Risk Reduction Activities for the Near-Earth Object Surveillance Satellite Project

Donald Bédard, Lauchie Scott, Brad Wallace
Defence R&D Canada Ottawa, 3701 Carling Avenue, Ottawa, ON, K1A 0Z4
Stefan Thorsteinson
Royal Military College of Canada, P.O. Box 17000, Stn Forces, Kingston, ON, K7K 7B4
William Harvey, Siamak Tafazoli, Michel Fortin
Canadian Space Agency, 6767 route de l'Aéroport, Saint-Hubert, QC, J3Y 8Y9
Jaymie Matthews, Rainer Kuschnig, Jason Rowe
Department of Physics and Astronomy, University of British Columbia, Vancouver, BC, V6T 1Z1

ABSTRACT

The Near-Earth Object Surveillance Satellite (NEOSSat) is a joint project between Defence Research and Development Canada (DRDC) and the Canadian Space Agency (CSA). The NEOSSat project is developing the Canadian multi-mission micro-satellite bus to satisfy two concurrent missions: detecting and tracking of near-Earth asteroids (Near Earth Space Surveillance: the NESS mission) and obtaining metric data on deep-space satellites (High Earth Orbit Surveillance System: the HEOSS mission). To ensure both science teams can employ the NEOSSat spacecraft to its full potential, a Mission Planning System (MPS) will be developed to automate the scheduling of both the HEOSS and NESS observations. As a first risk reduction activity for the NEOSSat project, a prototype of the MPS software has been developed to help in the definition of the system requirements as well as to identify and reduce the risks associated with the development of this software system. In a second risk-reduction effort, a space-based satellite tracking experiment was conducted using the MOST (Microvariability Oscillations of STars) microsatellite. Good quality metric tracking data were obtained and the satellite brightness was estimated. This paper discusses the NEOSSat project, the MPS prototype, and the MOST satellite tracking experiment and results.

1. INTRODUCTION

Following a successful launch in June 2003, the CSA's **M**icrovariability and **O**scillations of **St**ars (MOST) astronomy mission demonstrated that microsatellites (satellites with a mass less than 100 kilograms) possessed many of the critical capabilities that could make these platforms very useful to the defence community. At the forefront of these capabilities was an attitude determination and control system that far exceeded performance expectations and is on par with the performance of larger spacecraft. This successful demonstration of Canadian capability led researchers at Defence R&D Canada (DRDC), the research arm of the Canadian Department of National Defence, to initiate the High Earth Orbit Space Surveillance (HEOSS) technology demonstration project. The aim of this project is to demonstrate the military utility of microsatellites by procuring and operating a microsatellite equipped with a passive optical sensor to obtain metric Surveillance of Space (SofS) data and to evaluate new concepts for future operational Canadian Forces SofS missions. HEOSS data is intended to meet the data quality standards of the U.S. Space Surveillance Network (SSN) to which it may contribute orbital observations. In parallel, researchers at the University of Calgary, sponsored by the Canadian Space Agency (CSA), proposed a microsatellite mission, also largely inspired by the MOST mission, to detect and track Near Earth Objects (NEOs) such as asteroids and comets. In 2005, DRDC and the CSA established a Joint Project Office (JPO) to procure and deliver a microsatellite system to perform both of these science missions; this dual-use spacecraft has been named the Near Earth Object Surveillance Satellite – NEOSSat [1].

The nature of both science missions requires the NEOSSat spacecraft to point and observe a different location of the sky every five minutes on average. The constant slewing from point to point will necessitate a great deal of planning and will involve hundreds of commands to be generated every single day of operations. Since practically no on-board autonomy will be implemented into NEOSSat and since operation costs must be kept at a minimum, the planning of the daily science observations has rapidly emerged as the forefront issue to be addressed by the JPO. Contrary to the space segment, which is being procured, the risks associated with the development of the ground segment rests entirely on DRDC and the CSA. In response, DRDC initiated the prototyping of the NEOSSat Mission Planning System (MPS) as a tool for the requirements definition phase and as a learning tool that helped the JPO better understand the problem of scheduling space-based SofS observations. Unexpectedly, it also verified some of the Phase A results such as the power generation capabilities of the spacecraft's power subsystem.

Until quite recently there was some scepticism that a microsatellite could in fact meet HEOSS' stringent requirements. As a risk-reduction exercise for NEOSSat, DRDC was allowed to task MOST to attempt to observe a satellite. In October 2005, MOST successfully obtained images of satellite streaking against stellar backgrounds for two GPS Block IIR satellites. This pioneering effort validates the HEOSS and NEOSSat concept for a low-cost microsatellite-based SofS sensor. In addition, these data allowed metric and photometric estimates to be made, providing insights for the NEOSSat mission.

This paper discusses the NEOSSat space and ground segment and provides an update of the project schedule. The NEOSSat MPS high-level requirements are discussed as is an overview of the prototyping activities that have been accomplished in the past year. Finally, a detailed description of the MOST SofS experiment and its results is presented.

2. NEOSSat PROJECT OVERVIEW

DRDC and the CSA established a JPO in 2005 to deliver a micro-satellite system that will satisfy two distinct science missions. The HEOSS science mission is sponsored by DRDC and has as a goal of demonstrating the military utility of microsatellites by obtaining metric data for deep-space Resident Space Objects (RSOs), Earth-orbiting objects having orbital altitudes between 15,000 and 40,000 km, with a goal of tracking objects down to 6,000 km. The NESS science mission is sponsored by the CSA and has a goal of detecting and tracking Aten-class asteroids whose average distance from the Sun lie inside Earth's orbit with aphelion greater than Earth's orbit. The objective of the NESS science mission is to discover up to 60% of potentially hazardous inner-earth objects larger than 1 km in size during the mission lifetime. The two science missions will equally share time on NEOSSat.

NEOSSat Space Segment

In 2005, the JPO awarded two contracts to proceed with the development of the NEOSSat concept up to a spacecraft level System Requirements Review (SRR). Following a competitive process, the first contract was awarded in January 2005 to Dynacon Incorporated of Mississauga, Ontario, to study and propose a multi-mission micro-satellite bus capable of meeting the requirements for three separate missions: 1) the NEOSSat mission, 2) a radar altimeter mission, and 3) a technology demonstration mission meant provide flight opportunity to innovative, but as yet undefined, payloads. The overarching aim of this contract was to lower the total costs of all three missions by designing a multimission micro-satellite bus that minimizes recurring engineering costs. The second contract, which was also preceded by a competitive process, focused solely on the development of an instrument design that would satisfy the science requirements for the HEOSS and NESS missions. The instrument contract was awarded to a team led by researchers at the Department of Astronomy of the University of British Columbia.

A graphical depiction of the NEOSSat design as proposed by the Phase A contractors is illustrated in Fig. 1. The similarity in the proposed NEOSSat design to the MOST micro-satellite reflects the fact that the teams awarded the Phase A contracts were collectively responsible for the MOST spacecraft.

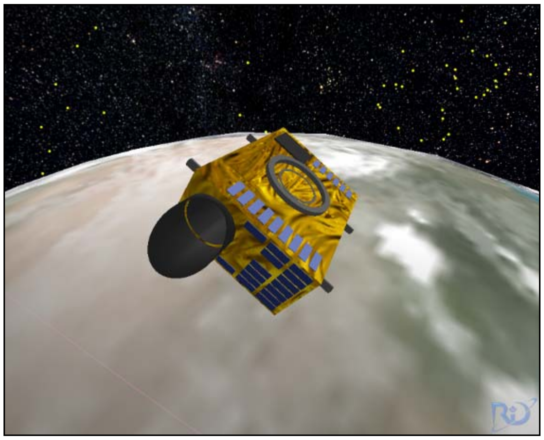


Fig. 1. Artistic depiction of the NEOSSat spacecraft following SRR.

Although the proposed design and concept for the NEOSSat spacecraft could change during Phase B, the efforts of the Phase A confirmed that the ambitious HEOSS and NESS missions were indeed feasible on a micro-satellite platform. As is customary with micro-satellites, the spacecraft houses a single instrument, in this case a 15 cm passive optical telescope. In order to reach the sensitivity levels required by the NESS science team, the concept developed under Phase A proposed an on-axis optical telescope requiring the use of a baffle to reduce stray light. Some of NEOSSat's critical capabilities to satisfy the mission requirements (and met by the Phase A design) are:

- Three-axis pointing stability in pitch and yaw of less than 0.5 arcsecond for 100-second exposures (1σ).
- Orbit absolute positional knowledge of ± 50 m (1σ) during nominal operations.
- Timing accuracy and precision of 1 millisecond.
- Capability to track at relative angular speeds of up to an including 60 arcseconds per second for up to 30 seconds with a pointing stability wander of less than 24 arcseconds.
- Ability to acquire and hold in memory a minimum of 288 images per day with a goal of 460.
- S-band, CCSDS-compatible communications to the ground.

The NEOSSat spacecraft will operate in a dawn-dusk sun-synchronous orbit at an altitude of approximately 750 km. The microsatellite slated for launch by mid-2009 as a secondary payload on a yet to be selected launch vehicle. The minimum requirements set for the lifetime of the NEOSSat spacecraft is one year of operations with a goal of two. If the performance of the MOST microsatellite after its third year of operation is any indication, there is confidence that the NEOSSat spacecraft will meet and potentially exceed the stated lifetime expectations.

With completion of Phase A studies, the JPO is now moving towards Phases B, C and D of the NEOSSat microsatellite development. A "Request for Proposals" is currently available and bidders are expected to submit their proposal by the end of September 2006. Pending unforeseen problems or delays, the JPO expects the start of the Phase B to begin in early 2007 following a thorough evaluation and selection process.

NEOSSat Ground Segment

The JPO has taken on the responsibility of developing and integrating the ground system that will command and control the NEOSSat spacecraft. As illustrated in Fig.2, the principal components employed to command and control the NEOSSat spacecraft will be: 1) the ground stations, 2) the Mission Operations Centre (MOC), and 3) the NEOSSat Mission Planning System (MPS).

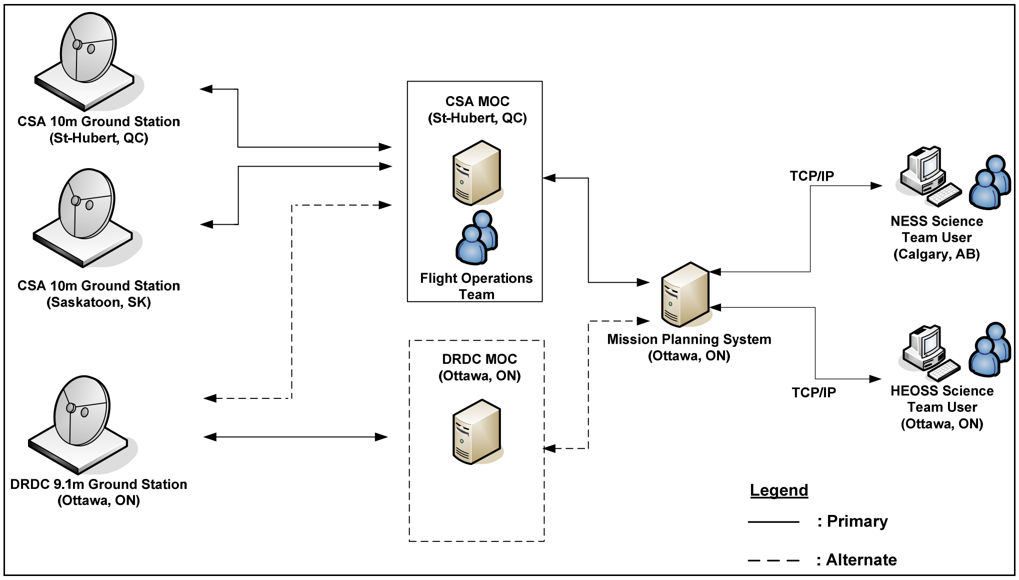


Fig. 2. NEOSSat Ground Segment Architecture.

Two CSA ground stations, each a 10 metre diameter antenna, are currently baselined as the primary system used throughout the life of the micro-satellite. The prime ground station will be located in St-Hubert (Québec) and the co-prime will be in Saskatoon (Saskatchewan). The use of these two facilities will allow for, on average, approximately 50 minutes of communications with NEOSSat per day. The DRDC ground station represents a third ground station that may be used during the life of the NEOSSat spacecraft. Due to its proximity to the St-Hubert ground station, the addition of the DRDC facility will not add contact times to what is already achievable with the CSA resources.

The CSA MOC, which will be the primary operations centre for the lifetime of NEOSSat, is an extant facility manned by a Flight Operations Team (FOT) responsible for operating all satellites owned by the CSA. The MOC participates in the mission planning of spacecraft activities, preparing the commands to be uplinked, configuring the ground stations to support contacts, monitoring real-time telemetry during contacts, and assessing the spacecraft health and performance over time. These tasks are currently labour intensive and have high costs associated with them, an impractical business model for a microsatellite mission. In an effort to reduce operations costs for the NEOSSat mission, the JPO will automate as many of these functions as possible into a reliable software system. The MPS has been selected as the logical location where these functions should reside.

The MPS will be the interface between the active MOC and the HEOSS and NESS science teams. The two teams expect, at a minimum, to point the NEOSSat sensor to a different position in the sky every five minutes for every 24 hours of operation. For this reason, an automated planning system is deemed critical if both teams wish to employ the NEOSSat spacecraft to its full potential while keeping operations costs to a bare minimum. The MPS is the subject of the following section.

3. NEOSSAT MPS HIGH-LEVEL REQUIREMENTS

For the purposes of the NEOSSat project, the JPO identified the following set of high-level activities that must be executed by the MPS: 1) Observation scheduling, 2) Schedule simulation and assessment, and 3) Spacecraft command scripting, 4) Data pre-processing, and 5) MPS housekeeping (Fig.3). The elaboration of the NEOSSat MPS functions was drawn from the heritage provided by the U.S. Space-Based Visible (SBV) program [2]. The highly successful SBV program not only demonstrated the feasibility of space-based SofS but also laid the foundation for future efforts in this field.

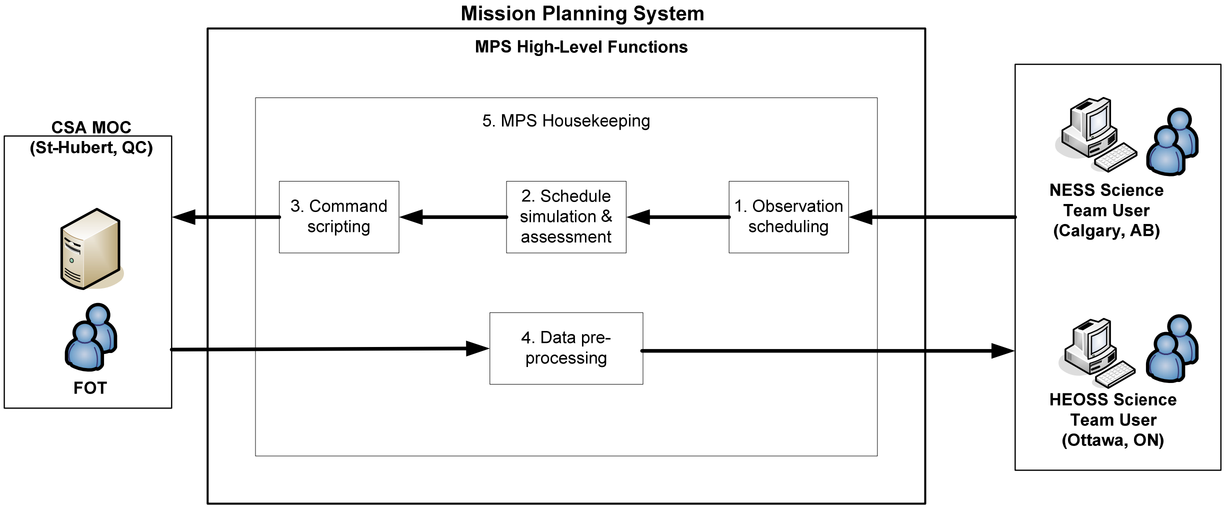


Fig. 3. MPS High-Level Functions

Observation scheduling begins when users submit their observation request to the MPS. The observation request must be in a format with which the users feel comfortable with, such as the one they would normally use with their ground based telescope. Therefore, three types of inputs will be available: HEOSS mode, NESS mode, and science tasks. HEOSS mode inputs will be mainly in the form of SSN tasks. A list of SSN numbers, observation types and priorities will be supplied to the MPS, along with a time period during which to schedule all observations. NESS mode inputs will be in the form of specific locations and times to image. Science tasks will also be specified at specific times and locations, but done for a variety of reasons, in support of either mission. Other type of tasks (e.g. search) may be incorporated over time following the successful implementation of these nominal request formats. Observation scheduling continues with the analysis of viewing opportunities while considering any other restrictions that could have an adverse impact on NEOSSat's health. It is desirable, but not required in the first version of the system, that the MPS should also schedule observations so as to minimize slews, providing for more imaging opportunities. Observation scheduling will conclude with an integrated list of time-ordered, constraint checked activities to acquire the necessary science data.

Schedule simulation and assessment consists of test and validation of the products received from the observation scheduling. The aim is to employ a modest NEOSSat simulator to ensure that the list of scheduled activities can be performed by the spacecraft without straining it beyond its capacity or placing it into an undesirable attitude. Although not yet defined, a series of outputs will also allow for a rapid manual assessment of the desired set of activities. Once the system has confirmed that the list of time-ordered observations is feasible, the MPS will translate the activity schedule into a time-tagged command script which will then be sent to the MOC to be uploaded to NEOSSat, which will then obtain the desired data.

Following the successful downlink of telemetry and science data from the NEOSSat spacecraft to the MOC, the science data and relevant telemetry data will be extracted by the MPS. As a minimum, the MPS will verify which observations were completed and the science data will be sent or made accessible to the respective science team. The returned science data will also include the necessary telemetry information that the science teams require for the reduction and interpretation of their data. Finally, general housekeeping data such as percentage of usage of the NEOSSat spacecraft by each science team and MPS failure report will be readily made accessible for management purposes.

Although the functions described above appear to be rather simple to implement into software, DRDC has decided to take a very cautious approach to the development of the MPS due to inherent risks associated with any software development project. Additionally, the automation of MOC functions that have historically been assigned to humans, is perceived by some, who are used to "conventional" space programs, as too risky. To address both of these concerns, DRDC began the requirements definition process of the MPS development concurrently with a prototyping activity.

4. MPS PROTOYPE

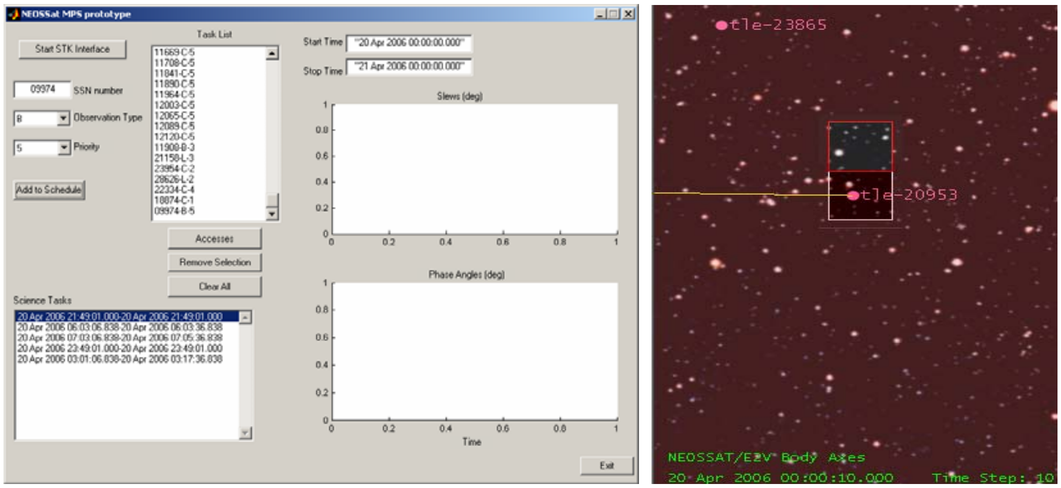
The MPS prototype was authored in Matlab 6.5 using Satellite Tool Kit (STK) as an astrodynamics engine [3]. It runs on a Pentium PC where Matlab creates a socket connection to STK using the STK/Connect module. A graphic user interface manages tasking input (Fig. 4) where a user enters the SSN number, tasking type and timeframe over which the images are to be acquired. The output of the MPS prototype is an observation schedule and a 3D graphical visualization of the observation accesses. For this first design iteration of the prototype, only the SSN-type task requests were modeled.

There are physical constraints that must be respected for NEOSSat observations. These constraints consist of South Atlantic Anomaly exclusion areas, solar and lunar exclusion angles, minimum Earth limb exclusion angle, and Earth shadow exclusion. As NEOSSat will be imaging in an inertially fixed, star-stare mode (SSM), observation times must also be constrained due to the target's angular rate. During SSM observations, NEOSSat will track stars such that moving objects (e.g. satellites) passing through the field of view will appear as streaks in the exposure. Objects moving too slowly would appear as stars and objects moving too quickly will have a signal to noise ratio (SNR) that would be too weak to be detected. The MPS respects these constraints to ensure that the resulting data is of high quality.

The figure of merit on which the MPS schedules is based upon a proxy signal to noise ratio (SNR) using relations based on [4]. This estimate is quite coarse as target satellite brightness is not usually known beforehand. At this stage it is not expected that this proxy SNR will be consistent with the true measured SNR that NEOSSat will detect, but is intended as a first order approximation. As satellite brightness is generally a function of phase angle, a simple linear target brightness model is used which assumes all targets have magnitudes from 14th to 10th over phase angles of 90 to 0 degrees respectively. The proxy SNR is calculated for all relative positions of target and observer and the peak signal to noise ratio time is selected as the time interval to schedule the observation. If overlaps occur, the scheduler selects the first object in the list, and then moves on to the second.

As a linear phase-magnitude model was assumed, the scheduler tends to schedule its observations toward the anti-sunward direction from Earth. A side benefit of this is a tendency for the scheduler to reduce slew angles for objects in GEO, but this is not necessarily true for a tasking mix of various satellite orbits. The MPS prototype has helped create various tracking scenarios helping mission planners understand the geometry of the space-based surveillance problem. Using STK's solar panel tool, estimates for the power generation on each solar panel face can also be made helping planners know if the spacecraft will be operated in a power positive/negative condition during the execution of the tracking schedule.

Future revisions of the MPS prototype will explore relaxing the scheduling restrictions so a larger arc of a target satellite's orbit is considered, and be will implementing a means to minimize the slew angles between tasks. The next version will also implement NESS-type planning for observations of asteroids to within 45 degrees from the Sun. Once DRDC is satisfied with the MPS prototype's handling of observation scheduling, the techniques and algorithms will be integrated into the production version of the MPS.



Start Time "20 Apr 2006 00:00:00.000"
Stop Time "21 Apr 2006 00:00:00.000"
SSN number 09974
Observation Type B
Priority 5

Task List
11669-C-5
11708-C-5
11841-C-5
11890-C-5
11964-C-5
12003-C-5
12065-C-5
12089-C-5
12120-C-5
11908-B-3
21158-L-3
23954-C-2
28626-L-2
22334-C-4
18874-C-1
09974-B-5

Science Tasks
20 Apr 2006 21:49:01.000-20 Apr 2006 21:49:01.000
20 Apr 2006 06:03:06.838-20 Apr 2006 06:03:36.838
20 Apr 2006 07:03:06.838-20 Apr 2006 07:05:36.838
20 Apr 2006 23:49:01.000-20 Apr 2006 23:49:01.000
20 Apr 2006 03:01:06.838-20 Apr 2006 03:17:36.838

Fig. 4. MPS Prototype user interface and science field of view on a simulated
starfield background as seen from NEOSSat.

The MPS prototyping activity directly supports the requirements definition process by allowing the NEOSSat team members to better understand how they would interact with the MPS. This results in more focused functional and non-functional requirements, which in turn should lower the risks associated with software development. The early prototyping activity also allow the development team to get a better understanding of the physics involved in planning space-based observations, especially in the area of SofS. Finally, the MPS prototype also allows the JPO to verify some results obtained from the Phase A contractors design proposal such as the power generation capabilities of the spacecraft's power subsystem.

5. RISK REDUCTION FOR NEOSSat USING THE MOST MICROSATELLITE

As a risk reduction measure for the NEOSSat mission the CSA granted permission to use the MOST micro-satellite to conduct a basic satellite tracking experiment. MOST is an excellent test bed for micro-satellite based satellite tracking as it features a high performance attitude control system and an optical telescope that can be used for limited starfield imaging. The objectives of this test were to ensure that a micro-satellite could 1) acquire starfield imagery with a streaking satellite, 2) validate the techniques used for space-based scheduling of satellites and if the acquisition was successful, 3) determine the metric accuracy and photometric characteristics of the observed spacecraft. Opportunities to track satellites were reserved to brief time periods when software updates and other maintenance were being performed by the spacecraft operator so as to not interfere with MOST's primary astronomy science mission. In October 2005, two separate days were allocated to perform the tests where one image-track would be performed per day; this resulted in MOST's first success at satellite tracking.

MOST is 65x65x30 centimetres in size (Fig. 5), weighs 54 kilograms and was launched into a dusk-dawn, Sun-synchronous, 830-kilometer orbit. MOST is three axis stabilized and has demonstrated pitch and yaw stability within three arcseconds [5]. The spacecraft payload is a 15 centimetre Rumak-Maksutov optical telescope, shared between the science instrument and the startracker for precision attitude control. MOST does not normally take starfield images but usually takes measurements using Fabry lenslets to spread starlight onto the science CCD permitting micromagnitude detection of brightness oscillations on stars to V~6 [6]. A portion of the science CCD is not covered by the Fabry lenslet array and this area can take starfield images. MOST has three ground stations located in Vienna, Vancouver, and Toronto. During science collection, MOST locks onto a bright star and maintains fine-pointing attitude control lock for up to 8 weeks. A small stellar snapshot is taken every thirty seconds and is downloaded to the science team during ground station passes. MOST has produced new science on stellar pulsations [7] and recently surpassed its goal lifetime of 2 years. The program cost of MOST was estimated to total $13 million Canadian, including launch.

To conduct the satellite tracking experiment, DRDC Ottawa prepared a set of look angles to upload to the spacecraft. During the planning of this experiment, accommodation for MOST's Continuous Viewing Zone (CVZ - see Fig. 6) constraint was required as MOST could not look outside of this area during tracking as fine pointing lock would be lost. This limited the area in which satellite tracks could be taken. Fortunately, two Block IIR GPS spacecraft flew into the CVZ region during the times allocated to the experiment. Both of these GPS are operational NAVSTAR satellites and have precision orbital ephemerides regularly produced by the National-Geospatial Intelligence Agency. These satellites were selected for observation as they were ideal calibrators for the metric accuracy portion of this tracking experiment.

Both images were acquired in star-stare mode, where MOST is inertially fixed relative to the stars. This has the effect of producing an image where the satellite produces a short streak on the field of view, and stars appear as points. This is a natural mode of operation for MOST as the microsatellite acquires the bulk of its imagery in the inertially fixed frame while staring at its target stars for many weeks.

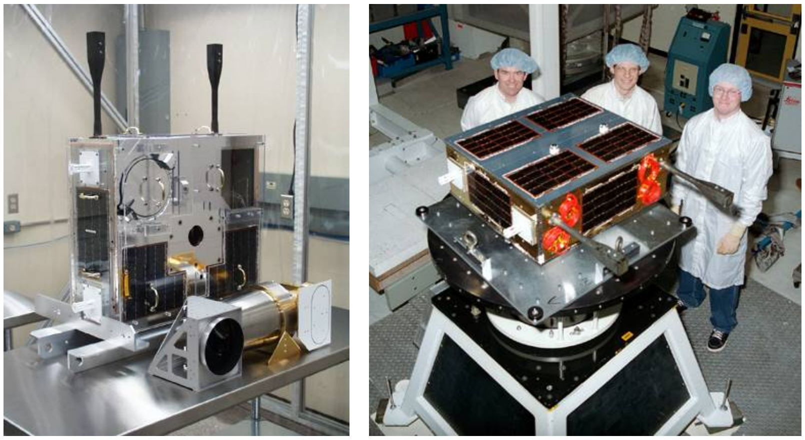


Fig. 5. – (Left) MOST microsatellite and telescope. (Right) testing at David Florida Labs in Ottawa.
Image credits: University of British Columbia. http://www.astro.ubc.ca/MOST

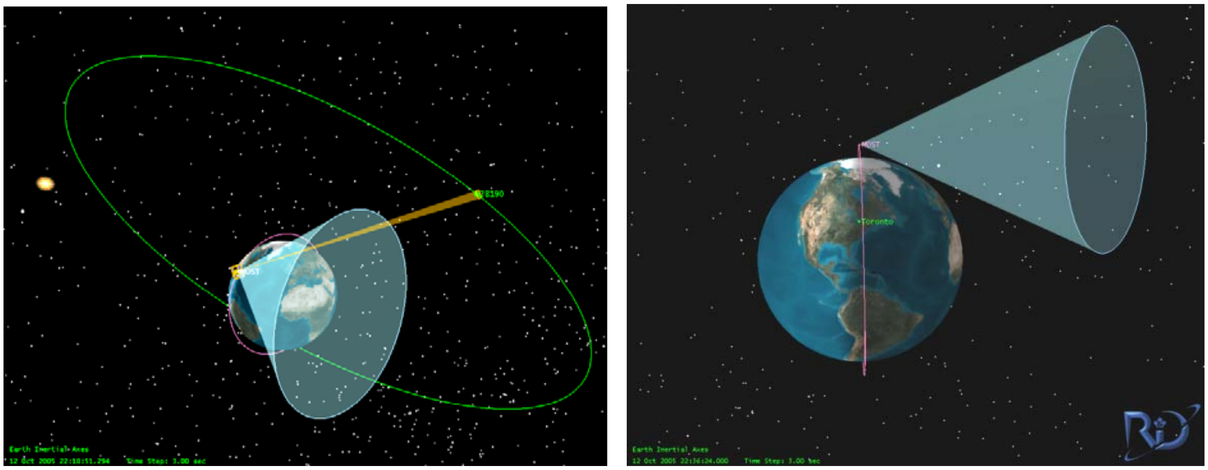


Fig. 6. (Left) MOST orbit and conical Continuous Viewing Zone (CVZ) in blue. (Right) Sun, MOST, Earth, CVZ and 1st targeted GPS satellite #28190 during the first acquisition on 12 Oct 2005.

MOST acquired its first successful track of GPS IIR-11 on 12 Oct 2005 (Fig. 7), and repeated this success by acquiring IIR-04 the following day. In each image, a satellite streak is visible towards the center of the field of view. The exposure time of the images were deliberately lengthened to ensure some portion of the satellite streak would be recorded if MOST did not point to the correct attitude and to ensure proper sampling of the background stars for astrometry. Each image was solved astrometrically referencing the Hubble Guide Star Catalog (GSC) using Pinpoint astrometry software.

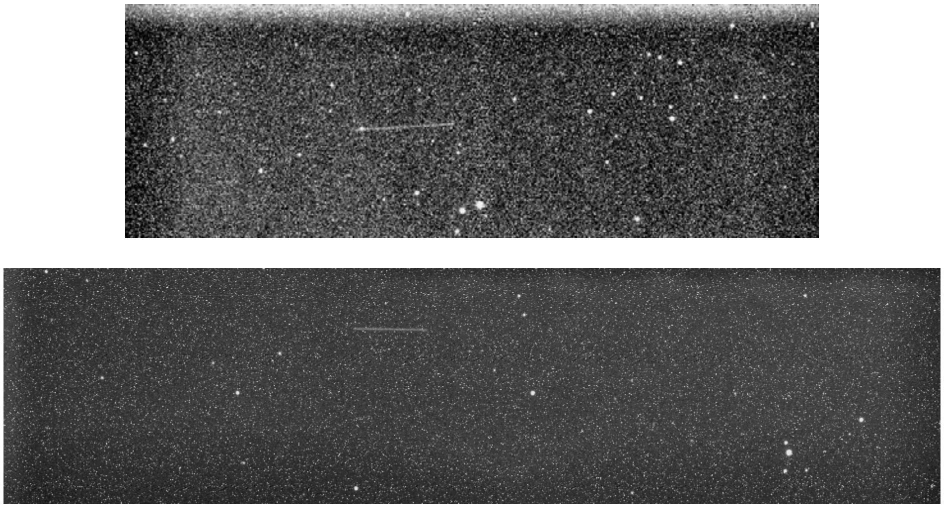


Fig. 7. Tracks of GPS satellites observed by MOST. (TOP) #28190 GPS IIR-11. (Bottom) #26360 GPS IIR-04

In order to make accurate space based metric observations, the position of the observing satellite (MOST) must be known to within 50 meters or better for deep space objects. MOST was not built with a GPS receiver or coherent range transponder to produce a precision orbital ephemeris, forcing the use of two line element sets to approximate the MOST's orbital position. This is generally an unreliable method to determine a spacecraft's position as two line element sets inherently lack the precision to produce position estimates better than tens of meters [8] and are typically in error by kilometers. Fortunately, the SSN released element set updates on both days of the tracking-experiments, helping to minimize this error. Comparing the radial position of MOST using element sets on Epoch Days 2005-285 and 2005-286, the positions agree to within 120 meters. Given that the targeted GPS spacecraft were greater than 23,000 kilometers distant; this reduces the parallax error effect due to ephemeris uncertainty to less than one arcsecond.

Prior to the tracking experiment, MOST's metric performance was estimated to be ~12 arcseconds. Image time-tagging uncertainty was estimated by Dynacon to be approximately 0.1 seconds which would contribute the largest portion of the metric error. This would result in an along track error of ~8 arcseconds for the first GPS track and ~4 arcseconds for the second. MOST's metric accuracy results (Table 1) are consistent with the expectations for the microsatellite's performance at 13 arcseconds. This metric accuracy determination is rather coarse as there are few measurements in order to properly estimate the bias and sigmas for the tracks.

Inspection of the satellite tracks showed a noticeable along-track component reaffirming that timing error is the likely source of most of the extra metric error. After discussions with the MOST Astronomy Science team, it was agreed than an unmodelled systematic effect between time stamping of the image and CCD exposure is likely responsible for this variation. Unfortunately there are relatively few samples in this experiment to fully quantify this effect. It is possible that some ephemeris error could produce the along-track variation, but is less likely due to the good consistency of the element sets.

Table 1. Metric Accuracy Evaluation

Track	RA Residuals (arcsec)	DEC Residuals (arcsec)	
1st – 28190	-8.2	-6.0	
1st – 28190	2.1	15.3	
2nd – 26360	-9.9	-12.2	
2nd – 26360	-2.9	0.9	
Bias	***-4.7***	***-0.5***	***Total***
Sigma	***5.4***	***11.8***	***13.0***

Brightness estimates of the observed GPS satellites were made using differential photometry. An estimate of each image's photometric zeropoint [9] was made using background stars and instrumental magnitudes of the satellite streak counts were measured. These measures revealed that MOST detected the GPS satellites with apparent magnitudes of 12.1±0.2 and 11.5±0.1 M_{MOST} (Table 2). This is a MOST specific magnitude which tends to be sensitive between 500-700 nm due to the properties of MOST's optics, CCD and filter [6]. The measured magnitudes, when normalized for range, are consistent to within 0.2 magnitudes with ground based V-band measurements of Block IIR GPS [10]. Some of the discrepancy may be due to the broadband nature of MOST's instrument and the stellar magnitude errors inherent in the GSC catalog used to determine the photometric zeropoint of the images.

Table 2. MOST Photometry of Satellite Streaks

	1st Track (IIR-11)	2nd Track (IIR-04)	Units
M_{GPS} (apparent)	12.1 ± 0.2	11.5± 0.1	M_{MOST}
M_{GPS} (normalized to 20,000 km)	11.7	11.2	M_{MOST}
Phase Angle	21.0	17.1	Degrees
Streak S/N Ratio	4.9	12.3	
Sky Brightness	18.3	17.9	M_{MOST} / arcsec^2

Background sky brightness in each image was found to average 18 magnitudes arcsec^{-2}. This bright background is likely due to stray light emitted by the illuminated portion of Earth's limb or possibly from a light leak in the construction of the MOST spacecraft. The exact source of this stray light is unclear but Earth limb stray light will be an important consideration during NEOSSat scheduling as it will limit its ability to detect faint objects.

Despite the fact that the MOST's metric errors were rather large in comparison to many SSN optical tracking systems, it is very good performance given the fact that MOST was not intended to image star fields, let alone attempt satellite tracking. This test demonstrated that the basic principle of NEOSSat works and predicts exciting capabilities for satellite detection with NEOSSat.

6. CONCLUSION

Over the last year, two distinct activities were conducted to reduce some of the risk associated with the NEOSSat project. The MPS prototyping activities have permitted the NEOSSat team to gain a better insight into the problems associated with autonomously scheduling surveillance of space tasking, and better define the system requirements. In addition, the MPS prototype also allowed further verification of Phase A results and thus increasing DRDC and CSA's confidence into the NEOSSat mission.

The MOST risk reduction experiment was a valuable first step towards Canada's space based surveillance of space activities. The MOST experiment provided the NEOSSat team with confidence that the NEOSSat requirements were achievable on a microsatellite platform. Although not designed for this type of mission, MOST demonstrates that the NEOSSat mission concept is sound.

7. ACKNOWLEDGEMENTS

The authors wish to thank representatives of the *Space Astronomy and Planetary Exploration Directorate* of the *Canadian Space Agency* for their authorization to use MOST for the satellite tracking tests. Appreciation is extended to the *Department of Physics and Astronomy* at the *University of British Columbia*, for their support and assistance interpreting MOST data. Appreciation is also extended to *Dynacon Inc*. (*Dr. Simon Grocott, Daniel Faber and David Cooper*), for their expertise in making the MOST risk reduction experiment a success and the *Department of National Defence Surveillance of Space Project (SofSP)* for their support of this work.

8. DATA CREDITS

Risk Reduction for NEOSSat Using The MOST Microsatellite is based on data from the MOST satellite, a Canadian Space Agency mission jointly operated by Dynacon Inc., the University of Toronto Institute for Aerospace studies and the University of British Columbia, with the assistance of the University of Vienna. Data ownership is maintained by the MOST Science team.

9. REFERENCES

1. Wallace, B, et al, The Near-Earth Orbit Surveillance Satellite (NEOSSat), International Astronautical Congress, October 2004.
2. Burnham, W.F. et al., Mission Planning for Space-Based Surveillance with the Space-Based Visible Sensor, *Journal of Guidance, Control, and Dynamics*, Vol. 23, No.1, January-February 2000.
3. Thorsteinson, S., et al, A Prototype Mission Planning System fro NEOSSat, August 2006.
4. Hedjuk, M.D., Satellite Detectability Modeling for Optical Sensors, 2004 AMOS Technical Conference, Maui, HI. Sept 2004.
5. Grocott, S., et al, The MOST Microsatellite Mission: One Year in Orbit, 18th AIAA/USU Small Satellite Conference, Logan, Utah, August 2004, SSC04-1X-1.
6. Walker, G. et al., The MOST Astroseismology Mission: Ultraprecise Photometry from Space, *Publications of the Astronomical Society of the Pacific* 115:000-000, September 2003.
7. Matthews, J. et al., No Stellar p-mode oscillations in space-based photometry of Procyon, *Letters to Nature*, Nature, vol. 430, 1 July 2004.
8. Vallado, D. , *Fundamentals of Astrodynamics and Applications, 2nd Edition*, Microcosm Press 2001.
9. Sydney, P. et al., High Precision Satellite Astrometry and Photometry, 2004 AMOS Technical Conference, Maui HI., Sept 2004.
10. Vrba, F et al., Optical Brightness Measurements of GPS Block II, IIA and IIR Satellites on Orbit, AMOS Technical Conference 2002.