Near Earth Object Surveillance Satellite (NEOSSAT) Artificial Star

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Abstract

The NEOSSat microsatellite is a research and development spacecraft operated jointly by Defence Research and Development Canada (DRDC), the Canadian Space Agency (CSA), and the University of Calgary. The microsatellite was used as a space based reflector to direct a ‘glint’ of sunlight off of its reflective surface to a ground-based observer. The experiment was designed to simultaneously trial the spacecraft’s attitude control system and characterize the resulting light curve.

Significance to Defence and Security

This experiment was carried out to exercise the fidelity of the spacecraft’s attitude control system and characterize the resulting light curve. The findings from this experiment will act as a starting point for further characterization experiments of the spacecraft.

Résumé

(U) Le microsatellite NEOSSAT est un engin spatial de recherche et développement exploité conjointement par Recherche et développement pour la défense Canada (RDDC), l’Agence spatiale canadienne (ASC) et l’Université de Calgary. Le microsatellite a été utilisé comme réflecteur spatial pour diriger un reflet solaire de sa surface réfléchissante vers un observateur au sol. L’expérience a été conçue pour tester simultanément le système de commande d’attitude de l’engin spatial et caractériser la courbe de lumière résultante.

Importance pour la défense et la sécurité

(U) Cette expérience a été réalisée pour mettre à l’épreuve la fidélité du système de commande d’attitude de l’engin spatial et caractériser la courbe de lumière résultante. Les résultats de cette expérience serviront de point de départ à d’autres expériences de caractérisation de l’engin spatial.

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Acknowledgements

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1 Introduction

The NEOSSAT microsatellite is currently performing Space Situational Awareness (SSA) experiments on geostationary (GEO) satellites from its sun-synchronous, dawn-dusk 776 km x 792 km orbit. The microsatellite is equipped with a body-fixed 15cm electro-optical telescope and was launched in February 2013. The microsatellite was manufactured by Microsatellite Systems Canada Incorporated (MSCI) of Mississauga, ON.

A unique experiment performed in Fall 2015 where the external body of the spacecraft was used as a reflector to intentionally redirect sunlight onto select geographical areas on the Earth. The intent of the artificial star experiment was to exercise the fidelity of the spacecraft's attitude control system while simultaneously characterizing the light curve produced by NEOSSat as a space-based reference object.

2 Methodology

The artificial star experiment performed in Fall 2015 utilized the body of NEOSSAT as a reflector to intentionally redirect sunlight onto a select geographical area on the Earth. NEOSSat was commanded into an inertially fixed orientation where the spacecraft was statically pointed with a specific Yaw (Z-axis), Roll (X-axis), and Pitch (Y-axis) orientation.

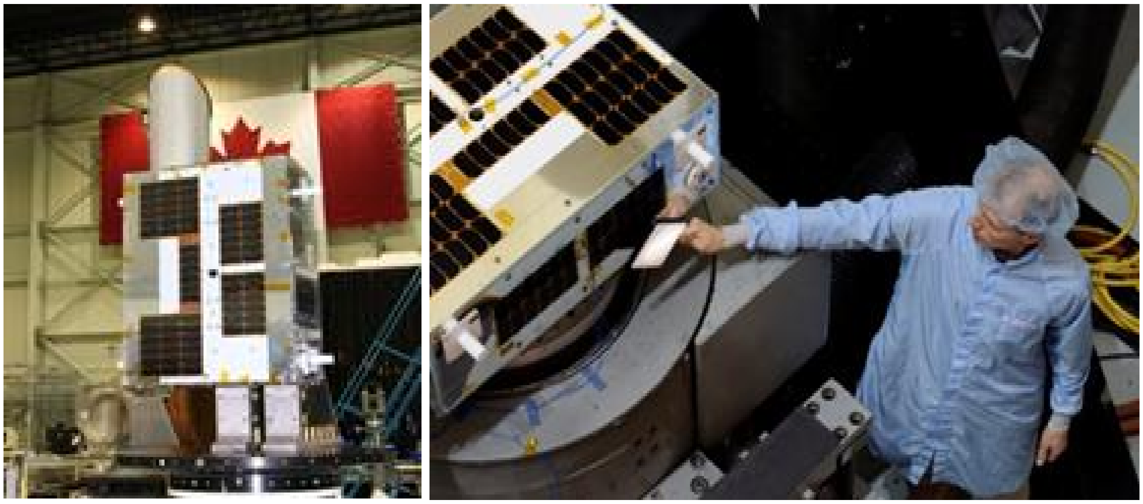


Image credit: DRDC.

Figure 1: (Left): *NEOSSat undergoing testing at the David Florida Lab (DFL) in Ottawa.* ***(Right):*** *Surface reflectivity measurements conducted at DFL.*

The –Z face of NEOSSat (Figure 1 left) [1] is the largest side of the satellite, and is primarily covered with solar cells, a white painted heat radiative patch and silvered aluminum comprising the exterior surface of the vehicle. The -Z face is the most highly reflective surface of the satellite.

A primary consideration during the experiment was to orient the spacecraft in such a way as to provide both the maximum amount of sunlight reflected to the target while simultaneously taking into consideration the physical pointing constraints of the spacecraft. NEOSSat has two primary constraint sets; the first being a solar incidence angle of no more than 45° on either +Y or –Y faces, while the second being the boresight of the spacecraft not pointing within 45° of the sun. Taking in these considerations would result in a geometry optimal for the experiment (Figure 2).

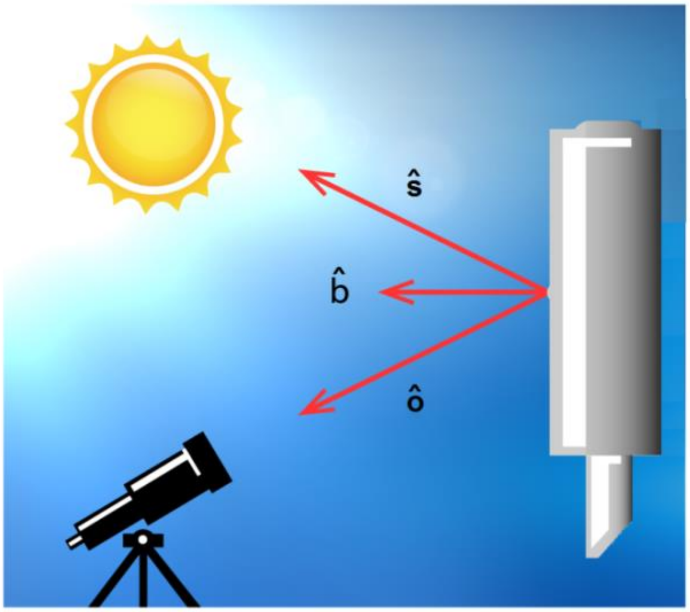


Figure 2: *Glint geometry of NEOSSat with respect to the Sun and an Earth-based observer.*

The scenario was further constrained to a time of year when the ground based observer experienced night time conditions and the spacecraft was fully illuminated by the sun. This led to an experiment window from early September to late November.

As NEOSSat must reflect sunlight to the observer, the normal vector of the reflecting surface must be equivalent to the unit phase angle bisector $\hat{\mathbf{b}}$, which is defined in Equation 1:

$$\hat{\mathbf{b}} = \frac{\hat{\mathbf{o}} + \hat{\mathbf{s}}}{|\hat{\mathbf{o}} + \hat{\mathbf{s}}|} \tag{1}$$

where $\hat{\mathbf{o}}$ and $\hat{\mathbf{s}}$ are the normalized direction vectors from NEOSSat to the observer and NEOSSat to the sun.

This vector is subsequently manipulated, using defined rotation matrices of NEOSSat, to convert from the J2000 reference frame to the body frame. Using a manually selected body Yaw, the body Roll and Pitch can be calculated and used, provided they comply with the pointing constraint sets:

$$Roll = \sin^{-1}\left(-\mathbf{b}_x \sin(Yaw) + \mathbf{b}_y \cos(Yaw)\right) \tag{2}$$

$$Pitch = \sin^{-1}\left(\mathbf{b}_x \frac{\cos(Yaw)}{\cos(Roll)} + \mathbf{b}_y \sin(Yaw)\right) \tag{3}$$

The reflected flux from the –Z panel can be predicted and the visual magnitude m_v can be estimated using Equations 4 & 5 [2]:

$$F(\Phi) = \frac{4\cos\left(\frac{\Phi}{2}\right)}{\pi\Delta^2} \tag{4}$$

$$m_v = -26.78 - 2.5\log\left(\frac{\rho A F(\Phi)}{R^2}\right) - (k_0 * \chi) \tag{5}$$

where Φ is the phase angle of reflected light, Δ is the width of the reflected beam of light, ρ is the panel albedo, A is the surface area of the panel, and R is the range of NEOSSat to the observer. k_0 is the atmospheric extinction per atmospheric thicknesses in the observation band and χ is the number of atmospheres through which the object is being observed. Representative values for the variables described here are $\Delta = 0.0093$ radians (diameter of the Sun from Earth's perspective), a –Z panel average albedo of 0.462, surface A of 1.07 m^2, a small swath of ground would be illuminated by this experiment from the glint cone of reflected light (Figure 3).

***Figure 3:** NEOSSAT illuminating a small band of ground with reflected sunlight from the glint cone.*

The predicted apparent magnitude of the spacecraft is a product of Equations 4 & 5, which describe the reflectivity and apparent magnitude of a specular flat plate, the given conditions of the reflecting surface. Equation 5 predicts the theoretical maximum magnitude of reflected light to be brighter than magnitude -6.0 for the expected reflection angle of 90°.

The Charge Coupled Device (CCD) camera used for this experiment was the Apogee Alta U42, attached to the DRDC Ottawa Space Surveillance observatory's (SSO) 14" optical telescope (Figure 4). Prior to both tracks of NEOSSat, a series of test images were used to determine the zero point of the CCD for the day of the trial. The visual magnitude of the object can be determined by using the flux count produced by the CCD, the exposure length of the image taken, the zero point (M_{Zpt}) of the CCD, and the atmospheric extinction for the waveband being observed, as shown in Equation 6:

$$M_{det} = M_{Zpt} - 2.5log_{10}\left(\frac{Flux}{T_{exp}}\right) - (k_0 * airmass) \tag{6}$$

Image credit: DRDC Ottawa.

Figure 4: *DRDC Space Surveillance Observatory main telescope.*

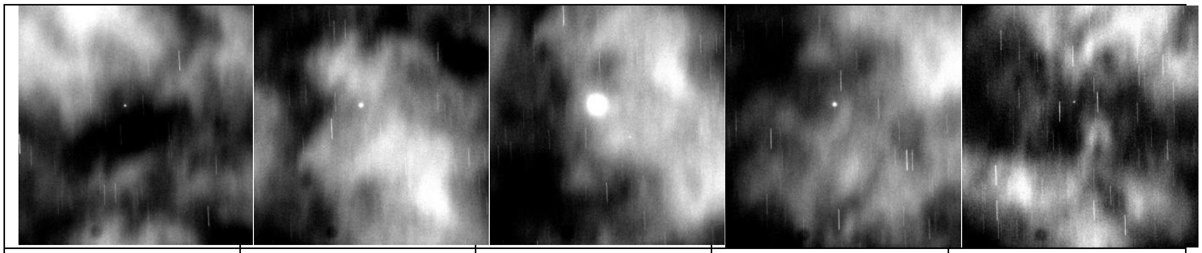
3 Statement of Results

The experiment was carried out in two trials in order to observe the glint in favourable weather conditions. The DRDC Ottawa SSO was used to collect measurements by programming its robotic mount to track the two line orbital element estimate of NEOSSat's trajectory relative to the sensor. The trials and results are shown in Sections 3.1 and 3.2.

3.1 Trial 1

The first trial occurred at 00:34:04 UTC on 2015-265. This trial was partially successful as the spacecraft was clearly visible to the naked eye during the peak glint, with brightness estimates in the vicinity of magnitude -2. Sample imagery captured with the Alta U42 camera at the DRDC Ottawa Space Surveillance Observatory (SSO) is shown in Figure 5. Using MATLAB scripts developed for ground based tracks collected on deep space objects, a light curve was generated in Figure 5 showing the time variation in the observed brightness of NEOSSat during its pass over DRDC Ottawa. Accurate results were difficult to attain due to the obscuration from partial cloud cover. However, the expected peak in magnitude is partially visible in Figure 6, circled in red.

Spacecraft Orientation:
Yaw = 80
Roll = 52.5679
Pitch = 35.0101



00:33:52.814
00:33:59.615
00:34:04.280
00:34:08.913
00:34:15.543

Figure 5: *Sample imagery with UTC timestamps collected on 201-265 during Trial #1.*

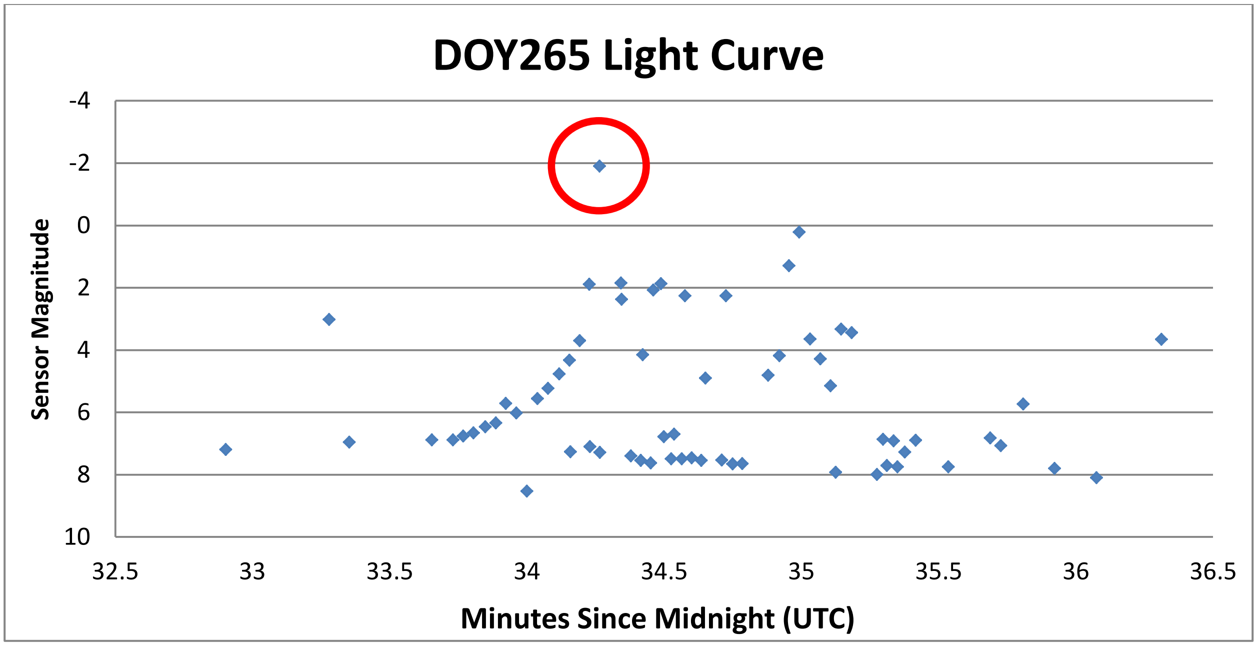
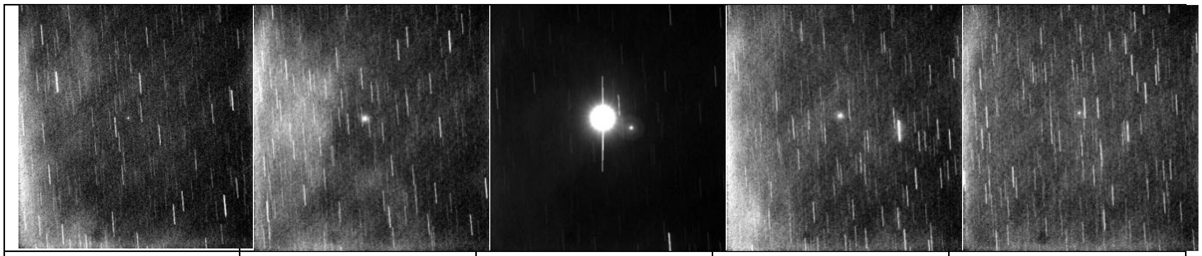


Figure 6: *NEOSSat light curve from observations collected on 2015-265.*

3.2 Trial 2

The second trial occurred at 00:33:00 UTC on 2015-274. This trial was successful in that the spacecraft was both clearly visible to the naked eye, as well as in imagery collected. Sample imagery captured with the Alta U42 camera at the DRDC Ottawa SSO is shown in Figure 6. The weather conditions were more favorable for photometric measurement in this attempt as the skies were considerably clearer in comparison to 2015-265. Sample imagery during this pass are shown in Figure 7 and its corresponding light curve is shown in Figure 8.

Spacecraft Orientation:
Yaw = 250
Roll = -58.4357
Pitch = -7.1836



00:32:49.827	00:32:56.519	00:33:00.965	00:33:05.442	00:33:12.399

Figure 7: *Sample imagery with UTC timestamps collected on 201-265 during Trial #2.*

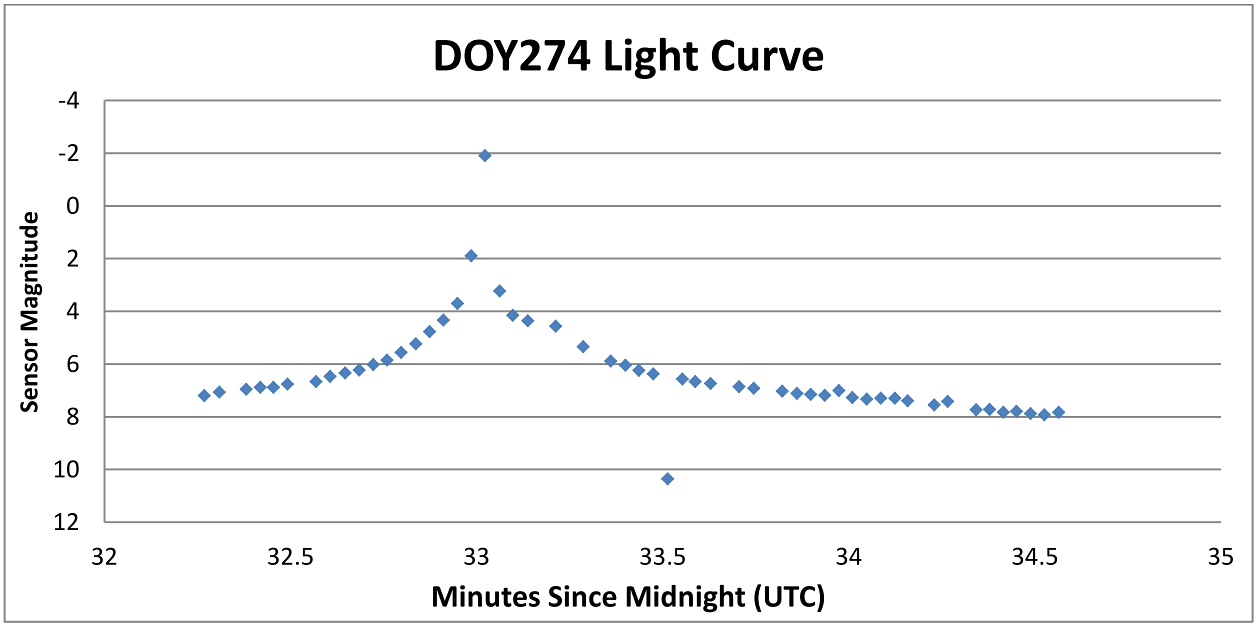


Figure 8: *NEOSSat light curve from observations collected on 201-274.*

An unexpected finding occurred by observers not located at the SSO. Independent observers watching the event around the greater Ottawa area reported a distinctive red tint in the reflected light. The observers at the SSO saw a bright white glint with no chromatic tint.

4 Discussion of Results

From the imagery taken in the first and second trial, it was apparent that the images generated by the CCD camera were saturated due to the very bright NEOSSat overwhelming the CCD's sensing capabilities. It is therefore difficult to determine the actual magnitude of the glint. The observed magnitudes generated from the images for both trials were far below the theorized maximums.

The fainter than expected magnitude in brightness is primarily attributed to the fact that the optimum orientation to ensure maximum illumination by the spacecraft was instantaneous. Since the exposures had a duration of 0.8 seconds, the intensity would be spread over the course of the integration time of the image. Unfortunately, the saturation of the images at the moment of peak reflectance made it difficult to accurately measure the brightness of the satellite.

Since the time of year in which this experiment could be carried out was short, considerations have been made for another trial incorporating the lessons learned in trials 1 & 2 for the next optimal observing between September and late November 2016. Considerations include: observing at a lower phase angle, adjusting CCD settings to prevent over-saturation, as well as a dynamic pointing state to allow the reflected light to dwell on a particular ground location.

The unexpected finding of a red chromatic tint by some observers is theorized to be that the different features on the –Z panel of NEOSSat reflected different wavelengths of light off of the reflected beam directed to the SSO. This could have caused observers not directly under the glint cone to observe different colours as opposed to the distinct white glint seen at the SSO.

Follow-on characterization activities based on these tracks will examine the ability of estimating the orientation of the spacecraft using the light curve data shown in Figures 5 & 7. Glints observed on satellites constrain the orientation of flat facet surfaces with respect to the sun and observer making the estimation of object orientation possible [3]. This estimation approach will be examined at a future date.

5 Conclusion

The Artificial Star experiment was a proof of concept trial used to demonstrate that NEOSSat's attitude control system had the fidelity to hold precise pointing states as well as prove that the microsatellite could be easily viewed from the ground by the un-aided eye. This experiment was successful and allowed for several lessons and techniques to be learned and developed for future operations with the microsatellite.

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[3] Hall, D., Calef, B., Knox, K., Bolden, M., Kervin, P. (2007). “Separating Attitude and Shape Effects for Non-resolved Objects”, SPIE, (2007).

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