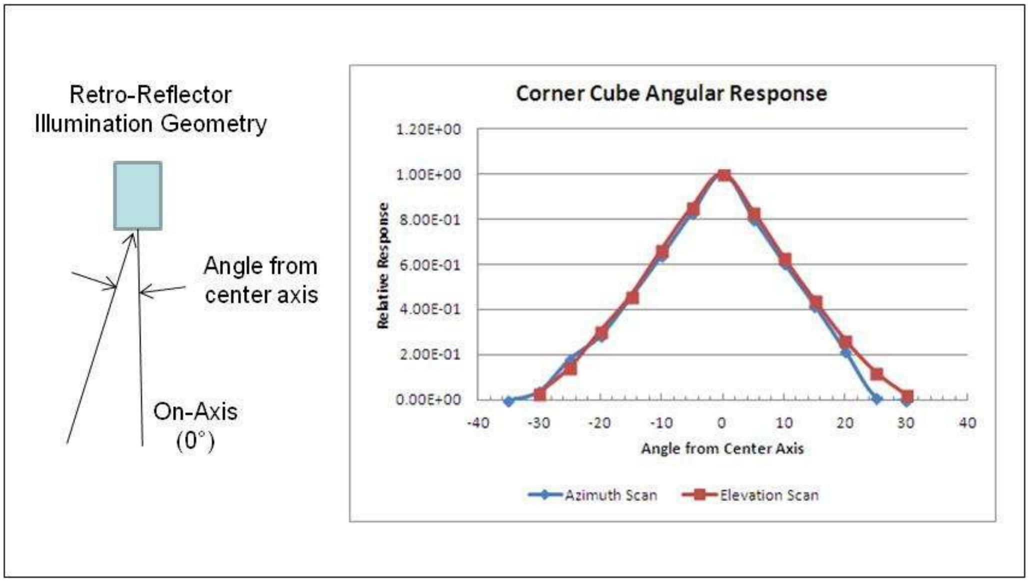

Figure 2: Laboratory field of view measurement of the STPSat-2 retro-reflector

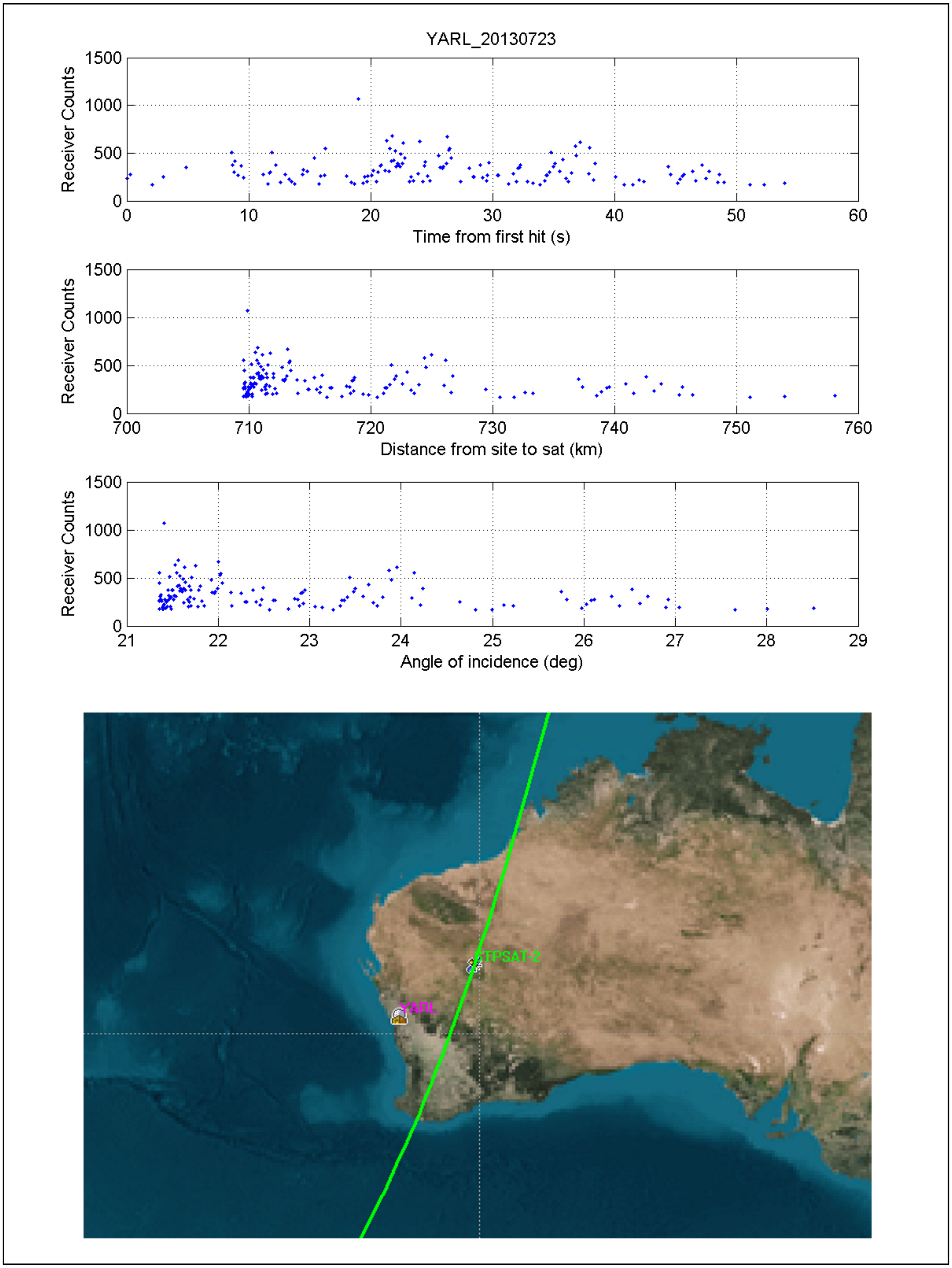

Figure 3: YARL Data from July 23, 2013

3.2 Laser Sites Used in Evaluation of 2016 Data

Table 1 presents a summary of the ILRS facilities that produced ranging data on the STPSAT-2 satellite during the 2016 test campaign. A total of 11 sites ranging to STPSat-2 collected sufficient data to generate normal point data.

Table 1: Summary of activity during 2016 STPSat-2 ILRS test campaign

Station	First engagement (GMT Date, HHMM)	Last engagement (GMT Date, HHMM)	Number of satellite passes that produced ranging data
Badary, Russia (BADL)	11 APR, 1304	-	1
Changchun, China (CHAL)	5 APR, 1228	29 May, 0114	11
Greenbelt, Maryland (GODL)	12 Apr, 0022	26 Apr, 0729	3
Herstmonceux, U.K. (HERL)	31 Mar, 2205	16 May, 2113	11
Irkutsk, Russia (IRKL)	4 May, 1651	-	1
Katzively, Ukraine (KTZL)	18 Apr, 0120	-	1
Mendeleevo 2, Russia (MDVS)	5 Apr, 1902	14 May, 1850	2
Monument Peak, California (MONL)	11 May, 2038	-	1
Shanghai, China (SHA2)	16 Apr, 2011	3 May, 1636	3
Svetloe, Russia (SVEL)	3 May, 2119	-	1
Yarragadee, Australia (YARL)	31 Mar, 0139	17 May, 1528	10

In order to provide a relatively consistent basis to evaluate any change in retro-reflector performance from 2013 to 2016, only the data sets from Yarragadee were utilized because a significant number of passes with data occurred during both years (10 passes in 2013 and 10 passes in 2016).

4.0 Results

The goal of this analysis is to evaluate if there was any change in SATSat-2 retro-reflector based on the incidence angles over which it can be used. To achieve this goal, the aggregated data from all of the 2013 YARL passes with returns (10 passes) was compared to the aggregated data from all of the 2016 YARL passes with returns (10 passes). All such data for this study was obtained from the NASA ILRS ftp site[3]. The primary data of interest is the number of times the ILRS site was able to successfully execute a time-of-flight measurement to STPSat-2 as a function of incidence angle to the retro-reflector.

Figure 4 presents histograms showing the total number of time-of-flight measurements by YARL to STPSat-2 versus incidence angle for the 2013 and 2016 test campaigns, respectively. The angles are shown in 1 degree wide bins. The primary observation of interest is that in both instances, there is an abrupt cutoff at an angle of 31 degrees. Not only is this consistent with the original laboratory field of view measurement shown in Figure 2, but this also demonstrates that aging effects does not appear to have altered the field of view response. In addition, it is interesting to note that although both distributions cut off at the same point, their shapes differ somewhat: for example, the 2013 distribution has many returns in the 5- to 10-degree region, but these are not replicated in the 2016 data set.

---

[3] ftp://cddis.gsfc.nasa.gov/slr/data/npt_crd/stpsat2

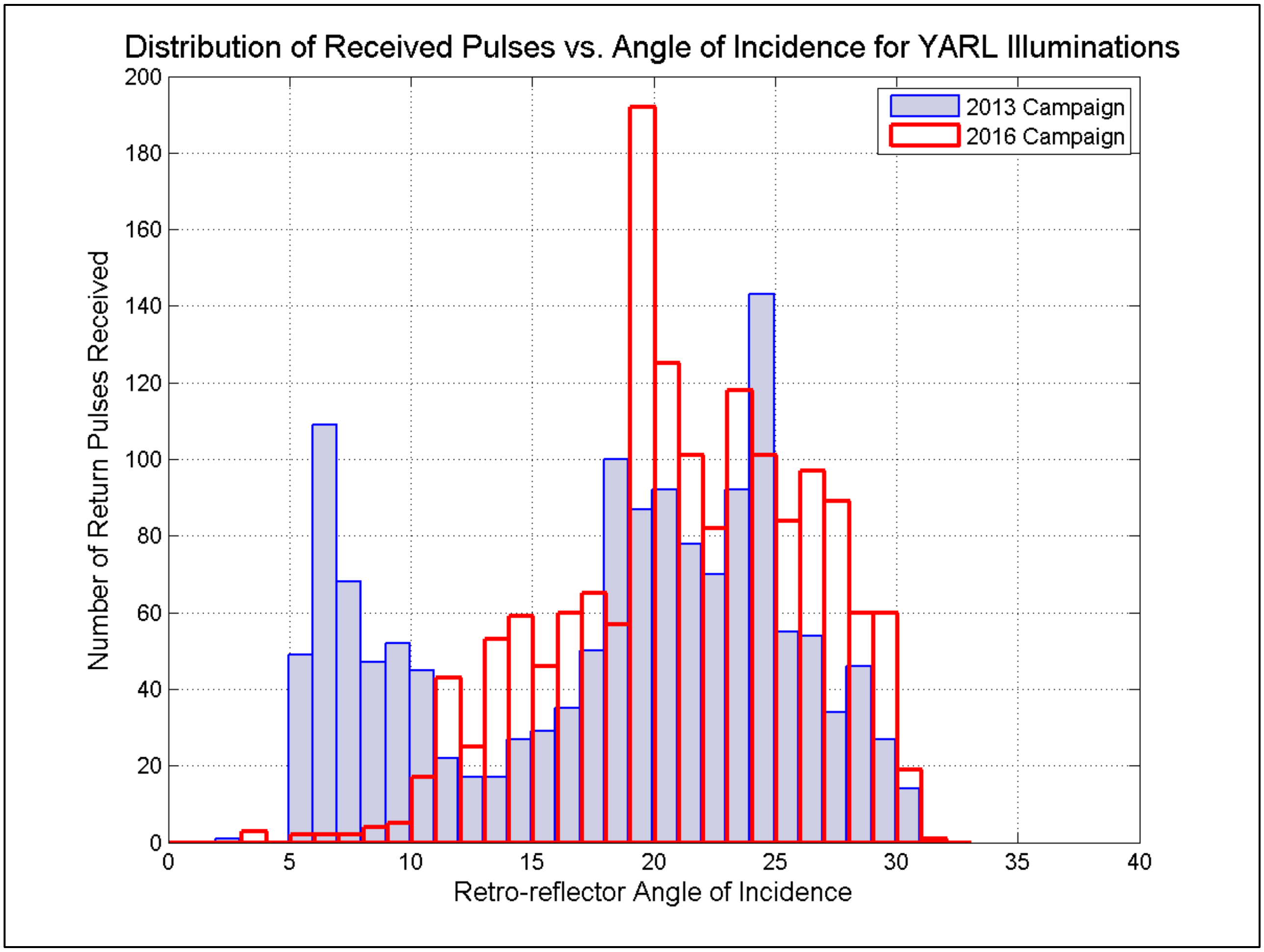

Figure 4: Distribution of Received Pulses vs. Angle of Incidence for YARL Illuminations

The observed variation in histogram shape between 2013 and 2016 can be explained by looking at the satellite pass geometries from the two campaigns, again aggregated across all passes for each year. To this end, Figure 5 shows histograms of the total time spent at each look nadir angle (again, binned in 1 degree steps) from SATSat-2 to YARL. The height of each bar is the total number of seconds at those angles. It is apparent that the passes in 2013 produced more opportunities to lase the satellite at incidence angles in the 5- to 10-degree range than in 2016. Similar correlations between the look zenith angle distributions and the time-of-flight data can also be observed at other angles.

Another observation from Figure 4 is that there were almost no time-of-flight measurements at incidence angles less than 5 degrees, despite the fact that Figure 5 indicates that there were some opportunities in both campaigns to hit that range of angles. These cases would correspond to the satellite moving almost directly overhead as viewed from YARL. Not only might this geometry be difficult for the station to track (or perhaps impossible within a few degrees of zenith – the ‘keyhole’ effect), but the instances of these cases would only last for perhaps a couple of seconds per pass which decreases the probability that such an engagement would be feasible.

Finally, it is also noteworthy in Figure 5 that there were a significant number of opportunities to engage the satellite between 30 and 40 degrees. This strengthens the conclusions that the 31-degree cutoff shown in Figure 4 is a real effect of the retro-reflector rather than a by-product of how the YARL site performed their operations and that the cutoff did not measurably change over the three-year period.

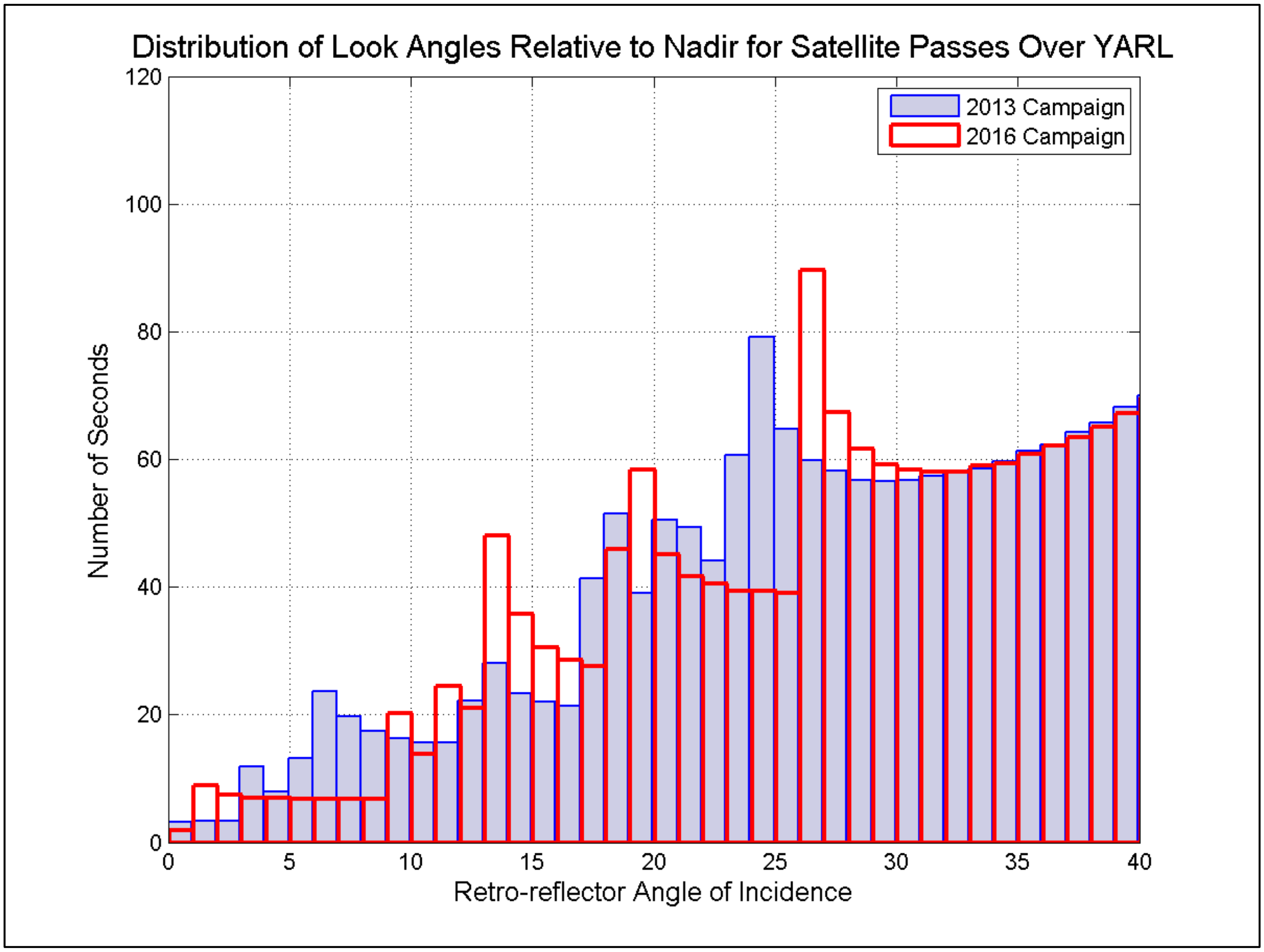

Figure 5: Distribution of Look Angles Relative to Nadir for Satellite Passes Over YARL

5.0 Conclusions

A second successful experimental campaign was carried out with the ½ inch hollow retroreflector on the STPSAT-2 satellite to re-verify its utility for supporting tracking studies with ILRS-class lasers. An advantage of using a hollow retro-reflector rather than glass-filled is that it can be used with a larger range of laser wavelengths and the STPSAT-2 experiments showed that the hollow device survived launch and was functioning properly after 5.5 years on-orbit. The additional three years of time in the space environment did not change the ability of the retro-reflector to support tracking experiments in any measurable way. This reinforces the original conclusion that hollow corner cubes demonstrate suitability for actively pointed small satellite missions that may benefit from a narrower angular response.