

NEOSSat : A Collaborative Microsatellite Project for Space Based Object Detection

William Harvey
 Canadian Space Agency
 6767, Route de l'Aéroport, St-Hubert, QC, Canada, J3Y 8Y9; (450) 926-4477
william.harvey@space.gc.ca

Tony Morris
 Defence Research and Development Canada
 3701 Carling Avenue, Ottawa, Ontario, K1A 0Z4; 613 990-4326
Tony.Morris@drdc-rddc.gc.ca

ABSTRACT

Recognizing the importance of space-based Near Earth Object (NEO) detection and Surveillance of Space (SoS), the Canadian Space Agency and Defence Research and Development Canada are proceeding with the development and construction of NEOSSat. NEOSSat's two missions are to make observations to discover asteroids and comets near Earth's orbit (Near Earth Space Surveillance or NESS) and to demonstrate surveillance of satellites and space debris (High Earth Orbit Space Surveillance or HEOSS). This micro-satellite project will deploy a 15 cm telescope into a 630 km low earth orbit in 2010. This will be the first space-based system of its kind.

NEOSSat represents a win-win opportunity for CSA and DRDC who recognized there were significant common interests with this microsatellite project. The project will yield data that can be used by the NEOSSat team and leveraged by external stakeholders to address important issues with NEOs, satellite metric data and debris cataloguing. In the contexts of risks and rewards as well as confidence building, NEOSSat is providing CSA and DRDC with valuable insights about collaboration on a microsatellite program and this paper presents our views and lessons learned.

INTRODUCTION

The Near Earth Object Surveillance Satellite (NEOSSat) is the first jointly sponsored microsatellite project between the Canadian Space Agency CSA and Defence Research and Development Canada (DRDC). The detailed development and construction contract awarded in July 2007 to Dynacon is managed through a Joint Project Office (JPO). The project Preliminary Design Review (PDR) held in April 2008 was completed successfully. Proceeding through 2008, activities will now focus upon the detailed design and the use of engineering models to ensure unit functionality and initial systems integration through a "flatsat" or "bench-top" approach. These efforts will lead to the NEOSSat Critical Design Review scheduled for January 2009. Subsequent to the CDR the NEOSSat spacecraft will go through its manufacturing, assembly, integration and test before it is shipped for launch that is expected in early 2010. The micro-satellite will deploy a 15 cm telescope into a 630 km low earth orbit and will be jointly operated by CSA and DRDC with equal time allocated to the NESS and HEOSS missions. This will be the first space-based system of its kind.

The NEOSSat microsatellite project satisfies several objectives: 1) discover and determine the orbits of Near-Earth Objects (NEO's) that cannot be efficiently detected from the ground, 2) demonstrate the ability of a microsatellite to produce desirable surveillance-of-space (SoS) metric data on artificial earth-orbiting objects with orbital altitudes between 15,000 and 40,000 km, and 3) carry out a flight demonstration of the CSA's first multi-mission microsatellite bus (MMMB).

A graphical rendition of the NEOSSat spacecraft systems and an external isometric view of the spacecraft body (approximately 1 m x 0.8 m x 0.4 m) is provided in Figure 1. The telescope baffle extends beyond the body and attenuates stray light when the spacecraft is observing at solar elongations as low as 45 degrees.

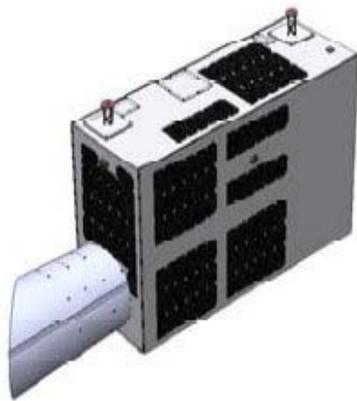
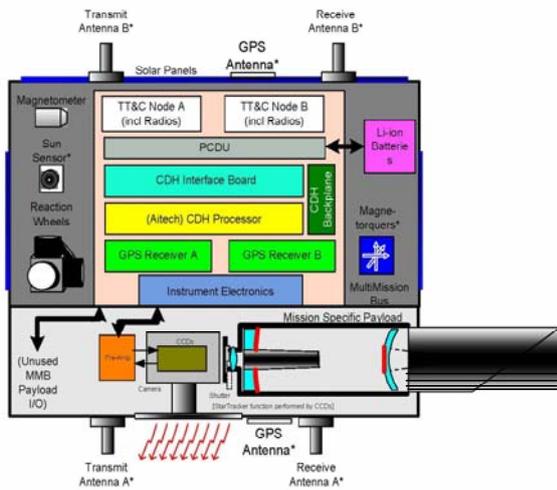


Figure 1 - The NEOSat spacecraft

THE NESS MISSION – FINDING NEOS

A Step Towards NEO Preparedness

The vast majority of asteroids are found in the main asteroid belt (between Mars and Jupiter from 1.8 to 4.5 A.U.) of which it is estimated that there is likely to be well over a million. Near Earth asteroids (NEAs) represent significant smaller populations of asteroids with their perihelia (closest approach to the sun) nearer to the sun than Mars and even the Earth and Venus. The Amor class asteroids cross Mars orbit, the Apollo class asteroids cross Earth orbit and the Aten class asteroids are just inside Earth orbit. Discovery of the Amor, Apollo and Aten asteroids really began only about 20 years ago and a concerted effort is being made to find and characterize these small bodies. As of 4 June 2008 there were more than 5,450 of them catalogued. From

this population of asteroids, 942 have been designated as potentially hazardous objects indicating that there is a real non-zero probability (but not a certainty) that an impact with Earth could eventually occur. Near Earth asteroids that do not get any closer to the Earth than 0.05 AU (roughly 7,480,000 km) or are smaller than about 150 m are **not** considered PHAs.

In fact, a very large number of very small (milligram sized particles) meteoroids enter Earth atmosphere each day amounting to more than a hundred tons of material. The average meteoroid enters earth atmosphere at between 10 and 70 km/sec and all but the very largest are decelerated to a few hundred km/hour by atmospheric friction. Craters on the Earth, the Moon and Mars provide ample evidence of what happens when asteroids do not entirely burn up in the atmosphere and impact the surface of a planetary body. Based upon assessment of craters on Earth in Table 1, the diameter of the impactor and energy released upon impact have been determined.

| Impactor Diameter (meters) | Yield (megatons) | Interval (years) | Consequences |
|----------------------------|---------------------|------------------|---|
| < 50 | < 10 | < 1 | meteors in upper atmosphere most don't reach surface |
| 75 | 10 - 100 | 1000 | irons make craters like Meteor Crater; stones produce airbursts like Tunguska; land impacts destroy area size of city |
| 160 | 100 - 1000 | 5000 | irons,stones hit ground; comets produce airbursts; land impacts destroy area size of large urban area (New York, Tokyo) |
| 350 | 1000 - 10,000 | 15,000 | land impacts destroy area size of small state; ocean impact produces mild tsunamis |
| 700 | 10,000 - 100,000 | 63,000 | land impacts destroy area size of moderate state (Virginia); ocean impact makes big tsunamis |
| 1700 | 100,000 - 1,000,000 | 250,000 | land impact raises dust with global implication; destroys area size of large state (California, France) |

Table 1 - Data from 'The Impact Hazard', by Morrison, Chapman and Slovic, published in Hazards due to Comets and Asteroids

– posted at :
<http://www.nineplanets.org/meteorites.html>

Clearly, all asteroids more than 75 meters in diameter that could impact Earth give us cause to be concerned. Thus the possibility of detecting the close approach of an asteroid to Earth, the implications of any perturbations and inaccuracies in the characterization of its orbital elements and our ability to predict an impact with sufficient time to act or mitigate the consequences is being taken very seriously. It is clear that a pro-active approach to understanding the risks, their likelihood and consequences has arisen due to the discovery of NEO asteroid populations over the last 20 years.

INTERNATIONAL NEO STAKEHOLDERS

NEO SCIENCE COMMUNITY

Apart from the need to identify potentially hazardous NEOs, scientists want to study asteroids for several other reasons:

- NEOs represent well preserved evidence of conditions existing in the early creation of our solar system, and therefore are one of the best laboratories to study and unlock more knowledge about asteroid origins,
- NEO data is needed to develop a consistent model of the physical and dynamical properties of the minor bodies in our solar system, accounting for specific differences/common properties between the populations and describe their relationships, and
- Data is needed to evaluate the potential population of NEOs for future rendez-vous or in-situ resource extraction missions due to their proximity to Earth.

Through NEOSat, Canada intends to become a valuable contributor of accurate NEO data. International interest has grown as concerned scientific communities have engaged in developing repositories and catalogs of NEO information such as the efforts of SpaceGuard, Space Watch and NASA. The NEOSat Science Team includes some international representation already (U.S. and Finland) and interest is expected to grow.

UN COPUOS

At the Forty-fifth Session of the Committee on the Peaceful Uses of Outer Space (COPUOS) during the review of international activities on Near Earth Objects, Canada announced NEOSat to the Scientific and Technical Subcommittee in Vienna in February 2008. The Canadian delegation reported that Canada recognized the “importance of space-based Near Earth

Object (NEO) detection and Surveillance of Space (SoS) and was proceeding with the development and construction of NEOSat”, a microsatellite that will deploy a 15 cm passive optical telescope into a nominal 630 km low earth orbit expected in 2010. NEOSat will be able to detect objects down to 20th visual magnitude; and is the first space-based system of its kind. The distribution of expected NEO discoveries with respect to their apparent magnitude is shown in Figure 2 in which increasing magnitude indicates fainter objects. For reference an apparent magnitude of 6.5 corresponds to the faintest stars observable with the unaided eye under perfect conditions at night.

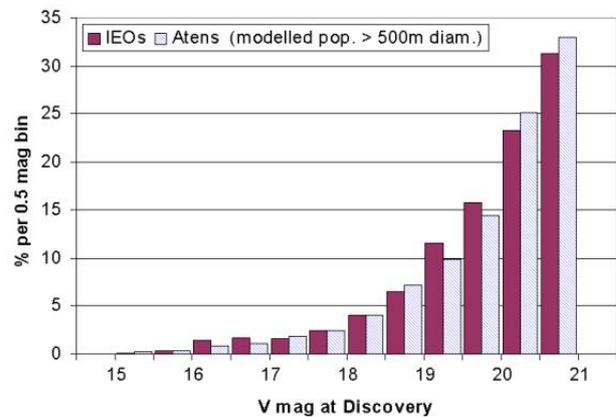


Figure 2 - Expected percentage of NEOs by limiting magnitude

NASA

In 2005 NASA was directed by U.S. congress to provide an analysis of alternatives to detect, track, catalogue and characterize potentially hazardous near-Earth objects (NEO) greater than 140 meters. CSA and NASA are currently discussing how the NEOSat project could contribute.

FINDING NEOS

The Search Survey Region

The systematic NEO search survey planned with NEOSat has the goal of detecting and cataloging 50% of Aten-class asteroids greater than 1 km. As a space-based platform to conduct NEO observations, NEOSat is designed to observe continuously, compared to ground-based survey telescopes that are limited to survey observations in the nighttime sky. Furthermore, NEOSat will not be disturbed by clouds or atmospheric attenuation. Figure 3 illustrates the NEO search areas in the sky that NEOSat will investigate. NEOSat’s design enables it to look sunwards up to 45 degrees as well as 40 degrees above and below the

ecliptic on both sides of the sun. The greatest apparent concentration of NEA is in a direction towards the sun. However, the telescope must contend with very harsh stray light from the sun when pointing at small solar elongations; this introduces very strong requirements on the telescope baffle.

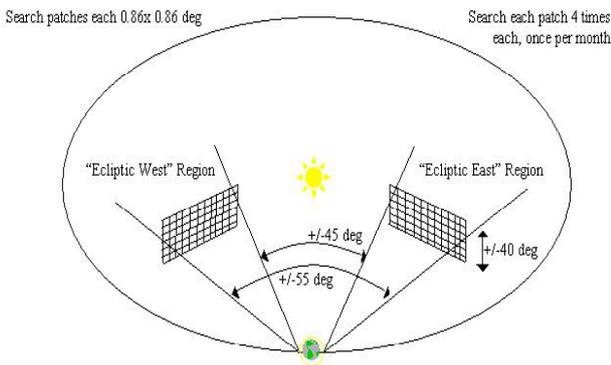


Figure 3 - NEO Survey Region. From 45° to 55° solar elongation and -40° to +40° in elevation.

THE HEOSS MISSION – ASSURING SPACE IS A SAFE AND PEACEFUL PLACE

SURVEILLANCE OF SPACE – SoS

Established in 1958 by Canada and the United States the North American Aerospace Defence (NORAD) organization detects and validates orbits of man-made space objects to differentiate them from ballistic missiles approaching North America. NORAD’s primary source for space situational awareness is the Space Surveillance Network (SSN), a worldwide network of ground based optical and radar sensors.

Canada as a member of NORAD recognizes that space is a vital resource that supports national and international interests. Global space investments are huge and widely integrated into the world economy. Until the 1980s Canada contributed to the SSN with two ground based Baker-Nunn cameras situated in eastern and western Canada. Canada is seeking to renew this contribution to the surveillance of space mission first via the HEOSS mission of NEOSSat and later through the operations of the Sapphire spacecraft.

DRDC aims to demonstrate that NEOSSat can be a significant Canadian contribution to the SSN that offers a low-cost passive optical solution that is not subject to atmospheric disturbances. Once the NEOSSat

spacecraft commissioning is complete the DRDC team will perform a set of experiments on the NEOSSat data and complete a system verification with the appropriate authorities of the SSN.

Internationally all space missions are exposed to the increasing risk of space collisions and need to predict hazardous situations and avert debris. Orbital crowding has been a fact of life for spacecraft located in MEO and GEO for some time now. To prevent space collisions, orbits must be known with maximum accuracy so that maneuvers and re-entry plans can be assessed and de-conflicted with other space assets. By delivering orbital characterization data of high accuracy, NEOSSat can demonstrate how space-based sensors can add valuable knowledge to handle such operational situations.

NEOSSat is meant to promote the safe, responsible and peaceful uses of space and therefore should be considered as an exemplary means of assisting in the implementation of current space treaties or agreements as monitoring orbits will verify compliance or transgressions objectively. Providing accurate orbital information that can be combined with space environmental data is highly desirable and observing compliance with orbital plans authorized by the ITU and the UN debris mitigation guidelines should eventually enable enforcement of the “rules of the road”.

NEOSSat can demonstrate several advantages over ground-based surveillance of space systems. NEOSSat allows timely optical tracking that is unaffected by the diurnal lighting cycle or the weather. From its LEO sun-synchronous orbit , rapid monitoring can be done when on-orbit spacecraft or launch vehicles break-up due to either fragmentation or collision induced by debris or man-made fragmentation. NEOSSat’s design can image satellites in a wide variety of orbits and will demonstrate that more frequent opportunities for surveillance is a strength of space-based SoS platforms. In addition, NEOSSat has the potential to be tested in-tandem or concurrently with other surveillance platforms thereby opening the possibility of demonstrating the potential for constellations or multiple spectral coverage of the same events. The power of Surveillance of Space (SoS) systems to predict risky situations in sufficient time to mitigate or resolve problems depends on the number and timeliness of observations and this is an area where space-based systems can excel.

To protect space assets in near Earth orbits, there will be on-going needs to evaluate shielding techniques, orbital maneuvers, reduced debris architectures, and to

verify treaty compliance. Space based SoS systems may have an important role to play in development of these matters .

A MULTI-MISSION MICROSATELLITE BUS – MMMB

CSA's highly successful Microvariability and Oscillation of STars (MOST) astronomy microsatellite that launched on June 30th, 2003 demonstrated the effectiveness of microsatellite spacecraft. MOST continues today to perform on-orbit well beyond its original design life and continues to contribute to considerable science returns. Already, NEOSSat and its predecessor MOST have had mutual benefits as attitude control system updates designed for NEOSSat are providing a performance enhancement for MOST that is serving as a testbed for on-orbit trials. Earlier in 2005, apart from its primary mission, MOST was also used to test the capability of a microsatellite-based telescope to demonstrate one facet of NEOSSat's missions: to observe near earth satellites and characterize their trajectory.

While the design of the NEOSSat spacecraft has benefited from the heritage gained from the MOST spacecraft, the NEOSSat mission requirements have led to a more sophisticated spacecraft. This places higher demands on power output, processing capabilities, attitude control, imaging performance and data throughput and downlink bandwidth. As the Multi-Mission Microsatellite Bus design has developed, some additional expansion capabilities have been designed-in to ensure that hardware developed for future missions is supported. This multi-mission aspect relies upon standard signals and I/O interfaces as well as modular components to ensure a significant level of re-useability while reducing non-recurring engineering. The microsatellite design provides a platform suitable for many payload/instrument types and can also serve to fly some technology demonstration payloads. S-band and telecommand telemetry using CCSDS protocol establishes the communications link with the Mission Operations Centre located in Saint-Hubert, Quebec.

CSA – DRDC COLLABORATION

The NEOSSat project is a win-win opportunity for CSA and DRDC:

BUILDING A RELATIONSHIP

- Complementary skills and resources are available from sponsoring organizations.

- Common organizational processes and business practices are defined for the collaborative efforts.

BUILDING A PORTFOLIO

- With the development of the MMMB specification, both CSA and DRDC have control over a microsatellite bus, its baseline performance and its standard interfaces.
- Enforcing commonality between microsatellite projects, the non-recurring aspect is reduced on subsequent missions and hence over a series of missions there is an appropriate learning curve and cost reductions.

DEVELOPING A ROADMAP

- Both CSA and DND are in the midst of long term planning. Evolution of microsatellite missions, technology and operations is assisted by a modular incremental approach. As objectives and priorities develop, microsatellites are an effective path to demonstrate capabilities while providing an option to incrementally scale missions. NEOSSat for example builds upon the heritage of the MOST project while introducing upgrades and standards that can be the stepping-stones to future missions.

SHARING COMMON INTERESTS

- Development and construction costs and risk elements are spread over the partnership.
- Both CSA and DND contribute to a common NEOSSat ground infrastructure is shared and therefore costs the users individually less than if each partner had attempted to do the project alone.

LESSONS AND INSIGHTS LEARNED FROM COLLABORATION

ESTABLISH AN AGREEMENT FRAMEWORK

The NEOSSat Supporting Arrangement and CSA-DND MOU documents spell out roles, duties, commitments and responsibilities for the partnership. This provides the overarching framework for the project while serving as a model to be tested over time before the next project is kicked-off.

USE CONSENSUS TO BUILD THE TEAM

Governance by consensus helps to assure partners have a voice in decisions, management, and other issues. The partnership benefits from building consensus by

identifying major interests and jointly planning activities.

COMMIT TO PROJECT PRIORITIES

The strengths and weakness of a collaborative effort is that with a larger number of stakeholders, resources and risk are spread but there is some loss of autonomy while priorities of the project take precedence. In addition, the consultation process can be complex and can slow down the pace of efforts.

BALANCE THE RISK

Microsatellite projects are fine balance between performance, cost and quality. To attain lower cost, some rebalancing with performance and quality is needed. To attain a faster development cycles, one may need to forego layers of rigorous quality checking and rely on cost effective technology and processes to achieve a tactical advantage. To attain mission success, the quality of risk judgment must be shrewdly exercised to keep cost and performance in-bounds. There is no substitute for practical experience in all of this activity, lessons learned need to be applied, rebalancing is on-going, attention to effective application of technology and processes provides advantages and the exercise of sound judgment to develop, test and launch a microsatellite is an object lesson in taking calculated risks.

FUTURE DIRECTIONS FOR NEOSSAT

The NEOSSat NESS and HEOSS missions are on track to demonstrate microsatellite technology from a single low cost platform. One interesting mission extension is to run operational trials with NEOSSat to work in concert with other satellites and ground based assets. Performing in tandem, they could provide simultaneous observations from separate points resulting in excellent characterization of orbital parameters.

Canada may soon be in a position to prove this assertion on its own since the NEOSSat spacecraft should still be operational when DND's Sapphire spacecraft is expected to be deployed in 2011. There is also international interest in building similar or more ambitious spacecraft for NEO surveys; NEOSSat will likely be the first dedicated NEO spacecraft and can serve as a confirmation of the validity of this type of mission. This could result in future international collaboration or participation, both technical and scientific.

With the ability to acquire simultaneous observations, it is possible to extract the three-dimensional state vector

of the NEOs or objects of interest. NEOSSat uses the proven dual CCD configuration first flown on the MOST mission shown in Figure 4 in which the boresight of the imager also serves as the boresight of the star tracker supplemented with GPS data. With excellent pointing accuracy performance, NEOSSat provides for state measurements and estimates comparable in performance to much larger satellites but at a much lower cost.

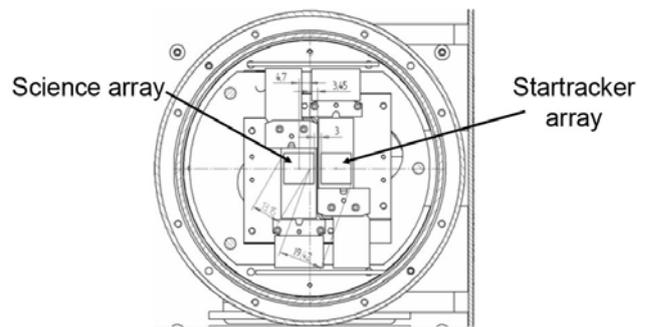


Figure 4. CCD outlines, showing arrangement for close packaging of 2 CCDs sharing focal plane

NEOSSat's exceptional pointing accuracy has attracted interest in applications as a microsatellite platform to perform line-of-sight laser communications experiments such as intersatellite-linking, secure LEO communications as well as LIDAR space-based applications.

In summary, while the NEOSSat mission was conceived to address NESS, HEOSS and Multi-Mission Microsatellite Bus objectives, it is clear that the approach can lead to many other opportunities, including in-tandem, formation or even constellation spaceflight demonstrations. With the high-performance pointing accuracy of the low-cost NEOSSat microsatellite platform, many line-of-sight applications should now be considered within reach of Canadian capabilities.

References

1. Harvey, W., Doherty, J., Tafazoli, S., Laurin, D., Capt. Morris, T., "Development Update: The NEOSSat Microsatellite Project", Astro 2008, Montreal, Quebec, April 2008.
2. Laurin, D., Hildebrand, A., Cardinal, R., Harvey, W., Tafazoli, S. "NEOSSat – A Canadian small space telescope for near Earth asteroid detection", SPIE 2008, Marseille, France, June 2008
3. Harvey W., Garon S., Martens S., Brassard G., Tafazoli S., Souza M., Bédard D., Scott R.L., Wallace B. "The Near Earth Object Surveillance Satellite (NEOSSat)", Astro 2006, Montreal, Quebec, April 2006.
4. Williams P., Canadian Report to the Forty-fifth Session of the Committee on the Peaceful Uses of Outer Space (COPUOS), Scientific and Technical Subcommittee, Item 12: Near Earth Objects, Vienna, Austria, February 2008.
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. MOST, Canada's First Space Telescope, <http://www.astro.ubc.ca/MOST/overview.html> And <http://www.space.gc.ca/asc/eng/satellites/most.asp>
7. Gaposchkin, E. et al., "Space-Based Space Surveillance with the Space-Based Visible" Journal of Guidance, Control and Dynamics, vol. 23, No.1 Feb 2000, pp148-252.
8. Wallace, B. et al. "The Near Earth Orbit Surveillance Satellite (NEOSSat). International Astronautical Congress 2004. Vancouver.
9. Hildbrand, A. R., et al. « The Canadian Near Earth Space Surveillance (NESS) Microsatellite Project will Discover and Track Low Delta V near-Earth Asteroids by Observing at Low Solar Elongations" 55th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law, Vancouver, Quebec, Oct. 4-8, 2004
10. S. C. O. Grocott (a), R. E. Zee (b), G. J. Wells (a), R. Wessels (a), A. Beattie (b), S. Park (b), "EXPANDING CAPABILITIES OF THE MOST SPACECRAFT", CASI 2006, Montreal, Qc.
11. NASA "Near-Earth Object Groups" <<http://neo.jpl.nasa.gov/neo/groups.html>> Last Updated: 09 Jun 2008, Date of access 6/9/2008
12. Arnett, W. "Meteorites and Impacts" <<http://www.nineplanets.org/meteorites.html>> Last updated: 2005 Apr 03, Date of access 6/10/08